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Production of *metates* in central Mexico: Techniques (know-how) and *chaine operatoire* of a traditional lithic craft in Turícuaro (Michoacán, Mexico)☆

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ABSTRACT

In Mesoamerica, metates and molcajetes are traditionally used for daily food preparation. These grinding tools are still made today by specialized craftsmen (metateros), who share their work between the quarries and their home workshops. In the Purépecha village of Turícuaro (Michoacán, Mexico), a systematic documentation of the work processes and techniques used to make these tools was carried out with the help of skilled metateros. By presenting the tools, processes, and know-how required for this activity, this study contributes to archaeological considerations on this millennial activity. The comparison of detailed production processes from different documented areas of Mesoamerica provides insights into the organization of the work, the individual variability, and the cultural characteristics that are reflected in this technical social activity.

1. Introduction

As a remarkable case in the history of techniques, grinding tools are one of the few artisanal products to have survived the centuries worldwide (Alonso 2019; Bhattacharya et al. 2025; David 1998; Hamon and Le Gall, 2013; Roux 1985). In Mesoamerica, fundamental work on the manufacture and current use of tripod grinding tools has been carried out, particularly in southern Mexico and Guatemala, where metates and molcajetes represent a symbol of Mesoamerican culinary traditions (Cook 1973, 1982; García Chávez 2002; Hayden 1987; Katz 2003; Nelson 1987a,b; Rodríguez-Yc, 2024; Searcy 2011, Searcy and Pitezel 2018; Vargas Díaz 2010, 2016). Made out of volcanic or sedimentary rocks, metates are used to prepare maize (masa), and molcajetes for pounding and mixing other ingredients to make sauces, which have been the staple diet of Mesoamerican populations for almost three millennia. These hispanized terms originated from the Nahuatl language: *metatl* = grinding stone; *molcaxitl* and *texolotl* = mortar and pestle (Gran Diccionario Náhuatl 2012). Beyond their role as domestic utensils, metates and molcajetes have a strong cultural, symbolic, and social dimension for the communities that use them. Paradoxically, because of the apparently unchanging and commonplace nature of this activity, few studies have explored the detailed technical processes involved in their production and use over the long term, including those from an archaeological perspective (e.g., Abramiuk et al., 2006; Biskowski and Watson 2013; van Pool and Leonard 2002).

The METATE project aims to characterize the organization of production, the technical choices made, and the know-how involved in the production of these tools in Michoacán, a region with great geological, archaeological, and ethno-historical potential in central-western Mexico (Fig. 1). There, at the El Metate volcano, andesite lava exploitation for metate and molcajete production has a long history (León 1906; West 1948; Chevrel et al. 2016a; Hamon et al. 2023). The El Metate volcano

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was formed in a single eruptive episode radiocarbon-dated to around CE 1250 that generated several voluminous andesite lava-flows (Chevrel et al., 2016a; Chevrel et al., 2016b; Mahgoub et al. 2017). The volcano represents an incredible source of lithic raw materials, whose abundance and quality are among the most prized for the regional production of grinding tools, in both present-day and archaeological contexts (Chevrel et al., 2016a; Chevrel et al., 2016b). The still ongoing grinding tool production on the slopes of this volcano is therefore a particularly favorable starting point for characterizing the evolution of grinding territories and know-how from Prehispanic times to the present day. Our work has enabled us to document and map large areas of quarrying activities, some probably dating back to Prehispanic times, and others still in operation (Hamon et al. 2024). Today, in the village of Turícuaro, few remaining Purépecha metateros are still using “traditional” techniques with metal picks and stone tools, for the extraction of blocks and the working of andesite (Hamon et al. 2023, 2025). In the last decades, this activity has suffered major changes, in link with the progressive abandonment of the daily use of metates and molcajetes. This has occurred due to the spread of electric mills in village shops, and of blenders in domestic kitchens that resulted in the collapse of the demand for metates and molcajetes. Consequently today, a change in metate function and use is also perceptible. Metates are not common anymore in larger towns, but in small villages, they are still used frequently on a daily basis by families for masa making, and more rarely for grinding grains, or on special occasions such as weddings, baptisms or other traditional events.

From an anthropological perspective, our detailed study of the current sequences of metate and molcajete productions is based on the concept of *chaine operatoire*, a powerful tool to systematize, compare, and analyze the sequences of production. On this basis, this paper explores the adaptation of producers to the availability and mechanical characteristics of the rock, and the individual variability of products in link with the level of know-how, age, and gender, of the artisans. Finally, the recent developments resulting from the introduction of technical innovations and increased economic pressure are also discussed. The organization and sequencing of the production is compared with other regions in Mesoamerica where metate and molcajete production has been documented, such as in Oaxaca or in the Maya highlands (e.g., Cook 1973; Hayden 1987; Katz 2003; Searcy 2011), to highlight cultural variations and specificities. Our final goal is to deliver an overview of different organizations of metate production, including technical and sociological aspects, to enlighten archaeological interpretations at three levels: 1) The morphology and organization of quarries as deduced from their material remains, 2) reconstruction of complete sequences of production, including body movements, tools, and debitage, and 3) contextualization of this activity in its social and economic dimensions.

2. Materials and methods

The *chaine opératoire* concept is helpful for systematizing the description and creating the conditions for the comparison of technical processes, which in turn allow to reconstruct the economic, cultural and anthropological systems in which they were developed (Leroi-Gourhan 1943, Creswell 1976, Lemonnier 1983).

A field survey was conducted during seven weeks in the springs of 2018 and 2019, to follow the work of one family of craftsmen, the Vidales, with three generations of men still involved in the production of metates and molcajetes in the village of Turícuaro. Pre-established questionnaires were used to obtain necessary information about the context of apprenticeship and practice of the current activity of each craftsman. Don Pedro Vidales (72 years old, one of the last great masters of metate production in the village), his wife Doña Livia Vidales, and their son Nicolás Vidales (38 years old) were our guides and informants. Occasionally, the elder sons of Don Pedro also shared their knowledge with us, in particular Héctor, Cristián, and Tino Vidales. Both informants and archeologists were communicating directly in Spanish language.

We followed and registered the production of six metates and five molcajetes of different sizes and morphologies, made by Don Pedro and Nicolás Vidales from the selection of the blocks in the quarry to the finishing of the stone tools in the workshop and their final delivery to the customer.

