

C. A. Bland et al.
NAA of northern Chilean ceramics and clay samples

Archaeometry ●●, ●● (2016), ●●-●●. Printed in Great Britain

**1500 YEARS OF POTTERY: NEUTRON ACTIVATION ANALYSIS OF
NORTHERN CHILEAN DOMESTIC CERAMICS FROM CALETA VITOR
AND CLAY SAMPLES FROM NEARBY VALLEY, COAST AND HIGHLAND
CONTEXTS***

C. A. BLAND† and A. ROBERTS

Archaeology Department, Flinders University, Adelaide, South Australia, Australia

R. S. POPELKA-FILCOFF

*School of Chemical and Physical Sciences, Flinders University, Adelaide, South Australia,
Australia*

C. M. SANTORO

Instituto de Alta Investigación, Universidad de Tarapacá, Arica, Chile

C. CARTER

*School of Archaeology and Anthropology, Australian National University, Canberra, ACT,
Australia*

J. W. BENNETT and A. STOPIC

*Australian Nuclear Science and Technology Organisation (ANSTO), Lucas Heights, New
South Wales, Australia*

This paper presents the findings arising from neutron activation analysis (NAA) of northern Chilean domestic ceramic samples from Caleta Vitor (n = 38) and clay samples (n = 15) from nearby valley, coast and highland contexts. This study presents the first NAA data set of ceramics spanning a temporal period of 1500 years (c.2000 to c.476 BP) from the Vitor Valley as well as the first attempt to use NAA to characterize potential clay sources in the region. On the basis of this study, we argue that the majority of domestic ceramics from Caleta Vitor share compositional similarities with clay samples collected from nearby valleys, allowing us to infer that the Caleta Vitor populations primarily procured their clay for domestic ceramics from local sources throughout a 1500-year period. Thus, despite the fact that there were inter-regional interactions during this period that included the influence of powerful Andean polities, it would appear that domestic ceramics continued to be produced locally, and by implication it can be argued that such interactions did not substantially affect this sphere of material culture. Further, the apparent

This is the author manuscript accepted for publication and has undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process, which may lead to differences between this version and the Version of Record. Please cite this article as doi: [10.1111/arcm.12277](https://doi.org/10.1111/arcm.12277)

continuities in domestic ceramic production allow us to reflect on local decision-making processes throughout the cultural phases considered in this research.

KEYWORDS: SOUTH-CENTRAL ANDES, NORTHERN CHILE, NEUTRON ACTIVATION ANALYSIS, DOMESTIC CERAMICS, CLAY PROCUREMENT

*Received 28 February 2016; accepted 1 July 2016

†Corresponding author: email catherine.bland@flinders.edu.au

© University of Oxford, 2016

INTRODUCTION

The primary aim of this research was to analyse domestic ceramics from the Caleta Vitor Archaeological Complex using neutron activation analysis (NAA) in order to assess whether the origin of everyday cooking and storage vessels in this region of northern Chile remained locally produced (i.e., within the Vitor and nearby valleys) or whether they were items of exchange, such as occurred for decorated prestigious vessels and textiles (Bray *et al.* 2005; Barbra *et al.* 2015; Williams *et al.* submitted). Thus, this study sought to further understand the decisions made by local people in the Caleta Vitor region regarding the production of their domestic pottery over time. To investigate this aim, it was first necessary to establish whether or not distinct compositional groups could be determined for the ceramic data set. Further clay sources from nearby valleys, a coastal site and a highland area were sampled and analysed to provide comparative baseline data.

REGIONAL BACKGROUND AND RELEVANT PRIOR RESEARCH

The Caleta Vitor Archaeological Complex

The Caleta Vitor Archaeological Complex is located 30 km south of Arica, within the Atacama Desert (see [Figs 1](#) (a) and 1 (b)). The Atacama region of northern Chile and southern Peru is one of the world's driest areas, with extremely harsh geo-ecological conditions and marginal resources (Grosjean *et al.* 2007; Jordan *et al.* 2014). Most of the Atacama region receives less than 1 mm of rain per annum (DGA 2007) and has minimal vegetation (Marquet *et al.* 1998, 2002; Ramirez de Bryson *et al.* 2001; Latorre *et al.* 2005; Petruzzelli 2012; Roberts *et al.* 2013). By exploiting marine resources along the coast and localized sources of fresh water (from Andean summer

rainfall), people were able to survive on the margins of this harsh landscape (Santoro *et al.* 2005; Roberts *et al.* 2013; Pestle *et al.* 2015; Standen *et al.* 2016).

The Caleta Vitor Archaeological Complex is located at the mouth of the Vitor Valley (Bird 1943; Mujica *et al.* 1983; Roberts *et al.* 2013; Swift *et al.* 2015). The Vitor Valley is a steep-sided ravine that cuts into the flat desert above to a depth of 400 m (Roberts *et al.* 2013). Caleta Vitor consists of a broad sandy beach bordered to the north and south by cliffs reaching 800 m above sea level (Roberts *et al.* 2013; Latorre *et al.* 2015). The complex spans a large chronological sequence, from *c.*8000 BP to the Hispanic Period (from 476 BP) (Roberts *et al.* 2013; Latorre *et al.* 2015; Swift *et al.* 2015). The archaeology of the area includes ‘occupation sites, middens, mounds, human remains (including burials and mummy bundles) and various materials such as lithics, ceramics, textiles, fauna/flora remains, and woven matting’ (Roberts *et al.* 2013, 2361).

The ceramics, which are the subject of this paper, were excavated between 2008 and 2010 by Chris Carter and a team of volunteers, and have subsequently been made available to the authors for investigation. The archaeological complex of Caleta Vitor includes seven sites/zones of which only three contained ceramics (CV2, CV4 and CV6) (Fig. 1 (b)). However, ceramics from CV2 were few in number and as such this research has focused on the assemblages from CV4 and CV6.

CV4 covers a broad area to the east of the beach (Fig. 1 (b)). Two trenches were excavated at CV4 (CV4/1 and CV4/6) and ceramic material was excavated from both (Carter in progress). CV4/1 was excavated through a dense midden with 19 stratigraphic units identified and ceramics were collected from all layers (Carter in progress). CV4/1 dates entirely to the Late Period (660–476 BP) (Carter in progress). CV4/6 contained no distinct stratigraphic layers, so 100 mm spits were employed (Carter in progress). A total of 10 spits were excavated, all of which contained ceramic material. CV4/6 has been radiocarbon-dated from the Formative (4000 BP) through to the Late Periods ([Table 1](#)) (Carter in progress).

A total of three trenches were excavated for CV6 (CV6/1, CV6/2 and CV6/3) (Fig. 1 (b)) (Carter in progress). Ceramics were collected from all trenches; however, this study has focused on analysing ceramics from CV6/1, as this trench provided the richest assemblage. CV6/1 was excavated to a depth of 1.2 m with 16 stratigraphic

units identified, with ceramics being found in all layers (Carter in progress). CV6/1 spans the Late to the Hispanic Periods (Table 1) (Carter in progress).

The ceramics excavated from CV4 and CV6 were primarily undecorated ceramics, probably used in domestic contexts (e.g., cooking and storage). Based on general paste characteristics (e.g., paste colour) of the sherds analysed, they were probably fired in an open firing system (e.g., a bonfire) (see Chatfield 2010). The sherds analysed in this study were primarily undiagnostic body fragments (Fig. 2); thus any definite assignation of vessel shape/size was unable to be determined.

CERAMICS AND CULTURAL CHRONOLOGY

While the samples analysed in this project are undecorated and probably used in domestic contexts, below we provide an outline of relevant ceramic styles and their relationship to sociocultural and political changes in order to contextualize later discussions in this paper.

During the Archaic Period (10 000–4000 BP), the system of subsistence for prehistoric peoples in the Caleta Vitor region was primarily based on marine hunting and gathering, complemented by the exploitation of inland resources (Núñez and Santoro 2011; Roberts *et al.* 2013; Olgúin *et al.* 2014; Salazar *et al.* 2015; Castro *et al.* 2016). At the end of the Archaic Period, irrigated agriculture in the oases and valleys of northern Chile began to emerge. However, during the Formative Period (4000–1500 BP), the influence of agriculture on diet may be locally varied, as was the case for Caleta Vitor, where a primary retention of coastal hunting and gathering appears to have been retained for much longer than other northern Chilean contexts (see Roberts *et al.* 2013; Garcia *et al.* 2014; Pestle *et al.* 2015). Other introduced items during the Formative Period include textiles, pottery and metal objects. The introduction of the latter-mentioned items reflects the existence of a complex network of inter-regional interactions at local and regional scales, including exchanges with the Lake Titicaca Basin, the central coast of Peru and the eastern side of the Andes (Rivera 1991, 2008; Rothhammer *et al.* 2009; Aguero and Uribe 2011; Uribe and Vidal 2012). Ceramics from the Formative/Neolithic Period are predominantly undecorated and very coarse, with smoothed surfaces, and are irregular in thickness (Rivera *et al.* 1974; Santoro 1981; Santos 2003).

