Volume XIV ● Issue 2/2023 ● Pages 201–217

INTERDISCIPLINARIA ARCHAEOLOGICA
NATURAL SCIENCES IN ARCHAEOLOGY

homepage: http://www.iansa.eu

Obsidian Sources of Prehispanic Artefacts from Cultures near Ceboruco Volcano, Nayarit, Mexico

Anne-Kyria Robin[1], Katrin Sieron[2,3*], José Carlos Beltrán Medina[4]

[1]*Laboratoire de Geographie Physique, Université Pantheon-Sorbonne Paris 1, 191 Rue Saint-Jacques, 75005 Paris, France*
[2]*Geological Survey at State Office for Mining, Geology and Resources of Brandenburg (department 24), Inselstraße 26, 03046 Cottbus, Brandenburg, Germany*
[3]*Centro de Ciencias de la Tierra (Center for Earth Sciences), Universidad Veracruzana, Lomas del Estadio s/n, Col. Zona Universitaria, C.P. 91000, Xalapa, Veracruz, Mexico*
[4]*Instituto Nacional de Antropología e Historia (INAH), Mexico, Avenida México No. 91 Norte, Centro Histórico, C.P. 63000, Tepic, Nayarit, Mexico*

ARTICLE INFO

Article history:
Received: 11th July 2023
Accepted: 6th November 2023

DOI: http://dx.doi.org/10.24916/iansa.2023.2.4

Key words:
obsidian mines
geochemical analyses
source
Mesoamerican cultures
western Mexico
Mahalanobis

ABSTRACT

Ceboruco, located in the western part of the Trans-Mexican Volcanic Belt is an active stratovolcano in Nayarit, Mexico, with the last historic eruption in 1870–1875. The fertile valleys around this volcano have been occupied for several thousands of years. The recognised pre-Hispanic human settlements include the Shaft tomb and Aztatlán cultures, which were present in the vicinity of the volcano before and after the well-studied Plinian Jala eruption in 890 AD, respectively. Both cultures left abundant archaeological materials in housing units and cemeteries, including obsidian tools. In this study, we compare archaeological samples (poorly preserved tools or parts of them) with obsidian samples from local outcrops, as well as other known regional obsidian mine sites. We use hand sample and chemical analyses of main and trace elements. The results are statistically evaluated by using the Mahalanobis distance-method in order to assign probable sources. We show that obsidian has been locally extracted from long-known obsidian mines near Ixtlán del Río, but also from obsidian layers at the nearby Sierra Madre Occidental Mountain Range and the Pochotero obsidian dome. Nevertheless, clear evidence for obsidian trade since the earliest occupations has also been found, as we identified sources from the neighbouring states such as Jalisco.

1. Introduction

Ceboruco stratovolcano is located in the Graben Tepic-Zacoalco in the western part of the Mexican Volcanic Belt (CVM) in the State of Nayarit, Mexico (Figure 1). Ceboruco volcano has been active since about 300,000 years ago (Ferrari *et al.*, 1997), but it shows a quite long time span of inactivity between 40,000 and 1000 years BP (Frey *et al.*, 2004). During that period only minor volcanic activity at smaller monogenetic volcanoes occurred in the study area (Sieron *et al.*, 2019). It had the last documented eruption in 1870 (*e.g.*, Iglesias, 1875; 1877; García, 1875) and a major Plinian eruption around 1060 ± 55 years BP, corresponding to ca. 890 AD (Sieron and Siebe, 2008), which was followed by the emission of multiple lava flows within 150 years (Boehnel *et al.*, 2016). The cataclysmic Plinian eruption around 890 AD must have disrupted any human activity with an area of more than 500 km^2 (Sieron and Siebe, 2008). But the smaller scale post-Plinian eruptions must also have severely affected people's life in that area.

In the surroundings of the volcano, there are different types of smaller (monogenetic) volcanic edifices, including 18 cinder cones built by Strombolian-type eruptions, 8 high-silica lava domes and at least 2 phreatomagmatic volcanoes (Agustín-Flores *et al.*, 2021; Sieron and Siebe, 2008; Figure 2), both volcanoes often associated with explosive eruptions. Among the eight silicic domes in the immediate surroundings of Ceboruco volcano lies the Pochotero obsidian dome, one of the research targets in this study. Seven of these monogenetic volcanoes have erupted in the last 6000 years (Sieron and Siebe, 2008).

The Ceboruco volcano, as well as the aforementioned monogenetic vents, lies within a graben, bound to the north by Sierra Madre ignimbrites and rhyolites. Rhyolites include

*Corresponding author. E-mail: ksieron@gmail.com

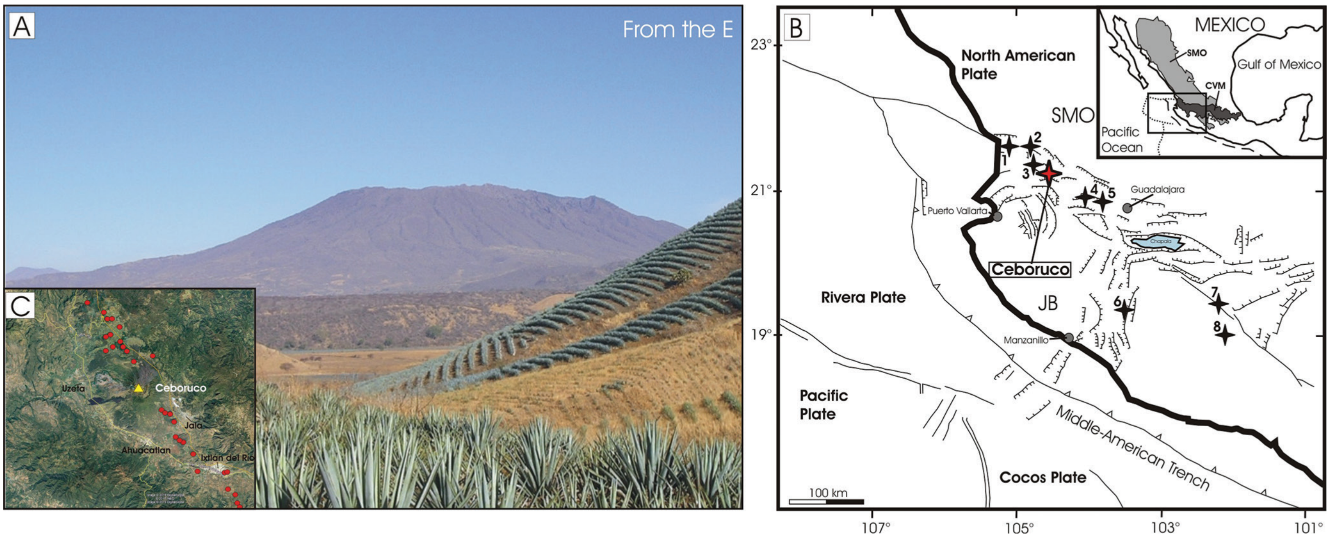

Figure 1. A: The Ceboruco volcano as seen from the East (front right: Molcajete scoria cone). B: Tectonic overview of western Trans-Mexican Volcanic Belt and localisation of the Ceboruco volcano, modified after Prost and Aranda (2000) (JB=Jalisco Block; SMO=Sierra Madre Occidental; black stars indicate the following volcanoes: 1=San Juan, 2=Sanganguey; 3=San Pedro volcanic complex; 4=Tequila; 5=Primavera caldera; 6=Colima volcanic complex; 7= Paricutin; 8=Jorullo; lines indicate tectonic faults). C: Red dots represent monogenetic volcanoes in the surroundings of the Ceboruco volcano.

other obsidian sources that were potentially used by the pre-Hispanic population who were inhabiting this volcanic landscape for the last several thousand years (up to the Spanish conquest).

Archaeological studies are relatively scarce in western Mexico. One reason for this could be that larger “stone”-buildings are absent – one of the few known larger “stone”-structures is the Los Toriles site near Ixtlán del Río (Gifford, 1950). For detailed reviews on why so little attention has been paid to western-Mexican Archaeology, see, for example, Pollard (1993; 1997), Weigand (1985a; 1985b; 1989; 1991) or Hers (1991).

The original idea of a “Western Mexico” (as distinct from the wider Mesoamerica) was based on the distribution of the Mexican Shaft tomb culture (Beekmann, 2010; Kan *et al.*, 1989) and Teuchtitlán temple architecture (Weigand, 2000) in the Mexican states of Jalisco, Nayarit and Colima, sometimes adding southern Sinaloa and southern Zacatecas (where shaft tombs also occur) and Michoacán (the Purépecha Empire). The study area lies within this zone and Shaft tomb culture remains are evident around the Ceboruco volcano (Figure 2). Most of the sites lie buried beneath the Jala eruption deposits on its southern flank (Figure 2). Re-occupation after this important volcanic eruption is evident; see INAH internal reports (*e.g.*, Beltrán, 2015) (Figure 2), for which can be mentioned the cist-builders (cist is a small stone-lined mortuary box) and the Aztatlán culture.

In recent decades, studies in western Mexico have increased, mainly due to INAH salvage projects, but unfortunately most of the resulting reports still remain unpublished. One of the few publications offers information about shell material from The Pitayera´s shaft tombs (Beltrán, 2018), while another gives information about funerary practices in Ahuacatlan (Beltrán *et al.*, in press). Here we will publish part of such reports, together with geological studies in the area, and focus on the provenance of obsidian over time (and hence different cultures). Answers to the following questions will be sought: Are local obsidian sources in Nayarit, western Mexico, being used? How important was trade throughout the pre-conquest human occupation (Formative to Post-classic)? Are there differences through time? What about the interplay between culture and the volcanic landscape?

2. Overview of cultures present in the study area over time

The earliest occupation known in western Mexico would have been before 2500 BC and consisted of small groups of hunters and gatherers during the Lithic Period (Schöndube, 1987; Oliveros, 1975). Archaic cultures in Nayarit state include the shell culture (Mountjoy *et al.*, 1972) along the coastline and the San Pedro phase on the mainland (Pollard, 1997). After the Preclassic or Formative Period, the Capacha culture represents the earliest agro-ceramists in western Mexico (near Colima; Kelly, 1980), but also along the Pacific Coast, which was in contact with central Mexico and El Opeño in Michoacán. The El Opeño Shaft tomb tradition followed (1500–800 BC; Oliveros Morales and de los Rios, 1993), with some cultural interaction along the Santiago-Lerma River system with cultures to the west (Jalisco and Nayarit), and east. Later, between 1200 and 300 BC, increasingly larger populations of Capacha and El Opeño culture descendants occupied Jalisco and southern Nayarit (Pollard, 1997). The Shaft tomb tradition is thought to correspond to the by then advanced agro-ceramists spreading along the Nayarit, Colima and Jalisco states, southern Zacatecas and western Michoacán between 300 AD and 500 AD (Mountjoy, 2000, p.88), highlighting the Etzatlan area (*e.g.*, Weigand, 1974). Around 400/300 BC

