

**BUILDING A CONSERVATION MATERIAL
RECORD: A STUDY OF PAINTINGS BY
CHEONG SOO PIENG AND GEORGETTE CHEN**

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ABSTRACT

Despite the growing visibility of prominent figures in modern Singaporean art history, there is limited material knowledge of the art practices of paintings from Nanyang artists such as Georgette Chen (1906–1993) and Cheong Soo Pieng (1917–1983). Scholarly interest in Singaporean artist materials and techniques has focused attention on the study of easel paintings through art historical and technical art history methodologies. There are art material and conservation records, but to compare these studies, the consistency and structure of the data collection make it challenging.

In response, this thesis re-assesses the development of accessible documentation methods for studying paintings by considering the type of data to be collected, the structure of the record, and whether it is possible to produce quality insights without solely relying on advanced material analysis. Employing a standard technical art history methodology, a total of 67 artworks from Cheong Soo Pieng and Georgette Chen, dated from the 1940s to the 1980s, were examined through a combination of historical and archival sources, visual examination, technical photography, and advanced material analysis. To extend the data and produce quality insights, a robust documentation record was produced where observations were recorded outlining 110 defining properties of each painting, resulting in verifiable data points to be analysed.

Differences in access to paintings and availability of archival sources affected the methodologies that could be used to gain insights. This meant that although only eight Georgette Chen paintings were studied, but nevertheless, solid correlations and consistency in canvas preparation and painting techniques were still uncovered. In a more extensive study of 59 Cheong Soo Pieng artworks, where samples were removed and analysed, the data produced improved the depth and quality of the artist's record. In addition, the data structure of the documentation record enabled datasets to be extracted and visualised through visual graphics to uncover patterns of each artist's art practice.

The datasets from Cheong Soo Pieng provided depth to undertake unsupervised machine learning with Principal Component Analysis (PCA) and k-means to uncover relationships from data generated from non-invasive techniques and results from the material analysis. This clustered data on Cheong Soo Pieng's practice into four clusters, and its characteristics were examined using an interactive Microsoft Power BI dashboard.

The methodologies proposed in this study aim to build a material record of Singaporean artists that can accommodate future datasets to build onto. Using the large amounts of text and image-based data produced by this study, machine learning algorithms, including deep learning models, were explored to discover possible future uses to improve efficiencies between text and technical image diagnostics. In light of such a data rich field, the presented methodologies showcase how knowledge discovery can be accessed by employing data science methods that produce evidential, verifiable and quality data through data structure. In doing so, a better understanding of Cheong Soo Pieng and Georgette Chen's practice is produced, contributing to the development of a robust material record and our knowledge about paintings in Singapore and potentially the wider Southeast Asian region.

DECLARATION

This is to certify that:

- (i) the thesis comprises only my original work towards the PhD except where indicated in the Preface,

due acknowledgement has been made in the text to all other material used,

the thesis is fewer than 100,000 words in length, exclusive of tables, figures, bibliographies and appendices.

Diana Tay

PREFACE

This preface outlines the publications, collaborative research agreements, funding sources, and editorial assistance that this thesis has been informed by and has received.

PUBLICATIONS

The following publications by the author during candidature have been incorporated into the body of this thesis. Unless cited in the text only my own original contribution to the research is included:

Tay, D 2020, 'Expanding the Singaporean discourse: exploring artist materials from the 1950s to 1970s', *AICCM Bulletin*, vol. 41, no. 2, pp. 106–117.

Mostly incorporated as paragraphs throughout Chapter 3.

Tay, D 2021, 'Building a material record of Singaporean art through technical art history: a case study of the paintings of Cheong Soo Pieng', *Journal of the Institute of Conservation*, vol. 44, no. 3, pp. 197–209.

Mostly incorporated as paragraphs throughout Chapter 2 and Chapter 5.

RESEARCH AGREEMENTS AND FUNDING

The following research agreements have been established by the University of Melbourne and the parties which form an important part of the research and access to paintings studied.

Collaborative Research Agreement (33419) between The University of Melbourne and Mr Koh Seow Chuan, which includes providing access up to 100 paintings in Koh's private collection for technical in-situ examination, removal of paint samples, provision of working space for on-site examination, purchase of analytical equipment and reasonable travel expenses to undertake the project.

Research Agreement (32694) between The University of Melbourne and The National Heritage Board, which includes providing access up to 40 paintings in the National Collection for technical in-situ examination and for provision of working space for on-site examination to undertake the project.

For both agreements, due to the pandemic, less works were examined and accessed.

In addition, this research was funded by a University of Melbourne's Research Scholarship for the duration of the course. A one month graduate internship programme was undertaken with the University of Melbourne's Digital Studio as well as a fellowship with the Melbourne Centre for Data Science, both of which have provided financial and technical support to this research.

EDITORIAL ASSISTANCE

This thesis has had the benefit of being copyedited and proofread by Dr Rebecca Hazleden following Parts D and E of the Australian Standards for Editing as outlined by accreditation body, the Institute of Professional Editors Limited (IPEd). These edits include clarity of expression, flow of the text, correct use of grammar, spelling, and punctuation as well as consistency in the presentation, format and layout of the thesis. Further changes were made to this thesis after the editing process.

COVID-19 DISRUPTIONS

This thesis has undergone a significant restructuring due to the COVID-19. The closure of international borders resulted in a cancellation of all international fieldwork to Singapore in 2020, resulting in a 40% reduction of planned data collection. In addition, the Melbourne-wide lockdowns limited access to material analysis in scientific laboratories. However, this allowed the thesis to pivot towards data analysis and data science to analyse existing dataset deeper as the research methodology will show.

iTHENTICATE

This thesis is attached with an iThenticate similarity report for submission and has been provided with the thesis's supervisors. The filters used for the report include filters to exclude quotes, bibliography, abstract and sources that are less than 1%.

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This thesis is a continuation of the work of many individuals who believe in the importance of building regional specific knowledge, especially about our modern Singaporean artists, where in doing so, we present a new narrative of our history through conservation studies and material studies. The possibility of such an undertaking began with a serendipitous moment and a phone call from a dear friend and mentor, Linda Neo, whose passion and knowledge about Singaporean artists inspired me to want to better understand the works I conserved. That phone call soon led to a valuable partnership with Koh Seow Chuan; I have had the privilege to study works from his extensive collection and have been fortunate to have his financial support in facilitating this research study. It is this commitment to understanding Singaporean art and the emphasis on the importance of placing our Singaporean artists on the map which have been a driving force for this research.

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Table of Contents

ABSTRACT.....	2
DECLARATION.....	4
PREFACE.....	5
ACKNOWLEDGEMENTS	7
Table of Contents	9
List of Figures.....	13
List of Tables	23
Chapter 1: Introduction	25
Chapter 2: Research Design.....	37
2.1 Introduction.....	37
2.2 Securing the quality of the material record.....	38
<i>The quality of the material record</i>	<i>39</i>
<i>An object-centred approach to creating the material record</i>	<i>41</i>
2.3 Data collection techniques	42
<i>Painting selection criteria.....</i>	<i>43</i>
<i>Non-invasive examination.....</i>	<i>45</i>
<i>Visual examination and written documentation</i>	<i>45</i>
<i>Multispectral technical photography.....</i>	<i>46</i>
<i>Primary sources</i>	<i>48</i>
<i>Invasive material analysis.....</i>	<i>48</i>
2.4 Sampling and analysis	50
<i>Sample removal and documentation method</i>	<i>50</i>
<i>Sample analytical pathway</i>	<i>51</i>
<i>Cross-sections.....</i>	<i>51</i>
<i>Fourier transform infrared spectroscopy with attenuated total reflectance (FTIR-ATR).....</i>	<i>52</i>
<i>Portable x-ray fluorescence (pXRF).....</i>	<i>52</i>
<i>Environmental scanning electron microscope with energy-dispersive x-ray spectroscopy (ESEM-EDS).....</i>	<i>53</i>
<i>Summary</i>	<i>54</i>
2.5 Documentation Record	56
<i>Raw data, transformation and pattern identification</i>	<i>57</i>
<i>Structuring data with ontology</i>	<i>60</i>
<i>Data dictionary and fixed terminologies</i>	<i>63</i>
<i>Summary</i>	<i>64</i>
2.6 Data science framework.....	65
<i>Databases: data management and dataset extraction</i>	<i>67</i>
Existing databases	67
Data management tool: Airtable	69
<i>Data analysis</i>	<i>71</i>

Data visualisation tools	72
Machine learning algorithms to interpret data	73
Summary	75
2.7 Conclusion	75
Chapter 3: Developing a Singaporean art scene: historical context and artist supplies	77
3.1 Introduction.....	77
3.2 Historical and cultural context: an art perspective.....	79
<i>Early modern period leading to independence: a historical timeline</i>	79
<i>Assimilation of Western art in Singapore through art education</i>	81
<i>Chinese communities: building a local art scene in Singapore</i>	84
<i>The building of Singapore's local art landscape</i>	85
3.3 Art Academies in Singapore	87
<i>Art academies</i>	87
<i>Nanyang Style</i>	90
3.4 Artist Supplies in Singapore	92
<i>Suppliers of artist materials: from bookstores to Straits Commercial</i>	92
<i>Artist materials: other Japanese manufacturers</i>	95
Claessens, Japan	96
Funaoka's Canvas, Japan	96
Holbein, Japan.....	98
3.5 Summary	101
Chapter 4: Technical study of Georgette Chen materials and techniques	103
4.1 Introduction.....	103
<i>Artist background</i>	103
Georgette Chen's artistic career	104
Georgette Chen and the Academy	107
Negotiation with nationality	109
4.2 Research Methodology	110
4.3 Painting Construction Materials and Techniques	112
<i>Strainers/ Wooden frames</i>	113
<i>Use of pre-primed canvas</i>	117
4.4 Paint application	121
4.5 Underdrawings: Mooncake series.....	130
4.6 Conclusion	138
Chapter 5: Technical study of Cheong Soo Pieng's materials and techniques	139
5.1 Introduction.....	139
<i>Artist background</i>	141
<i>Categorising Cheong Soo Pieng's paintings</i>	143
5.2 Research Methodology	147
5.3 Findings from the technical examination of paintings.....	148
<i>Painting supports</i>	148
Solid supports: hardboard and wood	152
Marouflage	155
Auxiliary supports	158
<i>A deeper look into canvas supports</i>	161

Overview of fibres.....	164
Manufacturer stamps: Holbein.....	166
Characterisation of artist or commercially prepared canvasses	168
Canvas preparation (strainers/stretcher).....	172
Localisation of Western canvas practices	177
<i>Blank canvas to image</i>	182
Underdrawings	184
Preliminary sketch-like corrections.....	188
Hidden figures: Changes in detail from the final composition	193
Signature changes.....	197
Paint characteristics.....	202
Solid supports: impasto layers thick, multiple layers of paint.	203
Canvasses: thin and few layers of paint.	205
Mixed media: fewer paint layers over a thicker preparatory layer.....	212
5.4 Conclusion	216
Chapter 6: Statistical Analysis of ground and canvas.....	218
6.1 Introduction.....	218
6.2 Ground	221
<i>Detecting trends through a statistical exploratory approach of elemental data ..</i>	<i>221</i>
<i>Statistical methodology in detail (Spearman).....</i>	<i>225</i>
<i>Preliminary clustering with Spearman correlation: identifying key compounds and elements</i>	<i>227</i>
6.3 Pigment identification through data clustering	236
Methodology	238
Reds and yellows.....	240
Blues	251
Blacks	256
Whites.....	261
Summary	265
6.4 Unsupervised learning methodology	266
A note on data bias	268
Raw data	269
Clean and transform	269
Feature engineering.....	273
K-means clustering and Principal Component Analysis	274
PCA modelling	276
Improving results	279
Creation of order columns for text values.....	280
Interactive dashboard using Microsoft Power BI.....	280
6.5 Analysis	286
Cluster 1: Works on solid supports (1947–1960).....	287
Cluster 2: Pre-primed canvasses (1963 and 1965)	291
Cluster 3: Later experimental works (1966 to 1975).....	293

<i>Cluster 4: Marouflaged works between Stylisation and Nanyang Style</i>	295
<i>Summary</i>	296
6.6 Conclusion	298
Chapter 7: Conclusion and recommendations: methodologies for knowledge discovery	301
7.1 Introduction.....	301
7.2 Factors influencing data collection and interpretation.....	302
7.3 Material links between Cheong Soo Pieng and Georgette Chen using descriptive and diagnostic analytics	307
7.4 Recommendations: Using deep learning’s predictive and prescriptive analytics for image and text-based diagnostics.....	311
<i>Text-based caption diagnosis using deep learning neural networks</i>	312
<i>Technical image diagnosis using Perceiver IO and Optical Flow</i>	319
7.5 Data integration: Methodologies and approaches to data collection	322
<i>Challenges and recommendations</i>	324
Chapter 8: Conclusions	327
List of References	337
Appendix A: List of Paintings Studied	351
Appendix B: Specifications of digital multispectral photography techniques	355
Appendix C: Data Dictionary	360
Appendix D: Findings from ESEM-EDS analysis on cross-sections	412
Endnotes	505

List of Figures

Figure 1. Visualisation of ontological relationships in this research.	60
Figure 2. Foundational methodology for data science (Rollins 2015).....	66
Figure 3a. First tab of the Airtable database in text format.	70
Figure 3b. First tab of the Airtable database in gallery view.	70
Figure 4. Airtable database of artist materials and suppliers in Singapore from newspapers and exhibition catalogues of English and Chinese sources, 1861–1975.	94
Figure 5. Funaoka’s Canvas manufacturer stamp. Georgette Chen, <i>Flower Composition with Smiling Buddha</i> , c. 1970 (73 x 60 cm, oil on canvas). Collection: NGS.	97
Figure 6. 50x Magnification of Funaoka’s canvas fibres showing tight and plain weave. Georgette Chen, <i>Flower Composition with Smiling Buddha</i> (1970).	97
Figure 7. Image of unidentified stamp similar to Funaoka’s Canvas (Lizun 2022). Liu Kang, <i>Village</i> , c. 1950 (99 x 131.5 cm, oil on canvas 1950) Collection: NHB.	97
Figure 8. Image of unidentified stamp similar to Funaoka’s Canvas similar to Figure 7. Georgette Chen, <i>Girl from New Delhi</i> , c. 1971 (81 x 65cm, oil on canvas). Collection: NGS.	97
Figure 9. 50x Magnification of canvas fibres of canvas from Figure 7 showing uneven threads and open weave. Georgette Chen, <i>Girl from New Delhi</i> (1971).	97
Figure 10. Detail of red ‘Holbein 3’ canvas stamp on verso (left) and digitally enhanced black and white image of the same to accentuate details of the canvas stamp. Cheong Soo Pieng, <i>Untitled (Red)</i> , c. 1963 (80 x 100cm, mixed media on canvas). Collection: KSC.	100
Figure 11. Detail of verso showing ‘Holbein 10’ canvas stamp. Georgette Chen, <i>Satay Boy</i> , c. 1964 (133 x 160cm, oil on canvas). Collection: National Museum Singapore.	100
Figure 12. 50x Magnification of Holbein’s canvas fibres showing uneven threads and open weave. Georgette Chen, <i>Satay Boy</i> (1964).	100
Figure 13. Distribution of Georgette Chen auxiliary supports studied.	114
Figure 14a. Presence of double tacks at the 45-degree angle of the top and bottom edges. Georgette Chen, <i>Mooncakes with Green Pomelo</i> , c.1965-68 (32 x 40cm, oil on canvas). Collection: NGS.	116
Figure 14b. Presence of double tacks at the 45-degree angle of the top and bottom edges. Georgette Chen, <i>Mooncakes with Golden Pomelo</i> , c.1965 (45 x 54cm, oil on canvas). Collection: NGS.	116

Figure 14c. Presence of double tacks at the 45-degree angle of the top and bottom edges. Georgette Chen, <i>Still Life. (Moon Festival Table)</i> , c.1962 (73 x 60cm, oil on canvas). Collection: NGS.	116
Figure 15. Venn diagram of four factors of auxiliary support attributed to Georgette Chen.	117
Figure 16. Diagram of Georgette Chen canvasses featuring Holbein canvas stamps.	119
Figure 17a. Digitally enhanced detail of ‘Holbein 1’ stamp. Georgette Chen, <i>Mooncakes with Green Pomelo</i> (1965-68).	120
Figure 17b. Digitally enhanced detail of ‘Holbein 1’ stamp. Georgette Chen, <i>Still Life (Moon Festival Table)</i> (1962).	120
Figure 17c. Digitally enhanced detail of ‘Holbein 10’ stamp. Georgette Chen, <i>Satay Boy</i> (1964).....	120
Figure 17d. Magnification of weave from verso of 17a. Georgette Chen, <i>Mooncakes with Green Pomelo</i> (1965-68).	120
Figure 17e. Magnification of weave from verso of 17b. Georgette Chen, <i>Still Life (Moon Festival Table)</i> (1962).	120
Figure 17f. Magnification of weave from verso of 17c. Georgette Chen, <i>Satay Boy</i> (1964).	120
Figure 18a. Transmitted light photography showing high light transmission. Georgette Chen, <i>Assorted Mooncakes</i> (1955-60).	123
Figure 18b. Transmitted light photography showing high light transmission. Georgette Chen, <i>Mooncakes with Golden Pomelo</i> (1965).	123
Figure 18c. Transmitted light photography showing high light transmission. Georgette Chen, <i>Mooncakes with Green Pomelo</i> (1965-68).	123
Figure 18d. Transmitted light photography showing medium light transmission due to re-lining. Georgette Chen, <i>Mooncakes</i> , c. 1970 (65 x 54cm, oil on canvas). Collection: National Library Board.....	123
Figure 18e. Transmitted light photography showing light transmission. Georgette Chen, <i>Tropical Fruits</i> , c. 1969 (72 x 92cm, oil on canvas). Collection: NGS.	124
Figure 18f. Transmitted light photography showing light transmission. Georgette Chen, <i>Satay Boy</i> (1964).	124
Figure 18g. Transmitted light photography showing high light transmission. Georgette Chen, <i>Still Life (Moon Festival Table)</i> (1962).	124
Figure 18h. Transmitted light photography with little light transmission. Georgette Chen, <i>Coq</i> , undated (81 x 60cm, oil on canvas). Collection: KSC.....	124

Figure 19. Comparison image of transmitted light and transmitted infrared photograph detailing change in rambutans and basket (outlined in white box). Georgette Chen, <i>Tropical Fruits</i> (1969).	125
Figure 20. Comparison image of visible light and transmitted infrared photograph detailing change in sleeve of figure as outlined in white box. Georgette Chen, <i>Satay Boy</i> (1964).	126
Figure 21a. 400x magnification of cross-section featuring a thin red paint layer of 5µm. Georgette Chen, <i>Mooncakes</i> (1970).	126
Figure 21b. 100x magnification of cross-section featuring a build-up of paint layers, each measuring approximately 25 µm thick. Georgette Chen, <i>Coq</i> (undated).	126
Figure 22a. Transmitted infrared photography detailing transmission and brushstrokes. Georgette Chen, <i>Mooncakes with Golden Pomelo</i> , (1965).	128
Figure 22b. Transmitted infrared photography detailing transmission and brushstrokes. Georgette Chen, <i>Mooncakes</i> (1970).	128
Figure 22c. Transmitted infrared photography detailing transmission and brushstrokes. Georgette Chen, <i>Assorted Mooncakes</i> (1955-60).	128
Figure 22d. Transmitted infrared photography detailing transmission and brushstrokes. Georgette Chen, <i>Mooncakes with Green Pomelo</i> (1965-68).	128
Figure 22e. Transmitted infrared photography detailing transmission and brushstrokes. Georgette Chen, <i>Satay Boy</i> (1964).	129
Figure 22f. Transmitted infrared photography detailing transmission and brushstrokes. Georgette Chen, <i>Still Life (Moon Festival Table)</i> (1962).	129
Figure 22g. Transmitted infrared photography detailing transmission and brushstrokes. Georgette Chen, <i>Tropical Fruits</i> (1969).	129
Figure 22h. Transmitted infrared photography detailing transmission and brushstrokes. Georgette Chen, <i>Coq</i> (undated).	129
Figure 23. 200x magnification of detail of painting technique of charcoal underdrawing raw sienna wash observed in yolk area (110,75mm). Georgette Chen, <i>Mooncakes with Green Pomelo</i> (1965-68).	131
Figure 24. Diagram showing ordered strokes for the Chinese character ‘an’.	133
Figure 25a. Visible and, transmitted infrared images illustrate how the Chinese character stroke is written. Georgette Chen, <i>Assorted mooncakes</i> (1955–1960).	134
Figure 25b. Visible and, transmitted infrared images illustrate how the Chinese character stroke is written. Georgette Chen, <i>Mooncakes</i> (1970).	134

Figure 25c. Visible and, transmitted infrared images illustrate how the Chinese character stroke is written. Georgette Chen, <i>Mooncakes with Golden Pomelo</i> (1965).	134
Figure 26a. Visible and transmitted infrared photography detailing how the red character is constructed. Georgette Chen, <i>Mooncakes with Green Pomelo</i> (1965–1968).....	136
Figure 26b. Visible and transmitted infrared photography detailing how the red character is constructed. Georgette Chen, <i>Still Life (Moon Festival Table)</i> (1962).	136
Figure 26c. Visible and transmitted infrared photography detailing how the red character is constructed. Georgette Chen, <i>Coq</i> (undated).....	136
Figure 27. Breakdown tree showing the main trends of underdrawing media transparency and any changes observed in Georgette Chen paintings studied.....	137
Figure 28a. Distribution of support type across decades of the 57 Cheong Soo Pieng paintings studied.....	151
Figure 28b. Distribution of support type across periods of the 57 Cheong Soo Pieng paintings studied.....	151
Figure 29a. Recto painted on the toothed side of hardboard. Cheong Soo Pieng, <i>Still Life</i> , c. 1950 (60x54 cm, oil on hardboard). Collection: KSC.....	153
Figure 29b. Verso painted on the smooth side of hardboard. Cheong Soo Pieng, <i>Still Life</i> (1950).....	153
Figure 30a: Newspaper clipping from The Singapore Free Press 1957.	154
Figure 30b: Newspaper clipping from The Singapore Free Press 1957 (continued).....	154
Figure 31. Scatterplot diagram showing the range of materials that have been used as a marouflage support by Cheong Soo Pieng.	157
Figure 32. Ribbon chart of auxiliary support distributed across the years where the preferential trends are visualized through the thickness of the ribbon through the decades.....	160
Figure 33. Image of label printed: ‘Ernest Wheatley Ltd / Picture Framer / 32 Foubert’s Place, Regent St / London, W.1 / Tel: Gerard 8739’’. Cheong Soo Pieng, <i>Landscape</i> , c.1961 (46 x 71cm, oil on canvas). Collection: KSC.	161
Figure 34a. Stacked bar chart showing the distribution of fibres by decade as identified from 32 sampled canvas fibres from Cheong Soo Pieng paintings. Highlighting the bast and cotton preference in the 1960s vs the 1970s.....	163
Figure 34b. Stacked bar chart showing the distribution of fibres by period as identified from 32 sampled canvas fibres from Cheong Soo Pieng paintings where the use of cotton is very prominent in the Artistic Maturation period.....	163

Figure 35. The presence of manufacturer stamps on Cheong Soo Pieng canvas paintings studied showed there were either no stamps or Holbein stamps recorded.	165
Figure 36. Detail of verso showing red 'Holbein 3' canvas stamp (left) and digitally enhanced image of the same in Adobe Lightroom in black and white with masking to accentuate canvas stamp. Cheong Soo Pieng, <i>Busy Planters</i> , c. 1968 (84 x 106cm, oil on canvas). Collection: KSC.....	167
Figure 37. Stacked bar chart showing the distribution of ground layers visibility on tacking margin edge identified from 32 Cheong Soo Pieng paintings with fibre analysis.	169
Figure 38a. 100x magnification of cross-section from a canvas with Holbein stamp. Cheong Soo Pieng, <i>Nature's Inspiration</i> , c. 1963 (92 x 122cm, oil on canvas). Collection: KSC.	171
Figure 38b. 100x magnification of cross-section from a canvas with Holbein stamp. Cheong Soo Pieng, <i>Untitled (Red)</i> (1962).	171
Figure 38c. 100x magnification of cross-section from an artist-prepared canvas. Cheong Soo Pieng, <i>Worshipper</i> (1978).....	171
Figure 39. Distribution of 18 strainers and stretchers of Cheong Soo Pieng canvas paintings studied across the decades.	173
Figure 40a. Chop Hung Sun frame-makers stamp found on a Cheong Soo Pieng backing board. Image provided by KSC.	174
Figure 40b. Hung Wah frame-makers stamp found on a Cheong Soo Pieng backing board found on <i>Resting</i> 1972. Image from Gomez Lobon 2010a.	174
Figure 41a. Verso of canvas showing the excess canvas folded over straight down. Cheong Soo Pieng, <i>Untitled (Two Figures, Mynah)</i> , c.1964 (99 x 80cm, oil on canvas). Collection: KSC.....	176
Figure 41b. Comparison of canvas fold by Georgette Chen showing the excess canvas neatly folded over with a 45-degree angle. Georgette Chen, <i>Mooncakes with Golden Pomelo</i> , 1965.	176
Figure 42a. Painting on gunny sack. Cheong Soo Pieng, <i>Landscape</i> , c. 1978 (101 x 71cm, oil on jute, marouflaged on canvas). Collection: KSC.	179
Figure 42b. Verso of painting in 42a featuring the marouflaged cotton canvas. Cheong Soo Pieng, <i>Landscape</i> (1978).	179
Figure 42c. 65x magnification of painting on gunny sack with details of open weave and no paint on marouflaged cotton canvas. Cheong Soo Pieng, <i>Landscape</i> (1978).	179

Figure 43a. Painting on gunny sack. Cheong Soo Pieng, <i>Worshipper</i> , c. 1978 (127 x 91cm, oil on straw mat, marouflaged on canvas). Collection: KSC.	180
Figure 43b. Verso of painting in 43a featuring the marouflaged cotton canvas. Cheong Soo Pieng, <i>Worshipper</i> (1978).....	180
Figure 44a. ESEM-EDS backscatter imaging of thin gold layer on the upper top surface of <i>Green Landscape</i> (1975) as represented by a white layer.....	181
Figure 44b. Spectra from ESEM-EDS from Fibre 44a showing the presence of gold (Au). 182	
Figure 45a. Cheong Soo Pieng, <i>Sarawak Sisters</i> , c. 1953 (76 x 60cm, gouache? on hardboard). Collection: KSC.	190
Figure 45b. Close up detail of right figure's face from 45a. Cheong Soo Pieng, <i>Sarawak Sisters</i> (1953).....	190
Figure 45c. Infrared image @1000nm of close up detail of 45b, featuring black outlines particularly in nose and lip and forehead. Cheong Soo Pieng, <i>Sarawak Sisters</i> (1953).	190
Figure 46. Infrared image @ 1000nm detailing preliminary outlines in the eyebrows. Cheong Soo Pieng, <i>Untitled (Three Figures, Musical Instruments)</i> , c. 1968 (71 x 96cm, oil on canvas). Collection: KSC.	191
Figure 47a. Details in figure's feet in visible illumination. Cheong Soo Pieng, <i>Bali Women</i> , c. 1952–1964 (192 x 130, oil on canvas marouflaged on hardboard). Collection: KSC. ..	192
Figure 47b. Reduction of details in figure's feet as shown in fig. 47a visible in infrared image @ 1000nm. Cheong Soo Pieng, <i>Bali Women</i> (1952–1964).	192
Figure 48a. Detail of one 'hidden' figure in visible image. Cheong Soo Pieng, <i>Construction</i> , c. 1956 (49 x 60cm, oil on hardboard). Collection: KSC.....	193
Figure 48b. Detail of figure in 48a made visible in infrared image @ 1000nm. Cheong Soo Pieng, <i>Construction</i> (1956).....	193
Figure 48c. Detail of two 'hidden' figures in visible image. Cheong Soo Pieng, <i>Construction</i> (1956).....	193
Figure 48d. Detail of figures in 48c made visible in infrared image @ 1000nm. Cheong Soo Pieng, <i>Construction</i> (1956).....	193
Figure 49a. Cropped image of visible illumination of figures. Cheong Soo Pieng, <i>Busy Planters</i> (1968).	195
Figure 49b. Cropped image of 49a in transmitted infrared, displaying preliminary sketches of two 'hidden' figures which were later removed from the final composition. Cheong Soo Pieng, <i>Busy Planters</i> (1968).	195

Figure 50. Detail of compositional changes observed in transmitted infrared (left) which highlights paint density compared to reflected infrared image (right). Cheong Soo Pieng, <i>Calm Motion</i> , c. 1969 (81 x 100cm, mixed media on canvas). Collection: KSC.	196
Figure 51. Distribution of Cheong Soo Pieng signature types through the various curatorial categorisation and years.....	197
Figure 52a. Cheong Soo Pieng, <i>Bali Women</i> (1952-1964).....	199
Figure 52b. Reverse of 52a showing Masonite board supporting the canvas painting. Cheong Soo Pieng, <i>Bali Women</i> (1952-1964).	199
Figure 53a. Details of signature. Cheong Soo Pieng, <i>Bali Women</i> (1952-1964).....	200
Figure 53b. Details of signature observed in an infrared image @ 1000nm featuring ‘Cheong Soo Pieng 53’ highlighted in white square. Cheong Soo Pieng, <i>Bali Women</i> (1952-1964).	200
Figure 54a. Chinese signature in visible image. Cheong Soo Pieng, <i>Untitled (Three Figures, Musical Instruments)</i> (1968).	201
Figure 54b. Detail of change of signature position of 54a as shown in infrared photography @ 1000nm. Cheong Soo Pieng, <i>Untitled (Three Figures, Musical Instruments)</i> (1968). ..	201
Figure 54c. Chinese signature in visible image. Cheong Soo Pieng, <i>Busy Planters</i> (1968). ..	201
Figure 54d. Detail of change of signature position of 54c as shown in infrared photography. Cheong Soo Pieng, <i>Busy Planters</i> (1968).	201
Figure 55a. Paint application layers observed under raking light. Cheong Soo Pieng, <i>Sunflowers</i> , c. 1957 (61 x 42, oil on paper marouflaged on board). Collection: KSC. ...	204
Figure 55b. Close up of paint application layers observed under raking light. Cheong Soo Pieng, <i>Sunflowers</i> (1957).....	204
Figure 56a. Paint application layers observed under raking light. Cheong Soo Pieng, <i>Construction</i> (1956).....	205
Figure 56b. Close up of paint application layers observed under raking light. Cheong Soo Pieng, <i>Construction</i> (1956).....	205
Figure 56c. 100x magnification detail of paint application technique featuring thin layers of paint observed in cross-section. Cheong Soo Pieng, <i>Construction</i> (1956).	205
Figure 57a. Comparison images of visible light and transmitted-infrared photography showing less paint density around the figures and heavier paint in the background. Cheong Soo Pieng, <i>Untitled (Three Figures, Musical Instruments)</i> (1968).	207
Figure 57b. Comparison images of visible light and transmitted-infrared photography showing less paint density around the figures and heavier paint in the background.	

Cheong Soo Pieng, <i>Long House People</i> , c.1975 (86 x 122, oil on canvas). Collection: KSC.	207
Figure 58. Detail in raking light featuring crack patterns that occur in areas with thicker paint layers. Cheong Soo Pieng, <i>Long House People</i> (1975).....	209
Figure 59. Transmitted infrared image showing horizontal losses of paint which suggest horizontal stresses such as rolling of the painting. Cheong Soo Pieng, <i>Untitled (Blue Abstract)</i> , c. 1962 (131 x 102cm, oil on canvas). Collection: KSC.	210
Figure 60. Transmitted infrared showing horizontal losses of paint which suggest horizontal stresses such as rolling of the painting. Cheong Soo Pieng, <i>Untitled (Red)</i> (1962).....	211
Figure 61. Stacked bar chart showing distribution of elements per sample analysed as an unprocessed sample using pXRF, where each column represents a painting's ground composition. Grey represents % of Ca, orange represented % of Pb and blue represents % of Zn.	222
Figure 62. Correlation matrix of 13 elements present and 3 ground topography findings in ground layers of 35 Cheong Soo Pieng cross-sections analysed using ESEM-EDS. The 16 variables are plotted against each other in the x and y axis to examine the correlation between each other.	229
Figure 63. Preliminary clustering resulting from the binary dataset of ground layers could be categorized into three main groups.....	232
Figure 64a. ESEM-EDS backscatter imaging of coarse ground layer. Cheong Soo Pieng, <i>Green Landscape</i> , c.1975 (45 x 61cm, mixed media on canvas). Collection: KSC.	233
Figure 64b. ESEM-EDS backscatter imaging of coarse ground layer. Cheong Soo Pieng, <i>Construction</i> , c.1966 (107 x 68cm, mixed media on wood). Collection: KSC.....	233
Figure 65. Correlation matrix of elements present in 19 red and yellow paint layers.	241
Figure 66. Cluster map illustrating the groups of red and yellow pigments and their characteristics found within the dataset of 19 Cheong Soo Pieng paint samples.	248
Figure 67. Correlation matrix of elements present in 12 blue paint layers.....	251
Figure 68. Cluster map illustrating the groups of blue pigments and their characteristics found within the dataset of 12 Cheong Soo Pieng paint samples.	254
Figure 69. Correlation matrix of elements present in 26 black paint layers.	256
Figure 70. Cluster map illustrating the groups of black pigments and their characteristics found within the dataset of 26 Cheong Soo Pieng paint samples.....	259
Figure 71. Correlation matrix of elements present in 12 white paint layers.....	261

Figure 72. Cluster map illustrating the groups of white pigments and their characteristics found within the dataset of 12 Cheong Soo Pieng paint samples.....	264
Figure 73. Feature engineering model illustrating the process of data transforming from raw data to insights.	268
Figure 74. Exploration of data through visualisation of 13 selected features to include in unsupervised learning dataset.	272
Figure 75. Utilising the elbow-method visualisation to locate the first point of the curve that identifies the optimal number of clusters for the dataset (4, 159.68).	276
Figure 76. Scatterplot of two principal components from the initial dataset showing four clusters.	277
Figure 77. Scatterplot showing that 20 of 67 components can explain 95% of the data.	278
Figure 78. New scatterplot showing reassignment of two points highlighted in box after re-modelling.	279
Figure 79. Screen capture of order creation using Python.....	281
Figure 80a. Screenshot of interactive Power BI dashboard.....	284
Figure 80b. Example screenshot of when Cluster 1 is selected on Power BI dashboard, highlighting only relevant fields.....	285
Figure 81. Cluster 1, purple, comprising of 11 paintings, highlighted within scatterplot.	287
Figure 82a. Cheong Soo Pieng, <i>Untitled (Indian Lady with Veil)</i> , c.1966 (61 x 45, oil on hardboard). Collection: KSC.	289
Figure 82b. Close up of signature in centre right edge of painting. Cheong Soo Pieng, <i>Untitled (Indian Lady with Veil)</i> (1966).	289
Figure 82c. Top right corner of overpainted signature in visible light. Cheong Soo Pieng, <i>Untitled (Indian Lady with Veil)</i> (1966).	289
Figure 82d. Top right corner of overpainted area under UVF. Cheong Soo Pieng, <i>Untitled (Indian Lady with Veil)</i> (1966).	289
Figure 83. Hidden signature discovered top right corner in reflected infrared photograph. Cheong Soo Pieng, <i>Untitled (Indian Lady with Veil)</i> (1966).	290
Figure 84. Cluster 2, orange, comprising of seven paintings, highlighted within scatterplot.	291
Figure 85. Cluster 3, green, comprising of nine paintings, highlighted within scatterplot.	293
Figure 86. Cluster 4, red, comprising of eight paintings, highlighted within scatterplot.	295
Figure 87. Radar diagram showing the spread of five factors in the current study which can affect the depth and breadth of data points collected.	303

Figure 88. Four pillars of data analysis ranging in complexity and value (Kalsbeek 2020).	305
Figure 89. Visualisation of paintings studied by year between the two artists with the 1960s which is a common period between them.	307
Figure 90. Compilation of Holbein canvas stamps images from eight Cheong Soo Pieng and Georgette Chen paintings from the 1960s.	308
Figure 91. Tree diagram showing the distribution of strainer profile thickness for both Cheong Soo Pieng and Georgette Chen paintings.	309
Figure 92. Organisation of technical images (specular and transmitted photography) to be trained in model.	315
Figure 93. Organisation of transmitted infrared technical images to be trained and how the images are classified.	315
Figure 94. Extract of diagnostic description dataset.	316
Figure 95. Images of Georgette Chen paintings, and table depicting the difference between human and AI diagnosis with differences highlighted in red, and process of image and text recognition.	317
Figure 96. Images of Cheong Soo Pieng paintings, and table depicting the difference between human and AI diagnosis with differences highlighted in red.	318
Figure 97. Colour code visualisation of optical flow movement (Liu, Yuen & Torralba 2016).	319
Figure 98. Optical flow produced highlighting differences in visible and infrared image, similar to mylar overlay.	320
Figure 99. Specular images of selected paintings overlay across the generated optical flow visualisations which correspond with the high gloss reflectance.	321
Figure 100. Flowchart of data collection, the types of data and the workflow employed during the research project with the aim to build a material record.	325

List of Tables

Table 1. Metrics of the quality of the record used for this study.	40
Table 2. Four stage process of how raw data is transformed into a documentation record.	57
Table 3. List of Georgette Chen paintings studied.	110
Table 4. Dataset data points and variables for the study of how a painting is constructed. ..	112
Table 5. Details of inscriptions found on auxiliary supports.	115
Table 6. Dataset data points and variables for the study of type of pre-primed canvasses. ..	118
Table 7. List of diary entries referring to autumn or mooncake festival.	132
Table 8. Broad re-categorisation of support types used for data point ‘medium’.	149
Table 9. Variables of auxiliary support groups for the data point ‘type’	159
Table 10. Data points and variables extracted for the analysis of canvas material dataset. ..	162
Table 11. Distribution and count of ‘fibre findings’ (data point) from 32 Cheong Soo Pieng paintings by periods and decades.	164
Table 12. Data points and variables for the analysis of the types of commercial canvasses dataset.	169
Table 13. Organised by decades to understand primed canvas edges visible on the verso of Cheong Soo Pieng paintings.	170
Table 14. Dataset data points and variables for the study of canvas preparation techniques.	175
Table 15. Map showing trends in bast and cotton fibres by decade.	178
Table 16: List of artworks that have changes observed- how was this recorded in the Airtable or documentation record- can this be explained above.	186
Table 17. Data points and variables for the analysis of the underdrawings dataset.	188
Table 18. Data points and variables for the analysis of paint application dataset.	203
Table 19. Paintings studied with count of stratigraphy of each cross-section	208
Table 20. List of eight paintings from the 1970s alongside representative cross-sections featuring a thin paint layer and an ‘uneven’ and thicker ground layer.	213
Table 21: Key material patterns observed by period.	216
Table 22. Summary of correlations for ground layers.	230
Table 23. Summary of correlations for red and yellow pigments.	241
Table 24. List of pigment references used for the test dataset for red and yellow pigments.	244
Table 25. List of common paint extenders to be identified.	246
Table 26. Summary of correlations for blue pigments.	252

Table 27: List of pigment references used for the test dataset for blue pigments.	253
Table 28. Summary of correlations for black pigments.....	257
Table 29. List of pigment references used for the test dataset for black pigments.	258
Table 30. Summary of correlations for white pigments.	262
Table 31. List of pigment references used for the test dataset for white pigments.....	263
Table 32. Feature engineering by machine learning transforming 16 data points into 67 categorical variables.	273
Table 33. List of illumination techniques and assigned diagnosis which will be used to train deep learning dataset.	313

Chapter 1: Introduction

Singaporean art has set record auction prices in recent years, including works by pioneer Singaporean artists, Georgette Chen (1906–1993) and Cheong Soo Pieng (1917–1983), both prominent figures in modern Singaporean art, recognised as ‘Nanyang artists’ (Christie’s 2022)ⁱ. The interest in Singaporean artists is similarly reflected in growing scholarly interest, as investment by national institutions increases and growth in the private art market accelerates. As national institutions and private collectors in Singapore historicise and negotiate the cultural identities of modern artists in the region, examination of the situated influences and relationships that occur within localised contexts has followed. At present, research on Singaporean modern artists has mainly been guided by curatorial and art historical studies based on stylistic and historical narratives, and less so on technical art history. Within the museum and heritage sector, however, case studies in technical art history are growing, including object-centred visual examinations, technical photography, and archival and analytical research on Singaporean ‘Nanyang artists’.

While previous technical art history and conservation research has helped bridge the knowledge gap on the materials and techniques of Singaporean artists and looked towards technical examination for the generation of new material knowledge, but to compare these studies, consistency and structure of the data collection makes it challenging. These records were created for individual artists studies and research projects and were not designed for longitudinal technical art history studies. If longitudinal studies are the goal, where findings can be compared over time, then the development of a robust documentation record where datasets can be extracted and built onto is necessary to allow for expansion. This raises the question of how future studies can develop this material record, what should be recorded, and how individual studies on Singaporean artists can be structured to build material knowledge for longer term relevance and access.

This thesis will examine how data obtained from technical art history methodologies can be analysed to give insights into the artists’ materials and techniques. It will investigate which types of conservation research and technical examination methodologies can be employed to produce verifiable, comparable, and evidential data, through a study of Cheong Soo Pieng and Georgette Chen paintings. The complexity of technical art history and conservation datasets is in how data are drawn from a range of sources which represent both qualitative and quantitative information. As such, the generation of insights from such broad

and interdisciplinary knowledge domains are therefore, challenging. One way to navigate these challenges is the development of a documentation record which can offer structure to data from across various data types to then support analysis is one way to manage this challenge.

Through the study of 67 paintings produced from the 1940s to the 1980s by the two artists, this thesis explores a range of examination methods to produce verifiable data through a semi-quantitative approach that focuses on object-centred data collection as a means to generate extensive datasets required for the comprehensive analysis and insights into the artist's practice. This is necessary because data comparability, relationality and standards are important baselines given the data-rich process and nature of technical examination. Various data types are produced, such as images, text and spectra, that necessitates different modes of interpretation and analysis.

This research expands on existing studies on Cheong Soo Pieng and Georgette Chen, which were undertaken by Gomez Lobon (2010a) and O'Donnell (2014). By adopting a data science methodology, this study proposes a data structure that can be extended to machine learning algorithms to uncover patterns through non-invasive methods, such as documentation records and multispectral technical photography, as well as accessible invasive analysis, such as cross-sections and fibre identification, without solely relying on advanced material analysis. Investigating the materials and techniques of Singaporean artists Cheong Soo Pieng and Georgette Chen, this approach aims to build material knowledge through the collection of evidential data from individual paintings. This can then be transformed and further interrogated to see if new information exists.

Cheong Soo Pieng and Georgette Chen are both *émigré* artists, defined as someone whose migration is often driven by political reasons, having moved from China to Singapore in 1943 and 1953 respectively. While they are recognised as pioneer Singaporean artists for recognition of their artistic contributions, art production has occurred there since the early eighteenth century, as Singapore was a site of connection for several sojourning artists from countries such as China. Researchers Tse and Sloggett (2008b), Mustafa (2016) and Kwa (2017) maintain that the history of easel paintings in Singapore and its broader geographical area of Southeast Asia is relatively recent. Thought to be enabled by Western Europe's early colonialism and trade, art practices were shaped by the socio-political, historical and economic influence on the region and the ecosystem. As such, Western Europe is often used

as a springboard to understand easel paintings in Singapore (Seng 2017). Rather, a 1963 publication in Chinese by Marco Hsü on Malayan art history, has argued that easel paintings were the primary medium for art instruction in Malayan schools and the painting traditions can be traced to the efforts of Chinese artists who resided in Malaya (Hsü 1999, p. 65).

Two of the most influential Nanyang artists, Cheong Soo Pieng and Georgette Chen, both Chinese artists who taught in the Western art department in NAFA and were referred to as Singaporean Nanyang artists. Cheong Soo Pieng (1917–1983) is already recognised as one of the most innovative and influential artists of Singapore’s modern art development in the 20th century (Sullivan 1956). His oeuvre has been well researched from a curatorial standpoint with a major focus on his experimental practice and contributions to the Nanyang style. Georgette Chen’s involvement in the Academy occurred at a turning point when the Academy expanded from having a predominantly local Chinese student intake to taking in international students.

Marco Hsü (1908-1993) came to Malaya in the early 1900s to work as an educator in Singapore. Having a deep interest in the arts, Hsü became a regular columnist in the local Chinese newspaper, *Nanfang Evening Post*, and wrote about the history of art in Malaya in the 1950s and 1960s. *A Brief History of Malayan Art* is Hsü’s fourth book on art in Malaya, with the first edition of Hsü’s 1963 book in Chinese was first translated into English in 1999. This book is critical in the understanding of Singapore’s art history, as emphasised by an exhibition curated around the book in the National University of Singapore’s (NUS) Museum in 2013. One of the more prominent views that can be drawn from Hsü’s book is an awareness of the complexities and cultural nuances linked to definitions of what a ‘Western painting’ is, particularly those produced in Singapore, and the role the Chinese community played in the development of a local art scene. This thesis therefore aims to examine Hsü’s views and the deeper meaning that may be obtained from the material evidence obtained from the visual analysis of 20th century paintings — in this case, the works of art by Cheong Soo Pieng and Georgette Chen.

Like many of the countries of Southeast Asia, Singapore has experienced several name changes and shifting political boundaries. Contemporary art history and conservation literature refers to some Singaporean artists as ‘Malayan’, ‘pioneer’ or ‘Nanyang’ artists; while terms such as ‘Malaya’, ‘British Malaya’ and ‘Straits Settlement’ have been used to

refer to Singapore. These various geopolitical boundaries hint at the multiple identities of Singapore throughout history.

Historically, the terms ‘Malaya’ and ‘British Malaya’ encompassed Malaysia and Singapore. In 1824, Singapore became a British colony. In the late 19th century, Malaysia and Singapore were known collectively as Malaya, which included the Straits of Malacca. Later, under British colonial rule leading into the early 20th century, ‘British Malaya’ was used in reference to the Straits of Malacca, and Singapore was part of the British Crown Colony. In 1942, Singapore was known as ‘Syonan’ during the Japanese occupation. The British Crown Colony was dissolved in 1959 when Singapore was granted self-governance. However, in 1963, Singapore officially became part of Malaysia, following a merger with the Federation of Malaya Sabah, Sarawak, and the Federation of Malaya. It was only for two years that Singapore was part of Malaysia. The years 1946 to 1964, when the artists Cheong Soo Pieng and Georgette Chen were active, were a period of political change in Singapore. In 1965, Singapore’s separation from Malaysia led to a formation of the independent nation as it is today and, following its independence, took the name Singapore. Consequently, the challenge of categorising Singaporean art and its meaning requires careful navigation through time, socio-political change, and the associated identities.

The paintings in this study date from 1946 to 1982. In this thesis, an artwork’s meaning is important if it influences the types of art materials used and the techniques employed. The conceptual, historical and curatorial interpretations are of less concern, although this thesis engages with these themes to some extent, they are not a major focus. Likewise, the geographic terms as they relate to time as noted above, are important considerations. Although there have been many political names for Singapore, the city was mainly referred to as Singapore throughout all the transitions, and this thesis will use the terms ‘Singapore’ to refer to the geographical place of production to frame the discussion of the materiality of paintings and to understand the availability of artists materials and supplies in the region.

Another important term to consider is ‘Nanyang artists’ which is often used to refer to a group of Chinese artists practising in Singapore in the 1940s to 1960s. The term ‘Nanyang art’ has been commonly used as a term that refers to Singapore’s first critical period in art history where local artists attempted to develop a critical art discourse (Seng 2017). Drawing from a broader context, *Nanyang*, a Chinese term translated as the ‘south seas’, took

reference for being south of China, encompassing geographical areas where the Chinese had traded including Indonesia, Malaya (Malaysia and Singapore), Philippines and Thailand (Tay 2020). While the term ‘Nanyang’ itself does not solely refer to Singapore, the term ‘Nanyang art’ refers to an important period in Singapore’s art development, which saw artists consciously attempting to create a local art discourse (Seng 2017). Some of these Nanyang artists, such as Cheong Soo Pieng and Georgette Chen, who had an impact in Singapore’s art development, were conferred ‘pioneer artist’ status.

Through the building of educational institutes and philanthropy, the overseas Chinese community in Singapore made significant contributions (Lim 2012). After the 1940s, the Chinese migrant community’s impact on the modernisation of art practices and the development of the local art scene saw several artist-educators migrating to Singapore. This period saw the migration of Cheong Soo Pieng and Georgette Chen, who moved to Singapore for different reasons in 1947 and 1953 respectively. While Cheong Soo Pieng was invited to Singapore to teach at the Nanyang Academy of Fine Arts (NAFA), Georgette Chen did not know about the NAFA prior to her arrival. Eventually, both these artists became influential Western art educators at the NAFA and had a significant impact on the transmission of art knowledge to students throughout their years of teaching (Hsü 1999, p. 71). They have both been conferred ‘pioneer artist’ status in Singapore and they are also associated with the Nanyang Style of art as ‘Nanyang artists’, as noted above. However, the differences between these two artists in their educational and personal backgrounds may offer some interesting insight into the similarities and differences in their materials and techniques.

More broadly, the study of easel paintings by the Nanyang artists presents an opportunity to develop material knowledge and investigate the degrees of assimilation of artist materials and techniques within the Singaporean art (or Nanyang art) community. Scholarly interest in Singaporean artist materials and techniques has focused attention on the Nanyang artists of Singaporean modern art history. Retrospective exhibitions of Cheong Soo Pieng and Liu Kang (1911–2004) were held at the Singapore Art Museum in 2010 and 2011, respectively, and of Georgette Chen at the National Gallery of Singapore in 2021. Studies have often been institutionally led, with Singapore’s Heritage Conservation Centre’s (HCC) 2019 conference proceedings (HCC 2019) highlighting recent conservation scholarship in this field.

Earlier technical art history research on the Nanyang Singapore artists has also been conducted by Tse and Sloggett (2008a), O'Donnell, Tse and Ahmad (2015), Lizun (2021) and Cusso and Dominguez (2022), but most notably, and relevant to this thesis, Gomez Lobon (2010a), with her study on Cheong Soo Pieng. Although each project followed a technical art history approach, the data collection framework and type of data collected within each of the case-studies, varied. Should a comparison of data be of scholarly interest or a longitudinal study on the art materials and techniques of Nanyang artists evolve, data comparability could be challenging as the individual studies do not often follow the same data collection structure (Newey, Bradley & Lees 1993; Taylor 2013; Taylor & Stevenson 1999).

To the author's knowledge, very limited research in Singapore has focused on works of art from private collections. Notably, most of these studies have occurred within national institutions on their collections and could benefit from the inclusion of material knowledge and technical research drawn from private and lesser-known collections. As such, two fundamental project partners were essential to the study of this thesis: the public collection from National Heritage Board Singapore (NHB), which contains one of the most expansive collections of Southeast Asian paintings, and the private collection of Koh Seow Chuan, who has long been committed to collecting the work of Singaporean artists. From the private collection of Koh Seow Chuan (KSC), 59 artworks were selected by the collector, dating from 1946 to 1982. Five of the eight Georgette Chen paintings studied were from the National Gallery Singapore (NGS), one from the National Museum of Singapore (NMS), one from the National Library Board (NLB) and one from the KSC collection. Both these prominent collections are housed in Singapore and the paintings were studied on-site in Singapore. The plan was to study more works, however, because of the pandemic, on-site studies were interrupted and cut short.

One of the broad fields of enquiry that centres on building an understanding of paintings through technical art history investigation is the use of collection surveys and condition reports, which can shed light on the materiality and techniques across a group of paintings (Bomford 2008). Collection surveys as a tool for risk assessment analysis were popularised in the United Kingdom by Suzanne Keene (1991; Taylor 2017; Taylor & Stevenson 1999). Both authors, Keene and, Taylor and Stevenson, highlight the subjective nature of collection surveys and the reliability of the datasets produced. Although collection

surveys are not the same as a condition report, visual examination is similarly employed where subjectivity may apply. In such circumstances, Taylor and Stevenson argue that the reliability of collection surveys is dependent on the accuracy of the information documented, the formats used, the way data is collected, organised and analysed (1999; see also Taylor 2017). These are the key features of the verification process which is important to any conservation and technical art history research. This means that the design of the data collection process for collection surveys, condition reports or any collection documentation record, is critical for data clarity, analysis and successful collection documentation processes. During the design and structuring of the data collection process, a key consideration for its success is how recorded data from a painting can be verified, quantified, and translated consistently. This includes the identification of the defining properties of a painting such as the construction of its auxiliary support, how the canvas is attached to the auxiliary support, if there are underdrawings that can be uncovered under reflected infrared photography, and testing whether the same observations and properties are consistently recorded during documentation processes.

As such a vital driver for this research was the assessment and development of a documentation record for the study of paintings. One practice is the recording of free text in a condition report which is drawn from visual examinations. Undertaking analysis from unstructured data such as condition reports can work for smaller collections and sample sizes, and can produce incisive and compelling analysis. However, it has limited longevity for longitudinal conservation research projects, when further data analysis is intended with a long-term goal of building onto the dataset. In this study, further explanation will be provided on how technical examination data is recorded in Chapter 2.5, but briefly, free-text observations will be directly recorded from the paintings to form part of the raw data collected. The raw data will be structured and developed using a set of terminologies to understand the painting's defining properties. This is key to the consistency and reliability of the documentation record in this research.

For this study, 110 data points, each representing defining properties of a painting, are collected, and recorded in a documentation record, which are discussed in further detail in Chapter 2.5. Similar to a condition report but in an extended and/or more structured format, these data points are organised following a painting's stratigraphy from the auxiliary support, primary support, ground layer, paint and to the surface layer. The data points further record

observations on the paintings construction, techniques, artist intention and changes, which are gathered from descriptive visual examination, the use of different technical photography techniques, and various material analyses. In structuring how visual examination, technical photography and research evidence is recorded, it is argued that the type or quantity of data to be collected can help us to understand the defining properties of an artwork. For example, paintings are documented using reflected infrared photography, from which the image is then studied for whether there are any evidence of underdrawings and if there are changes in these underdrawings observed. These observation are then recorded in text in the documentation record. From this, a baseline can be identified, such as whether underdrawings are common practice for an artist's paintings, and this enables comparative analysis. Similar to many database formats, this includes the use of fixed terminologies as value descriptors for each data point. The aim is that, by providing a structured format for documentation, discrepancies will be minimised and standardised ways to record information developed. These value descriptors will be used to interpret occurrences, observations, and findings, documented in a text-based documentation record and as mentioned, will be elaborated on in Chapter 2.5.

Data were collected over two phases: the first phase focused on non-invasive techniques carried out onsite in Singapore, and the second phase was invasive analysis, in which removed samples were analysed through embedded cross-sections and ESEM-EDS in the University of Melbourne to gain a deeper insight. In the first phase, the non-invasive techniques such as visual examination and technical photography focused on developing an understanding of the artist's materials and techniques. Both these techniques are cost-effective and have the potential to generate large amounts of technical data. Using a visual examination process as one would use to carry out a condition report, the visual examination of each painting follows the 110 data points to record the paintings defining properties. As mentioned, some details are first recorded in a free-text documentation format for later input into a documentation record using fixed terminologies. This includes the technical photographs and the data obtained from visible light illumination such as transmitted, specular and raking, ultraviolet fluorescence (UVF), reflected infrared (IRR) and transmitted infrared. Each technical photograph contributes towards an informed understanding of the materials and techniques of the painting and its present condition. As such observations from technical photography are also reported in the documentation record.

During the onsite examination in Singapore, fibre and paint samples were removed from Cheong Soo Pieng paintings for further analysis, with the owner's consent. Where appropriate, these samples were analysed in the University of Melbourne, using various analytical methods including the embedding of cross-sections, fibre analysis, optical microscopy and advanced material analysis, achieved by using three instrumentations such as an environmental scanning electron microscope (ESEM) with an attached X-ray energy dispersive system (ESEM-EDS), Fourier transform infrared spectroscopy-attenuated total reflectance (FTIR-ATR) and handheld X-ray fluorescence (pXRF). Together, these techniques provide an in-depth understanding of the artwork's materials. Results from elemental analysis are discussed in this research.

The availability and use of these techniques for more detailed investigations, however raises several considerations, such as permissions for sampling and the circumstances of research within institutions or private collections, access to scientific infrastructure, and the costs associated with undertaking advanced material analysis. In terms of best practices, embarking on advanced analytical techniques without a good understanding of the works of art being examined might not be very useful if visual examination data and situated knowledge is not initially recorded. As with any technical art history research, an interdisciplinary record of primary and secondary sources, historical research and a suite of technical examination analysis is needed to build a relational understanding of the artist's processes and material choices. Therefore, as part of this study there is a greater focus on non-invasive visual examination and technical photography of both Cheong Soo Pieng and Georgette Chen's paintings and the further interrogation of data. This includes the analysis of qualitative data, such as technical images, and the data obtained from visual examination.

The methodological approaches and investigative methods that have been adopted in this research are influenced by the characterisation of objects as described by Appelbaum (2012) and the object centred approach by Eastop (2006) and Joy (2009). Therefore, equally important to contextualising material findings is the access to archival primary sources, such as exhibition catalogues, digitised archives, newspapers, and letters from the artists, some of which have yet to be included in existing studies. Such sources were readily available for Georgette Chen's painting practices but the same level of access to archival records was not possible for the works of Cheong Soo Pieng. Limited access to personal records and accounts by the artist is a challenge to any research on Cheong Soo Pieng. Working with so few

primary sources might therefore present limitations when attempting to build first-hand knowledge of the artist's practice, such as the significance or identity of materials or the artist's "specific modes of making" (Cotte, Tse & Inglis 2016, p. 108).

Therefore, this thesis centres on the collection of data through the visual examination, technical photography and analysis of 67 paintings painted by Cheong Soo Pieng and Georgette Chen. It examines how data can be transformed from raw information into data-driven insights on the materials and techniques of the studied works of art by adopting a data science framework. This approach focuses on data understanding, data preparation, and the data requirements prior to collecting data and it ensures that the fields are standardised and fixed. To discover any patterns and trends that will emerge across the 67 paintings studied, data analysis and data visualisation through graphic visuals such as charts and diagrams can be helpful. The insights produced will support discussions on any degree of assimilation such as the availability of artist materials to the materials used or techniques employed within Singaporean artist localities.

This study is divided into three sections. Part 1 (Chapter 2) focuses on the three major theoretical underpinnings of the research methodologies and methods to develop a comprehensive approach. Chapter 2 considers what it means to secure the artist record, and discusses the object biographical approach and how it frames the data collection techniques and how data is structured in the database. This section is dense but necessary, as it outlines how insights into the artists' practice are arrived at, and the verifiability and quality of the collected data which form the backbone of this research and justify its adaptation for future projects.

Part 2 (Chapters 3 to 5) presents material evidence from the paintings studied and contextualises them within the local art landscape. Chapter 3 begins with the historical and cultural context of the development of local art and the role of the Chinese community in Singapore, and presents archival and material evidence of the artist materials and suppliers in Singapore. Building onto the methodological and historical context, Chapter 4 reports on the patterns identified in the study of Georgette Chen's materials and techniques and the research methodology employed, given the smaller study size. Chapter 5 examines the patterns found in the study of Cheong Soo Pieng's paintings. Preliminary findings of Cheong Soo Pieng's materials and techniques have been published in Tay (2020). Chapters 4 and 5 are informed mainly by the visual examination and technical photography which provide most of the

findings, and explore whether there is value in a broad survey methodology for data collection and its feasibility for building a material record, which will be addressed later in this thesis.

Part 3 (Chapters 6 to 7) builds on the descriptive data and material evidence of Cheong Soo Pieng with the findings from material analysis presented in Part 2 and tests statistical inquiries and unsupervised machine learning models to improve methodologies for knowledge discovery. Chapter 6 focuses on the ground and canvas of Cheong Soo Pieng's paintings and explores methodologies to cluster the results from material analysis and a broad examination to discover any relationships. The intention is to identify whether distinct clusters can be drawn from the material and technical aspects of Cheong Soo Pieng's practice, and if so, add value to existing curatorial categorisations. Chapter 7 reviews the methodologies employed and proposes various avenues of deep learning to improve the workflow for the broad examination of artworks. It considers the use of neural networks to provide diagnostics for images and to identify differences between technical photographs, with the aim of improving data consistency to expand the record in the future.

This thesis continues the work begun by many other scholars, collectors, curators, historians, and researchers to build an understanding of Singaporean art paintings and history. Through the generous support of Koh Seow Chuan and YH Conservation Studio, a space dedicated to studying works from private collections was equipped with technical equipment and made available for the project's duration, while further material analysis utilising scientific instrumentations was supported by the Grimwade Centre for Cultural Materials Conservation (Grimwade Centre) and the University of Melbourne (UoM). Colleagues at the Heritage Conservation Centre supported the study of Georgette Chen paintings and provided pXRF data of the ground layer analysis, building onto the Georgette Chen research which continues today. In addition, the National Gallery of Singapore (NGS) provided access to their extensive Research Centre, which has added depth to the research through access to archives of digitised exhibition copies and the letters of Georgette Chen.

In summary, this research hopes to further our knowledge and understanding of this history by uncovering new aspects of Cheong Soo Pieng and Georgette Chen's attributed materials and techniques and the material supplies in Singapore from the 1940s to the 1980s. The data collected has the potential to be further analysed and will be helpful for future research. For instance, the description of the generation of these datasets is important to

inform the exploration of machine learning algorithms and, through its data-rich study of paintings, this work presents various opportunities for conservation technical examination to consider in the future. This study aims to collect as much data as possible from the study of paintings through cost-efficient and accessible technical examination methodologies, in order to build a robust dataset that can be analysed to produce insights on the materials and techniques of Cheong Soo Pieng and Georgette Chen. An article outlining this thesis's research methodology has been published (Tay 2021). It hopes to inspire further technical art history research around the Southeast Asian region and provide an inclusive environment for research, inside and outside of institutions.

Chapter 2: Research Design

2.1 Introduction

This research investigates a series of paintings by Cheong Soo Pieng and Georgette Chen by studying 67 paintings from these two artists using a series of methodical, analytical studies such as visual examination, technical photography including multispectral imaging and advanced analysis to identify patterns. The gathering of data from each painting to establish an understanding of the artist's practice and the features attributed to each artist, is central to the research design. The study adopts the object biographical approach as part of the technical art history framework. The documentation record consists of qualitative and quantitative data. Most of the data are concerned with qualitative determinations; some of these forms include curatorial categorisations of an artist's oeuvre, the interpretation of scientific analysis or the artistic techniques visually examined. The proposed methodology focuses on analysing qualitative data quantifiably to reveal insights into the artist's oeuvre.

As discussed in the introduction, the growing body of technical art research in Singapore highlights an interest in technical and material knowledge. Some of these studies such as Cusso and Dominguez's recent paper on Georgette Chen's research have directly stressed the need for a structured data collection model to build an artist's material record (2022). Another such study is Tse's (2008) PhD research, which investigated whether local productions were mimetic copies of Western art practices through a survey of more than 200 artworks. This included studies of approximately 20 artworks each of Cheong Soo Pieng and Georgette Chen using visual examination and materials analysis (Tse 2008). As the research criteria for the database structure were not the same as this study's aims, it was not used as basis for this research.

In this study, eight paintings by Georgette Chen from four collections in Singapore and 59 paintings from the Koh Seow Chuan private collection consisting of Cheong Soo Pieng and Georgette Chen, all dating from between 1943 and 1983, were examined. While the artists had developed their artistic careers before their arrival in Singapore, these paintings were created in Singapore. Consequently, they are used to understand the range of materials, techniques and practices employed in Singapore and the local circumstances and influences on their choices.

This chapter aims to set out the technical art history methods and conceptual framework used to produce verifiable and evidential data about the materials and techniques used in Cheong Soo Pieng's and Georgette Chen's paintings, following which it will outline how such insights are gained.

The research design can be broken down into four main sections, each of which discusses and describes the methods used in this investigation. The first section begins with a discussion on the quality of the record and how it contextualises the data collection strategy using an object-centred approach. The second section outlines the documentation record, which is key to the data collection gained from the examined paintings. It discusses how the record is designed, the data structure and the ontological framework behind it. The third part then summarises the various non-invasive and invasive examination techniques employed, including visual examination, technical photography and advanced material analysis. An underlying concept of the research design is to prioritise accessible and cost-efficient means to generate as much data as possible and explore ways to efficiently study and create a robust record that can be built on in future research. The final section focuses on how the prepared data is translated into insights through data analysis. This covers the use of data visualisation tools to visualise the data gathered by producing visual graphics and how the prepared data is used for machine learning algorithms to uncover patterns.

2.2 Securing the quality of the material record

The technical study of paintings attempts to unravel the influences on artists and their materials. In varying degrees, the study of works of art can provide information on artist techniques and materials, an artist's stylistic development, and aspects of social, political or personal history (Getty Conservation Institute 2013, p. 2). Principally concerned with the processes of artmaking through technical and documentary means, such studies are undertaken to understand the physical materials and structures of works of art, how they are prepared, used, combined and manipulated. Technical art history as a method gathers empirical knowledge through many forms, such as the gathering of recorded visual examinations or the rigorous scientific analysis of an object. While single object-based case studies are helpful, their nature makes it challenging to identify relationships with other objects and contexts or different timeframes. As such, in this research, emphasis is placed on the importance of studying a group of paintings to gain a broader overview and better contextualise and inform the findings.

Primary and secondary sources are used to situate the findings, balancing the visual examinations from a vast range of works with scientific validation and close analysis. As Bomford states, the data generated can clarify and reconstruct long-past sequences of creation and evolution or later change and decay, drawing similarities to the object-centred approach (Bomford 2008, p. 199; Nadolny 2012). By adopting a technical art history approach to various modes of inquiry, this research design offers a model for understanding Cheong Soo Pieng's and Georgette Chen's materials and techniques through a study of their paintings. The final documentation record that will be described in Chapter 2.5 will enable future inferences to be made from the data collected from other paintings by the artists. This may possibly suggest a pattern or highlight any deviations, presenting a more robust method of understanding the paintings under investigation. This discussion begins with understanding how the quality of the documentation record can be optimised and the metrics that can be used to improve its quality and moves onto the object-centred approach which underpins how the study of paintings is anchored, and in doing so, reveal the necessary data to collect.

The quality of the material record

The material record is essentially a record made of data. However, data on their own are stagnant and require data transformation for meanings to be evolved through data visualisations, which require a data structure to produce verifiable insights. How and what is required to make meaning from data to create value? Establishing the context of the objects is essential to understand a group of objects collectively, allowing each object to be driven by context. As the analysis and insights generated are mainly dependent on the quality of the record, the data should likewise be of good quality. The quality of the record depends largely on how much information about the past and present has been preserved and is accessible, the paintings that are available for study and the data that can be collected. Access to paintings for study plays a significant role in the sampling interval and subsequently in the amount of data generated. This segment discusses the foundations of the object record, such as the framework behind the data collection, and the challenges in analysing the record.

Data collected through visual examination and technical photography methodologies are qualitative but offer a pathway towards a quantitative and systematic method. However, the quality of the data is key, as the worth of the study is commensurate with the amount of information a dataset contains and the clarity of the data. Drawing upon Perreault's (2019, p. 24) framework for archaeological underdetermination concerning the quality of scientific

data, the four main features to ensure the quality of the record are: (1) scope, (2) sampling interval, (3) resolution and (4) dimensionality. Table 1 below displays these features contextualised to the scope of this research.

Table 1. Metrics of the quality of the record used for this study.

Scope	The time period of 1940s to the 1980s in Singapore
Sampling interval	The interval of years between each painting
Resolution	The number of paintings represented within the dataset
Dimensionality	The number of independent data points of the painting that have been collected (documentation record comprising of 110 data points).

In terms of the scope, sampling interval, resolution and dimensionality of a dataset, there are metrics that can capture how much information the dataset contains by describing the properties and relationships between the analytical units that make up the dataset. These features can be adapted to describe the quality of any set of empirical observations by giving an overview of the dataset with an emphasis on the dimensionality and extent of data collected (Perreault 2019). To improve confidence in the data collection and its findings, these features must be critically examined to understand the depth of the dataset.

Furthermore, variations within each feature can affect the quality of the analysis and the use of non-standard terminologies can limit data comparability between studies in past or future research. For instance, in this research, there is the question of how studying a much smaller number of eight Georgette Chen paintings will affect the quality of the record, the type of analysis that can be performed, and the choice of visual graphics to present the data, even if the number of data points studied is the same as for the 59 paintings of Cheong Soo Pieng. Variations in the sampling interval and resolution of the data can affect the completeness or consistency of the data, which directly influences the quality of the data and the outcomes of the analysis. Considering that the quality of the two features, sampling interval and resolution, heavily depend on the quantity of paintings that can be accessed for study, the dimensionality of the data should be consistent and large enough to produce quality insights. As such, the dimensionality of the dataset, is structured in such a way that consists of 110 data points, to optimise the quality in the documentation record. In summary, while the

quality of the record is dependent on the amount of data collected as shown in the metrics listed in Table 1, the depth of the dataset can be influenced by increasing the dimensionality of the dataset characterised as the number of independent data points obtained from the painting. In view of all that has been discussed so far, the following section provides an overview of the object-centred approach, which is used to frame the defining characteristics of a painting that will make up the data points to be collected.

An object-centred approach to creating the material record

In creating the material record, a range of technical examination methods are employed alongside the investigation of primary and secondary sources to produce data for the study. As the research design uses an interdisciplinary and materially focused methodology, it was first informed by the conceptual underpinnings of the Arjun Appadurai (1986) and Igor Kopytoff's (1986) object biography approach, which considers the junctures of an object's construction to its present through contextual links between people, place and time (Hodge 2017). Centring on the 'material turn' grounded in object biographies and material culture, object biographies have emerged within material culture studies to reveal and understand object agency and has sparked new and often unexpected insights into the nature of objects and the people who produced, used, valued, and preserved them (Hölling, Brewer & Amman 2019; Kopytoff 1986). An increased interest in the materiality and materials of artworks and artefacts leads to questions around permanence, authorship, and authenticity, and has grounded such interest in studying objects, their properties, the materials they are made of, and how these material facets are central to understanding cultural and social relations (Hölling, Brewer & Amman 2019).

The writing of an object biography is a big undertaking and requires a wide variety of sources to draw information about "an object's genealogy, its manufacture, use, possession, exchange, alteration, movement and destruction or preservation" (Schamberger et al. 2008, p. 277). While this conceptual underpinning was not utilised fully in this research, it does have the potential to extend the current research for future studies. Currently, the research adopts an object-centred approach towards the development of the documentation record. Eastop argues that each object has a potential 'evidential value' (2006, p. 519). What is considered important to document as evidence can significantly influence the way objects are investigated, documented, preserved, and presented. For instance, Villers (2000) noted that the documentation and study of the textile substrate (canvas) of easel paintings was as

important a consideration as the study of the painted surface and underdrawings for documentation and attribution studies. The inclusion of these details can improve dimensionality of the record.

While material characterisation may form a critical element in the development of a documentation record, developing a contextualised and informed perspective of a painting requires the inclusion of non-material attributes as part of the dataset. These are drawn from primary sources, such as archived letters and oral history interviews, as well as secondary sources such as curatorial literature. For instance, in the case of Cheong Soo Pieng, curatorial categorisations are recorded for each painting as a data point. While Georgette Chen does not have distinct curatorial categorisations, information on her painting techniques was found in her letters, offering confirmation of material observations and could likewise be incorporated as data points. Including both technical material data and art historical and curatorial categorisations as data points improves and contextualises the dimensionality of the dataset.

The research aim is to collect data from the paintings to understand Cheong Soo Pieng's and Georgette Chen's art practices, both individually and comparatively, while building an understanding of the availability of art materials in Singapore. Thus, framing the study of objects within their contexts of people, place and time, provides solid grounds for adopting the object-centred approach to inform the design, type of data points and structure of the data collection model used in this thesis. The goal is to evaluate and identify how these attributes connect and how their values can be extracted and quantified through a structured data model that relies on the identification of core attributes, baseline attributes, their sequencing and relationships. In particular, this study brings clarity to the record by proposing 110 data points as defining characteristics of a painting that record original materials and changes to those materials, as discussed below.

2.3 Data collection techniques

So far, the discussion has suggested that the object-centred approach provides a suitable framework for the data collection, in line with building a robust material record of Singaporean paintings. This has provided insight into the type of data that needs to be collected, which leads to a discussion of the range of techniques used to generate and obtain the data. This section is divided into three parts. The first discusses the painting criteria and the parameters for the paintings selected, and clarifies some of the terminology used to

describe the paintings. The second and third parts provide more detail about the non-invasive and invasive methods used in this study, respectively. As described, non-invasive methods include the visual examination of paintings and technical multispectral photography using a modified DSLR camera, and using primary sources, such as exhibition catalogues, oral history, and archived artist letters or diary entries. This research was undertaken in Singapore. Where sampling was permitted for the Cheong Soo Pieng paintings, material analysis of these samples was undertaken in the University of Melbourne. These invasive methods included the preparation of cross-sections, fibre analysis and advanced analyses, such as pXRF, FTIR-ATR, and ESEM-EDS.

Painting selection criteria

The scope of the research focuses on works of art produced in Singapore between the 1940s and 1980s by Cheong Soo Pieng and Georgette Chen as shown in Table 1 (page 39), which describes the quality of the record. Curatorial associations with the Nanyang Style of art during this period refers to works embodying both Western and Eastern art materials and techniques (Sabapathy 2018). However, in designing the data collection method, it was challenging to classify these techniques, as they were found to be concerned with the visual style and interpretations of the time. Therefore, the research adopts an understanding that Western art mainly concerns easel paintings while Eastern art concerns Chinese ink on paper. This move is not intended to discount or ignore the cultural influences on art practices; instead, it focuses on the meaning-making of data through the study of materials and techniques as part of the research methodology.

There are broad meanings and connections with the terms used to describe paintings in past research on Singaporean paintings. Winter's (2008) book, *East Asian Paintings: Materials, Structures and Deterioration Mechanisms* is one of the first conservation books in English on the topic, which has expanded scholarly knowledge of the material character of Asian art. However, it mainly addresses paper-based works of art often painted in ink, particularly from China, Korea and Japan.

The terms 'Western art', 'Western painting', 'Western style paintings', 'Western informed paintings', 'modern paintings', 'oil paintings', 'easel paintings', or 'canvas paintings' are often used to describe 20th century works of art, typically paintings that share a European or American tradition. The terms can be theoretical concepts used in Western art

theory or they can be used to describe the physical fabric of works of art, such as the flexible support used, such as canvas, or ‘oil’ paint. Given the broad associations, colonial legacies and conceptual meanings associated with ‘Western painting’, which also raises the question of what is non-Western, the term will not be used. Tse’s work focuses on the physical structure of paintings and not their socio-political aspects and refers to ‘canvas paintings’ in her survey as “oil paintings” or “oil paintings on canvas paintings” or “Western art” (2008, p. 2). To improve clarity in the terminology used, this thesis uses the term ‘easel paintings’ to describe the physical elements of the works of art examined. Easel paintings are movable works of art and are paintings on hardboard or canvas with any applied media. This research uses the term ‘canvas paintings’ as well as ‘easel paintings’ to include paintings on both solid supports and canvas supports.

To improve the resolution of the dataset, this research prioritised having access to a broad range of paintings, and a total of 67 paintings were studied. At the beginning of this project, the paintings selected were limited to oil on canvas paintings. However, as the project developed after the pilot study, the paintings selected included mixed media on canvas and works on hard support, which were used as part of Cheong Soo Pieng’s artistic practice. It was found that a variety of media were used in the period investigated or the scope of the study; and as medium classification is not possible unless material analysis is undertaken, they were included. As such, terms such as ‘oil on canvas’ or ‘acrylic on canvas’ are used by first relying on their catalogue information, while its primary support is informed by the study’s visual examination.

In summary, the criteria for selected paintings were as follows:

- easel paintings of Cheong Soo Pieng’s and Georgette Chen
- paintings that were painted in Singapore
- paintings from private collection to be selected by the collector
- paintings from institutions to be selected based on availability

Through this process, 100 paintings by Cheong Soo Pieng and Georgette Chen were identified, although only 67 were ultimately examined, due to the pandemic. These included 59 artworks from Cheong Soo Pieng and eight from Georgette Chen. Given the timeframe of the artists’ practices, the period studied was from the 1940s to the 1980s. This period includes the development of the local Singaporean art landscape of the 1950s and the period of post-

war industrialisation when modern paints became more widely available. These are useful anchors and enable references to be drawn from the pool of literature on technical art history studies of post-war artist materials and techniques in Singapore as well as the material behaviours and trends of modern paints. The works of art from the Koh Seow Chuan private collection were selected by the collector himself, while the Georgette Chen paintings belonging to the NGS, were selected by the researcher according to their availability for study. The complete list of paintings under investigation in this study is in Appendix A.

Non-invasive examination

Technological advancements shape many of the developments in conservation examination and analytical techniques. As instruments become more accessible, more conservators and curators benefit from understanding works of art through accessible technical examination and materials analysis (Tilley et al. 2006, p. 21). Developments in instrumental techniques have allowed more cost-effective options and the exploration of non-invasive analytical techniques (Macbeth 2012; Stuart 2007). As well as scientific analysis, on which convention technical analysis places significant emphasis, collection surveys and condition reports are also a critical part of the technical examination and involve the extensive gathering of information. For this research, where the paintings were located overseas, accessible and non-invasive methods were employed as a major part of the data collection. This section outlines the range of non-invasive methods that were used in this research for the 67 works of art examined in Singapore. The fieldwork was conducted over eight trips across two years, which demonstrates the importance placed on the process of data collection. Details of the non-invasive methods of visual examination and technical multispectral photography are discussed below.

Visual examination and written documentation

The uses of written documentation in conservation activities range from recording the condition of the work at the time of the study to influencing a painting's attribution (Sherring & Barnott-Clement 2021, p. 68). Written documents fall into two main categories: 'reports' and 'records'. Reports are often used to relate details or report information of an event in a more descriptive format while records are data that often is created to constitute a piece of information on the past (Finn 2012). Although these terms are often used interchangeably and draw on one another, there is a distinction between the two categories in terms of differences

in the content and format of the written documentation (Finn. 2012, p.271; Sherring & Barnott-Clement 2021, p. 68).

In this study, as the first point of examination, each painting in the collection survey undergoes visual examination where free-text observations are recorded into a documentation report which will later be translated into 56 of the 110 data points in the documentation record. At this stage, free-text observations describe occurrences and include visual details such as how a canvas is folded or cut, whether the work is signed and the signature's location, any inscriptions found on the verso of the painting, artwork dimensions and more. These observations are then transformed from free text into the documentation record which uses fixed categories to structure the data. (This is discussed in more detail in Chapter 2.5). The main feature of the visual examination is to generate and collect data broadly across the 67 paintings in order to reduce reliance on advanced material analysis, which may not always be accessible. In undertaking this verifiable and evidential based mode of investigation, the value of non-invasive analysis is explored.

Multispectral technical photography

Building on the visual examination is the use of technical photography, which extends observations beyond what is visible to the naked eye and can offer insight into aspects of objects, such as surface topography, and can help with materials identification, as well as registering changes in the painting process. The American Institute of Conservation (AIC) offers a helpful guide to digital photography and conservation documentation with help for setting up digital imaging (Warda 2017). However, the sourcing for equipment available locally in Singapore was challenging as some of the equipment such as an ultraviolet (UV) light stand, various camera lenses and tungsten lighting were not readily available and had to be purchased from overseas which added to the costs. As part of the research collaboration agreement, the cost and purchase of the equipment was supported by Koh Seow Chuan. In summary, the available budget and time, and the portability of the available equipment influenced the choice of multispectral imaging techniques used in the research for all paintings examined in this research.

Given the length of the study period and the multiple on-site examinations, the ability to reproduce the exact settings for multispectral imaging in all eight field trips was crucial to the study. Factors such as the consistency of light sources and the quality of produced images

can affect the accuracy of the visual analysis from technical photographs. Multispectral techniques aid and add value to the visual examination by providing insights into surface topography, possible materials used, and any changes made during the painting process.

To minimise costs, a pre-used DSLR camera (Nikon D800) was purchased and underwent a full-spectrum modification by Imaging By Design in Melbourne. The modification included a replacement of the camera's internal IR filter with a clear filter, allowing the camera to capture the entire light spectrum.

The following technical images were produced for each painting analysed:

1. visible light photography of the recto and verso in normal illumination
2. visible light photography of the recto and verso in raking illumination
3. visible light photography of the recto and verso in specular illumination
4. visible light photography of the recto and verso in transmitted illumination
5. reflected infrared digital photography (780nm) of the recto
6. transmitted infrared digital photography (780nm) of the recto
7. ultraviolet-induced visible fluorescence (365nm) photography of the recto.

To ensure consistency and comparability between images, all paintings were photographed with an X-Rite ColorChecker Passport which was later used to colour correct images. The digital images were colour-corrected following the Grimwade Centre for Cultural Materials Conservation (GCCMC)'s photography guidelines for conservation documentation by adjusting the RGB levels to 200 (+/- 5) in Adobe Photoshop which reduced variation between photographs. Photography in visible light was illuminated with two LED studio lights and shot with a 35mm single focal length lens and an XNite CC167 filter. Reflected infrared digital photography (IR) with two incandescent lamps was taken with a 67mm zoom lens and XNite 780nm filter as well as an XNite 1000nm filter. Illuminated by two UV-LED floodlights at 365nm, ultraviolet-induced visible (UV) fluorescent imaging was carried out with a 67mm zoom lens and both an XNite CC1 filter and a HOYA UV-barrier filter. The specifications of each technique are presented in Appendix B. Observations from the digital images are fed into nine data points of the

documentation record which uses a set of fixed variables to categorise the findings. This transforms the visual features from the images into text-based data which is then used to identify patterns within the dataset and to create a data-driven and meaningful understanding of the paintings.

Primary sources

Primary sources, such as digitised newspapers, exhibition catalogues, artist letters and oral interviews, played an important role in interrogating historical data. Such documents helped to contextualise the material findings, contributed to the data points entries and to confirm the availability of artist materials and suppliers in Singapore before the 1980s. The NGS Resource Centre was a valuable resource in studying exhibition catalogues and artist letters and diaries. Historical printed materials allow contextual investigation into the past to locate materials and artworks to provide a better understanding of the material historical context. For this study of Singaporean art history, knowledge of the Chinese language was helpful in understanding printed advertisements, given there was a strong Chinese community in the art scene during the period studied. These advertisements proved to be one of the most useful resources for understanding the trajectory and development of the Singaporean art scene, as few artist sources have been archived in the resource centre. However, recently digitised carbon copy letters and diary entries of Georgette Chen were available, and these were accessed during the fieldwork. They also provided invaluable background and context to the paintings and materials and painting techniques used.

Archived newspapers were searched for artist material suppliers using the NewspaperSG, an online resource of current and historic Singapore and Malaya newspapers where digital archives of English, Chinese and Malay language newspapers published between 1831–2009 can be searched (Kia et al. 2014, p. 2). This initiative by the National Library Board Singapore has made over 20 million published newspaper articles accessible through searchable text analytics.

Invasive material analysis

Following the non-invasive analysis, samples taken from the Cheong Soo Pieng paintings were analysed further. In recent years there has been a growing number of studies into the artist materials and techniques of Singaporean artists. This has been facilitated by conservators, mainly within public institutions, having increasing access to benchtop

analytical systems, which can be used for either examining minute samples from artworks or for non-destructive, non-sampling techniques. These systems are becoming standard within museums and institutions with research capacity such as the HCC. But considerable dedicated research is required to develop standards and historical studies to provide context for analysing results. Unfortunately, no existing paint materials from the artists studied were available for baseline comparisons.

The conservation discipline demands a balance between scientific knowledge and contextual knowledge. Science can contribute to conservation in three ways. First, it provides information, particularly about materials and their properties. It offers analytical and imaging techniques — a method of inquiry that can be applied to all categories of information. The toolsets provided by science for conservation are one such means of investigation. However, scientific data alone on artist materials without drawing upon other knowledge sources to offer context, such as the historical context or the artist's archive, provide little interpretation of the findings. Scientific data does not position itself in context and thus interdisciplinarity and other forms of knowledge are needed to contextualise the meaning and its relevance to the object studied. As such, this research draws upon various sources of information to value add any scientific findings. This includes research into the artist background and the conditions that shaped their practice, access to primary sources, and drawing upon observations through visual examination of paintings.

One of the objectives of applying science to the examination of objects of artistic and historical significance is to understand the materials they were made of and the causes of their deterioration, in order to tailor the conservation approach. The inclusion of scientific examinations in the disciplinary development of technical art has influenced how we think of objects through studying materials and techniques, and using integrated investigation and dialogues methods that can bridge scientific research and art history. Interpretation of findings based on scientific information plays a prominent role in knowing the object and in meaning-making.

For this study, a sequential analytical pathway was developed for the paint samples that allowed for information to be extracted without affecting the next technique used. As there was no access to on-site scientific analysis, non-invasive techniques such as FTIR-ATR and p-XRF were used to study the removed samples. Some techniques destroyed the samples in the process such as FTIR-ATR, while some were embedded into a cross-section

for optical microscopy. Material analysis was conducted on-site at the University of Melbourne. Organic and inorganic elements of the samples were studied using instrumentation analysis such as the pXRF, FTIR-ATR and the ESEM-EDS. These analytical techniques have been most used in material characterisation (Stuart 2007; Townsend & Boon 2012). Given the limitations of time, only findings from the elemental analysis were discussed and not all the samples involved in this study underwent the same level of material analysis due to a combination of circumstances, such as the pandemic lockdowns which limited access to the laboratories. Therefore, the decisions behind the analytical instrumentation and the analysis of the resulting spectra were based on the criteria of gaining deep insights on the canvas and ground layers. This provided an analytical pathway to deepen the understanding of the materiality of the ground and canvas layer in Cheong Soo Pieng's paintings through a quantifiable interrogation, supporting and increasing confidence in the interpretation of findings through a data-driven approach. The various material analyses are detailed in the following sub-sections.

2.4 Sampling and analysis

Micro samples are well-suited to provide information on the stratigraphy of art objects. The chemical composition of individual layers can be determined using complementary techniques. Areas for sampling were first subject to non-invasive examination as this provided crucial information on the materials present, including the distribution of a medium over the painting. Several representative samples of a painting's stratigraphy, fibre strands and ground only samples were removed from each painting. The selection of appropriate sampling sites as well as the quantity of samples removed were crucial steps, given the circumstances of overseas fieldwork in which it was unlikely the painting could be retrieved again. Where possible, and when research questions focused on the materiality of individual layers within a paint matrix, it was necessary to remove a sample from the cross-section for analysis.

Sample removal and documentation method

The samples were acquired using a hand-held digital microscope and tungsten needle. As the samples were small, they were vulnerable to loss, dissociation, and contamination, so each sample was given a unique identifier ID and stored in a labelled glass vial with its location (x,y coordinates) recorded. While the location of each sample removed was recorded

in a document as well as mapped onto an image of a painting with the x,y coordinates for future analysis. Nonetheless, room for error and misattribution is still possible.

All samples in glass vials were stored in a locked and secure cabinet. To better understand the samples, they were photo documented in both verso and recto in their unprocessed states using a Dinolite handheld microscope.

For fibre analysis, samples were removed from canvas and hardboard support when accessible. Fibre strands from the samples were observed under transmitted light using optical microscopy at 100x magnification. Where applicable, findings were then recorded into the documentation record.

Sample analytical pathway

The documentation of each sample after removal was valuable to the decision-making process determining the research use of the sample and whether it was possible to cut the samples in half prior to any analysis to maximise their research potential. As some analytical instruments involved destructive techniques, samples were cut in half to maximise analytical techniques wherever possible. The analytical pathway of the material analysis of a sample first considers non-destructive instrumental analysis such as pXRF or FTIR-ATR. This is then followed by the preparation of cross-sections. Unexamined samples are archived for future analysis.

Cross-sections

Following the photo documentation of the samples, samples that were found to be representative of the painting were then selected for cross-section analysis. The samples were embedded in a polyester resin and hand polished prior to examination. Three to eight samples were taken per painting, to determine which had a representative ground layer. These were then embedded in polyester and prepared as cross-sections by sanding down with a micromesh up to 12000 grit along the transverse plane. Each cross-section had the sample's unique identifier printed and embedded in the resin to reduce the risk of dissociation. The cross-sections were observed with an optical microscope (OM) in reflected visible light under magnifications x100 to x400 and were photo documented. Observations of cross-sections under OM were primarily used to study the entire stratigraphy of the sample to assist in understanding the layered structure of a painting. Due to time constraints, cross-section

samples were studied in visible light to examine the stratigraphy, which revealed details about the materials and techniques used. Features that were recorded as data points included the thickness of the paint, number of paint layers, smoothness of the ground layer, and whether the paint was applied wet-on-wet or wet-on-dry. These cross-sections were also analysed using ESEM-EDS. In future research, these cross-sections could be re-examined for further analysis, including across a fluorescence microscopy and FTIR microscopy.

Fourier transform infrared spectroscopy with attenuated total reflectance (FTIR-ATR)

FTIR spectroscopy is a valuable tool to identify prominent peaks of compounds present in paint stratigraphy. It is capable of obtaining quantitative and qualitative data from both organic and inorganic materials. With FTIR-ATR, the sample is placed in the path of a beam of infrared radiation which penetrates through the sample and is absorbed by the sample. The spectrum is like a fingerprint of the chemical that is under examination, and it is possible to distinguish different chemicals using these spectra. The attenuated total reflection (ATR) enables samples to be examined directly without preparation. Due to time limitations caused by the impact of COVID lockdowns, findings from the FTIR-ATR are not included in this study. However, the FTIR-ATR was found to be most useful in identifying broad chemical classes, such as oil or synthetic mediums. One point of complication was when it was found that different sides of the sample picked up different spectra, such as the sample's canvas side as compared to the same sample's canvas layer. Therefore, the method was not able to identify a specific paint layer.

Portable x-ray fluorescence (pXRF)

The pXRF is a complementary technique to FTIR for identifying elements present in a sample. While the pXRF is most used for spot analysis on artworks directly, there was no pXRF available to study the Cheong Soo Pieng paintings from the private collection during fieldwork in Singapore. However, access to a pXRF in the Grimwade Centre allowed for non-destructive inorganic analysis of the samples collected. The pXRF was set up with a stage and platform without vacuum, where the sample was placed, and high energy beams of x-rays (40–50 kV) were emitted. For the Georgette Chen works studied at HCC, non-invasive spot elemental analysis of exposed ground on the painting's tacking margin was conducted with a pXRF (Thermo Scientific Niton XL3t-63680). The operating parameters were 50 kV,

200 μ A used without vacuum. The detector was mounted on a laboratory stand in contact with the ground layer without a barrier to collect elemental spectra, reducing interference. The acquired spectra were collected and analysed by HCC staff using the Niton Data Transfer Software Suite, and major elements of the ground composition were reported.

Initially, the pXRF was one of the main investigative techniques used to analyse the samples. However, there were certain drawbacks to this approach. The analysis technique on a removed painting sample did not allow the differentiation between the ground or media layers. Further there is an overlap between the titanium K-lines and barium L-lines. This overlap can mean it fails to identify titanium when barium is also present (van Driel et al. 2018a). Both these elements are crucial in the analysis of modern paints and grounds, and as such, the identification of the element is of interest. Overlapping peaks can complicate interpretation, which is especially challenging when investigating non-homogeneous multilayer materials, such as paintings, where all the elements of the multiple layers of the sample are represented within a single spectrum. Therefore, the low resolution analysis using the pXRF to analyse only the ground side of the sample was only exploratory, and helped to give an overview of key elements in the ground layer of the painting, such as the presence of lead, titanium, or zinc. To improve the accuracy, resolution and reliability in the analysis of a sample's individual layers, ESEM-EDS was used for elemental analysis as well as for imaging.

Environmental scanning electron microscope with energy-dispersive x-ray spectroscopy (ESEM-EDS)

ESEM–EDS is used to identify inorganic pigments and identify white hiding and extender pigments to characterise the composition of paint (Koussiaki 2002). In this study, ESEM-EDS was used in a targeted investigation of 35 Cheong Soo Pieng paintings to identify key elements in the ground layers. The decision to undertake this targeted analysis was supported by the presence of ground layers in most of the cross-sections. The cross-sections were first studied with optical microscopy for suitability before a technician conducted the ESEM-EDS analysis at the University of Melbourne. The cross-section resins were prepared with a carbon coating and mounted face-up on double-sided carbon adhesive tape attached to a glass slide and inserted into the instrument. The instrument (Philips FEI XL30 ESEM–EDS) was used for elemental analysis and was operated via an FEI Graphical User Interface running on a PC and a manual hardware interface that implemented basic

functions. The electron source was a tungsten filament, providing a beam of up to 30 kV at spot sizes. For EDS analysis, a beam of 15kV and spot size 6 is generally used. This EDS system used a liquid-nitrogen cooled Si–Li detector with an area of 10sq mm² and an atmospheric thin detector window (ATW2), which allowed which allows X-ray detection from elements higher than beryllium ($Z > 4$). The software can produce semi-quantitative standardless analysis.

Areas were analysed by point and shoot as well as box measurements where point and shoot analysed single particles while box measurements analysed an area of particles. To prevent large particles of a single pigment from influencing the results from box measurement, these were mainly avoided, making sure to measure an area representative of individual and entire layer. In addition, backscattered electron scanning electron microscopy (BSE-SEM) was performed. The results of elements present in the analysis were presented as absolute oxide mass percentage based on the amplitude of the energy peak for that element in the EDS spectrum, where the software normalises the total to 100%. The distributions of elements and their oxide percentages were then tabulated into a dataset.

Summary

Through these integrated approaches, an understanding of a painting's material, techniques and condition could be formed to give us a fundamental understanding of Cheong Soo Pieng's and Georgette Chen's painting processes and the construction of their paintings. The quality of the material record can be measured via the scope, sampling interval, resolution and dimensionality. Variations within these four features would affect how the data can be analysed and the quality of analysis.

The data collection techniques outlined here support the research aim of producing verifiable, comparable, and evidential data in the study of Cheong Soo Pieng and Georgette Chen paintings. By adopting a multi-disciplinary approach combining primary sources, visual examination and technical photography, the research design investigates the specific contexts of an object to contextualise material findings. Employing technical art history methodologies, the data collection method consisted of non-invasive and invasive analysis. The non-invasive methods collectively explored the possibility of producing verifiable and evidential data through visual examination, written documentation, multispectral technical imaging and access to primary sources such as exhibition catalogues, artist letters, oral

interviews and newspapers. All these were conducted on-site in Singapore across multiple fieldwork stages and its reproducibility is thus dependent on the processes in place and the comparability of the data. Samples were removed from the Cheong Soo Pieng paintings and analysis was carried out in the University of Melbourne. These samples were analysed in both non-destructive and destructive techniques, including cross-sections, fibre analysis, FTIR-ATR, pXRF and ESEM-EDS. The following section will focus on the documentation record and its central role in transforming and preparing the collected data to be analysed, and how it supports the generation of insights to better understand the artists' materials and techniques.

2.5 Documentation Record

The value of the documentation record lies in its content, consistency of recording and quality of data. The structure of the record emphasises data consistency and its purpose of consistent recording. The process of designing the documentation record took into account Taylor and Stevenson's view that meaningful results are produced when the research question is fully understood before the model is developed (1999, p. 2). The methodological approach taken in this study focuses on how an object is studied, what is to be recorded and how it is recorded as previously discussed. It is designed to document information from the creation of an artefact to observed changes in its current condition. Educated experience and empirical knowledge can also produce meaningful results by establishing a systematic recording system to identify trends and patterns (Bucklow 1996, p. 341). Burnstock and Morgan employed a systematic approach to create a database for cataloguing and research in the field of technical art history, which resulted in increased accessibility and interpretability of handwritten reports (Burnstock & Morgan 2002, p. 261). These scholarly works formed part of the considerations about the documentation record design used in this study.

In this thesis, the term 'documentation record' is used to describe the format of the data collected during survey are documented, while 'documentation report' is similar to a condition report, which is primarily used for travelling and conservation treatment purposes (Tse 2008, p. 55). A documentation record is an expanded condition report that details the observed materials, construction, techniques and condition of the painting, giving further insights and technical details. The first point of examination for each artwork under investigation is a visual examination, and observations are first recorded into a free-text documentation report. Following this, observations are structured into a documentation record which is created for each artwork and the observations are recorded using fixed categories, data points and variables. Prompted by the fundamental concern of identifying how a painting's defining properties can be established, the documentation record includes 110 data points to represent the paintings defining characteristics. This is a critical document that records visual examination observations of the object's materiality, which can reveal the artist's techniques.

The following section is divided into three parts. It begins by describing what raw data is collected before its transformation. This leads into a discussion of the ontological structure of the documentation record and ends with an overview of the distribution of data

points as well as the importance of building a data dictionary on which future research can build.

Raw data, transformation and pattern identification

The limitation of adopting a methodology which centres on the material data model employed in this study, is that the emphasis on material data generated from the artworks may overlook some qualitative elements. The artist's intent and contextual data obtained from primary sources is an example of this. However, the method allows the inclusion of specific key information and encourages clarity, efficiency and uniformity of data recorded into the database (Burnstock & Morgan 2002, p. 268). Despite its limitations, understanding of the paintings by the Singaporean Nanyang artists, Cheong Soo Pieng and Georgette Chen can still be achieved. This will be performed by utilising the qualitative information gathered from primary sources, visual examination, technical photography and materials analysis, (which are input into the documentation record) together with a quantitative approach towards data collection and data analysis. It will be shown that this will provide quantifiable evidence and reveal meaning and insights into the artists' painting materials, practices, connections and influences on art materials. These all feed into the research goal of building a material record.

The process from raw data to securing an understanding of the artist's attributions or the broader material record requires data transformation process to be established. These four stages are described below in a series of steps from collecting raw data, transforming data from free text, quantifying the occurrences and uncovering patterns, and lastly corroborating and contextualising the study (see Table 2).

Table 2. Four stage process of how raw data is transformed into a documentation record.

Stage 1	Collecting raw data directly from the object into documentation report	Detailing observations in free text from visual examination and technical photography (unprocessed data)
Stage 2	Transforming data from free-text report into documentation record	Structuring and preparing the unprocessed data to give structure by using categories,

		data points and their variables, which are recorded into a database platform, Airtable
Stage 3	Quantifying the occurrences and uncovering patterns through data analytics and machine learning algorithms	Selecting relevant data points to extract from Airtable to create new datasets. Depending on the quality of the dataset, datasets can be fed into Microsoft Power BI for data visualisations using visual graphics or undergo statistical analysis using machine learning models to uncover patterns about an artist's practice
Stage 4	Corroborating and contextualising current study's findings for future research to create a material record	Current research's data dictionary can offer data structure for future studies. In doing so, various datasets can eventually be merged to inform a larger study, for example, data on art material availability or the inclusion of more Nanyang artists.

As described, observations from the examination are written in free text, also known as raw data. In Stage One, the unprocessed raw data is unstructured and requires cleaning to transform its usability and comparability. This process allows qualitative data detailing observations in free-text which are gathered directly from the painting, as well as some contextual data gathered from primary sources, to be included and used for comparative analysis. This includes the curatorial categorisation of Cheong Soo Pieng's oeuvre, which was assigned accordingly for each painting. Collectively studied, the data can draw patterns and shape a preliminary understanding of the artist's materials and techniques. When there is sufficient knowledge of materials and techniques employed by the artists and their communities, a possible discussion on artist attributions can lead to improved conservation approaches.

The weakest point in this process is going from Stage Two of processed data to Stage Three. Stage Three involves making an assumption about the evidence collected by selecting a set of data points to be analysed, which can only be improved by increasing the quality of the data. For instance, the dominant patterns identified from the study's data points, present only some dimensions of the artist's practice, but are assumed to be representative of the artist's practice. In the interpretation of any findings from technical art history research,

Bomford notes that care and caution should be used when making general claims about an artist's practice or about a group of artworks (2008). This is especially important in Stage Three, where the selection of findings from the collection survey, are found to be representative of the study population. These are analysed alongside curatorial or art historical narratives and any available primary sources such as exhibition catalogues and artist letters to contextualise the material findings within the artist's overall practice. It is believed that the insights gained in Stage Three and Stage Four of this study will provide a foundation for future studies of other pioneer Singaporean artworks. While the long term aim is to develop a model that can transform qualitative sets of data to optimise the understanding and analysis of artworks.

By adopting a quantitative approach towards qualitative data, it aims to make optimal use of the data collected through the four stages. This includes the evaluation and comparison of the data, and highlights what can or cannot be learnt from the datasets (Reedy & Reedy 1988, p. 2). However, problems can occur at each of the different stages. First, when translating the findings from individual data to the overall collection survey, there are risks of research bias, such as whether the data has been accurately recorded from visual observations taken at the time of the study. Next, when contextualising the findings from the paintings to the broader artist oeuvre, the study is dependent on the quality of the data, and whether the evidence and observations accurately reflect what is in the collection survey. Going back to the discussion on the quality of the record, an improvement in or increased data from any of the four features could help mitigate these potential issues.

Navigating the analysis and finding patterns requires critical examination and meticulous data collection, from translating raw data to developing a full collection survey understanding. While all precautions can be in place to collect good data and assemble a good dataset, an understanding of the past cannot be achieved by statistical analysis alone. Overall, the findings in this research can provide insights, but are non-conclusive. Instead, this study is an invitation for further research into creating a broader understanding of Singaporean art history. The following section further discusses the factors for ensuring the reliability and validity of the data, which is crucial in ensuring the quality of the record.

Structuring data with ontology

Developing a model for data coherence and consistency involves engaging in one of the key features of data analysis: finding patterns by connecting entities and understanding their relationships (Golomitsou et al. 2017). A key aspect of data analysis is the order and structure given to the data from the onset, as the data fabric supports how data is managed, described, combined, and accessed from the documentation recorded hosted on the Airtable platform (this platform is discussed further in Chapter 2.6 below). The development of an ontology or how elements are grouped into categories can be seen as the bridge for transforming collected data via clear and robust analysis. A brief overview of this research's ontological relationships and hierarchy is illustrated in Figure 1 below. This is the beginning of the data fabric and ontology as will be explained below. Furthermore, the analysis of terms is vital when attempting to reuse existing ontologies and extend them (McGuinness et al. 2000).

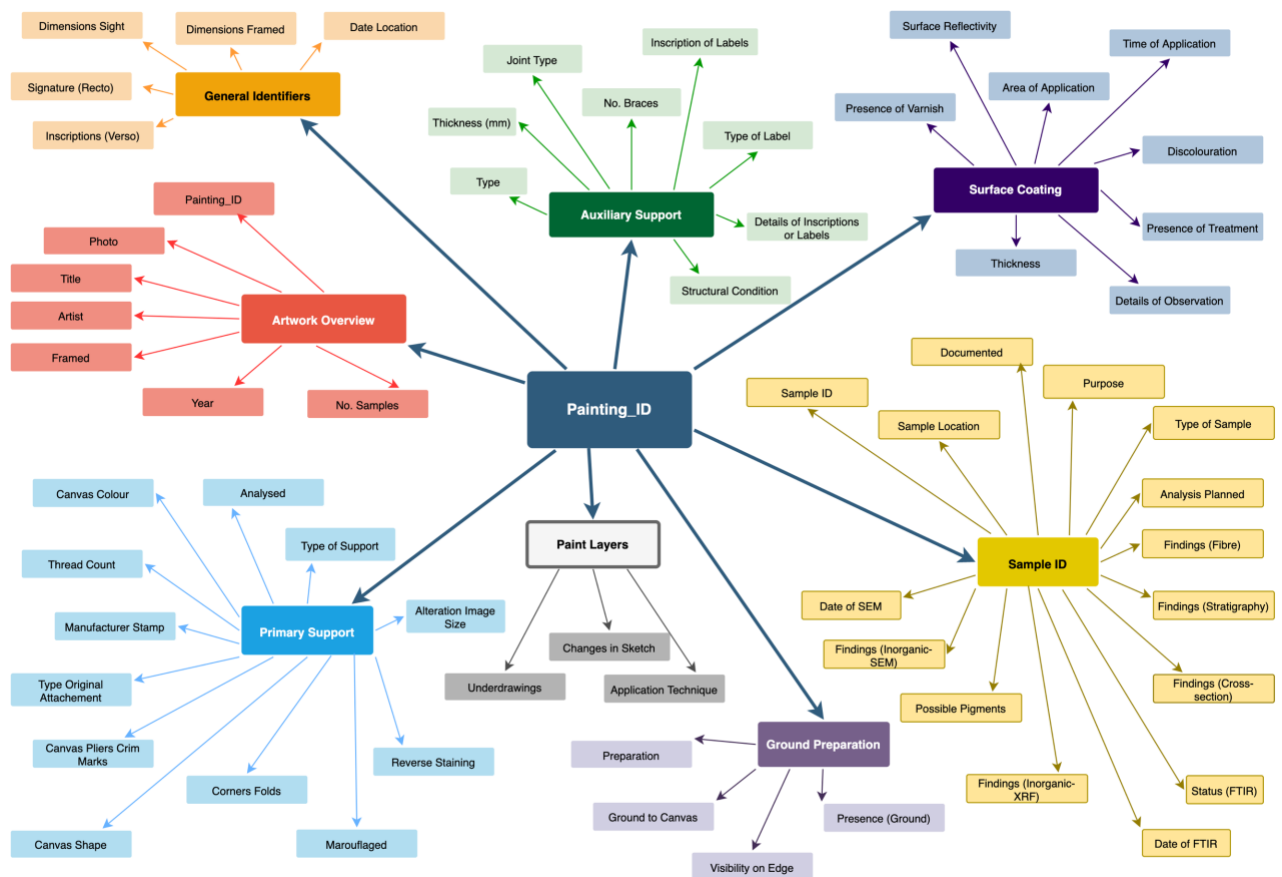


Figure 1. Visualisation of ontological relationships in this research.

The accuracy of this research's data standards is achieved through a standardised set of variables and its terminology, as an ontology is crucial to define a shared vocabulary for researchers who need to share information in a domain, including those using a machine-interpretable methodology. Enabling the reuse of domain knowledge was one of the driving forces behind recent surges in ontology research. Drawing upon Taylor and Stevenson's (1999) concern for subjectivity in reports, in which clarity can come from the processes and structures that are put into place, the development of the ontology for this project is based on five main features: to share a common understanding of information structure among practitioners and researchers, to enable reuse of domain knowledge, to make domain assumptions explicit, to separate domain knowledge from operational knowledge, and to allow the analysis of domain knowledge (Musen 1992; Gruber 1993; Noy & McGuinness 2001). Ontologies not only introduce sharable and reusable knowledge representation but can also add new knowledge about the domain.

As a formal, explicit description of concepts in a domain of discourse, an ontology is essentially a description through the specifications of the order of data points and its properties of describing various features and attributes (Noy & McGuinness 2001). These similarities are similarly found in elements of the condition report, such as the classification and organisation of how the various structures that make up a painting are recorded, and the terminologies used to describe occurrences. The ontology used in this thesis can be extracted for data analysis using statistical inquiries and machine-learning, which require a clear structure (Noy & McGuinness 2001). Although this could potentially limit the scope of technical descriptions and data points, the incorporation of fields recording details of data entry allows users to interpret technical data in its historical context (Burnstock & Morgan 2002, p. 268). This said, the fundamental principle when designing the ontology is acknowledging that in employing a knowledge engineering methodology, there are always viable alternatives (Strassner 2008).

Existing vocabularies such as the MONDIS Monument Damage Information System, CIDOC Conceptual Reference Model (CIDOC CRM) and OPPRA are the most closely related work in the field of knowledge capture relating to paintings and provide a data model for describing the provenance of artworks (Cacciotti et al. 2014; Doerr 2003; Hunter & Odat 2014). This section focuses on the OPPRA, which was an "integrated semantic knowledge

base” that emphasised ontologies relating to art conservation to enable data integration, knowledge acquisition and cross-linking for knowledge discovery purposes (Hunter & Odat 2014, p.174). Its purpose was to support knowledge management and discovery using existing ontologies and vocabularies that provide data models for describing aspects of art conservation by describing the classes, properties, and relationships between terminologies relevant to painting conservators. It drew on existing ontologies and vocabularies where available and extended and refined them as required. Specifically, OPPRA’s goal was to document descriptions of physical artefacts (e.g., genres, condition states, artists, artistic techniques), events (e.g., condition assessments, exhibitions, movements, treatments), deterioration mechanisms (e.g., discolourations, oxidation, damage), and related digital information (images, characterisation data, spectrographs, publications) associated with art and paint conservation, in a standardised, re-usable, and machine-processable format.

The goal of OPPRA was for it to become the backbone of an online semantic knowledge base that could be discovered, shared, re-used and reasoned across. The outcome was intended to be a framework to enable painting conservators to improve their understanding of paint degradation processes and identify and document new methods for stabilising, protecting, and restoring paintings. However, the repository has been archived and is now offline due to limited funds and the end of the project. This shows the need for a sustainable platform and organisational commitment that enables data retention and updating. The following section will briefly discuss how the ontological framework helps provide the structure of information to be documented in the condition report and higher resolution analysis.

The main challenge faced in this study was data consistency and structure in creating the record. The use of fixed terminologies as value descriptors aims to address these challenges by offering a structured format for documentation that can minimise discrepancies. The project first used an initial set of value descriptors and terminologies which were adopted from Tse’s (2008) PhD research which examined 208 oil paintings across Southeast Asia, which were further interrogated and assessed in the context of the paintings studied and recent literature. Throughout the study period, fields and terminologies underwent frequent revision to better suit the context of the objects and to interrogate the relationships between the data points. The contextual language of observations is evident in this work and is discussed in the following chapter. In addition, the record takes into account

findings that may be one-off in free-text fields. By assigning a fixed set of variables to structure each field, a structured method of documentation enables data extraction and manipulation for analysis to find patterns and material trends across the breadth of paintings investigated.

Data dictionary and fixed terminologies

The resulting structure of the documentation record is divided into eight main *categories* according to the structure of an easel painting, consisting of 110 *data points*, as well as a set of fixed terminologies that describe the occurrence or finding of each data point, which are referred to as *variables*. These data points provide a standardised and structured way to capture critical information for analysis, drawing upon the use of controlled vocabulary to allow for categorisation and indexing and retrieval of information (Harpring 2010). Five of the eight categories are organised following a painting's stratigraphy, from its primary support, auxiliary support, ground, paint layers to the surface coating — similar to a condition report, with expanded unique properties. The remaining three categories — artwork overview, general identifiers and sample identification — include information drawn from primary sources and material analysis, all of which are linked to each painting's unique identifier. The list of data points and terminologies are listed in Appendix C. The data points are collected from each painting using non-invasive and invasive methodologies. Non-invasive methodologies include descriptive visual observations from examination and various technical photography techniques, such as visible light, ultraviolet, and infrared imaging. Invasive methodologies, on the other hand, involves taking small samples from the painting for further analysis, such as through cross-sections and ESEM-EDS analysis. They also include some art practices such as marouflaging, where the primary painting substrate is adhered onto a secondary support. In some instances, a data point is not available to record. For example, when a painting is framed and its tacking margin cannot be accessed for visual examination, its inaccessibility would result in incomplete or missing data. This could also be the case when a sample cannot be obtained as it may be too obtrusive. In these scenarios, the data would be recorded as nulls instead of leaving the fields blank as it will not cause noise within the overall dataset and allow for a substantial quantitative analysis. In summary, the breakdown of the record's data points are as follows:

- 56 data points are drawn from visual examination (non-invasive)

- 9 data points are drawn from observations from the multispectral technical images (non-invasive)
- 31 data points are researcher issued identifiers or core data about painting (non-invasive)
- 14 data points are drawn from findings of the material analysis (invasive).

Given a large proportion of data points is drawn from non-invasive means, the value of the data collected and verifiability are explored. As the development of an ontology is iterative, these data points were revised throughout the data collection process to include or remove items after the first year of fieldwork. Each data point is assigned a fixed set of variables and its terminology associated with value descriptors to interpret occurrences and patterns and identify any material trends by the artists. Kept as consistent as possible, this ensured that standard terminology was used to match visual observations, alleviated some of the subjectivity of condition reports as raised by Taylor (2017) and mentioned earlier, and minimised the duplication of information.

By restricting the variables assigned for each data point, information may be constrained; however, minimising the variables allows for a broader categorisation of data, from which more targeted research inquiries can occur in future research. A data dictionary was created to ensure the reusability of the dataset in future projects by providing clarity about the categories, data points and the variables used by assigning a descriptive sentence (see Appendix C).

Summary

This section has shown how the transformation of raw data into an insight begins with the design and structure of the documentation record. With 87% of the data points generated through non-invasive means, this methodology shows that a robust dataset for understanding paintings can be built without heavy reliance on material analysis. Fixed variables were used as value descriptors which prepared the data for quantitative analysis. The ability to use a quantifiable approach to draw an overall understanding is key in undertaking the verifiable and evidential analysis of art materials, and especially paintings, as they are inherently heterogeneous and distinct in composition, form, and history. Having set the stage for how the data is prepared for analysis, this chapter will now outline the data science methodology

which is the backbone of how data is extracted and analysed to give insights. This includes the management and storage of data, as well as the tools employed to create compelling visual graphics and machine learning algorithms to uncover patterns within the data.

2.6 Data science framework

From the data-rich process of undertaking the technical examination of paintings, a great deal of data and information can be gathered. However, to build a material record that explores Cheong Soo Pieng's and Georgette Chen's art practices through the study of paintings, structured data must be collected in order to assign value and to prepare for analysis. As mentioned previously, data are a resource that can be used and reused, and which gains value from its context through the ontological structure and data dictionary, which is vital to ensure its credibility and verifiability. Deepening this discussion, this section focuses on the data science framework, which was adopted to provide clarity in the data processing strategies required to create meaning and insights into the data generated, as it seeks to explore how the data can be extended to machine learning algorithms to uncover patterns and build a material record.

As a broad umbrella term and in standard practice, data science solves problems and answers questions through data analysis by extracting meaningful insights from raw data and effectively communicating those insights to generate value through a series of iterative processes (Rollins 2015, p. 2). In short, data science produces data insights. As an emerging discipline, there is no commonly agreed definition of data science. However, the transdisciplinary aspect of data science is undisputed, as it incorporates principles, techniques, and methods from multiple existing academic disciplines and domains (Fayyad & Hamutcu 2020). A data science methodology and structure is dedicated to knowledge discovery through data analysis (Portela 2021).

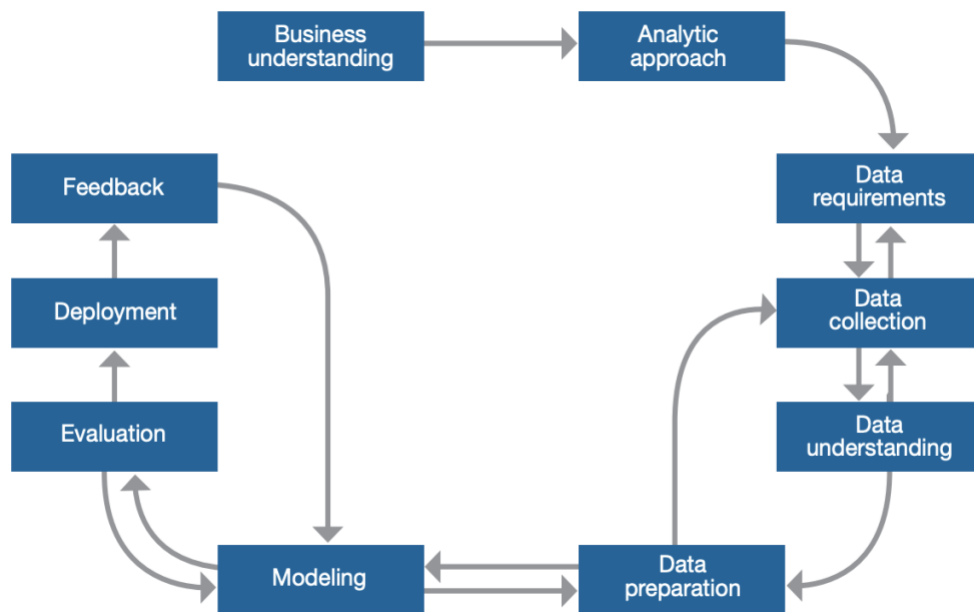


Figure 2. Foundational methodology for data science (Rollins 2015).

Rollins' data science methodology in Figure 2 consists of ten stages that form an iterative process for using data to uncover insights (Rollins 2015, p. 3). Each stage plays a vital role in the context of the overall methodology; however, the methodology is a general strategy that guides the processes and activities within a given domain, not a prescription for a particular set of tools.

While this thesis finds relevance in Rollins' model as an overarching methodology, this section adopts the OSEMN model, a data science process that describes the lifecycle of a data science project and how to work through a data problem (Mason & Wiggins in Janssens 2014). Consisting of five main processes, OSEMN stands for obtain, scrub, explore, model, and interpret (Cher 2019). This section will discuss how data can be obtained through the database which stores the documentation records. As the data have been processed using the fixed terminologies, the discussion will then consider how data visualisation tools and statistical methods are used to undertake exploratory data analysis. It will end with an overview on machine learning algorithms as a form of data modelling to give insights. The analysis of the data, where meaning is assigned, is crucial in generating visualisation insights and relies on a quantitative approach to understanding paintings, with the aim of building blocks of attribution through identifying patterns using visualisation tools.

Databases: data management and dataset extraction

Following the organisation and development of an ontology, it was necessary to make a database to manage and store the data collected. The creation of a database not only significantly increases the accessibility of valuable resources but, as a research tool, offers the opportunity to interpret existing data more fully, because the value of the resource increases as the data accumulates. Furthermore, particularly for the transformation of raw unstructured data into structured data, a database allows for cross-referencing, which provides a broader perspective on a variety of questions related to trends in the use of painting materials (Burnstock & Morgan 2002). The following section briefly outlines existing conservation databases and how *Airtable* is used as a data management tool for this project.

