Special Section
Monogenetic volcanism, environment and society

Geofísica Internacional (2024) **63-2**: 929 - 948

Quarrying volcanic landscapes: territory and strategies of *metate* production in Turícuaro (Michoacán, México)

Caroline Hamon[1], Gregory Pereira[2], Laurent Aubry[1], Oryaëlle Chevrel[3, 4, 5], Claus Siebe[6], Osiris Quezada[7] and Nanci Reyes-Guzmán[6]

Abstract

In the Purhépecha region of Michoacán in central-western Mexico, the village of Turícuaro has been for centuries a centre for the artisanal production of metates. There, these milling stones are crafted from andesite rocks exploited on the slopes of Hoya Urutzen and El Metate volcanoes. Surveys aimed at reconstructing the strategies adopted through time to extract the andesite were conducted in this volcanic territory with the help of some of the last *metateros* that still remain in Turícuaro, the Vidales family. This has allowed us to draw a map and propose a relative chronology of the quarry areas. Different types of exploitation could be recognized, from ancient quarries possibly related to Prehispanic occupations to those currently active. We observe that the morphology of the outcrops (walls, isolated blocks) partly conditioned the distribution of the quarries (flat areas, terraces, etc). From the observation of blocks, debitage, and roughouts at abandoned quarries, it was possible to reconstruct the different exploitation schemes and work organisation, offering a new perspective on Mesoamerican metate quarrying strategies.

Key words: Michoacán, volcano, andesite, quarries, archaeology, techniques, crafts.

Resumen

En la región purhépecha de Michoacán, en el centro-occidente de México, el pueblo de Turícuaro ha sido durante siglos un centro de producción artesanal de metates. Ahí, estas piedras de molienda son elaboradas a partir de rocas de andesita que se han explotado en las laderas de los volcanes Hoya Urutzen y El Metate. Con la finalidad de reconstruir las estrategias adoptadas a lo largo del tiempo para extraer la andesita, se realizaron prospecciones en este amplio territorio volcánico con la ayuda de algunos de los últimos *metateros* de Turícuaro, la familia Vidales. Esto ha permitido elaborar un mapa y proponer una cronología relativa de las diferentes zonas de extracción. También se han reconocido diferentes tipos de explotación, desde las canteras antiguas relacionadas con las ocupaciones prehispánicas, hasta las actuales. La morfología de los afloramientos rocosos (paredes, bloques aislados) condicionó en gran medida la organización de las canteras (áreas planas, terrazas, etc.). También se pudieron reconstruir las diferentes estrategias de extracción y organización del trabajo a través de la observación de los bloques, residuos y desbastes en canteras abandonadas, ofreciendo una nueva perspectiva sobre las estrategias de explotación en las canteras de metate mesoamericanas

Palabras clave: Michoacán, volcán, andesita, canteras, arqueología, técnicas, artesanía.

Received: November 29, 2023; Accepted: February 24, 2024; Published on-line: April 1, 2024.

Editorial responsibility: Dra. Marie-Noëlle Guilbaud

* Corresponding author: Caroline Hamon, caroline.hamon@cnrs.fr
[1] CNRS (French National Center for Scientific Research), UMR 8215 Trajectoires, 9 rue Mahler 75004 Paris, France.
[2] CNRS (French National Center for Scientific Research), UMR 8096 ARCHAM, 9 rue Mahler 75004 Paris, France.
[3] Université Clermont Auvergne, CNRS, IRD, OPGC, Laboratoire Magmas et Volcans, 63000 Clermont-Ferrand, France.
[4] Observatoire Volcanologique du Piton de la Fournaise, Institut de Physique du Globe de Paris, 97418 La Plaine des Cafres, France.
[5] Université Paris Cité, Institut de Physique du Globe de Paris, CNRS, 75005 Paris, France.
[6] Universidad Nacional Autónoma de México, Departamento de Vulcanología, Instituto de Geofísica, C.P. 04510 Coyoacán, Ciudad de México, México.
[7] Universidad Nacional Autónoma de México, Posgrado en Estudios Mesoamericanos, FFyL.

https://doi.org/10.22201/igeof.2954436xe.2024.63.2.1760

1. Introduction

The history of volcanic environments is structured around a strong dichotomy marked by alternating phases of profound landscape upheaval: brief eruptive episodes are followed by longer phases of recovery, occasionally accompanied by rapid anthropization motivated by the attractiveness of fertile land and abundant mineral resources (De Bélizal *et al.*, 2011; Sheets and Grayson, 1979). In Mesoamerica volcanic rocks (e.g., obsidian, andesite, basalt, etc.) were intensively used for construction (Robles 1992; Barba and Cordoba 2010; Quezada *et al.*, 2015; Quezada 2016), but also for more skilled crafts (Fujita and Poyatos 2007; Darras *et al.*, 2017; Quezada and Darras 2023; Gillespie 1994) that were highly valued for millennia. To address this duality over the long term, the METATE project aims to reconstruct the evolution of a volcanic territory organized around a specific activity: the exploitation of andesite for the production of *metates* (milling stones) and *molcajetes* (mortars). Emblematic of traditional Mesoamerican food preparation, these tools are part of the cultural expression of Mesoamerican groups, and their production constitutes a craft in its own right that has helped to define the identity of some villages.

Seminal ethnohistorical and ethnoarchaeological studies have shed fundamental light on the organization of grinding-stone production worldwide (Alonso 2019; David, 1998; Hamon and Le Gall, 2013; Roux, 1985), and more specifically in Mesoamerica, from Guatemala to Mexico (Cook, 1982; Hayden, 1987; Nelson, 1987, Rodríguez-Yc, 2013). Some studies have also explored the social context in which *metates* were used (Katz, 2006; Searcy, 2013), as well as their diffusion over shorter and longer distances (Abramiuk and Meurer 2006). These studies have also documented technical traditions that are presently in the process of being abandoned, and have provided archaeologists with clues for recognizing areas of ancient millstone quarries in Mesoamerica (Searcy and Pitezel, 2018).

In the Michoacán region of central-western Mexico, 'El Metate' volcano has been the subject of recent volcanological research (Chevrel *et al.*, 2016a, b; Mahgoub *et al.*, 2017): the morphological and geochemical characterization and dating of the various lava flows allow us to consider their potential impact on past and present settlers of the region, be it by exerting a repulsing or attracting effect. El Metate formed during a single eruption that began around AD 1250 and lasted more than 35 years (Chevrel *et al.*, 2016a), just prior to the emergence of the Tarascan civilization (Pollard, 1993, 2008). The present work highlights the exploitation of andesite lava flows from this volcano to produce high-quality metates, an activity that probably dates back to pre-Hispanic times (Hamon *et al.*, 2023). In the village of Turícuaro, located at the foot of the volcano on the Meseta Purépecha, a number of families still make and use these tools today (Figure 1). This very special configuration provides a unique opportunity to study the long-term territorial and chronological relationships between the exploitation of volcanic resources, anthropization linked to a targeted economic activity, and the evolution of a territory. In the last decades, the introduction of electronic devices has generated important changes, in terms of andesite selection and exploitation, organization of the work and social recognition at the regional scale.

The highest quality metate and molcajete production has tended to disappear, except for the cases in which some craftsmen produce masterpieces for the tourists. Today, most of the metates and molcajetes sold in the Purépecha region are imported from other villages, which exploit softer rocks to produce large -if not to say industrial- quantities of cheaper and lower quality tools. In this context, our study was aimed at reconstructing the impact of the long-term grinding tool activity on the territory and landscape around the El Metate volcano (Michoacán, Mexico), based on the memories of the last metateros (metate craftsmen) of Turícuaro.

By adopting a multi-disciplinary approach that combines volcanology, archaeology, and the anthropology of techniques, we seek to understand how these lava rocks have become a resource for the nearby inhabitants over time, how their exploitation has structured their environment and what role this exploitation has played on the anthropization of the landscape. We have centered our efforts on understanding the territorial organization of the grinding tool industry, from production to distribution, with the aim of proposing keys for recognizing such operations in ancient time periods. This paper focuses on the organization of the territory of metate exploitation, at its various spatial scales (from the quarries and workshops where the *metates* have been initially produced to the villages where they have been used) and temporal scales (from the 13th century to the present day).

Figure 1. Typical metate and molcajete produced by the Vidales in Turicuaro.

2. Eruption dynamic and raw material selection

'El Metate' volcano is an extinct andesitic volcano located in the middle of the "Meseta Purépecha" in the Michoacán-Guanajuato volcanic field (CVMG) of central Mexico (Chevrel *et al.*, 2016a and b; Mahgoub *et al.*, 2017). It is 900 m high, culminating at an altitude of 2,500 m, and extends over a circumference of 10 km in diameter. Due to its morphology and its gently sloping flanks, it can be catalogued as a shield volcano (Hasenaka *et al.*, 1994). The volcano is also considered to be monogenetic, meaning that it was formed by one single eruption that lasted between 35 and 270 years. The eruption was purely effusive (evidence of explosive activity was not found) and successively produced fifteen voluminous lava flows (up to 200-m-thick, 2-km-wide, and 15-km-long). The start of the eruption has been dated by the radiocarbon method at ~AD 1250, which shortly precedes the emergence of the Tarascan civilization and poses the question of the possible causal relationship between these two historical events (Chevrel *et al.*, 2016a).

The emitted lava was estimated at 9 to 10 km^3, which makes this one of the most voluminous eruptions of the Holocene in the Trans-Mexican Volcanic Belt. Knowledge of the physical characteristics and age of the lava flows allow to evaluate their potential impact, between repulsion and attraction, on past and present settlements in this region. Because the lava flows were only 950-1000°C and viscous, they advanced at low velocities (2 to 30 m/day). Chevrel *et al.* (2016b) estimated that the longest lava flows took ~2 years, while the thickest flows ~7 years to become emplaced. These so-called "block flows" are characterized by a surface that displays large angular blocks (1 to 2 m^3) with smooth faces. The andesitic rocks are partially crystallised (50 to 60 Vol.% crystals) and are mostly dense (less than 10 Vol.% vesicles), except for the last flow, which contains 30 Vol.% vesicles (Chevrel *et al.*, 2016b).

