BGSG

Volume 55

Review Paper

Correspondence to:
Argyrios Periferakis
argyrisperiferakis@gmail.com

DOI number:
http://dx.doi.org/10.12681/bgsg.20997

Keywords:
obsidian, South America, Inca, pre-Columbian civilisations

Citation:
Periferakis, A. (2019), A review of obsidian source exploitation in pre-columbian south America, Bulletin Geological Society of Greece, 55, 65-108.

Publication History:
Received: 12/08/2019
Accepted: 11/10/2019
Accepted article online: 15/10/2019

The Editor wishes to thank Ms Mailinta Tsampiri for her work with the scientific reviewing of the manuscript and Ms Emmanouela Konstantakopoulou for editorial assistance.

A REVIEW OF OBSIDIAN SOURCE EXPLOITATION IN PRE-COLUMBIAN SOUTH AMERICA

Argyrios Periferakis[1]

[1]National and Kapodistrian University of Athens, Department of Geology and Geoenvironment, University Campus, Ilissia, 15784, Athens, Greece

argyrisperiferakis@gmail.com

Abstract

The focus of this paper is the obsidian quarries of the Pacific coast of pre-Columbian South America, which were exploited by the indigenous populations since ca. 11000 BC. The importance of obsidian in geoarchaeology and palaeoanthropology has already been demonstrated in sites from all around the world. In this paper, the presence of obsidian in correlation to tectonic activity and volcanism of South America is presented, along with the main sources in their regional geological context. Obsidian artefacts were the mainstay of everyday life of indigenous populations and obsidian was also used in manufacturing weapons. Despite advances in metallurgy, which were comparable with those of contemporary European states, obsidian was never supplanted by metal implements and weapons, until the Spanish conquest. Obsidian is as useful today, as it was to these civilisations, albeit in the different role, of discerning interactions between local societies, elucidating aspects of everyday life, and tracing palaeomobility and trade networks.

Keywords: *obsidian, South America, Inca, pre-Columbian civilisations*

Περίληψη

Το θέμα αυτού του άρθρου είναι τα ορυχεία οψιδιανού της ακτής του Ειρηνικού ωκεανού της Προκολομβιανής Αμερικής, των οποίων η εκμετάλλευση είχε αρχίσει από τους ιθαγενείς πληθυσμούς περίπου από το 11000 π.Χ. Η σημασία του οψιδιανού στην γεωαρχαιολογία και στην παλαιοανθρωπολογία έχει ήδη αποδειχθεί σε περιοχές από όλα τα μέρη του κόσμου. Σε αυτό το άρθρο, παρουσιάζεται η ύπαρξη του οψιδιανού, συναρτήσει της τεκτονικής δραστηριότητας και της ηφαιστειότητας της

Νοτίου Αμερικής, μαζί με τα κύρια ορυχεία στο τοπικό γεωλογικό τους πλαίσιο. Τα αντικείμενα από οψιδιανό ήταν ο στυλοβάτης της καθημερινότητας των ιθαγενών πληθυσμών και ο οψιδιανός χρησιμοποιούνταν επίσης και στην κατασκευή όπλων. Παρά την πρόοδο στην μεταλλουργία, η οποία ήταν συγκρίσιμη με αυτήν συγχρόνων Ευρωπαϊκών κρατών, ο οψιδιανός δεν αντικαταστάθηκε ποτέ από μεταλλικά αντικείμενα και όπλα, μέχρι και την κατάκτηση από τους Ισπανούς. Ο οψιδιανός είναι χρήσιμος ακόμη και σήμερα, όπως και σε αυτούς τους πολιτισμούς, μολονότι σε έναν διαφορετικό ρόλο, αυτόν της διάκρισης των αλληλεπιδράσεων μεταξύ τοπικών κοινωνιών, της διαλεύκανσης όψεων της καθημερινής ζωής, και της ιχνηλασίας της παλαιοκινητικότητας και των δικτύων εμπορικής συναλλαγής.

Λέξεις κλειδιά: *οψιδιανός, Νότια Αμερική, Ίνκας, Προκολομβιανοί πολιτισμοί*

1. INTRODUCTION

The importance of lithic materials for human populations since an early stage in human Prehistory has been the subject of many studies. The transition from hunter-gatherer groups to more permanent societies signalled the need for the establishment of a social structure, formulated by reciprocal transactions, thus leading to a bartering system. The development of agricultural and hunting activities, as well as the emergence of primitive warfare between different social groups was based on the utilisation of suitable natural materials. Ever since the development of the Pastoral Neolithic - between ca. 2550 BC and ca. 750 AD, applying solely to the Neolithic of Africa (Garcea, 2004) - the use of obsidian tools became widespread and lead gradually to the development of a specialised working class (Merrick & Brown, 1984). However, obsidian tools are also found in Palaeolithic sites - the term «Palaeolithic» describes a very broad period of human Prehistory which ends at around 9700 BC (Toth & Schick, 2007) - such as the Franchthi Cave in Greece (Aspinall et al., 1972), in which case obsidian has been documented as originating from Melos Island (Jacobsen, 1969). Relevant evidence suggests the use of obsidian tools from even earlier individuals and societies in different parts of the world (Gallotti & Mussi, 2015). During the Bronze Age in Europe - in general the Bronze Age succeeds the Neolithic age at regional levels, and in the Aegean it starts at around 3700 BC (Bader, 2015), ending with the Mycenean Period, ca. 1100 BC (Weiss, 1982) - the use of bronze implements was supplemented by the use of obsidian implements (Tsampiri, 2018). The trade of obsidian was an important factor in the economic growth of Neolithic - this term, as well as the aforementioned temporal divisions, represents a slightly different timespan depending upon the locality; in

Europe, the Neolithic age starts at ca. 7000 BC and ends at ca. 3000 BC (Ammerman & Cavalli-Sforza, 1971) - and Bronze Age societies and, by implication, in the exchange of cultural and technological elements between different populations (Oka & Kusimba, 2008).

Specifically in South America, the intense volcanic activity and the presence of rhyolitic extrusives meant that obsidian was available in many different places, in different varieties, and quantities. Obsidian tools and implements were of prime importance since the time of hunter-gatherer populations, because foraging for food resources is linked to lithic technology and therefore to accessibility to obsidian acquisition and adequate knapping skills (Barbarena et al., 2018). Later more advanced societies, like the Wari, Tiwanaku and Inca, used obsidian for tools, weapons, medical implements and as a precious rock.

Likewise, around the Mediterranean, obsidian was used from the Early Neolithic up to the Early Bronze Age in some sites. Interestingly, in many sites, and mainly in the islands of central Mediterranean, obsidian artifacts often constitute a comparatively small part of the lithic assemblage. Most obsidian artefacts from these sites are either - weapons - arrowheads spearheads, blades - or tools - scrapes for animal hides, knives for cutting meat, and harvesting implements - which were most often the result of trade from places over 500 Km away (Tykot, 2011, 2017). Gradually, with the advances in metallurgy, obsidian was sidelined, but up until Roman times, varieties of obsidian were considered to be precious ornamental stones, (Schumann, 2013). It is this decline in the use of obsidian over the centuries which differentiates Europe from South America. Whereas obsidian was sidelined in favour of metal implements in Europe, native South American and Mesoamerican civilisations continued using obsidian well into the 16th century AD.

The archaeological focus on obsidian is intense and this is attributable to the near omnipresence of obsidian artefacts in pre-Bronze Age archaeological sites (Figure 1), not just in Mesoamerica and South America (Levine et al. 2011) but in Europe (Tsampiri, 2018) and Africa too (Gallotti & Mussi, 2015). In modern multidisciplinary research, obsidian distribution in archaeological sites is used in conjunction with other archaeological, palaeoanthropological and biogeographical data, to map not only ancient trading networks, but also to document human habitation patterns and cultural exchange instances. The chemical variation of obsidian from different sources allows, in many cases, to pinpoint the original site of obsidian mining (Brooks et al., 1997), and thus to formulate an understanding of regional and state patterns of behaviour (Salgán et al., 2015), in ancient trading and communication networks, and to offer an insight in the socioeconomic conditions prevailing in ancient settlements and social groups (eg. Heizer et al., 1965; Renfrew et al., 1966; Griffin et al., 1969; Mohr Chávez, 1977, 1982a, 1982b, 1983; Burger & Asaro, 1982; Burger et al., 1984).

The purpose of this article is to present concisely the sources of archaeological obsidian along the Pacific coast of South America, which were exploited by pre-Columbian societies, focusing mostly on the Inca Empire. The impact of the geological availability of raw materials, and by implication the impact of geology, in the historical course of civilisations, has already been mentioned by various authors (Ingbar, 1994; Shackley, 2005; Balkan-Atli et al., 2008; Nezafati et al., 2008; Özdoğan, 2008; Hirt, 2010; Beck and Jones, 2011; Moratto, 2011; Periferakis, 2019a, 2019b, 2019c; Periferakis & Paresoglou, 2019). In the course of this article, obsidian availability will be presented in correlation to geology on a regional and continental scale, followed by a brief presentation of the historical context, and the ultimate effects of the availability of obsidian in the sociopolitical structure and everyday life of pre-Columbian civilisations.

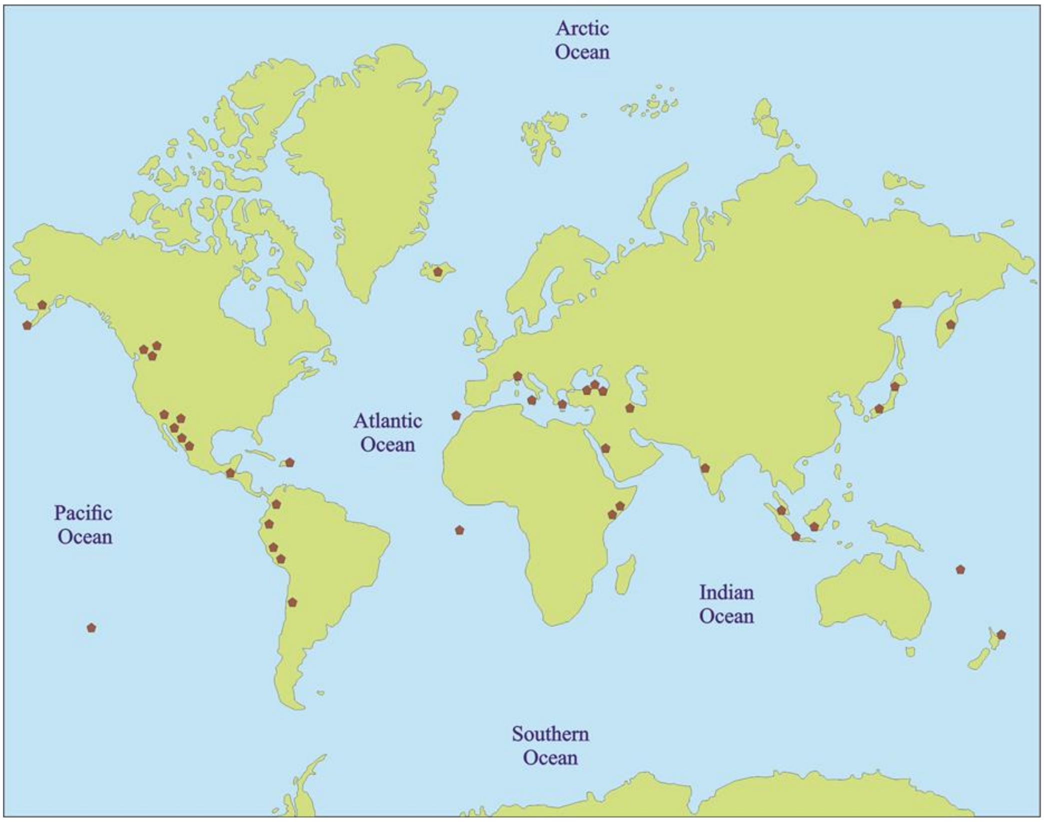

Fig. 1: A schematic map of the global distribution of obsidian sources, based on the data of Heide & Heide (2011).

2. OBSIDIAN FORMATION, PROPERTIES AND SIGNIFICANCE IN GEOARCHAEOLOGY

Summarily, obsidian is a silica-rich volcanic rock, in essence a volcanic glass, with a distinctive conchoidal fracture, formed by the rapid cooling of viscous acid lava (Pellant, 1992). It is this conchoidal fracture which allows for the easy manufacturing of many types of materials and weapons. Obsidian, if worked properly, has the sharpest edge amongst lithic materials, and is sharper than even many steel and iron tools (van Tuerenhout, 2005).