A protocol of systematic documentation (video, photo, technical

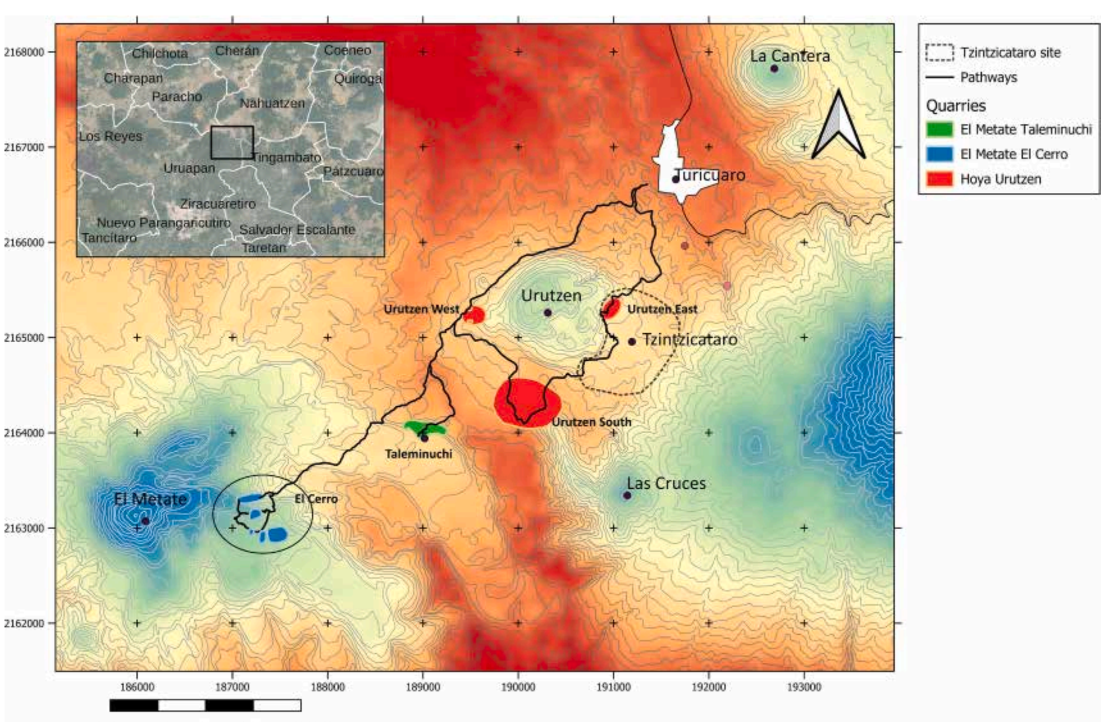

Fig. 1. Map showing the quarries at Hoya Urutzen and El Metate, near the village of Turícuaro (Michoacan) (map: L. Aubry, after Hamon et al. 2024).

schemes) was followed to document the sequences, body movements, tools, and state of surface-finishing at each stage of the production. The goal of each technical action was registered, when explained by the craftsman. Three-dimensional models (3-D) based on photogrammetry were produced to document the evolution of the morphology, loss of volume, and traces visible on the surfaces of a series of metates and molcajetes at different stages of production.

3. Results

Metates and molcajetes are made to meet the specific demands of the customer, hence each specimen is unique (Fig. 2). Although their use has declined considerably in recent decades, especially in the case of metates, they are still part of the traditional wedding-gift assortment. Work follows several main steps, which may correspond to different parts of a metate or molcajete (working face, sides and back/feet). Ultimately the sequence is rather organized around a series of goals, associating the work of several parts of the objects together to maintain the symmetry of the whole product (Fig. 3). The main production steps are summarized below, while schematic details of the shaping process are described in SD4 and SD5.

3.1. Tools and equipment

Each artisan, locally called *metatero,* owns and repairs his personal set of tools (SD1). Traditionally, the production of metates and molcajetes requires a set of particular forged steel picks. In recent years, portable electric stone-cutting tools have been also increasingly used, especially by the younger generation, as they make the work easier and quicker, although at the expense of higher quality.

−A set of four forged steel picks (*iawal uratarekua* in Purépecha language) is used by the Vidales (SD1a-b). The handles are of oak wood. The hardened steel is usually obtained at car junkyards, preferably from salvaged transmission shafts. The heavier picks are massive, with long handles, while the smallest measures 80 to 100 cm. For Don Pedro, the best way to control the gesture is to hold it with the right hand very close to the metal blade. The Vidales have their own forge in the courtyard of the house. This is convenient for sharpening the steel picks during the manufacturing process. The picks are rejuvenated before each new metate is made. It takes 20 min for the steel to reach the right temperature. The steel blades are then placed directly in the fire (SD1c). When the blade has turned white, the point is worked on an anvil (SD1d). It is flattened on its four sides to obtain a point with a square section. Once the point is obtained, it is polished with a fragment of andesite to flatten and stretch it. On the opposite side of the blade, the edge is flattened and thinned by hammering on 1 or 2 cm. The use of each pick is adapted to the specific operations, in direct relation to its weight (SD1e-f). The tools are regularly fixed to their wooden handle during the work, by pounding the metal blade on a block.

− Portable electric stone-cutting tool with metal discs are used either to cut the rock in a vertical position or to abrade the surface when handled horizontally. According to Cristián, an elder son of Don Pedro, it takes one disc to make one metate (SD1g).

−Andesite hammerstones are used in the final stages of surface finishing, including fine direct hammering and abrasion (SD1h). This andesite is harder and denser than that selected for the metates. These hammerstones are generally prismatic blocks with a large base for handling and a cutting edge on the distal part. Flakes and angular fragments can be used as hammerstones. Don Pedro considers stone tools to be cleaner than metal picks, as metallic residues were regarded as impurities, especially for food processing.

The color and state of dryness of the rock are important parameters to consider (see for details Hamon et al. 2023): it is tested by the sound of the pick, which is clear when completely dry. Once extracted, a block must be worked within 2 or 3 days before it becomes too difficult to work. The more humid, the softer and easier to carve; the drier, the harder and easier to abrade.

Additional tools are used by the metateros during their work for taking measures, such as pencils, plates of different sizes, straws, etc. (SD2). Nicolás also used his fingers to estimate the overall dimensions. Wooden sticks and wedges were also used to balance the back of the roughouts during the work, while boxes were bought to protect the surfaces from the ashy and abrasive soil.

The metateros rarely work sitting down. The standing position allows them to turn around the block, to make body movements of great amplitude, to hold the blocks with their feet, to estimate the symmetry with a constant look in the vertical axis of the block.

The metateros have to protect themselves from the sun with hats or caps, by working in the shade of trees and occasionally by installing tarpaulins; they also wear scarves for protection from fine dust. The movement of blocks from one area of the quarry to another is also influenced by the position of the sun: as the sun rises, the artisan looks for more shade, firstly for freshness, and then to obtain more contrasting light, which is necessary to correct the defects of the surfaces. This

FIg. 2. Examples of finished metate (a) and molcajete (b) from Turícuaro (photos C. Hamon).

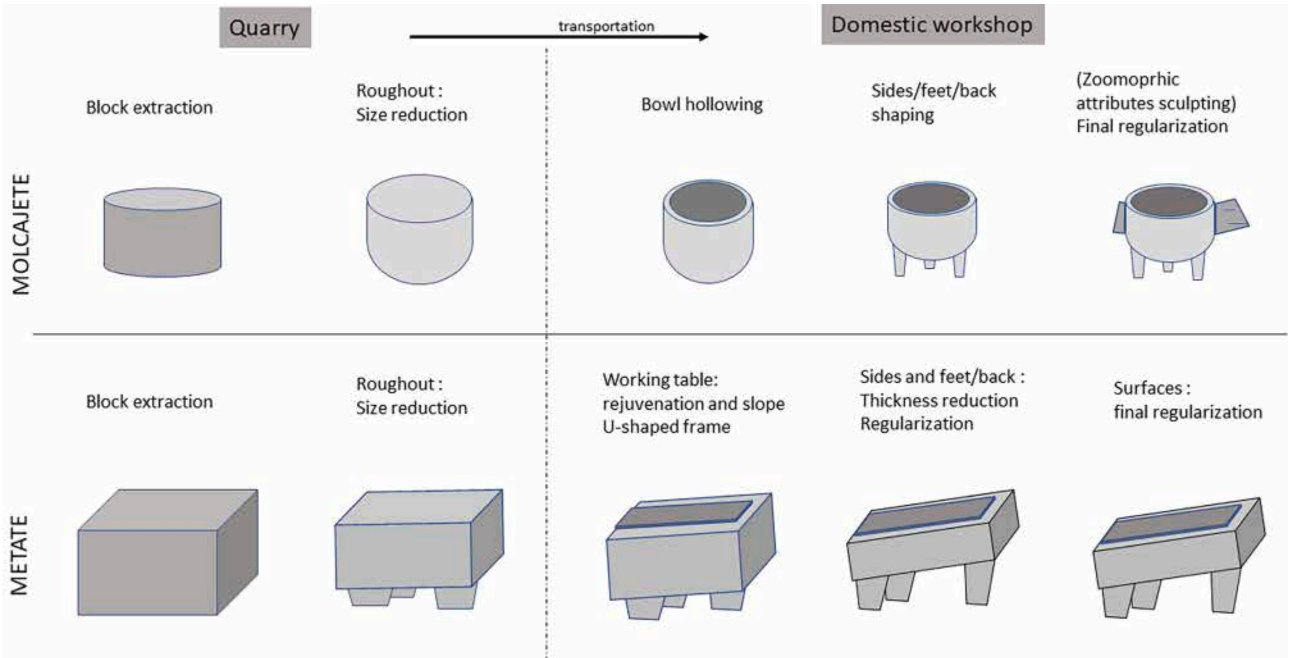

Fig. 3. Schematic representation of the main phases of molcajete and metate shaping in the quarry and in the domestic workshop.

parameter must be considered when interpreting the spatial organization of the working area.