Existing databases

Conservation research is often produced in individual case studies. The distributed, unstructured, heterogeneous nature of the relevant data makes it challenging for conservators to search and aggregate information to find answers to their research questions (Hunter & Odat 2011, p. 1). Currently, existing conservation databases focus on the building of web platforms that capture information about a specific topic, such as particular artists, pigments, paints and instrumental spectra. To name a few examples, some include the:

- Winsor and Newton (W&N), which provides access to digital images of pigments, paint, varnish and oil recipes from the 19th century archive of Winsor and Newton
- the International Network for the Conservation of Contemporary Art (INCCA) database for artists' archives, which contains metadata records describing all types and formats of artists' documents (e.g., interviews, technical drawings and installation instructions)
- the Getty Research Institute's vocabularies, which provide structured vocabularies describing art, architecture, decorative arts, material culture and archival materials

- the Infrared and Raman Users Group (IRUG) spectral database, which provides a forum for the exchange of infrared (IR) and Raman spectroscopic information, reference spectra and materials
- the Conservation and Art Materials Encyclopaedia Online (CAMEO), which provides a searchable information centre containing chemical, physical, visual and analytical information on historical and contemporary materials used in the production and conservation of artistic, architectural, archaeological and anthropological materials
- Art and Archaeology Technical Abstracts (AATA), which is a free research database containing literature abstracts since 1983 which pools together journals and conference readings from the conservation's field literature
- A database of artists' materials from paintings examined at the Courtauld Institute of Art from 1947, which started as text-only descriptions of paint cross-sections, and has subsequently incorporated other related data from technical reports and the linking of image files.

Each of the databases above is hosted online and is the responsibility of a larger institution. They have been designed to provide specific information to art conservators and material scientists, aiming to improve the discoverability of cultural heritage content via rich metadata. One of the most common knowledge bases used in conservation research has been built using the Filemaker Pro software such as the Courtauld Institute of Art database (Burnstock & Morgan 2002) and Tse's (2008) collection survey. The user interface and flexibility allow small-scale databases to be built. However, in some cases where the data is stored remotely on single computer devices, access to information is restricted to the subscription period and the database requires an annual software license.

Microsoft Excel has been used in several conservation projects as a recording system to record and manage research data (Museums and Galleries of New South Wales 2019). However, there are dangers of hosting data on spreadsheets and this method does not serve in the long run as an alternative to a database (Panko 2008). In addition, in some instances, Microsoft Excel stores data differently between operating systems which causes problems for downstream analyses (Broman & Woo 2018). During the pilot data collection phase of this

study, data were initially recorded on an Excel spreadsheet. However, minimising the risk of data loss was essential for the project, as well as data continuity and the ability to build onto the database. As the research project initially drew inspiration from Tse's work, which used FileMaker, this software was considered. However, the cost of software licensing and system upgrades was considered prohibitive and not sustainable in the long run. When selecting software for data management and analysis, several important considerations were taken into account. These included (1) financial sustainability of its initial uptake and recurring costs, as well as any associated hardware and infrastructure costs, (2) technical knowledge of query-oriented programming language was required to access and modify records and whether future users of the database will have the necessary technical skills required, and (3) fine-grained access control so that different stakeholders can only see information that is relevant to them, and (4) whether it was hosted and accessible via cloud computing for easy access.

Data management tool: Airtable

With many software options available for creating databases, Airtable was found to be the best platform to host the project database (Figure 3a). Airtable is a cloud-based spreadsheet-database hybrid that enables flexible relational data models with minimal programming (Airtable 2021). Airtable automatically creates snapshots of the database's revision histories, which allows earlier versions to be restored and minimises the risks of data loss. As a database management tool, Airtable can be used to import and store data from various sources, which are useful to build onto existing datasets. This data can then be organized, filtered, and analyzed using Airtable's suite of data visualization tools, which can help to identify patterns, anomalies, and correlations within the data to generate insights. The main appeal of Airtable is its suite of features for collaboration, including customised views where sensitive information can be password-protected and the ability to allow selected information disclosure for access and input (see Figure 3b, which shows data presented in gallery view). Having the possibility of an accessible material database is encouraging, although issues on data sensitivity will need to be navigated carefully. Another important factor for research continuity is cost-efficiency and as such, the free to use basic package of Airtable was chosen. At present, the database hosts text-based data and a snapshot of the painting to visualise each record.

Paintings ID										
Data Automations Interfaces										
Artwork Overview General Identifiers Primary Support Ground Preparatory Layer Auxiliary Support Paint Layers Surface Coating Sample ID SEM Analysis Extensions Manage fields										
Views	Grid view	1 hidden field	Filtered by Artist	Group	Sort	Color	Share view			
	Painting ID	Photo	Collection	Title	Artist	Period	Year	Medium	Framed	
1	PTG001_CSP001		Koh Seow Chuan	Long House People	Cheong Soo Pieng	Artistic Maturation	1975	Oil on canvas	✓	
2	PTG002_CSP002		Koh Seow Chuan	Untitled (Three Figures, musical ins...)	Cheong Soo Pieng	Stylisation	1968	Oil on canvas	✓	
3	PTG003_CSP003		Koh Seow Chuan	Untitled (Two Figures, Mynah)	Cheong Soo Pieng	Stylisation	1964	Oil on canvas	✓	
4	PTG004_CSP004		Koh Seow Chuan	Malay Boys	Cheong Soo Pieng	Stylisation	1966	Oil on canvas	✓	
5	PTG005_CSP005		Koh Seow Chuan	Untitled (Indian lady with veil)	Cheong Soo Pieng	Stylisation	1966	Oil on hardboard		
6	PTG006_CSP006		Koh Seow Chuan	A corner of art studio	Cheong Soo Pieng	Foundational Years	1947	Oil on wood	✓	
7	PTG007_CSP007		Koh Seow Chuan	Untitled (Two dancers)	Cheong Soo Pieng	Nanyang Style	1957	Unknown on hardboard	✓	
8	PTG008_CSP008		Koh Seow Chuan	Sarawak Sisters	Cheong Soo Pieng	Nanyang Style	1953	Unknown on hardboard		
9	PTG009_CSP009		Koh Seow Chuan	The Gardener	Cheong Soo Pieng	Nanyang Style	1958	Oil on hardboard		
10	PTG010_CSP010		Koh Seow Chuan	Landscape	Cheong Soo Pieng	Artistic Maturation	1978	Oil on canvas Marouflaged on canvas	✓	
11	PTG011_CSP011		Koh Seow Chuan	Three Women	Cheong Soo Pieng	Stylisation		Oil on canvas	✓	
12	PTG012_CSP012		Koh Seow Chuan	Ball Women	Cheong Soo Pieng	Nanyang Style	1952	Oil on canvas Marouflaged on hardboard	✓	
13	PTG013_CSP013		Koh Seow Chuan	Mosque in the Village	Cheong Soo Pieng	Nanyang Style	1956	Oil on paper Marouflaged on hardboard	✓	
14	PTG014_CSP014		Koh Seow Chuan	Sunflowers	Cheong Soo Pieng	Nanyang Style	1957	Oil on paper Marouflaged on hardboard	✓	
15	PTG015_CSP015		Koh Seow Chuan	Portrait	Cheong Soo Pieng	Foundational Years	1948	Oil on wood	✓	
	PTG016_CSP016		Koh Seow Chuan	Busy Planters	Cheong Soo Pieng	Stylisation	1968	Oil on canvas	✓	

Figure 3a. First tab of the Airtable database in text format.

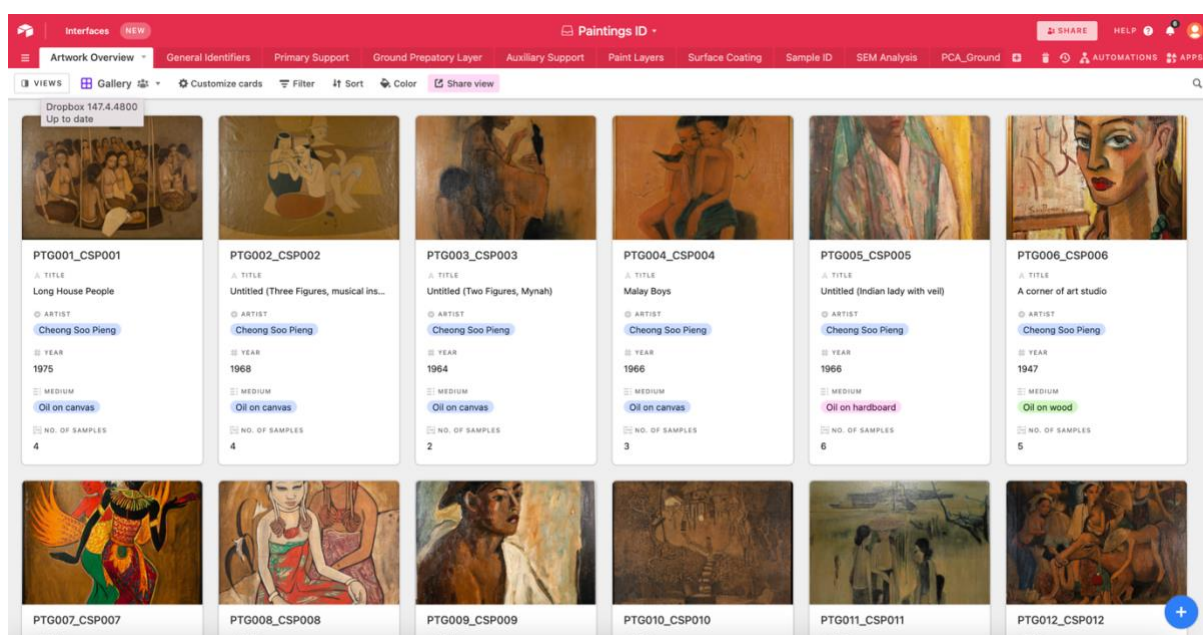


Figure 3b. First tab of the Airtable database in gallery view.

The database is built to record text-based information, such as the data from the documentation record, visual observations from the multispectral images, and results from the material analysis, as listed in the data dictionary found in Appendix D. This consists of eight tabs that represent category overviews organised by each layer of the painting, and the record of sampling analysis results (Artwork Overview/ General Identifiers/ Primary Support/

Ground Preparatory Layer/ Auxiliary Support/ Paint Layers/ Surface Coating and Sample Analysis). In addition, the database enables the linking of fields between tabs to reduce human error in data entry and maintain consistency of variables and its terminology. For instance, a result from a binder analysis of a paint sample recorded in ‘Sample Analysis’ could also be reflected in ‘Paint Layers’ using the same painting ID.

To ensure that the data collected and hosted on Airtable is readily accessible for future migration to a centralised and secured depository, a comma-separated values file (.csv) can be extracted from Airtable. This feature was used to archive the dataset after each fieldwork update to ensure that it could be accessed or loaded onto alternative platforms in the future. As one of the simplest file formats, .csv files are universally accepted by web-based analysis applications and are commonly used to transfer large datasets. When used for exporting and importing, .csv files avoid the risk of translation and misinterpretation of data, allowing accurate transfer of data into future system databases. Given the sensitive nature of the data privacy and legal agreements in place, the database in this project is not openly accessible to the public at present. However, the available data dictionary in Appendix C can be used by future researchers to build on.

Data analysis

Today, the benefits of data mining and evidence-based approaches is increasingly emphasised in conservation research, mainly to understand historical data such as conservation records, collection surveys and archival newspaper records. By using an evidence based and mixed quantitative and qualitative approach, conservation researchers have engaged in statistical analysis on non-structured or qualitative data to answer questions on material degradation and conservation decision-making within a collection (Cannon 2017; Duran et al. 2017; Golomitsou et al. 2017). Given the distribution of Cheong Soo Pieng and Georgette Chen paintings from the 1940s to the 1980s, it is helpful to perform an exploratory analysis of the data by uncovering patterns within the material alongside curatorial categorisations or chronology by data clustering. This approach is dependent on the type of data available and could lead to interesting areas of enquiry when given “careful reflection on both the scientific questions to be answered and the structure of the data collected” (Reedy & Reedy 1988, p. 3). An advantage of having a structured data collection is being able to extract datasets, search for data, and perform data mining and analysis.

To begin understanding the data at hand, exploratory data analysis is used to identify patterns within datasets. Data visualisations are one means to discover deeper insights into the occurrences and patterns within the datasets. Consistency during data collection is vital to obtain reasonable inferences and reliable answers, as it only takes a small amount of disproportionate information to devalue a dataset. In this section, an overview of data visualisation tools to uncover data will be given, as well as a discussion of using the structured data to engage in statistical approaches to further derive understandings from complex datasets. More detail about the specific methodologies employed can be found in Chapters 6 and 7.

Data visualisation tools

An open-ended approach employs experimental techniques to identify broad trends and anomalies. In this study, the approach was guided by formulating specific questions for confirmatory analysis. The data was explored on both Tableau and Microsoft Power BI — both data visualisation software that can produce visualisations as well as interactive dashboards to gain data insights. Data visualisation software enabled a deeper engagement with the data to provide insights without an in-depth statistical knowledge (Golfomitsou et al. 2017). Data visualisation uses visual representation with graphical elements that depict data insights in a visual format designed to converge the meaning and significance of data. The visual message allows the data to be more effectively communicated to make sense of the data, and different visualisations should be used, depending on the quality and dimensionality of the data.

Public versions of Tableau and Microsoft Power BI are accessible and free to all users. Microsoft Power BI enables visualisations to be created remotely on the desktop. Due to the sensitivities in the research findings of this study, both the Tableau and Microsoft Power BI desktop were password protected when used to create visualisations. From studying the distribution of paintings to exploring insights about correlations between ground and paint layers, using charts and diagrams to visualise the data was helpful for the exploration of the data. In addition, interactive dashboards were created to ‘deep dive’ into trends across various data points.

Machine learning algorithms to interpret data

An extension of data analysis is the use of machine-learning algorithms modelled to engage in various statistical approaches to improve the levels of confidence in data interpretability. Machine-learning tools are increasingly accessible and have been widely used to carry out complex statistical inquiries as well as to reduce human error. The use of machine learning is a practice of applying algorithmic models to data over and over until the computer discovers hidden patterns (IBM 2020a). Using the data-rich resource of metadata, machine learning algorithms can be employed as analytical models with various data inputs and outputs to predict or prescribe diagnosis for future research and new data sets. Recent conservation research has used machine learning models in various ways to simulate and predict the final visual outcome of extensive restoration of artworks using digital techniques prior to treatment, or to document and detect changes in paintings, and for the stylistic classification of paintings (Abate 2019; Gultepe, Conturo & Makrehchi 2017; Gupta et al. 2021).

This research places an emphasis on quantitative data which can benefit from the analysis of large datasets and machine learning models to support knowledge gain, problem-solving or answering the research questions. The key to optimising these machine learning models is reliable data, and data interpretability, as well as understanding how the model arrives at a conclusion — all of which are vital to detect biases and increase data acceptance and reliability (Doshi-Velez & Kim 2017). It is important to note that, in this study, there are possible risks of selection bias, as the paintings studied are not necessarily representative of the entire artist's oeuvre.

Two unsupervised learning machine learning models were explored in this research: k-means with Principal Component Analysis (PCA) and deep learning neural networks, using Google Colaboratory, a free to use Jupyter notebook environment that allows codes to be executed on the browser. Unsupervised learning methods utilise unlabelled datasets which do not have a right or wrong output for training data. The use of PCA as a statistical method of inquiry through an unsupervised machine learning model has been used in recent cultural material research to find correlations within large or complex datasets. PCA first reduces dimensionality of the dataset and can be combined with various statistical methods, such as the application of k-means clustering algorithm. Some of these case studies range from 39 to 492 studied objects, where PCA is then employed on a variety of spectra or imaging data. For

instance, PCA was used to categorise elemental data from ESEM-EDS analysis of ground layers in paintings by Jan Steen (1626-1679). When PCA is combined with Independent Component Analysis (ICA), it was used as part of an interdisciplinary approach that analyses spectral imaging data used to identify faded writings in caves (Kogou et al. 2020b). In addition, PCA and k-means have been used to study pigments and image segmentation of synchrotron X-ray absorption near edge structure (XANES) analyses (Keune et al. 2016). This growing body of research shows the applicability of employing statistical approaches to scientific analysis and when there is a complex datasets to process. In this research, PCA with k-means was used to cross-examine data between non-invasive observations, curatorial categorisations and ESEM-EDS data on 35 Cheong Soo Pieng paintings which clustered data based on characteristics and assigned each artwork into four clusters. The resulting dataset was then imported into Microsoft Power BI to visualise and analyse each cluster. Further discussion and details on the methodology are provided in Chapter 6.

Given the large amount of both text and image-data that has been produced during the documentation record and multispectral technical photography, these were used as training datasets for a deep learning neural network model using optical flow and Perceiver IO as will be discussed in Chapter 7. As Cheong Soo Pieng's and Georgette Chen's paintings display different and varied features, combining them in a single dataset optimised the model. With 233 technical images distributed across 56 of the 59 paintings which were found suitable for this project, a training dataset was created by the manual classification of images from each technical photography technique, setting the foundation for a structured diagnosis. This resulted in a technical image and diagnostic caption prediction, with the aim of improving reliability in results and to increase efficiency in the analysis of multiple technical images and paintings. A second deep learning model was employed on the technical images to generate an image comparison between the image of the painting under normal illumination and a technical image, similar to that of a mylar overlay during condition reporting which is often manually done by the researcher. While unsupervised machine learning models offer a data-centred analysis and insight, it can also result in a range of biases of which data bias is one that requires careful navigation in this research, given the availability of data. These biases and how they are approached are discussed in detail in Chapters 6 and 7. The use of machine learning models are explored as it supports the research's long-term aim to build a conservation material record through more studies to fill the knowledge gap of Singaporean artists.

Summary

The data science framework and OSEMN process adopted by this research methodology ensured the data structure and consistency of the data and systematic collection of the data reduced the processing of data before undertaking data analysis. Presented in this section was a discussion of the various applications and platforms that are accessible and free to use, such as Airtable, which was used to store and extract this project's datasets, Microsoft Power BI, which was used to produce the data visualisations as a tool for exploratory data analysis, and Google Colaboratory, which was used to execute the machine learning algorithms. All these methods aim to support the research goals of a data-driven understanding of Cheong Soo Pieng and Georgette Chen's art practice.

2.7 Conclusion

This chapter has presented the methods through which the data was collected, recorded, managed and analysed, all of which play an important role in the reliability and validity of the insights gained. It began with the underpinning conceptual framework which framed discussions on the quality of the record in Chapter 2.2, and the selection of data points to identify artist intent, changes made to the paintings, and the influences of materials. Chapter 2.3 discusses the series of non-invasive examination methods which were utilised on 67 paintings of Cheong Soo Pieng and Georgette Chen, examined in Singapore. Of these, 59 Cheong Soo Pieng paintings were sampled and some were later analysed in the University of Melbourne, forming the invasive material analysis outlined in Chapter 2.4.

One of the methodology's aims was to generate verifiable, comparable, and evidential data without relying on advanced material analysis, and therefore the documentation record plays a central role in recording the observations and findings as discussed in Chapter 2.5. The study of paintings is a data rich process, and the database is a critical research tool, as it offers the opportunity to interpret existing data more fully, with the value of the resource increasing as the data accumulate. To ensure data continuity and accessibility, Chapter 2.6 showcases how a database on Airtable was built to record, manage, store and extract the data collected. The 110 data points and its fixed variables used to describe occurrences and observations enabled the use of a suite of data analytics tools such as data visualisations and machine-learning algorithms to uncover data-driven insights.

Chapter 2.6 also features how the data science framework played a central role in the transformation of information into insights, which serves as the bridge that transforms the collected data into a clear and robust analysis; it is the beginning of the data fabric. The software and programmes used in this thesis, such as Airtable, Tableau and Microsoft Power BI, are free to use and are publicly accessible. The following chapter sets the historical context of the study of the paintings and investigates the historical narratives of Singaporean art, and discusses artist material supplies in Singapore.

For instance, Chapter 3 will discuss the supply of artist materials in Singapore which are informed by the presence of a common canvas stamp between Cheong Soo Pieng and Georgette Chen which were identified in this study. This is particularly useful in the case of Georgette Chen, as her paintings in this study were mostly undated while those of Cheong Soo Pieng's were dated by the artist himself. Both Cheong Soo Pieng and Georgette Chen were Western Art lecturers in the Nanyang Academy of Fine Arts, associated with the Nanyang Style of art and were regarded as Singaporean pioneer artists. As such, understanding the historical and cultural narrative in which their paintings are situated is important in framing the material findings and data analysis in Chapters 4 and 5. It underpins the similarities and differences in the materials and techniques that are found between the two artists that will be further discussed in Chapter 7.

Chapter 3: Developing a Singaporean art scene: historical context and artist supplies

3.1 Introduction

Technical art history is a broad field of inquiry that centres on the physicality of works of art to understand the materials, processes, and historical narratives surrounding art (Bomford 2008, p. 198). Importantly, technical art history is an interdisciplinary practice drawing on visual diagnostics, technical imaging, materials science and analysis, historical studies, and oral interview methods. The previous chapter outlined how the history of an artwork can be narrated through material and historical accounts, as well as data collection and analysis, which together form important context. This chapter will examine the historical development of the cultural landscape and its influences to build and frame the direct and indirect influences on art practices in Singapore. In this thesis, although a Western informed art practice will be examined, the emphasis is on the social mobility of the overseas Chinese and their localised networks in Singapore, which saw the development of art educational infrastructure and the transmission of easel painting practice. Some of these Chinese artists, such as Cheong Soo Pieng and Georgette Chen, were later recognised as pioneer Singaporean artists for their influence on easel painting practices in Singapore.

A considerable amount of literature has explored the practice of easel paintings in Singapore and, pre-independence, in the broader region of Malaya. Some of the earliest examples of easel paintings can be traced back to the 19th century in the topographical art produced by English landscape artists while in Malaysia and Singapore (Waterson 2010). In the early 20th century, the artistic environment was slowly transformed by the Chinese community. Clark states that the Chinese substantially conditioned the adoption of easel painting practice into Asia, with the level of influence depending on individual artists (Clark 1998, p. 30; Hsü 1999, p. 64; Tse 2008 p. 14). Clark and Hsü maintain that, although the Chinese artists were seminal in shaping the visual arts scene in Singapore, other factors, such as the native Malays and their pictorial traditions in Singapore, may have been important to the introduction of modern art history in Singapore — but these have historically been largely neglected by art historians (Aljeffri 2001, cited in Neo 2014, p. 79).

In studying Singapore's art history, Yeo Man Thong, a Singaporean scholar, argues that language is a significant barrier and a challenge when researching Singaporean art

history. In his research using archived Chinese newspapers to expand historical literature, he maintains that existing literature on Nanyang art has largely overlooked sources published in Chinese. Furthering his stand that prominent researchers on Singaporean art history such as Redza Piyadasa and T.K Sabapathy, “have never had the chance to access the pre-war material in Chinese” (2019, p. 132). It is uncertain how valid Yeo’s view is; however, limited access to such pre-war material may mean there is an incomplete record and therefore, knowledge gap. Likewise, *A Brief History of Malayan Art*, originally a Chinese publication in 1963 by Marco Hsü, was only translated 36 years later into English. This broadened access to key information on Singaporean artists. Nonetheless, critical discourse on the Nanyang artists and the classification of their artistic approaches were engaged by Piyadasa (1979), Sabapathy (1993) and Clark (1998), which are a useful entry point for this study.

This research focuses on two of the most influential Nanyang artists, Cheong Soo Pieng and Georgette Chen, both Chinese artists who taught in the Western art department in NAFA and were referred to as Singaporean Nanyang artists. As explored by various scholars, Singaporean art history illustrates how regional networks formed by artists can extend to the transmission of arts and cultural development by the Nanyang artists as supported by the strong Chinese immigrant community in Singapore (Hsü 1999; Yeo 2019; Sabapathy 2018). This includes Chinese merchants, who had been trading in the Malay Peninsula long before British colonisation. Therefore, when studying the Nanyang artists’ local influences on easel painting practice, the context and impact of the early Chinese communities in Singapore’s history should also be examined.

This chapter is in five sections. First, a brief historical account of the geopolitical history of Singapore is presented, which relies on historical accounts. This provides an entryway into the second section, a discussion of the assimilation of Western art in Asia and the processes that supported the assimilation of easel painting skills in Singapore, such as Chinese migration and trade. The third section gives an overview of the historical context of the early Chinese communities, which played an integral role in developing the local art scene. This discussion is informed by an assessment of recent art historical literature and includes an examination of indirect influences, such as the impact of Japanese art education in China. With these historical understandings, the section then examines the presence of art academies in Singapore and their role in the development of the Nanyang Style. Fourth, the chapter considers some historical perspectives on the development of art knowledge through

the Chinese communities as well as their influence on the supply of artist materials in Singapore. Then, the chapter provides the framework for investigating the historical supplies of art materials. Lastly, it will seed discussions on the artistic techniques identified in Chapter 4 on Georgette Chen and Chapter 5 on Cheong Soo Pieng. While setting up these themes of historical accounts, the uptake of easel painting practices in Singapore and the role of the early Chinese communities, this thesis continues to recognise the differences in backgrounds of and influences on Cheong Soo Pieng and Georgette Chen as individual practitioners.

3.2 Historical and cultural context: an art perspective

Early modern period leading to independence: a historical timeline

Narratives of Singapore's history tend to focus on the importance the British colonisation had in the establishment of Singapore as a trading port, which played an essential role in the Malayan economy (Lim 2012; Kobayashi 2019). However, even before the British colonisation in 1819, Chinese merchants were already trading in the Malay Peninsula, which included Singapore, and continued doing so even after Singapore was colonised by the British. Eventually, some Chinese sojourners settled in Singapore temporarily before returning to China when political conditions improved (Lim in Tay 2020). When China faced more political and economic tensions during the Second Sino-Japanese war (1937–1945), there was again an increase in Chinese migration to Malaya and Singapore. Discussed in this chapter is the context of the transnational Chinese communities' in Singapore and their influence on the development of a local art environment. This saw significant contributions such as the establishment of educational institutes, as well as the development of a local art scene and philanthropy (Kwa & Ke 2019; Lim 2012). While transnational perspectives of the Chinese diaspora have been explored in existing scholarship on art history, the influence of the Chinese community and their indirect impact on artist materials and transmission of art practices in Singapore has yet to be examined closely. Analysing the extent of influence the Chinese community had on the trading of artist supplies in Singapore and the development of the Nanyang Academy of Fine Arts can provide insight into their direct and indirect influence on the art and on how the conditions of 20th century paintings in Singapore were shaped and produced. As such, this thesis aims to examine this claim and to explore the broader influences that may reside in the material evidence obtained from the visual analysis of the works of art by Cheong Soo Pieng and Georgette Chen.

Arriving in Malaya in 1942, the Japanese occupation lasted three years. Singapore was incorporated into the Japanese Empire, and indoctrination with Japanese propaganda began almost immediately, as evidenced by the name changes of official newspapers within five days (O'Neill 2014). The impact of the war on the artistic community is exemplified by the execution of Tchang Ju Chi (1904–1942), one of the earliest practising artists in Singapore, who had arrived in 1927, and was taken away by the Japanese military during the Sook Ching massacre in 1942 as part of the move to systematically remove anti-Japanese elements within the Chinese community in Singapore. This highlights the challenges faced by artists and the disruptions to organisational structure and governance at the time. It would likewise have had a profound effect on the artists in Singapore in terms of the continuation of art practices, art training opportunities, art material supplies and artistic networks throughout the period of war in Singapore.

After the surrender of the Japanese in 1945, Singapore reverted to British control. However, the end of the war did not mark the end of conflict in China. The unrest caused by the Chinese Civil War (1927–1949) between the Nationalist and Communist parties made return to China impossible for many people, and waves of Chinese migrants arrived in Malaya, including artists familiar with easel painting practice and Chinese calligraphy.

Historian Tim Harper's (2009) analysis of colonisation and its impact in shaping post-war modern Malayan culture concluded that it was primarily "a product of colonial administration" (Ong 2006, p.66). After the war, the idea of a national culture for Malaya was promoted by the British government to deal with the diverse cultures and to maintain social equilibrium among the various racial communities in Singapore. As part of this, easel painting was seen as "more suitable as a medium as it could be learnt and appreciated by all races" (Hsü 1999). The authorities reasoned that promoting a unifying Malayan culture would be an ideal solution to forge new loyalties to the state and replace the old connections between the various communities in order to minimise racial tensions. Such tensions were present in the artistic community, with concerns about art schools such as the Nanyang Academy of Fine Arts serving mostly the Chinese community by conducting most of its courses in Mandarin (Low 2015, p. 468).

The timeline provided here is brief and presents one narrative of how easel painting practice was assimilated into Singapore's developing art scene through the Chinese community and to the conditions that informed it. As discussed, many Chinese artists, such as

the artists studied in this research, Cheong Soo Pieng and Georgette Chen, had migrated to Singapore in the early to mid-20th century. The next section provides a more detailed account of how easel painting practice was likely to have been introduced into Singapore and how understanding the history of assimilation of Western art in China can offer a contextual understanding of the indirect influence of the artistic background of the Chinese artists.

Assimilation of Western art in Singapore through art education

The practice of easel paintings and watercolour paintings in Malaya appears to have first arrived through Portugal and later, in the late 18th century, from Great Britain and Holland (Abdullah 2018; Hsü 1999). By the 19th and early 20th centuries, most of Southeast Asia, with the exception of Thailand, was under Western colonial rule. However, keeping in mind that Southeast Asia is a broad region, with each country having its own language(s), cultural practices, and socio-political histories, that shape the cultural fabric of each country, therefore, many forms of art exist in the region. Given the vast array of cultural materials and art forms available in Southeast Asia, it is challenging to know where to start to investigate the heritage and introduction of the practice of easel painting in Singapore. While art forms such as watercolour paintings and portraits on easel painting were introduced to Singapore during the British colonisation in the early 19th century, whether or not this provided impetus for the adoption of these techniques in Singapore requires further examination (Taylor 2011; Waterson 2010). As such, this section presents one of the many possible narratives of how easel paintings was assimilated into Singapore.

Starting with understanding the root of Western colonisation as “the intensity of colonial intervention in the region [that] connected the places and cities, moved peoples and transferred ideas in the region” (Seng 2017, p. 232). As an established port along the major shipping routes between China and Europe, the movement of ideas and people saw Singapore’s growth in its artistic activities. The role that Singapore played as a site of connection lasted beyond the second world war, even when Georgette Chen, who arrived in Singapore in 1953, described Singapore as a site of connection where East meets West (Chen 1962). This insight is a point worth investigating to as it offers a means to understand the earlier interwoven cross-border influences and their impacts. By understanding the conditions which enabled both artists to migrate to Singapore for art, the analysis of artist materials and practices of Cheong Soo Pieng and Georgette Chen can then be situated and well-positioned to understand how their art practices.

At present, much of the history of easel paintings in Singapore has been examined through an historical framework looking at the intersecting periods of colonisation and war, events undoubtedly had an impact on the livelihoods of people and the supplies of art materials locally, as produced by scholars such as Kwok (1996), O'Donnell, Tse and Ahmad (2015), Ong (2007) and Sabapathy (1993). However, when considering art practices in Singapore from the late 1950s, colonisation and war were not necessarily the main factors influencing the development of local transfer of art knowledge or the forms of painting practices. In fact, it was equally the transnational Chinese communities, their ecosystem and networks between artists' groups that played a significant role in the development of artistic knowledge in Singapore, such as the establishment of the Nanyang Academy of Fine Arts (NAFA), which is the focus of this study (Hsü 1999; Seng 2017; Tse 2008).

As an entry point for this discussion, the artistic practice and career of Tchang Ju Chi, who was one of the earliest recorded Chinese artists in Singapore, offers insight into the parameters of easel painting practice in a Singaporean context. Tchang first engaged with easel painting, not in a European country, but in China. Having studied Western painting at the Shanghai Academy of Fine Arts, he then attended the Marseille Academy of Fine Arts in France to further his education. While on his return journey home to China in 1927, he settled in Singapore at the locals' invitation. He established his studio in Singapore and became the founding president of the Society of Chinese Artists in 1936 (Hsü 1999). While other influential Chinese artists, such as Xu Bei Hong and Liu Hai Su, stayed in Singapore for considerable lengths of time before the war, Tchang Ju Chi had an enduring influence on the painting of local subject matter and the immediate surroundings of the artist, which is the representation schema adopted by the first generation of Nanyang artists (Hsü 1999; Sabapathy 2018).

Ong (2007) and Abdullah (2018) maintain that the British only begun providing formal art education in Malaya schools in the early 20th century, more than 100 years after it colonised Malaya and suggest that the British colonisers were not necessarily the key parties who influenced the introduction of traditional Western canvas paintings. For instance, it was only in 1923, when the British colonial administration brought in Richard Walker as a British art educator and administrator to teach in Singapore's government schools and in 1938 when he became an Art Superintendent and taught art to non-English speakers for the first time (Ong 2015, p. 43; Yeo 2019 p. 466). Hsü argues that the impact of British colonisation and

art development was limited (1999), instead, he links the assimilation of easel painting practices in Singapore to the efforts of several Chinese artists who stopped in Singapore in the 1930s along their sojourns between China and Europe, some who eventually resided permanently (Hsü 1999, p. 65).

According to Ong (2006), art academies such as the Shanghai Academy of Fine Arts, National Beijing Art College, and the Xiamen Academy of Fine Arts, among many others, were modelled after Japanese and European art schools. The Xiamen Academy of Fine Arts, established in 1922, was one of the earliest art academies in China to embrace a Western art curriculum which included Western painting, sculpture, Chinese ink painting, design and art teaching (Ong 2006). This arts curriculum, made up of Western and Chinese art subjects, was taught by teachers who were graduates from schools in Japan and Western Europe (Liu 2011, p. 227). Many of the art schools in China had produced their first batch of graduates by the late 1920s, who looked overseas for opportunities either to pursue further study or as a career (Ong 2006, p.28).

To add a layer of indirect influence, the teaching of Western art in China did not only originate from Europe but was also through Japanese influence. The Japanese played a crucial role in assimilating Western artistic knowledge about mediums such as oil, gouache, watercolour, acrylic and printmaking in Asia as part of its modernisation process of the Meiji Reforms in the late 19th century (Liu 2011, p. 228). The main essence of Western painting, as differentiated from Chinese painting, was understood as painting with these mediums (Liu 2011, p.228). This prompted trade agreements between Japan and Europe, which enabled a flow of artistic transmission between the two regions, such as *Japonisme* in Europe, when woodblock prints were introduced and influenced Impressionist and Post-impressionist artists. Japan soon established itself as a leader in Western art in Asia and expanded into the manufacturing of artist materials. Japanese canvas manufacturers such as Holbein and Funaoka's Canvas, established in the 1910s, were local drivers in producing art materials suitable for the Japanese market and environment. Japan's manufacture of artist materials such as canvas in the 19th century suggests a growing interest in and demand for easel painting. Thus it is worth a brief examination of the impact and influence Japan had on the transfer of artistic knowledge in its surrounding region of Asia.

The transformation of China's art practices, particularly in adopting easel painting, was driven by a series of events that occurred as part of a modern education system in 1902

which looked towards a new art curriculum and the empirical sciences (Andrews & Shen 2006; Carter 2017). This prompted Japanese art educators and locally trained Chinese artists to begin to teach easel painting in the art curriculum. In 1906, the curriculum of the first art academy to teach Western art and painting practice in China had its roots in Japanese models and “its curriculum was very similar to that of the art major at Tokyo Higher Normal School” (Andrews & Shen 2006, p. 5). Some years later, the Japanese had a similar direct and positive influence throughout Southeast Asia in the dissemination of Western artistic knowledge. Given Cheong Soo Pieng and Georgette Chen’s first contact with Western art was in China, it can be argued that the knowledge transfer of easel painting practices suggests a possible indirect Japanese influence on their practices, which would eventually be a part of Singapore’s local art practices. Further research on the Japanese influence and any distinct techniques might present an interesting study.

Recentring this discussion back in Singapore at the turn of the 20th century, this curriculum had an impact on Singapore’s domestic art scene, as the practice of easel painting was a result of these graduates of fine art academies in China later teaching at Singaporean art academies (Liu 2011, p. 227). From this perspective, we can understand the ways in which Chinese artists viewed Japan and Europe in their contribution to Western art assimilation in Singapore. It suggests an expansion of the discourse on artists’ practices without a focus solely on Western influences as the major source of artistic knowledge. In this thesis, the examination of a painting’s material and artistic techniques is proposed to offer evidence of the material influences on 20th century painting practice in Singapore. As the Chinese community played a pertinent role in the transmission of easel painting practices in Singapore, the next section begins by exploring the conditions of the growing art community in Singapore in the early 20th century, which enabled and supported a developing art scene.

Chinese communities: building a local art scene in Singapore

After the second-world war, various artists transitioned and visited Singapore, some from Europe, America, as well as those from neighbouring countries like Indonesia. However, the Chinese artists and calligraphers were some of those who frequented Malaya more commonly. Importantly, those that settled down or stayed for a considerable time in Singapore, showed to have an impact on the development of easel painting practice (Hsü 1999, p. 65; Seng 2017; Yeo 2019). Some of the earliest surviving advertisements in a local

newspaper, *Sing Po*, can be traced to as early as 1894 which showed some Chinese initiated art activities (Yeo 2019, p. 19).

The close-knit circle of the Chinese community in Singapore contributed significantly to the developing modern art world of Singapore (Koay 2011; Mustafa 2016). The Society of Chinese Artists (SCA) was set up by a group of like-minded artists from Shanghai and Hangzhou in 1935 to forge close ties with their homeland and promote the arts. SCA members were graduates from art academies in Shanghai (Shanghai Fine Arts College and Xinhua Fine Arts Academy), Japan and Europe and conversant in Chinese and Western painting. The SCA was quite influential in the Malayan art world, and many transnational Chinese artists were recognised as Singaporean ‘Nanyang’ artists. The term ‘Nanyang art’ will be discussed in detail below in Chapter 3.3.

Referring back to the case study artists, Cheong Soo Pieng and Georgette Chen, their cultural backgrounds and reasons for settling in Singapore were vastly different. Their individual differences in artistic training and painting practices cannot be generalised into one type of practice or reduced to a particular point in time. In the case of Cheong Soo Pieng, his first artistic training in Western Art was undertaken in Shanghai in 1936, and did not travel to Europe prior to arriving in Singapore, which was enabled by the support offered by the strong networks of the Chinese artist societies in Singapore (Mashadi 2010; Siew & Lee 2018; Yeo 2010). On the other hand, Georgette Chen had frequented China, Paris and New York, where she undertook artistic training, prior to arriving in Singapore in 1953. Both Cheong Soo Pieng and Georgette Chen were of Chinese descent and born in China, settled in Singapore and later recognised as pioneer Singaporean artists. However, their history, personal ecology and knowledge systems differed. These artists serve as a springboard to situate the development of Singapore’s art materials and knowledge transmission as educators in early modern art. From this critical lens, it will be shown how the study of the materials and techniques between the two artists can offer an interesting perspective on the dynamism of the Singaporean art landscape and its material culture.

The building of Singapore’s local art landscape

Despite the development of the local art landscape, Chinese scholars dismissed Singapore as a ‘cultural desert’. Multiple critical essays from Liu Kang and Ho Ho Ying reflecting on the art development of Singapore have given insight into the changing cultural

landscape of Singapore. Liu was well known as one of the pioneers of the Nanyang Style. He emerged as one of the leading artists in Singapore in the 1950s (Kwok 1996, p. 50). Ho is a proponent of abstraction and a leading figure of the Modern Art Society who has written and promoted non-objective abstraction in art (Kwok 1996, p. 79).

Liu argued that the period between 1910 and 1960 can be divided into two phases: the first phase was between 1910 and 1935, which was chaotic, and the second phase occurred after 1935, when foreign talents arrived armed with the responsibility to teach (Liu 2011). The latter is where artists such as Cheong Soo Pieng and Georgette Chen, who arrived to Singapore in 1946 and 1953 respectively, and were both Western Art educators at the NAFA is situated. Liu's observation supports Hsü's stand that the assimilation of Western painting traditions into a Singaporean art scene first began with the efforts of Chinese artists who arrived in Singapore before the war and those that resided in Singapore permanently after the 1930s (Hsü 1999, p. 65). The late 1930s to the late 1940s saw Singapore growing as a significant art and cultural centre for the Chinese overseas (Yow in Liu 2011, p. 18). However, this was disrupted by the Japanese Occupation. Little has been written about the cultural landscape during the Japanese Occupation, but it has been noted that many arts and cultural heritage objects were destroyed during the period.

After the war, Liu Kang lamented that Nanyang was considered a 'cultural desert' and criticised both the British administration's exploitation of the economy and the local inhabitants' 'laziness', which he believed impeded aspirations of more noble activities, such as pursuing culture and arts (Liu 2011, p.36). Recovering from the early post-war years where culture had taken a back seat, the government's lack of strategy for art matters or a proper organisation to promote arts prompted the Nanyang artists to build an international audience to develop the cultural landscape. The re-opening of Nanyang Academy of Fine Arts, one of the first formal art schools in Malaya to offer tertiary art education, in 1946, saw an invigorated sense of purpose along with new directives for the school's roles and function. Between 1946 and 1955, several established Chinese artists were invited from China to live in Singapore as art educators.

The unique conditions of post-war Singapore provided fertile grounds for the fermentation of 'new' identities, which transformed the social, cultural and economic landscape (Low 2015, p. 463). The 'cultural desert' characterisation was not about the vibrant arts scene already in existence, but rather, about the lack of an art ecosystem. Ho and Liu

blame the lack of an institutional structure for the lack of opportunities to raise artistic standards in Singapore. Before the 1970s, the visual arts landscape was sustained mainly by private initiatives, as the arts and culture were not national priorities for the newly independent country. The lack of an art ecosystem in Singapore meant that there were no art galleries or art dealers to support artists, or a dedicated art museum where local art could inspire future artists (Ho 2005, p. 64). Concerted government support for visual arts only began in the 1970s with a clear nation-building agenda behind the support (Hoe & Chong 2018, p. 2).

In the 1970s, the rise of institutions promoting national art and culture included the financing and building of cultural centres, museums, art galleries and academies. The urgency of establishing a common identity was vividly felt in Singapore, which sought to bridge the gulf separating it from the rest of Malaya (Low 2015). In the late 1980s to the early 1990s, Cheong Soo Pieng and Georgette Chen, the two artists in this study, and Liu Kang, Chen Chong Swee, Chen Wen Hsi, Lim Hak Tai, and Lim Cheng Hoe, who were associated with the Nanyang Style of art, were all conferred with ‘pioneer artist’ status (Tan 2014). The Nanyang artists played a vital role in disseminating techniques among artists, and thus it is helpful to consider the art academies in which they taught in in Singapore.

3.3 Art Academies in Singapore

Art academies

The Nanyang Academy of Fine Arts (NAFA) was not the first school of arts in Singapore, although it was the only one that continued operations after World War II (2022). Before 1942, a further seven art educational schools and several small art studios were in existence, representing the beginnings of professional attempts at artistic education in Singapore and Malaya (Yeo 2019, p. 102). These were:

- Angel Art Academy (*Tianshi Meishu Xueyuan*), founded by Zhong Ming Shi, graduate of Fujian Provincial Teachers’ Training College
- White Egret Art Academy (*Bailu Meishu Yuan*), founded by Lin Zunde, graduate of the University of Wyoming
- Southwest Art Academy (*Xinan Meishu Yuan*) Fine Arts Institute, founded by Jiang Xiuhua, graduate of Nihon Bunka University Japan

- Westlake Art Academy (*Xihu Meishu Xueyuan*), founded by Deng Qiyi and Chen Daju
- Apollo School of Fine Arts, founded in 1937 by Russian artist, Vasily Zasiipkin
- Rose Art Institute, founded in 1929 by Lin Youfei
- The Nanyang Academy of Fine Arts, founded in 1938 by Lim Hak Tai.

Where possible, founding dates are recorded and from the list above, compiled by Yeo (2019) and Woo (2019), it can be seen that the establishment of art education institutions in early Singapore was mostly achieved by overseas Chinese artist educators from a diverse education background, which suggests a strong community of Chinese support for the arts in Singapore. Most of these academies were founded before 1938 when the British colonial administrator, Richard Walker, first taught art to non-English speakers. This is explored in detailed accounts by Ong (2006) and Low (2015), both of whom have written on the establishment of art societies in Singapore.

Focusing on the Nanyang Academy of Fine Arts (NAFA) where Cheong Soo Pieng and Georgette Chen taught easel painting, between 1947 to 1961 and 1954 to 1981 respectively, two leading overseas Chinese associations played a pivotal role in NAFA's success and formation in Singapore in 1938: the Jimei Overseas Students Association and the Society of Chinese Artists (SCA). The SCA proposed establishing a school that specialised in fine art. The SCA, founded by Tchang Ju Chi, had its networking roots in the Shanghai Academy, Xin Hua Arts Academy and Shanghai University of Arts (Low 2015). It included members such as Liu Kang and Penang-based Yong Mun Sen (1896–1962). In the 1930s, Huang Suibi, a Japanese-trained principal of the Xiamen Academy of Fine Arts, visited Singapore on returning from a study tour of Japan (Kwa & Ke 2019). He saw the possibility of starting an art school in Singapore and approached Lim Hak Tai, one of the founders of the Xiamen Academy of Fine Arts, with the idea of starting an art school (Ong 2006). The Second Sino-Japanese war in 1937 saw Lim Hak Tai and some of his students and colleagues escaping to Singapore to avoid the conflict. In Lim Hak Tai's affiliation and capacity with the Jimei Overseas Student Association (Xiamen), the group became more involved in the founding process of the Academy. Lim Hak Tai proposed that including the word 'Nanyang' in the school name would reflect its tropical surroundings and location in a multicultural society. Hence, the Nanyang Academy of Fine Arts (NAFA) was formed (Ong 2006).

As the first formal art school in Malaya to offer tertiary art education in Singapore, once formally established, NAFA followed the French *Ecole des Beaux-Arts* tradition (Masahiro 2017, p.137; Koay 2011). When NAFA was first founded in 1938, there were four main faculties: Western Painting, Art Education, Applied Fine Art and Sculpture. Subjects were weighted towards Western visual arts (Ong 2006; Low 2015). The Nanyang School was first built as an extension of the Xiamen Art School, hiring former teachers of Xiamen Art School who had a variety of artistic training backgrounds. For instance, Xie Touda received his education in the Philippines and France, Lin Junde was educated at the University of Wyoming in America and Guo Yinglin had studied in France, highlighting the various indirect influences that impact how Western art is taught through these Chinese artists through their varied backgrounds (Ong 2006). Faced with financial difficulties early on, NAFA started to thrive in 1941. However, the disruption of the Japanese occupation caused it to cease operations and lose key members of staff, including Tchang Ju Chi of the Western Art Department.

When NAFA re-opened after the war, it continued to take on its staff members from the pool of Chinese artists. The teaching of Western art at the Academy was taken over by several new teachers, including Cheong Soo Pieng, who immigrated to Singapore in 1946. Cheong was a former student of Lim Hak Tai at the Xiamen Art Academy and was invited by Lim to teach at the school after he arrived in Singapore. Cheong entered the department in 1947, where he worked until 1961. Cheong Soo Pieng taught at NAFA as a lecturer in Western Art, and worked and experimented there with different styles and media. His students were observed to follow suit. Low argues that NAFA's faculty staff acted as authorities for professional development in the fine arts (2015, p. 474). Emigré artist-educators, defined as those who migrated often due to political reasons, who were teaching in NAFA were at the height of their influence. Their exploration of a different Southeast Asian socio-cultural experience underpinned the Nanyang Style and further encouraged their students' experimental use of materials (Koay 2001; Sabapathy 1979).

Until the 1950s, the teaching of Western Art in Singapore through NAFA was mainly dominated by overseas Chinese, and it served the overseas Chinese community; students of other nationalities remained relatively uncommon, since the main language of instruction was Mandarin (Low 2015, p. 468). Given the widespread Chinese background of the Academy, a question for consideration is the extent to which NAFA accommodated the diversity of the

Malayan vision. Since it was the Chinese who formed the dominant group within the visual arts in post-war Singapore, it was often assumed that the creation of the Nanyang style was driven by social and political conditions (Zou & Eaksittipong 2014). The hiring of Georgette Chen in 1954 coincided with NAFA's expansion into engaging with multi-ethnic Malayan society, taking on non-Chinese students, and establishing connections with art institutions outside of China.

Nanyang Style

The term 'Nanyang art' has been commonly used as a term that refers to Singapore's first critical period in art history where local artists attempted to develop a critical art discourse (Seng 2017). Drawing from a broader context, *Nanyang*, a Chinese term translated as the 'south seas', took reference for being south of China. Encompassing geographical areas where the Chinese had traded including Indonesia, Malaya (Malaysia and Singapore), Philippines and Thailand, various scholars have examined how an exploration of narratives surrounding Singaporean art history through Nanyang art can illustrate an extension of regional networks formed by sojourning artists (Clark 1998; Sabapathy 1993; Seng 2017; Tse 2008).

When discussing art movements or styles of Singaporean art holding influence at NAFA, Impressionism, Post-impressionism, Cubism (1907–1914) and Fauvism (1904–1910), are often referenced as inspirations (Ong 2006, p. 82; Sabapathy 2018, p. 343). However, this is not the case, as the artists did not have a common painting style and their varied body of work depicted different subjects (Neo 2014, p. 30). Liu Kang, a Singaporean first-generation Nanyang artist, describes the concept of Western art as theoretical and scientific, while Eastern painting's technical application is abstract, minimal and pure in expression, with brushwork an indicator of a good painting (Liu 2011, p. 116). Seeing Western art as an extension of Eastern art, Liu argues that the main differences between Western art and Eastern painting techniques is the choice of paint medium as well as the importance of chiaroscuro, perspective, and anatomy. Other differences between Western and Eastern art include aesthetic representations such as pictorial differences when Western artists "represent the world with a central perspective and focus on salient objects in a scene" while "Chinese artists concentrate on context information in their paintings" (Bao et al. 2016, p.1).

In the 1960s, historians T. K. Sabapathy and Redza Piyadasa first drew the parameters of the ‘Nanyang Style’ in the catalogue, *Pameran Retrospektif Pelukis-Pelukis Nanyang*. The style was coined during a retrospective study of the art produced at NAFA. The Nanyang artists “worked within the general framework of the easel painting tradition where the implicit approach is a painting consisting of a framed ‘worked’ surface that is hung on the wall at eye level ... proposing an independent entity for aesthetic appreciation” (Sabapathy 2018, p. 340) and adopted an experimental approach which used styles and techniques derived from two sources: Chinese pictorial traditions and the school of Paris. Sabapathy maintains that artists such as Cheong Soo Pieng and Georgette Chen, who were the first generation of Nanyang artists, studied in various institutions in Shanghai where this approach formed the basis for their education, and their activity in Singapore can be viewed as an extension and elaboration of this approach (Sabapathy 2018, p. 341). This period was particularly important for Cheong Soo Pieng’s oeuvre, as the Nanyang Style was one of his longest curatorial categorisations, spanning 11 years, which will be discussed in detail in Chapter 5.

One pivotal point for art development in understanding the Nanyang style was the 1952 trip to Bali by Singaporean artists Liu Kang, Cheong Soo Pieng, Chen Wen Hsi and Chen Chong Swee. However, by the 1960s, art practices that were prominent during the Nanyang Style of art in the 1950s, had departed from conventional ways of working (Ho 2005, p. 64). Ho maintains that in the 1960s, the development of the art scene of Singapore was championed by artists like Cheong Soo Pieng, who adopted new approaches, rather than those who continued practising traditional painting techniques such as the likes of Georgette Chen, who was criticised for remaining fixed in the Impressionist phase. While it is beyond the scope of this research to engage in such a curatorial discourse, Ho’s view highlights the diversity of the Nanyang artists in their artistic development and offers a foundation understanding of differences between Cheong Soo Pieng and Georgette Chen’s materials and techniques, which will be relevant to later Chapter 7.3. This thesis thus engages in questions about the similarities and differences between the materials and techniques of these two artists.

3.4 Artist Supplies in Singapore

Suppliers of artist materials: from bookstores to Straits Commercial

Following discussions on the development of a Singaporean art scene, this chapter now examines the ecosystem of trade and distribution of materials, as an interconnected area of study to frame a technical art history of paintings in Singapore. The goal is to build an understanding of the artworks produced in Singapore from locally available artist supplies by artists who are recognised as Singaporean artists. So far, research on art materials by Singaporean artists often include oral interviews with various descendants of the Straits Art Company (Straits Commercial) to understand the material availability of art supplies (Gomez Lobon 2010a; O'Donnell, Tse & Ahmad 2015; Tse & Sloggett 2008). These interviews have been used to understand the material availability of Singaporean artists such as Cheong Soo Pieng, Georgette Chen and Yeh Chi Wei, who practiced Western canvas paintings.

Tay Long founded Hai Xia Art Supplies in 1947, later known as Straits Commercial, together with Chong Pai Mu, an art educator who taught at the NAFA. To date, there are three known interviews conducted with Mr Tay Nam Seng, son of Tay Long, to understand artist materials availability in Singapore (Ong 2006; Gomez Lobon 2010a; O'Donnell, Tse & Ahmad 2015; Tse 2008). However, drawing data from interviews necessitate a closer scrutiny, particularly as they rely on memory, albeit these interviews serve as crucial oral history (Cotte, Tse & Inglis 2016, p. 111). In one of his interviews, Mr Tay Nam Seng noted that from 1947 until the early 1980s, Straits Commercial was the “sole supplier of Western art materials in Singapore” (Gomez Lobon 2010a). While there has been a focus on the prominent role Straits Commercial has played in the supply of artist materials in Singapore, research such as O'Donnell, Tse and Ahmad's (2015) study on Georgette Chen had identified other suppliers of materials in Malaya. Similarly, this study examines other sources of art materials distribution to investigate the sources of artist colourmen goods available in Singapore.

Enabling access to archived newspapers, the NewspaperSG collection, an online resource of current and historic Singapore and Malaya newspapers where digital archives of English, Chinese and Malay language newspapers published between 1831 and 2009 can be searched (Kia et al. 2014, p. 2). This initiative was begun in 2013 by the National Library Board Singapore, which has made over 20 million published newspaper articles accessible through searchable text analytics. As a good starting point for this project, the keywords

utilised were ‘artist’, ‘canvas’, ‘drawing materials’, ‘oil colours’, ‘paint’, ‘reeves’ and ‘winsor newton’.

The study accessed both archived national newspapers and found sources from 1899 to the early 1970s as well as archived exhibition catalogues from the 1950s to 1970s. Findings suggest that several distributors and stores in Singapore sold art materials. These companies were mainly printers, book, stamp or stationery shops which sold artist colourmen materials and were owned by local Malay, Indian, Chinese, and Eurasian people, as well as German and English traders. Artist colourmen brands such as Winsor & Newton (1899), Reeves (1925) and Kroma (1931) were available in Singapore and were distributed through various shops, such as Katz Brothers Ltd (German brothers), C.A Ribeiro & Co., Peter Chong & Coy, E.J. Motiwalla (India) and Kelly & Walsh (Shanghai). Interestingly, ready prepared artist canvasses on stretchers were first advertised in 1905 by Katz Brothers Ltd and in 1931 by Wah Heng & Co photo stores. After the war in 1945, Peter Chong and E.J. Motiwalla appeared to resume business, while companies such as Katz Brothers left Singapore prior to the start of the war. As most of the advertisements during the pre-war period were in English, the audience catered to could be inferred to be English speakers. While the supply of materials before the war may not be relevant to the paintings produced by Cheong Soo Pieng and Georgette Chen, it does show an earlier precedent and market for Western art materials and adds context to the choice of materials used in Singapore.

Interestingly, there was a change in artist catalogues around the 1950s, where advertisements were predominantly in Chinese, suggesting a change in the audience ecosystem and communities engaged in the art scene. Several artist colourmen brands sold in Chinese bookstores could be found in these advertisements. For instance, Pelikan oil colour was sold in Guang Ming bookstore as advertised in 1955, while a Japanese paint manufacturer, Sakura Colour Products, advertised in the 1965 Society of Chinese Artists’ 20th anniversary souvenir magazine. In 1967, a more general advertisement for artist materials such as Chinese ink painting and oil paints was advertised by the Shanghai Book Company (Tay 2020). The advertisement of Pelikan brand art materials in Guang Ming bookstore presented an interesting insight into the two Pelikan artist boards dated 1939 and 1946 recorded by Tse (2008, p. 125). Tse (2008) concluded that it was “not known when or from where these two Pelikan boards were obtained” and that they “were presumably imported through alternative avenues” as the artworks were created before the establishment of Straits

Commercial (Tse 2008 p. 139). Such archival evidence emphasise that artist materials were available through a range of distribution channels and countries. However, the known facts are limited and cover a long timeframe from the 1940s to the 1960s and as such, links between the availability of materials and those used by artists are to be made with caution. One way to increase confidence and support such conclusions are by gather further evidence and data mining, which is the intention of this study. Chapters 4 and 5 will discuss how these findings can inform Georgette Chen and Cheong Soo Pieng’s art practices which set the stage for Chapter 7, where detailed discussions on how such data can be mined will follow.

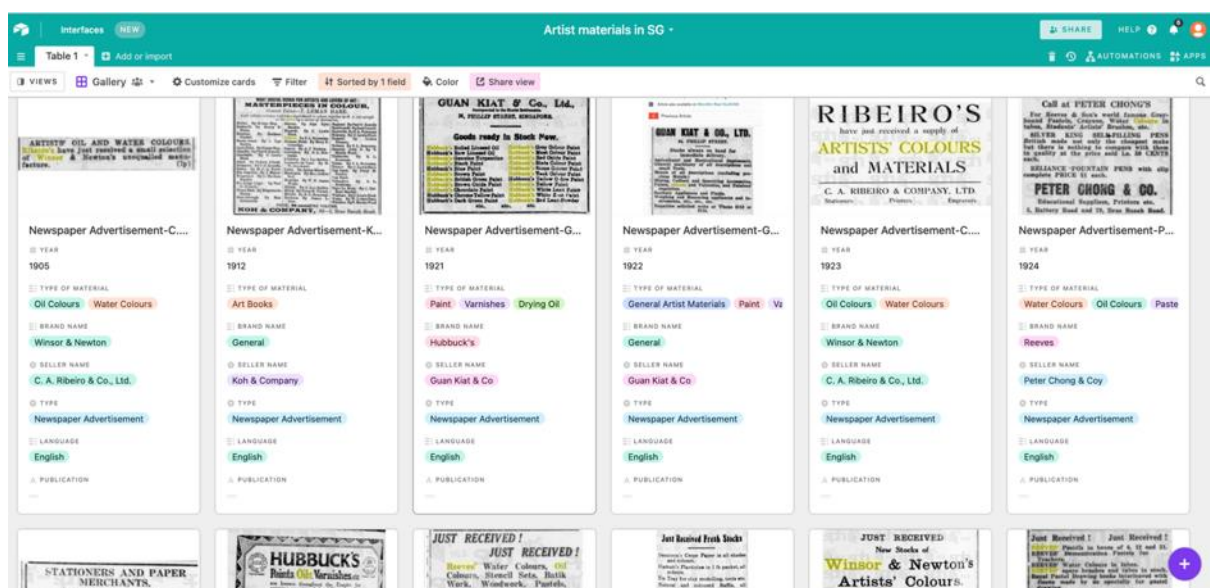


Figure 4. Airtable database of artist materials and suppliers in Singapore from 94 newspapers and exhibition catalogues of English and Chinese sources, 1861–1975.

Further archival research and evidence shows that these advertisements were published mainly in Chinese. These Chinese advertisements indicated the presence of Chinese bookstores as a source of artist supplies in Singapore from 1954 to 1970 and features an interesting aspect of the social and cultural ecology of the practising artists at that time. This appears to be similar to how artistic training has been argued to have been influenced and “largely precipitated by the arrival of Chinese artists” (Ong 2015, p. 43). While little has been documented about the supply of artist materials in Singapore before the establishment of Straits Commercial, Chinese archival sources present a potential avenue to inform future research. As part of this study, an online database consisting of advertisements from archived national newspapers and selected artist exhibition catalogues from the National Gallery of

Singapore Resource Centre has been built on Airtable and features around 60 artist colourmen suppliers from 1899 to the 1970s (Figure 4). In this study, this content is used to provide context for any material evidence that may be found in the technical examination of paintings as well as insights into particular artist colourmen or art suppliers in Singapore during the time period studied (1940 to 1980s). The database was a result of exploring suppliers of artist colourmen materials in Singapore and critically examines how artists may utilise materials outside those sold by Straits Commercial. With a long-term aim in mind of building a conservation material record, the database aims to serve as a base for future research on Singaporean artist materials and techniques that necessitate material references for analysis.

Artist materials: other Japanese manufacturers

To date, research on Western artist materials in Singapore has focused mainly on identifying artist colourmen paints. Some brands identified in recent studies include Winsor & Newton and Rowney, both of which are British companies. It can be argued that the discovery of British artist colourmen materials and British colonisation in Singapore have shaped the present narrative on artist supplies. However, this research has encountered the use of Japanese artist colourmen, encouraging an expansion of the current understanding of artist materials and supplies in Singapore. Few published studies have focused on the sources in Singapore of one of the most significant aspects of easel paintings, the canvas layer. Tay Nam Seng said that canvas and art materials were very expensive in the 1950s, and only the English soldiers would buy them (Gomez Lobon 2010c). In the 1960s, they became more accessible to local artists. From oral histories obtained from Tse (2008), Straits Commercial imported pre-primed canvas from Belgium, which was in rolls of 2.1 x 10m and had rabbit skin glue and an oil priming. However, as will be later shown in Chapters 4 to 6, through the technical examination of the works of art by Cheong Soo Pieng and Georgette Chen, canvas supports of Japanese origin were identified in the course of this study. They were used for works from three Nanyang artists from the 1950s through to the 1970s, and the specific details will be part of the discussion later. The section below will provide some historical background for the Japanese canvas support identified in Singapore paintings. These include Claessens, Japan, Funaoka's Canvas and Holbein, which will be significant to discussions later in the thesis.

Claessens, Japan

Archival research and informal discussions with Claessens, a Belgian canvas manufacturer, suggested that exports into the Asian market began in the 1960s (Hackney 2020, p. 15). Before 1964, Claessens mainly exported Belgian-produced canvas into the Asian market. However, in 1964, Claessens Japan (Cresan Japan) was established to manufacture canvasses under brands such as A-line Canvas, TAC Canvas, and Funaoka's Canvas for export to Asia (Umeda, personal communication, 2020). From 1964 to 1985, Claessens used rabbit-skin glue for sizing. However, after receiving feedback from customers that the canvas moved too much in response to their damp climate, Claessens changed the size of the canvas to synthetic glue polyvinyl alcohol. In addition, for oil-based grounds, titanium pigment replaced lead white (Carlyle & Hendriks 2009; Hackney 2020, p. 15). The use of polyvinyl alcohol instead of conventional rabbit skin glue after 1985 illustrates Claessens Japan's commitment to the Japanese and its export art market. It also shows the development of materials suited to the climate and high humidity. Correspondence with Phillippe Huyvard noted that to his knowledge, Claessens was probably the only Belgian canvas manufacturer that exported canvasses to Asia (personal communication, 2020), and may account for the oral history evidence from Tay Nam Seng of the availability of Belgian canvas in Singapore (Tse 2008).

Funaoka's Canvas, Japan

Funaoka's Canvas was founded in 1918 and began manufacturing Western canvas material after the First World War when the importation of oil paints and canvasses from Europe and materials was scarce (Funaoka's Canvas 2006). Funaoka also embarked on research to understand the materials that could be applied to the fabric to suit the climate of Japan (Funaoka's Canvas 2006). Like Claessen's Japan, Funaoka's Canvas incorporated PVA in its sizing layer to minimise fluctuations; however, its date of introduction is unknown. Funaoka's canvasses are tight and close woven, as shown in Figure 5, and its ground composition consists of lead white and titanium white with lithopone and kaolin (Dang 2009). Funaoka's canvas stamps were identified in several of Georgette Chen's paintings in the 1970s, and analysis of the ground composition with handheld XRF identified Zn, Ba, Sr, Pb, and Fe with a thread count of 16x13/cm (Figures 5 & 6). This information will have relevance in the later discussions and analytical sections in this thesis.

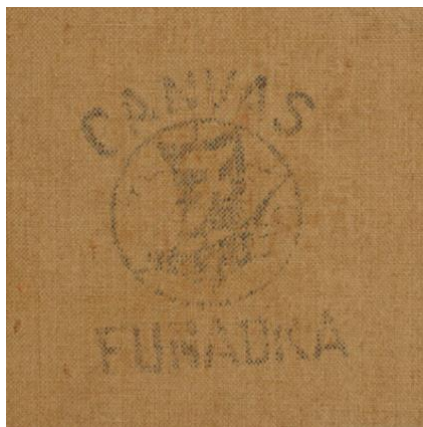


Figure 5. Funaoka's Canvas manufacturer stamp. Georgette Chen, *Flower Composition with Smiling Buddha*, c. 1970 (73 x 60 cm, oil on canvas). Collection: NGS.



Figure 6. 50x Magnification of Funaoka's canvas fibres showing tight and plain weave. Georgette Chen, *Flower Composition with Smiling Buddha* (1970).



Figure 7. Image of unidentified stamp similar to Funaoka's Canvas (Lizun 2022). Liu Kang, *Village*, c. 1950 (99 x 131.5 cm, oil on canvas 1950) Collection: NHB.

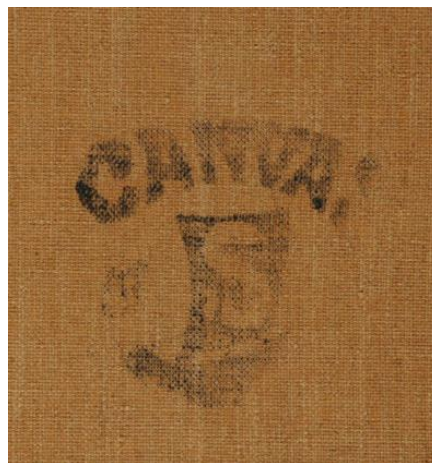


Figure 8. Image of unidentified stamp similar to Funaoka's Canvas similar to Figure 7. Georgette Chen, *Girl from New Delhi*, c. 1971 (81 x 65cm, oil on canvas). Collection: NGS.



Figure 9. 50x Magnification of canvas fibres of canvas from Figure 7 showing uneven threads and open weave. Georgette Chen, *Girl from New Delhi* (1971).

Worth noting is another unidentified canvas stamp that closely resembles Funaoka's canvas stamp. The similarities include the rectangular sail below the inscriptions. However, the 'F' is replaced with an 'S', and there is no circle. This was observed on a Georgette Chen painting, *Girl from New Delhi*, dated 1970 and a Liu Kang painting, *Village* (1950) identified by Lizun (2022) (see Figures 7 & 8). Lizun (2022) noted that the canvas had a pre-primed ground layer composed of lead white (PW1) mixed with lithopone (PW5) and/or barium white (PW21) and zinc white (PW4), and some titanium white (PW6). These observations were similarly recorded in the Georgette Chen painting. The ground composition shares a close correlation with Funaoka's ground composition. However, the canvas weave is loose and appears uneven compared with Funaoka's tight and even weave pattern (Figure 9). While the manufacturer is yet to be established, different letters may denote various types or grades (Simon, personal communication, 2020).

Holbein, Japan

The Japanese played a significant role in understanding the necessity for manufacturing artist materials that accommodated the region's humidity. As early as 1935, another Japanese brand, Holbein, undertook material research, as cited in the Holbein catalogue (Yoshimura 1935). First established in 1935 and closed during the war, Holbein reopened after the Second World War in 1946 and eventually began international exports in 1952. Holbein claimed to have dedicated and highly skilled trained craftsmen who were making and sustaining the highest quality of canvas, contributing to the world of Western painting (Yoshimura 1935, p.36). They stated that temperature was an important part of the canvas making process. In creating a canvas suited for Japan, the 1935 Holbein catalogue noted two main factors which affect the durability of a canvas (Yoshimura 1935) as quoted below:

1. **Nitrogen-containing water-soluble adhesive** (such as animal glue and particularly, rabbit skin glue $C_{102}H_{151}O_{39}N_{31}$). While it adequately fills the cloth, the priming causes decomposition and prevents the adhesion of the oil-based substance. While the deterioration process is natural, Holbein noted that the changes would be faster in humid conditions, which can cause fungal growth. Additionally, if the filling in the canvas weaves between the fibres become damaged, it will no longer be insulated from the air, and the canvas properties will change. If priming is insufficient,

oxidation from the oil will allow the oil's acidity to permeate into fibres and result in a brittle and brown state, which can cause damage and require lining.

2. Canvas is susceptible to change, shrinkage and swelling, dependent on the area of canvas and amount of moisture in the environment. The characteristic is known, and while it does not cause damage in the priming, it causes unnatural swelling and shrinkage in the paint layer. The differences in temperatures between the fibre and paint cause cracking. This was observed to have caused extreme damage to the painting. It is necessary to consider the irregular changes in canvas with the movement of the warp in different directions to the various directions in which the weft moves.

In the current study, a red Holbein manufacturer's stamp was identified on 8 out of the 40 Cheong Soo Pieng and Georgette Chen paintings studied which were on canvas supports. This finding is significantly high given the random selection by the collector. These stamps were found on canvas paintings dated between 1962 and 1968 and, under microscopy, the canvas appeared to be pre-primed. Interestingly, Straits Commercial, the main artist material supply shop in Singapore, confirmed that they have never sold Holbein canvas, which further indicates that the distribution of Western artist materials and supplies were not limited to one source (Tay, personal communication, 2020).

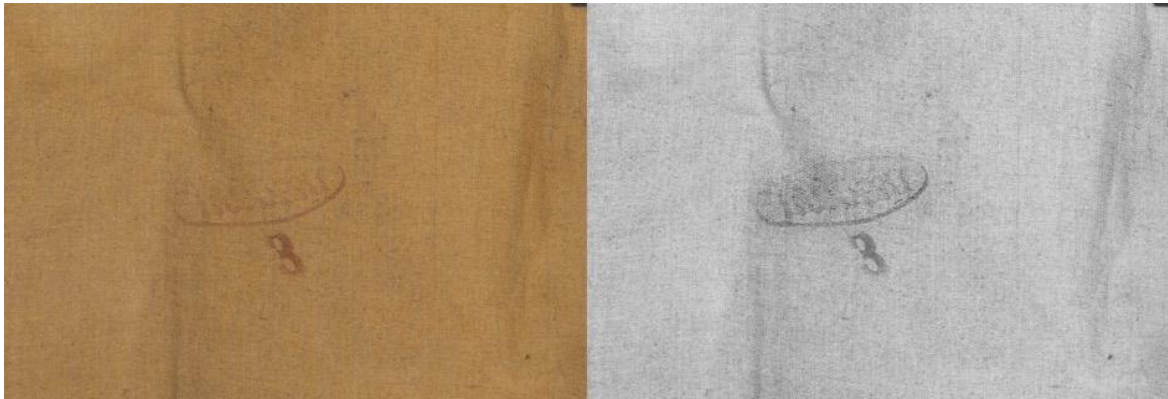


Figure 10. Detail of red ‘Holbein 3’ canvas stamp on verso (left) and digitally enhanced black and white image of the same to accentuate details of the canvas stamp. Cheong Soo Pieng, *Untitled (Red)*, c. 1963 (80 x 100cm, mixed media on canvas). Collection: KSC.



Figure 11. Detail of verso showing ‘Holbein 10’ canvas stamp. Georgette Chen, *Satay Boy*, c. 1964 (133 x 160cm, oil on canvas). Collection: National Museum Singapore.



Figure 12. 50x Magnification of Holbein’s canvas fibres showing uneven threads and open weave. Georgette Chen, *Satay Boy* (1964).

From examining Georgette Chen and Cheong Soo Pieng’s canvas supports, these Holbein canvasses were found to share similar thread count, fibre type, and visual characteristics. The Holbein canvasses examined have a 14x15/cm or 15x16/cm thread count and contain Pb and Ti elements (Figures 10-12). Under microscopy, bast was identified from fibres sampled from Holbein canvasses. The only variation within the Holbein manufacturer stamps is the numbers below the branding — either 1, 2, 3 or 10. Future research could

benefit from further investigation into the numbers found on the Holbein canvas stamps to establish their significance. At time of study, the Holbein company was contacted, but they could not provide any information.

3.5 Summary

This chapter examined the historical context and assimilation of easel painting practice in Singapore in order to understand the conditions of which Cheong Soo Pieng and Georgette Chen practiced in. As a result, this chapter found there were multiple avenues for the distribution of art materials, such as Chinese bookstores and Straits Commercial, and there was a variety of Western art materials available in Singapore, as early as 1899. Notably, the early Chinese community in Singapore played a critical role in establishing the infrastructure, support and environment for art activities to flourish. The chapter traced the events leading to the development of Singapore's local art scene from the 1930s and offered an insight into the factors that enabled the ecosystem to flourish, such as the establishment of the Nanyang Academy of Fine Arts in 1938. These events influenced some of the stylistic categorisation of Singaporean artists, such as the Nanyang Style, which is part of Cheong Soo Pieng's oeuvre and is used as part of the dataset. However, the summary of brief events discussed in this section only examined activities occurring in Singapore and has not examined the materials or supplies from neighbouring cities such as Penang, which could be further explored in future research.

Overall, this section has shown that the artist materials available were sourced from a range of suppliers, including Japanese, American and British manufacturers. The wide range of artist materials available in the late 19th and early 20th century was observed through archival exhibition catalogues and through direct material evidence from the paintings studied. The presence of Japanese canvas manufacturers, discovered through canvas stamps in this study, was significant with 8 of 40 canvas supports identified. Further archival research has demonstrated the Japanese presence in the production and distribution of artist materials in Asia, including Singapore. Research on Holbein has shown a commitment to material research as early as the 1930s to creating artist materials to cater to a more humid climate. Shared material links between Singaporean Nanyang artists were demonstrated through the discovery of use of the same type of canvas by Liu Kang and Georgette Chen (unidentified S stamp) and Georgette Chen and Cheong Soo Pieng (Holbein), as identified through canvas stamps on the verso of the paintings. This material evidence will be explored

in further detail in Chapter 4 on Georgette Chen that directly follows and Chapter 5 on Cheong Soo Pieng.

Chapter 4: Technical study of Georgette Chen materials and techniques

4.1 Introduction

Georgette Chen's (1907 – 1993) time in Singapore was her longest in any place, and it was also her most artistically productive. Arriving in Singapore at 47 years old, the journey to Singapore had been a long one, as her commitment to her art practice saw her travel through many countries. Georgette Chen frequently wrote to friends and family during her travels, and her method of assiduously keeping carbon copies of the letters she sent to friends and family constitutes the publicly available archival materials at the National Gallery of Singapore (NGS). Archived letters help provide insights into Georgette Chen's practice and, in some cases, serve as reference points to dating her works, most of which are undated by the artist. When the study was first proposed, technical art history studies of Georgette Chen have yet to cross-examine the NGS archival sources with technical findings following a data collection structure. This chapter introduces the findings from a technical art study of eight paintings with the research methodology outlined in Chapter 2. It then seeks to contextualise these findings with archival sources and discover whether any critical characteristics of the artist can be identified. The section is divided into four parts. The first part gives an overview of the artist's background to set the context; the second briefly describes the research methodology; the third examines the materials used in the painting's supports; and the fourth investigates the paint application techniques.

Artist background

Born Chang Li Ying, Georgette Chen was one of nine daughters of Zhang Renjie, a Chinese merchant who dealt in Asian art and antiques in Shanghai, New York and London. He had studied and worked in France, and in 1902, he established Ton-Ying, the company first of its kind exporting Chinese tea, silk and art from Shanghai to France. The company later branched out to New York. This profile is typical of the Chinese merchants of that time, trading Asian products with Western countries.

The birthplace of Georgette Chen is debated (Chia 1997). The most common belief is that she was born in France in 1906. However, her marriage certificate from 1930 states she was born in Zhejiang, China, in 1906 (Chia 1997). Growing up, she was exposed to politics, as her father was dissatisfied with Chinese politics and society. He was a political figure and financial entrepreneur who used the wealth from his company and stocks to make financial

contributions to Sun Yat-sen and Chiang Kai Shek and to support Chinese students to study in France. Like Sun, Zhang opposed traditional ideas of gender and considered the expansion of women's education a top priority (Wong 1995). Georgette Chen's education is a product of the post Sino-Japanese War (1894) period, which saw an increase in the number of girls' schools initiated by the local Chinese.

Because of her frequent travels between New York, Shanghai and Paris with her family in her early life, Georgette Chen has often been referred to as 'cosmopolitan', with close relations to France and an international education. However, Georgette Chen's first encounter with art was in China. In an interview with Radio Malaya in 1953, she revealed:

"I started to study painting seriously in Shanghai under a private teacher. My father expected me to study Chinese painting, but I had a different idea. I told him I wanted to study the oil medium, which would enable me to paint everything around me [...] Finally, I convinced him [so] that he found a professor in Western painting and insisted that I buy two easels, two sets of colours, so that he too, could learn to handle the charcoal with me" (Chen 1953).

Georgette Chen's father had encouraged her interest in art from a young age, and under the Russian artist Viktor Podgorsky, father and daughter attended lessons together. The intersection of East and West is first found in the foundations of her Western art practice in Shanghai. In this instance, the definition of 'Western' painting appears to be embodied in the materials and technique, such as charcoal, oil paint and easels. This foundation was further developed after graduation from McTyriere School in Shanghai in 1926 when she set sail to New York (1926–27) and then to Paris for further studies. While Georgette Chen's privileged background and the support of her father enabled her to pursue art formally, it was not uncommon to travel to Europe in the 1920s, as this decade saw an increased movement of Chinese, following the change in "China's political and social structure at the turn of the 20th century" (Ong 2006, p.23).

Georgette Chen's artistic career

Paris was not an unfamiliar city for Georgette Chen, having spent some part of her childhood there, and she spoke fluent French. However, she reminds us there is no single definition for Western art, saying in an interview in 1953:

“My troubles began when I arrived in Paris. I found so many different types of art schools as there were different artists. It was difficult to decide which school would be suitable. I decided to take private lessons in the classical to get the discipline and attended freer studios as well [...] For instance in the classical school, I would draw a hand with all its lines and veins and muscles and anatomy in a detailed way. In the freer studios, emphasis would be laid more on the ensemble of a picture” (Chen 1935).

Brought up in a cosmopolitan way, revisiting Paris in her early 20s as a young artist further deepened Georgette Chen’s relationship with the city. Enrolling in the less structured art schools of the Académie Biloul and Académie Colarossi, she carved herself an education that extended far beyond formal training, with an emphasis on the techniques of painting. In less than three years, Georgette Chen earned recognition for her art practice, exhibiting one of her first paintings in Salon d’Automne. By this time, this annual exhibition had transcended its beginnings as an alternative to the official conservative salon to become an influential, progressive platform in the Parisian art world (Siew & Lee 2018). Also exhibiting in the show was Liu Kang, who studied art in Paris between 1929 and 1933 and was later acknowledged as one of Singapore’s pioneer artists. The presence of these two Chinese artists in Salon d’Automne emphasises the contributions and quality of art of the Chinese community in Paris.

Paris augured exciting beginnings for Georgette Chen, not just in art but in her personal life. In 1930, she married Eugene Chen, a political journalist and respectable diplomat, whom she had met in Paris through an introduction from a mutual friend, the wife of Sun Yat Sen. Eugene had been the minister for foreign affairs in the nationalist government in China, before its collapse in 1927, when he found himself exiled to Europe. Like Georgette’s father, Eugene’s father was one of the principal funders of Sun Yat Sen’s political activities in China. When they married, Georgette took on Eugene’s last name, which she retained even when she remarried after his death. Sharing her love for the arts, Eugene played an essential role in encouraging Georgette to become an artist. In various personal diary entries from 1935, Georgette reveals how Eugene and Paris formed an indivisible thread in her life, which she would often reminisce about in later years. The diary details her time in Paris, including painting *en plein air*, in entries such as “Cold and grey day, but painted seascape until the wind got too strong” (23 August 1935). Entries also show

that Eugene often posed for portraits or searched for fruits for her to paint in a still life. Between 1930 and 1939, they travelled between Asia and Paris as part of Eugene's political activities. However, as Georgette's artistic career started to progress, the outbreak of the Second Sino-Japanese War in 1937 directed them to Hong Kong, Eugene's base for anti-Japanese activities. Living in the British colony when Japan took it in 1941, they were captured and placed under house arrest before being transferred to Shanghai. During this time, the Japanese did not treat them poorly, as they hoped to induce Eugene's collaboration. Georgette could still paint during this period, as her subject matter was from China. Eugene did not live to see the end of World War II and died from health problems in 1944.

After the Japanese surrendered in 1945, China was still in a state of civil unrest. Georgette Chen stayed in China until 1947 before leaving for New York, where she married Eugene's aid and mutual friend, Dr Ho Yung Chi. All the while, the couple harboured hopes of eventually returning to China. She left for Paris by steamer in 1949, after an absence of eleven years, to regain possession of her studio at 23 Rue Raynouard, Paris. When she arrived, she described it as showing the "aftermath of war [...] entirely denuded of all its furniture, [and] beautiful objects of art", illegally occupied by a family who refused to move out (Chen 1953).

Meanwhile, she continued her art practice and held New York and Paris exhibitions. She also attended a ceramics training course at Atelier Lafourcade (22 rue du Ranelagh). Yung Chi was to join her in the latter part of the year, and he sold Georgette Chen paintings 'for soap' to settle their bills in New York.

Despite her recurring visits to Paris and New York, Georgette Chen always looked to China as her motherland. She writes to family and friends, "We just feel that China is the place for us no matter what the situation" (1949, 15 November). However, her plans to rebuild her life with Yung Chi in China when the political situation calmed were cut short when China fell to Communist rule in 1949. In the absence of better prospects, and as a bridging move, they accepted an offer to teach at Han Chiang High School in Penang, Malaya, in 1951. They travelled from Paris via Suez on a newly built English steamer sailing from London, and arrived in early May.

Georgette Chen lived in Penang between 1951 and 1953. During this tumultuous period, she found herself undergoing a divorce from Yung Chi. However, this did not

dampen her fascination with the beauty of Malaya or her hopes of continuing her artistic practice there. She wrote:

“I have always had a sort of weakness for this little island while passing through it on my many journeys westward and hoped that someday I might have more than just a glance at it [...] If Malaya does not prove to be a fruitful period for me artistically, it shall not be for the lack of beauty which seems to be everywhere” (Chen 1953).

In less than two years, Georgette Chen produced more than 80 still life paintings of local fruits and landscapes of Penang and Ipoh, which she would debut in Singapore in 1953. She also developed a “relatively new love” for ceramics from Paris and was “looking forward to moulding Malayan clay” (Chen 1953). Scholars categorising her practice as cosmopolitan or Western art often reference her early life and international art education in New York and Paris, but in her artistic productivity and subject matter, several points of convergence can be explored in her art practice in Malaya and her negotiation with her cultural identity.

While Georgette Chen’s artistic career was flourishing, the relationship between her and Yung Chi deteriorated. Her intention in moving to Singapore was not to join the Academy but to avoid Yung Chi, who often asked Georgette Chen’s friends for her whereabouts. In March 1953, she took Mrs Yew-Koh’s car from Penang to Singapore via Kuala Lumpur. Upon arrival, she stayed in two friends’ houses, marking the end of her relationship with Yung Chi and the start of her life as an artist and art educator in Singapore. Less than four days after her arrival in Singapore, she wrote to her friends, asking for her canvas pliers to be sent via airmail to stretch her paintings onto frames. She mentioned a paintbox left in Penang that would be delivered to her in a week, suggesting that her artist materials had followed her through her travels and that friends had been sending materials to her.

Georgette Chen and the Academy

“When I arrived in Singapore four years ago, I did not know of the existence of the Nanyang Academy of Fine Arts” (Chen 1962).

It was only when the Chinese Artists’ Association and the Academy gave a tea to welcome Georgette Chen. She would eventually find employment in a part-time teaching post there in 1954, where she remained until her retirement in 1980. While her background

undoubtedly influenced her ability to pursue her studies in art, she was no longer in a privileged position when she arrived in Singapore. When she started her life there in 1953, she did it alone, “without station nor material wealth” and often referred to her employment in NAFA as “bread without butter” (Chen 1953).

As an art educator, Georgette Chen’s art training and preference for still-life and landscapes was clear. In 1956, she wrote: “Students paid more attention to life drawing than doing much abstract painting. I hope it is due to my small influence” (Chen 1956). However, her influence was more than just in art practices. Her involvement in the Academy occurred at a turning point when the Academy expanded from having a predominantly local Chinese student intake to taking in international students. In her letter of 12 April 1954, she wrote that her role in the Academy was as an interpreter, secretary, chauffeur to the principal Lim Hak Tai, and providing help with English. She was a valuable asset for Lim Hak Tai in his campaign to promote the school and deal with the government. It was also her presence on the staff that allowed the Academy to engage with the multi-ethnic Malayan society and take on some non-Chinese students, who were placed in her class. NAFA’s first occidental student was Patricia Kennison, whose teacher was Georgette Chen.

Moreover, in 1965, she wrote that South American and New Zealand students were enrolled in the Academy. She was later one of the editors for the school’s annual graduation catalogues and was responsible for the English foreword in the catalogues published from the late 1950s onwards. She was also responsible for establishing the Academy’s first connection with an overseas art institution, through her association with L’Ecole Nationale Supérieure des Beaux-Arts (LNSBA) in Paris. As a result, the Academy and LNSBA established a program that allowed many Academy students to pursue further training in France (Yeo 1994; Ong 2005). Her contributions to NAFA were recognised when Lim Hak Tai, the founding principal, offered her the position of principal as the Academy’s successor. However, she declined.

Georgette also refused a full-time teaching position to make time for her artistic practice. Her health was a further factor contributing to the speed of her painting. She recorded the first signs of pain in 1951. In her diary, she documented pain in her wrist, which came to be diagnosed as wrist arthritis. Often directing humour against herself, Georgette referred to herself as “escargot tropica” for being slow while dealing with her wrist arthritis (Chen 1970). It affected her art practice, as she stopped painting outdoors and eventually

focused on still-life and portraits. She found herself in hospital in 1979, having suffered a bad fall, and this happened again in 1981. She spent the next 12 years in care and retired officially as a teacher in NAFA.

Negotiation with nationality

“We have all found peace of mind in a land which is not our own” (Chen 1961).

From this statement, which she wrote in 1961, eight years after her move to Singapore in a letter to Dorothy Lee, Eugene’s cousin, it appears that Georgette Chen had renewed hopes for a peaceful life when moving to Singapore. However, evident in her various letters to family and friends, is that she was still navigating her national and cultural identity when she reminisced about China. This sense of displacement was observed in a letter where she wrote, “at times I seem to lose my sense of nationality” (Chen 1961). Yet in another letter, she wrote, “feeling immediately at home in this world at East meets West (after all, is not my very being a synthesis of these two worlds?)” (Chen 1962). Having lived in both China and Europe, as a sojourner and as an artist, Chen’s self-reflexivity in navigating her cultural identity is a reminder that East and West are not two binary worlds. Instead, it invites a consideration of the possibilities of integration between them, turning the focus from defining or categorising what East or West is into one that questions what a synthesis would look like.

Despite Georgette Chen’s privileged background, raised in cosmopolitan and elite echelons, she experienced first-hand the vagaries of politics and war, the scattering of her family, the death of her first husband and subsequent divorce and debilitating illness. Nevertheless, despite it all, she remained devoted to her first and most enduring love, art. Georgette Chen was a much-celebrated Singaporean female artist, earning a Cultural Medallion in 1982.

Current literature and research on Georgette Chen has focused on historical and curatorial perspectives. Whilst archival evidence has contributed most of the narrative, the full potential of these primary sources has yet to be explored in the context of technical art history. This study is one to combine archival sources and findings from technical examination and material analyses. It does so using eight paintings studied over 2020 in an attempt to uncover a narrative of Georgette Chen’s painting methodology.

4.2 Research Methodology

The depth of the study was impacted by the COVID-19 pandemic, which resulted in fewer fieldwork studies than had been planned in 2020. Eight canvas paintings attributed to Georgette Chen were studied: five paintings from the NGS collection, one from NMS, one from the NLB collection, and one from Koh Seow Chuan's collection (Table 3). Given the variety of collections and the degrees of provenance, the paintings studied presented an interesting case study and reduced sampling bias. All paintings underwent non-invasive examination, including visual examination, written documentation and a suite of multispectral images. Additionally, the ground layer of the paintings from the NGS and NMS collection was analysed using pXRF by a member of the HCC staff as detailed in Chapter 2.3.

Table 3. List of Georgette Chen paintings studied.

Painting ID	Collection	Title of work	Attributed date by curator, if any	Dated on painting?
PTG027_GC001	KSC	<i>Coq</i>	Undated	No
PTG038_GC002	NLB	<i>Mooncakes</i>	1970	No
PTG056_GC003	NGS	<i>Assorted Mooncakes</i>	1955–1960	No
PTG057_GC004	NGS	<i>Mooncakes with Green Pomelo</i>	1965–1968	No
PTG058_GC005	NGS	<i>Mooncakes with Golden Pomelo</i>	1965	No
PTG059_GC006	NGS	<i>Still Life (Moon Festival Table)</i>	1962	No
PTG060_GC007	NMS	<i>Satay Boy</i>	1964	Yes
PTG061_GC008	NGS	<i>Tropical Fruits</i>	1969	Yes

The pictorial development of Georgette Chen's practice is far less experimental than that of some of her peers and, to some extent, feature a consistent pictorial style. Several themes emerge from her oeuvre, including landscapes, portraits, and still-lives. In the later years, she painted fewer landscapes, as she painted these *en plein air*, and had to start painting more still-lives as her arthritis worsened (1972). The selection of paintings for the study included mostly still-lives and dated from the 1960s, which is after Georgette Chen arrived in Singapore, to minimise any confusion. Five of the eight paintings are from the *Mooncake* series, dated between 1960 and 1970.

The data in this chapter are drawn from four primary sources: text-based documentation records, multispectral images, primary archival sources, such as carbon-copied letters written by Georgette Chen, and existing research on her art practice. One of the early challenges identified in the study is that Georgette Chen seldom dated her paintings in her signature. As seen from Table 3, only two paintings were dated by the artist herself while four of the paintings from NGS were attributed dates by curators, as extracted from the collection management system. In addition, the dates of her travels are inconsistently reported in various studies, causing a lack of clarity, and aligning material findings by chronology is approached cautiously. However, access to a wide range of well-documented primary archival materials from Georgette Chen enabled the investigation to utilise an interpretative approach on material findings and context-setting for observations. The letters were written in French, Chinese, English, and Malay, but only the archival evidence in English was used which may represent a knowledge gap. The primary evidence from her letters plays a vital role in tracing material attribution and finding any shifts in materials or techniques, more than the date. Data from the same primary evidence have been examined to inform a curatorial perspective, as published by Siew in 2018. Georgette Chen recorded many details of her daily life and, significantly, information on her art and the subjects she was studying or portraying. On occasion, she would also briefly mention if her painting or study had been successful or if it had to be executed again. These details, which she recorded dispassionately and faithfully, offer precious insights into the often hidden and banal aspects of artistic practice, as well as the hard work and dedication behind an artist's craft (Siew & Lee 2018).

As described in Chapter 2, the approach to technical art history adopted for this research study combines data sources drawn from visual observations, technical photography, material analysis, which are transformed into structured data using a documentation record, and contextualised using available primary sources (see Table 2, page 56). The development of a documentation record on Airtable enables various datasets to be extracted for data analysis through quantification. Given the small sample size, these modes of enquiry that were employed illuminated patterns in the materials and techniques of the paintings studied. However, the quality of the data can be optimised by increasing the resolution of the dataset (increasing the number of paintings studied). The chapter begins with an overview of the painting preparation, including canvas and auxiliary supports, followed by visual examination of paint application. Drawing from the documentation record to extract key

information on technical photography and visual observations as described in Chapter 2.5 and 2.6, the final section discusses the key findings through a case study featuring the five paintings from the mooncake series, which approaches understanding the artist’s hand through underdrawings in Chinese characters. Due to practical constraints and limited opportunities for material analysis, this paper cannot provide a comprehensive review of artist attributes or specific materials used by the artist. However, as an investigatory methodology based on the structured documentation record, it invites future research to build on the observed patterns and grounds the research in Chapters 5 to 6.

4.3 Painting Construction Materials and Techniques

“Already in Singapore. I find that the canvas stretcher which is in my paint box very necessary for the stretching of the paintings to the wooden frames. It is a steel tool that looks something like [sketch]. Could you take it out of the box and air-mail it to me?” (Chen, March 30, 1953).

Written by Georgette Chen a week after she arrived in Singapore in 1953, the excerpt above offers some crucial insights into the artist’s tool and paintbox. It opens the discussion on Georgette Chen’s preparation of the painting and its construction. It suggests that a steel canvas plier was used to stretch the canvas over wooden auxiliary support, with a possibility that the pliers, along with other tools in a paint box, travelled with her. To further explore any evidence that may arise during the examination, the following data points and variables in Table 4 were extracted from the primary dataset from the Airtable database to analyse and the patterns that have emerged (see Appendix C for the full list of 110 data points).

Table 4. Dataset data points and variables for the study of how a painting is constructed.

<i>Data point</i>	<i>Variables</i>
Findings (from Sample ID)	Cotton; linen; linen-blend fabrics
Manufacturer stamp	Holbein 1; Holbein 2; Holbein 3; Holbein 10; Masonite; Masonite Preswood; None
Ground to Canvas	Exposed linen; to edge; not accessible; not applicable
Visibility on tacking margin	Primed; unprimed; not accessible; not applicable

Type Original Attachment	Adhesive; staples; tacks; unattached; unknown; unmounted
Canvas Pliers	Yes; No
Canvas Shape	Cut to face; cut to reverse edge; cut to tacking margin; not accessible; not applicable
Corner Folds	Folded over 45; folded over straight; not accessible; not applicable
Type (Auxiliary Support)	Stretcher; strainer; strainer-board; hardboard; wood; foam core; paper; not accessible; not applicable
Thickness mm (Auxiliary Support)	Free text

Strainers/ Wooden frames

Georgette Chen's phrase 'wooden frames' refers to the auxiliary support the canvas is mounted onto, such as common supports like strainers or stretchers. Previous research has established that Georgette Chen's preferred auxiliary supports identified from the National Art Gallery in Kuala Lumpur, were most likely locally constructed strainers rather than Western strainers, due to her financial situation (O'Donnell, Tse & Ahmed 2015, p. 157). As these works are from 1940, 1950 and 1960, findings amongst several archival letters accessed in this study provide further evidence on the source of the auxiliary supports. In 1953, Georgette Chen writes that she had sent her wooden frames by "air-mail" into Singapore and had "unpacked the frames" before painting (Chen 1953). In another letter, Georgette Chen writes "I remember sending my frames by boat as the railway fee was prohibitive" (Chen 1953). Both these quotes suggests that auxiliary supports, particularly those used by her in the early years in Singapore, were sent from overseas, which may suggest artist preference more so than financial concerns. The country of origin, however, is not known.

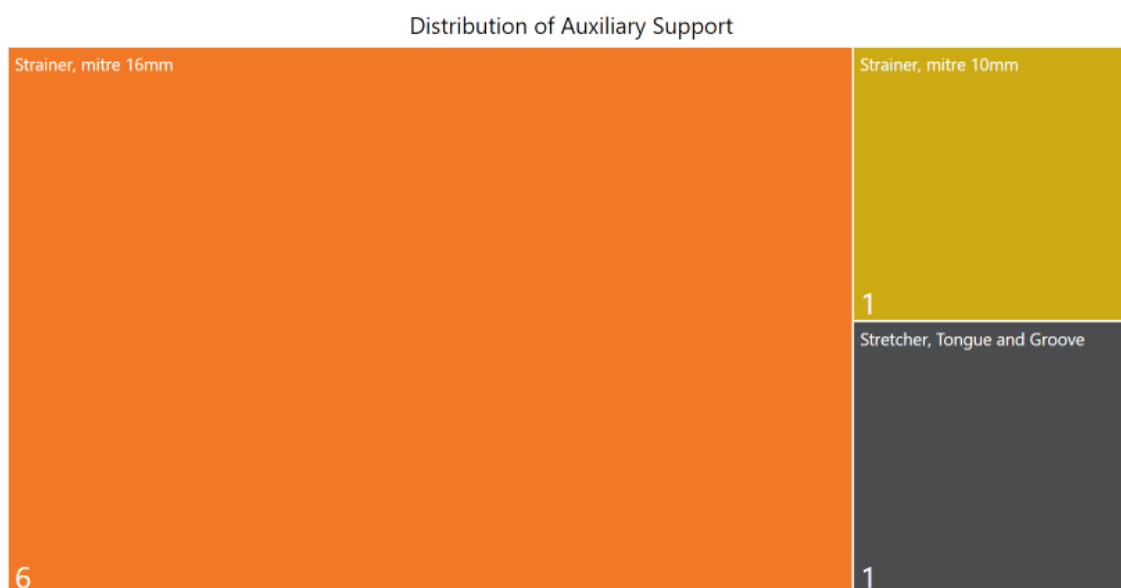


Figure 13. Distribution of Georgette Chen auxiliary supports studied.

Figure 13 illustrates the distribution of auxiliary supports from the eight paintings studied, still mounted onto its original auxiliary support. Seven wooden strainers with mitre joints made up the majority, with six of these wooden strainers measuring 16mm thick. In addition, one stretcher with a tongue-and-groove joint was identified. On the reverse strainers, blue and red numbers were inscribed on the top right corner. These were similarly identified in O'Donnell's study from the *Balai Seni Visual Negara* collection (2014). While it is not known what the numbers signify or who wrote it, the details are recorded in Table 5 below for future reference.

Table 5. Details of inscriptions found on auxiliary supports.

Painting ID	Title	Attributed year	Inscription on auxiliary support
PTG027_GC001	<i>Coq</i>	Undated	N/A
PTG038_GC002	<i>Mooncakes</i>	1970	N/A
PTG056_GC003	<i>Assorted Mooncakes</i>	1955-1960	‘64’ written in red
PTG057_GC004	<i>Mooncakes with Green Pomelo</i>	1965-1968	‘85’ written in blue and 132 in red on top right corner tacking margin on strainer
PTG058_GC005	<i>Mooncakes with Golden Pomelo</i>	1965	‘72’ written in blue and 133 in red on top right corner
PTG059_GC006	<i>Still Life (Moon Festival Table)</i>	1962	N/A
PTG060_GC007	<i>Satay Boy</i>	1964	‘117’ written in blue and 136 in red on top right corner tacking margin on strainer
PTG061_GC008	<i>Tropical Fruits</i>	1969	‘151’ written in blue

Evidence of canvas crimp marks on the reverse edge on seven of the eight paintings supported the use of canvas pliers during the construction of the painting. Five of these paintings were untreated, featured the original tacks, and had a 45-degree corner fold. Closer inspection of the tacking folds shows an interesting detail: the presence of double tacks at the 45-degree angle of the top and bottom edges, as illustrated in examples (Figures 14a–c). In addition, tack holes in the corners have been observed in paintings that have been re-stretched and tack replaced with staples.



Figure 14a. Presence of double tacks at the 45-degree angle of the top and bottom edges. Georgette Chen, *Mooncakes with Green Pomelo*, c.1965-68 (32 x 40cm, oil on canvas). Collection: NGS.



Figure 14b. Presence of double tacks at the 45-degree angle of the top and bottom edges. Georgette Chen, *Mooncakes with Golden Pomelo*, c.1965 (45 x 54cm, oil on canvas). Collection: NGS.



Figure 14c. Presence of double tacks at the 45-degree angle of the top and bottom edges. Georgette Chen, *Still Life. (Moon Festival Table)*, c.1962 (73 x 60cm, oil on canvas). Collection: NGS.

The use of archival sources has informed much of the preliminary understanding of the auxiliary supports used, particularly in the early years of Chen's arrival in Singapore. In addition to the consistency observed so far, she appears to have remained faithful to her academic training in Paris throughout her career, particularly in her use of the French standard sizes for paintings. From 1935 to 1966, diary entries reference paintings with annotations such as 'Nature morte 6F' and 'Rambutans 10P'. In this instance, P refers to Size 10 Paysage, a 55 x 38cm painting standard size while 6F refers to Size 6 Figure, a 41 x 33cm painting standard size. While the diary entries do not record all the paintings created, these notes are useful for future attribution of undated paintings.

Characteristics of auxiliary support (materials and techniques)

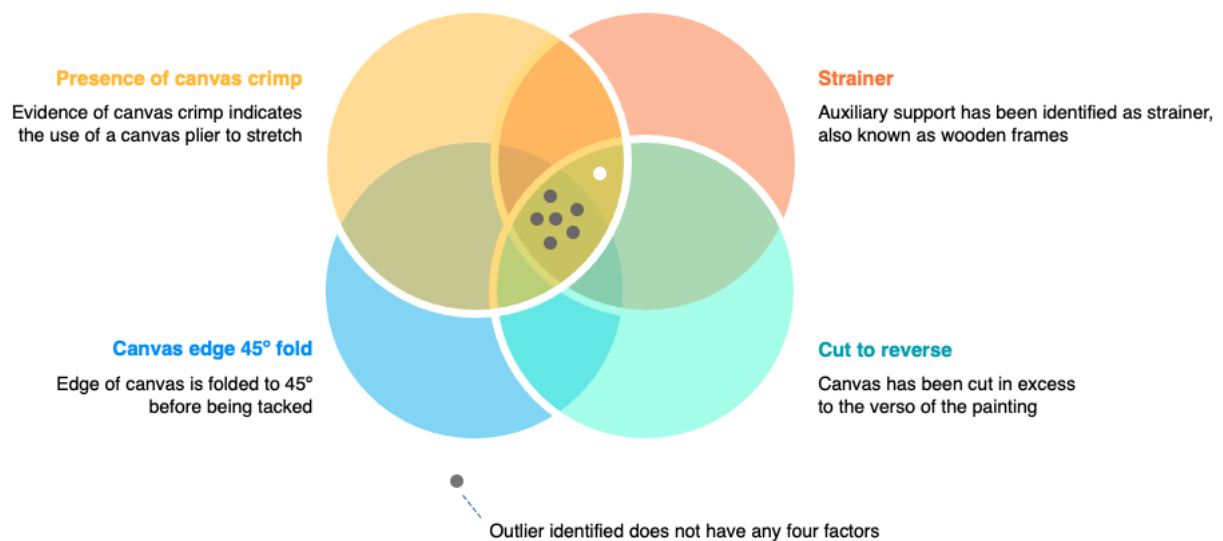


Figure 15. Venn diagram of four factors of auxiliary support attributed to Georgette Chen.

Drawing upon four main data points analysed on the auxiliary support, Figure 15 illustrates how each point representing a painting falls within the Venn diagram. With 75% of the paintings having all four factors, one outlier has been identified without commonalities in the auxiliary support. The evidence reviewed so far suggests a sense of consistency in canvas preparation, such as canvas preparation stretching onto the strainer. The model will significantly benefit from broader studies to find stronger associations and patterns. In addition, comparative studies between the auxiliary support from earlier Singapore years and the strainers analysed in the study, attributed to the 1960s, are necessary. In the following section, an investigation into the canvas support will enhance the current understanding of Georgette Chen's painting preparation materials.

Use of pre-primed canvas

Studies of Georgette Chen's materials and techniques have often focused on her training in Western centres and her early cosmopolitan lifestyle, during which she would likely have used Western materials. O'Donnell's study (2014) is one of the first studies on Georgette Chen which included a preliminary examination of four paintings painted in 1940, 1950 and two in the 1960s, leading to an interpretation of her possible use of linen supports

and artists' quality oil paints from Straits Commercial, which were "most probably British colourmen firms" (p. 150). However, a new outcome of the technical examination of the eight paintings painted between the 1955 and 1970, presents new evidence for the use of Japan-manufactured canvas by Georgette Chen in the 1960s. The table below illustrates the data points and variable descriptors used to identify pre-primed canvasses (see Appendix C for the full list of 110 data points).

Table 6. Dataset data points and variables for the study of type of pre-primed canvasses.

<i>Data point</i>	<i>Variables</i>
Visibility on tacking margin	Primed; unprimed; not accessible; not applicable
Ground to canvas	Exposed linen; to edge; not accessible; not applicable

All paintings studied featured a primed ground layer that extended beyond the front face of the painting, indicative that the ground layer was prepared on another auxiliary support before being stretched for painting. Additionally, evidence shows five paintings having exposed fabric and an unprimed selvedge edge. Without the preparation of a cross-section, identification of the ground layer of commercially available canvasses is limited. However, canvas stamps were found and recorded as a data point and variable for the documentation record and data dictionary, and present strong evidence about Georgette Chen's commercially available canvasses.

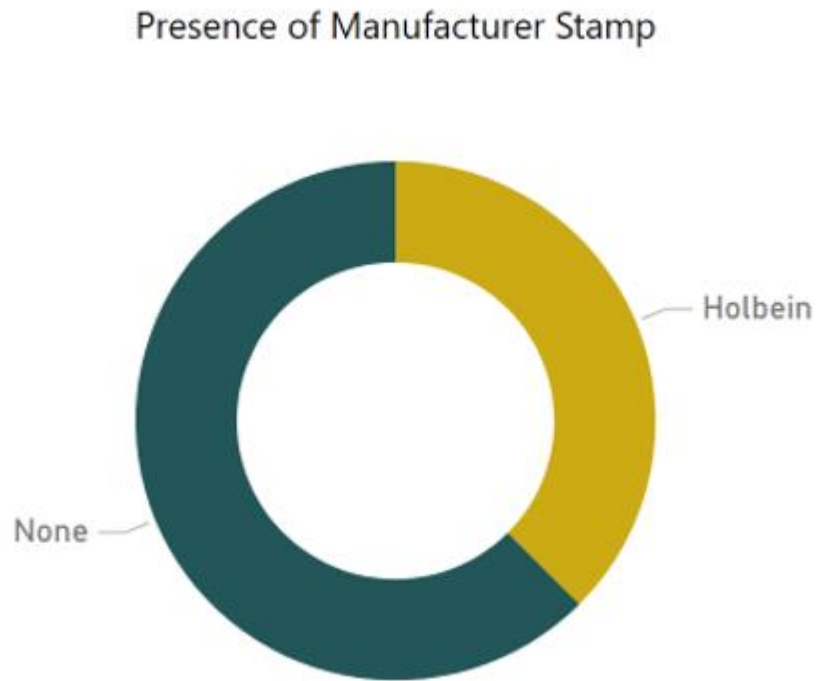


Figure 16. Diagram of Georgette Chen canvasses featuring Holbein canvas stamps.

Figure 16 illustrates the distribution of paintings that feature a red canvas stamp from Holbein, a Japanese canvas manufacturer for the paintings dated 1962, 1964 and 1965. Figures 17a–c show the canvas stamps found on the verso of three paintings. These stamps feature a number below the company logo, in which ‘1’ and ‘10’ are found. The thread count of these Holbein supports, labelled ‘1’, was 14x15/cm, while ‘10’ had a count of 15x16/cm. All three canvasses featured a slightly open weave, making the ground layer visible, as displayed in Figures 17d–f. In addition, the ground layer, which extended to the reverse edge of the canvas, features a uniform line along the selvedge edge, which confirms that the canvas was commercially primed.

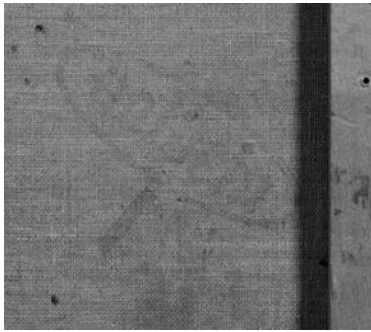


Figure 17a. Digitally enhanced detail of 'Holbein 1' stamp. Georgette Chen, *Mooncakes with Green Pomelo* (1965-68).



Figure 17b. Digitally enhanced detail of 'Holbein 1' stamp. Georgette Chen, *Still Life (Moon Festival Table)* (1962).

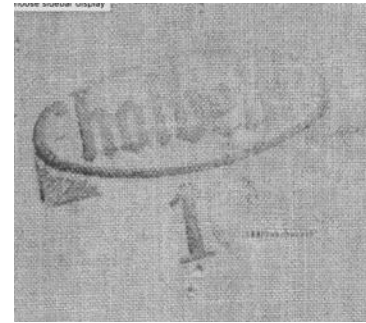


Figure 17c. Digitally enhanced detail of 'Holbein 10' stamp. Georgette Chen, *Satay Boy* (1964).



Figure 17d. Magnification of weave from verso of 17a. Georgette Chen, *Mooncakes with Green Pomelo* (1965-68).

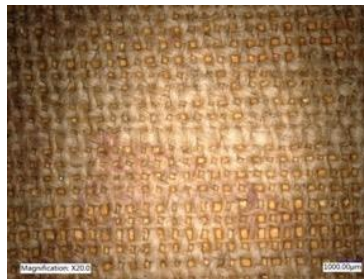


Figure 17e. Magnification of weave from verso of 17b. Georgette Chen, *Still Life (Moon Festival Table)* (1962).



Figure 17f. Magnification of weave from verso of 17c. Georgette Chen, *Satay Boy* (1964).

Preliminary findings from the pXRF done on-site on tacking margin with a ground layer indicated that the ground layer with Holbein stamps had a consistently high amount of lead and titanium elements. However, in *Tropical Fruits* (1969) and *Mooncakes with Golden Pomelo* (1965), the elements traced in a pXRF study differed from those with the Holbein stamps, and variations of elements were present as zinc, barium, lead and calcium. An examination of the ground layer shows that, while it extends across the reverse edge, it had a rough finishing, which suggests an artist preparation on another auxiliary support. In addition the relative peak heights of these two paintings imply higher levels of zinc in comparison to lead. Drawn together with visual observations, the presence of both zinc and carbonates (calcium) suggests that the ground layer of these two paintings could be using an industrial

paint, which often contain higher levels of zinc to traditional artist paints (Arslanoglu et al. 2013, p. 146; O'Donnell, Tse & Ahmed 2015, p. 154). Ground layers from the Holbein canvas feature a lead and titanium ground, suggesting that traditional artist materials would follow a low zinc content. A further analysis on the ground layers to identify pigments, fillers and binding media would be useful to be able to identify if industrial paints were used (Arslanoglu et al. 2013, p.150).

This section has provided a summary of the primary construction materials and techniques employed by Georgette Chen during her time in Singapore. The presence of Japanese canvas stamps from Holbein in the period from 1962 to 1965, shows that Georgette Chen's association with using exclusively Western materials needs reconsideration especially as this time period is after the British colonisation had left Singapore. From archival support and technical examination, pre-primed canvas and the importation of wooden frames by plane or boat suggest that the materials used were not necessarily supplied by Straits Commercial, rather were sourced from overseas (country unknown). The following part of this paper moves on to describe in greater detail Georgette Chen's paint application techniques to build on the understanding gained so far.

4.4 Paint application

Georgette Chen's painting technique is often referred to as post-impressionistic oil painting. The Post-Impressionist style often included thick applications of paint, one of the exploration interests of this section. Limited by advanced analysis or sampling of paint, this section is mainly informed by observations from transmitted light and transmitted infrared photography. These techniques have yet to be undertaken in previous studies of Georgette Chen's paintings. Notwithstanding the relatively limited sample size, the study offers valuable insights into the artist's techniques.

There has been little research on Georgette Chen's paint materials, although it has been hypothesised that she used imported artist colourmen materials (O'Donnell, Tse & Ahmed 2015). Utilising archival data, in the early months of 1953, when Georgette Chen was making her move to Singapore, she thanked her friend for a 'parcel of materials', saying that "Tan Ee Leong ... brought [her] paint box from Penang to Singapore" (Chen 1953). While the materials sent to Chen are unknown, she had a paintbox that travelled with her, so it is possible that her materials might not necessarily be useful location indicators. Towards the

1960s, it appears that Georgette Chen had begun using paint materials bought from Singapore, as suggested by a diary entry on April 1, 1965, which read “fetch paints at Zion Road”. Historical research did not show any art shops along Zion Road, with most art shops or bookstores concentrated around South Bridge and North Bridge Road. However, during this period, Cheong Soo Pieng’s studio was at 28A Zion Road, and it is possible that Georgette Chen might have shared materials with him, highlighting the artists networks and supply of materials through non-commercial sources



Figure 18a. Transmitted light photography showing high light transmission. Georgette Chen, *Assorted Mooncakes* (1955-60).



Figure 18b. Transmitted light photography showing high light transmission. Georgette Chen, *Mooncakes with Golden Pomelo* (1965).



Figure 18c. Transmitted light photography showing high light transmission. Georgette Chen, *Mooncakes with Green Pomelo* (1965-68).

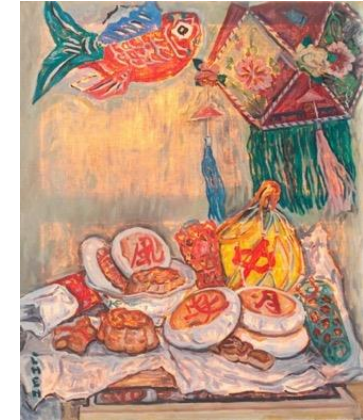


Figure 18d. Transmitted light photography showing medium light transmission due to re-lining. Georgette Chen, *Mooncakes*, c. 1970 (65 x 54cm, oil on canvas). Collection: National Library Board.



Figure 18e. Transmitted light photography showing light transmission. Georgette Chen, *Tropical Fruits*, c. 1969 (72 x 92cm, oil on canvas). Collection: NGS.



Figure 18f. Transmitted light photography showing light transmission. Georgette Chen, *Satay Boy* (1964).



Figure 18g. Transmitted light photography showing high light transmission. Georgette Chen, *Still Life (Moon Festival Table)* (1962).



Figure 18h. Transmitted light photography with little light transmission. Georgette Chen, *Coq*, undated (81 x 60cm, oil on canvas). Collection: KSC.

The technical examination of the eight paintings indicated that the paint layers were in good condition, with no cracks or active flaking observed. Studied in relation to each other, observations on the amount of light transmission can indicate the thickness of the paint layer as shown in Figures 18a – h. Having kept the photography specifications and set-up constant, the clarity of the strainer’s crossbars is more evident when there is more light transmission. The vertical brushstrokes of the background are more visible in most paintings and feature less paint in the background. Five paintings from the mooncake series present significantly similar visual characteristics, while paintings such as *Satay Boy* (1964) and *Tropical Fruits* (1969) feature a heavier paint density. One possible reason for the heavier paint application could be that these paintings were reworked over a period. An inspection of areas with less light transmission in *Tropical Fruits* (1969) is compared in Figure 19 below to the image in transmitted infrared, revealing a change in the final composition.



Figure 19. Comparison image of transmitted light and transmitted infrared photograph detailing change in rambutans and basket (outlined in white box). Georgette Chen, *Tropical Fruits* (1969).

Alongside evidence from archival sources, two years after the composition planning of *Satay Boy* in 1962, a diary entry on February 25, 1964, indicated that Georgette Chen had begun working on the painting. However, three months later, on May 31, 1964, she wrote that she had “worked on background (Satay man)” before scraping it off and then using “linseed oil to recover” before working on it the next day “baby oil start paint (Satay man)”. Whilst it is unclear when the painting was eventually completed, drawing upon the diary entries within following the three months, it can be understood that Georgette Chen reworked the painting, which explains the heavier paint density. One such reworking is evidenced in the transmitted infrared image shown in Figure 20, which reveals a change in the sleeve of

the figure. The darker outlines around the figure are a painting technique characteristic of the Nanyang Style artists.



Figure 20. Comparison image of visible light and transmitted infrared photograph detailing change in sleeve of figure as outlined in white box. Georgette Chen, *Satay Boy* (1964).

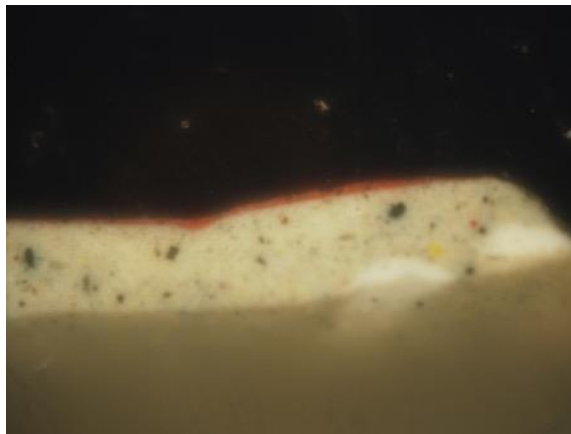


Figure 21a. 400x magnification of cross-section featuring a thin red paint layer of 5µm. Georgette Chen, *Mooncakes* (1970).

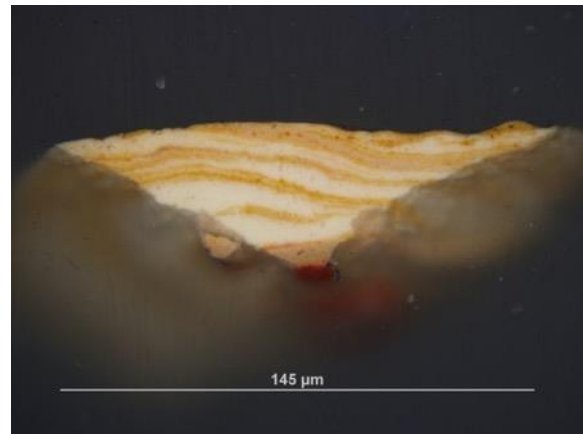


Figure 21b. 100x magnification of cross-section featuring a build-up of paint layers, each measuring approximately 25 µm thick. Georgette Chen, *Coq* (undated).

The paint density and paint application techniques observed so far show that seven of the eight paintings feature an overall thin amount of paint with low impasto layers and more

paint distribution in the foreground. Figure 21a shows a cross-section from *Mooncakes*, evidencing the thin paint application, with a single layer of paint measuring approximately 5µm in thickness. *Coq*, which did not share as many similarities, featured more paint application in the background with defined impasto, and a heavier paint density, as observed in cross-sections, with each layer of paint measuring approximately 25µm. It also featured embedded fingerprints near the tacking margin edge, presenting an interesting case for further material analysis in the future. Most of the findings from technical photography so far have not supported a thick paint application in post-impressionist work and instead feature thin paint layers. Having looked at the paint density, this discussion will now move on to the details of the brushstrokes.

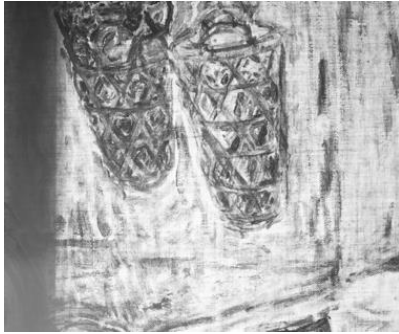


Figure 22a. Transmitted infrared photography detailing transmission and brushstrokes. Georgette Chen, *Mooncakes with Golden Pomelo*, (1965).



Figure 22b. Transmitted infrared photography detailing transmission and brushstrokes. Georgette Chen, *Mooncakes* (1970).



Figure 22c. Transmitted infrared photography detailing transmission and brushstrokes. Georgette Chen, *Assorted Mooncakes* (1955-60).



Figure 22d. Transmitted infrared photography detailing transmission and brushstrokes. Georgette Chen, *Mooncakes with Green Pomelo* (1965-68).