Chevrel *et al.*, 2016a were the first to report the intensive exploitation of the latest lava flow from El Metate for the production of high-quality metates by the inhabitants of Turícuaro. While andesites that were too dense were excluded from the outset because they were too hard to cut, vesicular materials were favored because of their roughness, which is better suited for grinding maize. Since the beginning of the 20th century, the lava flow near the summit of the volcano has been exploited exclusively by quarrymen from Turícuaro. The rare and distinctive micro-porosity of the rock at this site makes it suitable for sculpting. It is also rough enough for grinding maize and compact enough for cleaning the surface of the metate after use, e.g., after mixing tortilla dough on its surface (Hamon *et al.* 2023). Knowledge of the combination of these diagnostic criteria enabled us to better identify lava flows likely to have been exploited in Prehispanic times, and to pinpoint potential areas for archaeological prospection.

The porosity within a lava flow is heterogeneous. Pores are formed from the voids left by gas bubbles or by the difference in volume when crystals form during cooling (diktytaxtic cavities). Porosity is also the result of microfracturation during cooling and flow advance (brittle failure). Heterogeneity is hence found at the scale of the flow as well as at the scale of a single block. The porosity may change longitudinally along the lava flow due to degassing, vesiculation, crystallization and fracturing during emplacement. The porosity may also vary from the base to the top of the flow, where scoriaceous texture are often found (e.g. Fink *et al.* 1992) and from the core to the margins of a single block. Rocks are usually more porous near the vent in comparison to denser distal lava margins (e.g. Riker *et al.* 2009). Finding the right area for exploitation and the optimal blocks is hence not an easy task for the metateros.

A highly porous rock (scoriaceous texture) is often more altered due to the ease at which water percolates through the material. Such rocks are usually too friable to make good metates. Denser blocks may be to too hard to cut and have a smooth surface and hence are inefficient for grinding maize. The right porosity and the right vesicle shape must be found (Hamon *et al.*, 2023). One large block (1 or 2 m^3) may have a scoriacious carapace that the metateros need to remove to get to a denser core, but other parts of the block may be too dense and also need to be removed in order to obtain a roughout.

During emplacement and cooling of this type of block-lava flow, the lava surface becomes highly fractured while the core is massive. Large fractures divide the rock into blocks while smaller fractures and microfractures extend across the blocks. The *metateros* may use those fractures to cut down a block, however, they must be careful not to direct a blow at the wrong place which could fracture the roughout and destroy the emerging metate.

3. Studying the long-term evolution of metate quarrying around Turícuaro

Within the volcanic territory of the Meseta Purépecha, the production of metates from andesites has been the main craft activity in the village of Turícuaro since at least the 19th century (Leon, 1906; West, 1948, map 20); the village is located to the north-east of the Hoya Urutzen and El Metate volcanoes. But changes in food habits and the widespread development of mechanical mills (which sell masa at low prices in the village) have contributed to the decline of manual milling (Hamon *et al.*, 2023). Today, metates are mainly used as tables for mixing maize paste, and much more rarely for grinding hard grains,

while *molcajetes* are still used for preparing sauces and spices. Although there were almost 200 metateros in the village at the beginning of the 20th century, only 5 extended families currently make a living from this activity, and the know-how is no longer passed on to the younger generations due to the low profitability of this difficult and strenuous activity.

Our surveys were conducted in 2018 and 2019 with the invaluable help and knowledge of one of the last metateros families, the Vidales, who live in the village of Turícuaro. Most of the knowledge regarding the volcanic territory and the techniques of metate production was related by the men of the family: Don Pedro Vidales, his son Nicolás Vidales and, on particular aspects, his grandsons especially Tino and Héctor Vidales. Information regarding the use of metates and the organization of food preparation was mainly provided by Doña Livia Vidales, wife of Don Pedro, as this activity remains exclusively women's work. With their invaluable help, we felt it important to document the past and present metate quarries and production areas on the two nearby volcanoes: Hoya Urutzen and the north-eastern flanks of El Metate (Figure 2).

We present here the mapping of four areas of grinding stone quarries in the natural volcanic landscape: the East Hoya Urutzen, the West Hoya Urutzen (within the Tzintzicátaro area), the El Metate Taleminichi and El Cerro quarries. We acquired geographical data using Geographic Positionning System (GPS) with an accuracy of 3 to 5 m to map the paths used by the metateros to reach the various quarries. A differential GPS (Trimble) with decimetric accuracy was used for the quarry areas themselves. A data dictionary was defined for the differential GPS in order to harmonize and simplify data collection in the quarries. To complement the GPS surveys, the quarry areas were surveyed in 3D using photogrammetry, with ground acquisition for all areas. Four of these areas (A, B, C and D) were also surveyed by drone. The data acquired by GPS was projected into the UTM 14N (WGS84) cartographic system in order to be processed in a Geographic Information System (GIS). The base maps used in the GIS were taken from the INEGI E14A21 map base in vector format and the Digital Elevation Model (DEM) used was taken from the ASTER base interpolated to a spatial resolution of 40m.

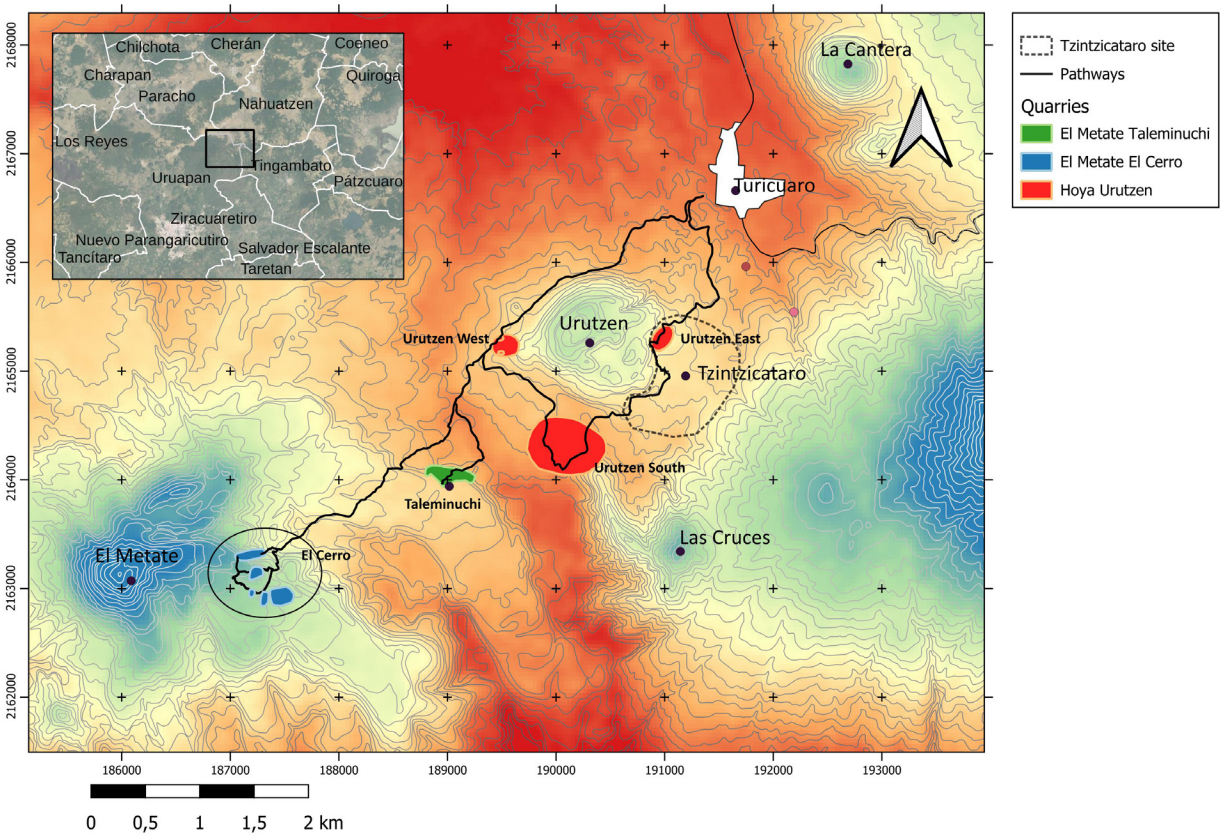

Figure 2. Map showing the quarries at Hoya Urutzen and El Metate, near Turícuaro.

Precise walking distances between the villages and the quarry areas were calculated from GPS surveys. By projecting the data onto the DEM, we obtained a first elevation profile between the start and end of the route (Table 1).

Coupling the path data with the DEM enabled us to establish more precise movement profiles, highlighting the constraints associated with the topography and the effort required to reach the quarry areas (Figure 3).

For each quarry, we measured the surface of the explored extraction and workshop areas (Table 2). However, due to the difficulties of access and the presence of extensive vegetation, we are unable to offer a precise estimation of the extent of the quarry areas.

The values presented therefore only correspond to the surfaces observed and documented as part of the study, but do not represent the total surface area of quarrying operations.

Considering the difficulty of finding elements to date these quarries, we relied on several clues, first and foremost the memory of the metateros, but also the type of tools produced and their location (proximity to the archaeological site, access, etc.).

Table 1. Main pathways from Turícuaro to the quarrying areas, with estimations of distance and overall altitude variation.