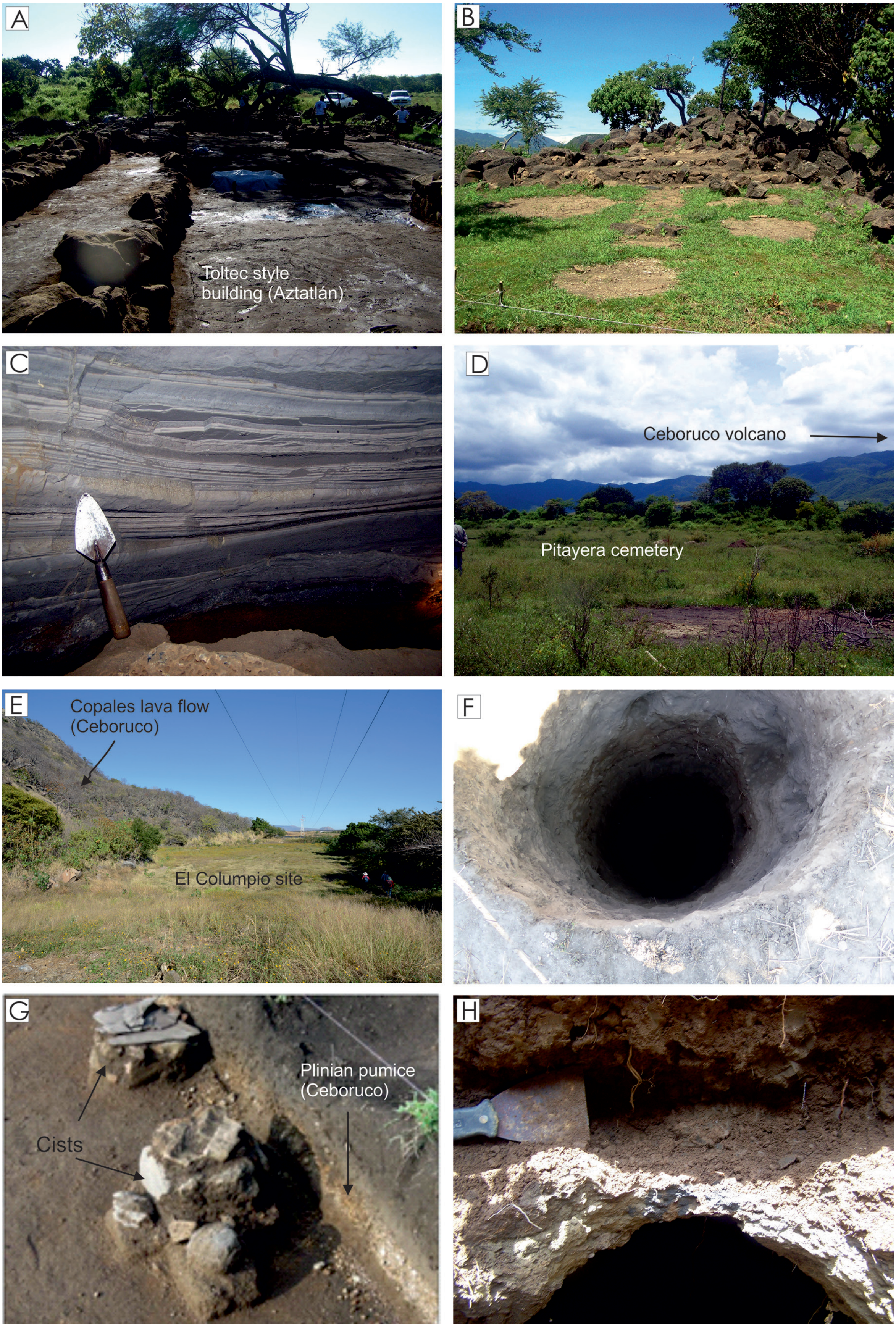

Figure 2. A: Aztatlán building (Toltec style) Ahuacatlán complex. B: Terrace at the Ahuacatlán complex. C and D: Shaft tombs at the Pitayera cemetery (Ahuacatlán complex). E and F: Shaft tombs at the Columpio site to the S of Ceboruco volcano (see also Figure 3). G: Stone-lined cists. H: Entrance to a shaft tomb.

Table 1. Overview of the local cultures present in the study area over time.

CHRONOLOGICAL CHART OF THE NAYARITAN ARCHAEOLOGICAL PROVINCE, AHUACATLÁN SITE AND THE CENTRAL ALTIPLANO				
DATE	**PERIOD**	**PROVINCES AND ARCHAEOLOGICAL SITES**		
1532–1521 AD	SPANISH CONQUEST	NAYARIT	AHUACATLAN SITE	CENTRAL ALTIPLANO
1500	POST-CLASSIC (POSTCLÁSICO)	Late Ixtlán (Ixtlán tardío)	Late Ixtlán (Ixtlán tardío)	Mexica
1250	LATE (TARDÍO)	Aztatlán-Mixteca		Mixteca
1000	POST-CLASSIC (POST-CLÁSICO)		Cist-builders (Cistas), local Toltec (Tolteca local)	Tolteca
900	EARLY (TEMPRANO)	Aztatlán-Tolteca	Cist-builders (Cistas), Middle Ixtlán (Ixtlán medio)	Tolteca
750	EPI-CLASSIC (EPICLÁSICO)	Red/white tradition (Tradición rojo/bayo)	Red/white Tradition (Tradición rojo/bayo)	Metepec-Coyotlatelco Teotihuacán-Xolalpan
500	CLASSIC (CLÁSICO)	Shaft tomb culture/tradition (Tumbas de Tiro)	Shaft tomb culture/tradition (Tumbas de Tiro)	Teotihuacán
AD	–	Polychrome Ixtlán (Ixtlán Polícromo)	Polychrome Ixtlán (Ixtlán Polícromo)	Tlalmimilolpan
0	–	Chinesco	Early Ixtlán (Ixtlán Temprano)	–
BC	–	Shaft Tomb culture/tradition (Tumbas de Tiro)	Shaft tomb culture/tradition (Tumbas de Tiro)	–
250	PRECLASSIC (PRECLÁSICO)	Chinesco	El Columpio	Copilco
	FINAL	–	–	–
500	PRECLASSIC (PRECLÁSICO)	San Blas	local Capacha	–
750	MIDDLE (MEDIO)	–	–	Tlatilco
1000	PRECLASSIC (PRECLÁSICO)	local Capacha	–	–
1500	EARLY (TEMPRANO)	–	–	–
2000 BC	CONCHEROS	Matanchén	–	–
Sources: Gifford, 1971; Mountjoy, 2000; González and Beltrán, 2013; Townsend, 1992				

to 200 AD the Teuchtitlan (Guachimonton) culture appeared in Jalisco (Weigand, 1979; 1985a; 1985b).

During the Classic Period in western Mexico, further cultural transformations took place in Michoacán (between 300 and 900 AD), mainly affected by social processes occurring in central Mexico. But our study area (Nayarit) and Jalisco seems to have been more influenced by the Teuchitlán culture, according to Weigand (1979; 1985a; 1985b) and Pollard (1997). Later the culture declined (Teuchitlán phase II 600–900 AD), evidenced by a gradual replacement of mortuary habits (shaft tombs) and the associated concentric circle architecture by rectilinear plaza pyramid centres (Pollard, 1997). In southern Nayarit, new plaza pyramid centres emerged during the Classic Period, for example, Ixtlán del Río (Gifford, 1950) in our study area.

The Postclassic Period is characterised by major changes in settlement areas (around 900 AD), which has been mainly associated with climate changes (*e.g.*, Jimenez Betts, 1988). Shifts in ceramic styles (polychrome), predate the later emerging Tarascan culture. Certain ceramic types and other materials have been traded along the Santiago River (previously also used as a trade route) from Chapala Lake to the Pacific coast; this interaction has resulted in the term "Aztatlán complex" (a big trading network). The influence of the Toltecs and La Mixteca-Puebla has been mentioned (with Mazapan-like figurines, copper metallurgy, and codex-style polychrome ceramics, and bronze metallurgy later on).

In conclusion, there has been a long pre-Hispanic occupation of probably more than 3500 years (Oliveros Morales and de los Rios, 1993) in western Mexico (Table 1).

3. Archaeological Salvage projects in the study area

In our study area, close to the Ceboruco volcano (Nayarit state, Mexico), apart from the surface survey and archaeological excavations in Ixtlán del Río, the only extensive archaeological excavations in the region were conducted at the sites of Ahuacatlán and El Columpio (Figures 2 and 3), close to the Ceboruco volcano, by way

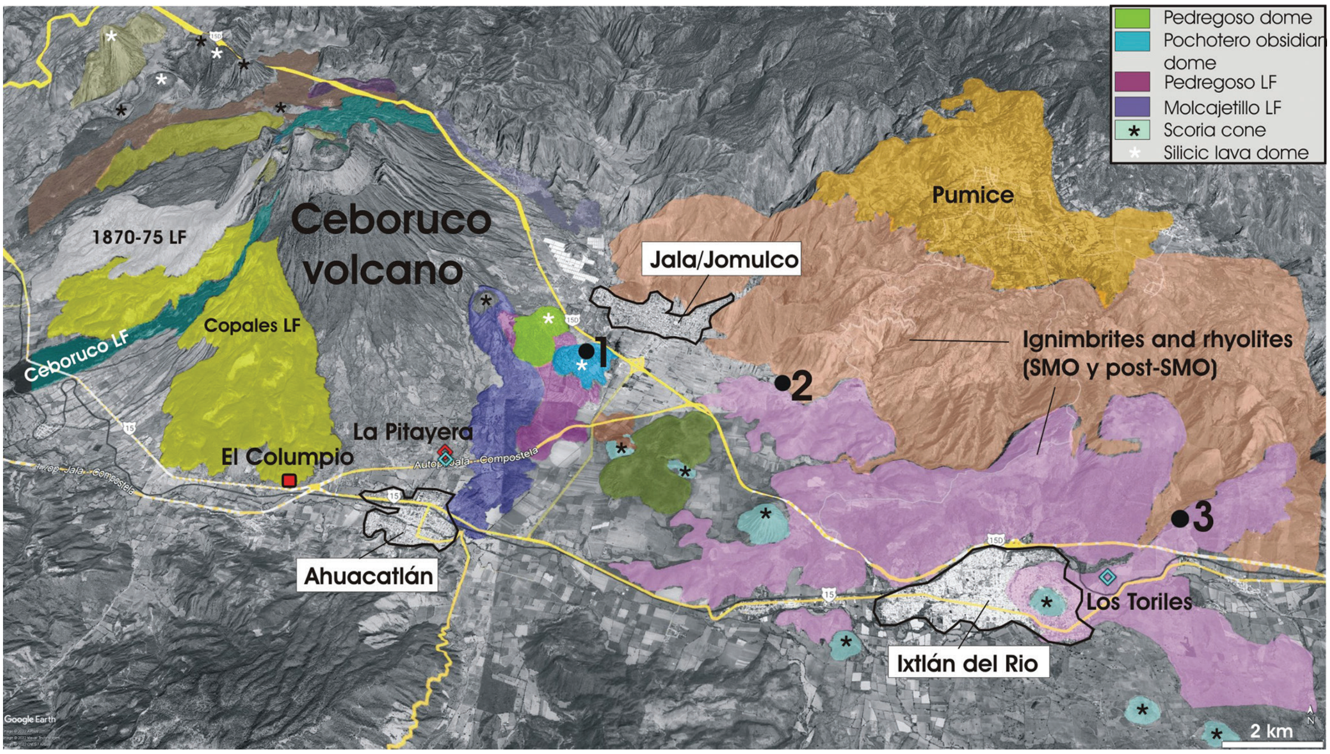

Figure 3. Geological sketch map of the Ceboruco region. Sampled obsidian sources near Ceboruco volcano are also indicated (black dots), 1: Pochotero obsidian dome. 2: Sierra Madre Occidental obsidian. 3: Ixtlán del Río obsidian mine. We also show the archaeological sites open for visitors: Los Toriles and Ahuacatlán (La Pitayera) and el Columpio sites, as well as some of the modern settlements.

of INAH salvage projects (*e.g.*, González-Barajas and Beltrán-Medina, 2013; Beltrán, 2015).