3.2. *Sequences of block selection and shaping in the quarry*

The production sequence of molcajetes and metates is a continuum and subject to different constraints in space and time. Firstly, the main risk during this initial phase is the accidental fracturing of the blocks, as this generally means the loss of hours of work near the top of the volcano. In the past, the metateros used to pray prior to climbing the volcano in order to maintain concentration, inspiration, and motivation during their work.

In the quarry, the sequence is divided into four major production steps, each one corresponding to a specific working area. The blocks are moved from one work area to the other, as the shaping progresses (Fig. 4). The degree of completion of the roughouts is mostly determined by the time available at the quarry near the top of the volcano during daylight, and the maximum weight the donkey can carry back to the village before sunset.

After the selection of the different areas of block concentration (step 1), the block is extracted (step 2), then it is moved to a second working area where it is broken and reduced to the expected size (step 3). The first morphological characteristics of the roughout are then formed, in particular the back and feet, if necessary on a third workstation, which is cleaned of waste and flattened (step 4). The resulting roughout is then transported by donkey to the village (step 5).

3.2.1. *Selection of blocks*

According to Don Pedro and Nicolás Vidales, it takes an entire day to find a dozen blocks of good quality. Walking through the apparent chaos of blocks forming the surface of lava flows, particular blocks are tested according to different criteria, such as their dimensions, accessibility and external color, as a first indicator of the hardness of the rock. They are then tested with a pick to estimate their hardness, but also their density (vesicularity), according to the vibrations and the sound they make. Blocks with internal fractures must be avoided, so most of the blocks visible on the surface are generally excluded in favor of partly buried ones. Because of his long experience, Don Pedro is considered the most qualified to quickly select good quality blocks. In order to indicate to his sons that a block is of good quality, he draws a star to mark and claim it. The block can then be easily recognized by the metateros of his family. However, in general, each metatero selects the blocks for his own production, being more or less demanding in terms of quality, depending on his level of expertise and the time/effort he is willing to invest in this stage of production.

3.2.2. *Block extraction*

Depending on the location of the selected block, it may be necessary to first remove the blocks and incipient soil partly covering it. The selected block is then broken by superficial flaking with a mace. One or more vertical grooves are then made to divide the block into 2 to 4 pieces (Fig. 5a–d). Due to the physical strength required for this work, the assistance of two metateros may be necessary. The area underneath is then cleared of any remaining fragments of the block in order to facilitate the access. Leverages and wedges are then used to separate the block fragments, lift them from the ground and push them across the debitage, following the slope.

3.2.3. *Block reduction to desired shape and size*

Once installed on a more stable and flattened area, the block is then progressively reduced to reach the desired shape and dimensions (Fig. 5e). The future active surface is reduced by alternating large and small size removals made with the cutting edge of the pick, and by coarse pecking made with the point of the pick; here, the goal is to obtain a curvature with general longitudinal and transverse concavity (Fig. 5f–g, SD4). Measures are taken and the sides then successively flaked and regularized (SD4). Each side is completely flattened by pecking, using the cutting edge of the massive pick. Then, a series of flakes are detached starting from this flattened side to reduce the thickness of the neighboring one, and so on. Up to 10 cm can be taken away of each side by this technique.

3.2.4. *Roughing out the back and the feet*

It is at this stage that the processes for making metate and molcajete preforms diverge. The molcajete feet are usually designed in the domestic workshop in the village, as a preform without feet is less fragile and less likely to break during transport.

In the case of metates, the first step of the roughing out of the back

Fig. 4. Workshops (a, c) in the quarry at El Metate volcano with selected blocks surrounding a platform covered with waste. Block extracted (a), to be worked (b) and raw preform ready for transportation (c). Nicolás Vidales working in his parents' domestic workshop (d). In the background is a traditional Purépecha wooden house («troje») that serves as a kitchen area (photos C. Hamon and C. Siebe).

consists in taking off material between the side and the future feet on the distal and proximal ends of the metate (Fig. 6a–d). Large flakes are detached starting from the back and ending along the future side in order to design the external face of the feet (SD4). Up to 10 cm can then be detached from the back, to reach the base level of the metate. After taking measurements on the sides, a certain thickness of material is taken off with the cutting edge to obtain a level of reference for the flattened back (SD4).

In the second step, the feet are shaped. This involves removing an important amount of material. The boundary between the side and the back is delineated by pecking. The outer surface of the central foot is then flattened from the base. At the distal end, two feet are formed from the remaining transverse edge of the material. A thick ridge is left between the proximal and distal feet, to prevent any accidental breakage; it is then slightly hollowed out between the distal feet. In order to maintain the symmetry and alignment of the three feet, their dimensions are progressively and simultaneously reduced on the three sides, as well as on the inside and outside. The central ridge is then broken by centripetal chipping from the edges towards the center.

3.2.4.1. Transportation. Since Prehispanic times, metateros carry metate roughouts from the quarries down to the village on their back and shoulders, with the help of resistant ropes. Nowadays, donkeys are commonly used to bring back several roughouts altogether. The load must be balanced on both sides of the animal and tied strongly with ropes. Up to four metate roughouts can be transported by a single animal (Fig. 6e–f).

3.3. Sequences of metate production in the workshop

According to Nicolás Vidales, five days are necessary for the production of a metate (*iawal*), with its mano (*parekua* a). On average, one day is dedicated to the search of a good block in the quarry, and another day for the production of the preform, while three additional days are necessary for the final shaping and finishing in the family workshop. All metates produced by Nicolás and Don Pedro Vidales are tripod metates, but the size of the feet can slightly vary from one craftsman to another. The sloping and slightly concave grinding surface are delimited by a rectangular frame of 2 to 3 cm in width. Small and large-sized metates are produced, and are usually between 30 and 50 cm in length.

In the domestic workshop contiguous to the Vidales' house (Fig. 4d), the sequence of metate shaping can be interrupted by other domestic activities, as well as constraints posed by the drying time of blocks, the smoothing of tool's points, the orientation of the sun, or bad weather conditions. The breaks taken by Don Pedro and Nicolás Vidales are directly related to specific moments in the sequence, that may be considered as turning points. The design of the upper face (edge and table), the shaping of the sides, and the sculpting of the feet and the back are the three main steps of metate production, prior to the adjustment of symmetry and dimensions, and the finishing of the surfaces.

Fig. 5. Work in the quarry: block extraction and production of roughouts. Step 1–2 – Extraction of a semi-buried block: a) Making a groove; b) splitting; c) extraction of the block; Step 3 – d) moving the block to the workshop; e) installation of the block; Preparation of the active surface of a metate: f) adjustment by pecking of the table and sides; g) active surface of the roughout with traces of flaking and pecking (photos C. Hamon).

Fig. 6. In the quarry, from roughing out to transport. Step 4 – a) to d): Roughing the back and feet of a metate; Step 5 – e) transportation of metate roughout on man's back, f): Packing the roughouts on a donkey for final transportation to the domestic workshop in the village (photos C. Hamon and C. Siebe).

Sequence and symmetry.

