80th ANNIVERSARY OF PARÍCUTIN VOLCANO

FIELDTRIP GUIDE

ARCHAEOLOGY AND RECENT VOLCANISM IN THE ZACAPU LACUSTRINE BASIN (MICHOACAN, MEXICO)

February 24 - 26, 2023

Leaders: Claus Siebe, Gregory Pereira, Antoine Dorison, Nanci Reyes-Guzmán
Israel Ramírez-Uribe, Osiris Quezada-Ramírez


Malpaís Prieto archaeological site


Alberca de los Espinos tuff cone

Instituto de Geofísica
UNAM

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Archaeology and recent volcanism in the Zacapu lacustrine basin (Michoacán, Mexico)

A guidebook for the post-meeting fieldtrip (February 24-26) in conjuntion with the conference

"Celebrating the 80th anniversary of Paricutin volcano, preserving our heritage and preparing for future eruptions"

Morelia, Mexico, February 19-24, 2023

Leaders: Claus Siebe[1], Gregory Pereira[2], Antoine Dorison[2], Nanci Reyes-Guzmán[3], Israel Ramírez-Uribe[1], Osiris Quezada-Ramírez[4]

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ABSTRACT

The Michoacán-Guanajuato Volcanic Field in the Trans-Mexican Volcanic Belt contains the largest concentration of monogenetic vents on Earth associated with a subduction-related continental arc, holding more than 1400 edifices consisting of abundant scoria cones, ~300 medium-sized shields and domes, and ~22 maars. Paricutin (1943-1952) is the youngest volcano of this field and together with Jorullo (1759-1774) the only monogenetic volcano formed since the Spanish conquest (1519-1521) in Michoacán. Both volcanoes are said to be monogenetic because they were produced entirely by single eruptions and hence will presumably never erupt again. Nonetheless, another monogenetic eruption will certainly occur in the future and form a new volcano on Michoacán territory. In order to minimize losses of life and property it is desirable to learn more about these types of eruptions and with this knowledge design preventive strategies. In recent years, it has become clear that monogenetic eruptions can be quite diverse in style and duration. For this reason, we will visit different examples of monogenetic volcanoes (e.g., maars, scoria cones, isolated lava flows) to cover the spectrum of monogenetic volcanism and discuss the possible causes of its eruptive variability.

Most of the volcanoes in the Michoacán-Guanajuato Volcanic Field formed well before the arrival of Early Human to this area, but dozens of them erupted during the Holocene impacting directly the environment and early populations. A prime example is the Malpaís de Zacapu cluster of volcanoes at the western margin of Zacapu lake, where large cities (e.g., El Palacio, Malpaís Prieto, etc.) were constructed on the rugged surface of Late Holocene lava flows in pre-Hispanic time. Subsequent eruptions induced temporal abandonment and resettlement of the area, as revealed by the recent application of LiDAR (Light Detection and Ranging) imagery and modern dating techniques. These studies allowed to gain greater insight into the prehistory of this area, which holds the roots of the Tarascan empire that flourished during the Postclassic period (AD 900-1521) of Mesoamerican archaeology around its capital Tzintzuntzan at the shore of Lake Pátzcuaro. The excursion is aimed at providing greater insight into the complex interplay between volcanic activity and human settlement in the lacustrine environments of the highlands of Michoacán. This guidebook is designed as a companion for a post-meeting field trip but might also be a handy tool for those wishing to visit the area with condensed and updated information at hand. The guide contains excursions to maars and springs of the Zacapu lacustrine basin (1 day/1 night), archaeological sites (pre-Hispanic ancient cities) on the young andesite lava flows of the Malpaís de Zacapu monogenetic cluster (1 day/1 night), and to the archaeological sites of Tzintzuntzan (the capital city of the Tarascan empire) and Angamuco (built on young lava flows of Rancho Seco volcano), both located at the SE margin of the Pátzcuaro lake basin. The trip starts and ends at Morelia with overnight stays at the town of Naranja, near the modern city of Zacapu.

INTRODUCTION

This fieldtrip guide is devoted to monogenetic volcanoes and pre-Hispanic archaeological sites of the Zacapu and Pátzcuaro lacustrine basins. Most of the area can be easily reached on paved roads from Morelia, the capital city of Michoacán (Fig. 1). It partly follows up and is complementary to previous guides (Guilbaud *et al.*, 2009; Siebe *et al.*, 2014) that were in great part devoted to the historic eruptions of Jorullo (1759-1774) and Paricutin (1943-1952) volcanoes, located to the S and W of Morelia, respectively.

THE MICHOACÁN-GUANAJUATO VOLCANIC FIELD

The Trans-Mexican Volcanic Belt (TMVB) is an active volcanic arc related to the subduction of the oceanic Cocos and Rivera Plates underneath the continental North America Plate along the Middle America trench (e.g., Demant, 1978; Fig. 2). This arc forms an angle of ~15° with respect to the trench (Nixon, 1982) and traverses the Mexican Altiplano, a highland characterized by active normal faulting and horst-and-graben structures that resulted in the formation of basins often occupied by broad (but shallow) lakes such as the Chapala, Pátzcuaro, Cuitzeo, and the paleo-lake of Zacapu in Michoacán (Johnson and Harrison, 1990, see also Figs. 1 and 2). The TMVB is formed of ~8000 volcanic vents that include calderas, stratovolcanoes, medium-sized shield volcanoes, scoria cones with associated lava fields, lava domes, and maars, whose products are largely calcalkaline andesitic in composition, although basalts, rhyolites, and rare alkaline rocks also occur (Gómez-Tuena, 2007).

The MGVF, located in the central part of the TMVB (Fig. 2), has the highest concentration of monogenetic volcanoes in the entire belt, which are distributed over an

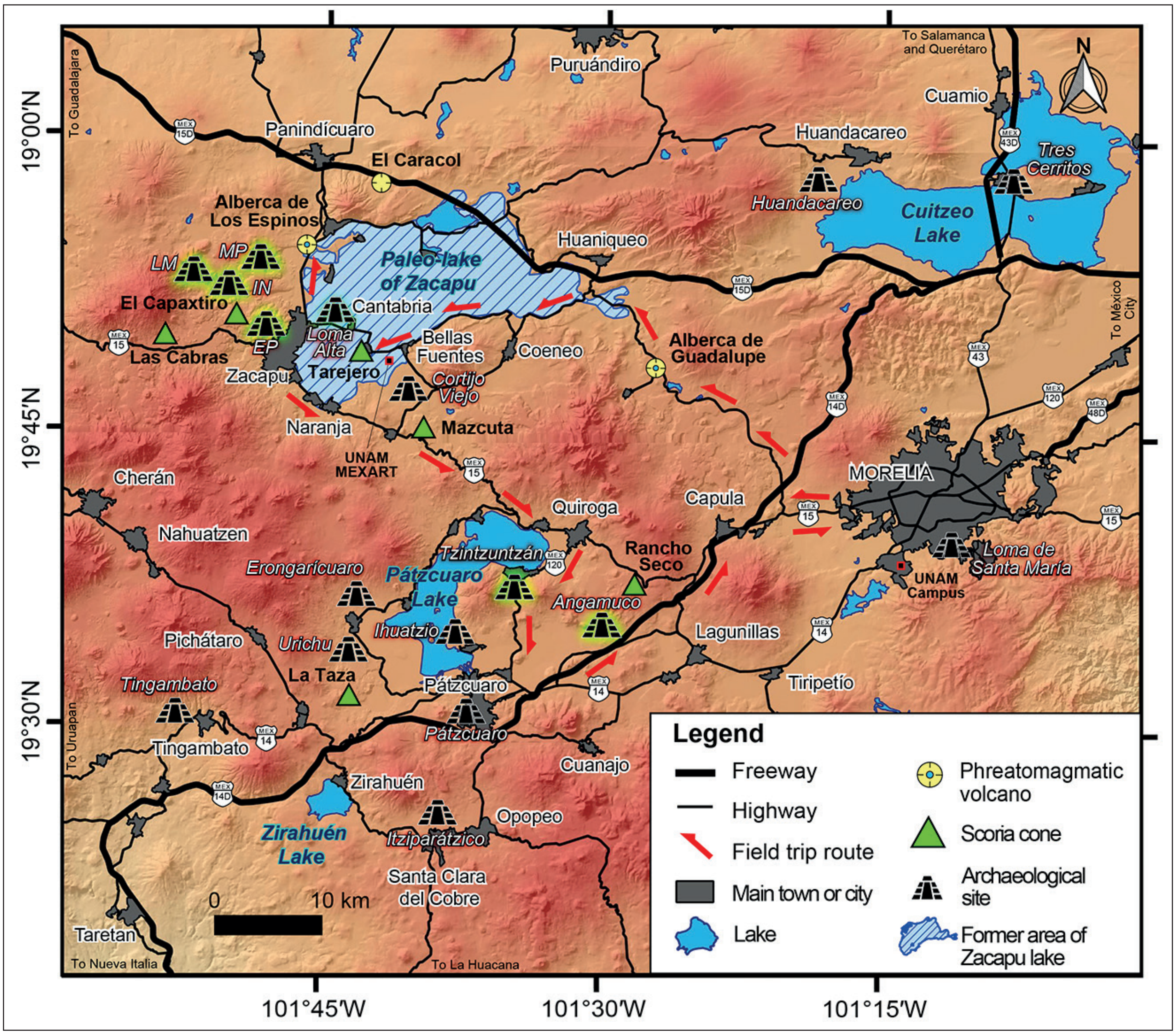

Figure 1: Road map of the itinerary showing main cities (Morelia, Zacapu, Pátzcuaro) and towns (Tarejero, Naranja), archaeological sites (El Palacio, Malpaís Prieto, Infiernillo, Tzintzuntzan, Angamuco), and volcanoes (Alberca de Guadalupe, Alberca de los Espinos, Malpaís de Zacapu, Las Cabras) to be visited. MP=Malpaís Prieto, LM=Las Minas, IN=El Infiernillo, EP=El Palacio. Map by Israel Ramírez.

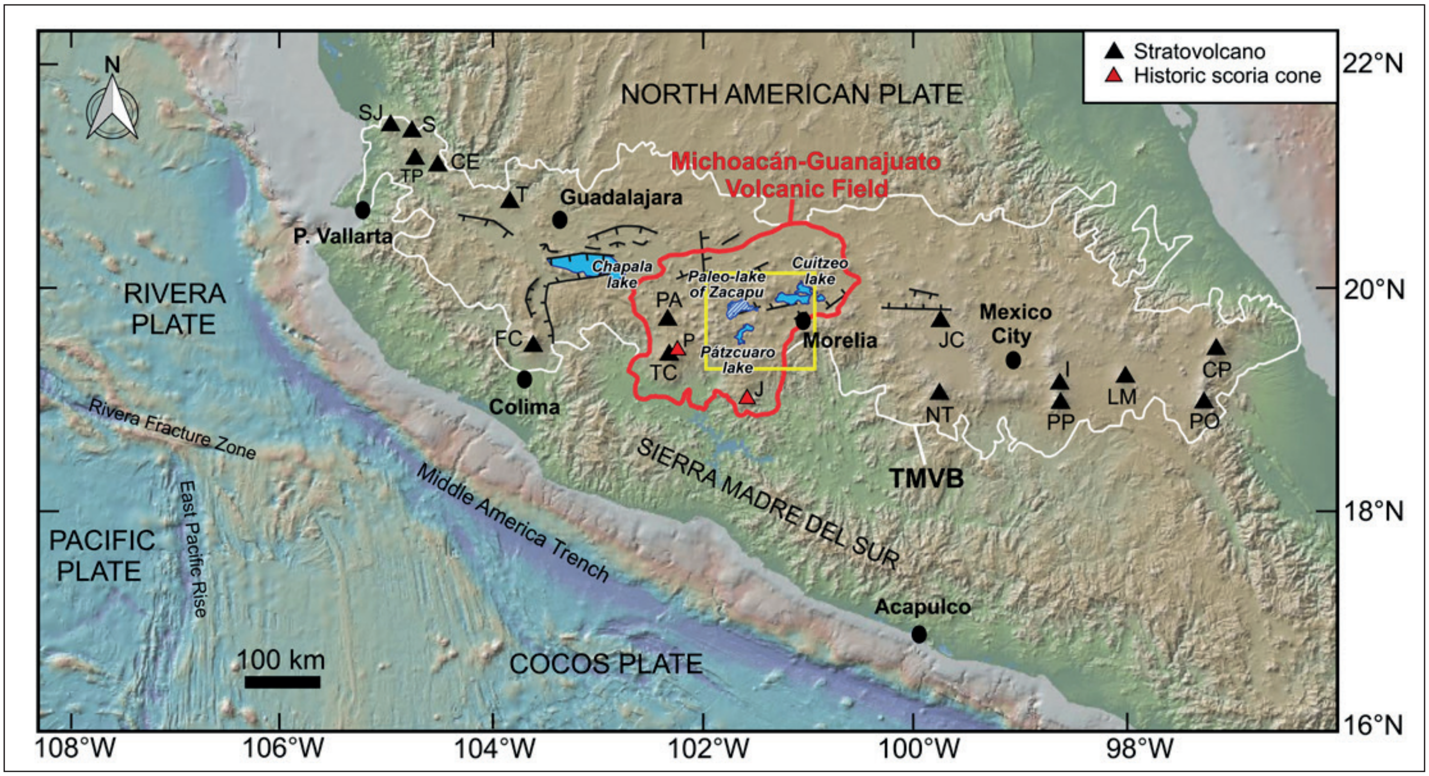

Figure 2: Map of central Mexico showing the Michoacán-Guanajuato volcanic field (red outline) within the Trans-Mexican Volcanic Belt. Yellow rectangle denotes area within the Michoacán-Guanajuato Volcanic Field covered in Fig. 1 and to be visited during the excursion. Major cities, lakes, and main tectonic features are indicated. Stratovolcanoes: SJ=San Juan, S=Sangangüey, TP=Tepetiltic, CE=Ceboruco, T=Tequila, FC=-Fuego de Colima, PA=Patamban, TC=Tancítaro, JC=Jocotitlán, NT=Nevado de Toluca, I=Iztaccíhuatl, PP=Popocatépetl, LM=La Malinche, PO=Pico de Orizaba, CP=Cofre de Perote. Historic scoria cones Jorullo (J) and Paricutin (P) are also shown. Modified from Kshirsagar *et al.* (2015).

area of ~40,000 km^2. It hosts >1000 small monogenetic volcanoes, mainly scoria cones, that include the historical Jorullo (1759-1774; e.g., Guilbaud *et al.*, 2011; Rasoazanamparany *et al.*, 2016) and Paricutin volcanoes (1943-1952; e.g., Luhr and Simkin, 1993; Pioli *et al.*, 2008; Larrea *et al.*, 2017; 2019a; 2021). In addition, shields, domes, viscous lava flows, and rare maars occur (e.g., Hasenaka and Carmichael, 1985a; 1987; Hasenaka, 1994; Guilbaud *et al.*, 2011; 2012; 2019; 2021; Pola *et al.*, 2014; Kshirsagar *et al.*, 2015; 2016; Chevrel *et al.*, 2016a; 2016b; Mahgoub *et al.*, 2017; 2018; Reyes-Guzmán *et al.*, 2018; 2021; Osorio-Ocampo *et al.*, 2018; Larrea *et al.*, 2019b; Ramírez-Uribe *et al.*, 2019; 2021; Avellán *et al.*, 2020; Gómez-Vasconcelos *et al.*, 2020). Furthermore, the MGVF encloses two stratovolcanoes, Tancítaro and Patamban (Fig. 2), both probably extinct (Ownby *et al.*, 2007; Siebe *et al.*, 2014). The small-to-medium sized volcanoes of the MGVF were classified by Hasenaka (1994) into scoria cones, A-type and B-type shield volcanoes, lava domes and flows, and composite volcanoes. According to this author, the shields *(Mexican shields)* are 2-12 km in basal diameter, 100-1000 m in height and 0.5 to 10 km^3 in volume. A-type and B-type shield volcanoes have gentle slope angles around 5° and 10°, respectively, while lava domes have higher slope angles (>15°). Lava flows can be associated with a scoria cone or have hidden vents, and their average thickness is widely variable (<150 m). In his work, Hasenaka (1994) estimated that the average volcanic output rate for the last 1 Ma in the MGVF was 0.7 km^3/ka, whereas the rate for the preceding period (3-1 Ma) was much less (0.2 km^3/ka), but these figures still require further refinement and confirmation.