Ahuacatlán (including La Pitayera cemetery; Figures 2 and 3) comprises an area of 80 hectares, including several squares, mounds and housing complexes, as well as a rich, long-used pre-Hispanic cemetery. The site includes shaft tombs (since the Formative Period) and shows a surprising cultural development (funerary cists with metal artefects and Postclassic Aztatlán with Toltec influenced figurines) (González-Barajas and Beltran Medina, 2013), concluding with the arrival of the Spaniards in 1530 (Muria, 1980, p.290) to this region (Arregui, 1946; Ciudad Real, 1976).

Near the Ceboruco volcano (southern slopes), a few pottery and lithic materials of Capacha style (ca 1200 BC) were found in the deep levels of the Ahuacatlan and Columpio archaeological sites (Figures 2 and 3). The continuation of this tradition is called San Blas, proving to be the transition in this region towards the Shaft tomb tradition (Mountjoy, 2000). A clear Shaft tomb tradition in the Jala-Ahuacatlán region started from 550 BC to 300 BC. Together, at Ahuacatlán and El Columpio (Figures 2 and 3) more than 50 shaft and vault tombs have been detected, and more than 150 skeletons (NMI) recovered, accompanied by some rich and varied offerings (Beltrán, 2018; Beltrán, in press).

Human occupation continued during the Epiclassic period with the presence of the stone-lined funerary cist-builders, see Figure 2G (550–950 AD), which are contemporary to the Amapa and Armería phases, sharing materials. A group of 17 stone-lined funerary cists dated to the Epiclassic period was found, containing the cremated remains of at least 22 individuals (NMI), accompanied by 338 artefects of different materials, including obsidian. The first pieces of metal appear to be associated with the cist-builders. Afterwards, the Aztatlán tradition begins in the Early Postclassic (850–1200 AD) and the Middle Postclassic (1200–1350 AD) periods. Thence the cultural sequence continues (Late Ixtlán phase) until the Spanish conquest in 1530 AD.

This quite long cultural sequence near the Ceboruco volcano was based mainly on the exploitation of volcanic deposits in the vicinity of the site, among them obsidian sources, and agriculture (fertile volcanic soils). In fact, lithic materials in general were of great importance as they served to elaborate various working artefacts (*e.g.*, hand axes, hammers, chisels, metates or mealing stones, anvils, knives and blades) (García Cook, 1967), with which they transformed the environment (terraces, platforms, embankments, channels, housing structures, and ponds) González-Barajas and Beltran Medina, 2013). Elaborated obsidian artefacts were used as cutting and precision instruments (like blades, punches, drills knives, lacquers, spears, arrow heads, scrapers), the finds of which we here compare to natural sources nearby (see next section).

In the cemetery (Figure 2) a Toltec style building (of Aztatlán age; Figure 2A) was excavated (González-Barajas and Beltran Medina, 2013). Apart from the shaft tomb obsidian samples, fragments of tools found inside the Toltec-style building were also selected to compare with the samples obtained from natural local obsidian sources, such as the

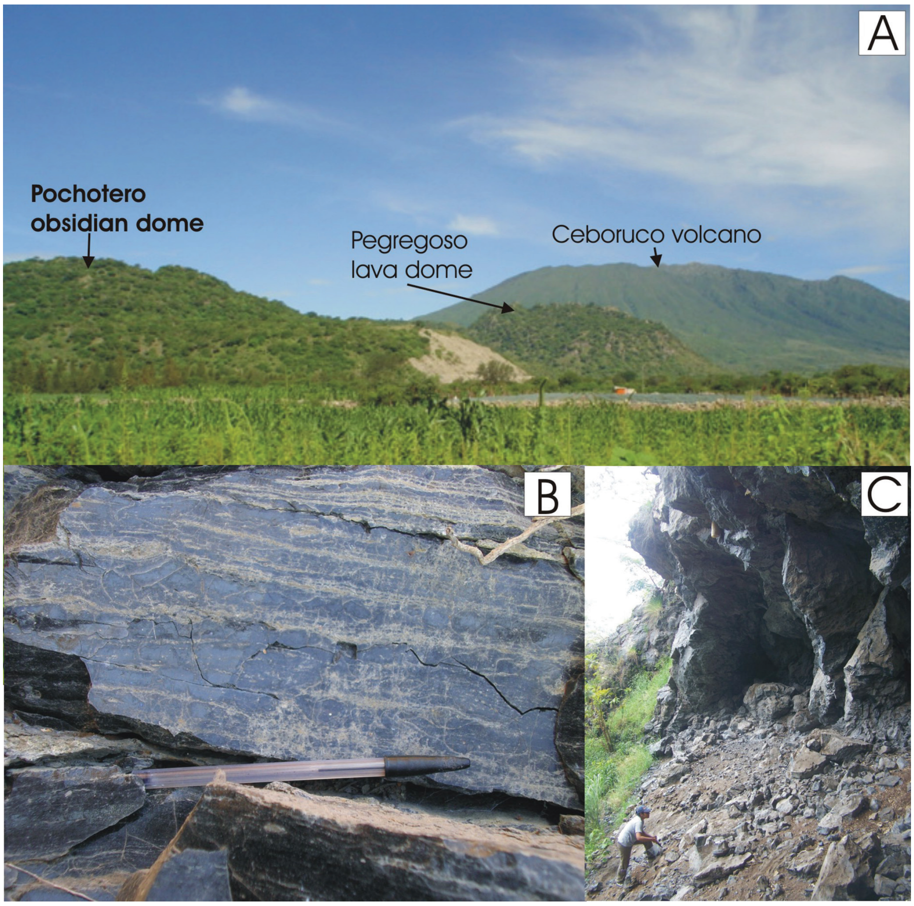

Figure 4. Photos of Ceboruco volcano and Pochotero obsidian dome (A), as well as the Pochotero obsidian sample site (B and C).

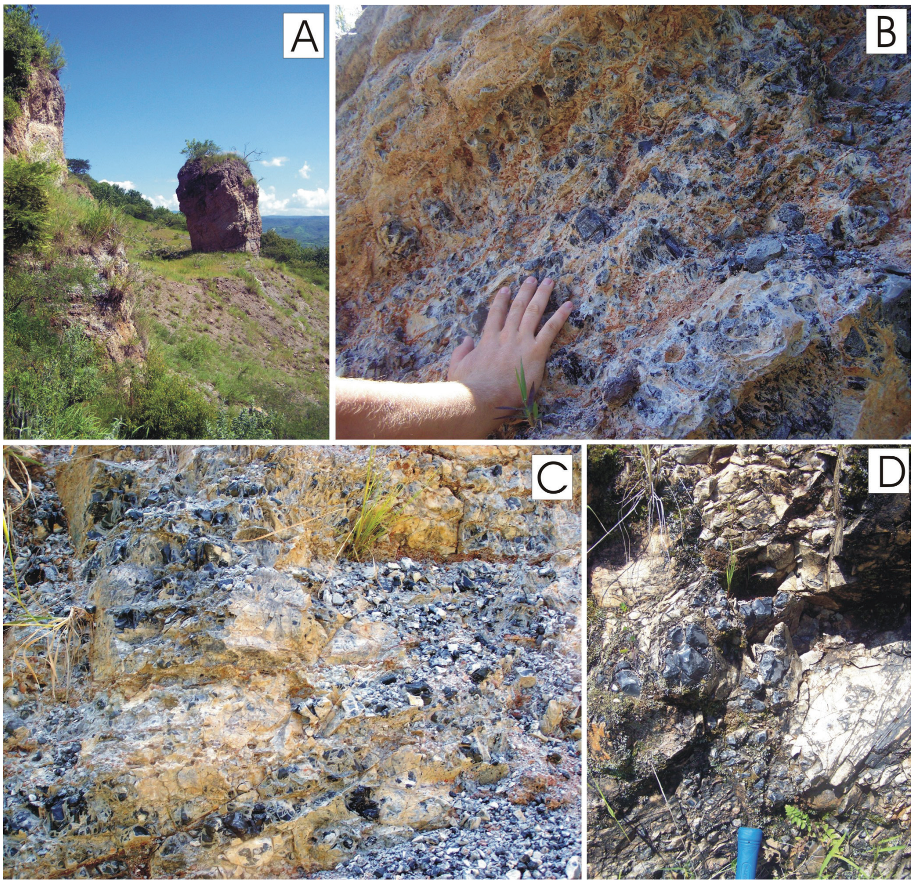

Figure 5. Photos of the Ixtlán del Río obsidian mines, showing the mine at its current state (A) and the obsidian nodules surrounded by very weathered obsidian (B–D). See also Figure 3.

Figure 6. Sierra Madre Occidental obsidian lenses and layers (A, B; see also Figure 3).

Pochotero dome, the Ixtlan del Río mine (Figures 3 to 6) and the deposit at the foot of the nearby Sierra Madre Occidental Mountain Range (near the village of Agua Blanca). There is a quarry next to the site (Pochotero obsidian dome, to the NE) and an obsidian workshop in the ceremonial centre or group B (Figure 2B). Here, we analyse obsidian samples from cultures at both extremes of the timeline: the oldest occupation (Shaft tomb culture) and the late Aztatlán culture (shortly before the Spaniards arrived), separated by the Ceboruco Plinian eruption.

This work should be considered important, especially as in western and northern Mexico few obsidian sources have been characterised due to their difficulty of access (Sierra Madre Occidental Mountain Range) as well as the sources being widely spread geographically (Trombold *et al.*, 1993). Previous works have focused on larger high-quality sources, such as Las Navajas, Tequila volcano and La Quemada (Zacatecas) (*e.g.*, Trombold *et al.*, 1993). Here we would like to add some information on obsidian sources as compared to the usage of obsidian in the area close to the Ceboruco volcano.

4. Geology

4.1 Main geological features in the study area

The study area is characterised by three geological domains of great scale and regional importance: the Sierra Madre Occidental to the northeast (the former volcanic arc (Jurassic-Tertiary), the Jalisco Block (JB) to the southwest, and the western part of the Trans-Mexican Volcanic Belt (TMVB), which separates the Sierra Madre Occidental from the JB (Figure 1B). The basement of western and central Mexico in general forms part of the Guerrero Terrain (Ortega *et al.*, 2008) with a crust no older than Palaeozoic.

The Ceboruco Graben is part of a large-scale depression called the Tepic-Zacoalco Graben, which has an NW–SE orientation (*e.g.*, Ferrari *et al.*, 1999). The limit to the NE of the semi-graben Ceboruco is marked by a normal fault with a scarp that cuts the sequence of rhyolites and Jala ignimbrites as well as Sierra Madre Occidental ignimbrites and rhyolites (Figures 1B and 3) (Ferrari *et al.*, 2002), some of which include obsidian lenses and/or layers. The south-western limit of the Ceboruco Graben is marked by a successive elevation of the southern mountain range called the Sierra el Guamuchil (SEG) which is part of the Jalisco Block and is composed mainly of rhyolites and ignimbrites, as well as fewer dated dacites and andesites, from the past 65 million years (Ferrari *et al.*, 2003) (Figure 3). At the foot of the SEG, ignimbrites appear that are part of the younger sequence of ignimbrites and rhyolites Jala north of the depression.