Obsidian is one amongst many of volcanic glasses (Table 1), and along with perlite and pitchstone, takes up most of the volume of volcanic glasses on Earth (Heide & Heide, 2011). These volcanic glasses are formed by the cooling of siliceous melts close to or on to the surface. Obsidian occurs as a result of rhyolitic to rhyodacitic volcanism, in subduction settings namely in the circum-Pacific belt, the Alpine mountain belt between the Alps and the Himalayas, New Guinea, and New Zealand (Wyllie, 1971); around intra-plate volcanoes, like those found at Easter Islands, Reunion and the Canaries, and hot-spot volcanoes, like those of Yellowstone (Heide & Heide, 2011).

According to Keary et al. (2009), the youngest obsidian formations are reported in Iceland and California, while there is no known current obsidian-producing magmatism. Particularly for South America, and in the context of geoarchaeology, the obsidian sources of interest are dated between Miocene and Pleistocene. So, obsidian can be found both in active continental arcs, be they at an early stage or not, and in extensional zones of continental cratons and ocean basins (Macdonald et al., 1992). Obsidian can occur either as elongated flows, with a thickness of up to 10 m, as domes or as nodules and as interbedded glassy strata in a felsic framework (Heide & Heide, 2011). Obsidian-forming melts can differ chemically, and accordingly their rheology depends upon the water content, the temperature, the dimensions of the magmatic chamber, the presence of volcanic vents and the strong volatile gradient assumed for most such magma chambers (Hildreth, 1981). Various researchers (Dingwell, 1987; Dunbar et al., 1989) have commented on the complex reactions between F, H_2O and Cl, noting that a complete understanding of these reactions is necessary in order to deduce the rheological characteristics of obsidian forming melts. Castro et al. (2002) also note that the viscosity, and hence the rheology, of such melts, is controlled by the orientation of crystal microlites, whose alignment is parallel to the flow's direction (Wagner, 2003).

<table>
<caption>Table 1: Types and Characteristics of Volcanic Glasses</caption>
<tr><th>Type of Volcanic Glass</th><th>Chemical Composition</th><th>Colour</th><th>Texture</th><th>Occurrence</th><th>Geological Setting</th><th>References</th></tr>
<tr><td>Obsidian</td><td>Mostly rhyolitic subalcalic silicic rocks (SiO_2>70 %), with a normative excess of corundum</td><td>Black to bluish black</td><td>Presence of granular and idiomorphic crystals and microlites</td><td>Either as elongated flows or as domes, nodules and interbedded glassy strata in a felsic framework</td><td rowspan="2">Active continental arcs and extensional zones of continental cratons and ocean basins</td><td rowspan="2">Carmichael (1962); Ross (1962); Macdonald et al. (1992);</td></tr>
<tr><td>Pumice</td><td>Rhyolitic alkalic to subalkalic rocks</td><td>White to light grey</td><td>Highly vesicular frequently with complete absence of crystals</td><td>As elongated flows and as fragments and blocks around volcanoes</td></tr>
<tr><td>Perlite</td><td>Essentially hydrated obsidian, with rhyolitic to dacitic composition</td><td>White to dark grey</td><td rowspan="2">Characteristic perlitic texture, with concentric fissures in a vitreous matrix createing pearl-like spheres</td><td>Mostly as effusive flows, and frequently on top of obsidian flows. Alternatively, perlite flows are found on top of domes and dykes</td><td>Collision-related settings. Frequently found in close association with obsidian. Perlites are believed to occur in submarine environments</td><td>G. Heide et al. (2001); Heide & Heide (2011)</td></tr>
<tr><td>Pitchstone</td><td>Rhyolitic to trachytic composition</td><td>Black to dark grey</td><td>Believed to be the result of cooling of a melt with high water content in sills and dykes</td><td>Collision-related settings.</td><td>Zirkel (1866); Thorpe & Thorpe (1984)</td></tr>
<tr><td>Tachylite</td><td rowspan="2">Basaltic glasses , with wide-ranging composition from tholeiitic to strongly alkalic</td><td>Black to dark brown</td><td rowspan="2">Textures vary significantly between different occurences depending upon the available nuclei for vitrification</td><td rowspan="2">Surface of sub-aerial or sub-volcanic flows, on the selvage of basaltic sills and dykes and also in meteorites</td><td rowspan="2">Around volcanoes with the appropriate geochemical character of lava effusions</td><td rowspan="2">Stroncik & Schmincke (2002) Heide & Heide (2011)</td></tr>
<tr><td>Sideromelane</td><td>Yellow to brown</td></tr>
</table>

While obsidian is regarded as being the product of rapid melt cooling, in reality the cooling rate of rhyolitic glasses is only rapid in comparison to the cooling rate of basaltic glasses, and studies on cooling rates are nowadays conducted using the Differential Scanning Calorimetry method, known as DSC (Heide & Heide, 2011).

Results from the geospeedometre developed on the basis of this method indicate that the cooling rate of rhyolitic glasses varies between 1 ° K/sec and 1 ° K/day (Wilding et al., 1995; Gottsmann et al., 2002). While some volatiles escape from the magma, most of them are frozen within the glass matrix of the obsidian, at different temperatures (K. Heide et al., 1996).

The textural analyses of different obsidian samples indicate that the structural characteristics of this volcanic glass cannot, usually, be attributed to a single cooling process (Heide & Heide, 2011). From a geochemical point of view, obsidians are rhyolitic subalkalic silicic rocks with a SiO_2 wt. % greater than 70 (Carmichael, 1962). The variations of trace elements in obsidian samples, namely Th, Cs, Hf, La, and Ba, are instrumental in geoarchaeology, for use in obsidian provenance studies (Oddone et al., 2000). Mineralogically, apart from amorphous silica, obsidian may frequently contain alkali feldspar, plagioclase, biotite, pyroxene, amphibole and Fe-Ti-oxides, while zircon, apatite, garnet and quartz are scarcer (Viramonte et al., 1994; Gautier et al., 1994).

3. TECTONICS AND VOLCANISM OF THE ANDEAN CORDILLERA

The mountain range of the Andes is the most extensive active orogenic system, stretching across more than 8000 Km, along the Pacific coast of South America, starting from the Caribbean, all the way to the Tierra del Fuego Island. According to Gansser (1973), the Andes can be divided in three parts, the Northern, Central and Southern Andes, based on petrological, geochronological, and structural evidence (Fig. 2).

Along the Pacific margin of South America subduction has been continuous at least since the Jurassic (Flament et al., 2015). The Pacific margin of South America itself was the result of the breakup of the Rodinia continent. All the terranes of the Pacific margin have a Mesoproterozoic age basement as an important structural component, with very few exceptions (Keppie & Dostal, 2007; Ramos, 2008, 2009). Some of the blocks of Rodinia remained attached to South America whereas others stayed in Laurentia. According to Cawood (2005), the breakup of Rodinia accelerated the opening of the Pacific Ocean. This massive cordillera is divided into different morphotectonic units which reflect the diverse temporal and spatial geological history and development of different parts of the Andean orogeny (Ramos, 2009).

The Northern Andes are characterised by a complex tectonic evolution, in part determined by the interaction with the Caribbean plate, whose start can be traced at the breakup of the Pangea (Ramos, 1999). This interaction resulted in the accretion of oceanic crust to the Northern Andes, with the obduction beginning in Early Cretaceous (Ramos, 2009). The Central Andes constitute a typical Andean-type orogen, exhibiting different uplift mechanisms, mostly within a compressional tectonic regime, driven by subduction. Several compressional pulses have resulted in important crustal thickening in the Central Andes (Allmendinger et al., 1997), and, according to Isacks (1988), the present uplift of the Altiplano plateau is thermally induced. The Southern tip of the Andean Cordillera is bounded by the Scotia Plate, in a tectonic setting dominated by strike-slip faults. The result of this tectonic regime is the removal of continental crust which is then transported to the Scotia Ridge (Cunnigham et al., 1995; Barker, 2001). The Southern Andes are developed to the South of the Chile Triple junction (Gorring et al., 1997).

The unifying factor of the present diverse tectonostratigraphic terranes of the Andes is the flat slab subduction configuration (Figure 2), which determines the absence or presence of magmatism, and the regional structural evolution. It is believed that there have been changes in the geometry of subduction, which have brought about changes in the topography of South America since the Miocene (Guillaume et al., 2009; Dávilla & Lithgow-Bertelloni, 2013, 2015). Climatic factors have also a dominant role in the present-day morphology of the Andes (Montgomery et al., 2001; Ramos & Ghiglione, 2008). The diverse geochemical characteristics of the igneous rocks of the Andean Cordillera have been the subject of studies from early on (e.g. Iddings, 1893). Modern studies (e.g. Kay & Abbruzzi, 1996; Ramos, 1999) assert that the volcanism of the Pacific coast of South America is defined by the subduction geometry, and four distinct volcanic zones can be delineated (Table 2). The areas of flat-slab subduction in essence delineate the temporal and spatial shifting of volcanism in the Andes, with magma fractionation becoming more pronounced to the South, while magma volume decreases in that direction.

The Northern Volcanic Zone (NVZ) extends on the Western and Central Cordilleras of Colombia, and continues to the depression of Ecuador. The lavas of the NVZ volcanoes, and the associated magmas, exhibit a medium degree of fractionation, ranging from basaltic andesites to andesites (Thorpe, 1984). According to Harmon et al. (1984), the magmatism of the NVZ is the result of fractional crystallisation of the asthenospheric wedge, with contributions of oceanic lithosphere and possibly of younger continental crust as well. The Central Volcanic Zone (CVZ) extends on the Western Cordillera of Peru, bounding the Altiplano, and comprises hundreds of volcanoes. Dacitic and andesitic lavas are dominant, while Late Cenozoic dacitic ignimbrites are present in significant volumes (Davidson et al., 1993).

Fig. 2: Simplified tectonic map of the Andean orogen, after Ramos (1999, 2009). The Pacific coast of South America is divided into three distinct segments, separated by flat slab subduction areas. In addition, the geometry of subduction and its temporal and spatial variations have resulted in the emergence of four volcanic zones, with three volcanic gaps in-between.

Table 2: Volcanic Zones and Volcanoes of the Andean Cordillera			
Volcanic Zone	Limits	Major Volcanoes	References
Northern Volcanic Zone	5° N to 2° S	Nevados de Ruiz, Galeras, Cerro Bravo, Mojanda, Chimborazo, Pichincha	Méndez Fajury (1989);
Central Volcanic Zone	16° S to 26° S	Villarica, Llaima, Tupungatito, Lascar	Muñoz (1983); Gardeweg et al. (1998)
Southern Volcanic Zone	34° S to 46° 30 S	Tupungato, San José, Lonquimay, Hudson	López Escobar et al. (1995)
Austral Zone	47° S to 55° S	Lautaro, Aquilera, Diablo, Burney, Cook	Stern & Kilian (1996)

Hilderth & Moorbath (1988) have concluded, based on geochemical and isotopic data, that there was an extensive modification of magmas from the mantle, during their ascend through the crust, which can reach a thickness of 70 Km. Coira et al. (1994) and Kay el al. (1999) have concluded that there was a significant change in the subduction geometry, based on the presence of rhyolitic and dacitic calderas, along with associated ignimbrites, which in turn indicates a steepening of the Wadati-Benioff Zone.

The Southern part of the Central Andes comprises the Southern Volcanic Zone (SVZ), and is characterised by Late Cenozoic magmatism. In the Northern part of the SVZ, where crustal influence is more pronounced, the magmas and the associated lavas are of basaltic to andesitic affinities, while the Southern part of the SVZ is characterised by magmas of rhyolitic to basaltic affinities (López Escobar et al., 1995). In the Northern part of the SVZ there is also significant retroarc alkaline basaltic magmatism, associated with the trenchward migration of the volcanic front (Muñoz & Stern, 1988). Finally, Stern & Kilian (1996) defined the Austral Volcanic Zone (AVZ) as the area comprising the volcanoes of the Patagonian Andes, where volcanism is associated with ridge subduction (Stern, 1991). The lavas are mostly adakitic, and are the result of the partial melting of the subducted slab and of contributions by the asthenospheric wedge.

The volcanic and tectonic setting of the Andes has provided favourable conditions for the formation of obsidian deposits, since the Pliocene (Muñoz & Stern, 1988; Kay et al., 2006). Of the most interest to this research are the Northern and Central Volcanic Zones, where the presence of rhyolitic to rhyodacitic magmatism created the proper conditions for the formation of voluminous obsidian deposits. Some minor obsidian sources are also found at the Northern limits of the South Volcanic Zone.