The shaping of each part of the metate alternates between the table, the sides and the back, and so on until, the final metate is finished. The design of the individual parts is therefore not a continuous sequence, but rather a succession of sequences separated by the design of other components of the metate. This organization of the work is mainly motivated by the need for symmetry. This need requires time to adjust the shaping and regularity of the individual surfaces and, ultimately, the whole metate as precisely as possible. This aim for symmetry has consequences on various levels. Firstly, it ensures that the metates can be sold at a higher price because symmetry of the product is regarded as a sign of higher quality. Secondly, symmetry is necessary for good stability and functionality of the metate, for the comfort of its use in a kneeling position, and to ensure an even and efficient progression of the mano on the grinding table. In all these cases, a deviation from symmetry can have a significant impact, not only on the final product and the quality of the masa, but also on the health of the woman using the metate. A deviation of the main foot from the longitudinal axis can lead to a distortion of the grinding movement from the chest to the shoulders, arms and hands, which can ultimately lead to permanent pathologies and make this daily activity painful. The dissymmetry of the table can lead to a loss of efficiency, an increase in the time required to obtain a quality product and, finally, a distortion of the tool that renders it unusable. Therefore, producing a symmetrical and high quality metate requires not only expertise but also time, and time is money. The details of the different sequences are listed in SD5. Below we summarize the main steps needed to design each part of the metate and describe the challenges presented by each step.

Designing the table.

The design of the grinding table has various objectives (Figs. 7-8). First, pecking aims to sharpen the surface to increase the efficiency of grinding operations. But given the recent developments in the use of metates, from the initial crushing of the corn grains to the mixing of the masa, the preparation has a more superficial effect on the active surface, alternating between the cutting edge and the tip of a pick. The efficiency of the «grinding» now aims less at the opening of the maize grains with a strong pressure on two grinding surfaces than in facilitating the gesture of mixing the maize paste in a very fast and fluid sliding movement.

The peripheral frame (Fig. 8h) of the active surface is not only decorative, but plays an important role in ensuring the symmetry of the entire metate and obtaining a uniform active surface. This frame serves as a reference for a horizontal plan, which can be used to estimate the degree of carving at different points of the active surface. The regular measurement of the active surface aims to maintain a strict symmetry in order to avoid an obstacle to the smooth movement of the mano on the metate. The active surface is pecked from the proximal to the distal edge and from the edge to the center of the table. It helps maintain the appropriate longitudinal and transverse curvatures to ensure the preservation of moisture in the center while facilitating the evacuation of water and product through the distal end. This is probably also the reason why the surface is divided into quarters, whereby the central part of the table is also the intersection of the four quarters and the surface may be hollowed out as much as possible to keep water during masa preparation (to liquefy the masa mixture) and avoids any irregular contact between the surfaces of the mano and the metate.

Regularizing the sides.

The regularization of the sides of the metate is organized in two complementary sequences: one is linked to the shaping of the table, especially the peripheral edge, and the other is ed to the sculpture of the feet and back (Fig. 9). These two sequences are made one after the other, with the metate turned upside down at each step. Hence, the sides of the metate make the link between the faces and the sides, and are important elements to ensure the stability and symmetry of the whole. The most important stage is to obtain straight vertical or slightly convex sides, regular enough to serve as a surface of reference to ensure the symmetry and alignment of all other surrounding parts of the metate. That is probably why their shaping aims at flattening the surfaces. First by flaking the very edge of the side starting from the active surface, then by linear pecking with the heavy pick, again from top to bottom of the side to get off material by following a vertical plan and finally by using the

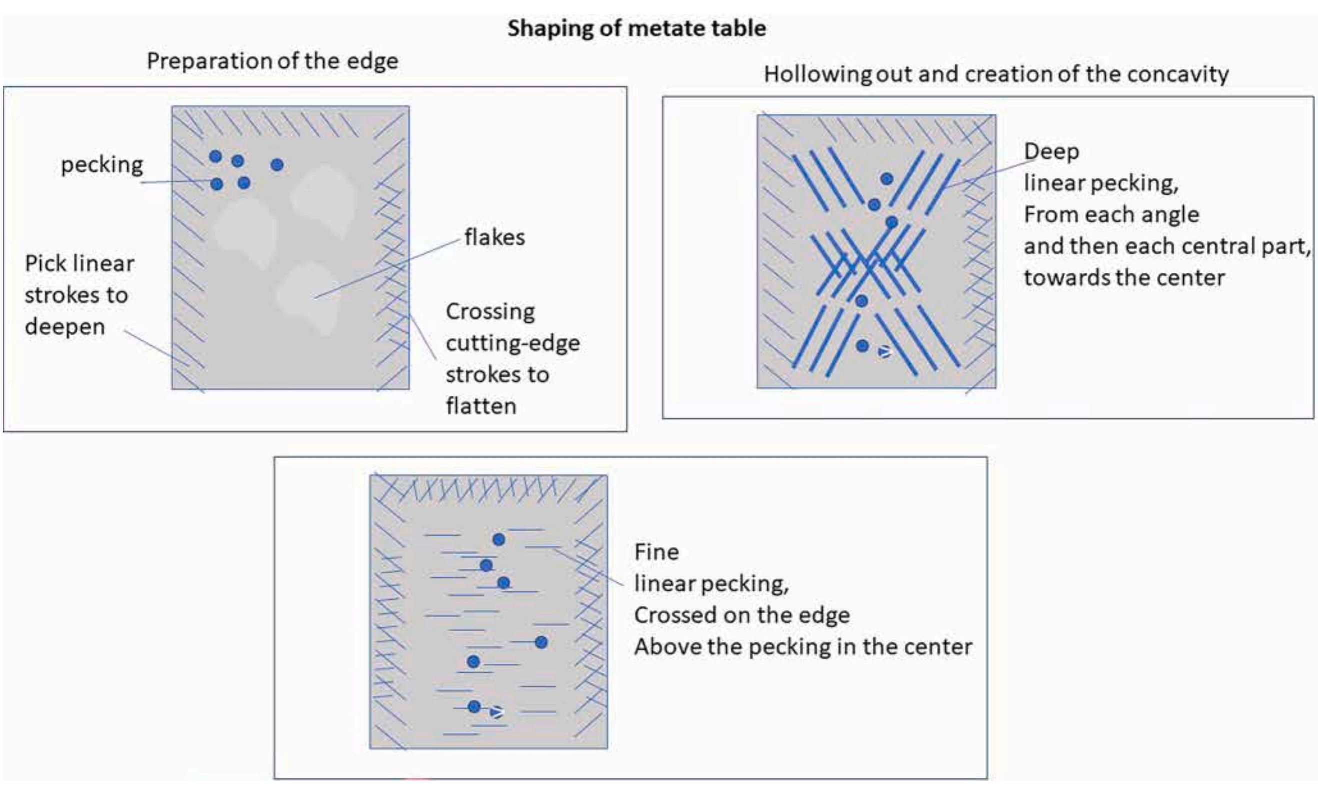

Fig. 7. Schematic representation of the technical processes involved for the main stages of metate table shaping.

Fig. 8. Shaping the metate table. a) first steps of thickness reduction; b) and c) initial coarse followed by fine pecking to shape the frame; d) to f) shaping of the slope and concavity by removing thick flakes and carving by pecking towards the center; g) regularization with smoothed frame by pecking with the flat edge of the pick and by coarse pecking in the center with the pointed end of the pick; h) examples of surface shaped with electric cutting disk, then coarsely but regularly pecked, then flattened by linear crushing (photos C. Hamon).

Fig. 9. Shaping the lateral sides of the metate. a) first pecking stage to flatten the sides vertically; b) second pecking stage to regularize coarsely the convexity of the side; c) regularization with oblique linear strokes with the sharp edge of the pick; d) final regularization with crossed linear strokes to flatten the entire side (photos C. Hamon).

cutting edge of the picks in two different and obliquely crossed orientations to get rid of the remaining protruding material.

Sculpting the feet and the back.