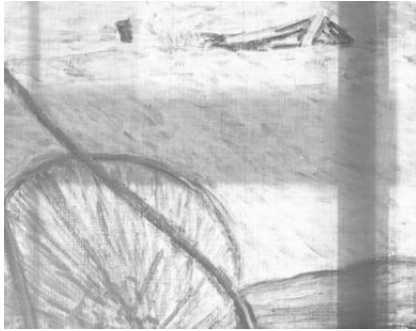


Figure 22e. Transmitted infrared photography detailing transmission and brushstrokes. Georgette Chen, *Satay Boy* (1964).



Figure 22f. Transmitted infrared photography detailing transmission and brushstrokes. Georgette Chen, *Still Life (Moon Festival Table)* (1962).



Figure 22g. Transmitted infrared photography detailing transmission and brushstrokes. Georgette Chen, *Tropical Fruits* (1969).



Figure 22h. Transmitted infrared photography detailing transmission and brushstrokes. Georgette Chen, *Coq* (undated).

Transmitted infrared is a complementary technique to transmitted light imaging and offers a more profound understanding of the paint application technique. Closer inspection of the brushstrokes in transmitted infrared reveals that the brushstrokes in the background are most likely worked on after the foreground subjects are painted, as presented in Figures 22a–i. Most of the background appears to have been applied with thin and vertical paint strokes with minimal overlapping. When the background merges into the foreground subjects, the strokes follow the curve of the foreground subjects. In addition, the canvas texture is visible mainly in the background, which is consistent with the thin layers of paint application.

Thus far, this section has briefly discussed the paint application techniques of Georgette Chen through technical examination and various forms of imaging. Without the use of advanced analysis or material investigations, the findings presented can only be offered as exploratory and for future research to build on. So far, the technical photographs have demonstrated a consistent association between more light transmission and thin paint layers. In further investigations, preparation of cross-sections can offer a better understanding of the paint stratigraphy, which is potentially a fruitful avenue in this arena. In the section that follows, the discussion will focus on the outlines observed in the transmitted infrared images. Then, a more detailed account of underdrawings will be given to understand how the composition is first executed on a blank canvas, using the case study of the *Mooncake* series of paintings.

4.5 Underdrawings: Mooncake series

Some artists start painting straightaway in the construction of a painting, while some do preliminary drawings on the ground before paint is applied. Reflected infrared and transmitted infrared photography can reveal the presence of underdrawings made with a carbon-based medium on a white ground layer (NGA). Drawing upon several archival sources, Georgette Chen's use of charcoal as an underdrawing medium appears to be consistent. This is supported by Liu Kang's historical account of seeing Georgette Chen's paintings in her studio when they were only charcoal sketches before colours were added (Liu 2011, p. 55). However, the account of Patricia Kennison, an Australian student who studied in NAFA under Georgette Chen, allows possible deeper insight into the construction of the paintings.

In a 1969 letter, Kennison describes how Georgette Chen taught her to paint. A “careful charcoal drawing” is made and rubbed out, before being painted over in raw sienna and turpentine as an underpainting (Chen 1969). Then, paint is applied to adopt the fat-over-lean technique. This knowledge transfer from a teacher to student suggests a possible painting technique which was used by Georgette Chen and features in a surface examination of *Mooncakes with Green Pomelo* (1965-68). Under 200x magnification, a pigmented black medium with a thin brown wash is observed under the paint layers, supporting the account of Kennison (see figure 23).



Figure 23. 200x magnification of detail of painting technique of charcoal underdrawing raw sienna wash observed in yolk area (110,75mm). Georgette Chen, *Mooncakes with Green Pomelo* (1965-68).

With the evidence of charcoal used as an underdrawing medium, the study here examines and focuses specifically on how the Chinese characters in the *Mooncake* series are painted. Georgette Chen’s fascination with the autumn festival, also known as the mooncake festival, can be traced to the period after her move to Malaya, with one of the earliest paintings, *Still Life (Moon Festival Table)* (1962), evidenced by its label from the reverse. The autumn festival, also known as the moon festival, is a Chinese festival that is celebrated differently within different Chinese communities. Table 7 presents a list of diary entries that mention the autumn festival from 1959 to 1969:

Table 7. List of diary entries referring to autumn or mooncake festival.

Year of entry	Title of work	Description
1959	<i>Autumn Festival</i>	“Start autumn festival painting” (September 13)
1959	<i>Mooncake</i>	“These past weeks have been spent with mooncakes. I try to paint one picture a week” (November 1)
1961	<i>Mooncakes 12F</i>	“Mooncakes 12F” (June 10) *61 x 50cm
1962	<i>Moon Festival</i>	“Lent Moon Festival and Lion head to Mr Seah” (March 14)
1967	<i>Mooncake</i>	“Mooncake composition” (April 6)
24 days		“Painted mooncake painting. Did not go to Agnes” (April 15) “Continue mooncakes” (April 29) “Continue mooncakes” (April 30)
1968	<i>Moon Festival, Dragon</i>	“Moon Festival” (October 5)
10 days		“Sunday painting Moon Festival large picture again. Change basket with pomelos” (Oct 13) “Complete Large Moon festival dragon painting” (10 days) (Oct 14)
1969	<i>Moon Festival, Rabbit</i>	“Rabbit lantern instead of Dragon in Moon cake paintings” (March 11)

A total of six paintings from this study are from the mooncake series; none of these paintings is dated, except for *Moon Festival* (1962), which has been dated from letters and diary entries. Various mooncakes are presented in the still life, with Hokkien style mooncakes imprinted with various Chinese characters being a common subject of the

composition. Technical photography using transmitted infrared has revealed clear underdrawings of the Chinese characters, allowing for a study of the brushstrokes. The interest of this investigation is the Chinese characters painted on the mooncakes as the stroke order is a critically important part of writing. Would the characters follow the stroke order as it is written or be painted as a figure? So far, there has not been research undertaken on Singaporean artists' Chinese characters painted into canvas paintings, which could open a dialogue on how language and cultural context can be considered during technical art analysis.



Figure 24. Diagram showing ordered strokes for the Chinese character ‘an’.

One of the most common characters painted in red, which is featured in three paintings, is 安 (an), which means safety. Its stroke order is illustrated in Figure 24 and comprises six separate strokes. The brushstrokes are particularly evident in transmitted infrared, displayed in Figures 25a–c alongside the stroke order observed. The order of the artist's strokes is then numbered from the first to the last. Interestingly, the character observed from the three paintings does not follow the formal stroke order. Instead, it appears to be painted in two parts, outlined in blue and red, with slight variations in the order of the stroke, suggestive of Georgette Chen's style in calligraphy. The evidence presented suggests that the characters were painted and were not outlined by charcoal underdrawings.

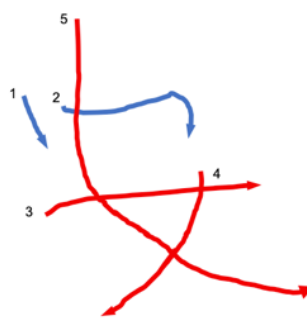


Figure 25a. Visible and, transmitted infrared images illustrate how the Chinese character stroke is written. Georgette Chen, *Assorted mooncakes* (1955–1960).

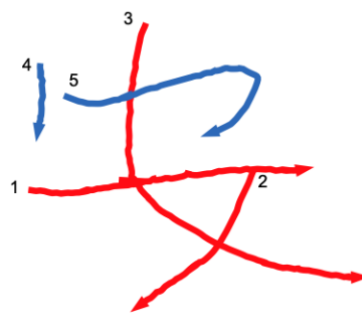


Figure 25b. Visible and, transmitted infrared images illustrate how the Chinese character stroke is written. Georgette Chen, *Mooncakes* (1970).

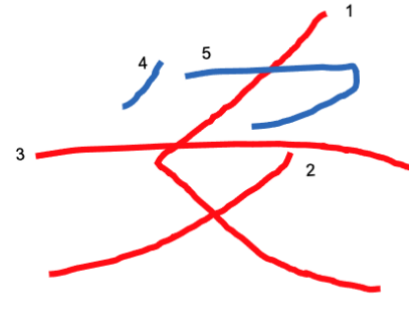


Figure 25c. Visible and, transmitted infrared images illustrate how the Chinese character stroke is written. Georgette Chen, *Mooncakes with Golden Pomelo* (1965).

As a further exploration of the artist's hand in the painting of Chinese characters, a selection of more prominent characters was studied, particularly the red characters on the pomelos. The pomelo, one of the primary festive foods of the autumn festival, features in three paintings in the moon festival series. The Chinese characters 吉(ji) and 壽(shou) symbolise luck and longevity and are written in various calligraphy styles; they are lucky symbols usually found adhered onto fruits during the festival. The most surprising aspect of the technical images is in the details of how the symbol is painted. The transmitted infrared image displayed in Figure 26a features several brushstrokes, and show an initial outline of the ideogram prior to being painted. Figure 26b's outline features thick and singular brushstrokes, while outlines in Figure 26c feature thin and multiple lines. One of the most notable aspects of the charcoal underdrawing is its transparency in transmitted infrared photographs, as the medium translucency features a visible canvas texture.



Figure 26a. Visible and transmitted infrared photography detailing how the red character is constructed. Georgette Chen, *Mooncakes with Green Pomelo* (1965–1968).



Figure 26b. Visible and transmitted infrared photography detailing how the red character is constructed. Georgette Chen, *Still Life (Moon Festival Table)* (1962).



Figure 26c. Visible and transmitted infrared photography detailing how the red character is constructed. Georgette Chen, *Coq* (undated).

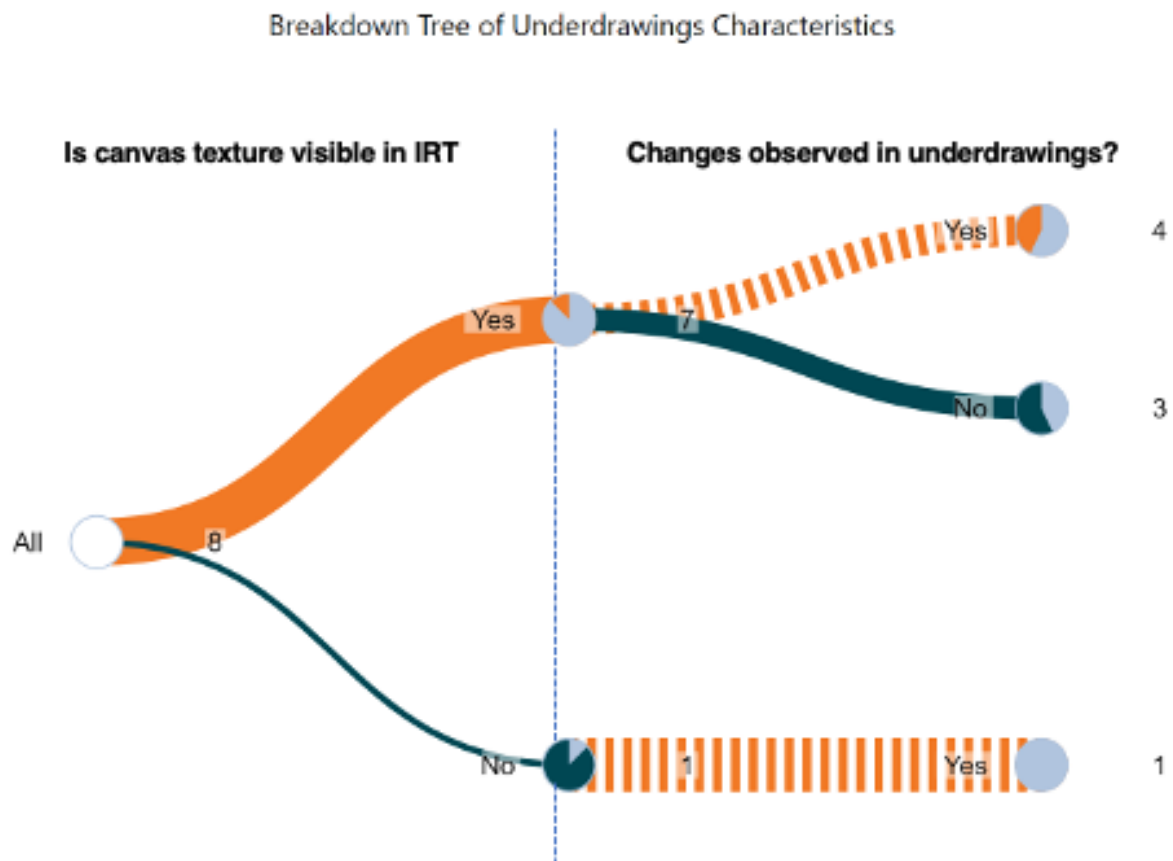


Figure 27. Breakdown tree showing the main trends of underdrawing media transparency and any changes observed in Georgette Chen paintings studied.

To summarise all that has been mentioned so far, a breakdown tree is used above to visualise the relationship between the two main characteristics of the underdrawings: the transparency of the canvas texture in transmitted infrared and the identification of any compositional changes observed (see Figure 27). These factors individually are present in more than 50% of paintings in the study. From the visualisation, seven out of eight paintings demonstrate a strong association of canvas visibility, which can be seen as a critical attribute of Georgette Chen's underdrawings. The transparency of the underdrawings studied so far is supported by the documented and observed technique of Georgette Chen's 'rubbing out' of the charcoal in her underdrawing. However, the presence of charcoal underdrawings does not necessarily indicate whether the paintings feature any compositional changes. Further investigations with a greater focus on the underdrawings under transmitted infrared could help to establish a greater degree of accuracy on the pattern observed.

There has not yet been a study of Chinese characters in Chen's paintings, and this study presents exciting areas for further research on Chinese artists who practice Western

canvas painting. However, the current study aims only to understand the painting preparation methodology that Georgette Chen employed. The evidence that has emerged has so far supported Kennison's account of Georgette Chen's painting methodology, particularly in the presence of charcoal underdrawings and preparation prior to painting. However, this study is limited by the sample size, and these results might not represent the general underdrawing techniques of Georgette Chen. In terms of future work, it would be interesting to repeat the methodology described here for a broader study of her underdrawings to identify any key artist attributes.

4.6 Conclusion

Using non-invasive examination techniques and archival sources, this section has identified three key aspects of Georgette Chen's artist materials and techniques: choice of auxiliary supports, paint density, and underdrawings. The results reported here show that the canvas is evident in transmitted illumination, indicating a thinner paint layer, and charcoal underdrawings that were most likely rubbed out. Given the small sample size, a quantitative analysis could not be undertaken without in-depth data mining, and these analyses are therefore considered qualitative.

While the exploratory nature of this study has thrown up many questions needing further investigation, data extracted from the structured documentation record have suggested some consistencies and trends. These findings support the notion that a significant advantage of the study is having access to an extensive resource of archival material that strongly supports the technical art research methodology. From the records of letters and diary entries, key attributes, such as the painting methodology of Georgette Chen, were identified, from which data analysis drilled deeper. Considerably more work will need to be done to determine if the consistencies identified in this section can be firmly attributed to Georgette Chen's paintings from the 1960s. The methods examined in Chapter 4 and also applied to the next chapter which moves on to discuss a technical art analysis methodology but without access to primary sources. Instead, it has a broader study with more data collected, from the works of Cheong Soo Pieng.

Chapter 5: Technical study of Cheong Soo Pieng's materials and techniques

5.1 Introduction

Art historian Thiagarajan Sabapathy contends that, when the story of art in Singapore is finally told, Cheong Soo Pieng will assume a pre-eminent role and emerge as a formative presence in modern Southeast Asian art (Sabapathy in Seng 2010). Indeed, Cheong Soo Pieng (1917–1983) is already recognised as one of the most innovative and influential artists of Singapore's modern art development in the 20th century (Sullivan 1956). His oeuvre has been well researched from a curatorial standpoint with a major focus on his experimental practice and contributions to the Nanyang style. Born in 1917 in Xiamen, China, Cheong Soo Pieng was trained in Western Art in Shanghai from 1936. He practised Western-style art in China before moving to Singapore in 1946, which he continued with the support of the well-established Chinese artist societies in Singapore.

Cheong Soo Pieng's was a highly influential artist in the development of modern Singaporean art and his impact is demonstrated by the 19 solo exhibitions held in Singapore and around the world from 1942 through to 1982, and the retrospective show organised by the National Gallery Singapore in 2010. The literature maps his artistic developments and place in Singaporean art history; however, "a comprehensive review of his practice is certainly not complete" (Mashadi 2010, p. 4). Over four decades, Cheong Soo Pieng's practice ranged from two-dimensional formats and media such as Chinese ink paintings and abstract oil paintings, to sculptures and mixed-media using found objects. However, as Kwok states, the practice of Cheong Soo Pieng is not fully comprehended. Areas where further research on Cheong Soo Pieng's impact on the art history of Singapore, the connections of Cheong Soo Pieng's education background in China and its influence on his practice in Southeast Asia (2010, p. 9).

In fact, research into his practice has occurred recently, with the first significant book on the subject published in 2010 by the National Gallery Singapore. It is uncertain why so few publications exist, but unlike other Nanyang artists such as Liu Kang or Georgette Chen (p. 71), Cheong Soo Pieng rarely wrote about his art practice and few personal accounts can

be found. Friends and acquaintances of Cheong Soo Pieng also report that he spoke little English, which has resulted in only a few known artist interviews in English. His children often served as translators from Chinese to English during interviews and they also played a role in Cheong Soo Pieng's artistic practice (Tan 2013, p. 1, Steinle 1972). Due to time limitations, interviews in Chinese were not studied for this research.

Art historian Kwok Kian Chow notes that texts on Cheong Soo Pieng focus on his formalistic development and less on the theoretical underpinnings of his artistic practice (Kwok 1996). In addition, there is no catalogue *raisonné* of Cheong Soo Pieng's works of art held in private and public collections, nor in fact for any Singaporean artists. Given the dearth of written material such as archival records or interviews conducted in English, this research employs a technical art investigation to build an understanding of Cheong Soo Pieng's experimental art practice.

As raised in the introduction, the few existing conservation papers and the recent retrospective exhibitions present an opportunity to expand current knowledge on Cheong Soo Pieng's artistic production against empirical data. For this study, the data will be generated from a study of 59 works of art using a technical art history and data analytics methodology. Dating between 1947 to 1982, 59 works were selected from the Koh Seow Chuan private collection by its owner. The investigation employed both on-site visual examination and material analysis techniques to understand and identify the structure and media of each work of art. The data was recorded in a systematic and structured manner into the documentation record to allow for further analysis. This includes the use of data visualisations to uncover patterns in artist materials and techniques as well as the use of machine learning models to cluster data drawn from both non-invasive and invasive techniques, as described in Chapter 2 and will be briefly detailed below. This is with the goal of characterising and identifying particular material choices and processes that are unique to the Cheong Soo Pieng and curatorial categories used to understand his oeuvre.

To provide some background, first this chapter will introduce Cheong Soo Pieng and the art historical narratives that inform the curatorial categories of his work. Then, it will move to a focus on the visual examination, technical photography and identification of Cheong Soo Pieng's materials and techniques, in particular his supports and ground layers.

Then, before the artwork's non-material and conceptual links are explored through an art historical lens, the identified material data will be analysed and grouped according to their curatorial categories. This is with the aim to compare the clustered material findings with the written art historical narratives to situate, corroborate or dispute the findings.

This chapter thus first presents and then builds on existing curatorial literature, by reporting on material findings and characteristic traits of the various junctures in Cheong Soo Pieng's practice. The findings, drawn from various datasets extracted from the documentation record, begin with an overview of the artworks studied in the survey, the types of primary and auxiliary support, artist's techniques of painting construction, such as underdrawings and paint application. Using data visualisation tools to analyse the datasets, described in detail in Chapter 2.6, patterns and trends will be identified, to give a better understanding of artist preference and material availability. The discussion then leads to Chapter 6's statistical analysis of the data of the ground layer as introduced in Chapter 2.6, where correlations in the composition of a common preparatory layer throughout Cheong Soo Pieng's oeuvre are discussed. The chapter then closes with a discussion of the paint application and identified trends. To provide a better contextual understanding of the artistic practice of Cheong Soo Pieng and his influence in Singapore, the next section outlines the development of Cheong Soo Pieng's art education and career. The material narrative in this research aims to build the artist's record and understanding of a localised practice of Western informed art in Singapore.

Artist background

Cheong Soo Pieng's art education began in 1933 in the Xiamen Academy of Fine Arts under Lim Hak Tai (1893–1963). Also known as the Amoy Academy of Fine Arts, it was the first art institution in Xiamen to adopt Western ideas and forms, and offered classes Western-style painting, sculpture and design, as well as in traditional ink painting. The academy was co-founded in 1923 by Huang Suibi, a Japanese-trained Chinese artist, Yang Gengtang and Lim Hak Tai, under whom Cheong Soo Pieng studied and who would later play an instrumental role in Cheong Soo Pieng's life (NAFA 2016). Between 1933 and 1935, the two years that Cheong Soo Pieng was recorded to have studied in the school, he would have been exposed to Western and Japanese art, with Chinese teachers who had visited both

France and Japan for their studies, as well as a Dutch teacher who had been appointed instructor and head of the sculpture department in 1931 (Hong in Tan 2013).

Following his graduation in 1936, Cheong Soo Pieng ventured towards Shanghai to continue his studies in Xinhua Academy. Founded and based on the French Concession in Shanghai in 1926, Xinhua was a prestigious institution for modern art education that offered an education in both Chinese and Western art forms. Almost all members of its faculty had studied in France, and by 1934, Xinhua's library was already stocked with over 3,000 American, Japanese, French and English publications on art, including the classics from Chinese history. Unfortunately, the Academy was destroyed and ceased its operation during the second Sino-Japanese war and Cheong Soo Pieng's education there was cut short after only six months. He returned to Xiamen in 1938 and taught at Yi Zhong School from 1939 to 1943. He held his first solo exhibition in Xiamen in 1942, which featured mainly watercolour works, as art materials were scarce during war time in China (Seng 2010).

The social and political turbulence in China did not end with the surrender of the Japanese in 1945. A civil war between the Chinese Communist Party and the Kuomintang caused a further destabilisation of the country, prompting many intellectuals and artists to leave China in 1946 (Seng 2010). The civil war saw an increase in migration to various parts of the world and especially to Malaya, where the Chinese community offered support. Cheong Soo Pieng's decision to move to Singapore was in large part owing to the overseas Chinese diaspora who played a vital role in developing a modern art scene. Leaving mainland China in 1945, he spent time in Hong Kong for a year before arriving in Singapore. It was in Singapore where the second phase of his artistic career began (Seng & Tng 2010, p. 76).

Cheong Soo Pieng's former art teacher, Lim Hak Tai, had just reopened the Nanyang Academy as the founding principal and was ready to recruit new teachers following a steady intake of students (Ong 2006). Having established his artistic career in China, Cheong Soo Pieng was offered a position at the Nanyang Academy of Fine Arts (NAFA) in the Western Art Department in 1947 where he worked until 1961. He also worked at the Chinese High School in Singapore from 1948 to 1961 (Mashadi 2010, p. 21). It is likely that Cheong Soo Pieng was recognised for his knowledge of Western Art and accompanying skills from his studies in China, which it is argued, also materialised in his works of art. Lim Hak Tai

provided Cheong Soo Pieng with lodging and a studio at NAFA, where he lived and worked before moving to River Valley Road in the mid-1950s to accommodate his wife and two sons, who moved from Xiamen to join him.

This section has provided a brief overview of the artist's personal history to provide a context to the study of transnational Singaporean artists like Cheong Soo Pieng, whose artistic practice was a product of Chinese education reform and influenced his migration to Singapore. Cheong Soo Pieng's artistic oeuvre which will be discussed in the section that follows, draw from some of these events, and are used as data points for the period of production. The synergy in his work of Western art and traditional Chinese ink painting draws upon his exposure to both Chinese and Western arts. Additionally, Cheong Soo Pieng's background highlighted that European exposure or education was not necessary in order to adopt a Western art practice in Asia. Over the years, Cheong Soo Pieng played an influential role in shaping a generation of Singaporean artists through his teaching in the Western art department. Seng observed that younger Singaporean artists copied and imitated his work, as "he was such a dominant force that many younger artists struggled to break out of his influence" (Seng in Kolesnikov-Jessop 2010). With a new atmosphere and plentiful art supplies available, Cheong Soo Pieng developed and mastered Western painting — something which is said to have happened in Singapore, the place credited with the development and maturation of his art practice (Singapore Art Society 1956).

Categorising Cheong Soo Pieng's paintings

"He kept on reinventing himself, time and again. I think that's really important and what really distinguishes him from some of the other pioneer artists. We see him as a bridge between the modern and the contemporary in Singapore" (Seng in Kolesnikov-Jessop 2010).

It is such continual reinvention in Cheong Soo Pieng's practice, that new works provided new opportunities for interpretation as he experimented with one style to another throughout his oeuvre. With limited texts written by the artist, most of this discourse has focused on the formalistic development and curatorial interpretation of Cheong Soo Pieng's practice (which are used to inform the 'period' data point in the later data analysis). In 2015,

the first bilingual publication of Cheong Soo Pieng was published by Ho Sou Ping and Ma Peiyi, owner and curator of Artcommune Gallery, featuring works from private collections. While the 2010 exhibition catalogue from the National Gallery presented Cheong Soo Pieng's oeuvre chronologically and by material types, Ho and Ma offered another perspective on his stylistic development through his practice. Taking into account the visual style of the image, chronology and important junctures that might influence his practice, Ho and Ma presented six broad curatorial categories of Cheong Soo Pieng's art practice:

- Formative Years (1946–49)
- Nanyang Style (1950–61)
- Lyrical Abstract (1962–63)
- Stylisation (1964–69)
- Artistic Maturation (1970–78)
- Late Developments (1979–83)

The Formative Years was the period when Cheong Soo Pieng first arrived in Singapore. Arriving in 1946, he undertook a position at the NAFA in the Western Art Department in 1947. The cost of canvasses and oil paints was relatively high during this period and as such, watercolours and sketches, as well as smaller works, were more common during this period (Ho & Ma 2015, p. 30).

The watershed Bali trip in 1952 proved to be a critical turning point in Cheong Soo Pieng's early practice, and his pictorial language evolved to depict the landscape around him. Later in 1959 and 1961, he travelled to Borneo and spent considerable time observing and drawing the longhouses of the native tribes, such as the Dayaks. From these trips, Cheong Soo Pieng amassed volumes of sketches that would be used for basic reference for works he went on to produce throughout his career, including paintings in the 1980s. These trips fall within the Nanyang Style period. Spanning across 11 years, the Nanyang Style period is the longest of the six curatorial categorisations.

Having cemented his position as a forerunner in the Singapore art scene in the 1950s, and upon gaining financial stability from his artistic career, he retired from teaching at NAFA to become a full-time artist in 1961, and embarked on his first trip to Europe between 1962

and 1963. Georgette Chen and Cheong Soo Pieng, as colleagues in the Western Art department at the Academy, shared a common student, Patricia Kennison, who frequently wrote to Georgette Chen. While references to academic writings are useful in tracing Cheong Soo Pieng's history, primary evidence, such as correspondence between Patricia Kennison and Georgette Chen also gives insights into Cheong Soo Pieng's practice. In 1962, Kennison inquired about Cheong Soo Pieng's trip to London, while sharing some of her thoughts on his practice:

“Did Mr Cheong go to London? Thomas Yeo tells me that Mr Cheong is in London and Paris [...] were only interested in his abstract oils and not at all in his Chinese style water colours which I always felt were far better” (Chen 1962).

The abstract oils were painted during the Lyrical Abstract period (1962–1963), a time of material and technical experimentations on canvas by Cheong Soo Pieng. The Lyrical Abstract period was short, but the works produced while he was in Europe broke away dramatically from previous styles, being derived through an “integration of the principles of the easel picture from Europe” and the “conventions of scroll paintings from Chinese pictorial traditions”. Cheong Soo Pieng's high standards of artistic achievement were recognised by the government of Singapore at this time, who awarded him the *Pingat Jasa Gemilang* (Meritorious Service Medal) in 1962 for his contributions to Singaporean art.

Returning to Singapore around July 1963 with some of his paintings, Cheong Soo Pieng set up an art studio at 28A Zion Road, Singapore 1024, and gave private art lessons which may be linked to the supply of art materials Georgette Chen mentions (Mashadi 2010). Upon his return to Singapore, the Stylisation (1964–69) period featured a range of different pictorial languages as well as different materials and techniques used. The most distinctive feature of Cheong Soo Pieng's art lies in the intersection and interactions of Eastern and Western techniques and traditions, and it was after the trip to London and Europe that the influences of Cubism and geometric abstracts developed Cheong Soo Pieng's practice (Seng 2010, p. 222) Cheong Soo Pieng's view on his art was that, “Singapore is the junction of East and West, so I felt my work should combine East and West” (Seng 2010, p. 226).

This was followed by the Artistic Maturation period in the 1970s, which saw an increase in the incorporation of mixed-media and local materials, suggesting Cheong Soo Pieng's localisation of the Western canvas painting. There was a sense of revisitation of subjects from the Nanyang Style which continued towards the end of his practice.

The impact and significance of Cheong Soo Pieng in the development of the art scene in Singapore were to be honoured in a solo exhibition at the National Museum Art Gallery in 1983. However, months shy of this retrospective exhibition, Cheong Soo Pieng died unexpectedly from heart failure at the age of 66. Several works were left unfinished due to his sudden death, a hint of his continuing dedication to his practice.

At present, the literature and research surrounding his artist's techniques have considered mostly the curatorial and historical context of his oeuvre, which is one of the many ways to understand Cheong Soo Pieng's artistic practice. However, this approach is limited in establishing the artist's attribution and the materiality of his artworks. To further our understanding, this study is a systematic study of the artist's materials and techniques alongside curatorial frameworks examined above. The goal is to map the evidence of the artist's materials and techniques chronologically as well as alongside the six main curatorial categories of the Formative Years, Nanyang Style, Lyrical Abstract, Stylisation, Artistic Maturation and Late Developments, to find correlations within the material data and assess whether any patterns exist. The six curatorial categorisation of Cheong Soo Pieng's practice are used as variables for the data point, 'period', which anchors much of the material findings. This will be supported by a wide range of qualitative data, such as curatorial observations, as well as oral and archival interviews about artist materials in Singapore. In this way, the two forms of disciplinary knowledge, art historical and cultural materials conservation, can be cross verified to demonstrate the significance of interdisciplinarity and the value of data collection and analysis, and of gaining insights through data visualisations. Such a study can play a pivotal role in understanding the artist's techniques as well as the materials available in Singapore during the 1940s to the 1980s.

5.2 Research Methodology

Following on from Chapter 2.3 which outlined the painting selection scope, the majority of Cheong Soo Pieng's surviving works in Singapore dated from 1946 onwards, the 59 artworks available for study were selected by the collector, and were based on availability. The date range was 1946–1982. While canvas paintings were identified as the key research area, not all these 59 works were canvas paintings, as other types of supports such as Masonite, wood and local materials were included. This study constitutes a small sample size of his art practice, which spans mixed-media metal sculptures, watercolour paintings, sketches, sculptures, Chinese ink scrolls and found objects, many of which are not within the scope of this study. As most of the works (94%) in this study were dated by the artist, material findings will be considered chronologically within the curatorial categorisation framework examined in this chapter.

As described, it is now well established that visual examination and material analysis, are some of the most successful techniques used for gathering valuable information from artworks. This collection of raw data kickstarts the development of the documentation record (refer to Table 2 in Chapter 2.5, page 56). The transformation of raw data from Stage One to Stage Two occurs when these observations from visual examination and material analysis are input into Airtable, following the data structure of categories, data points and variables. As such, the current study employs an approach that is verifiable, structured and comparable. This not only allows for the expansion of the dataset through further research but importantly, it allows statistical data analysis of the data gathered from the technical study of Cheong Soo Pieng's artworks, which is Stage Three of the documentation record process and will be discussed in Chapter 6. The discussion in this chapter begins by examining the evidence gathered from the collection survey of the painting and auxiliary support. This plays an important role in understanding the data collected, identifying the relevant data points and variables from the documentation record on Airtable and selecting datasets to be extracted for analysis. This vital component is presented through data visualisations as described in Chapter 2.6 that report the insights. These semi-qualitative methods provide a means of exploratory research through an unsupervised learning model, also mentioned in Chapter 2.6, which combines data from technical examination as well as scientific analysis of the ground

and canvas layers. The potential advantage of using unsupervised learning in studying across a range of metadata will be of interest to conservators engaging in artist surveys to build an exploratory and holistic understanding of an artist's oeuvre.

5.3 Findings from the technical examination of paintings

By utilising a holistic approach integrating qualitative modes of enquiry and quantitative data analysis, some of the narratives in the materiality and techniques of Cheong Soo Pieng's art practices will be illuminated. Establishing more technical evidence missing from the current literature was made possible through a broad collection survey as introduced in Chapter 2, and structured documentation of visual examination data recorded in the documentation record that will be reported in this chapter. This is the start of Stage One which will form the base for a statistical inquiry into the various data points which will be discussed in Chapter 6 (see Table 2 on the four stages of the documentation record). From the 59 artworks, key findings from more than 600 images, 285 cross-sections and 110 data points drawn from each painting are presented. The study acknowledges that despite the large amounts of data collected, the sample size does not provide a comprehensive and definitive review of Cheong Soo Pieng's oeuvre, and is representative of the painting examined and their time period of production. It does, however, support further investigations and highlight the need for more data collection. In the pages that follow, a brief overview of the characteristic materials (mainly the supports and grounds) and techniques of the curatorial categorisations drawn from the survey will be presented. The raw data is presented within each category and broad categorisations are raised and structured around the existing curatorial frameworks mentioned above.

Painting supports

The distribution of the primary support layer is an entry point for an overview of the investigation and the narrative of Western paintings in Singapore. From the 59 works chosen by the collector, 57 of them fitted the selection criteria for the following study on painting supports. Two works were excluded as they were painted ceramic plates. As such, this section will refer to the total number of works studied as 57. Of these 57 artworks, 39 were painted on flexible supports and 18 were painted on solid supports, which are recorded into

the data point ‘Type of Support’, which has two variables, ‘flexible’ and ‘solid’. Table 8 shows the hierarchy and types of supports that were found to be present. However, to offer an overview of the supports from the study through data clustering, a re-categorisation for the data point ‘medium’ was broadened into five categories was necessary. However, this does not reduce the level of detail, as substrates that are later analysed, are recorded in the data point ‘Fibre ID’, later used for data clustering in Chapter 6. In addition, while support types are often categorised as primary or secondary supports in condition reports and documentation records, the broad re-categorisation considered the secondary support of marouflaged works as the main support type.

Table 8. Broad re-categorisation of support types used for data point ‘medium’.

<i>Variable</i>	<i>Medium (broad)</i>	<i>Support substrates include</i>	<i>Represented Colour in Figs. 28a & 28b</i>	<i>Quantity</i>
Flexible	Canvas	Cotton, linen, linen-blend fabrics	Blue	33
Flexible	Paper	Prepared and non-prepared	Orange	6
Solid	Hardboard	Compressed wood fibres, Masonite boards	Purple	12
Solid	Wood	Plywood or wooden panels	Light blue	5
Others	Others	Acrylic sheets	Pink	1

The distribution of support by decades indicates the dominant use of canvas from the 1960s. Works on hardboards were not present after the 1970s, as illustrated in Figure 28a. Given the span of a decade and uneven distribution in the number of artworks per decade, the dataset was re-classified by artist oeuvre as part of the Stage One to Two process outlined in Table 2 (see page 56). This provides an example of how data points are developed and how

the data quality is made more reliable (as introduced in Chapter 2.5). Figures 28a and b were produced by extracting the dataset of the broad support categories, year and periods and visualised using Tableau as introduced in Chapter 2.6. From the stacked bar chart, the different support types are assigned colours — for instance, hardboards are purple. Figure 28a shows a distribution of hardboard across three decades, from the 1940s through to the 1970s. However, the distribution of hardboard used as a support type during the Formative Years and Nanyang Style periods (Figure 28b) offers more clarity when presented and grouped by curatorial categorisation. This allowed for stronger patterns of distribution and opens the discussion into the use of marouflage and choices of auxiliary support, which will be the focus of this section.

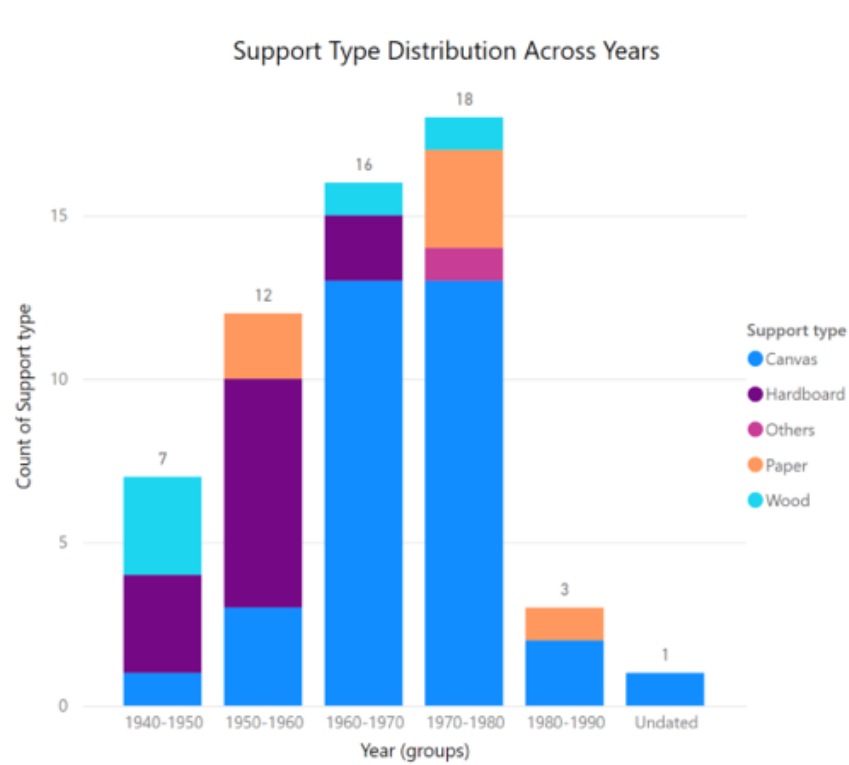


Figure 28a. Distribution of support type across decades of the 57 Cheong Soo Pieng paintings studied.

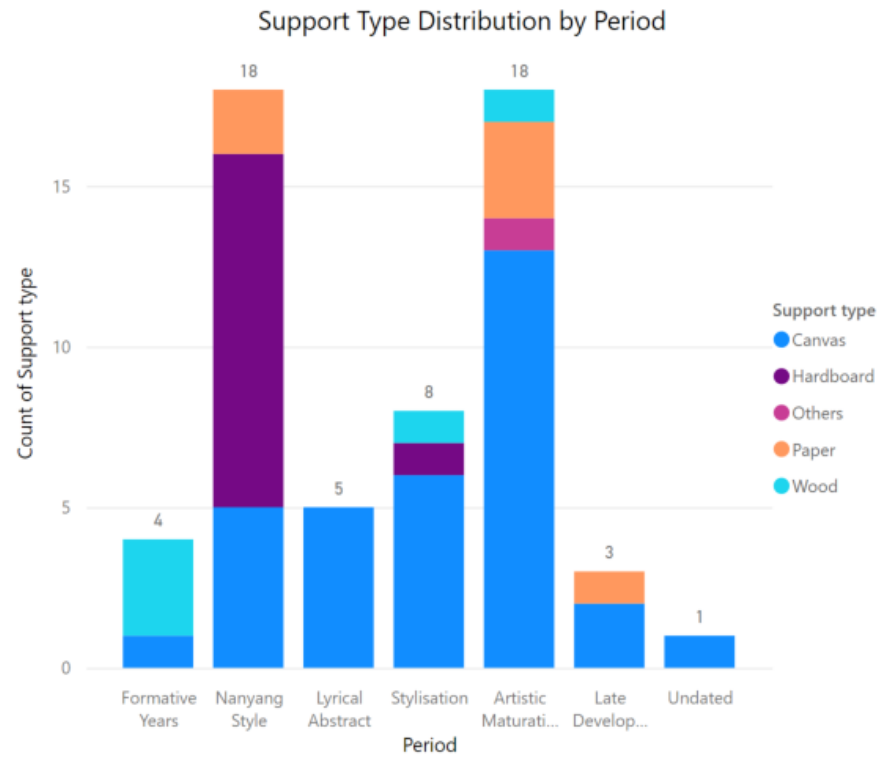


Figure 28b. Distribution of support type across periods of the 57 Cheong Soo Pieng paintings studied.

Solid supports: hardboard and wood

The use of solid supports such as hardboard and wood were observed more often in the first two periods of Cheong Soo Pieng's curatorial categorisation, and evidence suggests this could be related to material availability and artist resources. Beginning with the Formative years (1946–1949) when Cheong Soo Pieng had just arrived in Singapore, the paintings he produced were mainly small in size, with few exceeding a metre in length. Smaller painting sizes may have been Cheong Soo Pieng's personal choice or because of limited space, time and his teaching commitments (Ho & Ma 2015). Of the 57 painting supports examined, 17 were solid supports, such as hardboard and wood. As previously mentioned, two supports were excluded as they were on ceramic. Most of the wood supports were present in the earlier periods of the Formative Years, while hardboard appeared to be a preference during the Nanyang Style period. Works with hardboard supports included ones that were painted directly onto the hardboard and ones that were marouflaged onto hardboard, such as paper adhered onto hardboard support.

Three of the four Cheong Soo Pieng's paintings studied from 1947–49 are characterised by the use of wooden supports. *A Corner of Art Studio* (1947) and *Portrait* (1948) are painted on wood panels mounted onto strainers, while *Forest* (1948) is painted on plywood. *A Corner of Art Studio* is said to be Cheong Soo Pieng's first painting produced in Singapore. It and *Portrait* are both approximately 40 x 30cm and are likely to have been prepared at around the same time. The dimensions of these paintings on wooden panels are the smallest of the paintings by Cheong Soo Pieng in this study. Similarly, the first stretched canvas painting produced in Singapore, *Indian Girl* (1949), measures 45 x 36cm. Cheong Soo Pieng's use of solid supports were in the earlier years in Singapore, between 1947 and 1971, with 17 of the 57 studied works produced within this period, of these, three were painted on wood panels and the rest were on Masonite board.

As the art scene grew in the 1950s, Cheong Soo Pieng found an abundance of subject matter and available materials, leading to his material experimentations and pictorial language development throughout his career. The collection survey of his works supports this view with a greater range of support types between 1970–1980, where there is a shift in his artistic choice of supports from wood to canvas. Emerging in the 1950s, experimentation with

medium, particularly on solid supports, was prominent. One of the earliest uses of hardboard was in 1950. These hardboards are typical of compressed fibre boards with a smooth side and a toothed side, made of compressed wood fibres; they are sometimes referred to as Masonite boards. However, not all hardboards are Masonite™, which is a commercial brand of compressed fibre board developed by the Masonite Corporation, a company established in 1929. Masonite boards are stamped in yellow on the reverse, as observed in *Bali Women* (1952–1964). Based on the survey results, overall Cheong Soo Pieng painted mostly on the smooth side of the compressed fibre board with the exception of *Still Life* (1950) (Figure 29) which is the only painting in the study painted on the toothed side.



Figure 29a. Recto painted on the toothed side of hardboard. Cheong Soo Pieng, *Still Life*, c. 1950 (60x54 cm, oil on hardboard). Collection: KSC.



Figure 29b. Verso painted on the smooth side of hardboard. Cheong Soo Pieng, *Still Life* (1950).

Cheong Soo Pieng's use of compressed fibre boards was mainly during his Nanyang Style period, coinciding with the plentiful supply of hardboards in the 1950s in Singapore and their popular use by artists. Leng Guat, Cheong Soo Pieng's daughter, claims that Masonite was used only in the 1950s because canvas and stretchers were not readily available (Gomez Lobon 2010c). Even art shops like Straits Commercial sold Masonite boards during the 1950s, when such products would usually be procured from a hardware shop and not a fine art supplier. In 1957, a newspaper article in *The Singapore Free Press* notes, "This hard board is better than natural wood" (Figure 30a). It advertises the hardwearing qualities of Masonite

panels and their superior quality to justify their higher cost compared with “other types of hardboard” (Singapore Free Press 1957). The manufacturing process of the wood fibres results in a complete absence of grain, which eliminates splinters or cracks, and some specific Masonite products claim to be water resistant and hardwearing. This may suggest that Masonite is suitable for humid climates, and many of the examined paintings on hardboard were found to have significantly less warping than works on plywood, such as *Forest* (1948). Two yellow Presdwood Masonite stamps were identified on the supports of *Bali Women* (1952-1964) and *Sunflowers* (1957), suggesting that there is potential for further research and discussion.



Figure 30a: Newspaper clipping from The Singapore Free Press 1957.

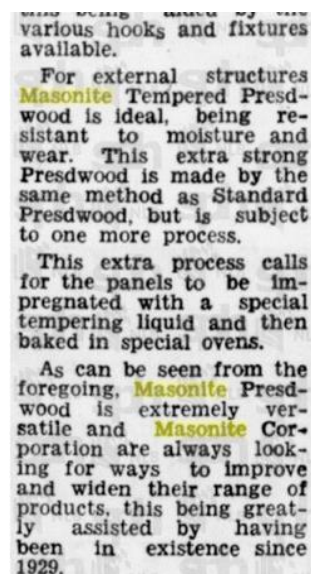


Figure 30b: Newspaper clipping from The Singapore Free Press 1957 (continued).

As highlighted, the Nanyang Style (1950–1961) period, which lasted eleven years, was the longest period in the artist’s oeuvre, and mainly featured works on hardwood supports, as shown in Figure 28b. The departure from hardboard supports occurred during the latter part of the Nanyang Style, which saw the transition to the use of canvas supports that would eventually become Cheong Soo Pieng’s preferred primary support.

One unanticipated result during the technical examination of the works on hardboard was the use of with canvas or paper supports adhered onto hardboards, known as marouflaging, and a more detailed account will now be examined.

Marouflage

Marouflaging is a technique employed by artists for affixing canvas onto walls that is said to date back to the 17th century in France (Hensick, Olivier & Pocobene 1997). Introduced by Richard Buck in the 1950s, marouflage was used as a conservation treatment for reinforcing works on thin panels and was used as part of a conservation lining treatment when a painting on canvas is attached onto a solid rigid support, either to provide support or as protection against humidity (Bergeon et al. 1998, p. 267). With this understanding, this term is used to classify Cheong Soo Pieng's paintings where a primary support is adhered onto a secondary support. This includes flexible supports, such as paper or canvas, affixed onto solid supports, as well flexible supports affixed onto another flexible support. From visual examinations, these were not previously treated and appeared to be artist applied. The findings of this study reflect those of Gomez Lobon who also found paint found on the sides of the Masonite board in her 2010 study, suggesting that the marouflaged board was applied by the artist. This section explores the importance of the marouflage technique employed by the artist. It is possible that the intention was to provide support or protection against humidity.

Given the limited material supply chains in the early 1950s, when art materials were scarce and artist supply shops were few, it seems reasonable that stretched canvas paintings were not as commonly produced. From the previous discussion, 17 of the 57 paintings were on solid supports, including 14 of the 22 paintings dated to the Formative Years (1946-1949) and Nanyang Style (1950-1961). This initially suggests that the majority of hardboards present in the study were selected due to artist preference or the availability of materials. However, in taking a closer look into the remaining eight paintings on flexible supports, it was observed that four paintings from the Nanyang Style were, in fact, canvas and paper supports marouflaged onto hardboards. From the verso, these four paintings appear to have been painted directly onto hardboard. This highlights the difficulty of identifying flexible supports and shows how the classification of supports can easily be mistaken. For example,

when examined from the reverse, the hardboard support is observed and recorded, but when examined from the front, the thick layers of paint mean that the difference in primary support is not immediately visible. In this study, the primary support in contact with the preparatory layers is documented as the primary support, while the marouflaged support was recorded as the auxiliary support. In most instances, the marouflaged works were identified, as the primary support was lifted from the marouflaged support.

Employing this definition and looking more closely at Cheong Soo Pieng's marouflaged artworks, *Cat* (1957) is a linen canvas cut to size and marouflaged on hardboard, and *Mosque in the Village* (1956) and *Sunflowers* (1957) are paper marouflaged onto hardboard. One of the largest canvas paintings is also the first marouflaged canvas painting, *Bali Women* (1952-1964), which is an oil cotton canvas painting adhered onto a Masonite Presdwood board. In such instances, these flexible supports appear to be hand prepared with a ground layer, like a traditional canvas painting before being adhered onto the hardboard with a variation of adhesives. These variations are plotted on a scatter plot in Figure 31 showing the 12 marouflaged works and the material of the marouflaged secondary support.

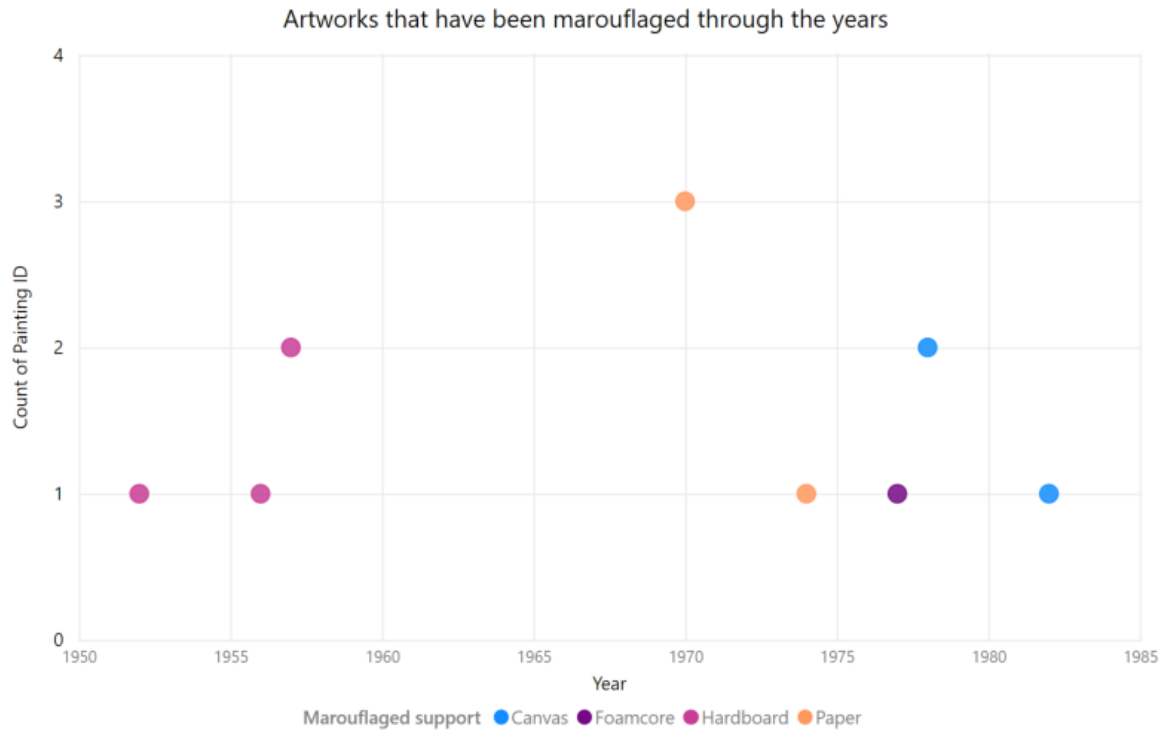


Figure 31. Scatterplot diagram showing the range of materials that have been used as a marouflage support by Cheong Soo Pieng.

Overall, it was found that 12 of the 57 Cheong Soo Pieng paintings were marouflaged, a technique that was used early on and then revisited in the 1970s, as shown in Figure 31 which illustrates the spatial distribution of these findings. What stands out from the plot is a gap during the 1960s, when no works were marouflaged. The earlier period coincides with Cheong Soo Pieng's return from Bali in 1952, when he worked primarily on hardboards using various paint mediums as well as using hardboards as marouflaged supports for paper and canvas supports. The later period, after 1970 during the Artistic Maturation phase, saw more flexible supports being used as the secondary support. The significance and importance of marouflaging as part of Cheong Soo Pieng's practice is suggested through several findings of marouflage supports which range from hardboards to canvas supports. These observations can be categorised in two main instances: (1) in the 1950s (Nanyang Style), four paintings are found to be marouflaged onto a hardboard; (2) in the early 1970s (Artistic Maturation), a total of seven paintings were found marouflaged onto a variety of supports, such as four paintings onto "thick paper support, one onto a foam board, and two

paintings onto a stretched canvas” (Tay 2021, p.8). It appears that the canvas was primed and stretched before being used as marouflage support, as will be discussed in more detail below. Overall, these findings support the idea that the use of hardboard as marouflaged support in the earlier years may have been a matter of material availability, while the later periods suggest artist technique or preference, as by the 1970s, there were many more options available. Why this is the case is a point of interest which will be further discussed below in reference to the localisation of Western canvas paintings.

The presented data on works that feature marouflage highlight the importance of careful and detailed examination. It shows that an understanding of Cheong Soo Pieng’s individual processes and choices of material is essential for conservation decision making and also to understand the implied social and economic meanings of the materials he used. The study highlights Cheong Soo Pieng’s intended use and value of hardboard supports and as an artist-applied support, they should be retained. The use of hardboard both as a primary support and as an artist-intended marouflage reiterate the importance of adopting a customised conservation approach.

The topics raised in this section have focused on solid supports, both as a primary and secondary or marouflaged support. The section provided a brief overview of solid supports used by Cheong Soo Pieng, which were more common in his earlier practice, during the Nanyang Style period from 1950 to 1960. This includes the use of flexible supports attached to a hardboard, which dominated Cheong Soo Pieng’s practice from the same period with a particular interest in the use of paper as a support for oil paintings. Revisited later in his practice, marouflaging was used in affixing a flexible support onto another flexible support. The following part of this paper moves on to describe in greater detail the choice of auxiliary supports that were used for Cheong Soo Pieng’s paintings through the years.

Auxiliary supports

Of the 57 paintings studied, 48 were still mounted onto their original auxiliary supports. In this study, the auxiliary support is defined as the outer framework over which the primary support is stretched and to which it is attached. While the term usually refers to a stretcher or strainer where the flexible support is mechanically attached to the side edges with tacks, staples or the like, in this study, a range of flexible supports, such as paper or canvas,

are adhered with glue onto a solid auxiliary support to hold the flexible support in place (as described above with reference to the marouflaged flexible support and the first two variables, ‘Foam core’ and ‘hardboard’). These are included in the category of auxiliary supports, and are recorded under the data point ‘type’, forming part of the 110 data points in the documentation record. Table 9 lists the variables for the data point ‘type’ of auxiliary supports which this study includes.

Table 9. Variables of auxiliary support groups for the data point ‘type’.

<i>Variable</i>	<i>Observed use</i>	<i>Colour</i>	<i>Quantity</i>
Foam core	Support for marouflaged flexible supports	Red	1
Hardboard	Support for marouflaged flexible supports or unmounted	Purple	13
Paper	Thick paper is used as a support for thin marouflaged flexible supports	Pink	6
Strainer	Framework for flexible canvas supports	Blue	22
Strainer-board	Framework for flexible canvas supports	Green	2
Stretcher	Framework for flexible canvas supports	Orange	2
Wood	Framework for mixed media works (metal relief)	Dark blue	2

The ribbon chart is an effective way to visualise the rank change of the various auxiliary supports, with the highest value displayed at the top. What stands out in this chart is the dominance of strainers in the 1960s, a time which also saw the rapid decrease in the use of hardboard as an auxiliary support. The previous section showed that hardboards were used as both an auxiliary support and a primary support. In these instances, the majority of works with hardboards were unmounted. Across the decades, strainers were the most widely used auxiliary support, particularly after the 1960s.

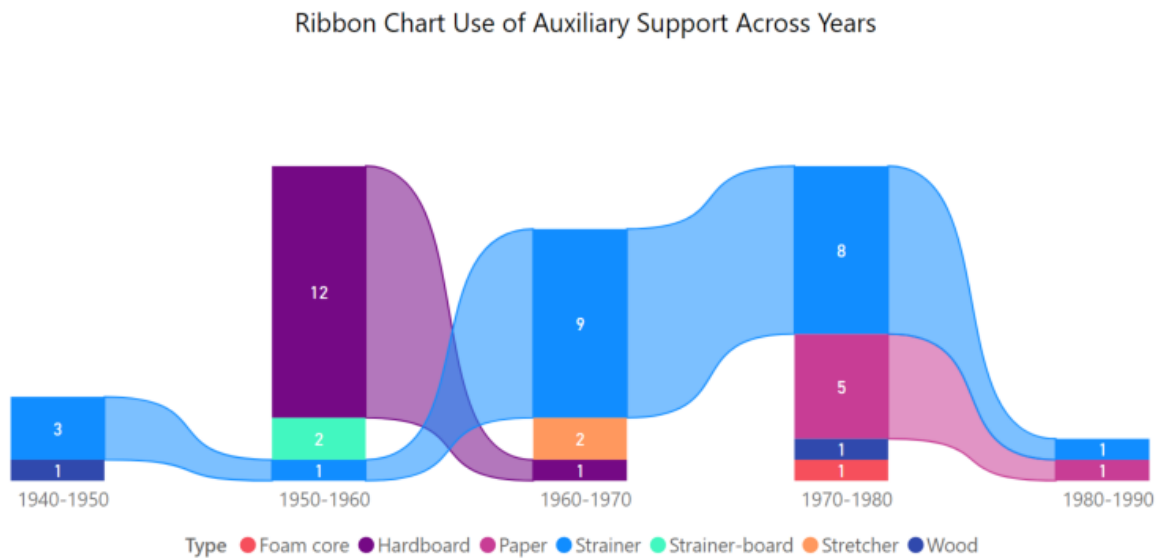


Figure 32. Ribbon chart of auxiliary support distributed across the years where the preferential trends are visualized through the thickness of the ribbon through the decades.

The 1960s appear to be the transitory period from solid to flexible supports, just as stretchers were first being used by Cheong Soo Pieng found to have been purchased in London in 1961. In particular, *Landscape* (1961), suggests a shift in material preference in the construction of paintings, possibly during his trip and increased exposure to more canvas paintings overseas.. The auxiliary support of *Landscape* (1961) is one of the two paintings stretched on a stretcher with a half-visible label on the centre of the top member of the stretcher *that reads* “...ourteenth open exhibition” and “..nest Wheatley picture framer ... 32” (see Figure 33).

In an interview about Cheong Soo Pieng’s choice of materials, his daughter, Leng Guat maintained that her father only purchased strainers, strainer boards and frames from Hung Wah framers in Singapore (2010c). However, a stamp from Chop Hung Sun framers (the predecessor of Hung Wah framers), as well as a label attributed to British framer Ernest Wheatley (see Figure 33) were found on the stretcher bar of *Landscape* (1961), suggesting that the source of auxiliary supports was not limited to one supplier. The stretcher was likely purchased during Cheong Soo Pieng’s trip to Europe, as a similar finding was recorded in

Gomez Lobon's survey where a stretcher was found on a 1962 painting, *A Vision*, which was painted in the United Kingdom (2010a, p. 7).



Figure 33. Image of label printed: ‘Ernest Wheatley Ltd / Picture Framer / 32 Foubert’s Place, Regent St / London, W.1 / Tel: Gerard 8739’. Cheong Soo Pieng, *Landscape*, c.1961 (46 x 71cm, oil on canvas). Collection: KSC.

The ribbon chart as illustrated in Figure 32 is revealing, particularly for the later period of the 1970s. This period features a range of auxiliary supports not previously used, such as paper, wood and foam core. These results corroborate the findings previously shown in Figure 31 on the use of marouflage supports in the later phase of the artist’s oeuvre as an artist preference, rather than a material limitation. To develop a better picture of Cheong Soo Pieng’s Western canvas painting techniques, the following sections are dedicated to a further study of the canvas and ground layer.

A deeper look into canvas supports

As can be observed from previous discussions, there is a general pattern in the transition from solid supports towards canvas supports, particularly after the Lyrical Abstract (1962-1963) period. Painting on canvas supports is a historical practice linked to Western art

canvas paintings. This section focuses on canvas as a major area of interest to understand the localisation of Western canvas paintings and the available materials or artistic preferences to shed light on an imported or localised supply. The examination method characterises both canvas and the artist's canvas preparation methods.

Of the 57 artworks studied, 34 were canvas paintings, making up a majority of the sample size. Of these, 32 had fibres sampled and identified, and 23 of the 34 canvas paintings could be accessed from the reverse. In this investigation, there were some disadvantages during the physical examination of the artworks. For instance, marouflaged works can conceal the canvas manufacturer stamps while complex-framed works can limit access to the corner edges of the canvas to record how it was folded. Notwithstanding these limitations, the following fields in Table 10 were extracted from the documentation record for analysis and offer some valuable insights into the canvas supports. As described in Chapter 2.5, the data points and variables were determined in Stage Two in the process of developing the documentation record (see Table 2 on page 56 for details). Given the consistency and structure of the recorded data, the data points for the analysis of canvas material draws upon fibre analysis (invasive analysis) as well as three other data points from visual examination (see Appendix C for the full list of data points). As the resolution of the dataset increases with the number of Cheong Soo Pieng paintings studied, and the dimensionality of the dataset improves with findings from fibre analysis included, quality data insights can be produced in a verifiable and comparable way.

Table 10. Data points and variables extracted for the analysis of canvas material dataset.

Data point	Variables
Findings (Fibre)	Cotton; linen; linen-blend fabrics
Manufacturer stamp	Holbein 1; Holbein 2; Holbein 3; Holbrein 10; Masonite; Masonite Preswood; None
Ground to canvas	Exposed linen; to edge; not accessible; not applicable
Visibility on tacking margin	Primed; unprimed; not accessible; not applicable

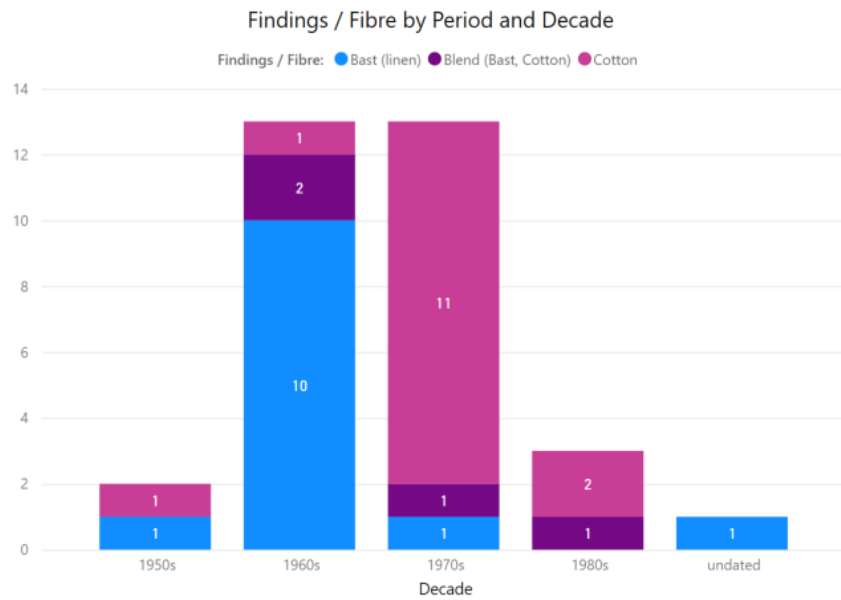


Figure 34a. Stacked bar chart showing the distribution of fibres by decade as identified from 32 sampled canvas fibres from Cheong Soo Pieng paintings. Highlighting the bast and cotton preference in the 1960s vs the 1970s.

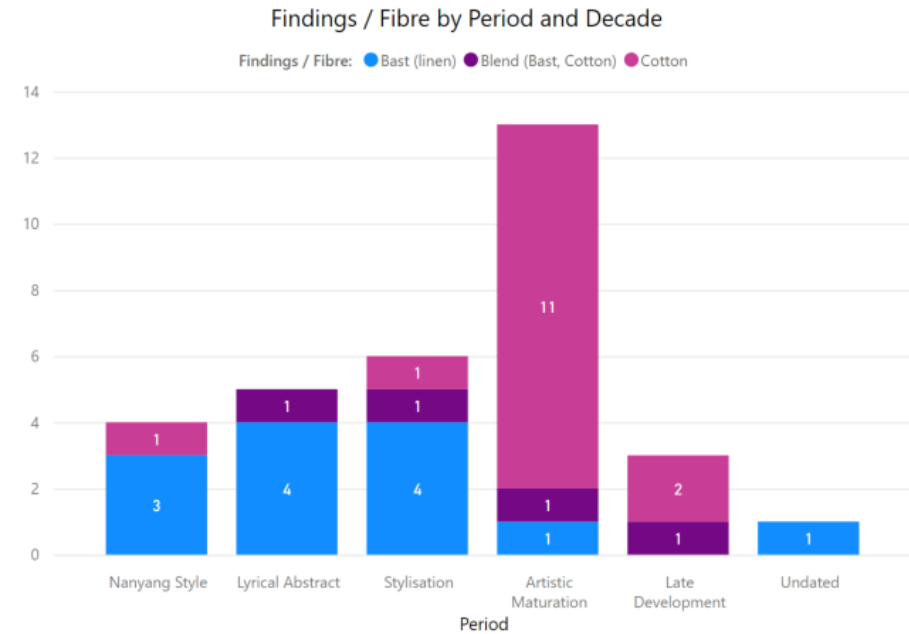


Figure 34b. Stacked bar chart showing the distribution of fibres by period as identified from 32 sampled canvas fibres from Cheong Soo Pieng paintings where the use of cotton is very prominent in the Artistic Maturation period.

Overview of fibres

Fibre analysis of 32 Cheong Soo Pieng canvas supports between 1947 and 1982 showed a variety of results, which indicates that various canvas supplies were available. Figure 34a presents an overview of the fibres which have been identified by microscopy. A total of 13 works on bast, 15 on cotton and four canvas blends were found when sourced from the documentation record on Airtable.

Table 11. Distribution and count of ‘fibre findings’ (data point) from 32 Cheong Soo Pieng paintings by periods and decades.

Period	Decades	Findings	Count of Painting ID
Artistic maturation	1970s	Bast (linen)	1
Nanyang style	1950s	Bast (linen)	1
Nanyang style	1960s	Bast (linen)	2
Stylisation	1960s	Bast (linen)	8
unknown	undated	Bast (linen)	1
Artistic maturation	1970s	Blend (Bast, Cotton)	1
Late development	1980s	Blend (Bast, Cotton)	1
Stylisation	1960s	Blend (Bast, Cotton)	2
Artistic maturation	1970s	Cotton	11
Late development	1980s	Cotton	2
Nanyang style	1950s	Cotton	1
Stylisation	1960s	Cotton	1
Total			32

Table 11 draws upon two main data points, ‘period’ and ‘fibre findings’ and illustrates the preference for the type of canvas fibres such as the ten bast and one cotton fibre in the 1960s, while cotton-blend and cotton canvasses were dominant in the 1970s (13 cotton and one bast fibre). The most striking result to emerge from the data is the significance of

cotton canvasses during the Artistic Maturation period (1969–1979). Canvas made from bast fibres appear to be more common in the earlier exploration of flexible supports, while cotton and canvas blends were more commonly used after 1966. Closer inspection of canvas with bast fibres dated between 1963 to 1968, revealed that five canvasses had a red Holbein manufacturer stamp on their verso as also found in Georgette Chen's paintings. All five Holbein canvasses were bast linen fibres and presented similar characteristics, such as a thread count of 14x15/cm or 15x16/cm.

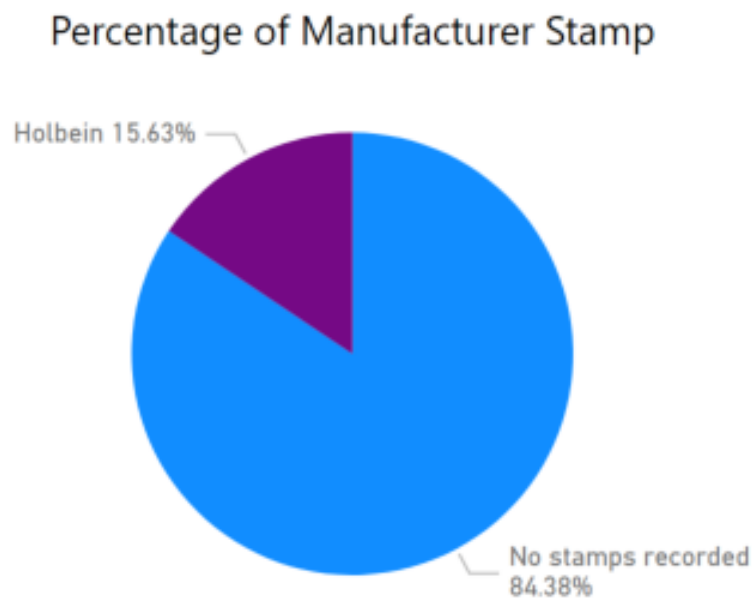


Figure 35. The presence of manufacturer stamps on Cheong Soo Pieng canvas paintings studied showed there were either no stamps or Holbein stamps recorded.

Whilst Holbein stamps were not common in the overall study as illustrated in Figure 35, with 15.63% present in the total paintings of Cheong Soo Pieng studied in this survey, this discovery offers new evidence to support our understanding of material availability in Singapore as there is a limited knowledge on canvas manufacturer brands. In addition, there is no indication of Holbein canvas as a prominent brand in the artist supplies archival research in Chapter 3.4. The next section will provide greater insight on works of art with the Holbein stamp and the significance of its presence to better understand the type of canvasses

used and available in Singapore during the 1960s, the period which saw Cheong Soo Pieng's transition towards canvas support.

Manufacturer stamps: Holbein

The discovery of Holbein stamps initiated closer investigation into the availability of commercially prepared canvasses in Singapore during the 1960s. Previously, knowledge on commercial canvasses has tended to focus on Belgian canvasses sold by Straits Commercial in the 60s, which was informed by conservator-led interviews with the key artist materials supplier. Interviews conducted by Gomez Lobon (2010c) and Tse (2008) with the then-owner of Straits Commercial, Tay Nam Seng (now deceased), highlighted that the company started importing pre-primed canvas in rolls of 2.1 x 10 metres from Belgium in the 1960s (Gomez Lobon 2010c). In addition, Straits Commercial claimed to be the only artist materials shop selling Western art materials until the 1980s (Gomez Lobon 2010c). The existing knowledge about suppliers of artist materials within the ecosystem was discussed in further detail in Chapter 3.

As previously discussed, Japanese canvas manufacturer Holbein was established in 1935 and began overseas exports in 1952. As an example of Japan's interest, uptake and assimilation of Western canvas painting into mainstream practice and local art supply by producing locally made art materials, they were also interested in developing canvas supports suited to Japan's temperatures and humidity (Tay 2020, p.114). For instance, a 1935 catalogue includes research findings on nitrogen-containing water-soluble adhesives to reduce environmental impacts (Yoshimura 1935). The identification of a Japanese manufacturers' stamp on canvas supports was unexpected, and contributes to the study of artist materials in Singapore, specifically in the 1960s when Holbein canvas supports dominated.

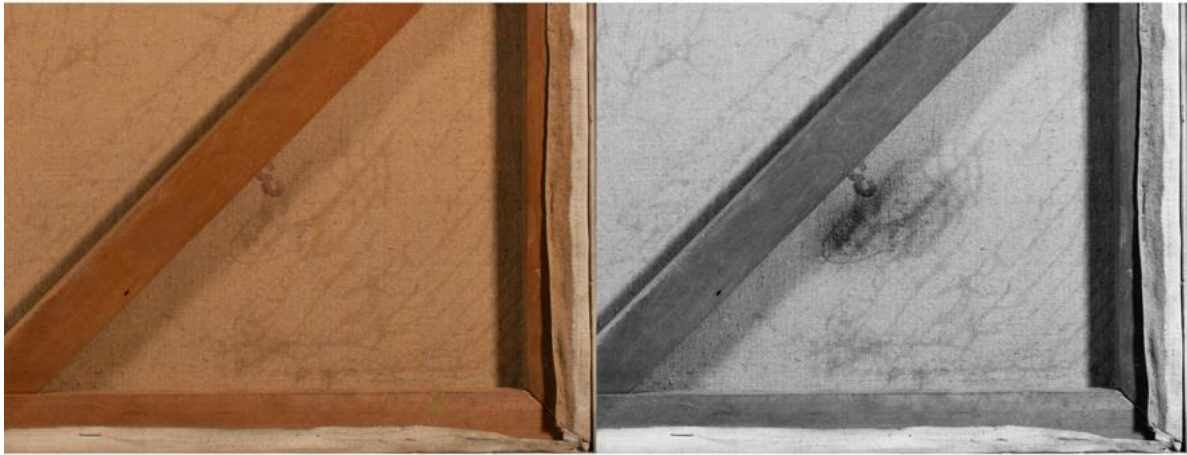


Figure 36. Detail of verso showing red 'Holbein 3' canvas stamp (left) and digitally enhanced image of the same in Adobe Lightroom in black and white with masking to accentuate canvas stamp. Cheong Soo Pieng, *Busy Planters*, c. 1968 (84 x 106cm, oil on canvas). Collection: KSC.

The earliest canvas stamp documented in the study was from 1963 on an unmounted painting, *Untitled (Red)* (see Figure 10). The identification of the red Holbein manufacturer's stamp was found on five out of the 13 canvas paintings from 1963 to 1968, as well as on three works by Georgette Chen, which were produced within the same period. These Holbein canvasses share similar profiles of thread count, fibre type and visual characteristics (Figure 36). The Holbein canvasses examined have a thread count of 14x15/cm. Under microscopy, the Holbein canvasses were identified as a bast fibre. The only variations to the Holbein manufacturer stamps are the numbers 1, 2, 3 or 10 below the branding, the purpose of which is unknown. No further information could be provided by the Holbein company on the significance of the numbers (Seriguchi, personal communication, 2020). In addition, several replies to an open inquiry on the Global Conservation Forum on 17 February 2020 were received. Conservators from National Museum of Modern and Contemporary Art Korea, the TATE Britain, and TOKAI University in Japan noted that similar stamps had been observed in their collection but no further information on the stamps had been sourced.

By exploring Cheong Soo Pieng's materiality more broadly, observations through visual examinations and the subsequent data analysis have shed some light on alternative

artist supplies available in Singapore, particularly in this period of transition. The increased use of canvasses suggest artist preference, and the canvas stamps from the Japanese artist supply manufacturer Holbein support the notion that the distribution of materials through Chinese transnational networks played a pertinent role in material availability. Regarding commercially available canvasses, it would be useful at this stage to consider the forms available to purchase and whether they were pre-primed or bought unprepared. In the next section, the results obtained from the data mining ontology on classifying pre-primed canvasses will be discussed to shed light on Holbein canvasses.

Characterisation of artist or commercially prepared canvasses

The presence of manufacturer stamps leads to the question of whether the canvas was bought pre-primed or was artist prepared. Based on non-invasive examination of the ground layer at the face, side tacking margins and reverse of the canvas, Table 12 shows the data points of the variables of ‘primed,’ ‘unprimed,’ ‘not accessible,’ and ‘not applicable’ for the tacking margin, and ‘exposed linen,’ ‘to the edge,’ ‘not accessible’ and ‘not applicable’ for the ground to canvas (see Appendix C for full 110 data points). These data points and variables sourced from documentation record are based on the premise that canvas with ground layers extending beyond the tacking margin edge of the canvas has a ground layer prepared on another support before being stretched onto its current auxiliary support. The absence of exposed fabric and ground to the edge of the canvas suggests that the ground was probably prepared on another support. Nine of the 34 samples could not be characterised, as the verso of the canvas was not accessible.

Table 12. Data points and variables for the analysis of the types of commercial canvasses dataset.

Data point	Variables
Visibility on tacking margin	Primed; unprimed; not accessible; not applicable
Ground to canvas	Exposed canvas; to edge; not accessible; not applicable

Figure 37 shows there were 15 paintings with ground applied to the tacking margin edge (1952–1982); three paintings with exposed linen on the verso (1972–1975), ten not accessible, and six not applicable. The distribution of visible ground on the tacking margin included 15 primed (1952–1982), four unprimed (1972–1975), nine not accessible, and seven not applicable (cut to face or marouflaged).

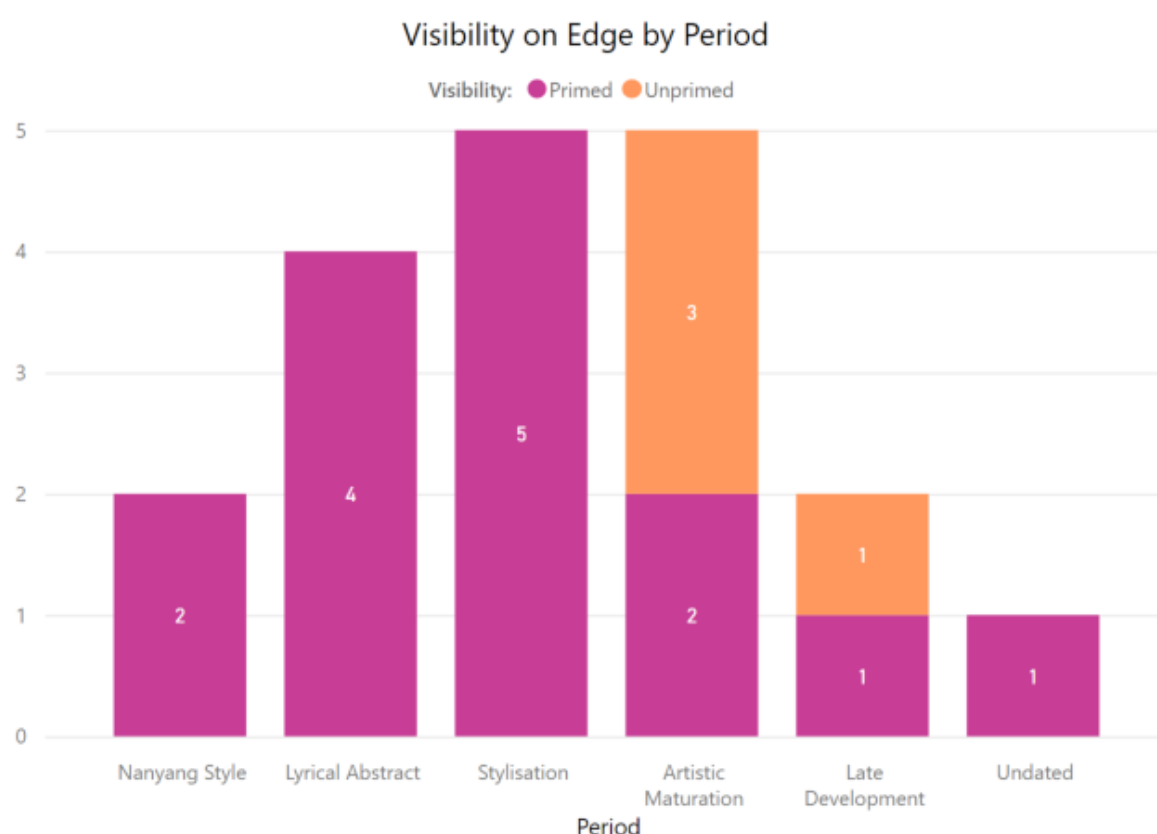
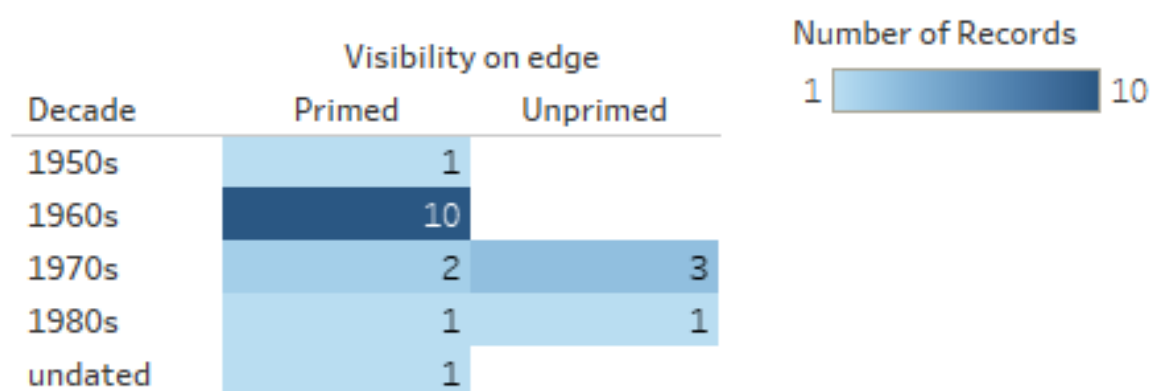


Figure 37. Stacked bar chart showing the distribution of ground layers visibility on tacking margin edge identified from 32 Cheong Soo Pieng paintings with fibre analysis.

Collectively, the evidence seems to indicate that unprimed paintings and those with exposed fabric were artist prepared. It is thus probable that the paintings were prepared on their existing auxiliary support. If the ground layer extended beyond the edge of the painting, with no exposed unprimed fabrics, it was most likely pre-primed on another support and could be either commercially pre-primed canvas or artist applied. It is suggested that microscopic examination of the top topography of a ground may provide further evidence on whether a ground is commercially or custom applied. On this basis, identification of ground layer cross-sections and the classification of their ‘uneven’ or ‘smooth’ upper interface, indicated whether the ground layer was artist or commercially applied.

Table 13. Organised by decades to understand primed canvas edges visible on the verso of Cheong Soo Pieng paintings.



Upon further analysis, Table 13 shows ten pre-primed canvasses with the ground extending past the canvas edge from the 1960s. There was no presence of a ground layer along the tacking margin for the three works dated in the 1970s. The five canvasses with Holbein stamps were all recorded as having white primed edges which extended beyond the turnover edge to the verso and edge of the canvas, a strong indicator that the ground was pre-primed and prepared on another auxiliary support. With the ground layer extending to the tacking margin edge, these canvasses were likely purchased pre-primed before being stretched onto their current auxiliary supports. Examination of the paint cross-section with

microscopy also showed a smooth topography of the ground layer at the ground and paint interface, as shown in Figures 38a and 38b.



Figure 38a. 100x magnification of cross-section from a canvas with Holbein stamp. Cheong Soo Pieng, *Nature's Inspiration*, c. 1963 (92 x 122cm, oil on canvas). Collection: KSC.



Figure 38b. 100x magnification of cross-section from a canvas with Holbein stamp. Cheong Soo Pieng, *Untitled (Red)* (1962).



Figure 38c. 100x magnification of cross-section from an artist-prepared canvas. Cheong Soo Pieng, *Worshipper* (1978).

The canvasses with an unprimed tacking edge or verso appeared only during the 1970s, which coincides with Cheong Soo Pieng's change to cotton canvasses. Overall, the data distribution corresponds with the analysis of 1960s to 1970s paint cross-sections, as will be discussed in detail in below. In analysing the findings from fibre analysis with the data points from the painting's canvas, it is suggested that pre-primed canvasses were largely present in the 1960s and had bast fibres. Canvasses composed of cotton fibres were a dominant feature in the 1970s and were probably prepared by the artist, given the uneven

ground topography (see Figure 38c). Importantly, these paintings featured unprimed tacking margin edges, which had exposed fabric, suggesting that the ground was prepared after the canvas was stretched and the ground was only applied onto the face of the painting. Taken together, these factors suggest that cotton canvasses were used when Cheong Soo Pieng prepared his ground layer.

Thus far the data show the availability of other commercially pre-primed canvasses in the 1960s and a confirmation of their use by Cheong Soo Pieng. While it is not possible to determine the reasons why Cheong Soo Pieng chose to prepare his canvasses in the 1970s, some considerations and possibilities include lower costs, unavailability of pre-primed canvas, or material incompatibility with Singapore's tropical weather. Oral interviews with Leng Guat on Cheong Soo Pieng's practice have suggested that Cheong Soo Pieng stopped using "English canvasses supplied by Straits Commercial" as it was "not suitable for tropical climate" (Gomez Lobon 2010c). While the pre-primed canvasses featured in the study were not English manufactured, this sheds light on the change from bast and cotton canvasses in the 1970s.

In summary, what has emerged in Chapter 5 is an outline of the canvasses available to Cheong Soo Pieng in the 1960s and 1970s. This preliminary understanding has drawn on visual technical examinations and results from fibre analysis and cross-sections. With 85% of the painting supports left untreated, the next section will move on to examine the auxiliary support and any patterns that may emerge in the artist's method of canvas preparation.

Canvas preparation (strainers/stretcher)

The review of Cheong Soo Pieng's canvasses provided a reasonably strong association between commercially pre-primed and artist-prepared supports, which prompts a similar area of inquiry for the auxiliary supports used by the artists. From the 32 canvas paintings, this study focuses on 18 paintings dated between 1960 to 1982 that were still mounted onto their original stretchers or strainers. Access to the tacking margin also contributes to a deeper understanding of Cheong Soo Pieng's canvas preparation techniques and his preferred methods. Figure 39 shows the dominance of strainers, which make up 89% of the sample size.

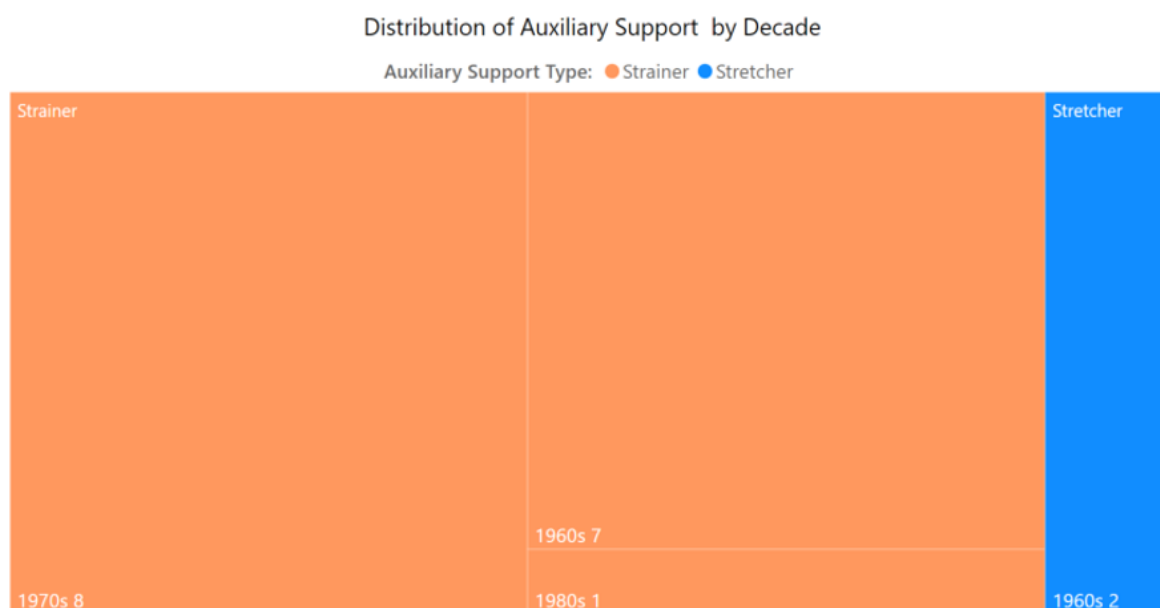


Figure 39. Distribution of 18 strainers and stretchers of Cheong Soo Pieng canvas paintings studied across the decades.

Marked in blue in Figure 39, the two stretchers with tongue-and-groove joints were produced between 1961 and 1963. One of the stretchers is marked with the label of a British frame maker, and it is known that Cheong Soo Pieng travelled to Europe in 1961. Most of the remaining original auxiliary supports were strainers with mitre joints, measuring either 7, 10 or 15mm. Specifically, seven of the canvas paintings during the Stylisation period from 1964–1969 were stretched over 7mm strainers, with a mitre joint and tacked to the side and reverse edges.



Figure 40a. Chop Hung Sun frame-makers stamp found on a Cheong Soo Pieng backing board. Image provided by KSC.



Figure 40b. Hung Wah frame-makers stamp found on a Cheong Soo Pieng backing board found on *Resting* 1972. Image from Gomez Lobon 2010a.

From archival materials and interviews with Leng Guat, it has been suggested that strainers were always purchased from the framer (Gomez Lobon 2010c). This study, like Gomez's study, has recorded stamps of the local frame-makers Chop Hung Sun and Hung Wah Frame Makers, on the verso of wooden boards (Figures 40a-b). Both companies are family businesses based in Singapore; Hung Wah is the son of Chop Hung Sun. From advertisements in the national newspaper, it is understood that Chop Hung Sun Frame Makers was in business from 1935, located at 23-4 Coleman Street, Singapore, 6, while Hung Wah began trading in 1975 and was located at No. 5 Tiong Poh Road, Singapore 3. The consistency in the strainers suggest Cheong Soo Pieng's continued relationship with these two frame makers. From interviews, it is understood that Cheong Soo Pieng was loyal to Hung Wah, who framed his paintings as well as making his strainers (Gomez Lobon 2010c, p. 15).

Another significant result is the method of attachment of the canvas to the auxiliary support. This includes how the canvas was stretched, attached and cut. Table 14 provides the variables used while Figures 41a and 41b illustrate in detail the canvas folds and how these are interpreted and recorded in the database.

Table 14. Dataset data points and variables for the study of canvas preparation techniques.

Data point	Variables
Type Original Attachment	Adhesive; staples; tacks; unattached; unknown; unmounted
Canvas Pliers	Yes; No
Canvas Shape	Cut to face; cut to reverse edge; cut to the tacking margin; not accessible; not applicable
Corner Folds	Folded over 45; folded over straight; not accessible; not applicable
Type (Auxiliary Support)	Stretcher; strainer; strainer-board; hardboard; wood; foam core; paper; not accessible; not applicable
Thickness mm (Auxiliary Support)	Free text



Figure 41a. Verso of canvas showing the excess canvas folded over straight down. Cheong Soo Pieng, *Untitled (Two Figures, Mynah)*, c.1964 (99 x 80cm, oil on canvas). Collection: KSC.



Figure 41b. Comparison of canvas fold by Georgette Chen showing the excess canvas neatly folded over with a 45-degree angle. Georgette Chen, *Mooncakes with Golden Pomelo*, 1965.

Making up the majority of the works in the study, 16 canvas paintings had excess canvas on the verso which was cut to the edge of the inner verso strainer bar. The excess fabric was then folded over straight and secured onto the reverse strainer bar. Of these, six had canvas crimp marks which were evidenced by imprinted canvas crimp marks on the reverse edge, suggesting the use of a canvas plier to stretch the paintings. These features were mainly found in paintings after 1963; two earlier 1960s paintings were cut to the tacking margin edge. Taken together, this evidence supports the notion that Cheong Soo Pieng developed a preference for this canvas preparation method from 1963. Figures 41a and 41b show the differences between Cheong Soo Pieng and Georgette Chen's excess canvas folding technique on the verso of their paintings.

This study set out to gain a better understanding of Cheong Soo Pieng's painting preparation. Although the current study is based on a small sample of the dataset of 34 canvas paintings, the findings provide the following insights informed by collective analysis of canvas and auxiliary supports through the years 1952 to 1982. The methodology of attaching

the canvas onto the auxiliary support was generally consistent through the years, despite the shift in the material of the canvasses. However, these practices appeared most prominent between 1963 and 1968, which correlates with the increased availability of pre-primed canvas. For this reason, the 1970s will be discussed in the following section. This decade has not only been referred to as a period of artist maturation but, as shown, was also a period of hand preparation of the canvas support.

Localisation of Western canvas practices

As discussed, after the 1950s, Cheong Soo Pieng's styles and mediums showed a sense of experimentation and attempts to integrate Western canvas traditions with the local pictorial imagery. Towards the later phases of Cheong Soo Pieng's practice in the 1970s, there was a shift to incorporate more local materials in his paintings and a departure from the use of commercially pre-primed canvas. This evidence suggests an assimilation of art practices and localisation of Western art influences, and that art practices in Singapore followed its own trajectory and character.

This section traces the development of Cheong Soo Pieng's practice in the 1970s. It outlines the patterns in marouflaging as well as the set of analyses of canvas fibre types by examining the distribution of bast and cotton fibres. Table 15 shows the breakdown of fibres by decade where there is a clear trend and move towards cotton in the 1970s. An inspection of the data of the 16 works after the 1970s reveals that 31.25% of these works were painted onto local materials which were later adhered onto another support. These supports include stretched and primed canvasses, foam boards and thicker pieces of paper. These rather intriguing findings share similarities with the marouflaging technique first found in the 1950s.

Table 15. Map showing trends in bast and cotton fibres by decade.

Fibre Type per Decade				
Year (groups)	Bast (linen)	Blend (Bast, Cotton)	Cotton	Total
1950-1960	1		1	2
1960-1970	10	2	1	13
1970-1980	1	1	11	13
1980-1990		1	2	3
Undated	1			1
Total	13	4	15	32

A trend was observed here of the use of two flexible supports marouflaged together. The incorporation of local materials into a Western style of canvas preparation is of particular interest, as was similarly noted in Gomez’s study of the NGS Collection. For example, two paintings, *Landscape* (1978) (Figure 42) and *Worshipper* (1978) (Figure 43) were painted onto an inexpensive jute fabric commonly known as ‘gunny sack’ and a straw mat respectively and then adhered onto a secondary support of primed canvas. ‘Gunny sack’ fabric is commonly used for sack-making, while the woven straw mat was of a type used to lie on when resting in Southeast Asia. From the NGS Collection, *Figures with a Donkey* (1979) appeared to have a similar appearance with the painting studied in this research, *Worshipper* (1978), where the latter is painted on a woven straw mat. Both works of art were “painted directly onto these materials without a ground layer, before being cut and adhered onto stretched pre-primed canvas” (Tay 2021, p.9). It appears that Cheong Soo Pieng’s use of local materials was intentional and not due to a lack of available materials. Given the loose and open-weave structure of the gunny sack, attaching it onto a stretched canvas would allow the painting to be hung on the wall.



Figure 42a. Painting on gunny sack.
Cheong Soo Pieng, *Landscape*, c. 1978 (101 x
71cm, oil on jute, marouflaged on canvas).
Collection: KSC.



Figure 42b. Verso of painting in 42a
featuring the marouflaged cotton canvas.
Cheong Soo Pieng, *Landscape* (1978).

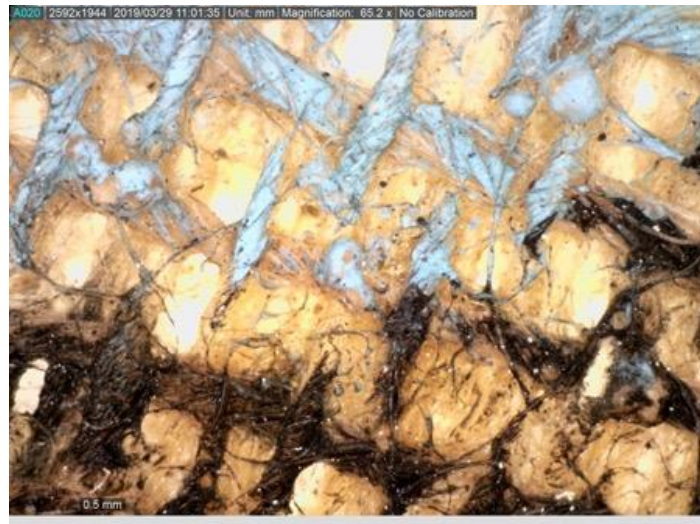


Figure 42c. 65x magnification of painting on gunny sack with details of open weave
and no paint on marouflaged cotton canvas. Cheong Soo Pieng, *Landscape* (1978).

It is interesting to note that *Landscape* (1978) was first painted over a gunny sack, made of jute fibres, which was then marouflaged onto an artist-prepared ground on cotton canvas and stretched (Figure 42). A likely explanation is that jute is a less flexible support with open-weaves, and as a result, it would have been challenging to paint onto and stretch. The absence of paint between the weaves of the jute reveals the presence of a white ground layer beneath, resulting in the discovery of different fabrics on the recto and verso upon closer examination.

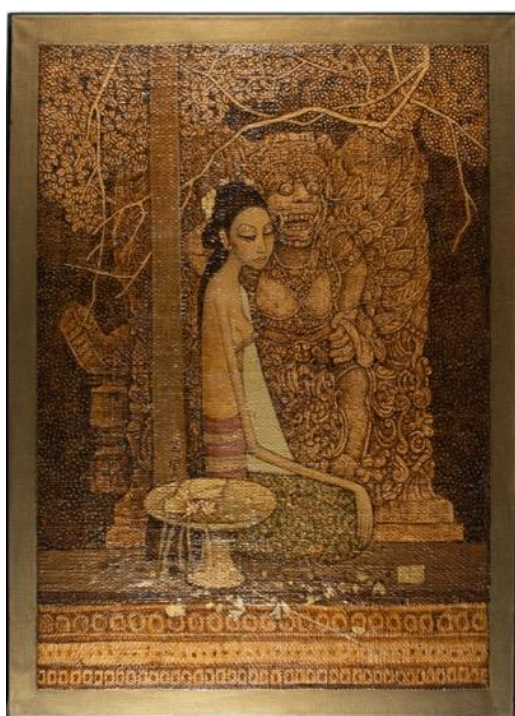


Figure 43a. Painting on gunny sack.
Cheong Soo Pieng, *Worshipper*, c. 1978 (127 x 91cm, oil on straw mat, marouflaged on canvas). Collection: KSC.



Figure 43b. Verso of painting in 43a featuring the marouflaged cotton canvas.
Cheong Soo Pieng, *Worshipper* (1978).

Worshipper (1978), was identified as using another local material that was then marouflaged onto a stretched cotton canvas. The woven straw mat was painted on separately, before being adhered to the stretched canvas. Unlike the canvas support, the straw mat was not prepared with a ground layer. This indicates that the canvas was first stretched, primed, and prepared before the straw mat was adhered to it. While the earlier use of marouflage was done to provide solid support, marouflaging local materials onto a stretched canvas could be

argued to be an integration of the local into the Western canvas painting practice. This development of materials and techniques by the artist in the late phase of his Artistic Maturation period suggests an intersection of the various past elements.

Another example of the incorporation of local materials into canvas paintings includes the use of mixed-media elements. The use of gold colour was commonly found in paintings during the 1970s. Analysis of the gold paint in *Worshipper* (1978) and *Gold Green* (1977) using ESEM-EDS, showed long rectangular fibrous structures, indicating the use of modern paints that contained both titanium and iron elements. Surprisingly, *Green Landscape* (1975) and *Untitled (Green Landscape #2)* (1972) featured the presence of thin layers of gold leaf, approximately 200nm thick (see Figure 44). It is widely known that one of the most common uses of gold leaf in Southeast Asia is for the gilding of Buddhist statues.

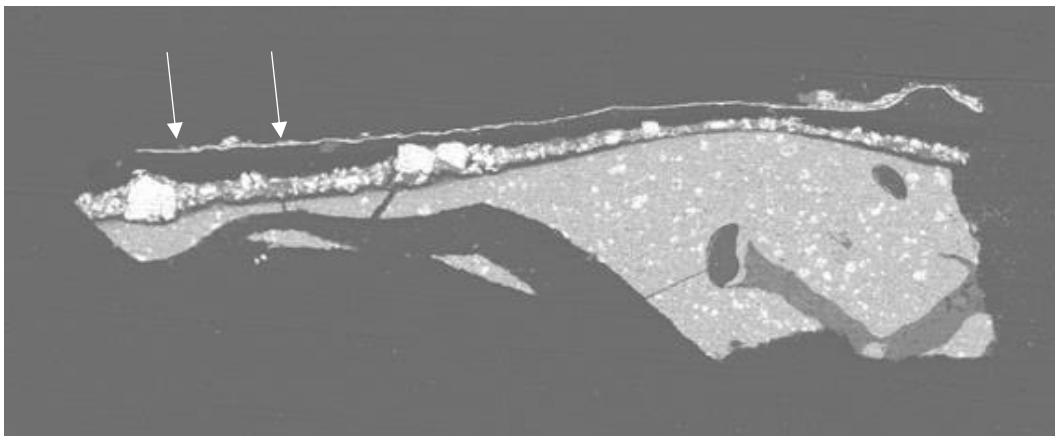


Figure 44a. ESEM-EDS backscatter imaging of thin gold layer on the upper top surface of *Green Landscape* (1975) as represented by a white layer.

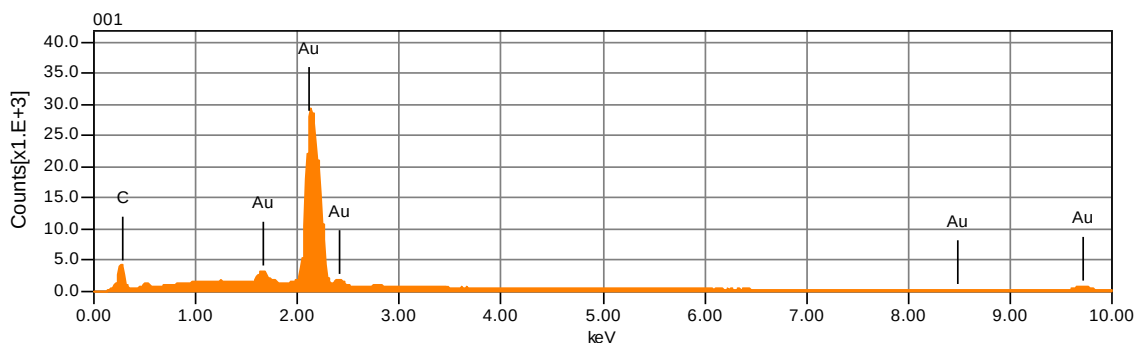


Figure 44b. Spectra from ESEM-EDS from Fibre 44a showing the presence of gold (Au).

Many scholars propose that artists use local materials for reasons of limited material availability or because they are unable to access artist colourmen materials. However, by looking closely at the findings of this study, it can be seen that the incorporation of local materials in the later periods of Cheong Soo Pieng's practice do not share a strong correlation with the unavailability of these materials. By 1970, with the presence of Straits Commercial and other artist shops in Singapore, artist materials were widely available, and yet Cheong Soo Pieng preferred to explore the use of local materials as a move away from commercially available canvasses.

The evidence presented here suggests that the data analysis methodology is key to the identification of emerging patterns through the evidence collected from data points and variables sourced from the documentation record on Airtable. As the dimensionality of the dataset improves with inputs from invasive analysis to build onto data points drawn from curatorial categorisations, visual examination, technical photography, the quality of the record improves (see Table 1 for metrics on the quality of the record on page 39). While the use of advanced material analysis has been useful in identifying specific materials, its full potential has yet to be tapped onto. Chapter 6 aims to build on the data analysis methodology and explore how advanced material analysis can be studied deeply and broadly. This approach will prove useful in expanding our understanding of the ground layer in Chapter 6. Before then, the next section analyses and transforms the technical photography data into data points and variables for understanding Cheong Soo Pieng's techniques in the construction of the painted image. It will show how this structured data approach can be used to identify if underdrawings are a common practice, if there are any compositional changes and if so, if there are commonalities between them.

Blank canvas to image

Understanding the complexity of the experimental nature of Cheong Soo Pieng's practice is fundamental in understanding how the artist constructed the painted image. While

there are many ways to examine the techniques and materials used in the execution of an artwork, this section considers the numerous sources that have commented on Cheong Soo Pieng's experimental relationship with paint and its application techniques. The discussion will be divided into three distinct sections, each section informed by different data collecting methodologies. The first section is concerned with the findings from technical photography gathered through transmitted infra-red. It uncovers underdrawings that detail the changes in the artwork's composition as well as the significance of the artist's signature. The second section presents the characteristics of the paint layer through the visual observation of representative cross-sections. The third section provides a discussion of pigment identification using the exploratory data methodology previously employed for the ground layers.

Paint characterisation is a key interest in many technical examinations concerning the artist's materials. Establishing an in-depth inquiry is beyond the scope of this study, as its aims are broader. To date, several studies on artist materials have sought to assess if the paint used in these paintings is artist colourmen or industrial paint through material analysis (O'Donnell, Tse & Ahmed 2015; Dredge 2020). This approach appears to be rooted in understanding the quality of the paint. However, the experimental nature of media which has been briefly discussed through the localisation of materials incorporated into paintings highlights two main challenges which will make the accurate characterisation of artist or industrial paints challenging. As there is no existing material reference for oil paints used by Singaporean artists at the time of writing, this makes referencing challenging, as many industrial paints were composed of the same materials as traditional artist's paints (Arslanoglu et al. 2013, p. 140). Most widely used decorative paints were based on oil, natural resins and gums and thus could be chemically similar to artists' oil paints, although the latter are generally formulated with a smaller ranges of materials, higher pigment content and less additives (Standeven 2011). The fact that manufacturers failed to document alterations to their formulas further complicates the analytical characterisation of these paints and makes results difficult to interpret meaningfully (Standeven 2007). Given the time limits due to the pandemic and focus of the research to interrogate the data obtained from visual examination, technical photography and material analysis, organic analyses on the paint binders were also not included in full in this study.

Discussions so far have shown a preliminary trend in Cheong Soo Pieng's practice, which has been substantiated by inquiries into the materials and techniques of substrate and ground. To further investigate how the paintings are constructed, findings from the various examination techniques will be combined to obtain in-depth information on any preferential or characteristic techniques which Cheong Soo Pieng employed. It is hoped that data-mining the various points of construction of the painted image will help to build an understanding of the artist's materials and techniques and identify if there are any trends or preferences.

Underdrawings

Understanding what happens after the painting is stretched and the artist is presented with a blank canvas is an integral part of constructing the painted image. Cheong Soo Pieng's paintings were worked off sketches that he compiled from during his trips, and it is in the interest of this study to consider the build-up of the painted image from these sketches. Since the advent of x-radiography, conservation's capacity to conduct technical examinations of works of art has expanded. Some of the most well-known applications for works of art are the examination of underdrawings and the detection of changes in composition. Infrared photography has been a common and valuable examination tool for this in conservation since the 1930s (Warda 2017 p. 131).

Underdrawings can offer insights into what the painter's hand produces and what it can reveal about the changes of mind that may occur during the development of works. The underdrawings were identified from comparative technical imaging in reflected infrared photographs. The reading of an infrared image can be a highly complex undertaking, and interpretations must consider the possibility and potential for ambiguities; therefore, this study is considered exploratory and interpretative.

All paintings in the study were documented using reflected infrared, and works of art with non-opaque supports were additionally documented with transmitted reflected infrared. This research used a modified DSLR with near-infrared (NIR) sensitivity and X-Nite 780 infrared lens, which is an advanced alternative for imaging in the infrared spectrum. Reflected infrared photography revealed most of the information in this section. In particular, the use of transmitted reflected infrared photography helped further insights in most of this period's techniques, given the high lead content in some of the paintings.

From the 57 artworks, a total of 15 underdrawings were documented by reflected infrared digital photography and transmitted infrared digital photography, with ten of these having documented changes. Table 16 lists the details of these artworks. Compositional changes in the signature, changes in underdrawings and the paint distribution observed in transmitted infrared enabled an understanding of Cheong Soo Pieng's method of painting construction. These changes in signature or underdrawings were not limited to any chronological or stylistic timeframe and were observed through various works of art in the study. Interestingly, a significant number of works of art produced after 1963 featured changes of signature from the English signature to the Chinese monogram, emphasising the importance of the artwork's signature.

Table 16: List of artworks that have changes observed- how was this recorded in the Airtable or documentation record- can this be explained above.

Painting ID	Title	Year	Media	Details of underdrawings/changes	Possible media	Type
PTG008_CSP008	<i>Sarawak Sisters</i>	1953	Unknown on hardboard		paint	Sketch-like
PTG021_CSP021	<i>Construction</i>	1956	Oil on hardboard	Figures missing	paint	Removal of detail
PTG028_CSP027	<i>Westminster Abbey, London</i>	1963	Oil on canvas		paint	Sketch-like
PTG012_CSP012	<i>Bali Women</i>	1964	Oil on canvas,	Change of stylisation of figures	paint	Reduction of detail
PTG003_CSP003	<i>Untitled (Two Figures, Mynah)</i>	1964	Oil on canvas	Hand and clothes of figures	paint	Sketch-like
PTG011_CSP011	<i>Three Women</i>	1966?	Oil on canvas	Observed in figures	paint	Sketch-like
PTG004_CSP004	<i>Malay Boys</i>	1966	Oil on canvas	Next to the right figure, boy's knee over rock	paint	Sketch-like
PTG002_CSP002	<i>Untitled (Three Figures, Musical Instruments)</i>	1968	Oil on canvas	Two figures' eyebrows	paint	Sketch-like
PTG016_CSP016	<i>Busy Planters</i>	1968	Oil on canvas	Figures missing, change of signature	paint	Removal of detail
PTG030_CSP029	<i>Calm Motion</i>	1969	Mixed media on canvas	The horizontal line at left area	paint	Removal of detail
PTG039_CSP037	<i>Untitled (Orange Landscape)</i>	1970	Oil on paper		paint	Sketch-like
PTG033_CSP032	<i>Mountain Landscape</i>	1974	Oil on paper		paint	Sketch-like

PTG001_CSP001	<i>Long House People</i>	1975	Oil on canvas	Character's breast and change of composition for the figure on the far right	paint	Sketch-like
PTG034_CSP033	<i>Women washing</i>	1977	Oil on canvas	Change of composition women, poles	paint	Removal of detail
PTG050_CSP048	<i>Resting (Taiwan)</i>	1982	Unknown on canvas	arms and eyes	paint	Sketch-like

Whilst the uses of reflected infrared photography are many and can include pigment identification, due to practical constraints, findings on compositional changes and changes in signature were shortlisted and documented into the main dataset, as displayed in Table 17.

Table 17. Data points and variables for the analysis of the underdrawings dataset.

Data point	Variables
Underdrawings	Yes; No
Changes in signature	Yes; No
Changes in sketch	Yes; No

Through data analysis of the findings documented in the Airtable, patterns found within Cheong Soo Pieng's oeuvre suggest a consistent and explorative nature in painting technique throughout his practice. Overall, the results reported here fall into three main interpretations:

- Preliminary sketch-like corrections
- Changes in details in the final painted image
- Changes in signature placement.

Key findings for each interpretation will be presented briefly alongside any historical knowledge of Cheong Soo Pieng's practice. The limitations of categorizing the findings means that in-depth findings need to be interpreted cautiously. One disadvantage is that the media used for the underdrawings cannot be completely ascertained at this stage. However, the texture and thickness of the underdrawing might offer insight for further investigation. It is suggested that the underdrawings' media appears to be the same as the paint medium used to outline the figures or subjects; these 'graphic outlines', which are a common technique in Chinese ink paintings, were a prominent feature of the underdrawings.

Preliminary sketch-like corrections

Preliminary sketch-like corrections are the changes from the initial sketch work of the composition which do not have a major impact on or do not significantly differ from the final painted image. The presence and recording of the preliminary underdrawings are informed by

evidential observations and considers the medium that may have been used to construct the final image. In an oral interview, Leng Guat maintains that Cheong Soo Pieng used brown paint as an outline medium before the painting process, as it dried more quickly than black. She said he never used black for the outline for this reason, and nor did he use charcoal for underdrawings, as it was ‘too dirty’ (Gomez Lobon 2010c). Observed in the infrared image alongside a closer inspection of the surface using microscopy, a dark brown medium, featured in thick strokes, appears to be layered over paint in *Sarawak Sisters* (1953). The dark brown medium appears to have been used to sketch the composition, which was then layered over by darker outlines before paint was applied over the outlines. In some instances, the outline was re-painted for emphasis. These findings appear to support the oral record of the artist’s use of brown paint for underdrawings and a possible explanation of the thickness could be the use of paint. Figures 45a–b highlight some of these sketch-like correction details, particularly in the nose and mouth areas of the figures. These were similarly observed in *Untitled (Three Figures, Musical Instruments)* (1968), where the current position of the eyebrows is lower than in the initial sketch (see figure 46). In total, 11 paintings feature these sketch-like corrections throughout the works.

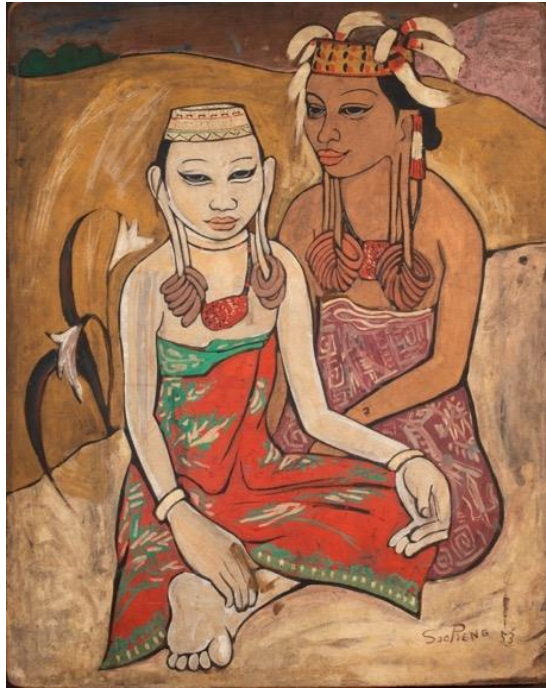


Figure 45a. Cheong Soo Pieng, *Sarawak Sisters*, c. 1953 (76 x 60cm, gouache? on hardboard). Collection: KSC.



Figure 45b. Close up detail of right figure's face from 45a. Cheong Soo Pieng, *Sarawak Sisters* (1953).

Figure 45c. Infrared image @1000nm of close up detail of 45b, featuring black outlines particularly in nose and lip and forehead. Cheong Soo Pieng, *Sarawak Sisters* (1953).



Figure 46. Infrared image @ 1000nm detailing preliminary outlines in the eyebrows. Cheong Soo Pieng, *Untitled (Three Figures, Musical Instruments)*, c. 1968 (71 x 96cm, oil on canvas). Collection: KSC.

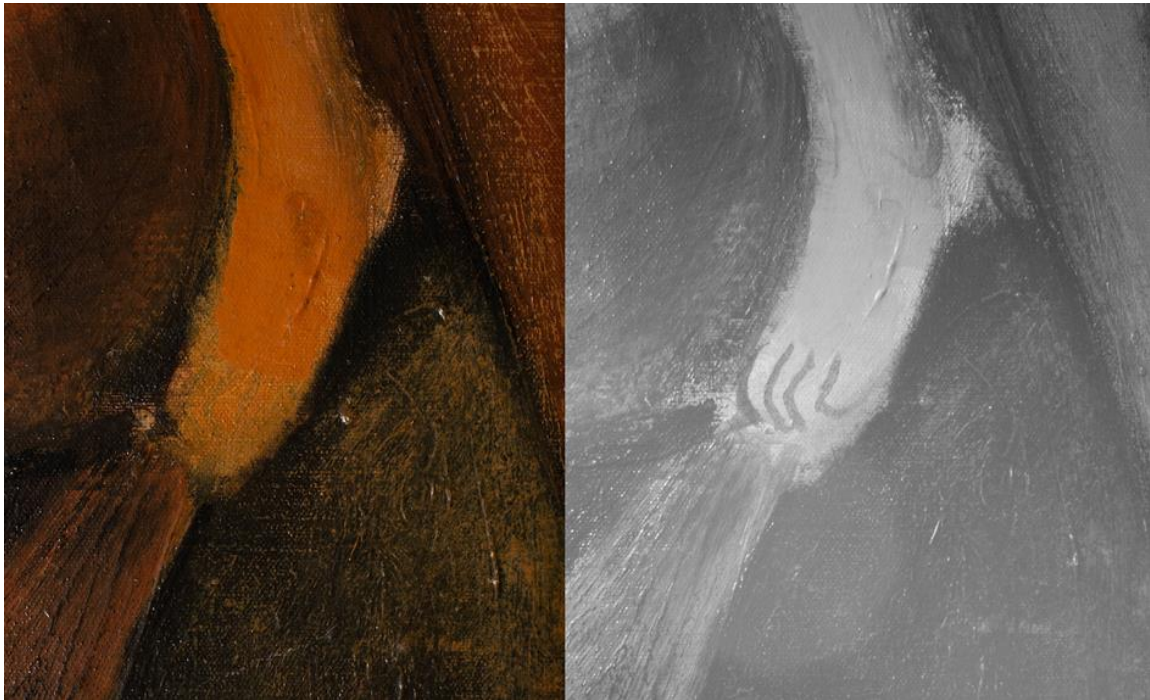


Figure 47a. Details in figure's feet in visible illumination. Cheong Soo Pieng, *Bali Women*, c. 1952–1964 (192 x 130, oil on canvas marouflaged on hardboard). Collection: KSC.

Figure 47b. Reduction of details in figure's feet as shown in fig. 47a visible in infrared image @ 1000nm. Cheong Soo Pieng, *Bali Women* (1952–1964).

Worth noting is the reduction of detail in the final image as shown in Figure 47a-b, particularly characteristic of the Stylisation period. Documented in *Bali Women* (1952–64), where the painting was first conceived in 1952 but reworked in 1964 (Stylisation period), figures were 'stylised' to have elongated limbs and simplified forms reminiscent of Wayang Kulit puppets hands (Seng in Kolesnikov-Jessop 2010). It is likely that the stylisation of the figures and subjects were changed during the painting's later reworking.

Hidden figures: Changes in detail from the final composition

Documented changes from the final composition were also recorded. Interestingly, the changes that emerge are ‘missing’ figures, which were observed across several paintings such as *Construction* (1956) and *Busy Planters* (1968). These suggest that, despite working off sketches, compositional changes were still being made during the painting process (see Figure 48 for such changes in figures).



Figure 48a. Detail of one ‘hidden’ figure in visible image. Cheong Soo Pieng, *Construction*, c. 1956 (49 x 60cm, oil on hardboard). Collection: KSC.



Figure 48b. Detail of figure in 48a made visible in infrared image @ 1000nm. Cheong Soo Pieng, *Construction* (1956).



Figure 48c. Detail of two ‘hidden’ figures in visible image. Cheong Soo Pieng, *Construction* (1956).



Figure 48d. Detail of figures in 48c made visible in infrared image @ 1000nm. Cheong Soo Pieng, *Construction* (1956).

The changes in *Busy Planters* (1968) show a range of underdrawings featuring ‘missing’ figures and foreground subjects (Figure 49). These findings suggest that before the final composition, the artist painted a sketch of the preliminary composition using a paint brush with black paint before painting the foreground and figures. In transmitted reflected infrared, it is observed that the paint distribution and brush application were less in the figures and brushstrokes were painted around the sketches.



Figure 49a. Cropped image of visible illumination of figures. Cheong Soo Pieng, *Busy Planters* (1968).