The activity of the modern Ceboruco Graben probably started in the early Pliocene (Righter *et al.*, 1995; Ferrari *et al.*, 2003). Graben-related modern volcanism has included the emission of a variety of products ranging from basalts to rhyolites, associated either to single volcanoes (poly- and monogenetic), or attributed to fissure related activity (see Ferrari *et al.*, 2000; 2003).

The Sierra Madre Occidental is a volcanic platform with a thickness of more than 1000 m, which is composed of ignimbrites and rhyolites, formed during several stages of volcanic activity, together with major tectonic displacements that occurred during the massive appearance of ignimbrites between 38 and 18 million years (Figure 1B) (*e.g.*, McDowell *et al.*, 1990). In the Ceboruco area, the younger ignimbrites of the Sierra Madre Occidental (~ 20 million years) (Ferrari *et al.*, 2000) occur only in restricted outcrops near the Ixtlán del Río (Figures 1B and 3). Elsewhere, they are covered with silicic sequences (rhyolites and "Jala" ignimbrites), as well as younger basaltic-andesitic rocks (basalts and andesites "Ixtlán and Buenavista") (Ferrari *et al.*, 2000; 2003). Obsidian frequently/occasionally occurs associated with these ignimbrites.

Although the overwhelming part of the monogenetic volcanoes are basaltic-andesitic scoria cones, silicic domes are also present within the Ceboruco Graben, some of which present obsidian.

4.2 Obsidian outcrops

4.2.1 Pochotero obsidian dome

The Ceboruco volcano has been active since at least the Late Quaternary (0.37±0.2 million years, Ferrari *et al.*, 1997) and had its most recent eruption in 1870. The products comprise andesitic and dacitic lavas, as well as pyroclastic deposits ranging from andesite to rhyodacite. The surrounding monogenetic volcanic edifices include scoria cones, but also several silicic domes, of which one is an obsidian dome (Pochotero; Figures 3 and 4), which has been sampled (Figure 4A). In several outcrops it can be observed that the Pochotero obsidian shows flow banding and there are grey dense pumice layers and true glassy obsidian layers. Recrystallization can be observed, which has an effect on the "obsidian quality" (Figure 4B).

Nevertheless, a cavern-like structure can be noticed on the E-flank of the dome (Figure 4C) where the obsidian shows a more uniformly glassy texture (better quality). Therefore, it can be assumed that it might have been used in pre-Hispanic times. In the surroundings of the Pedregoso and Pochotero domes (see Figure 4A), archaeological surface material (ceramic sherds and obsidian blades and arrowheads) can be observed.

4.2.2 Ixtlán obsidian mines

To the northeast of Ixtlán del Río town and Los Toriles archaeological site (Gifford, 1950) (Figure 3), at a distance of 2 km, a prehispanic obsidian mine is located (Figure 5).

According to previous works (*e.g.*, Ferrari *et al.*, 2003) to the north of the Ceboruco Graben (and therefore Ixtlán del Río as well) Jala rhyolites and ignimbrites (age: 4.95–4.1 million years) and Ixtlán and Buenavista basalt and andesite crop out abundantly, overlying Sierra Madre Occidental ignimbrites and rare andesites (age: 34–19 million years) (see also Figure 3). According to the Mexican Geological Survey (SGM; geological map F13D43; scale 1:50,000), the obsidian mines NE of Ixtlán del Río town belong to the unit "QptB-TR" (Pleistocene age – not older than 1.5 million years) which is composed of grey basalt with rhyolitic tuff intercalations; the mine would belong to the latter or one of the surrounding units, which are Pliocene–Pleistocene rhyolites and rhyolitic tuffs (see Figure 3).

4.2.3 Sierra Madre obsidian lenses/layers

The obsidian layers found to the southeast of Jala and Jomulco villages (see Figure 3) belong to the unit "TplQptA-TR" (Pliocene age), which is composed of greenish andesites with rhyolitic tuff intercalations according to the Mexican Geological Survey (SGM; geological map F13D42; scale 1:50,000). But we think it rather belongs to the adjacent unit "TplQptTR-R" (corresponding to ignimbrites and rhyolites in Figure 3; see also D13D42 SGM-map), as it is described showing rhyolites and rhyolitic tuffs with obsidian lenses (Figure 6). The obsidian shows banding (greyish-black obsidian with red bands).

5. Methodology

5.1 Identification of sites and physical characterisation of the geological samples

5.1.1 Geological sampling

Known obsidian outcrops, identified during previous geological and archaeological studies (*e.g.*, Sieron and Siebe, 2008; INAH internal reports) in the area, were revisited in 2014 during the "archaeological salvage" campaign when the beltway to Puerto Vallarta was constructed (Guadalajara-Tepic highway no 15). Samples were taken at each site

Figure 7. Obsidian hand samples. A: CBA-4 Ixtlán del Rio. B: Pochotero dome Ptr-d. C: CBA-5°. D: CBA-5B. E: CBA-5C from SMO.

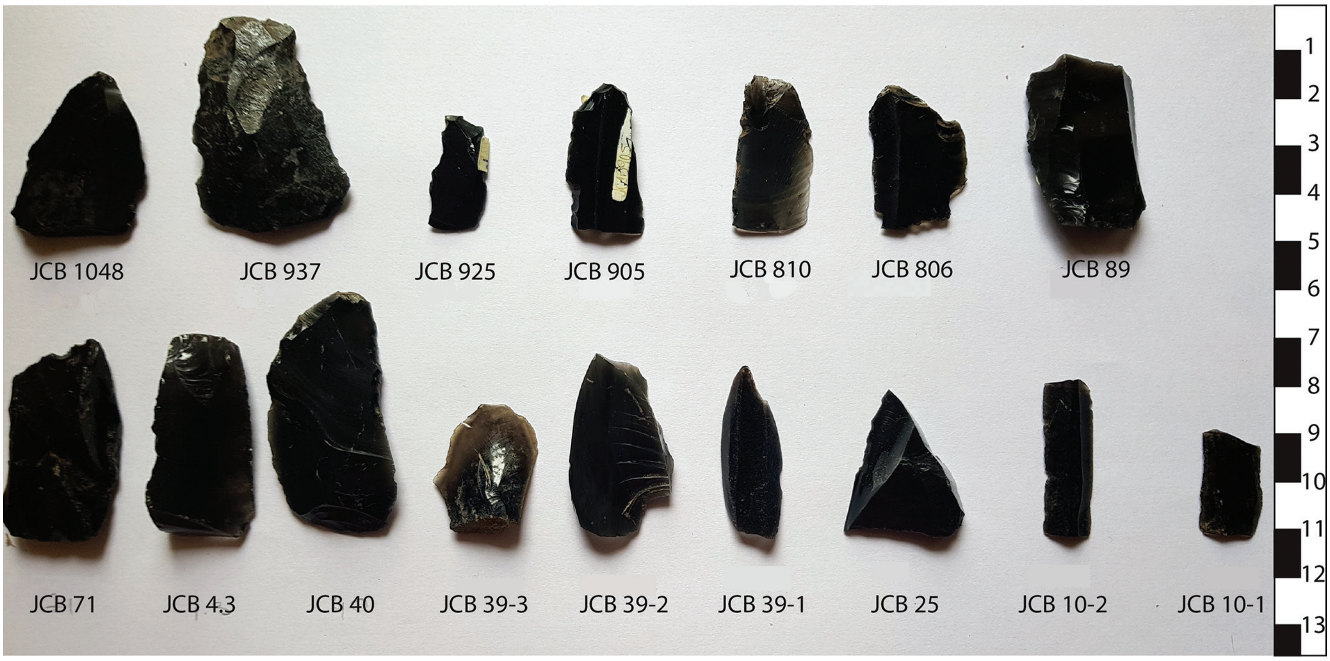

Figure 8. Postclassic obsidian artefacts from cemetery Pitayera of the Ahuacatlán site, (see also Figure 3).

described in the geologic section using a geological hammer. In the case of the existence of visually different obsidian along one single outcrop, several samples were taken (as in the case of the post-SMO ignimbrite obsidian layer; sample CBA-5). The samples were later bagged and shipped to the Laboratory of Physical Geography (UMR8591), University Paris 1 Pantheon-Sorbonne.

The obsidian samples were taken from each of the sources identified near to the Ceboruco volcano, described in the geology section: Ixtlán del Río obsidian mine (sample CBA-4; 21.049000/104.329611; 1230 m asl); Pochotero obsidian dome (Ptr-d; 21.088543/-104.446334); and obsidian lenses of post-SMO rhyolites and ignimbrites (sample CBA-5; 21.085199/-104.410370; 1137 m asl). CBA-4 is made up of one piece of black obsidian (Figure 7).

The second sample group CBA-5 is made up of three obsidians that present three different facies. Therefore, we added a complementary letter CBA-5A, CBA-5B, CBA-5C (Figure 7).

5.1.2 Morphological studies

Both, geological and archaeological samples were physically described as hand samples taking into account their colour, texture, pattern and lustre. Some of them that were big enough were analysed as a thin section under an optical Leica microprobe. These thin sections were elaborated by the Thin Section Lab in Toul (France).

5.2 Chemical and statistical analyses

In this study a portable XRF (X-ray fluorescence) Thermo Scientific NITON XL3t was used to analyse and measure the concentration of chemical elements in the obsidian archaeological artefacts and geological samples without any destruction. The X-ray source of the analyser is a 50-kV tube with an Au anode target. As this work aims at determining the source of obsidian used for prehispanic artefacts, we used the "mining mode" that provides a wide range of elements, from heavy elements to light elements generally used in obsidian sourcing (Chataigner, 1994; Gratuze, 2013).

To be in agreement with another method of reference (LA-ICP-MS) that could be used in this study, the p-XRF was calibrated using 16 obsidians from Eastern and Central Anatolia that provide a wide range of chemical signatures, defined as *house standards* and previously analysed by LA-ICP-MS at IRAMAT laboratory in Orleans. After the calibration we obtained strong correlations (Pearson's r = 0.88–0.98) between LA-ICP-MS (resp. B. Gratuze, IRAMAT UMR 5060, Orléans) and portable XRF (resp. D. Mouralis, LGP, UMR 8591, Paris) on the 16 obsidians defined as *house standards* (Mouralis *et al.,* 2018).

Furthermore, at the beginning of each analysing session, during the session, and at the end, the stability of the p-XRF was verified by using three house standards corresponding to the lowest, middle and highest values that are often found in obsidian. These samples have been cut to approximately one cubic centimetre blocks and the same face was analysed every time. The samples were analysed during 240 s. Each sample was analysed three times at different positions to estimate the chemical variability within the sample.