The metate is turned with its front side against the floor or, better, against a piece of cardboard to protect it from dust and dirt. Then the back is slowly flattened, removing a thick layer of material from one end of the metate by pecking. In the meantime, the feet are gradually modelled by first reducing their thickness and then giving their outside surface a curved shape by flaking (Figs. 10-11). The sides of the feet are not shaped straight, mainly because a curved shape provides greater

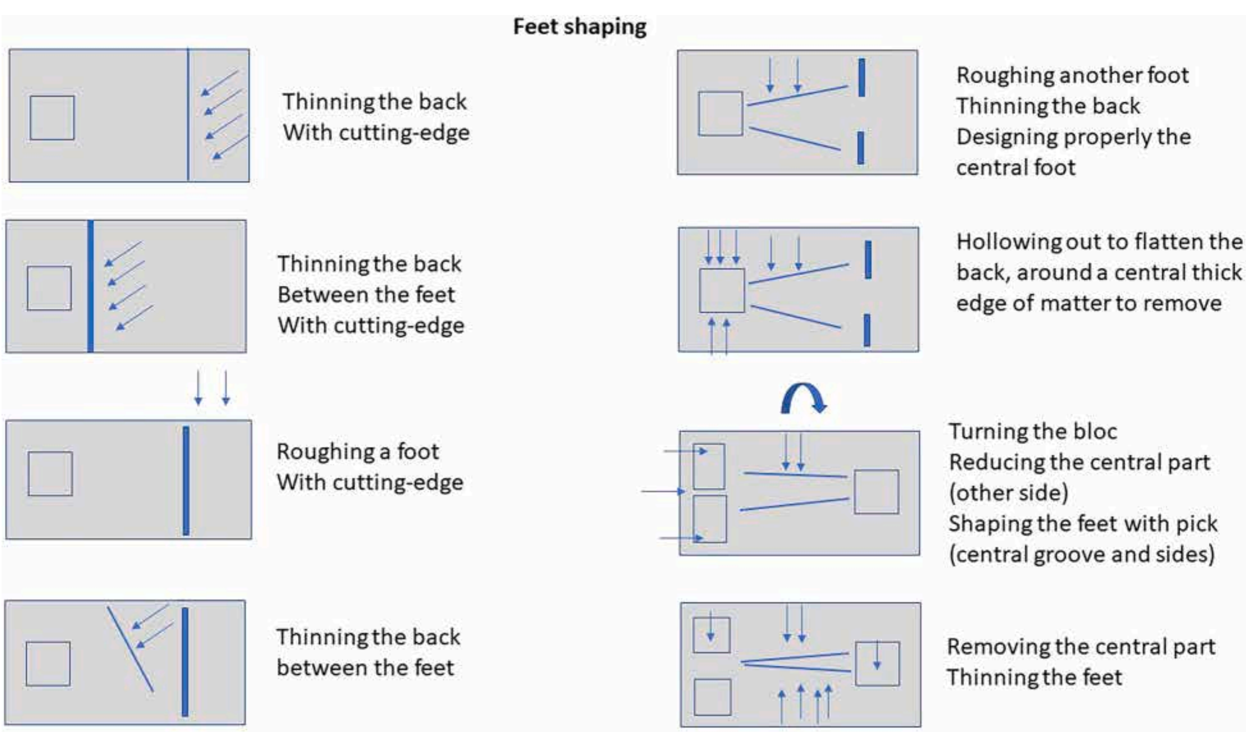

Fig. 10. Schematic representation of the technical processes involved for the main stages of a metate's underside and feet.

Fig. 11. Shaping the metate's underside and feet. a) pecking with the heavy pick to regularize the bottom; b) general shaping of the feet; c) thinning of the feet; d) finer thinning of the feet's sides; note the curvature; e) regularization of the feet and underside by pecking; f) regularization of the feet and underside with the linear cutting edge (photos C. Hamon).

stability when turned outwards. This also allows a small plate to be attached to the distal end of the metate to catch water and masa. The two small feet on the distal edge are shaped altogether, while the forming of the main foot requires the highest investment. Shaping by pecking is done from top to bottom and from the edges to the center of the foot, successively for each side. To achieve an elegant design of the feet, their sides are flattened starting from the edges. These edges are sharpened with the edge of the pick to flatten their sides to less than 2 cm. The base of the feet can be easily flattened by flaking and pecking. However, this step must be done carefully to avoid accidental rough flaking or breaking of the base of the foot. Similar care is required to remove a certain thickness of material between the feet, where the surface is less accessible and can only be worked with a more direct angle, and on the contact surface between the foot surfaces and the back, which must be clearly drawn. The shaping of the feet alternates with the shaping of the corresponding areas on the back, which is progressively flattened and regulated with the heavy and medium pick and later with the cutting edge of the pick. Sculpting the feet seems to be a delicate step that requires strong control of the force and angle of the tool to avoid an unexpected breakage that could ruin days of work. Here too, the sequence

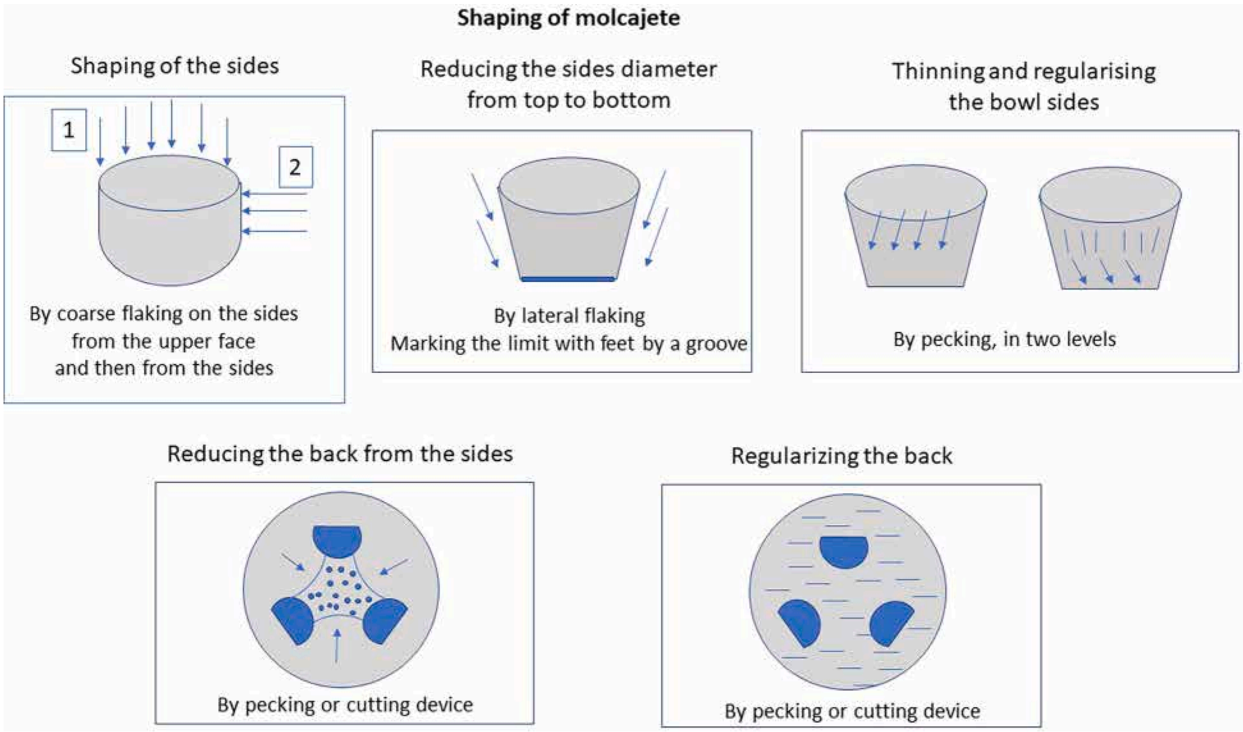

Fig. 12. Schematic representation of the technical processes involved in the main stages of molcajete shaping.

of different operations on the same parts of the metate aims to gradually reduce the thickness of the feet and back to limit at the same time the wedge that could inevitably damage the blank.