Figure 49b. Cropped image of 49a in transmitted infrared, displaying preliminary sketches of two 'hidden' figures which were later removed from the final composition. Cheong Soo Pieng, *Busy Planters* (1968).

Transmitted infrared photography is a useful technique in identifying compositional changes. Particularly with the high presence of lead white and titanium white in ground layers around the 1960s, the pigments reflected a lot of incoming infrareds and did not produce much contrast between the ground and underdrawings. This was observed in figures in paintings such as *Busy Planters* (1968) as well as abstract form details in *Calm Motion* (1969) which gave an insight into how a sketch was first produced on the blank canvas before the execution of the final painting (see Figures 49 and 50).

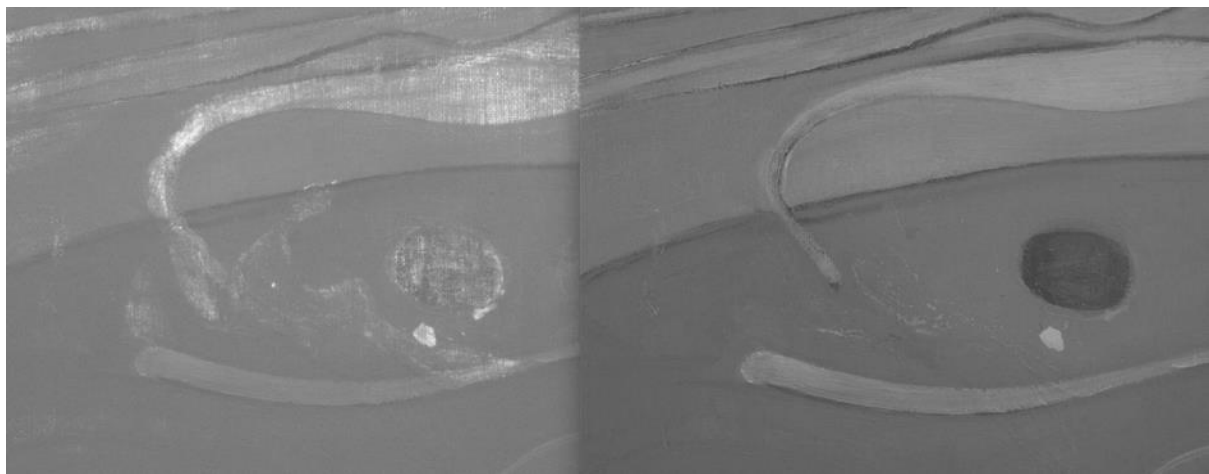


Figure 50. Detail of compositional changes observed in transmitted infrared (left) which highlights paint density compared to reflected infrared image (right). Cheong Soo Pieng, *Calm Motion*, c. 1969 (81 x 100cm, mixed media on canvas). Collection: KSC.

These findings and various categories of underdrawings offer an insight into the execution of a painted image. This shows the importance of the large mass of sketches that Cheong Soo Pieng worked his paintings off, as no drastic compositional change in the final image was recorded. Despite the experimental nature of the works of art, it appears that Cheong Soo Pieng adopted a possibly systematic method of painting execution, particularly towards the later years, alternating between outlining the elements under and over the paint layer. The following section will further elaborate on a possible pattern that is one of the most surprising findings from the infrared technical examination.

Signature changes

Throughout the 1960s, Cheong Soo Pieng's art evolved dramatically. Art historians see the 1964–1970 period as his fertile period of experimentation, as he sought to expand his visual vocabulary. At this point, he had departed from the earlier paradigm saturated with Nanyang compositional frameworks and hardboards, while developing an increasingly stylised artistic language (Ho & Ma 2010, p. 94). Findings from eight paintings surveyed from this period have led to an investigation into the signature of choice on the verso of the paintings shown in Figure 51, which is often regarded as a mark of authenticity and completion of a painting. These findings present a narrative of a possible negotiation with cultural identity and the artist's exploration of the localisation of Western art.

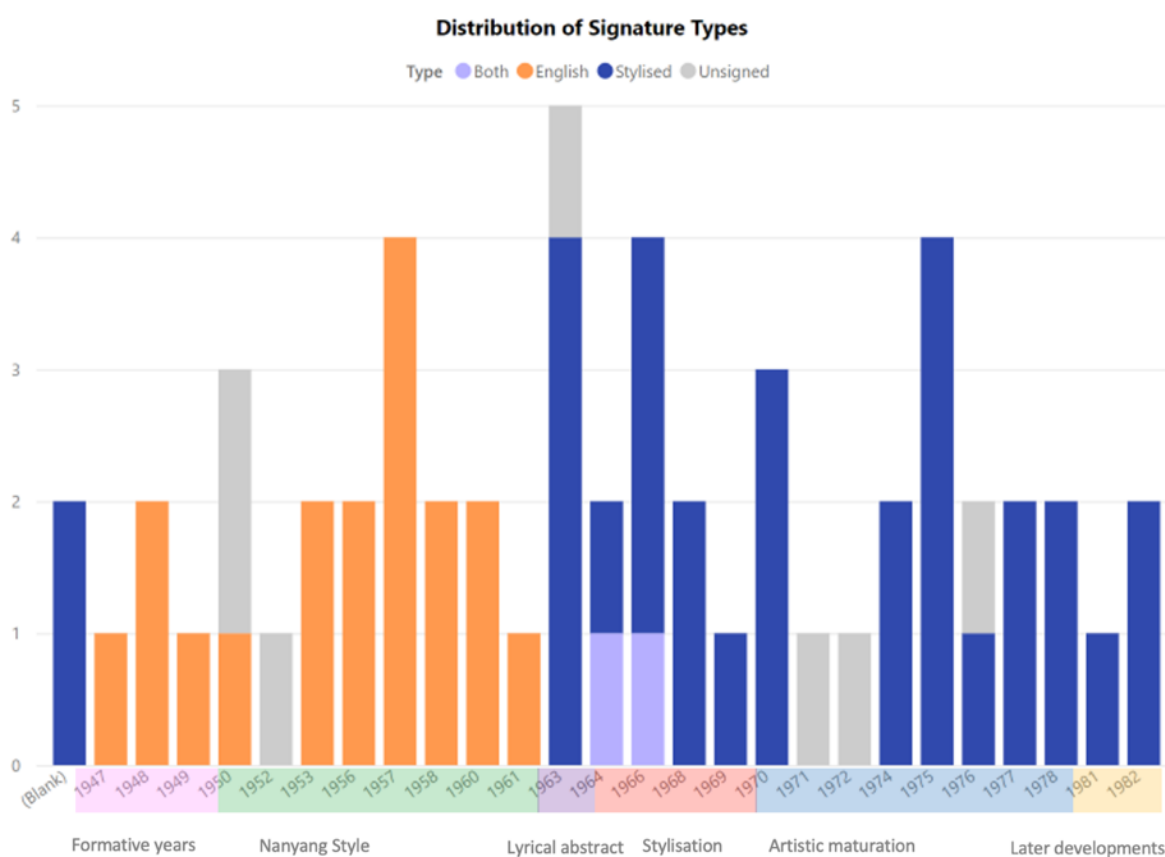


Figure 51. Distribution of Cheong Soo Pieng signature types through the various curatorial categorisation and years.

With 52 of the 57 paintings signed, Figure 51 shows the distribution of signature types through the periods. Some 19 of the 22 works of art studied in the Nanyang Style,

before 1961, were signed in English, with ‘Cheong Soo Pieng’. The three remaining works were unsigned. After his return from Europe, 29 of the 33 paintings from 1962 were signed and dated, and all of these used the Chinese signature. *Bali Women*, a painting which Cheong Soo Pieng had re-worked on in 1964 displays the Chinese signature (see Figure 53). He revisited subjects from previous Southeast Asian trips as well as embarking on abstract works during this period, and the use of the Chinese signature is consistent. While the change of signature has not been widely studied in curatorial literature, findings from reflected infrared photography have shown ‘hidden’ signatures underneath the paint layer in three of the eight paintings during the Stylisation period. In addition, the findings are presented here in the hope of opening up discussions to discuss the significance of the choice of signature and whether it could suggest Cheong Soo Pieng’s negotiation with his cultural identity.

The eight paintings studied during this period have been signed with the stylised Chinese monogram. *Riverside* (1960) and *Landscape* (1961) were the only Western canvas paintings that were signed in English before the stylised Chinese monogram was adopted, which appeared on most of the canvas paintings in the study. It must be noted that this finding is related to canvas paintings, as in the case of paintings on paper, the presence of the stylised Chinese signature was accompanied with a red seal stamp from as early as 1958. The artist thus primarily used two signatures: one in English ‘Cheong Soo Pieng’, and the other in Chinese characters which depict a playful interpretation of the Chinese character 三 (san, three) from three horizontal lines to four (sì) instead of 四 (four, sì).

Cheong Soo Pieng was photographed with *Untitled (Blue Abstract)* in 1962 in Europe which suggests that Cheong Soo Pieng started the use of his Chinese signature on easel paintings while he was in Europe. Some paintings from the Lyrical Abstract series (1962–1963) were painted while Cheong Soo Pieng was overseas. It is possible that the trip created an awareness of his cultural negotiation.

This proposal that there was a shift to a Chinese signature after the European trip was driven by a technical discovery in one of the largest canvas paintings first mentioned in the Nanyang Style, *Bali Women*, an oil painting which is dated 1952–1964 by the artist (Figure 52). This was one of the paintings that had been dated by the artist over a date range, suggesting that Cheong Soo Pieng reworked the painting 12 years after his initial conception.

Measuring 190.7 x 128.7cm, it is one of Cheong Soo Pieng's largest paintings on canvas, and the cotton canvas is marouflaged onto a Masonite Presdwood board featuring two 'MASONITE PRESWOOD' stamps on the verso of the board. The hardboard support is attached to a strainer, which appears to be a later modification to the auxiliary support. The present painting has been repainted over another painting with several alterations of the image size, observed from an exposed paint layer observed along the edges.



Figure 52a. Cheong Soo Pieng, *Bali Women* (1952-1964).

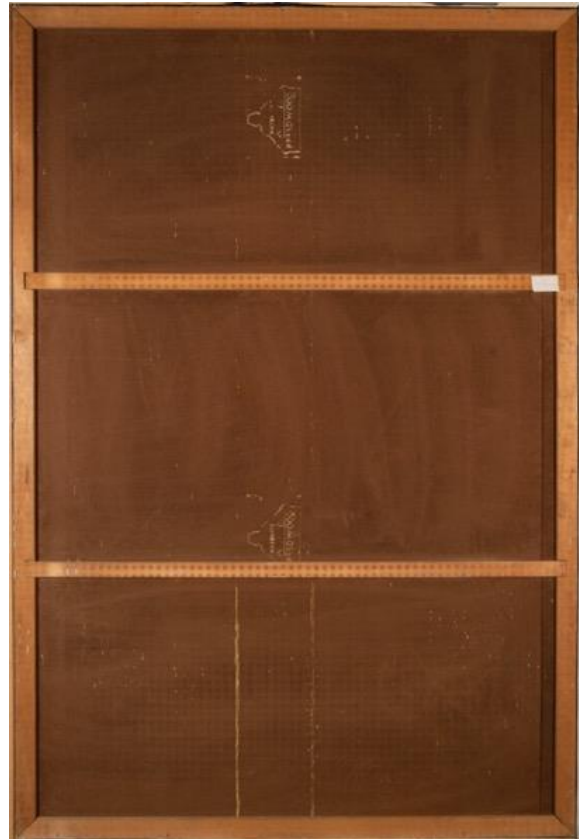


Figure 52b. Reverse of 52a showing Masonite board supporting the canvas painting. Cheong Soo Pieng, *Bali Women* (1952-1964).

The current signature in the bottom left corner of the painting is Cheong Soo Pieng's signature in Chinese characters and dated 1952-64, in black. However, in IRR, another signature is hidden underneath the paint; 'Cheong Soo Pieng 53' is observed in the lower bottom right corner underneath the existing paint layer (Figure 53). Several reworkings were

noted, including a reduction of detail, particularly in the figure's limbs, where the fingers were stylised. These changes support the development in the stylisation of Cheong Soo Pieng's distinctive figures, which have extended limbs.



Figure 53a. Details of signature.
Cheong Soo Pieng, *Bali Women* (1952-1964).

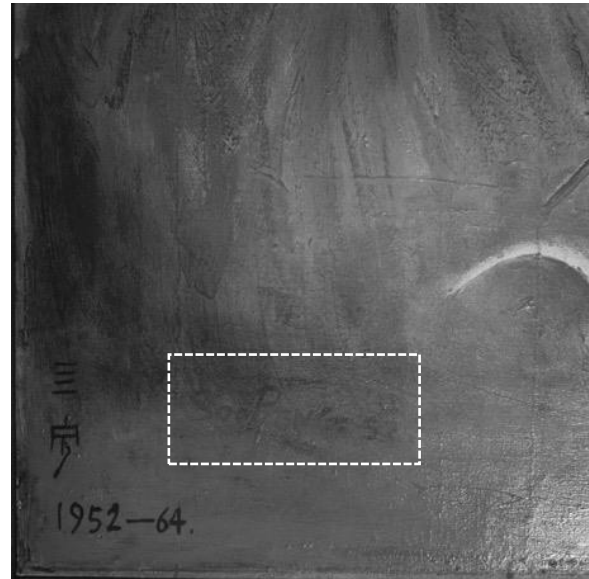


Figure 53b. Details of signature
observed in an infrared image @ 1000nm
featuring 'Cheong Soo Pieng 53' highlighted
in white square. Cheong Soo Pieng, *Bali*
***Women* (1952-1964).**

The importance of the location of the signature has been discussed by Leng Guat, who said that the signature's location and choice of colour were an integral part of the artwork (Gomez Lobon 2010c). This was evidenced by two paintings in 1968, *Untitled (Three Figures, Musical Instruments)* and *Busy Planters*, which show changes in the placement of the signature supports (Figure 54). The Chinese monogram signature was used in these paintings. Observed in reflected infrared photography, the signature was repainted onto a nearby area. This evidence supports Leng Guat's understanding that the placement is a critical part of the painting's final composition for the artist.



Figure 54a. Chinese signature in visible image. Cheong Soo Pieng, *Untitled (Three Figures, Musical Instruments)* (1968).

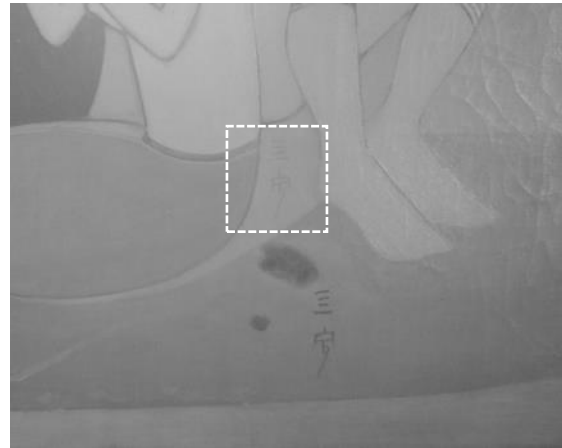


Figure 54b. Detail of change of signature position of 54a as shown in infrared photography @ 1000nm. Cheong Soo Pieng, *Untitled (Three Figures, Musical Instruments)* (1968).



Figure 54c. Chinese signature in visible image. Cheong Soo Pieng, *Busy Planters* (1968).



Figure 54d. Detail of change of signature position of 54c as shown in infrared photography. Cheong Soo Pieng, *Busy Planters* (1968).

This study set out to understand the construction of the painted image from sketches, and through this process, it has identified the techniques employed, ranging from preliminary sketches to changes in the final composition. One of the more significant findings to emerge from is the changes in the signature and its placement, which plays a significant role in understanding Cheong Soo Pieng's practice and the possible narrative around cultural

identity. From the transmitted reflected infrared images, the paint distribution of canvas paintings also presents interesting findings, which will be discussed in the following section.

Paint characteristics

Furthering our knowledge of how the composition is first sketched onto the canvas for the painted image, paint application and techniques are key focus areas to build our current understanding of the artist's practice. Findings from transmitted infrared photography are central to understanding the paint distribution of canvas paintings. Paint layers of the 57 Cheong Soo Pieng paintings studied for this research were documented to understand the paint topography and paint density. Data points and variables aimed to record any distinctive visual, physical, and textural characteristics observed through a series of visual examination methods and technical photography. As underlying layers may affect the appearance of subsequent applications of paint, transmitted infrared photographs enabled an understanding of the paint density beneath visible paint films.

A series of in-depth material analyses was undertaken with x-ray fluorescence (XRF) and scanning electron microscopy-energy dispersive spectroscopy (ESEM-EDS). Paint samples representative of the stratigraphy were mounted in polyester resin. The paint layers were measured under the cross-section and the number of visible layers was documented into the dataset. These were further analysed together with the auxiliary support and ground layers to identify any trends. In studying paint application, cross-sections prepared from the samples have revealed complexities of the paint layer and trends through the years. However, non-invasive XRF analysis would not have provided insight into the elemental composition of the individual paint layers, and ESEM-EDS analysis of the embedded cross-section samples was used to explore the range of pigments where possible. The study of the elemental compositions is purely exploratory at this stage, as it was modelled after the ground study. The dataset containing the elements found in the ground layer of each sample identified during the ESEM-EDS analysis are then analysed using a Spearman correlation matrix and another binary dataset to propose preliminary pigments present in various colours. Due to the limitations on research time, organic analysis, which is necessary to establish the paint

composition, could only be carried out on selected artworks and not in full in the study. Table 18 below presents a list of data points that inform this study.

Table 18. Data points and variables for the analysis of paint application dataset.

Data point	Variables
Paint density	Thick; thin
Application technique	Wet-on-wet; wet-on-dry; not applicable
Findings (stratigraphy)	Even ground; uneven ground; thick paint layer; thin paint layer; support prepared without ground; more than three paint layers

Together, these results provide important insights about the paint application techniques, which can be divided into three broad categories:

- solid supports displaying wet-on-wet paint application with impasto
- canvas paintings displaying build-up of thin layers of paint and density in the background, and
- minimal thin paint layers over a thicker preparatory layer during the Artistic Maturation period.

Solid supports: impasto layers thick, multiple layers of paint.

Having arrived in Singapore in 1946, with a new atmosphere and plentiful art supplies available through Chinese bookshops selling art materials, Cheong Soo Pieng was enthralled by using oil paints and plunged into painting in oils. In China, he had had little opportunity to paint in oils, mainly owing to the scarcity of those materials at that time. Perhaps this partly explains the generosity of paint application observed, particularly during the earlier phases of his practice.

In the Formative Years (1946-1949) and Nanyang Style (1950-1961) periods, smaller-sized paintings on solid supports such as wood or plywood were typical of Cheong Soo Pieng's practice. The paint layers during this period feature high impasto layers which appear to be built of various colours and on multiple levels. Distinguished by the layers of paint and

the overall depth in cross-section, the first two paintings on wood by Cheong Soo Pieng, *Corner of Art Studio* (1947) and *Portrait* (1948) display similar characteristics and have approximately eight layers, amassing thick layers of paint.



Figure 55a. Paint application layers observed under raking light. Cheong Soo Pieng, *Sunflowers*, c. 1957 (61 x 42, oil on paper marouflaged on board). Collection: KSC.



Figure 55b. Close up of paint application layers observed under raking light. Cheong Soo Pieng, *Sunflowers* (1957).

Given the opacity of the solid support, raking light photography was instrumental in the understanding of the surface topography. The 1950s saw thicker paint layers with an increased paint application of wet on wet (see Figure 55). Paint layers are thick, with overall areas of impasto, as observed in cross-sections of *Construction* (1956), which was painted on

the smooth side of a hardboard with ten paint layers underneath the surface which were applied thinly between white and yellow layers (Figure 56).



Figure 56a. Paint application layers observed under raking light. Cheong Soo Pieng, *Construction* (1956).



Figure 56b. Close up of paint application layers observed under raking light. Cheong Soo Pieng, *Construction* (1956).



Figure 56c. 100x magnification detail of paint application technique featuring thin layers of paint observed in cross-section. Cheong Soo Pieng, *Construction* (1956).

Canvasses: thin and few layers of paint.

The shift towards canvas supports, particularly after 1963, mirrored a change in painting techniques. From the thick impasto layers, the transition to canvas paintings shows thinner and more defined paint layers in the 1960s. These were similarly observed by Gomez Lobon, who remarked on Cheong Soo Pieng's thinner and more diluted application of paint

(Gomez Lobon 2010a). Findings from various analytical techniques support both these observations in Cheong Soo Pieng's painting techniques, which appear to be more dominant from 1963. As most of the paintings during this period are on translucent flexible supports, transmitted infrared photography was a much more effective imaging method to understand the build-up technique of the painter to shape the figures (Cultural Heritage Science Open Source 2022). These were further supported by cross-sections taken from the paintings which give an understanding of the paint layers.

The transition to the use of canvasses emphasised certain techniques adopted by Cheong Soo Pieng, such as preliminary sketches on the canvas before painting and reworking the composition during the painting process. Some 11 of the 45 paintings showed, with transmitted infrared photography, that the build-up of paint following the sketches had a thicker paint density in the background with less paint in the foreground and subjects (see Figure 57). Eight of these 11 paintings were dated between 1963 and 1969, and this finding had no correlation with whether the canvas was artist-prepared or commercially bought. Table 19 lists the paintings studied and details the number of layers of paint observed as well as any manufacturer stamps on the canvas. The cross-sections of the paintings support Leng Guat's comments that her father would build up the painting with four or five layers of paint and would leave it to dry until the next day before applying the next layer.



Figure 57a. Comparison images of visible light and transmitted-infrared photography showing less paint density around the figures and heavier paint in the background. Cheong Soo Pieng, *Untitled (Three Figures, Musical Instruments)* (1968).



Figure 57b. Comparison images of visible light and transmitted-infrared photography showing less paint density around the figures and heavier paint in the background. Cheong Soo Pieng, *Long House People*, c.1975 (86 x 122, oil on canvas). Collection: KSC.

Table 19. Paintings studied with count of stratigraphy of each cross-section

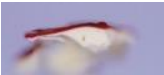
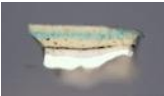
PTG ID	Title	Year	Manufacturer stamp	Count of stratigraphy	Cross-section image
PTG020_CSP020	<i>Nature's Inspiration</i>	1963		7	
PTG029_CSP028	<i>Landscape 1</i>	1963		5	
PTG003_CSP003	<i>Untitled (Two Figures, Mynah)</i>	1964	Holbein, 3	2 – incomplete	
PTG004_CSP004	<i>Malay Boys</i>	1966	Holbein, 3	5	
PTG002_CSP002	<i>Untitled (Three Figures, Musical Instruments)</i>	1968		4	
PTG016_CSP016	<i>Busy Planters</i>	1968	Holbein, 3	3 – incomplete	
PTG030_CSP029	<i>Calm Motion</i>	1969		4	
PTG042_CSP040	<i>Untitled (Green Landscape #2)</i>	1972		2	
PTG001_CSP001	<i>Long House People</i>	1975		4	
PTG050_CSP048	<i>Resting (Taiwan)</i>	1982		2	
PTG011_CSP011	<i>Three Women</i>	Undated	Holbein, 2	6	



Figure 58. Detail in raking light featuring crack patterns that occur in areas with thicker paint layers. Cheong Soo Pieng, *Long House People* (1975).

The overall topography of the surface layers of the works from the 1960s was viewed under raking light and was significantly flatter and lower in impasto than earlier works on solid supports. When examined under raking light, a tight network of cracks appears to correspond with the paint density (see Figure 58), suggesting that there is a thicker ground layer than on the paint surface, an observation which is corroborated by the cross-sections (Karpowicz 1990, p. 170). There is also another notable pattern of physical change, which was observed in four of the five paintings dated 1963. This group of paintings belongs to the Lyrical Abstract series (1962–1963), which began in 1962 during Cheong Soo Pieng's trip to Europe. Having encountered artworks in Europe, a significant development was his adoption and recurring use of thin oil techniques, which is said to have been inspired by J. M. W.

Turner. As noted by Ho and Ma (2015), Lyrical Abstract series works in 1962 have shown traces of surface cracks, amongst other physical changes (see Figures 59 and 60).



Figure 59. Transmitted infrared image showing horizontal losses of paint which suggest horizontal stresses such as rolling of the painting. Cheong Soo Pieng, *Untitled (Blue Abstract)*, c. 1962 (131 x 102cm, oil on canvas). Collection: KSC.



Figure 60. Transmitted infrared showing horizontal losses of paint which suggest horizontal stresses such as rolling of the painting. Cheong Soo Pieng, *Untitled (Red)* (1962).

Untitled (Red) (1962) was the only untreated painting brought in for study directly from the artist's studio (Figure 60). Unmounted and rolled, the paint layer had extensive peeling and separation, rendering it structurally unstable. The circular peeling of the top paint layer suggests the use of synthetic paints, while the delamination from the preparatory layer indicates paint incompatibility. Advanced organic analysis would be necessary to identify the precise paint medium.

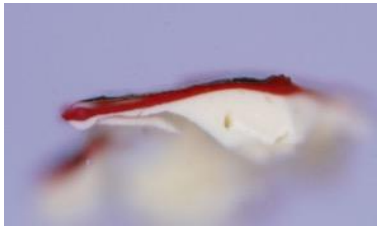
The thin application of paint layers, as well as the density of paint layers in the background, demonstrate a transition from the application technique of wet-on-wet with impasto paint layers. Whilst this technique was employed from the 1960s and was practised in other years, paintings that incorporated mixed media elements appear to employ a different paint application technique.

Mixed media: fewer paint layers over a thicker preparatory layer.

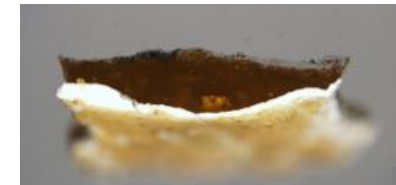
The departure from using commercially available canvas after 1969 saw an increase in the incorporation of local materials in canvas paintings as well as the presence of artist-prepared supports, which was briefly discussed in the section on localisation of Western art practices. From the 1970s, eight canvas works with mixed media elements were observed to have a change in paint application techniques. As may be seen from the cross-sections, a thin paint layer is applied over a thicker preparatory layer (see Table 20). In comparison to the previous two categories, there is significantly less paint build-up. Most of the ground layers in this group of paintings feature uneven surfaces while visual characteristics of the paint layers include a luminescent sheen for bronze or silver paints, indicating increased use of modern paint. It is possible that the lesser application of paint could be due to the increased opacity of modern paints.

However, furthering the discussion on cross-sections, the application of thinner layers of paint was observed over the thicker ground layer during this phase. In *Construction* (1976), the paint layer appears to be laid over a thicker filling layer above the ground, adding bulk to the paint. This is in contrast to the paint density and build-up from previous phases in his oeuvre, where multiple layers of paint were observed. Tse (2008) stated that an interview with Malaysian artists mentioned the possibility of artists during the period utilising a filler to add density, with less paint required. Further analysis is required to build up the dataset and attribute it to this period. Table 20 displays a list of paintings that fall within this category and a snapshot of their cross-sections.

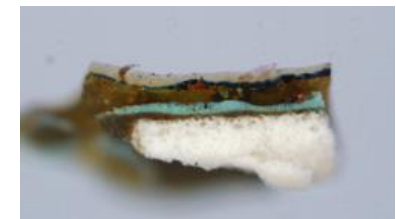
Table 20. List of eight paintings from the 1970s alongside representative cross-sections featuring a thin paint layer and an ‘uneven’ and thicker ground layer.

PTG ID	Title	Media	Year	Image	Cross-section
PTG040	<i>Untitled (Blue landscape #1)</i>	Thin fabric marouflaged on paper	1970		
PTG042	<i>Untitled (Green Landscape)</i>	Gold leaf collage on canvas	1972		

PTG019 *Untitled*
 (Collage) Paper elements
 on canvas 1974



PTG024 *Green*
 Landscape Gold leaf
 collage on
 canvas 1975



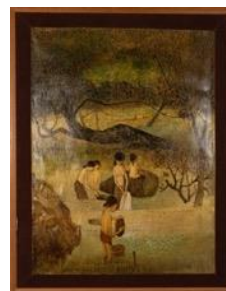
PTG036 *Sleeping Lady* Acrylic sheet,
 metal strings,
 granules on
 canvas 1975



PTG037	<i>Landscape</i>	Acrylic sheet mounted on canvas	1975



PTG034	<i>Women washing</i>	Marouflaged canvas painting on foamcore	1977



PTG018	<i>Worshipper</i>	Rattan mat mounted on canvas	1978



Whilst this research is limited without undertaking organic analysis, which would have greatly benefited paint characterisation and would have given more insight, the technical examination methodology employed has shed new light on some patterns in Cheong Soo Pieng's practice. The visual examination and documentation record of the paintings together with the use of transmitted infrared photography and cross-section microscopy have informed the findings in this section, which demonstrates the benefits of a structured documentation record where selected datasets can be extracted, verified and compared for analysis. The three broad interpretations present a shift from thick impasto layers of paint towards thinner and diluted paint layers, the latter of which appears to be correlated with the incorporation of local materials. The next chapter explores preliminary pigment trends, which resulted from the ESEM-EDS analysis undertaken on the cross-sections.

5.4 Conclusion

Evidence suggests that a transitory phase in Cheong Soo Pieng's materials occurred after the Europe trip in 1963. This is earmarked by two major events: the transition from solid supports towards flexible supports such as canvas, and the change of signature from an English script to a Chinese monogram. These were identified by the data collected from the range of technical images, fibre analysis and cross-sections.

The classification of the material and techniques within existing curatorial frameworks appear to be representative of an emerging trend as illustrated in Table 21 below.

Table 21: Key material patterns observed by period.

Year range	Period	Key patterns observed
1946–1949	Formative Years	Smaller image sizes, only period with paintings on wood panels
1950–1961	Nanyang Style	Marouflaging of flexible supports onto hardboards, wet-on-wet application of paint

1962–1963	Lyrical Abstract	Start of pre-primed canvasses, signature change, the transition phase
1964–1969	Stylisation	Further exploration of Western canvas paintings, using similar materials and techniques; underdrawings suggest painting methodology
1970–1978	Artistic Maturation	Adaptation of Nanyang style and stylisation, marouflaging prominent, use of localised materials in Western canvas painting

The present study lays the groundwork for future research into Cheong Soo Pieng's practice and is one of the first attempts to employ unsupervised learning to data-mine metadata from technical examinations across various analytical techniques. The methodology is designed to provide a basis for other technical research that has limited archival evidence. As data clustering has the potential to identify outliers, a larger dataset of artworks would present opportunities for further investigation and aid artist attribution. The following chapter will deepen this discussion and review the similarities and differences of the two methods as well as providing a comparison with the methodology used for the survey of Georgette Chen's work.

Chapter 6: Statistical Analysis of ground and canvas

6.1 Introduction

The above discussions in Chapter 5 on Cheong Soo Pieng's materials and techniques have provided an investigation into his art practice where patterns have emerged, generating fresh insights on canvas materials, support preparation technique and paint characteristics. Cheong Soo Pieng was a prolific artist who worked from the year he arrived in Singapore to his death in 1983. Across six curatorial categorisations, Cheong Soo Pieng's practice spans from Chinese ink paintings, sculpture and easel paintings, which are the focus of this study.

The aim of Chapter 6 is to explore how findings from both non-invasive examination and invasive methods can be looked at holistically and comparatively. With a verified basis for comparison, this chapter explores how various uses of machine learning models can accommodate small to larger datasets, with the long-term goal of building a material record for future studies as identified as Stage Four of how raw data is transformed into the documentation record (see Table 2, page 56). Chapter 6.2 and 6.3 further analyses the results from ESEM-EDS analysis undertaken on representative ground layers of 35 paintings using a correlation matrix to identify compounds in ground and pigment compositions. Chapter 6.4 and 6.5 build onto these findings using statistical techniques, Principal Component Analysis (PCA) and k-means, clusters the findings of 35 Cheong Soo Pieng paintings to understand the relationships and links of the paintings studied. In this chapter, the methodology by which data was collected, synthesised and assessed is discussed as well as the findings that led to the identification of these four clusters.

Given the diversity of Cheong Soo Pieng's art practice, this chapter begins with the study of the ground layer as a common point to discuss the variations in his paintings. The first layer to a painting's execution, the ground layer offers insights into an artist's preference for painting construction and also into material availability. Before a painting on either hardboard or canvas support could be executed, a ground layer is commonly applied to prepare the support. The ground layer, also known as primer, is the layer between the canvas and the first layer of paint, and is a crucial component of a painting preparation. The function

of this layer is to provide an intermediate structural layer between the support and paint layers and to smoothen out irregularities in the support, create a degree of absorbency so that the paint layer will adhere well and not flake off (Albrecht et al. 2019). In addition, the ground layer protects the primary support from degradation caused by the oxidation of the oil in oil paint (Mayer 1991). Materials used for ground layers tend to be less costly than the paint and can be prepared by the artist or are part of commercially pre-primed canvasses (Albrecht et al. 2019, p. 2; Hackney 2020, p. 2).

As ground layers can be assumed to have been applied quite homogenously across the surface of a support, samples taken anywhere will most likely be representative of the entire surface (Albrecht et al. 2019, p. 1). As part of the research methodology, the ground layers studied in this section are those that are embedded in cross-sections which have already undergone a careful selection process to ensure it can best represent the painting, as outlined in Chapter 2.4. In addition, observations of the ground layer from the verso and tacking margin can contribute to the overall understanding of the canvas preparation method. This segment is not limited to canvas paintings and takes a broader approach to include all supports such as wood, hardboard and canvas.

Previously discussed in Chapter 3.4, commercially prepared artist canvas supports were available as early as 1905 in Singapore. In Cheong Soo Pieng's practice, the use of commercially available canvasses was dominant only in the 1960s, as evidenced by the differences in canvas fibres and the visual observation of the ground topography in cross-sections and the presence of Holbein canvas stamps. This also draws our attention to the canvasses with artist prepared grounds and the increased incorporation of locally available materials in the 1970s as discussed in Chapter 5.3 on the localisation of Western art materials. Was there a preference for commercially available supports or did Cheong Soo Pieng prefer preparing his supports? Are there any trends in the canvas supports used during his oeuvre? Are the artist-prepared supports distinguishable by the materials that were used? By investigating the composition of Cheong Soo Pieng's ground layers and canvas supports in detail, it is hoped that insights can be gained to answer these questions.

One of the main obstacles in pattern-finding analysis from data gathered from the visual examination, technical photography and material analysis data recorded in the Airtable, is how the metadata from the non-invasive examination and the findings from material analyses are studied separately, then brought together in reference by the researcher. While this manual method of analysis might work in smaller datasets, as was shown in the study Georgette Chen's paintings in Chapter 4, are the correlations between the advanced material analysis and technical analysis reliable? For instance, linen fibres are more dominant in the Cheong Soo Pieng paintings from the 1960s, as are lead-based ground layers. This raises the questions of whether we are able to cluster these groups of artworks and whether there are outliers within the dataset.

A growing body of research has shown that unsupervised machine-learning models can establish clusters through statistical analytics, which may play a pivotal role in addressing these issues (Ding and He 2004; Downey 2014; Dua 2020). As introduced in Chapter 2.6, statistical methods, such as Principal Component Analysis (PCA) and k-means, can be used together as an approach to cluster and group evidential data, particularly when there are no existing standards for references, while visualising patterns. PCA is used for dimensionality reduction where the number of input variables are reduced within the dataset while retaining as much information as possible and k-means is a clustering method (Pitsillides 2020). The clustering is an important technique in pattern analysis to identify any distinct groups of data.

In conservation, PCA employed using machine learning models has been featured in recent cultural material research. For instance, PCA was used to clean and categorise elemental data from ESEM-EDS analysis of ground layers in paintings by Jan Steen (1626-1679) (Albrecht et al. 2019), the prediction of protein-protein interactions from amino acids (You et al. 2013) as well as to analyse spectral imaging data to identify faded writings in caves (Kogou et al. 2020b). PCA and k-means have been used to study pigments and image segmentation of synchrotron X-ray absorption near edge structure (XANES) analyses (Keune et al. 2016).

The study presented here explores the use of unsupervised learning and a suite of business intelligence tools to offer a fresh perspective on the analysis of findings from the technical examination. In particular, data science models which utilise unsupervised learning tasks to analyse non-structured text-based data, the relationships between ground, fibre, and periods in Cheong Soo Pieng's oeuvre and distribution of the data. This chapter is broken down into four sections. First, elemental data gathered from ESEM-EDS studies of the ground layer are analysed using a statistical correlation matrix employed through Python to identify possible common ground compositions from the ESEM-EDS results. Then, this methodology is then applied to identify elements that could potentially provide preliminary pigment identification of Cheong Soo Pieng's paintings. Following the qualitative exploratory approach, a set of possible ground compositions are identified for each painting which are then integrated with the data points sourced from the documentation record to create a new dataset to combine non-invasive examination findings to material analysis findings. The last section demonstrates how each artwork will be assigned a cluster using PCA and k-means. The dataset is further analysed through an interactive dashboard that allows the user to identify specific artworks and characteristics of each cluster. Neither model is conclusive given the semi-quantitative nature of the datasets, but the proposed approach in this study opens up future possibilities for detecting patterns when working with diverse or large datasets without reference samples. This chapter will conclude with a comparative analysis between the clusters produced and findings from the evidence-based model. The methodologies and findings in this chapter are important for analysing and amassing large amounts of data in future research projects on Singaporean artists. It applies to data collected through a diverse range of non-invasive and invasive examination methods. Using unsupervised learning models provide the structure and quantifiable parameters for the analysis of material data.

6.2 Ground

Detecting trends through a statistical exploratory approach of elemental data

The starting point of this investigation utilises an evidence-based approach from a combined dataset of elemental analysis results and observations during the technical

examination of the paintings. Some 50 of the 57 artworks studied from the Koh Seow Chuan collection had a ground layer that were sampled on site in Singapore and some material fragments were analysed in the University of Melbourne. As outlined in Chapter 2.4, non-invasive analysis using a benchtop Bruker pXRF on a raw sample removed from the painting was undertaken and its spectra were later processed. However, there are certain drawbacks to this approach. A notorious difficulty, applicable to white ground and paint layers, is the overlap between Ti K-lines and Ba L-lines. This overlap can cause problems in the identification of titanium when barium is also present (van Driel et al. 2018a) While peak areas are used to facilitate interpretation, the results from the pXRF are considered qualitative, as it can only show presence of elements and trends in the overall sample which can be especially challenging when investigating non-homogeneous multilayer materials such as paintings.

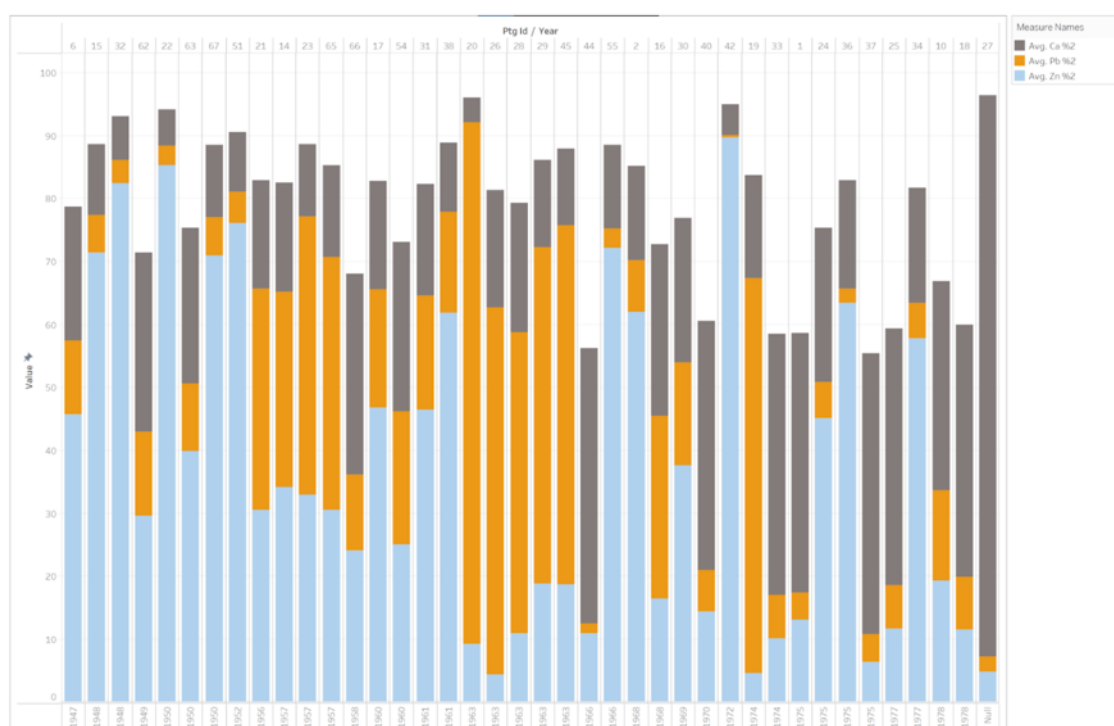


Figure 61. Stacked bar chart showing distribution of elements per sample analysed as an unprocessed sample using pXRF, where each column represents a painting's ground composition. Grey represents % of Ca, orange represented % of Pb and blue represents % of Zn.

Factoring the limitations of the pXRF in analysing Ti and Ba, an exploratory analysis of only Ca, Pb and Zb is presented in Figure 61, which shows the breakdown of each painting's ground layer composition. What stands out in the figure are three main patterns: the dominance of zinc before 1961 (blue), the concentration of lead, particularly in 1963 (orange), and a larger presence of calcium in the later years (grey). While these patterns suggest a possible correlation with patterns in artist-prepared and commercially available canvasses, this method is not valid for use in a comparative dataset of ground layers as the methodology does not guarantee that only the ground layer from the paint sample is analysed. With a small sample size and only selected elements considered in the visualisation, caution must be applied as the findings might merely reflect selected areas and are not representative. Normally, the use of pXRF is preferential in an analytical pathway, given its ability to analyse without removal of sample and the possibilities to be used in-situ. Utilising pXRF as a non-invasive technique to undertake elemental analysis of artworks can be used to aid material identification when coupled with unsupervised machine learning based on neural networks to deduce paint sequence (Kogou et al. 2020a). However, the main limitation of this research's methodology is the lack of access pXRF onsite in Singapore. As pXRF was accessible only in the University of Melbourne to analyse already removed samples, using the sample's findings to be an extrapolated to the entire painting may be challenging and as such, a higher resolution analytical technique such as the ESEM-EDS would be beneficial in increasing confidence in the analysis.

A total of 35 representative ground samples were collected from each painting and prepared as a cross-section, before undergoing analysis using ESEM-EDS. Details of the selection process are discussed in Chapter 2.4. These 35 sampled paintings are representative of the curatorial categorisations in Cheong Soo Pieng's oeuvre, with the earliest dating to 1947 and the latest to 1982. All the paintings were dated by the artist, which serves as a reference for any material findings and chronology. A microscope was then used to examine the cross-section visually to understand the sample and plan for areas of analysis as outlined in Chapter 2.4. Cross-sections were photographed and the texture of the ground layer was documented as 'smooth', 'uneven' or 'unidentified' in Airtable.

Cross-section samples were then analysed using ESEM-EDS. As cross-sections, the ground layers are able to be identified with ESEM-EDS and sample points selected, unlike the pXRF which does not differentiate between the ground and paint layers. Since ground layers are assumed to be applied quite homogeneously across the surface of the support, and the selected samples are most likely be representative of the entire surface which can be located. It is argued that comparison of the data is possible and can be verifiable. By looking in detail at the relative amounts of the elements present in the materials, trends can be observed. For the elemental composition, a normalised quantification was carried out. This was based on the weight percentages of the oxides of the elements present in each sample was listed for comparability. The 16 elements that were detected in the ground layers followed the research methodology on Jan Steen's ground layers (Albrecht et al. 2019): Na, Mg, Al, Si, P, S, Cl, K, Ca, Ti, Mn, Fe, Co, Cu, Zn and Pb. The data for each point of analysis was recorded into an Excel spreadsheet and the resulting dataset was built.

Turning the data into the identification of compounds and pigments required a combination of data analysis and the creation of a binary dataset before trends could be mapped. Data analysis on the resulting dataset was used to find correlations between variables and the clustering of samples. Furthermore, a deeper exploration of the data from the elemental analysis obtained by ESEM-EDS was performed to include findings from the verso and tacking margin of the paintings obtained during visual examination. A larger dataset can offer more information about the artist's canvas preparation method by aiding understanding of the ground application and the relationship with the support.

Several limitations to this pilot study need to be acknowledged. First, only 60% of the studied artworks are represented in this analysis as only 35 cross-sections of the 58 artworks were analysed using ESEM-EDS. In addition, given how prolific Cheong Soo Pieng's practice is, the findings of 35 samples out of hundreds of paintings, may not necessarily reflect the entire oeuvre of the artist. However, this can be optimised with further studies. In addition, the interpretation of ESEM-EDS spectra and its resulting analysis in terms of the percentage of elements present are semi-quantitative (see Appendix D for ESEM-EDS spectra and normalised results).

Statistical methodology in detail (Spearman)

Statistical analysis techniques have been used in various forensic investigations to detect trends (Gauthier 2001). A relatively simple technique that can be used for exploratory data analysis is the Spearman rank correlation coefficient to detect trends within datasets. The methodology utilised proposes the use of trend analysis to detect elemental ‘footprints’, either as compounds or individual elements in the ESEM-EDS datasets. This ‘footprint’ considers the overall pattern created by an elemental dataset detected across multiple samples (Gauthier 2001). Using a correlation matrix, the strength of the relationship between the values of two variables can be studied. In studying correlation, pairs of values are studied against each other within the dataset. The correlation coefficient (r) is a statistic that can be used as a measure of similarity between variables. As it is a summary of association, it cannot be used to conclude if there is an underlying relationship between the two elements and does not imply any causation between the variables.

There are several different methods of producing correlation coefficients. This model adopts a non-parametric formula to produce a rank correlation coefficient. It assesses the degree of similarity between two variables and can be used to assess the significance of the relationship between the two variables. As the weight-percentage values are only semi-quantitative, Spearman’s correlation model is adopted, as it assesses the statistical relationship between the variables using a monotonic function (Downey 2014, p. 101). The monotonic function gives an idea about the behavior between the variables, as it measures if it is either always increasing or always decreasing. As explained by Gauthier, the Spearman’s rank correlation considers the ranks of the data rather than specific values (2001). The value in considering the rank of the data is key in identifying the elemental compounds which make up the ground composition. For instance, if two elements (Ba and S) share a strong positive correlation, the more likely that compound (BaSO_4) is present within the dataset. This enables an evidence-based and verifiable overview of the possible elemental compositions directly related to the dataset.

Represented between the range +1 and -1, the closer the correlation coefficient is to +1, the stronger the correlation. Similarly, '0' would imply there is no correlation between the two variables and '-1' would represent an anti-correlation through a decreasing monotonic trend. In addition, qualitative variables presented as data of the ground layer's visual observations in texts like 'uneven' or 'smooth', were included as part of the dataset. Qualitative data such as text is a categorical variable and can be converted into a series of zeros and ones (dummy variables), allowing them to be quantified and compared (Langford 2017). By using machine learning, text can be assigned a value of 0 or +1, where the dummy variable can indicate presence within the dataset and add value to the correlation matrix (Fernandes, Solimun & Nurjannah 2022).

As support for the evidence-based exploration of a dataset, this method can help identify relationships of elements within the dataset and shortlist compounds that may be present. The Spearman rank correlation coefficient is a nonparametric technique for evaluating the degree of correlation between independent variables (Gauthier 2001). As information about the distribution of the dataset and elements is currently unknown, and parameters of the elemental 'footprints' are not fixed, the use of nonparametric techniques are used to test the hypothesis for the population. This is beneficial for the research methodology as the technique operates on the ranks of the data, it is relatively insensitive to outliers and draws attention to the elements which appear to be strongly correlated in the dataset, from which compounds can be assumed. It can also be used with small sample sizes and factors in text-based data, and it is easy to apply. The idea behind the rank correlation coefficient is to rank each variable in the dataset (element) separately, from lowest to highest. The difference between ranks for each data pair is recorded. This technique is employed to explore the relationships of elements of datasets to identify any prominent compounds that may be present. The disadvantage is that there is a loss of information when the data are converted to ranks and that a positive correlation does not mean more presence — it can only reflect the relationships between the elements. However, this assists in giving an overview of possible additives or elements that could be present in the ground or paint layer. It is important to note that the model used in this analysis stops short of predictions and regression

analysis as the aim is to focus on compounds or elements that could be present and their relationships.

To perform the analysis, the programming language Python was used with the three key packages NumPy and Matplotlib to clean, analyse and visualise the dataset. The code used for this study was written in collaboration with Luisa Rincon and Santos Borom. NumPy is often used for statistical calculations and includes many tools for data analysis, including functions that can calculate the Spearman rank correlation coefficient. Pandas is used for data preparation, manipulation as well as creating data frames, and Matplotlib visualises the data which is then exported for analysis. For the correlation matrix, only elements above 1% are factored and fields without a value are replaced with null to reduce noise during the calculations.

The primary objective of a correlation matrix is to list context-driven compounds and elements to consider for the binary dataset. While binary datasets can be created with known general pigments or additives for the data to be tested against, the correlation matrix focuses on evidence of highly correlated elements and compounds from within the dataset. A binary dataset based on Boolean ‘true’ or ‘false’ values is then created with a list of additives and pigments that were either present in the ground layer or not. Each row of data is then tested against this, and the findings documented in Airtable. Preliminary findings show several clusters of trends that follow a chronology.

Preliminary clustering with Spearman correlation: identifying key compounds and elements

The results produced by the ESEM-EDS, in the form of percentages of weight oxide and elements present, can only be considered semi-quantifiable and may be prone to systematic errors due to the heterogenous nature of paint samples. This also means that while care has been used in selecting representative samples, there is a chance that the results from a single sample may not be extrapolated accurately to its painting. In addition, there are no existing references for ground or paint layers in modern Singaporean paintings and therefore

it is argued that the data correlation may be able to offer a bottom-up approach towards understanding ground layers without need of a comparative reference. The resulting dataset from 35 ground layers analysed using the ESEM-EDS necessitated exploratory research of elements and the identification of any relationships between them, combined with the text observation of the ground layer as ‘uneven’ or ‘smooth’. The analysis of relationships within an elemental dataset can suggest the presence of selected compounds by identifying variables that share a strong correlation. Using Spearman’s correlation diagram, positive and negative correlations can be easily identified in the visualisation. When there is a positive correlation between two variables, in this case two elements, the strength of the linear relationship between the two elements suggests that there is a positive relationship and therefore, might make an elemental compound. Similarly, where there is a negative correlation, there is an inverse relationship where the two elements are unlikely to be related and there is a decreased likelihood of the two elements to be present as a compound within the dataset.

Interpreting the significance of the correlation coefficient, the model uses the following scales of positive correlation coefficient to interpret the findings.

- 0.0 to 0.4 there is a possibility of correlation between the two element variables
- 0.4 to 0.8 the two element variables are moderately correlated
- 0.8 to 1.0 the two element variables are very strongly correlated, and are highly likely to be an elemental compound

Overall, the Spearman rank correlation coefficient can be a useful tool for exploratory data analysis and is the first step to deciding what compounds or elements are prominent in the dataset. This has been applied to study the ground layer, and later, pigment colours, such as black, blue, red, yellow and whites. The identification of possible elemental compounds present within the ESEM-EDS dataset forms another dataset which lists the compounds and elements present.

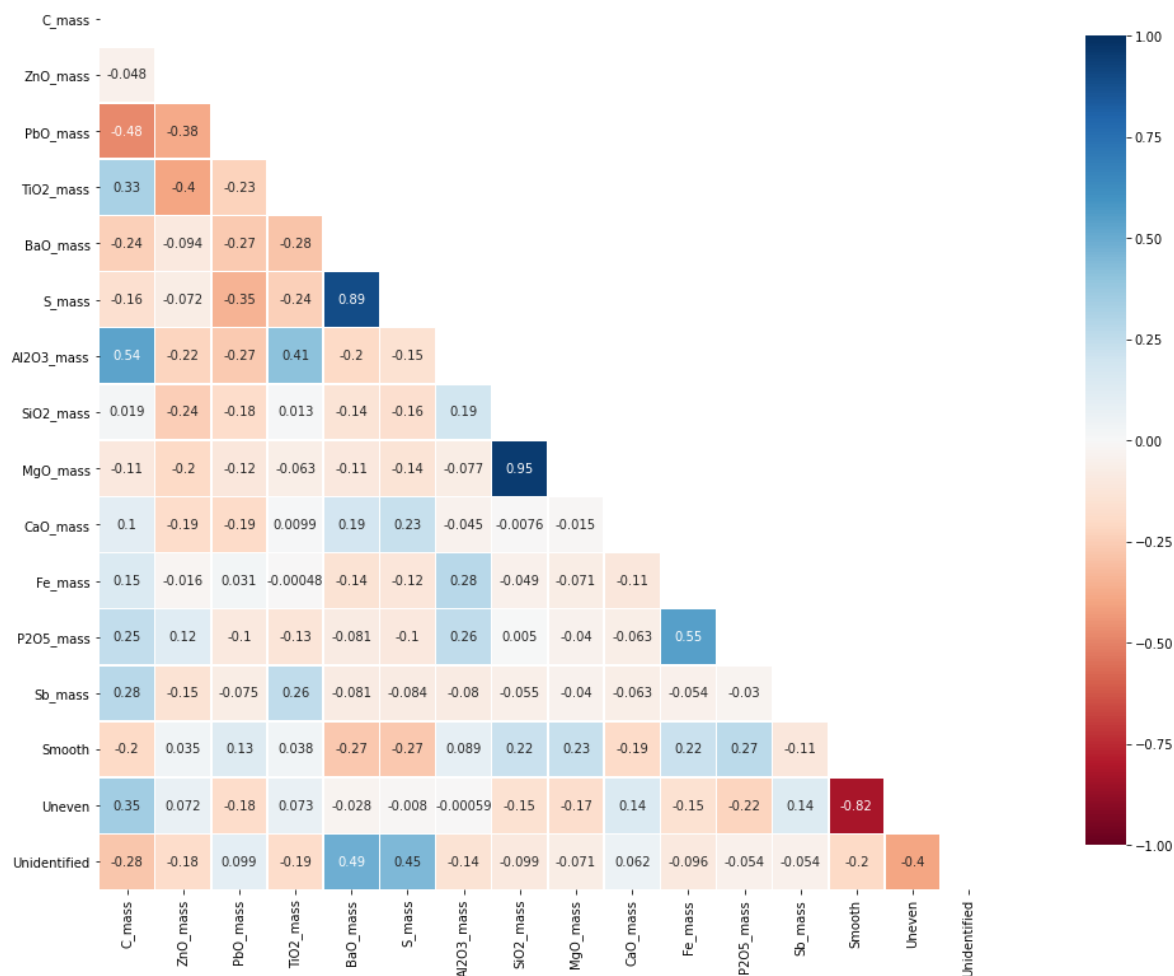


Figure 62. Correlation matrix of 13 elements present and 3 ground topography findings in ground layers of 35 Cheong Soo Pieng cross-sections analysed using ESEM-EDS. The 16 variables are plotted against each other in the x and y axis to examine the correlation between each other.

The ground layer's correlation matrix in Figure 62 represents the elemental ranks of 35 painting area scans taken from cross-sections and outlines the possible compounds present within the dataset of ground layers. The values in blue represent a positive correlation which is summarised in Table 22.

Table 22. Summary of correlations for ground layers.

Element	0.8-1.0 very strong, high	0.4 – 0.7 moderate	0.0 – 0.4 present
Zn			P
Pb			Fe
Ti		Al, Sb	C
Ba	S		Ca
Ca			S, C
Al			Fe, P, Si
Si	Mg		
Possible compounds present in the dataset			
Mg, Si	Magnesium silicate		
Ba, S	Barium sulphate/ lithopone* (if there is presence of Ba, S and Zn. To be tested individually in the binary dataset)		
Al, Si	Aluminium silicate/ Mica		
Ca, S	Calcium sulfate (gypsum)		
Ca, C	Calcium carbonate		
Possible compound combinations to look out for			
• If there is a presence of barium, is there calcium? • Titanium and aluminium?			
Texture	0.8-1.0 very strong, high	0.4 – 0.7 moderate	0.0 – 0.4 present
Smooth			Fe, P, Mg, Si, Pb
Uneven	C		Ti, Zn, Ca, Sb
Unidentified		Ba, S	Pb, Ca

In the ground layer dataset, non-structured data, such as the textural observations of the ground layer, were factored into the correlation matrix which offered elemental footprints related to the observations. The smooth texture of the ground layer, which suggests commercially available pre-primed canvas, appears to share correlations with the presence of magnesium silicate and lead, while ‘uneven’ grounds that are likely artist-prepared shared positive correlations with titanium, zinc, and calcium-based additives. These findings form the foundation of the second stage of compound identification for each painting, which factors the presence of zinc, titanium and lead as main elements in the ground layer and attempts to identify compounds that could represent additives. From the ground layers and the possible clusters, a new column is added to the dataset which is populated by the ground layer’s most dominant element groups. The possible ground compounds were categorised as ‘lithopone_titanium’, ‘zinc’, ‘talc’, ‘lead_zinc’, ‘lithopone’, ‘lead_titanium’, ‘lead’, ‘titanium_zinc’, ‘titanium’. This categorisation will be critical for the unsupervised analysis phase as it seeks to understand the grounds’ correlation more broadly. In the binary dataset, all elements present in each of the 35 samples were listed and each sample was tested against the categories of possible ground compounds. For instance, in ‘lithopone_titanium’, a sample would have to test ‘TRUE’ if it contains Ba, S, Zn and Ti. If it does not contain Ti, but tests ‘TRUE’ for Ba,S and Zn, it would then be categorised as ‘lithopone’.

Preliminary clustering resulting from the findings of the binary dataset shows three main clusters, which have been identified and grouped by the patterns observed in the ground layer. This was organised by a count function on Excel then the findings are illustrated through a diagram manually drawn the draw.io software (Figure 63). “Since the presence of a pigment provides neither information on its absolute (relative) amount, nor on its chemical composition, only limited information can be obtained for dating purposes” (Albrecht et al. 2019, p.11), although occurrences have been observed to fall within specific time periods. It is important to note that not all paintings fell into these clusters, and the preliminary clustering simply aims to group findings and observe any trends chronologically.

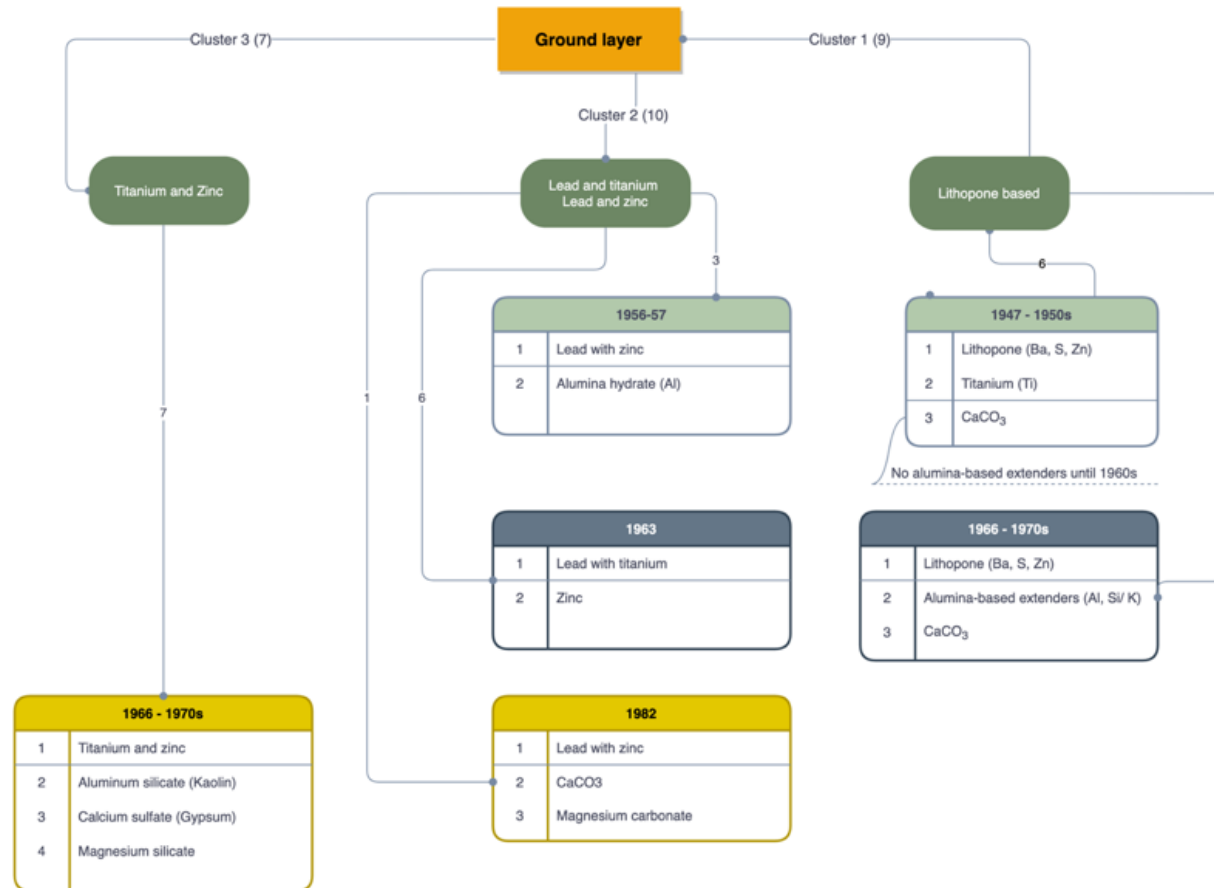


Figure 63. Preliminary clustering resulting from the binary dataset of ground layers could be categorized into three main groups.

Lithopone-based grounds were identified in nine of Cheong Soo Pieng's works. The presence of lithopone was identified from the presence of the main elements Ba, S and Zn. From the binary dataset, 'lithopone' was only present if the sample's ESEM-EDS results contained all three elements. The first was identified in 1947 and the last in 1975. Six of these were identified during the 1947–1952, spanning across the Formative Years (1946-1949) to early Nanyang Style (1950-1961) periods, and 50% of the paintings were lithopone-based with a trace of titanium, and had either calcium-based additives or none identified. This also explains why the elemental data showed correlations between barium, sulphur and calcium. This group of paintings was not limited to any one support type, having wood, plywood and canvas supports. The works displayed mostly uneven surfaces in cross-sections, indicating that the ground was prepared by the artist. In later parts of Cheong Soo Pieng's oeuvre, lithopone was found (in 1966 and 1975); these ground layers were also artist-prepared, and both displayed large particles in BSE (Figures 64a and 64b) and contained higher levels of barium sulphate than zinc.

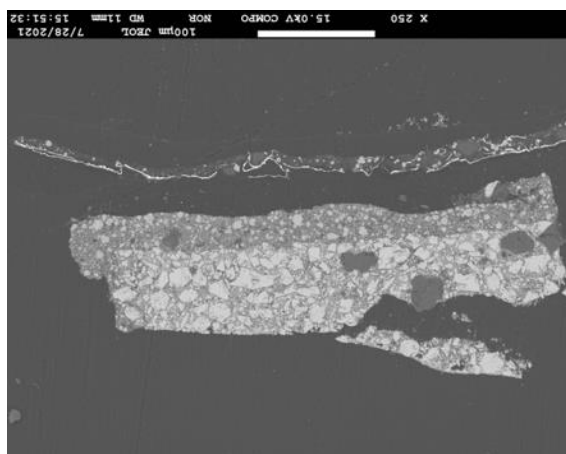


Figure 64a. ESEM-EDS backscatter imaging of coarse ground layer. Cheong Soo Pieng, *Green Landscape*, c.1975 (45 x 61cm, mixed media on canvas). Collection: KSC.

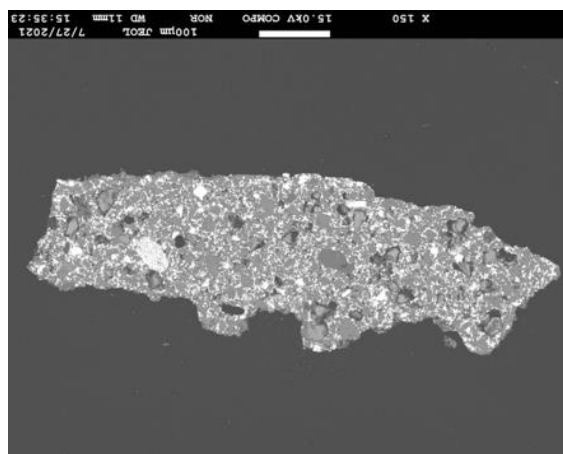


Figure 64b. ESEM-EDS backscatter imaging of coarse ground layer. Cheong Soo Pieng, *Construction*, c.1966 (107 x 68cm, mixed media on wood). Collection: KSC.

Lead-based grounds are one of the largest clusters in the dataset. Ground based on lead with a trace of zinc were largely used between 1956 to 1960 (Nanyang Style period) while lead with titanium pigments were more common in 1963, during the Lyrical Abstract (1962-1963) period, where six paintings had a large presence of ground composed of lead with titanium pigments. The four paintings during the Nanyang Style period which had a lead and zinc-based ground and an aluminium-based additive were similar in morphology, which featured rectangular structures. Interestingly, three of these ground layers were on flexible supports, such as paper and canvas, that were marouflaged onto hardboard during 1956–1957. This type of ground appears to be characteristic of paintings produced during the Nanyang Style period. One of the last paintings in Cheong Soo Pieng's practice in 1982 features a lead ground with zinc. However, the difference from the earlier lead and zinc grounds is that the composition includes additives, such as calcium carbonate and magnesium carbonate.

In 1963, five paintings contained grounds based on both lead and titanium, where the weight percentage of lead content was higher than titanium in these ground layers. Three of these grounds did not have any additives identified during analysis and featured smooth ground layers in cross-section. The other two grounds had a trace of zinc, one of which is in a painting with a Holbein stamp. All five paintings featured a smooth ground visual observation, which identifies the positive correlation between lead-based grounds and smooth topography. Overall, the presence of lead within the dataset was an unexpected finding as modern grounds are likely made of titanium or zinc (Mayer 1991).

The last group consists of seven ground layers with titanium and zinc, found in the later works of Cheong Soo Pieng. These paintings were dated between 1966 and 1977. There are two distinct groups within this cluster. Those with a higher weight percentage of zinc had no additives picked up during analysis, while those with a higher weight percentage of titanium included additives such as aluminium silicate, calcium sulphate (gypsum) and traces of magnesium (< 1%). Four of these paintings presented uneven ground layers, which is reflected in the positive correlation of an uneven topography in cross-sections and elements titanium, zinc and calcium.

While there are a total of six samples with both magnesium and silica, the strong positive correlation of magnesium and silica is not explained through the trace elements as additives. Instead, one painting with a ground layer composition of primarily magnesium and silica is featured. *Bali Women* (1952-1964) is the only painting that has a ground layer composed of talc. It is also the largest canvas painting in the survey. From the three main clusters, it can be observed that additives in the composition of ground layers are mainly found in paintings after 1966.

The findings of this investigation have extended our knowledge of the ground composition and possible patterns within the dataset of Cheong Soo Pieng's painting materials. While the patterns are non-linear, the clustering of similar ground characteristics appears to fall into three groups, each with its chronological patterns. These three broad categories similar reflect the shift in Cheong Soo Pieng's art techniques: the thick impasto layers of paint in the earlier painting periods of Formative Years (1946-1949) towards thinner and diluted paint layers in the Stylisation period (1963-1969) before the Artist Maturation (1970-1978) period which appears to be correlated with the incorporation of local materials. While it was not possible to investigate more deeply the significant relationships between additives and the ground, given the small sample size, the methodology was able to confirm the similarities in the Holbein canvasses. Further data collection is required to determine the efficiency of the model and to test its long-term usability in research.

Advanced material analyses such as ESEM-EDS tend to be utilised for in-depth understanding on a case-by-case basis, however, the methodology proposed has the potential to draw together complementary findings from technical examination to develop a deeper insight into the artist materials and techniques. The understandings gained here can help to further develop various analytical models which can enable a broad yet valuable insight into artist materials and techniques, and will further be proven useful in a later discussion of the unsupervised learning model. Having built an understanding of the ground and canvas materials and techniques of Cheong Soo Pieng's practice, the execution of the painting and the materials and techniques will be described in greater detail in the following section.

Whilst the research is limited without undertaking organic analyses, which would have greatly benefited paint characterisation and given greater insight, the technical examination methodology employed has shed new light on the patterns in Cheong Soo Pieng's materials and techniques. The detailed documentation of paintings, particularly using the visual observations from cross-sections alongside ESEM-EDS results, has informed most of the findings in this section, which demonstrates the benefits of a broad-based study. The next segment explores preliminary pigment trends which resulted from ESEM-EDS analysis undertaken on the cross-sections.

6.3 Pigment identification through data clustering

When undertaking studies of an artist's paint, pigment identification is a key research area in building knowledge about paint technology and availability at the time of execution. Scientific instruments such as X-ray fluorescence (XRF) or ESEM-EDS have been instrumental in identifying pigments. As pXRF was not an available option for on-site examination for the Cheong Soo Pieng paintings in Singapore, extracted paint samples were mounted into cross-sections and analysed using ESEM-EDS. The information obtained from ESEM-EDS includes backscattered electron images, a list of each element present in the analysed area, and the element's oxide weight percentage.

Arising from broader investigations into methodologies for determining artist attribution, results from scientific inquiries can inform us about the aims of artists of the past and the science and technology of their times. Technical investigations provide a foundation for historical research and can illuminate the history of painters' pigments and the interconnections between artists. It would be advantageous to employ a series of simultaneous analyses for the identification and mapping of pigments over the macro- to molecular series. Apart from the advantages that improved instrumental methods could provide, this research focuses on developing a methodology that allows exploratory analysis to identify future research areas.

Information about painting techniques can be collected in a variety of ways, including the chemical or physical analyses of the materials found in paintings. Analysis of a large

number of paintings attributed to certain regions and artists can contribute to a history of painting techniques. While the pigments characterised from a single painting cannot be representative of the entire painting, the study of pigments presented collectively can give insights into a foundational understanding of material availability in Singapore and the art materials used by Cheong Soo Pieng. While some artists have written sources and documentation on painting techniques, Cheong Soo Pieng's lack of written documentation on artist supplies or evidence of used artist materials such as paint tubes present challenges in finding a starting point: in the last interview with his daughter, she said all that was left were three pots with brushes and easels.

Paint based on white pigments is one of the most commonly used by artists (Plisson et al. 2014, p. 135). Confirmed by different studies performed in the past, analyses have shown that coloured painting layers are commonly made of white pigments with a small amount of coloured pigment (Plisson et al. 2014, p.135). Paints based on white pigments such as lead, zinc and titanium are the basic materials often found in ground layers of ready-made canvasses as well as in painting layers mixed with other colours (D'Imporzano et al. 2021; Plisson et al. 2014). Perhaps the findings from possible ground compositions could be used as an opening to the pigments present.

At the end of the 19th century, two types of pigments were available to produce white paints: lead white and zinc white. The identification of lead white has been an interest in conservation research, as it can provide information about trading practices over a long socio-historical timescale (D'Imporzano et al. 2021, p. 2). However, since 1900s, discussions about the replacement of lead white by zinc white has been raised as the preparation of lead paint was hazardous. In addition, the presence of titanium white after 1921 was partly due to industrialisation. The factors in choosing between zinc, lead and titanium white to be used as pigments are not only an optical difference but the different pigments can affect drying time, tincture, texture and hiding power which may be a deciding factor in an artist preference or commercial purposes (Bomford et al. 1990). With the presence of lead-based grounds in Cheong Soo Pieng's paintings in the later periods of the 1960s, one of the aims of this study was to understand if artist materials followed a chronology in the context of Cheong Soo Pieng's artworks.

Methodology

By considering the presence of the elements in the paint layer in detail, trends within the dataset can be observed. For the elemental composition, normalised quantification was carried out of the 16 elements that were detected in the paint layers, namely Na, Mg, Al, Si, P, S, Cl, K, Ca, Ti, Mn, Fe, Co, Cu, Zn and Pb. This was based on weight percentages of the oxides of the elements present. The data for each point of analysis was recorded into an Excel spreadsheet and a dataset was built. Transformation of the data into identification of pigments required a combination of data analysis with a pigment element reference, and a resulting binary dataset was built. Each row of data was then tested against the possible pigments present and the findings were documented in Airtable. As previously mentioned, the quantitative results produced by the ESEM-EDS can only be considered semi-quantifiable and may be prone to systematic errors due to the heterogenous nature of paint samples. In addition, the presence of a pigment does not offer information on its absolute amount nor does it mean the results from a sample can be extrapolated to the entire painting.

The ESEM-EDS analysis targets an understanding of two main paint components in modern paints: inorganic pigments and extenders. Extenders are used to add bulk to paint, to achieve the desired surface texture or appropriate properties and to reduce the cost of the formulation (Learner 2004, p. 28). The chemical purity of pigments varies greatly, as a result of ingredients being added during manufacture to modify colour or pigment properties. Modern pigments and extenders can be detected by analytical techniques. While analytical techniques using organic analysis can identify binders, elemental analysis plays a useful part in identifying the inorganic aspects of pigments and extenders. While there is a limitation on organic pigments, drawing an understanding from the available inorganic analysis has shown value in the findings.

As with the methodology in the above exploratory research on ground layers and their composition, the Spearman rank correlation coefficient is considered a useful tool for exploratory data analysis and is the first step in drawing an understanding of what pigments

may be present in the dataset. As there are no existing reference libraries for modern paints found in Singapore artworks to build on, this exploratory research is a step towards developing a context-relevant understanding. The exploratory analysis sets the stage for future analysis for pigments to be verified through careful visual examination of the cross-sections under normal reflected light and ultraviolet light, looking at the colour, size and shape of the pigment particles, combined with their particle morphology.

The analysis of relationships within an elemental dataset could propose the classification of pigments that may be present by identifying variables that are connected and establishing the nature of relationships between two or more variables. In Spearman's correlation diagram, positive, negative and zero correlations can be easily identified in the visualisation. The five coloured pigments that will be discussed are black, blue, red, yellow and whites where preliminary clustering of these pigments has indicated the presence of certain elements. Preliminary clustering from the study of occurrences considers the date when the work was produced and major elements that compose white pigments such as zinc, titanium and lead. The following discussion will begin with a discussion of the hues of red-orange-yellow, followed by blues, blacks and then whites.

Reds and yellows

The colours of red to yellow are quite distinct in the study of the selected Cheong Soo Pieng's works. In this section, red and yellow pigments are grouped together given the differences in elemental compounds (see Table 23). Some 19 samples embedded in cross-sections with red or yellow paint layers from 1947 to 1977 were available for study. 11 of these were brighter coloured hues of reds and yellows from before 1957. The red and yellow paints correlation matrix in Figure 65 represents the elemental ranks of 35 painting area scans taken from cross-sections and presents possible pigments and extenders within the dataset of paint layers. The darker values represent a positive correlation, which is summarised in Table 23. In addition, non-structured data, such as data concerning the colour observations of the paint layer, were factored into the correlation matrix, which offered elemental footprints related to the observations.

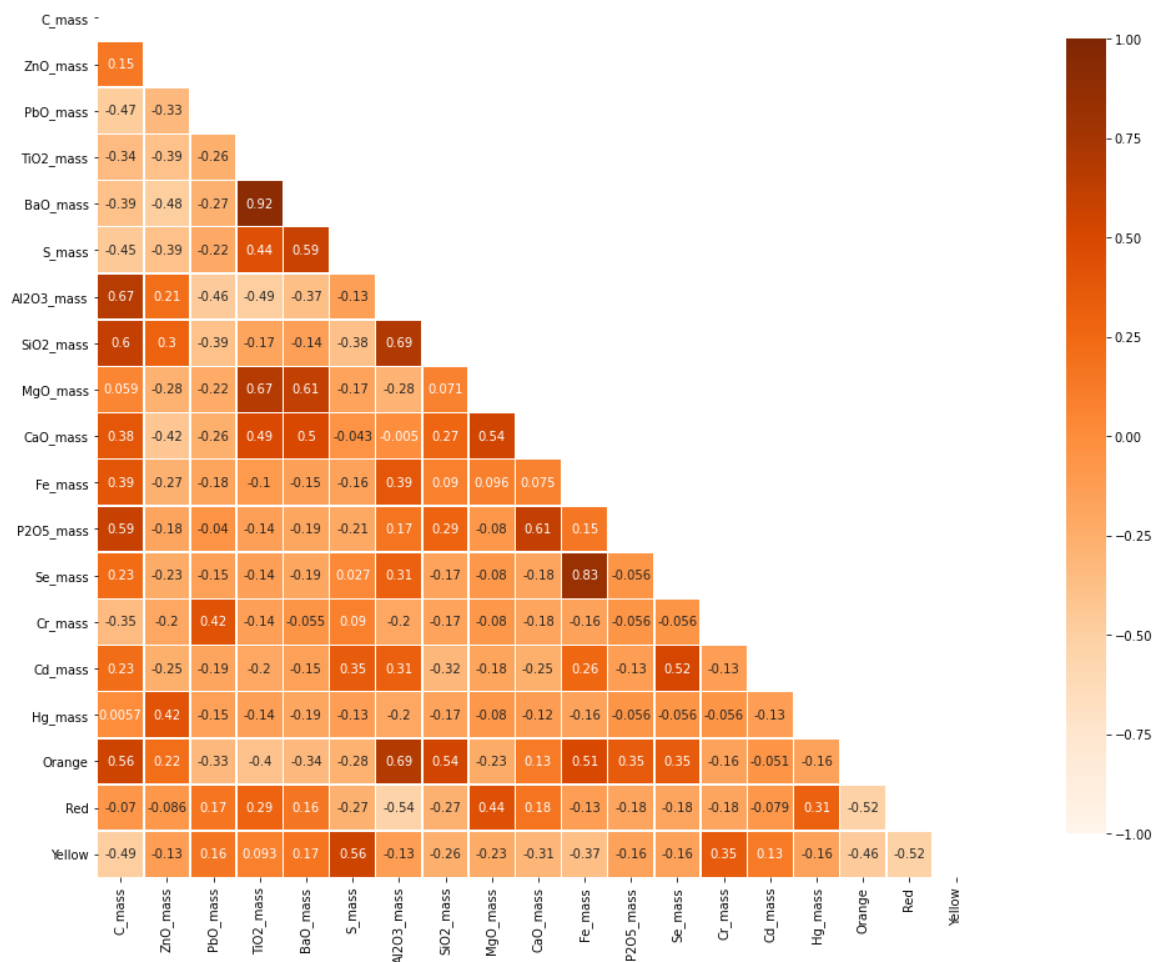


Figure 65. Correlation matrix of elements present in 19 red and yellow paint layers.

Table 23. Summary of correlations for red and yellow pigments.

Element	0.8 – 1.0 very strong, high	0.4 – 0.7 moderate	0.0 – 0.4 present
Zn		Hg	Al, Si, C
Pb		Cr	
Ti	Ba	Mg, Ca, S	

Ba		Mg, Ca, S	
S		Ti, Ba	Cd
Al		Si	C, Fe, Se, Cd
Mg		Ca, Ti, Ba	
Ca		P2O5	C
Possible compounds present in the dataset			
Mg, Ca	Magnesium carbonate		
Ba, S	Barium sulphate/ lithopone* (if there is presence of Ba, S and Zn. To be tested individually in the binary dataset)		
Al, Si	Aluminium silicate/ Mica		
Ca, C	Calcium carbonate		
Possible pigments present in the dataset			
Cd, Ba, S	Cadmium-barium/ Cadmium sulfide		
Pb, Cr	Lead chromate/ Chrome orange/ chrome yellow/ lemon yellow		
Fe, Cr			
Notes			
- Titanium with Ca, Mg or S compositions - Hg with Zn, Al, Si compositions			
Colour	0.8 – 1.0 very strong, high	0.4 – 0.7 moderate	0.0 – 0.4 present
Orange		Al, Si, C, Fe	P, Se, Zn
Red		Mg	Hg, Ti, Ca
Yellow		S	Cr, Ba, Pb

These exploratory findings form the foundation of the second stage of compound identification for each painting, which attempts to identify pigment and extender compounds. While it is not enough to ascertain the pigments present, it gives an insight into potential pigments that may be present and any relationships with extender compounds. By compiling the list of red and yellow pigments in a dataset, each sample was then tested for its presence against a reference list of extenders and pigments which was built based on existing conservation literature on modern paint (Learner 2004; Mayer 1991; Standeven 2011). The inorganic pigments commonly used in paint formulations and extenders are shown in Table 24. For each pigment, the pigment name, chemical composition and colour index are listed. For each extender, the compound name and chemical composition are listed (see Table 25). These references guide the exploratory analysis of pigments and extenders that are present within the dataset of red–yellow pigments.

Table 24. List of pigment references used for the test dataset for red and yellow pigments.

Colour	Pigment classical names	Colour index	Chemical composition	Elements (inorganic)
Orange-Red	Mars red/ red iron oxide	PR101	Fe ₂ O ₃	Fe
Orange-Red	Vermillion	PR106	HgS	Hg, S
Orange-Red	Chrome orange		PbO • PbCrO ₄	Pb, Cr
Orange-Red	Cadmium red	PR108	CdS	Cd, S
Orange-Red	Cadmium red	PR108	CdS, xCdSe	Cd, S, Se
Orange-Red	Cadmium orange		CdS	Cd, S
Orange-Red	Cadmium-barium red		CdS, BaSO ₄	Ba, Cd, S
Yellow-brown	Umbers (raw/burnt)		Fe ₂ O ₃ . MnO	Fe, Mn
Yellow-brown	Siennas (raw/burnt)		Fe ₂ O ₃	Fe
Yellow-brown	Yellow ochre/ Mars yellow		Fe ₂ O ₃	Fe

Yellow	Barium chromate yellow	PY31	BaCrO ₄	Ba, Cr
Yellow	Cadmium-barium yellow		CdSZnBaSO ₄	Ba, Cd, S, Zn
Yellow	Cobalt yellow		CoK ₃ N ₆ O ₁₂	Co, K, N
Yellow	Mars yellow/ Siderin Yellow		Fe ₂ (CrO ₄) ₃	Fe, Cr
Yellow	Naples yellow		Pb ₃ (SbO ₄) ₂	Sb, Pb
Yellow	Chrome yellow/ Lemon yellow	PY34	PbCrO ₄	Pb, Cr
Yellow	Arylide yellow		C ₁₆ H ₁₂ Cl ₂ N ₄ O ₄	C, Cl, N
Yellow	Zinc chromate yellow	PY36	ZnO, K ₂ O, CrO ₃	Cr, K, Zn
Yellow	Cadmium yellow	PY37	CdS	Cd, S
Yellow	Cadmium-barium yellow		CdSBaSO ₄	Ba, Cd, S
Yellow	Cadmium zinc yellow		CdSZn	Cd, S, Zn

Table 25. List of common paint extenders to be identified.

Extender	Compound name	Chemical composition	Elements (inorganic)
Alumina hydrate	Aluminium trihydrate	$\text{Al}(\text{OH})_3$	Al
Antimony oxide	Antimony oxide	Sb_2O_3	Sb
Barium sulfate/ barites/ blanc fixe	Barium sulphate	BaSO_4	Ba, S
Chalk/ Whiting	Calcium carbonate	CaCO_3	Ca, C
Gypsum/ Calcium sulfates	Calcium sulfate dihydrate	$\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$	Ca, S
Kaolin; china clay	Aluminium silicate	$\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$	Al, Si
Lead sulphate	Lead sulphate	PbSO_4	Pb, S
Lithopone	Lithopone	Zn, BaSO_4	Ba, S, Zn
Magnesium carbonate	Magnesium carbonate	MgCO_3	Mg, C
Manganese Oxide	Manganese oxide	MnO	Mn
Mica	Potassium aluminium silicate	AlKO_6Si_2	Al, K, Si
Quartz; ground silica	Silica	SiO_2	Si

Talc	Magnesium silicate	$\text{Mg}_{12}\text{Si}_4\text{O}_{19}(\text{OH})_2$	Mg, Si
Terebine/ Lead oxide	Lead oxide	PbO	Pb

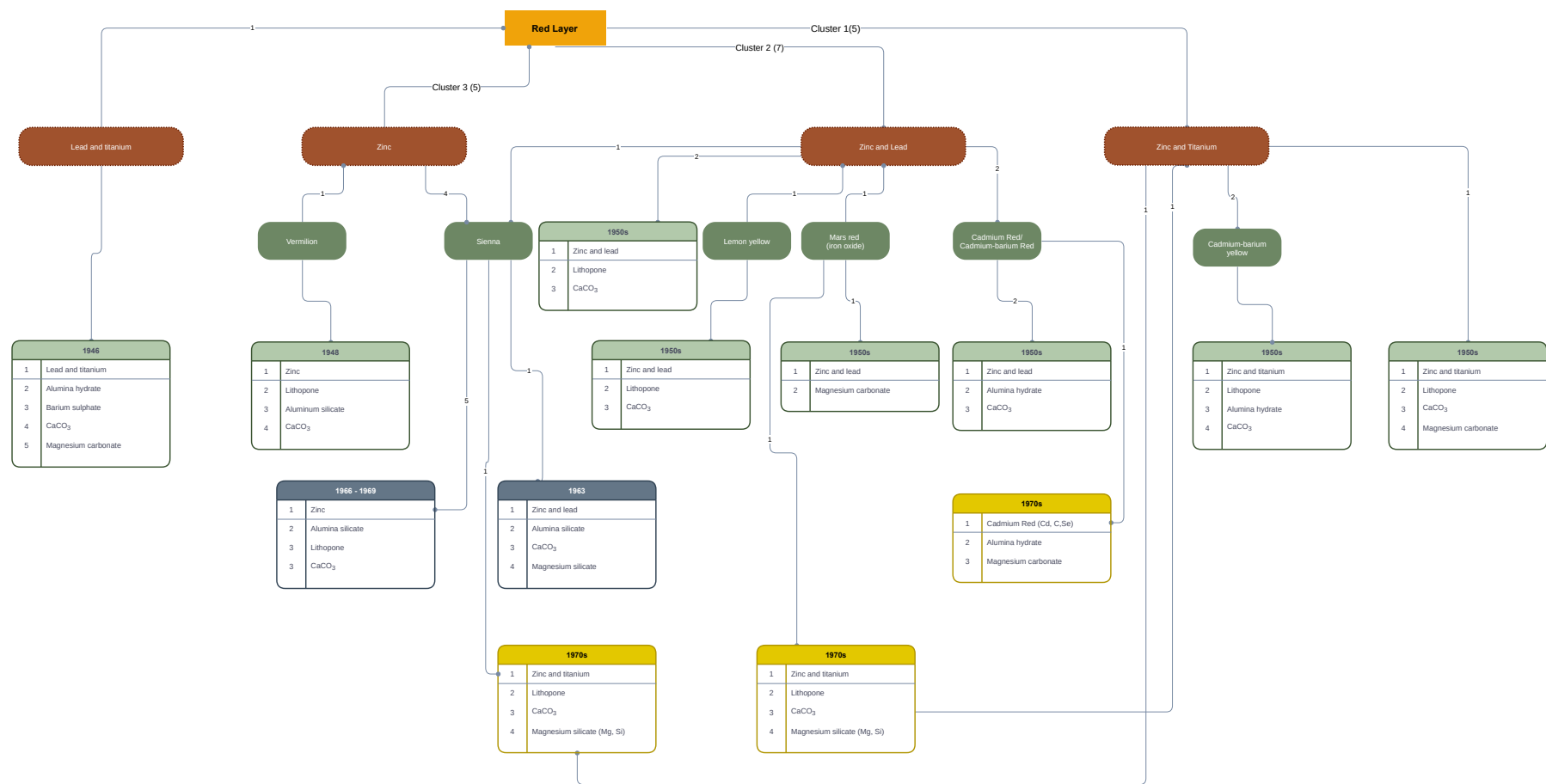


Figure 66. Cluster map illustrating the groups of red and yellow pigments and their characteristics found within the dataset of 19 Cheong Soo Pieng paint samples.

Each row of data is assigned a main pigment presence as well as any extenders that may be present. From the studying of trends and occurrences following the same methodology as the ground study, four preliminary clusters have been identified based on major elements present (Figure 66). These are:

- Lead and titanium (Pb, Ti)
- Zinc (Zn)
- Zinc and lead (Zn, Pb)
- Zinc and titanium (Zn, Ti)

Within these clusters, seven possible inorganic pigments are included:

- Cadmium-barium yellow (Ba, Cd, S, Zn)
- Cadmium-barium red (Ba, Cd, S)
- Cadmium red (Cd, S, Se)
- Mars red (Fe)
- Lemon yellow (Pb, Cr)
- Siennas/ Yellow Ochre (Fe)
- Vermillion (Hg, S)

Supporting visual observations that reds and yellows were widely used before the 1960s, the dataset reflects a range of pigments during the period. Vermillion was present in *Portrait* (1947), one of the earliest paintings Cheong Soo Pieng produced when arriving in Singapore. While it is not known if he brought paints with him or if they were purchased in Singapore, the history of vermillion shows that it was largely supplemented by cadmium red, and one of the best manufactured grades was from China (Mayer 1991, p. 97). While brighter colours were characteristic of the earlier works, Cheong Soo Pieng's palette gravitated towards muted colours, particularly in the 1960s. This supports the finding that most of the iron-based yellow pigments present after 1963 could be siennas or yellow ochres. Overall, the relationship between elements from the correlation matrix suggested possible red–yellow pigments. For instance, there were no cobalt-based pigments, and cadmium-based pigments that were correlated to lead.

A range of extenders was expected to be identified from the paint samples given the variety of elements that were detected per sample. Both chalk and lithopone were present in the paint compositions while magnesium silicate as an extender was more present after 1963. Further research could be done to analyse the difference in paint properties of the paintings with varying extenders as it can influence the performance of the paint properties such as adhesion or gloss levels. Zinc-based paints were common with most of the paint composition containing zinc. Paints with lead elements mainly dated between 1952 and 1957, while paints with titanium were present during the period 1947–1956 and again in 1972 and 1977. Given the small sample size, the findings provide a baseline understanding of the pigments present in the red and yellow paints used by the artist such as the presence of vermillion only in the earlier period of 1948.

Blues

A total of 12 samples embedded in cross-sections with blue paint layers from 1949 to 1978 were analysed using ESEM-EDS. While pigments can be characterised by the presence or absence of certain elements, not all the samples contained the presence of a key element to characterise blue pigments (see Table 27 for blue pigment references). Therefore, following on from the previous discussion on how white pigments such as zinc, lead or titanium could determine a colour-based compositions, which was more useful and suggests possible pigments and extenders that could be identified within the dataset of paint layers. The darker values represent a positive correlation, summarised in Table 26. The blue correlation matrix in Figure 67 was executed only on the elemental metadata without non-structured visual observations.

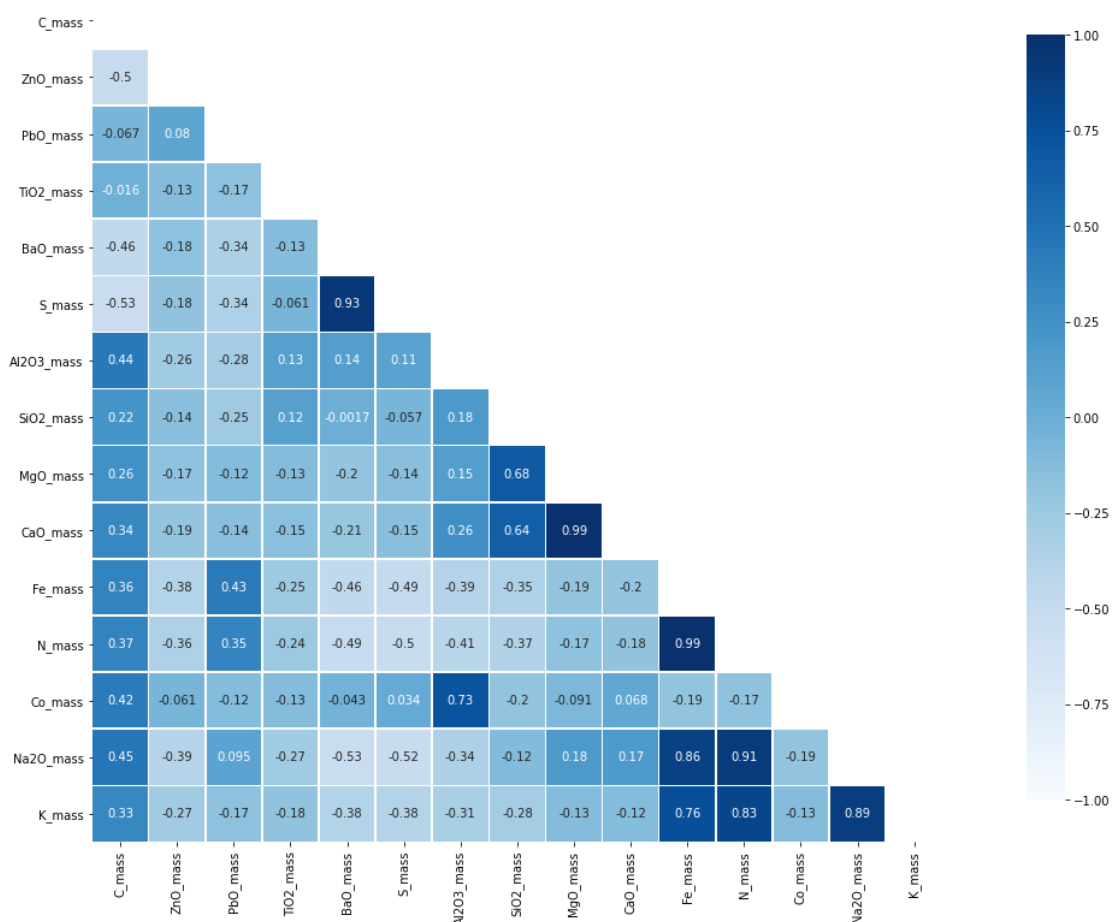


Figure 67. Correlation matrix of elements present in 12 blue paint layers.

Table 26. Summary of correlations for blue pigments.

Element	0.8 – 1.0 very strong, high	0.4 – 0.7 moderate	0.0 – 0.4 present
Zn			Pb
Pb		Fe, N	Na
Ti			Al, Si
Ba	S		Al
S			Al
Al		Co, C	Ca, Mg, Si
Mg		Si	Al, Si, Ca, Na, C
Ca	Mg	Si	Na, Al, C
Fe	Na, N	K, Pb	C
Possible compounds present in the dataset			
Mg, Ca	Magnesium carbonate		
Ba, S	Barium sulphate/ lithopone* (if there is presence of Ba, S and Zn. To be tested individually in the binary dataset)		
Al, Si	Aluminium silicate/ mica		
Ca, C	Calcium carbonate		
Possible pigments present in the dataset			
Al, Co	Cobalt blue		
Fe, C, N	Prussian blue		
Al, Na, Si	Ultramarine blue		
Notes			
- Ca, Mg, C, Al, Si strong correlations suggest a high presence of extenders - A high correlation between Mg and Ca			

Table 27: List of pigment references used for the test dataset for blue pigments.

Colour	Pigment classical names	Colour index	Chemical composition	Elements (inorganic)
Blue	Cobalt blue	PB28	$\text{CoO} \cdot \text{Al}_2\text{O}_3$	Al, Co
Blue	Ultramarine blue	PB29	$\text{Na}_8\text{Al}_6\text{Si}_6\text{O}_{24}$	Al, Na, Si
Blue	Manganese blue	PB33	$\text{BaMnO} \cdot \text{BaSO}_4$	Ba, Mn, S
Blue	Cerulean blue		$\text{CoO} \cdot \text{SnO}_2$	Co, Sn
Blue	Prussian blue/ Paris blue	PB27	$\text{C}_6\text{FeN}_6 \cdot \text{H}_4\text{N}$	Fe, C, N

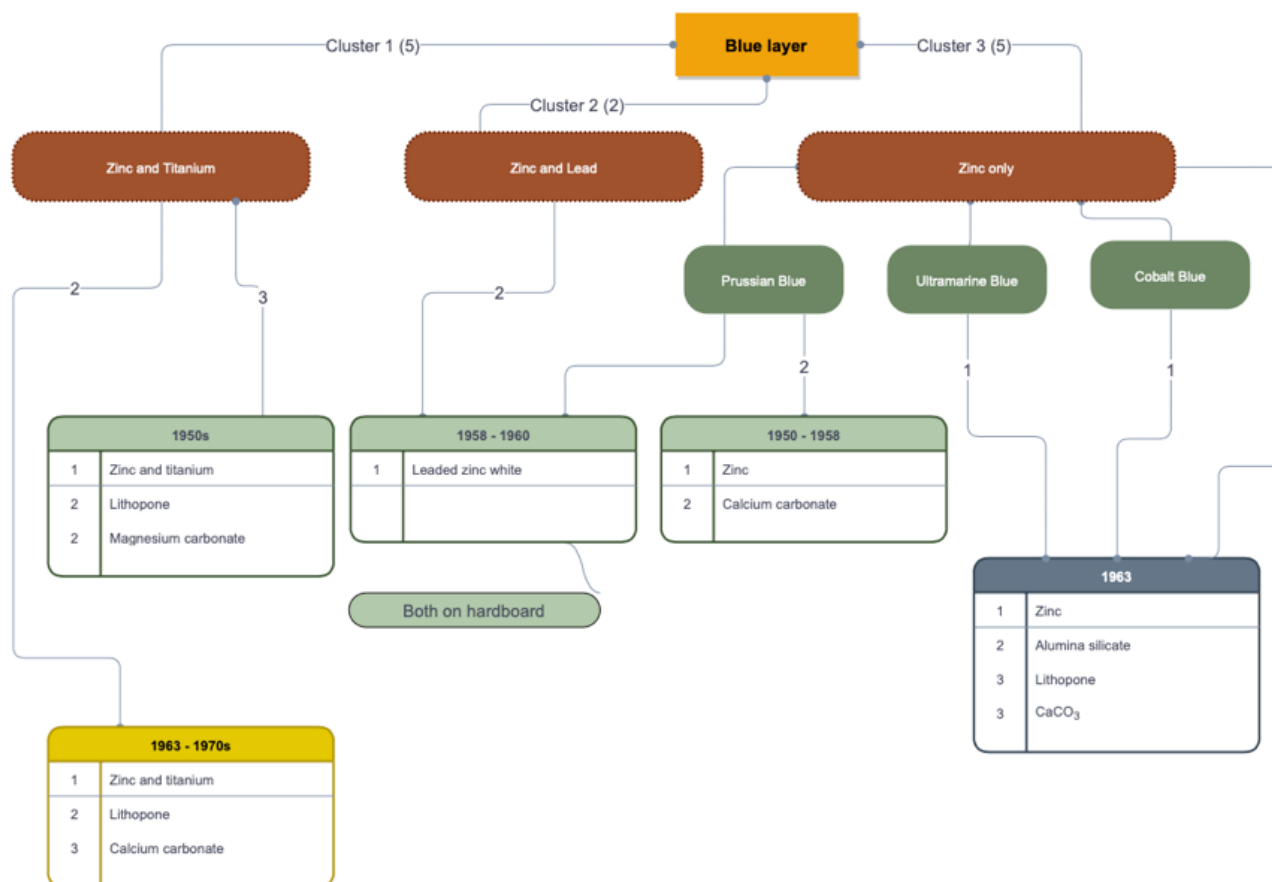


Figure 68. Cluster map illustrating the groups of blue pigments and their characteristics found within the dataset of 12 Cheong Soo Pieng paint samples.

The new dataset of blue pigments was used on the initial ESEM-EDS findings for each sample to test for its presence against a reference list of extenders and pigments built based on existing conservation literature on modern paint (Learner 2004; Mayer 1991; Standeven 2011). The inorganic elements commonly attributed to the blue paint and modern paint extenders are shown in Table 27.

Three preliminary clusters were identified based on major elements present as illustrated in Figure 68.

- Zinc (Zn)
- Zinc and lead (Zn, Pb)
- Zinc and titanium (Zn, Ti)

Within these clusters, three possible inorganic pigments are included.

- Prussian blue (Fe, C, N)
- Ultramarine blue (Al, Na, Si)
- Cobalt blue (Al, Co)

Zinc is present in all paint samples from the 1950s through to the 1970s, which could be indicative of the paint quality and opacity selected. Most of the elements that could be attributed to pigments are found to have only zinc in their composition. The amount and variation of extenders for each cluster are significantly less than for the reds. An intriguing observation following the binary dataset is that not all blue pigments had attributed elements such as cobalt, iron or manganese. Paint compositions with elements attributed to Prussian blue appear to fall into two categories: those with leaded zinc were found in paintings on hardboard in the 1950s, and the others had zinc and calcium-based extenders. Ultramarine and cobalt blue shared similar paint compositions, the majority with zinc and various extender pigments, such as kaolin (aluminium silicate), lithopone (zinc sulphide and barium sulphate) or chalk (calcium carbonate). As with the reds, both lithopone and chalk were highly present in the paint compositions as extenders which could encourage further research on whether the paints were purchased in a similar time period or possibly the same brand.

Blacks

Some 26 samples embedded in cross-sections with blue paint layers from 1949 to 1978 were available for study. Black is an important colour for Cheong Soo Pieng's paintings as it was found to have been used for outlines in the paintings studied. The darker values represent a positive correlation, summarised in Table 28. The black correlation matrix in Figure 69 was executed only on the elemental metadata without non-structured visual observations and a list of black pigment references are listed in Table 29.

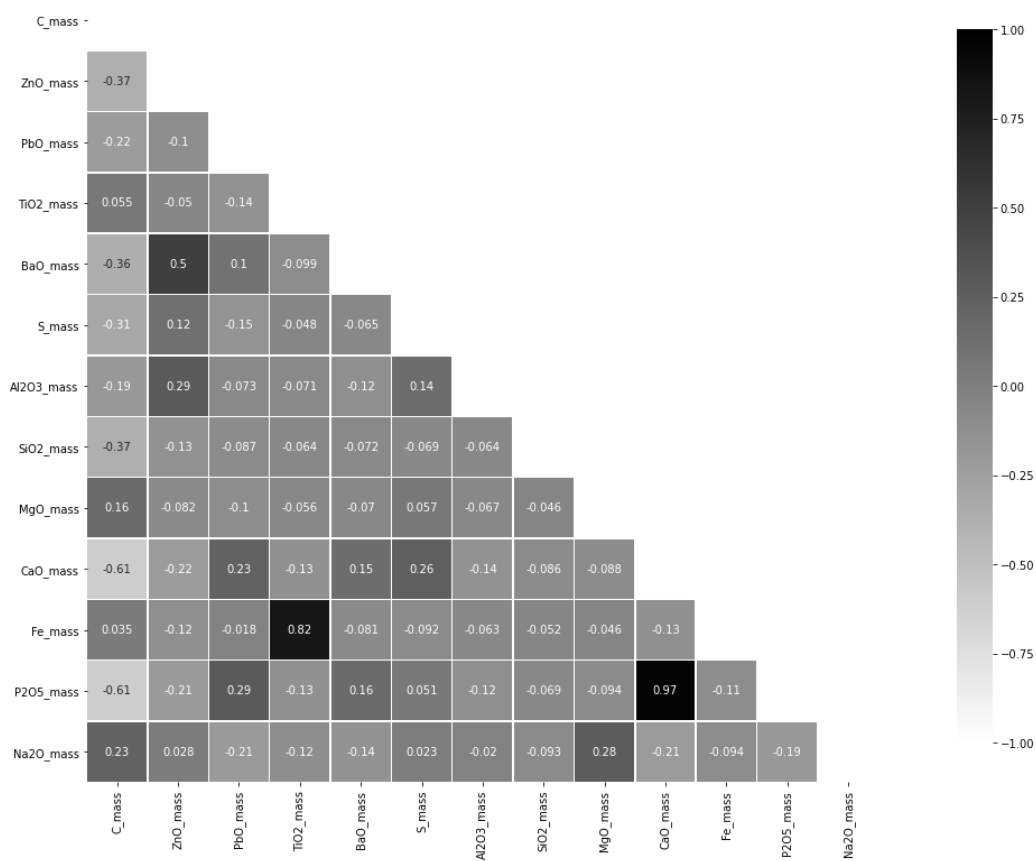


Figure 69. Correlation matrix of elements present in 26 black paint layers.

Table 28. Summary of correlations for black pigments.

Element	0.8 – 1.0 very strong, high	0.4 – 0.7 moderate	0.0 – 0.4 present
Zn		Ba	Al, S
Pb			P, Ca, Ba
Ti	Fe		
Ba	Zn		P, Ca, Pb
S			Ca, Al, Zn
Al			Zn, S
Mg			Na, C
Ca	P		Pb, Ba, S
Possible compounds present in the dataset			
Zn, Ba, S	Lithopone		
Mg, C	Magnesium carbonate		
Ba, S	Barium sulphate/ lithopone* (if there is presence of Ba, S and Zn. To be tested individually in the binary dataset)		
Ca, S	Calcium sulfate (gypsum)		
Possible pigments present in the dataset			
Ca, P	Bone black		
Fe	Iron oxide black		
C	Carbon black		
Notes			
Low correlation between Al and Si			
Ca, S appears which previous pigments did not have			

Table 29. List of pigment references used for the test dataset for black pigments.

Colour	Pigment classical names	Colour index	Chemical composition	Elements (inorganic)
Black	Carbon black/ Lamp black	BK1	C	C
Black	Bone black	BK2	$\text{Ca}_3(\text{PO}_4)_2 + \text{CaCO}_3 + \text{C}$	C, Ca, P
Black	Mars (iron oxide) black	BK3	Fe_3O_4	Fe
Black	Spinel black	BK4	MnFe_2O_4	Fe, Mn

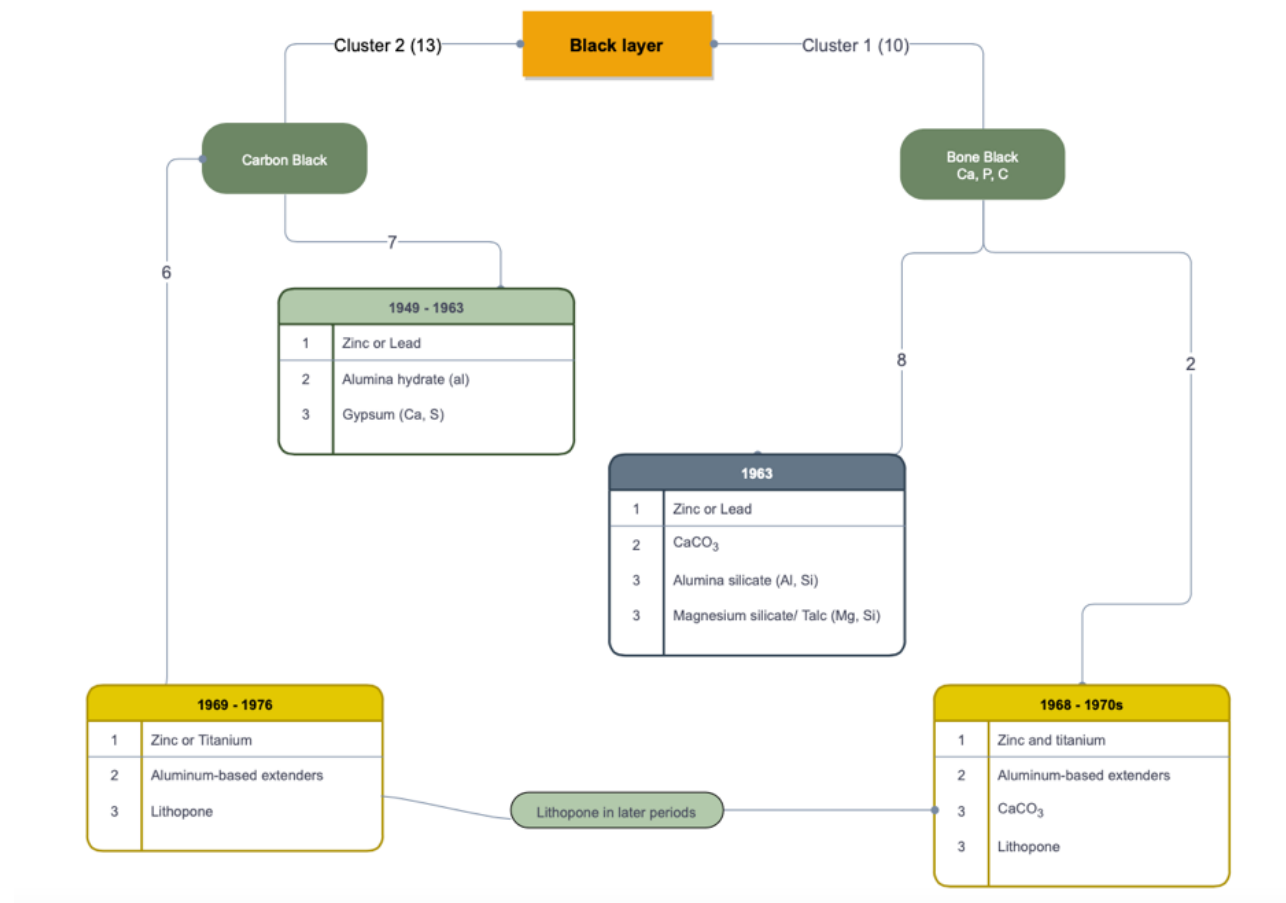


Figure 70. Cluster map illustrating the groups of black pigments and their characteristics found within the dataset of 26 Cheong Soo Pieng paint samples..

The clustering of the black pigments differs from the previous coloured pigments clustering, which was through the major components. The two preliminary clusters identified bone black and carbon black as major clusters (Figure 70). The differences between bone black and carbon black in terms of their optical qualities is that bone black tends to be semi-opaque to semi-transparent and is often lower in tinting strength, with a uniqueness in its warmth, from a yellow or brown undertone. Carbon black is usually very opaque with a high tinting strength, with smaller and dense pigment particles and a cooler tint.

Bone black, made of animal bones, is characterised by the presence of phosphorus (P) and with eight of ten samples attributed to 1963, the artist was likely using a particular brand during this period. Carbon black was present in two periods. The first is in pre-1963, where carbon black is with lead content. The second is during the later periods, from 1969 to 1976, which contained titanium in its composition. Present in ten of the 26 samples between 1949–1963, gypsum (Ca, S) appears unique to carbon black pigment and included aluminium-based extenders such as mica (potassium aluminium silicate) or kaolin (aluminium silicate). Zinc-based paints, together with aluminium-based extenders, were present in a majority of the samples through the years. However, it appears that lead was present from 1956 to 1963, and titanium after 1968. In later periods, after 1968, paint compositions contained lithopone, a compound known to have been used as a substitute for lead carbonate (van Driel et al. 2018b). However, the clusters presented are only presented to show the majority of samples and do not represent outliers, such as the presence of spinel black which had iron and manganese as well as titanium, in *Sleeping Lady* (1975).

Whites

A total of 12 samples embedded in cross-sections with white paint layers from 1948 to 1976 were available for study. The darker values represent a positive correlation, summarised in Table 30. The white correlation matrix in Figure 71 was executed only on the elemental metadata without non-structured visual observations as listed in Table 31.

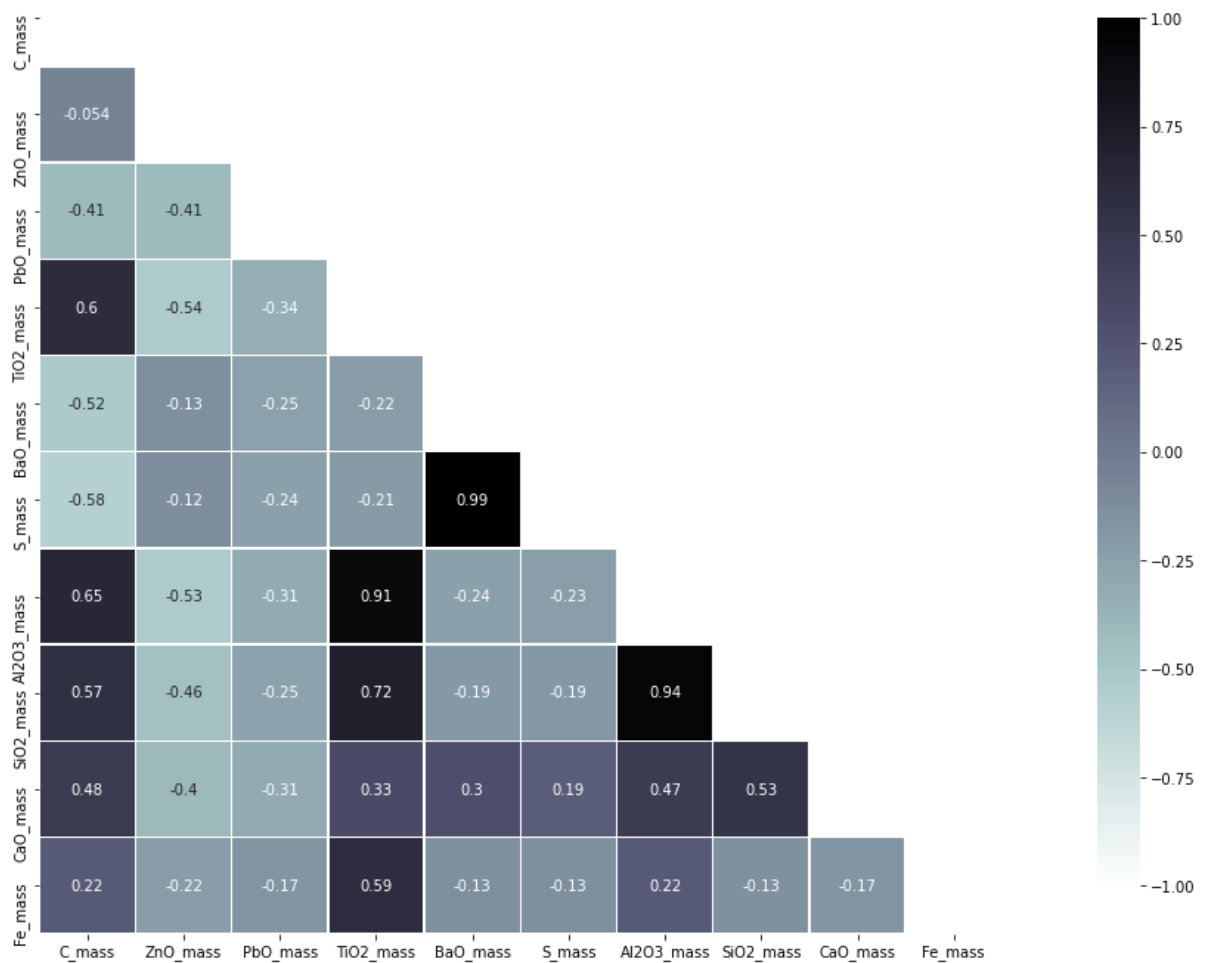


Figure 71. Correlation matrix of elements present in 12 white paint layers.

Table 30. Summary of correlations for white pigments.

Element	0.8 – 1.0 very strong, high	0.4 – 0.7 moderate	0.0 – 0.4 present
Zn			
Pb			
Ti	Al, Si	Fe, C	Ca
Ba	S		
Al	Si, Ti	Ca, C	Fe
Ca		Al, Si	Ti, Ba, S, C
Possible compounds present in the dataset			
Ba, S	Barium sulphate/ lithopone* (if there is presence of Ba, S and Zn. To be tested individually in the binary dataset)		
Al, Si	Aluminium silicate/ Mica		
Ca, C	Calcium carbonate (chalk)		
Notes			
- No presence of magnesium - Various extender-related elements (Al, Si, Ba) share a higher correlation with Ti - Negative correlations with Zn or Pb			

Table 31. List of pigment references used for the test dataset for white pigments.

Colour	Pigment classical names	Colour index	Chemical composition	Elements (inorganic)
White	Lead white		PbCO_3	C, Pb
White	Titanium white	PW6	TiO_2	Ti
White	Leaded titanium white	PY47	$2\text{PbCO}_3 \cdot \text{Pb}(\text{OH})_2, \text{TiO}_2$	Pb, Ti
White	Leaded zinc oxide white		PbZnO	Pb, Zn
White	Titanium zinc white		$\text{Zn}_2\text{Ti}_3\text{O}_8$	Ti, Zn
White	Zinc sulfides hydrate	PW7	ZnS	Zn, S
White	Lithopone	PW5	$\text{BaO}_5\text{S}_2\text{Zn}_2$	Ba, S, Zn
White	Zinc white oxide	PW4	ZnO	Zn

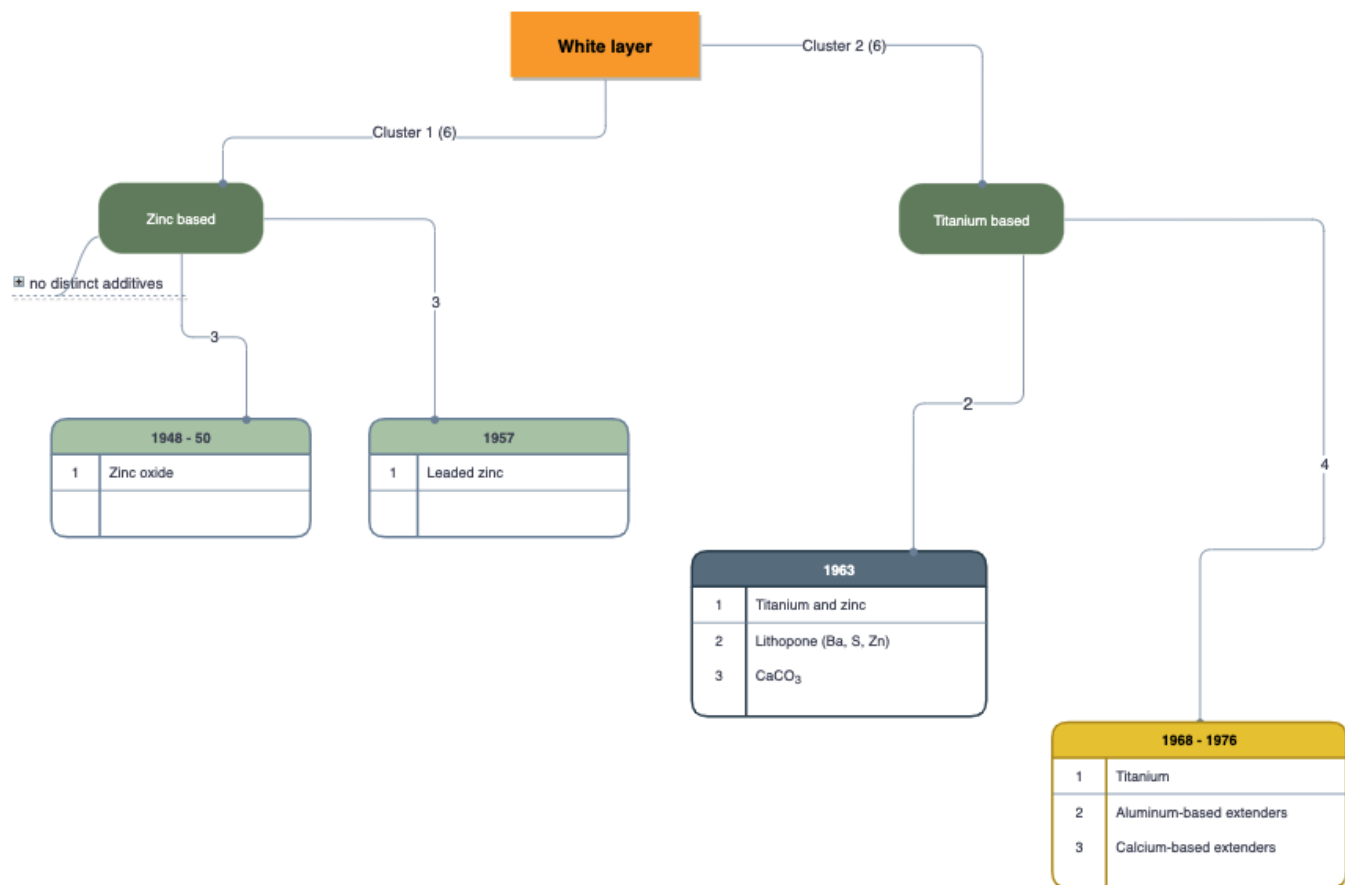


Figure 72. Cluster map illustrating the groups of white pigments and their characteristics found within the dataset of 12 Cheong Soo Pieng paint samples.