Pathways	Distance	Global variation of altitude
Turicuaro - Hoya Urutzen west	2.2 km	130 m
Turicuaro - Hoya Urutzen east	2.7 km	160 m
Turicuaro - El Metate Taleminuchi	4.5 km	100 m
Turicuaro - El Metate El Cerro	6.4 km	310 m

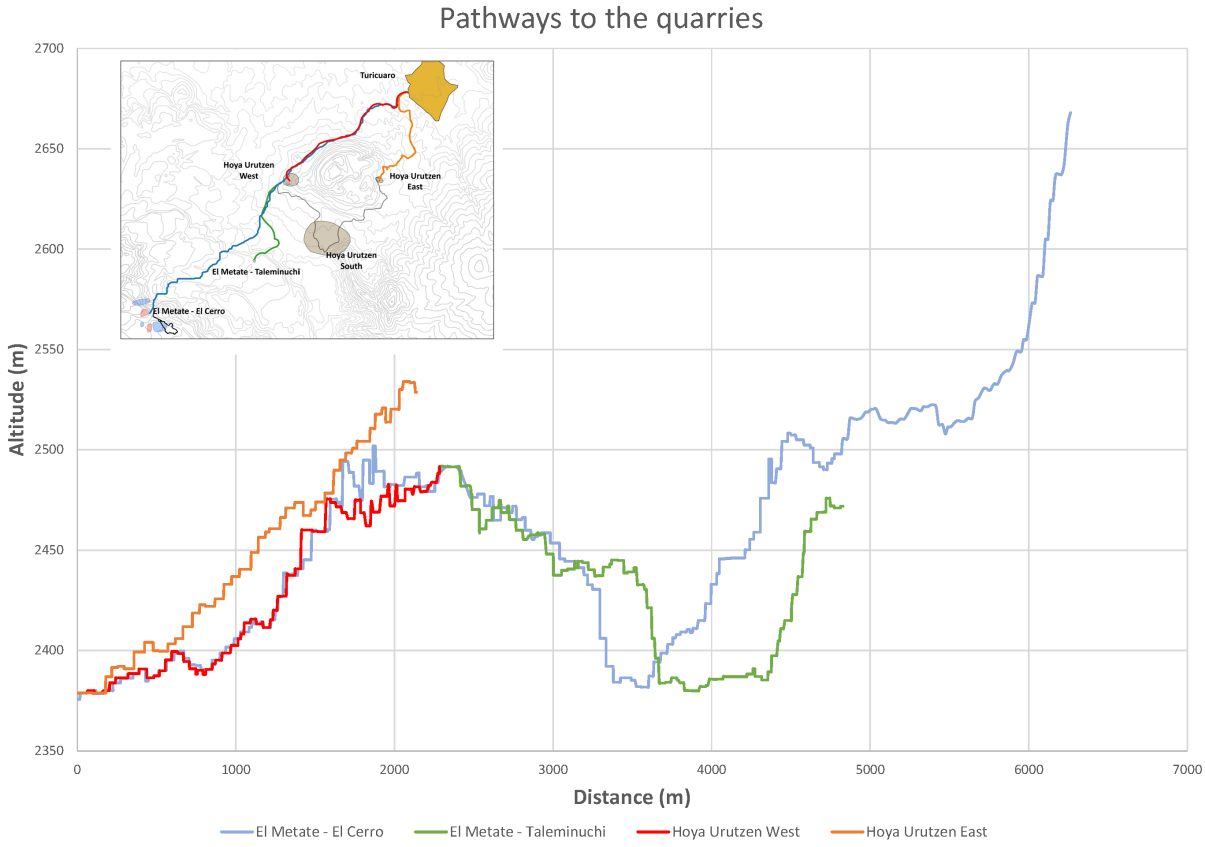

Figure 3. Altitudinal profiles of the pathways (in meters) from the Vidales workshop in Turícuaro to the different quarries.

Table 2. Main quarrying areas on Hoya Urutzen and El Metate, with estimations of the surface explored during our surveys.

Quarries	Explored Area
Hoya Urutzen west	40 000 m2
Hoya Urutzen east	8000 m2
El Metate Taleminuchi	1500 m2
El Metate El Cerro	< 70 000m2

4. Results for the Tzintzicátaro and the Hoya Urutzen quarries

In the vicinity of the present-day village of Turícuaro, our surveys uncovered an archaeological site. This settlement, known locally as Tzintzicátaro (Figure 4), has been partially surveyed, mapped and documented. It has revealed remains dating from the Late Postclassic (14th-early 16th century) and Early Colonial periods (16th century).

Located 500 m south of the present-day village, the Tzintzicátaro site ("built place" in Purépecha) occupies the eastern foothills of the Hoya Urutzen volcano. In this area, we observed archaeological concentrations of artefacts (sherds, obsidian) on the surface of cultivated plots, as well as a number of architectural remains preserved in the southern part of the surveyed area. As far as we know, the site extends over a strip at least 1200 m long (north-south) and 300 m wide (Figure 5). Observable archaeological remains can be dated to the Prehispanic period (potsherds, obsidian), and more specifically to the Middle/Recent Postclassic period (AD 1200-1522),

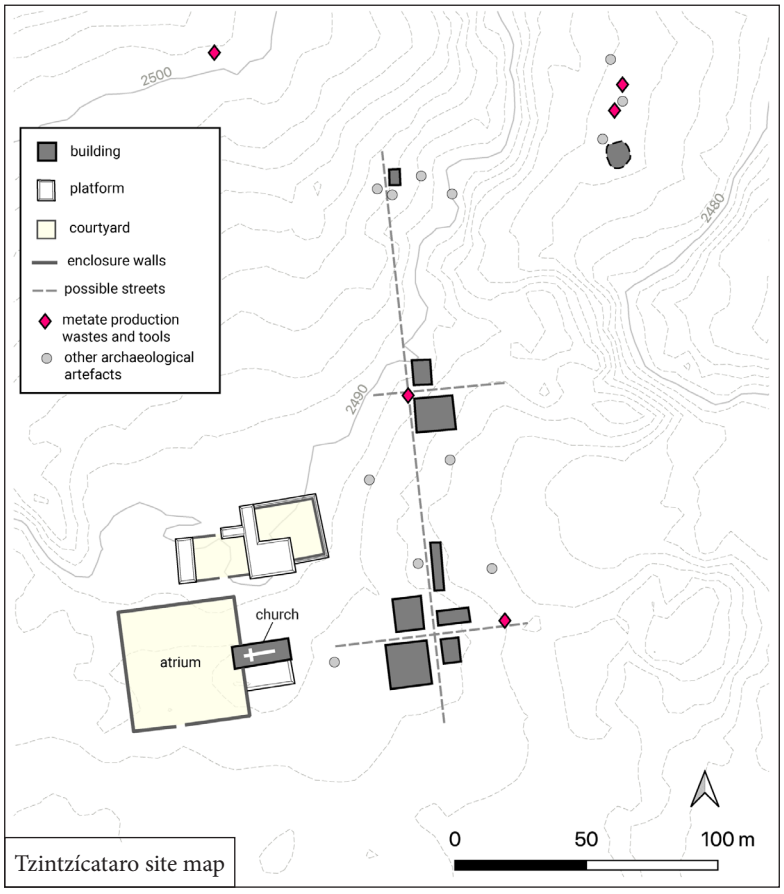

Figure 4. General map of the archaeological site of Tzintzicátaro.

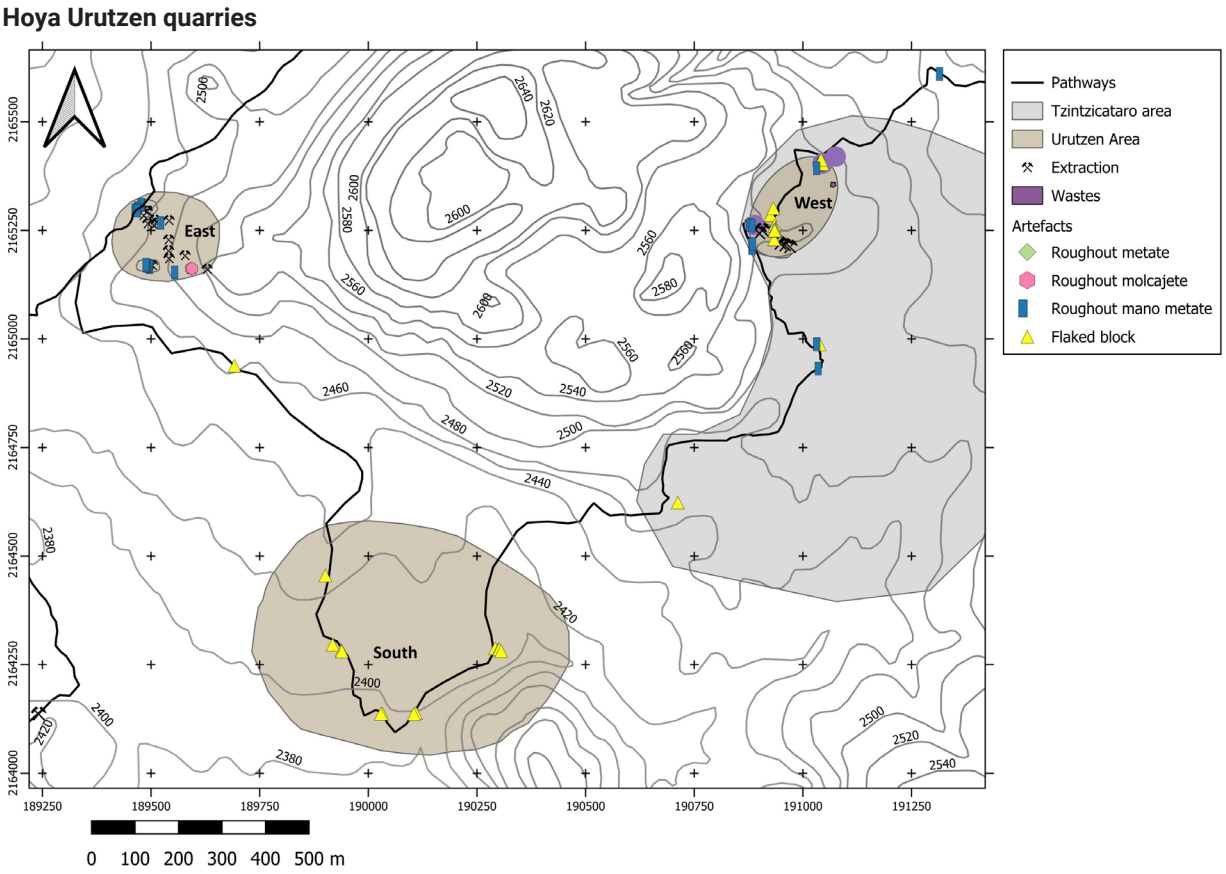

Figure 5. Map showing the quarry areas around Hoya Urutzen.

but also to the Early Colonial period (Romita-type ceramics). The southern part of the site, also contains clear evidence of a settlement from this period. A monumental area features a 45 m square plaza surrounded by a wall and bordered on the east by a rectangular stone building some 18-m-long (E-W) and 9-m-wide. This layout clearly corresponds to a colonial religious complex consisting of a church and its atrium, as documented elsewhere in the region (Lefebvre *et al.*, 2023). The rectangular building is still referred to locally as "tioxtacua", the Purépecha term for church, showing that the memory of this now-abandoned settlement is still alive. The structures located around the religious complex are organized on a grid pattern, another typical feature of the colonial period. To the north of the complex, there are buildings (residential platforms?) organized around two courtyards. Forty meters east of the church, there is a group of five residential structures organized around the crossroads of two perpendicular streets oriented north-south and east-west.