Shaping the mano.

The process of mano production can be described as follows (SD3a-c). Manos are generally made from large flakes recycled from the waste of metate production, or from blocks abandoned because of accidental breakage. The active surface is designed parallel or perpendicular to the natural orientation of the rock (in the case of andesites and other volcanic rocks, the natural orientation usually stems from flow-banding due to the alignment of minerals and micro-vesicles prior to the solidification of the lava). After taking measurements on the grinding surface of the metate, the dimensions are recorded on the mano with a pencil. The main edges of the mano are cut first, while the ends are cut to the correct size. Flakes are removed along the edge with the cutting edge. Starting from each end, the surface is simultaneously hollowed out and levelled by linear blows with the pick; the remaining ridge of andesite in the center is then removed by flaking. To obtain a slightly tapered shape, flakes are removed from the periphery of each end. The mano is then turned upside down to continue on the other sides. Each side is regularized by linear blows with the pick; these linear marks are arranged in 2 lines along the edges and arranged in a herringbone pattern (SD4). After final measurement, the ends are first cut and then pecked. The sides are regularized with the cutting edge, taking particular care to preserve the symmetry. After drying, the entire surface is regularized by pecking and abrasion with a hammerstone in order to obtain a “polished” surface according to Don Pedro. The mano is then tested directly on the metate to verify the correct adequacy of the curvature of both tools.

3.4. Sequences of molcajete production in the workshop

According to Nicolás Vidales, four days are necessary for the production of a simple molcajete (*chumatakwa in purepecha*), with its pestle (*huapa in purepecha*). One day is dedicated to the search of a good block in the quarry, and another for the production of the preform, while two more days are necessary for the final shaping and finishing in the family workshop. Basic molcajetes are made with three feet for more stability. The bowl of the molacajetes are of 15 to 20 cm in average diameter, though varied sizes may be produced (from 10 cm in diameter for children toys, to 1 m in diameter for masterpieces made for festivals). Don Pedro was the first craftsman to design zoomorphic molcajetes in Turícuaro (donkeys, cows, pigs, etc.).

In the domestic workshop of the Vidales, the sequence of molcajete shaping follows four major steps: the design of the bowl, the shaping of the side, feet and back, the sculpture of the zoomorphic attributes, and finally, the finishing of the surface. They must always respect the symmetry and dimensions of the whole molcajete.

Hollowing the bowl.

After cutting a quadrangular block to the adapted dimensions, the main profiles of the bowl and feet are shaped (Fig. 13).

The bowl is hollowed out step by step from the periphery to the center (Fig. 14). The first step is to design a 2-cm-wide frame to obtain a circular area of uniform diameter; this is quickly flattened with the cutting edge. This area is then gradually hollowed out, first by flaking, then by deep strokes with the cutting edge of the pick, rough random pecking, and finally, by fine linear pecking. To ensure a certain regularity in the hollowing process, the circular area is divided into sections in a star-shape pattern. Each triangular section is first demarcated by a straight cut, then hollowed out by lateral flacking and then flattened on the inside by a series of smaller cuts. The diameter is measured and drawn regularly to maintain symmetry, with circular vessels of two different sizes for the external and internal dimensions.

Shaping the feet and external surface.

The shaping of the external surface and feet of a molcajete takes approximately three hours (Fig. 15).

The outer surface of the molcajete is modelled as a whole, from the top of the bowl to the base of the feet. The first step aims to remove as much material as possible in order to obtain a bowl of the expected size and with vertical sides. After a short flaking starting from the active surface, the upper part of the sides is regulated by linear, fine pecking. The outer sides of the molcajete are then roughly smoothed with the

Fig. 13. Molcajete roughing. a) block down-sizing; b) roughout shaping; c) and d) design of the general shape, from bottom to top (photos C. Hamon).

heavy pick in a vertical movement to remove the material. The outer surface is worked in two different planes, always from top to bottom. At this stage, the boundary between the bowl and the upper part of the feet is also drawn more clearly.

The molcajete is then turned over on a cardboard, either on its side or on its front, to remove the material at the bottom of the bowl around the entire circumference. The feet are then shaped vertically with the pick to remove the material on the outside. They are then flattened from the periphery towards the inside. The height is measured regularly with a stick between the base of the foot and the top of the mortar. The feet are cut with the edge of the pick from the inside outwards to gradually make them thinner. The base of the foot is then flattened. The area between the feet are then thinned out and straightened by rough chopping. The edges of the feet are then sharpened: the sides are flattened with the cutting edge to form an angular edge. When using the electric cutting disc, the feet are cut to the correct size directly on the sides and at the base. Particular attention is paid to the correct alignment of the outer surfaces of the feet. The material between the feet is pre-cut before pecking.

Sculpting zoomorphic attributes.

With the evolution of the production of mortars from food implements to more decorative items, the sculpture of zoomorphic attributes has complicated the sequence of production (SD6). The symmetry is even more needed, and the gestures must be more accurate. It also requires a better knowledge of the rock behavior to sculpt the volumes. New tools are also used for this specific step together with the small pick, such as the hammer and chisel (less than 10 cm in length). These tools are used to delineate the main edges and the hollowing of the different parts of the animals. Most of these parts are carved by taking off material up to 1 cm in thickness between the ears or the horns, under the nose to the neck, around the tail of a bull, for example. When the portable electric stone-cutting tool is used, the volumes are precut prior to being flaked with the pick, and then regularized by very fine and linear pecking with the cutting edge. All these stages require great caution when finishing the surface, and great accuracy as each part is fragile and susceptible to break, if the angle and strength of stroke are imprecise.

Shaping the tejolote.

Tejolotes (pestles) are generally tronconical in shape and their dimensions adapted to those of the molcajete. Any fragments of good quality andesite can be reused to make a tejolote. The general shape is given by rough flaking of the sides and the largest end (SD3 d-g). The surface is then flattened and regularized either by abrasion with a portable electric stone-cutting tool or by pecking with the cutting edge of the pick. A series of flakes are removed from the sides of the largest end before being shaped by pecking. The sides are then cut in half, with the cutting edge leaving linear and crossed marks. The entire surface is finished by fine pecking with a hammerstone.

3.5. *Finishing the working surfaces*

The final stage of shaping aims to homogenize the entire surface (SD7). This final stage of finishing may seem insignificant, but it definitely enhances the “blue” color of the stone, increases its visible quality and ultimately leads to a better selling price.

Fig. 14. Hollowing out the molcajete bowl. a) hollowing out inside the round frame with the heavy pick; b) delinating the bowl; c) and d) regularizing and flattening the round frame; e) deep star-shaped incisions at the center of the bowl made with the electric cutting-stone device; f) removal of material with the pick to shape the concavity of the bowl (photos C. Hamon).

This stage requires regularity and precision. This probably explains why it is the only stage that is done in a sitting position. It is carried out with the cutting edge of the metal pick and then with the stone pick. Different shapes and sizes of stone picks can be used. The surface to be regularized is generally held vertically, while the pick is generally thrown at an oblique angle onto the surface of the mortar.

Furthermore, it is carried out on dry stone in order to penetrate only superficially into the material and to obtain the expected texture. If necessary, the mortar or metate is left to dry in the sun for an hour to "harden" the stone. It takes a while, about a couple of hours, to make the working area and the outer part as homogeneous as possible. Particular attention is paid to the visible surfaces of the feet and sides, as well as the frame that delimits the active surface.

In the Vidales family, this work step was regularly carried out by the women of the family and even by the children (SD8). Today, it also serves to remove the traces of use from the discs, and give the appearance of a "traditional" metate.