The causes for the existence of such a great number of monogenetic volcanoes in the MGVF, which is also the region where the TMVB is widest, are still poorly understood. Their high density may be related to the peculiar geometric configuration of the subduction zone (Pardo and Suárez, 1995; Johnson *et al.*, 2009; Blatter and Hammersley, 2010) that controls the location and size of magma generation areas and the magnitude of crustal extension. As proposed by Chevrel *et al.* (2016b) the large number of monogenetic volcanoes in the MGVF might be related to the flat position at a depth of 90-120 km of this segment of the subducting oceanic Cocos plate underneath the continental North American Plate (Kim *et al.*, 2012). Such a low subduction angle at depth might be inducing partial hydrous melting of the mantle wedge (Carmichael, 2002) over a wide area underneath a ~40-km-thick continental crust.

THE ZACAPU LACUSTRINE BASIN: GEOLOGY AND HYDROLOGY

The Zacapu intermontane basin (Fig. 3) is a tectonic graben whose lower parts (~1980 m asl) are today occupied by a cultivated flat surface of lacustrine origin. It is surrounded by Plio-Quaternary volcanoes that are mostly intermediate (calc-alkaline basaltic andesite to andesite) in composition (e.g., Demant, 1992; Reyes-Guzmán *et al.*, 2018). Fewer silicic rocks (dacites and rhyolites) also occur as domes and ignimbrite sheets (Darras *et al.*, 2019; Kshirsagar *et al.*, 2015). Because of the complete regional cover by Plio-Quaternary volcanics and derived sediments, the exact nature of the local basement remains unknown.

The area is cut by active normal faults that follow a N65°E to N85°E trend (Kshirsagar *et al.*, 2015; 2016) and represent the western extent of the seismically active Cuitzeo

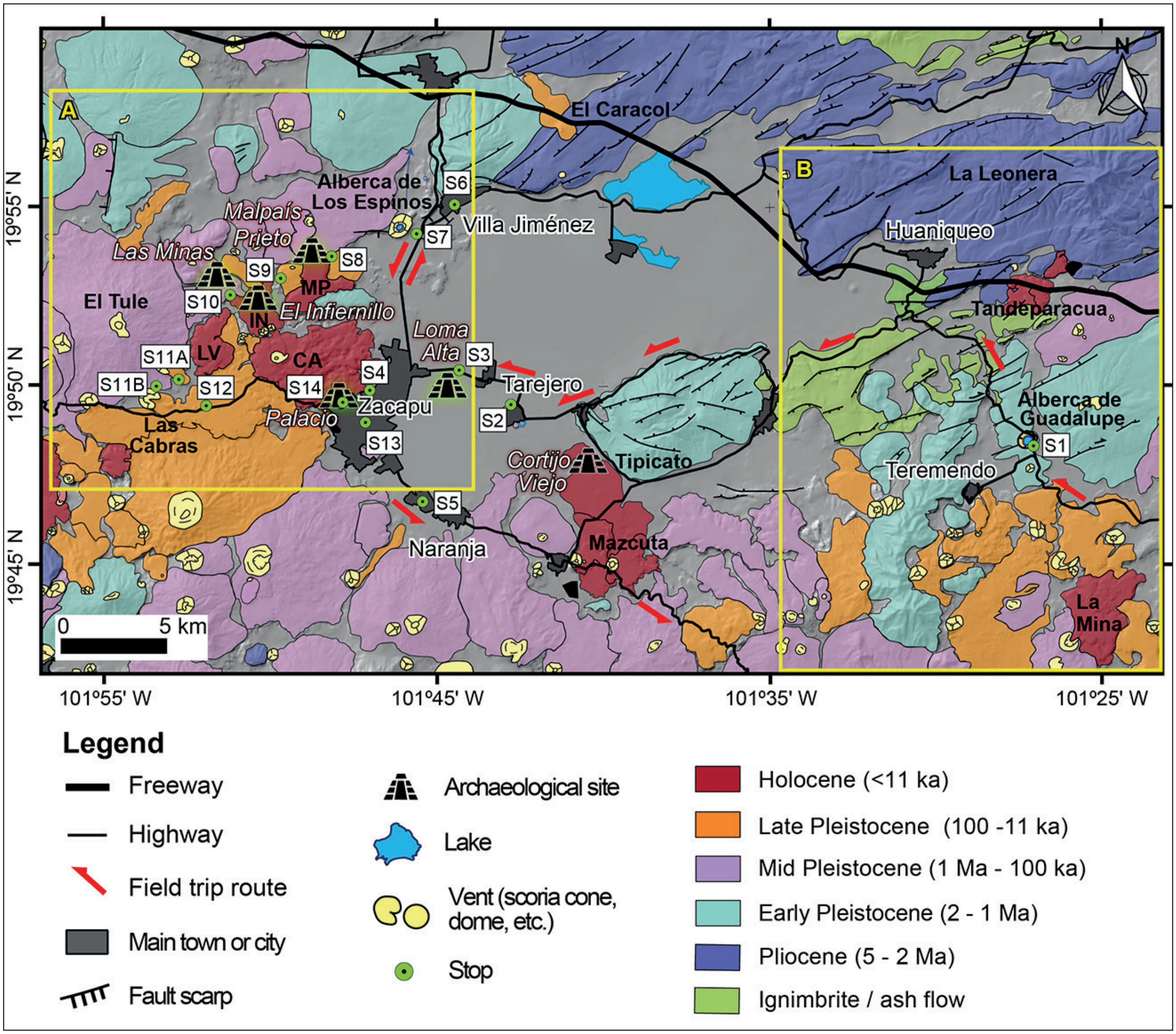

Figure 3: Simplified geologic map of the Zacapu intermontane lacustrine basin showing travel route (red arrows) and Stops 1 to 14 to be visited during the first part of the excursion. Yellow rectangles A and B denote areas covered by detailed maps in Figs. 8 and 15, respectively. Lava flows: CA=Capaxtiro, MP=Malpaís Prieto, IN=Infiernillo, LV=Las Víboras. Modified from Siebe *et al.* (2014).

Fault System (CFS in Fig. 3; Johnson and Harrison, 1990), also called the Morelia-Acambay Fault System (Suter *et al.*, 2001; Garduño-Monroy *et al.*, 2009). Since volcanic vents are frequently aligned in this direction, we presume that eruptions were fed by dikes emplaced along these faults during final magma ascent.

The graben-basin of Zacapu, like other such lacustrine basins in Michoacán (e.g., Cuitzeo, Pátzcuaro, etc.), was originally occupied by a several tens of meters deep lake in the Pliocene before turning shallower and even marshy in the Late Pleistocene/Holocene (Israde-Alcántara *et al.*, 2010). This means that the current lacustrine Zacapu basin underwent a continuous and active paleoclimate evolution since its formation during the Late Pliocene-Pleistocene (3-1 Ma) related to the development of an extensional tectonic regime (Demant, 1992; Pétrequin, 1994). Shallow drillings into the lake sediments were undertaken to investigate its paleoclimatic history and Lozano-García and Xelhuantzi-López (1997) and Metcalfe (1997) reported significant variations of the lake level, which these authors related mostly to temperature and precipitation changes. However, the evolution of the lacustrine environment has also been influenced by volcanic (Siebe *et al.*, 2012), as well as human activity (Ortega *et al.*, 2002). The latter initiated at least ~3000 years ago, as evidenced by *Zea mays* (corn) in pollen records from lake beds in Michoacán (first detected in lake Pátzcuaro by Watts and Bradbury, 1982). The paleoclimate studies in the Zacapu basin have been largely based on the analysis of lake sediment drill-cores that reach only up to 10 m in depth. Hence, the total thickness of the basin fill remains unknown, but we estimate that the lacustrine sequence might reach a total of several hundred meters.

During previous centuries, in years of unusually high precipitation (today the average annual precipitation around the basin ranges between 670 and 880 mm, see also climate-diagrams in Kshirsagar *et al.*, 2015), the lake had an ephemeral natural outlet in the N near Villa Jiménez (Fig. 3) at its NW shore (Siebe *et al.*, 2012). The original lacustrine habitat was changed dramatically during the late 19th and early 20th centuries, when a canal was excavated to deepen the outlet (Noriega and Noriega, 1923). As a result, the lake was drained into the Río Angulo that connects to the Río Lerma in the N to gain more land for agricultural exploitation (Reyes-García and Gougeon, 1991).

The total catchment area of the basin is ~1500 km² (lowest elevation at 1980 m asl) and includes the surrounding volcanic highlands (<3200 m asl). These fractured rocks are vegetated by patches of deciduous pine and oak forest, and grassland with a high infiltration rate. As a result, the region lacks major streamlets and a large part of the precipitation (mostly from June to September) flows as groundwater that is channelized toward the interior of the basin as shown by numerous high-discharge springs occurring at the margin of the lacustrine flats (Kshirsagar *et al.*, 2015; 2016). Today, corn and sorghum agriculture encompass the largest part of the former lake surface (~310 km²) and produces high yields due to the presence of these springs (several with temperatures >20 °C) and a system of irrigation canals. Only a small remnant of the former lake persists at its lowest area.

THE MALPAÍS DE ZACAPU LATE HOLOCENE VOLCANIC CLUSTER

Malpaís de Zacapu is a term used by local people to collectively name the young lava flows characterized by rugged surfaces largely devoid of soil that occur to the NW of the city of Zacapu. *Malpaís* is a Spanish word that means "badland" (land unsuitable for agriculture), while *Zacapu* is a Purépecha word that means "stony place". Both names refer to the fresh rocky surfaces of lavas produced by volcanic eruptions. Geologically, the Malpaís de Zacapu is a Holocene cluster formed by four different vents that erupted at different times less than 3 km apart from each other (Fig. 4). It started with the eruption of Las Vigas scoria cone, that produced the Infiernillo lava flow field at ~1450 BC (Reyes-Guzmán *et al.*, 2018). Chronologically, the Infiernillo was followed by Malpaís Las Víboras at ~1340-940 BC, Capaxtiro at ~200-80 BC, and Malpaís Prieto at ~AD 900 (Mahgoub *et al.*, 2018). These volcanoes were investigated by Reyes-Guzmán *et al.* (2018; 2021) with the aid of a high-resolution LiDAR image. The erupted volumes, petrographic and geochemical characteristics of the lavas, and their viscosities and emplacement times were determined.

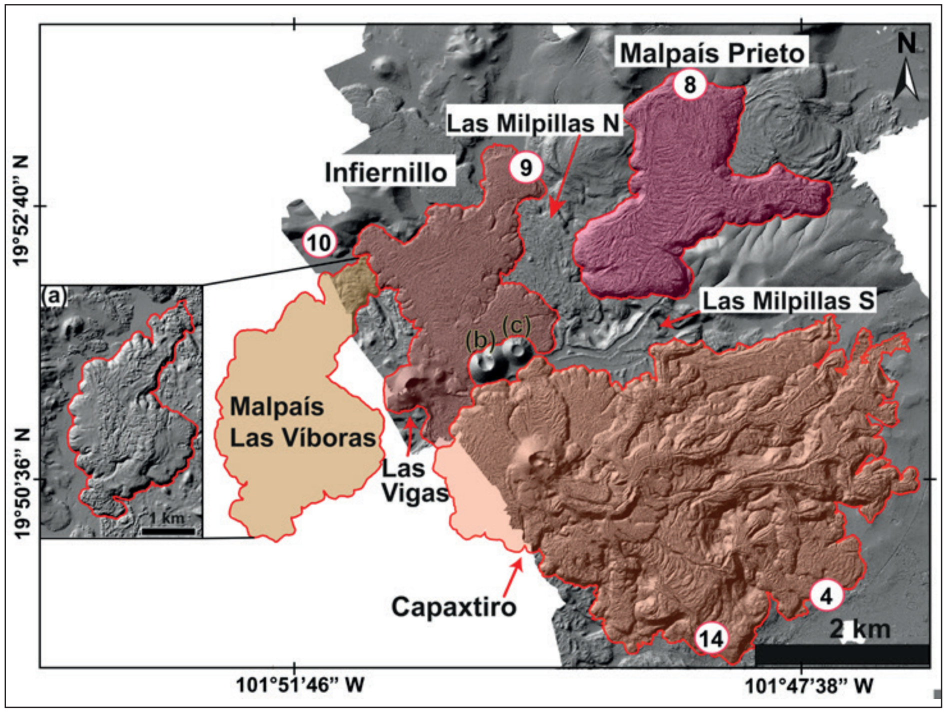

Figure 4: Hill-shaded LiDAR image of the Malpaís de Zacapu lava flow field. Colored polygons delimit the area covered by lavas of each of the four Late Holocene eruptions. Note that Malpaís Las Víboras is not covered by the LiDAR image but by a 5-m-resolution digital elevation model (DEM) taken from INEGI (2020) and shown in (a). (b) denotes the middle nameless cone, and (c) the eastern nameless cone of the Tres Cerritos scoria cone alignment. Stops to be visited during the excursion are indicated with red circles. Modified after Reyes-Guzmán *et al.* (2021).

The first eruption, known as Infiernillo, started in a Strombolian fashion that led to the rapid formation of the Las Vigas scoria cone (Fig. 4) which displays a horseshoe-shaped crater opened to the SE. During the initial stage of the eruption, a gas-rich magma (SiO_2 = 57 wt.%) was emitted. It was followed by a more degassed and silicic magma (SiO_2 ~59 wt.%) that formed the *Infiernillo* ("little hell" in Spanish) that consists mainly of two lava flow units. One of the units flowed northward forming two main lobes: one to the N-NW, and the other to the N-NE. This first unit has a maximum reach of 3.1 km from the vent, an average thickness of 27 m, and a width ranging from 250 to 1000 m. The second unit flowed to the NE where it reached a distance of 1.7 km. In average, it is ~500 m wide and ~25 m thick. Both flows were classified as blocky ʻAʻā to blocky in type due to the broken flow surface composed of a heterogeneous rubbly mixture of irregular rock fragments with vesicular surfaces and denser inner parts with angular dense blocks with a flat and smooth surface (Reyes-Guzmán *et al.*, 2021). The total area covered by this eruption is ~5.1 km² with a volume of ~0.3 km³ of andesitic lava with a mineral assemblage of olivine ± clinopyroxene + plagioclase ± hornblende (Reyes-Guzmán *et al.*, 2018; 2021).

The second eruption, Malpaís Las Víboras, was purely effusive and erupted two lava flow units. The first flow is mainly elongated towards the N-NE reaching a length of ~2.5 km, a width of ~1.6 km, and a thickness of ~100 m. The second flow was emplaced to the SW where it leans against the lavas of the Late Pleistocene Las Cabras scoria cone (Guilbaud *et al.*, 2021). The vent is poorly visible due to the overlapping of the two lava flow units, but distinguishable in the south-central area of the rugged terrain with the aid of digital elevation models and elevation profiles. Malpaís Las Víboras is a block type lava flow field that covers an area of ~5.9 km² with ~0.5 km³ of andesitic (SiO_2= 61-63 wt.%) lava with a mineral assemblage of pyroxene + plagioclase (Reyes-Guzmán *et al.*, 2021).

The third eruption, Capaxtiro, produced the most complex lava flow field in morphological terms. This extensive compound lava flow field consists of 28 flow units (including 10 probable breakout flows) and a dense-spatter cone. This eruption was almost purely effusive since clear evidence of ash-fallout was not found on the neighboring volcanoes. The lava of this field spread radially around the vent with a preferred direction to the E, where it reached the Zacapu lake shore at a distance of ~5 km. The flows are of the 'A'ā to blocky type with steep fronts. Some flows have narrow and sinuous channels, while others are wide with a fan shape; on average, the flows have a thickness ranging from 30 to 60 m. The total area of the field is 21 km^2 and it has a total average thickness of ~150 m that represents the overlapping of different lava units. The total volume is 3.1 km^3 of high-silica andesite to dacite (SiO_2 = 62-64 wt.%) lava with a mineral assemblage of pyroxene + plagioclase ± rare olivine (Reyes-Guzmán *et al.*, 2021).