4. HISTORICAL OVERVIEW

The documented existence of human populations in South America dates back to 35000 BC. Between this date and the emergence of organised city-states and sociopolitical entities millennia ensued. While there are numerous archaeological evidences for the use of lithic materials, namely flint and obsidian, by these populations, further examination is beyond the scope of this article. Thus, the historical background provided here will commence from the culture of the Chavín. For easier reference to the archaeologically defined cultural historical periods of South America, these are provided in Table 3, although for reasons of simplification they will be minimally referred to within the text.

Table 3: Archaeological Cultural Periods of Precolumbian Andes*

Cultural Period	Time Span	Corresponding Major Cultures†
Andean Pre-Ceramic	ca. 9500 BC - 900 BC	-
Andean Ceramic - Initial Period‡	1800 BC - 900 BC	-
Andean Ceramic - Early Horizon‡	900 BC - 200 BC	Chavín, Marcavelle
Andean Ceramic - Early Intermediate Horizon	200 BC - 600 AD	Moche, Nazca, Chanapata
Andean Ceramic - Middle Horizon	600 AD - 1000 AD	Wari, Tiwanaku
Andean Ceramic - Late Intermediate Horizon	1000 AD - 1476 AD	-
Andean Ceramic - Late Horizon	1476 AD - 1534 AD	Inca

* Based on the cultural-chronological delineation of Lanning (1967)

† Only cultures mentioned in this article

‡ Alternatively referred to collectively as the Formative Period

4a. South America before the Inca

The Inca conquest of the East part of South America, and much more so the ensuing Spanish conquest of the Inca themselves, had a homogenising effect on the indigenous populations, which were, at first, different ethnic groups, speaking different languages and having different customs. The absence of native historical records and the, many times vague, archaeological ones, do not permit a full understanding of the pre-Inca cultures.

The earliest evidence point to an enigmatic civilisation, termed the Chavín by modern researchers, who appeared in South America around 1400 BC, and by 500 BC their influence had extended from Cajamarca to the North, to Ayacucho to the South. The Chavín took their name from the archaeological site of Chavín de Huantar, where evidence of their existence was first discovered (Burger & van der Merwe, 1990). Very few things are known about this peculiar culture, who was however quite advanced in terms of architecture, sculpture, metalworking, and arts. They were characterised by elaborate rituals, which meant that quite possibly, religion was the cardinal unifying feature of their society (Contreras, 2017).

At roughly the same temporal period the Marcavelle culture occupied the future heartland of the Inca Empire. However, after 400 BC, for reasons as yet unknown, the Chavín were supplanted by the Moche to the North and by the Nazca to the South. In the broader region of Cuzco, the Chanapata are thought to be have replaced the Marcavelle (McEwan, 2006).

Gradually, the first South American empires would arise, encompassing different cultures and covering large expanses. In the Southern Andes, the Tiwanaku Empire emerged, named after the major settlement developed by the shores of Lake Titicaca (Kolata, 1993). The expansion of this Empire (Fig. 3) started in 500 AD, and continued for several centuries, until its decline and disappearance, sometime between the 11^{th} and 13^{th} century AD.

The great Northern empire, the Wari Empire was developed around its capital, at Ayacucho Valley in the Central Peruvian Andes. Between 540 AD and 640 AD the Wari conquered the surrounding areas, including Cuzco (Fig. 3). Their empire lasted up to around 1000 and 1100 AD, when it was rapidly dissolved, probably as a result of organisational and economical problems. The absence of written records does not allow for an understanding of the causes behind the collapse of these Empires (Pemberton, 2011).

Both the Tiwanaku and the Wari Empire left an enduring cultural legacy, and paved the way for the development of the Inca Empire. Between the dissolution of these Empires and the ascendance of the Incas, many small kingdoms and city-states developed in these areas, enriching the cultural mosaic of the soon-to-be Inca Empire (McEwan, 2006).

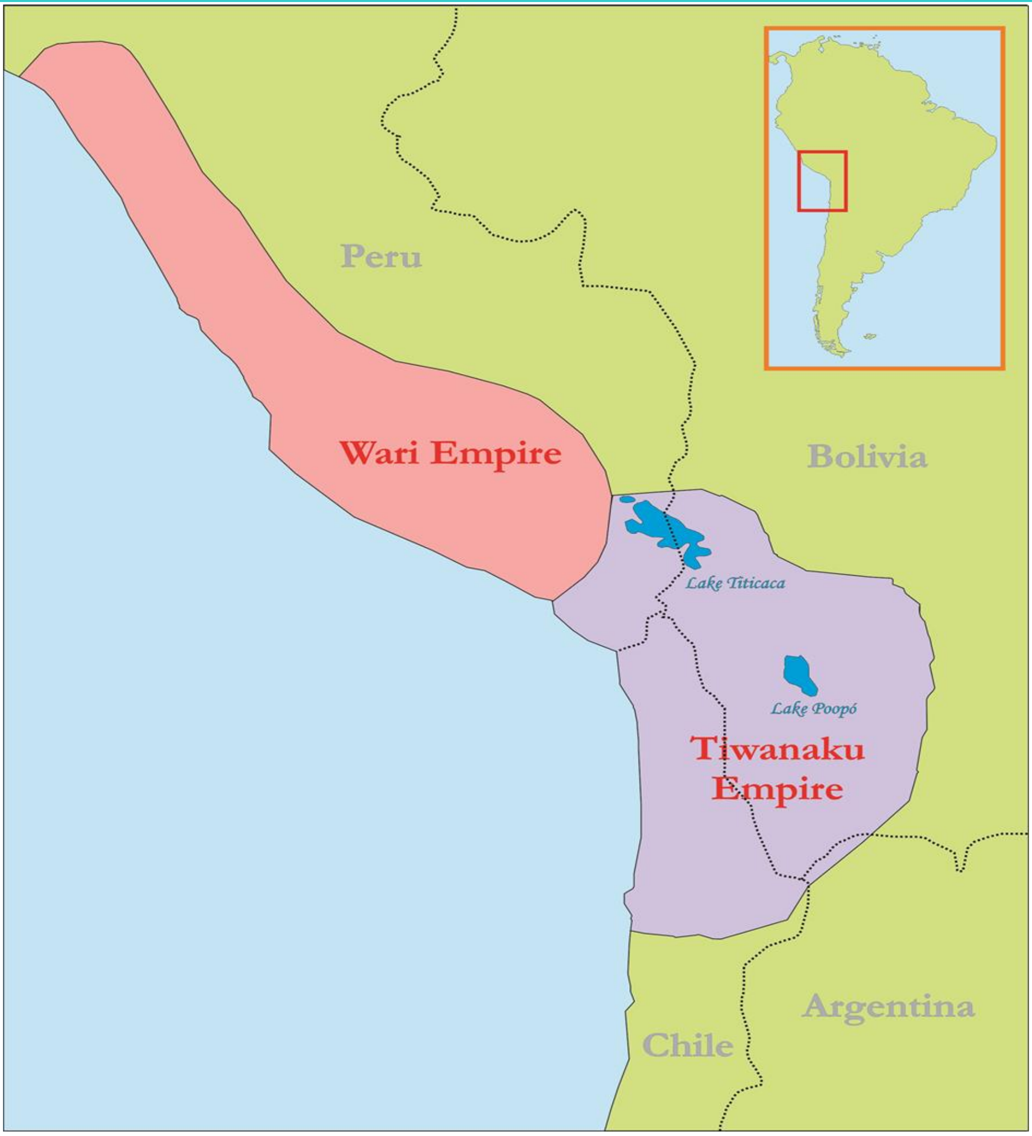

Fig. 3: Schematic map of the estimated areas covered by the Wari and Tiwanaku Empire, according to McEwan (2006). The dashed lines indicate the borders of modern-day states.

4b. The Empire of the Inca

The Inca were, for about a century, between 1438 and 1532 AD, the dominant power in Andean South America, encompassing modern-day Peru, parts of Ecuador, Chile, Argentina, Colombia and Bolivia (Fig. 4). Within the approximately 906000 Km^2 of the Inca Empire, which the Inca called «the Land of the Four Quarters» - «Tawantinsuyu» in the native language, named so because it consisted of the provinces of Chinchaysuyu, Antisuyu, Qullasuyu and Kuntisuyu, the names corresponding to the North, East, South and West province respectively; the native word «suyu» is translated as «region» - there existed a multitude of environments, from seashores to plateaus, from deserts to tropical lowlands. The term «Inca» ment «lord» in the native language, and was used by the Spanish to describe the Empire and its inhabitants (McEwan, 2006).

Historical sources place the appearance of the first Inca around 1200 AD, at a place not far from Cuzco. The term «Inca» or «Incas», has been used in literature to refer to the Empire itself, to its inhabitants and to its supreme ruler, known as the Sapa Inca. However, conquered peoples were not mentioned by that name, and they were just subject individuals, who were allowed a modicum of private cultural and religious freedom, as long as they conformed to the general sociocultural and political framework of the Empire (Somervill, 2002).

The first Inca ruler, Manco Capac, is a figure shrouded in myth, but it is probable that he was a real historical figure, who emerged as the leader of a Andean small clan, founding the City of Cuzco, at around 1200 AD. The Inca themselves claimed to have come from caves at Pacariqtambo - a place about 30 Km away from Cuzco, whose name translates to «house of production» - while some legends also mention some island in Lake Titicaca, as their ancestral ground. Manco Capac was regarded as an offspring of Viracocha, which was the Creator in the Inca mythology.

Those three caves were named Maras Tocco, Sutic Tocco, and Capac Tocco, with the latter being the central one, from where eight married couples, four brothers and four sisters, emerged to form the ancestors of Inca royalty. From the other two caves, the ancestors of Inca commoners came forth. Amongst the four male siblings, Ayar Manco, which was later named Manco Capac - which can be broadly translated as king or ruler; therefore Capac Tocco means the Cave of Kings, «tocco» being the native word for cave - was selected to lead the group. In order to select where to settle he used a golden rod to test the ground, finally founding Cuzco in the place where the rod sank to the ground. From then on, under the leadership of Manco Capac, the ancestors of the Inca, conquered the local peoples. One of the sons of Manco Capac, Sinchi Rocha, succeeded his father as the next King of the Incas. Although there are other legends pertaining to the emergence of the Inca mentioned by early chroniclers (e.g. de Gamboa, 1572; de la Garcilaso, 1609) this one is the dominant version in the various iterations of the Inca mythology (McEwan, 2006; Pemberton, 2011). In any case, the Inca rulers chose to portray themselves as being offsprings of the gods, who came about to invent culture and civilisation, and to subdue the «lesser» pre-existing populations.

Through political alliances and military endeavours, the Inca gradually began to acquire more power and expand their territory. Upon solidifying their power, after 1438 AD, the Inca set in motion an intensive building programme, founding new cities, building forts and unifying their ever-expanding territory (Fig. 4) by building royal highways (McEwan, 2006). It seems that the Inca preferred diplomacy rather than warfare as a means of expanding their rule, but if their diplomatic overtures were met with intransigence, a war of expansion was very likely to follow. While some tribes undoubtedly welcomed the safety provided by the Inca army, against other invading tribes, many others resented the rule of the Inca, but any dissidents were usually swiftly subdued (Pemberton, 2011). Towards its end, between 1525 and 1529 AD the Empire was decimated by an epidemic, most probably smallpox, brought about by the Spanish. This epidemic resulted in the deaths of the Inca Emperor and his heir, bringing about a civil war, which further depleted the manpower of the Empire.

In 1532 AD, Pizarro arrived at Peru, precisely at the moment of the power shift from the defeated aspiring emperor to the winner, finding the Empire still recovering from a bloody civil war. While, the Spanish defeated the bulk of the Inca army within a year, the conquest of the Inca was not completed until 1572 AD, when the last mountain strongholds were subdued.

The engineering and technological feats of the Empire are admirable to this day. From the metalworking and gilding techniques, to temple building and to the construction of a vast roadway network, by far superior to anything found in Europe at the time, the Inca Empire was a compete sociopolitical entity, which had achieved its status without any of the cultural and technological advances considered paramount for any contemporary European power. The conspicuous absence of animals for riding and hauling, of wheeled vehicles, of a system of writing and of knowledge of iron and steel did not inhibit the Incas in their quest for power and expansion (McEwan, 2006). The Andean environment, to which most of the Incas lived, was and remains to this day, challenging for human survival and habitation. To the South the desert environment of Chile and to the North, the dense Amazonian forests present other, but equally difficult to surmount, difficulties (Burger, 1992). Yet in each and every case the Incas managed to create permanent settlements and the assorted infrastructure. Practically, the regulator of significant settlement appearance was the availability of water.