The Middle Period (c.1500–1000 BP) has traditionally been associated with the spread of the Tiwanaku polities throughout much of the central Andes, and this time period has thus been thought to represent the first political integration of the northern Chilean area (although the nature of this integration has been debated—e.g., direct influences versus dynamic processes of interaction [see Torres-Rouff and Hubbe 2013; Korpisaari *et al.* 2014; Goldstein 2015]). The Cabuza ceramic style is generally associated with this time period and has been interpreted to reflect a local manifestation of the Tiwanaku style (Rivera 1991; Uribe 1999; Augustyniak 2004; Torres-Rouff and Hubbe 2013; Korpisaari *et al.* 2014; Goldstein 2015). However, recent research by Korpisaari *et al.* (2014), which focused on refining the dates for the emergence of the Cabuza style, has indicated that it may more correctly reflect the timing of the collapse of the Tiwanaku polity. The Maitas–Chiribaya ceramic style is also associated with the Middle Period, and Uribe (1999) has suggested that this style was restricted to the area around Arica and reflects a local style. While the association of ceramic iconography with Tiwanaku influence is now subject to new interpretations (e.g., Korpisaari *et al.* 2014), there are other artefacts, such as textiles and snuffing paraphernalia, found in northern Chile—in particular, in San Pedro de Atacama—which provide a different perspective in relation to the interaction with the Tiwanaku polity (Uribe and Agüero 2004; Isbell and Knobloch 2006; Llagostera 2006; Rivera 2008; Goldstein 2015; Valenzuela *et al.* 2015).

After the collapse of the Tiwanaku polity, northern Chile was the scene of several political and economic rearrangements that resulted in a period of regional development referred to as the Late Intermediate Period (1000–660 BP) (Table 1) (Rivera 1991, 2008). There are a number of local styles expressed in ceramics, textiles and rock art, for example, which devised and constituted a regional tradition known as the Arica Culture (see Rivera 1991, 2008; Uribe 1999; Horta and Agüero 2009). The San Miguel and Pocoma Gentilar pottery styles are widely distributed in enclaves along the Pacific littoral and coastal valleys and oases in northern Chile (Uribe 1999). It has been suggested that, although there was no longer any overarching polity in the south-central Andes, independent social groups in northern Chile maintained complex systems of inter-regional interaction (e.g., between local fishing and farming communities and between Andean groups) (Duffait 2012; Horta 2015; Pestle *et al.* 2015). Decorated ceramics from this period have been described as being well-

manufactured, with polished smooth surfaces and painted geometric iconography (Santos 2003).

During the consolidation of the Inca State that corresponds to the Late Period (660–476 BP), there were important civil works undertaken, including the construction and maintenance of roads that integrated a substantial territory from Ecuador to central Chile, on both sides of the Andes (see D’Altroy 2007; Santoro *et al.* 2010; Quilter 2014). The Inca State established various levels of control over communities in northern Chile, which depended on the social and economic features of each group. In some areas, Inca presence was more defined than in others. For example, in the mountains and highlands near Arica (northern Chile), buildings have been identified with architectural and symbolic Inca royalty features that D’Altroy (1992) has interpreted as representing direct territorial control (e.g., in the areas of Zapahuira, Tarapacá Viejo and Catarpe) (Lynch 1977; Alden *et al.* 2006; Santoro *et al.* 2010; Uribe *et al.* 2012; Zori and Urbina 2014; Santoro and Uribe 2016). On the coast and low valleys, including Caleta Vitor, however, state presence is much less visible architecturally and reduced to the introduction of Inca stylistic artefacts (excluding *cappacocha* of Cerro Esmeralda in Iquique, due to the presence of a silver mine and sea-bird guano resources) (Santoro and Uribe 2016). Inca ceramics are characterized by fine pastes, high-quality finishes, and geometric and zoomorphic polychrome iconography (Santos 2003). NAA has been a useful tool to discern whether Inca-style ceramics were traded into areas or were locally manufactured copies, thus demonstrating the importance of analysing ceramics via multiple methods, as explored further below (see Bray *et al.* 2005; Williams *et al.* submitted).

RELEVANT PRIOR RESEARCH/CASE STUDIES

NAA is a sensitive technique useful for undertaking quantitative multi-elemental analysis of major, minor and trace elements present in ceramic and clay materials, and has been one of the preferred analytical techniques for addressing archaeological questions concerned with the procurement and use of raw materials and the trade or exchange of finished goods (Neff 1998; Vaughn and Neff 2000; Glascock and Neff 2003). Compositional grouping of ceramics, based on NAA, allows archaeologists to investigate questions of local and non-local clay procurement, from which inferences about ceramic production and exchange systems can be made.

Sources of chemical or mineralogical variation in ceramic composition include the distribution of geological source materials, variability within geological resources, clay and temper procurement practices (such as the sourcing of raw materials from more than one location), technological alteration of materials during ceramic paste preparation, and the use-life and post-depositional alteration of the artefact (Glascock and Neff 2003; Stoltman 2006; Anderson *et al.* 2011). Matching clay sources and ceramic composition is more difficult than can be the case with other raw materials such as obsidian, because a clay source is not the result of a single depositional episode (Glascock and Neff 2003; Anderson *et al.* 2011). Clay deposits are therefore not as discrete as other raw materials and typically do not have a homogenous internal composition (Neff 2000). However, sourcing is possible if the chemical or mineralogical differences between natural sources are greater than they are within each source—this is known as the provenance postulate, as proposed by Weigand *et al.* (1977).

While NAA has been well-utilized to investigate differences and similarities in ceramic and clay compositions in other parts of the world (see Neff *et al.* 1988; Glascock 1992; Neff and Bove 1999; Glascock and Neff 2003; Vaughn and Neff 2004), it has only recently been used to analyse ceramic and clay compositions in a northern Chilean context (Bray *et al.* 2005; Alden *et al.* 2006; Falabella *et al.* 2013; Uribe and Vidal 2015; Williams *et al.* submitted). The region of San Pedro de Atacama, in northern Chile (see Fig. 1 (a)) has been the focus of a number of recent ceramic and clay NAA studies (see Alden *et al.* 2006; Falabella *et al.* 2013, 2015; Uribe and Vidal 2015). A study conducted by Alden *et al.* (2006) analysed 157 ceramic and clay samples using NAA from two Inca administrative centres located in San Pedro de Atacama—this research revealed that the ceramics associated with Inca provincial styles were made with locally sourced clay (Alden *et al.* 2006). Studies by Williams *et al.* (submitted) and Bray *et al.* (2005) also conclude that while some Inca-style ceramics were being traded, local potters were manufacturing a proportion of Inca-style ceramics.

Uribe and Vidal (2015) recently conducted NAA on Early Formative and Late Intermediate Period ceramics from the Tarapacá region (near Iquique). Uribe and Vidal's (2015) results indicate minimal compositional variation, suggesting continuity in local-level production. This latter mentioned study illustrates that even during times

of heightened external political and socio-economic influence, ceramic production was both stable and local, which allowed them to conclude that 'local populations were active agents and not merely passive recipients of external civilizing influences' (Uribe and Vidal 2015, 31).

In the highlands of Bolivia, north-west of our study area, Alconini (2013) and Villanueva (2015) undertook research that also illustrated the usefulness of elemental analyses for addressing small-scale, localized ceramic manufacturing processes (see also Szilágyi *et al.* 2012; Falabella *et al.* 2015; Toohey 2015). Our study contributes to this prior research in the wider region and provides new data regarding the composition of domestic ceramics and their relationship to potential local clay sources.

The majority of previous NAA studies conducted in the south-central Andes have focused on ceramics from either specific time periods or styles, with the exception of the work conducted by Uribe and Vidal (2015). However, as a general point of difference, our research focuses on ceramic samples from a single site representing a temporal period of 1500 years, which allows us to investigate changes/continuities in clay procurement over time.

As already noted, the ceramics used in this study are predominantly domestic (storage or cooking vessels). Decorated and prestigious vessels, often associated with burials, have been preferred for NAA analyses over ceramics associated with domestic contexts (see Bray *et al.* 2005). While these studies have contributed to our understanding of inter-regional interactions, the use of decorated and high-status vessels, in isolation, limits the ability of such studies to make generalized interpretations regarding the overall managerial network involved in the production, movement and consumption of pottery in the wider region. Thus the above case studies, as well as other recent projects (e.g., Falabella *et al.* 2013), illustrate the potential of NAA analysis of undecorated, domestic ceramics to contribute to a more holistic understanding of inter-regional interactions and local-scale ceramic production (see Fernández 2011; Szilágyi *et al.* 2012; Falabella *et al.* 2013). The current study thus aims to contribute to this growing body of research relating to local and social processes by investigating the compositional variation of domestic vessels from Caleta Vitor.

REGIONAL GEOLOGY AND GEOCHEMISTRY

There has been little published about the region's geological variability (Sernageomin 2003; Baeza Bravo 2010). The current geomorphological characteristics of northern Chile are the product of the Andean tectonic cycle, taking place between the late Early Jurassic and the present day (Zori 2011). As seen in Figure 1 (c), the coast is characterized by Jurassic marine and continental volcanic sequences consisting of basaltic lavas and andesitic rhyolitic tuff interbedded with sandstone and limestone, while the valleys are characterized by Pliocene–Pleistocene conglomerates of sandstone, siltstone and claystone (see Fig. 1 (c)) (Zori 2011). While the geological descriptions are useful, there is a lack of any description of the region's geochemistry. While attempting to determine all possible clay deposits used for ceramic production is impractical due to the variables involved (e.g., depletion of deposits over time), it is reasonable to expect that the clays found within broad geological or geomorphological units will have certain compositional characteristics in common (Steponaitis *et al.* 1996). Previous studies have shown, for example, that alluvial clays found within a single drainage basin tend to be similar to each other and different from the clays found in other drainages, which have cut through distinctive geological formations (see Steponaitis *et al.* 1996). As it was the goal of this study to determine compositional similarities/differences between domestic ceramics, it was pertinent to characterize the geochemical composition of the Vitor Valley (within which Caleta Vitor is located). In order to contextualize the Vitor Valley composition, it was also necessary to collect clay samples from neighbouring valleys—to determine if alluvial clays from drainage basins with similar geomorphological units share similar in chemical compositions. Clay samples from a nearby coastal site and slightly further afield in the highlands were also analysed to provide additional comparison.