The fourth and last volcano to erupt was the Malpaís Prieto, a single lava flow. Due to its young age, the flow has not yet developed any soil or notable vegetation cover, and still displays a fresh and dark rocky surface, hence its name (*prieto* means "dark" in Spanish). The Malpaís Prieto lava flow originated at a vent to the N from where it flowed southward before leaning against the older volcanic structure of Mesa El Pinal, which divided the main flow into two lobes: one flowed to the E, and the other continued to the SW. The Malpaís Prieto is a block-lava flow with an average width of 1.4 km, a thickness of ~100 m, and a length of 3.4 km. It covers an area of 5.7 km^2 with 0.5 km^3 of andesitic lava (SiO_2 = 61-62 wt.%) with a mineral assemblage of pyroxene + plagioclase ± hornblende (Reyes-Guzmán *et al.*, 2021).

The spatial-temporal proximity and geochemical progression from a gas-rich mafic magma to a SiO_2-rich degassed magma, both suggest a genetic relationship between the eruptions that formed the Malpaís de Zacapu cluster. Ongoing isotopic analysis combined with major and trace elements (Reyes-Guzmán, PhD thesis, in prep.) will be used to test whether the cluster tapped a single progressively evolving larger magma reservoir or if it was produced by different small magma batches that evolved separately en route from the upper mantle to the surface.

The recent volcanological study by Reyes-Guzmán *et al.* (2021) revealed that these monogenetic eruptions ranged from Strombolian (mildly explosive) to purely effusive in style. Seismic and acoustic premonitory phenomena, high initial temperatures (~1000 °C) of lava flows, and their relatively long emplacement durations ranging from months to years (~7 months for El Infiernillo, ~3 years for Malpaís Las Víboras and Malpaís Prieto, and little less than 30 years for Capaxtiro) made the area unsafe. Although this type of eruptions can hardly be termed catastrophic, they ultimately changed the local environment impacting the daily life of surrounding human populations.

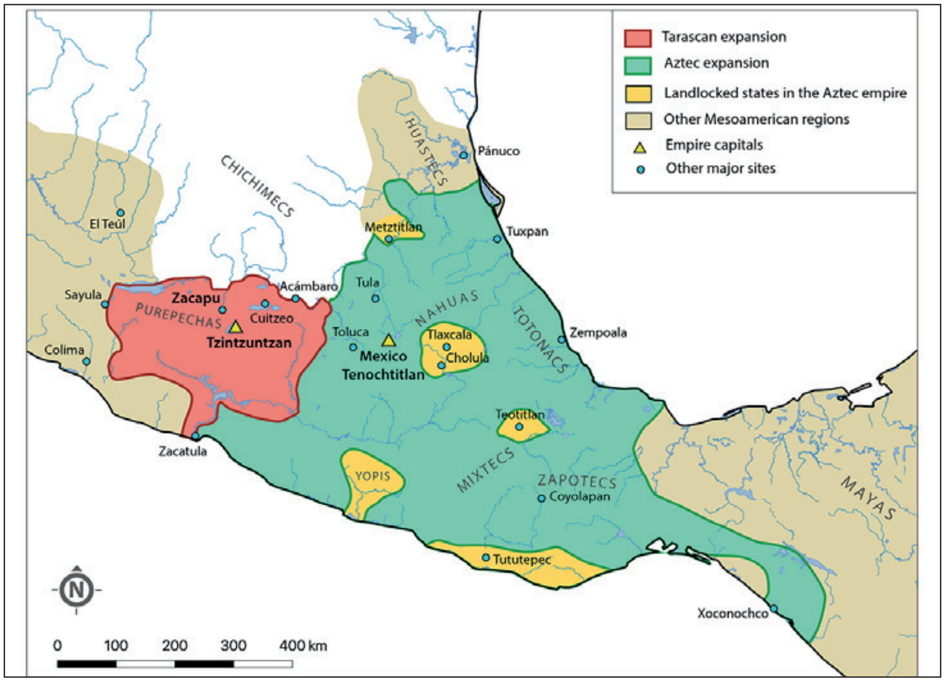

Figure 5: Map of Mesoamerica around AD 1519 showing the extent of the Tarascan and Mexica (Aztec) empires. Map by Grégory Pereira.

ZACAPU AND THE HISTORY OF THE TARASCAN EMPIRE

At the time of the Spanish conquest in AD 1521, a powerful state, the Tarascan empire, dominated the Michoacán region and surrounding areas. Its dominion extended from the semi-arid lands of the Bajío to the Pacific coast and also included several neighboring territories in the present states of Guanajuato, Jalisco, and Guerrero (Fig. 5). The inhabitants of this region were the main rivals of the Aztecs, who never managed to invade their territory. The Tarascan empire had a powerful army and was defended on its eastern border by a series of fortified sites. Despite its important role in Postclassic history, this Michoacán civilization is still little known. Named as *Tarascans* or *Michoaques* in written sources, its inhabitants were the ancestors of today's Purépecha people.

At the beginning of the 16th century, the Tarascan empire was ruled by a king called *Cazonci* and Tzintzuntzan, its capital, was located in the Patzcuaro Lake Basin (PLB). According to archaeological data and written sources, the city of Tzintzuntzan was home to about 30,000 inhabitants organized in neighborhoods (Pollard, 2008). The center of the city is well known for its immense esplanade on which five, large, so called *yácatas* were built: pyramid temples characterized by combining a circular and rectangular plan. The goods from the conquered lands flowed there, the gods were worshipped, and the best potters, lapidaries, and goldsmiths produced goods that have survived the passage of time.

The Zacapu region, located NW of the PLB, had been integrated into the empire and seemingly occupied by then a peripheral position. However, according to the *Relación de Michoacán*, a manuscript written by Fray Jerónimo de Alcalá in 1541, Zacapu was of great importance in the historical narrative of the ruling dynasty. According to the oral traditions transmitted by the main priest and remembered every year during an important festival, it is precisely in the surroundings of *Zacapu Tacanendan*, "place of stones", that their mythical story begins: around the 13th century, Hire Ticatame, ancestor of the Cazonci and then leader of a Chichimec migrant group known as Uacúsecha, settled there. This stage of their migration is very significant, because, in Zacapu, the Chichimecas established their first alliances with those who already lived there. The major archaeological sites located on the Malpaís de Zacapu lava flows are related to this period and results from recent excavations suggest the arrival of a large population around that time.

Before the Uacúsecha

Archaeological and paleoenvironmental studies carried out in the Zacapu basin indicate that the area was populated much earlier. The first evidence of human presence in the Zacapu basin has been detected in the pollen record recovered in lacustrine deposits and was dated to the second millennium BC, indicating the first evidence of agricultural activities (Pétrequin, 1994).

Unfortunately, not much is known about those early Preclassic farmers. A clearer picture of the cultural attributes of the inhabitants of the region has been obtained for the end of the Preclassic (~100 BC) and onwards, a period characterized by the Loma Alta tradition (Arnauld *et al.*, 1993; Carot, 2004), which ends around the fifth century AD. This cultural phase is mainly known from excavations carried out at the eponymous site of Loma Alta, located on an island near the western shore of the Zacapu lake. These studies revealed a particularly elaborate pottery tradition, the first evidence of monumental architecture, and funerary practices involving cremation. All of these point toward a complex society that exhibits early aspects of distinct Purépecha culture, but that was also in contact with Teotihuacan in the basin of Mexico (Carot, 2004).

The Epiclassic period (AD 600-900) is a phase of major demographic growth with settlements spreading from the lakeshores toward almost all the surrounding areas (foothills, hills, *malpaises*, valleys, etc.). Archaeological evidence for landscape modification related to agriculture and mining activities is widespread. The settlement pattern is usually dispersed but organized itself around major civic-ceremonial centers with pyramids, plazas, sunken patios, and ball courts. During this period, members of the elite were buried in mortuary chambers together with luxury goods that reveal a wide commercial exchange network reaching distant areas (Pereira, 1997).

The end of this period coincides with the eruption of the Malpaís Prieto lava flow, which seemingly led to the abandonment of several areas. The Early Postclassic period (Palacio phase; AD 900-1200) is poorly understood. However, this time period is marked by the rise of a new settlement that would become prevalant in the late history of the region, the site of El Palacio-La Crucita, on the SE margin of the Malpaís de Zacapu lava flows. At this time, the pottery still displays the influence in style from Central Mexico, particularly from Tula, capital of the Toltecs (Jadot *et al.*, 2019).

Cities built on the Malpaís de Zacapu lava flows

The 13th century witnessed a significant change in the settlement pattern of the area. It was marked by two probably related phenomena. First, the complete abandonment of the regions located to the N of the Zacapu basin (Faugère, 1996); second, the massive colonization of the lava flows of the Malpaís, which, until then, had been little occupied. The available dates suggest that this process began around AD 1250, that is, in the period corresponding to the arrival of the Uacúsecha in the region. The foundation of the large settlements of the Malpaís is surely related to the Chichimec migrations. However, the archaeological reality contrasts with the image provided by the textual evidence from the *Relación de Michoacán* that presents those migrant groups as small nomadic tribes of hunters. Their settlements rather indicate the arrival of numerous and strongly organized populations, clearly accustomed to sedentary life. In the Malpaís, they lived in thousands of houses, built pyramids, and stored their agricultural production in granaries (Michelet, 1992, 1998; Forest, 2014; Migeon, 2015). Between AD 1250-1400/1450, the population that occupied the rocky terrain of the Malpaís was distributed in four large urban agglomerations (Malpaís Prieto, Las Milpillas, El Infiernillo, and El Palacio) totaling around 20,000 people. As evidenced by LiDAR data, they intensively modified the environment to create an unprecedented urban system built on lava flows (Pereira and Forest, 2022).

It is important to clarify that the cities of the Malpaís de Zacapu predate the culmination of the Tarascan empire, since they were mainly occupied during the 14th century and abandoned at the beginning of the 15th century. It is possible that a significant part of its inhabitants migrated to the PLB, where, a short time later, the Uacúsecha dynasty consolidated its dominion in this area.

VOLCANIC IMPACT ON PRE-HISPANIC OCCUPATION OF THE WESTERN ZACAPU BASIN

The four volcanoes that comprise the Malpaís de Zacapu volcanic cluster were all dated to the Late Holocene, and erupted between ~1450 BC (~3,200 y. BP, El Infiernillo; Reyes-Guzmán *et al.*, 2018) and AD 900 (Malpaís Prieto; Mahgoub *et al.*, 2018). Such geologically young ages imply that these eruptions were almost certainly witnessed by human populations (Reyes-Guzmán *et al.*, in press). According to Faugère (2006), the first human occupation archaeologically recorded near the Zacapu Lake Basin (ZLB) dates back to the time between 5000 and 2000 BC near the Lerma river valley to the north. Around 2000 BC, shortly before the Las Vigas (Infiernillo) eruption, the ZLB also started to become sparsely populated, as revealed by sediment cores extracted from the drained lacustrine plain. These cores registered anthropogenic artifacts as well as pollen indicating an episode of forest reduction related to agricultural activities (Pétrequin, 1994). Although the archaeological record is better documented from 100 BC onward, earlier occupations may have occurred in the region but have not yet been truly documented. It is also possible that the volcanic activity during the Early and Late Preclassic periods (1500 BC – AD 200) discouraged ancient farmers to establish villages on the western fringe of the basin. Indeed, although the eruption of Las Vigas (Infiernillo) was short-lived, it had a profound impact on the environment. The volcanic ash covered surrounding areas, and once deposited it must have taken many years before pedogenetic processes formed sufficient soil to allow renewed plant growth. In addition, the El Infiernillo lava flow buried ~400 ha of land under a hard rocky substrate. A similar scenario was observed in the case of the historical Paricutin volcano, where the accumulation of ash and lava affected the local flora and fauna limiting severely most agricultural activities for several years (Rees, 1979). Several centuries after the Infiernillo eruption, the subsequent eruptions of Malpaís Las Víboras and Capaxtiro impacted again the region by covering large areas (~25 km^2) with lava flows that drastically modified the landscape of the western shore of the Zacapu lake. In this context, Pétrequin (1994) has suggested a direct relationship between the Capaxtiro eruption and the geologic uplift of the Lomas area (on the western shore of the ZLB). If his hypothesis is correct, the topographic emergence of this zone above the otherwise flat lacustrine plain would have occurred much more recently than previously assumed, and would therefore only precede by a short period of time the beginning of the major human occupation of the Lomas around 100 BC (Arnauld *et al.*, 1993; Arnauld and Faugère-Kalfon, 1998). However, more research is needed to test this.

According to Carot *et al.* (1998), the Loma Alta site, located in the Lomas area and dated between 100 BC and AD 500 (Loma Alta phase), shows evidence for a cult related with fire and volcanoes. This is suggested by the orientation of some of the ceremonial buildings and the presence of an early representation of the fire god. This could mean that the inhabitants of the site witnessed the Capaxtiro eruption and dedicated a ceremonial center to an associated deity. In addition, the Capaxtiro cone is crowned by a ceremonial site of the later Lupe phase (AD 600-850) consisting of a plaza surrounded by four pyramidal mounds clearly indicating the sacred character of the volcano.

During the Lupe phase, the ZLB was still inhabited by local people, but the human occupation spread to the entire region. An important cluster of monumental and residential sites developed on the NW edge of the Malpaís de Zacapu, on the footslope of the Las Flores dome complex, and on the Las Minas, El Malpaisillo, Mesa del Bolsón, and the N margin of El Infiernillo lava flows (Pereira *et al.*, in press). Interestingly, the abrupt abandonment of this area at the end of La Joya phase (AD 850-900) coincides with the eruption of Malpaís Prieto. Although the latter was solely effusive, it was certainly terrifying enough to cause the abandonment of the settlements located at the NW edge of the Malpaís de Zacapu (Reyes-Guzmán *et al.*, in press).

Consequently, the subsequent Palacio phase (AD 900-1200) was marked by a drastic population decrease in the N edge of the Malpaís de Zacapu and the Lomas area (Arnauld *et al.*, 1993). The population moved to the N (Lerma valley) and to the SW of the ZLB. The number of settlements on the lakeshore decreased, whereas the site of El Palacio, located on the distal margin of El Capaxtiro's largest lava flow unit, raised in size and became the largest human agglomeration in the area.

The Milpillas phase (AD 1200–1450) was characterized by dramatic changes in the settlement pattern: from the 13th century onwards, the lava flows of the Malpaís de Zacapu were rapidly recolonized by a large population clustering in four unprecedented urban centers (Michelet, 1998; Forest, in press; Pereira and Forest, 2022). The Malpaís de Zacapu urbanization process roughly coincides with the timing of two contemporary events. The first one is the eruption of El Metate shield volcano around ~AD 1250, which could have caused the migration of people towards other areas of the MGVF including the ZLB (Chevrel *et al.*, 2016a). The second event is the abandonment of the southern Lerma basin, possibly due to drier climatic conditions. It has been proposed that a large part of the population that clustered in the Malpaís de Zacapu came from that area (Arnauld and Faugère-Kalfon, 1998).

As briefly outlined, recent studies thus show that the ancient inhabitants of the region had to face several eruptive events during the last four millennia. The relatively long duration of lava flow emplacement (up to several years) probably forced the displacement of people away from the immediate surroundings of the eruption sites. However, the relatively gentle effusive style could have also inspired enough confidence to return to the areas affected by the eruptions, once these had ceased and the flows had cooled, and even to eventually recolonize parts of the newly formed lava flows (Reyes-Guzmán *et al.*, in press).

The archaeological information shows that the pre-Hispanic societies also knew how to develop original strategies to benefit from the volcanic environment. First of all, they took advantage of a wide range of volcanic materials. A good example is that of dacite, whose intensive mining at the Las Minas and Las Lajitas sites, not far from the edge of the Malpaís de Zacapu, allowed to produce and distribute a large quantity of lithic tools (Darras *et al.*, 2017, Quezada and Darras, in press). In addition, people were able to meet their need for sharper tools by extracting obsidian from the Zináparo-Varal deposits, located only ~30 km further to the NW (Darras, 1999). They were also well accustomed to dwelling on top of rugged, rocky lava flows, often devoid of soil and vegetation, by modifying their surfaces to create real urban agglomerations. Volcanic stones were used to erect walled edifices and terraces were built by modifying the structural reliefs of lava flows (e.g., pressure ridges, levées, etc.). In other words, the recent volcanic activity of the western Zacapu basin provided natural benefits, such as on-site construction materials as well as topographically elevated positions ensuring a panoramic view over the basin from which approaching enemies could be easily spotted. Finally, studies of the pre-Hispanic agricultural landscape in and around the Malpaís de Zacapu showed that the mineral-rich volcanic ash soils had been widely exploited (Dorison *et al.*, 2022; Dorison and Siebe, in press). Not only were the smoother areas of older (Early to Late Pleistocene) volcanic formations covered with agricultural terraces, but also the rugged stony areas of younger flows were methodically modified to concentrate soil and create small arable plots. Even Holocene flows might have been exploited by farmers, as suggested by current investigations at El Infiernillo (see below). In sum, more than displaying a unilateral impact of the volcanic environment on its inhabitants, the prehistory of the western Zacapu basin is a fine example of complex interactions between humans and nature through time, from symbolism to economy.