The study of white pigments identified prominent clustering, through the two major clusters of having a majority of zinc-based or titanium-based compositions (Figure 72). It appears to support a chronological trend where zinc-based compositions are present in the earlier period, of 1948 to 1957, while titanium-based compositions are present from 1963. Each of these clusters can be further classified into two groups. The zinc-based layers appear to have no distinct additives in the composition and there are three samples in 1957 which are characteristic of leaded zinc. The presence of lead in white paint compositions was limited to 1957, unlike the lead in artist grounds, which was found in the 1960s. Paint compositions with zinc oxides were not associated with other elements and are assumed to not have the presence of any distinct paint additives. Titanium-based paints in the later years fall into two categories. Paint compositions comprising titanium and zinc appear to have both lithopone and calcium-based extenders while titanium-only compositions were associated with the presence of calcium and aluminium-based extenders.

Summary

Exploratory analysis is an important phase in providing an overview of the data from which to develop specific research questions. The current methodology has shown that, while the identification of preliminary pigments remained consistent, the identification of clusters was executed in various ways, either by major elements such as titanium, zinc and lead, or by pigments. The correlation matrix and clustering of the overall ESEM-EDS dataset, focusing on five colours, reds, yellows, blues, blacks, and whites, establishes a preliminary understanding of pigments that may be present in Cheong Soo Pieng's painting materials and their presence in Singaporean artworks. Using an elemental reference built from existing conservation literature, elemental compound groups can be established (Learner 2004; Mayer 1991; Standeven 2011). The references formed the binary dataset which was used to suggest if an elemental compound is present or not. While the clusters and results are non-definitive and non-conclusive at this stage, this method has allowed insights into the distinctions between the various datasets, such as the presence of gypsum in black paints or the absence of magnesium-based extenders in white paint. The clustering of pigments is performed in the hope of forming a baseline foundation for future research on Cheong Soo

Pieng and other Singaporean artists' materials in the 1940s to 1980s, and can serve as a reference. This can be further optimised by including organic analyses and more in-depth elemental studies to give detailed insights on the paint composition and binders. This segment, having focused on quantitative-based findings, has set the stage for a more targeted overview of the trends and patterns utilising unsupervised learning of the ground and canvas layers, which will dive deeper by undertaking in-depth data mining with statistical methodologies of the paintings collectively.

6.4 Unsupervised learning methodology

The large number of metadata paintings generated from the paintings' technical examination and conservation analysis formed a large dataset that can be extracted to explore the relationships from the data collected. All data are text-based and have been structured following the ontology previously outlined in Chapter 3. While the limitations in text-based data are subjected to a semi-qualitative nature. However, language has a referential function and to some extent can be used to perform classification (Zhao et al. 2021, p. 1). The proposed methodology is inspired by recent research in computer science which has moved from computer vision being used to extract image information towards a focus on the metadata of artworks (Zhao et al. 2021, p. 2; Gultepe, Conturo & Makrehchi 2017, p. 14). Such research has mainly focused on the stylistic representation of paintings utilising classification and clustering. The various forms of analysis documented for each painting present opportunities for exploratory research on both ground and canvas preparation techniques through text-based classification and clustering across multiple variables. However, such approaches are unsupervised and would therefore require a careful analysis of the efficiency and accuracy of the results produced.

To perform the analysis, programming language Python was used in Google CoLab with NumPy, Pandas, Scikit-learn and Matplotlib libraries to clean, manipulate, visualise and analyse the dataset. The model adopts Pitsillides's (2020) model for clustering and correlation analysis, which was executed on a dataset containing both binary and text-based data. There are five main stages in the data analysis model (Figure 73). First, data sources are extracted from Airtable where 16 selected features are then used to form the main dataset,

before the dataset is further cleaned and transformed. The 16 features are detailed in the section ‘feature engineering’ below. The statistical modelling employs both Principal Component Analysis (PCA) and k-means and for unsupervised dimension reduction and clustering which undergoes several rounds of remodelling to reduce the dimensionality and improve the k-value to ensure the model’s best performance. The purpose of PCA is to reduce the number of variables from a larger dataset by transforming a larger set of variables while still preserving as much information as possible. While datasets with smaller dimensionality are easier to explore and visualise, the transformation process does result in questions of accuracy. K-means is used as a complementary technique to PCA to partition the variables into k clusters in which each variable belongs to a cluster with the nearest mean. Together, PCA and k-means is an exploratory tool that can visualise a diverse range of variables into a two-dimensional graph. Once the data processing reaches an optimal score, each painting is then assigned a cluster group. The resulting dataset is extracted and visualised as an interactive dashboard using Microsoft Power BI, a free-to-use data visualisation software that can produce visualisations as well as interactive dashboards to gain data insights. The interactive dashboard is built to visualise the relationships of the clusters and to enable the study of any commonalities within the clusters, which allows a study of the cluster’s characteristic traits to be summarised and discussed.

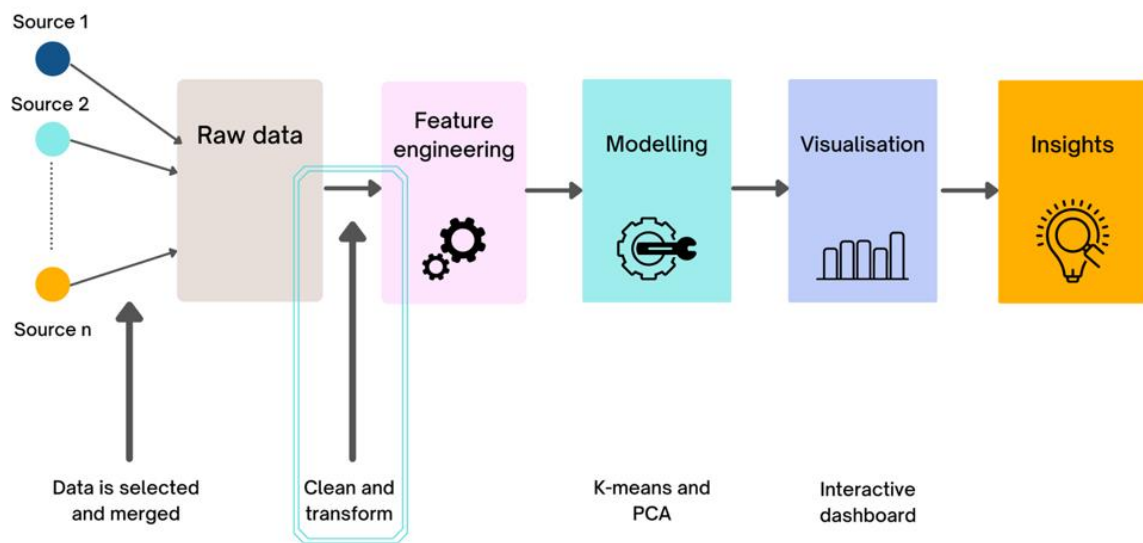


Figure 73. Feature engineering model illustrating the process of data transforming from raw data to insights.

A note on data bias

At this point, it is important to note that the data collected and used for the development of machine learning models are non-conclusive and offers only a partial understanding of Cheong Soo Pieng's practice based on the data collected. Drawing conclusions based on machine learning models can produce bias in the data used to train them (Veale & Binns 2017). While unsupervised learning models help to identify structures and correlations within the data, data bias will exist when the available data is not representative. In this case, only more research and more data can minimise this bias.

In addition, k-means is an unsupervised learning algorithm that is used to group variables with similar characteristics. K-means predicts the clusters based on a 'yes / no' rule which means that the data can only belong to one label (Jin & Malthouse, 2015). The approach taken in this paper to identify and correct such information deficit in the context of a fairer machine learning model is first a clear understanding of how the data was generated.

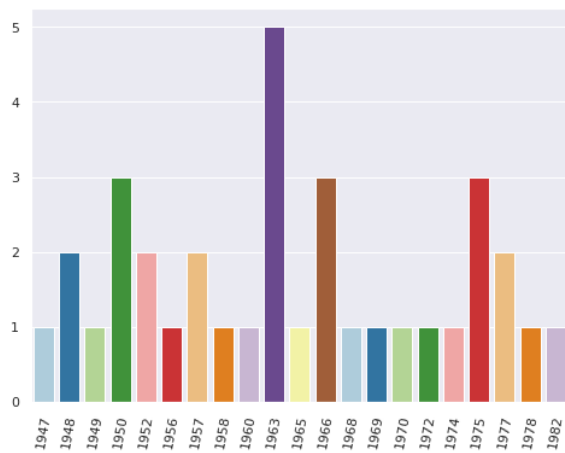
Mapping the data generation process can help to anticipate what type of bias can be presented and the interventions to mitigate it (Krishnamurthy 2019). Secondly, executing a comprehensive exploratory data analysis can help to identify patterns that might lead to bias. This has been addressed in Chapter 5 through exploratory analyses on various datasets to better understand Cheong Soo Pieng's materials and techniques. The visual representation of the data in the exploratory data process offer a first impression of potentially discriminatory patterns in the dataset.

Raw data

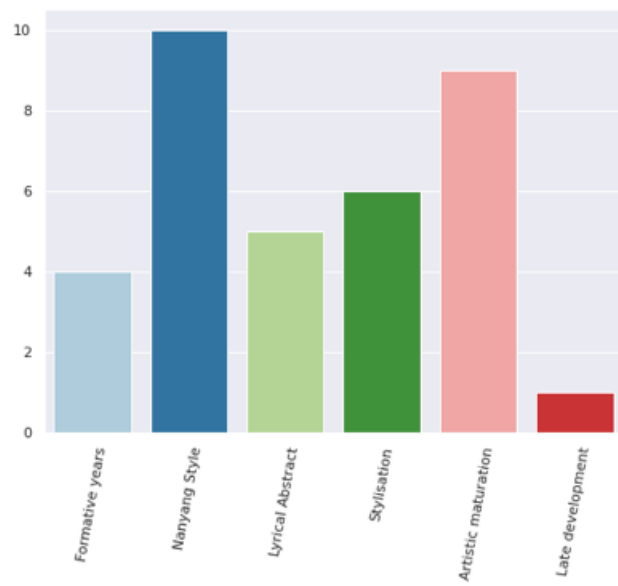
The statistical clustering of ground layers in the discussion above is a key feature when pulling together various sources to form the raw data for unsupervised learning. This section will integrate data across the scientific analysis and the observations recorded from the paintings' technical examination. The resulting dataset contains a total of 16 labelled metadata points, including the artwork's identification number, year, period, medium, support, fibre analysis, canvas manufacturer stamps, ground preparation, the texture of ground layer, main pigments of the ground layer, the presence of aluminium, calcium, or magnesium additives, count of additives in the ground layer and the analytical instrumentation. From the 57 paintings, 35 were selected, based on accessibility of all metadata points. Findings from this group of paintings have been discussed in the previous sections.

Clean and transform

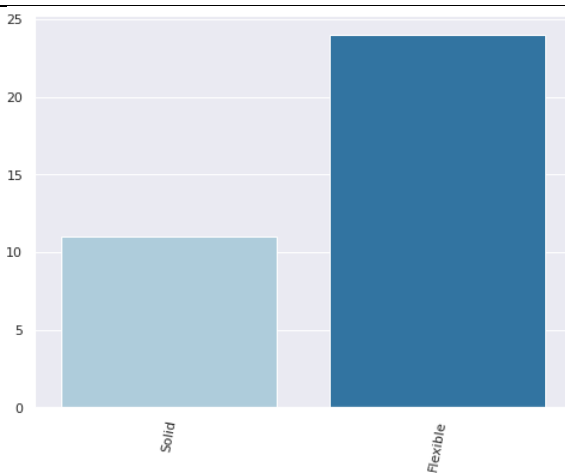
The dataset was checked for null values and all features (variables in columns) were visualised individually to understand the distribution of data (Figure 74 across four pages). Overall, the dataset appears distributed. While there are more samples from the Nanyang Style period (1950–1961), there is also a large number of paintings from 1963, from the Lyrical Abstract period (1962–1963). In addition, wood and cotton fibres appear to be evenly presented. As the metadata was built in a structured manner from the onset, minimal cleaning had to be performed.



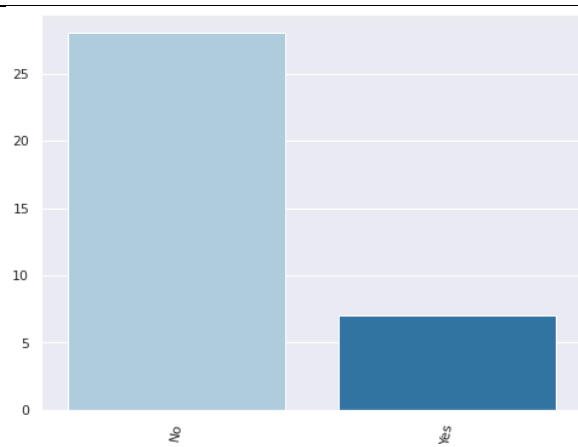
Year



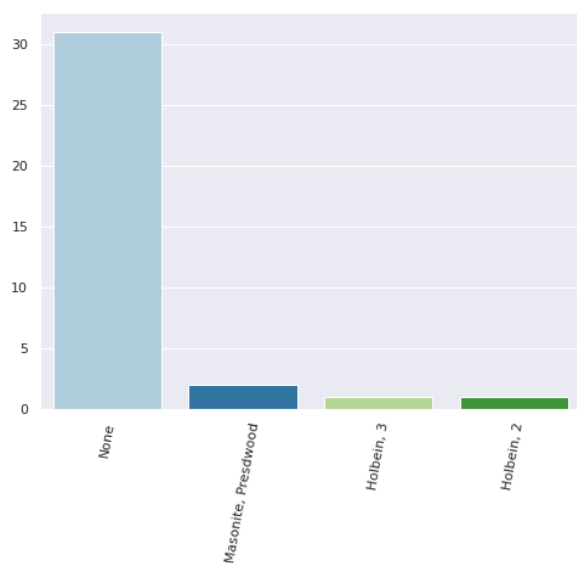
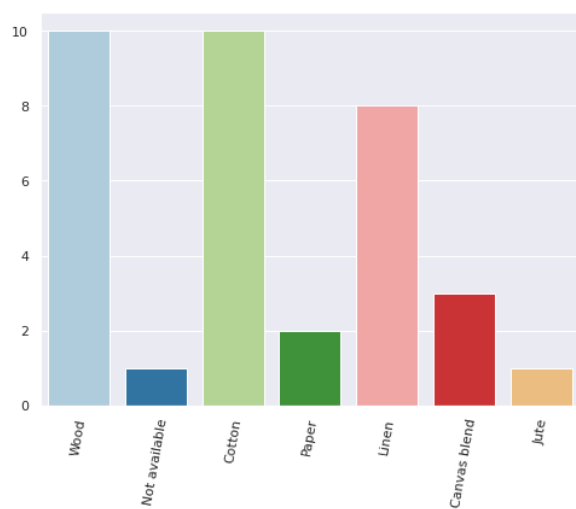
Period



Support

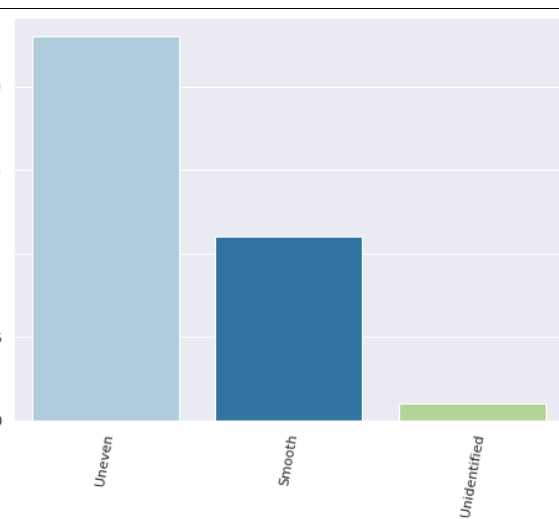
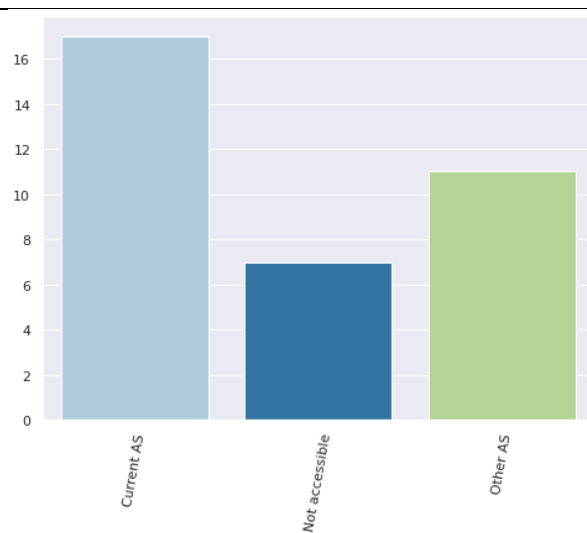


Marouflaged



Fibre type

Presence of manufacturer stamp



Ground preparation

Ground texture

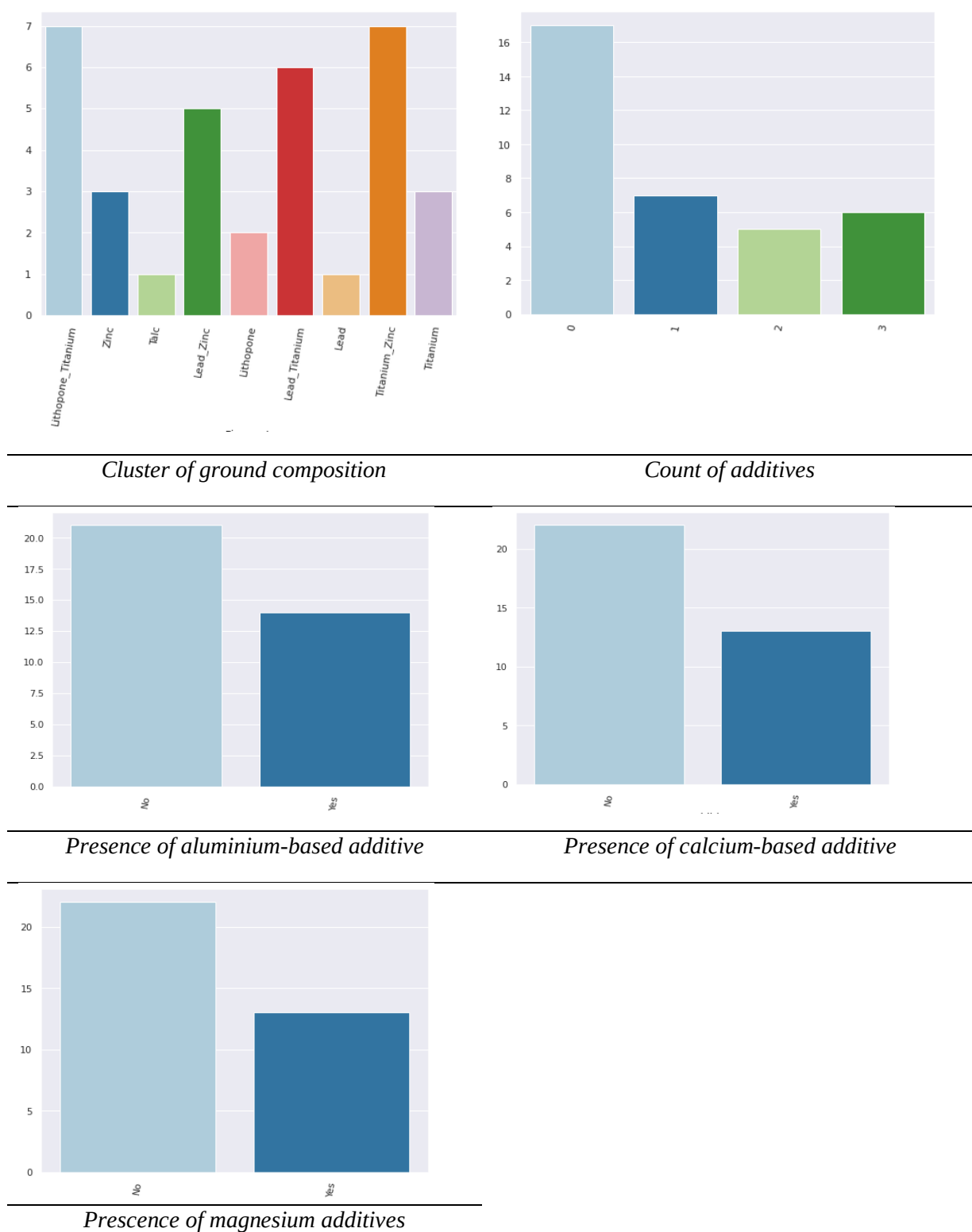


Figure 74. Exploration of data through visualisation of 13 selected features to include in unsupervised learning dataset.

Feature engineering

In data science models, the performance of the model is dependent on the data pre-processing and data transformation. Feature selection and engineering is key to improving the performance of the model. Features are required independent variables, for which this dataset has selected 16 data points from the documentation record from the onset. However, as the data is present in string (text) form, each variable was converted by the algorithm into a categorical variable and into a series of zeros and ones (dummy variables), allowing them to be quantified and compared (Langford 2017). Normalised to 1, the dummy variables indicate their presence within the dataset or not. The initial 16 features drawn from the documentation record make up the 16 data points, ranging from the period of Cheong Soo Pieng's oeuvre, the medium, support of each painting and whether it is marouflaged drawn from visual examinations as well as material analysis of fibre, ground topography and ground pigment findings from the ESEM-EDS. Each of these data points have fixed responses which form a total of 67 categorical variables based on the findings of each data point (see Table 32).

Table 32. Feature engineering by machine learning transforming 16 data points into 67 categorical variables.

Description	Details
Initial 16 data points	Painting_ID; Method; Year; Period; Medium; Support; Marouflaged; Fibre; Stamp; Preparation; Texture; Pigment; Al_additive; Ca_additive; Mg_additive; No_additives
67 categorical variables	Year_1947; Year_1948; Year_1949; Year_1950; Year_1952; Year_1956; Year_1957; Year_1958; Year_1960; Year_1963; Year_1965; Year_1966; Year_1968; Year_1969; Year_1970; Year_1972; Year_1974; Year_1975; Year_1977; Year_1978; Year_1982; Period_Artistic maturation; Period_Formative years; Period_Late development; Period_Lyrical Abstract; Period_Nanyang Style; Period_Stylisation; Support_Flexible; Support_Solid; Marouflaged_No; Marouflaged_Yes; Fibre_Canvas blend; Fibre_Cotton; Fibre_Jute; Fibre_Linen;

Fibre_Not available; Fibre_Paper; Fibre_Wood; Stamp_Holbein,
2; Stamp_Holbein, 3; Stamp_Masonite, Presdwood; Stamp_None;
Preparation_Current AS; Preparation_Not accessible;
Preparation_Other AS; Texture_Smooth; Texture_Uneven;
Texture_Unidentified; Pigment_Lead; Pigment_Lead_Titanium;
Pigment_Lead_Zinc; Pigment_Lithopone;
Pigment_Lithopone_Titanium; Pigment_Talc; Pigment_Titanium;
Pigment_Titanium_Zinc; Pigment_Zinc; Al_additive_No;
Al_additive_Yes; Ca_additive_No; Ca_additive_Yes;
Mg_additive_No; Mg_additive_Yes; No_additives_0;
No_additives_1; No_additives_2; No_additives_3

K-means clustering and Principal Component Analysis

Principal Component Analysis (PCA) is a widely used statistical technique for unsupervised dimension reduction while k-means is a commonly used data clustering technique for unsupervised learning tasks. Ding and He (2004) discuss the shared beneficial relationship of employing both PCA and k-means for clustering as the unsupervised dimension reduction in PCA is closely connected to unsupervised learning models. The main basis of a PCA-based dimension reduction is that PCA picks up the dimensions with the largest variances while the objective of k-means is to group similar data points and discover underlying patterns through a fixed number of clusters. An in-depth discussion of the mathematical formulas is beyond the scope of this project and is not discussed, as Python libraries are used to compute the calculation. In some cases, PCA computation occurs before k-means clustering. However, the model employed for the study applies k-means clustering first to gain first-order knowledge by creating preliminary clusters. These clusters will be re-engineered after PCA and returned to k-means for model and cluster improvements.

With 35 samples and 67 categorical variables, the model is first defined with four preliminary clusters, proposed as proportionate to the number of samples where each cluster would be represented by eight to nine paintings. In this research, only 35 samples were

analysed and as such, the clusters might not appear as tight as when compared to a larger dataset. However, keeping in view the long-term goal of accommodating larger datasets generated from future conservation studies on Singaporean artists, PCA and k-means cluster as a data exploration methodology that combines non-invasive and material analysis findings will increase efficiency and reduce human error in the cross-analysis. That said, the number of clusters may be changed in a later stage when the inertia score is calculated. The inertia score is a calculation that describes how well the data is clustered, and can be an indicator of how coherent the clusters are. A good model is one with low inertia and a low number of clusters. However, the score is relative to each model as the lower the inertia score, the higher the number of clusters. Given the small dataset of 35 paintings sampled, a lower number of clusters that features more paintings within each cluster might be able to provide a better overview. However, this process is subjective and characteristics of each cluster can change when the number of clusters chosen changes. As such, the balance between the number of clusters to best represent the dataset can influence the eventual analysis. The current initial inertia score for the preliminary four clusters and 67 categorical variables is 159.68.

To reduce the inertia score and find the optimal number of clusters for the dataset, the elbow-method is used to find the point where the decrease in inertia begins to slow and where the steepness of the curve is least. Furthermore, the inertia score is calculated between a range of two to 30 clusters. The elbow-method for clustering is a heuristic approach in determining the best number of clusters to represent a dataset which involves picking on the first elbow of the curve. While the inertia score is the least for 29 clusters, the clusters may not be useful for data representation. In the visualisation, the fourth cluster appears to be where the first elbow occurs (Figure 75) and therefore the cluster size will be kept at four with a inertia score of 159.68 for PCA analysis.

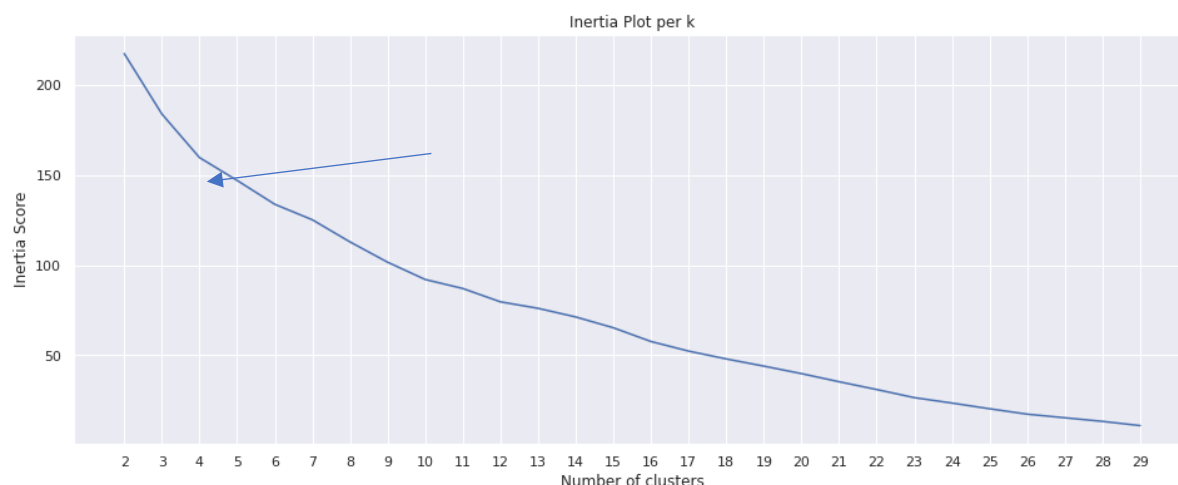


Figure 75. Utilising the elbow-method visualisation to locate the first point of the curve that identifies the optimal number of clusters for the dataset (4, 159.68).

The paintings are distributed across the four preliminary clusters which will be re-visited after PCA. In this initial clustering, Cluster 1 has 11 paintings, Cluster 2 has 9, Cluster 3 has 9 while Cluster 4 has 6 paintings. Overall, it appears to have sufficient paintings in each cluster to analyse characteristics at a later stage.

PCA modelling

PCA is a statistical dimensionality reduction technique whose main goal is to extract the most delineating information from the dataset. It transforms possibly correlated variables into a reduced number of uncorrelated variables via noise reduction, which are the principal components. As an unsupervised dimension reduction, it has been applied in broad areas such as image processing, information retrieval, and medical studies (Ding & He 2004). Given the current size of the dataset, 35 rows by 67 categorical variables, there is room for dimensional reduction. In the unsupervised learning model where the number of principal components is chosen, it is hoped that the model will achieve 95% explained variance. This means that at least 95% of the dataset can be explained by a specified number of principal components. However, the fewer principal components, the lower the variance, which means less Information is captured in the clustering. Figure 76 presents a scatter plot when only two such components are selected, which provides an initial overview of the clusters before re-modelling.

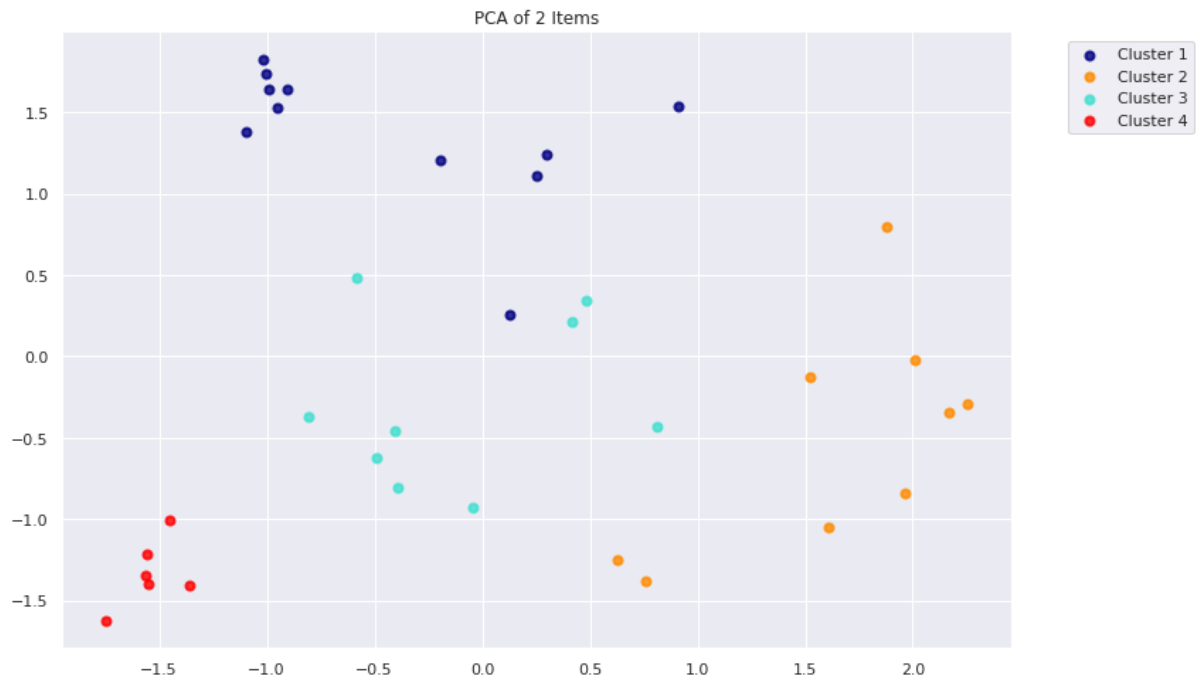


Figure 76. Scatterplot of two principal components from the initial dataset showing four clusters.

With the dataset, PCA is executed using the Python Scikit-Learn library. The dimensionality of the dataset is first reduced to two principal components for the visualisation of the distribution of data and the preliminary four clusters through a scatterplot. From the visualisation, the four clusters are already observed to occupy distinct spaces within the diagram, with a tight clustering for Cluster 4 (red). While the total explained variance ratio of two principal components is 36% variance, this does not represent the quality of the results. The second step is to identify the best number of components for PCA.

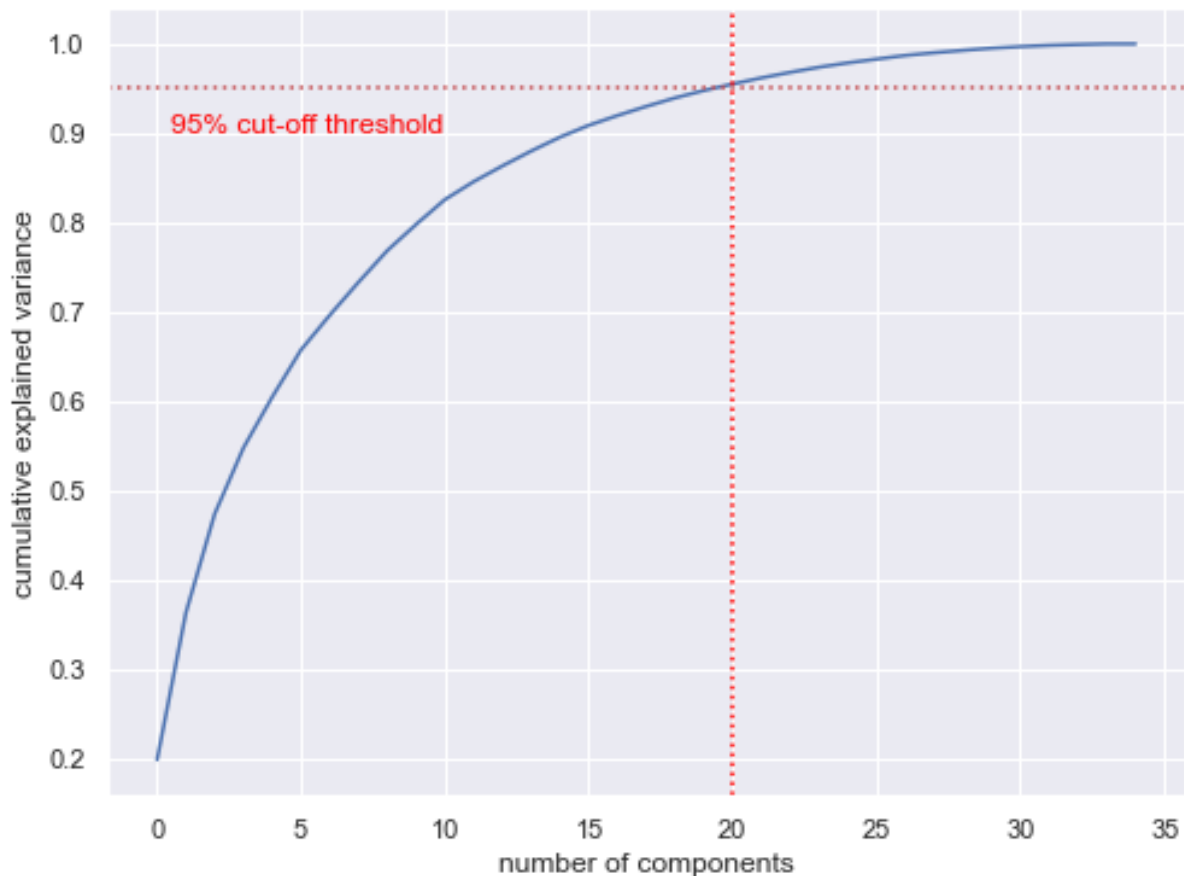


Figure 77. Scatterplot showing that 20 of 67 components can explain 95% of the data.

Before undergoing a re-engineering of the k-means cluster, PCA will help to improve the model. A useful measure is the explained variance, which summarises how much information (variance) can be attributed to the number of principal components. Figure 77 shows a scatter plot illustrating that, with 20 of the 67 components, 95% of the data can be represented. Python is executed to calculate the total variance in the dataset, which is 7.59, while 95% variance would require a score of 7.21. Individual components from a range of 15 to 35 components are then calculated to identify the closest number of components that hit the 7.21 variance. The variance of 20 components at 7.19 was found to achieve a 95% variance of the data. Using 20 principal components, the k-means model was rerun. The resulting k-means inertia score for four clusters was reduced from 159.68 to 146.44, which improved the model after running PCA with 20 principal components.

Improving results

One way to further improve results is by combining variables. Six of the 67 categorical variables were grouped and resulted in 65 categorical variables instead, as shown in the following:

Stamp: 'Stamp_Holbein, 2' and 'Stamp_Holbein, 3' were combined as a single category 'Stamp_Holbein, 2&3' as it was not necessary to identify the manufacture stamp series of 'Holbein 2' or 'Holbein 3' in an overview of four clusters. Instead, by combining the two categories, whether a Holbein stamp was present or not is still identifiable.

No_additives: No_additives_0; No_additives_1; No_additives_2; No_additives_3 were grouped into three categories: '0', '1-2', '3'

All steps for the PCA and k-means were run again with the new combined columns. In the new scatter plot (Figure 78), some reorganisation of the data points and clusters at the bottom of the chart is observed. Previously a part of Cluster 2 (Figure 78), two data points have been re-classified as Cluster 4, represented as red dots, in the new model.

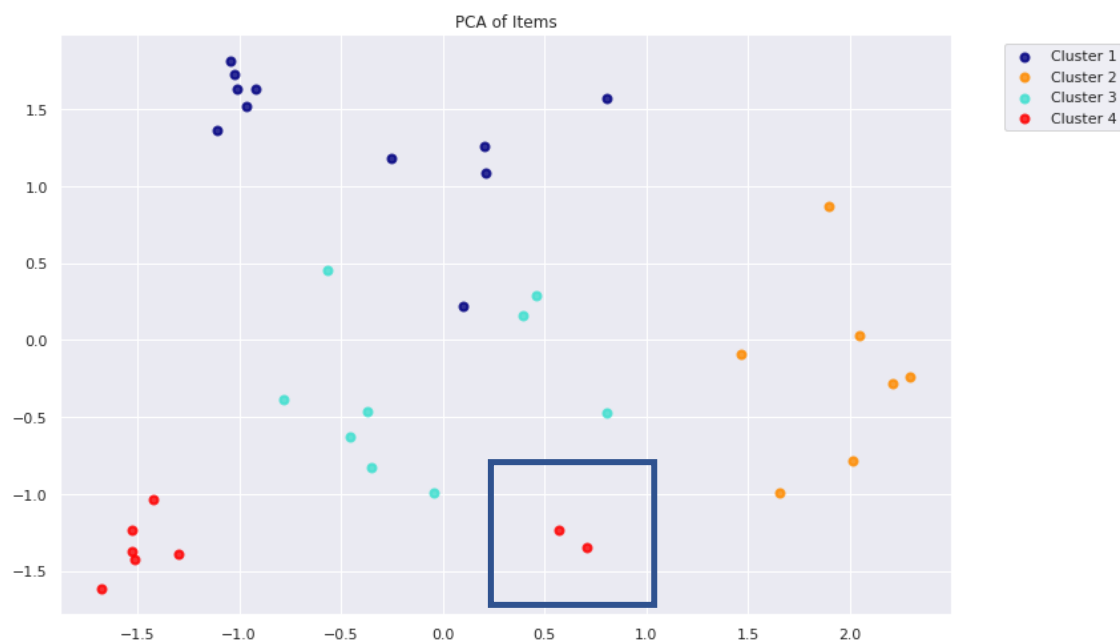


Figure 78. New scatterplot showing reassignment of two points highlighted in box after re-modelling.

Following the combining of the data, a final PCA was run. The resulting inertia score for four clusters is 138.81, compared with the initial score of 159.68, indicating that the model has been improved. The clusters profile is then attached back to the initial dataset. In the improved model, Cluster 1 still features 11 paintings. However, Cluster 2 has 7 instead of 9, Cluster 3 remained the same with 9 paintings and Cluster 4 currently has 8. In the changes, Cluster 2 and 4 have different number of paintings assigned to their clusters.

Cluster 1	Cluster 2	Cluster 3	Cluster 4
11	7	9	8

Creation of order columns for text values

To improve the visualisations in the interactive dashboard on Power BI, order columns for the string (text) values are created. This step does not affect the analysis but helps to organise the data. The columns that were organised were period, fibre, stamp, preparation, and ground texture as seen in Figure 79. The resulting dataset was exported as a .csv file to be visualised in Microsoft Power BI.

Interactive dashboard using Microsoft Power BI

Across the four clusters of 35 artworks, the distribution of the data is presented across 15 individual bar chart visualisations in Figure 80a (spread across three pages for readability). The benefit of an interactive dashboard is that it allows for rich insights to be gained for each cluster. Furthermore, it allows the user to select and filter key areas of interest, and to identify outliers in clusters to be further investigated as seen in Figure 80b when specific cluster is selected. The characteristic traits for each cluster are discussed in the next section.

```
[ ] # Creating an order for Period

raw_data['Period Order'] = 0
raw_data['Period Order'].loc[raw_data['Period'] == 'Formative years'] = 1
raw_data['Period Order'].loc[raw_data['Period'] == 'Nanyang Style'] = 2
raw_data['Period Order'].loc[raw_data['Period'] == 'Lyrical Abstract'] = 3
raw_data['Period Order'].loc[raw_data['Period'] == 'Stylisation'] = 4
raw_data['Period Order'].loc[raw_data['Period'] == 'Artistic maturation'] = 5
raw_data['Period Order'].loc[raw_data['Period'] == 'Late development'] = 6

# Creating an order for Fibre

raw_data['Fibre Order'] = 0
raw_data['Fibre Order'].loc[raw_data['Fibre'] == 'Wood'] = 1
raw_data['Fibre Order'].loc[raw_data['Fibre'] == 'Linen'] = 2
raw_data['Fibre Order'].loc[raw_data['Fibre'] == 'Cotton'] = 3
raw_data['Fibre Order'].loc[raw_data['Fibre'] == 'Canvas blend'] = 4
raw_data['Fibre Order'].loc[raw_data['Fibre'] == 'Paper'] = 5
raw_data['Fibre Order'].loc[raw_data['Fibre'] == 'Jute'] = 6
raw_data['Fibre Order'].loc[raw_data['Fibre'] == 'Not available'] = 7

# Creating an order for Stamp

raw_data['Stamp Order'] = 0
raw_data['Stamp Order'].loc[raw_data['Stamp'] == 'Holbein, 2'] = 1
raw_data['Stamp Order'].loc[raw_data['Stamp'] == 'Holbein, 3'] = 2
raw_data['Stamp Order'].loc[raw_data['Stamp'] == 'Masonite, Presdwood'] = 3
raw_data['Stamp Order'].loc[raw_data['Stamp'] == 'None'] = 4

# Creating an order for Preparation

raw_data['Preparation Order'] = 0
raw_data['Preparation Order'].loc[raw_data['Preparation'] == 'Other AS'] = 1
raw_data['Preparation Order'].loc[raw_data['Preparation'] == 'Current AS'] = 2
raw_data['Preparation Order'].loc[raw_data['Preparation'] == 'Not accessible'] = 3

# Creating an order for Texture

raw_data['Texture Order'] = 0
raw_data['Texture Order'].loc[raw_data['Texture'] == 'Smooth'] = 1
raw_data['Texture Order'].loc[raw_data['Texture'] == 'Uneven'] = 2
raw_data['Texture Order'].loc[raw_data['Texture'] == 'Unidentified'] = 3
```

Figure 79. Screen capture of order creation using Python

No. of Data Points

35

Ground Clusters PCA & K-Means

1. Filters

Clusters

Cluster 1

Cluster 2

Cluster 3

Cluster 4

Year

All



Period

All



Marouflaged

No

Yes

Medium

All



No. of Additives

All

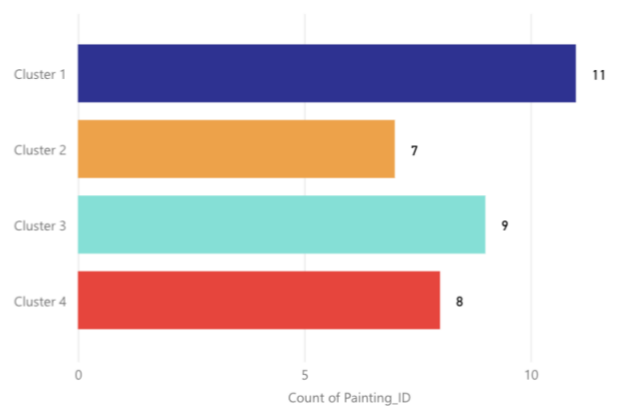


Method

SEM

2. Summary by Paintings Samples

Painting Samples Per Clusters



Clusters Description

Painting_ID	Clusters Category	Period	Year
PTG005_CSP005	Cluster 1	Stylisation	1966
PTG006_CSP006	Cluster 1	Formative years	1947
PTG009_CSP009	Cluster 1	Nanyang Style	1958
PTG015_CSP015	Cluster 1	Formative years	1948
PTG022_CSP022	Cluster 1	Nanyang Style	1950
PTG032_CSP031	Cluster 1	Formative years	1948
PTG051_CSP049	Cluster 1	Nanyang Style	1952
PTG054_CSP052	Cluster 1	Nanyang Style	1960
PTG063_CSP055	Cluster 1	Nanyang Style	1950
PTG067_CSP059	Cluster 1	Nanyang Style	1950
PTG002_CSP002	Cluster 3	Stylisation	1968
PTG011_CSP011	Cluster 2	Stylisation	1965
PTG019_CSP019	Cluster 3	Artistic maturation	1974
PTG020_CSP020	Cluster 2	Lyrical Abstract	1963

3. Cluster Analysis

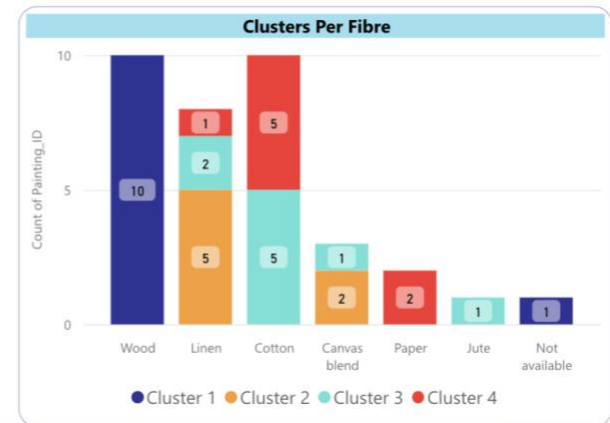
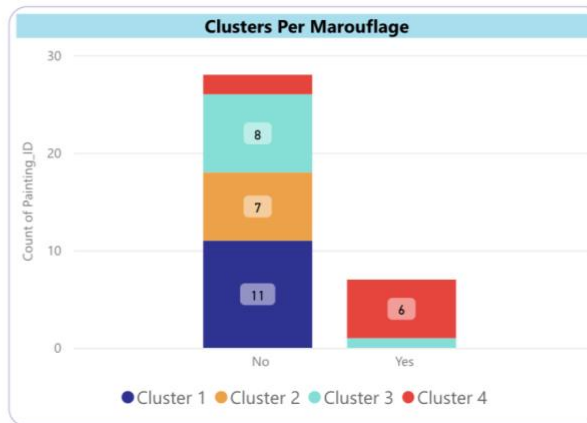
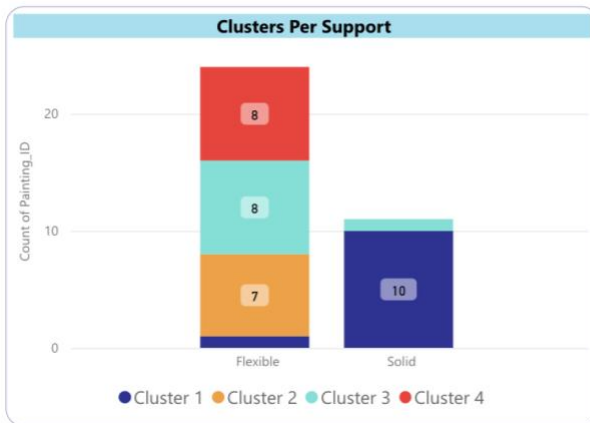
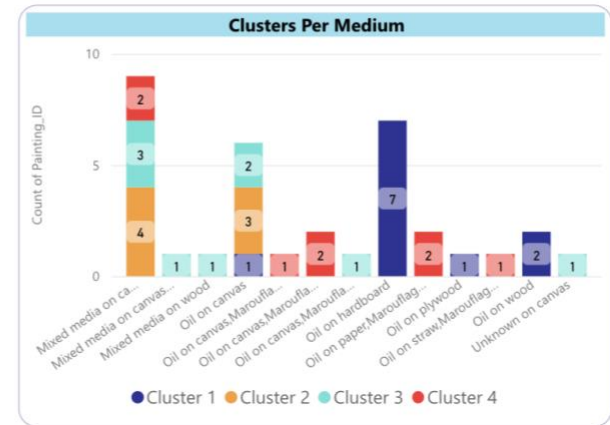
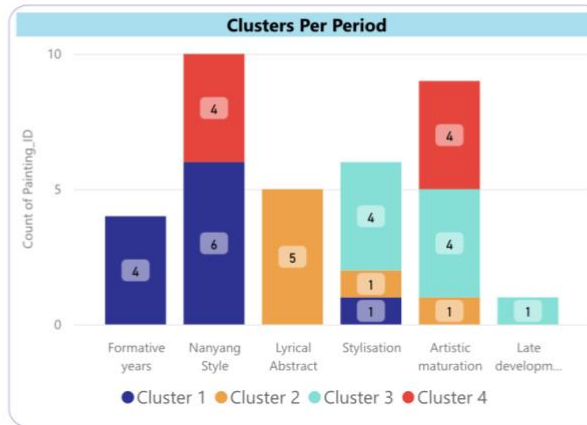
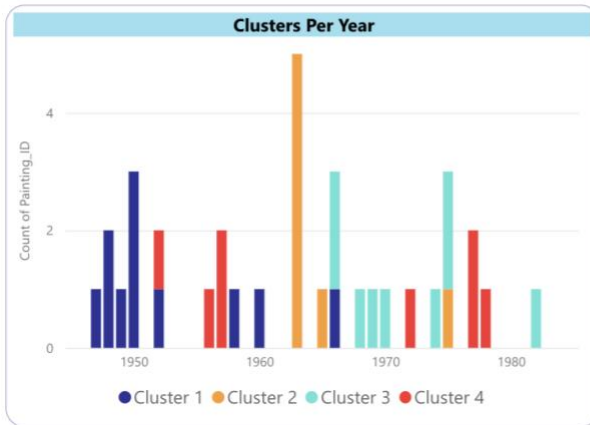
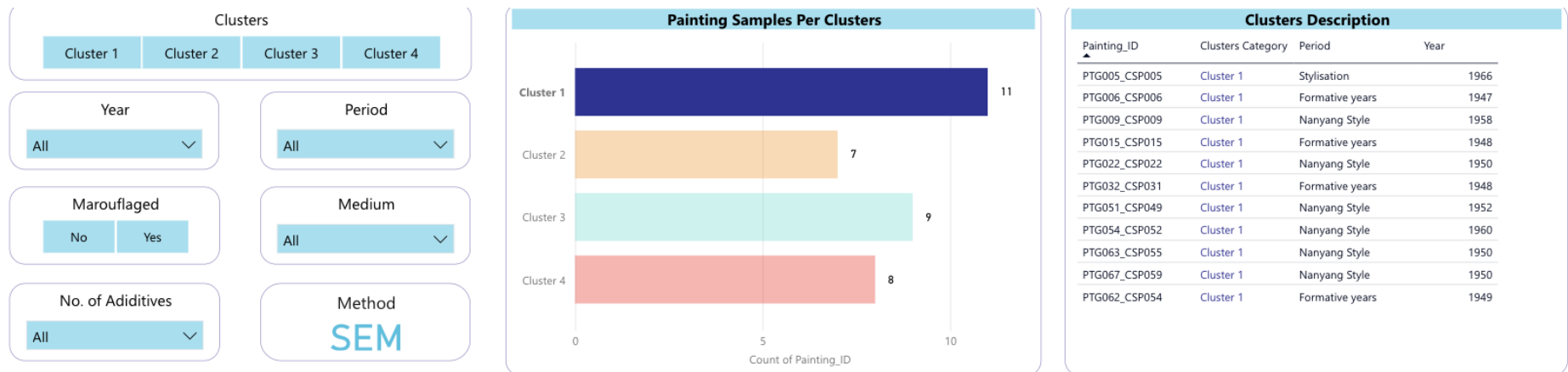




Figure 80a. Screenshot of interactive Power BI dashboard



3. Cluster Analysis

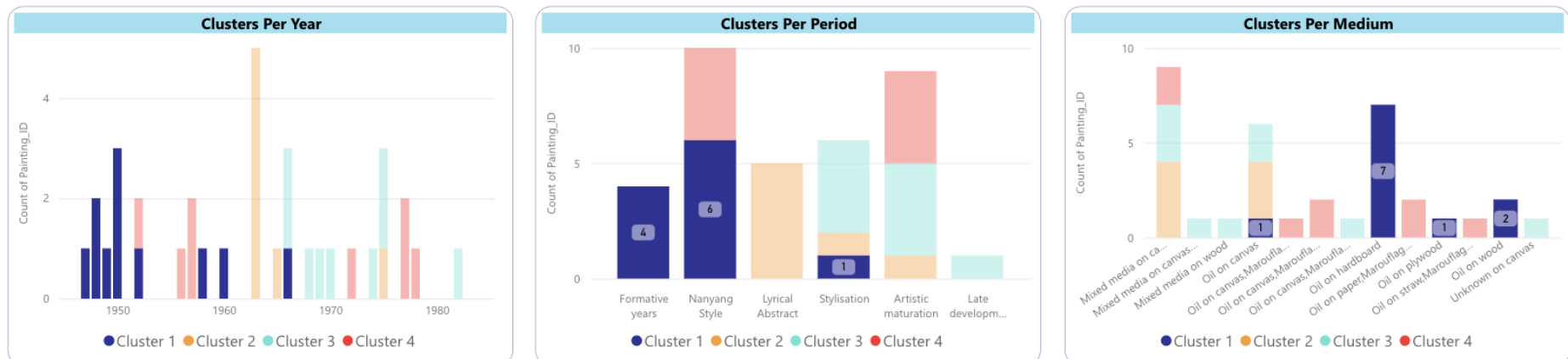


Figure 80b. Example screenshot of when Cluster 1 is selected on Power BI dashboard, highlighting only relevant fields.

6.5 Analysis

The clusters presented here are created through an unsupervised machine-learning model, and the generalisability of these results is subject to certain limitations. For instance, the selection of clusters affects how the data are interpreted and the small sample size affects the density of each cluster, all of which are subject to subjective interpretations.

Notwithstanding these limitations, this work offers valuable insights into how relationships between metadata can be grouped and collectively mapped. The outliers presented in each cluster do not suggest or indicate non-attributed works but are instead a suggestion for further analysis and an indicator of the artist's exploratory nature. The characteristics of each of the four clusters are presented below.

Cluster 1: Works on solid supports (1947–1960)

Main attributes: Works on a solid support during the Formative Years (1946-1949) and Nanyang style periods (1950–1961).



based on calcium or aluminium. There is one artwork on canvas within this cluster. However, it does not present as an outlier, because its ground composition is similar to that of the works on solid supports.

Possible outliers: One sample distinctly not within the clusters is *Untitled (Indian Lady with Veil)* (1966). Despite being an oil on hardboard painting, it has a lead and titanium ground layer, which has otherwise only been attributed to Cluster 3's ground layers, comprising pre-primed canvas supports from 1963. Furthermore, this painting has an observed change of signature which was uncovered by reflected infrared photography (IRR) at 780nm. Further analysis is required for this painting.

Untitled (Indian Lady with Veil) presented challenges in its attribution despite a signature and date. On the right, there is Chinese script that says 一九六六年 (1966) with Cheong Soo Pieng's signature (see Figure 82). However, in the top right corner, as shown in Figure 83, an overpainted inscription with year is visible in IRR, which appears to read 'L Lim 灵 5?'. The change was made at a later stage, as identified under ultraviolet-induced visible fluoresce illumination (UVF). Another point of discussion is the presence of Cheong Soo Pieng's Chinese signature, which was defining of his practice after Europe, as discussed in detail in Chapter 5.3, page 196.



Figure 82a. Cheong Soo Pieng, *Untitled (Indian Lady with Veil)*, c.1966 (61 x 45, oil on hardboard). Collection: KSC.



Figure 82b. Close up of signature in centre right edge of painting. Cheong Soo Pieng, *Untitled (Indian Lady with Veil)* (1966).



Figure 82c. Top right corner of overpainted signature in visible light. Cheong Soo Pieng, *Untitled (Indian Lady with Veil)* (1966).



Figure 82d. Top right corner of overpainted area under UVF. Cheong Soo Pieng, *Untitled (Indian Lady with Veil)* (1966).



Figure 83. Hidden signature discovered top right corner in reflected infrared photograph. Cheong Soo Pieng, *Untitled (Indian Lady with Veil)* (1966).

Cluster 2: Pre-primed canvasses (1963 and 1965)

Main attributes: Pre-primed canvasses in Cheong Soo Pieng's curatorial categorisations, Lyrical Abstract (1962-1963) and Stylisation (1964–1969), made of linen fibres and with no additives in the ground layer.

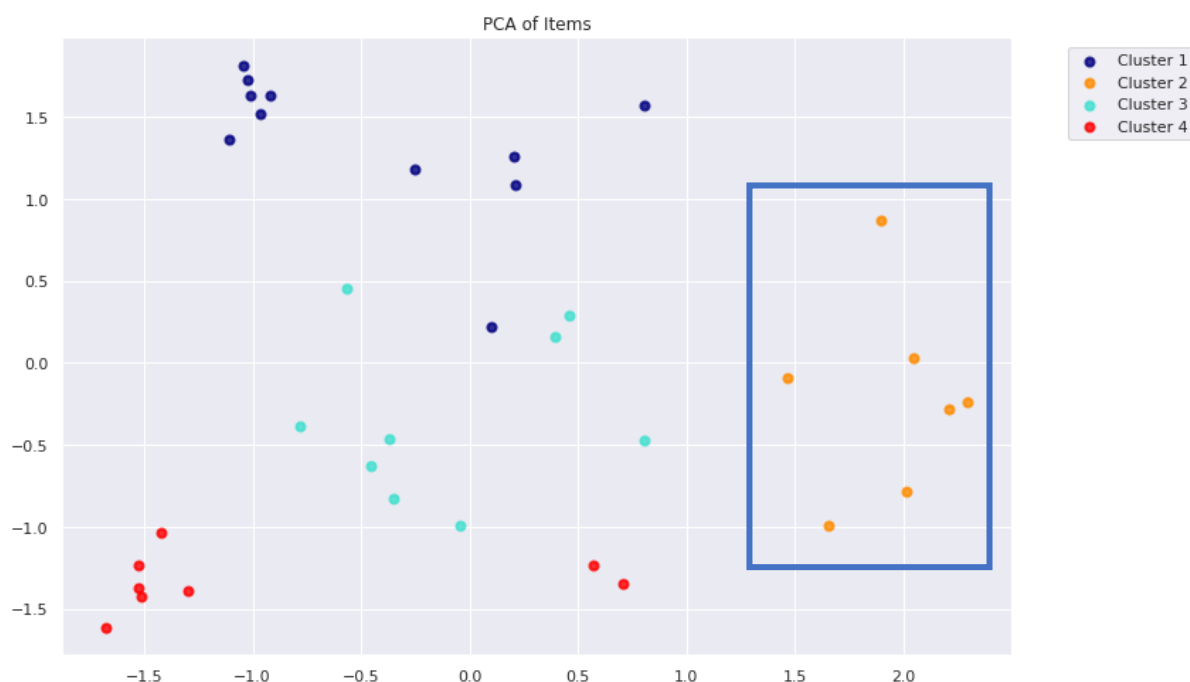


Figure 84. Cluster 2, orange, comprising of seven paintings, highlighted within scatterplot.

As the smallest cluster of the four, six of these seven artworks are dated between 1963 and 1965 (Figure 84). While most of the artworks are dated 1963, one painting, *Green Landscape* (1975), outside the highlighted square. All seven paintings are on canvas supports and are not marouflaged. The fibres were identified as linen or canvas blends. Most of the ground layers had a smooth texture and were prepared on another auxiliary support. This is the only cluster that features Holbein stamps, indicative of commercially available pre-primed canvasses. The most common ground composition of the ground layers is lead and titanium. It is the only cluster with no additives in the ground composition.

Possible outliers: One outlier was identified in the cluster, which is probably due to a later date attribution of 1975. It had a ground composition of lithopone and titanium. However, it shared similarities with the others, such as having no ground additives and being made of linen fibre, which is probably why it was classified within this cluster. A larger sample size of paintings from between 1963 and 1975 would be able to improve the model.

Cluster 3: Later experimental works (1966 to 1975)

Main attributes: Works of art between 1966 and 1975 which are mixed media but are not marouflaged and contain a ground composition of two to three types of additives.

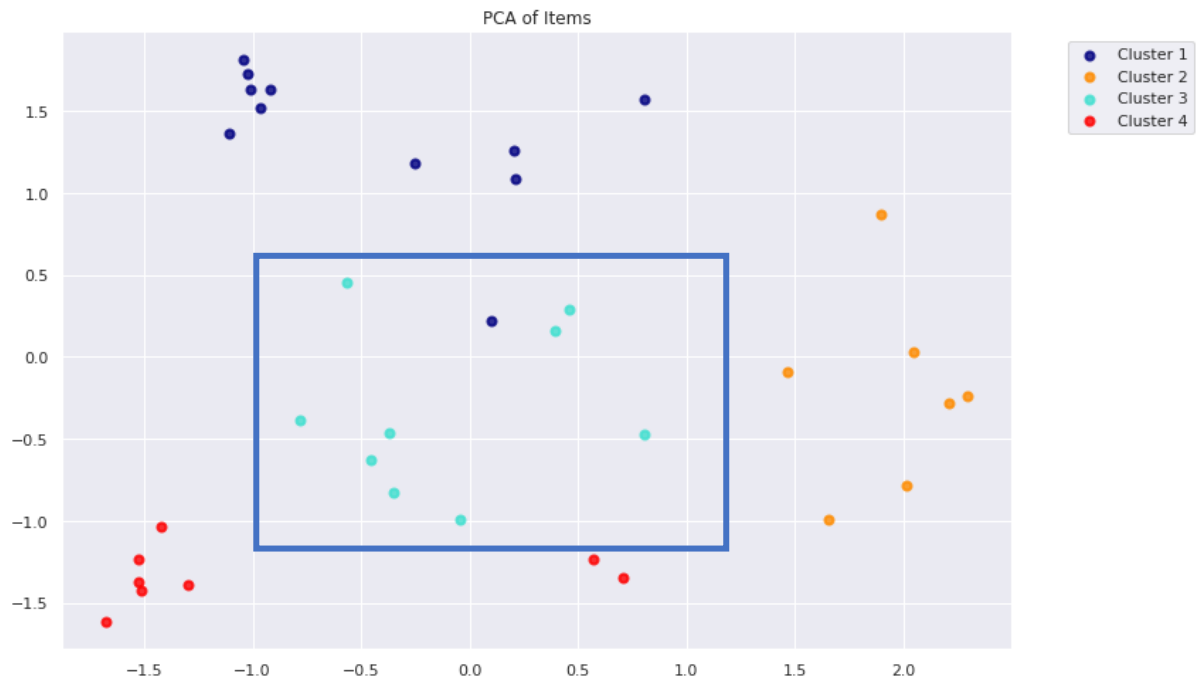


Figure 85. Cluster 3, green, comprising of nine paintings, highlighted within scatterplot.

Paintings in this cluster illustrated in Figure 85 span the later period of Cheong Soo Pieng's oeuvre, from Stylisation (1964-1969) to the Late Developments periods (1979-1983). Most of the works are mixed media on flexible support and are not marouflaged, except for one mixed media work on wood with jute fabric. It is proposed that the lack of cluster density is because of the diverse range of artworks, representing new phases and experimentation with a variety of mediums and a variety of fibres.

The clusters identify 1966 as the year of material transformation, departing from Clusters 1 and 2, which had a distribution over one to two types of fibres. Much of the ground composition contains titanium and zinc, and two or three additives. All the ground composition in this cluster contains both aluminium and calcium-based additives, while 67%

of them also contained magnesium-based additives. This cluster has the most additives in the ground composition. In the Artistic Maturation (1970-1978) period, most of the canvasses were prepared on the existing supports. There is no distinct outlier in this cluster, given the varied mediums. However, the data point of Cluster 1, a 1966 oil on hardboard, is within range, possibly sharing the commonality of the year range.

Cluster 4: Marouflaged works between Stylisation and Nanyang Style

Main attributes: Artistic Maturation (1970-1978) period as a revisitation of the Nanyang Style (1950-1961) through the localisation of Western art practice and marouflaging.

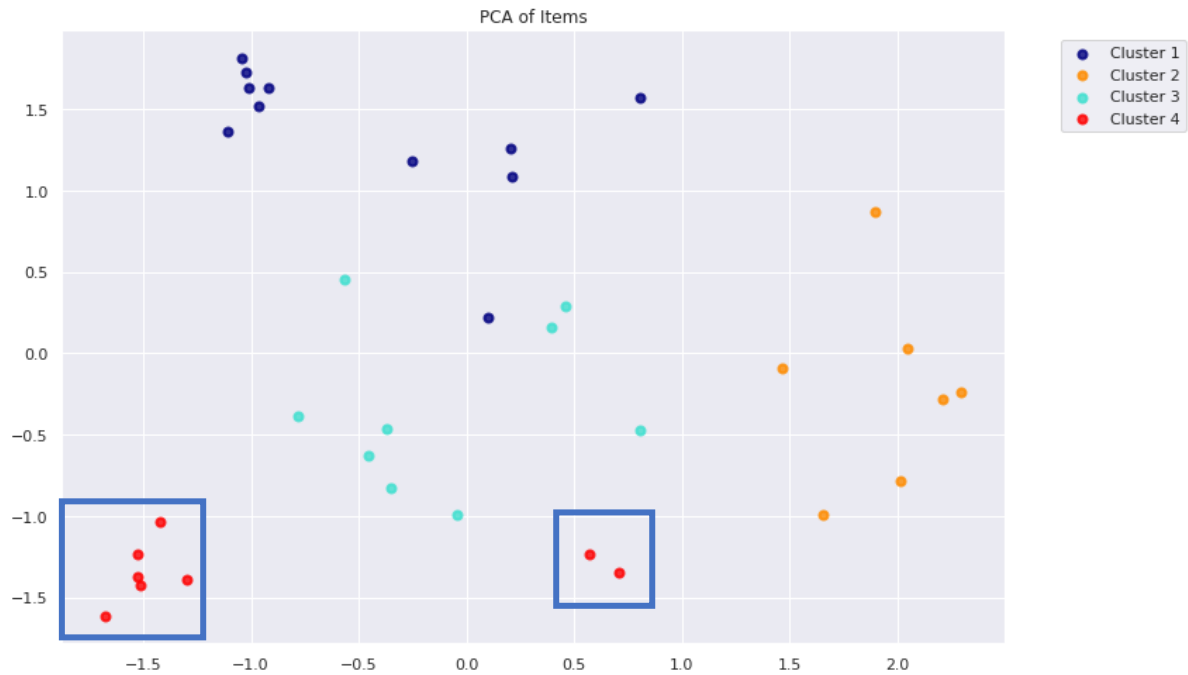


Figure 86. Cluster 4, red, comprising of eight paintings, highlighted within scatterplot.

Surprisingly, this cluster's features are uniquely distributed, with four artworks from the Nanyang Style period (1951–1960) and four from Artistic Maturation (1970–1978) as illustrated in Figure 86. All the works are on flexible support and the works in this cluster are marouflaged. The even distribution between the two periods does not correlate visually with the scatterplot, given that there are four from each period. However, it does suggest that the two works represented in the box on the right featuring two paintings are marouflaged. A detailed discussion on the use of marouflage and the localisation of Western art practices can be found in Chapter 5.3, pages 154 and 176. The fibres identified during the Nanyang Style period are linen and paper, while fibres from the Artistic Maturation period are all cotton.

Given the distribution of the cluster, the ground compositions are varied. Works on hardboard contain either lead or zinc-based grounds while titanium-based grounds appeared only after 1972. Overall, this cluster features a maximum of one additives. There are no distinct outliers in this cluster.

Curators and scholars have referred to the 1970s as a period where the various dynamics and elements of the past phases, such as the Nanyang Style, cross paths. Interestingly, the material-based metadata from which the clusters are built supports this curatorial narrative. Cheong Soo Pieng revisited the earlier Nanyang works in the later phases of his oeuvre.

Summary

Central to the clusters created using unsupervised statistical methods such as PCA and k-means was a range of structured metadata built on understandings across various evidence-based results. In particular, the elemental groupings of the ground layer, which were identified in the first phase using the correlation matrix, were further developed through the statistical methods of PCA and k-means clustering. The variations in ground layers shared a close relationship with primary supports and the artist's oeuvre. This segment offers a new model for understanding the artist's materials and techniques through an exploratory analysis of the inter-connections between variables and testing the efficacy of the unsupervised model against known findings.

Emerging from these clusters are the following suggested key characteristics of the artist's practice:

1. Cluster 1 featured works of art on solid supports, such as hardboard or wood, which had lithopone and titanium ground compositions and mainly dated from the earlier years of 1947–1960.
2. Pre-primed canvasses were identified during 1963–1965 in Cluster 2. Shared attributes within this cluster included a smooth ground application, linen fibres and a

lead and titanium ground composition, suggesting a preference for the use of commercially available pre-primed canvas, including those of Holbein.

3. Cluster 3 featured later works dated between 1966 and 1975 that appear to be characterised by material experimentation. It further identifies 1966 as a period of transition with the presence of a variety of media.
4. Cluster 4's later works of art are observed as a revisitation of materials and subjects from the Nanyang style.
5. Artworks in the later years contained more compounds in the ground composition

What stood out from the clusters was the distribution of works from the Nanyang Style into two main clusters, Cluster 1 and Cluster 4, supporting the curatorial narrative that the later phases of the artist's oeuvre were a revisitation of the Nanyang style. The link between these two clusters was the use of marouflage. The use of marouflage by the artist was linked to the lack of access to materials as well as to the localisation of Western art practices, as discussed earlier in Chapter 5.3, pages 154 and 176 respectively.

Some evidence on the links between the ground featured the titanium and zinc-based grounds which were present in both Clusters 3 and 4 and appeared in both the Stylisation and Artistic Maturation phases after 1966. These ground compositions shared positive correlations across several data points. They had an uneven ground topography, as seen from cross-sections, and were further examined by technical means, which established that they were prepared directly onto the cotton canvas's current auxiliary support. When taken together, these findings suggest a shift towards artist-prepared canvasses from pre-primed canvasses. This resonates with Cheong Leng Guat's statement that he stopped using pre-primed canvas in favour of artist-prepared canvas because the "paint would come off and [...] the canvas was not good for the climate in Singapore" (Gomez Lobon 2010c). It should be noted that titanium-based and zinc-based grounds during the Artistic Maturation period had no additives while titanium and zinc grounds during Stylisation had two to three counts of additives. Further work is required to establish the compositions of these ground layers to fully substantiate these findings. Due to the COVID impact, limited accessibility to scientific instruments impacted on the ability to conduct further organic analyses on the ground layers.

However, this is a simple process that can be picked up in future research to be included into the dataset for a rerun of the PCA and k-means model.

The evidence-based data analysis established a good understanding of the possible patterns and trends within the dataset, and the unsupervised model further developed these insights through the clustering of metadata. The methods and findings highlight the potential usefulness of using Power BI to create a dashboard, which was an instrumental tool in visualising the samples collectively and individually, and enabled data mining of larger datasets with multiple variables.

6.6 Conclusion

This chapter set out to explore and examine the materials and techniques of Cheong Soo Pieng through a series of methodologies to mine data collected from technical examination and material analysis. Evidence suggested a change in Cheong Soo Pieng's materials occurred after the Europe trip in 1963. Earmarked by two major events, the first change was the transition from solid supports to flexible supports such as canvas, and the second was the choice of signature from English script to Chinese monogram. These were informed by the data collected from the range of technical images and fibre analysis cross-sections. The methodologies were designed to address one of the main obstacles in this pursuit, which was the lack of reference artist materials or archival documentation to support the findings.

Overall, the findings provide supportive evidence for the efficacy of the unsupervised model for datasets that want to understand relationships between the findings gathered from non-invasive and material analysis. At the same time, the methodology emphasises the benefit of data exploration by utilising visualisations such as data clustering to understand the distribution of the dataset. The two methodologies work together to provide a deeper narrative than individual analysis, drawing our attention to the possibility of employing unsupervised learning models to analyse data from future technical studies comprising of larger and more complex datasets. This method also highlights the importance of evidence-based findings, as the understandings built from technical examination and material analysis

earlier in the chapter are mirrored in some of the clusters, which present similar patterns and trends mirroring stylistic categorisation.

Employing Principal Component Analysis and k-means for unsupervised clustering has been a useful exploratory analysis tool for finding patterns and correlations in large and heterogeneous datasets. In the case of elemental results generated from the ESEM-EDS without reference samples, the Spearman correlation matrix proved to be a useful starting point for discovering relationships between the elements and served as a good foundation in the creation of a binary dataset to identify elemental compositions of major and minor amounts of the analysed ground layers. Interpretation of the statistical methods is still a necessary step in which interactive dashboard visualisations have helped pull together all the various sources of data.

The findings from the unsupervised model reveal something about the variety of ground layers and primary supports Cheong Soo Pieng used throughout his practice. Patterns observed in the ground composition were mapped alongside stylistic categorisation, which will add value to current curatorial understandings. As mentioned, organic analyses on the ground layer was not within the scope of the research due to COVID impact, which the study could benefit from to reach a better understanding about the ground characteristics. Notwithstanding these limitations, the exploration of metadata obtained from various analysis and examinations add to a growing body of evidence that suggests the artist's techniques in painting construction and material availability, to some extent, have a correlation with the stylistic categorisation. This is an important issue for future research and further studies will need to be undertaken taking these variables into account. Taken together, it was the structuring of the data input that enabled deeper data mining.

The present study lays the groundwork for future research into Cheong Soo Pieng's practice and has been one of the first attempts to employ unsupervised learning to data-mine metadata from technical examinations across various analytical techniques. The methodology is designed to provide a basis for other technical research that has limited archival evidence but can collect material data through the study of paintings using accessible means, such as visual examination. So long as the data collection method is structured for data analysis, the

data set can be expanded and accommodate future research to build on.. As data clustering has the potential to identify outliers, a larger dataset of artworks would present opportunities for further investigation and aid artist attribution. The statistical inquiry and unsupervised learning models in this chapter have demonstrated the feasibility of data clustering for an integrated understanding of each artwork. The following chapter furthers this discussion by considering the four pillars of data analytics and how data can be looked at to collectively facilitate knowledge discovery as well as to build an artist's record through various data mining methodologies to uncover links within a group of paintings.

Chapter 7: Methodologies for knowledge discovery

7.1 Introduction

The building of a robust material record combines historical, archival and technical pathways, which inform knowledge about artistic production and materials employed. Relying on various interdisciplinary avenues of enquiry with multiple perspectives, material knowledge can be gained by working directly with object sources, collectors and communities while building new informed knowledge pathways (Scott 2015). This was echoed in O'Donnell and Tse's (2018) proposal to build an artist record through sharing knowledge of conservation treatments about the making, materiality and meaning of artworks. Through these technical studies of Cheong Soo Pieng and Georgette Chen, large amounts of data have been amassed from various data sources, some of which have been explored and communicated as insights in previous chapters. At present, most of these insights have focused on descriptive data and are contextualised within each artist's practice. Grounded in material investigations, the approach towards building a material record looks towards integrating various forms of data built efficiently and consistently from individual artworks.

The exploration of the materials and techniques of Cheong Soo Pieng and Georgette Chen discussed in the previous chapters has shown that gathering and analysing the data necessitated various methodologies. The works of each artist have been analysed following the structured dataset, which was built from several methods of examination. Critical factors such as access and availability of the artworks affected the type of methodologies employed to build an understanding. When there is wider availability of data, such as in the case of works by Cheong Soo Pieng, the development and testing of data science models can be used to explore datasets. However, smaller datasets, such as in the case of Georgette Chen's works, have also shown potential in gaining an in-depth understanding. The potential impact of the various methodologies indicates a need to evaluate what a material record of Singaporean artworks would look like, and how links between artists can be made.

This chapter sets out to further examine the links between the artists and contribute to a growing area of interdisciplinary research by proposing a methodology to increase

efficiency in comparing technical images through the exploration of deep neural networks to discover links gathered from spatial data as technical images. So far, the analysis has engaged in descriptive and diagnostic analytics, the foundations of modern data analytics. This chapter extends the analysis using predictive and prescriptive analytics, offering the possibility of building a material record.

The first section of the chapter will examine the data sources between Cheong Soo Pieng and Georgette Chen to identify areas that have the potential for data mining. This is followed by an investigation of material links between the two artists gathered from descriptive data in the second section. The third section explores the potential use of deep learning neural network models on spatial data to integrate, classify and diagnose technical images. The final section of the paper brings together these findings from the various investigations and evaluates the approaches to propose the building of a material record.

7.2 Factors influencing data collection and interpretation

Having analysed the materials and techniques of Cheong Soo Pieng and Georgette Chen in some detail, this thesis is now in a position to return to a discussion on any possible links between the two artists, the methodologies employed for data mining, and the approaches used for technical examination. In addition to the development of models for data analysis, a new approach that employed unsupervised learning for the manipulation and analysis of data was used to gather and cluster evidence on how findings from the technical examination and scientific analysis can be analysed correlatively in a broad sense. On the one hand, this approach is based on the amount of data available to decide which factors should be included as contributions to an overall understanding. On the other hand, using a statistical approach, groups of objects were analysed, differing in their level of data resolution, which might affect the degree of analysis available. Using a radar diagram, Figure 87 illustrates the spread of data and analysis between the two artists to identify factors that can influence how the data analysis and patterns can be found in these groups of objects.

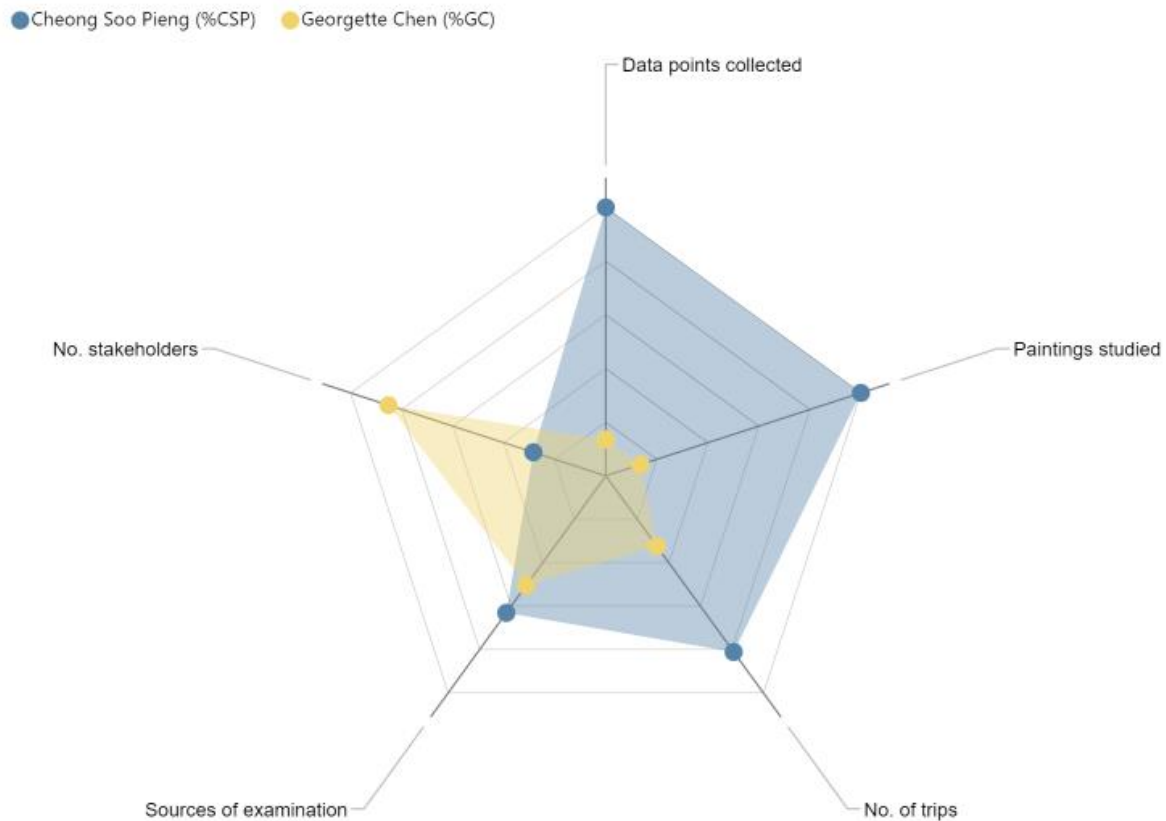


Figure 87. Radar diagram showing the spread of five factors in the current study which can affect the depth and breadth of data points collected.

The positive association between the number of paintings studied and data points collected emphasises the importance of data collection from a breadth of paintings. However, drawing attention to the number of stakeholders involved in the project and the number of paintings studied, suggests that it may have an impact on the efficiency of the project's execution. Central to building a material record, the sources of examination between the two artists are of interest, as a depth of examination sources was still achievable with a small number of Georgette Chen paintings, and has enabled the generation of new knowledge, such

as her canvas preparation techniques and types of canvas used, through data analysis. Centring back to the discussion on the resolution and dimensionality of the dataset as outlined in Table 1 (page 39), factors such as the number of paintings and the total number of data points collected require considerable attention as it influences how the data set can be used to explore similarities between the two artists.

Data were collected and analysed on two separate levels: text-based data gathered from the structured data points and technical images. Findings and occurrences from the technical images observed by the researcher were recorded as text based. For most of the discussion in previous chapters, the text-based datasets were used for the analysis and visualisations, including unsupervised clustering of the data. Non-invasive examination techniques played a critical role in generating new technical data, with 79 of the 110 data points extracted from technical photography. There were approximately eight technical images taken for each painting, and the images were studied together. This was one of the most challenging tasks in the study, given that this image processing approach was lengthy and mostly restricted to limited comparisons due to the manual aspects of the current methodology using the human eye to study digital images.

In the art investigation domain, increasing use of digital technical imaging techniques is being made in parallel with the widespread adoption of a range of recent imaging and analytical modalities not previously applied in the field (Sabetsarvestani et al. 2019). These techniques mean that there is a wealth of digital data available within the sector, offering tremendous scope to provide new insights and presenting new computational challenges to the domain. Furthermore, various other disciplines experiencing similar data growth have significantly benefited from recent breakthroughs in artificial intelligence in the past decades. For example, the availability of machine learning algorithms and the enhanced computation power and frameworks necessary to deal with unstructured and complex datasets have yielded outstanding results in computer vision, speech recognition, speech translation, natural language processing, and more. It is, therefore, natural to develop similar techniques to address challenging tasks arising in art investigation, including material identification within different strata of paintings, analysis of brushstroke style, automatic canvas thread counting, digital inpainting of cracks, and visualisation of concealed designs and underdrawings.

Digital image processing could be a valuable addition to the process of analysing paintings, drawing upon similarities from the medical field, the use of computed tomography and the algorithms used for digital reconstruction in medical imaging (Cornelis et al. 2009, p. 1). A cross-disciplinary interaction between computer science and the technical examination of paintings is an emerging field, with several projects having been carried out over the years. However, experts concerned with digital image processing and its reliability in conservation research have identified five main areas that could benefit from authentication: dating through brush strokes, identifying distinguishing features, image enhancement and integration, and digital reconstruction for inpainting. Most of the research performed so far on x-ray and infrared images has identified complexities and challenges in the study process and has attempted to integrate digital tools through neural networks to allow the images to be studied comparatively (Cornelis et al. 2009; Getty Conservation Institute 2013; Gupta et al. 2021; Sabetsarvestani et al. 2019). In recent years, deep neural networks have advanced in their architecture and usage, and their applicability in conservation research has focused chiefly on digital reconstruction, but it is possible that deep learning could be used to extrapolate qualitative data from technical images to add value to qualitative analyses.

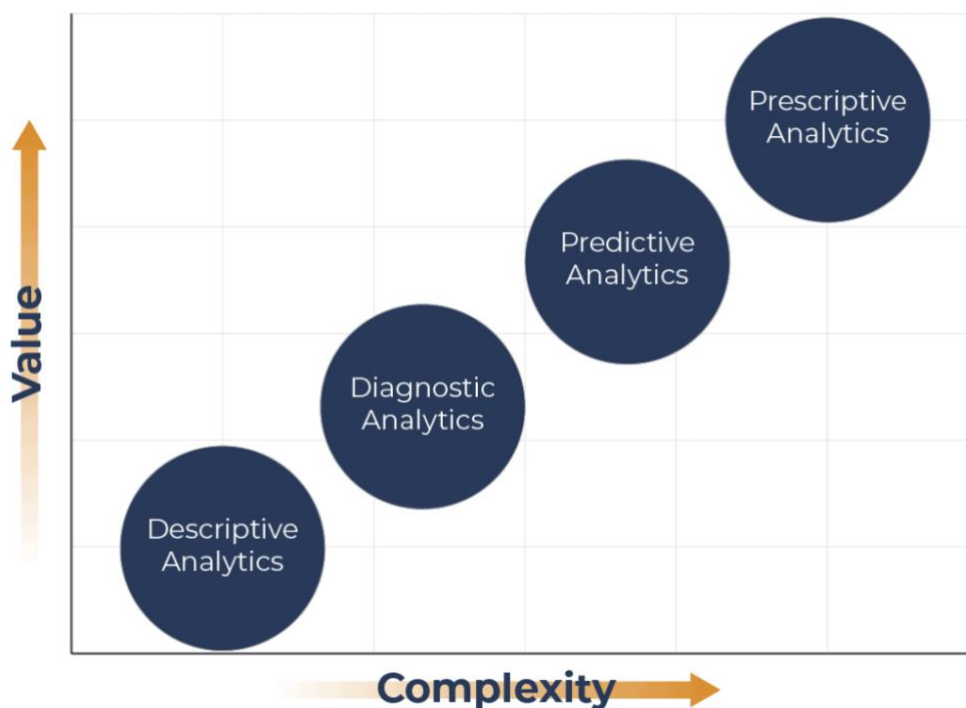


Figure 88. Four pillars of data analysis ranging in complexity and value (Kalsbeek 2020).

In modern analytics, categories can be identified, each working together with an increasing scale of complexity and value (see Figure 88). The analyses presented in Chapters Four and Five engaged in both descriptive and diagnostic analytics, visualising historical data through a series of graphs. Descriptive analytics were used to understand what happened, through the use of historical data that were collected through technical examination and documentation records. Diagnostic analytics considers why certain occurrences happened by studying the patterns within the dataset. This included the observed chronological change of signature and the presence of underdrawings in the artists' paintings preparations. Having established a build-up of data to understand the artists' practice, data can be mined further to predict a future outcome, and its reliability depends on how well the historical data has been understood. Predictive and prescriptive analytics are the basis for understanding what is likely to happen next and includes the development of machine learning models.

Turning now to the interpretation of qualitative data, deep and insightful interactions with data are a prerequisite to generating knowledge discovery. Historical data that consist of descriptive and diagnostic analytics are used as the basis for building predictive analytics models. To make sense of the data and generate an understanding, a constant interaction with the data is required through the interpretation of the data. In ensuring rigour in qualitative data analysis, there is a relationship between data collection and analysis, where uncovered patterns can direct subsequent data collection towards any analytical issues that may arise. Constant comparison of data with data and between metadata is crucial to the success of the research methodology and the analytical process leading to the interpretation. The requirements for demonstrating rigour in qualitative analysis differ from those in quantitative studies, as reliability, replication and validity are less applicable (Maher et al. 2018, p. 3). Instead, it focuses on credibility, transferability, dependability and confirmability. Credibility ensures that the study measures what is intended, transferability relates to the ability of findings to be transferred to other contexts (especially as qualitative research is specific to a particular context), dependability ensures that the process is described in sufficient detail to facilitate another researcher to repeat the work, and confirmability is comparable to objectivity, in which the goal is to minimise researcher bias (Korstjens & Moser 2018; Maher et al. 2018, p. 3). Taken together, these criteria have been identified as vital in building a material record. Having established the necessary rigour in data collection and interpretation,

the following section begins to build the material record by integrating descriptive data and discovering relationships between the two artists.

7.3 Material links between Cheong Soo Pieng and Georgette Chen using descriptive and diagnostic analytics

The Nanyang style of art's association with Georgette Chen and Cheong Soo Pieng is seldom discussed in curatorial literature, as their pictorial language, art backgrounds and trajectories were very different. In previous chapters, it was shown that the existing body of research suggests links between the stylistic development of Cheong Soo Pieng and the wide range of materials and techniques explored through the decades, displaying trends that can be categorised. In contrast, Georgette Chen's materials and techniques present a more consistent trend. However, as Georgette Chen and Cheong Soo Pieng were colleagues at the Western Art Department in NAFA in the later 1950s, one might expect to see standard material links. The specific questions which drive this research segment are whether there were any standard material links between Cheong Soo Pieng and Georgette Chen and the depth of examination required to establish a baseline knowledge. The primary aim of this section is to explore the relationship between two artists' materials and to discuss some of the prominent findings and whether they can inform a broader knowledge of Singaporean art landscape materials and techniques.

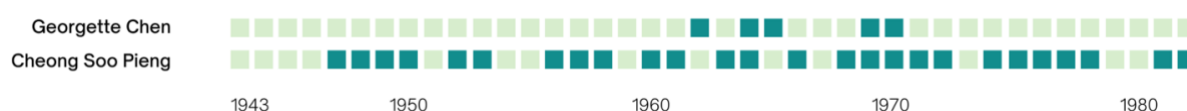


Figure 89. Visualisation of paintings studied by year between the two artists with the 1960s which is a common period between them.

Through the generation of new technical information about the source objects, the paintings studied in the 1960s revealed a series of findings, as illustrated in Figure 89. The common sources of examination between the two artists were: documentation, technical photography, and the use of historical sources. Drawing upon common data points from the non-invasive examination techniques, a significant amount of information relating to the canvas supports and the artist preparation appeared to share a correlation. This discussion begins with the surprising evidence of Holbein canvas stamps in both the artists' artworks in

the 1960s. A total of eight Holbein manufacturer stamps were found on paintings dated between 1962 and 1968, with variations in the numbers below the stamp: 1, 2, 3 or 10 (Figure 90). It is possible that the numbers represented the size of the canvas roll or canvas grade, but this is yet to be confirmed. All the paintings with the Holbein stamp had bast-fibres (linen) identified and had a thread count of 14x15/cm or 15x16/cm. In Gomez Lobon’s research on Cheong Soo Pieng in 2010, she identified pre-primed linen canvas with a thread count of 15x14/cm (2010a, p. 4). However, there was no mention of stamps.

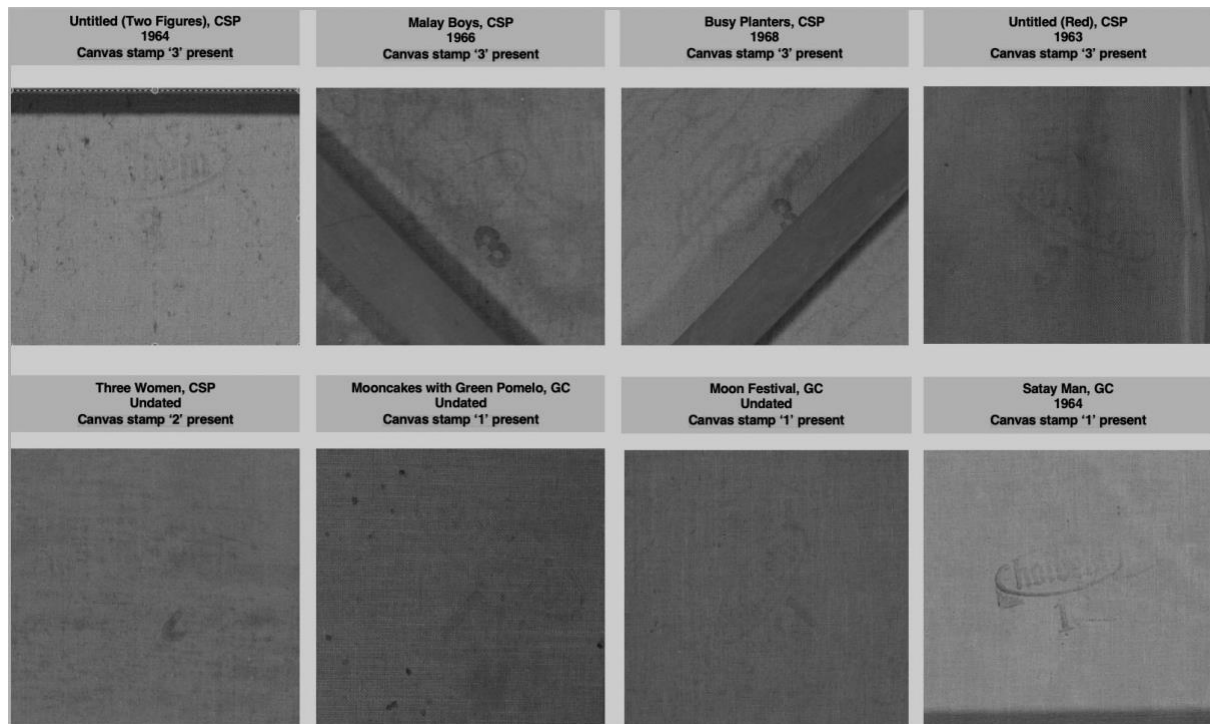


Figure 90. Compilation of Holbein canvas stamps images from eight Cheong Soo Pieng and Georgette Chen paintings from the 1960s.

The presence and use of pre-primed canvasses, particularly of Holbein, gives new information on the availability of artist materials in Singapore in the 1960s and further suggests that those broader investigations are required to uncover these narratives. Current knowledge of artist materials supply in Singapore is based on interviews with Straits Commercial Co., and these require critical examination for knowledge bias (O’Donnell, Tse & Ahmed 2015; Tse 2008). This study raises the question of whether there was an art supplier that has yet to be documented or if the artists ordered and shared materials among themselves. From Georgette Chen’s diary entry in 1965, where she was to “fetch paints from

Zion”, the possibility of sharing artist materials emerges and a new understanding of the relationship between Cheong Soo Pieng and Georgette Chen could perhaps be explored.

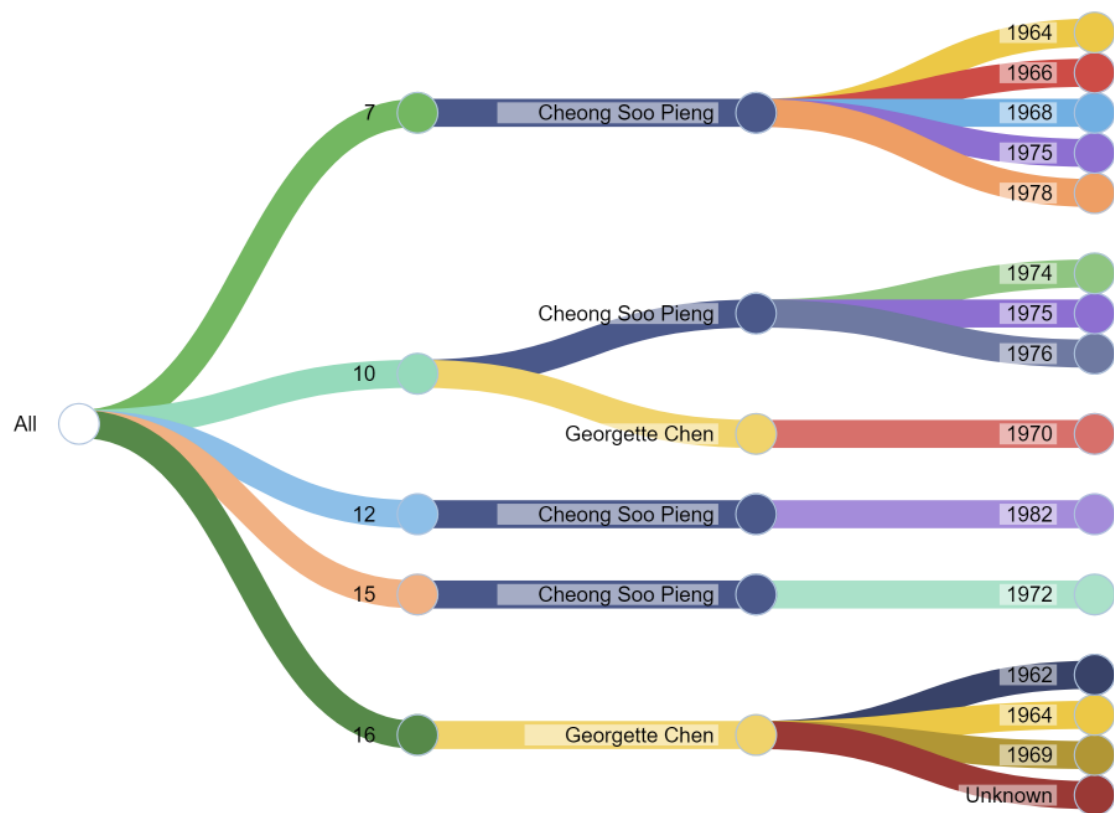


Figure 91. Tree diagram showing the distribution of strainer profile thickness for both Cheong Soo Pieng and Georgette Chen paintings.

A total of 21 original strainers between the two artists were identified from 42 canvas paintings, representing most of the auxiliary supports used. As can be seen from the tree diagram in Figure 91 the distribution of the strainers between the two artists displays patterns in the thickness, decades and artists, which possibly suggests the use of preferred makers. Most of Georgette Chen’s strainer profiles measure 16mm thick, while most of Cheong Soo Pieng’s strainers measure 7 or 10mm in depth. What is striking in the visualisation is that the 10mm strainers, which were present only in the 1970s, have been identified in both artists’ paintings, which suggests the possibility of the same manufacturer.

Although previous interviews with Leng Guat suggest that Cheong Soo Pieng only used Hung Wah frame makers to construct his strainers, the collective evidence from other stamps and strainer profiles suggests that various frame-makers probably made the strainers through the years. Hung Wah frame-makers, incorporated only in the 1970s, were previously identified in Cheong Soo Pieng studies by Gomez Lobon in *Resting*, painted in 1972 (2010a, p. 5). When taken together, the use of strainers and the patterns of the strainer profiles could be indicators of the availability of additional supports in Singapore in the 1960s. It would be interesting to compare the strainer supports of Singaporean artists in a future broader study, particularly in the 1950s and 1960s, to assess if there are similarities.

As well as the common material trends identified in the works of Georgette Chen and Cheong Soo Pieng, the use of canvas pliers to stretch paintings and tacks were found in paintings by both artists. Notably, canvas crimp marks were found in Cheong Soo Pieng's paintings after his trip to Europe. To a certain degree, this could suggest a commitment to the Western practice, as proposed by Tse concerning the presence of linen canvas (2008). The method of stretching the canvas differed between the two artists, as observed from the canvas fold. Therefore, broadening future investigations on the presence of canvas crimp marks would make an interesting study for Singaporean canvas paintings from the 1950s to 1970s, as it could suggest knowledge transmission or a commitment to a particular practice.

The discussion on material links stops short at what can be identified through non-invasive examination, as the findings are limited by the analysis carried out and the number of artworks studied. These results may reflect a selection effect, given the limited study size, but also highlights the importance on the resolution of the dataset (refer to Table 1 on page 39 for metrics on the quality of the record).

However, despite the relatively small size of the study, it offers valuable insights into some material links between Georgette Chen and Cheong Soo Pieng, and thus offers some insight into the materials available in 1960s Singapore. Importantly, it also emphasises the importance of data collection using non-invasive examination. The broad data collection methods generated more extensive data that can be manipulated and drilled deeper alongside invasive material analysis, such as the use of unsupervised learning in clustering. The next section provides a discussion of how the material record can be expanded to include other

works of art and the harvesting of data from non-descriptive data. It will focus on many technical images from the dataset and propose unsupervised learning to explore commonalities and relationships.

7.4 Recommendations: Using deep learning's predictive and prescriptive analytics for image and text-based diagnostics

Technical photography, such as transmitted infrared, is instrumental in understanding artist techniques such as paint distribution and changes, while specular illumination techniques give an insight into the reflectance of the surface. While a data dictionary has been created to clarify each value descriptor assigned to a feature, the current methodology of translating visual data into text-based data presents a source of subjectivity and error. The present manual classification of images can be described as a traditional feature extraction, as it requires professional knowledge and experience in a specific field. Furthermore, the use of manual extraction of features would reduce the efficiency and accuracy of the system if the study were to be expanded to include more works of art or input from other researchers. Deep learning can play a pivotal role in addressing these weaknesses as it looks towards expanding and building a knowledge record of Singaporean artists.

The development of machine learning tools and data mining techniques has enabled more extensive and more detailed data to be collected than ever before. For instance, neural networks and deep learning techniques have been employed for image recognition and diagnostics in disciplines such as healthcare (Cornelis et al. 2009). Furthermore, there is currently no model to draw on to analyse images across paintings. This section sets the foundation for using a neural network to study image-based technical data and how it can be used to provide evidence while supporting a more efficient study of technical images by combining existing value descriptors as diagnostics. The use of prescriptive analytics involves the merging of descriptive, diagnostic and predictive analytics, and includes deep learning models such as neural networks and machine learning.

Text-based caption diagnosis using deep learning neural networks

Deep learning using artificial intelligence (AI) is a powerful tool in image processing and machine vision, making coding tasks efficient and robust (Gupta et al. 2021). Image classification includes two procedures: feature extraction and classification. The process uses visual data to allow artworks to be studied comparatively not only between artworks from one artist but across several artists. In modelling a platform that can accommodate an expansion of visual data, a combination of deep learning neural networks is employed, particularly, both convolutional neural networks (CNN) and recurrent neural network (RNN), which are commonly applied for the analysis of visual imagery. Neural networks are a subset of machine learning and are inspired by the human brain and how neurons interact (IBM 2020b). The use of CNN and RNN allows for pattern identification in unstructured data, such as images, voice recognition and natural language processing by looking for a pattern in a sequence (Kone 2019), while a Perceiver IO is a transformer that integrates all forms of data sources to decode structured outputs. They are applied in image classification and signal processing. The family of neural network architectures can help researchers to study patterns and predict or anticipate an outcome. This experiment aims to create a model that can eventually calibrate and diagnose future technical images accurately within the same parameters. In doing so, it can minimise the risk of human subjectivity during the examination of large amounts of technical photography, while at the same time, increasing accuracy, and therefore, create and allow for possibilities to expand the material record of artist materials in Singapore more efficiently.

Cheong Soo Pieng's and Georgette Chen's paintings display different and varied features, and combining them in a single dataset can thus optimise the model. With 233 technical images distributed across 56 paintings which were found suitable for this project, a training dataset was created by the manual classification of images from each spectral technique, setting the foundation for a structured diagnosis. The lighting conditions were consistent within each spectral technique, and images were labelled for a diagnostic description. The aim was for the AI to recognise and assign a classification to the technical images and eventually find patterns in the artists' techniques, simulating a conservator diagnosis. Table 33 displays the illumination techniques, a description of the diagnosis and the classification score used to build the model:

Table 33. List of illumination techniques and assigned diagnosis which will be used to train deep learning dataset.

Illumination technique	Description of diagnosis	Levels of classification
Specular illumination	Diagnose surface reflectance based on amount of light reflected off surface	1: High surface reflectance
		2: Moderate surface reflectance
		3: Low surface reflectance
Transmitted illumination	Paint distribution based on amount of light transmission	1: Overall light transmission with low paint density
		2: Moderate light transmission with areas of low paint density
		3: Little to no light transmission with high paint density
Transmitted infrared (780nm)	Paint density based on light transmission	1: Overall even and low paint build-up
		2: Heavier paint build up in background with low build-up in central figures
		3: Overall heavy paint build-up with low paint around outline of subjects
		4: Overall heavy paint build-up
Reflected infrared @ 1000nm	Any changes between visible photography are recorded	1: No underdrawings observed
		2: Evidence of underdrawings observed but no changes
		3: Underdrawings and changes observed

Raking illumination	Surface topography distribution	1: No defined impasto layers and no craquelure patterns
		2: No defined impasto layers but features raised craquelure patterns
		3: Defined impasto layers and no craquelure patterns
		4: Defined impasto layers and features raised craquelure patterns
		5: Overall undulations with no defined impasto layers and no craquelure patterns
Visible	Title, medium, year and artist of painting	N/A

The techniques were selected to obtain a good distribution during modelling the algorithm: the number of variables in each technique, availability of the data, and text-based diagnostic data for each painting have been assigned following the ontology that was created during the documentation record. This is important as it enables exploratory data analysis through the data collected from images and text, which can be used in frame semantic parsing. However, this type of analysis at this point can not be representative of the artist's oeuvre as a whole as only 56 paintings were included and more data is required. The paintings studied during this research had around six to eight technical images taken for each painting, however, only five were used to create and test the training dataset. To build the training dataset, a manual organisation of the images was used to assign a level of classification, from which a new dataset was created, cleaned, and prepared before mining (see Figures 92 to 93). Figure 94 shows an extract from the diagnostic description dataset.

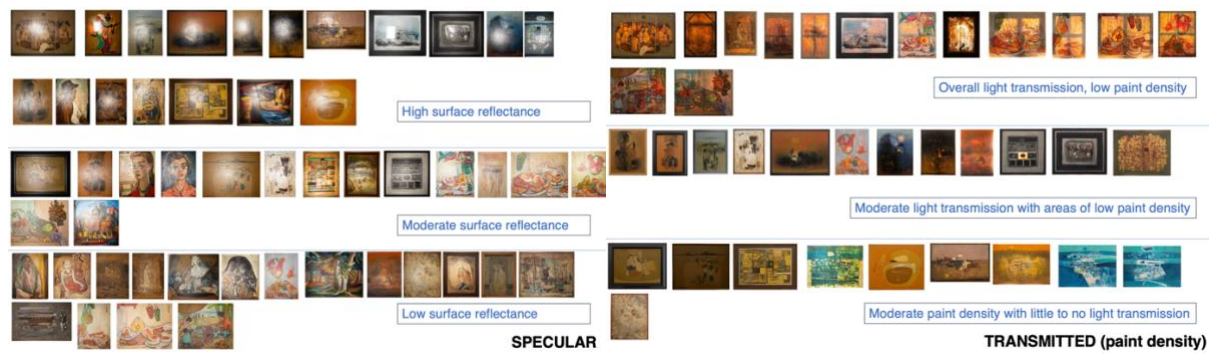


Figure 92. Organisation of technical images (specular and transmitted photography) to be trained in model.

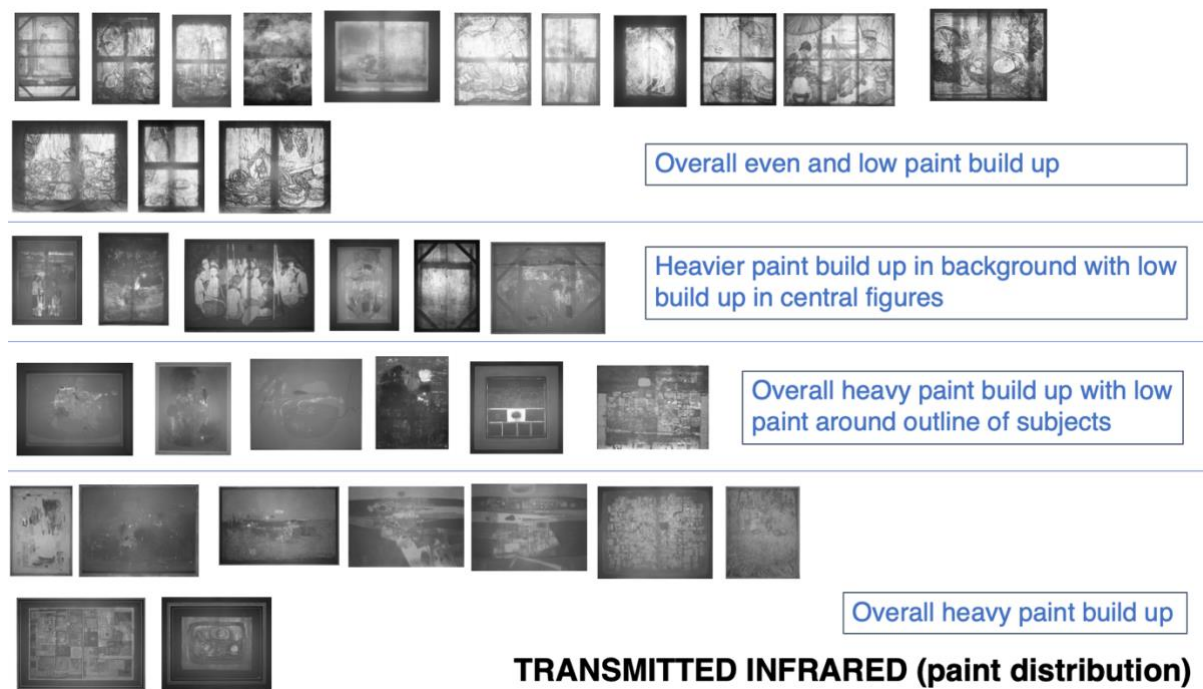


Figure 93. Organisation of transmitted infrared technical images to be trained and how the images are classified.

PTG_ID	Technique	File_name	Diagnostic_description
PTG001_CSP001	IRR	PTG001_CSP001_IRR1000	Reflected infrared photograph shows underdrawings and changes observed in Long House People by Cheong Soo Pieng (1975) oil on canvas in character's breast and change of composition figure on far right
PTG002_CSP002	IRR	PTG002_CSP002_IRR1000	Reflected infrared photograph shows evidence of underdrawings observed but no changes in Untitled (Three Figures, musical instruments) by Cheong Soo Pieng (1968) oil on canvas
PTG003_CSP003	IRR	PTG003_CSP003_IRR1000	Reflected infrared photograph shows underdrawings and changes observed in Untitled (Two Figures, Mynah) by Cheong Soo Pieng (1964) oil on canvas in hand and clothes of figures
PTG004_CSP004	IRR	PTG004_CSP004_IRR1000	Reflected infrared photograph shows underdrawings and changes observed in Malay Boys by Cheong Soo Pieng (1966) oil on canvas in right figure near the boy's knee over rock
PTG005_CSP005	IRR	PTG005_CSP005_IRR1000	Reflected infrared photograph shows underdrawings and changes observed in Untitled (Indian lady with veil) by Cheong Soo Pieng (1966) oil on hardboard in inscription at top right and change of signature
PTG006_CSP006	IRR	PTG006_CSP006_IRR1000	Reflected infrared photograph shows no underdrawings observed in A corner of art studio by Cheong Soo Pieng (1947) oil on wood
PTG007_CSP007	IRR	PTG007_CSP007_IRR1000	Reflected infrared photograph shows no underdrawings observed in Untitled (Two dancers) by Cheong Soo Pieng (1957) unknown medium on hardboard
PTG008_CSP008	IRR	PTG008_CSP008_IRR1000	Reflected infrared photograph shows evidence of underdrawings observed but no changes in Sarawak Sisters by Cheong Soo Pieng (1953) unknown medium on hardboard
PTG009_CSP009	IRR	PTG009_CSP009_IRR1000	Reflected infrared photograph shows no underdrawings observed in The Gardener by Cheong Soo Pieng (1958) oil on hardboard
PTG010_CSP010	IRR	PTG010_CSP010_IRR1000	Reflected infrared photograph shows no underdrawings observed in Landscape by Cheong Soo Pieng (1978) oil on canvas, marouflaged on canvas
PTG011_CSP011	IRR	PTG011_CSP011_IRR1000	Reflected infrared photograph shows underdrawings and changes observed in Three Women by Cheong Soo Pieng (undated) oil on canvas in figures
PTG012_CSP012	IRR	PTG012_CSP012_IRR1000	Reflected infrared photograph shows underdrawings and changes observed in Bali Women by Cheong Soo Pieng (1952-64) oil on canvas, marouflaged on hardboard in stylisation of figures and change of signature
PTG013_CSP013	IRR	PTG013_CSP013_IRR1000	Reflected infrared photograph shows no underdrawings observed in Mosque in the Village by Cheong Soo Pieng (1956) oil on paper, marouflaged on hardboard
PTG014_CSP014	IRR	PTG014_CSP014_IRR1000	Reflected infrared photograph shows no underdrawings observed in Sunflowers by Cheong Soo Pieng (1957) oil on paper, marouflaged on hardboard

Figure 94. Extract of diagnostic description dataset.

In the training model, the images were randomly selected for simulation with 80% used for training and 20% for validation. Employing Python with the Keras and TensorFlow libraries for machine learning, a larger training dataset consisting of 8,000 non-art specific images with different captions was used (Brownlee 2020). The model, combining both diagnostic description and the technical image, was run with 1,000 epochs for better learning. Deep learning for image captioning of technical images using CNN and RNN produced accurate results, as seen in the following examples (see Figures 95 and 96).

Visible illumination (PTG056_GC003_VIS)	Transmitted infrared (PTG056_GC003_IRT780)
	
Human conservator diagnosis	AI diagnosis
<start> <i>transmitted infrared</i> photograph shows overall <i>even and low paint</i> build up in <i>assorted mooncakes</i> by <i>georgette chen</i> undated oil on canvas <end>	<start> <i>transmitted infrared</i> photograph shows overall <i>even and low paint</i> build up in <i>tropical fruits</i> by <i>georgette chen</i> undated oil on canvas <end>

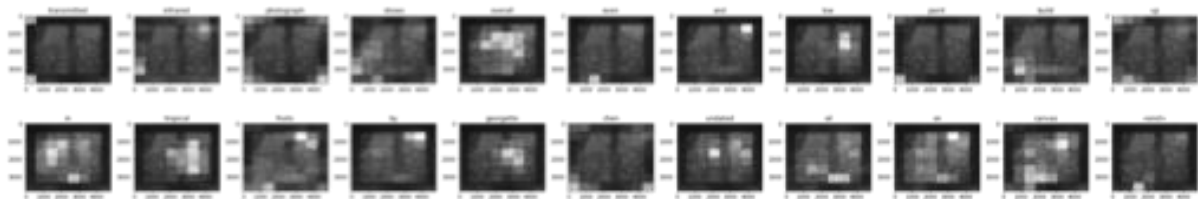


Figure 95. Images of Georgette Chen paintings, and table depicting the difference between human and AI diagnosis with differences highlighted in red, and process of image and text recognition.

Visible illumination (PTG052_CSP050_VIS)	Specular illumination (PTG052_CSP050_SPEC)
	
Human conservator diagnosis	AI diagnosis
<start> specular illumination photograph shows low surface reflectance in sisters by cheong soo pieng 1971 mixed media on wood <end>	<start> specular illumination photograph shows overall undulations with no defined impasto layers and no craquelure patterns in sisters by cheong soo pieng 1971 mixed media on wood <end>

Figure 96. Images of Cheong Soo Pieng paintings, and table depicting the difference between human and AI diagnosis with differences highlighted in red.

From the diagnosis provided by the conservator, the AI was able to accurately describe the lighting type, technique and characteristics of the Georgette Chen painting (see Figure 95). However, it identified objects in the painting instead of the title and it was not able to identify the correct diagnosis that was related to the lighting type. In another example, a mixed media work by Cheong Soo Pieng, the AI was able to accurately describe the lighting type, artist and title (Figure 96). These results from the neural network model have shown the possibility of expanding knowledge discovery and finding technical links between artists through the use of artificial intelligence and deep learning. One of the main benefits of employing deep learning with CNN and RNN algorithms is that the data can be used to search for features that correlate between the diagnosis and images to combine for faster learning. To further improve the model's efficiency, it is recommended that captions for the diagnosis by the conservator be improved for future training datasets. These changes should

include the removal of the title of the artwork, as it does not present any value for the AI predictions or diagnosis. Building on the promising utility of using deep learning for caption-based diagnosis, the section below presents a complementary method of computer vision that has the potential to add value and increase diagnostic reliability in larger technical studies.

Technical image diagnosis using Perceiver IO and Optical Flow

With the technical images dataset cleaned and organised, a second model for predictive analytics using deep learning was explored using optical flow between two images. One of the considerations of building a material record that can be expanded is to improve the current toolsets that are employed. In this case, the workflow for comparing the differences between two technical images included an examination of the digital images followed by a recording of the observations in the dataset using the structured ontology. With each painting having between six and eight technical images, this process can be streamlined through prediction modelling.