In order to discriminate chemical groups among the geological obsidian samples and the archaeological obsidian artefects, we used the FDA (Factorial Discriminant Analysis) function. FDA is one of the commonly used methods with respect to obsidian sourcing, if groups of obsidian sources are already known. Each group is identified and related to an outcrop in the field. In this study, we were aiming at determining if each of the archaeological artefects can be related to a known geological outcrop. First, we compared

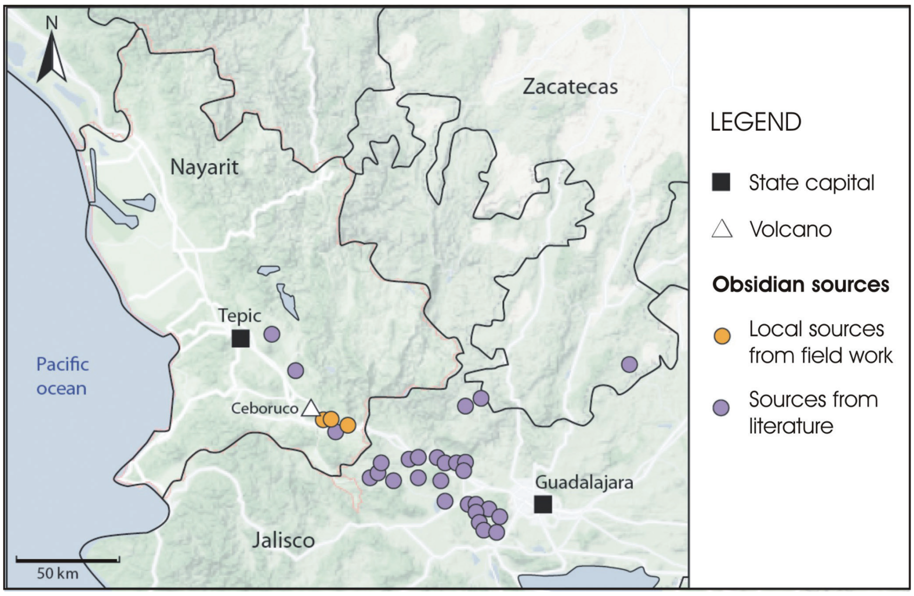

Figure 9. Western Mexico. Purple dots – Glascock *et al.* (2010) sample locations. Orange dots: our local sources. White square: the Ceboruco volcano.

chemical signatures between our local obsidian sources near Ceboruco and the archaeological artefacts, and then we compared them with other obsidian sources from archaeological sites farther away, as referenced in the literature.

The FDA was conducted on the nine chemical elements that were common during the XRF analyses made by Glascock *et al.* (2010) on obsidian samples from western Mexico. These elements are K, Ti, Fe, Mn, Rb, Sr, Y, Zr, and Nb. Results from Glascock *et al.* (2010) were used to increase the number of sources that could have provided raw material in the Nayarit area and constrain the statistical analyses (Figure 9).

In total, 18 archaeological artefacts were analysed by p-XRF. Artefectgroup JCB 4.3 (see Table 3) consists of 3 pieces with similar chemical composition. We present the average composition of this group in Table 3. Relevant elements for the comparison with the geological obsidian sources are also presented in Table 3. Some archaeological artefects present no value for Mn or Sr due to levels being below the limit of detection. For those artefects we replaced the no value by zero in Table 3.

6. Results

6.1 Geochemical analyses and attribution

The geochemical signature of a set of archaeological obsidian artefects from the Jala-Compostela salvage project was compared to the nearby geological obsidian sources Pochotero dome, Ixtlán mine and post-SMO. First results showed that the chemical signature of obsidian samples CBA 5A and CBA 5B, taken from different outcrops of post-SMO obsidian lenses and layers in ignimbrites, were close enough to be included into one single statistical group CBA 5. Some archaeological artefects can be attributed to a local source but many of them cannot be related to a local source (Table 3, Figure 10). Two local obsidian sources seem to have been Ixtlán del Rio (CBA 4) and post SMO (CBA 5). Archaeological artefects JCB 39-3, JCB 4.3, JCB 71 and JCB 89 were attributed to the post SMO (CBA 5) source. Archaeological artefects JCB 39-2, JCB 40 and JCB 25 were attributed to the Ixtlán del Rio (CBA 4) source. JCB 40 presents as an outlier from the group.

As some artefects could not be attributed to one of the three near-Ceboruco sources, we compared their chemical signature to the ones of sources from the neighbouring Jalisco and Zacatecas states (Figure 11). For this purpose, we included chemical data from Glascock *et al.,* (2010) (XRF results; Figure 9). We employed the nine most discriminant elements from our analyses and from the data extracted from Glascock *et al.* (2010).

The results shed light upon the provenance of most of the obsidian archaeological artefects from the Jala-Compostela archaeological salvage project, taking into account the discriminant factorial analyses (Figure 12) and the Mahalanobis distance (Table 4).

Based on the Mahalanobis distance among the known obsidian sources from Nayarit, Jalisco and Zacatecas, the archaeological artefects JCB 89, JCB 25, JCB 39-2, JCB 39-3, JCB 40, JCB 4.3 and JCB 806 present the closest distance with the CBA 5 (post SMO obsidian source) group. Considering the Mahalanobis distance, the first four archaeological pieces can be attributed to the post-SMO source with a very good degree of probability. This result confirms the previous attribution of JCB 89, JCB 39-3 and JCB 4.3 to the post-SMO source. JCB 39-2 was previously attributed to Ixtlán del Rio (CBA 4); it is now attributed to the post-SMO (CBA 5) source. In regard to the Mahalanobis distance, it appears that the archaeological artefect JCB 39-2 cannot be significantly distinguished from the post-SMO source and Ixtlán del Rio source. The closest group from JCB 39-2 is CBA 5 (post-SMO) with a Mahalanobis distance equal to 9.6 compared to Ixtlán del Rio with a 10.7 distance.

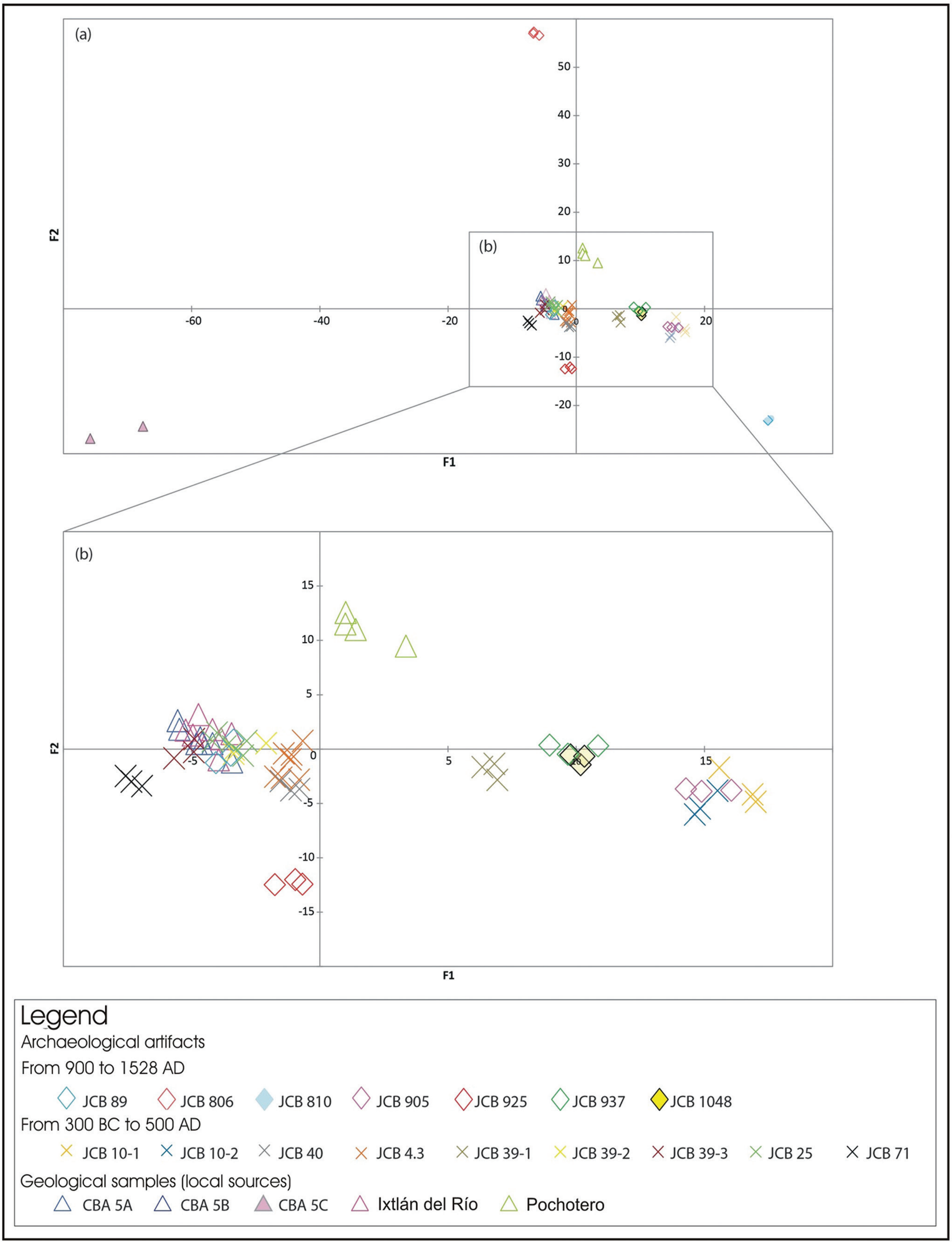

Figure 10. A: Graphical representation of the factorial discriminant analysis (FDA; F1 and F2 axes) based on the 5 most disseminated chemical elements (Rb, Sr, Y, Zr, Nb)., archaeological artefects vs local sources; (b) zoom of the (a) window.