TRIP ITINERARY

Day 1: General geology and hydrology of the the Zacapu basin, Alberca de Guadalupe maar, Tarejero springs, Loma Alta and La Angostura archaeological sites, and colonial church of Naranja

The first day of the excursion will be mostly devoted to the general geology and hydrology of the Zacapu lacustrine basin and some of its most notorious features; e.g., phreatomagmatic crater of Alberca de Guadalupe (Stop 1) and high-discharge springs of Tarejero (Stop 2) occurring in the periphery of the basin. In addition, we will visit the archaeological site of Loma Alta (Stop 3), the ancient petroglyphs at La Angostura (Stop 4), and the colonial church of Naranja (Stop 5).

<u>*Itinerary:*</u> *Leave the main square of Morelia on Av. Francisco Madero in the direction of Capula and Quiroga to the west (*Fig. *1). This*

avenue further transforms into federal highway No. 15. After passing several new social housing complexes, at ~15 km (25 Mins.) turn right (north) at the natural gas storage facility and continue on state highway towards Cuto de Esperanza and Huaniqueo. To the left several remnants of quarried scoria cones can be seen. About 30 years ago these cones were still intact before extensive quarrying for building materials led to their almost complete destruction. Today most of the quarries are being used as garbage dumps for the city of Morelia. Further on along this route, the great variety in the young volcanic landforms can be viewed at several late Pleistocene-Holocene scoria cones like La Mina, Sajo Grande, Coro Grande, etc. Early Pleistocene El Zirate dome complex (3345 m) and Picacho Gendo shield (2550 m) are also easily visible from the road. Continue on this route and after a drive of ~23 km (25 Mins.) arrive at the eastern crater rim (terrace with panoramic view at Guadalupe town) of the Alberca de Guadalupe maar crater (Stop 1). The view allows grasping fundamental issues related to the phenomenon of maar formation, as one can see that the crater literally forms a hole in the otherwise relatively planar topography of the early Pleistocene lava flows. To the left from the panoramic view point, a small road leads down to the crater lake along which typical maar deposits can be observed (see description below).

From here, drive north towards Huaniqueo for ~14 km (19 Mins.) and arrive at the eastern lacustrine flat of the Zacapu paleo-lake at Puente San Isidro. Here, turn left toward Coeneo and shortly before entering this town turn right and continue toward Quencio. From here on, follow the road surrounding the northern base of Cerro Tipicato volcano (1.5 Ma, Early Pleistocene, Kshirsagar et al., 2015) along the shore of the former Zacapu lake until you arrive at Bellas Fuentes, a small town at a major water spring. Here, turn right and follow the road until you reach the town of Tarejero, built on the lower slope of a scoria cone. Enter town and drive to its NW margin, where an elongated ~300-m-large pond is fed by several high-discharge springs (Stop 2). The entire stretch from Alberca de Guadalupe to Tarejero (~40 km) takes ~1 hour of driving.

From the springs return to the main road and exit Tarejero to the N. After ~3 km, arrive at the town of Cantabria, continue ~1.5 km to the WNW (total of 10 Mins.) and arrive on the right side of the road at the Loma Alta archaeological site (Stop 3). From here, continue W on the paved road toward Zacapu for ~3 km. Immediately after crossing the railway tracks, at a major junction at the outskirts of Zacapu, cross highway No. 15 and continue on Av. Colorines. After passing a complex of chemical factories (on the left hand) and driving ~1 km, arrive at the junction with Av. 20 de Noviembre. Here, turn left and after ~300 m, arrive at the La Angostura petroglyph site (Stop 4), located at the base of a massive lava flow from El Capaxtiro volcano, just N of La Laguna, a small pond fed by nearby springs.

Return to highway No. 15 and at the intersection turn right and drive to the SW on the main road that passes the city of Zacapu on its eastern outskirts until reaching a roundabout (Bicentenario monument). Continue to the SE and exit Zacapu toward Pátzcuaro and after a total of ~8 km (15 Mins.) from Stop 4, arrive at the outskirts of the town of Naranja, turn left and drive to a small pond nourished by a spring. At its margins is the hotel "Cabañas Lagoverde", where we will stay for the night. After check-in, the nearby (300 m walking distance) colonial church of Our Father Jesus with its interesting architecture and interior decoration at the main square of Naranja (Stop 5) will be visited.

Stop 1: Alberca de Guadalupe maar crater (19°48'28.7", 101°26'56.4"; 2141 m)

The view-point (Figs. 6, 7) displays a wide crater (~1 km in diameter) with a depth of ~140 m that bears a lake (~9-m-deep), formed ~21,000 y. BP ago (Kshirsagar *et al.*, 2015). It is the youngest of the three phreato-magmatic constructs occurring within the Zacapu basin (Kshirsagar *et al.*, 2016). It

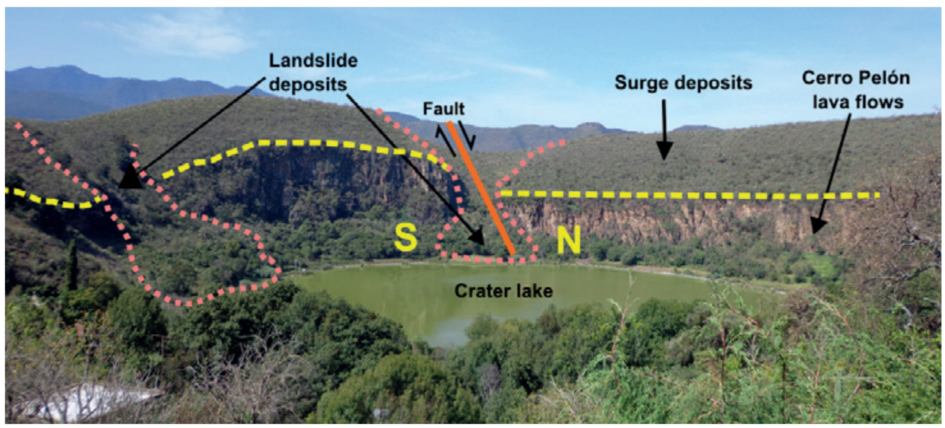

Figure 6: View of Alberca de Guadalupe maar from its eastern crater rim (Stop 1) towards the W. Phreatomagmatic deposits produced by the eruption cover an older lava flow (vertical cliff) from Cerro Pelón scoria cone. Normal fault and vertical displacement of ~30 m between southern (S) and downthrown northern (N) block are clearly visible. Post-eruption landslides contributed to further increase the width of the crater. Lake is ~9 m deep. Taken from Siebe *et al.* (2014).

Figure 7: Aerial photo of Alberca de Guadalupe maar crater from the E. Note normal faults (red arrows), one of them displacing cliff-forming lava in the interior crater wall. Red circle denotes Stop 1 (terrace with panoramic view). Photo taken November 30, 2011 by Sergio Salinas.

originated by perforating early Pleistocene lava flows from nearby Cerro Pelón. The northern block of the crater wall is downthrown ~30 m by an ENE-WSW trending regional normal fault that has been active since Pliocene times (Figs. 8, 9).

This unusual phreato-magmatic construct, in the semi-arid highlands of Zacapu, was favored by local hydrological and topographical conditions, especially the shallow aquifer parameters (e.g., high permeability and flow direction) that allowed funneling enough ground-and-surface water along narrow valleys to the eruption site (Fig. 9) in order to fuel continuous phreato-magmatic explosions (Kshirsagar *et al.*, 2015). Today, shallow groundwater conditions still prevail as exemplified by several high-discharge springs near Puruátiro (~3 km NNW from the maar crater) and on the ENE inner wall of the crater, within the contact of the lava flows and the overlying surge deposits (Fig. 8), making it feasible that such an event could occur again in this area.

The maar deposits are observable along the small paved road to the left of the viewing point that leads down to the crater lake. A well-stratified sequence of alternating dry and wet surge deposits that are disrupted by several ballistic lithics (angular andesite lava and ignimbrite clasts), displaying decimeter-scale impact sags (Fig. 10), can be seen. The dry surge deposits are friable and consist of medium-to-coarse lapilli, that are mainly clast-supported, and poorly sorted (Mdφ: -1.56 to -3.75, σφ: 1.43 to 3.23). In contrast, the wet surge deposits are fairly indurated and consist of thin stratified layers of fine ash with accretionary lapilli (~1 cm in diameter). The deposits are poor in juveniles (cauliflower-type bombs of basaltic andesite, SiO_2=54-58 wt.%) that only constitute 12-49% of the deposits. Note the detailed characteristics of these deposits, since the deposits that will be encountered later during this excursion at the Alberca de los Espinos tuff cone (Stop 6) bear some resemblances, but also some noteworthy differences.

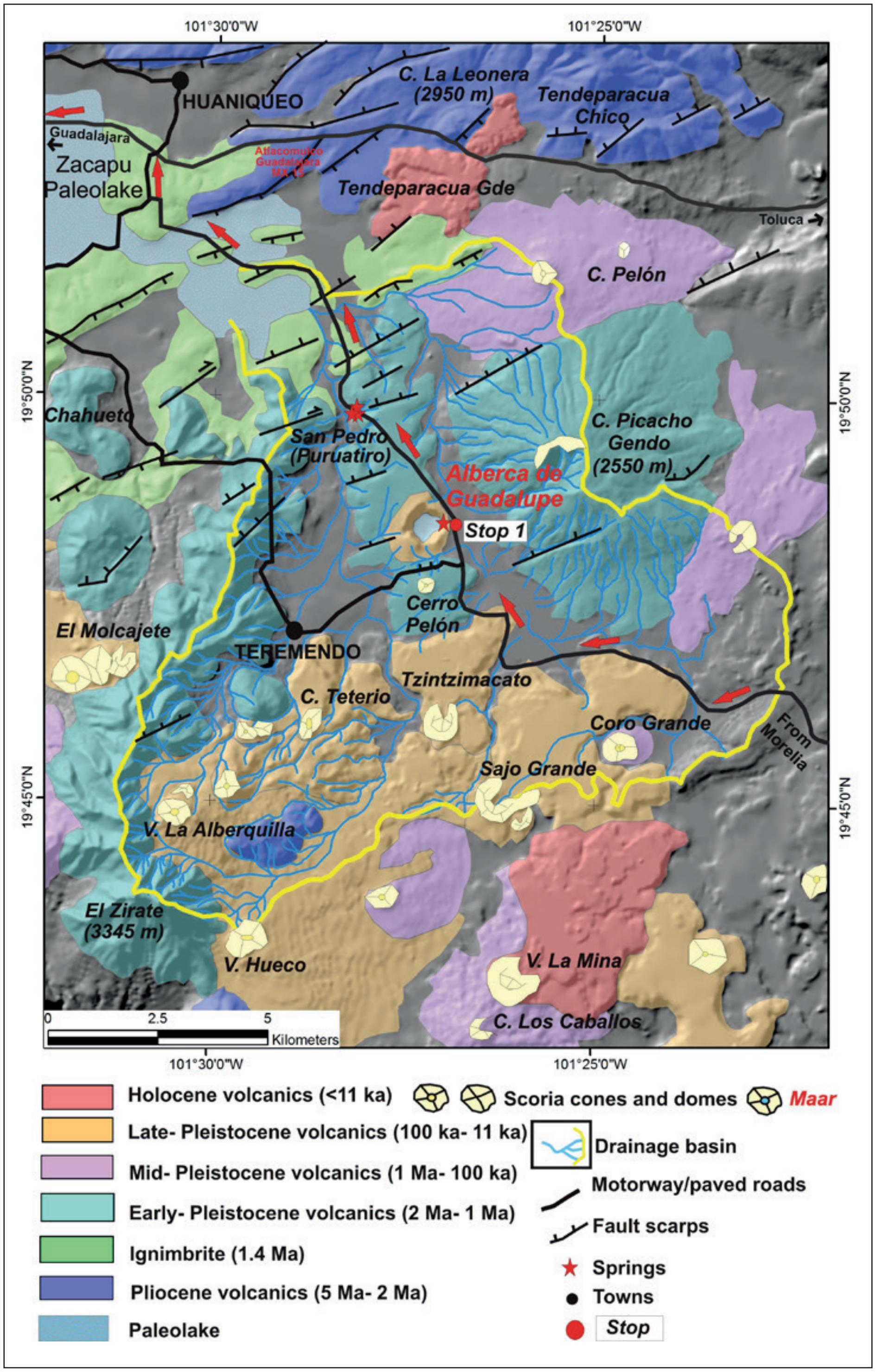

Figure 8: Geological map of the eastern Zacapu lake basin and location of Alberca de Guadalupe maar crater (Stop 1) in the middle of a tributary drainage network. Red arrows denote travel route. Taken from Siebe *et al.* (2014) and drafted by P. Kshirsagar.

Stop 2: Tarejero scoria cone and springs (19°49'25.3", 101°42'58.4"; 1990 m)

Tarejero is an ancient Purépecha town built around the W lower slope of the homonymous small (~100-m-high) scoria cone, located within the SW sector of the lacustrine plain (Figs. 1, 3, 11). The NW margin of the town coincides with the limit of a lava flow. At its base, numerous high-discharge springs produce crystalline potable water (pH = 6-6.5). Around several of the springs, rectangular pools with walls of lava boulders and concrete were built to serve as bathing and laundry-washing facilities for the local population (Fig. 12). The spring water is warmer (Temp. = 21.7 °C, at the exits) than expected (~15 °C) for average groundwater in this region and flows from the pools into a pond that is narrowly elongated in a SW-NE direction with a width of ~50 m and a length of ~300 m. At its NW end it overflows a weir and from here it is conducted into a system of irrigation canals. At the weir we were able to crudely estimate the total discharge of the springs at 0.5-1 m^3/sec.