MATERIALS AND METHODS

Ceramic and clay selection and preparation

The ceramic samples ($n = 38$) used for this study were excavated from CV4/1 ($n = 8$), CV4/6 ($n = 26$) and CV6/1 ($n = 4$). These trenches (in addition to reasons already outlined) were selected as they provided the most chronologically secure contexts, given that they had been more extensively dated. As an aim of this study is to investigate changes/continuities in clay procurement over time ceramics from the

Formative ($n = 7$), Middle Horizon ($n = 5$), Late Intermediate ($n = 9$) and Late ($n = 17$) Periods were sampled. More samples were selected from the Late Period (in comparison to other periods), as it represents a time of heightened external political and socio-economic pressures, a result of the consolidation of the Inca State.

Minimal sample preparation is required for NAA (Glascock *et al.* 2004). For this study, ceramics were prepared at Flinders University (South Australia) for NAA by removing slips and old exposed surfaces with a tungsten carbide high-speed burr. The cleaned samples were crushed and homogenized into a fine powder by hand, in a Brazilian agate mortar and pestle. Approximately 50 mg was sampled for each of the short and long irradiations. The combination of the two irradiation protocols allows for the measurement of up to 40 elements from each sample. Additionally, standard reference material SRM 1633b Coal Fly Ash, SRM 688 Basalt rock and the widely used Ohio red clay were irradiated with the samples to allow for inter-laboratory comparisons.

As previously noted, determining all possible original clay sources is probably unachievable given all of the variables involved (e.g., unknown numerous locations and changes to the landscape, as well as clay mixing). However, given the aims of this study, it was pertinent to sample and analyse clay sources from nearby valley, coast and highland contexts in order to provide baseline geochemical data to consider in the assessment of potential clay procurement sites.

The clay samples were collected during fieldwork in 2013, with the aid of a local professional potter, Miguel Moreno. The clay samples from the valleys nearest to the Caleta Vitor Archaeological Complex were collected from stream beds and the samples collected from the highlands were collected from deposits made visible as a result of road cuts. The clay samples collected for this study are intended to provide comparative geochemical data only. Given the aims of the project, the majority of samples were collected from the Vitor Valley, which leads directly into the Caleta Vitor Archaeological Complex. Additional clay samples were collected from the Azapa and Lluta Valleys, the Zapahuiria in the Arica highlands (~3400 masl) and the coastal site of Playa Miller, near the city of Arica (for site descriptions, see Bird 1943; Santoro 1995). A total of 15 clay samples were collected for this analysis, including samples from: Vitor Valley ($n = 8$), Azapa Valley ($n = 3$), Lluta Valley ($n = 1$), Playa

Miller (Arica in Fig. 1 (c)) ($n = 1$) and Zapahuira in the Arica highlands ($n = 2$) (Fig. 1 (c)).

The 15 clay samples were sieved to remove organic matter and large inclusions. Deionized water was then added to each sample until the mixture was combined and could be formed into small bricks. These bricks were left in a temperature-controlled room for at least 2 days to dry. When the samples were dried, they were fired in a furnace at maximum temperature of 750°C for 1 h. Samples were left to cool before being crushed into a fine powder and weighed. Sample preparation, irradiation, decay and counting measurements followed standard procedures at the NAA facility at the Australian Nuclear Science and Technology Organisation (ANSTO), Australia (Bennett 2008; Bennett *et al.* 2012).

Neutron activation analysis

The high precision, accuracy and sensitivity of NAA, as well as the technique's ability to analyse small samples, were the primary reasons for selecting this method over other types of bulk chemical analyses (Glascock and Neff 2003). Minimizing the impact of destructive analysis is particularly important, as the ceramic material is also required for other analyses as part of a larger research project, of which NAA is one aspect (other analyses undertaken as part of the broader project include thin-section petrography, X-ray diffraction and scanning electron microscopy—indeed, it is expected that the integration of these methods will result in an even more refined understanding—and traditional ceramic recording also took place as part of the project, although we would note that we did not set out to improve the typological framework in this region, which has already been well developed by Uribe and others [see Uribe 1999; Uribe 2009; Uribe *et al.* 2007]). Thus, only a small portion, less than 1 g, from each sherd was crushed during preparation for NAA (of this, only 100 mg was irradiated—the remaining powdered samples have been kept as a reference material for potential further analysis). The samples were irradiated in the 20 MW OPAL research reactor operated by ANSTO at Lucas Heights, Australia. NAA was performed using the k_0 method of standardization (k_0 -NAA), following established protocols for archaeological samples at ANSTO (see Montoya *et al.* 2003; Bennett 2008; Bennett *et al.* 2012; Popelka-Filcoff *et al.* 2012). In addition, as already noted, the use of standards was also included to allow for potential future inter-laboratory comparisons.

Statistical analyses were subsequently carried out using the GAUSS MURRAP routine (MURR Archaeometry Laboratory 2014), as has been employed in previous NAA studies of archaeological materials (Popelka-Filcoff *et al.* 2012). Of the elements reported, 28 were used in the final analyses of the domestic ceramic data set. Some elements were not used in the analysis because their concentration was either incomplete across the entire data set or below the limit of detection. Na and Cl were also excluded from the analyses, as these elements may be present due to the inclusion of salt within the ceramic paste, which may occur if seawater was used during the paste preparation or as a result of post-depositional contamination. Br was also removed due to its association with post-depositional contamination and because of its limited interpretative value in provenance studies (see Trindade *et al.* 2011). The elements removed from the ceramic data set were also removed from the clay data set to allow for comparison.

Principal component analysis (PCA), one of several commonly used pattern recognition techniques typically applied to archaeological geochemical data (Glascock 1992; Neff 2000), was used in this project to analyse the NAA results. The primary aim of PCA is to identify any potential compositional groups within the ceramic database. Such compositional groups may be inferred to represent distinct clay deposits. If compositional groups exist within the ceramic data set, this may reflect access to numerous clay deposits, exchange or changes to the production of domestic ceramics.

In northern Chile, high levels of arsenic have been recorded in skeletal remains (see Swift *et al.* 2015), drinking water (Steinmaus *et al.* 2013) and the natural environment. As such, this element was selected for specific analysis in this study to determine if compositional groups could be identified that may reflect natural variation in the landscape. In addition to arsenic, rare earth elements (REE), such as samarium, were used to analyse the ceramic and clay data sets. REE have been selected for analysis in previous similar studies due to their potential for identifying compositional groups (Anderson *et al.* 2011; Popelka-Filcoff *et al.* 2011) and their association with localized bedrock erosion (Baeza Bravo 2010).

RESULTS

Ceramic analysis

Statistical analyses were subsequently carried out on base-10 logarithms of concentrations on 28 elements. The use of log concentrations rather than raw data compensates for differences in magnitude between major elements, such as iron and trace elements (e.g., REEs). The results from the PCA for the ceramic data set showed high variability for the following elements: Sb, Cr, Mg, Co, As, Hf, Ti and Fe (Fig. 3 (a)). The PCA was able to account for 90% of the total ceramic data set variability in the first eight PCAs. Figure 3 (b) presents a bivariate plot of Sm and As concentrations for the domestic ceramics. The ceramics are represented in their associated time periods with 90% confidence ellipses.

Clay sources

Clay samples were selected to provide geochemical baseline data (from nearby valley, coast and highland contexts) to aid in contextualizing the ceramic chemical data. The results from the PCA for the clay data set showed high variability for the following elements: As, Cs, Mn, Co, Na, Ca, Sr and Zn (Fig. 4 (a)). The PCA was able to account for 95% of the total ceramic data set variability in the first six PCAs. Figure 4 (b) presents a bivariate plot of Sm and As concentrations of the clay samples. The ellipse for the Vitor Valley samples represents 90% confidence; thus the presence of all three Azapa Valley clay samples within this ellipse indicates compositional similarities.

Clay sources and ceramics

The results of the domestic ceramic and clay data sets are presented in Figure 5. The Vitor Valley ellipse (90% confidence interval of group membership) encompasses 28 out of 38 ceramic samples (see Fig. 5), illustrating significant compositional similarities. A total of 10 ceramic samples fell outside the Vitor Valley clay ellipse but are still clearly differentiated from the Lluta, Playa Miller and Zapahuira samples, suggesting minor compositional variation within the ceramic data set.