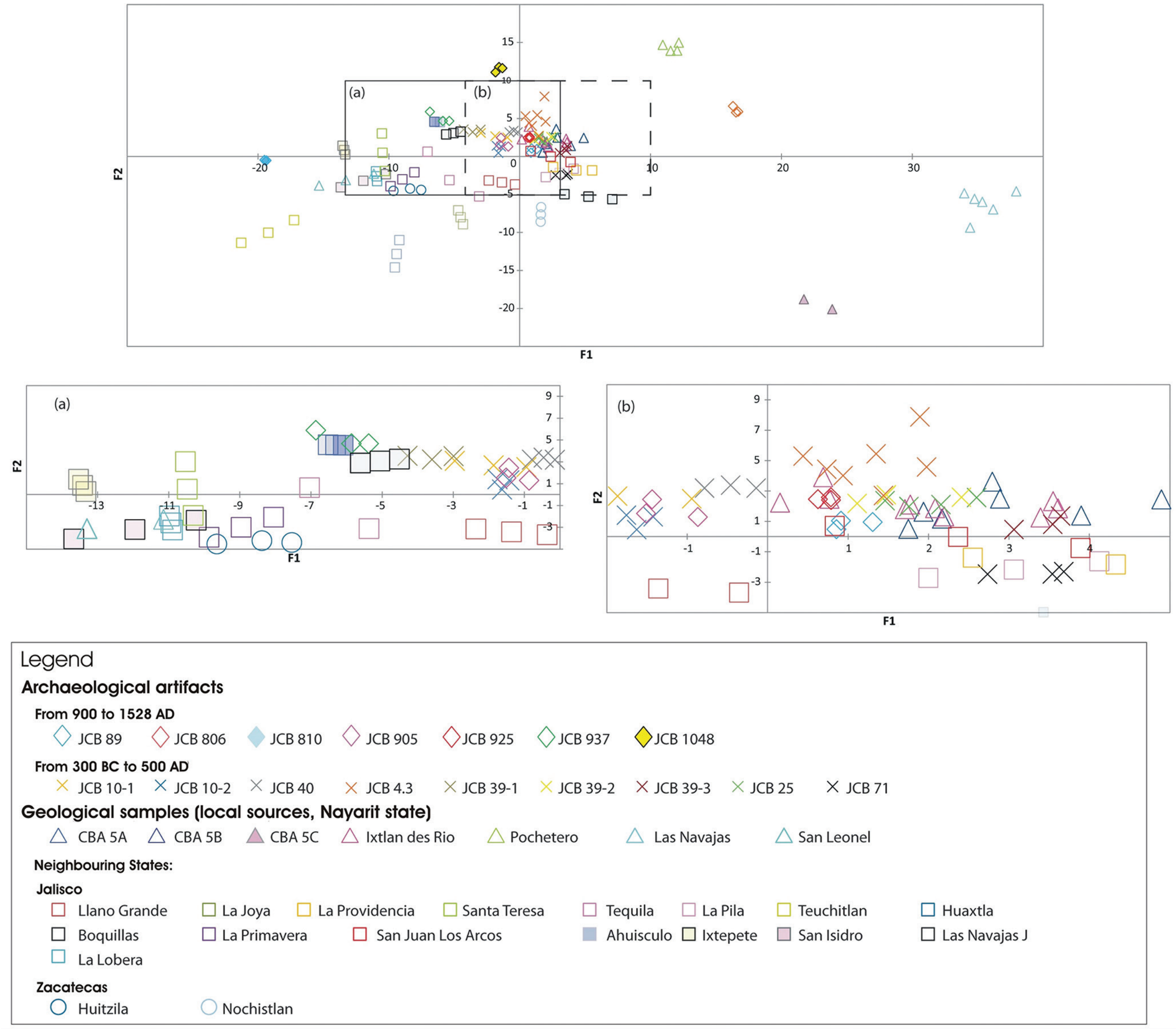

Figure 11. Graphical representation of the factorial discriminant analysis (F1 and F2 axes) based on the 5 most disseminated chemical elements (Rb, Sr, Y, Zr, Nb). Chemical compositions for Jalisco and Zacatecas sources are from Glascock *et al.* (2010) and Pierce (2015).

JCB 40 was reattributed to the post-SMO source with a high probability. JCB 806 might stem from another obsidian source as its Mahalanobis distance presents an important deviation from the group.

Samples JCB 905, JCB 39-1, JCB 10-1 and JCB 10-2 seem to have their origin at the Llano Grande (Jalisco) obsidian source. JCB 71 has been reassigned to La Pila with a very good degree of probability, if we only consider the Mahalanobis distance. JCB 937 was extracted at Las Navajas (Jalisco). This source presents excellent knapping quality; the obsidian from Las Navajas being black. JCB 810 was attributed to San Isidro. JCB 925 has two possible sources. Regarding the first possibility, La Providencia, the obsidian is of poor quality, as mentioned by Glascock *et al.* (2010). Therefore, we suggest that the obsidian artefacts stem most probably from the source La Pila.

The origin of the three artefects JCB 806, JCB 10-1 and JCB 1048 can be discussed: their Mahalanobis distance is respectively the lowest for CBA 5 (post-SMO), Llano Grande and Ahuisculo, but presents a farther distance compared to the other attributions.

6.2 Morphological studies

The results of the morphological studies of geological and archaeological obsidian samples, based on hand sample descriptions and some thin section analyses, can be summarised as follows:

6.2.1 CBA-4 – Ixtlán obsidian mine

CBA-4 is a black obsidian with a vitreous to greasy lustre with no pattern. It has a massive aspect. It is smooth, opaque and breaks with a characteristic “conchoidal” fracture.

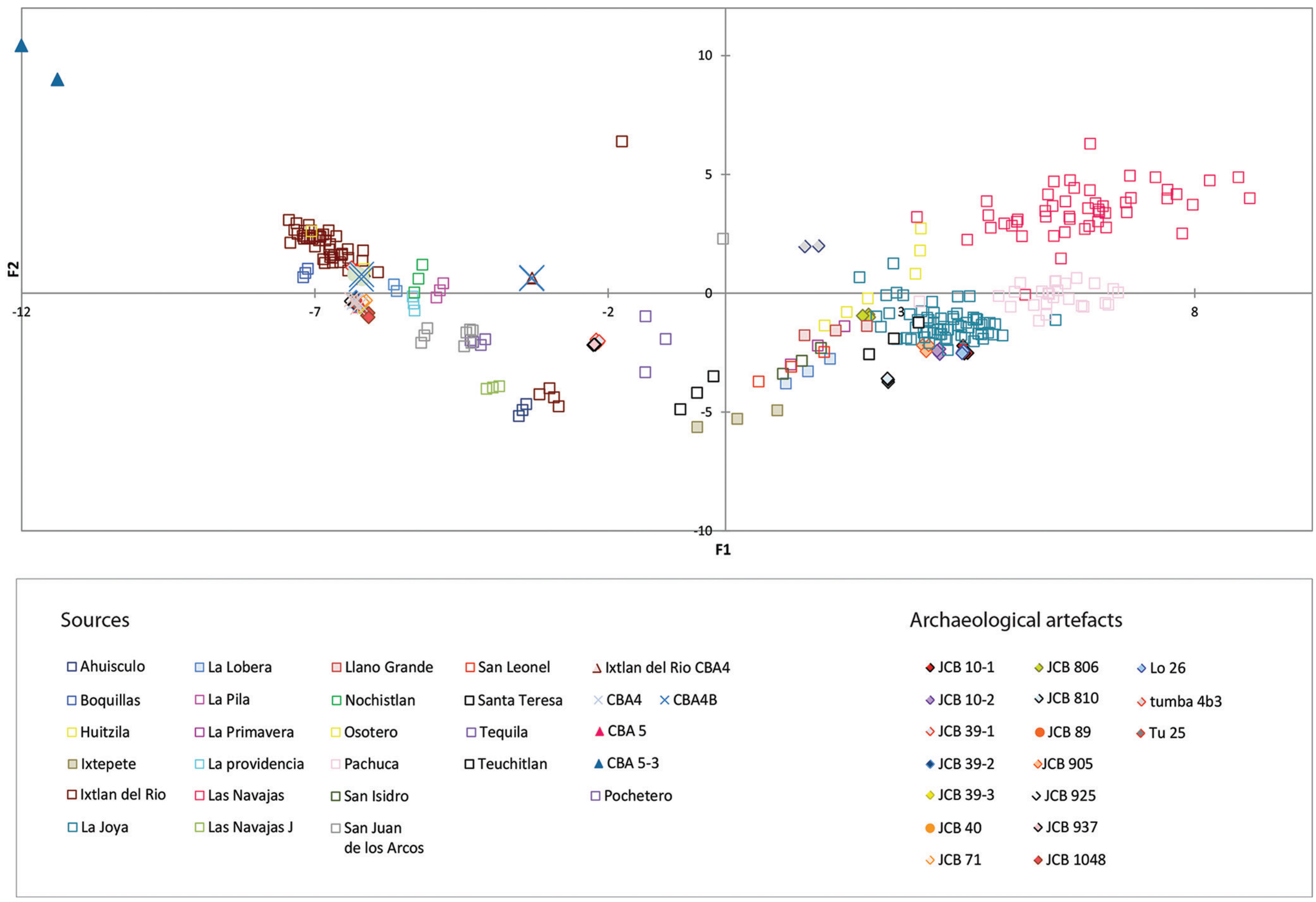

Figure 12. Factorial discriminant analysis (most probable provenance of the obsidian archaeological artefacts from the Jala-Compostela archaeological salvage project).

6.2.2 CBA-5 group – SMO/post-SMO obsidian

CBA-5A is a black obsidian that presents fine grey bands. The bands are parallel to each other. CBA-5A is a smooth, opaque obsidian with a massive aspect, showing conchoidal fracturing. On its surface we can observe a red and rough patina (Figure 7).

CBA-5B is a black and brown obsidian, drawing a mottled pattern and showing a vitreous to greasy lustre (Figure 7). This obsidian is also smooth, opaque when thick, and presents a massive aspect. In flake this obsidian is transparent, and it also shows conchoidal fracturing. The surface presents no patina but many tiny vacuoles, giving it a rough texture.

CBA-5C is also a black obsidian with a greasy to dull lustre (Figure 7). It is opaque and rough and presents a flecked aspect. Flecks are white to light grey and seem to correspond to phenocrysts. It presents irregular fracturing.

6.2.3 Pochotero dome

Pochotero dome is represented by just one obsidian sample (and type), (Ptr-D), which is black to greyish with a dull lustre. This obsidian has a banded pattern and a fine grainy texture (Figure 7).

6.3 Archaeological sample description

6.3.1 Archaeological artefects

There are 16 obsidian samples, which all stem from the Ahuacatlán cemetery (Figures 2, 3, and 8); nine of them come from shaft tombs, while the other seven come from mound 7 (Toltec-style building; Aztatlán culture, Figure 2A; Table 2).

La Pitayera is the cemetery of the Ahuacatlán site (Figure 2D). The collected samples encompass two groups of archaeological artefects.

All the archaeological artefects are black in colour. Most of them present a smooth texture, except for two, JCB 937 and JCB 39-1, which are rough. Ten of the 16 archaeological artefacts present a vitreous to silky lustre, while six of them, JCB 937, JCB 925, JCB 810, JCB 39-1, JCB 10-2 and JCB 10-1, have a greasy lustre. Ten artefects are opaque, and six are transparent (JCB 905, JCB 810, JCB 806, JCB 25, JCB 10-2 and JCB 10-1). From this set of archaeological artefects and based on lustre and opacity, three main groups can be distinguished: a first group, with a vitreous to silky lustre and opacity; and a second group with a greasy lustre and transparency; and a third one with a vitreous lustre and transparency (Table 2).

Table 2. Physical description of the 16 archaeological artefects.

Group 1 Vitreous to silky lustre + opacity	**Group 2** Greasy lustre + transparency	**Group 3** Vitreous lustre + transparency
JCB 1048, JCB 89, JCB 71, JCB 4.3, JCB 40, JCB 39-3, JCB 39-2	JCB 937, JCB 925, JCB 810, JCB 39-1, JCB 10-2, JCB 10-1	JCB 905, JCB 806, JCB 25

Physical characteristics such as colour, texture, lustre or pattern as complementary indicators to the Mahalanobis distance result in the confidence indicator (Table 4) for each attribution. If we compare the colour and texture between artefects and geological samples, we can assume that all artefects attributed to the Ceboruco volcano are in accordance with the geological samples. Obsidian from La Joya source is described as dark green obsidian with a homogenous composition profile and an excellent knapping quality (Weigand and Spence, 1982; Glascock *et al.*, 2010). Archaeological artefects attributed to La Joya source present a black to dark grey colour for the three artefects (JCB 10-1, JCB 10-2 and Lo 26). Obsidian from the Tequila source (Jalisco) is described as black brittle obsidian with a poor knapping quality, but JCB 905 is a nucleus with a good knapping quality. The other obsidian source that presents a close chemical signature and similar physical characteristics is the La Joya (Jalisco) source.

These first results show a predominant use of post-SMO local sources during the Shaft tomb culture, whereas during the Aztatlán culture obsidian sources were more diversified and more distant (Table 4).

7. Discussion

The statistical analysis is made among the known obsidian sources, which means that each artefect can be attributed to a source, even though their chemical signatures are quite different to their attributed one. Therefore, it is necessary to look at the Mahalanobis distance that corresponds to the statistical distance between the barycenter of a group and the sample that has to be attributed. The larger the distance is from a group, the more the probability of attribution decreases.