The Tarejero scoria cone is basaltic-an-

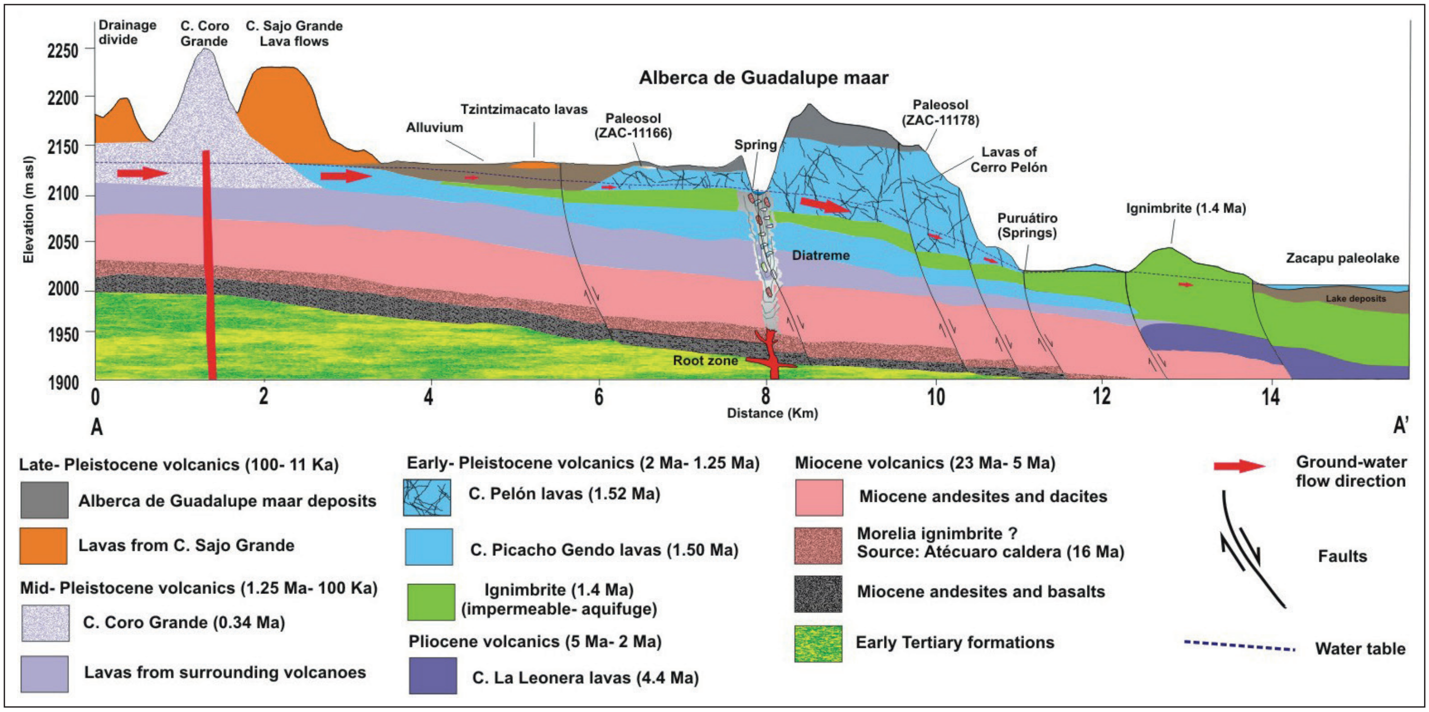

Figure 9: SE-NW profile cutting through the Alberca de Guadalupe maar showing the observed and inferred geological units (as indicated in Fig. 8) and horizontal groundwater flow direction (red arrows). Taken from Kshirsagar *et al.* (2015).

desitic (SiO_2 = 55 wt.%) in composition and its age was estimated on morphological grounds to fall within the Mid-Pleistocene period (Ramírez-Uribe *et al.*, 2019). Before the draining of the Zacapau lake, Tarejero was frequently surrounded by shallow water and the ancient Purépecha town could only be reached by boat, especially during the rainy season. Hence, Tarejero is not only special for its relatively warm high-discharge springs, but also because it is the only volcanic "island" that occurs within the lacustrine plain. These facts beg for an answer in regard to their original causes. We speculate that the general absence of volcanic vents within the limits of the lacustrine plain might be related to the thickness of the sedimentary infill. If thick enough, this sequence of loose unconsolidated materials might act as a density trap for small magma bodies rising to the surface. As a result, such magmas would not erupt at the surface but form sills and/or laccoliths at the contact between the local basement and the younger overlying infill. The interior of these hot bodies would cool slowly by transmitting their heat to the water-saturated infill and by this process eventually contribute to the unusually warm temperature of the spring waters. In such a geologic environment, the eruption of Tarejero would represent an exception, that could be explained by postulating that the sedimentary infill underneath the volcano is not thick enough to allow for rising magmas to be trapped. In this context it is worth mentioning that in respect to the frequent absence of volcanoes within lacustrine basins, the case of Zacapu is not unique. Many other lake basins in central Mexico (e.g., Chapala, Pátzcuaro, Cuitzeo) are also characterized by the absence of volcanoes within their interiors, a feature that might be rooted in a common cause. Deeper drilling and geophysical studies would be required to test this hypothesis.

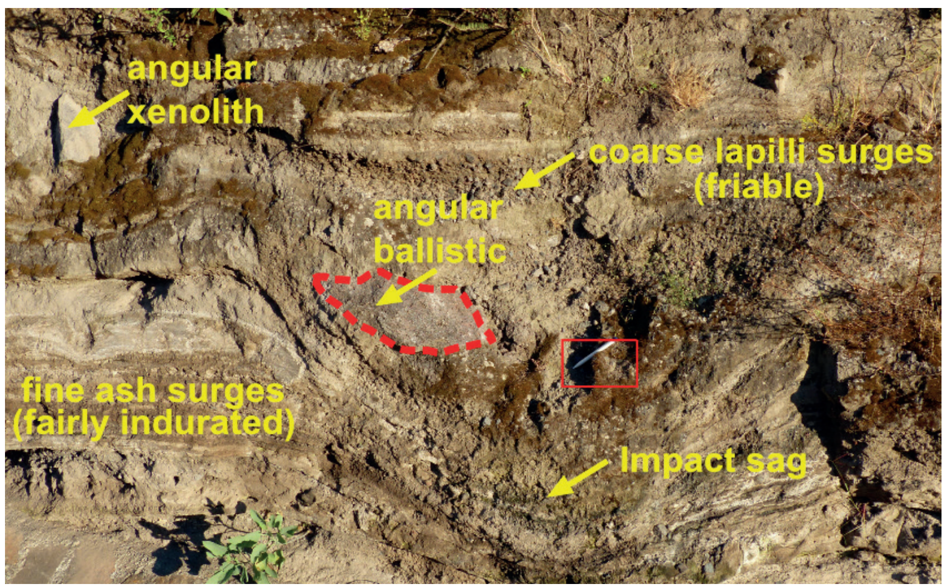

Figure 10: Typical surge deposits with ballistic impact sags observable at outcrop on the road leading from the crater rim down to the lake of Alberca de Guadalupe maar. Pen for scale (~18 cm) inside red rectangle. Taken from Siebe *et al.* (2014).

Stop 3: Loma Alta archaeological site and the area of Las Lomas near Cantabria (19°50'24.2", 101°44'34.9"; 1990 m)

Although paleoenvironmental data (Pétrequin, 1994) suggest the existence of agricultural settlements as early as 1500 BC in the Zacapu basin, these sites have not yet been discovered. To date, the earliest human sites within the basin were identified at Las Lomas, an 18 km^2 area located west of the ancient Zacapu lake (Fig. 11). This

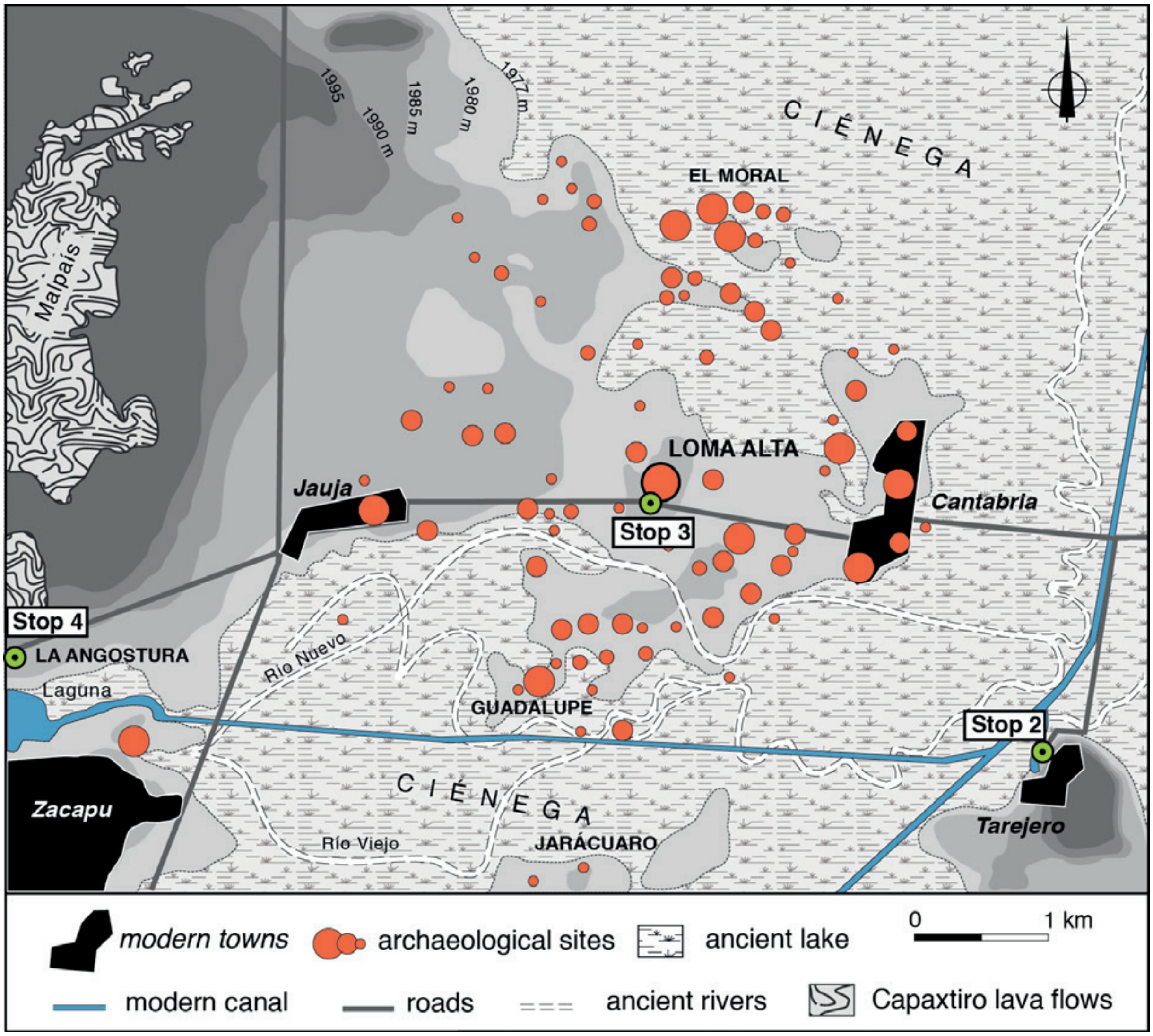

Figure 11: Archaeological map of the Las Lomas area. Stop 2 (Tarejero) and Stop 4 (La Angostura) are indicated. Modified from Arnauld *et al.* (1993).

Figure 12: High-discharge springs (total discharge of ~0.5-1.0 m^3/sec; *Temp=21.7 °C, ph=6.0-6.5*) at the base of the Tarejero lava flow (see boulders behind ramp in upper-right section of photo). The springs discharge first into bathing pools, before the water flows into a ~300-m-long pond (visible behind the pools), and from there conducted into a network of irrigation canals. Photo Claus Siebe.

Figure 13: Photo showing the contrast between the whitish-gray soils of Las Lomas and the dark soils developed on the surface of the former lake. The modern village of Tariácuri can be seen in the background. Photo courtesy of Jennifer Saumur.

area is characterized by a series of terrain undulations that stand out slightly from the otherwise flat surface of the ancient lake bed. In addition, distinct light-colored soils that contrast starkly with the otherwise dark sediments (histosols) of the lake bed also distinguish this area (Fig. 13). Before the artificial drying of the lake in the early 20th century, this sector formed a peninsula with associated islets that were occupied from 100 BC onward until the arrival of the Spaniards in Michoacán in 1522.

The geologic origin of Las Lomas is not entirely clear, but it has been hinted that it could be the product of a volcanic event that generated the uplift (emplacement of a sill?) of the lacustrine sediments, possibly following the emplacement of nearby lava flows. Work carried out in the late 1980s (Pétrequin, 1994) attributed this phenomenon to the eruption of Capaxtiro and dated the formation of Las Lomas at ~6000 BC. But more recent work (Mahgoub *et al.*, 2018) indicates that the eruption of Capaxtiro occurred ~100 BC or shortly before the first reported occupation of Las Lomas.

The Loma Alta site is the most important in the area for its size and long occupation sequence. Excavations carried out at different places on the elongated hill (Arnauld *et al.*, 1993) show that deposits bearing evidence for human occupation reach up to 4 m in thickness. The main occupation of the site began ~100 BC and peaked during the first millennium of our era. The site functioned as a monumental ceremonial center with platforms, patios, and altars (Carot *et al.*, 1998). Several cemeteries, including funerary jars containing fine ashes obtained from the intentional grinding of cremated bones (Carot and Susini, 1990) were also discovered.

The ceramic tradition of Loma Alta stands out for its rich polychrome decoration style that depicts zoomorphic (birds, snakes, squirrels) and anthropomorphic figures, which are similar to those related to the cultural traditions of NW Mexico and the SW United States (Carot, 2004). In addition, several stone sculptures have been found. One of them is an early representation of the fire god. Much later, this god, named Caricaueri, became the main god of the Tarascans.

Stop 4: La Angostura petroglyphs, north of Zacapu (19°49’46.1”, 101°47’19.4”; 1989 m)

The petroglyph site of La Angostura is a natural promontory of lava boulders (Fig. 14) located in a semi-urbanized area on the northern outskirts of the city of Zacapu, in the “*ejido*” (public land) of La Angostura. The rocky promontory is part of the distal margin of one of the early lava flows that emanated from the Capaxtiro volcano (Figs. 11, 15, 16), known locally as Achembo, which also houses an important pre-Hispanic settlement. Next to it is the flat area of the northern shore of the Laguna de Zacapu, a small pond fed by nearby springs.

Figure 14: View of the small promontory of lava boulders at La Angostura on which the petroglyphs were chisseled. Foto Grégory Pereira.

The petroglyphs of La Angostura are known since the 1930’s when the locality was first reported by Wilfrido Du Solier. The ongoing systematic study of the site by Areli Huerta and Eric Gelliot has recorded more than 80 engraved designs on about 20 boulders. The petroglyphs were made by picketing the naturally flat and smooth surface of the rocks to make simple or complex geometric designs (Fig. 17), as well as numerous anthropomorphic and zoomorphic figures.

Although it is generally difficult to date rock art, the regional study conducted by Faugère (1997) has proposed grouping this style of design in the tradition called “*Malpaís*”, which would correspond to the Postclassic. Several other volcanic lava outcrops that were used for rock art have been reported from the E margin of the Malpaís de Zacapu.

Stop 5: Naranja and its colonial church (19° 46’ 34”, 101° 45’ 38”; 1990 m)

The village of Naranja de Tapia is one of the original Purépecha villages of the basin, mentioned in 16th century sources as *Naranjan*. According to the Relación de Michoacán (Alcalá, 2000 [1541]), *Naranjan* was a prominent lordship of the Zacapu basin when the Uacúsecha Chichimecs arrived in the 13th century. It was led by the Zizambanecha lineage who made an alliance with Hire Ticátame, the leader of the Chichimecs, after his marriage to the sister of the local ruler. Shortly thereafter, a conflict broke out with his brothers-in-law and Hire Ticátame was forced to leave. Six generations later, when the Uacúsecha secured their power in Pátzcuaro and began the conquest of neighboring regions, Naranjan and the other towns in the Zacapu basin fell under their domination.

In the surroundings of the present town are several archaeological sites that were occupied mainly during the Postclassic period but some of them already since earlier Classic and Epiclassic (AD 500-900) times.