Fig. 4: A map of the maximum estimated extent of the Inca Empire after Somervill (2004), McEwan (2006) and Pemberton (2011). The thin black lines represent the borders of the modern states of South America.

5. OBSIDIAN QUARRIES OF SOUTH AMERICA

As a tool for archaeology, obsidian is of cardinal importance, since it permits the reconstruction of widespread trading networks, through correlation of obsidian artefacts with their sources, using chemical analyses (Hirth, 2006). Moreover, Santley (1984, 1989) and Spence (1981,1984) have suggested that the import and use of obsidian was an instrumental factor in the formation of complex pre-Columbian societies and the preservation of obsidian tools in the archaeological record provides a comprehensive view of the material aspect of different cultures (Hirth et al., 2013). These possibilities of elucidation of the past are even greater in the case of pre-Columbian civilisations, where there was a multitude of exploited sources (Figure 5), which have mostly been identified, through geochemical fingerprinting, while some remain elusive to this day (Burger et al., 2000).

Not all obsidian sources available to the indigenous South Americans were equally exploited, and this was not only due to obsidian quality but also depended upon a sources' accessibility (Shackley, 1992). The earliest evidence of exploitation, are found in the Alca and Chivay sources, where archaeological research has documented quarrying activities since ca. 11000 BC and 9400 BC respectively (Burger et al., 2000). Obsidian sources in South America can be divided roughly in two groups: high altitude sources and low altitude sources. This categorisation is important, since altitude determines, at least partly, accessibility and permanent habitation, hence becoming a factor in obsidian exploitation and export from each site. In general, high-altitude sources were characterised by semi-permanent habitation and exploitation (Barbarena et al. 2011), or at least a reduction in exploitation during those months with adverse weather effects. Low-altitude sources were continuously accessible, and hence exploitation and transport of obsidian was much easier. In Table 4 the elevation of the obsidian sources examined in this article is presented, for the purposes of determining a source's accessibility and interpreting relevant archaeological record. In general, all the Pre-Hispanic societies and civilisations of South America used obsidian for utilitarian and ornamental or religious purposes.

A common feature in all these societies and sociopolitical entities is that metallurgy, as developed in the Old World, never replaced the use of various stones for the manufacturing of everyday items (Pastrana & Carballo, 2016). Although there are many documented obsidian sources used in modern-day Peru, Chile and Ecuador, which were exploited during pre-Hispanic times, the bulk of the obsidian artefacts found originate from three major sources: Quispisisa, Chivay and Alca. According to Sandweiss et al. (1998), the sparsely distributed sources of high quality obsidian in Peru were exploited from an early stage. Obsidian of lower quality was avoided when and where possible, giving a significant impetus for the establishment of early trading networks. The identified Peruvian sources for this lower quality obsidian - which will not be examined further in this paper - are Anillo, Jampatilla, Lisahuacho and Potreropampa (Eerkens et al., 2010).

Obsidian Source	Region	Elevation (m)	References
Quispisisa	Ayacucho District, Peru	3750	Burger et al. (2000); Burger & Glascock (2000a); Vaughn & Glascock (2005)
Puzolana	Ayacucho District, Peru	3400	Burger et al. (2000); Burger & Glascock (2000b)
Potreropampa	Chalhuanca District, Peru	4100	Burger et al. (2000, 2006)
Jampatilla	Ayacucho District, Peru	3500	Burger et al. (1998c)
Lisahuaco	Chalhuanca District, Peru	4000	Burger et al. (2000, 2006)
Anillo	Arequipa District, Peru	2850	Eerkens et al. (2010)
Alca	Arequipa District, Peru	2850	Burger et al. (1988a, 2000)
Chivay	Arequipa District, Peru	4900	Burger et al. (1988b, 2000); Tripcevich & Mackay (2011)
Mullumica	Pichincha Province, Ecuador	4300	Ogburn et al. (2009)
Callejones	Pichincha Province, Ecuador	4200	Ogburn et al. (2009)
Yanaurco-Quiscatola	Pichincha Province, Ecuador	4000	Ogburn et al. (2009)
Carboncillo	Loja Province, Ecuador	3000	Ogburn (2011)
Laguna del Diamante	Mendoza Province, Argentina	3000	Cortegoso et al. (2016)
Cerro Huenul	Neuquén Province, Argentina	1000	Cortegoso et al. (2016)
Las Cargas	Mendoza Province, Argentina	2500	Salgán et al. (2015)
Laguna del Maule	Talca Province, Chile	2300	Seelenfreund et al. (1996); Barbarena et al. (2019)

Table 4: Obsidian Sources Mentioned in the Text

The Quispisisa source in Ayacucho, is the source of the vast majority of obsidian artefacts of Central and Southern Peru (Burger & Glascock, 2000a; Eerkens et al., 2010). It is still doubtful if this is a case of a single obsidian outcrop being exploited, since around the site where an ancient quarry has been found, additional obsidian outcrops may have existed, or may still be there obscured by foliage - there is still the need for extensive field work in this particular site. This obsidian outcrop, located near Cerro Hatuntangra, has a minimum thickness of 30 m and displays a horizontal banding of quartz and feldspar crystals. According to Castillo et al. (1993) the Quispisisa obsidian outcrop belongs to the Grupo Barroso. This is a formation of andesitic lavas, which are dated between Late Miocene and Early Pliocene (Palacios et al., 1993). Carbon dating indicates that this source was exploited since 11000 BC, from hunter-gatherer populations. Archaeological evidence indicates that obsidian from this source was transported over 100 Km, between 11000 and 2000 BC to early settlers at Ayacucho, who were not apparently satisfied with the obsidian of the Puzolana source, which was nearby and significantly more accessible (Burger & Glascock, 2000a).

Fig. 5: Schematic view of the obsidian sources (after Brooks et al., 1997; Burger et al., 1998a, 1998b, 2000a, 2000b; Ogburn et al., 2009; Barbarena et al., 2011, 2019; Salgán et al., 2015) discussed in the text, in relation to the frontiers of the Inca Empire (after Somervill, 2004; McEwan, 2006; Pemberton, 2011) and the Cenozoic volcanism of the Andes (after Baker & Francis, 1978; Ramos, 1999, 2009). The numbers correspond to distinct sources: 1: Mullumica, 2: Callejones, 3: Yanaurco-Quiscatola, 4: Carboncillo, 5: Puzolana, 6: Quispisisa, 7: Jampatilla, 8: Potreropampa, 9: Lizahuaco, 10: Anillo, 11: Alca, 12: Chivay, 13: Laguna del Diamante, 14: Las Cargas, 15: Laguna del Maule, 16: Cerro Huenul.

The Chivay obsidian quarries, also found within lavas of the Grupo Barroso, were the source of the so-called "Titicaca Basin type" obsidian. Here, obsidian is presumed to have formed due to the rapid cooling upon contact with the older andesitic lavas and breccias of the Tacaza formation, which are dated between Early and Middle Miocene (Burger et al., 1998b). Archaeological evidence indicate that this source was quite extensively exploited before 600 AD, while newer obsidian artefacts, correlated with an earlier period of human habitation termed Pre-ceramic, indicate that this source was used for obsidian procurement since ca. 2500 BC (Tripcevich & Mackay, 2011).

Quite possibly this was the first major source used to supply obsidian for tool making to the inhabitants of the Titicaca basin. Obsidian artefacts from this source were also used by Browman (1974, 1975) and Flores (1990) to document the initial use of llama caravans for the transport of bulky and heavy commodities. The sociopolitical changes between ca. 2500 BC and ca. 1500 were reflected in the fluctuations of obsidian mining in Chivay, which for a time was, probably, the site of a frontier confrontation between the Wari and Tiwanaku Empires, and was subsequently also used by the Inca (Goldstein, 1990). According to Burger & Asaro (1977), this source was utilised continuously, by the Chavín, the Wari and finally the Inca. Each successive Empire intensified obsidian extraction and organised far-reaching trading networks, possibly utilising llamas. The shifting patterns of obsidian extraction and trade from this single source provide a useful indicator of the relations between different communities, in correlation with the changing political situation.

The Alca obsidian source is the source for the "Cuzco-type" obsidian artifacts, which are mostly found in the Southern Peruvian highlands (Burger et al., 1998a). The Alca source is located in the region of Cotahuasi, in Arequipa, and the obsidian nodules are part of the Tacaza formation mentioned above. Its lithology is varied, with the dominant rock types being ignimbrites and dacites. Although overlooked at first, the Cotahuasi region is now recognised as an important centre of human habitation since the time of the Marcavelle culture. The importance of the region can be partly attributed to its obsidian resources, and the Inca, due to this reason, built extensive fortifications and situated their regional administrative centre nearby. The location of Alca, along the natural route of communications between Cuzco and the Peruvian South coast served to further increase its importance (Burger et al., 1998a).

The Puzolana source, in the Ayacucho region, comprises small irregular nodules of obsidian found between the City of Ayacucho and the hamlet of Chupas. This obsidian is of high quality, albeit even the largest nodules, measuring between 3 and 4 cm, would not have been enough for the construction of large tools (Burger & Glascock, 2000b). Regardless of this limitation, it was used since ca. 7000 BC by hunter-gatherer populations (MacNeish, 1981), up until ca. 500 AD, when it was practically abandoned. In general, the archaeological evidence points to a gradual decline in the use of the Puzolana source, as the quantity of imported obsidian from the Quispisisa source increased. It seems that this source was not of any interest at the late stages of the Wari Empire and subsequent populations did not exploit it at all (Burger & Glascock, 2000b).

Major sources of obsidian are also located in modern-day Ecuador (Bigazzi et al., 1992), which was under Inca control, at the height of the Empire's power. Archaeological research indicates that four sources were exploited, beyond doubt, during the time of the Incas: Mullumica, Callejones, Yanaurco-Quiscatola (Salazar, 1980, 1982; Asaro et al., 1994), and Carboncillo (Ogburn et al., 2009). The first three are located in the Sierra de Guamaní, within the massive Chacana Caldera Complex. This is a caldera of Pleistocene age, whose flanks comprise ignimbrites, tuffs and vitrophyres of andesitic to rhyolitic composition, interbedded with subordinate andesitic-dacitic lavas. The infilling of the caldera comprises thick tuff and breccias, black porphyritic andesitic lavas and lava flows, of andesitic to dacitic composition (Hall & Mothes, 2008). The Carboncillo source consists of relatively small obsidian nodules, and was not mined extensively. Still, it was probably the only locally available source of obsidian, as it is 1250 km from the nearest obsidian source in Peru and 380 km from the nearest major obsidian source in Ecuador (Ogburn, 2011). According to Obgurn et al. (2009) more sources of Ecuadorian obsidian remain to be identified, as there are artefacts with geochemical signatures which do not match with the currently known sources. The obsidian deposits of the Paletará caldera (Bellot-Gurlet et al., 2008) in Colombia on the other hand, were not exploited by the Incas, as they were outside the limits of the Empire.

Finally, sources from as far as in Chile and Argentina were exploited, albeit not so frequently. Classic examples of these sources are Laguna del Diamante in Mendoza Province, Argentina (De Francesco et al., 2006) Cerro Huenul in Neuqén Province, Argentina (Barbarena et al., 2011), Las Cargas and Laguna del Maule in Talca Province, Chile (Seelenfreund et al., 1996). These last two sources where much more intensely exploited in comparison to the first two mentioned (Durán et al., 2012). Obsidian originating from the Laguna del Maule is chemically varied, while the obsidian quarries are now, as then, accessible mostly during the summer months. The obsidian nodules at Laguna del Maule are found within lava flows, originating from successive post-Pliocene eruptions (Singer et al., 2014; Sruoga et al., 2015). The different varieties of obsidian originating from this source were used for different purposes according to their mechanical properties. In addition, different varieties where apparently acquired by different societies, in accordance to the transience of communities at the site (Barbarena et al., 2018). Recently, a new source of pre-Colonial obsidian artefacts was identified by Fernández et al. (2019) and further investigation is required as to its importance in a wider cultural and anthropological context.

The Las Cargas source was exploited at a very early stage, with archaeological evidence indicating the first signs of human activity at ca. 6000 BC. This source was on the border between Chile and Argentina, on the bank of the Arroyo El Cura river, and like Laguna del Maule was not habitable during the winter. Obsidian is present both in the form of nodules inside ignimbrites or as blocks and outcrops exposed by weathering (Salgán et al., 2015). Since the first exploitation of this source during Prehistory, obsidian was extracted by many different populations, with a varying temporal and cultural profile. Intensity of use and obsidian export are known to have increased gradually (Neme & Gil, 2012).