DISCUSSION

Likely clay procurement sites

The Azapa Valley clay samples all fall within the Vitor Valley ellipse, suggesting strong compositional similarities between clays in these valleys (Figs 4 (b) and 5). Likewise, 28 out of 38 of the ceramic samples fall within the Vitor/Azapa Valley

ellipse (Fig. 5). The ceramics outside the Vitor/Azapa Valley ellipse may reflect the natural variation in local clay deposits, a clay deposit that was not sampled or mixing of clays. Further sampling and investigation is thus warranted. Although 10 ceramic samples fell just outside the ellipse, those samples are still clearly differentiated from the other clay samples from further afield (Lluta Valley, Playa Miller and Zapahuira).

It is widely recognized that ceramic materials are often heterogeneous, since pottery manufacture involves many stages that generally alter the original raw materials (Shepard 1956; Rye 1981; Rice 2005). Due to these processes, there is often little chance of finding a perfect match between a specific clay's chemical profile and ceramic samples from vessels manufactured using that same clay (Arnold *et al.* 1991, 2000). Despite this, in this study we have sufficient data to suggest that the primary location for the procurement of raw clays used in the manufacture of domestic ceramics from Caleta Vitor was probably the Vitor Valley and/or the nearby Azapa Valley. However, unless the quality of clay raw material in the Azapa Valley is significantly better it seems more likely that the ceramics if made in the Caleta Vitor area (coastal/valley) would have been made from clay sourced from the Vitor Valley.

Ceramic production over time

When the ceramics are grouped within their associated time periods (see Fig. 3 (b)), there are no discrete compositional groupings, suggesting no correlation between time periods and clay sources (although additional sampling per period could refine this modelling). Thus, the use of local clays from the Vitor/Azapa Valleys appears to remain consistent over a 1500-year time period.

The 1500-year period under discussion encompassed the rise, consolidation and collapse of two large Andean states—Tiwanaku and Inca—as well as other inter-regional interactions. A hypothesis that was considered at the outset of this investigation was that the production of domestic ceramics associated with the Formative and possibly the Late Intermediate Periods would probably have similar elemental compositions, as such vessels from these time periods are generally considered to have been manufactured locally (Fernández 2011). In contrast, it was hypothesized that the ceramics associated with the Middle and Late Periods, (corresponding with Tiwanaku/Inca expansion) could have greater elemental variation, reflecting an increase in political and socio-economic interaction that

included the trade/exchange of ceramic vessels (see Williams *et al.* submitted). The ceramic samples presented in Figures 3 (a) and 3 (b) are coordinated according to their temporal period with which they have been associated (see Table 1). However, the results indicate that the compositional variation within specific time periods (e.g., Late Intermediate and Late Periods etc.) is greater than between time periods. Therefore, we would argue that no correlation between time periods and composition could be established on the basis of this study (Fig. 3 (b)).

As noted above, the lack of association between compositional groups and time periods (see Fig. 3 (b)) instead suggests that the same local clay sources were probably being utilized continuously over the past 1500 years—thus allowing us to infer that the production of domestic ceramics remained local. Moreover, this supports the inference that even in times of heightened external political and socio-economic influence, ceramic manufacturing at Caleta Vitor was both stable and local. Previous stable isotope research conducted on human remains from the Caleta Vitor complex by Roberts *et al.* (2013) similarly highlights continuities in the region, albeit in relation to subsistence practices throughout the Formative to Late Periods. This narrative of the existence of some stable and continuous cultural traditions in northern Chile, even during periods of heightened external influence, is thus being borne out from a range of investigations (Roberts *et al.* 2013; Salazar *et al.* 2015; Uribe and Vidal 2015; Andrade *et al.* 2016).

Clay sources

There has been little published about the region's geological and geochemical variability (Sernageomin 2003; Baeza Bravo 2010). As such, it was necessary to collect local clay samples in order to provide baseline geochemical data to assess potential clay procurement sources. The results of this study indicate that the elemental composition of the Vitor and Azapa Valley clay samples are similar, while there appears to be considerable variation between the samples from Playa Miller (coast), Lluta Valley and Zapahuira in the highlands of Arica (see Fig. 4 (b)). The Vitor/Azapa similarity is probably a reflection of the shared geological history of the valleys, with the clay deposits probably forming as a result of sediments transported down the valleys from the western slopes of the Andes mountain range during summer rainfall (Santoro *et al.* 2005). Such compositional similarities between the alluvial clay deposits of the Vitor and Azapa Valleys suggest that the underlying

geomorphology of each valley is also similar. There is considerable compositional variation between clay samples collected from relatively more distant valley and highland contexts as well as a coastal context, which highlights the variability between the geological histories of these landforms.

CONCLUSIONS

While acknowledging that this is a preliminary study, we feel that the results reflect the potential of NAA analysis conducted on domestic ceramics to contribute to current debates surrounding change/continuity in ceramic production during times of heightened external influences in northern Chile. Indeed, our results indicate that compositional similarities were identified for the domestic ceramics that we sampled in this study, which cover a 1500-year period. Further, our data suggest that the primary location for the procurement of clays for the production of domestic ceramics excavated from Caleta Vitor was probably the surrounding Vitor and Azapa Valleys. Thus, the nature of clay procurement over the 1500-year time period appears to remain local despite increasing external influences that occurred after the Formative Period arising from the Tiwanaku and Inca polities. As such, it can be argued that inter-regional interactions did not substantially affect this sphere of material culture.

The results, as outlined above, reflect recent similar studies (e.g., Uribe and Vidal 2015) that also argue for continuity of local-level production of ceramics despite changing external political influences. Thus, future avenues for research should continue to consider why some aspects of ceramic production/consumption remain stable while other material culture changes significantly (e.g., iconography on decorated ceramics, textiles and rock art) (Romero 2002; Santoro *et al.* 2004; Uribe and Agüero 2004). Indeed, we can question whether, for example, continuities in the production of domestic ceramics represent a form of social/cultural refuge or even resistance to change in the face of powerful external influences. Further, as Uribe and Vidal (2015, 31) concluded in their study, we should not disregard the fact that local populations could be active agents who did not passively accept external influences. Or perhaps such stability relates to community perceptions that emphasize the lack of necessity for change in the production of utilitarian items, or even whether the lack of change simply relates to the fact that domestic pottery was not considered to be an exchangeable commodity. More research into the above-mentioned possibilities, from

a variety of perspectives, may allow greater insights into the continuities proposed in this paper.

ACKNOWLEDGEMENTS

We wish to thank the Australian Institute of Nuclear Science and Engineering (AINSE) for providing the grants that funded this study (ALNGRA13503, ALNGRA14011 and ALNGRA14516). R. Popelka-Filcoff acknowledges the support from the AINSE Research Fellowship. We thank Miguel Moreno, a local professional potter, for assisting us to identify suitable sources of clay for pottery production, which were then sampled in this project. C. Santoro thanks the FONDECYT project grant 1150763 and CONICYT's Programa de Investigación Asociativa (PIA), Proyecto Anillo Código SOC1405. C. Bland wishes to thank Mariela Santos from the Azapa Valley Museum for allowing access to their ceramic collection. We also thank Chris Carter for making the ceramics available for study and for dealing with all ethical/permit issues. Thanks are also due to the useful comments provided by two anonymous referees, as well as the Editors of *Archaeometry*.

REFERENCES

- Aguero, C., and Uribe, M., 2011, Las sociedades formativas de San Pedro de Atacama: asentamiento, cronología y proceso, *Estudios Atacameños*, **42**, 53–78.
- Alconini, S., 2013, El territorio Kallawayaya y el taller alfarero de Milliraya: evaluación de la producción, distribución e intercambio interregional de la cerámica Inka provincial, *Chungara, Revista de Antropología Chilena*, **45**(2), 277–92.
- Alden, J. R., Minc, L., and Lynch, T. F., 2006, Identifying the sources of Inka period ceramics from northern Chile: results of a neutron activation study, *Journal of Archaeological Science*, **33**(4), 575–94.
- Anderson, S. L., Boulanger, M. T., and Glascock, M. D., 2011, A new perspective on Late Holocene social interaction in northwest Alaska: results of a preliminary ceramic sourcing study, *Journal of Archaeological Science*, **38**(5), 943–55.
- Andrade, P., Castro, V., and Aldunate, C., 2016, Reconstrucción del modo de vida de individuos del arcaico de la costa arcaica del norte de Chile: una aproximación bioarqueológica desde el sitio Copaca 1, *Chungara Revista de Antropología Chilena*, **48**, 73–90.
- Arnold, D. E., Neff, H., and Bishop, R. L., 1991, Compositional analysis and 'sources' of pottery: an ethnoarchaeological approach, *American Anthropologist*, **93**(1), 70–90.