The present town of Naranja de Tapia is located 5 km SE of Zacapu on the former S shore of the ancient lake. Nearby is one of the many springs that used to feed the Zacapu lake. Today, the spring nourishes a small pond known as *Lago Verde* (“green lake”, in Spanish). The center of town preserves a nice example of traditional colonial Michoacán architecture: the main square is surrounded by adobe buildings with tile roofs and large wooden porches. It exhibits the façade of the church of Our Father Jesus (Fig. 18). The interior of this colonial building preserves a magnificent wooden coffered ceiling decorated with polychrome paintings made during the eighteenth cen-

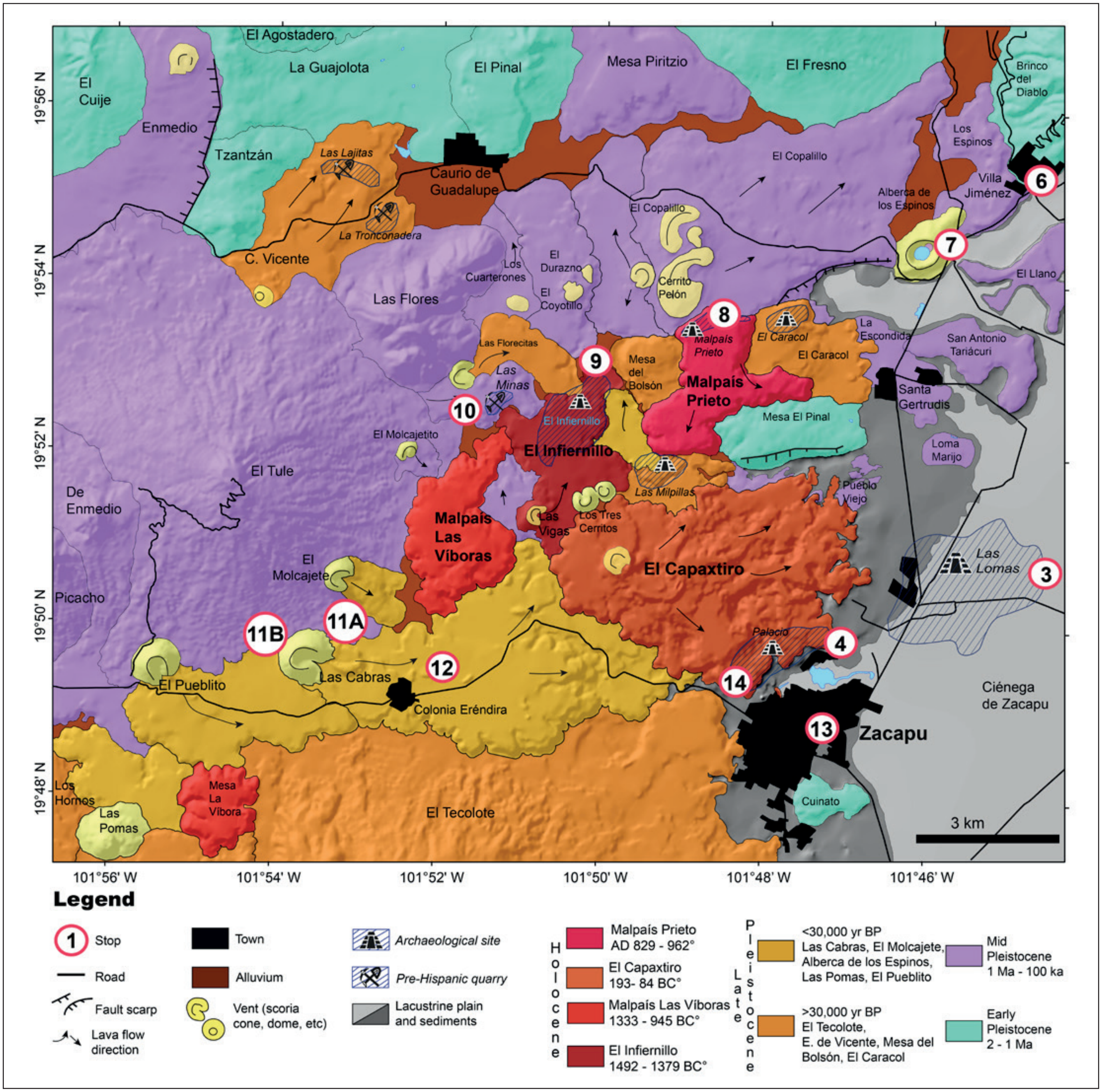

Figure 15: Geologic map of the western part of the Zacapu basin indicating Stops 3-13 to be visited. From Reyes-Guzmán *et al.* (2018).

tury (Ruiz Caballero, 2010) including about sixty painted images of saints, the virgin Mary, and musician angels and cherubs, all surrounded by a lush and colorful vegetal decoration (Fig. 19).

Day 2: Canal at Villa Jiménez, Alberca de los Espinos tuff cone, Malpaís de Zacapu monogenetic cluster and archaelogical sites on young lava flows, Las Cabras scoria cone, and main square of Zacapu

On the second day young volcanoes and archaeological sites at the NW and W margin of the Zacapu basin will be visited (Figs. 15, 16). We will first drive from Naranja to Villa Jiménez (Stop 6), where the present artificial outlet that helped drain the lake in the early 20th century is located. Nearby is the Alberca de los Espinos tuff cone (Stop 7), a phreatomagmatic volcano that erupted ~25,000 years ago at the former outlet of the paleo-lake and caused a significant rise of the lake's level. Then we will inspect the Holocene Malpaís de Zacapu cluster of volcanoes and its lava flows. On the surface of the young lava flows several archaeological sites of urban dimensions and an extraordinary degree of preservation occur. Two of the most notable are Malpaís Prieto (Stop 8) and El Infiernillo (Stop 9). Nearby are the unique Las Minas pre-Hispanic dacite quarries (Stop 10). Then we will drive to the Las Cabras scoria cone (Stop 11) and its debris avalanche deposit (Stop 12), before returning to Naranja. In

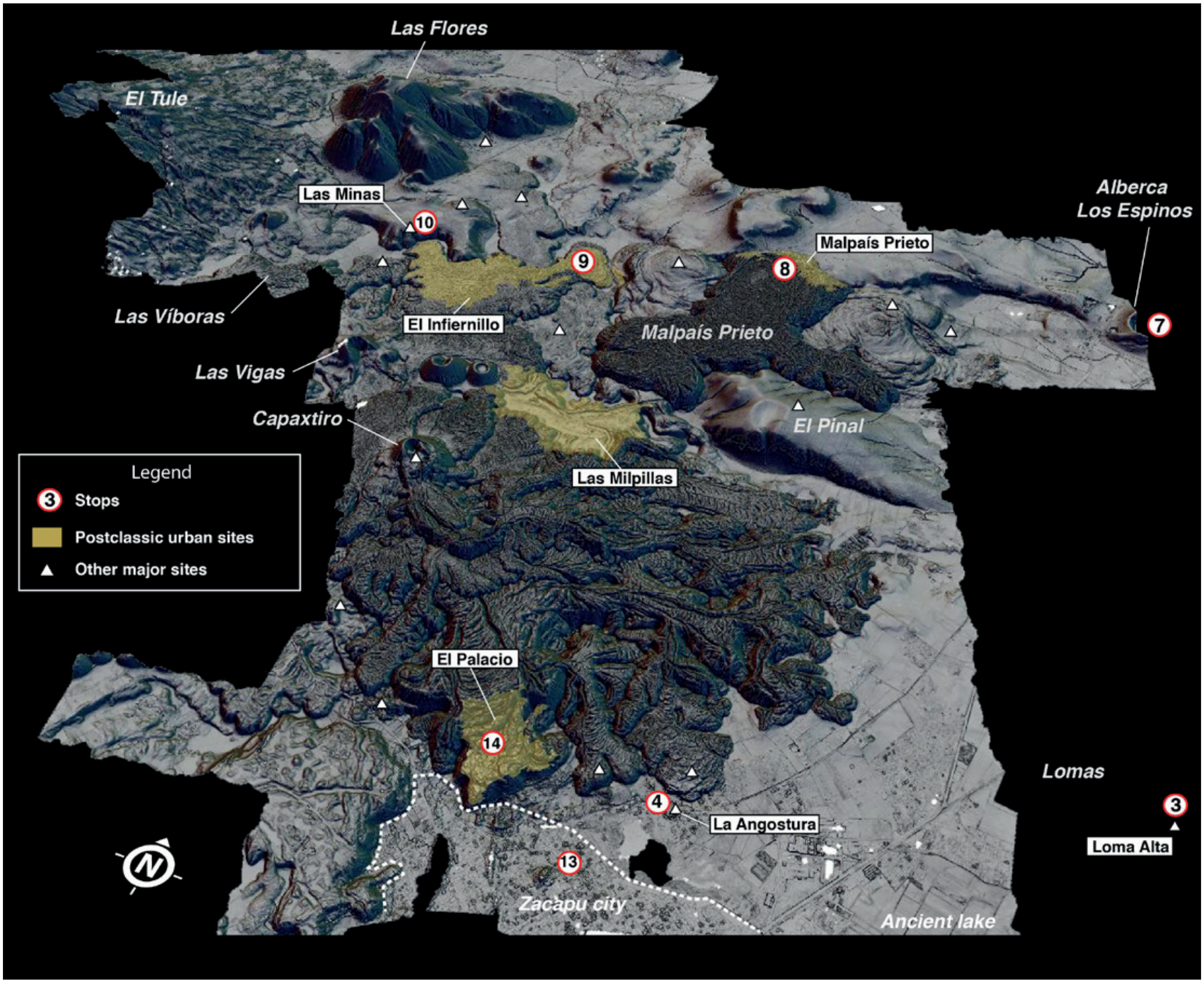

Figure 16: 3D-view of the Malpaís de Zacapu area showing main archaeological sites (yellow) and stops (red circles) to be visited. Generated from LiDAR data by Antoine Dorison.

the late afternoon, we will drive to Zacapu and have a stroll in the downtown area, where its colonial church Santa Ana and main square (Stop 13) are worth visiting. The night will be spent again at Naranja near Zacapu (Cabañas Lagoverde).

Itinerary: *Exit Naranja to the NW and at the roundabout (Bicentenario monument) at the entrance of Zacapu turn right to the N. Exit Zacapu and continue N to Villa Jiménez (~19 km, ~30 Mins.) and arrive at the bridge over the canal (Stop 6; Figs. 15, 20). Return on the same road to the W and after ~2 km (~5 Mins.) arrive at the parking lot at the outer southern slope of Alberca de Los Espinos tuff cone. From here, climb on foot to the crater rim (Stop 7A) and enjoy the panoramic view of the crater lake and surrounding volcanic landforms. The plain of the former Zacapu lake and the present outlet of the lacustrine basin (canal at Villa Jiménez) can also be observed. Afterwards, two major quarries displaying the phreatomagmatic deposits of the tuff cone (Stops 7B and 7C) will be visited. From the quarry at the W slope of Alberca de los Espinos (Stop 7B) continue W on the paved road that conducts to Caurio. After ~800 m (~4 Mins.), exit the road on the left side and follow a dirt road for ~4 km (10 Mins.) that leads directly to the N margin of the Malpaís Prieto lava flow (Stop 8). From here climb on foot on a path up the steep terraced margin of the flow and inspect the core area of the Ciudad Perdida archaeological site on the upper part of the rugged terrain. Numerous housing remains, including monumental ceremonial buildings of this impressive former city can be discerned on the blocky surface of the flow. After lunch under the trees of a nearby oak forest, continue on the unpaved road toward the W and arrive after ~3 km (~15 Mins.) at the N margin of the El Infiernillo lava flow (Stop 9) and archaeological site, which will be inspected on foot. Not far from here, to the W, and also on foot, is the Las Minas pre-Hispanic dacite quarry area (Stop 10). From here continue ~10 km (30 Mins.) on the dirt road, first to the W. At the lower slope of El Tule shield, the road turns S along the W margin of the thick Malpaís Las Víboras lava flow toward the town of Eréndira. Before entering Eréndira, turn right (NW) and after ~2 km (10 Mins.) reach an area of quarries located between the Las Cabras and Molcajete scoria cones (Fig. 15). One of these quarries (Stop 11A, see details below) displays the entire*

Figure 17: Detail of two engraved rocks with geometric designs at La Angostura. Foto Grégory Pereira.

Figure 18: Front of the church of Nuestro Padre Jesús in Naranja. Foto courtesy of Martín Serrato Juárez.

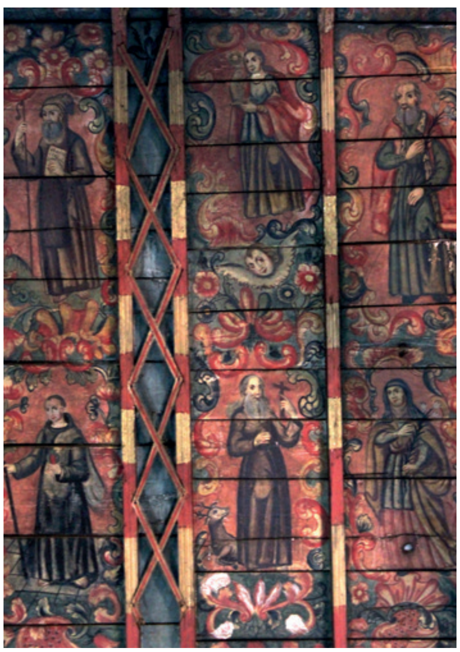

Figure 19: Detail of the 18th century polychrome coffered ceiling in the interior of the parish church of Naranja. Foto coutesy of the Zacapu city council.

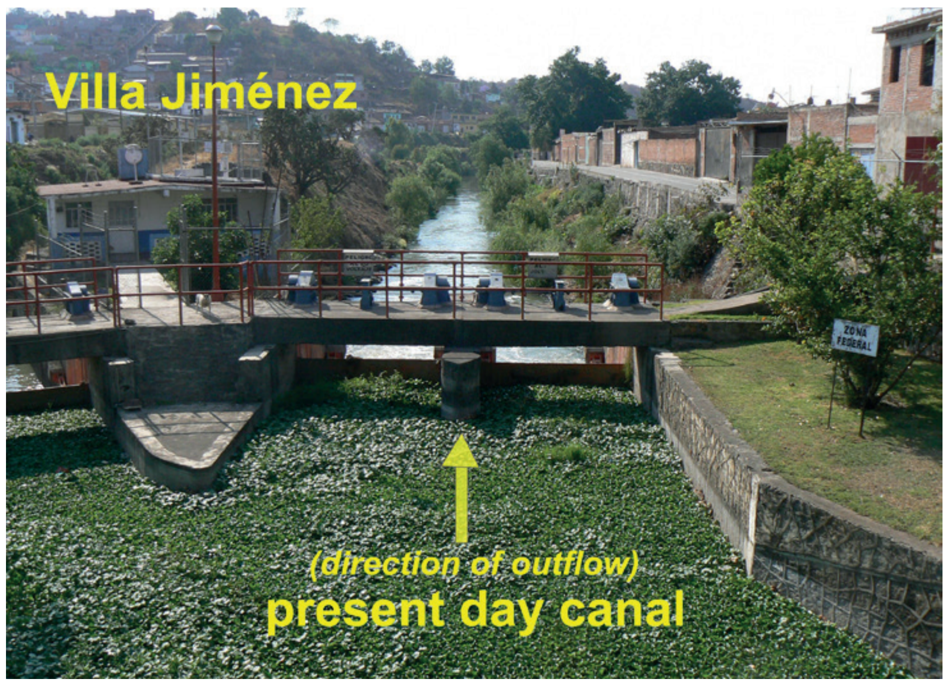

Figure 20: Canal at Villa Jiménez (Stop 6) that served for draining Zacapu lake more than 100 years ago (direction of the outflow is indicated by arrow). Foto Claus Siebe.

Las Cabras fallout sequence. Drive back to Eréndira, cross town and reach federal highway No. 15. Here, turn right and drive W in the direction of Carapan for 1.5 km. Here turn right and follow the unpaved road for ~2 km (10 Mins.) and arrive at another quarry (Stop 11B) displaying 10 m of Las Cabras proximal scoria fallout deposits. After paying a visit to the quarry, return to highway 15 and back to Eréndira. From here continue E toward Zacapu and after only ~500 m, turn left on an unpaved road and continue few hundreds of meters towards a quarry (Stop 12). Here, one of the largest hummocks dotting the surface of the proximal lava flow field produced by Las Cabras breached scoria cone can be inspected. Later return to paved road and drive E toward Zacapu. Before arriving at Zacapu (~10 km, 30 Mins.), on the left side of the road, the dark grey Capaxtiro andesite lava flow field is encountered. Its age is ~2,000 years and the 'A'ā-type flows are almost devoid of vegetation and display steep flow fronts that are >30 m high. In Zacapu, follow the signs toward the center of town (Stop 13). After visiting the main square, church of Santa Ana, etc., drive to Naranja and spend again the night at hotel "Cabañas Lagoverde".

Stop 6: Canal at Villa Jiménez (19°55'12.6", 101°44'48.3"; 1992 m)

This canal (Fig. 20) was initially excavated at the end of the 19th century at the topographically lowest point of the NW Zacapu lake shore. Only during unusually rainy years the water level of the shallow lake would be high enough to overspill at this site and empty into the Río Angulo to the N. This observation encouraged greedy owners of nearby haciendas to dig a canal to drain the entire lake to gain an enormous area of new arable land and, at the same time, eliminating marshy areas considered to be unhealthy. This endeavour took several years and culminated between 1902 and 1908 (Guzmán-Ávila, 1985; Reyes-García and Gougeon, 1991). As a result, the ecology and economy of the region changed abruptly. Previous lacustrine and riparian habitats disappeared quite suddenly and the native population (mostly Purépecha Indians) that had inhabited towns and hamlets at the margin of the lake and had spent for generations part of their lives on canoes fishing, hunting water fowl, etc. had to adapt quickly to an unforseen situation that was imposed on them quite arbitrarily in the name of modernity. Today, the main crops grown in the basin include corn and sorghum.