During our surveys, mano and metate roughouts and manufacturing wastes were found in association with archaeological structures of the dwelling type, in areas where both Prehispanic and Colonial remains are present (Figure 6). They were made from highly vesicular andesite. The metateros quickly interpreted these remains as the remains of a metate producer's workshop, comparable to the organization of their own work area. This evidence suggests that this craft activity must have been present from these early periods, allowing us to assume that Turícuaro's craft tradition dates back at least to the 15th - 16th centuries and has been maintained over a period of more than 500 years.

At least three ancient quarry zones were detected on the eastern, western and southern flanks of Hoya Urutzen (Figure 5). Highly vesicular andesites were extracted here, either as massive flow fronts or in the form of erratic boulders, depending on the sector. Though their dating is debatable, the exploitation of vesicular basalt would fit with archaeological exploitations, as these qualities of rocks were not exploited anymore during the 20th century according to the Vidales.

On the western slope, early quarries, hereafter called the West Hoya Urutzen quarries, were identified along the current pathway from Turícuaro to El Metate that passes along the Hoya

Figure 6. Tzintzicátaro: a) mano roughouts ; b) hammerstones found in the Tzintzicátaro area. Scale = 10 cm.

Urutzen volcano (Figure 7). This area is no longer exploited by the metateros, with the exception of some abandoned roughouts that are frequently recycled to produce small implements. Along the pathway, the lava flows front has been exploited in several areas. They are organized as follows: just in front of the extraction wall (Figure 8), a cleaned area served as a workshop to produce roughouts. Interestingly, production waste (larges flakes and mano roughouts) was piled to the side or downslope, depending on the topography. Some flaked blocks were put aside too. In other places, extracted blocks were reused to build terrace walls. On the flanks of the volcano, moving up towards the summit, extensive areas of quarrying sometimes yielded large quantities of flakes and waste, fragments of blocks and metate and molcajete roughouts (Figure 9).

On the East of Hoya Urutzen, quarries were detected on a lava flow directly overhanging the archeological site (Figure 10). Approaching the quarries from the site, more flakes and hammerstones (some are massive, 0.8 to 2 kg) were found in a ploughed plot. Manos and metate roughouts were found in this location. Among dense vegetation, quarry fronts of massive blocks were observed on the lava flow front. Depressions, with diameters of 6 to 7 m, contained blocks while waste material was dumped on the peripheries.

To the south, towards San Angel and the Las Cruces volcano, more random exploitations were identified (Figure 5). The metatero Nicolás Vidales recalls that he visited this area with his grand-parents but had no memory of when it was exploited. Several zones of activity, centered on small groups of blocks with random wastes, are visible in this area at the very south of the Hoya Urutzen volcano. No real extraction zone or roughouts have been recorded in this sector.

Among living metateros, the absence of any memory of mining at quarries that surround Hoya Urutzen, and the regular presence of andesitic hammerstones rather than metallic picks, both suggest a fairly early date. This is particularly true for the zone at the south-east of Hoya Urutzen where quarries could be directly connected to activities at the archaeological site. The archaeological site itself is said to produce metates Although their dating still needs to be precised, the close spatial relationship suggests that these quarries could have been exploited as far back as in the Postclassic period.

5. Results for the El Metate quarries

On the slopes of the El Metate volcano, several quarrying areas were identified, and at least two flows were exploited (Figure 2).

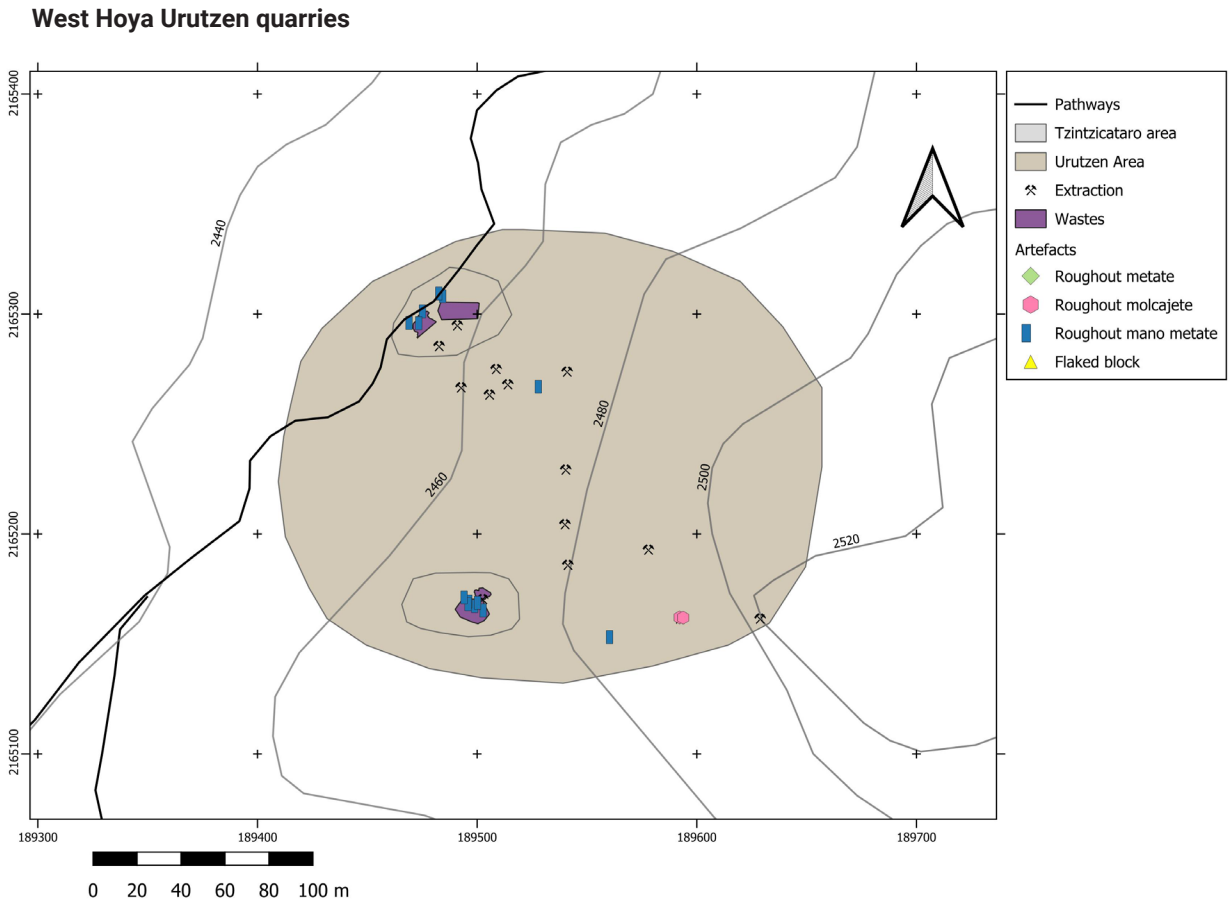

Figure 7. Detailed map of the West Hoya Urutzen quarry area

Figure 8. Front wall of andesite-block extraction at West Hoya Urutzen quarry. Scale = 50 cm.

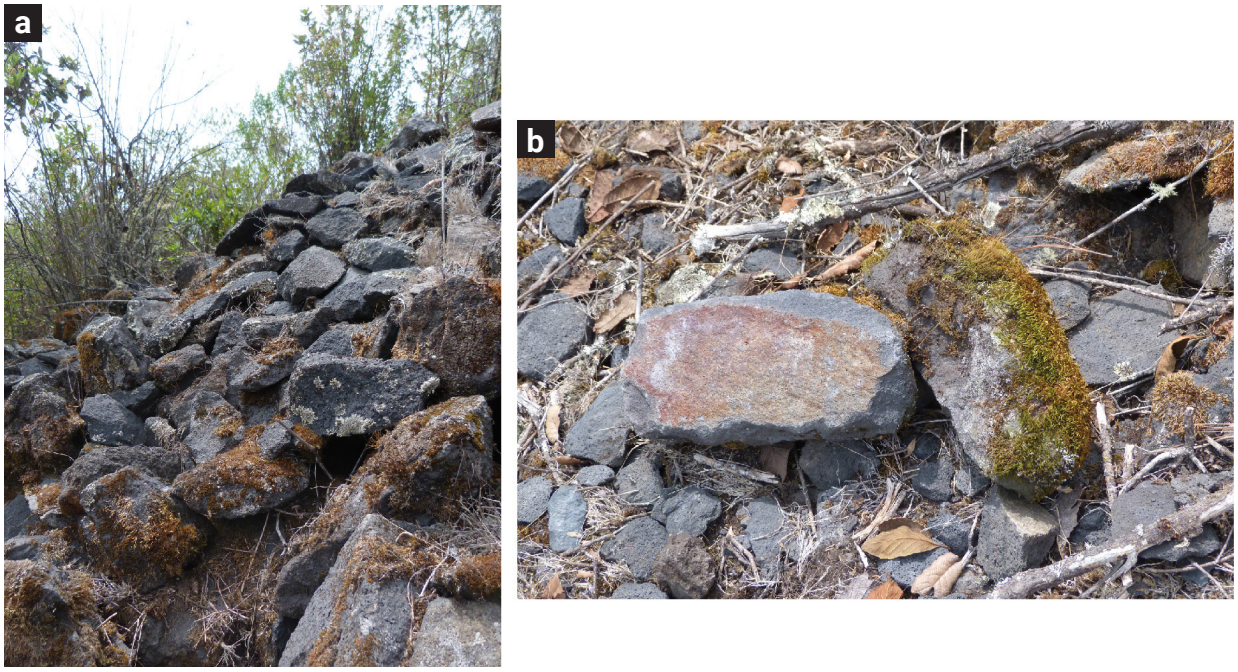

Figure 9. Exploitation debitage (a, scale = 50 cm) and mano roughouts (b; scale = 10 cm) on the slopes of West Hoya Urutzen