The Laguna del Diamante source is found in a large volcanic caldera, while the Cerro Huenul source is associated with ignimbrite deposits of the Tilhué formation (Cortegoso et al., 2016), and the obsidian nodules exploited exhibit a broad and discontinuous spatial distribution (Barbarena et al., 2018). In both cases, obsidian was mined from nodules of varying sizes and dimensions. It is noteworthy that, despite the existence of many obsidian sources in the region, obsidian from Cerro Huenul was transported over disproportionally great distances, and this despite considered as subsidiary to obsidian from other sources (Giesso et al., 2011).

6. OBSIDIAN WITHIN THE INCA SOCIETY

The use of obsidian was as widespread in Southern America, as in Mesoamerica. From the time of ancient Peruvian hunters, obsidian was used to manufacture spear points and knives. This obsidian came usually from one of the main sources outlined above and when that was not possible from one of the sources characterised by inferior quality obsidian. The manufacturing of obsidian tools and implements progressed, building upon the already established manufacturing tradition, with occasional advances in the qualitative and quantitative aspects of production. Curiously, in the Southern Peruvian highlands, obsidian use seems to have decreased slightly during late Inca times, along with the use of other lithic materials (Burger et al., 2000), probably because of advances in metallurgy. Everyday items, as well as ornaments were made of obsidian, while the military industry of the Incas required a constant flow of this lithic material to provide soldiers with swords, spear tips and arrowheads. Peoples subject to Inca control occasionally paid tribute in the form of obsidian quantities, which were then funnelled, according to evidence, to the weapons making industry.

Both within Inca settlements and Inca forts and outposts, the plethora of obsidian artefacts testifies to the cardinal significance of obsidian in Inca military material culture. In addition, the distribution of known Inca forts and settlements is such that quite possibly it was partly planned to encompass major obsidian sources (Ogburn et al., 2009). Moreover, the constant need for obsidian to supply the army, may have led to a quicker integration of the conquered provinces of modern-day Equador, as it signified the introduction of the conquered peoples into the socioeconomic matrix of the Empire. In other words, in order to maximise obsidian procurement, the Incas had to quickly conquer and then establish their control over provinces. Hence, the need for more obsidian of reasonable quality lead to imperial expansion, and, ultimately, to strict control over the economy of conquered territories. One interesting conclusion reached by the temporal and spatial analyses of obsidian artefacts from different sites is that production and trade of obsidian was subject to and reflects the changes in political and military influence over time, in different areas (Eerkens et al., 2010).

The need for the intensification of obsidian production was instrumental in forming the Inca policy of forced resettling of labourers. According to D'Altroy (2002), about a quarter of the populations subject to Inca rule, where included in the «mitmaq» policy and became «mitmaqkuna», transplanted labourers in Inca language. Of course, there were other ends met by the implementation of this policy, namely socio-political reshuffling (D'Altroy, 1992) which ensured the subjugation of conquered peoples (Rowe, 1946). It is still a matter of conjecture whether the Incas were directly aiming for control of goods and provisions or if this was a side effect of their focus on averting the emergence of potential destabilising elements within their own Empire. In any case, first and foremost this was an economically oriented policy, and obsidian quarrying was a major factor in shaping it.

By analysing the obsidian found in different archaeological sites, and by calculating the percentages of the presence of obsidian from given sources, in different sites, the adherence to the Law of Monotic Decrement can be observed. In short, this Law states that for a given obsidian source, there should be fewer artefacts from that source the further away a site is located from that particular source. If this is not the case, then a political mediation in trading and economy can be observed (Renfrew, 1984;

Molyneaux, 2002). In theory, the spatial distribution of obsidian sources, would most certainly favour local procurement, from a source within 150 Km or so, which given the prevalent topography for higher elevation sources, would correspond to a maximum of three days travel time (Kellett et al., 2013).

However, the decrease is not always uniform with the spatial increase from the source, and that indicates that there were interregional interactions, through trading and travelling of individuals, in an effort to acquire higher quality obsidian. The interregional trade of obsidian, as well as other goods, was tightly regulated by the Incas (Murra, 1980; Yacobaccio et al., 2002; Hu & Shackley, 2018). This no doubt was, at least partially, an effort to prevent the formation of political alliances between subject and transplanted populations, which could potentially pose an internal threat to the Empire's sociopolitical coherence and integrity.

The tools and weapons manufactured using obsidian were knives, tips for spears and arrows and general bifacial blades (Burger, 2007), while ceremonial bloodletting knives were also widespread (Figure 6). A remnant of pre-Inca cultures was the obsidian-tiped darts, rarely used in hunting by the Late Horizon (Rowe, 1946). It must be noted that in all probability the Incas in particular and the South American civilisations in general used slings for hunting, and there is no evidence to indicate that obsidian-tipped arrows were used in hunting (DeLeonardis, 1997). Rather, obsidian arrowheads have been documented to be used in battle and to be capable of piercing even through thick human bones (Engel, 1966). A concise inventory of the everyday implements and weapons which were made using obsidian is provided in Table 5.

Table 5: Common obsidian tools and implements of the Incas

Tool/Implement	Use	Comments	References
Arrowheads	Combat	Attached to wooden shafts to construct arrows	Marino & Gonzales-Portillo (2000); Burger (2007)
Spearheads	Combat	Attached to long pikes to construct spears (turcunas)	Marino & Gonzales-Portillo (2000); Burger (2007)
Dartheads	Hunting	Used most commonly by ancient Andean civilisations	Marino & Gonzales-Portillo (2000)
Knife blades	General	Attached to wooden handles and used in everyday life	Marino & Gonzales-Portillo (2000); Burger (2007)
Spiked clubs	Combat	Thick wooden clubs with obsidian spikes	Marino & Gonzales-Portillo (2000)
Scalpel knives	Medicine	Semicircular knives used for incisions	Marino & Gonzales-Portillo (2000)

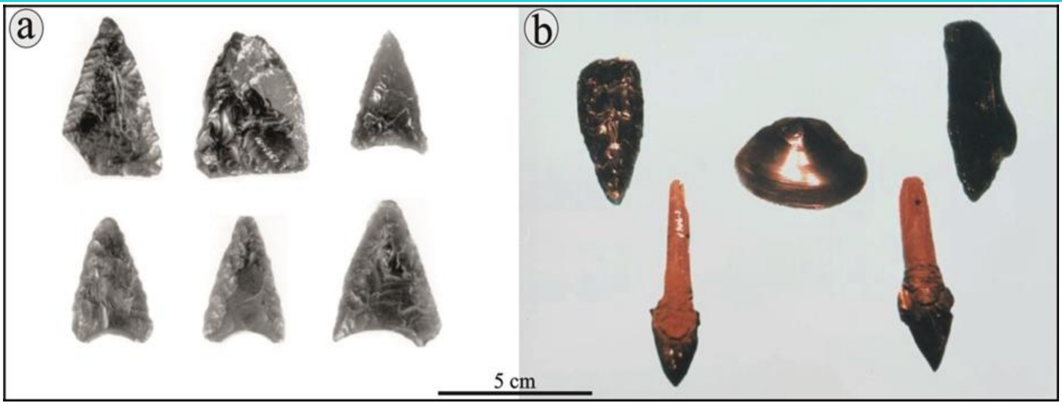

Fig. 6: Obsidian artefacts from obsidian mining sites and settlements. (a) Obsidian arrowheads and spearheads, in various states of finishing (Burger, 2007) (b) Obsidian blades used in Inca surgical instruments (Marino & Gonzales-Portillo, 2000).

Another very important consequence of obsidian availability was the development of advanced surgical instruments which in turn enabled Inca surgeons to perform trephinations and craniotomies (Rifkinson-Mann, 1988). Obsidian lances and scalpels were the prime tools for Inca neurosurgeons, along with other medical instruments made from various metals and alloys. Depictions, mentions in Spanish texts and examination of skeletons, have revealed that the medical knowledge and the associated skill, and anatomical knowledge, of these ancient pre-Columbian surgeons was comparable to that of Western medical practitioners of the 17th and 18th century (Escardo, 1992; Froeschner, 1992). Trephination and craniotomy were performed using different techniques depending on the occasion and were utilised to treat a variety of illnesses (Allison, 1976).

One interesting change in the use of obsidian within the Inca society, towards the later years of the Inca Empire, was its elevation to the status of a semiprecious rock. Offerings of obsidian in the form of pebbles were found in Machu Pichu (Bingham, 1930), and it is significant that they are not from the nearby Alca source, but rather from the faraway Chivay source, which indicates that they were intentionally purchased and brought by visitors, most likely of higher social echelons, as an offering to the residing Inca royalty. According to Rowe (1946), by this time, ornamental obsidian pebbles were considered comparable as offerings to quartz crystals.

7. DISCUSSION AND CONCLUSIONS

Obsidian was the major contributing factor in establishing interregional social networks (Hirth et al., 2013), thus linking different communities and different peoples. Contrary to the assertions of Clark (1987), it seems that for early South American, as well as

Mesoamerican civilisations, obsidian was an integral part of the social fabric and its import and use was not linked to the power fluctuations of a ruling elite. Rather, an intricate trading network ushered in a relative economical prosperity to communities, and by implication, administrative districts, related directly to obsidian production. Cortegoso et al. (2016), using obsidian provenance analysis and palaeoanthropological research (Bender & Wright, 1988) in correlation with the results of Barge & Chataigner (2003), asserted that the use of highland Andean settings was asymmetrical, with a dominant vector of access from the western lowlands.

In any case, the people of the Andes, from an early stage, were prepared to go to great lengths to find new obsidian sources and acquire workable lithic material. An intricate and far-reaching trade network provided access to obsidian of various qualities from different sources, to early and late pre-Columbian civilisations. It is significant that once found, obsidian sources were seldomly completely abandoned, resulting in most cases, in millennia of continuous exploitation, leaving a rich archaeological record. The Spanish conquest marked the effective end of obsidian quarrying, trading and use in the regions formerly controlled by the Inca Empire. This is a marked contrast with the status quo in Mesoamerica, where obsidian tool usage continued well after the Spanish conquest (Pastrana et al., 2019). Obsidian was mostly used in tool production and was very rarely used as an offering or as an ornamental stone, at least before the final years of the Inca Empire, contrary to what happened in the Near East and Mesoamerica (Burger et al., 2000). Most interestingly, obsidian was used up until the end of the Empire, despite the development of metallurgy. This is probably the only case in history, were a civilisation already well into the Bronze Age, utilised lithic materials on par with metals and alloys. It is impossible to study Andean archaeology and history and not take into account the formative effect of the existence of obsidian and the accessibility of many different sources in different areas.

While obsidian was used early in Prehistorical times as the main lithic material for tool and weapon manufacturing, only certain areas and regions were «privileged» enough to be endowed with adequate sources. It must be noted that, for a source to be exploitable, it must not only be accessible, but it must also have obsidian of certain mechanical properties - this is determined by the impurities in obsidian as discussed by Heide & Heide (2011) and by local erosion conditions - and to be characterised by nodules of workable size. This last parameter is important in the context of the evolution of knapping skills. Indeed, successive populations and civilisations in the Andes, as elsewhere in the world, usually had more skilled knappers than previous ones, no doubt building upon hundreds of years of experience. However, while this potentially meant that sources of inferior quality and quantity could be more adequately exploited, in many cases such sources were abandoned, as skilled knappers were in a constant search for superior quality obsidian.

Taking all these into account, the intensity of exploitation of a source was a multivariable function. Earlier populations, from semi-nomadic groups of people, to the Chavín, Wari and Tiwanaku societies, used any source that was locally available, for quick and easy procurement of obsidian, while trading for smaller or larger amounts of obsidian whenever possible, with traders coming from distant sources. Most probably, traders constituted a distinct socioeconomic class, delineated by their frequent travels to acquire and then sell obsidian, on a permanent or semi-permanent basis. The Inca did not organise a complex market society as did the Aztecs, but rather enforced a tight control on existing economic structures and functions, which linked individual polities (Stanish, 2001), the only notable exception to this early "quasi-laissez-faire" policy being the aforementioned «mitmaqkuna» policy. An important constraining factor was the yearly accessibility of a source. Sources in higher elevations were most likely accessible and workable during a six month period, or even less, which hampered obsidian procurement. This is particularly notable in the sources of North Argentina.

In the end, the many uses of obsidian permeated all the pre-Columbian Andean civilisations, and in many cases determined their economic prosperity, their social standing and political course - most notably in the case of the resettled labourers of the Inca Empire (Hu & Shackley, 2018). From hunting (Burger, 2007) to medicine (Marino & Gonzales-Portillo, 2000), most everyday functions were performed using obsidian tools and implements. In addition, as in the case of the pre-Columbian civilisations of Mesoamerica, the Inca army fought mostly using obsidian weapons, which was an important contributing factor to their relatively easy defeat at the hands of the Spanish (Pemberton, 2011; Periferakis, 2019a, 2019b).