The canal observable today has been refurbished on several occasions and still serves as an outlet for the Zacapu basin. It connects to the Río Angulo which flows north to the Río Lerma, the main river draining western-central Mexico into the Pacific.

Stop 7 (A, B, C): Alberca de Los Espinos: A phreatomagmatic tuff cone that obstructed the former outlet of Zacapu lake and changed the environment

Stop 7A: Crater rim (19°54’19.3”, 101°45’57.8”; 2045 m)

After visiting the canal of Villa Jiménez, arrive at the S slope of the geologically significant Alberca de Los Espinos phreatomagmatic tuff cone located at the NW margin of the Zacapu tectonic lacustrine basin (Figs. 3, 15, 21, 22). From here, climb on foot to the crater rim (Stop 7A) to enjoy a panoramic view of the crater and better understand the surrounding landscape, which includes the Malpaís Prieto, the youngest lava flow in the region (see also photos at inner front cover). The highest point of the crater rim (2100 masl) rises ~110 m above the ground of the lacustrine plains to the SE. The crater has an NE-SW oriented elliptical shape and a maximum

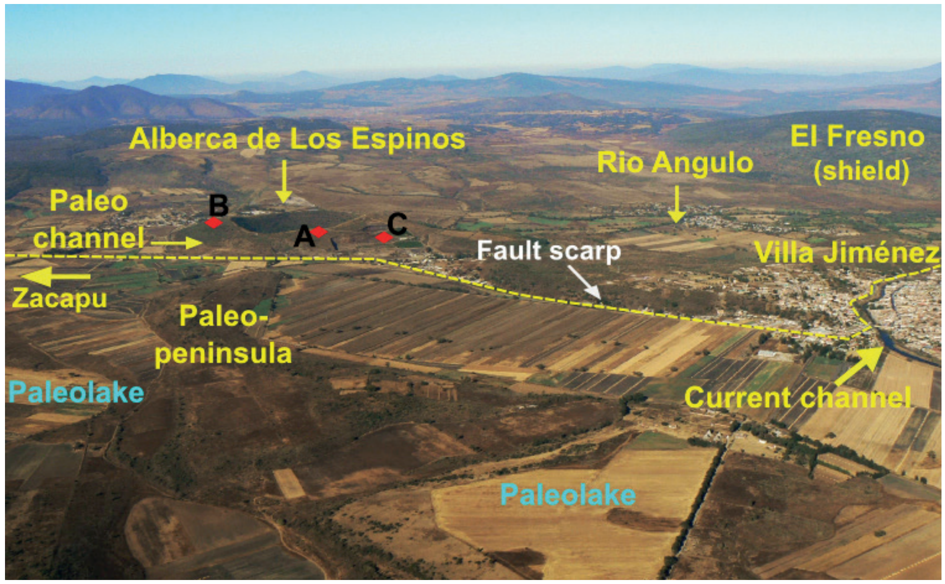

Figure 21: Aerial view toward the NNW of Alberca de Los Espinos tuff cone and canal at Villa Jiménez. The eruption of the tuff cone occurred at the location of the former natural outlet of the Zacapu paleolake obstructing the outflow. As a result, the level of the lake rose several meters until it could spill over at the location of the present canal of Villa Jiménez (see also Fig. 22). A, B, C (see text) denote places to be visited at Stop 7. Taken from Siebe *et al.* (2014).

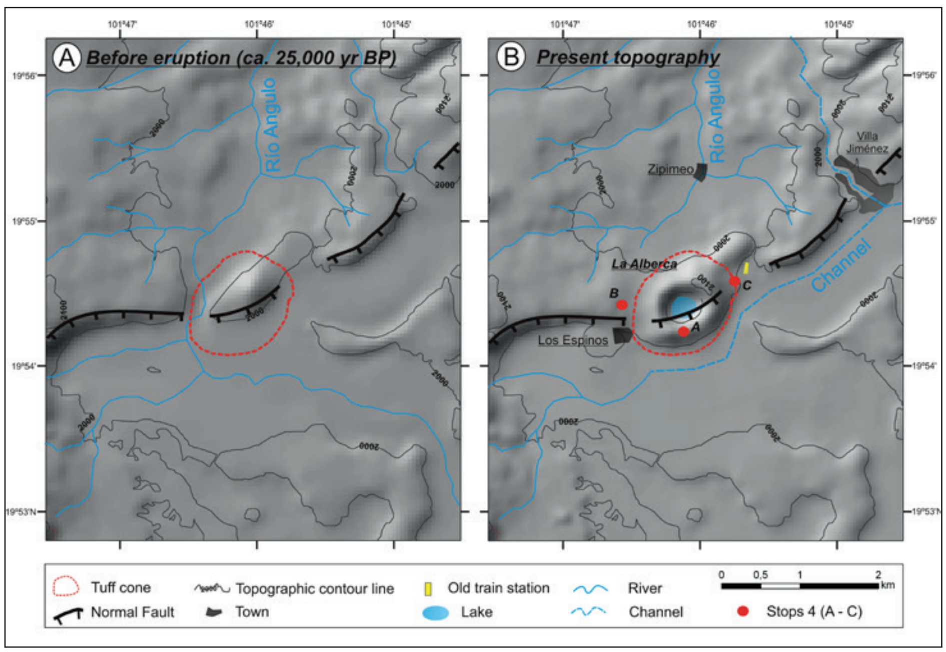

Figure 22: Topography of the Alberca de los Espinos area before (A) and after (B) the eruption of the tuff cone ~25,000 years ago. Note that the drainage pattern of the Río Angulo changed significantly as a result of the eruption (see also Fig. 21). A, B, C (see text) denote places to be visited at Stop 7. Taken from Siebe *et al.* (2014).

diameter of 740 m. Its interior is occupied by a maar lake that has a maximum diameter of 350 m and reaches a maximum depth of 29 m below its present surface at 1980 masl. The tuff cone has an average basal diameter of 1200 m and surge deposits are preserved as far as 2 km from the present crater rim. The maximum elongation axis of the crater is parallel to a regional fault trending NE-SW that runs through the cone dropping the SE block (Fig. 22). Remnants of an old pre-existing scoria cone are exposed on the NE inner walls of the crater, as evidenced by cliff-forming lava flows topped by layers of spatter agglutinate (Kshirsagar *et al.*, 2015).

The occurrence of a phreatomagmatic volcano such as Alberca de los Espinos at the northern limit of a lacustrine basin is not surprising. What makes this volcano special is its exact location at the former outlet of the Zacapu lake (Siebe *et al.*, 2012). As a result of the eruption, the outlet became

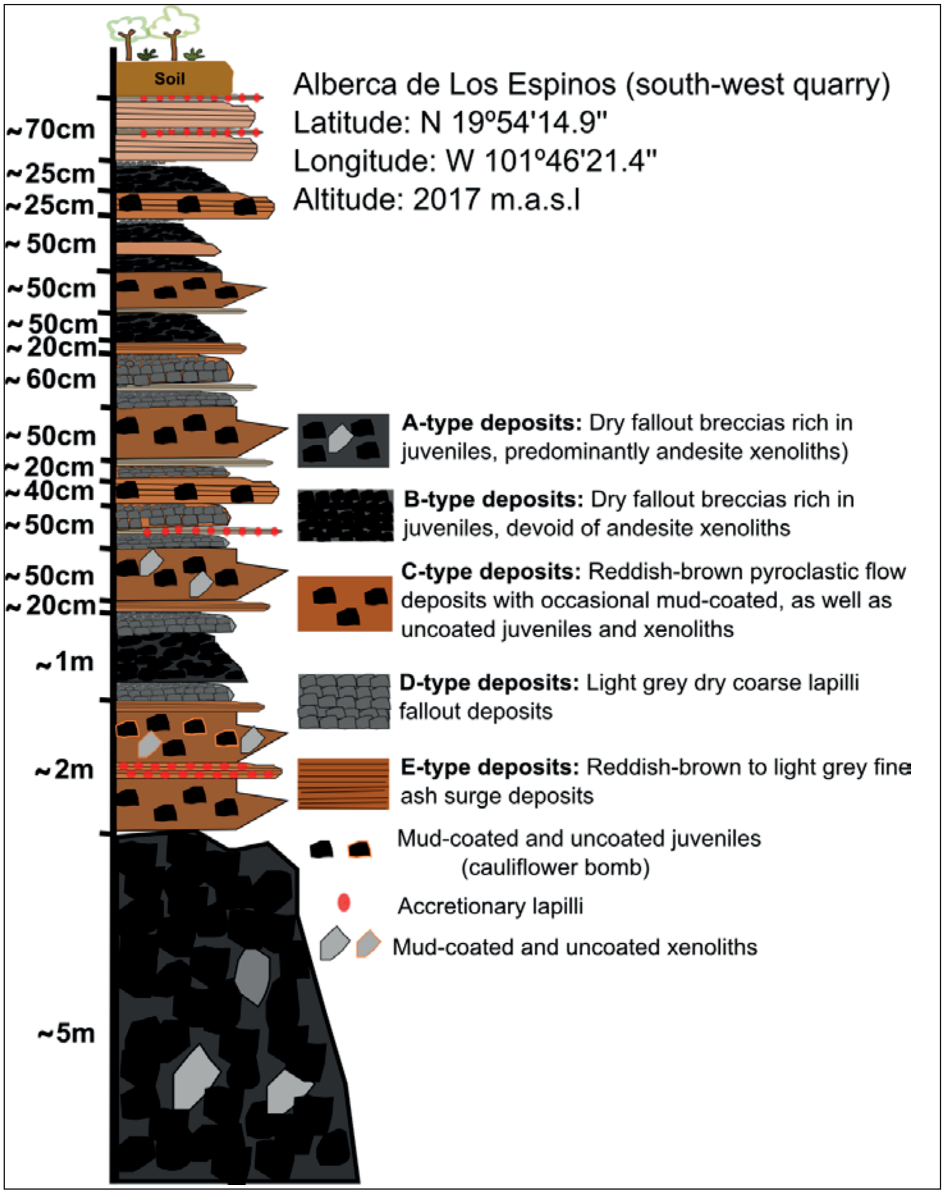

Figure 23: Stratigraphic sequence (mostly phreatomagmatic surge-and-fallout deposits) of Alberca de Los Espinos tuff cone exposed at SW quarry (Stop 7B). Taken from Siebe *et al.* (2014).

sealed and the water table of the lake rose several meters, before a topographic low near Villa Jiménez (present location of the canal) situated 2 km to the NE of Alberca de los Espinos, could serve as a new outlet reconnecting the basin with the drainage of the Lerma river to the N. As a result of the lake level rise, the surface area of the lake increased by ~30% from ~205 to ~310 km^2. Hence, the Zacapu lake deposit sequence potentially records a significant transgression after the timing of this short-lived monogenetic eruption.

Several of the large quarries at the outer slopes of the tuff cone expose clean contacts with the underlying paleosol. Samples from this paleosol obtained at different quarries yielded radiocarbon dates of ~25,000 y. BP. This age is of importance because it not only dates the eruption, but indirectly also dates a major lake transgression and in consequence an important environmental change which in this case was not controlled by climate (e.g., changes in temperature and precipitation), but by endogenous forces (those forces that also created the fault-controlled lacustrine basin surrounded by volcanoes in the first place). Hence, the formation of this tuff cone subsequently led to the expansion of a habitat hosting numerous aquatic and riparian plant and animal communities that attracted nomadic early humans and promoted the development of agriculture in this area as evidenced by the numerous pre-Hispanic archaeological sites discovered nearby (e.g., Arnauld *et al.*, 1994).

In order to better understand the environmental factors that fostered the rise of early human civilization in this region, palaeo-climate studies focusing on the analysis of the lake sediments (and particularly on their microfossil contents) have been carried out (e.g., Metcalfe, 1992). Although particular attention has been paid to the Holocene, some of these records go back as far as 52,000 y. BP (e.g., Tricart, 1992; Metcalfe and Harrison, 1984; Ortega *et al.*, 2002). Interestingly enough, these studies (which include the analysis of lake sediment cores, up to 10 m in length) have identified a major discontinuity dated at 28,000-25,000 y. BP. Interpretation by these authors in regard to the origin of this discontinuity varies (some interpret it to represent a regression or "hiatus", others mention a transgression of the lake) but all share a marked reluctance to come up with a clear-cut answer. As hinted above, we think that we have found the answer to the question of the nature of this discontinuity by dating the eruption of the Alberca de los Espinos tuff cone at ~25,000 y. BP. Our research shows that palaeo-environmental studies of lake sequences need to consider not only climatic factors (which are admittedly important), but also tectonic and volcanic activity as potential variables controlling the level of the water table, which especially in the case of shallow lakes such as Zacapu, can have considerable ecological impact. In this context, it is worth mentioning that so far, we have been able to identify a total of 12 Late Pleistocene/Holocene (<25,000 y. BP) monogenetic volcanoes within the catchment area (~1500 km^2) of the Zacapu basin which has a perimeter of ~230 km. Judging by the young morphology of the numerous NE-SW oriented extensional fault escarpments, and the occurrence of coeval lake deposits at different altitudes (vertical displacements of tens of meters), this area is certainly still seismically active. Hence, study of the lake deposits should not only consider volcanic eruptions, but also the occurrence of sudden catastrophic differential vertical movements of the lake floor.

Stops 7B and 7C: Proximal deposits of the tuff-cone at the W and NE quarry sections (4B: 19°54'14.78", 101°46'21.72"; 2016 m, and 4C: 19°54'34.51", 101°45'53.06"; 2069 m)

The deposits of this tuff-cone are superbly exposed at several quarry sections. Stops

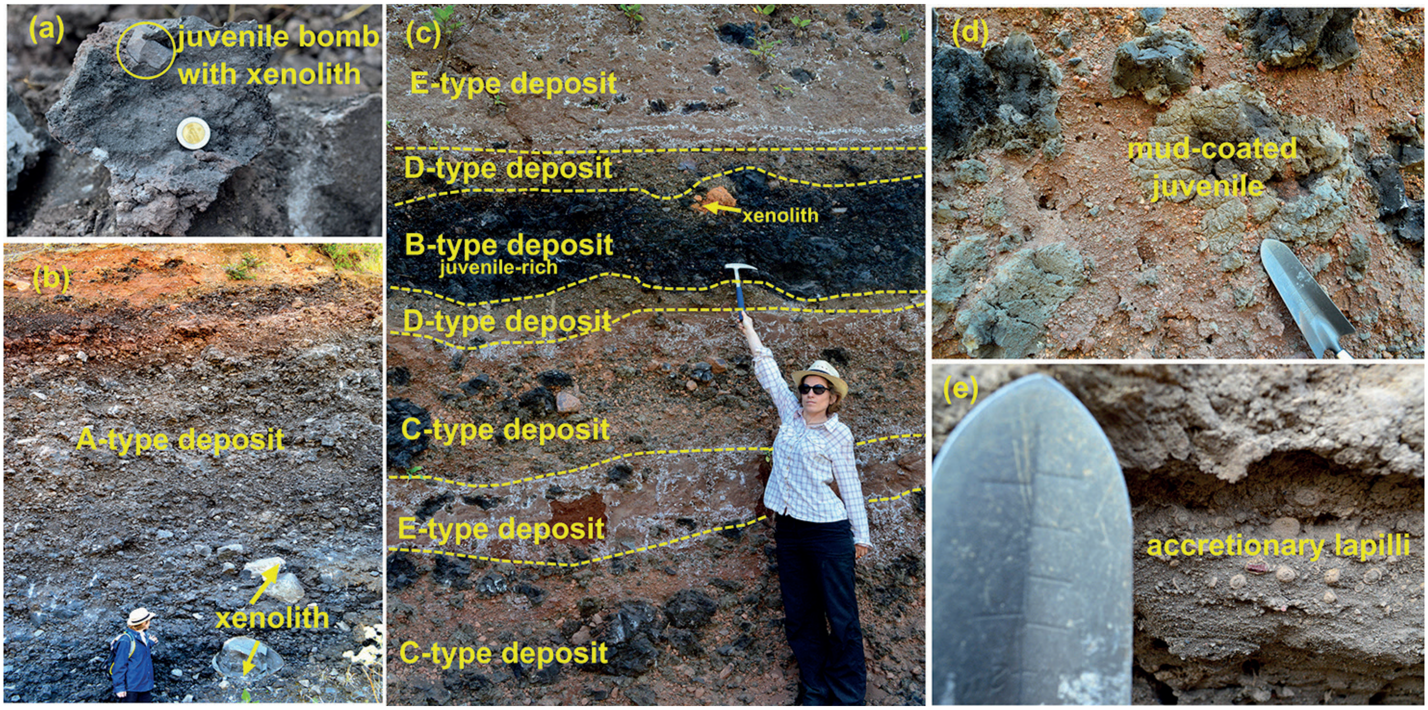

Figure 24: Photos displaying details of Alberca de los Espinos phreato-magmatic deposits at the SW quarry (Stop 7B). The types of deposits are outlined in Fig. 23. a) Andesite xenolith in dark juvenile cauliflower-type clast from A-type deposit at the base of the startigraphic section (coin diameter=2 cm, for scale) b) A-type deposit: Clast-supported, juvenile-rich with few angular xenoliths (grey, vesicular and non-vesicular andesite fragments, containing micro-phenocrysts of plagioclase) indicating a drier magmatic episode. c) Alternating stack of different deposit types: B-type deposits are similar to the A-type, but devoid of xenoliths. C-type deposits were produced by pyroclastic flows (surges) and consist of mud-coated and non-coated juveniles and angular xenoliths embedded in fairly indurated, reddish-brown fine ash. D-type deposits consist of friable fallout units containing grey-colored, clast-supported, coarse lapilli, that are always present at the base and top of the B-type deposits, forming a symmetric arrangement. E-type deposits predominate in the upper part of the sequence and consist mainly of several thin units of fairly indurated, reddish-brown to gray, fine surge deposits stacked together bearing occasional accretionay lapilli. d) Mud-coated juveniles embedded in C-type deposits (small shovel for scale is 15 cm long). e) Accretionary lapilli in E-type deposits (small shovel for scale). Taken from Siebe *et al.* (2014).