Some sources present close geochemical signatures; the Mahalanobis distance from one to another is small, based on the 9 most discriminated elements. Therefore, some archaeological artefects such as JCB 806, JCB 10-1 JCB 40 and JCB 1048 cannot be clearly attributed to a specific obsidian source (Table 3).

We find here that most of the studied obsidian artefects are from a local provenance near the Ceboruco volcano. A part of them seem to stem from the Llano Grande sources (the neighbouring Jalisco State) with a degree of certainty, but some of the attributions still remain uncertain. As a consequence, we suppose that more research has to be done to more precisely determine the proportion of artefects from local sources and those derived from trade.

Chemical groups formed by known obsidian sources must be precisely characterised with a significant number of samples to cover the chemical variability within an obsidian outcrop (Shackley, 1998; Robin 2017) and constrain the attribution. Also, it is important to know the geological and the geomorphological context of each potential obsidian source to determine criteria of exploitability such as accessibility, extractability and quality of the raw material (Robin *et al.*, 2016; Robin, 2017).

Elsewhere, for example in Chacalilla near San Blas, 33% of obsidian artefects found come from Las Navajas volcano (dark green obsidian), near Tepic. This obsidian was used in the production of bifacial pieces, while 75% was made with grey obsidian from Ixtlán predominantly for the production of blades from prismatic cores (Pierce, 2015). The green obsidian of the knives was apparently used to make generalised reductions. In other places further north, such as Amapa, Coamiles and San Felipe Aztatlán, obsidian predominates from the three already-mentioned sources (Ixtlán, Navajas, La Joya), and some others but in less quantity (Pierce, 2015).

The slopes of the Tequila volcano, about 80 km to the south-east, are rich in obsidian deposits, and in the northern part of Jalisco state there are a number of important deposits located in the Tequila-Coli corridor, some of which were exploited intensively in pre-Hispanic times (Glascock, 2010). This same territory is the core area of the Teuchitlán

Table 3. Archaeological samples and local vs distal sources. Bold letters indicate the assignation of two potential sources.

Ixtlan (local source 1) CBA4	**Pochotero (local source 2)**	**SMO (local source 3) CBA5**	**Distal sources**
Archaeological samples (Shaft Tomb culture)	–	Archaeological samples (Shaft Tomb culture + Azatlán (806))	Azatlán culture + Shaft Tomb culture
JCB 25, JCB 39-2, JCB 40	There were no artefects attributed to this outcrop	JCB 4.3, **JCB 40**, JCB 39-3, **JCB 39-2**, **JCB 25**, JCB 806, JCB 89, **JCB 71**	JCB 810, JCB 905, JCB 925, JCB 937, JCB 1048, JCB 10-1, JCB 10-2, JCB 39-1, **JCB 71**

Table 4. Potential sources of the 16 archaeological obsidian fragments from the Shaft tomb and Aztatán cultures based on their physical characteristics (see text) and the Mahalanobis distance. Brown coloured sources cannot be clearly attributed to one source. Green coloured sources show a very high confidence level respect to the attributed source, while the white ones show a good confidence, yet not as high as the green ones.

Periods	Archaeological artefects	Archaeological site	Potential sources	Mahalanobis distance
900–1530 AD Aztatlán culture	JCB 89	Ahuacatlán	post SMO	10,7
	JCB 806	Pitayera	post SMO	397,4
	JCB 810	Pitayera	San Isidro	91,7
	JCB 905	Pitayera	Llano Grande	75,8
	JCB 925	Pitayera	La Providencia	71,8
	JCB 937	Pitayera	Las Navajas	36,7
	JCB 1048	Pitayera	Ahualisco	145,8
300 BC–500 AD Shaft Tomb culture	JCB 10-1	Tumba 4 boveda 1	Llano Grande	131,3
	JCB 10-2	Tumba 4 boveda 1	Llano Grande	81,5
	JCB 25	Tumba 25	post SMO	3,5
	JCB 39-1	Tumba 11	Llano Grande	45,8
	JCB 39-2	Tumba 11	post SMO	9,6
	JCB 39-3	Tumba de Tiro	post SMO	11,2
	JCB 40	Tumba 29	post SMO	49,6
	JCB 4.3	Tumba 4 boveda 3	post SMO	54,7
	JCB 71	Tumba 7	La Pila	17,5

tradition, whose development is intimately linked to the exploitation, processing and trade of obsidian. Specialised production workshops have also been found in San Juán de los Arcos, Navajas and Ahuisculco (Glascock, 2010).

In Ahuacatlán, like the rest of Mesoamerica, the artefects of obsidian and flint achieved a high quality and high development, showing the existence of a well-developed technology. In the lithic collection of Ahuacatlán there is a large bifacial knife of brown-red obsidian with black veins (inclusions). This is a remarkable and large example, but unfortunately it is incomplete and has no context since it was donated by a collector from Ahuacatlán. Its own form and manufacturing technique are indicators of its use and function; it is a single piece that has a grip and a sharp blade. At first sight it resembles to some extent the red obsidian of the CBA5 deposit, near Agua Blanca. The ceremonial pieces of this area are associated with the exercise of power and with a high symbolic content.

There are some similar pieces that come from the western deposits. Unfortunately, these artefects come from collectors, so no accurate information is known (Darras and Fields, 2003). It appears that most bifacial artefects in western Mexico are from after 900 AD.

With regard to the culturally-related quality differences of the obsidian pieces, we recognise that the Shaft Tomb tradition produced and used the obsidian in a more limited way. Blades were shorter in general and triangular in shape, giving priority to the flint, while later in the cultural sequence (Aztatlán) the technology was refined notably, and there was access to fine trapezoidal blades – and the items were of a better quality. After 900 AD, during the Aztatlán tradition, the control of the production and distribution of these blades and other high quality products is apparent.

8. Conclusion

Archaeological samples, like poorly preserved tools or pieces of them from the Ahuacatlán area (Ahuacatlán site and Pitayera cemetery), a long used archaeological site (Shaft tomb culture to Aztatlán) on the south-eastern flanks of the still active Ceboruco volcano, have been chemically and morphologically analysed. These results were used, together with the Mahalanobis distance technique, to assign potential natural obsidian sources, both, from local outcrops and more distant ones. It was interesting to find that the Shaft tomb culture (predominant culture before the 1000 AD Plinian eruption of Ceboruco volcano) related pieces were primarily extracted from local obsidian mines, as there is the Sierra Madre Occidental Mountain Range just a few kilometres to the north, and the Ixtlán del Río Mine around 13 km to the east. The Pochotero obsidian dome could not be assigned as a potential source to any of the recovered artefacts, even though a mining site had been identified. Nevertheless, the obsidian is of a generally poor quality with just spatially limited outcrops of better-quality obsidian. After the decline of the Shaft tomb culture near Ceboruco, the cist-builders and Aztatlán culture used obsidian from a great diversity of places, both local and very distant ones, evidencing extensive trade despite the distances of hundreds of kilometres across the country. Also, the quality of tools increased with time, as observed by others before. It would be desirable to increase the number of chemical analyses of more archaeological pieces in order to further constrain sources over time in western Mexico.

Acknowledgements

We are grateful to INAH Nayarit (Mexico) for the open collaboration in this interdisciplinary research, in respect to sample donation and access to internal information (reports *etc.*). We also thank D. Mouralis for giving us access to the p-XRF.

References

AGUSTÍN-FLORES, J., SIEBE, C., FERRÉS, D., SIERON, K., and GONZÁLES-ZUCCOLOTTO, K., 2021. Monogenetic volcanoes with initial phreatomagmatic phases in the Ceboruco graben, western Mexico: The cases of Potrerillo I, Potrerillo II, and San Juanito. *Journal of Volcanology and Geothermal Research*, 412, 107184. DOI: 10.1016/j.jvolgeores.2021.107184

ARREGUI, D.L. de, 1946. *Descripción de la Nueva Galicia.* Sevilla: Escuela de Estudios Hispano-Americanos.

BEEKMAN, C.S., 2010. Recent Research in Western Mexican Archaeology. *Journal of Archaeological Research*, 18, 41-109. DOI: 10.1007/s10814-009-9034-x

BELTRÁN, J.C., 2015. *Proyecto de salvamento arqueológico autopista Jala-Compostela km 0+000 al 27+000.* MS. Internal report. Mexico City: Instituto Nacional de Antropología e Historia (INAH).

BELTRÁN, J.C., 2018. Los materiales malacológicos de Ahuacatlán. In: M. Alcántara, M. García Montero, F. Sánchez López, eds. *Arqueología: 56.º Congreso Internacional de Americanistas.* Salamanca: Ediciones Universidad de Salamanca, p.1989. DOI: 10.14201/0AQ0251_2

BELTRÁN, J.C., GONZÁLEZ, L., TALAVERA, J., and MORALES, J., in press. *Funerary practices during the Epiclasico and Postclasico: La Pitayera, Nayarit.* Salt Lake City: University of Utah Press.

CHATAIGNER, C., 1994. Les propriétés géochimiques des obsidiennes et la distinction des sources de Bingöl et du Nemrut Dag. *Paléorient*, 20(2), 9–17.

CIUDAD REAL, A. de, 1976. *Tratado curioso y docto de las grandezas de la Nueva España.* 2nd ed., Mexico City: UNAM.

DARRAS, V., and FIELDS, V., 2003. Un cuchillo ceremonial de obsidiana roja. *Arqueología Mexicana*, 63,74–77.

FERRARI, L., CONTICELLI, S., VAGGELI, G., PETRONE, C.M., and MANETTI, P., 2000. Late Miocene volcanism and intra-arc tectonics during the early development of the Trans-Mexican Volcanic Belt. *Tectonophysics*, 318, 161–185.

FERRARI, L., LOPEZ-MARTÍNEZ, M., AGUIRRE-DÍAZ, G., and CARRASCO-NÚÑEZ, G., 1999. Space–time patterns of Cenozoic arc volcanism in central Mexico. From the Sierra Madre Occidental to the Mexican volcanic belt. *Geology,* 27, 303–306.

FERRARI, L., LÓPEZ-MARTÍNEZ, M., and ROSAS-ELGUERA, J., 2002. Ignimbrite flare-up and deformation in the southern Sierra Madre Occidental, western Mexico: implications for the late subduction history of the Farallón plate. *Tectonics*, 21(4), 17–24.

FERRARI, L., NELSON, S.A., ROSAS-ELGUERA, J., AGUIRRE-DÍAZ, G., and VENEGAS-SALGADO, S., 1997. Tectonics and volcanism of the western Mexican Volcanic Belt. In: G. Aguirre-Díaz, J. Aranda-Gómez, G. Carrasco-Núñez, and L. Ferrari, eds. *Magmatism and tectonics in central and northwestern Mexico – A selections of the 1997 IAVCEI General Assembly excursions.* Mexico City: Instituto de Geología, Universidad Nacional Autónoma de México, pp. 85–129.

FERRARI, L., PETRONE, C.M., FRANCALANCI, L., TAGAMI, T., EGUCHI, M., CONTICELLI, S., MANETTI, P., and VENEGAS-SALGADO, S., 2003. Geology of the San Pedro-Ceboruco Graben, western Trans-Mexican Volcanic Belt. *Revista Mexicana de Ciencias Geológicas*, 20, 165–181.