- Arnold, D. E., Neff, H., and Glascock, M. D., 2000, Testing assumptions of neutron activation analysis: communities, workshops and paste preparation in Yucatan, Mexico, *Archaeometry*, **42**, 301–16.
- Augustyniak, S., 2004, Dating the Tiwanaku State, *Chungara, Revista de Antropología Chilena*, **36**(1), 19–35.
- Baeza Bravo, L. I., 2010, *Estudio ambiental y económico: análisis mineralógico y geoquímico de sedimentos del sistema fluvial del río Lluta, XV Región de Arica y Parinacota, Chile*, Undergraduate thesis, Universidad de Chile, Facultad de ciencias Físicas y matemáticas, Departamento de Geología, Santiago.
- Barba, L., Muñoz, I., Ortiz, A., and Blancas, J., 2015, El uso de técnicas geofísicas para determinar sistemas constructivos y materiales presentes en los túmulos del período Formativo en el valle de Azapa, Arica, Chile, *Chungara Revista de Antropología Chilena*, **47**, 131–56.
- Bennett, J. W., 2008, Commissioning of NAA at the new OPAL reactor in Australia, *Journal of Radioanalytical and Nuclear Chemistry*, **278**(3), 671–3.
- Bennett, J. W., Grave, P., and Stopic, A., 2012, Establishing a basis for nuclear archaeometry in Australia using the 20 MW OPAL research reactor, *Journal of Radioanalytical and Nuclear Chemistry*, **291**, 13–17.
- Bird, J., 1943, Excavations in northern Chile, *Anthropological Papers of the American Museum of Natural History*, **38**(4), 173–316.
- Bray, T. L., Minc, L. D., Ceruti, M. C., Chávez, J. A., Perea, R., and Reinhard, J., 2005, A compositional analysis of pottery vessels associated with the Inca ritual of *capacocha*, *Journal of Anthropological Archaeology*, **24**(1), 82–100.
- Carter, C., in progress, The marine economies of prehistoric northern Chile, Australian National University, Australia.
- Castro, V., Aldunate, C., Varela, V., Andrade, P., Olgún, L., García-Albarido, F., Rubio, F., Castro, P., and Ruiz, I. J., 2016, Ocupaciones arcaicas y probables evidencias de navegación en la costa aricaica de Antofagasta, *Chungara, Revista de Antropología Chilena*, **48**.
- Chatfield, M., 2010, Tracing firing technology through clay properties in Cuzco, Peru, *Journal of Archaeological Science*, **37**(4), 727–36.
- D'Altroy, T., 1992, *Provincial power in the Inka Empire*, Smithsonian Institution Press, Washington, DC.
- D'Altroy, T., 2007, *The Incas*, Blackwell, Oxford.
- DGA, 2007, *Informe final: estimaciones de demanda de agua y proyecciones futuras: zona norte regiones I a IV*, Ministerio de Obras Públicas, Santiago

- Duffait, E., 2012, Vías prehispánicas y culto de los muertos en el norte chileno (Arica–Tarapacá) durante el período Intermedio Tardío y el Horizonte Tardío (ca. 1.000–1.532 d.C.), *Chungara, Revista de Antropología Chilena*, **44**(4), 621–35.
- Falabella, F., Sanhueza, L., Correa, I., Fonseca, E., Roush, C. C., and Glascock, M. D., 2015, Tradiciones tecnológicas del período Alfarero Temprano de Chile central: un estudio de bordes, materias primas y pastas de vasijas de cocina en la microrregión de Angostura, *Chungara, Revista de Antropología Chilena*, **47**(3), 353–68.
- Falabella, F., Sanhueza, L., Correa, I., Glascock, M. D., Ferguson, T. J., and Fonseca, E., 2013, Studying technological practices at a local level: neutron activation and petrographic analyses of Early Ceramic Period pottery in Central Chile, *Archaeometry*, **55**, 33–53.
- Fernández, M. S. M., 2011, Modelando en arcilla: aproximaciones a la producción y el consumo de cerámica durante el periodo Formativo de los valles costeros del norte de Chile (1400 a.C. – 500 d.C.), Universidad de Tarapacá, Chile.
- García, M., Vidal, A., Mandakovic, V., Maldonado, A., Peña, M.P., and Belmonte, E., 2014, Alimentos, tecnologías vegetales y paleoambiente en las aldeas de la Pampa del Tamarugal: dos expresiones del periodo Formativo en Tarapacá (ca. 900 a.C. – 800 d.C.), *Estudios Atacameños Arqueología y Antropología Surandina*, **47**, 33–58.
- Glascock, M. D., 1992, Characterization of archaeological ceramics at MURR by neutron activation analysis and multivariate statistics, in *Chemical characterization of ceramic pastes in archaeology* (ed. H. Neff), 11–26, Monographs in World Archaeology, No. 7, Prehistory Press, Madison, WI.
- Glascock, M. D., and Neff, H., 2003, Neutron activation analysis and provenance research in archaeology, *Measurement Science and Technology*, **14**(9), 1516–26.
- Glascock, M. D., Neff, H., and Vaughn, K. J., 2004, Instrumental neutron activation analysis and multivariate statistics for pottery provenance, *Hyperfine Interactions*, **154**(1–4), 95–105.
- Goldstein, P., 2015, Multiethnicity, pluralism, and migration in the south central Andes: an alternate path to state expansion, *Proceedings of the National Academy of Science*, **112**(30), 9202–9.
- Grosjean, M., Santoro, C. M., Thompson, L. G., Núñez, L., and Standen, V. G., 2007, Mid-Holocene climate and culture change in the South Central Andes, in *Climate change and cultural dynamics: a global perspective on mid-Holocene transitions* (eds. D. G. Anderson, K. A. Maasch and D. H. Sandweiss), 51–115, Elsevier, San Diego, CA.
- Horta, H., 2015, *El Señorío Arica y los Reinos Altiplánicos*, Universidad Católica del Norte, Quillqa/Universidad Católica del Norte, Santiago.

- Horta, H., and Agüero, C., 2009, Estilo, iconografía y función de las inkuñas prehispánicas del norte de Chile durante el periodo Intermedio Tardío (1.000–1.470 D.C.), *Chungara, Revista de Antropología Chilena*, **41**(2), 183–227.
- Isbell, W. H., and Knobloch, J., 2006, Missing links, imaginary links: staff god imagery in the South Andean past, in *Andean Archaeology 3: North and South*, (eds. W. H. Isbell and H. Silverman), 307–51, Springer, New York.
- Jordan, T. E., Kirk-Lawlor, N. E., Blanco, N., Rech, J. A., Cosentino, N., 2014, Landscape modification in response to repeated onset of hyperarid paleoclimate states since ~15 Ma, Atacama Desert, Chile. *Geological Society of America Bulletin*, B30978.30971, doi:30910.31130/B30978.30971.
- Korpisaari, A., Oinonen, M., and Chacama, J., 2014, A reevaluation of the absolute chronology of Cabuza and related ceramic styles of the Azapa Valley, northern Chile, *Latin American Antiquity*, **25**(4), 409–26.
- Latorre, C., De Pol-Holz, R., Carter, C., and Santoro, C. M., 2015, Using archaeological shell middens dating as a proxy for past local coastal upwelling in northern Chile. *Quaternary International*, doi:org/10.1016/j.quaint.2015.11.079.
- Latorre, C., Betancourt, J. L., Rech, J. A., Quade, J., Holmgren, C., Placzek, C., Maldonado, A. J. C., Vuille, M., and Rylander, K. A., 2005, Late Quaternary history of the Atacama Desert, in *23° South: archaeology and environmental history of the Southern Deserts* (eds. M. Smith and P. Hesse), 73–90, National Museum of Australia Press, Canberra.
- Llagostera, A., 2006, Contextualización e iconografía de las tabletas psicotrópicas Tiwanaku de San Pedro de Atacama, *Chungara, Revista de Antropología Chilena*, **38**(1), 83–111.
- Lynch, T., 1977, Tambo incaico Catarpe Este (informe de avance), *Estudios Atacameños*, **5**, 145–50.
- Marquet, P. A., González, H., Pinto, R., Santoro, C. M., Standen, V. G., and Zeballos, H., 2002, Desiertos costeros del Perú y Chile, in *Wildness: Earth's last wild places* (eds. R. A. Mittermeier, G. M. C. P. Robles, J. Pilgrim, G. Fonseca, T. Brooks and W. R. Konstant), 364–73, CEMEX, Mexico.
- Marquet, P. A., Bozinovic, F., Bradshaw, G. A., Cornelius, C., González, H., Gutiérrez, J. R., Hajek, E. R., Lagos, J. A., Lopez-Cortés, F., Núñez, L., Rosello, E. F., Santoro, C. M., Samaniego, H., Standen, V. G., Torres-Mura, J. C., and Jaksic, F. M., 1998, Los ecosistemas del desierto de Atacama y área andina adyacente en el norte de Chile, *Revisia Chilena de Historia Natural*, **71**(4), 593–617.
- Montoya, E., Glowacki, M., Zapata, J., and Mendoza, P., 2003, Chemical characterization of archaeological ceramics using k_0 based INAA: a study in the production and distribution of Middle Horizon pottery from Cuzco, Peru, in