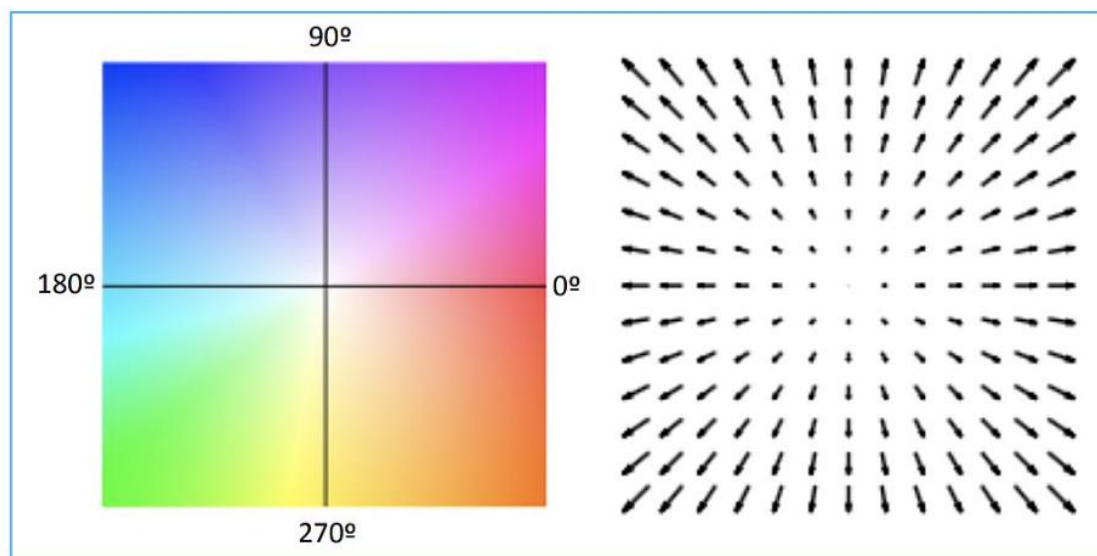


Figure 97. Colour code visualisation of optical flow movement (Liu, Yuen & Torralba 2016).

Optical flow has been used as a motion estimation technique in computer vision for object tracking or video processing, as it tracks how the surfaces are moving around in a scene instead of an individual object (Andrade-Miranda 2017). In this exploratory model, optical flow is used as a possible alternative to identify motion or changes in the comparison between the technical images. Using Perceiver IO to generate these optical images, the model is designed to detect pixel-by-pixel changes between two images. If there are differences detected, the visualisation output shows the movement of every pixel by using colour coding to highlight these changes. Figure 97 illustrates how white areas (centre) indicate no flow while the top left (dark blue portion) indicates flow direction to the left and top (Gituma 2019). When two images are compared, the model estimates the two-dimensional placement of each pixel and produces an image. Figure 98 shows the generated optical flow image comparison between a visible and an infrared image. Similar to a mylar overlay commonly used in condition reporting, Figure 98 shows highlighted details in shapes identified from the infrared image, such the underdrawing changes in the figure's headpiece (top centre) and dress details (lower left corner).

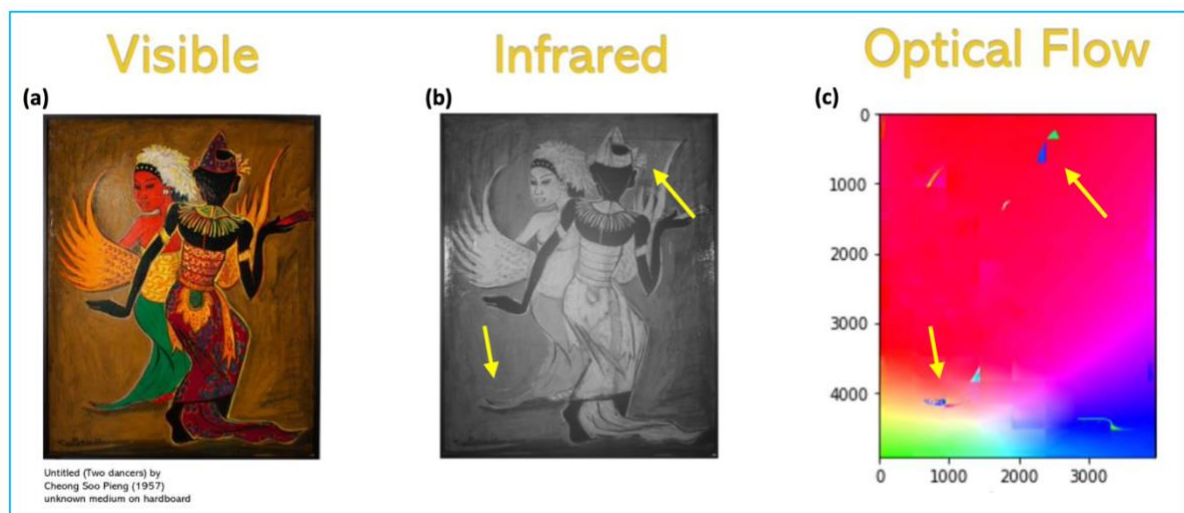


Figure 98. Optical flow produced highlighting differences in visible and infrared image, similar to mylar overlay.

Comparisons between visible and specular images also produced favourable results. To better visualise the differences between the images, the generated optical flow images were placed over the specular images (Figure 99). The optical flow visualisation produced overlays successfully over areas with high surface reflectance as shown by the yellow arrow in the bottom row of Figure 99. This supports the possibility of utilising computer vision and future image captioning using Perceiver IO. Moving forward, the various types of technical images and the generated optical flow can be evaluated to understand if there are any patterns or potential usability for future diagnosis.

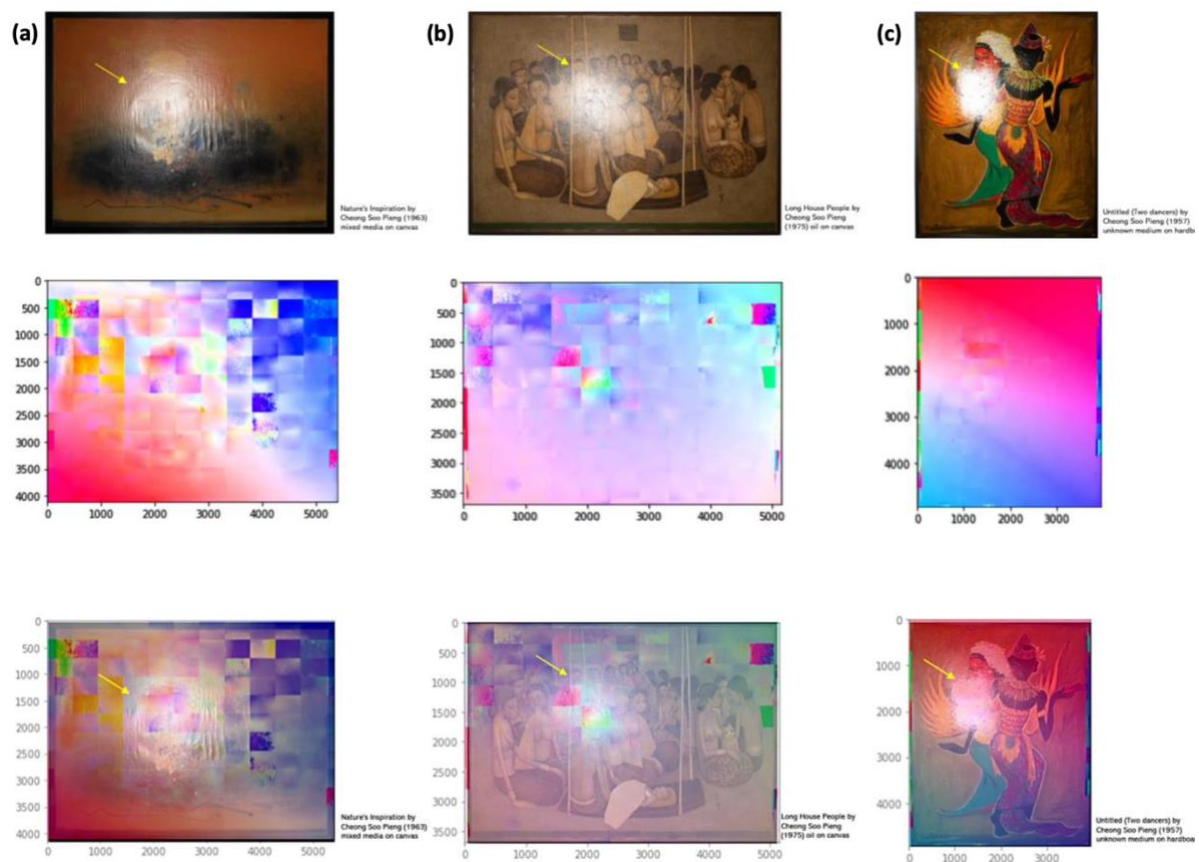


Figure 99. Specular images of selected paintings overlay across the generated optical flow visualisations which correspond with the high gloss reflectance.

The advantages of neural networks, which include storing information on the entire network, working with limited knowledge, and having distributed memory, present a possibility to build a material record for future studies. To further optimise the algorithms, the current examples suggest that more technical images are required to train the model — in

particular, a dataset of only conservation technical images which can be used to increase the overall reliability of the model. Overall, this study strengthens the idea that employing unsupervised machine learning models on digital images can increase efficiency in knowledge discovery. The next section draws together the various data sources and reviews how data integration is essential in building a material record.

7.5 Data integration: Methodologies and approaches to data collection

Research on works of art can generally be categorised as falling into one of five broad areas that can overlap: “conservation issues, attribution questions, determination of provenance, elucidating historical technologies, and understanding and predicting change over time” (Getty Conservation Institute 2013, p. 7). The underlying work in each area is the need to find connections between different works of art, materials, observations or points in time. Data, in various forms, are an essential means to making such connections, and making these connections is facilitated by the availability of directly comparable datasets. The data collected showed potential in addressing the five categories in the two projects studying Cheong Soo Pieng’s and Georgette Chen’s works of art. However, as demonstrated in earlier sections, the variation in the completeness of each artist’s dataset means that this would be difficult or impractical to replicate. This section draws upon the methodologies employed in data collection and discusses the emerging themes that influence how a material record can be built.

The overarching motivation and purpose of the research methodology was to explore the extent to which machine-learning technologies can help integrate different types of data in a way that facilitates the extraction, sharing and understanding of new information broadly. For this to occur, and for the methodology to be successful, a concerted effort is required in the way that data are collected, stored, accessed, shared, analysed and interpreted (Getty Conservation Institute (GCI) 2013). A seven-year research project on *Ghent Altarpiece* by van Eyck has been previously used as an example of a project which utilised data integration of multispectral scanning and instrumental analyses; this resulted in a digital archive on a web application that enabled open-access to view, study and compare images in full resolution (Spronk in GCI 2013). This paradigm shift was the focus of GCI’s 2013 meeting about data integration for conservation science, which identified a need to consider how the

integration of multiple types of data into a consistent, accurate, and valuable representation is expected to facilitate comparisons between different studies and works of art over time. The linking of data from multiple sources will add value to each data source, and the building of communities of experts with an interest in the shared data will improve the quality. This means that the methods of collecting, storing, accessing, sharing, analysing, and interpreting data should be designed from the onset. Taken together, an integrated methodology can better leverage technical studies to advance research on artist materials and techniques.

This thesis set out to generate and collect an enormous amount of data during a technical examination and analysis of paintings by Cheong Soo Pieng and Georgette Chen. Several types of data were collected in this data-rich process. Broader data accessibility allows research teams to pool data and conduct analysis with greater confidence in their results. Furthermore, the more data a researcher has, the more statistical power they have to validate research conclusions and pre-empt data quality questions. However, the amount of generated information surpassed the capacity to incorporate technical information to interpret these findings. This posed the risk of becoming lost in the overwhelming amount of data and perhaps of losing sight of subtle phenomena or relationships. This emphasised the need to understand the information collected during the study — it is vital to improving the understanding of works that we avoid the frustration of having data that cannot be effectively managed and understood. Incorporating data integration into the workflow from the onset included the development of standards for vocabularies and relevant ontologies and standards on how the images would be captured.

As evidenced in both pilot projects, the limitations of working with several stakeholders, such as the access to paintings and whether samples can be removed, dictated the types of techniques that could be employed, which ruled out specific techniques such as material analysis for Georgette Chen. These limitations inhibited the ability to collect the same suite of information from multiple works of art and consequently, the ‘completeness’ of the dataset varied considerably between the artists. However, although differences inevitably occurred in both the types and depth of the analyses that could be performed on each object in the study group, taken together, the large number of works surveyed provides greater statistical relevance than could be gleaned from the study of any single object (Patterson & Trentelman in GCI 2013, p. 11). Tailored data processing, the interpolation of sparsely

sampled data, and combining existing data with new data required research into data mining techniques and statistical analysis of results.

Challenges and recommendations

One of the significant challenges for data integration is comparing different datasets to facilitate broader investigations. In this study, data was generated through three primary sources — documentation records, technical photography and digital images and material analysis — which were processed to gain insights (Figure 100). The integration of data, images, and observational data opens new avenues of research. However, the varied data sources can suffer from too many forms of data (descriptive, spatial and analytical) or using non-standardised vocabularies. In order to gain insights at the knowledge discovery level, data integration presents several challenges that could hinder the system's efficiency and possibilities in terms of choices. Imaging techniques undoubtedly serve as a foundation for the integrated data methodology; they can serve as a framework to integrate not only different types of imaging technologies with each other but also other types of analytical or descriptive data. For data that are not inherently integrated, such as archival or historical sources, the digital image can serve as a control point to aggregate the different data types associated with the object. Unique locators can be created to connect data to specific points to increase verifiability. However, as most of the data collected is unstructured before being recorded into Airtable, the consistent collection of metadata, schemas, ontologies, controlled vocabularies or quantities plays a critical role in the quality of the data. This is best exemplified from findings from technical photographs into a text-based data point into the documentation record. Larger datasets combining both artists' works can provide better statistics, with an overall increase in confidence in results and data integration of multiple data types into a consistent, accurate and helpful representation. Quality metadata is critical for data integration to be effective.

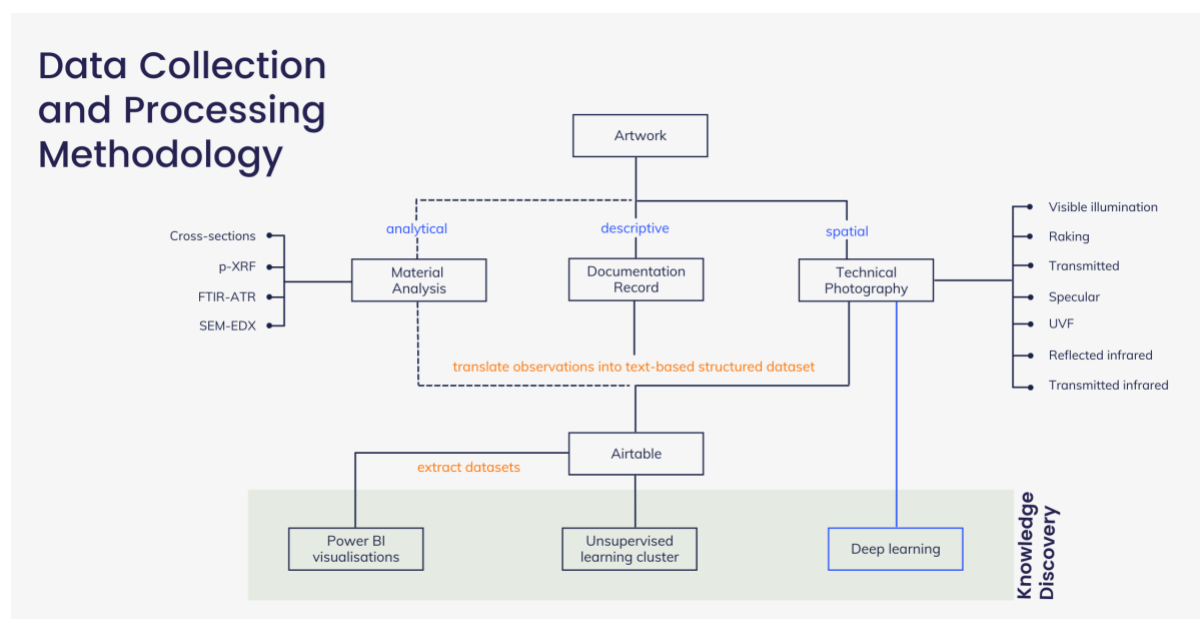


Figure 100. Flowchart of data collection, the types of data and the workflow employed during the research project with the aim to build a material record.

Several research questions were raised during the study on the type of data collected, the software approaches that would be best adapted and how the process can be repeated and adapted sustainably. The pilot projects in the technical study of paintings by Cheong Soo Pieng and Georgette Chen embarked on testing unsupervised machine learning to improve the contribution of scientific and technical studies for the understanding of works of art through the integration of imaging and analytical data, that can facilitate the extraction and sharing of new information and knowledge discovery. The valued intellectual product is not in the raw data itself but the scholarly distillation and interpretation of the data, bringing new insights to the conservation industry and understanding of works of art. The research utilised a suite of software to extract, manipulate and process data. For example, descriptive data extracted from Airtable were translated from a range of sources such as instrumental spectra, images and unstructured free-text, which later utilised data structuring and data visualisation tools to display insights. However, spatial data such as digital images from technical examination showed potential in engaging in deep learning to find the links between images and would allow for an expansion to train the model further.

Some of the research capabilities identified include advancing technical studies, such as linking materials to chronology or an artist's methods, determining classification, and discovering similarities of objects using machine learning to define characteristics. Doing so can advance conservation practice; mining and sharing data can allow data from different techniques to be linked to one another and create visualisations informed by data. The findings of this study suggest that building a material record would require an expansion and development of the data collection, which could see the development of an active community to build and sustain data integration efforts. Furthermore, an evaluation of the robustness of the existing data and metadata for integrating, sharing, searching and querying is required to promote the adoption and sustainability of such a methodology involving the integration of technical examination and machine learning. This study contributes to existing data mining methods from the technical examination of paintings by providing several methodologies to extract material links between artists from a broad-based study and lays the groundwork for future research on building a material record of Singaporean Nanyang artists.

Chapter 8: Conclusion

The existing limited knowledge of the materials and techniques of Singaporean Nanyang artists presented an opportunity to build on existing research by developing an evidence-based understanding through broad data collection. With an area of research enquiry spanning Cheong Soo Pieng's and Georgette Chen's art practices individually and collectively through a series of examination methodologies, the research found that the use of the non-invasive techniques and various methodologies that were employed demonstrated the importance of how data are collected, structured and analysed for valuable insights to be gained.

This thesis has addressed the main research questions on the materiality of Cheong Soo Pieng's and Georgette Chen's works of art and material sources and developed an interdisciplinary methodology that is evidence-based, semi-quantitative and predictive. When this research was first proposed, it set out to primarily collect data during the technical examination stage and analysis of paintings by Cheong Soo Pieng and Georgette Chen. However, three challenges were encountered: (1) assessing what technical information would present material knowledge of the artists' oeuvres, (2) determining what methodology would best support and provide a framework for interrogation, analysis and integration of the research topic, and (3) finding which technical methods and tools can be accessed in non-institutional settings in Singapore that are cost-efficient, portable and accessible. As a conservation research sector, access to instruments and equipment when researching outside of institutions to conduct technical art history research can be challenging when met with the reality of financial limitations. Therefore, the study adopted a data collection approach through surveys to produce a broad study of the paintings, and also employed technical photography and archival sources, such as digitised newspapers, exhibition catalogues, artist letters and oral interviews. The overarching motivation and purpose of the research methodology was to explore the extent to which machine-learning technologies can help integrate different types of data to facilitate the extraction, sharing, and understanding of new information broadly. This is important when designing a methodology that can accommodate the analysis of future research datasets to enable cross-examination across multiple datasets, with the goal of building onto a material record.

The data obtained from the broad survey and advanced material analysis were used to uncover patterns and trends within and between the artists' oeuvres. Microsoft Power BI and Tableau were used to produce compelling data visualisations to gain better insights from individual datasets and their relationships. Effective visualisation of data from documentation records, technical photography and material analysis uncovered multiple narratives and patterns. These included insights on the local influences and the availability of artist materials in Singapore as well as on the techniques that both the artists employed. In particular, the identification of patterns from the larger Cheong Soo Pieng dataset enabled hypotheses and predictive modelling to be developed concerning the relationship between visual observations and material analysis.

To date, most existing conservation research on Singaporean artists has identified the need for more paintings to be studied (Gomez Lobon 2010a; Cusso & Dominguez 2022). Notably, research has focused on institutional collections and infrastructure. Having access to artworks from different sources is a critical factor in undertaking a representative study and survey of Singaporean paintings. To broaden the scope of paintings studied, private collections offer an opportunity to expand the research beyond institutions by providing access to artworks as well as permitting samples to be removed for analysis. In total, 67 paintings by Cheong Soo Pieng and Georgette Chen dated between the 1940s and the 1980s were studied. This included a larger group of Cheong Soo Pieng paintings from the Koh Seow Chuan private collection and a smaller group of paintings by Georgette Chen from the collection of the National Gallery Singapore.

The impact of the pandemic resulted in a limitation of the intended breadth and depth of data collection. While the number of works studied was half that originally intended, there was still a large amount of data produced from broad and non-invasive examinations. These datasets revealed emerging patterns and trends in the works of each artist. Due to the varying levels of breadth and depth of the data from both the artists studied, as well as the primary sources available, understanding the materials and techniques of Cheong Soo Pieng and Georgette Chen necessitated the undertaking of various methodologies. Data collected through visual examination, technical photography as well as findings from the cross-sections and material analysis using ESEM-EDS were recorded into the documentation record following an ontological framework, forming the methodological framework adopted in this

thesis. In all instances, it was important for the methodology to be accessible and sustainable for this research to be continued and easily adopted in Southeast Asia to increase material knowledge.

In the first data collection process, factors such as access to and availability of the artworks affected the methodologies that could be employed to address the research question. Data was collected in two phases: non-invasive examination techniques focused on the collation of technical examination and photographic data, and invasive material analysis included fibre analysis, cross-section preparation and advanced elemental analysis. An important aspect of this collation was the recording of observations into a documentation record through the development of an ontology. The ontological framework in the documentation record consists of 110 data points representing defining properties were collected from each painting. The use of fixed terminologies as value descriptors for each data point aimed to offer a structured documentation format that would minimise discrepancies and provide a standardised and structured way to capture critical information. These value descriptors interpret occurrences, observations, and findings, which are used to structure data in the documentation record on *Airtable*.

A broad survey was applied to the paintings studied in the private and public collections for the 59 Cheong Soo Pieng and eight Georgette Chen paintings. However, as sampling was not permitted for the six Georgette Chen works from public collections, the data obtained from the study were mainly used to uncover patterns and trends within each artist's oeuvre and between them. This approach required the collected data to be structured, cleaned, analysed and visualised. Where there was wider availability of data in the case of Cheong Soo Pieng, data science models were developed and tested. Datasets obtained from the ground and canvas were further explored and statistically analysed. However, smaller datasets from the non-invasive examination gathered from the eight paintings of Georgette Chen also showed potential for gaining an in-depth understanding of her painting techniques and materials. In addition, access to primary sources including past interviews conducted with Cheong Soo Pieng's daughter and the archived letters of Georgette Chen contributed to the material evidence. These methodologies suggest a possible means to build a material record of Singaporean artworks by considering how links within an artist's practice as well as material links between artists can be made.

The non-invasive data offered insights into the availability of materials. At the same time, primary sources such as digitised newspapers and past exhibition catalogues of Singapore helped to contextualise the material findings and added value to the discussion. For example, while Straits Commercial is the most cited artist colourmen supplier in Singapore from the 1950s, little was known about other suppliers or brands available at that time in Singapore. This study found that, in exhibition catalogues from the 1950s, most advertisements for art material supplies were in Chinese, which suggests that the central art community was Chinese. Supplies were often distributed and sold by Chinese bookstores and stationery shops, which supports the curatorial narrative that the Chinese community played an essential role in developing the local art scene in the 1950s. While there was no distinct evidence in this research that suggested Cheong Soo Pieng or Georgette Chen had purchased art materials specifically from Chinese bookstores, the findings of Holbein canvas stamps indicated that Straits Commercial was not their only artist materials supply as supported by interviews with Straits Commercial. The degrees of assimilation of art materials in Singapore can be observed in the art materials used between the two artists which were studied through comparison between datasets generated from the documentation record and archival knowledge of artist materials present in Singapore.

This formed part of a deeper search into digitised archived newspapers for artist materials, which found that locally owned bookstores had been selling imported artist colourmen materials from the early 1900s into the 1970s, expanding the knowledge of artist materials and supplies. This is relevant to the examined paintings in this study from the 1940s to the 1970s, and has a broader relevance to other Nanyang artist paintings in Singapore. Imported oil paint brands, such as Winsor & Newton, Reeves, Sakura and Talens, were distributed by local bookstores. In support of these primary sources, which provided evidence for imported American or British artist colourmen materials, was the surprising find of a canvas stamp by Japanese manufacturer Holbein, on canvasses of both Georgette Chen and Cheong Soo Pieng. Further research into the brand suggests that Japan was actively producing canvasses that were tailored to the climate (which differs from that of European countries), and began distribution of these canvasses internationally, but more specifically in Asia after 1952.

In total, eight Holbein stamps were found in this survey between 1962 to 1968. The Holbein canvasses found were characterised by a red brand stamp and were most likely pre-primed with a lead and titanium-based ground, composed of linen fibres with a weave count of 14x15/cm or 15x16/cm. Both artists used canvasses that had various numbers stamped underneath the logo (1, 2, 3 and 10), but the significance of the numbers is unclear. The stamps in the study were present in the 1960s. However, this could be because of the timeframe this study is concerned with and presents an interesting avenue for further research.

With the analysis of the data and its visualisation, it was found that 50% of Georgette Chen paintings dated in the 1960s had the Holbein stamp as well as lead and titanium elements detected under pXRF. Although only eight Georgette Chen paintings were studied, the various data points in the broad examination suggested strong correlations and consistency in Georgette Chen's canvas preparation and painting techniques. The paintings studied were dated from 1960 to the 1970s to frame the discussion of artist materials and availability in Singapore. Given the small sample size and non-invasive examination techniques, qualitative modes of enquiry were employed on the data points to illuminate patterns in the materials and techniques, together with access to the artist's archived letters.

Transmitted photography indicated consistency in paint application and showed thin paint density with the canvas texture visible in seven of the eight paintings studied. This consistency was visualised and demonstrated most clearly in Georgette Chen's canvas preparation techniques — most notably in the use of canvas pliers, the canvas fold, strainer profile depth, original nail attachment and how the canvas was cut to the reverse. Access to the artist's letters, which detailed many of her practices, was secured only after the analysis of the findings from the in-depth and structured examination, which further supported the findings observed during visual examination, valuable in understanding an artist's record. The use of canvas pliers and the practice of underdrawing using charcoal, turpentine and raw sienna were uncovered using microscopic surface analysis and infrared photography, revealing details of changes in the sketch. Despite the small sample size, outliers could be identified through data clustering. However, more data are required to ensure a robust artist record and the ability to use the data confidently for attribution.

In a more extensive and broader study, seven times more paintings of Cheong Soo Pieng were analysed, and more data were generated, leading to various datasets which improved the depth and quality of understanding of the artist's record. This highlights how the resolution and dimensionality of the record is key in optimising the depth and quality of the data and its analysis (see Table 1 on page 39). While data were collected from condition surveys and technical photography, the study also included samples and invasive analysis, which increased the data points collected for analysis.

During data analysis, findings were grouped chronologically and by curatorial categorisation to explore the possibilities of where patterns could be found. The six broad curatorial categorisations, namely the Formative Years, Nanyang Style, Lyrical Abstract, Stylisation, Artistic Maturation and Late Developments specific to Cheong Soo Pieng's oeuvre, contextualised the findings to a broader art historical narrative. Cheong Soo Pieng's reputation as an experimental artist was supported by the data analysis, which identified four characteristic clusters of material and techniques. Based on the paintings studied and the methodology utilised, it appears no strong artistic practices emerged following a chronological order. However, strong patterns emerged when analysed against the curatorial categorisations, which suggested consistency within each period in terms of the preference for canvas supports, canvas preparation techniques and the revisitation of marouflaging. In addition, these findings indicated patterns in the material choices. For example, primary and auxiliary supports saw a shift from solid supports towards a preference for canvas and strainers which were more present in the 1960s in the Lyrical Abstract period. Further observations of Cheong Soo Pieng's artistic techniques were made concerning the Artistic Maturation period, where ground preparation of supports appeared to be artist applied. A change of signature from English to Chinese occurred after the Lyrical Abstract period and evidence of underdrawings was observed in canvas paintings during the Stylisation period.

From detailed examination, Cheong Soo Pieng's use of solid supports such as panels and hardboard were found to be more dominant in the earlier period before the 1960s, with works of art being of smaller dimensions. Interestingly, some hardboards had secondary support marouflaged onto them, such as paper or linen canvas. In 1961–62, Cheong Soo Pieng travelled to Europe for an exhibition, and during this period, he created more canvas paintings. Auxiliary supports such as strainers were preferred, and the presence of stretches

was mainly detected in paintings produced in Europe. Increased use and preference for canvas paintings and a shift towards the use of a Chinese signature were observed after Cheong Soo Pieng's return to Singapore.

During the 1960s, there was a shift towards canvas supports and pre-primed Holbein canvasses were more commonly used. From transmitted infrared photography, the method of how Cheong Soo Pieng constructed the painted image was revealed through changes in underdrawings. In addition, the importance of the location of his signature in the final composition of the image, as suggested through past oral interviews with his daughter, is evidenced by 'hidden' signatures. In the 1970s, canvas supports were still being used by Cheong Soo Pieng, but this period was marked by a shift in preference for artist-prepared canvas supports, as more canvasses were hand-primed by the artist. The canvasses themselves were composed of cotton fibres. There was also an increase in the incorporation of local materials onto stretched canvas supports using the marouflaging technique, which had been prevalent in the 1950s.

Given the wide availability of artist materials and supplies in Singapore during the 1970s, the incorporation of local materials suggests the artist's attempts to localise Western art in the form of canvas paintings. These findings were informed by advanced analysis such as the examination of cross-sections and elemental analysis of the ground layer using ESEM-EDS, which produced more verifiable data. In exploring links and analysis of the relationships between advanced scientific analysis and broad examination data, interactive dashboards helped enable a deeper understanding of the relationships within these complex datasets. This emphasises that the data quality depends on accessibility and interpretation.

With the large amounts of text and image-based data produced from the study of 67 paintings, it was important for the research to understand how further insights into the data could be gained, and to consider methods to improve efficiency and accuracy in the process. Having analysed the qualitative data generated from non-invasive analysis such as visual examination and technical photography, descriptive and diagnostic data analytics helped the understanding of the trends within and across the data points. Building on these two pillars of data analytics, which provided the foundation for understanding the dataset, data mining techniques such as machine learning enabled more extensive and more detailed data insights

through predictive and prescriptive analytics. Deep learning models using artificial intelligence were employed to search for features between text diagnosis and technical image. As a result, the study could accurately describe the diagnosis of the technical images across both artists. At present, the impact of such an algorithm may appear small, as it does not replace the role of the conservator in analysing each technical image. However, as the long-term aim of building a material record will require processing large amounts of data, the algorithm has the potential to generate diagnosis and build datasets from large amounts of technical images, reducing bias and improving accuracy in future analysis.

Another possible model presented in this thesis experimented with the use of optical flow movement and Perceiver IO, the motion estimation technique that was able to identify differences between technical images, such as the differences between a visible image and infrared photography, by highlighting areas of change, similar to an overlay that would conventionally be used in conservation and manually recorded. These two examples of employing artificial intelligence to a verifiable dataset generated from the technical survey have proven to be a useful diagnostic tool for analysing the large and varied datasets required to build a material record.

The study of 67 paintings between two artists is not representative of the Singaporean material record; however, these preliminary findings offer a foundation to build on for research on artists practising from the 1940s to the 1980s. Several types of data were collected in this data-rich process and analysed to produce a better understanding of the individual artist's record and a broader material understanding of Singaporean artists when considered collectively. Having broader data accessibility allows the pooling of data and the ability to analyse with greater confidence. Further, the more data there are, the more statistical power there is to validate research findings while asking essential questions about the quality of the data.

Although the impact of the pandemic limited the data collection for Georgette Chen's paintings in this research, colleagues at the HCC are currently employing the methodology designed in this thesis, in an ongoing study of 61 paintings. Concerning further studies, access to the in-situ technical photography equipment outside of public institutions will encourage avenues for further research into paintings by Singaporean pioneer artists. By

building on the current dataset following the same methodology, the patterns found in this survey can be tested to see the extent of similarities in the material available from the 1940s to the 1980s. The optimisation of the deep learning models would significantly improve the system. This requires more data to be fed into the model by researchers and support and permission from future research partners. This would benefit researchers in the long run when collecting comprehensive examination survey data on Singaporean artists.

The cross-sections prepared during this study were analysed with advanced material analysis techniques such as ESEM-EDS to identify the pigments found in the ground layer of these paintings and to relate the results more conclusively to periods within Cheong Soo Pieng's practice. While there was access to non-destructive techniques such as pXRF or the FTIR-ATR, the results of these identified multiple layers of the paint sample and could not isolate the results of only the ground layer. There is significantly more scientific analysis to be done, particularly with some of the unprepared samples obtained during this study. Some were analysed for their organic components, most of which were not presented in this research. While this thesis has only undertaken the targeted analysis of the ground layer, the representative cross-sections prepared offer an opportunity for further scientific analysis to maximise the potential of this research, such as in the identification of pigments and paint.

Overall, this thesis has investigated the materials and techniques of two prominent Singaporean artists, Cheong Soo Pieng and Georgette Chen, through a series of broad examination techniques such as visual examination and technical photography. With respect to current conservation literature, this study undertakes one of the most expansive technical examinations of Singaporean paintings to date. It has brought up distinct areas of interest, such as the availability of art materials and artist techniques practised across time. While there were material similarities between the artists, the difference in painting construction techniques and choices suggest a reflection of their varying backgrounds, social, economic and cultural contexts. The presented evidence from the broad examination survey and the record of multiple structured data points enabled an in-depth data analysis to inform each artist's record and demonstrated the value of non-invasive techniques. By establishing an explicit ontology for recording observations, data analytics uncovered verifiable patterns to give insights.

Interactive dashboards enabled a cross-study of relationships between the breadth and depth of data, such as the results from the elemental analysis of ground layers and its relationship with visible observations of the primary support. This research is not conclusive, but it does establish some necessary groundwork upon which further studies can be based. The two machine learning models presented in this thesis offer an efficient and robust diagnostic and analytical method that could increase efficiency and reduce bias in data collection, with recommendations to optimise the models by inputting future data from paintings studied.

In such a data-rich field, the technical art study methodologies presented in this thesis showcase how the study of paintings does not necessarily require inaccessible means or expensive equipment to collect data. It demonstrates that the opportunity to build our material understanding exists in various environments, as long there is access to paintings for study and structured methodologies. The collection of technical knowledge through accessible means encourages the continuation and development of research beyond this research. Further studies in this area of research will be well positioned to produce incisive research outcomes that support longitudinal studies of Singaporean artists, and with a methodology in place to cross-examine datasets, it will contribute to the development of a robust material record, increasing our understanding of paintings in Singapore and the wider Southeast Asian region.

List of References

- Abate, D 2019, 'Documentation of paintings restoration through photogrammetry and change detection algorithms', *Heritage Science*, vol. 7, no. 1, p. 1—19.
- Abdullah, S 2018, 'Expanding the Historical Narrative of Early Visual Modernity in Malaya', *Wacana Seni Journal of Arts Discourse*, vol. 17, pp. 41–75.
- Airtable 2021, *About us*, viewed 19 July 2021, <<https://www.airtable.com/about>>.
- Albrecht, M, de Noord, O, Meloni, S, van Loon, A & Haswell, R 2019, 'Jan Steen's ground layers analysed with Principal Component Analysis', *Heritage Science*, vol. 7, no. 1, <<https://doi.org/10.1186/s40494-019-0295-5>>.
- Andrade-Miranda, G 2017, 'Analyzing of the vocal fold dynamics using laryngeal videos', PhD dissertation, Universidad Politécnica de Madrid.
- Andrews, JF & Shen, K 2006, 'The Japanese Impact on the Republican Art World: The Construction of Chinese Art History as a Modern Field', *Twentieth-Century China*, vol. 32, no. 1, pp. 4–35.
- Appadurai, A 2013, *The social life of things: commodities in cultural perspective*, Cambridge Univ. Press, Cambridge.
- Appelbaum, B 2012, *Conservation treatment methodology*, Butterworth-Heinemann, Amsterdam.
- Arslanoglu, J, Centeno, SA, Digney-Peer, S & Duvernois, I 2013, '"Picasso in the Metropolitan Museum of Art": an investigation of materials and techniques', *Journal of the American Institute for Conservation*, vol. 52, no. 3, pp. 140–155.
- Bao, Y, Yang, T, Lin, X, Fang, Y, Wang, Y, Pöppel, E & Lei, Q 2016, 'Aesthetic Preferences for Eastern and Western Traditional Visual Art: Identity Matters', *Frontiers in Psychology*, vol. 7, viewed 20 July 2022, from <<http://journal.frontiersin.org/article/10.3389/fpsyg.2016.01596/full>>.
- Bergeon, S, Emile-Mâle, G, Huot, C & Baÿ, O 1998, 'The restoration of wooden painting supports: two hundred years of history in France', in K Dardes & A Rothe (eds), *The structural conservation of panel paintings: proceedings of a symposium at the J. Paul Getty Museum, 24–28 April 1995*, Getty Conservation Institute, Los Angeles, pp. 264–288.
- Bomford, D 2008, 'Forbes prize lecture', *Studies in Conservation*, vol. 53, no. 3, pp. 198–203.
- Bomford, D, Kirby, J, Leighton, J & Roy, A 1990, *Art in the making: Impressionism*, National Gallery Publications Limited, London.

- Broman, KW & Woo, KH 2018, 'Data organization in spreadsheets', *The American Statistician*, vol. 72, no. 1, pp. 2–10.
- Brownlee J, 2020, *How to develop a deep learning photo caption generator from scratch*, Machine Learning Mastery, viewed 24 February 2022, <<https://machinelearningmastery.com/develop-a-deep-learning-caption-generation-model-in-python/>>.
- Bucklow, S 1996, 'Formal connoisseurship and the study of paintings techniques', in J Bridgland (ed.), *ICOM committee for conservation: 11th triennial meeting, Edinburgh, Scotland, 1–6 September 1996 : preprints*, James & James, London, pp. 341–347.
- Burnstock, A & Morgan, S 2002, 'A database of artists' materials from paintings examined at the Courtauld Institute of Art', in *ICOM Committee for Conservation, ICOM-CC:13th Triennial Meeting, Rio de Janeiro, 22-27 September 2002 : preprints*, James & James (Science Publishers), London, pp. 261–268.
- Cacciotti, R, Valach, J, Kuneš, P, Čerňanský, M, Blaško, M & Křemen, P 2014, 'Introduction to an Ontology-Driven Documentation System of Damages to Cultural Heritage', *International Journal of Heritage in the Digital Era*, vol. 3, no. 2, pp. 255–269.
- CAMEO 2022, *Conservation & art materials encyclopedia online*, viewed 16 August 2021, <https://cameo.mfa.org/wiki/Main_Page>.
- Cannon, A 2017, 'Data harvesting for art materials research: a case study using the Trove newspaper collection', in *ICOM-CC 18th Triennial Conference preprints, Copenhagen, 4–8 September 2017*, International Council of Museums, Paris.
- Carlyle L & Hendriks E 2009, Visiting Claessens, artists' canvas manufacturers. *News in Conservation*, vol. 11 (April), pp. 4–5.
- Carter, CL (ed.) 2017, *Unsettled boundaries: philosophy, art, ethics east/west* first [edition], Marquette University Press, Milwaukee, Wisconsin.
- Chen, G 1953, Georgette Chen to friends, 30 March, held at National Gallery Singapore Resource Centre.
- Chen, G 1953, Interview Radio Malaya, 7 September, held at National Gallery Singapore Resource Centre.
- Chen, G 1956, Georgette Chen to friends, 8 December, held at National Gallery Singapore Resource Centre.
- Chen, G 1961, Georgette Chen to Dorothy Lee, undated letter, held at National Gallery Singapore Resource Centre.
- Chen, G 1962, Georgette Chen to unknown, 5 February, held at National Gallery Singapore Resource Centre.

- Chen, G 1966, Pat Kennison to Georgette Chen, undated letter, held at National Gallery Singapore Resource Centre.
- Chen, G 1967, 'To the class of 1967', *Nanyang Academy of Fine Arts 2 Graduation Magazine*, 1967, p. 44.
- Chen, G 1970, Georgette Chen to unknown, 13 January, held at National Gallery Singapore Resource Centre.
- Cher, HL 2019, '5 steps of a data science project lifecycle', *Towards Data Science*, viewed 15 January 2022, <<https://towardsdatascience.com/5-steps-of-a-data-science-project-lifecycle-26c50372b492>>.
- Chia, J 1997, *Georgette Chen*, Singapore Art Museum, Singapore.
- Christies 2022, 'Live auction 12531, Lot 368', viewed 2 June 2022, <<https://www.christies.com/en/lot/lot-5956179>>.
- Clark, J 1998, *Modern Asian art*, University of Hawaii Press, Honolulu.
- Clavir, M 2009, 'Conservation and cultural significance', in A Richmond & A Bracker (eds), *Conservation: principles, dilemmas and uncomfortable truths*, Routledge, London, pp. 139–149.
- Cornelis, B, Doms, A, Daubechies, I & Schelkens, P 2009, 'Report on digital image processing for art historians', paper presented to the SAMPTA'09 special session on sampling and (in)painting, Marseille, May 2009.
- Cotte, S, Tse, N & Inglis, A 2016, 'Artists' interviews and their use in conservation: reflections on issues and practices', *AICCM Bulletin*, vol. 37, no. 2, pp. 107–118.
- Cultural Heritage Science Open Source 2022, 'Transmitted infrared photography', viewed 2 July 2021, <<https://chsopensource.org/transmitted-infrared-photography-irt/>>.
- Cusso, M & Dominguez, I 2022, 'From the conservators' eyes: examining Georgette Chen's paintings', in R Storer (ed.), *Georgette Chen: at home in the world*, National Gallery Singapore, Singapore, pp. 164–171.
- Dang, ND 2009, 'Về sơn dầu: sơ lược lịch sử và kỹ thuật' ['About oil paint: a brief history and techniques'], viewed 8 May 2022, <<https://www.scribd.com/doc/310708040/V%E1%BB%81-S%C6%A1n-D%E1%BA%A7u-S%C6%A1-L%C6%B0%E1%BB%A3c-L%E1%BB%8Bch-S%E1%BB%AD-Va-K%E1%BB%B9-Thu%E1%BA%ADt>>.
- D'Imporzano, P, Keune, K, Koornneef, JM, Hermens, E, Noble, P, Vandivere, ALS & Davies, GR 2021, 'Time-dependent variation of lead isotopes of lead white in 17th century Dutch paintings', *Science Advances*, vol. 7, no. 49, art. no. eabi5905, DOI: 10.1126/sciadv.abi5905.

- Ding, C & He, XF 2004, 'K-means Clustering via Principal Component Analysis', in *Proceedings of the 21st International Conference on Machine Learning*, Banff, Canada, 2004.
- Doerr, M 2003, 'The CIDOC CRM, an ontological approach to schema heterogeneity', *AI Magazine*, vol. 24, no. 3, p.75 – 93.
- Doshi-Velez, F & Kim, B 2017, 'Towards a rigorous science of interpretable machine learning', *ArXIV*, viewed 7 May 2022, <<https://arxiv.org/abs/1702.08608>>.
- Downey, A 2014, *Think stats: exploratory data analysis in Python*, Green Tea Press, Needham.
- Dredge, P 2020, *Sidney Nolan: the artist's materials*, Getty Conservation Institute, Los Angeles.
- Dua, S 2020, 'K-Means Clustering and PCA to categorize music by similar audio features', *Towards Data Science*, viewed 15 June 2022, <<https://towardsdatascience.com/k-means-clustering-and-pca-to-categorize-music-by-similar-audio-features-df09c93e8b64>>.
- Duran, C, Grau-Bové, J, Fearn, T & Strlič, M 2017, 'Data mining in collections: from epidemiology to demography', in *ICOM-CC 18th Triennial Conference preprints, Copenhagen, 4–8 September 2017*, International Council of Museums, Paris.
- Eastop, D 2006, 'Conservation as material culture', in C Tilley, W Keane, S Küchler, M Rowlands, & P Spyer (eds), *Handbook of material culture*, SAGE, London, pp. 516–533.
- Fayyad, U & Hamutcu, H 2020, 'Toward foundations for data science and analytics: a knowledge framework for professional standards', *Harvard Data Science Review*, vol. 2, no. 2. doi:10.1162/99608f92.1a99e67a.
- Fernandes, A, Solimun, S, Nurjannah, N, 2022, 'Computational Statistics with Dummy Variables', in R López-Ruiz (ed.), *Computational Statistics and Applications*, IntechOpen, London. 10.5772/intechopen.101460.
- Funaoka's Canvas 2006, 'Background of the founding', viewed 23 February 2020, <<http://www.funaoka-canvas.com/funaoka/funaokacanvas7.htm>>.
- Gauthier, T 2001, 'Detecting trends using Spearman's rank correlation coefficient', *Environmental Forensics*, vol. 2, no. 4, pp. 359–362.
- Getty Conservation Institute 2013, 'Report of an experts meeting' in *Integrating imaging and analytical technologies for conservation practice, 10–12 September 2013*, The Getty Conservation Institute, Los Angeles.
- Getty Research Institute n.d., *Getty vocabularies*, viewed 30 April 2021, <<https://www.getty.edu/research/tools/vocabularies/index.html>>.

- Gituma M, 2019, 'What is optical flow and why does it matter in deep learning', *Medium*, viewed 23 February 2022, <<https://medium.com/swlh/what-is-optical-flow-and-why-does-it-matter-in-deep-learning-b3278bb205b5>>.
- Golfomitsou, S, Ravaioli, F, Tully, C, Mcarthur, G & Lithgow, K 2017, 'Off the record: using data mining to review decision making in conservation practice', in *ICOM-CC 18th Triennial Conference preprints, Copenhagen, 4–8 September 2017*, International Council of Museums, Paris.
- Gomez Lobon, M 2010a, 'The life of experimentation: an insight into Cheong Soo Pieng's painting materials and techniques', viewed 23 April 2021, <<https://www.roots.sg/learn/resources/publications/Heritage-Conservation-Centre/The-Life-of-Experimentation--An-insight-into-Cheong-Soo-Pieng-painting-materials-and-techniques>>.
- Gomez Lobon, M. 2010b, 'Beyond the painted surface: conserving the Yeh Chi Wei paintings in the National Heritage Board collection, in WW Yeo (ed.), *The Story of Yeh Chi Wei*, The National Art Gallery Singapore, Singapore, pp. 112–123.
- Gomez Lobon, M. 2010c, 'Interview with Cheong Leng Guat', interview transcript. Singapore, 24 July.
- Gruber, TR 1993, 'A translation approach to portable ontology specifications', *Knowledge Acquisition*, vol. 5, no. 2, pp. 199–220.
- Gultepe, E, Conturo, TE & Makrehchi, M 2017, 'Predicting and grouping digitized paintings by style using unsupervised feature learning', *Journal of Cultural Heritage*, vol. 31, pp. 13–23.
- Gupta, V, Sambyal, N, Sharma, A & Kumar, P 2021, 'Restoration of artwork using deep neural networks', *Evolving Systems*, vol. 12, no. 2, pp. 439–446.
- Hackney, S 2020, *On canvas: preserving the structure of paintings*, Getty Conservation Institute, Los Angeles.
- Harper, TN 2009, *The tools of transition: education and development in modern Southeast Asian History*, Brooks World Poverty Institute, Manchester.
- Harpring, P 2010, *Introduction to controlled vocabularies: terminology for art, architecture, and other cultural works*, 1st edn, Getty Research Institute, Los Angeles.
- Heritage Conservation Centre (HCC) 2019, *Collections Care: Staying Relevant in Changing Times, ASEAN & Beyond*. Singapore: HCC.
- Hensick, T, Olivier, K & Pocobene, G 1997, 'Puvis de Chavannes's allegorical murals in the Boston public library: history, technique, and conservation', *Journal of the American Institute for Conservation*, vol. 36, no. 1, p. 59–81.

- Ho, HY 2005, 'The current art scene in Singapore (1960s)', in TK Sabapathy & CH Cheo (eds), *Re-connecting: selected writings on Singapore art and art criticism*, Institute of Contemporary Arts Singapore; LaSalle-SIA College of the Arts, Singapore, pp. 64–67.
- Hodge, C 2017, 'A guide to object biography', viewed 22 December 2021, <https://suac.stanford.edu/sites/g/files/sbiybj12066/f/suac_2017_guide_to_object_biography_0.pdf>.
- Hoe, SF & Chong, T 2018, 'Nurturing the cultural desert: the role of museums in Singapore', in T Chong (ed.), *The State and the Arts in Singapore*, World Scientific, Singapore, pp. 241–265.
- Hölling, H, Bewer, FG & Ammann, K (eds) 2019, *The explicit material: inquiries on the intersection of curatorial and conservation cultures*, Brill, Leiden .
- Ho, SP & Ma, P 2015, *The story of Cheong Soo Pieng*, Oxford Graphic Printers, Singapore.
- Hsü, M 1999, *A brief history of Malayan art*, Millenium Books, Singapore.
- Hunter, J & Odat, S 2011, 'Building a semantic knowledge-base for painting conservators', in *2011 IEEE Seventh International Conference on eScience*, IEEE, Stockholm, Sweden, pp. 173–180.
- IBM 2020a, 'What is machine learnings', viewed 14 April 2022, <<https://www.ibm.com/sge/en/cloud/learn/machine-learning>>.
- IBM 2020b, 'What are neural networks', viewed 6 July 2022, <<https://www.ibm.com/cloud/learn/neural-networks>>.
- INCCA n.d., 'INCCA founding project', viewed 7 October 2021, <<https://incca.org/articles/project-incca-founding-project-1999-2002>>.
- IRUG 2022, 'History of IRUG', viewed 19 June 2022, <<http://www.irug.org/about-us/history>>.
- Janssens, J 2014, *Data science at the command line*, O'Reilly Media, California.
- Jin, C & Malthouse, EC 2015, 'On the bias and inconsistency of K-means clustering', viewed 25 August 2022, from <<http://rgdoi.net/10.13140/RG.2.1.4300.5528>>.
- Joy, J 2009, 'Reinvigorating object biography: reproducing the drama of object lives', *World Archaeology*, vol. 41, no. 4, pp. 540–556.
- Kalsbeek R 2020, 'Where to start with the 4 types of analytics', viewed 12 June 2022, <<https://iterationinsights.com/article/where-to-start-with-the-4-types-of-analytics/>>.
- Karpowicz, A 1990, 'A study on development of cracks on paintings', *Journal of the American Institute for Conservation*, vol. 29, no. 2, pp. 169–180.

- Keene, S 1991, 'Audits of care: a framework for collections condition surveys', in SJ Knell (ed.), *Care of collections*, Routledge, London, pp. 6–16.
- Keune, K, Mass, J, Mehta, A, Church, J & Meirer, F 2016, 'Analytical imaging studies of the migration of degraded orpiment, realgar, and emerald green pigments in historic paintings and related conservation issues', *Heritage Science*, vol. 4, no. 1, p. 1—14.
- Kia, SH, Lim, CK, Balakumar, C, Law, C & Pak, P 2014, 'News Alike – Text analytics to link related NewspaperSG articles', *International Federation of Library Associations and Institutions (IFLA) Lyon, France*, viewed 7 March 2022, <https://www.ifla.org/wp-content/uploads/2019/05/assets/newspapers/Geneva_2014/s6-kia-en.pdf>.
- Koay, S 2011, 'Singapore: multi-cultural cross roads' in ASEAN Committee on Culture and Information (ed.), *Visual arts in ASEAN: continuity and change*, ASEAN Committee on Culture and Information, Kuala Lumpur, pp. 161–200.
- Kobayashi, A 2019, 'Growth of regional trade in modern Southeast Asia: the rise of Singapore, 1819–1913', in K Otsuka & K Sugihara (eds), *Paths to the emerging state in Asia and Africa*, Springer Singapore, Singapore, pp. 95–113.
- Kogou, S, Lee, L, Shahtahmassebi, G & Liang, H 2020a, 'A new approach to the interpretation of XRF spectral imaging data using neural networks', *X-Ray Spectrometry*, vol. 50, pp. 310–319.
- Kogou, S, Shahtahmassebi, G, Lucian, A, Liang, H, Shui, B, Zhang, WY, Su, B & van Schaik, S 2022b, 'From remote sensing and machine learning to the history of the Silk Road: large scale material identification on wall paintings. *Scientific Reports*, vol. 10, no. 1, 19312, <<https://doi.org/10.1038/s41598-020-76457-9>>.
- Koh, SC 2013, 'Foreword', in BT Tan, *Soo Pieng*, Nanyang Academy of Fine Arts, Singapore, p. 3.
- Kolesnikov-Jessop, S 2010, 'In art exhibit, Singapore honors a son of China', *New York Times*, 6 October 2010.
- Kone C, 2019, 'Introducing convolutional neural networks in deep learning', *Towards Data Science*, viewed 20th December 2021, <<https://towardsdatascience.com/introducing-convolutional-neural-networks-in-deep-learning-400f9c3ad5e9>>.
- Kopytoff, I 1986, 'The cultural biography of things: commoditization as process', in A Appadurai (ed.), *The social life of things: commodities in cultural perspective*, Cambridge University Press, Cambridge, pp. 64–92.
- Korstjens, I & Moser, A 2018, 'Series: practical guidance to qualitative research. part 4: trustworthiness and publishing', *European Journal of General Practice*, vol. 24, no. 1, pp. 120–124.

- Koussiaki, F 2002, 'The influence of non-traditional art materials on the paintings of Pablo Picasso', in *Paintings Conservation Specialty Group postprints: The American Institute for Conservation 30th Annual Meeting, Miami, AIC, Washington DC*, pp. 39–48.
- Krishnamurthy P, 2019, 'Understanding data bias: types and sources of data bias', *Towards Data Science*, viewed 20th December 2021, <<https://towardsdatascience.com/survey-d4f168791e57>>.
- Kwa, CG 2017, 'The 19th-century "origins" of Singapore art', in SW Low & P Flores (eds), *Chartering thoughts: essays on art in Southeast Asia*, National Gallery Singapore, Singapore, pp. 34–43.
- Kwa, CG & Ke, M (eds) 2019, *A general history of the Chinese in Singapore*, World Scientific, Singapore.
- Kwok, KC 1996, *Channels and confluences: a history of Singapore art*, Singapore Art Museum, Singapore.
- Langford, R 2017, 'Stats models vs SKLearn for linear regression', viewed 7 January 2022, <<https://rowanlangford.com/tag/python/>>.
- Learner, T 2004, *Analysis of modern paints*, Getty Conservation Institute, Los Angeles.
- Lim, J 2012, 'Chinese Merchants in Singapore and the China Trade, 1819-1959', *Chinese Southern Diaspora Studies*, vol. 5, pp. 79–115.
- Liu, C, Yuen, J & Torralba, A 2016, 'SIFT Flow: Dense Correspondence Across Scenes and Its Applications', in T Hassner & C Liu (eds), *Dense Image Correspondences for Computer Vision*, Springer International Publishing, Cham, pp. 15–49.
- Liu, K 2011, *Liu Kang: essays on art & culture*, National Art Gallery, Singapore.
- Lizun, D 2021, 'From Paris and Shanghai to Singapore: a multidisciplinary study in evaluating the provenance and dating of two of Liu Kang's paintings', *Journal of Conservation Science*, vol. 37, no. 4, pp. 322–339.
- Lizun, D, Kurkiewicz, T, Mądry, M & Szczupak, B 2022, 'The emergence of Liu Kang's new painting style (1950–1958): a multi-analytical approach for the study of the artist's painting materials and technique', *Heritage Science*, vol. 10, no. 1, p. 1–38.
- Low, Y 2015, 'Becoming professional artists in postwar Singapore and Malaya: Developments in art during a time of political transition', *Journal of Southeast Asian Studies*, vol. 46, no. 3, pp. 463–484.
- Macbeth, R 2012, 'The technical examination and documentation of easel paintings', in JH Stoner & RA Rushfield (eds), *The conservation of easel paintings*, Routledge, Abingdon, pp. 291–305.
- Maher, C, Hadfield, M, Hutchings, M & de Eyto, A 2018, 'Ensuring rigor in qualitative data analysis: a design research approach to coding combining nvivo with traditional

- material methods’, *International Journal of Qualitative Methods*, vol. 17, no. 1, art. no. 160940691878636. DOI: 10.1177/1609406918786362.
- Masahiro, U 2017, ‘The birth of “Fine Art” in Southeast Asia, 1900-1945’, in SW Low & P Flores (eds), *Chartering thoughts: essays on art in Southeast Asia*, National Gallery Singapore, Singapore, pp. 130–139.
- Mashadi, A 2010, *Encountering Cheong Soo Pieng*, National University of Singapore Museum, Singapore.
- Mayer, R 1991, *The artist’s handbook of materials and techniques*, 5th edn, Viking, New York.
- McGuinness, DL, Fikes, R, Rice, J & Wilder, S 2000, ‘An environment for merging and testing large ontologies’, in AG Cohn, F Giunchiglia & B Selman (eds), *Principles of knowledge representation and reasoning: proceedings of the seventh international conference (KR2000)*, Morgan Kaufmann, San Francisco, pp.1 – 12.
- Molnar, C 2022, ‘Interpretable machine learning: a guide for making black box models explainable’, viewed 19 June 2022, <<https://christophm.github.io/interpretable-ml-book/>>.
- Musen, MA 1992, ‘Dimensions of knowledge sharing and reuse’, *Computers and Biomedical Research*, vol. 25, no. 5, pp. 435–467.
- Museums and Galleries of New South Wales 2019, ‘How to: collection management systems’, viewed 9 February 2022, <https://mgnsww.org.au/wp-content/uploads/2019/01/how-to_collection-management-systems.pdf>.
- Mustafa, S 2016, ‘The question of art in Singapore’, in National Arts Council (ed.), *Singapore’s visual artists*, National Arts Council, Singapore, pp. 9–11.
- Nadolny, J 2012, ‘A history of early scientific examination and analysis of painting materials ca. 1780 to the mid-twentieth century’, in JH Stoner & R Rushfield (eds), *Conservation of easel paintings*, Routledge, Abingdon, pp. 337–340.
- Nanyang Academy of Fine Arts 2013, *Soo Pieng*, Nanyang Academy of Fine Arts, Singapore.
- Nanyang Academy of Fine Arts 2022, ‘Our history’, viewed 7 February 2022, <<https://www.nafa.edu.sg/about-nafa/corporate-information/history>>.
- Neo, C 2014, ‘Constructing a national identity: pioneers of a ‘Singaporean art’, BA dissertation, The Glasgow School of Art Singapore.
- Newey, HM, Bradley, SM & Leese, MN 1993, ‘Assessing the condition of archaeological iron: an intercomparison’, in J Bridgland (ed.), *ICOM-Committee for Conservation 10th Triennial Meeting, preprints*, James and James, London, pp. 786–791.

- Noy, N & McGuinness, D 2001, 'Ontology development 101: a guide to creating your first ontology', viewed 15 April 2021, <https://protege.stanford.edu/publications/ontology_development/ontology101-noy-mcguinness.html>.
- O'Donnell, E 2014, 'The materials and techniques of Singapore pioneer artist Georgette Chen: an investigation into painting practice and material availability', Masters thesis, University of Melbourne, Melbourne.
- O'Donnell, E, Tse, N & Ahmad, A 2015, 'Material availability and painting practice: a case study of Singapore artist Georgette Chen', *AICCM Bulletin*, vol. 36, no. 2, pp. 147–159.
- O'Donnell, E & Tse, N 2018, 'Materiality, making and meaning: building the artist record through conservation in Indonesia', *International Journal of Creative and Arts Studies*, vol. 5, no. 2, pp. 11–25.
- O'Neill, J 2014 *Syonan Shimbun: Singapore's wartime newspaper*, paper presented to the 2014 Design History Society conference: Design for War and Peace, University of Oxford, 4–6 September 2014.
- Ong, ZM 2006, 'A history of the Nanyang Academy of Fine Arts (1938–1990)', Masters thesis, National University of Singapore, Singapore, <<http://scholarbank.nus.edu.sg/handle/10635/15776>>.
- Ong, ZM 2015, 'Nanyang reverie', in S Siew & National Gallery Singapore (eds), *Siapa nama kamu? Art in Singapore since the 19th century: selections from the exhibition*, National Gallery Singapore, Singapore.
- Panko, R 2008, 'Spreadsheet errors: what we know. What we think we can do', viewed 30 July 2021, <<https://arxiv.org/ftp/arxiv/papers/0802/0802.3457.pdf>>.
- Perreault, C 2019, *The quality of the archaeological record*, University of Chicago Press, Chicago.
- Pitsilledes, Y 2020, 'Unsupervised learning', viewed 4 September 2021, <<https://github.com/Pitsillides91/Python-Tutorials/tree/master/Unsupervised%20Learning>>.
- Piyadasa, R 1979, 'The Nanyang Academy of Fine Arts' in TK Sabapathy (ed.), *Pameran Retrospektif Pelukis-Pelukis Nanyang*, Muzium Seni Negara Malaysia, Kuala Lumpur, pp. 24–36.
- Plisson, J, de Viguerie, L, Tahroucht, L, Menu, M & Ducouret, G 2014, 'Rheology of white paints: how Van Gogh achieved his famous impasto', *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, vol. 458, pp. 134–141.
- Portela, F 2021, 'Data Science and Knowledge Discovery', *Future Internet*, vol. 13, no. 7, p. 1–4.

- Reedy, TJ & Reedy, CL 1988, *Statistical analysis in art conservation research*, Getty Conservation Institute, Marina del Rey.
- Rollins, J 2015, *Foundational methodology for data science*, IBM Analytics, New York.
- Sabapathy, TK 1979, 'The Nanyang artists: some general remarks', in TK Sabapathy (ed.), *Pameran Retropectif Pelukis-Pelukis Nanyang*, Kuala Lumpur, pp. 43-46.
- Sabapathy, TK 1993, 'Contemporary art in Singapore: an introduction' in C Turner (ed.), *Tradition and change: contemporary art of Asia and the Pacific*, University of Queensland Press, St. Lucia, p. 84—85.
- Sabapathy, TK 2018, *Writing the modern: selected texts on art & art history in Singapore, Malaysia & Southeast Asia, 1973-2015*, A Mashadi (ed.), Singapore Art Museum, Singapore.
- Sabetsarvestani, Z, Sober, B, Higgitt, C, Daubechies, I & Rodrigues, MRD 2019, 'Artificial intelligence for art investigation: meeting the challenge of separating x-ray images of the *Ghent Altarpiece*', *Science Advances*, vol. 5, no. 8, art. no. eaaw7416. DOI: 10.1126/sciadv.aaw7416.
- Schamberger, K, Sear, M, Wehner, K & Wilson, J 2008, 'Living in a material world: object biography and transnational lives', in D Deacon, P Russell, & A Woollacott (eds), *Transnational ties: Australian lives in the world*, ANU Press, Canberra, pp. 275–297.
- Scott, M 2015, 'Normal and extraordinary conservation knowledge: towards a post-normal theory of cultural materials conservation', *AICCM Bulletin*, vol. 36, no. 1, pp. 3–12.
- Seng, YJ 2010, 'The life of the artist, in W-W Yeo (ed.), *Cheong Soo Pieng: visions of Southeast Asia*, Asian artists series, National Art Gallery, Singapore, pp. 14–49.
- Seng, YJ 2017, 'Cultural wars in Southeast Asia: the birth of the critical exhibition in the 1970s' in SW Low & P Flores (eds), *Chartering thoughts: essays on art in Southeast Asia*, National Gallery Singapore, Singapore, pp. 214–232.
- Seng, YJ & Tng, G 2010, 'Bridging worlds', in W-W Yeo (ed.), *Cheong Soo Pieng: visions of Southeast Asia*, Asian artists series, National Art Gallery, Singapore, pp. 50–133.
- Sherring, A & Barnott-Clement, R 2021, 'Art Gallery of New South Wales Time-based Art Tool Kit: practical resources for the documentation and preservation of time-based artworks', *AICCM Bulletin*, vol. 42, no. 1, pp. 68–79.
- Siew, S & Lee, J (eds) 2018, *The artist speaks: Georgette Chen*, National Gallery Singapore, Singapore.
- Singapore Art Society 1956, *Cheong Soo Pieng*, Singapore Art Society: Singapore.
- Standeven, H 2007, 'Cover the world': A history of the manufacture of household gloss paints in Britain and the United States from the 1930s to the 1950s', in T Learner (ed.),

- Modern paints uncovered: proceedings from the modern paints uncovered symposium*, Getty Conservation Institute, Los Angeles, pp. 75–84.
- Standeven, H 2011, *House paints, 1900-1960: history and use*, Getty Conservation Institute, Los Angeles.
- Steinle, P 1972, 'Experimental Artist: Cheong Soo Pieng', *Arts of Asia*, vol. 2. no. 4, pp. 34–37.
- Strassner, J 2008, 'Knowledge Engineering Using Ontologies', in J Bergstra & M Burgess (eds), *Handbook of Network and System Administration*, Elsevier, pp. 425–455.
- Stuart, B 2007, *Analytical techniques in materials conservation*, John Wiley & Sons, Chichester.
- Sullivan, M 1956, 'Foreword' in Straits Commercial Art Co, *Cheong Soo Pieng*, Straits Commercial Art Co, Singapore, p. 35.
- Tan, B 2013, 'Soo Pieng in Nanyang', in BT Tan (ed.), *Soo Pieng*, Nanyang Academy of Fine Arts, Singapore, pp. 4–31.
- Tan, S 2014, 'Of the terms "pioneer" and "second generation" rethinking boundaries and categorisations in the study of Singapore modern art', *Be Muse*, vol. 7, no. 1, pp. 4–13.
- Tay, D 2020, 'Expanding the Singaporean discourse: Exploring artist materials from the 1950s to 1970s', *AICCM Bulletin*, vol. 41, no. 2, pp. 106–117.
- Tay, D 2021, 'Building a material record of Singaporean art through technical art history: a case study of the paintings of Cheong Soo Pieng', *Journal of the Institute of Conservation*, vol. 44, no. 3, pp. 197–209.
- Taylor, NA 2011, 'Art without history? Southeast Asian artists and their communities in the face of geography', *Art Journal*, vol. 70, no. 2, pp. 6–23.
- Taylor, J 2013, 'Causes and extent of variation in collection condition survey data', *Studies in Conservation*, vol. 58, no. 2, pp. 95–106.
- Taylor, J 2017, 'Improving Reliability in Collection Condition Surveys by Utilizing Training and Decision Guides', *Journal of the American Institute for Conservation*, vol. 56, no. 2, pp. 126–141.
- Taylor, J & Stevenson, S 1999, 'Investigation subjectivity within collection condition surveys', *Museum Management and Curatorship*, vol. 18, no. 1, pp. 19–42.
- Tilley, C, Keane, W, Küchler, S, Rowlands, M & Spyer, P 2006, *Handbook of material culture*, SAGE, London.
- Townsend, J & Boon, J 2012, 'Research and instrumental analysis in the materials of easel painting' in JH Stoner & R Rushfield, *Conservation of easel paintings*, Routledge, Abingdon, pp. 341–365.

- Tse, N 2008, 'The characterisation of oil paintings in tropical Southeast Asia', PhD dissertation, University of Melbourne.
- Tse, N & Sloggett, R 2008a, 'Southeast Asian oil paintings: supports and preparatory layers', in J Townsend, T Doherty, G Heydenreich & J Ridge (eds), *Preparation for painting: the artist's choice and its consequences*, Archetype Publications, London, pp. 147–155.
- Tse, N & Sloggett, R 2008b, 'A preliminary understanding of the behavior of oil paintings in tropical Southeast Asia', in J Bridgland & International Council of Museums (eds), *Preprints: ICOM Committee for Conservation 15th triennial conference: New Delhi, 22–26 September 2008*, vol. 2, Allied Publ, New Delhi, pp. 641–650.
- van Driel, BA, van den Berg, KJ, Smout, M, Dekker, N, Kooyman, PJ & Dik, J 2018a, 'Investigating the effect of artists' paint formulation on degradation rates of TiO₂-based oil paints', *Heritage Science*, vol. 6, no. 1, p. 1–14.
- van Driel, BA, van den Berg, KJ, Gerretzen, J & Dik, J 2018b, 'The white of the 20th century: an explorative survey into Dutch modern art collections', *Heritage Science*, vol. 6, no. 1, p. 1–16.
- Veale, M & Binns, R 2017, 'Fairer machine learning in the real world: Mitigating discrimination without collecting sensitive data', *Big Data & Society*, vol. 4, no. 2, p. 205395171774353.
- Villers, C (ed.) 2000, *The fabric of images: European paintings on textile supports in the fourteenth and fifteenth centuries*, Archetype Publications, London.
- Warda, J (ed.) 2017, *The AIC guide to digital photography and conservation documentation*, 3rd edn, American Institute for Conservation, Washington DC.
- Waterson, R 2010, 'First impressions: 19th century travellers' perceptions of Singapore landscape, cityscape and people', in *Singapore through 19th century prints & paintings*, National Museum of Singapore: Didier Millet, Singapore, pp. 10–29.
- Winsor & Newton 2018, 'Winsor & Newton Archive of 19th Century Artists' materials', viewed 21 April 2020, <<https://winsorandnewton.fitzmuseum.cam.ac.uk/>>.
- Winter, J 2008, *East Asian paintings: materials, structures and deterioration mechanisms*, Archetype Publications, London.
- Wong, YL 1995, 'Women's education in traditional and modern China', *Women's History Review*, vol. 4, no. 3, pp. 345–367.
- Woo, FW 2019, *The journey of minds: Chinese modernity and Chinese ink-painting in Singapore*, Singapore Chinese Cultural Centre, Singapore.
- Yeo, HK 1994, 'Nanyang Academy and l'Ecole Nationale Superieure des Beaux Arts', in National Museum Art Gallery (ed.), *Pont des Arts: Nanyang artists in Paris, 1925–1970.*, Singapore Art Museum, Singapore, pp. 21–33.

- Yeo, MT 2019, *Migration, transmission, localisation: visual art in Singapore (1886-1945)*, National Gallery Singapore, Singapore.
- Yoshimura, K 1935, *Holbein artists' colours and materials: general catalogue 5th edition*, Yoshimura Shoten, Osaka.
- You, ZH, Lei, YK, Zhu, L, Xia, J & Wang, B 2013, 'Prediction of protein-protein interactions from amino acid sequences with ensemble extreme learning machines and principal component analysis', *BMC Bioinformatics*, vol. 14, no. 8, viewed on 29 July 2022, <doi.org/10.1186/1471-2105-14-S8-S10>.
- Zhao, W, Zhou, D, Qiu, X & Jiang, W 2021, 'How to represent paintings: a painting classification using artistic comments', *Sensors*, vol. 21, no. 6, p. 19—40.
- Zou, K & Eaksittipong, S 2014, 'In search for “self” and “nation”: Liu Kang and the cultural interpretation of Nanyang art', in Chiang Mai University (ed.), *8th Humanities Research Forum Conference Preprints, Chiang Mai University, Thailand, 27–29 November 2014*, Chiang Mai University, Chiang Mai, pp. 431–446.

Appendix A: List of Paintings Studied

Painting ID	Collection	Title	Artist	Year	Medium
PTG001_CSP001	Koh Seow Chuan	<i>Long House People</i>	Cheong Soo Pieng	1975	Oil on canvas
PTG002_CSP002	Koh Seow Chuan	<i>Untitled (Three Figures, musical instruments)</i>	Cheong Soo Pieng	1968	Oil on canvas
PTG003_CSP003	Koh Seow Chuan	<i>Untitled (Two Figures, Mynah)</i>	Cheong Soo Pieng	1964	Oil on canvas
PTG004_CSP004	Koh Seow Chuan	<i>Malay Boys</i>	Cheong Soo Pieng	1966	Oil on canvas
PTG005_CSP005	Koh Seow Chuan	<i>Untitled (Indian lady with veil)</i>	Cheong Soo Pieng	1966	Oil on hardboard
PTG006_CSP006	Koh Seow Chuan	<i>A corner of art studio</i>	Cheong Soo Pieng	1947	Oil on wood
PTG007_CSP007	Koh Seow Chuan	<i>Untitled (Two dancers)</i>	Cheong Soo Pieng	1957	Unknown on hardboard
PTG008_CSP008	Koh Seow Chuan	<i>Sarawak Sisters</i>	Cheong Soo Pieng	1953	Unknown on hardboard
PTG009_CSP009	Koh Seow Chuan	<i>The Gardener</i>	Cheong Soo Pieng	1958	Oil on hardboard
PTG010_CSP010	Koh Seow Chuan	<i>Landscape</i>	Cheong Soo Pieng	1978	Oil on jute, Marouflaged on canvas
PTG011_CSP011	Koh Seow Chuan	<i>Three Women</i>	Cheong Soo Pieng		Oil on canvas
PTG012_CSP012	Koh Seow Chuan	<i>Bali Women</i>	Cheong Soo Pieng	1952	Oil on canvas, Marouflaged on hardboard
PTG013_CSP013	Koh Seow Chuan	<i>Mosque in the Village</i>	Cheong Soo Pieng	1956	Oil on paper, Marouflaged on hardboard
PTG014_CSP014	Koh Seow Chuan	<i>Sunflowers</i>	Cheong Soo Pieng	1957	Oil on paper, Marouflaged on hardboard
PTG015_CSP015	Koh Seow Chuan	<i>Portrait</i>	Cheong Soo Pieng	1948	Oil on wood
PTG016_CSP016	Koh Seow Chuan	<i>Busy Planters</i>	Cheong Soo Pieng	1968	Oil on canvas
PTG017_CSP017	Koh Seow Chuan	<i>Riverside</i>	Cheong Soo Pieng	1960	Oil on canvas

PTG018_CSP018	Koh Seow Chuan	<i>Worshipper</i>	Cheong Soo Pieng	1978	Oil on straw, Marouflaged on canvas
PTG019_CSP019	Koh Seow Chuan	<i>Untitled (Collage)</i>	Cheong Soo Pieng	1974	Mixed media on canvas
PTG020_CSP020	Koh Seow Chuan	<i>Nature's Inspiration</i>	Cheong Soo Pieng	1963	Mixed media on canvas
PTG021_CSP021	Koh Seow Chuan	<i>Construction</i>	Cheong Soo Pieng	1956	Oil on hardboard
PTG022_CSP022	Koh Seow Chuan	<i>Still Life</i>	Cheong Soo Pieng	1950	Oil on hardboard
PTG023_CSP023	Koh Seow Chuan	<i>Cat</i>	Cheong Soo Pieng	1957	Oil on canvas, Marouflaged on hardboard
PTG024_CSP024	Koh Seow Chuan	<i>Green Landscape</i>	Cheong Soo Pieng	1975	Mixed media on canvas
PTG025_CSP025	Koh Seow Chuan	<i>Gold Green</i>	Cheong Soo Pieng	1977	Mixed media on canvas
PTG026_CSP026	Koh Seow Chuan	<i>Untitled (Red)</i>	Cheong Soo Pieng	1963	Mixed media on canvas
PTG027_GC001	Koh Seow Chuan	<i>Coq</i>	Georgette Chen		Oil on canvas
PTG028_CSP027	Koh Seow Chuan	<i>Westminster Abbey, London</i>	Cheong Soo Pieng	1963	Oil on canvas
PTG029_CSP028	Koh Seow Chuan	<i>Landscape 1</i>	Cheong Soo Pieng	1963	Mixed media on canvas
PTG030_CSP029	Koh Seow Chuan	<i>Calm Motion</i>	Cheong Soo Pieng	1969	Mixed media on canvas
PTG031_CSP030	Koh Seow Chuan	<i>Landscape</i>	Cheong Soo Pieng	1961	Mixed media on canvas
PTG032_CSP031	Koh Seow Chuan	<i>Forest</i>	Cheong Soo Pieng	1948	Oil on plywood
PTG033_CSP032	Koh Seow Chuan	<i>Mountain Landscape</i>	Cheong Soo Pieng	1974	Oil on paper, Marouflaged on paper
PTG034_CSP033	Koh Seow Chuan	<i>Women washing</i>	Cheong Soo Pieng	1977	Oil on canvas, Marouflaged on foamcore
PTG035_CSP034	Koh Seow Chuan	<i>Construction</i>	Cheong Soo Pieng	1976	Mixed media on canvas
PTG036_CSP035	Koh Seow Chuan	<i>Sleeping Lady</i>	Cheong Soo Pieng	1975	Mixed media on canvas
PTG037_CSP036	Koh Seow Chuan	<i>Landscape</i>	Cheong Soo Pieng	1975	Mixed media on canvas
PTG038_GC002	National Library Board	<i>Mooncakes</i>	Georgette Chen	1970	Oil on canvas

PTG039_CSP037	Koh Seow Chuan	<i>Untitled (Orange Landscape)</i>	Cheong Soo Pieng	1970	Oil on paper, Marouflaged on paper
PTG040_CSP038	Koh Seow Chuan	<i>Untitled (Blue landscape #1)</i>	Cheong Soo Pieng	1970	Oil on canvas, Marouflaged on paper
PTG041_CSP039	Koh Seow Chuan	<i>Untitled (Blue landscape #2)</i>	Cheong Soo Pieng	1970	Oil on canvas, Marouflaged on paper
PTG042_CSP040	Koh Seow Chuan	<i>Untitled (Green Landscape #2)</i>	Cheong Soo Pieng	1972	Mixed media on canvas
PTG043_CSP041	Koh Seow Chuan	<i>Untitled (4 women)</i>	Cheong Soo Pieng	1982	Oil on paper, Marouflaged on canvas
PTG044_CSP042	Koh Seow Chuan	<i>Untitled (Village)</i>	Cheong Soo Pieng	1966	Oil on canvas
PTG045_CSP043	Koh Seow Chuan	<i>Untitled (Blue abstract)</i>	Cheong Soo Pieng	1962	Oil on canvas
PTG046_CSP044	Koh Seow Chuan	<i>Untitled (Basket of fruits)</i>	Cheong Soo Pieng	1981	Oil on canvas
PTG047_CSP045	Koh Seow Chuan	<i>Untitled (Blue silver)</i>	Cheong Soo Pieng	1970	Collage (Paper)
PTG048_CSP046	Koh Seow Chuan	<i>Plate 1</i>	Cheong Soo Pieng	n.d	Painted ceramic
PTG049_CSP047	Koh Seow Chuan	<i>Plate 2</i>	Cheong Soo Pieng	n.d	Painted ceramic
PTG050_CSP048	Koh Seow Chuan	<i>Resting (Taiwan)</i>	Cheong Soo Pieng	1982	Unknown on canvas
PTG051_CSP049	Koh Seow Chuan	<i>Pigeon and Lady</i>	Cheong Soo Pieng	1952	Oil on hardboard
PTG052_CSP050	Koh Seow Chuan	<i>Sisters</i>	Cheong Soo Pieng	1971	Mixed media on wood
PTG053_CSP051	Koh Seow Chuan	<i>Untitled (Abstract)</i>	Cheong Soo Pieng	1976	Mixed media on acrylic sheet
PTG054_CSP052	Koh Seow Chuan	<i>Untitled (Fishing Village?)</i>	Cheong Soo Pieng	1960	Oil on hardboard
PTG055_CSP053	Koh Seow Chuan	<i>Construction (结构)</i>	Cheong Soo Pieng	1966	Mixed media on wood
PTG056_GC003	National Gallery Singapore	<i>Assorted Mooncakes</i>	Georgette Chen	1955-60	Oil on canvas
PTG057_GC004	National Gallery Singapore	<i>Mooncakes with Green Pomelo</i>	Georgette Chen	1965-68	Oil on canvas
PTG058_GC005	National Gallery Singapore	<i>Mooncakes with Golden Pomelo</i>	Georgette Chen	1965	Oil on canvas

PTG059_GC006	National Gallery Singapore	<i>Still Life (Moon Festival Table)</i>	Georgette Chen	1962	Oil on canvas
PTG060_GC007	National Museum Singapore	<i>Satay Boy</i>	Georgette Chen	1964	Oil on canvas
PTG061_GC008	National Heritage Board	<i>Tropical Fruits</i>	Georgette Chen	1969	Oil on canvas
PTG062_CSP054	Koh Seow Chuan	<i>Indian Girl</i>	Cheong Soo Pieng	1949	Oil on canvas
PTG063_CSP055	Koh Seow Chuan	<i>Girl in Red</i>	Cheong Soo Pieng	1950	Oil on hardboard
PTG064_CSP056	Koh Seow Chuan	<i>Puppet Maker</i>	Cheong Soo Pieng	1953	Oil on hardboard
PTG065_CSP057	Koh Seow Chuan	<i>Malay Village</i>	Cheong Soo Pieng	1957	Oil on hardboard
PTG066_CSP058	Koh Seow Chuan	<i>Kampung</i>	Cheong Soo Pieng	1958	Oil on canvas
PTG067_CSP059	Koh Seow Chuan	<i>Untitled (Figure)</i>	Cheong Soo Pieng	1950	Oil on hardboard

Appendix B: Specifications of digital multispectral photography techniques

Camera specifications:

NIKON D800 modified to full-spectrum. Images are produced in both NEF and JPEG.

Lens: Single focal length, Sigma 35mm f1/4 DG HSM Art Lens Nikon

#	Category	Imaging Technique	Light sources, specifications	Filters	Camera Settings	Post-Processing	Outcomes
1.1	Visible Light Photography 400 – 700nm	Normal Illumination <i>Front (recto), total and detail</i>	2 LED studio lights with light diffusers Lamp brightness and hues set at 50%	XNite CC167 (400-700nm)	Manual mode: Aperture F8	Colour correction using X-Rite ColorChecker Passport and Adobe Photoshop RGB level brought to 200 RGB (+/- 5)	Provides a record of the appearance of the object as seen under standard viewing condition (AIC 2017, p.113) . Captures details
1.2		Normal Illumination <i>Back (verso), total and detail</i>	25° from object on easel, 1.5m away Light distribution corrected with exposure meter		Shutter speed 1/125 ISO 200 WB 5300		
1.3		Raking illumination (RAK)	1 LED studio lights Lamp brightness and hues set at 50% 5° from top left corner object on easel				Creates shadows that emphasize surface planarity. Documents surface topography and texture such as crack

							patterns, indentations, undulations, weaves
1.4	Visible Light Photography 400-700 nm	Specular illumination	1 LED studio lights Lamp brightness set at 100% Placed beside camera lens directly in front of painting	XNite CC167 (400-700nm)	Manual mode: Aperture F8 ISO 200 WB 5300	Colour correction using X-Rite Color Checker Passport and Adobe Photoshop RGB level brought to 200 RGB (+/- 5)	Surface texture and irregularities (uneven varnish application, cupping, peeling)
1.5		Transmitted illumination	2 Mono incandescent light Lamp brightness set at 100% From back of easel Light distribution corrected with exposure meter				Variations in density, visual opacity. Documenting characteristics of paint application, highlights loss, tears, etc.
2.1	Infrared-Imaging 780nm/1000nm	Infrared-Photography	2 Mono incandescent light Lamp brightness set at 100% 25° from object on easel, 1.5m away	XNite780nm filter 2mm (67mm) IR And/or	Manual mode: Aperture F8 +2 exposure Shutter speed 1/125	Colour correction using X-Rite Color Checker Passport and Adobe Photoshop Saturation -100	Belonging to the non-visible range of the electromagnetic spectrum. IR radiation penetrates through, looking below paint layer. Depth dependent on paint thickness. Imaging

			Light distribution corrected with exposure meter	XNite1000nm filter 2mm (67mm) IR	ISO 200 WB Incandescent	RGB level brought to 200 RGB (+/- 5)	underdrawings and preliminary sketches. Provides information on the painter's technique, construction of the painting, previous restorations and condition (p.11).
2.2	Infrared-Imaging 1000nm	Transmitted infrared reflectography Suitable only for translucent material (paper, canvas)	2 Mono incandescent light Lamp brightness set at 100% Light source from back of object	XNite1000nm filter 2mm (67mm) IR	Manual mode: Aperture F8 - 2 exposure Shutter speed 1/125 ISO 200 WB Incandescent	Colour correction using X-Rite Color Checker Passport and Adobe Photoshop Saturation -100 RGB level brought to 150 RGB (+/- 5)	Due to positioning of light source, it can provide a clearer image of the underdrawings, pentimenti and underpainting. Provides information on the painter's technique, construction of the painting, painting's previous restorations and condition (p.11). Well-suited for studying canvas stamps and other markings when highly reflective pigments are

							present (lead white, titanium white).
3.1	Ultraviolet Imaging UVF@365nm UVR@330nm	Ultraviolet-induced visible fluoresce illumination (UVF)	2 UV LED floodlights on tripods (MaxMax) 50 watt, emits consistent wavelength at 365nm (UVa)	XNiteCC1 filter (67mm) VIS + HOYA UV-barrier filter 67mm	Manual mode: Aperture F8 ISO 200 WB 5300 30 seconds for UVR	Colour correction using X-Rite Color Checker Passport and Adobe Photoshop Temperature set at 7000 Tint at +35	Surface visualisation technique to analyse fluorescent color emitted by the painted surface. Can be an indicator to visually identify the original state of the artwork, including revisions to the surface as discontinuities in the fluorescence, presence and relative aging of varnish layers

3.2		Ultraviolet Reflectography (UVR)		XNiteCC1 filter (67mm) VIS + XNite330nm filter 2.2mm (67mm) UV- R			Specific study for top most pigments or varnish. Can help detect presence of zinc and titanium white. Helpful in identifying retouching and paint microfissures.

Appendix C: Data Dictionary

A total of 520 variables over 110 data points (highlighted in green)

Category	Descriptors	Data format	Data type (text/string etc)	Count of variables	Variables	Labeling order	Assigned value	Data source
Artwork Overview	Painting ID	single line text	text	67	PTGxxx_[Artist initials]xxx	[PTGxxx_[3 letter artist initial]xxx	Unique identifier number given to each painting. Labeled in order of painting studied	Researcher issued
Artwork Overview	Photo	attachment	image	67	NULL	Not applicable	Image of front of painting	Researcher issued
Artwork Overview	Collection	single select	text	3	Koh Seow Chuan	Not applicable	Artwork belongs to the Koh Seow Chuan collection	Researcher issued
Artwork Overview	Collection	single select	text		National Library Board	Not applicable	Artwork belongs to the Koh Seow Chuan collection	Researcher issued
Artwork Overview	Collection	single select	text		National Heritage Board	Not applicable	Artwork belongs to the Koh Seow Chuan collection	Researcher issued
Artwork Overview	Period	single select	text	6	Formative Years	Not applicable	Artwork painted by Cheong Soo Pieng painted during (1946-1949)	Archival sources
Artwork Overview	Period	single select	text		Nanyang Style	Not applicable	Artwork painted by Cheong Soo Pieng painted during (1950-1961)	Archival sources
Artwork Overview	Period	single select	text		Lyrical Abstract	Not applicable	Artwork painted by Cheong Soo Pieng painted during (1962-1963)	Archival sources
Artwork Overview	Period	single select	text		Stylisation	Not applicable	Artwork painted by Cheong Soo Pieng painted during (1964-1969)	Archival sources
Artwork Overview	Period	single select	text		Artistic Maturation	Not applicable	Artwork painted by Cheong Soo Pieng painted during (1970-1978)	Archival sources
Artwork Overview	Period	single select	text		Late Developments	Not applicable	Artwork painted by Cheong Soo Pieng painted during (1980-1983)	Archival sources

Artwork Overview	Title	single line text	text	67	NULL	Not applicable	Title given to artwork as recorded on labels. If none, Untitled (short description of painting)	Object source, researcher issued
Artwork Overview	Artist	single select	text	2	Cheong Soo Pieng	Not applicable	Artwork attributed to Cheong Soo Pieng	Object source, collector attribution
Artwork Overview	Artist	single select	text		Georgette Chen	Not applicable	Artwork attributed to Georgette Chen	Object source, collector attribution
Artwork Overview	Date of Study	date	date		NULL	Not applicable	Date when painting was first studied	Researcher issued
Artwork Overview	Framed	checkbox	binary	2	checked	Not applicable	Artwork is framed upon receipt of study	Technical examination (visual)
Artwork Overview	Framed	checkbox	binary		unchecked	Not applicable	Artwork is framed upon receipt of study	Technical examination (visual)
Artwork Overview	Year	single line text	number		NULL	YYYY	Attributed year of the artwork. May be from signature/ inscriptions or archival sources	Object source
Artwork Overview	Medium	multiple select	text	20	ceramic	Not applicable	Ceramic object	Technical examination (visual)
Artwork Overview	Medium	multiple select	text		collage (paper)	Not applicable	Artwork on paper with collage elements	Technical examination (visual)
Artwork Overview	Medium	multiple select	text		marouflaged on canvas	Not applicable	Artwork is marouflaged onto a canvas fabric support	Technical examination (visual)
Artwork Overview	Medium	multiple select	text		marouflaged on cotton	Not applicable	Artwork is marouflaged onto a cotton-canvas support	Technical examination (visual)

Artwork Overview	Medium	multiple select	text		marouflaged on hardboard	Not applicable	Artwork is marouflaged onto a hardboard support	Technical examination (visual)
Artwork Overview	Medium	multiple select	text		marouflaged on paper	Not applicable	Artwork is marouflaged onto a paper support	Technical examination (visual)
Artwork Overview	Medium	multiple select	text		marouflaged on wood	Not applicable	Artwork is marouflaged onto a wood support	Technical examination (visual)
Artwork Overview	Medium	multiple select	text		metal relief	Not applicable	Artwork has a metal relief component	Technical examination (visual)
Artwork Overview	Medium	multiple select	text		mixed media on acrylic sheet	Not applicable	Artwork has mixed media elements on an acrylic sheet	Technical examination (visual)
Artwork Overview	Medium	multiple select	text		mixed media on canvas	Not applicable	Artwork has mixed media elements on canvas	Technical examination (visual)
Artwork Overview	Medium	multiple select	text		mixed media on wood	Not applicable	Artwork has mixed media elements on wood	Technical examination (visual)
Artwork Overview	Medium	multiple select	text		oil on canvas	Not applicable	Painting has oil on canvas	Technical examination (visual)
Artwork Overview	Medium	multiple select	text		oil on hardboard	Not applicable	Painting is an oil paint on hardboard	Technical examination (visual)
Artwork Overview	Medium	multiple select	text		oil on jute	Not applicable	Painting is an oil paint on jute fabric support	Technical examination (visual)
Artwork Overview	Medium	multiple select	text		oil on paper	Not applicable	Painting is an oil paint on paper support	Technical examination (visual)

Artwork Overview	Medium	multiple select	text		oil on plywood	Not applicable	Painting is an oil paint on plywood support	Technical examination (visual)
Artwork Overview	Medium	multiple select	text		oil on straw	Not applicable	Painting is an oil paint on straw support	Technical examination (visual)
Artwork Overview	Medium	multiple select	text		oil on wood	Not applicable	Painting is an oil paint on solid wood support	Technical examination (visual)
Artwork Overview	Medium	multiple select	text		unknown on canvas	Not applicable	Painting has an unknown paint medium on canvas support	Technical examination (visual)
Artwork Overview	Medium	multiple select	text		unknown on hardboard	Not applicable	Painting has an unknown paint medium on hardboard support	Technical examination (visual)
Artwork Overview	Details (Fibre)	look up	text		NULL	Not applicable	look up from sample record-findings (fiber)	Link from another record
Artwork Overview	Signed	look up	binary		NULL	Not applicable	look up from general identifiers-signature (recto)	Link from another record
Artwork Overview	& Inscribed	look up	binary		NULL	Not applicable	look up from general identifiers-inscription (verso)	Link from another record
Artwork Overview	Manufacturer stamp (from Primary Support 2)	look up	text		NULL	Not applicable	look up from primary support-manufacturer stamp	Link from another record
Artwork Overview	Labels	look up	text		NULL	Not applicable	look up auxiliary support- inscriptions or labels	Link from another record
Artwork Overview	Ground	look up	text		NULL	Not applicable	look up ground details-colour (ground)	Link from another record
Artwork Overview	General Identifiers	record-link	record		NULL	Not applicable	Links to General Identifiers record	Link from another record
Artwork Overview	Auxiliary Support	record-link	record		NULL	Not applicable	Links to Auxiliary Support tab	Link from another record
Artwork Overview	Primary Support	record-link	record		NULL	Not applicable	Links to Primary Support tab	Link from another record

Artwork Overview	Ground Details	record-link	record		NULL	Not applicable	Links to Ground Details tab	Link from another record
Artwork Overview	Paint Medium	record-link	record		NULL	Not applicable	Links to Paint Medium tab	Link from another record
Artwork Overview	Surface Coating	record-link	record		NULL	Not applicable	Links to Surface Coating tab	Link from another record
Artwork Overview	Sample Record	record-link	record		NULL	Not applicable	Links to Sample Record tab	Link from another record
Artwork Overview	No. of samples	count	number		NULL	Not applicable	Number of samples that has been extracted from the painting	Counts from Sample Record following Painting ID
Artwork Overview	Sample with Ground	look up	text		NULL	Not applicable	List of samples with ground layer	Looks up Sample Record>Sample ID>Ground Binder ID
Artwork Overview	Sample with Varnish	look up	text		NULL	Not applicable	List of samples with surface coating layer	Looks up Sample Record>Sample ID>Surface Coating ID
Artwork Overview	Sample with Paint	look up	text		NULL	Not applicable	List of samples with paint layers	Looks up Sample Record>Sample ID>Paint Pigment ID
General Identifiers	GI ID	single line text	text	67	PTGxxx.GI	PTG[reference artwork ID].GI	Unique identifier number given to each painting layer regardless of presence	Researcher issued
General Identifiers	Painting ID	record-link	record	67	NULL	Not applicable	Links to the Painting ID the ground is related to	Link from Artwork Overview> Painting ID
General Identifiers	Title	look up	text		NULL	Not applicable	Title of painting	Looks up Artwork Overview>

								Painting ID> Title
General Identifiers	Artist	look up	text		NULL	Not applicable	Attributed artist of the artwork	Looks up Artwork Overview> Painting ID> Artist
General Identifiers	Year	look up	text		NULL	Not applicable	Attributed year of the artwork	Looks up Artwork Overview> Painting ID> Year
General Identifiers	Medium	look up	text		NULL	Not applicable	Attributed medium of the artwork	Looks up Artwork Overview> Painting ID> Medium
General Identifiers	Framed	look up	binary		NULL	Not applicable	Whether the artwork is framed at time of study	Looks up Artwork Overview> Painting ID> Framed
General Identifiers	Dimensions Framed	single line text	text		NULL	H x W x D (cm)	Size of artwork inclusive of frame. If unframed, leave blank.	Technical examination (visual)
General Identifiers	Dimensions Sight	single line text	text		NULL	H x W x D (cm)	If it is framed, the visible portion of the painting is measured.	Technical examination (visual)
General Identifiers	Signature (Recto)	checkbox	binary	2	checked	Not applicable	Signature is present in the front of the painting. Any artist identifier (monograms/ text) etc.	Technical examination (visual)
General Identifiers	Signature (Recto)	checkbox	binary		unchecked	Not applicable	No signature identified in the front of the painting	Technical examination (visual)

General Identifiers	Signature Location	multiple select	text	9	Unsigned	Not applicable	There are no signatures on front of painting	Technical examination (visual)
General Identifiers	Signature Location	multiple select	text		Top right	Not applicable	Signature is located on top right, recto of painting	Technical examination (visual)
General Identifiers	Signature Location	multiple select	text		Top left	Not applicable	Signature is located on top left, recto of painting	Technical examination (visual)
General Identifiers	Signature Location	multiple select	text		Centre right	Not applicable	Signature is located on centre right, recto of painting	Technical examination (visual)
General Identifiers	Signature Location	multiple select	text		Centre left	Not applicable	Signature is located on centre left, recto of painting	Technical examination (visual)
General Identifiers	Signature Location	multiple select	text		Centre	Not applicable	Signature is located on centre, recto of painting	Technical examination (visual)
General Identifiers	Signature Location	multiple select	text		Bottom right	Not applicable	Signature is located on bottom right, recto of painting	Technical examination (visual)
General Identifiers	Signature Location	multiple select	text		Bottom left	Not applicable	Signature is located on bottom left, recto of painting	Technical examination (visual)
General Identifiers	Signature Location	multiple select	text		Bottom centre	Not applicable	Signature is located on bottom centre, recto of painting	Technical examination (visual)
General Identifiers	Details_Signature	long text	text		NULL	Not applicable	Recorded as what has been identified as a signature (written/painted onto recto of painting)	Technical examination (visual)
General Identifiers	Changes	checkbox	binary	2	checked	Not applicable	Changes in signature location were observed	Technical examination (Infrared Photography)

General Identifiers	Changes	checkbox	binary		unchecked	Not applicable	No changes were observed in signature location	Technical examination (Infrared Photography)
General Identifiers	Details of changes	long text	text		NULL	Not applicable	Details of changes on signature, recto of painting	Technical examination (Infrared Photography)
General Identifiers	Colour	multiple select	text	7	NULL	Not applicable	Colour of signature on recto of painting	Technical examination (visual)
General Identifiers	Inscriptions (Verso)	checkbox	binary	2	checked	Not applicable	Presence of artist-written inscriptions on verso of painting (possibly in pen/charcoal/paint)	Technical examination (visual)
General Identifiers	Inscriptions (Verso)	checkbox	binary		unchecked	Not applicable	No observed artist-written inscriptions on verso of painting	Technical examination (visual)
General Identifiers	Details of Inscription	long text	text		unchecked	Not applicable	Recorded as what has been identified as an inscription (written/painted onto verso of painting)	Technical examination (visual)
General Identifiers	Date location	multiple select	text	3	verso	Not applicable	Artist-written date located on verso of the painting	Technical examination (visual)
General Identifiers	Date location	multiple select	text		recto	Not applicable	Artist-written date located on recto of the painting	Technical examination (visual)
General Identifiers	Date location	multiple select	text		undated	Not applicable	No artist-written date on the painting	Technical examination (visual)
General Identifiers	Label (Location)	multiple select	text	2	verso	Not applicable	Presence of paper labels on the verso canvas of the painting	Technical examination (visual)

General Identifiers	Label (Location)	multiple select	text		stretcher bar	Not applicable	Presence of paper labels on the stretcher bar (verso/side) of the painting	Technical examination (visual)
General Identifiers	Secondary sources	long text	text		NULL	Not applicable	Any identified secondary sources that makes reference to identify painting	Archival sources
Primary Support	PS ID	single line text	text	67	PTGxxx.PS	PTG[reference artwork ID].PS	Unique identifier number given to each painting support regardless of presence	Researcher issued
Primary Support	Painting ID	record-link	record	67	NULL	Not applicable	Links to the Painting ID the ground is related to	Link from Artwork Overview> Painting ID
Primary Support	Title	look up	text		NULL	Not applicable	Title of painting	Looks up Artwork Overview> Painting ID> Title
Primary Support	Artist	look up	text		NULL	Not applicable	Attributed artist of the artwork	Looks up Artwork Overview> Painting ID> Artist
Primary Support	Year	look up	text		NULL	Not applicable	Attributed year of the artwork	Looks up Artwork Overview> Painting ID> Year
Primary Support	Medium	look up	text		NULL	Not applicable	Attributed medium of the artwork	Looks up Artwork Overview> Painting ID> Medium

Primary Support	Type of support	single select	text	3	flexible	Not applicable	Canvas is on a flexible support (canvas/ paper/ etc)	Technical examination (visual)
Primary Support	Type of support	single select	text		solid	Not applicable	Canvas is on a solid support (wood/ plywood/ hardboard/ masonite)	Technical examination (visual)
Primary Support	Type of support	single select	text		not applicable	Not applicable	Not applicable to the artwork studied	Technical examination (visual)
Primary Support	Analysed	checkbox	binary	2	checked	Not applicable	Fibre has been analysed	Technical examination (microscopy)
Primary Support	Analysed	checkbox	binary		unchecked	Not applicable	Fibre has not been analysed	Technical examination (microscopy)
Primary Support	Reference	record-link	record	67	NULL	Not applicable	Links to Fibre analysed	Link from Sample ID with Fibre
Primary Support	Findings (from Sample ID)	look up	text		NULL	Not applicable	List of fibre from findings from analysis	Looks up Sample ID> Findings (Fibre)
Primary Support	Canvas Color	single select	text	3	Creamy white	Not applicable	Colour of primary support is more cream-coloured than white	Technical examination (visual)
Primary Support	Canvas Color	single select	text		Brown	Not applicable	Colour of primary support is brown	Technical examination (visual)
Primary Support	Canvas Color	single select	text		White	Not applicable	Colour of primary support is stark white	Technical examination (visual)
Primary Support	Thread Count	single line text	text		NULL	xyy/cm	Thread count of canvas if available, if not, Unreocrded or Not accessble	Technical examination (visual)

Primary Support	Selvage edge	multiple select	text	7	Bottom	Not applicable	Selvage edge of canvas support is located on bottom of painting (measurement taken from verso)	Technical examination (visual)
Primary Support	Selvage edge	multiple select	text		Top	Not applicable	Selvage edge of canvas support is located on top of painting (measurement taken from verso)	Technical examination (visual)
Primary Support	Selvage edge	multiple select	text		Left	Not applicable	Selvage edge of canvas support is located on left of painting (measurement taken from verso)	Technical examination (visual)
Primary Support	Selvage edge	multiple select	text		Right	Not applicable	Selvage edge of canvas support is located on right of painting (measurement taken from verso)	Technical examination (visual)
Primary Support	Selvage edge	multiple select	text		None	Not applicable	There are no selvage edge observed	Technical examination (visual)
Primary Support	Selvage edge	multiple select	text		Not applicable	Not applicable	Selvage edge is not applicable	Technical examination (visual)
Primary Support	Selvage edge	multiple select	text		Not accessible	Not applicable	Selvage edge is not accessible for study	Technical examination (visual)
Primary Support	Manufacturer stamp	single select	text	7	Holbein 1	Not applicable	Presence of 1 or more red 'Holbein 1' stamp found on artwork	Technical examination (visual)
Primary Support	Manufacturer stamp	single select	text		Holbein 2	Not applicable	Presence of 1 or more red 'Holbein 2' stamp found on artwork	Technical examination (visual)
Primary Support	Manufacturer stamp	single select	text		Holbein 3	Not applicable	Presence of 1 or more red 'Holbein 3' stamp found on artwork	Technical examination (visual)
Primary Support	Manufacturer stamp	single select	text		Holbein 10	Not applicable	Presence of 1 or more red 'Holbein 10' stamp found on artwork	Technical examination (visual)

Primary Support	Manufacturer stamp	single select	text		Masonite	Not applicable	Presence of 'Masonite' stamp found on artwork	Technical examination (visual)
Primary Support	Manufacturer stamp	single select	text		Masonite, Preswood	Not applicable	Presence of 'Masonite, Preswood' stamp found on artwork	Technical examination (visual)
Primary Support	Manufacturer stamp	single select	text		None	Not applicable	No manufacturer stamp observed on artwork	Technical examination (visual)
Primary Support	Type Original Attachment	single select	text	6	Adhesive	Not applicable	Adhesive was used to attach the primary support to its auxiliary support	Technical examination (visual)
Primary Support	Type Original Attachment	single select	text		Staples	Not applicable	Staples were used to attach the primary support to its auxiliary support	Technical examination (visual)
Primary Support	Type Original Attachment	single select	text		Tacks	Not applicable	Tacks (nails) were used to attach the primary support to its auxiliary support	Technical examination (visual)
Primary Support	Type Original Attachment	single select	text		Unattached	Not applicable	The primary support is unattached to any auxiliary support	Technical examination (visual)
Primary Support	Type Original Attachment	single select	text		Unknown	Not applicable	The original attachment is unknown	Technical examination (visual)
Primary Support	Type Original Attachment	single select	text		Unmounted	Not applicable	The artwork is unmounted and does not require attachment	Technical examination (visual)
Primary Support	Canvas Pliers	checkbox	binary	2	checked	Not applicable	There is evidence of canvas crimp marks on reverse excess support	Technical examination (visual)
Primary Support	Canvas Pliers	checkbox	binary		unchecked	Not applicable	There is no evidence of canvas crimp marks on reverse excess support	Technical examination (visual)

Primary Support	Canvas Shape	single select	text	5	cut to face	Not applicable	Canvas is cut to face front of painting	Technical examination (visual)
Primary Support	Canvas Shape	single select	text		cut to reverse edge	Not applicable	Canvas is cut with excess fabric on verso	Technical examination (visual)
Primary Support	Canvas Shape	single select	text		cut to tacking margin	Not applicable	Canvas is cut to edge of tacking margin	Technical examination (visual)
Primary Support	Canvas Shape	single select	text		not accessible	Not applicable	Not able to access canvas edge at time of study	Technical examination (visual)
Primary Support	Canvas Shape	single select	text		not applicable	Not applicable	Not applicable to the artwork studied	Technical examination (visual)
Primary Support	Corner Folds	single select	text	5	folded over, 45	Not applicable	Canvas is folded over to the reverse with a 45° tuck observed on all edges	Technical examination (visual)
Primary Support	Corner Folds	single select	text		folded over, straight	Not applicable	Canvas is folded over to the reverse with a overlap-straight fold observed on the edges	Technical examination (visual)
Primary Support	Corner Folds	single select	text		folded top and bottom, 45	Not applicable	Canvas is folded over to the reverse with a 45° tuck observed only on top and bottom edges	Technical examination (visual)
Primary Support	Corner Folds	single select	text		not accessible	Not applicable	Not able to access canvas edge at time of study	Technical examination (visual)
Primary Support	Corner Folds	single select	text		not applicable	Not applicable	Not applicable to the artwork studied	Technical examination (visual)
Primary Support	Marouflaged	single select	text	2	yes	Not applicable	Artwork is marouflaged (adhered) onto another auxiliary support	Technical examination (visual)

Primary Support	Marouflaged	single select	text		no	Not applicable	Artwork is not marouflaged to another support	Technical examination (visual)
Primary Support	Reverse staining	multiple select	text	6	yes	Not applicable	There is staining evidenced on reverse of support	Technical examination (visual)
Primary Support	Reverse staining	multiple select	text		no	Not applicable	There is no staining observed on reverse of support	Technical examination (visual)
Primary Support	Reverse staining	multiple select	text		not applicable	Not applicable	Staining of the reverse is not applicable to the artwork	Technical examination (visual)
Primary Support	Reverse staining	multiple select	text		paint	Not applicable	The reverse is stained with paint	Technical examination (visual)
Primary Support	Reverse staining	multiple select	text		wax-lining	Not applicable	The reverse is stained with wax from wax-lining restoration	Technical examination (visual)
Primary Support	Reverse staining	multiple select	text		crack patterns	Not applicable	The reverse is stained through with crack patterns	Technical examination (visual)
Primary Support	Alteration image size	single select	text	2	yes	Not applicable	The image size of the artwork has been altered such as change of stretcher	Technical examination (visual)
Primary Support	Alteration image size	single select	text		no	Not applicable	The image size of the artwork has not been altered	Technical examination (visual)
Primary Support	Structural Condition	single select	text	3	stable	Not applicable	The condition of the primary support at time of study I is stable	Technical examination (visual)
Primary Support	Structural Condition	single select	text		moderately stable	Not applicable	The condition of the primary support at time of study i is satisfactory but is not prestine	Technical examination (visual)

Primary Support	Structural Condition	single select	text		unstable	Not applicable	The condition of the primary support at time of study is unstable and requires attention	Technical examination (visual)
Primary Support	Details of Condition	multiple select	text	12	bulges	Not applicable	Bulges (localised) are observed on the primary support at time of study	Technical examination (visual)
Primary Support	Details of Condition	multiple select	text		corner distortions	Not applicable	Corner distortions are observed on the primary support at time of study	Technical examination (visual)
Primary Support	Details of Condition	multiple select	text		corroded metal	Not applicable	Corroded metal elements are observed on the primary support at time of study	Technical examination (visual)
Primary Support	Details of Condition	multiple select	text		delamination (paint)	Not applicable	Paint has delaminated from the primary support as observed at time of study	Technical examination (visual)
Primary Support	Details of Condition	multiple select	text		delamination (auxiliary support)	Not applicable	Primary support has delaminated from its auxiliary support at time of study	Technical examination (visual)
Primary Support	Details of Condition	multiple select	text		loss of tension	Not applicable	Primary support has a loss of tension (slack) at time of study	Technical examination (visual)
Primary Support	Details of Condition	multiple select	text		paint loss	Not applicable	Paint loss has been observed on the primary support at time of study	Technical examination (visual)
Primary Support	Details of Condition	multiple select	text		stretcher bar marks	Not applicable	Stretcher bar marks are observed on the primary support at time of study	Technical examination (visual)
Primary Support	Details of Condition	multiple select	text		undulations	Not applicable	Undulations are observed on the primary support at time of study	Technical examination (visual)
Primary Support	Details of Condition	multiple select	text		unmounted	Not applicable	Primary support is unmounted onto any auxiliary support at time of study	Technical examination (visual)

Primary Support	Details of Condition	multiple select	text		vertical wood cracks	Not applicable	Vertical wood cracks are observed on the primary support at time of study	Technical examination (visual)
Primary Support	Details of Condition	multiple select	text		warping	Not applicable	Primary support is warped at time of study	Technical examination (visual)
Primary Support	Past treatment	checkbox	binary	2	checked	Not applicable	Past restoration efforts observed at time of study	Technical examination (visual)
Primary Support	Past treatment	checkbox	binary		unchecked	Not applicable	No past restoration efforts observed at time of study	Technical examination (visual)
Primary Support	Details of treatment	multiple select	text	6	Strip-lining	Not applicable	Painting has been strip-lined as part of previous restoration efforts, observed at time of study	Technical examination (visual)
Primary Support	Details of treatment	multiple select	text		Re-stretching	Not applicable	Painting has been re-stretched as part of previous restoration efforts, observed at time of study	Technical examination (visual)
Primary Support	Details of treatment	multiple select	text		Full-lining	Not applicable	Painting has been fully re-lined as part of previous restoration efforts, observed at time of study	Technical examination (visual)
Primary Support	Details of treatment	multiple select	text		Inpainting	Not applicable	Inpainting observed on painting as part of previous restoration efforts, observed at time of study	Technical examination (visual)
Primary Support	Details of treatment	multiple select	text		Extension of canvas	Not applicable	Additional canvas has been added to original primary support to extend the canvas length	Technical examination (visual)
Primary Support	Remarks	long text	text		NULL	Not applicable	Any additional comments that do not fit into any of the descriptors can be recorded here	Researcher issued
Ground prep	Ground ID	single line text	text	67	PTGxxx.GI	PTG[reference artwork ID].GI	Unique identifier number given to each painting support regardless of presence	Researcher issued

Ground prep	Painting ID	record-link	record	67	NULL	Not applicable	Links to the Painting ID the ground is related to	Link from Artwork Overview> Painting ID
Ground prep	Title	look up	text		NULL	Not applicable	Title of painting	Looks up Artwork Overview> Painting ID> Title
Ground prep	Artist	look up	text		NULL	Not applicable	Attributed artist of the artwork	Looks up Artwork Overview> Painting ID> Artist
Ground prep	Artist	look up	text		NULL	Not applicable	Attributed year of the artwork	Looks up Artwork Overview> Painting ID> Year
Ground prep	Medium	look up	text		NULL	Not applicable	Attributed medium of the artwork	Looks up Artwork Overview> Painting ID> Medium
Ground prep	Presence (Ground)	checkbox	binary	2	checked	Not applicable	Presence of ground layer on painting	Technical examination (visual)
Ground prep	Presence (Ground)	checkbox	binary		unchecked	Not applicable	No evidence of ground layer on painting	Technical examination (visual)
Ground prep	Colour (Ground)	single select	text	5	White	Not applicable	Colour of ground is stark white	Technical examination (visual)

Ground prep	Colour (Ground)	single select	text		Creamy white	Not applicable	Colour of ground is more cream-coloured than white	Technical examination (visual)
Ground prep	Colour (Ground)	single select	text		Yellow	Not applicable	Colour of ground is yellow	Technical examination (visual)
Ground prep	Colour (Ground)	single select	text		Grey	Not applicable	Colour of ground is grey	Technical examination (visual)
Ground prep	Colour (Ground)	single select	text		None observed	Not applicable	No ground layer observed	Technical examination (visual)
Ground prep	Visibility on edge	single select	text	4	primed	Not applicable	Ground layer is present on the tacking margin edge of the painting	Technical examination (visual)
Ground prep	Visibility on edge	single select	text		unprimed	Not applicable	No ground layer observed on the tacking margin edge of the painting	Technical examination (visual)
Ground prep	Visibility on edge	single select	text		not accessible	Not applicable	Unable to access tacking margin edge to make observations	Technical examination (visual)
Ground prep	Visibility on edge	single select	text		not applicable	Not applicable	The artwork has no tacking margin	Technical examination (visual)
Ground prep	Ground to Canvas	multiple select	text	4	exposed linen	Not applicable	From the verso, exposed linen and the edge of ground application is observed	Technical examination (visual)
Ground prep	Ground to Canvas	multiple select	text		to edge	Not applicable	From the verso, ground is applied to the edge of the canvas	Technical examination (visual)
Ground prep	Ground to Canvas	multiple select	text		not applicable	Not applicable	Not applicable to the artwork studied	Technical examination (visual)

Ground prep	Ground to Canvas	multiple select	text		not accesible	Not applicable	The edge of canvas is not accesible during point of study to observe the ground	Technical examination (visual)
Ground prep	Preparation	single select	text	3	current AS	Not applicable	If ground is applied only to face of painting or if it is unprimed on the edge, the ground is likely prepared on current auxiliary support	Researcher issued
Ground prep	Preparation	single select	text		other AS	Not applicable	If there is exposed linen or ground is to edge of canvas, the ground is likely prepared on another auxiliary support (strainer/stretcher)	Researcher issued
Ground prep	Preparation	single select	text		not accessible	Not applicable	Unable to access tacking margin edge to make observations	Technical examination (visual)
Ground prep	Texture Observations	multiple select	text	5	brushstrokes	Not applicable	Brushstrokes are observed on the ground layer	Technical examination (visual)
Ground prep	Texture Observations	multiple select	text		even	Not applicable	Ground is evenly applied	Technical examination (visual)
Ground prep	Texture Observations	multiple select	text		uneven	Not applicable	Ground is unevenly applied	Technical examination (visual)
Ground prep	Texture Observations	multiple select	text		thick	Not applicable	Ground layer is thicker than paint layers	Technical examination (visual)
Ground prep	Texture Observations	multiple select	text		thin	Not applicable	Ground layer is thin compared to the paint layers	Technical examination (visual)
Ground prep	Condition	single select	text	3	well-adhered	Not applicable	Ground layer is well adhered to the primary support at time of study	Technical examination (visual)

Ground prep	Condition	single select	text		delaminating	Not applicable	Ground layer is delaminating from the primary support at time of study	Technical examination (visual)
Ground prep	Condition	single select	text		slightly brittle	Not applicable	Ground layer is brittle (powdery)	Technical examination (visual)
Ground prep	Preparatory Layer	checkbox	binary	2	checked	Not applicable	Preparatory layer is observed between ground and paint layer	Technical examination (microscopy-cross section)
Ground prep	Preparatory Layer	checkbox	binary		unchecked	Not applicable	No preparatory layer was observed between ground and paint layer	Technical examination (microscopy-cross section)
Ground prep	Colour (Prep)	single select	text	2	Grey	Not applicable	Preparatory layer is grey in colour	Technical examination (microscopy-cross section)
Ground prep	Colour (Prep)	single select	text		Brown	Not applicable	Preparatory layer is brown in colour	Technical examination (microscopy-cross section)
Ground prep	Sample ID	record-link	record		NULL	Not applicable	Links to Sample ID of sample with a ground layer that has been studied	Link from another record
Ground prep	Findings (Inorganic)	look up	text		NULL	Not applicable	List of Inorganic findings relating to ground layer from material analysis (as identified from Sample ID)	Looks up Sample Record>Sample ID>Findings (Inorganic)
Ground prep	Findings (Binder)	look up	text		NULL	Not applicable	List of organic findings relating to binder of ground layer from material analysis (as identified from Sample ID)	Looks up Sample Record>Sample ID>Findings (Binder)

Auxiliary Support	AS ID	single line text	text	67	PTGxxx.AS	PTG[reference artwork ID].AS	Unique identifier number given to each painting support regardless of presence	Researcher issued
Auxiliary Support	Painting ID	record-link	record	67	NULL	Not applicable	Links to the Painting ID the ground is related to	Link from Artwork Overview> Painting ID
Auxiliary Support	Title	look up	text		NULL	Not applicable	Title of painting	Looks up Artwork Overview> Painting ID> Title
Auxiliary Support	Artist	look up	text		NULL	Not applicable	Attributed artist of the artwork	Looks up Artwork Overview> Painting ID> Artist
Auxiliary Support	Year	look up	text		NULL	Not applicable	Attributed year of the artwork	Looks up Artwork Overview> Painting ID> Year
Auxiliary Support	Medium	look up	text		NULL	Not applicable	Attributed medium of the artwork	Looks up Artwork Overview> Painting ID> Medium
Auxiliary Support	Original	single select	text	7	missing	Not applicable	Auxiliary support is missing from the artwork at point of study	Technical examination (visual)
Auxiliary Support	Original	single select	text		not applicable	Not applicable	Not applicable to the artwork studied	Technical examination (visual)

Auxiliary Support	Original	single select	text		original	Not applicable	The current auxiliary support is original, at point of study	Technical examination (visual)
Auxiliary Support	Original	single select	text		original with reinforcement	Not applicable	The original auxiliary support is present with added reinforcement structures (such as additional cross-bars)	Technical examination (visual)
Auxiliary Support	Original	single select	text		replaced	Not applicable	The original auxiliary support has been replaced	Technical examination (visual)
Auxiliary Support	Original	single select	text		unknown	Not applicable	It is unknown if the current auxiliary support is original or a replacement	Technical examination (visual)
Auxiliary Support	Original	single select	text		unmounted	Not applicable	The artwork is unmounted at point of study	Technical examination (visual)
Auxiliary Support	Type	single select	text	9	stretcher	Not applicable	The current auxiliary support is a stretcher (with adjustable bars, able to be tapped out)	Technical examination (visual)
Auxiliary Support	Type	single select	text		strainer	Not applicable	The current auxiliary support is a strainer (with fixed edges, often glued or stapled)	Technical examination (visual)
Auxiliary Support	Type	single select	text		strainer-board	Not applicable	The current auxiliary support is a strainer-board (fixed auxiliary structure with a flat panel board affixed ontop of a strainer)	Technical examination (visual)
Auxiliary Support	Type	single select	text		hardboard	Not applicable	The current auxiliary support is a hardboard (such as masonite or any plywood board)	Technical examination (visual)
Auxiliary Support	Type	single select	text		wood	Not applicable	The current auxiliary support is wood (one solid plank)	Technical examination (visual)