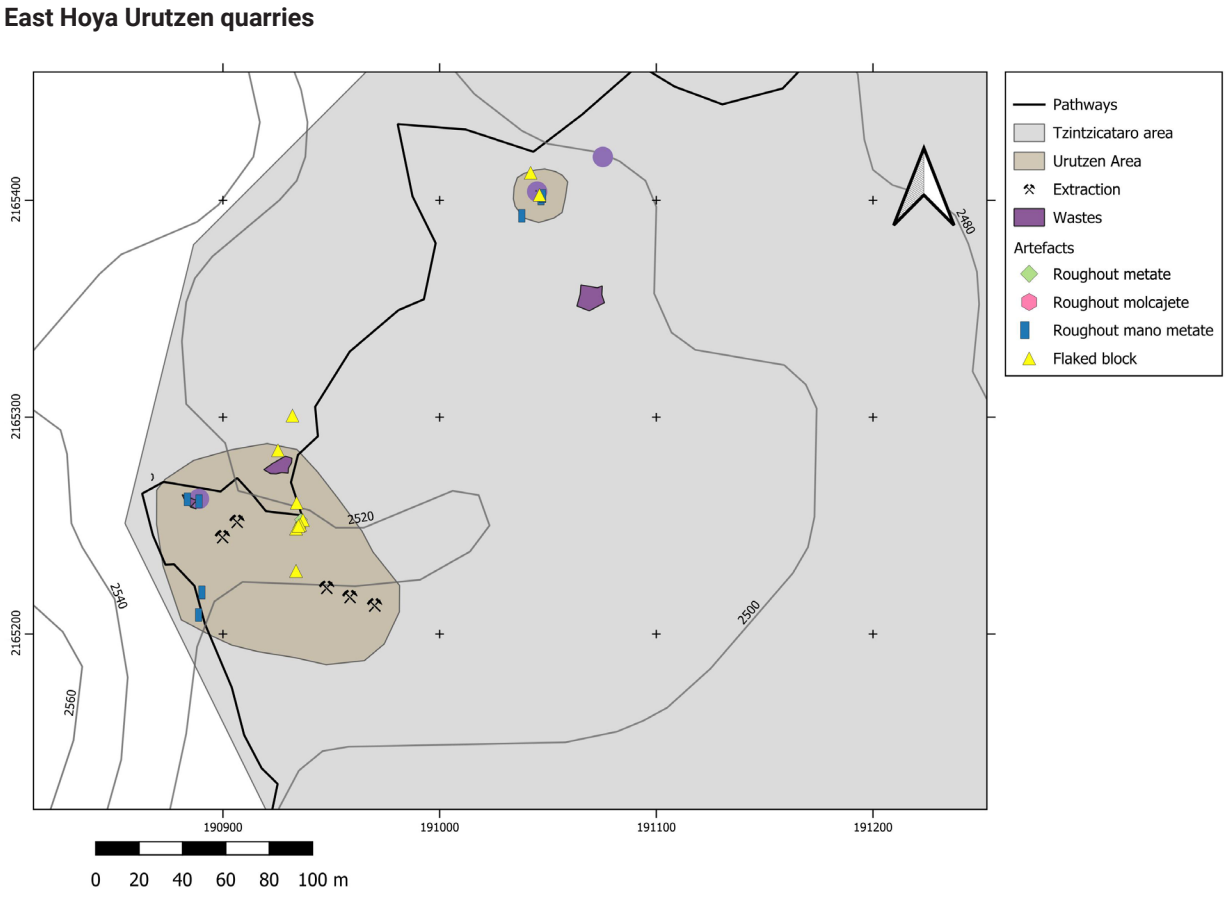

Figure 10. Detailed map of the quarry areas around East Hoya Urutzen.

5.1 "Taleminuchi"

The first area, called Taleminuchi or the «Cantera de los Abuelos» (Figure 11), is located at the foot of El Metate volcano, on lava flow n°7 as defined by Chevrel *et al.* (2016a). It is around 4 km south-east of the village of Turícuaro and is the smallest defined quarry area (7500 m^2, Table 2). Don Pedro learned quarrying from his uncles at the age of 9 in this area. Although easy to access and holding good rock quality, Don Pedros' brothers abandoned this area in the mid 20th century because of the exhaustion of unfractured blocks (Figure 12). They then decided to continue further away where blocks are bigger in size and less fractured.

5.2 "El Cerro"

The bulk of the quarrying area is located on lava flow n°12, as defined by Chevrel *et al.* (2016a), near the summit of El Metate, 6.5 km from Turícuaro (Figure 2). It was not possible to determine the exact extent of the quarrying area within this *malpaís* zone, which is particularly difficult to access due to the abundance of large boulders, the virtual absence of paths, and the presence of dense vegetation. According to our surveys, this zone close to the summit of El Metate appears to have been quarried over several hectares, and possibly over the whole surface of this lava flow.

The various past and present pathways from Turícuaro to the quarries on top of El Metate were mapped. Today, this area and the paths are shared with the timber harvesters. Directly installed on the chaotic malpaís, the quarry areas are only accessible on foot after a 3-hour walk, with heavy loads being carried by donkeys (Figure 13). Nicolás mentioned the existence of older paths, which are faster and more direct, but also steeper and more dangerous, especially with loads. Unfortunately, we could not map them.

A detailed study of the organization of the quarry zones was undertaken in 5 windows considered to be representative of the different morphologies of the flow and the associated andesite block mining strategies. Systematic recording was conducted, with standardized descriptive sheets, combined with a geo-ref-

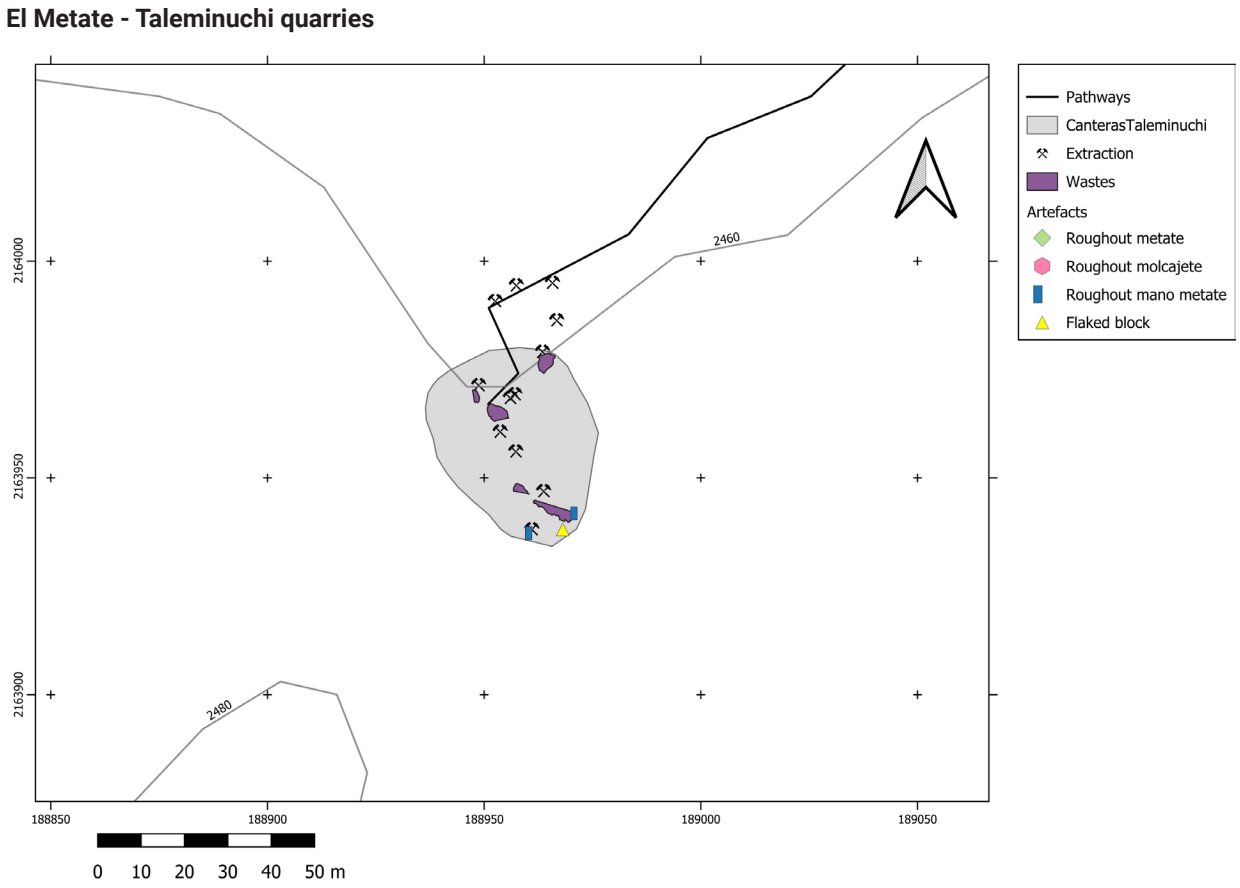

Figure 11. Detailed map of the quarry areas at El Metate "Taleminuchi".