- Nuclear analytical techniques in archaeological investigations*, 163–86, International Atomic Energy Agency, Vienna.
- Mujica, E., Rivera, M.A., and Lynch, T., 1983, Proyecto de estudio sobre la complementariedad económica Tiwanaku en los Valles Occidentales del Centro-Sur Andino, *Chungara*, **11**, 85–109.
- MURR Archaeometry Laboratory, 2014, GAUSS Runtime, http://archaeometry.missouri.edu/datasets/GAUSS_Download.html.
- Neff, H., 1998, Archaeological investigation of trade and exchange, *Reviews in Anthropology*, **27**(3), 317–35.
- Neff, H., 2000, Neutron activation analysis for provenance determination in archaeology, in *Modern analytical methods in art and archaeology* (eds. E. Ciliberto and G. Spoto), 81–134, Chemical Analysis Series, Wiley, Toronto.
- Neff, H., and Bove, F. J., 1999, Mapping ceramic compositional variation and prehistoric interaction in pacific coastal Guatemala, *Journal of Archaeological Science*, **26**(8), 1037–51.
- Neff, H., Bishop, R. L., and Arnold, D. E., 1988, Reconstructing ceramic production from ceramic compositional data: an example from Guatemala, *Journal of Field Archaeology*, **15**(3), 339–48.
- Núñez, L., and Santoro, C. M., 2011, El tránsito Arcaico–Formativo en la circunpuna y valles occidentales del Centro Sur Andino: hacia los cambios ‘neolíticos’, *Chungara, Revista de Antropología Chilena*, **43**(Número Especial 1), 487–530.
- Olguín, L., Salazar, D., and Jackson, D., 2014, Tempranas evidencias de navegación y caza de especies oceánicas en la costa pacífica de Sudamérica (Taltal, ~7.000 años cal. a.p.), *Chungara, Revista de Antropología Chilena*, **46**(2), 177–92.
- Pestle, W., Torres-Rouff, C., Santana, F., Pímentel, G., Gallardo, F., and Knudson, K. J., 2015, Explorando la diversidad dietética en la prehistoria del Desierto de Atacama: un acercamiento a los patrones regionales, *Chungara, Revista de Antropología Chilena*, **47**(2), 201–9.
- Petruzzelli, B., 2012, *Stable carbon and nitrogen isotopic analysis of skeletal remains from Azapa 71 and Pica-8, northern Chile: an assessment of human diet and landscape use in the late Holocene*, Master’s thesis, Flinders University, Adelaide.
- Popelka-Filcoff, R. S., Lenehan, C. E., Glascock, M. D., Bennett, J. W., Stopic, A., Quinton, J. S., Pring, A., and Walshe, K., 2011, Evaluation of relative comparator and k0-NAA for characterization of Aboriginal Australian ochre, *Journal of Radioanalytical and Nuclear Chemistry*, **291**(1), 19–24.
- Popelka-Filcoff, R. S., Lenehan, C. E., Walshe, K., Bennett, J. W., Stopic, A., Jones, P., Pring, A., Quinton, J. S., and Durham, A., 2012, Characterisation of ochre

- sources in South Australia by neutron activation analysis (NAA), *Journal of the Anthropological Society of South Australia*, **35**, 81–90.
- Quilter, J., 2014, *The ancient Central Andes*, Routledge World Archaeology, Routledge, New York.
- Ramirez de Bryson, L. M., Bryson, R. U., and Bryson, R. A., 2001, Paleoclimatic and material cultural perspective on the Formative period of northern Chile, *Chungara, Revista de Antropología Chilena*, **33**(1), 5–12.
- Rice, P. M., 2005, *Pottery analysis: a source book*, The University of Chicago Press, Chicago.
- Rivera, M. A., 1991, The prehistory of northern Chile: a synthesis, *Journal of World Prehistory*, **5**(1), 1–47.
- Rivera, M. A., 2008, The archaeology of northern Chile, in *The handbook of South America archaeology* (eds. W. H. Isbell and H. Silverman), 963–77, Springer, New York.
- Rivera, M. A., Soto, P., Ulloa, L., and Kushner, D., 1974, Aspectos sobre el desarrollo tecnológico en el proceso de agriculturización en el norte prehispano, especialmente Arica (Chile), *Chungara*, **3**, 79–107.
- Roberts, A., Pate, F. D., Petruzzelli, B., Carter, C., Westaway, M. C., Santoro, C. M., Swift, J., Maddern, T., Jacobsen, G. E., Bertuch, F., and Rothhammer, F., 2013, Retention of hunter–gatherer economies among maritime foragers from Caleta Vitor, northern Chile, during the late Holocene: evidence from stable carbon and nitrogen isotopic analysis of skeletal remains, *Journal of Archaeological Science*, **40**(5), 2360–72.
- Rothhammer, F., Santoro, C. M., Poulin, E., Arriaza, B. T., Moraga, M., and Standen, V. J., 2009, Archaeological and mtDNA evidence for Tropical Lowland migrations during the Late Archaic/Formative in northern Chile, *Revista Chilena de Historia Natural*, **82**(4), 543–52.
- Romero, A., 2002, Cerámica doméstica del valle de Lluta: cultura local y redes de interacción Inka, *Chungara, Revista de Antropología Chilena*, **34**, 191–213.
- Rye, O. S., 1981, *Pottery technology: principles and reconstruction*, Manuals on Archaeology 4, Taraxacum Press, Washington, DC.
- Salazar, D., Figueroa, V., Andrade, P., Salinas, H., Olgún, L., Power, X., Rebolledo, S., Parra, S., Orellana, H., and Urrea, J., 2015, Cronología y organización económica de las poblaciones arcaicas de la costa de Taltal, *Estudios Atacameños Arqueología y Antropología Surandinas* **50**, 7–46.
- Santoro, C. M., 1981, Formativo Temprano en el extremo norte de Chile, *Chungara*, **8**, 33–62.

- Santoro, C. M., 1995, *Late prehistoric regional interaction and social change in a coastal valley of northern Chile*, Doctoral dissertation, University of Pittsburgh, Pittsburgh.
- Santoro, C. M., and Uribe, M., 2016, Inca imperial colonization and ethnicity of northern Chile, in *The Oxford handbook of the Inca* (eds. S. Alconini and R. A. Covey), Oxford University Press (submitted).
- Santoro, C. M., Arriaza, B. T., Standen, V. G., and Marquet, P. A., 2005, People of the coastal Atacama Desert living between sand dunes and waves of the Pacific Ocean, in *Desert people: archaeology perspectives* (eds. M. A. Smith and P. Hiscock), 243–60, Blackwell, Oxford.
- Santoro, C. M., Romero, A. R., Standen, V. G., and Torres, A., 2004, Continuidad y cambio en las comunidades locales, períodos intermedio tardío y tardío, valles occidentales del área centro sur Andian, *Chungara, Revista de Antropología Chilena*, **36**, 235–47.
- Santoro, C. M., Williams, V. I., Valenzuela, D., Romero, A., and Standen, V. G., 2010, An archaeological perspective on the Inka provincial administration of the south central Andes, in *Distant provinces in the Inka Empire: towards a deeper understanding of Inka imperialism* (eds. M. A. Malpass and S. Alconini), 44–74, University of Iowa Press, Iowa City, IA.
- Santos, M., 2003, El Barro en las manos del hombre del pasado (alfarería prehispana), in *Manual de patrimonio cultural y natural Arica y Parinacota* (ed. J. Barraza), 95–104, Ministerio de Educacion, Santiago.
- Sernageomin, 2003, Mapa geológico de Chile: versión digital, in *Servicio Nacional de Geología y Minería, publicación geológica digital*, Santiago.
- Shepard, A. C., 1956, *Ceramics for the archaeologist*, Carnegie Institution of Washington, Washington, DC.
- Standen, V. G., Arriaza, B. T., Santoro, C. M., and Coleman, D., 2016, Mobility patterns of hunter–gatherer and fishermen Chinchorro population of the coast of the Atacama Desert (8900–3200 BP): the strontium isotope signatures, *Geoarchaeology, An International Journal* (submitted).
- Steinmaus, C. M., Ferreccio, C., Acevedo Romo, J., Yuan, Y., Cortes, S., Marshall, G., Moore, L. E., Balmes, J. R., Liaw, J., Golden, T., and Smith, A. H., 2013, Drinking water arsenic in northern Chile: high cancer risk 40 years after exposure cessation, *Cancer Epidemiology, Biomarkers & Prevention*, **22**(4), 623–30.
- Steponaitis, V., Blackman, M. J., and Neff, H., 1996, Large-scale patterns in the chemical composition of Mississippian pottery, *American Antiquity*, **61**(3), 555–72.
- Stoltman, J. B., 2006, Review of ‘Ceramics in archaeology: readings from *American Antiquity*, 1936–2002’ compiled by Hector Neff, *Geoarchaeology*, **21**, 643–5.