GARCÍA, S., 1875. *Una visita al pueblo de S. Cristóbal., Viaje al Ceboruco. Edición oficial. Informe y colección de artículos relativos a los fenómenos geológicos verificados en Jalisco en el presente año y en épocas anteriores. Tomo II.* Guadalajara: Tipografía de S. Banda.

GARCÍA COOK, A., 1967. *Análisis tipológico de artefactos.* Serie de Investigación, 12, Mexico City: INAH.

GIFFORD, E., 1971. *Surface exploration at Ixtlan del Rio.* University Publication in Archaeology and Ethnology, 43(2), Berkeley: University of California Press.

GLASCOCK, M., WEIGAND, P., ESPARZE, R., OHNERSORGEN, M., AMBRIZ, M., MOUNTJOY, J., and DARLING, A., 2010. Chapter 12. Geochemical characterization of obsidian in Western Mexico: the sources in Jalisco, Nayarit and Zacatecas. In: Y.V. Kuzmin, and M.D. Glascock, eds. *Crossing the Straits: Prehistoric Obsidian Source Exploitation in the North Pacific Rim.* BAR International Series, 2152, pp. 199–217.

GONZÁLEZ-BARAJAZ L., and BELTRÁN-MEDINA, J.C., 2013. *Proyecto de salvamento arqueológico autopista Jala-Compostela km 0+000 al 27+000.* MS. Internal report. Mexico City: INAH.

GRATUZE, B., 2013: Provenance analysis of glass artefacts. In: K. Janssens, ed. *Modern methods for analysing archaeological and historical glass.* Hoboken: Wiley, pp. 311–343. DOI: 10.1002/9781118314234.ch14

HERS, M.-A., 1991. Medio milenio después de la conquista. El estudio del pasado prehispánico. *Arqueologia,* 5, 3–7, Mexico City: INAH.

IGLESIAS, M., 1875. *La exploración científica del Ceboruco. Edición oficial., Informe y colección de artículos relativos a los fenómenos geológicos verificados en Jalisco en el presente año y en épocas anteriores. Tomo II.* Guadalajara: Tipografía de S. Banda.

IGLESIAS, M., BÁRCENA, M., and MATUTE, J.I., 1877. El Ceboruco. *Anales del Ministerio de Fomento de la República de México*, 1,168–196.

JIMENEZ BETTS, P., 1988. Ciertas inferencias de la arqueologia del sur de Zacatecas. In: R. Brambila, and A.M. Crespo, eds. *Primera Reunión sobre las Sociedades Prehispánicas en el Centro Occidente de México. Memoria,* Cuaderno de Trabajo, 1, Mexico City: INAH, pp. 39–50.

KAN, M., MEIGHAN, C.W., and NICHOLSON, H.B., 1989. *Sculpture of Ancient West Mexico: Nayarit, Jalisco, Colima; The Proctor Stafford Collection.* Los Angeles: Los Angeles County Museum of Art.

KELLY, I., 1980. *Ceramic Sequence in Colima: Capacha, an Early Phase*. Anthropological Papers, 37, Tuscon: University of Arizona Press.

MCDOWELL, F.W., WARK, D.A., and AGUIRRE-DÍAZ, G.J., 1990. The Tertiary ignimbrite flare-up in western Mexico. *Geological Society of America Annual Meetings Abstracts with Programs*, 22(3), 366.

MOUNTJOY, J., 2000. Prehistoric cultural Development along the Southern Coast of West Mexico. In: M. Foster, and S. Gorenstein, eds. *Greater Mesoamerican. The Archaeology of West and Northwest Mexico*. Salt Lake City: The University of Utah Press, pp. 81–106.

MOUNTJOY J.B., TAYLOR, R.E., and FELDMAN, L.H., 1972. Matanchén Complex: New radiocarbon dates on early coastal adaption in West Mexico. *Science*, 175, 1242–1243.

MOURALIS, D., MASSUSSI, M., PALUMBI, G., AKKÖPRÜ, E., BALOSSI RESTELLIE, F., BRUNSTEIN, D., FRANGIPANE, M., GRATUZE, B., MOKADEM, F., and ROBIN, A.K., 2018. The procurement of obsidian at Arslantepe (Eastern Anatolia) during the Chalcolithic and Early Bronze Age: Connections with Anatolia and Caucasus. *Quaternary International*, 467, 342–359.

MURIÁ, J.M., 1980. *Historia de Jalisco. Las expediciones Cortesianas. La conquista de la Nueva Galicia, Tomo I.* Guadalajara: Gobierno de Jalisco.

OLIVEROS, J.A., 1975. Arqueología del estado de Michoacán. In: *Los pueblos y señoríos teocráticos, México, Panorama Histórico y Cultural, VII.* Mexico City: INAH, pp. 207–214.

OLIVEROS, A., and DE LOS RIOS, M., 1993. La cronología del Opeño, Michoacán: nuevos fechamientos por radio-carbono. *Arqueología*, 9–10, 45–48.

ORTEGA-GUTIÉRREZ, F., ELÍAZ-HERRERA, M., and DÁVALOS-ELIZONDO, M.G., 2008. On the nature and role of the lower crust in the volcanic front of the Trans-Mexican Volcanic Belt and its fore-arc region, southern and central Mexico. *Revista Mexicana de Ciencias Geológicas*, 25, 346–364.

PIERCE, D.E., 2015. Visual and geochemical analyses of obsidian source use at San Felipe Aztatán, Mexico. *Journal of Anthropological Archaeology*, 40, 266–279, DOI: 10.1016/j.jaa.2015.09.002.

PIERCE, D., 2016. Volcán las Navajas: The chemical characterization and usage of a West obsidian source in the Aztatlán tradition. *Journal of Archaeology Science: Reports*, 6, 603–609.

POLLARD, H.P., 1993. Ethnicity and political control in a complex society: The Tarascan state of prehispanic Mexico. In E. Brumfiel, and J.W. Fox, eds. *Factional Competition and Political Development in the New World.* New York: Cambridge University Press, pp. 79–88.

POLLARD, H.P., 1997. Recent research in west Mexican Archaeology. *Journal of Archaeological Research*, 5(4), 345–384.

RIGHTER, K., CARMICHAEL, I., BECKER, T., RENNE, R., 1995. Pliocene to Quaternary volcanism and tectonics at the intersection of the Mexican Volcanic Belt and the Gulf of California. *Geological Society of America Bulletin*, 107, 612–626. DOI: 10.1130/0016-7606(1995)

ROBIN, A.K., 2017. *Identification et caractérisation des affleurements d'obsidienne en Anatolie orientale (Turquie), dans le cadre des études de provenance au Proche-Orient.* Unpublished thesis (PhD), Université Paris 1, Panthéon-Sorbonne.

ROBIN, A.K., MOURALIS, D., AKKÖPRÜ, E., GRATUZE, B., KUZUCUOGLU, C., NOMADE, S., PEREIRA, A., DOĞU, A.F., ERTURAC, K., KHALIDI, L., 2016. Identification and characterization of two new obsidian sub-sources in the Nemrut volcano (Eastern Anatolia, Turkey): The Sıcaksu and Kayacık obsidian. *Journal of Archaeological Science: Reports*, 9, 705–717. DOI: 10.1016/j.jasrep.2016.08.048

SCHAAF, P., MORÁN-ZENTENO, D., HERNÁNDEZ-BERNAL, M., SOLÍS-PICHARDO, G., TOLSON, G., and KÖHLER, H., 1995. Paleogene continental margin truncation in southwestern Mexico: geochronological evidence. *Tectonics*, 14, 1339–1350.

SCHÖNDUBE, B.O., 1987. El occidente de México: Algunas de sus características y problemas. In: *Homenaje a Román Piña Chan.* Instituto de Investigaciones Antropológicas, Serie Antropológica, 79, Mexico City: UNAM, pp. 403–410.

SHACKLEY, M.S., ed. 1998. *Archaeological Obsidian Studies. Method and Theory.* Advances in Archaeological and Museum Science, 3. Berlin: Springer.

SIERON, K., and SIEBE, C., 2008. Revised stratigraphy and eruption rates of Ceboruco volcano and surrounding monogenetic vents (Nayarit, Mexico) from historical documents and new radiocarbon dates. *Journal of Volcanology and Geothermal Research*, 176, 241–264.

TOWNSEND, R.F., 1992. Landscape and Symbol. In: R.F. Townsend, ed. *The Ancient Americas: Art from Sacred Landscapes*. Chicago: Art Institute of Chicago, pp. 29–47.

TROMBOLD, C.D., LUHR, J.E, HASENAKA, T., and GLASCOCK, M.D., 1993. Chemical characteristics of obsidian from archaeological sites in western Mexico and the Tequila source area: Implications for regional and pan-regional interaction within the northern mesoamerican periphery. *Ancient Mesoamerica*, 4, 255–270.

WEIGAND, P.C., 1974. The Ahualulco Site and the Shaft-Tomb Complex of the Etzatlan Area. In: B. Bell, ed. *The Archaeology of West Mexico.* Ajijic, Jalisco: West Mexican Society for Advanced Study, pp. 120–131.

WEIGAND, P.C., 1979. The Formative-Classic and Classic-Postclassic transitions in the Teuchitlán – Etzatlán zone of Jalisco. In: *Los Procesos de Cambio en Mesoamérica y Áreas Circunvecinas, 15.* Mesa Redonda, 1, Mexico City: Sociedad Mexicana de Antropología, pp. 413–423.

WEIGAND, P.C., 1985a. Evidence for complex societies during the western Mesoamerican Classic period. In: M.S. Foster, and P.C. Weigand, eds. *The Archaeology of West and Northwest Mesoamerica.* Boulder: Westview Press, pp. 47–91.

WEIGAND, P.C., 1985b. Considerations on the archaeology and ethnohistory of the Mexicaneros, Tequales, Coras, Huicholes and Caxcans of Nayarit, Jalisco and Zacatecas. In: W.J. Folan, ed. *Contributions to the Archaeology and Ethnohistory of Greater Mesoamerica.* Carbondale: Southern Illinois University Press, pp. 126–187.

WEIGAND, P.C., 1989b. The obsidian mining complex at La Joya, Jalisco. In: G.M. Gaxiola, and J.E. Clark, eds. *La obsidiana en Mesoamérica.* Colección Científica, Serie Arqueología, 176, Mexico City: INAH, pp. 205–211.

WEIGAND, P.C., 1991. The western Mesoamerican tlachco: A two-thousand-year perspective. In: V. Scarborough, and D. Wilcox, eds. *The Mesoamerican Ballgame.* Tucson: University of Arizona Press, pp. 73–86.

WEIGAND, P.C., 2000. The evolution and decline of a core of civilization: The Teuchitlán tradition and the archaeology of Jalisco. In: M.S Foster, and S. Gorenstein, eds. *Greater Mesoamerica. The Archaeology of West and Northwest Mexico.* Salt Lake City: University of Utah Press, pp. 43–58.

WEIGAND, P.C., 2008. Turquoise: Formal economic interrelationships between Mesoamerica and the North American Southwest. In: L.D. Webster, and M.E. McBrinn, eds. *Archaeology without Borders: Contact, Commerce, and Change in the U.S. Southwest and Northwestern Mexico.* Boulder: University of Colorado Press, pp. 343–353.

WEIGAND, P.C., and SPENCE, M., 1982. The obsidian mining complex at La Joya, Jalisco. *Anthropology,* 6(1–2), 175–188.