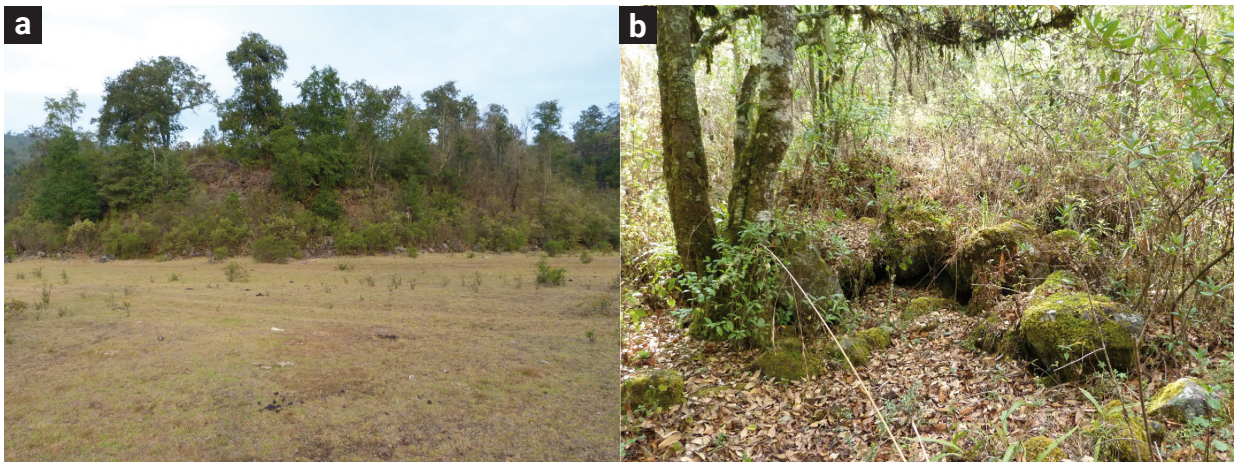

Figure 12. El Metate "Taleminuchi" quarry area: a) view of the lava-flow front; b) view of a former quarry area (scale = 50 cm).

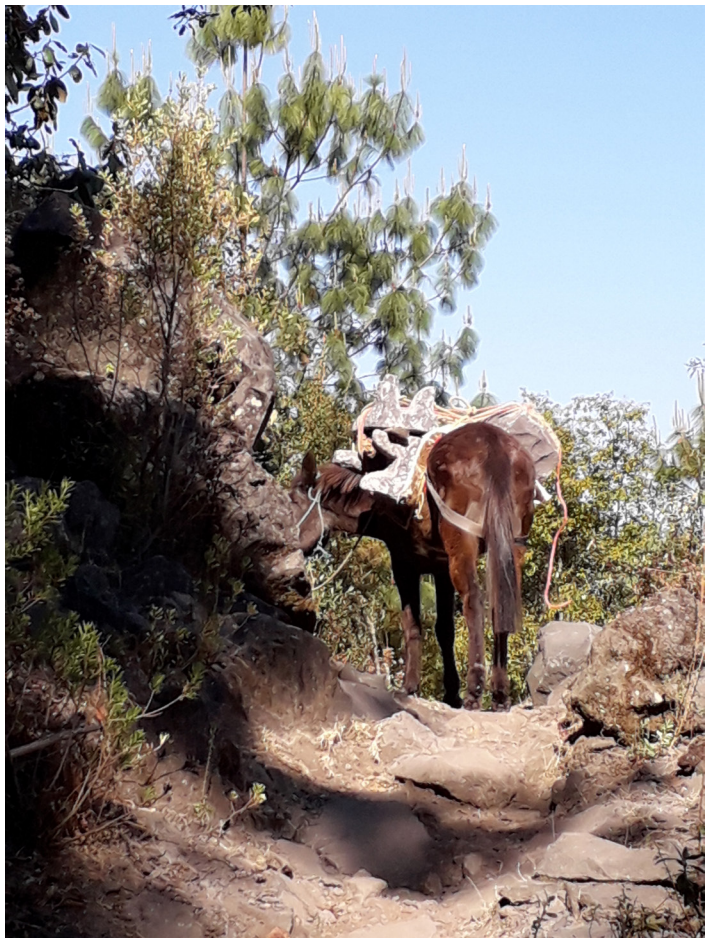

Figure 13. Transportation of metate roughouts by a horse on the main pathway to El Metate quarries.

erenced photogrammetric survey, on the ground and also by drone to provide a better idea of the topography of the extraction area and the organization of the various work areas (Figure 14).

Several forms and periods of exploitation were recognized at the summit of El Metate. They probably correspond to different periods of exploitation, to different groups of metateros, or to different strategies of adaptation to the configuration of the blocks and flows. The dating of these different sectors remains tricky in the absence of dates for associated characteristic material elements. Don Pedro explained to us that his brothers were the first to discover this area. But in fact, the area was already exploited before the mid-20th century. The abandoned roughouts evoke different types of metate: tripod forms that correspond to types still produced today in the village, but older types with shorter feet and of which the current metateros have no memory, were also produced (Figure 15a). Some of the areas identified by the village metateros as "old" also show much greater levels of sedimentation than others, both in the area closest to the summit and at the base of the lava flow (Figure 15b).

A strong spatial segmentation observed between the different stages of exploitation reflects on the organization of the quarry areas. The entire quarry zone is composed of a series of work areas linked to each other by a network of small paths. Each work area corresponds to a stage in the sequence of metate or molcajete production, from the natural block to the roughout. During work, roughouts may be abandoned for different reasons (breakage, problems of symmetry, etc.). Depending on the configuration of the quarry area, the organization of each workshop varies.

On a flat topography, quarry areas are generally organized into three components (Figure 16):

- one or several areas of block extraction, displaying broken blocks, natural blocks and depressions where former blocks were removed,
- an area of roughout shaping, where most of the roughouts are abandoned, and generally located in the middle of a group of extracted blocks,
- one or several areas for receiving wastes after cleaning of the workshop. This waste is generally located on the periphery of the shaping areas. Waste piles can be "sorted", with large and smaller flakes being separated,

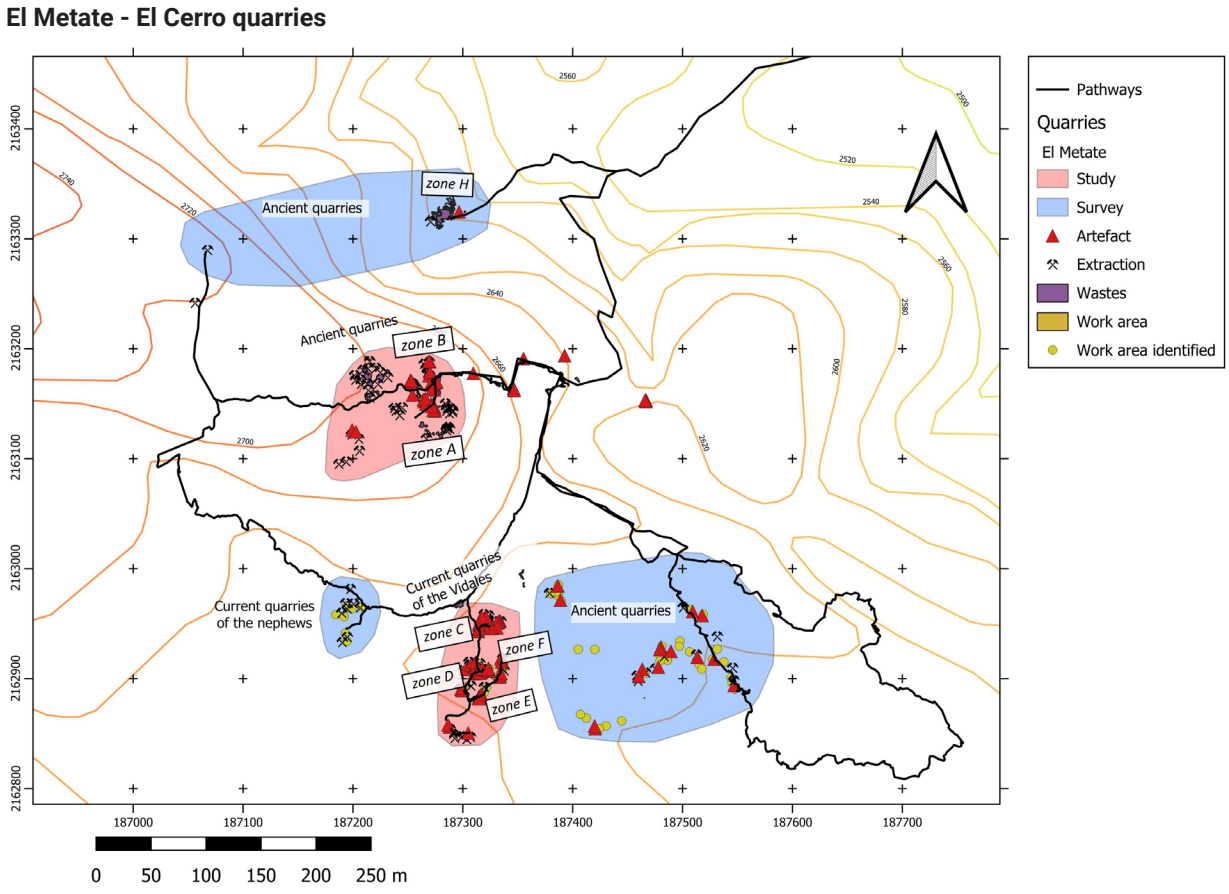

Figure 14. Detailed map of the quarry areas at El Metate "El Cerro".