In this paper, I have endeavoured to present the interplay between geology, civilisation and archaeology, in a concise manner, presenting in succession how the tectonic and volcanic setting of South America lead to the formation of obsidian deposits and how these deposits, in turn, shaped social, political and economical aspects of pre-Columbian Andean populations. Although the recent decades have seen a marked increase in the study of obsidian exploitation and distribution, there is still a lot of research to be undertaken, to lead to a fuller understanding of the complete context of obsidian's existence in all contexts of pre-Columbian Andean cultures.

8. REFERENCES

Allison, M.J., 1976. Treatment of head wounds in pre-Columbian and colonial Peru. *Medical College of Virginia Quarterly*, 12, 74-79.

Allmendinger, R.W., Jordan, T.E., Kay, S.M. Isacks, B.L., 1997. The evolution of the Altiplano-Puna Plateau of the Central Andes. *Annual Reviews of Earth and Planetary Sciences*, 25, 139-174.

Ammerman, A.J., Cavalli-Sforza, J.J., 1971. Measuring the Rate of Spread of Early Farming in Europe. *Man*, 6, 674-688.

Asaro, F., Salazar, E., Michel, H.V., Burger, R.L., Stross, F.H., 1994. Ecuadorian obsidian sources used for artifact production and methods for provenience assignments. *Latin American Antiquity*, 5, 257-277.

Aspinall, A., Feather, S.W., Renfrew, C., 1972. Neutron Activation Analysis of Aegean Obsidian. *Nature*, 237, 333-334.

Bader, B., 2015. Egypt and the Mediterranean in the Bronze Age: The Archaeological Evidence. *Oxford Handbooks Online*, doi: 10.1093/oxfordhb/9780199935413.013.35.

Baker, M.C.W., Francis, P.W., 1978. Upper Cenozoic volcanism in the Central Andes - Ages and volumes. *Earth and Planetary Science Letters*, 41, 175-187.

Balkan-Atli, N., Binder, D., Gratuze, B., 2008. Göllü Dağ (Central Anatolia): Obsidian Sources, Workshops and Trade. *Der Anschnitt, Zeitschrift für Kunst und Kultur im Bergbau*, IV, 203-210.

Barbarena, R., Fernández, M.V., Rughini, A.A., Borrazzo, K., Garvey, R., Lucero, G., Della Negra, C., Romero Villanueva, G., Durán, V., Cortegoso, V., Giesso, M., Klesner, C., MacDonald, B.L., Glascock, M.D., 2018. Deconstructing a complex obsidian "source-scape": A geoarchaeological and geochemical approach in northwestern Patagonia. *Geoarchaeology*, 34, 30-41.

Barbarena, R., Hajduk, A., Gil, A.F., Neme, G.A., Durán, V., Glascock, M.D., Giesso, M., Borrazzo, K., de la Paz Pompei, M., Laura Salgán, M., Cortegoso, V., Villarosa, G., Rughini, A.A., 2011. Obsidian in south-central Andes: Geological, geochemical, and archaeological assessment of north Patagonian sources (Argentina).*Quaternary International*, 245, 25-36.

Barge, O., Chataigner, C., 2003. The procurement of obsidian: factors influencing the choice of deposits. *Journal of Non-Crystalline Solids*, 323, 172-179.

Barker, P.F., 2001. Scotia Sea regional tectonic evolution: Implications for mantle flow and palaeocirculation. *Earth-Science Reviews*, 55, 1-39.

Beck, C., & Jones, G., 2011. The role of mobility and exchange in the conveyance of toolstone during the Great Basin paleoarchaic, in: R. Hughes R. (Eds.), *Perspectives on prehistoric trade and exchange in California and Great Basin*. University of Utah Press, 55-82pp.

Bellot-Gurlet, L., Dorighel, O., Poupeau, G., 2008. Obsidian provenance studies in Colombia and Ecuador: obsidian sources revisited. *Journal of Archaeological Science*, 35, 272-289.

Bigazzi, G., Coltelli, M., Hadler, N.J.C., Osorio Araya, A.M., Oddone, M., Salazar, E., 1992. Obsidian-bearing lava flows and pre-Colombian artifacts from the Ecuadorian Andes: first new multidisciplinarity data. *Journal of South American Earth Sciences*, 6, 21-32.

Bender, S.J., Wright, G.A., 1988. High-altitude occupations, cultural process, and high plains history: retrospect and prospect. American Anthropologist, 90, 619-639.

Bingham, H., 1930. Machu Picchu: A Citadel of the Incas. *Memoirs of the National Geographic Society*, Yale University, New Haven.

Brooks, S.O., Glascock, M.D., Giesso, M., 1997. Source of volcanic glass for ancient Andean tools. *Science*, 386, 449-450.

Browman, D., 1974. Pastoral Nomadism in the Andes. *Current Anthropology*, 15, 188-196.

Browman, D., 1975. Trade Patterns in the Central Highlands of Peru in the First Millennium B.C. *World Archaeology*, 6, 322-329.

Burger, R.L., 1992. Chavin and the Origins of Andean Civilization, Thames and Hudson Editions, London.

Burger, R.L., 2007. Late Paracas Obsidian Tools from Animas Altas, Peru. *Andean Past*, 8, 477-490.

Burger, R.L., Asaro, F, Michel, H.V., 1984. The source of the obsidian artifacts at Chavin de Huántar (Appendix E), in: Burger, R.L. (Ed.), *The Prehistoric Occupation of Chavin de Huántar*. University of California Press, 263-270pp.

Burger, R.L., Asaro, F., 1977. Trace Element Analysis Of Obsidian Artifacts From The Andes: New Perspectives On Pre-Hispanic Economic Interaction in Peru and Bolivia. *Lawrence Berkeley Laboratory Report*, 6343, University of California, Berkeley.

Burger, R.L., Asaro, F., 1982. La procedencia de artefactos de obsidiana de los sitios formativos en Ayacucho: Chupas y Wichqana. *Boletín del Museo Nacional de Antropología y Arqueología*, 7, 9-10.

Burger, R.L., Asaro, F., Salas, G., Stross, F.H., 1998b. The Chivay Obsidian Source and the Geological Origin of Titicaca Basin Type Obsidian Artifacts. *Andean Past*, 5, 203-223.

Burger, R.L., Asaro, F., Trawick, P.B., Stross, F.H., 1998a. The Alca Obsidian Source: The Origin of Raw Material for Cuzco Type Obsidian Artifacts. *Andean Past*, 5, 185-202.

Burger, R.L., Schreiber, K.J., Glascock, M.D., Ccencho, J., 1998c. The Jampatilla Obsidian Source: Identifying the Geological Source of Pampas Type Obsidian Artifacts from Southern Peru. *Andean Past*, 5, 225-239.

Burger, R.L., Fajardo Rios, F.A., Glascock, M.D., 2006. Potreopampa and Lisahuaco obsidian sources: geological origins of Andahuaylas A and B type obsidians in the Province of Aymaraes, Department of Apurimac, Peru, *Ńawpa Pacha,* 28, 109-127.

Burger, R.L., Glascock, M.D, 2000a. Locating the Quispisisa Obsidian Source in the Department of Ayacucho, Peru. *Latin American Antiquity*, 11, 258-268.

Burger, R.L., Glascock, M.D, 2000b. The Puzolana Obsidian Source: Locating the Geologic Source of Ayacucho Type Obsidian. *Andean Past*, 6, 289-307.

Burger, R.L., Mohr Chávez, K.L., Chávez, S.J., 2000. Through the Glass Darkly: Prehispanic Obsidian Procurement and Exchange in Southern Peru and Northern Bolivia. *Journal of World Prehistory*, 14, 267-362.

Burger, R.L., van der Merwe, N.J., 1990. Maize and the Origin of Highland Chavín Civilization: An Isotopic Perspective. *American Anthropologist*, 92, 85-95.

Carmichael, I., 1962. A note on the composition of some natural acid glasses. *Geological Magazine*, 99, 253-264.

Castillo, J.M., Barreda, J.A., Vela C.V., 1993. Geología de los cuadrángulos de Laramate y Santa Ana. *Bolétin*, 45, Instituto Geológico, Minero y Metalúrgico, Lima.

Castro, J., Manga, M., Cashman, K., 2002. Dynamics of obsidian flows inferred from microstrutures: insights from microlite preferred orientations. *Earth and Planetary Science Letters*, 199, 211-226.

Cawood, P.A., 2005. Terra Australis orogen: Rodinia breakup and development of the Pacific and Iapetus margins of Gondwana during the Neoproterozoic and Paleozoic. *Earth-Science Reviews*, 69, 249-279.

Clark, J., 1987. Politics, prismatic blades, and Mesoamerican civilisation, in: Johnson Morrow, C.A. (Eds.), *The Organization of Core Technology*. Westview Press, Boulder, 259-284pp.

Coira, B., Mahlburg Kay, S., Viramonte, J., 1994. Upper Cenozoic magmatic evolution of the Argentine Puna – A model for changing subduction geometry. *International Geology Review*, 35, 677-720.

Contreras, D.A., 2017. Rituals of the Past: Prehispanic and Colonial Case Studies in Andean Archaeology, in: Rosenfeld S.A., Bautista, S.L. (Eds.), *Rituals of the Past*, 51-77.

Cortegoso, V., Barbarena, R., Durán, V., Lucero, V., 2016. Geographic vectors of human mobility in the Andes (34−36° S): Comparative analysis of 'minor' obsidian sources. *Quaternary International*, 422, 81-92.

Cunningham, D.W., Dalziel, I.A.W., Tung-Yi, L., Lawver, L.A., 1995. Southernmost South America – Antarctic Peninsula relative plate motions since 84 Ma: Implications for the tectonic evolution of the Scotia Arc region. *Journal of Geophysical Research*, 100, 8257-8266.

D' Altroy, T.N., 1992. Provincial Power in the Inka Empire. Smithsonian Institution Press, Washington.

D' Altroy, T.N., 2002. The Incas. Wiley Blackwell, Chichester.

Davidson, J.P., Harmon, R.S., Worner, G., 1993. The source of Central Andean magmas: some considerations. In: Harmon, R.S., Rapela, C.W., (Eds.), *Andean Magmatism and its tectonic setting*. *Geological Society of America Special Paper*, 265, 233-243pp.

Dávila, F.M., Lithgow-Bertelloni, C., 2013. Dynamic topography in South America, *Journal of South American Earth Sciences*. 43, 127-144.

Dávila, F.M., Lithgow-Bertelloni, C., 2015. Dynamic uplift during slab flattening. *Earth and Planetary Science Letters*, 425, 34-43.

De Francesco, A.M., Durán, V., Bloise, A., Neme, G., 2006. Caracterización y procedencia de obsidianas de sitios arqueológicos del área natural protegida Laguna del Diamante (Mendoza Argentina) con metodología no destructiva por fluorescencia de rayos (XRF). *Anales de Arqueología y Etnología*, 61, 53-67.

de Gamboa, P.S., 1572. Historia de los Incas. Private Edition, Cuzco.

de la Garcilaso, V., 1609. Commentarios Reales. vol. 1, Officina de Pedro Crasbeeck, Lisbon.

DeLeonardis, L., 1997. Paracas Settlement in Callango, Lower Ica, 1st Millennium B.C., Peru. Ph.D. Thesis, Catholic University of America, Washington D.C.

Dingwell, D.P., 1987. Melt viscosities in the system $NaAlSi_3O_8$-H_2O-$F2_2O$., in: Mysen, B.O. (Eds.), *Magmatic Processes: Physicochemical Principles. The Geochemical Society, Special Publication*, 1, Pennsylvania, 423-431 pp.

Dunbar, N.W., Hervig, R.L., Kyle, P.R., 1989. Determination of pre-eruptive H_2O, F, and Cl contents of silicic magmas using melt inclusions: examples from Taupo volcanic center, New Zealand. *Bulletin of Volcanology*, 51, 177-184.

Durán, V., De Francesco, A.M., Cortegoso, V., Neme, G., Cornejo, L., Bocci, M., 2012. Caracterización y procedencia de obsidianas de arqueológicos del Centro Oeste de Argentina y Centro de Chile con metodología no destructiva por Fluorescencia de Rayos X (XRF), *Intersecciones en Antropología*, 13, 423-437.