- Swift, J., Cupper, M. L., Greig, A., Westaway, M. C., Carter, C., Santoro, C. M., Wood, R., Jacobsen, G. E., and Bertuch, F., 2015, Skeletal arsenic of the pre-Columbian population of Caleta Vitor, northern Chile, *Journal of Archaeological Science*, **58**, 31–45.
- Szilágyi, V., Gyarmati, J., Tóth, M., Taubald, H., Balla, M., Kasztovszky, Z., and Szakmány, G., 2012, Petro-mineralogy and geochemistry as tools of provenance analysis on archaeological pottery: study of Inka period ceramics from Paria, Bolivia, *Journal of South American Earth Sciences*, **36**, 1–17.
- Toohy, J., 2015, Ceramic exchange and community interaction in the Late Prehispanic Cajamarca Basin, northern Peru, in *Ceramic analysis in the Andes* (ed. I. Druc), 123–38, Deep University Press, Wisconsin.
- Torres-Rouff, C., and Hubbe, M., 2013, The sequence of human occupation in the Atacama oases, Chile: a radiocarbon chronology based on human skeletal remains, *Latin American Antiquity*, **24**(3), 330–44.
- Trindade, M. J., Dias, M. I., Rocha, F., Prudêncio, M. I., and Coroado, J., 2011, Bromine volatilization during firing of calcareous and non-calcareous clays: archaeometric implications, *Applied Clay Science*, **53**(3), 489–99.
- Uribe, M., 1999, La cerámica de Arica 40 años después de Dauelsberg, *Chungara, Revista de Antropología Chilena*, **31**(2), 189–228.
- Uribe, M., 2009, El período Formativo de Tarapacá y su cerámica: avances sobre complejidad social en la costa del Norte Grande de Chile (900 AC – 800 DC), *Estudios Atacameños*, **37**, 5–27.
- Uribe, M., and Aguero, C., 2004, Iconografía, alfarería y textilería Tiwanaku: elementos para una revisión del período Medio en el Norte Grande de Chile, *Chungara, Revista de Antropología Chilena*, **36**(Volumen Especial 2), 1055–68.
- Uribe, M., and Vidal, E. M., 2012, Sobre la secuencia cerámica del período Formativo de Tarapacá (900 a.c. – 900 d.C.): estudios en Pircas, Caserones, Guatacondo y Ramaditas, norte de Chile, *Chungara, Revista de Antropología Chilena*, **44**(2), 209–45.
- Uribe, M., and Vidal, E. M., 2015, Pottery and social complexity in Tarapacá: reviewing the development of ceramic technology in the Atacama Desert (northern Chile), in *Ceramic analysis in the Andes* (ed. I. C. Druc), 15–35, Deep University Press, Wisconsin.
- Uribe, M., Sanhueza, L., and Bahamondes, F., 2007, La cerámica prehispánica tardía de Tarapacá, sus valles interiores y costa desértica, norte de Chile (ca. 900–1.450 d.C.): una propuesta tipológica y cronológica, *Chungara, Revista de Antropología Chilena*, **39**(2), 143–70.

- Uribe, M., Urbina, S., and Zori, C., 2012, La presencia del inca y la incorporación de Tarapacá al Tawantinsuyo (norte grande de Chile), in *Actas del XVIII Congreso Nacional de Arqueología Chilena*, 217–27.
- Valenzuela, D., Santoro, C. M., Capriles, J. M., Quinteros, M. J., Peredo, R., Gayo, E. M., Montt, I., and Sepúlveda, M., 2015, Consumption of animals beyond diet in the Atacama Desert, northern Chile (13,000–410 BP): comparing rock art motifs and archaeofaunal records, *Journal of Anthropological Archaeology*, **40**, 250–65.
- Vaughn, K. J., and Neff, H., 2000, Moving beyond iconography: neutron activation analysis of ceramics from Marcaya, Peru, an early Nasca domestic site, *Journal of Field Archaeology*, **27**(1), 75–90.
- Vaughn, K. J., and Neff, H., 2004, Tracing the clay source of Nasca polychrome pottery: results from a preliminary raw material survey, *Journal of Archaeological Science*, **31**, 1577–86.
- Villanueva, J., 2015, Evaluando la frontera pacajes-carangas para el periodo Intermedio Tardío (1,100–1,450 d.c.) en el altiplano boliviano central a partir del análisis de pastas cerámicas, *Chungara, Revista de Antropología Chilena*, **47**(2), 211–18.
- Weigand, P. C., Harbottle, G., and Sayre, E. V., 1977, Turquoise sources and source analysis: Mesoamerican and the Southwestern USA, in *Exchange systems in prehistory* (eds. T. K. Earle and J. E. Ericson), 15–34, Academic Press, New York.
- Williams, V. I., Santoro, C. M., Speakman, R. J., Glascock, M. D., Romero Guevara, Á. L., Valenzuela, D., Standen, V. G., and D’Altroy, T. N., Instrumental neutron activation analysis of Inka and local pottery from northern Chile’s Atacama Desert and late prehistoric interregional interaction in the Southern Andes, *Journal of Archaeological Science: Reports* (submitted).
- Zori, C., 2011, *Metals for the Inka: craft production and empire in the Quebrada de Tarapaca, northern Chile*, Dissertation, University of California, California.
- Zori, C., and Urbina, S., 2014, Architecture and empire at late prehispanic Tarapacá Viejo, northern Chile, *Chungara, Revista de Antropología Chilena*, **46**(2), 211–32.

Table 1

<i>Northern Chilean cultural periods relevant to this study</i>			
<i>Age (years BP)</i>	<i>Period</i>		<i>Cultural phase</i>
c.4000–1500	Formative Period (Neolithic)	Early Formative	Final Phase of Chinchorro Culture (4000–3600) Azapa (3600–2500)
		Late Formative (2500–1500)	Alto Ramirez
c.1500–900	Middle Horizon		Tiwanaku polities expansion

Cabuza

c.1000–660 Late Intermediate

Maitas–Chiribaya (850–650)

San Miguel

Pocoma Gentilar

Inca Empire

c.660–476 Late Period
c.476 Hispanic Period

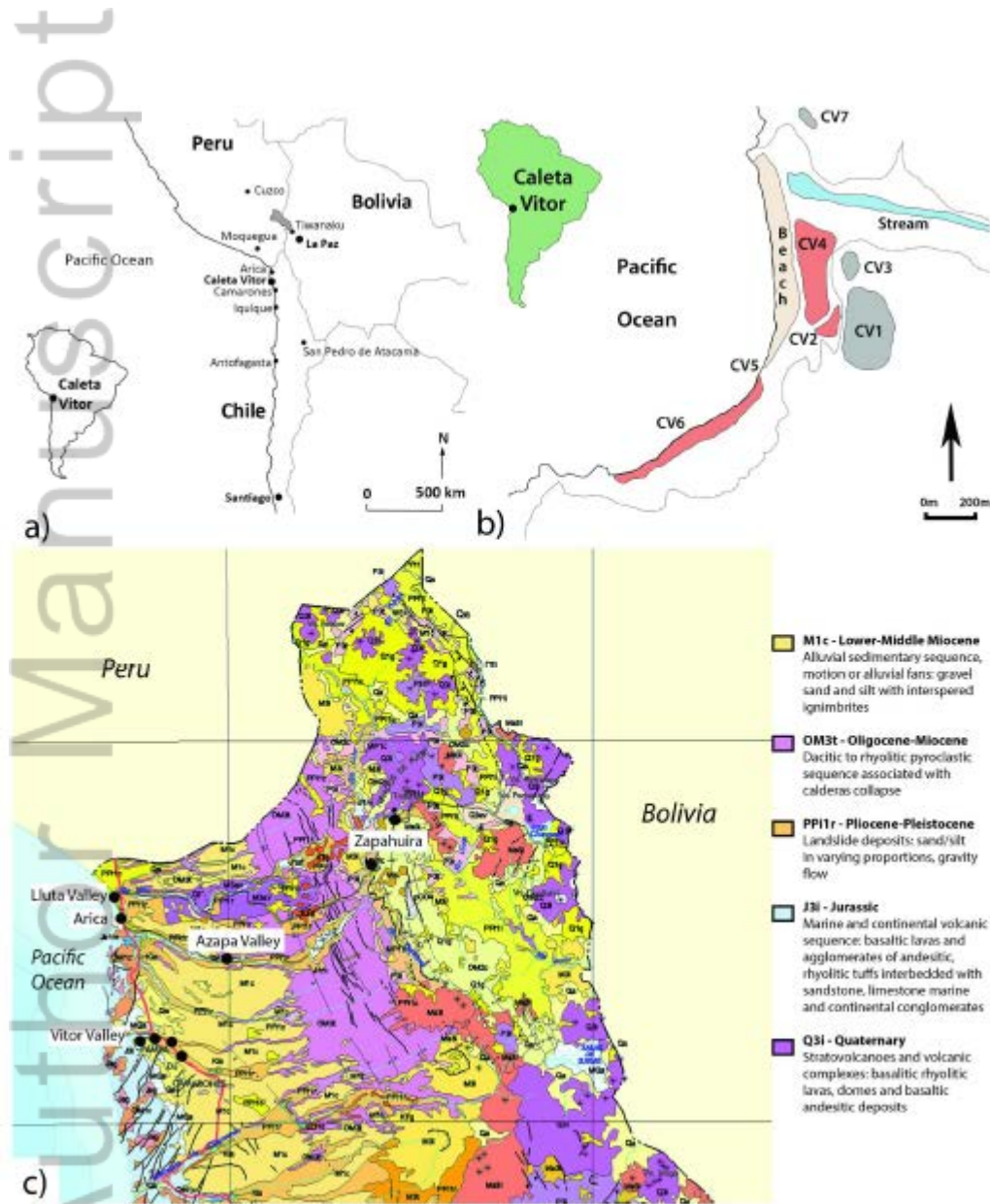


Figure 1

(a) A map of the south-central Andes, illustrating some of the major archaeological sites and areas discussed in this paper. (b) A map of the Caleta Vitor Archaeological Complex, illustrating the location of the sites. (c) A geological map of northern Chile, including the location of the clay deposits sampled as part of this study (adapted from Sernageomin 2003; scale 1:1 000 000).



Figure 2

Examples of the domestic ceramics used in this analysis.