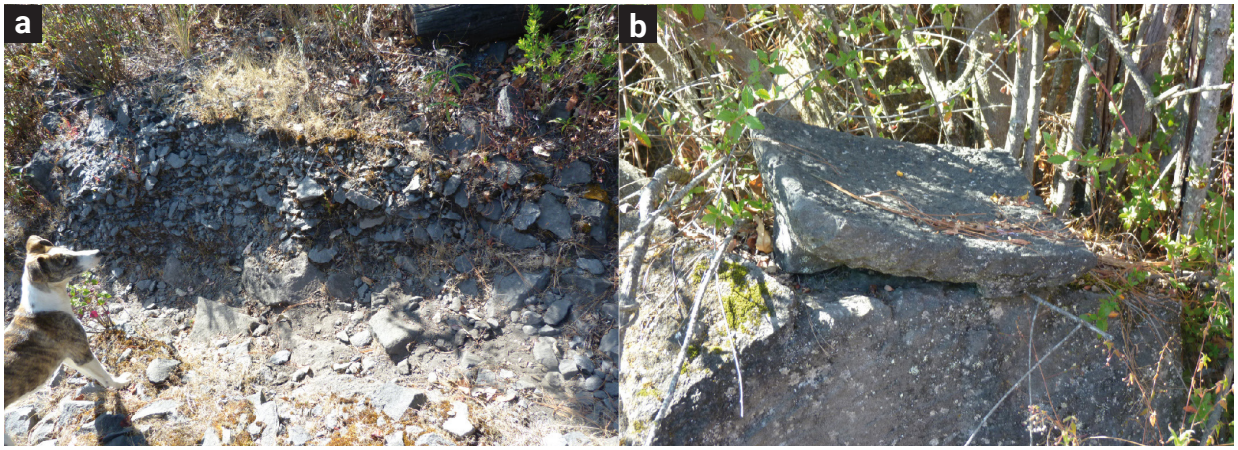

Figure 15. El Metate "El Cerro": old quarries from zone A-B with a) piles of andesitic debitage covered by humus and cut by a more recent pathway (scale = 50 cm), b) metate roughout with short feet and curved grinding surface (ancient type). Length of the roughout = 45 cm.

Figure 16. El Metate "El Cerro": recent quarries on the path to zones A and B, with blocks extracted in the back, and broken in the space toward the front that was formerly occupied by the andesite rock. The surface is occupied by debitage consisting of blocks and smaller flakes (Scale = 50cm).

if the cleaning of the workshop was carried out in several episodes during the roughing out process. They can also be shared by several shaping areas.

The distance between workshops can be very short, sometimes only separated by a group of blocks. This spacing is determined by the distribution of the blocks on the lava flow surface.

On a more sloping topography, quarrying areas may be organized into terraces, as follows (Figure 17):

- an area of block extraction,
- an area for block splitting (into cubic forms) with fragments of blocks and large sized flakes,
- an area for the coarse shaping stages of metate roughouts (step 1),
- an area for the fine shaping stages of metate roughouts (step 2),
- a resting area around a tree, both for the quarryman and the donkeys; that is also where roughouts will be loaded onto the donkeys

Blocks are rolled from one place to another at each stage of production. The last stage of production in the quarry corresponds to a cubic block, around 40 kg, featuring a table and three feet. Roughouts are then transported to the Vidales' house where a large area in the courtyard serves as a dedicated workshop used for all stages of metate shaping and finishing carried out over approximately a week.

This last configuration is the one observed in the quarry area exploited by Nicolás and Don Pedro Vidales for one year in 2019 (Figure 18). Contrary to other regions, dynamite is not used. Only metallic picks of various forms, weights and handle-length are used, together with long wooden sticks (up to 2 m) and stabilization blocks. According to Don Pedro, one day is necessary to find blocks of good quality (less fractured, possibly less dry), and one or two further days are necessary to split a block and shape a roughout from it. The entrance to a quarry area is materialized by abandoned metate and molcajete roughouts that serve as a sign of «ownership» of the areas within the framework of competition between village families. Continuing on the pathways to the current quarries, another area was exploited by Francisco Ruíz, Andrés y Santiago Vidales, nephews of Don Pedro Vidales. There, the strategy of exploitation appears to be slightly different (Figure 19). Soil is removed around and between groups of blocks which are left at the center before being exploited. This type of extraction

Figure 17. El Metate "El Cerro": workshop terraces from zone C exploited today by the Vidales family. Note the larger size of the flakes on top, the rolled roughout in the centre, and the second workshop for the finishing of the roughout below with smaller-sized flakes (Scale = 50cm).

Figure 18. El Metate "El Cerro": workshops on terraces from zone C exploited today by Nicolás Vidales, here shaping a metate roughout with an iron pick.

Figure 19. El Metate "El Cerro": quarry of Don Pedro's nephews, where the covering earth (humus) was removed prior to the breaking of the andesite blocks (Scale = 50cm).

leaves deep depressions and crescent-shaped waste areas in the direct vicinity.

On the steeply sloping areas, workshops sited downslope of extraction areas are generally covered by large amounts of flakes originating from the exploitations above. This is notably the case in Zone H (Figure 20), located at the foot of lava flow 12, in quite an isolated area adjacent to the ancient pathways to the summit quarries.

6. Discussion and comparisons

Grinding stone quarrying has left a strong imprint on the volcanic landscape. Andesite exploitation for the production of metate implies a close relationship between the configuration of lava flows, the accessibility of andesitic blocks of good quality, and the quarrying strategies adopted by metateros. It requires a perfect knowledge of the volcanic landscape and of the rock properties on the part of the metateros. In the vicinity of Turícuaro, the volcanic landscape has considerably evolved since the start of the El Metate eruption in AD 1250. Shortly after the volcanic eruption, it seems that new people settled at the foot of the Hoya Urutzen, in Tzintzincátaro, and began exploiting the andesite from this small volcano for the production of metates. Later on, the current town of Turícuaro was settled and, at an unknown date, its inhabitants started to exploit the slopes of El Metate volcano for the production of metates and molcajetes. Today the forest that took centuries to grow is intensively exploited for wood-based crafts, and fewer and fewer large trees are left, especially at the summit of the volcano. This intense exploitation of the volcanic resources in the current territory of Turícuaro has left important scars on the landscape, with quarrying creating holes and piles of extraction waste covering hectares of the lava flows. It is striking that the impact of human activities on the volcanic landscape has shifted within the territory and over time, in a dynamic trajectory.

The andesite exploitation strategies documented in Turícuaro echo those documented for other areas of Mesoamerica, such as Oaxaca (Cook, 1973, 1982) and Guanajuato (Rodriguez-Yc, 2013) in Mexico, and in the Maya Highlands of Guatemala (Hayden, 1987; Nelson, 1987; Searcy, 2011). Strongly determined by the configuration of the lava flows, the quarrying strategies differs significantly from the exploitation of other materials such as granite (Cook, 1973). In the Mayas area in Guatemala,

Figure 20. El Metate "El Cerro": quarry zone H, with large amounts of debitage and roughouts accumulated on a steep slope at the base of lava flow No. 12

extraction of large blocks from 1 or 2 meters underneath the *malpaís* soil is a strategy often chosen to access less fractured blocks (Searcy, 2011, p. 39; Hayden, 1987). Given the large size of the blocks, the goal is always to break them into smaller pieces that can be moved to the closest workshop within the quarry area (Searcy and PItezel, 2018). While the use of dynamite seems to have spread during the 20th century (Cook, 1973), this technique has not been documented in Turícuaro and in the Maya highlands, probably because it generates too much breakage of the rock for "traditional" production. Extraction is therefore mainly carried out with stone picks, and where these have been abandoned, by massive steel and iron picks; in all cases the quarrymen take advantage of the natural cleavage of the blocks. Documented extraction areas share many common points in terms of the organization of the work and the spatial segmentation of the stages of production (see also Nelson, 1987, p. 142). Depending on the slopes of the quarry, the workshops are generally located close to the extraction area, on a single flat surface or on a terrace system with spatial organization directly reflecting the technical sequence of shaping. These sites feature large pits surrounded by piles of waste material. In both contexts, quarries are organized on a personal or group basis, with no personal claim on the land (the land belongs to the municipality or *ejido*), contrary to what has been documented, for example, in Oaxaca (Cook,1973); however, implicit rules are respected, as expressed by the distance maintained between current extraction zones exploited by the Vidales family and those operated by their nephews. Working days are generally intense, stretching from early morning to late evening. However, in the Maya Highlands, for example, the exploitation of streambed blocks only occurs during the dry season, which implies different organizations of the work according to each region (Nelson, 1987).

7. Conclusions

Metate production in Turícuaro offers an example of the attractivity of volcanic areas, which can be seen as a source of economic development. Through the study of a plurisecular andesite quarrying activity, it has been possible to highlight the close relationship between men and volcano, and their invaluable knowledge of the volcanic resources as well as of the modeling of the landscape. Current metate production also offers a unique opportunity to define keys for the identification of ancient andesite exploitation. We sincerely hope that this study will be of great help for recognizing archaeological metate quarries in the near future.

Our study of the distribution networks for these products shows that Turícuaro's renowned products, made to order from the surrounding villages, are becoming less and less resistant to competition from mass-produced molcajetes from the La Piedad region, 120 km north of Turícuaro. The last remaining metateros in the village are now turning to the production of metates that are more decorative than functional. The metates thus contribute to retain a strong sense of identity and culture in one of the most traditional Purépecha villages, as part of wedding dowry. However, this will not preserve Turícuaro's centuries-old grinding stone industry. The disappearance of this activity also implies the loss of the memory and knowledge of the volcanic territory, which plays a central part in the intangible and cultural heritage of the Meseta Purépecha and beyond.

8. Acknowledgments

Our warmest thanks go to Nicolás, Don Pedro and Doña Livia Vidales, and all the members of their family in the village of Turícuaro, for transmitting their knowledge of metate production and of the El Metate volcano territory. Their time, patience and warm welcome were invaluable during these many weeks of learning. We also thank Karine Lefebvre (CIGA-UNA, Morelia, Mexico) for her expertise on the archaeological site of Tzintzicátaro.