Eerkens, J.W., Vaughn, K.J., Linares-Grados, M., Conlee, C.A., Schreiber, K., Glascock, M.D., Tripcevich, N., 2010. Spatio-temporal patterns in obsidian consumption in the Southern Nasca Region, Peru. *Journal of Archaeological Science*, 37, 825-832.

Engel, F.A., 1966. Paracas: Cien siglos de cultura peruana. Editorial Mejía Vaca, Lima.

Escardo, F.A., 1992. História de la Cirurgia en el Perú. Editorial Monterrico S.A., Lima.

Fernández, M.V., Leal, P., Klesner, C., Della Negra, C., MacDonald, B.L., Glascock, M.D., Barberena, R., 2019. Obsidiana Varvarco: Una nueva fuente en el noroeste de Patagonia (Neuquén, Argentina). *Revista del Museo de Antropologia*, 12, 35-44.

Flament, N., Gurnis, M., Dietmar Müller, R., Bower, D.J., Husson, L., 2015. Influence of subduction history on South America topography. *Earth and Planetary Science Letters*, 430, 9-18.

Flores, I., 1990. Evidencia Wari en el Valle Medio del Caplina. *Gaceta Arquelógica Andina*, 18/19, 159-163.

Froeschner, E.H., 1992. Two examples of ancient skull surgery. *Journal of Neurosurgery*, 76, 550-552.

Gallotti, R., Mussi, M., 2015. The Unknown Oldowan: ~1.7-Million-Year-Old Standardized Obsidian Small Tools from Garba IV, Melka Kunture, Ethiopia. *PLoS One*, 10, doi: 10.1371/journal.pone.0145101.

Gansser, A., 1973. Facts and theories on the Andes. *Journal of the Geological Society of London*, 129, 93-131.

Garcea, E.A.A., 2004. An Alternative Way Towards Food Production: The Perspective from the Libyan Sahara. *Journal of World Prehistory*, 18, 107-154.

Gardeweg, M.C., Sparks, R.S.J., Matthews, S.J., 1998. Evolution of Lascar Volcano, Northern Chile. *Journal of the Geological Society*, 155, 89-104.

Gautier, P.J., Deruelle B., Viramonte J., Aparicio, A., 1994. Garnets from La Pava Ramadas-rhyolite (NW Argentina) and from its granite xenoliths. *Comptes Rendus de la Académie des Sciences de Paris*, 318, 1629-1635.

Giesso, M., Durán, V., Neme, G., Glascock, M.D., Cortegoso, V., Gil, A.F., Sanhueza, L., 2011. A study of obsidian source usage in the Central Andes of Argentina and Chile. *Archaeometry*, 53, 1-21.

Goldstein, P., 1990. La ocupación Tiwanaku en Moquegua. *Gaceta Arqueológica Andina*, 18/19, 75-104.

Gorring, M.L., Kay, S.M., Zeitler, P.K., Ramos, V.A., Rubiolo, D., Fernandez, M.I. Panza, J.L., 1997. Neogene Patagonian plateau lavas: continental magmas associated with ridge collision at the Chile Triple Junction. *Tectonics*, 16, 1-17.

Gottsmann, J., Giordano, D., Dingwell, D.B., 2002. Predicting shear viscosity at the glass transition during volcanic processes: a calorimetric calibration. *Earth and Planetary Science Letters*, 198, 417-427.

Griffin, J.B., Gordus, A.A., Wright, G.A., 1969. Identification of the sources of Hopewellian obsidian in the Middle West. *American Antiquity*, 34, 1-14.

Guillaume, B., Martinod, J., Husson, L., Roddaz, M., Riquelme, R., 2009. Neogene uplift of central eastern Patagonia: dynamic response to active spreading ridge subduction? *Tectonics*, 28, TC2009.

Hall, M.L., Beate, B., 1991. El volcanismo plio-cuaternario en los Andes de Ecuador. *Boletín del Colegio de Geógrafos del Ecu*ador, 4, 5-17.

Hall, M.L., Mothes, P.A., 2008. The Chacana Caldera Complex in Ecuador, IOP Conference Series: Earth and Environmental Science, 3. *Collapse Calderas Workshop, Querétaro, 19-25 October*, Querétaro, Mexico, 012004.

Harmon, R.S., Barreiro, B., Moorbath, S., Hoefs, J., Francis, P.W., Thorpe, R.S., Deruelle, B., McHugh, J., Viglino, J.A., 1984. Regional O-, Sr-, and Pb-isotope relationships in late Cenozoic calc-alkaline lavas of the Andean Cordillera. *Journal of the Geological Society*, 141, 803-822.

Heide, G., Leschik, M., Frischat, G.H., 2001. Pechstein Teil I: Ein wassereich glasig erstarrter, vulkanischer Gesteinstyp. *Chemie der Erde*, 61, 187-213.

Heide, K., Heide, G., 2011. Vitreous state in nature - Origin and properties. *Chemie der Erde*, 71, 305-335.

Heide, K., Sadiklar, B., Gerth, K., Volksch, G., Hartmann, E., 1996. Obsidian from Buyuksulata and Sirikli Tepe, Eastpontides, Turkey: a glass chemical study. *Chemie der Erde*, 56, 313-322.

Heizer, E., Williams, H., Graham, J.A., 1965. Notes on Mesoamerican obsidians and their significance in archaeological studies. *Contributions of the University of California Archaeological Research Facility*, 1, 94-103.

Hildreth, W., 1981. Gradients in silicic magma chambers: implications for lithospheric magmatism. *Journal of Geophysical Research*, 86, 10152-10153.

Hildreth, W., Moorbath, S., 1988. Crustal contribution to arc magmatism in the Andes of Central Chile. *Contributions to Mineralogy and Petrology*, 98, 455-489.

Hirt, A.M., 2010. Imperial Mines and Quarries in the Roman World, Organizational Aspects, 27 BC - AD 235. Oxford Classical Monographs. *Oxford University Press*, Oxford.

Hirth, K.G., 2006. Obsidian Craft Production in Ancient Central Mexico. University of Utah Press, Salt Lake City.

Hirth, K.G., Cyphers, A., Cobean, R., De León, J., Glascock, M.D., 2013. Early Olmec obsidian trade and economic organization at San Lorenzo. *Journal of Archaeological Science*, 40, 2784-2789.

Hu, D., Shackley, M.S., 2018. ED-XRF analysis of obsidian artifacts from Yanawilka, a settlement of transplanted laborers (mitmaqkuna), and implications for Inca imperialism. *Journal of Archaeological Science: Reports*, 18, 213-221.

Iddings, J.P., 1893. The Volcanic Rocks of the Andes. *The Journal of Geology*, 1, 164-175.

Ingbar, E., 1994. Lithic material selection and technological organization, in: Carr, P. (Eds.), *The organization of North American prehistoric chipped stone technologies*. *Archaeological Series*, 7, 45-56 pp.

Isacks, B., 1988. Uplift of the Central Andean plateau and bending of the Bolivian orocline. *Journal of Geophysical Research*, 93, 3211-3231.

Jacobsen, T.W. 1969. Excavations at Porto Heli and Vicinity, Preliminary Report II: The Franchthi Cave 1967 - 1968. *Hesperia*, 38, 343-381.

Kay, S.M., Abbruzzi, J.M., 1996. Magmatic evidence for Neogene lithospheric evolution of the Central Andean “flat-slab” between 30˚ and 32˚S. *Tectonophysics*, 259, 15-28.

Kay, S.M., Burns, W.M., Copeland, P., Mancilla, O., 2006. Upper Cretaceous to Holocene magmatism and evidence for transient Miocene shallowing of the Andean subduction zone under the northern Neuquén Basin. In: Kay, S., Ramos, V. (Eds.), *Evolution of an Andean Margin. A Tectonic and Magmatic View from the Andes to the Neuquén Basin (35° – 39° S lat)*. *Geological Society of America Special Paper*, 407, 19-60pp.

Kay, S.M., Mpodozis, C., Coira, B., 1999. Neogene magmatism, tectonism, and mineral deposits of the Central Andes (22˚S to 33˚S). In: Skinner, B. (Eds.), *Geology and Mineral Deposits of Central Andes*. *Society of Economic Geology, Special Paper*, 2, 1-35pp.

Kearey, P., Klepeis, K.A., Vine, F.J., 2009. Global Tectonics. Wiley-Blackwell Editions, Oxford.

Kellett, L.C., Golitko, M., Bauer, B.S., 2013. A provenance study of archaeological obsidian from the Andahuaylas region of southern Peru. *Journal of Archaeological Science*, 40, 1890-1902.

Keppie, J.D., Dostal, J., 2007. Rift-related basalts in the 1.2–1.3 Ga granulites of the northern Oaxacan Complex, southern Mexico: Evidence for a rifted arc on the northwestern margin of Amazonia. *Proceedings of the Geologists' Association*, 118, 63-74.

Kolata, A.L., 1993. The Tiwanaku: Portrait of an Andean Civilization. Blackwell Editions, London.

Lanning, E.P., 1967. Peru Before the Incas. Prentice-Hall, New Jersey.

Levine, M.N., Joyce, A.A., Glascock, M.D., 2011. Shifting patterns of obsidian exchange in Postclassic Oaxaca, Mexico. *Ancient Mesoamerica*, 22, 123-133.

López Escobar, L., Cembrane, J., Moreno, H., 1995. Geochemistry and tectonics of Chilean Southern Andes basaltic Quaternary volcanism (37° - 46° S). *Revista Geológica de Chile*, 22, 219-234.

Macdonald, R., Smith, R.L., Thomas, J.E., 1992. Chemistry of the Subalkalic Silicic Obsidians. *US Geological Survey Professional Paper*, 1523.

MacNeish, R.S., 1981. Ayamachay, Ac102, in: MacNeish, R.S., Garcia-Cook, A., Lumbreras, L.G., Vierra, R.K., Nelken-Terner, A. (Eds.), *Prehistory of the Ayacucho Basin, Peru 2, Excavations and Chronology*. *University of Michigan Press*, 114-121 pp.

Marino Jr., R., Gonzalles-Portillo, M., 2000. Preconquest Peruvian Neurosurgeons: A Study of Inca and Pre-Columbian Trephination and the Art of Medicine in Ancient Peru. *Neurosurgery*, 47, 940-950.

McEwan, G.F., 2006. The Incas, New Perspectives, ABC-Clio Inc., Santa Barbara.

Méndez Fajury, R.A., 1989. Catálogo de volcanes activos de Colombia. *Boletín Geológico del Ingeominas*, 30, 1-75.

Merrick, H., Brown, F., 1984. Obsidian sources and patterns of source utilization in Kenya and northern Tanzania: some original findings. *African Archaeological Review*, 2, 129-152.

Mohr Chávez, K.L., 1977. Marcavalle: The ceramics from an Early Horizon site in the Valley of Cusco, Peru, and implications for south highland socio-economic interaction. Ph.D. Thesis, University of Pennsylvania, Philadelphia.

Mohr Chávez, K.L., 1982a. The archaeology of Marcavalle, an Early Horizon site in the Valley of Cuzco, Peru. Part I. *Baessler-Archiv*, Neue Folge, XXVIII, 203-329.

Mohr Chávez, K.L., 1982b. The archaeology of Marcavalle, an Early Horizon site in the Valley of Cuzco, Peru. Part II. *Baessler-Archiv*, XXIX, 107-205.

Mohr Chávez, K.L., 1983. The archaeology of Marcavalle, an Early Horizon site in the Valley of Cuzco, Peru. Part II, Baessler-Archiv, Neue Folge XXIX, 241-386.

Molyneaux, B.L., 2002. Exploring the Landscapes of long-distance exchange: evidence from Obsidian Cliffs and Devils Tower, Wyoming, in: Glascock, M.D. (Eds.), *Geochemical Evidence for Long Distance Exchange*. Bergin and Garvey, Westport, 133-151 pp.

Montgomery, D.R., Balco, G., Willett, S.D., 2001. Climate, tectonics, and the morphology of the Andes. *Geology*, 29, 579-582.

Moratto, M., 2011. Material conveyance in prehistoric California: Cultural context and mechanisms, in: Hughes R. (Eds.), *Perspectives on prehistoric trade and exchange in California and Great Basin*. *University of Utah Press*, 242-252 pp.

Muñoz, J., Stern, C., 1988. The Quaternary volcanic belt of the Southern continental margin of South America: transverse structural and petrochemical variations across the segment between 38˚S and 39˚S. *Journal of South American Earth Sciences*, 1, 147-162.

Muñoz, M., 1983. Eruption patterns of the Chilean volcanoes Villarica, Llaima, and Tupungatito. *Pure and Applied Geophysics*, 121, 835-852.