Fig. 15. Shaping the molcajete's sides and feet. a) and b) regularization of the upper side of the bowl; c) and d) shaping and regularization of the feet and downside; e) and f) shaping and regularization of the feet and downside with the portable electric cutting-stone device (photos C. Hamon).

4. Discussion

The detailed study of the sequences of metates and molcajetes manufacture in Turícuaro allows to better understand the organization of the production as well as of the individual variability and know-how. This has direct implications for archaeological interpretations of material remains of this activity and throws light on diverse technical choices and economic contexts.

4.1. Organization of the production

Traditionally, in Turícuaro, metates and molcajetes are produced upon request by customers, hence, each of these tools can be considered unique. In recent years, as a result of a decrease in demand, different production schemes have been developed and coexist. Don Pedro and his son Nicolás still work upon request to produce unique high-quality metates, but some of their nephews and cousins produce serial items to be sold in shops in the neighboring villages. In addition, some of the elder sons dedicate most of their work to the production of artistic masterpieces for festivals to gain visibility (SD9).

In view of the fall in demand and the low incomes of the metateros, the economic constraints are making it increasingly difficult to keep the traditional organization of production. According to Nicolás, the main problem is not only the drop in demand, but also the long distance to the lava flow and the difficulty of access to the quarries. A day at the quarry starts at 5 a.m. to reach the foot of El Metate volcano at sunrise and start climbing before the heat sets in. It ends at nightfall, around 6 pm, after descending from the volcano. The activity is seasonal, as during the rainy season it becomes dangerous to climb because of the violent thunderstorms in the afternoon. This distance to the lava flow also explains the spatial segmentation of the first stages of production on the quarry, and the shaping of the roughouts in the family workshop down in the village. As time goes by, the better-quality blocks are further away and the time to reach them is longer. As a result, the temptation to choose softer blocks closer to the main pathway to the quarry increases. This is another reason why Nicolás has decided to stop leaving his preforms in the quarries to prevent theft at night. Another trend is also clearly visible among the youngest craftsmen: the use of portable electric stone-cutting tools is becoming increasingly widespread. In fact, this technique saves a great deal of time, although the final quality of the metate is lower. However, if the older generations preferred products of good quality to stabilize their activity, the younger ones have to produce more to ensure a decent life for their families.

The production of metates and molcajetes is an individual work that would not be possible without the solidarity of the metateros at the different stages of the work. The dangerous nature of the work in the quarry, from the climbing to the extraction of the blocks, explains why the metateros often climb in groups. In addition, a pack of dogs accompany the metateros to the quarry: as this dangerous activity can seriously injure the workers, the dogs can sound the alarm if necessary. During the extraction process, it is not uncommon for two metateros to take turns breaking the blocks and transporting them to the preforming area. Another crucial step is the loading of the preforms onto the donkey: the preforms, each weighing up to 40 kg, have to be carried by one metatero, while the other ensures that the whole is securely tied up. Finally, during the preforming process in the workshop, each metatero can be called upon to help advance the work or to finish a metate in the event of a breakdown. The case of Don Pedro is peculiar because his long experience makes him an expert, especially in the selection of blocks for most of his elder sons. Don Pedro's courtyard and forge are also shared with Nicolás and are occasionally used by the older sons, who generally make the molcajetes in their own courtyard.

4.2. Interpreting individual technical variability

As a matter of fact, metate production is a highly gendered activity, only taken in charge by men, with rare exceptions. Don Pedro taught his daughter how to make metates, but she quit at her wedding, on demand of her husband.

The remaining metateros of Turícuaro all belong to the same network of apprenticeship, shared in between siblings and cousins. Don Pedro himself learned since the youngest age with his uncles on the quarries. This is also the case for Nicolás, who learned from his father since his childhood. Most of the elder sons have been taught the work by Don Pedro and Nicolás. Unfortunately, Don Pedro was not able to inform us in detail on the organization of apprenticeship networks of the previous generations of metateros in Turícuaro.

As the youngest metateros started their activity quite late around the age of 16 years, their experience and know-how are not equivalent, and their productions are of average quality, because they 1) often work softer rocks, 2) more often create accidental breakage leaving an unfinished product, 3) have difficulties to respect symmetry (for feet, table and bowls and for zoomorphic attributes), and 4) use systematically the portable electric stone-cutting tool. Don Pedro also taught one of his cousins, Francisco Ruiz, who in turn taught both of his sons (e.g., Andrés). Another cousin of Don Pedro, Copertino, learned from his uncles. In the young generation, most of the craftsmen quit rapidly the activity, or make it part of their time as a complementary source of money. The sons of Nicolás, do not know how to make a metate, though they may help for the finishing stages with the pick and hammerstone. Once Nicolás Jr., his 14-year-old son, tried to shape a molcajete, but it broke on a foot.

Don Pedro and Nicolás Vidales describe themselves as artists: they emphasize the creative dimension of their work and compare the concentration and happiness that their work brings with that of a painter. Don Pedro was the first to design zoomorphic molcajetes in the village, while Héctor Vidales has now dedicated his activity to decorated masterpieces (Hamon et al. 2023). For this reason, each metatero has his own "signature" in the way he makes metates. Nicolás Vidales lists several parameters that can vary depending on the craftsman, such as the height of the feet, their inclination, the regularity of the highest part of the edge and, finally, the central position of the proximal foot. He considers that his work is characterized by the fact that he prepares the active surface when the feet are still thick. This organization of the work is quite original, considering the risk of breakage during the shaping of the feet, and also reveals a certain self-confidence to ensure the whole process without accident.

The issue of accidental breakage mainly concerns less experienced metateros. It can happen at various points in the shaping process. Blanks left in the quarry may be broken due to flaws in the block or even the choice of a poor-quality stone. In the workshops, both the hollowing of the bowl and the shaping of the feet can be problematic if the thickness and angle of the pick are not properly controlled. Apart from the risk of breakage, the irregular symmetry of mortars and metates is another direct reflection of a low level of expertise. This is generally related to the short period of time needed to produce metates and molcajetes, which is facilitated by the use of discs.

If experience increases with age, pathologies too. Don Pedro told us about the pain in his knees and elbows, as well as in his back. The main risk remains to be trapped under a falling or rolling block in the quarry.

4.3. Comparing cultural traditions of metate and molcajete production in Mesoamerica

Our study helps to clarify the state of metate production practices and evolution in Mesoamerica. Considering the long tradition of metate production in different regions, archaeologists have paid special attention to modern practices and know-how related to these tools, adopting an anthropological perspective. These studies have documented in detail the quarry work and the *chaine operatoire* of shaping in different cultural contexts in order to shed light on the techniques and the social and economic contexts of these productions, providing key information for archaeological interpretations (Cook 1982, Hayden 1987, Nelson 1987a,b, Searcy 2011).

The greatest similarity between these areas lies in the production of three-legged metates and molcajetes, even though they have different morphological characteristics, especially in relation to the height of the central foot or the shape of the worktable, the degree of inclination and concavity of the worktable, or the presence or absence of a frame that delimits the worktable on certain parts or all sides. In Oaxaca in the 1980 s, metates that functioned with an overlapping mano had no frame (Cook 1982), while in the Maya communities that lived in the highlands, two types of metates were distinguished: an Eastern style with a short handstone and a highly concave metate with a peripheral frame, and a Western style with no obvious frame (Searcy 2011).

The production of metates and molcajetes can be a full-time occupation (Hayden 1987), but it can also be a part-time occupation. It can be shared with agricultural work (Cook 1982) or other activities (Hamon et al. 2023), depending on various parameters, including the difficulty of reaching the quarry during the rainy season or the difficulty of making a living from metate production alone. But be that as it may, metateros are considered specialized craftsmen (Nelson 1987b) who pass on their know-how from generation to generation, almost exclusively to men, at least until a few years ago.