Auxiliary Support	Type	single select	text		foam core	Not applicable	The current auxiliary support is foam-core	Technical examination (visual)
Auxiliary Support	Type	single select	text		paper	Not applicable	The current auxiliary support is paper-based	Technical examination (visual)
Auxiliary Support	Type	single select	text		not applicable	Not applicable	Not applicable to the artwork studied	Technical examination (visual)
Auxiliary Support	Type	single select	text		not accessible	Not applicable	Unable to access auxiliary support to make observations	Technical examination (visual)
Auxiliary Support	Thickness (mm)	number	number		NULL	x/mm	Thickness of auxiliary support in milimetres	Technical examination (visual)
Auxiliary Support	Joint Type	single select	text	3	Mitre	Not applicable	The joint of the strainer/stretcher is mitre (with a 45° angle)	Technical examination (visual)
Auxiliary Support	Joint Type	single select	text		Tongue and groove	Not applicable	The joint of the stretcher is tongue and groove (well-fitted insert)	Technical examination (visual)
Auxiliary Support	Joint Type	single select	text		not accessible	Not applicable	Unable to access reverse of auxiliary support to make observations	Technical examination (visual)
Auxiliary Support	Joint Type	single select	text		not applicable	Not applicable	Not applicable to the artwork studied	Technical examination (visual)
Auxiliary Support	Cross-brace	multiple select	text		corner	Not applicable	Auxiliary support has corner braces	Technical examination (visual)
Auxiliary Support	Cross-brace	multiple select	text		cross	Not applicable	Auxiliary support has a cross brace (horizontal and vertical)	Technical examination (visual)

Auxiliary Support	Cross-brace	multiple select	text		horizontal	Not applicable	Auxiliary support has a horizontal brace	Technical examination (visual)
Auxiliary Support	Cross-brace	multiple select	text		vertical	Not applicable	Auxiliary support has a vertical brace	Technical examination (visual)
Auxiliary Support	Cross-brace	multiple select	text		none	Not applicable	Auxiliary support has no braces	Technical examination (visual)
Auxiliary Support	Cross-brace	multiple select	text		not applicable	Not applicable	Not applicable to the artwork studied	Technical examination (visual)
Auxiliary Support	No of braces	number	number		NULL	Not applicable	Number of braces the auxiliary support has	Technical examination (visual)
Auxiliary Support	Inscriptions or Labels	multiple select	text	4	inscription	Not applicable	Hand-written inscription/s are found on the back of the auxiliary support and/or primary support	Technical examination (visual)
Auxiliary Support	Inscriptions or Labels	multiple select	text		label	Not applicable	Label/s are found on the back of the auxiliary support and/or primary support (include both present and evidence of loss)	Technical examination (visual)
Auxiliary Support	Inscriptions or Labels	multiple select	text		stamp	Not applicable	Stamps are found on the back of the auxiliary support and/or primary support	Technical examination (visual)
Auxiliary Support	Inscriptions or Labels	multiple select	text		none	Not applicable	No inscriptions, labels or stamps were found on the auxiliary support and/or primary support	Technical examination (visual)
Auxiliary Support	Type of label	multiple select	text	8	exhibition	Not applicable	Exhibition label/s found on the back of the auxiliary support and/or primary support	Technical examination (visual)
Auxiliary Support	Type of label	multiple select	text		artist label	Not applicable	Artist-made label/s found on the back of the auxiliary support and/or primary support	Technical examination (visual)

Auxiliary Support	Type of label	multiple select	text		frame maker	Not applicable	Frame-maker's label/s found on the back of the auxiliary support and/or primary support	Technical examination (visual)
Auxiliary Support	Type of label	multiple select	text		artwork details	Not applicable	Label/s with artwork details found on the back of the auxiliary support and/or primary support	Technical examination (visual)
Auxiliary Support	Type of label	multiple select	text		gallery	Not applicable	Gallery label/s found on the back of the auxiliary support and/or primary support	Technical examination (visual)
Auxiliary Support	Type of label	multiple select	text		others	Not applicable	Other label/s or inscriptions which do not confine to categories above	Technical examination (visual)
Auxiliary Support	Type of label	multiple select	text		missing	Not applicable	Label/s are missing from the current auxiliary support and/or primary support	Technical examination (visual)
Auxiliary Support	Details of inscriptions or labels	long text	text		NULL	Not applicable	Any additional comments that do not fit into any of the descriptors can be recorded here	Technical examination (visual)
Auxiliary Support	Structural Condition	single select	text	5	good condition	Not applicable	Auxiliary support is in a structurally good condition at point of study	Technical examination (visual)
Auxiliary Support	Structural Condition	single select	text		unstable; warping	Not applicable	Auxiliary support is structurally unsound and is warping at point of study	Technical examination (visual)
Auxiliary Support	Structural Condition	single select	text		missing	Not applicable	Auxiliary support is missing from the artwork at point of study and therefore unable to make an assessment of its condition	Technical examination (visual)
Auxiliary Support	Structural Condition	single select	text		not applicable	Not applicable	Not applicable to the artwork studied	Technical examination (visual)
Paint Layers	PL ID	single line text	text	67	PTGxxx.PL	PTG[reference artwork ID].PS	Unique identifier number given to each painting support regardless of presence	Researcher issued

Paint Layers	Painting ID	record-link	record	67	NULL	Not applicable	Links to the Painting ID the ground is related to	Link from Artwork Overview> Painting ID
Paint Layers	Title	look up	text		NULL	Not applicable	Title of painting	Looks up Artwork Overview> Painting ID> Title
Paint Layers	Artist	look up	text		NULL	Not applicable	Attributed artist of the artwork	Looks up Artwork Overview> Painting ID> Artist
Paint Layers	Year	look up	text		NULL	Not applicable	Attributed year of the artwork	Looks up Artwork Overview> Painting ID> Year
Paint Layers	Medium	look up	text		NULL	Not applicable	Attributed medium of the artwork	Looks up Artwork Overview> Painting ID> Medium
Paint Layers	Traditional or Mixed media	single select	text	3	traditional	Not applicable	Paint layer is likely to be composed of only 1 medium (oil-based or acrylic)	Researcher issued
Paint Layers	Traditional or Mixed media	single select	text		mixed media	Not applicable	Paint layer is likely to be composed of a mixed of mediums or support types (oil-based or acrylic)	Researcher issued
Paint Layers	Traditional or Mixed media	single select	text		unknown	Not applicable	Paint layer is undetermined at the point of study	Researcher issued
Paint Layers	Medium category	multiple select	text	9	acrylic	Not applicable	Paint layer displays acrylic or synthetic polymer-based properties	Technical examination (visual);

								Technical examination (material analysis)
Paint Layers	Medium category	multiple select	text		alkyd	Not applicable	Paint layer displays alkyd properties	Technical examination (visual); Technical examination (material analysis)
Paint Layers	Medium category	multiple select	text		chinese ink	Not applicable	Paint layer displays chinese ink properties	Technical examination (visual); Technical examination (material analysis)
Paint Layers	Medium category	multiple select	text		gouache	Not applicable	Paint layer displays gouache properties	Technical examination (visual); Technical examination (material analysis)
Paint Layers	Medium category	multiple select	text		manipulated paint medium	Not applicable	Paint layer displays manipulated paint medium properties	Technical examination (visual); Technical examination (material analysis)
Paint Layers	Medium category	multiple select	text		oil	Not applicable	Paint layer displays oil-based properties	Technical examination

								(visual); Technical examination (material analysis)
Paint Layers	Medium category	multiple select	text		plaster	Not applicable	Paint layer displays palster properties	Technical examination (visual); Technical examination (material analysis)
Paint Layers	Medium category	multiple select	text		spray paint	Not applicable	Paint layer displays spray paint properties	Technical examination (visual); Technical examination (material analysis)
Paint Layers	Medium category	multiple select	text		unsure	Not applicable	Unable to identify paint properties	Technical examination (visual); Technical examination (material analysis)
Paint Layers	Underdrawings	checkbox	binary	2	checked	Not applicable	Underdrawings have been observed under the paint layer	Technical examination (Infrared Photography)
Paint Layers	Underdrawings	checkbox	binary		unchecked	Not applicable	Underdrawings have not been observed under the paint layer	Technical examination (Infrared Photography)

Paint Layers	Material for UD	multiple select	text	6	Black medium	Not applicable	Black medium (details unknown) is observed	Technical examination (Infrared Photography)
Paint Layers	Material for UD	multiple select	text		Black paint wash	Not applicable	Black paint wash has been observed underneath the paint layers	Technical examination (Infrared Photography)
Paint Layers	Material for UD	multiple select	text		Brown paint wash	Not applicable	Brown paint wash has been observed underneath the paint layers	Technical examination (Infrared Photography)
Paint Layers	Material for UD	multiple select	text		Charcoal	Not applicable	Charcoal has been observed underneath the paint layers and corroborates findings from infrared	Technical examination (Infrared Photography)
Paint Layers	Material for UD	multiple select	text		Pencil	Not applicable	Pencil has been observed underneath the paint layers	Technical examination (Infrared Photography)
Paint Layers	Material for UD	multiple select	text		Unknown	Not applicable	Unable to identify underdrawing material	Technical examination (Infrared Photography)
Paint Layers	Changes in sketch	checkbox	binary	2	checked	Not applicable	Changes have been observed in the preliminary sketches by the artist before the final image	Technical examination (Infrared Photography)
Paint Layers	Changes in sketch	checkbox	binary		unchecked	Not applicable	Changes have not been observed in the preliminary sketches by the artist before the final image	Technical examination (Infrared Photography)
Paint Layers	Details	long text	text		NULL	Not applicable	Any additional details about underdrawings can be recorded here	Researcher issued

Paint Layers	Paint density	single select	text	2	thick	Not applicable	Paint application is thick in comparison to ground layer	Technical examination (visual); Technical examination (microscopy-cross section)
Paint Layers	Paint density	single select	text		thin	Not applicable	Paint application is thin in comparison to ground layer	Technical examination (visual); Technical examination (microscopy-cross section)
Paint Layers	Impasto	single select	text	4	defined	Not applicable	Majoriity of the paint layer can be classified as having defined impasto on the paint surface	Technical examination (visual)
Paint Layers	Impasto	single select	text		undefined	Not applicable	Majoriity of the paint layer can be classified as having defined impasto on the paint surface	Technical examination (visual)
Paint Layers	Impasto	single select	text		flat	Not applicable	Majoriity of the paint layer can be classified as having defined impasto on the paint surface	Technical examination (visual)
Paint Layers	Impasto	single select	text		smooth	Not applicable	Majoriity of the paint layer can be classified as having defined impasto on the paint surface	Technical examination (visual)
Paint Layers	Observations	multiple select	text	16	applied on primary canvas separately???	Not applicable	Paint was applied on primary canvas separately before being marouflaged onto current support	Technical examination (visual)
Paint Layers	Observations	multiple select	text		collage (acrylic sheet)	Not applicable	An acrylic sheet forms part of its collage which also contains paint layers	Technical examination (visual)

Paint Layers	Observations	multiple select	text		collage (canvas)	Not applicable	Canvas forms part of its collage which also contains paint layers	Technical examination (visual)
Paint Layers	Observations	multiple select	text		collage (gold)	Not applicable	Collage contains gold elements	Technical examination (visual)
Paint Layers	Observations	multiple select	text		collage (metal)	Not applicable	Collage contains metal elements	Technical examination (visual)
Paint Layers	Observations	multiple select	text		collage elements (paper)	Not applicable	Collage contains paper elements	Technical examination (visual)
Paint Layers	Observations	multiple select	text		drip marks	Not applicable	Drip marks are observed on the paint layer	Technical examination (visual)
Paint Layers	Observations	multiple select	text		etching	Not applicable	Ethicing is observed on the paint layer	Technical examination (visual)
Paint Layers	Observations	multiple select	text		fingerprints	Not applicable	Fingerprints are observed on the paint layer	Technical examination (visual)
Paint Layers	Observations	multiple select	text		layering	Not applicable	Layering of paint observed on the paint layer	Technical examination (visual)
Paint Layers	Observations	multiple select	text		medium manipulation	Not applicable	Manipulation of medium observed on the paint layer	Technical examination (visual)
Paint Layers	Observations	multiple select	text		no paint underneath primary support	Not applicable	No paint was discovered underneath secondary paint support indicating it was likely to have been painted separately before marfoualged	Technical examination (visual)
Paint Layers	Observations	multiple select	text		palette knife	Not applicable	Palette knife was used to apply the paint layer	Technical examination (visual)

Paint Layers	Observations	multiple select	text		stippling	Not applicable	Stippling (dotting with brush) was used observed on the paint layer	Technical examination (visual)
Paint Layers	Observations	multiple select	text		thin wash	Not applicable	Thin washes of paint observed on the paint layer	Technical examination (visual)
Paint Layers	Observations	multiple select	text		tinting	Not applicable	Tinting of paint observed on the paint layer	Technical examination (visual)
Paint Layers	Application technique	single select	text	3	wet on wet	Not applicable	Wet on wet paint application technique observed	Technical examination (visual); Technical examination (microscopy-cross section)
Paint Layers	Application technique	single select	text		wet on dry	Not applicable	wet on dry paint application technique observed	Technical examination (visual); Technical examination (microscopy-cross section)
Paint Layers	Application technique	single select	text		not applicable	Not applicable	Not applicable to the artwork studied	Technical examination (visual); Technical examination (microscopy-cross section)
Paint Layers	Paint distribution	single select	text	4	different in two supports	Not applicable	Paint application varies in thickness in the two primary supports	Technical examination (visual)

Paint Layers	Paint distribution	single select	text		even	Not applicable	Paint application is even throughout entire painting	Technical examination (transmitted light)
Paint Layers	Paint distribution	single select	text		more paint in background	Not applicable	Thicker paint distribution in the background with less light transmitted	Technical examination (transmitted light)
Paint Layers	Paint distribution	single select	text		more paint in foreground	Not applicable	Thicker paint distribution in the background with less light transmitted	Technical examination (transmitted light)
Paint Layers	Change in painting position	multiple select	text	2	None observed	Not applicable	Painting position is unchanged throughout its creation	Technical examination (visual)
Paint Layers	Change in painting position	multiple select	text		painting had upside down drips	Not applicable	Painting displays upside down drips which indicates the painting direction has been changed during its construction	Technical examination (visual)
Paint Layers	Extent of cracks	single select	text	3	localised	Not applicable	Localised areas with cracks are observed on the paint layer	Technical examination (visual)
Paint Layers	Extent of cracks	single select	text		overall	Not applicable	Overall areas with cracks are observed on the paint layer	Technical examination (visual)
Paint Layers	Extent of cracks	single select	text		None observed	Not applicable	No cracks were observed on the paint layer	Technical examination (visual)
Paint Layers	Crack areas/patterns	multiple select	text	9	deep and wide cracks	Not applicable	Deep and wide cracks observed in areas with thicker paints	Technical examination (visual)
Paint Layers	Crack areas/patterns	multiple select	text		colour-specific	Not applicable	Colour-specific areas display crack patterns	Technical examination (visual)

Paint Layers	Crack areas/patterns	multiple select	text		corner stress	Not applicable	Cracks are related to corner stresses	Technical examination (visual)
Paint Layers	Crack areas/patterns	multiple select	text		edges	Not applicable	Cracks are observed around the edges of the painting	Technical examination (visual)
Paint Layers	Crack areas/patterns	multiple select	text		extensive	Not applicable	Extensive cracks are observed throughout the painting	Technical examination (visual)
Paint Layers	Crack areas/patterns	multiple select	text		horizontal	Not applicable	Horizontal crack patterns are observed through the painting	Technical examination (visual)
Paint Layers	Crack areas/patterns	multiple select	text		None observed	Not applicable	No cracks were observed on the paint layer	Technical examination (visual)
Paint Layers	Crack areas/patterns	multiple select	text		vertical	Not applicable	Vertical crack patterns are observed through the painting	Technical examination (visual)
Paint Layers	Crack areas/patterns	multiple select	text		wood cracks	Not applicable	Wood-related crack patterns observed through the painting	Technical examination (visual)
Paint Layers	Cracks network	multiple select	text	2	tight	Not applicable	Tight crack patterns observed through the painting	Technical examination (visual)
Paint Layers	Cracks network	multiple select	text		broad	Not applicable	Broad crack patterns observed through the painting	Technical examination (visual)
Paint Layers	Crack condition	multiple select	text	5	cupping	Not applicable	Cupping of paint caused by cracks are observed through the painting	Technical examination (visual)
Paint Layers	Crack condition	multiple select	text		not applicable	Not applicable	No cracks were observed on the paint layer	Technical examination (visual)

Paint Layers	Crack condition	multiple select	text		separated from canvas	Not applicable	Cracks evidenced that paint layer has separated from canvas (losses show canvas)	Technical examination (visual)
Paint Layers	Crack condition	multiple select	text		separated from ground only	Not applicable	Cracks evidenced that paint layer has separated only from the ground, with the ground still attached to the canvas	Technical examination (visual)
Paint Layers	Crack condition	multiple select	text		well-adhered to painting	Not applicable	Cracks have no paint delamination and are well-adhered	Technical examination (visual)
Paint Layers	Details of cracks	long text	text		NULL	Not applicable	Any additional comments that do not fit into any of the descriptors can be recorded here	Researcher issued
Paint Layers	Overall Condition	multiple select	text	6	stable	Not applicable	Overall, the paint layer are stable and well-adhered to the painting	Technical examination (visual)
Paint Layers	Overall Condition	multiple select	text		stable except areas of cracks	Not applicable	Overall, the paint layers are stable with the exception of localised areas with cracks	Technical examination (visual)
Paint Layers	Overall Condition	multiple select	text		active flaking/losses	Not applicable	There are areas of acting paint flaking leading to losses	Technical examination (visual)
Paint Layers	Overall Condition	multiple select	text		paint delamination	Not applicable	Areas of delaminating paint evidenced on the painting	Technical examination (visual)
Paint Layers	Overall Condition	multiple select	text		brittle paint	Not applicable	Areas of brittle paint evidenced on the painting	Technical examination (visual)
Paint Layers	Overall Condition	multiple select	text		severe	Not applicable	Condition of the paint layer is severe	Technical examination (visual)
Paint Layers	Details of condition	long text	text		NULL	Not applicable	Any additional comments that do not fit into any of the descriptors can be recorded here	Researcher issued

Paint Layers	Restoration Treatments	multiple select	text	3	not observed	Not applicable	No restoration treatments have been observed on the paint layer	Technical examination (visual)
Paint Layers	Restoration Treatments	multiple select	text		overpainting	Not applicable	Overpainting was observed on the paint layer	Technical examination (visual)
Paint Layers	Restoration Treatments	multiple select	text		consolidation	Not applicable	Paint layer has been consolidated as observed on the paint layer	Technical examination (visual)
Paint Layers	Details of Restoration	long text	text		NULL	Not applicable	Any additional comments that do not fit into any of the descriptors can be recorded here	Researcher issued
Paint Layers	Findings (Inorganic-XRF) (from Sample ID)	look up	text		NULL	Not applicable	List of Inorganic findings from XRF analysis relating to ground layer from material analysis (as identified from Sample ID)	Looks up Sample Record>Sample ID>Findings (Inorganic)
Paint Layers	Findings (Inorganic-SEM) (from Sample ID)	look up	text		NULL	Not applicable	List of Inorganic findings from SEM from material analysis (as identified from Sample ID)	Looks up Sample Record>Sample ID>Findings (Inorganic)
Paint Layers	Findings (FTIR) (from Sample ID)	look up	text		NULL	Not applicable	List of organic findings relating to binder of ground layer from material analysis (as identified from Sample ID)	Looks up Sample Record>Sample ID>Findings (Binder)
Paint Layers	Paint stratigraphy	look up	text		NULL	Not applicable	List of Inorganic findings relating to ground layer from material analysis (as identified from Sample ID)	Looks up Sample Record>Sample ID>Findings (Inorganic)
Paint Layers	Sample ID for painting	record-link	record		NULL	Not applicable	Links to Sample ID of sample with a cross-section that has been studied	Link from another record
Surface Coating	SC ID	single line text	text	67	PTGxxx.PL	PTG[reference artwork ID].PS	Unique identifier number given to each painting support regardless of presence	Researcher issued

Surface Coating	Painting ID	record-link	record	67	NULL	Not applicable	Links to the Painting ID the ground is related to	Link from Artwork Overview> Painting ID
Surface Coating	Title	look up	text		NULL	Not applicable	Title of painting	Looks up Artwork Overview> Painting ID> Title
Surface Coating	Artist	look up	text		NULL	Not applicable	Attributed artist of the artwork	Looks up Artwork Overview> Painting ID> Artist
Surface Coating	Year	look up	text		NULL	Not applicable	Attributed year of the artwork	Looks up Artwork Overview> Painting ID> Year
Surface Coating	Medium	look up	text		NULL	Not applicable	Attributed medium of the artwork	Looks up Artwork Overview> Painting ID> Medium
Surface Coating	Presence of varnish	single select	text	3	yes	Not applicable	Painting is likely to have a varnish layer	Technical examination (visual)
Surface Coating	Presence of varnish	single select	text		no	Not applicable	Painting is unlikely to have a varnish layer	Technical examination (visual)
Surface Coating	Presence of varnish	single select	text		unsure	Not applicable	Unsure if painting has a varnish layer	Technical examination (visual)

Surface Coating	Surface reflectivity	single select	text	3	semi-gloss	Not applicable	Surface has a semi-glossy reflectance	Technical examination (Specular Photography)
Surface Coating	Surface reflectivity	single select	text		gloss	Not applicable	Surface has a glossy reflectance	Technical examination (Specular Photography)
Surface Coating	Surface reflectivity	single select	text		matte	Not applicable	Surface has a matte reflectance	Technical examination (Specular Photography)
Surface Coating	Fluoresce color	single select	text	7	blue	Not applicable	Painting has a blue fluoresce in ultraviolet luminescence	Technical examination (ultraviolet illumination)
Surface Coating	Fluoresce color	single select	text		dark brown	Not applicable	Painting has a dark brown fluoresce in ultraviolet luminescence	Technical examination (ultraviolet illumination)
Surface Coating	Fluoresce color	single select	text		light blue	Not applicable	Painting has a light blue fluoresce in ultraviolet luminescence	Technical examination (ultraviolet illumination)
Surface Coating	Fluoresce color	single select	text		non-distinct	Not applicable	Painting has a non-distinct fluoresce in ultraviolet luminescence	Technical examination (ultraviolet illumination)
Surface Coating	Fluoresce color	single select	text		not studied	Not applicable	Painting's ultraviolet luminescence has yet to be studied	Technical examination (ultraviolet illumination)
Surface Coating	Fluoresce color	single select	text		purple	Not applicable	Painting has a purple fluoresce in ultraviolet luminescence	Technical examination

								(ultraviolet illumination)
Surface Coating	Fluoresce color	single select	text		yellow	Not applicable	Painting has a yellow fluoresce in ultraviolet luminescence	Technical examination (ultraviolet illumination)
Surface Coating	Area of application	single select	text	3	overall	Not applicable	Painting appears to have an overall application of surface coating	Technical examination (ultraviolet illumination)
Surface Coating	Area of application	single select	text		uneven	Not applicable	Painting appears to have an uneven application of surface coating	Technical examination (ultraviolet illumination)
Surface Coating	Area of application	single select	text		none	Not applicable	Painting appears to have no application of surface coating	Technical examination (ultraviolet illumination)
Surface Coating	Dark patches	single select	text	2	yes	Not applicable	Dark patches are observed on the surface of the painting in ultraviolet luminescence	Technical examination (ultraviolet illumination)
Surface Coating	Dark patches	single select	text		no	Not applicable	No dark patches were observed on the surface of the painting ultraviolet luminescence	Technical examination (ultraviolet illumination)
Surface Coating	Brushstrokes Drips	multiple select	text	4	brushstrokes	Not applicable	In ultraviolet luminescence, brushstrokes on the surface coating can be observed on the painting surface	Technical examination (ultraviolet illumination)
Surface Coating	Brushstrokes Drips	multiple select	text		drips	Not applicable	In ultraviolet luminescence, drips on the surface coating can be observed on the painting surface	Technical examination (ultraviolet illumination)

Surface Coating	Brushstrokes Drips	multiple select	text		None observed	Not applicable	In ultraviolet luminescence, no distinct application techniques of the surface coating were observed on the painting surface	Technical examination (ultraviolet illumination)
Surface Coating	Brushstrokes Drips	multiple select	text		spray droplets	Not applicable	In ultraviolet luminescence, spray droplets on the surface coating can be observed on the painting surface	Technical examination (ultraviolet illumination)
Surface Coating	Details	long text	text		NULL	Not applicable	Any additional comments that do not fit into any of the descriptors can be recorded here	Researcher issued
Surface Coating	Time of application	multiple select	text	7	after cracks	Not applicable	Excess varnish is observed on the reverse going through the cracks	Technical examination (visual)
Surface Coating	Time of application	multiple select	text		after framing	Not applicable	Excess varnish is observed on frame edges	Technical examination (visual)
Surface Coating	Time of application	multiple select	text		after signature	Not applicable	Varnish layer evidenced above signature layer	Technical examination (visual)
Surface Coating	Time of application	multiple select	text		before cracks	Not applicable	Varnish was applied before cracks appeared as observed with cracks and no excess on verso	Technical examination (visual)
Surface Coating	Time of application	multiple select	text		before framing	Not applicable	Varnish layer evidenced before framing with no excess on frame	Technical examination (visual)
Surface Coating	Time of application	multiple select	text		before signature	Not applicable	Varnish layer evidenced under signature layer	Technical examination (visual)
Surface Coating	Time of application	multiple select	text		unknown	Not applicable	It is unknown when the time of surface coating application	Technical examination (visual)
Surface Coating	Thickness	single select	text	3	thick	Not applicable	Surface coating is thickly applied on the painting	Technical examination

								(visual); Technical examination (microscopy- cross section)
Surface Coating	Thickness	single select	text		thin	Not applicable	Surface coating is thinnly applied on the painting	Technical examination (visual); Technical examination (microscopy- cross section)
Surface Coating	Thickness	single select	text		unknown	Not applicable	Unknown of the thickness of the surface coating or if there is any surface coating	Technical examination (visual); Technical examination (microscopy- cross section)
Surface Coating	Discolouration	checkbox	binary	2	checked	Not applicable	In normal illumination, surface coating appears discoloured	Technical examination (visual)
Surface Coating	Discolouration	checkbox	binary		unchecked	Not applicable	In normal illumination, surface coating does not appear discoloured	Technical examination (visual)
Surface Coating	Presence of treatment	single select	text	3	yes	Not applicable	Surface coating appears to have been undergone restorative efforts	Technical examination (visual)
Surface Coating	Presence of treatment	single select	text		no	Not applicable	No presence of restorative efforts of the surface coating were observed	Technical examination (visual)
Surface Coating	Presence of treatment	single select	text		unknown	Not applicable	Unknown if there were any restorative efforts of the surface coating	Technical examination (visual)

Surface Coating	Details of observation	long text	text		NULL	Not applicable	Any additional comments that do not fit into any of the descriptors can be recorded here	Researcher issued
Sample ID	Sample ID	single line text	text	67	PTGxxx.PL	PTG[reference artwork ID].PS	Unique identifier number given to each painting support regardless of presence	Researcher issued
Sample ID	Painting ID	record-link	record	67	NULL	Not applicable	Links to the Painting ID the ground is related to	Link from Artwork Overview> Painting ID
Sample ID	Title	look up	text		NULL	Not applicable	Title of painting	Looks up Artwork Overview> Painting ID> Title
Sample ID	Medium (from Painting ID)	look up	text		NULL	Not applicable	Attributed medium of the artwork	Looks up Artwork Overview> Painting ID> Medium
Sample ID	Manufacturer stamp (from Primary Support)	look up	text		NULL	Not applicable	Manufacturer stamps associated to the painting	Looks up Artwork Overview> Painting ID> Medium
Sample ID	Artist	look up	text		NULL	Not applicable	Attributed artist of the artwork	Looks up Artwork Overview> Painting ID> Artist
Sample ID	Year	look up	text		NULL	Not applicable	Attributed year of the artwork	Looks up Artwork Overview>

								Painting ID> Year
Sample ID	Sample location	single line text	text		NULL	x,y mm	Location of where sample was removed. X being horizontal axis and Y vertical axis. Both points taken 0 from left corner.	Technical examination (visual)
Sample ID	Documented	single select	text	2	yes	Not applicable	Sample has been documented in its raw form by digital microscopy	Technical examination (microscopy)
Sample ID	Documented	single select	text		no	Not applicable	Sample was not documented in its raw form by digital microscopy	Technical examination (microscopy)
Sample ID	Type of sample	multiple select	text	11	adhesive	Not applicable	Sample contains adhesive	Technical examination (microscopy)
Sample ID	Type of sample	multiple select	text		conservation medium	Not applicable	Sample contains conservation medium	Technical examination (microscopy)
Sample ID	Type of sample	multiple select	text		fibre	Not applicable	Sample contains fibre	Technical examination (microscopy)
Sample ID	Type of sample	multiple select	text		ground	Not applicable	Sample contains ground	Technical examination (microscopy)
Sample ID	Type of sample	multiple select	text		mixed media element	Not applicable	Sample contains mixed media element	Technical examination (microscopy)
Sample ID	Type of sample	multiple select	text		paint	Not applicable	Sample contains paint	Technical examination (microscopy)
Sample ID	Type of sample	multiple select	text		paper	Not applicable	Sample contains paper	Technical examination (microscopy)

Sample ID	Type of sample	multiple select	text		preparatory layer	Not applicable	Sample contains a preparatory layer	Technical examination (microscopy)
Sample ID	Type of sample	multiple select	text		resin	Not applicable	Sample contains resin	Technical examination (microscopy)
Sample ID	Type of sample	multiple select	text		surface coating	Not applicable	Sample contains surface coating, not necessarily varnish	Technical examination (microscopy)
Sample ID	Type of sample	multiple select	text		varnish	Not applicable	Sample contains varnish layer	Technical examination (microscopy)
Sample ID	Details	long text	text		NULL	Not applicable	Any additional comments on the sample can be recorded here	Researcher issued
Sample ID	Color	multiple select	text		NULL	Not applicable	Colour of the top side of the sample	Technical examination (microscopy)
Sample ID	Purpose	multiple select	text	9	adhesive ID	Not applicable	Identify adhesive in the sample	Researcher issued
Sample ID	Purpose	multiple select	text		fibre identification	Not applicable	Identify fibre in the sample	Researcher issued
Sample ID	Purpose	multiple select	text		ground binder ID	Not applicable	Identify the binder of the ground layer in the sample	Researcher issued
Sample ID	Purpose	multiple select	text		ground pigment ID	Not applicable	Identify the pigment of the ground layer in the sample	Researcher issued
Sample ID	Purpose	multiple select	text		Material ID	Not applicable	Identify the material of the sample	Researcher issued
Sample ID	Purpose	multiple select	text		paint binder ID	Not applicable	Identify the binder of the paint layer in the sample	Researcher issued
Sample ID	Purpose	multiple select	text		paint pigment ID	Not applicable	Identify the pigment of the paint layer in the sample	Researcher issued
Sample ID	Purpose	multiple select	text		stratigraphy x-section	Not applicable	Cross-section the sample for the study of the stratigraphy	Researcher issued

Sample ID	Purpose	multiple select	text		surface coating ID	Not applicable	Identify the surface coating of the sample	Researcher issued
Sample ID	Destroyed	checkbox	binary	2	checked	Not applicable	Painting sample has been destroyed from analysis	Researcher issued
Sample ID	Destroyed	checkbox	binary		unchecked	Not applicable	Painting sample is not destroyed	Researcher issued
Sample ID	Status	single select	text	7	awaiting commencement	Not applicable	Status of sample analysis is currently awaiting commencement	Researcher issued
Sample ID	Status	single select	text		complete	Not applicable	Status of sample analysis is complete	Researcher issued
Sample ID	Status	single select	text		in progress	Not applicable	Status of sample analysis is in progress	Researcher issued
Sample ID	Status	single select	text		missing	Not applicable	Sample is currently missing and can not be found	Researcher issued
Sample ID	Status	single select	text		queued for study	Not applicable	Status of sample analysis is queued for study	Researcher issued
Sample ID	Status	single select	text		re-analyse	Not applicable	Sample analysis has been studied but requires re-analysis	Researcher issued
Sample ID	Status	single select	text		standby	Not applicable	Analysis of sample is on standby	Researcher issued
Sample ID	Analysis Planned	multiple select	text	7	Fibre analysis	Not applicable	Fibre identification has been identified as a suitable analysis of the sample	Researcher issued
Sample ID	Analysis Planned	multiple select	text		FTIR-ATR	Not applicable	Organic analysis using FTIR-ATR microscopy has been identified as a suitable analysis of the sample	Researcher issued
Sample ID	Analysis Planned	multiple select	text		FTIR-Bt	Not applicable	Organic analysis using FTIR-ATR microscopy with GCCMC benchtop instrumentation has been identified as a suitable analysis of the sample	Researcher issued
Sample ID	Analysis Planned	multiple select	text		SEM-EDX	Not applicable	Inorganic analysis using SEM-EDX has been identified as a suitable analysis of the sample following XRF analysis	Researcher issued
Sample ID	Analysis Planned	multiple select	text		Synchrotron	Not applicable	Synchrotron has been identified as a suitable analysis of the sample	Researcher issued

Sample ID	Analysis Planned	multiple select	text		X-section	Not applicable	Processing the sample into a cross-section has been identified as a suitable analysis of the sample	Researcher issued
Sample ID	Analysis Planned	multiple select	text		XRF	Not applicable	Inorganic analysis using XRF has been identified as a suitable analysis of the sample	Researcher issued
Sample ID	Due Date	date	date		NULL	Not applicable	Proposed end date for analysis to be completed	Researcher issued
Sample ID	Analysis Done	multiple select	text	8	Fibre analysis	Not applicable	Fibre analysis has been conducted on the sample	Researcher issued
Sample ID	Analysis Done	multiple select	text		FTIR-ATR	Not applicable	Sample has been analysed with the FTIR-ATR microscopy	Researcher issued
Sample ID	Analysis Done	multiple select	text		FTIR-Bt	Not applicable	Sample has been analysed with the FTIR-ATR benchtop	Researcher issued
Sample ID	Analysis Done	multiple select	text		Microscopy	Not applicable	Sample has been studied under microscopy	Researcher issued
Sample ID	Analysis Done	multiple select	text		None	Not applicable	No analysis has been done on the sample	Researcher issued
Sample ID	Analysis Done	multiple select	text		SEM-EDX	Not applicable	Sample has been analysed with the SEM-EDX	Researcher issued
Sample ID	Analysis Done	multiple select	text		X-section	Not applicable	A cross-section of the sample has been processed	Researcher issued
Sample ID	Analysis Done	multiple select	text		XRF	Not applicable	Sample has been analysed with the XRF	Researcher issued
Sample ID	Date of Analysis (Fibre)	date	date		NULL	[MMM DD, YYYY]	Date of fibre analysis	Researcher issued
Sample ID	Findings (Fibre)	multiple select	text	11	bast (linen)	Not applicable	Fibre identified resembles closest to bast (linen) canvas	Technical examination (microscopy)
Sample ID	Findings (Fibre)	multiple select	text		bast (paper)	Not applicable	Fibre identified resembles closest to bast (linen) paper	Technical examination (microscopy)

Sample ID	Findings (Fibre)	multiple select	text		blend (bast, cotton)	Not applicable	Fibre identified resembles closest to a blend of bast and cotton canvas	Technical examination (microscopy)
Sample ID	Findings (Fibre)	multiple select	text		cotton	Not applicable	Fibre identified resembles closest to cotton canvas	Technical examination (microscopy)
Sample ID	Findings (Fibre)	multiple select	text		hemp/burlap	Not applicable	Fibre identified resembles closest to hemp or burlap canvas	Technical examination (microscopy)
Sample ID	Findings (Fibre)	multiple select	text		jute	Not applicable	Fibre identified resembles closest to jute canvas	Technical examination (microscopy)
Sample ID	Findings (Fibre)	multiple select	text		paper	Not applicable	Fibre identified resembles closest to paper	Technical examination (microscopy)
Sample ID	Findings (Fibre)	multiple select	text		paper with resin	Not applicable	Fibre identified resembles closest to paper with resin	Technical examination (microscopy)
Sample ID	Findings (Fibre)	multiple select	text		wood fibres (hardboard)	Not applicable	Fibre identified resembles closest to wood fibres of a hardboard	Technical examination (microscopy)
Sample ID	Findings (Fibre)	multiple select	text		wood fibres (plywood)	Not applicable	Fibre identified resembles closest to wood fibres of a plywood board	Technical examination (microscopy)
Sample ID	Findings (Fibre)	multiple select	text		woven reed (seagrass)	Not applicable	Fibre identified resembles closest to woven reed	Technical examination (microscopy)
Sample ID	Primary Support	record-link	record		NULL	Not applicable	Links to Primary support of sample	Link from another record
Sample ID	Date of X-sections	date	date		NULL	[MMM DD, YYYY]	Date of when cross-section of paintings were processed	Researcher issued
Sample ID	Findings (Stratigraphy)	multiple select	text	18	charcoal	Not applicable	Charcoal has been observed between the paint layers	Technical examination

								(microscopy-cross section)
Sample ID	Findings (Stratigraphy)	multiple select	text		crack in paint layer	Not applicable	Crack/s in paint layers have been observed	Technical examination (microscopy-cross section)
Sample ID	Findings (Stratigraphy)	multiple select	text		destroyed	Not applicable	Sample was destroyed during cross-section preparation	Technical examination (microscopy-cross section)
Sample ID	Findings (Stratigraphy)	multiple select	text		ground even	Not applicable	Even and smooth ground layer application was observed (observe where ground contacts paint)	Technical examination (microscopy-cross section)
Sample ID	Findings (Stratigraphy)	multiple select	text		preparatory layer	Not applicable	Thin preparatory layer observed between ground and paint layers	Technical examination (microscopy-cross section)
Sample ID	Findings (Stratigraphy)	multiple select	text		more than 3 paint layers	Not applicable	More than 3 distinct paint layers observed	Technical examination (microscopy-cross section)
Sample ID	Findings (Stratigraphy)	multiple select	text		pigmented ground	Not applicable	Ground appears heavily pigmented	Technical examination (microscopy-cross section)
Sample ID	Findings (Stratigraphy)	multiple select	text		pigmented paint	Not applicable	Paint layer appears to have distinct pigments	Technical examination (microscopy-cross section)
Sample ID	Findings (Stratigraphy)	multiple select	text		support prepared without ground	Not applicable	No ground layer observed between support and paint	Technical examination (microscopy-cross section)

Sample ID	Findings (Stratigraphy)	multiple select	text		thick paint	Not applicable	Paint layer appears thick in comparison to its ground layer	Technical examination (microscopy-cross section)
Sample ID	Findings (Stratigraphy)	multiple select	text		thick surface coating	Not applicable	Surface coating application is distinct in cross-section and appears thickly applied	Technical examination (microscopy-cross section)
Sample ID	Findings (Stratigraphy)	multiple select	text		thicker ground	Not applicable	Ground layer appears thick in comparison to paint layers	Technical examination (microscopy-cross section)
Sample ID	Findings (Stratigraphy)	multiple select	text		thin paint layer	Not applicable	Paint layer is applied thinly in comparison to ground layers	Technical examination (microscopy-cross section)
Sample ID	Findings (Stratigraphy)	multiple select	text		thinner ground	Not applicable	Paint layer is applied thinly in comparison to ground layers	Technical examination (microscopy-cross section)
Sample ID	Findings (Stratigraphy)	multiple select	text		uneven ground	Not applicable	Uneven and tooth-y ground layer application was observed (observe where ground contacts paint)	Technical examination (microscopy-cross section)
Sample ID	Findings (Stratigraphy)	multiple select	text		varnish	Not applicable	Varnish/ surface coating layer is observed	Technical examination (microscopy-cross section)
Sample ID	Findings (Stratigraphy)	multiple select	text		wet on wet	Not applicable	Wet on wet paint application technique observed in cross-section	Technical examination (microscopy-cross section)
Sample ID	Findings (Stratigraphy)	multiple select	text		wet on dry	Not applicable	Wet on dry paint application technique observed in cross-section	Technical examination

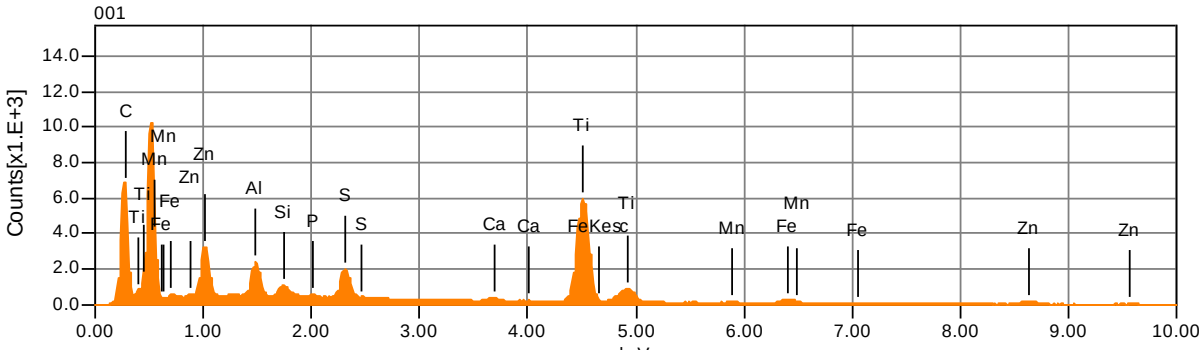
								(microscopy-cross section)
Sample ID	Findings (Cross-section)	long text	text		NULL	Not applicable	Any additional comments on the sample can be recorded here	Researcher issued
Sample ID	Status (FTIR)	single select	text	3	awaiting interpretation	Not applicable	Status of FTIR analysis is awaiting interpretation	Researcher issued
Sample ID	Status (FTIR)	single select	text		complete	Not applicable	Status of FTIR analysis is complete	Researcher issued
Sample ID	Status (FTIR)	single select	text		re-analyse	Not applicable	Status of FTIR analysis requires re-analysis	Researcher issued
Sample ID	Date of FTIR	date	date		NULL	[MMM DD, YYYY]	Date of when cross-section of sample was processed	Researcher issued
Sample ID	Details (FTIR)	long text	text		NULL	Not applicable	Any additional comments on the sample can be recorded here	Technical examination (material analysis-FTIR)
Sample ID	Ground Preparatory Layer	record-link	record		NULL	Not applicable	Links to Primary support of sample	Link from another record
Sample ID	Date of XRF	date	date		NULL	[MMM DD, YYYY]	Date of when XRF of sample was processed	Researcher issued
Sample ID	Findings (Inorganic-XRF)	multiple select	text	8	barium	Not applicable	Barium was detected during XRF analysis	Technical examination (material analysis-XRF)
Sample ID	Findings (Inorganic-XRF)	multiple select	text		calcium	Not applicable	Calcium was detected during XRF analysis	Technical examination (material analysis-XRF)
Sample ID	Findings (Inorganic-XRF)	multiple select	text		iron	Not applicable	Iron was detected during XRF analysis	Technical examination (material analysis-XRF)
Sample ID	Findings (Inorganic-XRF)	multiple select	text		lead	Not applicable	Lead was detected during XRF analysis	Technical examination

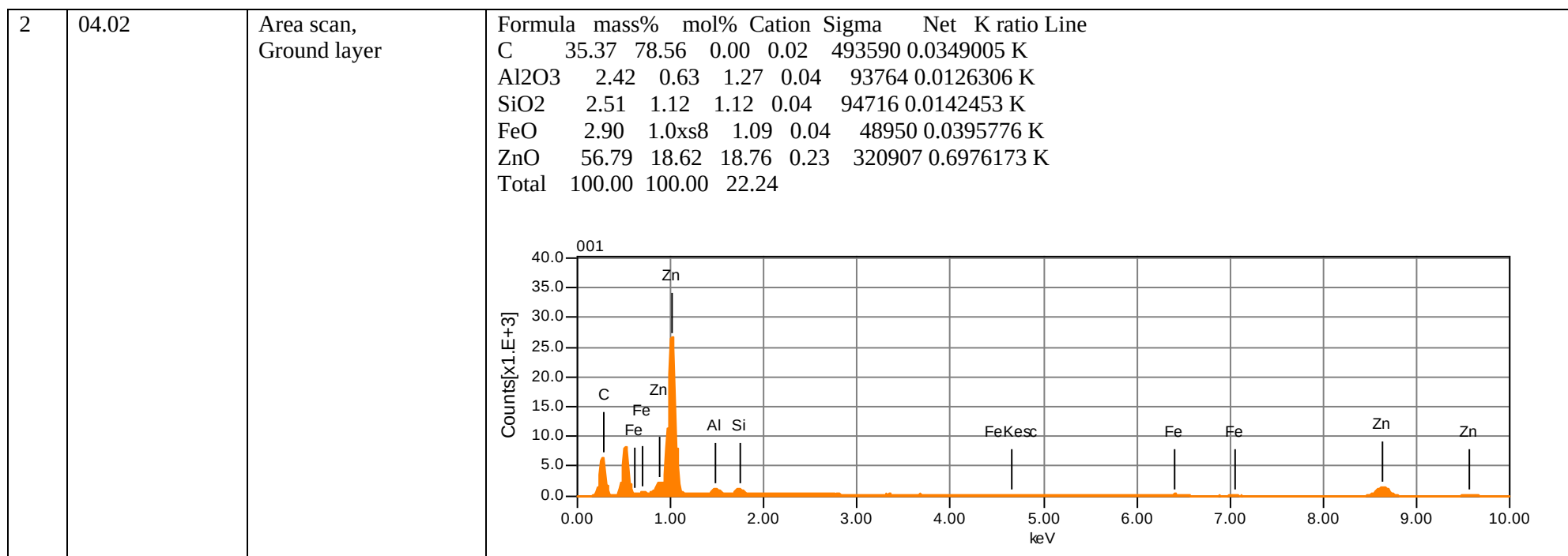
								(material analysis-XRF)
Sample ID	Findings (Inorganic-XRF)	multiple select	text		nickle	Not applicable	Nickle was detected during XRF analysis	Technical examination (material analysis-XRF)
Sample ID	Findings (Inorganic-XRF)	multiple select	text		sulfur	Not applicable	Sulfur was detected during XRF analysis	Technical examination (material analysis-XRF)
Sample ID	Findings (Inorganic-XRF)	multiple select	text		titanium	Not applicable	Titanium was detected during XRF analysis	Technical examination (material analysis-XRF)
Sample ID	Findings (Inorganic-XRF)	multiple select	text		zinc	Not applicable	Zinc was detected during XRF analysis	Technical examination (material analysis-XRF)
Sample ID	Possible pigments	multiple select	text	NULL	TBC	Not applicable		Researcher issued
Sample ID	Date of SEM	date	date		NULL	[MMM DD, YYYY]	Date of when SEM of sample was processed	Researcher issued
Sample ID	Findings (Inorganic-SEM)	multiple select	text	8	barium	Not applicable	Barium was detected during SEM analysis	Technical examination (material analysis-SEM)
Sample ID	Findings (Inorganic-SEM)	multiple select	text		calcium	Not applicable	Calcium was detected during SEM analysis	Technical examination (material analysis-SEM)
Sample ID	Findings (Inorganic-SEM)	multiple select	text		iron	Not applicable	Iron was detected during SEM analysis	Technical examination (material analysis-SEM)

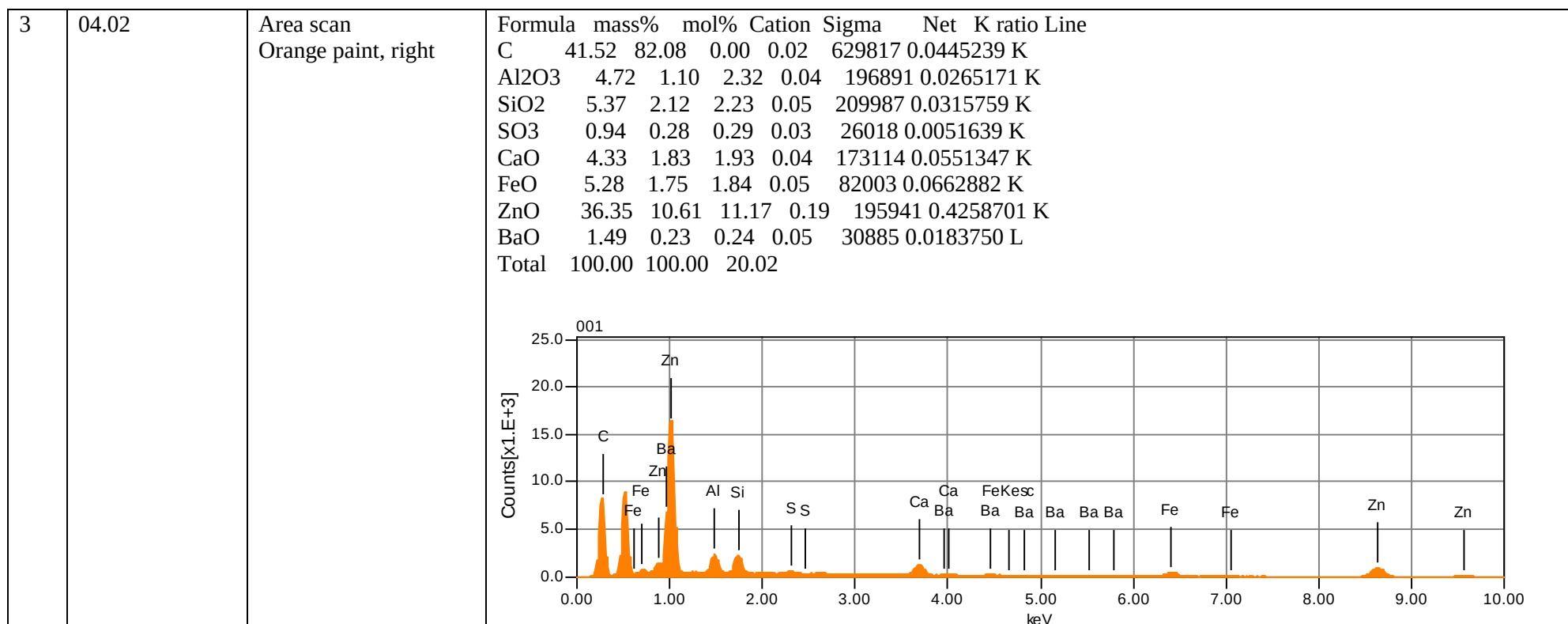
Sample ID	Findings (Inorganic-SEM)	multiple select	text		lead	Not applicable	Lead was detected during SEM analysis	Technical examination (material analysis-SEM)
Sample ID	Findings (Inorganic-SEM)	multiple select	text		nickle	Not applicable	Nickle was detected during SEM analysis	Technical examination (material analysis-SEM)
Sample ID	Findings (Inorganic-SEM)	multiple select	text		sulfur	Not applicable	Sulfur was detected during SEM analysis	Technical examination (material analysis-SEM)
Sample ID	Findings (Inorganic-SEM)	multiple select	text		titanium	Not applicable	Titanium was detected during SEM analysis	Technical examination (material analysis-SEM)
Sample ID	Findings (Inorganic-SEM)	multiple select	text		zinc	Not applicable	Zinc was detected during SEM analysis	Technical examination (material analysis-SEM)
Sample ID	Paint Layers	record-link	record		NULL	Not applicable	Links to Paint layer tab of sample	Link from another record
Sample ID	Comments	long text	text		NULL	Not applicable	Any additional comments on the sample can be recorded here	Researcher issued

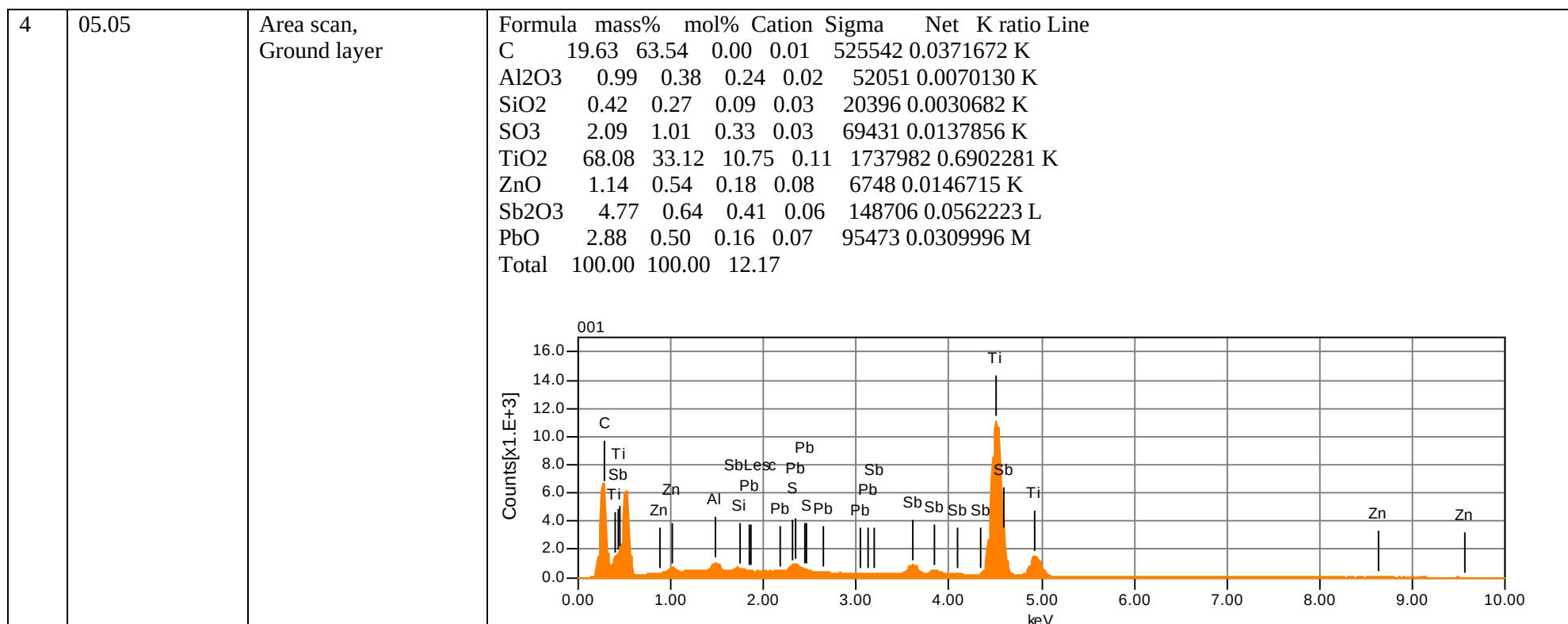
Appendix D: Findings from ESEM-EDS analysis on cross-sections

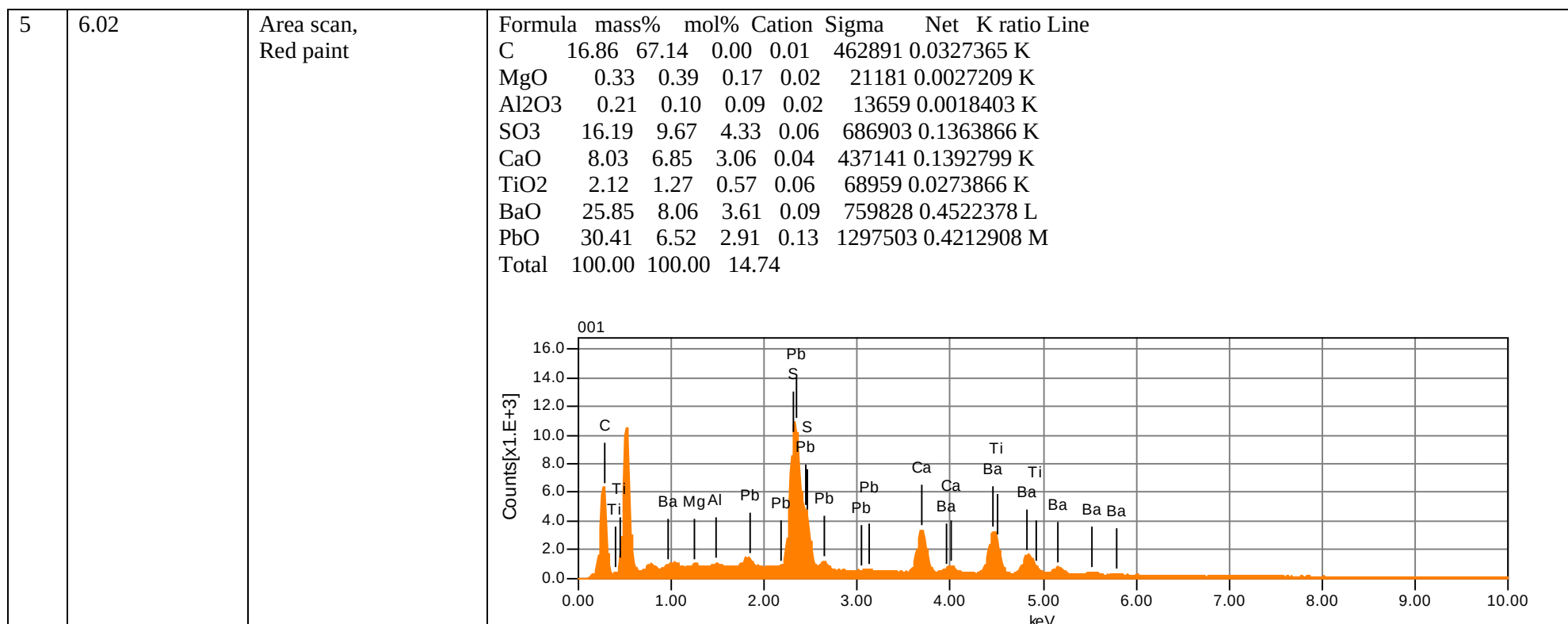
Findings from ESEM-EDS analysis on cross-sections for ground and paint layers featuring the normalized readings and spectra as provided by Graham Hutchinson.

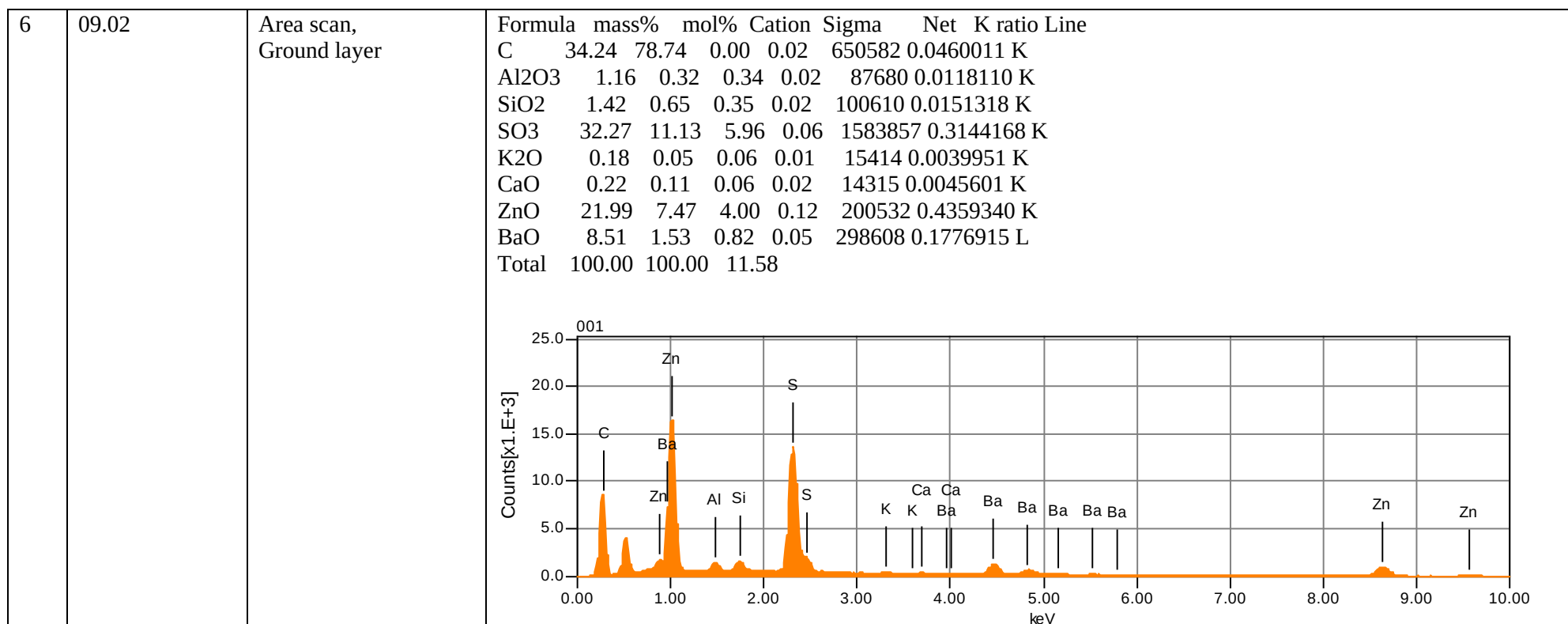
S/N	Sample ID	Description	Normalised reading and spectra
1	02.02	Area scan, Ground layer	Formula mass% mol% Cation Sigma Net K ratio Line C 30.29 74.32 0.00 0.02 529293 0.0374250 K Al₂O₃ 4.44 1.28 1.21 0.04 199646 0.0268935 K SiO₂ 1.49 0.73 0.35 0.04 60927 0.0091635 K P₂O₅ 0.53 0.11 0.10 0.03 17271 0.0033797 K SO₃ 7.14 2.63 1.24 0.04 199459 0.0395953 K CaO 0.66 0.34 0.16 0.02 26055 0.0083000 K TiO₂ 43.49 16.04 7.59 0.10 951587 0.3778409 K MnO 0.88 0.37 0.17 0.04 14103 0.0094407 K FeO 3.33 1.37 0.65 0.04 45473 0.0367662 K ZnO 7.75 2.81 1.33 0.12 38675 0.0840763 K Total 100.00 100.00 12.81 

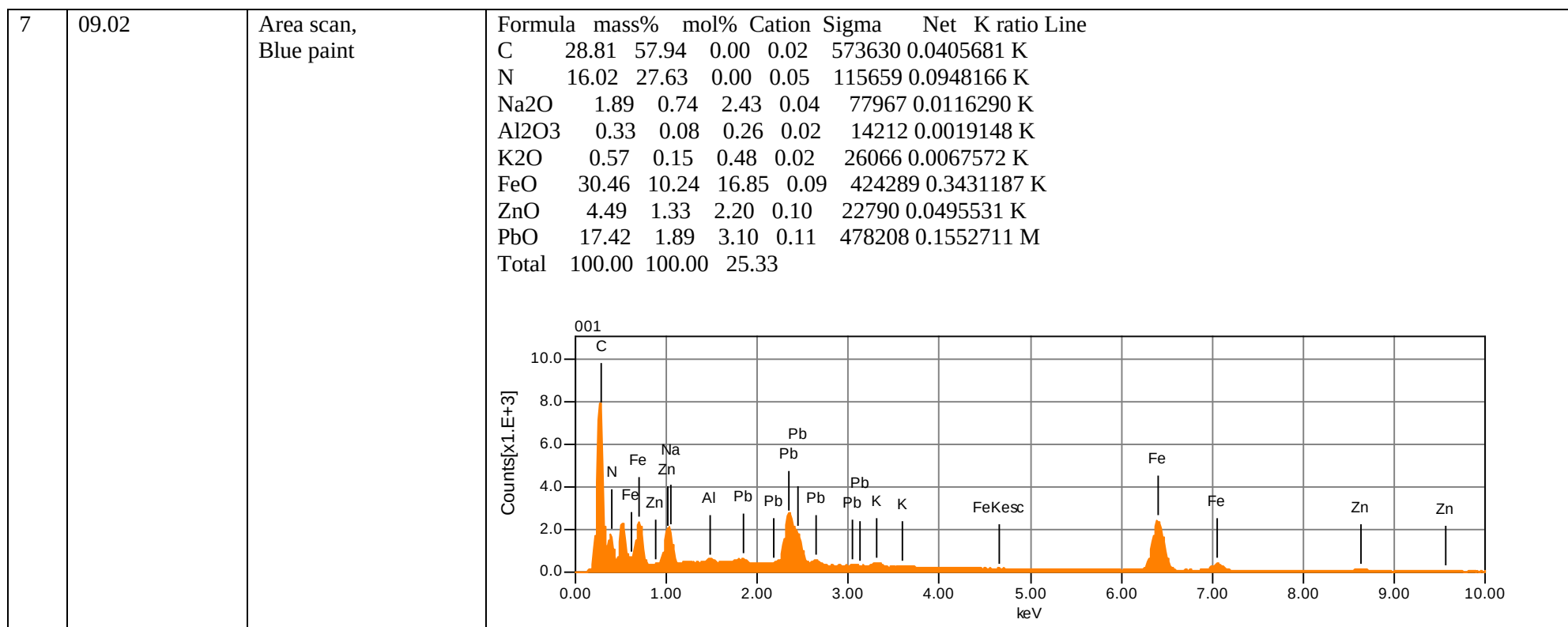






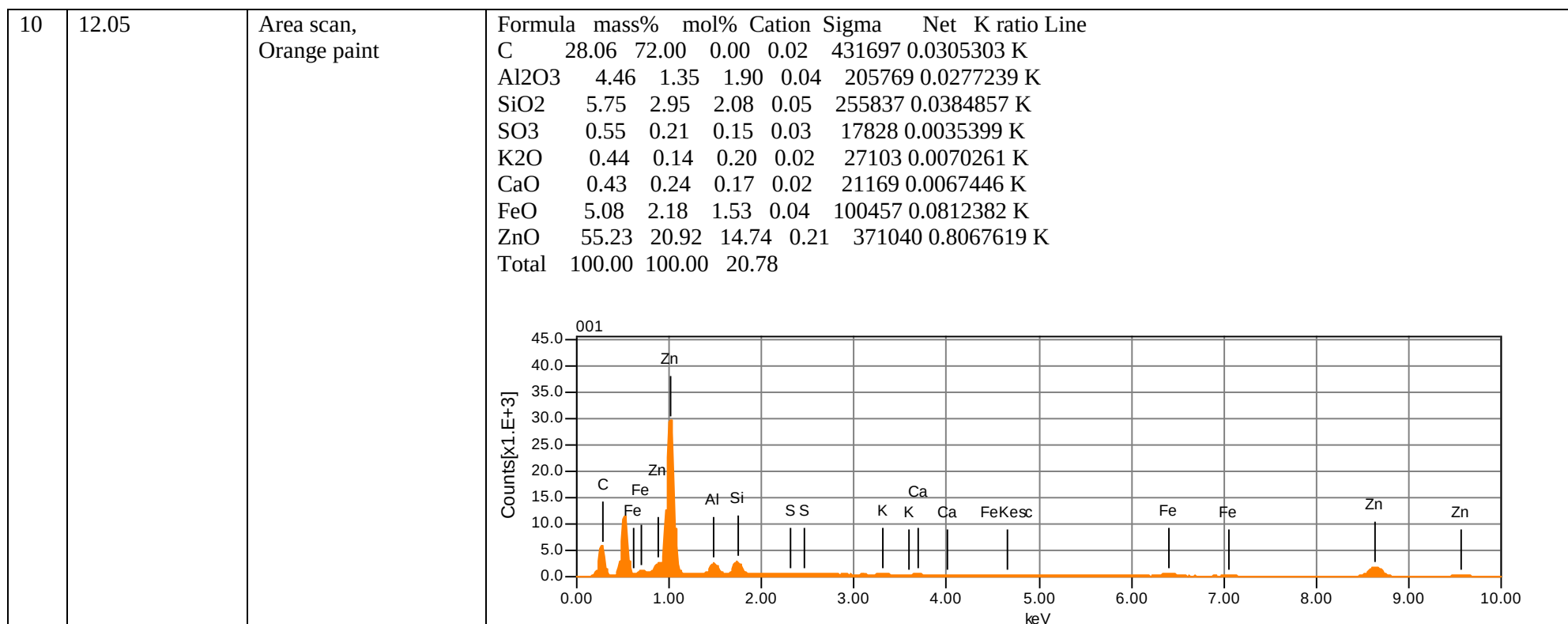






8	11.02	Area scan, Ground layer	Formula mass% mol% Cation Sigma Net K ratio Line C 13.87 64.66 0.00 0.01 381066 0.0269496 K CaO 0.77 0.77 0.34 0.03 34049 0.0108485 K TiO2 27.57 19.32 8.49 0.07 737145 0.2927521 K ZnO 1.69 1.16 0.51 0.09 11844 0.0257524 K PbO 56.09 14.07 6.18 0.14 2048199 0.6650368 M Total 100.00 100.00 15.51

9	12.05	Area scan, Ground layer	Formula mass% mol% Cation Sigma Net K ratio Line C 14.96 43.03 0.00 0.02 172386 0.0121914 K MgO 28.57 24.49 6.57 0.05 2303834 0.2959472 K SiO2 56.47 32.48 8.71 0.10 3330857 0.5010636 K Total 100.00 100.00 15.29

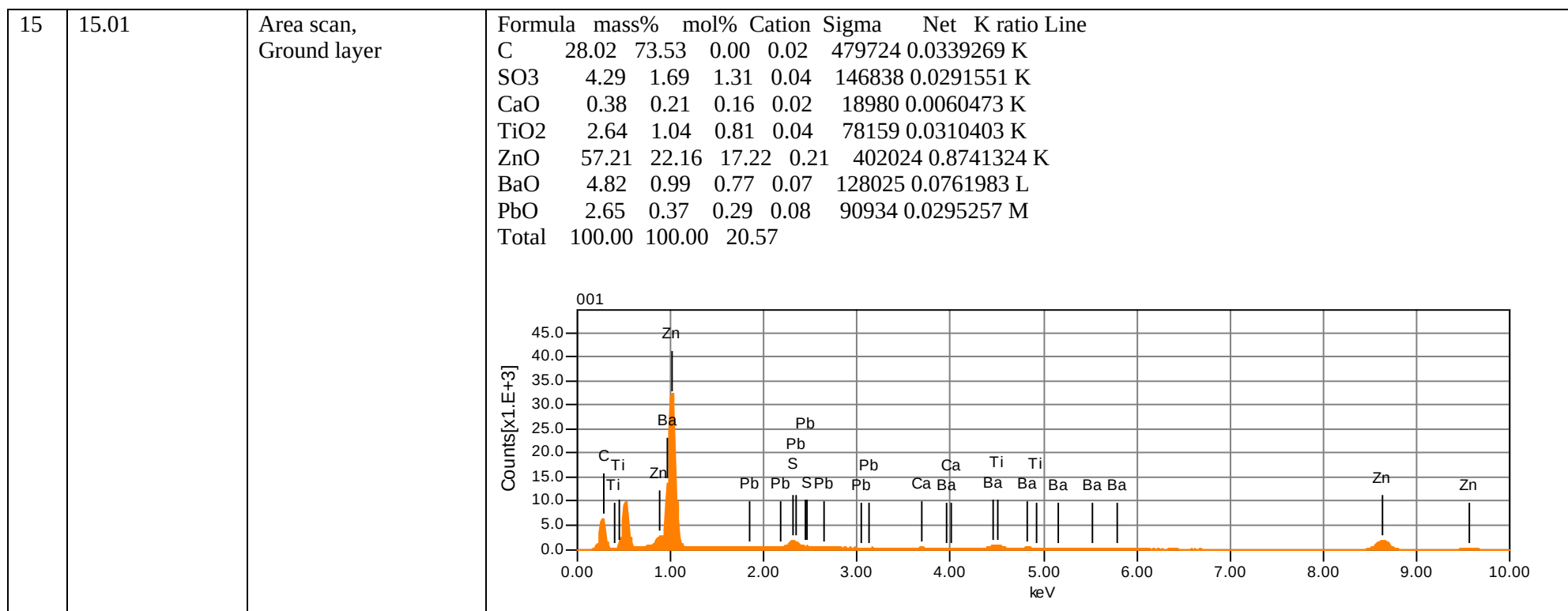


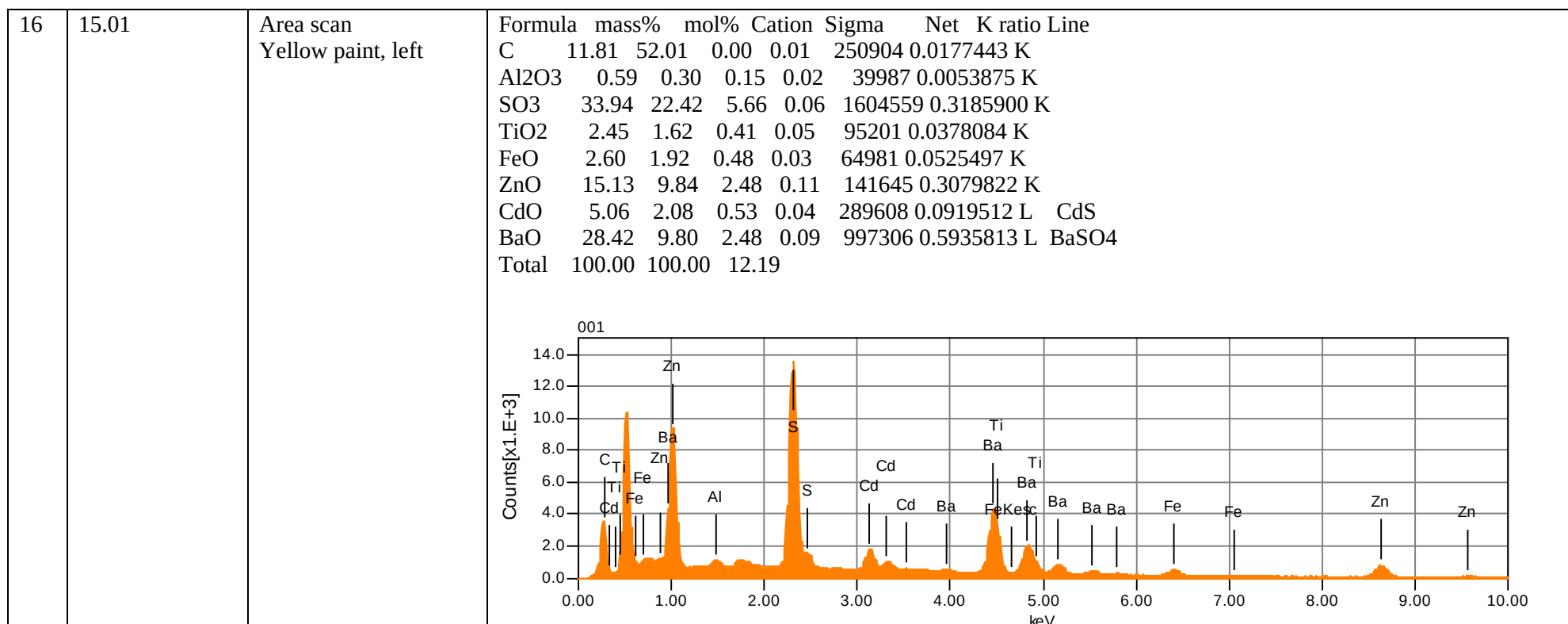
11	12.05	Area scan, White paint	Formula mass% mol% Cation Sigma Net K ratio Line C 28.95 74.31 0.00 0.02 466400 0.0329780 K ZnO 65.98 24.99 23.35 0.23 444858 0.9670732 K PbO 5.07 0.70 0.65 0.07 164581 0.0534275 M Total 100.00 100.00 24.00

12	13.02	Area scan, Ground layer	Formula mass% mol% Cation Sigma Net K ratio Line C 17.70 75.03 0.00 0.01 531461 0.0375858 K ZnO 15.60 9.76 9.38 0.13 137796 0.2996134 K PbO 66.69 15.21 14.62 0.14 2945330 0.9563291 M Total 100.00 100.00 24.00 001 Counts[x1.E+3] keV

13	13.02	Area scan, Yellow paint	Formula mass% mol% Cation Sigma Net K ratio Line C 34.76 80.95 0.00 0.02 756865 0.0535268 K Na2O 0.19 0.09 0.11 0.02 12310 0.0018361 K Al2O3 3.27 0.90 1.12 0.03 211293 0.0284681 K SO3 25.61 8.95 5.60 0.06 1040129 0.2065208 K Cl 0.78 0.62 0.00 0.01 81348 0.0165001 K CaO 3.29 1.64 1.03 0.03 173229 0.0551936 K TiO2 0.60 0.21 0.13 0.04 18249 0.0072474 K ZnO 1.73 0.60 0.37 0.07 12835 0.0279064 K CdO 17.51 3.82 2.39 0.06 829971 0.2635173 L BaO 12.26 2.24 1.40 0.07 337030 0.2005947 L Total 100.00 100.00 12.15 EDS spectrum showing peaks for various elements. The x-axis represents energy in keV from 0.00 to 10.00. The y-axis represents counts in units of 10^3 from 0.0 to 14.0. The spectrum shows several peaks corresponding to the elements listed in the table above. The most prominent peaks are for Carbon (C) at approximately 0.28 keV, Sulfur (S) at approximately 2.31 keV, and Cadmium (Cd) at approximately 3.32 keV. Other smaller peaks are visible for Sodium (Na), Zinc (Zn), Aluminum (Al), Calcium (Ca), Titanium (Ti), Barium (Ba), and Chlorine (Cl).

14	14.01	Area scan, Ground layer	Formula mass% mol% Cation Sigma Net K ratio Line C 22.06 79.32 0.00 0.01 551194 0.0389735 K Al2O3 0.36 0.15 0.35 0.02 20755 0.0027959 K ZnO 16.34 8.68 9.92 0.14 120067 0.2610137 K PbO 61.24 11.85 13.56 0.15 2266682 0.7358295 M Total 100.00 100.00 23.83



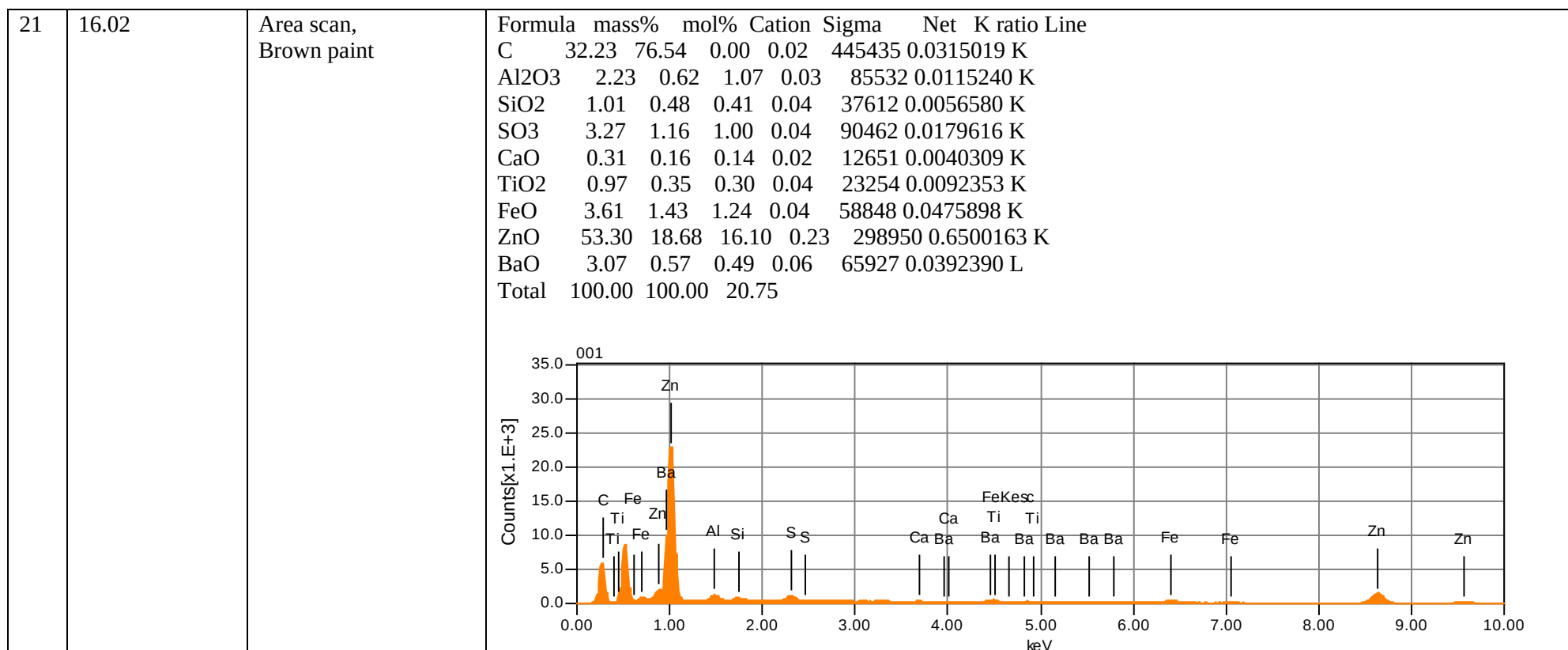


17	15.01	Area scan Red paint, top left	Formula mass% mol% Cation Sigma Net K ratio Line C 28.57 74.36 0.00 0.02 511582 0.0361799 K SO3* 3.52 1.37 1.16 0.04 128230 0.0254605 K CaO 1.04 0.58 0.49 0.02 56214 0.0179106 K ZnO 58.54 22.49 19.01 0.20 450173 0.9788243 K HgO 8.33 1.20 1.02 0.07 338004 0.1118140 M HgS Total 100.00 100.00 21.68
			001 Counts[x1.E+3] keV

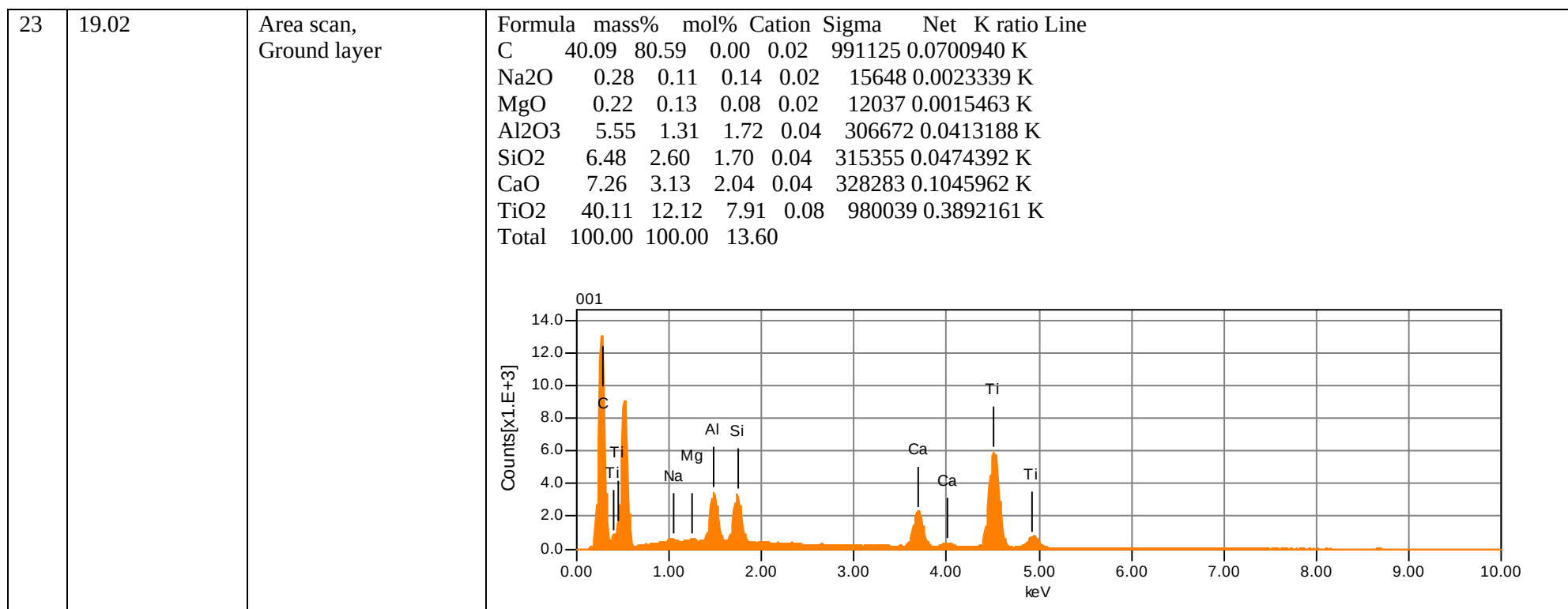
18	15.01	Area scan, White paint	Formula mass% mol% Cation Sigma Net K ratio Line C 23.80 67.91 0.00 0.02 383782 0.0271363 K ZnO 76.20 32.09 24.00 0.23 557756 1.2125007 K Total 100.00 100.00 24.00

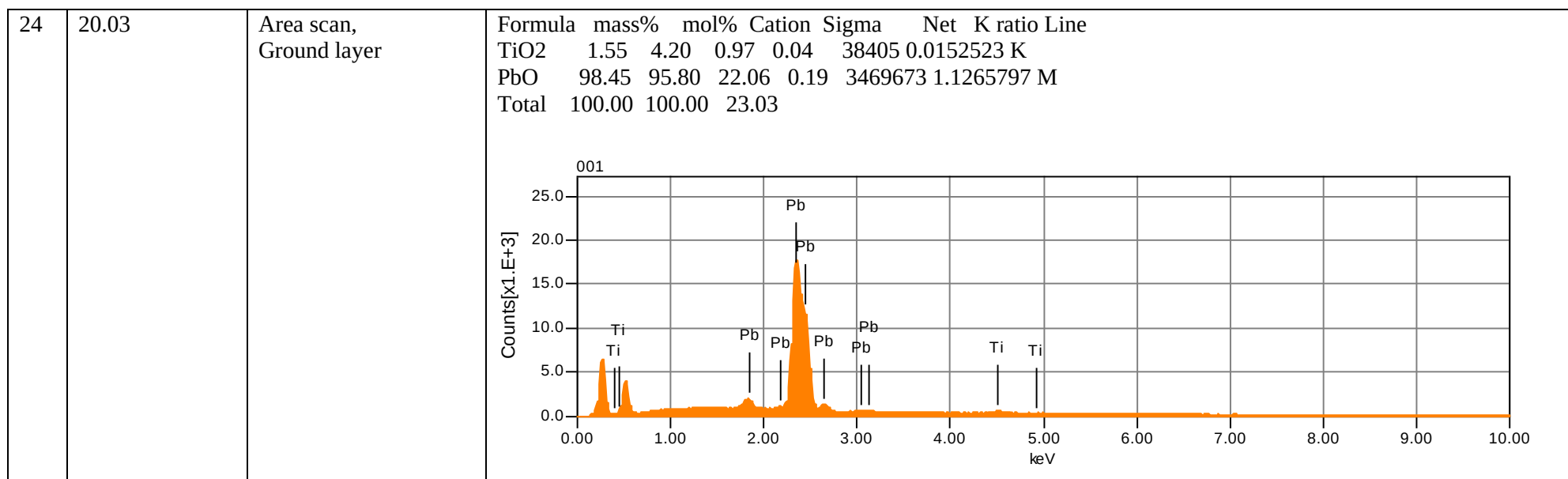
19	16.02	Area scan, Ground layer	Formula mass% mol% Cation Sigma Net K ratio Line C 35.45 78.14 0.00 0.02 481486 0.0340447 K Al₂O₃ 1.34 0.35 0.70 0.03 51010 0.0068714 K SiO₂ 2.63 1.16 1.16 0.04 97182 0.0146163 K SO₃ 0.54 0.18 0.18 0.03 14782 0.0029345 K Cl 0.29 0.22 0.00 0.01 21727 0.0044060 K CaO 3.51 1.66 1.67 0.03 140160 0.0446481 K ZnO 56.24 18.30 18.41 0.23 308010 0.6695813 K Total 100.00 100.00 22.12
			001 Counts[x1.E+3] 0.00 1.00 2.00 3.00 4.00 5.00 6.00 7.00 8.00 9.00 10.00 keV

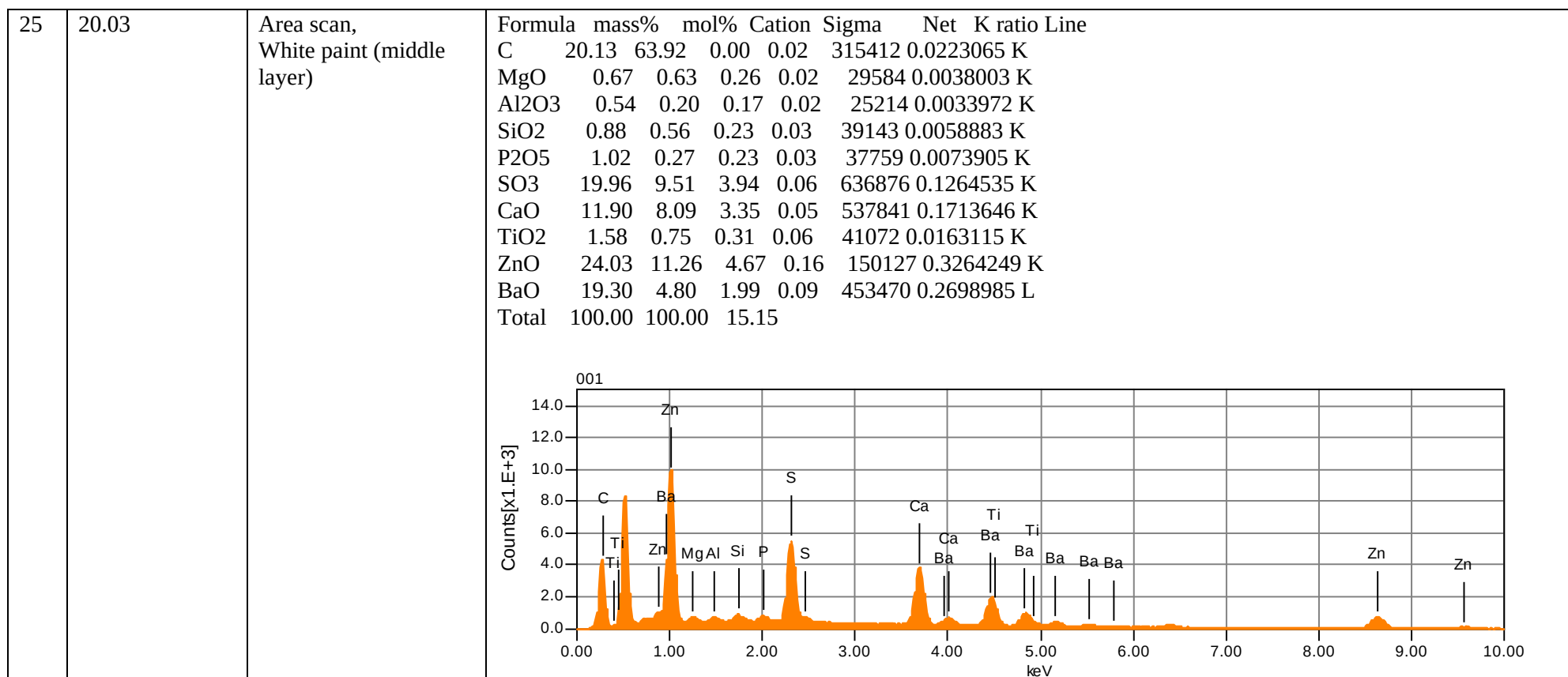
20	16.02	Area scan, Black paint	Formula mass% mol% Cation Sigma Net K ratio Line C 79.63 96.21 0.00 0.03 1420402 0.1004331 K SO3 3.25 0.59 2.96 0.04 71502 0.0141940 K Cl 0.48 0.19 0.00 0.01 27742 0.0056259 K CaO 0.50 0.13 0.66 0.03 14611 0.0046544 K ZnO 16.14 2.88 14.46 0.17 60706 0.1319684 K Total 100.00 100.00 18.08

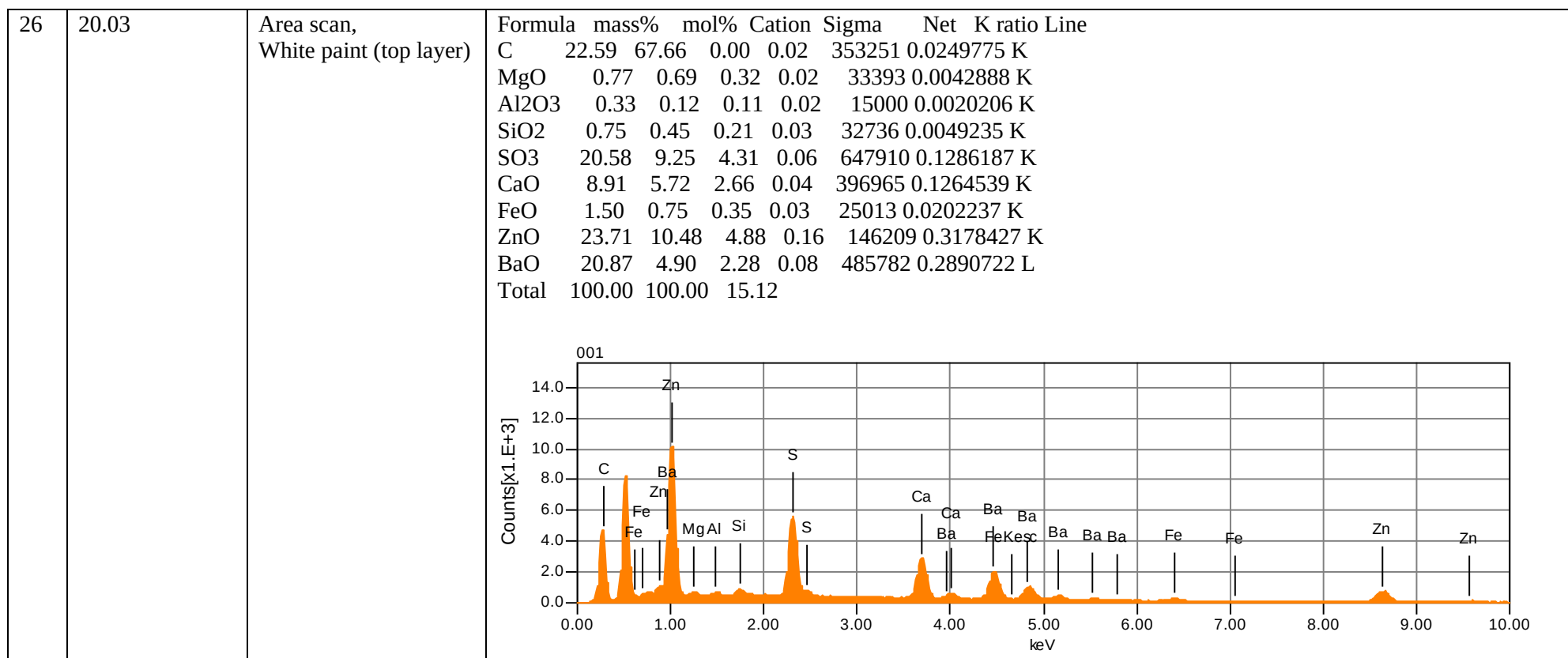


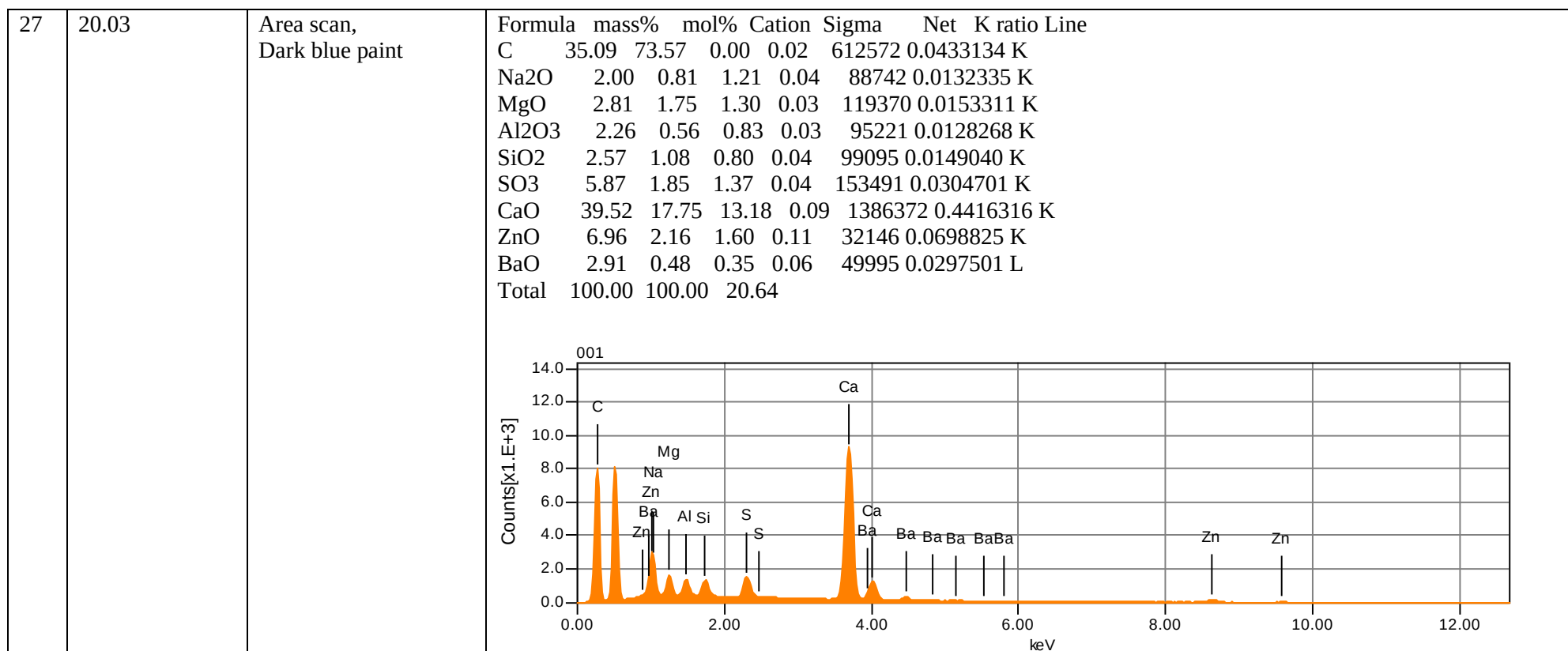
22	18.01	Area scan, Ground layer	Formula mass% mol% Cation Sigma Net K ratio Line C 61.53 91.02 0.00 0.02 1244006 0.0879781 K Al₂O₃ 6.93 1.21 3.04 0.04 334187 0.0450260 K SiO₂ 10.63 3.14 3.96 0.06 437894 0.0658728 K K₂O 0.57 0.11 0.27 0.02 26057 0.0067548 K TiO₂ 20.34 4.52 5.70 0.07 406495 0.1614367 K Total 100.00 100.00 12.96

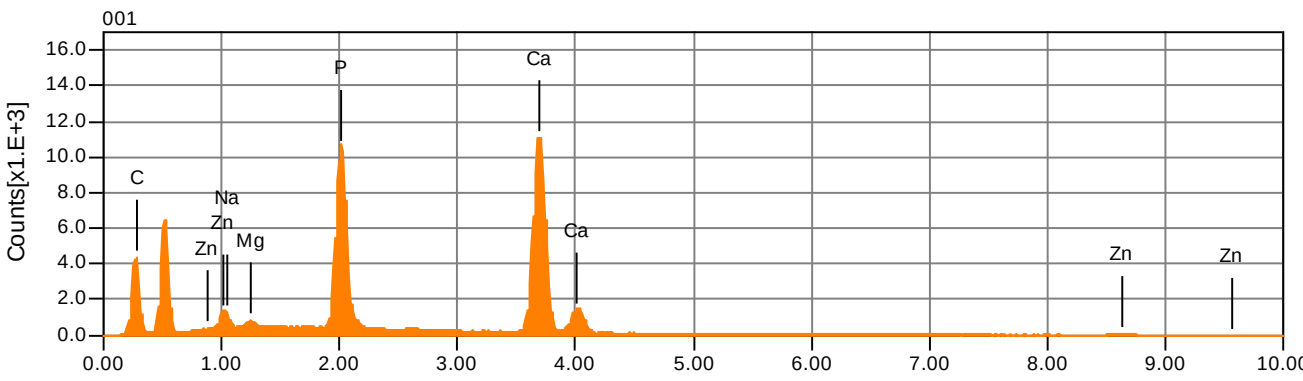


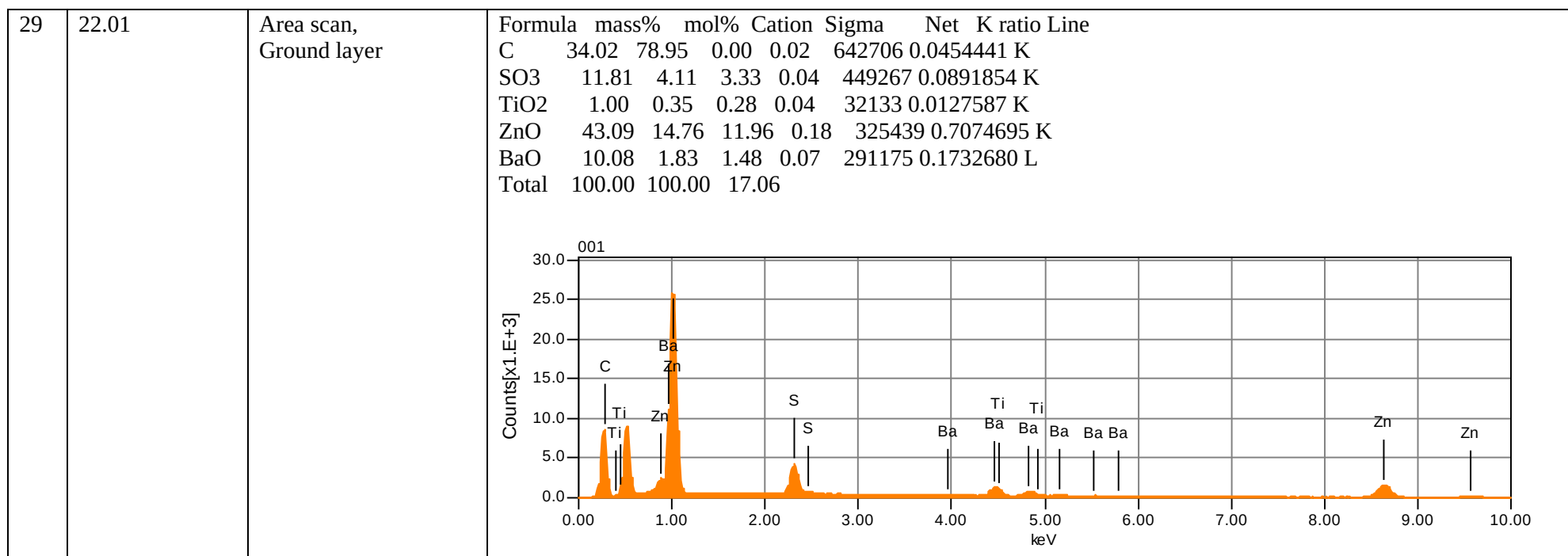








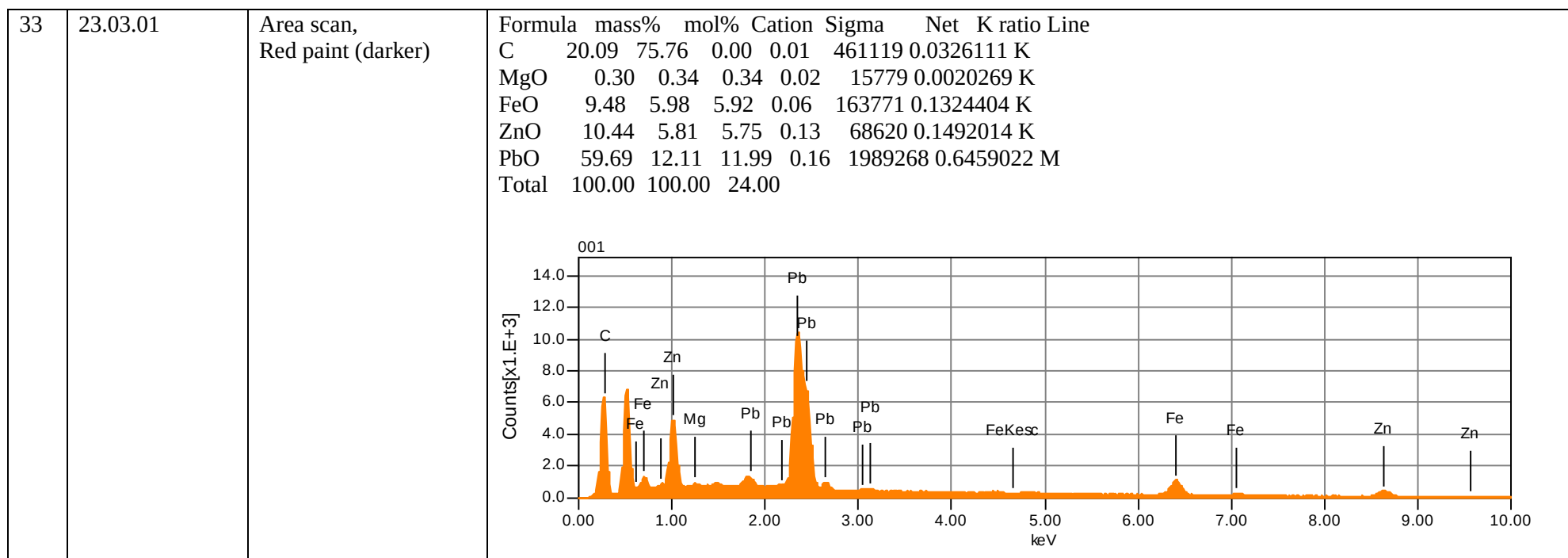
28	20.03	Area scan, Black paint	Formula mass% mol% Cation Sigma Net K ratio Line C 22.30 64.59 0.00 0.02 323109 0.0228508 K Na2O 0.81 0.46 0.32 0.02 43632 0.0065079 K MgO 0.58 0.50 0.18 0.02 31081 0.0039926 K P2O5 32.85 8.05 5.71 0.07 1251999 0.2450511 K CaO 40.63 25.20 8.95 0.08 1668485 0.5316054 K ZnO 2.81 1.20 0.43 0.08 15358 0.0333941 K Total 100.00 100.00 15.59  The EDS spectrum shows a series of peaks corresponding to the elements identified in the table. The x-axis represents energy in keV from 0.00 to 10.00, and the y-axis represents counts in units of 10^3 from 0.0 to 16.0. The most prominent peaks are for Carbon (C) at approximately 0.28 keV, Phosphorus (P) at 2.01 keV, and Calcium (Ca) at 3.69 keV. Smaller peaks for Sodium (Na), Zinc (Zn), and Magnesium (Mg) are visible between 0.5 and 1.5 keV. Two additional peaks for Zinc (Zn) are observed at approximately 8.6 and 9.6 keV.

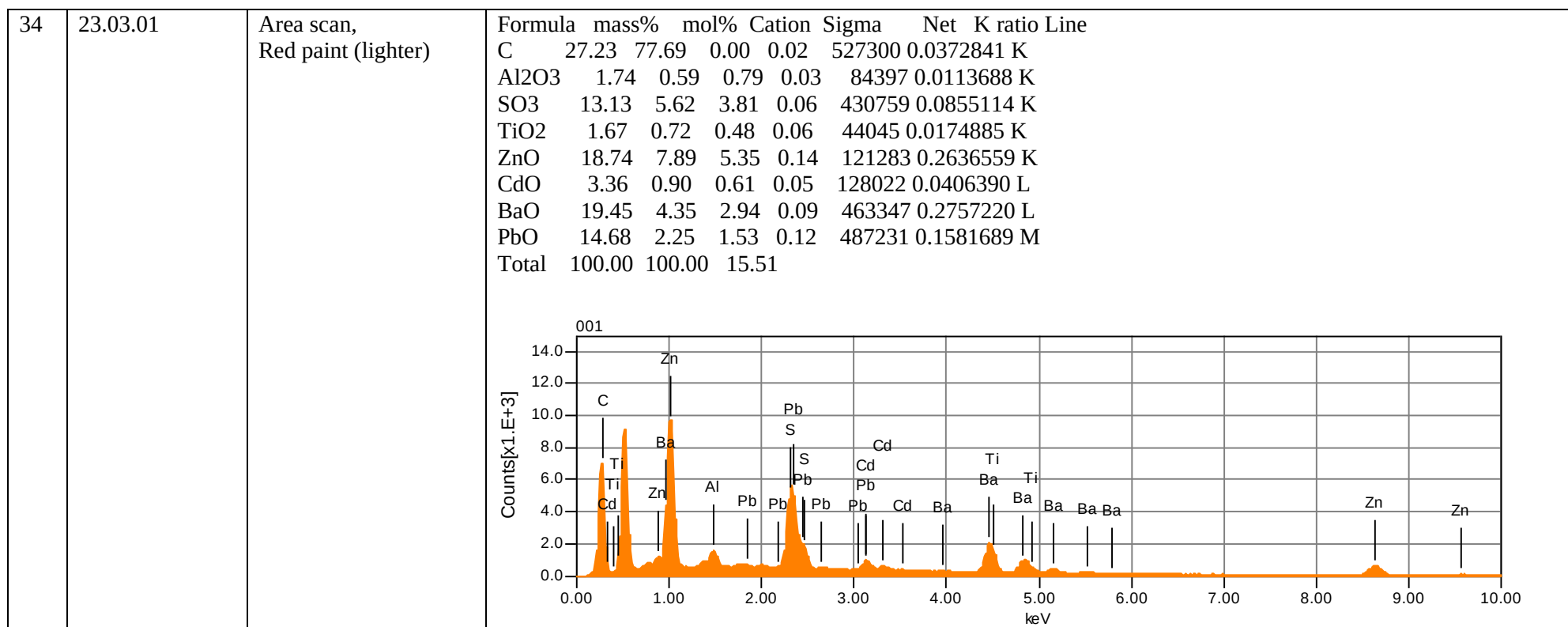


30	22.01	Area scan, Black paint	Formula mass% mol% Cation Sigma Net K ratio Line C 91.11 98.62 0.00 0.02 3104290 0.2195406 K P2O5 0.98 0.09 2.47 0.02 36127 0.0070711 K K2O 0.29 0.04 1.10 0.02 14606 0.0037864 K CaO 0.50 0.12 1.59 0.02 19550 0.0062288 K ZnO 7.13 1.14 15.70 0.10 35786 0.0778110 K Total 100.00 100.00 20.85 EDS spectrum showing peaks for Carbon (C), Zinc (Zn), Phosphorus (P), Potassium (K), and Calcium (Ca). The x-axis is energy in keV (0.00 to 10.00) and the y-axis is counts (0.0 to 35.0). The C peak is at ~0.28 keV, Zn at ~1.01 keV, P at ~2.01 keV, K at ~3.96 keV, and Ca at ~4.01 keV. There are also peaks at ~8.64 keV and ~9.59 keV labeled as Zn.