This work was financially supported by a Sardyn research grant from the Labex Dynamite (French National Agency of Research) and a research grant from Paris 1 Panthéon-Sorbonne University. It also benefited from the financial and scientific support of several laboratories within the CNRS (UMR 8215 Trajectoires, UMR 8096 Archam, CEMCA Mexico).

The work of O.M. Chevrel, N. Reyes, and C. Siebe was supported by *Dirección General de Asuntos del Personal Académico* through project UNAM-DGAPA IN-104221. C. Siebe also benefitted from a sabbatical stay at the Senckenberg Naturhistorische Sammlungen, Dresden and the kind hospitality of Jan-Michael Lange and Peter Suhr. O. Chevrel acknowledges the ClerVolc program of the University of Clermont Auvergne, this is the contribution number 642.

9. References

Abramiuk, M., William, A., Meurer, P. (2006). A preliminary geoarchaeological investigation of ground stone tools in and around the Maya Mountains, Toledo District, Belize. *Latin American Antiquity* 17(3), 335-354.

Alonso, N. (2019). First approach to women, tools and operational sequences in traditional manual cereal grinding. *Archaeological Anthropological Science* 11, 4307–4324.

Barba, L. A., Córdoba, J. L. (2010). *Materiales y energía en la arquitectura de Teotihuacán*, Universidad Nacional Autónoma de México, Instituto de Investigaciones Antropológicas, México. **http://ru.iia.unam.mx:8080/handle/10684/27**

Chevrel, M., Siebe, C., Guilbaud, M. N., Salinas, S. (2016a). The AD 1250 El Metate shield volcano (Michoacán): Mexico's most voluminous Holocene eruption and its significance for archaeology and hazards, *The Holocene*, October 2015, doi: **https://doi.org/10.1177/0959683615609757**

Chevrel, M., Guilbaud, M.-N., Siebe, C. (2016b). The AD 1250 effusive eruption of El Metate shield volcano (Michoacán, Mexico): magma source, crustal storage, eruptive dynamics, and lava rheology, *Bulletin of Volcanology 78*, 32. **https://doi.org/10.1007/s00445-016-1020-9**

Cook, S. (1982). Zapotec stone workers. *The dynamics of rural simple commodity production in modern Mexican capitalism*. M.D. Lanham, University Press of America.

Cook, S. (1973). Stone Tools for Steel-Age Mexicans? Aspects of Production in a Zapotec Stoneworking Industry. *American Anthropologist* 75, 1485–1503.

Darras, V., Mireles, C., Siebe, C., Quezada, O., Castañeda, A., y Reyes, N. (2017). The Other Stone. Dacite Quarries and Workshops in The Prehispanic Tarascan Territory, Michoacán, Mexico. *Journal of Archaeological Science:* Reports 12, 219-231. **https://doi.org/10.1016/j.jasrep.2017.01.034**

De Bélizal, E., Lavigne, F., Grancher, D. (2011). Quand l'aléa devient ressource : l'activité d'extraction des matériaux volcaniques autour du volcan Merapi (Indonésie) dans la compréhension des risques locaux. *Cybergeo: European Journal of Geography.* doi: **https://doi.org/10.4000/cybergeo.23555**

David, N. (1998). The ethnoarcheology of grinding at Sukur, Adamawa state, Nigeria. *African Review* 15(1),13-63.

Fink, J. H., Anderson, S. W., and Manley, C. R. (1992), Textural constraints on effusive silicic volcanism: Beyond the permeable foam model, *J. Geophys. Res.*, 97(B6), 9073–9083, doi: **https://doi.org/10.1029/92JB00416**.

Fujita, H., Poyatos de Paz, G. (2007). Prehistoric Quarrying and Stone Tool Production at El Pulguero, Baja California Sur, Mexico. Pacific Coast *Archaeological Society Quarterly* 39 (2–3), 23–36. **https://www.pcas.org/assets/documents/prehistoricquarryinga.pdf**

Gillespie, S. D. (1994). Llano de Jicaro. An Olmec monument workshop, *Ancient Mesoamerica*, 5, 231-242. doi: **https://doi.org/10.1017/S095653610000119X**

Hamon, C., Le Gall, V. (2013). Millet and sauce: the uses and functions of querns among the Minyanka (Mali), *Journal of Anthropological Archaeology*, 32,109-121. doi: **https://doi.org/10.1016/j.jaa.2012.12.002**

Hamon, C., Pereira, G., Chevrel O., Aubry, L., Siebe, C., Quesada, O., Reyes-Guzmán, N. (2023). Present Use and Production of Metates and Molcajetes in Turícuaro (Michoacán, Mexico): Deciphering the Evolution of Food Preparation Practices, *Ethnoarchaeology* 15 (2), 208-232. doi: **https://doi.org/10.1080/19442890.2023.2280379**.

Hasenaka, T., Ban, M., Delgado Granados, H. (1994). Contrasting volcanism in the Michoacán-Guanajuato Volcanic Field, central Mexico: Shield volcanoes vs. cinder cones. *Geofísica Internacional, 33*(1), 125-138. **https://doi.org/10.22201/igeof.00167169p.1994.33.1.544**

Hayden, B. (1987). Traditional metate manufacturing in Guatemala using chipped stone tools". In Hayden B., ed., *Lithic Studies Among Contemporary Highland Maya*. University of Arizona Press, Tucson, pp. 8–119.

Katz, E. (2003). Le metate, meule dormante du Mexique. In Barboff M., Sigaut F., Griffin-Kremer C., Kremer R., Meules à grains. *Actes du Colloque International de la Ferté-sous*-Jouarre (16–19 mai 2002), Ibis Press/ Maison des Sciences de l'Homme, Paris, pp. 32–50.

Lefebvre, K., Urquijo Torres, P., Dorison, A. (2023). Pueblos viejos-pueblos nuevos: transformación del paisaje en el norte de Michoacán (México) durante el período novohispano (siglo XIV)", *Ancient Mesoamerica*: 1-21. doi: **https://doi.org/10.1017/S0956536121000584**

León, N. (1906). Los Tarascos. Notas históricas, étnicas y antropológicas. Tercera parte. Etnografía pos-cortesiana y actual. *Anales Del Instituto Nacional De Antropología E Historia*, 2(3), 298-479.

Mahgoub, A.N., Böhnel, H., Siebe, C., Chevrel, M.O. (2017). Paleomagnetic study of El Metate shield volcano (Michoacán, Mexico) confirms its monogenetic nature and young age (AD 1250). *Journal of Volcanology and Geothermal Research*, 336, 209-218. **https://doi.org/10.1016/j.jvolgeores.2017.02.024**

Nelson, M. (1987). Site and content structure: metate quarries and workshops in the Maya Highlands, In Hayden B., ed., *Lithic Studies Among Contemporary Highland Maya.* University of Arizona Press, Tucson, pp. 8–119.

Pollard, H. (2008). A Model for the Emergence of the Tarascan State. *Ancient Mesoamerica*, 19 (2), 217-230.

Quezada, O., Pascal, G. C., González, L. A. (2015). De la Cantera a Tenochtitlán: presencia de rocas de origen volcánico en la construcción y la escultura del Templo Mayor. La explotación de andesita en la cantera de San Bartolo Tenayuca, una aproximación etnoarqueológica. En Maclung de Tapia E., Serrano C., coord., *Aportaciones antropológicas: 70 aniversario de la Sociedad Mexicana de Antropología (1937-2007)*. Universidad Nacional Autónoma de México, Sociedad Mexicana de Antropología, pp. 555-566.

Quezada, O. (2016). *El Templo Mayor de Tenochtitlan: Materiales, Técnicas y Sistemas Constructivos.* [Tesis de licenciatura en arqueología inédita], Escuela Nacional de Antropología e Historia, Ciudad de México, México.

Quezada, O., Darras, V. (2023). Caracterización espacial de un paisaje de extracción prehispánico: El yacimiento de dacita de Las Minas, Zacapu, Michoacán. *Ancient Mesoamerica,* 1-29. doi: **https://doi.org/10.1017/S0956536122000025**

Riker, J. M., K. V. Cashman, J. P. Kauahikaua, and Montierth, C. M. (2009). The length of channelized lava flows: Insight from the 1859 erup-tion of Mauna Loa Volcano, Hawai'i, *J. Volcanol. Geotherm. Res.*, 183, 139–156, doi: **https://doi.org/10.1016/j.jvolgeores.2009.03.002**.

Robles, G. N. (1992). La extracción y talla de cantera en Mitla, Oaxaca. Tecnología para la arquitectura monumental, *Arqueología*, 7, 85-112. **https://revistas.inah.gob.mx/index.php/arqueologia/article/view/12631**

Rodriguez-Yc, J. R. (2013). *La molienda en Mesoamérica, formas, fun-*

ciones, usos y manufactura de los Instrumentos: un estudio etnoarqueológico en México. Unpublished [Tesis doctoral inédita], Departamento de Prehistórica, Historia Antigua y Arqueología, Universitat de Barcelona, Barcelona, Spain.

Roux, V. (1985). *Le matériel de broyage. Etude ethnoarchéologique à Tichitt* (R.I) Mauritanie. Edition Recherches sur les civilisations, mémoire n°58, Paris.

Searcy, M. T. (2011). *The Life-Giving Stone: Ethnoarchaeology of Maya Metates*. The university of Arizona Press, Tucson, 168 p.

Searcy, M.T., Pitezel, T. (2018). An ethnoarchaeological perspective on ground stone production at the Santiago quarry in the casas grandes region of Chihuahua, Mexico, *Latin American Antiquity*, 29 (1), 169 -184.

Sheets, P. D., Grayson, D. K. (1979). *Volcanic Activity and Human Ecology.* Academic Press.

West, R. C. (1948). *Cultural Geography of The Modern Tarascan Area*, Cultural Geography of the Modern Tarascan Area (Institute of Social Anthropology Publication No. 7). Washington, DC: Smithsonian Institution.