The tools used to make metates have common characteristics: steel wedges of different sizes and weights are used to cut the stones and shape the metates. Although the use of stone picks for metate production was documented in the 1980's (Cook 1982, Hayden 1987), this technique has been replaced in most regions by metal tools, which in turn have been replaced in recent years by the portable electric stone-cutting tool. The occasional or widespread use of explosives has been documented in most regions since at least the 1980s (Nelson 1987a, b; Searcy 2011; Varga Dias 2010), although some metateros prefer not to use it because it is dangerous and tends to create cracks in the rock, as in the Malacatancito and Turícuaro areas (Hayden 1987; Hamon et al. 2023). These various developments in the tools used were always driven by the search for greater efficiency and better profitability, i.e. less time needed to obtain a metate. Considering the testimony of Ramón Ramos, who claims to have introduced metalworking in the Malacatancito area, steel-tools allow the working of harder stones, including blocks of denser basalts/andesites or blocks that have been dried for a long time, from an underground earth cover (Hayden 1987). The metal tools have different shapes: pointed (pick) and with a sharp flat edge in Turícuaro, sledge-hammers and wedges in Oaxaca (Cook 1982), all of which were used alternately to cut, chip, or flatten the blocks. Today, following the example of Turícuaro, the use of the portable electric stone-cutter once again significantly reduces the time needed to shape a metate, while providing more convenience (Hamon et al. 2023). Stone tools were kept everywhere for final finishing to smooth the surface. Metal points are usually carried to the quarry or hidden in caches to prevent theft.

The time it takes to make a metate varies from region to region and from metatero to metatero, although an average of a week seems to be common in most areas. One or two days are needed to find a suitable block, extract it and prepare a rough draft. Then, no less than 3 to 4 days are needed to shape the different parts of a metate or molcajete, i.e. the table/bowl, the sides and the feet/back (Hayden 1987, Hamon et al. 2023). In different areas, a day in the quarry starts at 5:30 am to work under cool air (Nelson 1987a, b).

At least two different strategies were documented for the acquisition of blocks: Prospecting in riverbeds or climbing to lava flows on the slopes of volcanoes. Most metateros assess the quality of the rock by its color, with a "blue" rock being considered of better quality and harder than a red one (Hayden 1987, Hamon et al. 2023, Searcy 2011). Vesicular rock is systematically sought as it is self-rejuvenating and has low mineral contamination. However, the optimal density and size of vesicles varies considerably from one context to another. While the metateros of Malacatancito (Maya area) considered less vesicular basalt to be inferior because it was more difficult to work and broke more easily (Hayden 1987), the metateros of Turícuaro (Purépecha area) tend to choose andesite with small vesicles (Hamon et al. 2023). Depending on the strategy (riverbeds or quarries), the choice of blocks may vary. Several authors emphasize that most metateros have to excavate and remove large amounts of soil to access the underlying blocks of good quality; this could be related to the search for a certain degree of moisture in the blocks, which facilitates their shaping. Implicitly, the ownership of each workshop in the quarry is respected between the metateros in a given area (Hamon et al. 2023), especially if the craftsmen have to rent their access to the quarry and the lava flow (Nelson 1987a, b).

Most Mesoamerican craftsmen have a common scheme for shaping metates, which comprises three main steps:

1. Quarrying the blocks and roughing on the quarry workstation: the aim is to remove the maximum amount of useless material to reduce the size and weight before transport to the "home workshop". This includes splitting the blocks and roughing the most important parts. Hayden (1987) quotes that "workers were extremely reluctant to leave metate blanks at the quarry sites, fearing that others might steal them". The heaviest stone or metal tools are needed at this stage. The blank is moved from one workstation to another by rolling. The workstation is usually full of debris, especially large (20 cm) to medium (5 cm) flakes (Hayden 1987, Hamon et al. 2023). If necessary, a platform can be quickly built to accommodate the metateros and their labor to have a flat and regular working area (Searcy 2011).
2. Shaping and volume reduction takes place in the"home workshop": the sequence of steps can vary from region to region, as can the height of the feet. But at this stage, the risk of breakage is always important, and the angle of the tools on the blank is crucial. The workshop is regularly cleaned of debris, and finished metates and molcajetes can be stored in its immediate vicinity.
3. Thinning and finishing: the surfaces are brought up to standard either by pecking or abrading. In this phase, the use of the mano on the metate table helps to adjust the two active surfaces. The investment in mano production varies significantly from one area to another: their production recycles waste from metate production in Turícuaro (Hamon and Le Gall, 2013), while they require on average one day of work (Searcy 2011), and even a return in the riverbed to select proper blocks in the Malacatancito area (Hayden 1987).

Finished metates and molcajetes are usually sold at markets (Cook 1982, Searcy 2011), but they can also be sold to shopkeepers in neighboring villages (Nelson 1987a, b) or directly to individual demanders as in Turícuaro (Hamon et al. 2023). The diffusion of metate and molcajete is mostly at the regional level. So far, no cases of exchange between regions have been documented in modern contexts, but this question could be of utmost importance for archaeological contexts.

4.4. *Clues to track archaeological metate and molcajete production*

All these observations form the basis for the future identification of quarries and workshops that produce metates and molcajetes in an archaeological context.

As for the extraction zones, the choice of vesicular andesite blocks makes it theoretically possible to delimit volcanic zones and potentially exploited flows based on their petrographic and geochemical analysis. The exploitation of these blocks would logically be reflected in the landscape by the association of fractured blocks and large-scale spreading debris, whether or not these are associated with the presence of massive hammerstones. The amount of such debris and fractured blocks would be highly variable, depending on the duration of the operation and the number of blocks mined. Such operations could therefore be inconspicuous in the case of fracturing of scattered blocks, whereas they would have a greater impact on the landscape in intensively quarried areas, particularly due to the production of significant quantities of wastes. Primary workshop zones directly associated with these extraction areas would be characterized by the presence of large quantities of shaping waste at the edge of the cleared and logically levelled working areas and by metates or molcajete broken roughouts left on site.

The workshops were located directly in the residential areas. They can be recognized by the combination of metate and molcajete blanks and hammerstones of various sizes. The presence of finished, unused metate and molcajete could also be a reliable indicator of the presence of specialized craftsmen; however, it should be kept in mind that the number of such tools could be very limited, especially in the case of on-demand production. Their storage in areas distinctly different from domestic food preparation areas would also be significant.

In other words, it is the combination of qualitative and quantitative indicators that will ultimately allow us to identify quarries and workshops for the production of metates and molcajete in an archaeological context.

5. Conclusion

The detailed study of the processes of metate and molcajete production in the Purépecha region of central-western Mexico helps to define the invariants common to all production areas and, on the contrary, the specific characteristics of each production center.

The geological context (e.g., morphology of lava flows and characteristics of the rocks) constrains the organization of quarries and lithic exploitation and production techniques (e.g., type of tools), while the social context (part or full-time activity, selling price) of metate and molcajete production greatly influences the organization of labor. However, most contexts share many similarities, which may be the legacy of stone working in general and the common types of practices among the different metate centers in contemporary Mesoamerica in particular.

By highlighting communities of practice, these comparative studies provide keys to interpreting the variability observed in the production sequences in the different regions. They provide archaeologists with clues for the interpretation of networks, for the diffusion of products, and know-how, making metate production a new proxy for the assessment of cultural evolution and diffusion in the long term.

CRediT authorship contribution statement

Caroline Hamon: Writing – original draft, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Gregory Pereira:** Funding acquisition, Data curation. **Laurent Aubry:** Methodology, Data curation. **Oryaëlle Chevrel:** Methodology, Data curation. **Claus Siebe:** Writing – review & editing, Methodology. **Osiris Quezada-Ramirez:** Writing – review & editing, Data curation. **Nanci Reyes-Guzmán:** Writing – review & editing, Methodology, Data curation.

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Appendix A. Supplementary data

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Data availability

No data was used for the research described in the article.

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