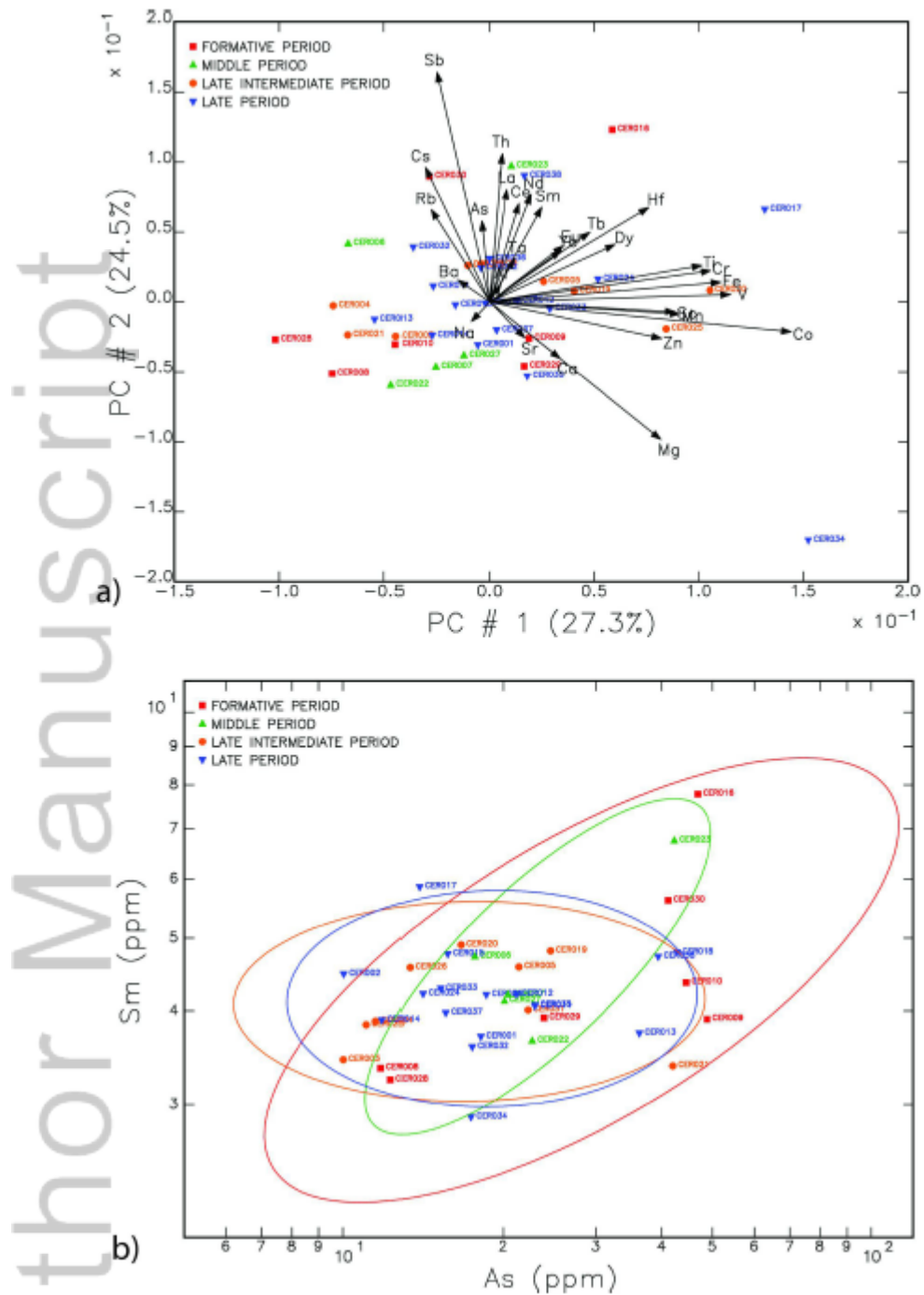


Figure 3

(a) A biplot of the first two principal components for the ceramic data set, which describes 51.8% of the cumulative variation in the data set. (b) A bivariate log-log

*plot of the samarium (Sm) and arsenic (As) concentrations for the ceramic data set.
The confidence ellipse for the ceramic temporal groupings is 90%.*

Author Manuscript

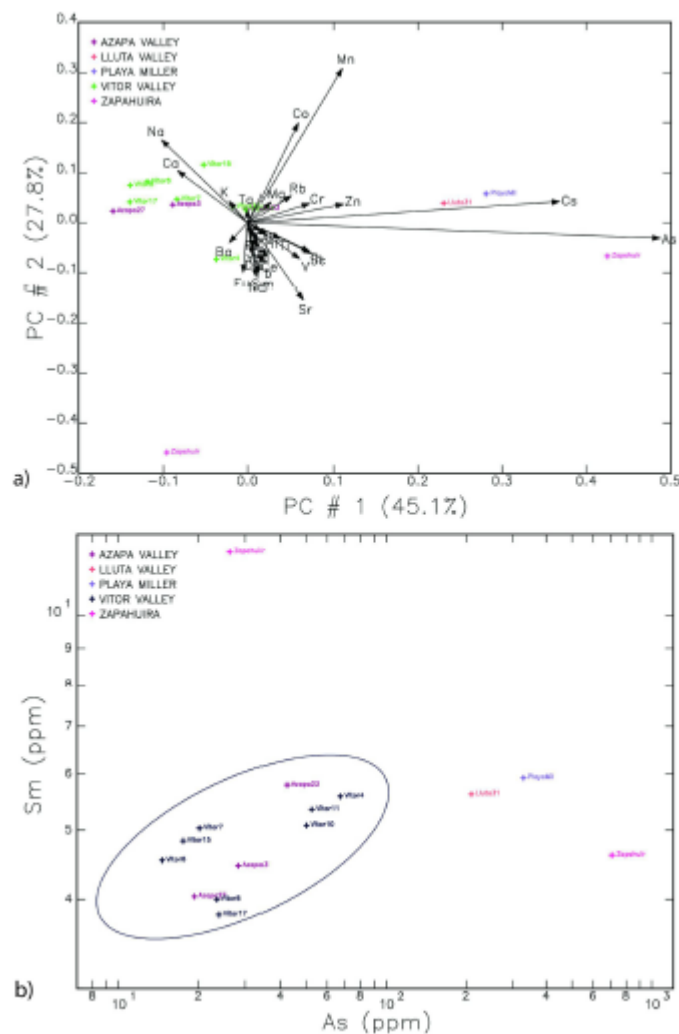


Figure 4

(a) A biplot of the first two principal component scores for the clay data set, which describes 72.9% of the cumulative variation in the data set. (b) A bivariate log-log plot of the samarium (Sm) and arsenic (As) concentrations for the clay data set. The confidence ellipse for the Vitor samples is 90%.

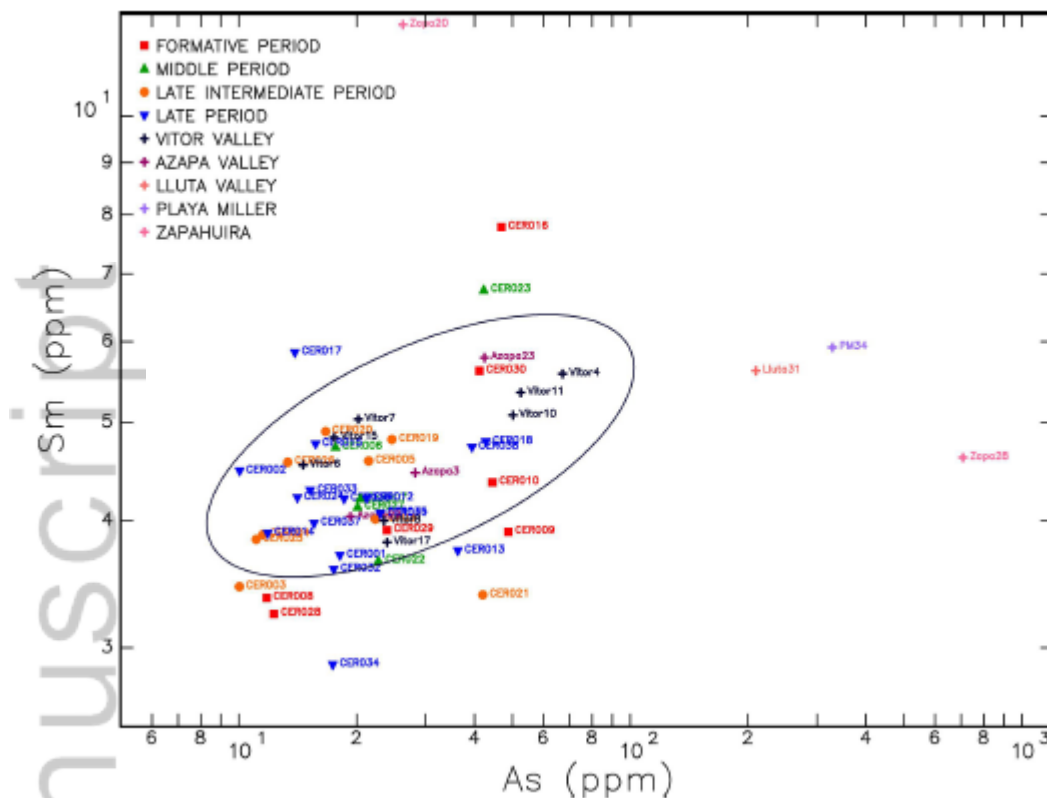


Figure 5

A bivariate log–log plot of the samarium (Sm) and arsenic (As) concentrations for the domestic ceramics (in their temporal periods) and the clay samples. The Vitor Valley ellipse represents a 90% confidence interval of group membership.