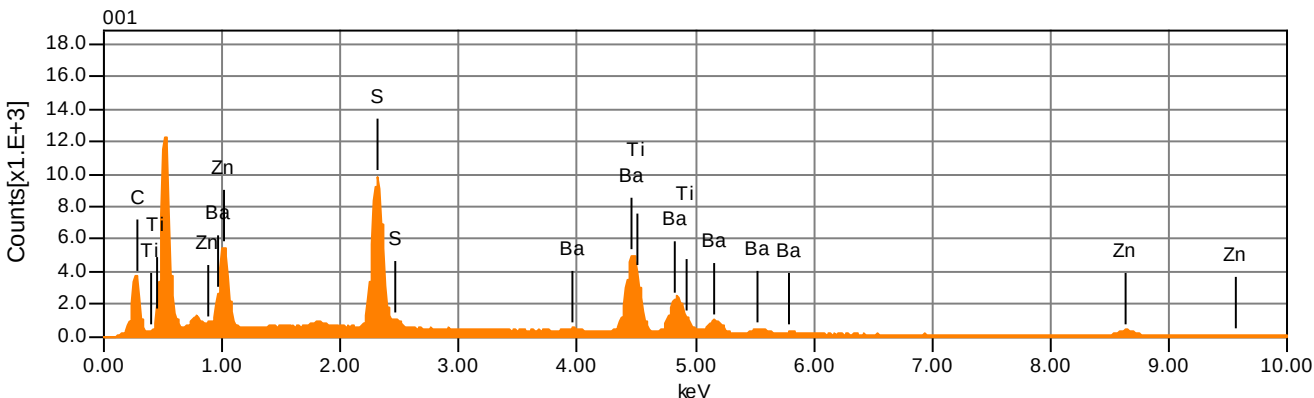
31	22.01	Area scan, White paint	Formula mass% mol% Cation Sigma Net K ratio Line C 20.93 64.19 0.00 0.02 320020 0.0226278 K ZnO 79.07 35.81 24.00 0.24 561945 1.2216082 K Total 100.00 100.00 24.00
			001 Counts[x1.E+3] keV

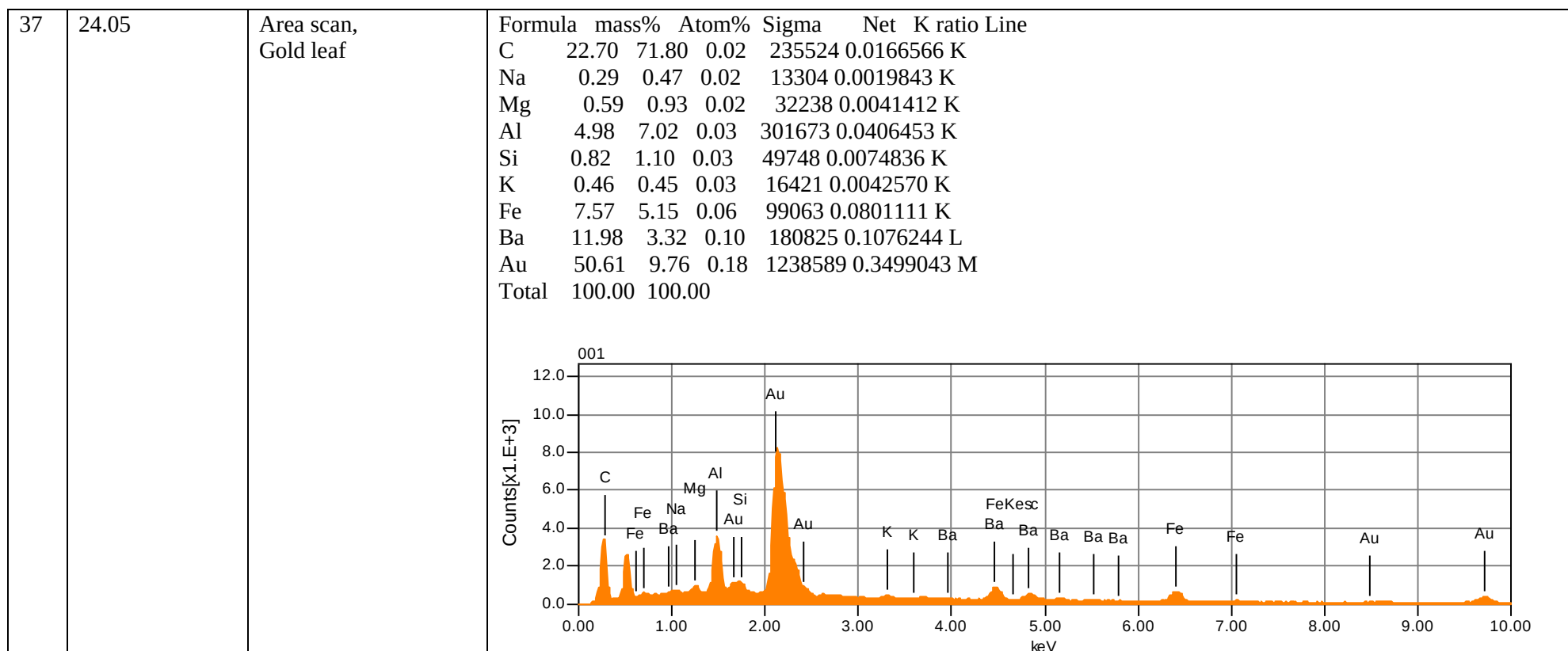
32	23.03.01	Area scan, White paint	Formula mass% mol% Cation Sigma Net K ratio Line C 24.13 79.89 0.00 0.01 530570 0.0375153 K Al₂O₃ 0.36 0.14 0.33 0.02 18195 0.0024510 K FeO 4.19 2.32 2.73 0.05 71424 0.0577480 K ZnO 15.94 7.79 9.17 0.14 102767 0.2234036 K PbO 55.38 9.86 11.61 0.15 1809433 0.5873933 M Total 100.00 100.00 23.84
			001 Counts[×1.E+3] keV



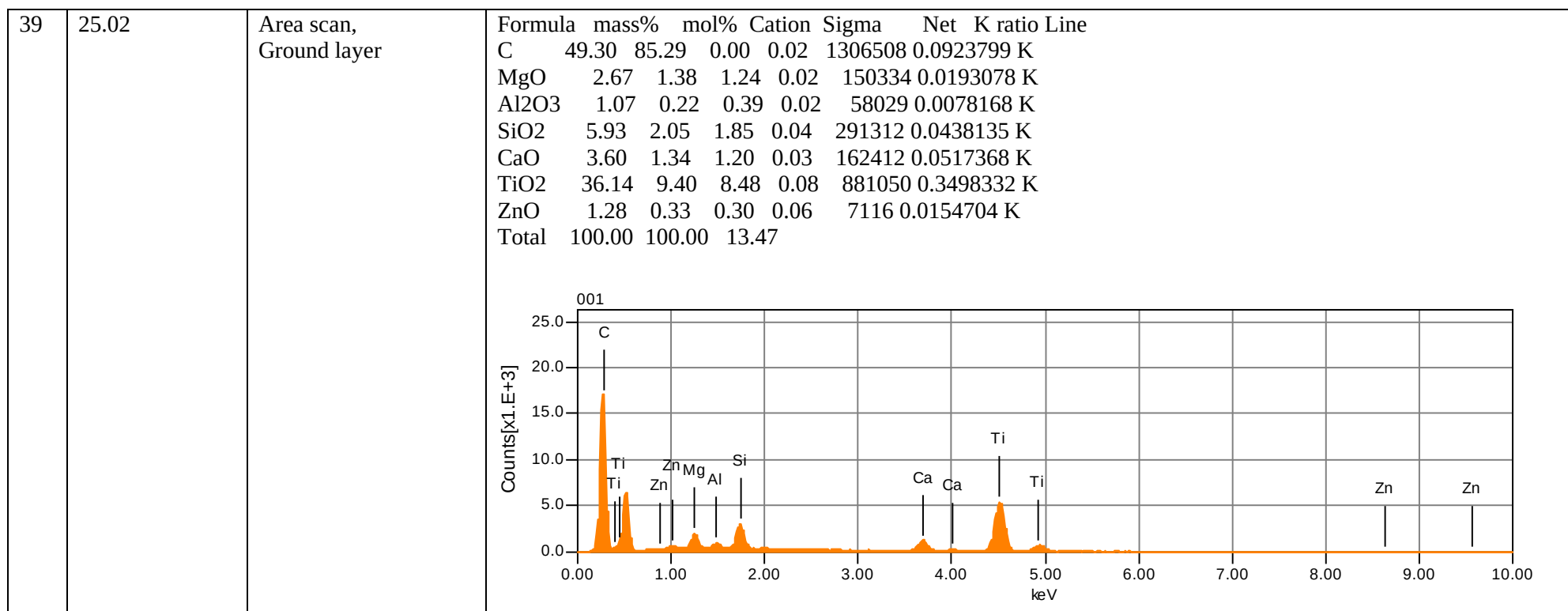


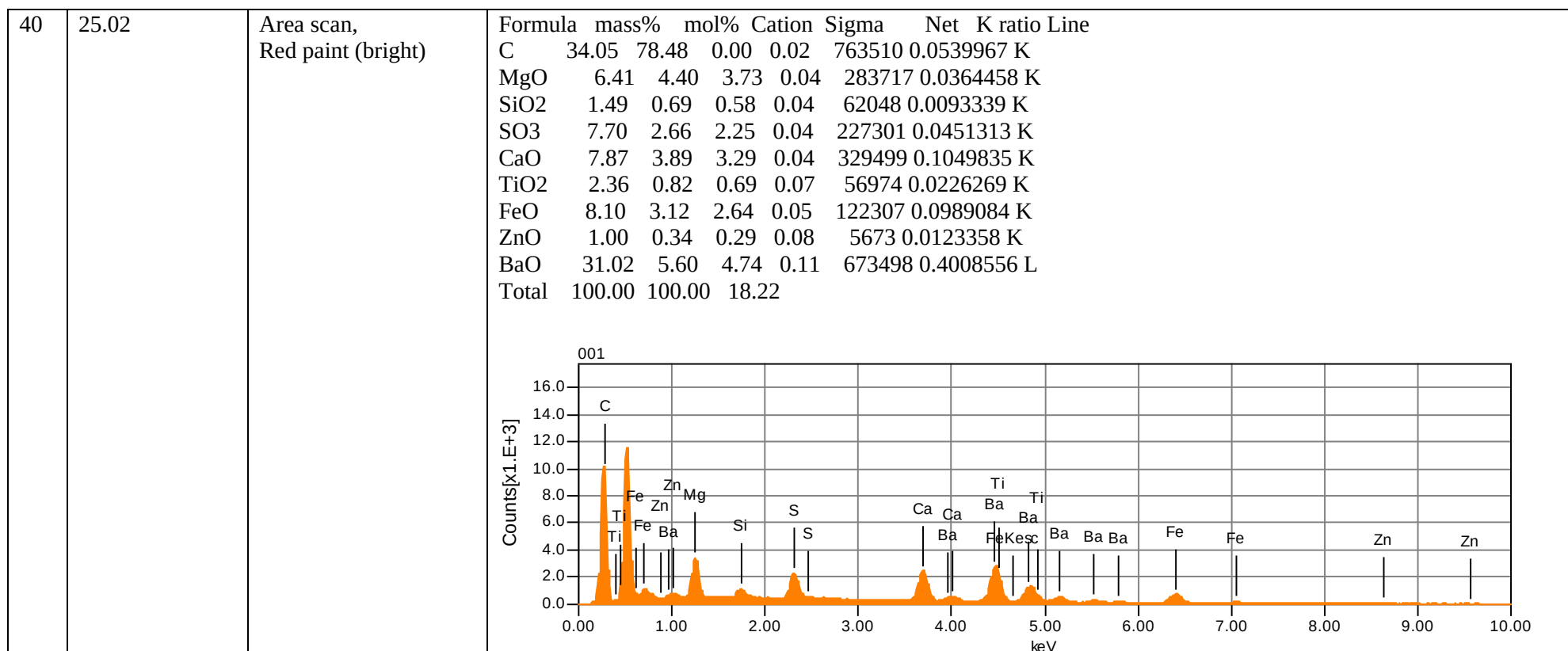
35	23.03.01	Area scan, Yellow paint	Formula mass% mol% Cation Sigma Net K ratio Line C 14.44 70.20 0.00 0.01 387976 0.0274383 K Al2O3 0.23 0.13 0.19 0.02 14560 0.0019617 K SO3 2.37 1.73 1.22 0.07 93847 0.0186336 K TiO2 0.50 0.36 0.26 0.04 14532 0.0057712 K ZnO 12.11 8.69 6.16 0.12 96090 0.2089301 K BaO 3.98 1.52 1.07 0.07 105549 0.0628213 L PbO 66.37 17.36 12.30 0.16 2626880 0.8529305 M Total 100.00 100.00 21.20

36	24.05	Area scan, Ground layer	Formula mass% mol% Cation Sigma Net K ratio Line C 13.89 58.55 0.00 0.01 267496 0.0189178 K SO3 30.89 19.53 5.66 0.06 1150673 0.2284695 K TiO2 3.55 2.25 0.65 0.07 111014 0.0440883 K ZnO 8.91 5.54 1.61 0.11 66516 0.1446274 K BaO 42.76 14.12 4.09 0.12 1207213 0.7185142 L Total 100.00 100.00 12.02 



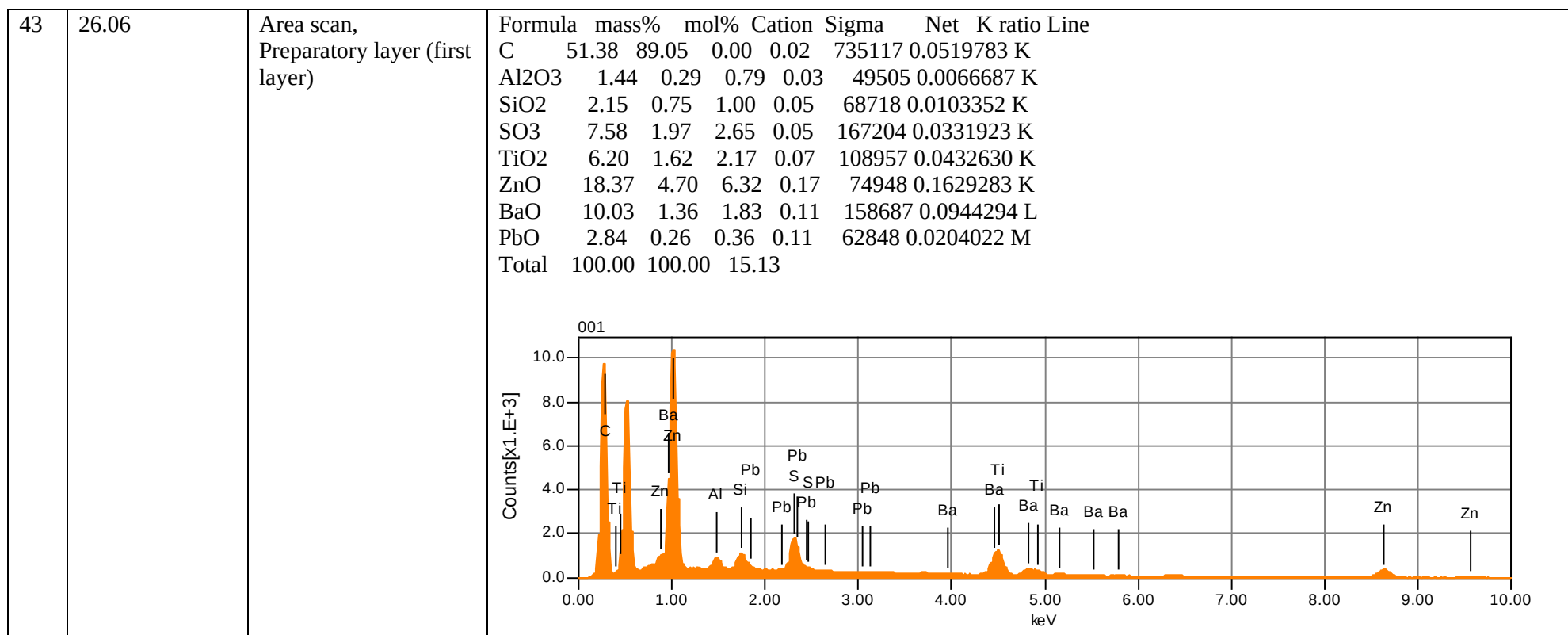
38	24.05	Point analysis, Gold leaf	Formula mass% Atom% Sigma Net K ratio Line C 12.05 69.19 0.01 278481 0.0196946 K Au 87.95 30.81 0.13 5261793 1.4864695 M Total 100.00 100.00
			001 Counts[x1. E+3] keV



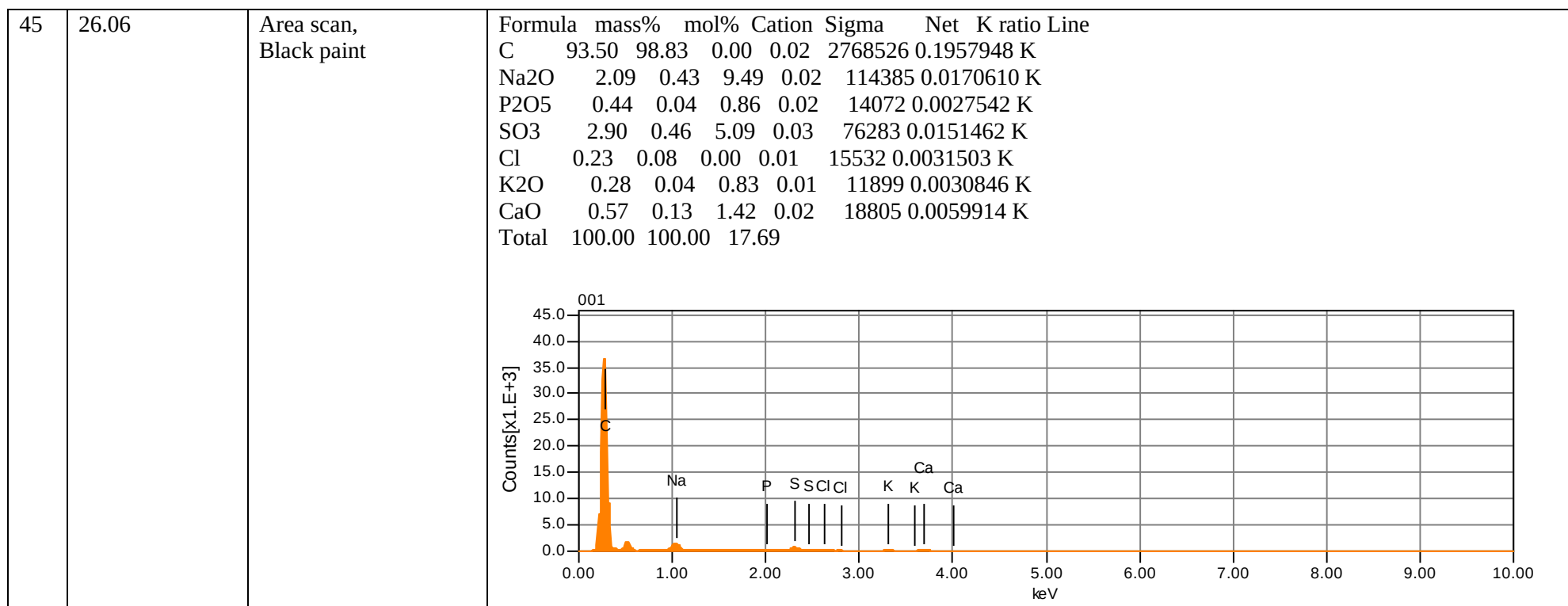


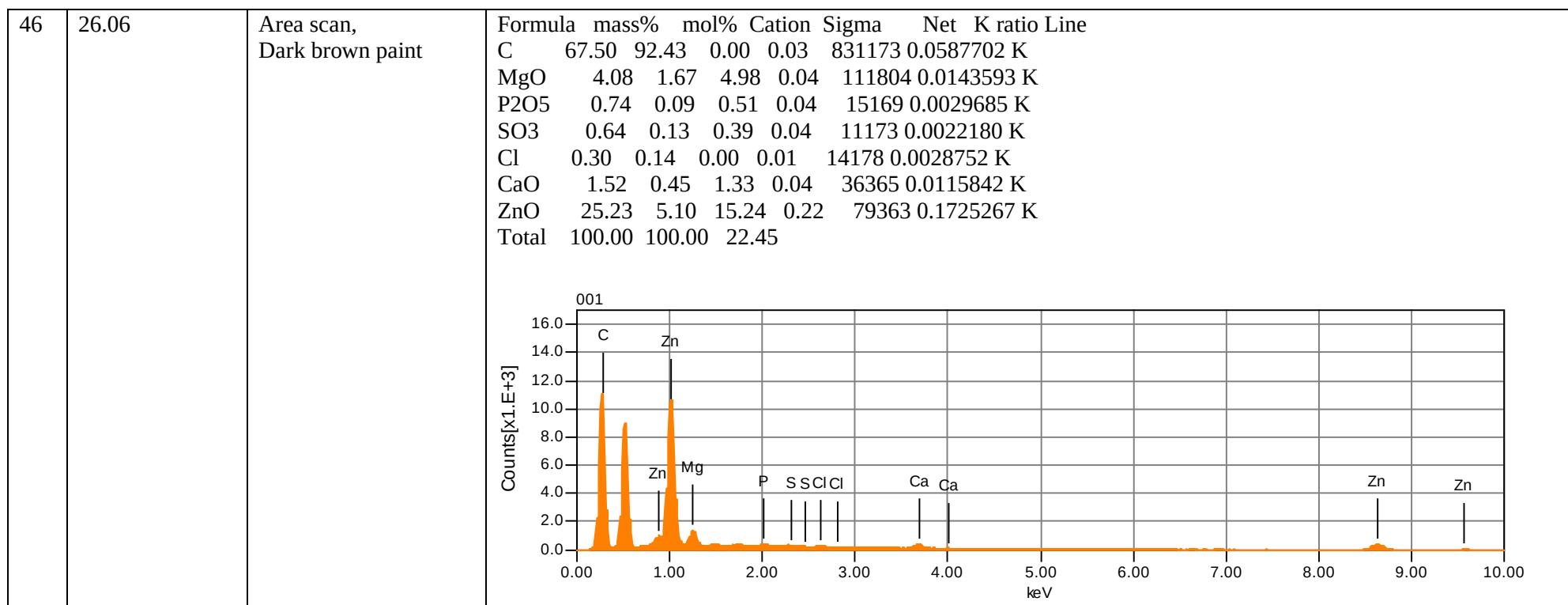
41	25.02	Area scan, Orange paint	Formula mass% mol% Cation Sigma Net K ratio Line C 39.00 82.27 0.00 0.02 801934 0.0567141 K MgO 0.95 0.60 0.54 0.02 47450 0.0060953 K Al2O3 3.39 0.84 1.51 0.04 166934 0.0224915 K SO3 10.60 3.36 3.01 0.05 336148 0.0667431 K FeO 24.98 8.81 7.89 0.08 398184 0.3220074 K SeO2* 2.89 0.66 0.59 0.06 110252 0.0210403 L SeS2 CdO 14.23 2.81 2.52 0.07 542389 0.1722094 L CdS BaO 3.96 0.65 0.59 0.05 87669 0.0521793 L Total 100.00 100.00 16.64 EDS spectrum showing peaks for Carbon (C), Iron (Fe), Aluminum (Al), Selenium (Se), Sulfur (S), Cadmium (Cd), Barium (Ba), and Potassium (K). The spectrum is labeled '001' in the top left corner. The x-axis is energy in keV, ranging from 0.00 to 10.00. The y-axis is counts, ranging from 0.0 to 16.0. The peaks are labeled with their corresponding elements: C, Fe, Al, Se, S, Cd, Ba, and K.

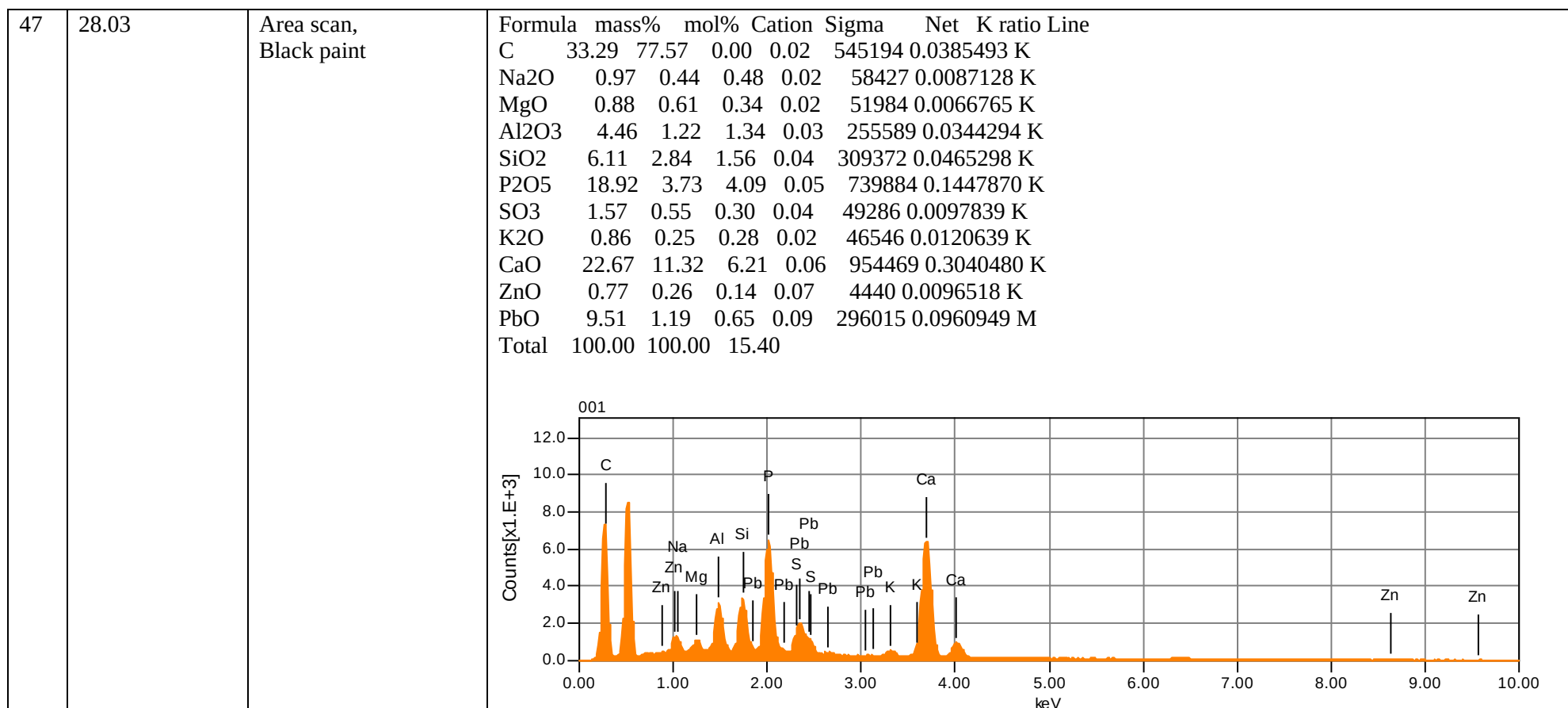
42	26.06	Area scan, Ground layer	Formula mass% mol% Cation Sigma Net K ratio Line C 16.79 70.09 0.00 0.01 424696 0.0300352 K Na2O 0.27 0.21 0.22 0.02 14752 0.0022003 K TiO2 26.09 16.37 8.49 0.07 639152 0.2538351 K ZnO 1.41 0.87 0.45 0.09 9043 0.0196630 K PbO 55.44 12.45 6.46 0.15 1856380 0.6027542 M Total 100.00 100.00 15.62



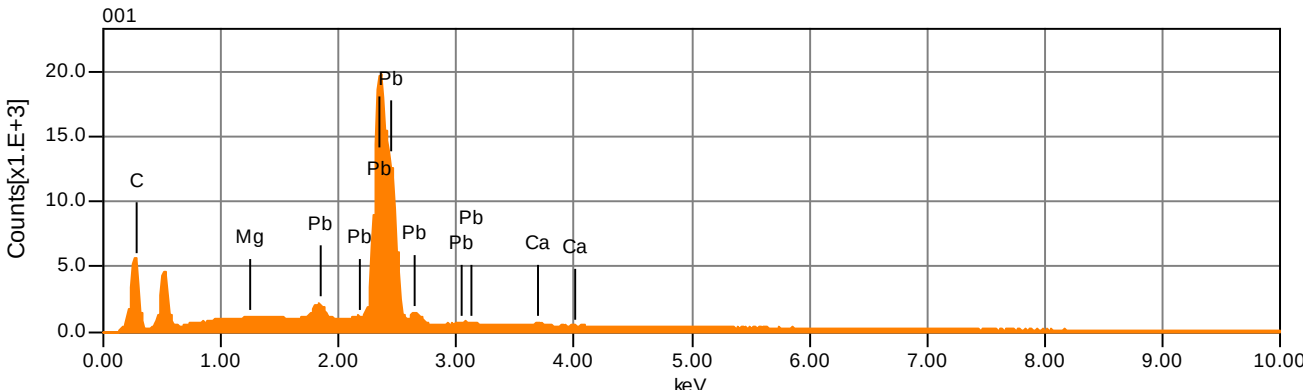
44	26.06	Area scan, Preparatory layer (second layer)	Formula mass% mol% Cation Sigma Net K ratio Line C 50.76 87.05 0.00 0.03 565737 0.0400099 K Al₂O₃ 2.36 0.48 1.42 0.04 71450 0.0096267 K SiO₂ 6.70 2.30 3.41 0.06 191267 0.0287725 K ZnO 40.17 10.17 15.07 0.24 154923 0.3368527 K Total 100.00 100.00 19.89
			The figure is an EDS spectrum plot. The x-axis represents energy in keV, ranging from 0.00 to 10.00 with major ticks every 1.00 keV. The y-axis represents counts, scaled by 10^3, ranging from 0.0 to 20.0 with major ticks every 5.0 units. The spectrum shows several peaks: a small peak for Carbon (C) at ~0.27 keV, a small peak for Zinc (Zn) at ~0.86 keV, a very large, sharp peak for the 002 plane of ZnO at ~1.01 keV, a small peak for Aluminum (Al) at ~1.33 keV, a small peak for Silicon (Si) at ~1.74 keV, and two small peaks for Zinc (Zn) at ~8.64 keV and ~9.59 keV. The baseline is relatively flat with some low-level noise.

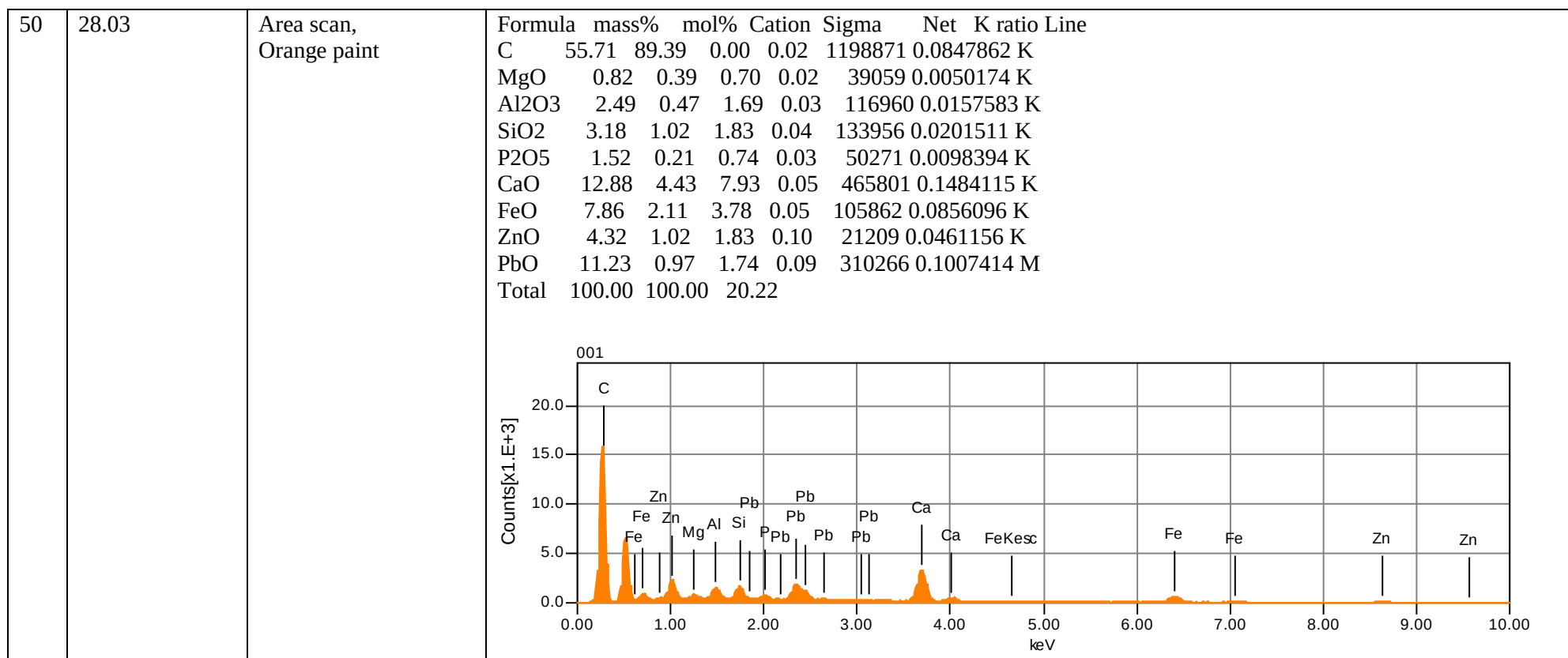






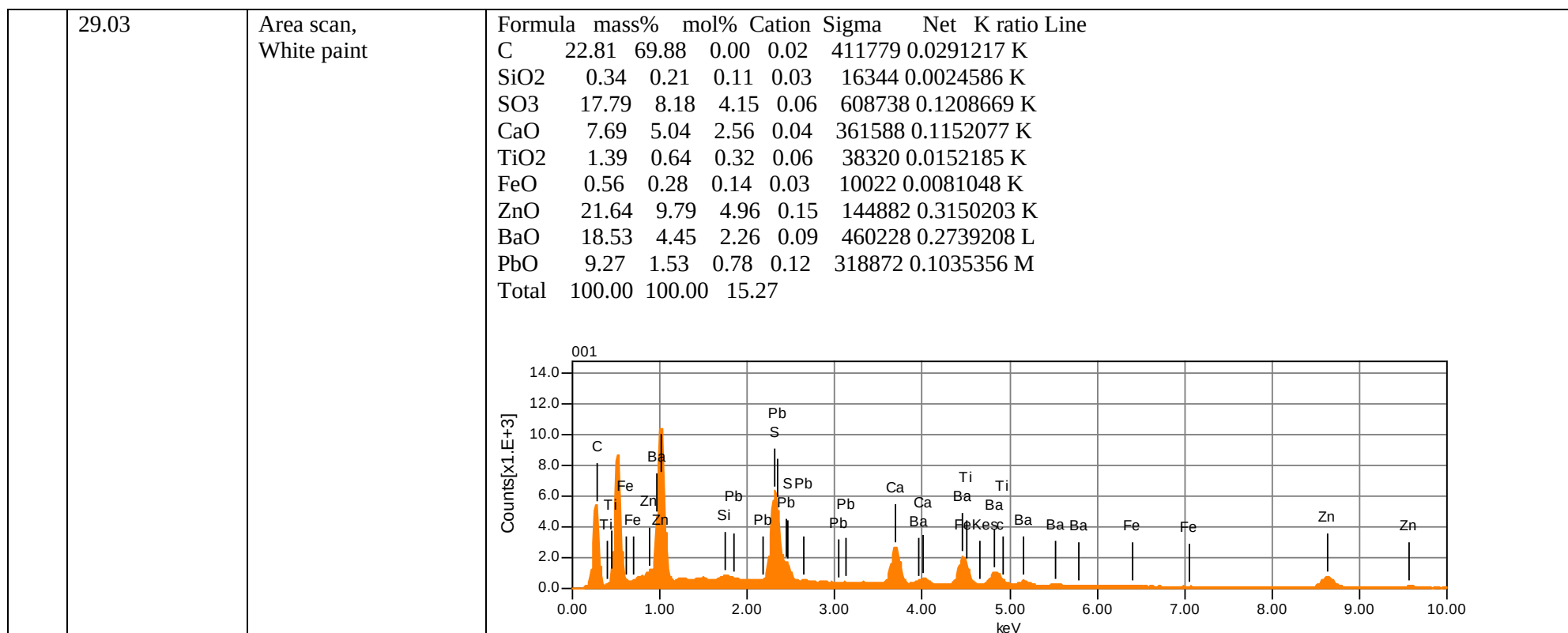
48	28.03	Area scan, Ground layer	Formula mass% mol% Cation Sigma Net K ratio Line C 15.03 67.76 0.00 0.01 457963 0.0323879 K TiO2 26.73 18.11 8.63 0.07 778444 0.3091540 K PbO 58.24 14.13 6.73 0.14 2329367 0.7563301 M Total 100.00 100.00 15.37

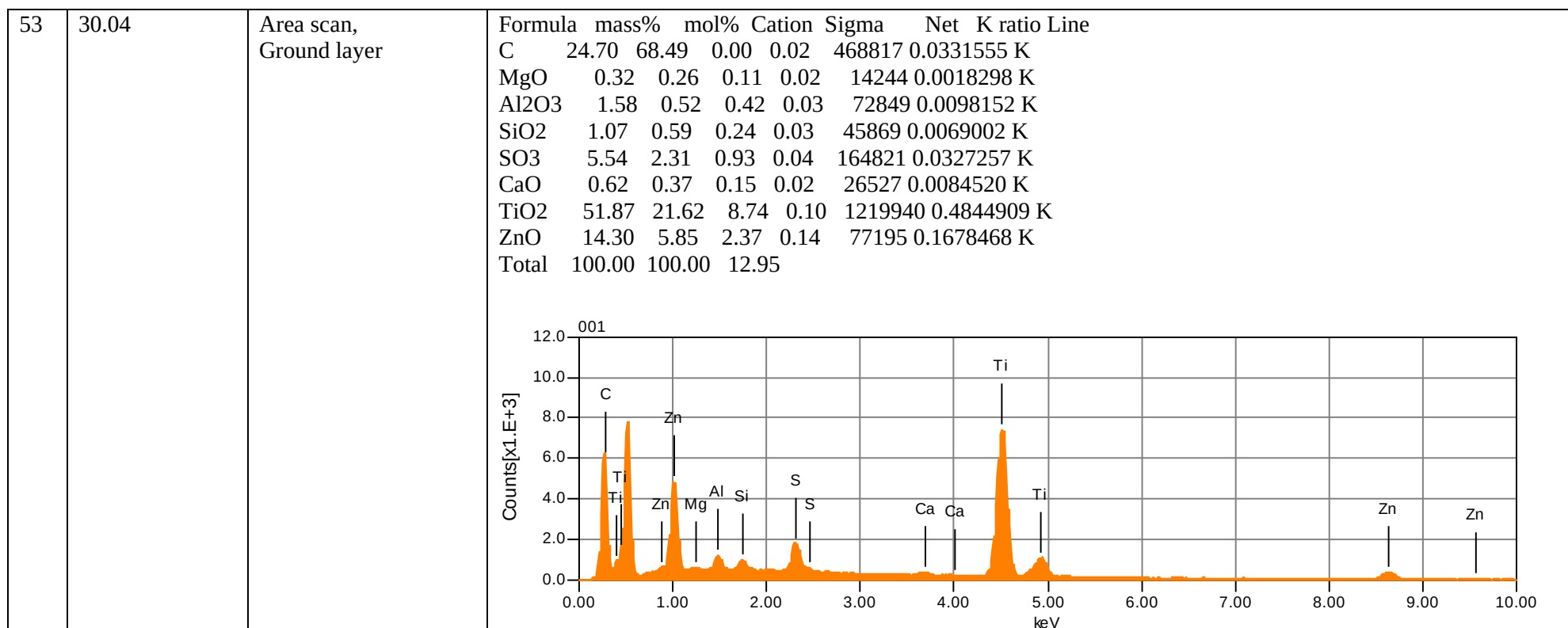
49	28.03	Area scan, White paint	Formula mass% mol% Cation Sigma Net K ratio Line C 11.83 70.84 0.00 0.01 390227 0.0275920 K MgO 0.20 0.36 0.30 0.02 15242 0.0019575 K CaO 0.46 0.59 0.49 0.03 22702 0.0072316 K PbO 87.51 28.21 23.22 0.16 3856157 1.2518183 M Total 100.00 100.00 24.00 

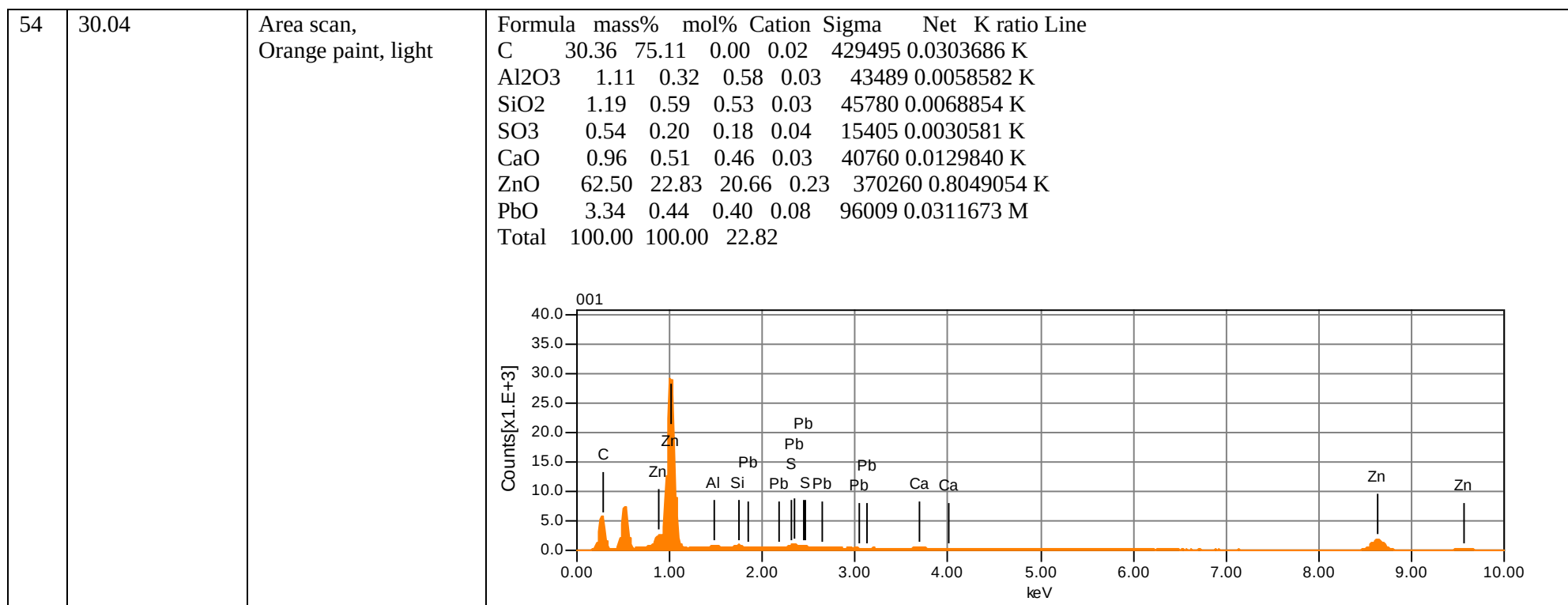


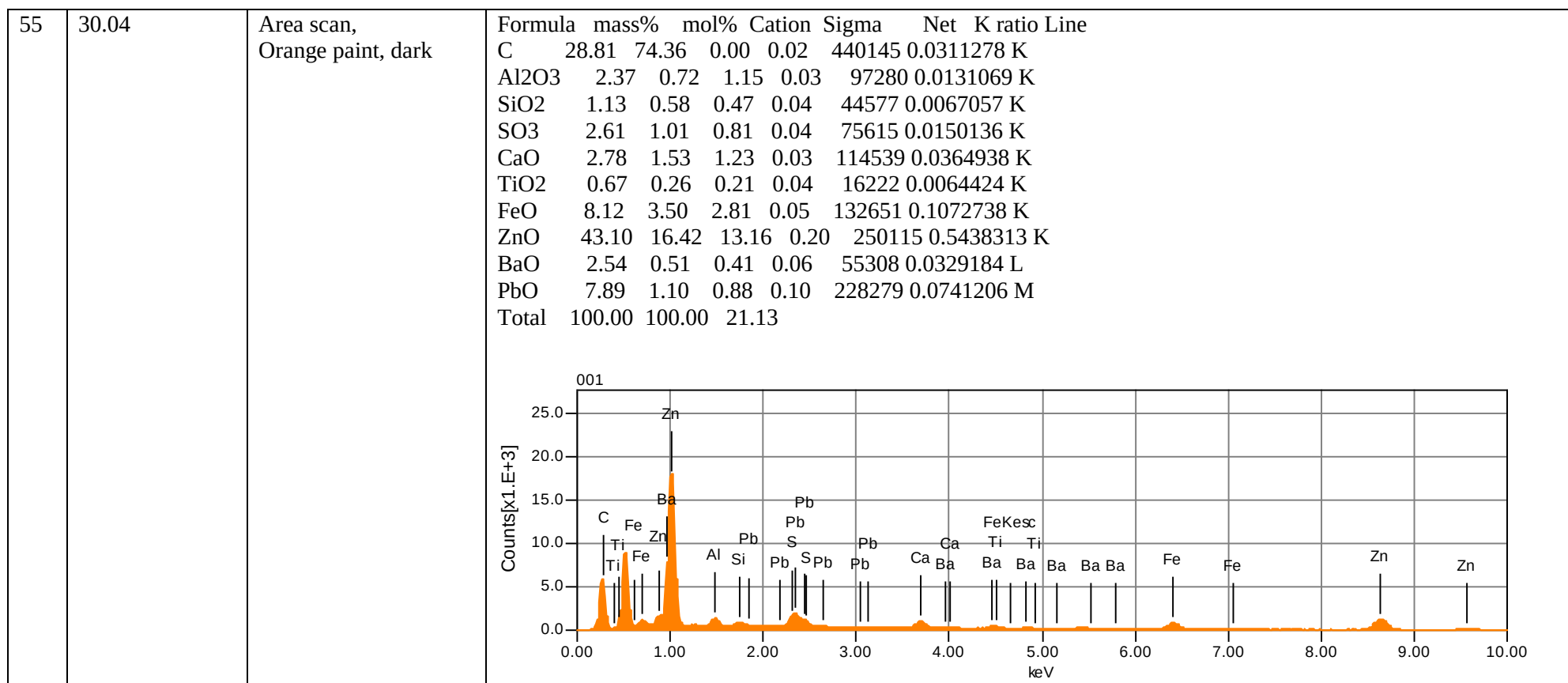
51	29.03	Area scan, Ground layer	Formula mass% mol% Cation Sigma Net K ratio Line C 14.69 75.65 0.00 0.01 470898 0.0333027 K TiO2 1.44 1.11 1.05 0.03 43465 0.0172619 K PbO 83.87 23.24 21.90 0.16 3582361 1.1631688 M Total 100.00 100.00 22.95 001 Counts[x1.E+3] keV

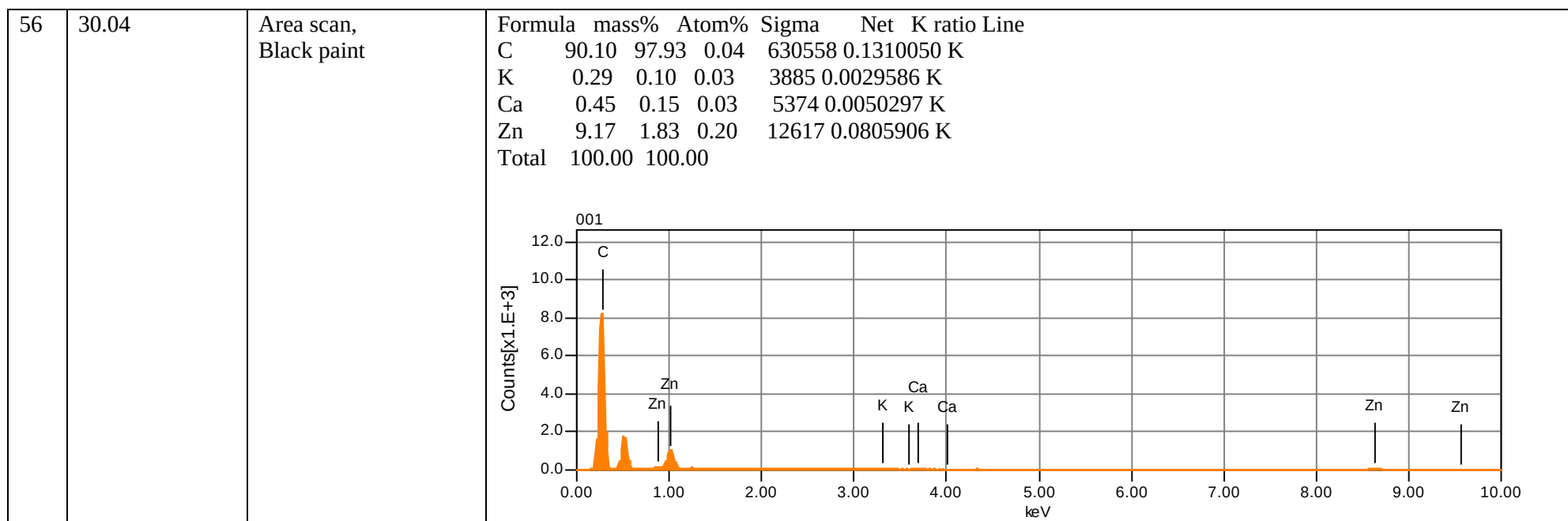
52	29.03	Area scan, Black paint	Formula mass% mol% Cation Sigma Net K ratio Line C 35.50 79.45 0.00 0.02 591617 0.0418401 K MgO 0.56 0.38 0.24 0.02 29540 0.0037946 K Al2O3 0.24 0.06 0.08 0.02 12192 0.0016427 K SiO2 0.64 0.29 0.18 0.03 30420 0.0045761 K P2O5 19.13 3.62 4.60 0.06 716587 0.1402561 K SO3 3.48 1.17 0.74 0.04 104295 0.0207081 K CaO 24.65 11.81 7.50 0.07 994574 0.3168868 K ZnO 5.67 1.87 1.19 0.10 31235 0.0679159 K BaO 2.34 0.41 0.26 0.05 47926 0.0285251 L PbO 7.79 0.94 0.60 0.09 231874 0.0752881 M Total 100.00 100.00 15.39 EDS spectrum showing peaks for various elements. The x-axis represents energy in keV (0.00 to 10.00) and the y-axis represents counts (0.0 to 9.0). The spectrum shows several peaks, with the most prominent ones labeled: C (Carbon) at ~0.28 keV, Zn (Zinc) at ~1.01 keV, Ba (Barium) at ~1.18 keV, Mg (Magnesium) at ~1.30 keV, Al (Aluminum) at ~1.39 keV, Si (Silicon) at ~1.74 keV, P (Phosphorus) at ~2.01 keV, S (Sulfur) at ~2.31 keV, Pb (Lead) at ~2.42 keV, Ca (Calcium) at ~3.69 keV, and Ba (Barium) at ~4.04 keV. There are also smaller peaks for Zn at ~8.64 keV and ~9.57 keV.



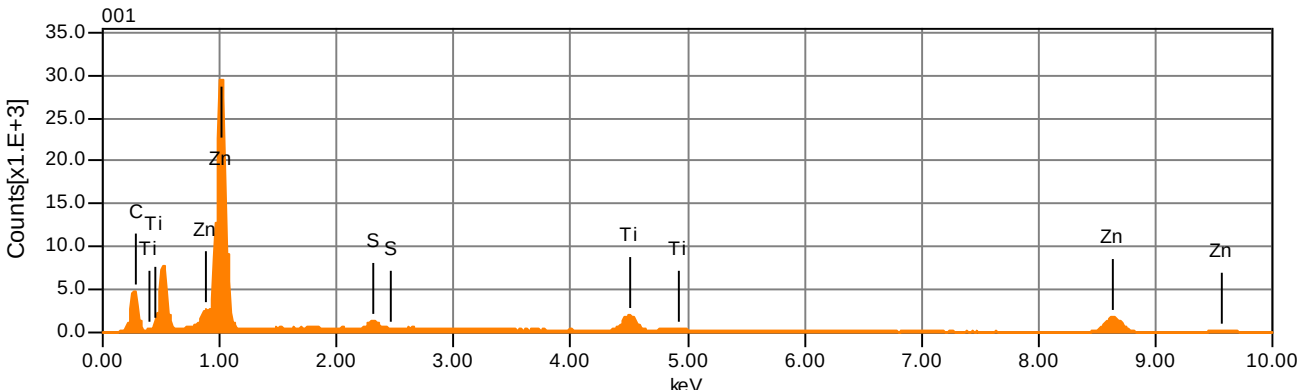


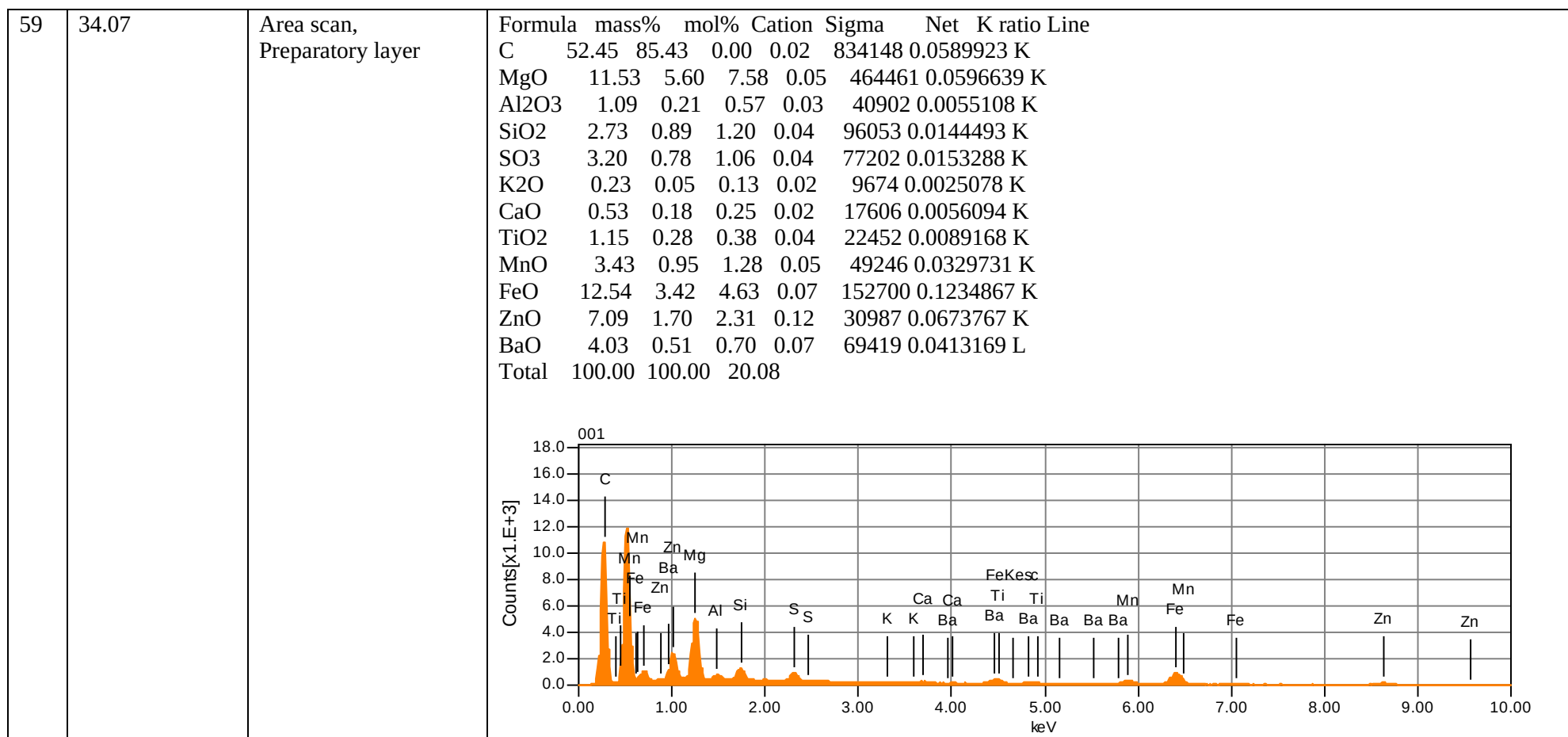


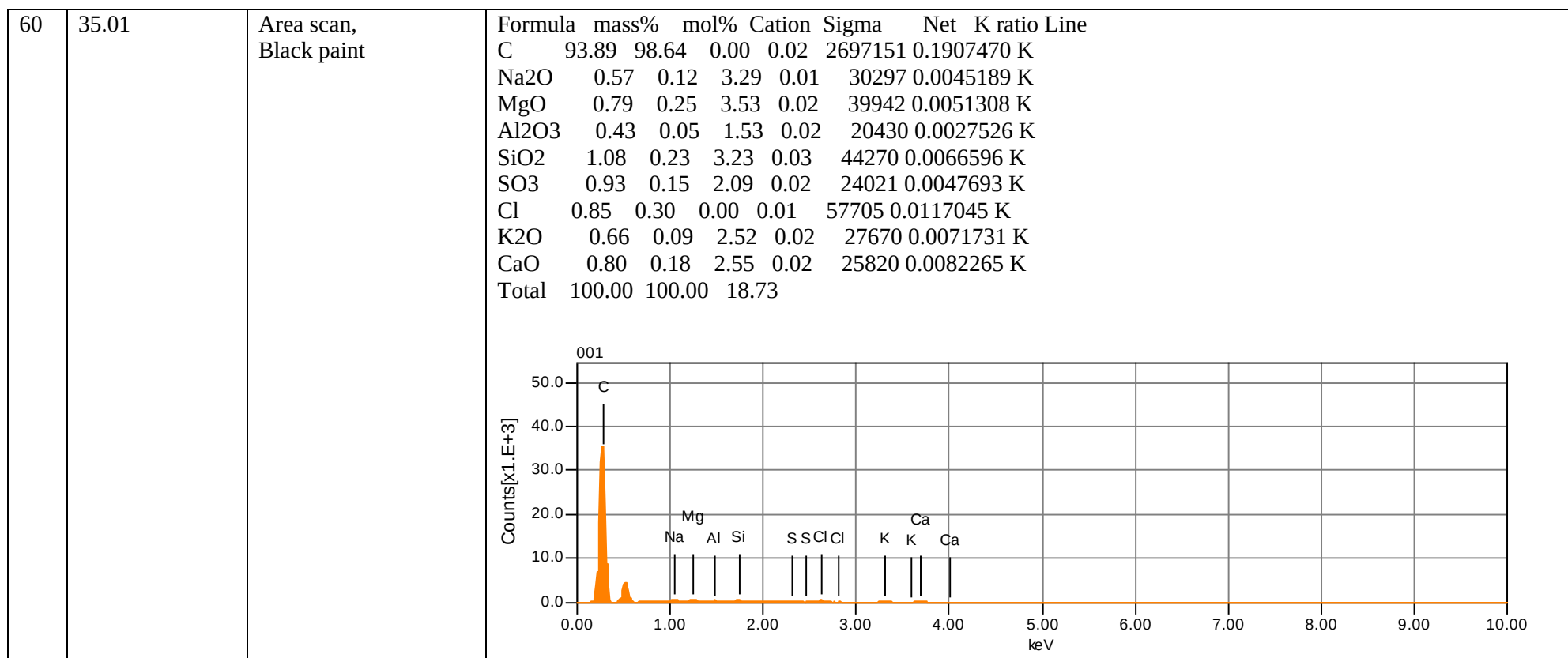




57	32.01	Area scan, Ground layer	Formula mass% mol% Cation Sigma Net K ratio Line C 25.01 69.32 0.00 0.02 430082 0.0304161 K ZnO 74.99 30.68 24.00 0.22 579269 1.2595214 K Total 100.00 100.00 24.00 001 Counts[x1.E+3] keV

58	34.07	Area scan, Ground layer	Formula mass% mol% Cation Sigma Net K ratio Line C 24.96 69.19 0.00 0.02 363665 0.0257190 K SO3 3.59 1.49 0.93 0.04 107832 0.0214105 K TiO2 11.12 4.63 2.89 0.05 290625 0.1154198 K ZnO 60.33 24.69 15.42 0.23 370039 0.8045849 K Total 100.00 100.00 19.24 

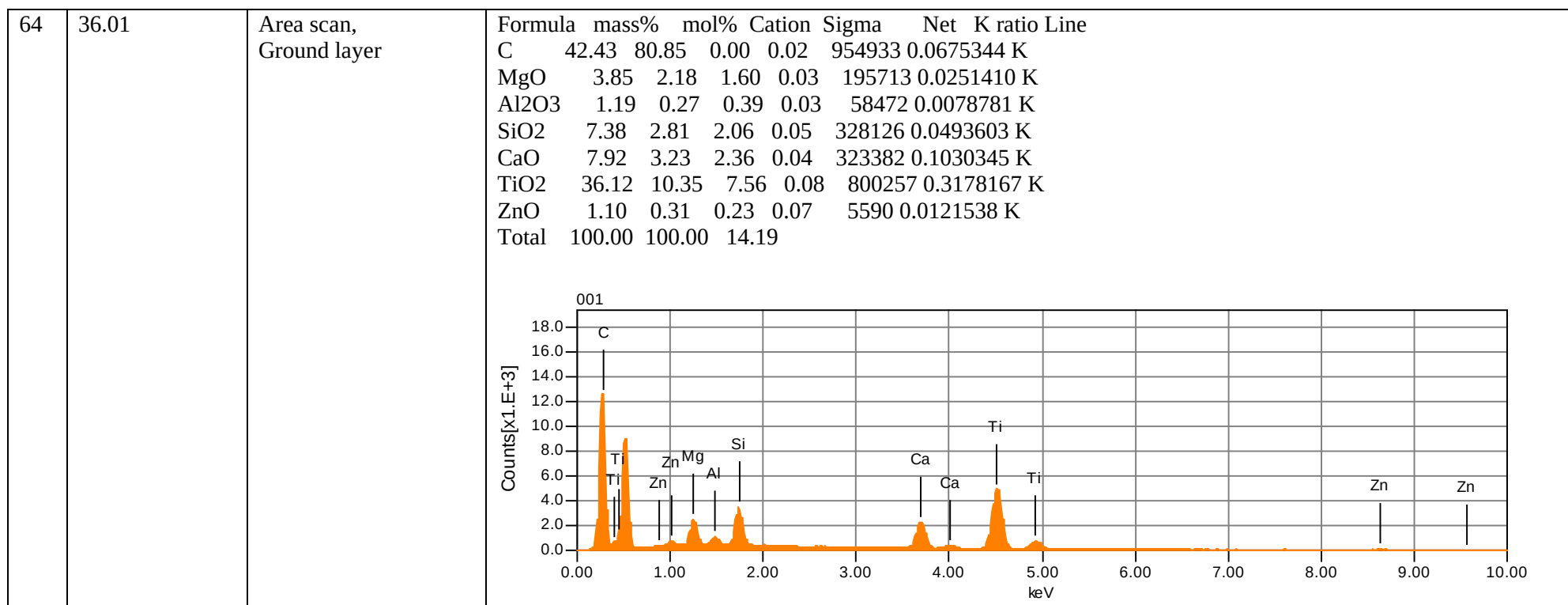


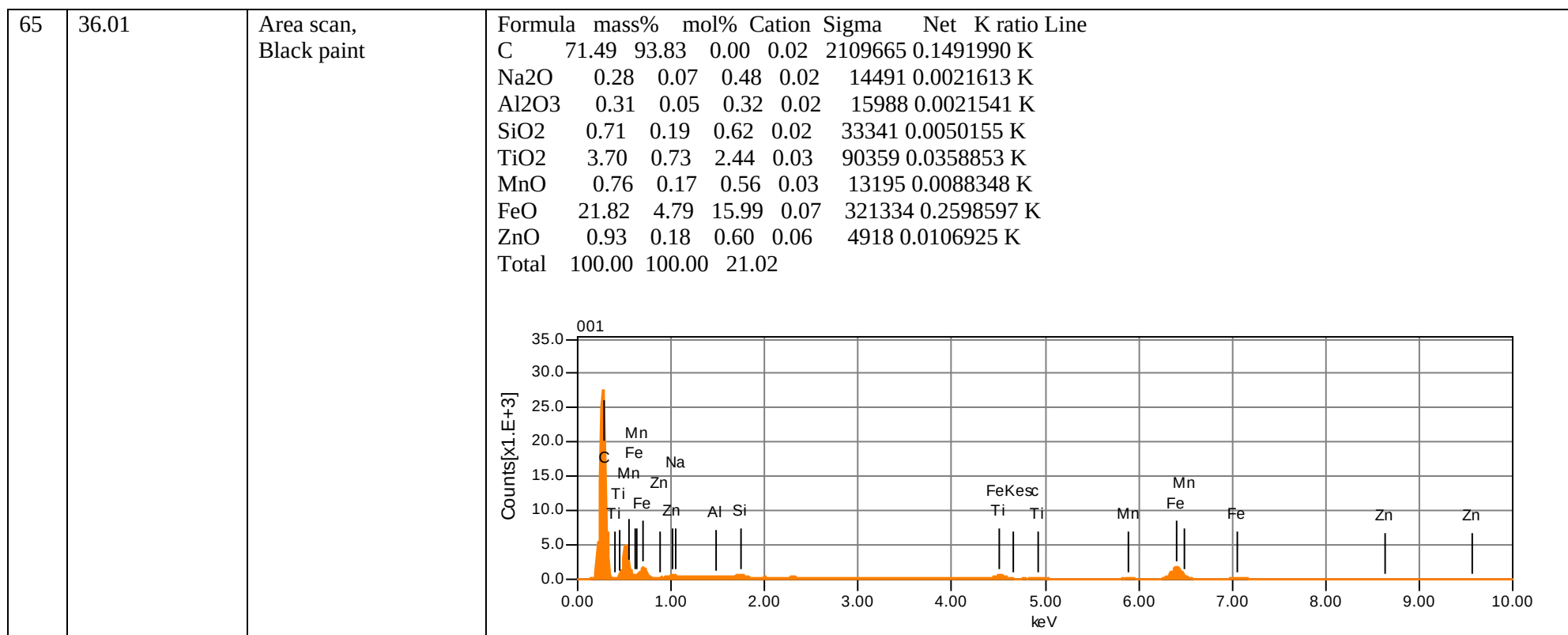


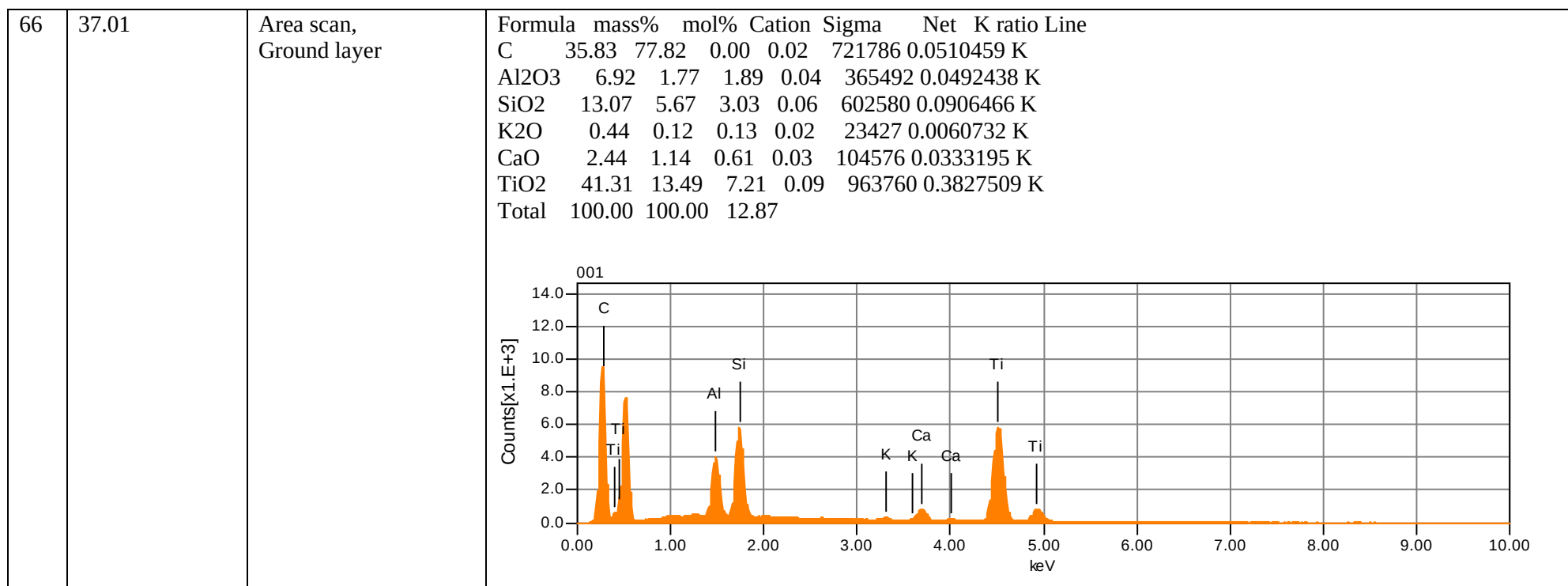
61	35.01	Aera scan, White paint	Formula mass% mol% Cation Sigma Net K ratio Line C 28.52 71.71 0.00 0.02 594020 0.0420101 K Na2O 0.16 0.08 0.07 0.02 7858 0.0011720 K Al2O3 6.53 1.93 1.67 0.04 332740 0.0448311 K SiO2 8.22 4.13 1.78 0.05 370057 0.0556679 K P2O5 0.53 0.11 0.10 0.02 18477 0.0036164 K SO3 0.43 0.16 0.07 0.02 12923 0.0025659 K K2O 0.84 0.27 0.23 0.02 45078 0.0116859 K CaO 5.56 2.99 1.29 0.04 236625 0.0753924 K TiO2 49.21 18.60 8.02 0.10 1134263 0.4504651 K Total 100.00 100.00 13.23
			001 Counts[x1.E+3] 0.00 1.00 2.00 3.00 4.00 5.00 6.00 7.00 8.00 9.00 10.00 keV

62	35.01	Area scan, Silver paint	Formula mass% mol% Cation Sigma Net K ratio Line C 52.17 90.25 0.00 0.02 948040 0.0670470 K Al2O3 47.83 9.75 16.00 0.07 3392168 0.4570368 K Total 100.00 100.00 16.00 EDS spectrum showing peaks for Carbon (C) and Aluminum (Al). The x-axis is energy in keV (0.00 to 10.00) and the y-axis is counts (0.0 to 30.0). A small peak for C is at ~0.28 keV and a large peak for Al is at ~1.55 keV.

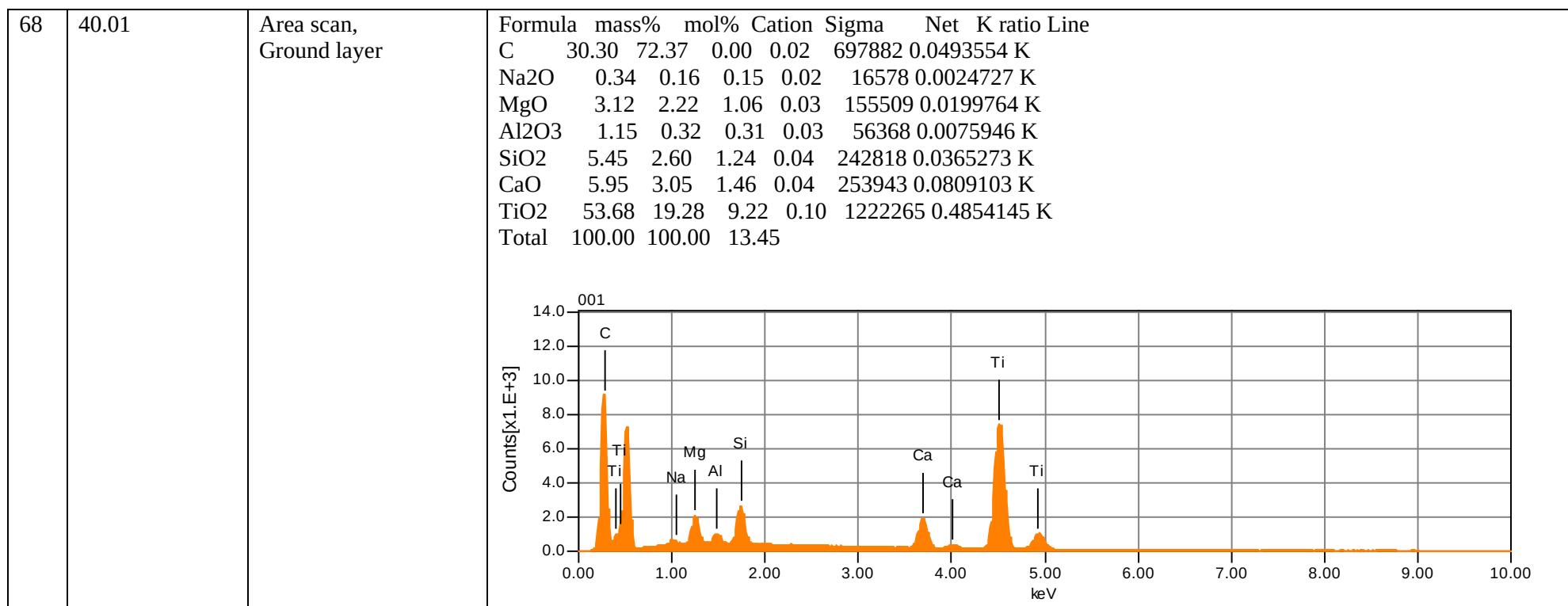
63	35.01	Point analysis, Lighter grey	Formula mass% mol% Cation Sigma Net K ratio Line C 72.42 93.72 0.00 0.04 593788 0.0419937 K Na2O 0.28 0.07 0.27 0.02 6005 0.0008957 K Al2O3 1.11 0.17 0.67 0.04 22464 0.0030267 K SiO2 0.93 0.24 0.47 0.04 16468 0.0024773 K SO3 13.78 2.68 5.26 0.08 155323 0.0308399 K K2O 0.49 0.08 0.32 0.03 9125 0.0023655 K CaO 10.99 3.05 5.99 0.08 156430 0.0498410 K Total 100.00 100.00 12.97 EDS spectrum showing peaks for Carbon (C), Sodium (Na), Aluminum (Al), Silicon (Si), Sulfur (S), Potassium (K), and Calcium (Ca). The x-axis is energy in keV (0.00 to 10.00) and the y-axis is counts (0.0 to 10.0). The C peak is the most prominent at approximately 0.28 keV.

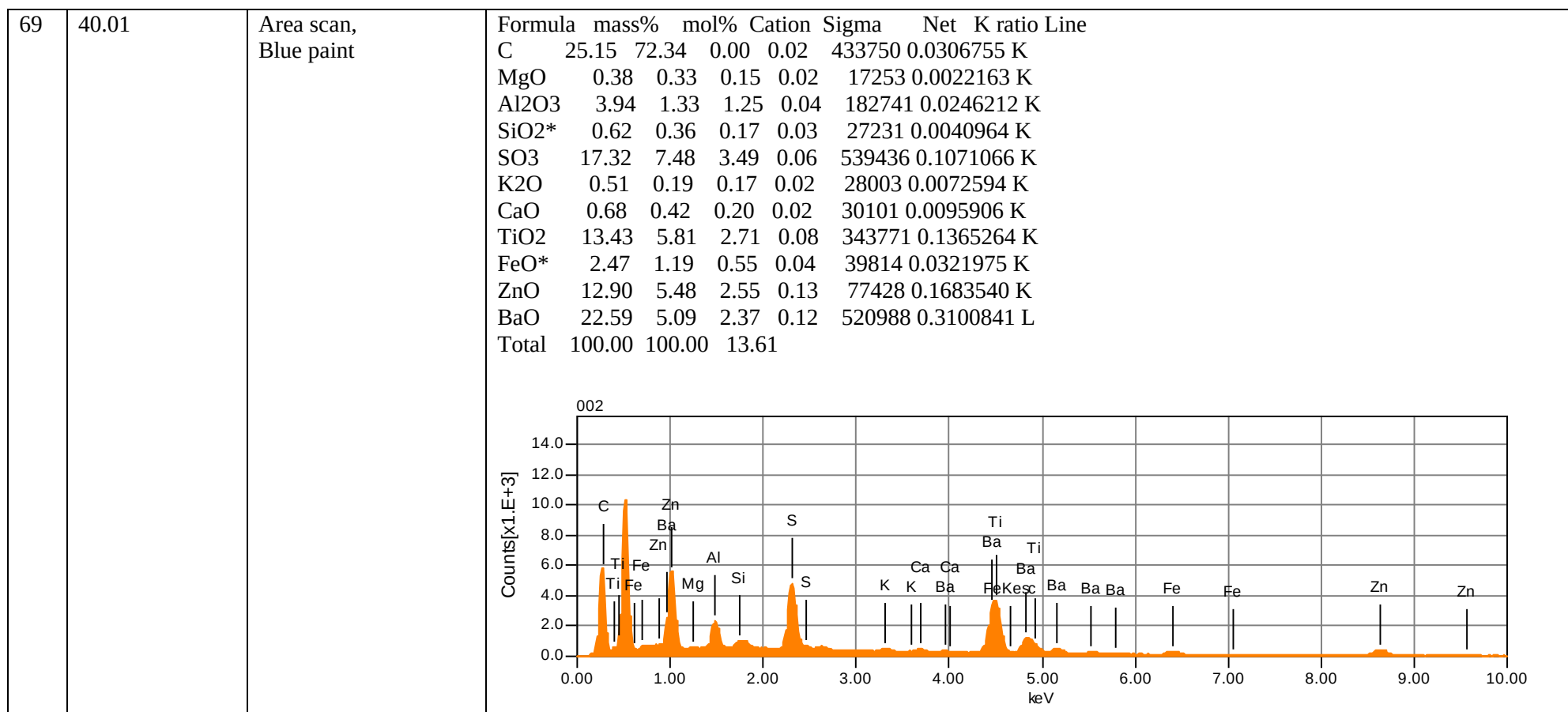




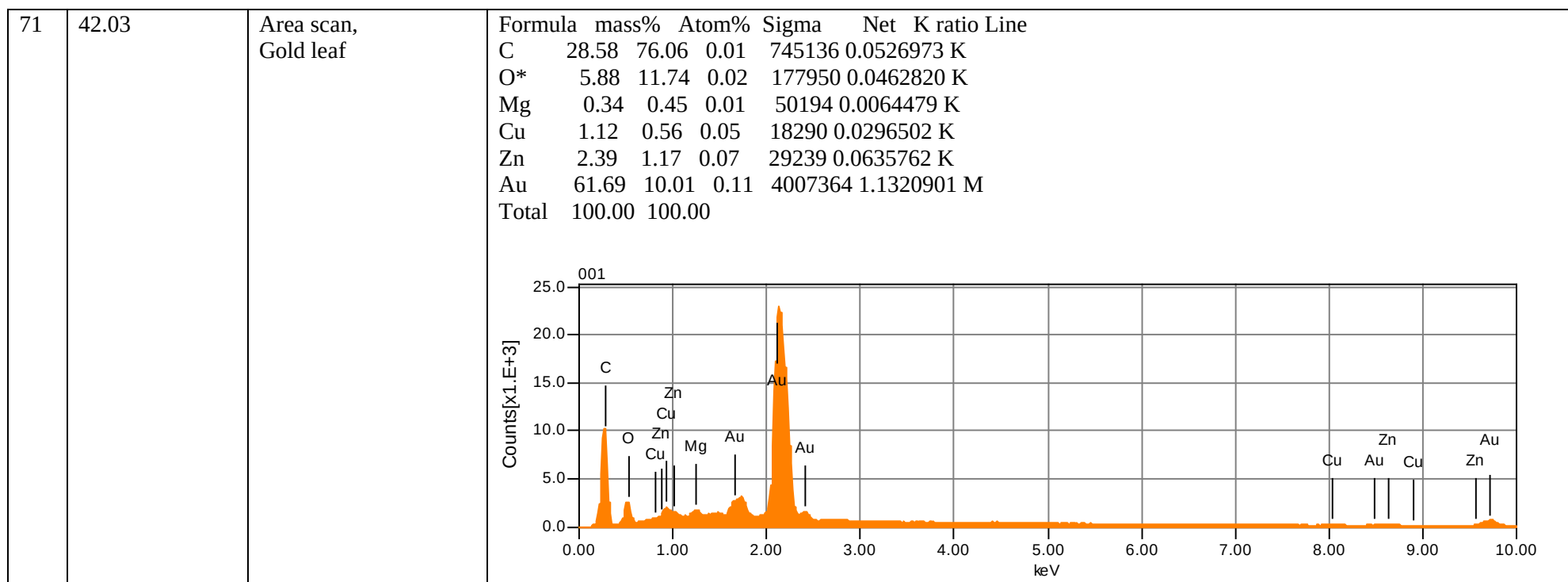


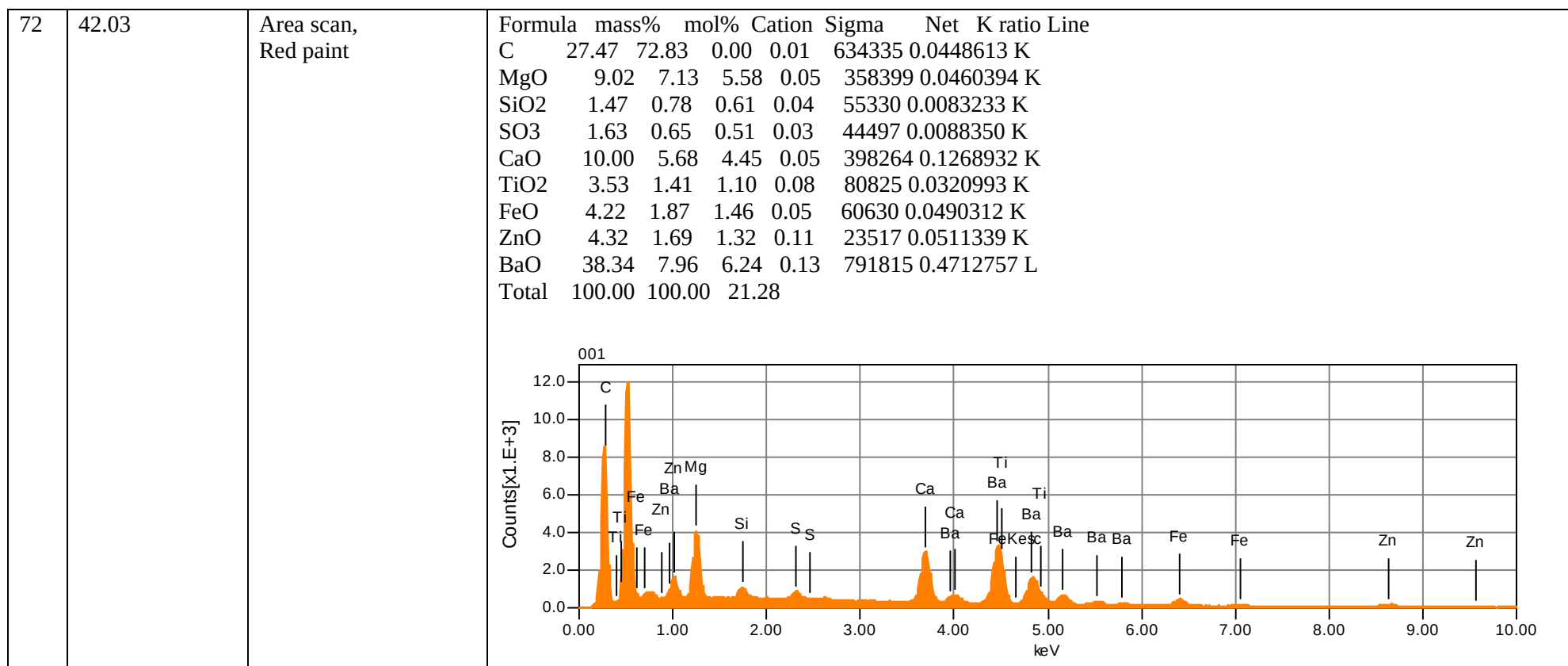
67	37.01	Area scan, Black paint	Formula mass% mol% Cation Sigma Net K ratio Line C 96.62 99.26 0.00 0.02 2976544 0.2104640 K CaO 3.38 0.74 24.00 0.03 95665 0.0304744 K Total 100.00 100.00 24.00 001 C Ca Ca Counts[x1.E+3] keV





70	42.03	Area scan, Ground layer	Formula mass% mol% Cation Sigma Net K ratio Line C 17.79 59.37 0.00 0.02 250339 0.0177044 K SO3 2.33 1.17 0.57 0.03 69461 0.0137917 K TiO2 11.67 5.86 2.88 0.05 308350 0.1224591 K ZnO 68.21 33.61 16.52 0.24 425370 0.9248931 K Total 100.00 100.00 19.97 EDS spectrum showing peaks for Ti, C, Zn, S, and Ti at various energy levels. The x-axis is energy in keV (0.00 to 10.00) and the y-axis is counts (0.0 to 50.0). The 001 peak of Zn is the most prominent at approximately 1.0 keV.



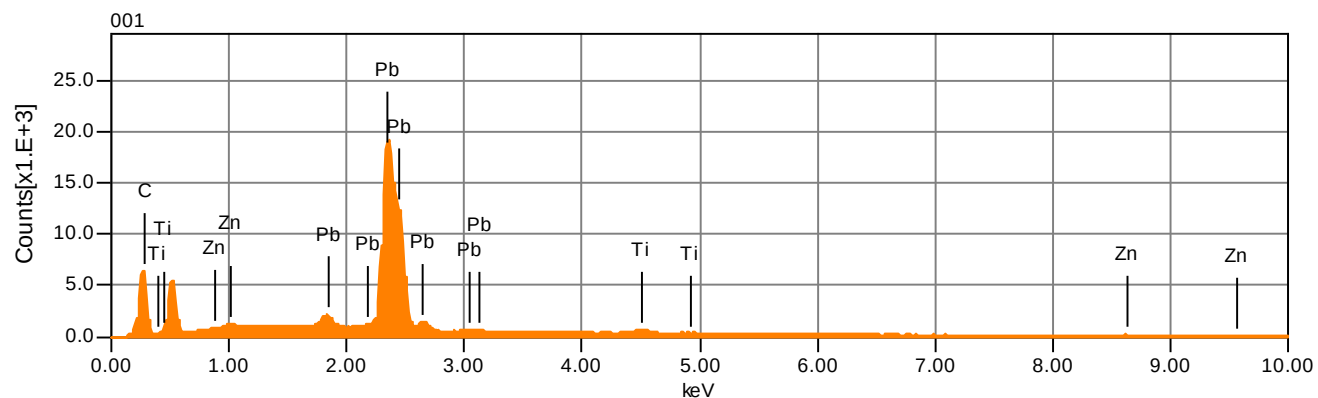


73	44.03	Area scan, White ground	Formula mass% mol% Cation Sigma Net K ratio Line C 47.33 85.39 0.00 0.02 1148219 0.0812040 K MgO 0.29 0.16 0.13 0.02 14413 0.0018515 K Al2O3 0.83 0.18 0.29 0.02 41213 0.0055528 K SiO2 0.37 0.13 0.11 0.03 16822 0.0025305 K SO3 4.67 1.26 1.05 0.04 140065 0.0278104 K CaO 2.50 0.96 0.80 0.03 104435 0.0332746 K TiO2 41.22 11.18 9.31 0.09 928763 0.3688519 K ZnO 2.79 0.74 0.62 0.08 14267 0.0310221 K Total 100.00 100.00 12.32 EDS spectrum showing peaks for C, Ti, Zn, Mg, Al, Si, S, Ca, and Ti. The y-axis is labeled 'Counts[×1.E+3]' and the x-axis is 'keV'. A '001' label is present at the top left of the plot area.

74	44.03	Area scan, Brown paint	Formula mass% mol% Cation Sigma Net K ratio Line C 47.84 85.07 0.00 0.02 1145723 0.0810274 K Al₂O₃ 1.05 0.22 0.38 0.02 52712 0.0071020 K SiO₂ 1.00 0.35 0.31 0.03 45306 0.0068154 K SO₃ 5.21 1.39 1.21 0.04 156680 0.0311093 K CaO 8.56 3.26 2.84 0.04 352070 0.1121750 K TiO₂ 33.91 9.06 7.89 0.08 757277 0.3007474 K ZnO 2.43 0.64 0.56 0.08 12471 0.0271156 K Total 100.00 100.00 13.19
			The figure is an EDS spectrum plot. The y-axis is labeled 'Counts[x1.E+3]' and ranges from 0.0 to 20.0. The x-axis is labeled 'keV' and ranges from 0.00 to 10.00. The spectrum shows several peaks: a large peak for Carbon (C) at approximately 0.27 keV, and smaller peaks for Titanium (Ti) at approximately 0.45 keV, Zinc (Zn) at approximately 0.86 keV, Aluminum (Al) at approximately 1.39 keV, Silicon (Si) at approximately 1.74 keV, Sulfur (S) at approximately 2.31 keV, Calcium (Ca) at approximately 3.69 keV, and another Titanium (Ti) peak at approximately 4.51 keV. There are also two small peaks labeled 'Zn' at approximately 8.64 keV and 9.57 keV. The label '001' is present in the top left corner of the plot area.

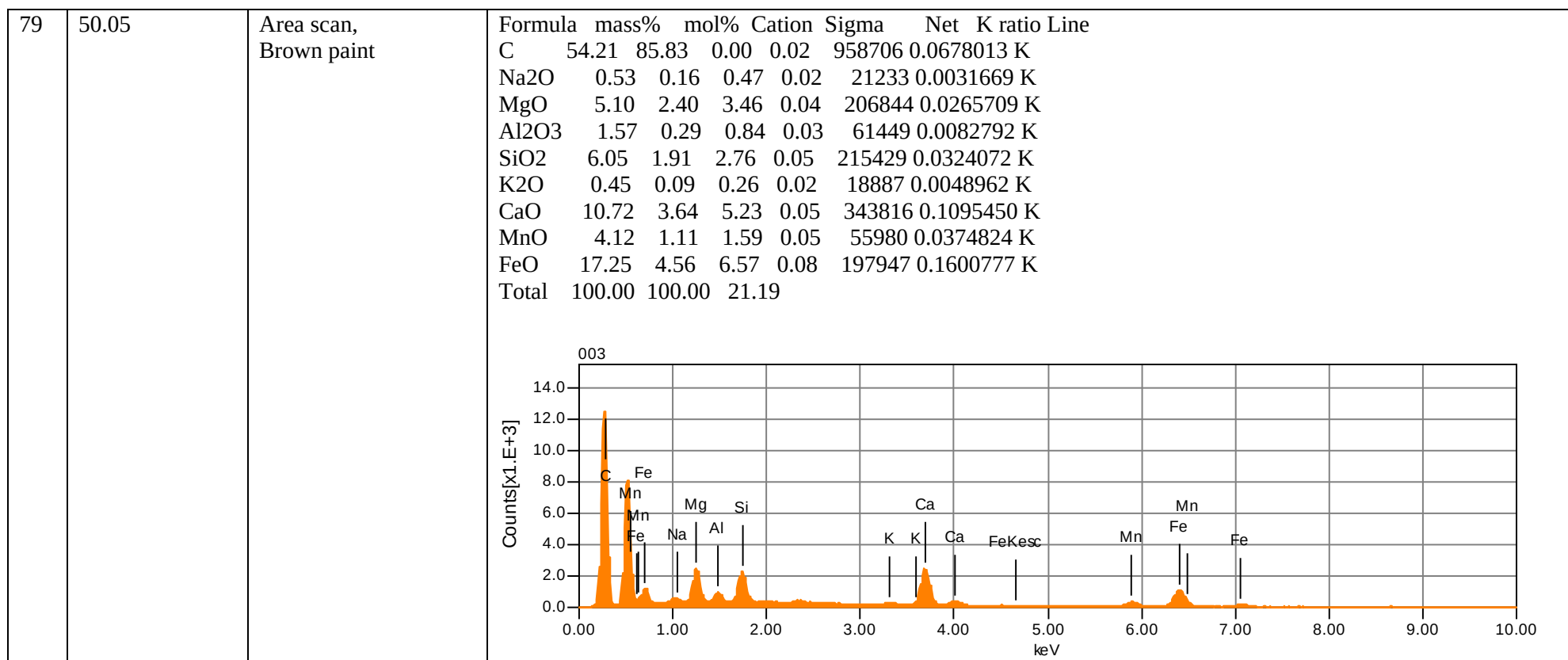
75	45.04	Area scan, Ground layer	Formula mass% mol% Cation Sigma Net K ratio Line C 11.11 69.30 0.00 0.01 360208 0.0254745 K TiO2 1.43 1.34 1.00 0.03 43604 0.0173172 K PbO 87.46 29.36 22.00 0.16 3780429 1.2274802 M Total 100.00 100.00 23.00 001 Counts[x1.E+3] keV

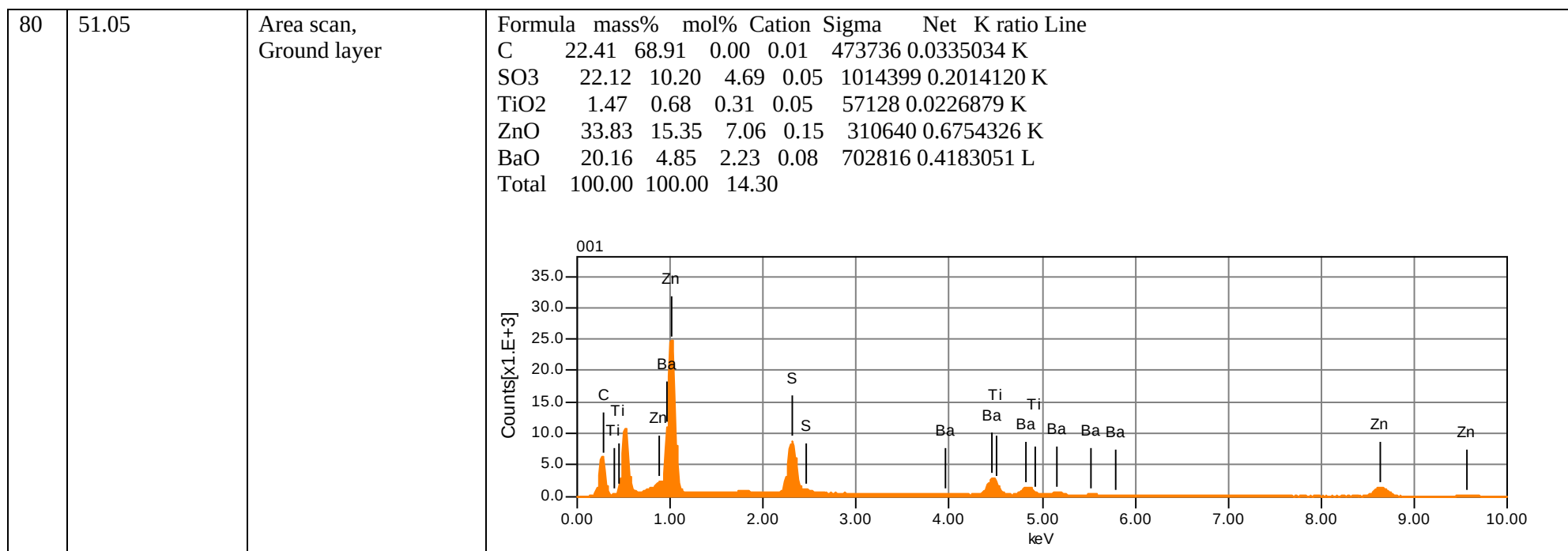
76	45.10	Area scan, Ground layer	Area scan white ground <table><thead><tr><th>Formula</th><th>mass%</th><th>mol%</th><th>Cation</th><th>Sigma</th><th>Net</th><th>K ratio</th><th>Line</th></tr></thead><tbody><tr><td>C</td><td>13.61</td><td>73.05</td><td>0.00</td><td>0.01</td><td>461835</td><td>0.0326617</td><td>K</td></tr><tr><td>TiO2</td><td>1.93</td><td>1.56</td><td>1.31</td><td>0.03</td><td>63084</td><td>0.0250535</td><td>K</td></tr><tr><td>ZnO</td><td>1.98</td><td>1.57</td><td>1.32</td><td>0.09</td><td>17944</td><td>0.0390167</td><td>K</td></tr><tr><td>PbO</td><td>82.48</td><td>23.82</td><td>20.05</td><td>0.15</td><td>3777170</td><td>1.2264221</td><td>M</td></tr><tr><td>Total</td><td>100.00</td><td>100.00</td><td>22.69</td><td></td><td></td><td></td><td></td></tr></tbody></table> 001 Counts[x1.E+3] keV	Formula	mass%	mol%	Cation	Sigma	Net	K ratio	Line	C	13.61	73.05	0.00	0.01	461835	0.0326617	K	TiO2	1.93	1.56	1.31	0.03	63084	0.0250535	K	ZnO	1.98	1.57	1.32	0.09	17944	0.0390167	K	PbO	82.48	23.82	20.05	0.15	3777170	1.2264221	M	Total	100.00	100.00	22.69				
Formula	mass%	mol%	Cation	Sigma	Net	K ratio	Line																																												
C	13.61	73.05	0.00	0.01	461835	0.0326617	K																																												
TiO2	1.93	1.56	1.31	0.03	63084	0.0250535	K																																												
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Total	100.00	100.00	22.69																																																



77	45.10	Area scan, Blue paint	Formula mass% mol% Cation Sigma Net K ratio Line C 42.51 84.05 0.00 0.02 789626 0.0558437 K Al2O3 6.03 1.40 2.39 0.04 326025 0.0439263 K P2O5 0.99 0.17 0.28 0.02 40250 0.0078780 K SO3 14.32 4.25 3.62 0.05 494427 0.0981699 K CaO 6.39 2.71 2.31 0.04 303812 0.0967992 K TiO2 0.79 0.23 0.20 0.04 21602 0.0085790 K CoO 2.71 0.86 0.73 0.04 38905 0.0388385 K ZnO 16.55 4.83 4.12 0.13 105879 0.2302150 K BaO 9.71 1.50 1.28 0.07 239284 0.1424183 L Total 100.00 100.00 14.94 EDS spectrum showing peaks for various elements. The x-axis represents energy in keV (0.00 to 10.00) and the y-axis represents counts (0.0 to 12.0). The spectrum shows several peaks, with the most prominent ones labeled as C, Ti, Co, Zn, Al, P, S, Ca, Ba, and Zn. The peak at 0.00 keV is labeled '001'.

78	50.05	Area scan, Ground layer	Formula mass% mol% Cation Sigma Net K ratio Line C 41.45 87.58 0.00 0.02 855056 0.0604710 K MgO 2.39 1.50 2.68 0.03 114523 0.0147115 K Al2O3 0.97 0.24 0.86 0.03 46019 0.0062003 K SiO2 1.36 0.58 1.03 0.03 59573 0.0089617 K CaO 3.11 1.41 2.51 0.03 116843 0.0372281 K ZnO 14.33 4.47 7.96 0.14 81092 0.1763196 K BaO 1.65 0.27 0.49 0.05 33457 0.0199130 L PbO 34.75 3.95 7.04 0.13 1037820 0.3369732 M Total 100.00 100.00 22.54 EDS spectrum showing peaks for Carbon (C), Zinc (Zn), Lead (Pb), Barium (Ba), Magnesium (Mg), Aluminum (Al), Silicon (Si), Calcium (Ca), and other elements. The x-axis is energy in keV (0.00 to 10.00) and the y-axis is counts (0.0 to 16.0). The spectrum shows a large peak for Carbon at approximately 0.28 keV, and several smaller peaks for other elements at higher energies.

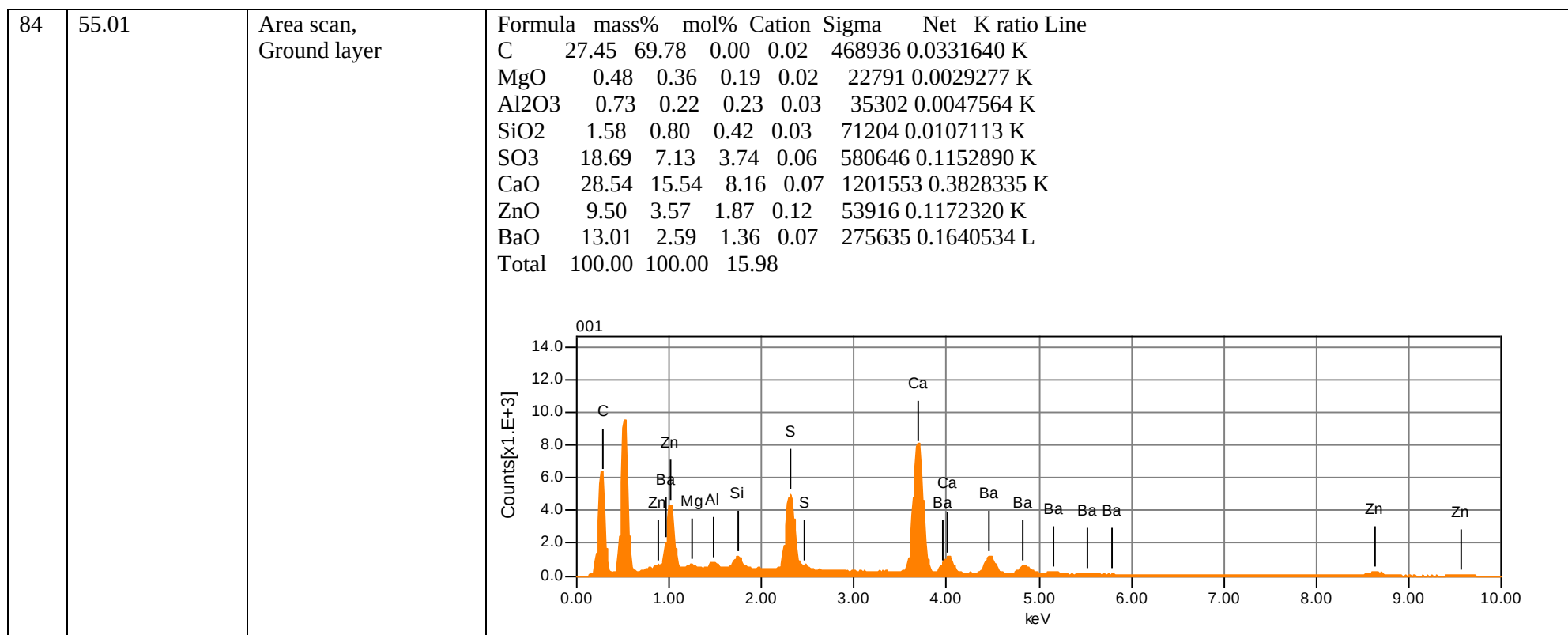


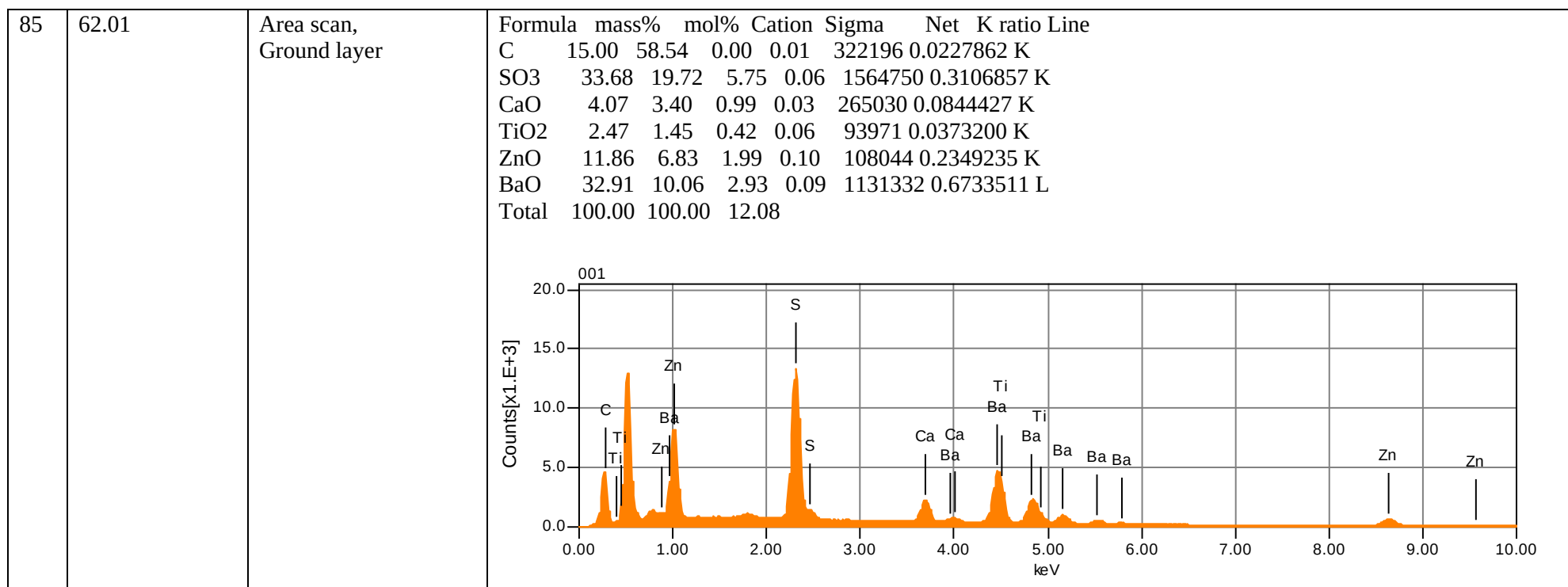


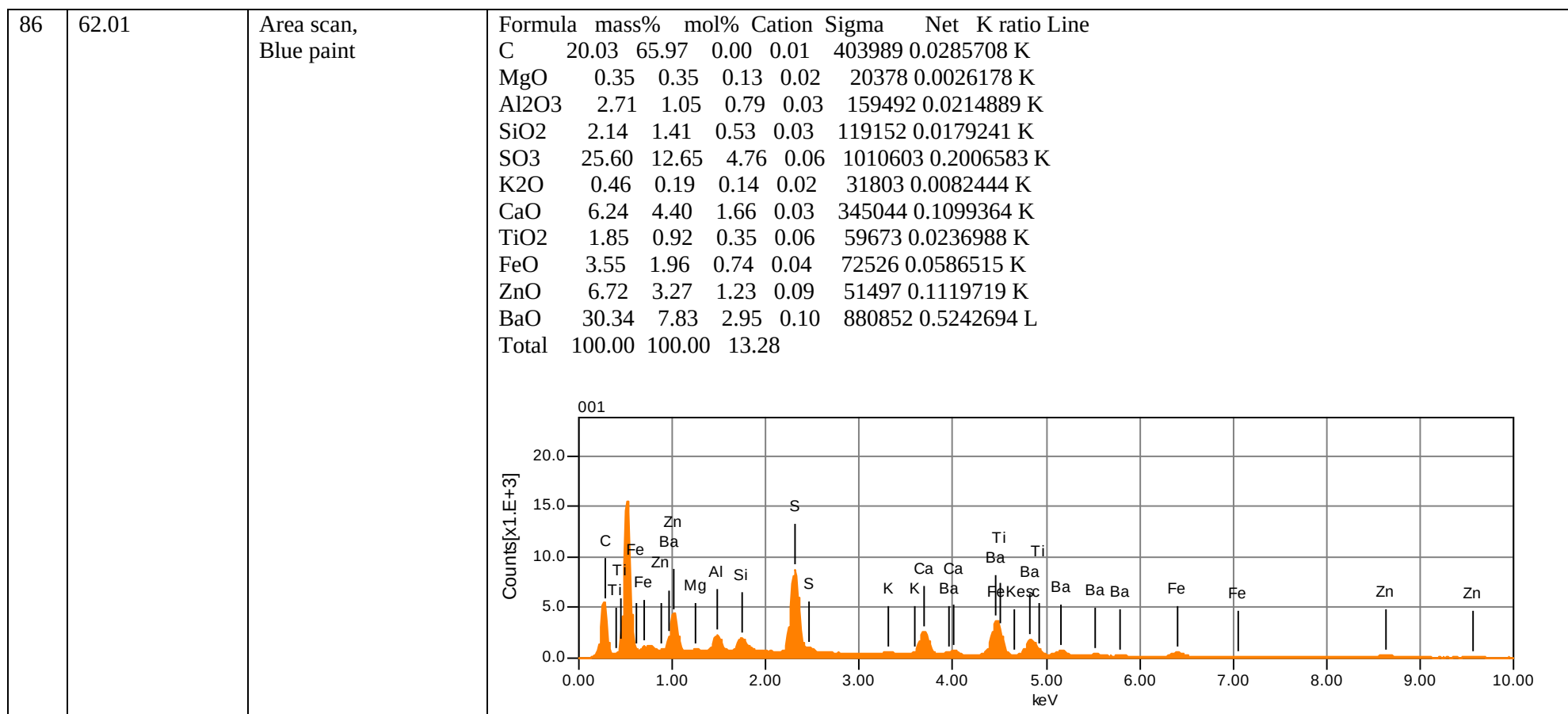
81	51.05	Area scan, Red paint	Formula mass% mol% Cation Sigma Net K ratio Line C 34.64 79.82 0.00 0.02 644635 0.0455897 K Al₂O₃ 1.46 0.40 0.75 0.03 72859 0.0098165 K SiO₂ 1.14 0.53 0.50 0.03 54997 0.0082732 K SO₃ 5.46 1.89 1.79 0.04 190075 0.0377399 K ZnO 43.88 14.93 14.17 0.19 302853 0.6585007 K CdO 8.55 1.84 1.75 0.05 364454 0.1157148 L CdS PbO 4.87 0.60 0.57 0.09 172253 0.0559293 M Total 100.00 100.00 19.54
			EDS spectrum showing peaks for C, Zn, Cd, Pb, Al, Si, S, and O. The x-axis is energy in keV (0.00 to 10.00) and the y-axis is counts (0.0 to 14.0). The 001 peak of ZnO is the most prominent.

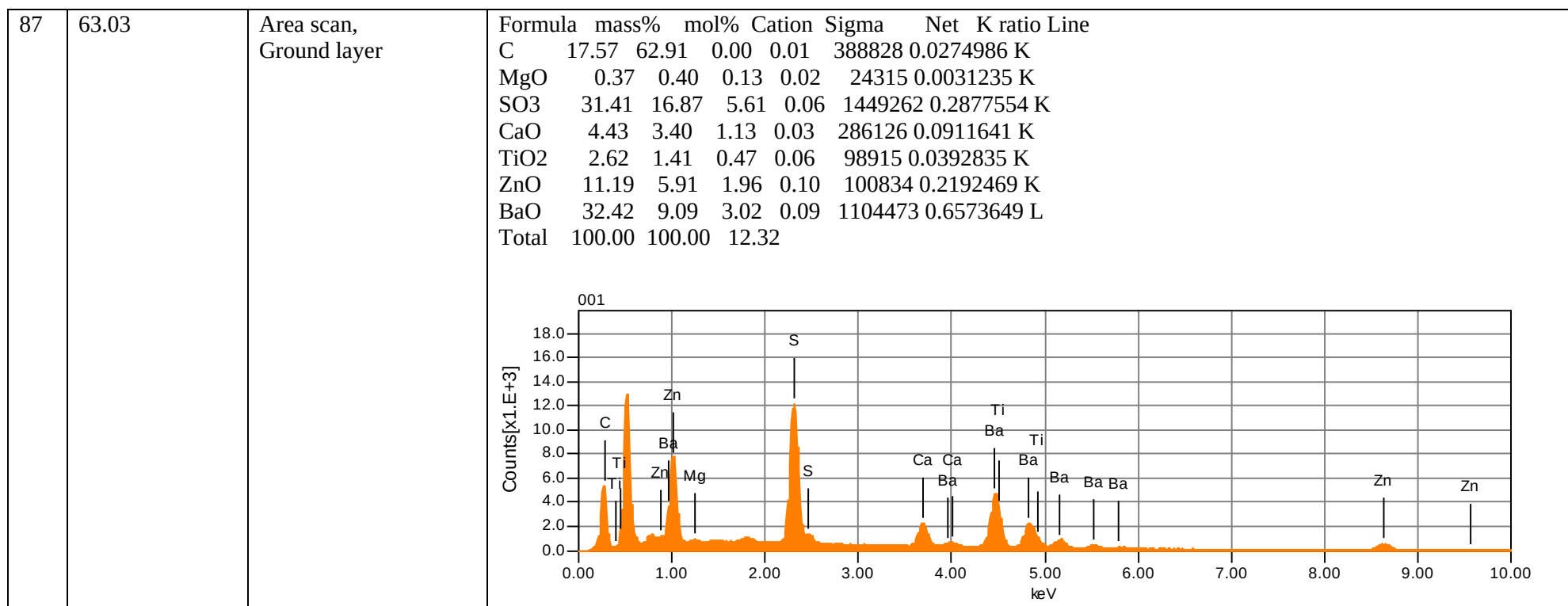
82	54.04	Area scan, Blue paint	Formula mass% mol% Cation Sigma Net K ratio Line C 26.76 75.39 0.00 0.02 459980 0.0325240 K CaO 13.72 8.28 8.07 0.06 480021 0.1529117 K ZnO 27.66 11.50 11.22 0.19 145815 0.3169872 K PbO 31.87 4.83 4.71 0.13 859136 0.2788999 M Total 100.00 100.00 24.00

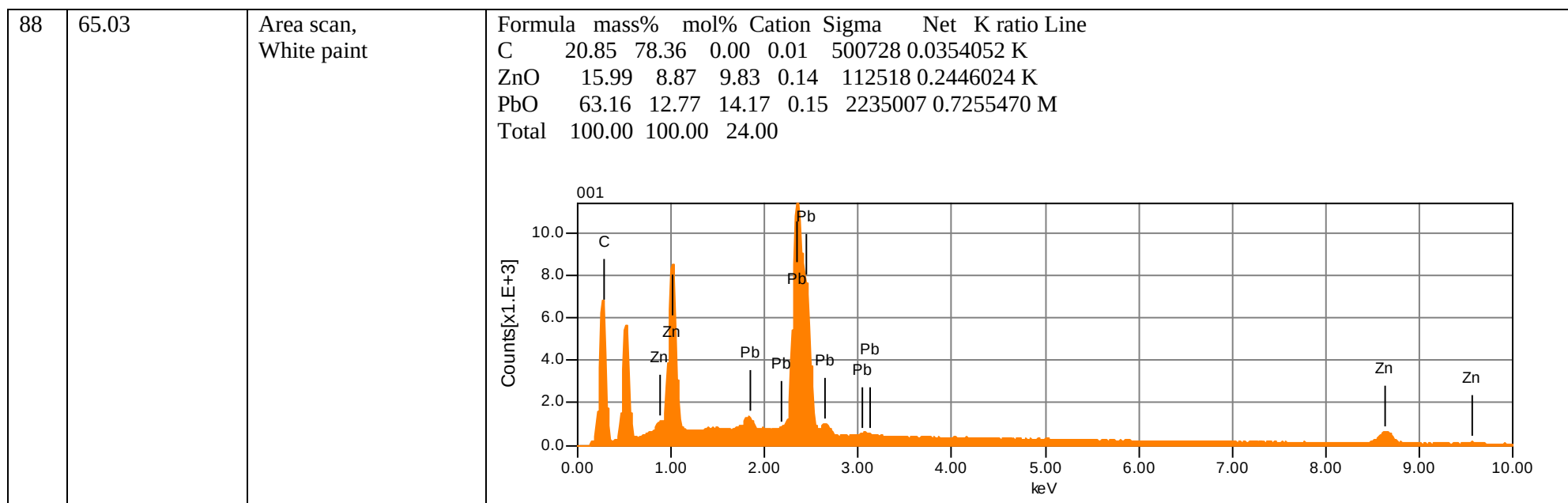
83	54.04	Point analysis, Blue particle	Formula mass% mol% Cation Sigma Net K ratio Line ZnO 5.79 14.43 3.46 0.11 47757 0.1038390 K PbO 94.21 85.57 20.54 0.17 3814674 1.2385995 M Total 100.00 100.00 24.00
			001



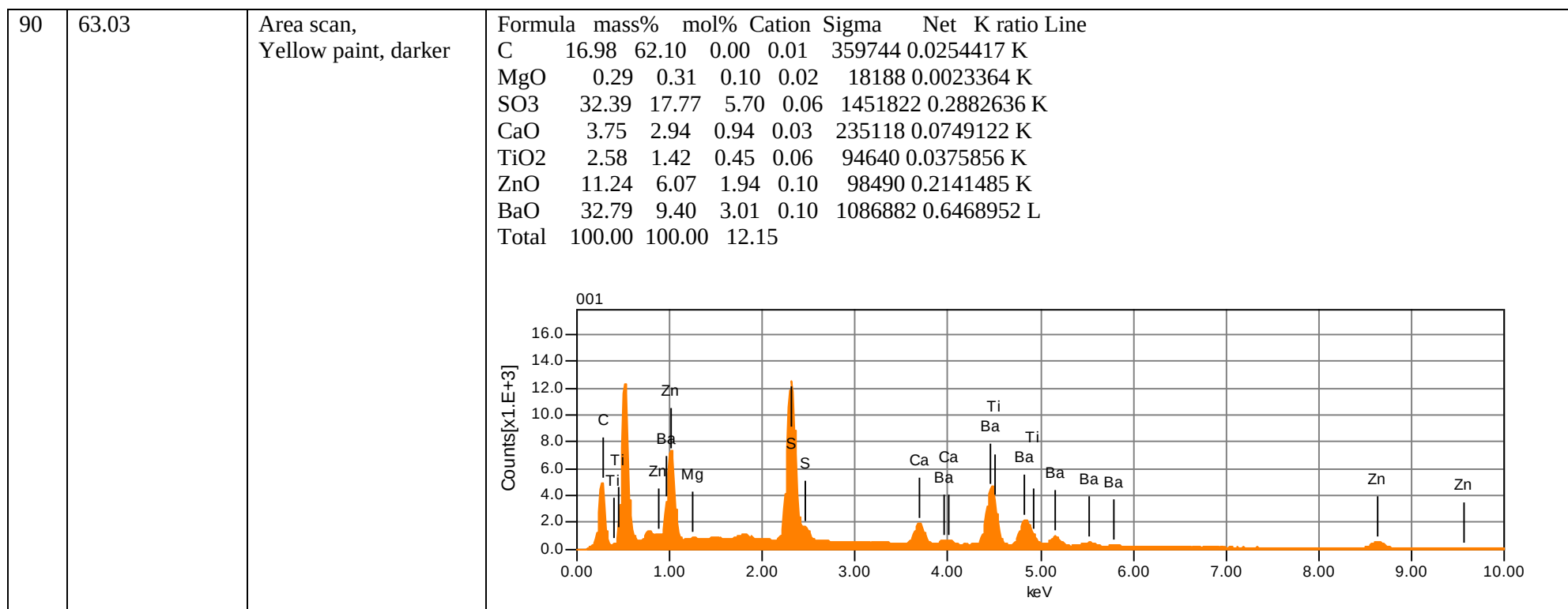


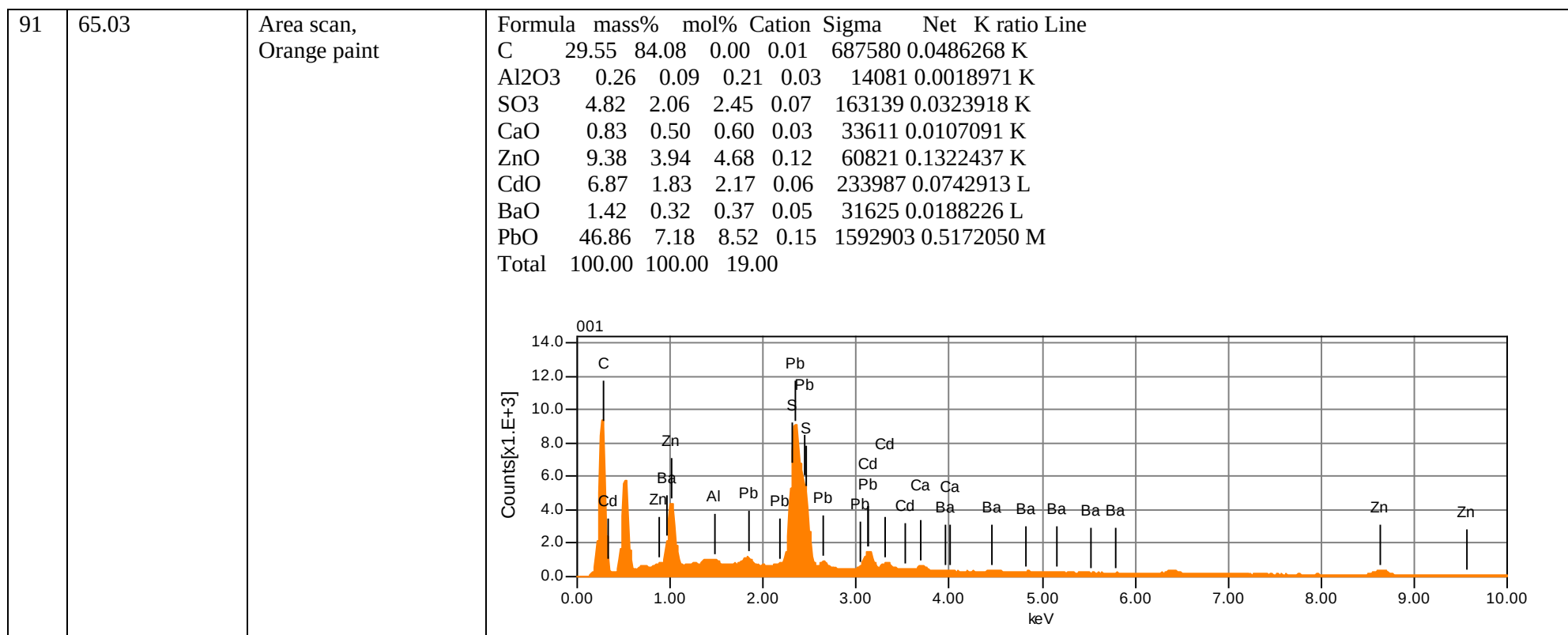


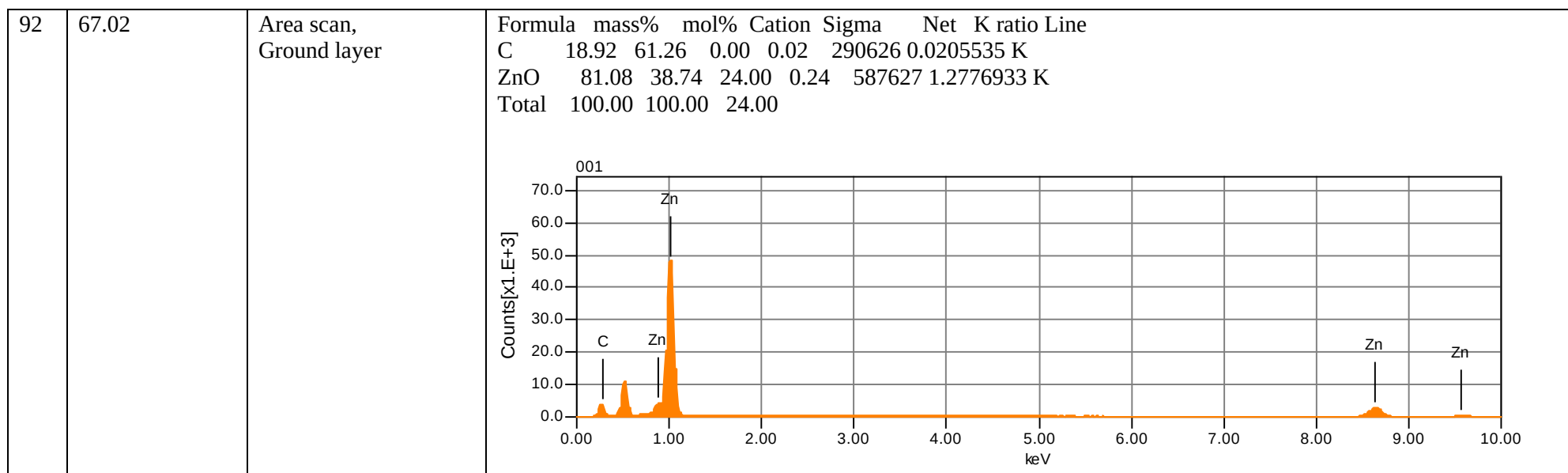




89	65.03	Area scan, Yellow paint, light	Formula mass% mol% Cation Sigma Net K ratio Line C 12.27 64.58 0.00 0.01 303074 0.0214339 K SO3 13.40 10.59 4.08 0.08 548754 0.1089567 K CaO 0.39 0.43 0.17 0.02 18804 0.0059914 K TiO2 0.46 0.36 0.14 0.04 13805 0.0054825 K Cr2O3 6.35 2.64 2.04 0.05 164866 0.0908182 K ZnO 2.77 2.15 0.83 0.09 22108 0.0480705 K BaO 7.81 3.22 1.24 0.07 212672 0.1265792 L PbO 56.56 16.02 6.18 0.16 2312292 0.7507858 M Total 100.00 100.00 14.68







Endnotes

ⁱ Record prices for both artists have been realised in recent times, with Cheong Soo Pieng's *Balinese Dance* (1953) auctioned for 995,000 USD in 2015 and Georgette Chen's *Still Life* (Mid-Autumn Festival) (1960s) auctioned for 1,296,085 USD in 2021.