Murra, J.V., 1980. The Economic Organization of the Inka State. JAI Press, Connecticut.

Neme, G., Gil, A., 2012. El registro arqueológico del sur de Mendoza en perspectiva biogeográfica. Paleoecología humana en el sur de Mendoza, in: Neme, G., Gil, A. (Eds.), *Paleoecología Humana en el Sur de Mendoza: Perspectivas Arquelógicas*. *Sociedad Argentina de Antropología*, 255-279pp.

Nezafati, N., Pernicka, E., Momenzadeh, M., 2008. Iranian Ore Deposits and Their Role in the Development of the Ancient Cultures. *Der Anschnitt, Zeitschrift für Kunst und Kultur im Bergbau*, IV, 77-90.

Oddone, M., Bigazzi, G., Keheyan, Y., Meloni, S., 2000. Characterisation of Armenian obsidians: implications for raw material supply for prehistoric artefacts. *Journal of Radioanalytical and Nuclear Chemistry*, 243, 673-682.

Ogburn, D.E., 2011. Obsidian in Southern Ecuador: The Carboncillo Source. *Latin American Antiquity*, 22, 97-120.

Ogburn, D.E., Connell, S., Gifford, C., 2009. Provisioning of the Inca army in wartime: obsidian procurement in Pambamarca, Ecuador. *Journal of Archaeological Science*, 36, 740-751.

Oka, R., Kusimba, C., 2008. The Archaeology of Trading Systems, Part 1: Towards a New Trade Synthesis. *Journal of Archaeological Research*, 16, 1-5.

Özdoğan, M., 2008. Obsidian in the Context of Near Eastern Prehistory: A Conspectus on the Status of Research, Problems and Prospects. *Der Anschnitt, Zeitschrift für Kunst und Kultur im Bergbau*, IV, 191-202.

Palacios, O., de la Cruz, J., de la Cruz, N., Klinck, B.A., Allison, R.A., Hawkins, M.P., 1993. Geología de la Cordillera Occidental y Altiplano al oeste del Lago Titicaca-sur del Perú. *Boletín*, 42, INGEMMET, Sector Energía y Metalúrgico, Lima.

Pastrana, A., Carballo, D.M., 2016. Aztec Obsidian Industries, in: Nichols, D.L. Rodríguez-Alegría E. (Eds.), *The Oxford Handbook of the Aztecs*. *Oxford University Press*, 329-341pp.

Pastrana, A., Fournier García, P., Parry, W.J., Otis, C.L., 2019. Obsidian Production and Use in Central Mexico after the Spanish Invasion, in: Alexander, R.T. (Eds.), *Technology and Tradition in Mesoamerica after the Spanish Invasion*. University of New Mexico Press, 15-33pp.

Pellant, C., 1992. Rocks and Minerals. Dorling Kindersley Limited, London.

Pemberton, J., 2011. Conquistadors, Searching for El Dorado: The Terrifying Conquest of the Aztec and Inca Empires. Futura, London.

Periferakis, A., 2019a. The influence of ore deposits to the development and collapse of the Inca civilisation between the 15th and 16th century. *Proceedings of the 15th International Congress of the Geological Society of Greece, 22-24 May, Athens, Greece,* 702-703.

Periferakis, A., 2019b. Geology and the Aztecs: how the ore deposits of Mesoamerica influenced the socioeconomic development of an empire, from its emergence to its downfall. *Proceedings of the 15th International Congress of the Geological Society of Greece, 22-24 May, Athens, Greece*, 700-701.

Periferakis, A., 2019c. The importance of emery in the cultural, social and economic development Naxos Island, Cyclades, Greece. *Proceedings of the 15th International Congress of the Geological Society of Greece, 22-24 May, Athens, Greece*, 708-709.

Periferakis, A., Paresoglou, N., 2019. Lavrion from Ancient Greece to the present day: a study of how an ore deposit shaped history. *Proceedings of the 15th International Congress of the Geological Society of Greece, 22-24 May, Athens, Greece*, 704-705.

Ramos, V.A., 1999. Plate tectonic setting of the Andean Cordillera. *Episodes*, 22, 183-190.

Ramos, V.A., 2008. The basement of the Central Andes: The Arequipa and related terranes. *Annual Review of Earth and Planetary Sciences*, 36, 289-324.

Ramos, V.A., 2009. Anatomy and global context of the Andes: Main geologic features and the Andean orogenic cycle, in: Mahlburg Kay, S., Ramos, V.A., Dickinson, W.R. (Eds.), *Backbone of the Americas: Shallow Subduction, Plateau Uplift, and Ridge and Terrane Collision*. *The Geological Society of America, Memoir*, 204, 31-65 pp.

Ramos, V.A., and Ghiglione, M.C., 2008. Tectonic Evolution of the Patagonian Andes, in: Rabassa, J., (Eds.), *Late Cenozoic of Patagonia and Tierra del Fuego*. *Developments in Quaternary Sciences*, 11, Elsevier B.V, 57-71pp.

Renfrew, C, Dixon, J.E., Cann, J.R., 1966. Obsidian and early cultural contacts in the Near East. *Proceedings of the Prehistoric Society*, 32, 30-72.

Renfrew, C., 1984. Approaches to Social Archaeology, Harvard University Press, Cambridge.

Rifkinson-Mann, S., 1988. Cranial surgery in ancient Peru. *Neurosurgery*, 23, 411-416.

Ross, C.S., 1962. Microlites in glassy volcanic rocks. *American Mineralogist*, 47, 723-740.

Rowe, J.H., 1946. Inca culture at the time of the Spanish conquest. In: Steward, J.H. (Eds.), *Handbook of South American Indians*. Smithsonian Institution Press, Washington, 183-330pp.

Salazar, E., 1980. Talleres prehistóricos en los altos Andes del Ecuador. Departamento de Difusión Cultural de la Universidad de Cuenca, Cuenca.

Salazar, E., 1992. El intercambio de obsidiana en el Ecuador precolombino: perspectivas teórico-metodológicas, in: Politis, G. (Eds.), *Arqueología en América Latina Hoy*. Banco Popular, Bogota, 116-131pp.

Salgán, L., Garvey, R., Neme, G., Gil, A., Giesso, M., Glascock, M.D., Durán, V., 2015. Las Cargas: Characterization and Prehistoric Use of a Southern Andean Obsidian Source. *Geoarchaeology*, 30, 139-150.

Sandweiss, D.H., McInnis, H.E., Burger, R.L., Cano, A., Ojeda, B., Paredes, R., del Carmen Sandweiss, M., Glascock, M.D., 1998. Quebrada Jaguay: Early South American maritime adaptations. *Science*, 281, 1830-1832.

Santley, R.S., 1984. Obsidian exchange, economic stratification, and the evolution of complex society in the Basin of Mexico, in: Hirth, K.G. (Ed.), *Trade and Exchange in Early Mesoamerica*. University of New Mexico Press, Albuquerque, 43-86 pp.

Santley, R.S., 1989. Economic imperialism, obsidian exchange, and Teotihuacan influence in Mesoamerica, in: Gaxiola González, M., Clark, J.E. (Eds.), *La Obsidiana en Mesoamérica*. INAH, Mexico City, 321-329 pp.

Schumann, W., 2013. Gemstones of the World, 17th Edition. Sterling Publishing Co., Toronto.

Seelenfreund, A., Rees, C., Bird, R., Bailey, G., Bárcena, R., Durán, V.,1996. Trace element analysis of obsidian sources and artifacts of Central Chile (Maule River Basin) and Western Argentina (Colorado River). *Latin American Antiquity*, 7, 7-20.

Shackley, M.S., 1992. The upper Gila river gravels as an archaeological obsidian source region: implications for models of exchange and interaction. *Geoarchaeology*, 7, 315-326.

Shackley, M.S., 2005. Obsidian: Geology and archaeology in the North American Southwest. University of Arizona Press, Tucson.

Singer, BS., Andersen, N. L., Le Mével, H., Feigl, K. L., DeMets, C., Tikoff, B., Thurber, C.H., Jicha, B.R., Cardona, C., Córdova, L., Gil, F., Unsworth, M.J., Williams-Jones, G., Miller, G., Fierstein, J., Hildreth, W., Vazquez, J., 2014. Dynamics of a large, restless, rhyolitic magma system at Laguna del Maule, southern Andes, Chile. *GSA Today*, 24, 4-10.

Somervill, B.A., 2004. Empire of the Incas, Chelsea House Publishers, New York.

Spence, M., 1981. Obsidian production and the state in Teotihuacan. *American Antiquity*, 46, 769-788.

Spence, M., 1984. Craft production and polity in early Teotihuacan, in: Hirth, K.G. (Ed.), Trade and Exchange in Early Mesoamerica. University of New Mexico Press, Albuquerque, 87-114 pp.

Sruoga, P., Elissondo, M., Fierstein, J., García, S., González, R., Rosas, M., 2015. Actividad explosive postglacial del centro Barrancas, Complejo Volcánico Laguna del Maule (36° 05'S, 70° 30'O). *Peligrosidad en Argentina, XIV Congreso Geológico Chileno. 4-8 October, La Serena, Chile*, p. 49-52.

Stanish, C., 2001. Regional Research on the Inca. *Journal of Archaeological Research*. 9, 213-241.

Stern, C.R., 1991. Role of subduction erosion in the generation of Andean Magmas. *Geology*, 19, 78-81.

Stern, C.R., Kilian, R., 1996. Role of the subducted slab, mantle wedge and continental crust in the generation of adakites from the Andean Austral Volcanic Zone. *Contributions to Mineralogy and Petrology*, 123, 263-281.

Stroncik, N.A., Schmincke, H.-U., 2002. Palagonite – a review. *International Journal of Earth Sciences*, 91, 680-697.

Thorpe, O.W., Thorpe, R.S., 1984. The distribution and sources of archaeological pitchstone in Britain. *Journal of Archaeological Science*, 11, 1-34.

Thorpe, R.S., 1984. The tectonic setting of active Andean volcanism, in: Harmon, R.S., Barreiro, B.A. (Eds.), *Andean Magmatism*. Cheshire, Shiva Pub. Ltd., pp. 4-8 pp.

Toth, N., Schick, K., 2007. Overview of Paleolithic Anthropology, in: Henke, W., Tattersall, I. (Eds.), *Handbook of Paleoanthropology*. Springer-Verlag, 3, 1943-1963 pp.

Tripcevich, N., Mackay, A., 2011. Procurement at the Chivay obsidian source, Arequipa, Peru. *World Archaeology*, 43, 271-297.

Tsampiri, M., 2018. Obsidian in the prehistoric Aegean: Trade and uses. *Bulletin of the Geological Society of Greece*, 53, 28-49, http://dx.doi.org/10.12681/bgsg.18588

Tykot, R.H., 2011. Obsidian finds on the fringes of Central Mediterranean. In: Vianello, A. (Eds.), *Exotica in the Prehistoric Mediterranean*. Oxbow Books, Barnsley, 33-44 pp.

Tykot, R.H., 2017. Obsidian Studies in the Prehistoric Central Mediterranean: After 50 Years What Have We Learned and What Still Needs to Be Done? *Open Archaeology*, 3, 264-278.

van Tuerenhout, D.R., 2005. The Aztecs: New Perspectives. ABC-Clio Inc., Santa Barbara.

Viramonte, J.G., Reynolds, J.H., Del Papa, C., Disalvo, A., 1994. The Corte Blanco garnetiferous tuff: a distinctive late Miocene marker bed in northwestern Argentina applied to magnetic polarity stratigraphy in the Rio Yacones, Salta Province. *Earth and Planetary Science Letters*, 121, 519-531.

Wagner, N., 2003. Mechanische Spektroskopie an vulkanischen Gläsern. Thesis, Friedrich Schiller Universität, Jena.

Weiss, B., 1982. The decline of Late Bronze Age civilization as a possible response to climatic change. *Climatic Change*, 4, 173-198.

Wilding, M.C., Webb, S.L., Dingwell, D.B., 1995. Evaluation of a relaxation geospeedometer for volcanic glasses. *Chemical Geology*, 125, 137-148.

Wyllie, P.J., 1971. The Dynamic Earth: Textbook in Geosciences. John Wiley Editions, New York.

Yacobaccio, H.D., Escola, P., Lazzari, M., Pereyra, F.X., 2002. Long-distance obsidian traffic in Northwestern Argentina, in: Glascock, M.D. (Eds.), *Geochemical Evidence for Long Distance Exchange*. Bergin and Garvey, Westport, 167-203 pp.

Zirkel, F., 1866. Lehrbuch der Petrographie, vol. 1. Engelmann Ed., Bonn.