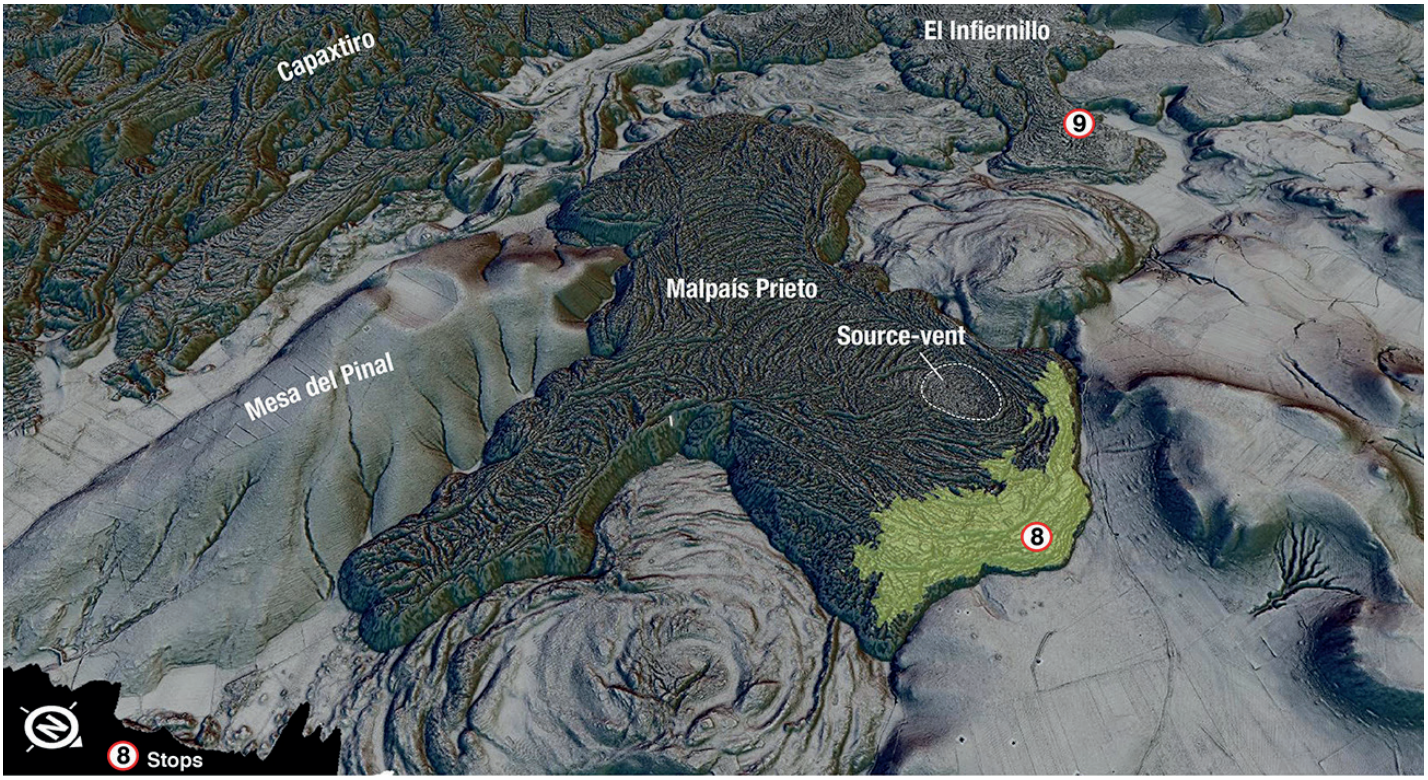

Figure 25: 3D-view of the Malpaís Prieto lava flow with indication in yellow of the area of the archaeological site (Stop 8). Generated from LiDAR data by Antoine Dorison.

7B and 7C show nearly complete sequences (Figs. 21, 22). The deposits are poorly sorted (Mdφ= -4.7 to 3.5, σφ= 1.38 to 3.88) and display several episodes of drier magmatic fallout units (rich in juveniles, SiO_2=57.6 wt.%) alternating with fairly indurated wet phreatomagmatic surge (with accretionary lapilli) along with thick pyroclastic flow sequences (displaying mud-coated juveniles and lithics in a fine matrix). The deposits were classified into different types in order to decipher the eruptive history (Figs. 23, 24). At the northern quarry near the railroad tracks (not to be visited on this occasion), tree casts are evident in the lower pyroclastic-flow units, suggesting the existence of ample vegetation at the time of the eruption.

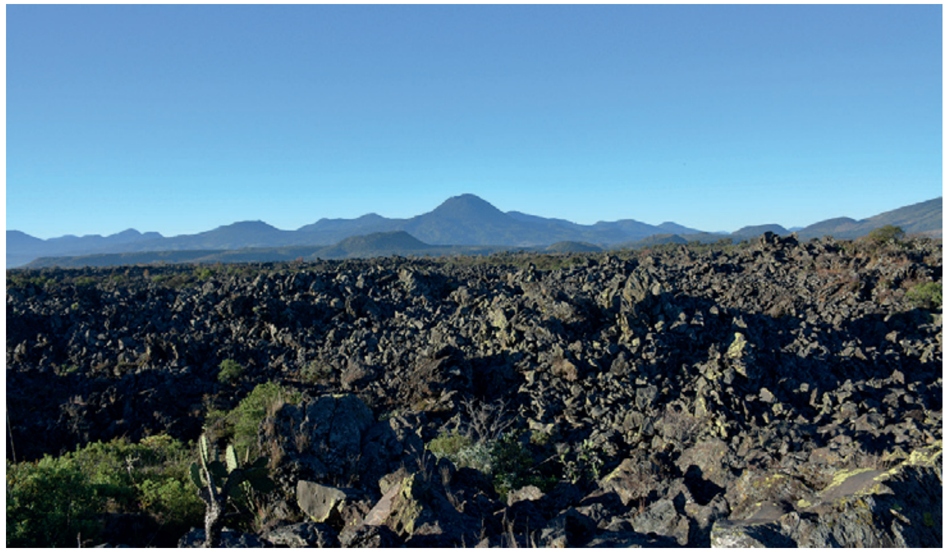

Figure 26: Natural rugged blocky surface largely devoid of soil and vegetation of the Malpaís Prieto lava flow. Photo Grégory Pereira.

Stop 8: The Malpaís Prieto lava flow and the pre-Hispanic city of Ciudad Perdida (19°53'38.6", 101°48'32.6"; 2217 m)

The Malpaís Prieto lava flow can be reached from its northern front by taking the road linking Los Espinos to Caurio. It formed by the fourth and most recent eruption of the Malpaís de Zacapu dated by paleomagnetic means at ~AD 900 (Mahgoub *et al.*, 2018). This eruption emitted a single 0.5 km^3 lava flow covering 5.7 km^2 (Reyes-Guzmán *et al.*, 2018; 2021). Similar to Malpaís Las Víboras, its eruption was purely effusive as no associated pyroclastic deposits were found (Reyes-Guzmán *et al.*, 2021). The lava was emitted from a source-vent near its northern margin and flowed southward before splitting into two distinct lobes: one continued southward and the other flowed eastward after being deflected by the Mesa El Pinal topographic obstacle (Fig. 25). To the N, the lavas encountered the natural step formed by the pre-existent lava from Cerrito Pelón, generating a front that is ~2-km-wide and ~70-m-high. The viscous andesite lava (eruptive temperatures between 950 and 1080 °C, Reyes-Guzmán *et al.*, 2021) formed a particularly rugged and inhospitable topography with a blocky surface presently still largely devoid of soil, humidity, and surface vegetation (Fig. 26).

Despite these constraints, the N front of the lava flow hosts numerous amazingly well-preserved remains of a pre-Hispanic city. The archaeological site bears the same name as the lava flow, although it has also been designated as *La Ciudad Perdida* ("The Lost City"). It covers an area of 40 ha that extends along the lava front (Fig. 25), which was intensively modified by the construction of a system of terraces and leveling fills (Figs. 27a, d). The latter were necessary to allow settling on the originally uneven and rugged surface of the lava flow and building an entire city that included about a thousand dwellings and a dozen civic-ceremonial spaces connected by causeways, roads, stairways, etc. (Forest, 2014; 2018). The occupation of the site began during the second half of the 13th century and lasted less than two centuries. It is estimated that its population might have reached between 5,000 and 6,000 inhabitants. This rapid nucleation of a large population in a previously unoccupied place illustrates the migration and social reorganization processes that preceded the formation of the Postclassic Tarascan state (Pereira *et al.*, 2021; Pereira and Padilla, 2018). Considering that this site was already abandoned several decades before the arrival of the Spaniards, its remains are particularly well preserved.

Excavations carried out in the living areas indicate that the domestic units consisted of one or two houses erected on a terraced space. The dwellings were built with stone walls and roofs of perishable materials. They consisted of a single room with a generally square floor plan in the center of which was a hearth (Fig. 27c). The outside spaces show evidence of different domestic activities: vestiges of granaries, areas dedicated to the preparation of food (grinding stones "*metates*"), to the realization of craft activities, or to the evacuation of waste (Forest *et al.*, 2018). The houses located near the ceremonial centers are usually larger and preserve vestiges that suggest better economic conditions of its dwellers.

The Malpaís Prieto site also includes thirteen pyramid temples associated with plazas and smaller monuments. Each complex shows a similar pattern that suggests a homogeneous political and religious organization. They are integrated by a pyramid temple called *yácata* (Fig. 27a, b), a plaza, at least one altar, and a large ceremonial house. Among these sanctuaries, one stands out for its magnitude and privileged location. Located in the center of the city and near the edge of the highest monumental terrace, it would have been the main focus of the community's ritual life (Pereira and Michelet, 2018). On the east side of the plaza, rises a massive pyramidal base (Fig. 28). In spite of the serious damages caused by looting, it is possible to reconstitute its shape and constructive history. Unlike the famous yácatas of Tzintzuntzan, which combine a circular and a rectangular base, those of the Malpaís all have a rectangular plan, often quite elongated. In its final state, the main pyramid of Malpaís Prieto measured 33 m long by 16 m wide and reached a height of 8.5 m. The walls were formed by thirteen stepped bodies with narrow landings. Its builders mobilized large amounts of blocks extracted from the *malpaís* itself to form the core of the pyramid. The external walls were covered by a face of carefully arranged slabs from quarries of older volcanic rocks located outside the lava flow. In front of this main building, are several other constructions and spaces that frame the plaza: two platforms that served as altars, a cemetery, and two

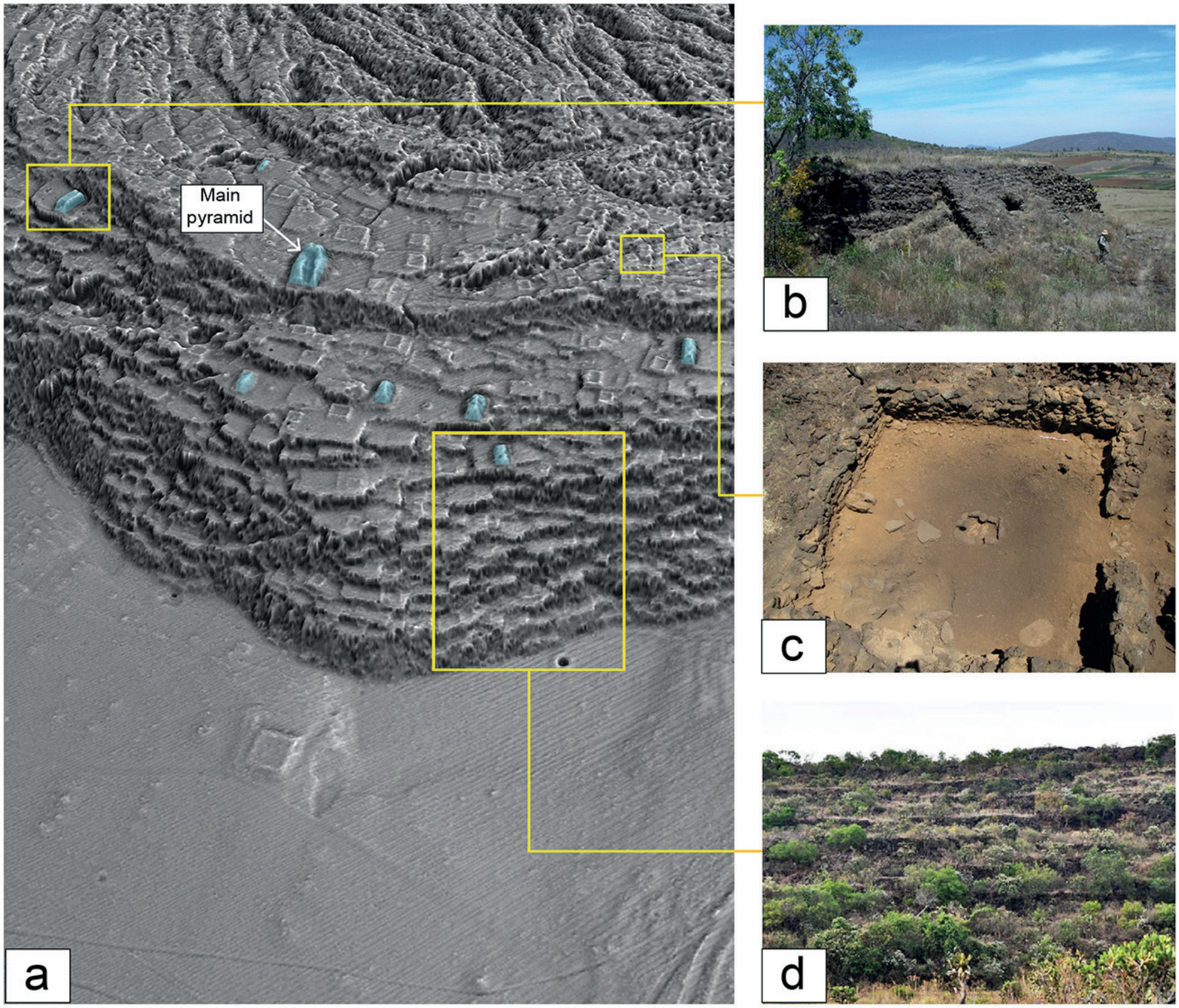

Figure 27: Images of the pre-Hispanic city of Malpaís Prieto. a) 3D-view of the central section of the site showing intensive modification of the northern edge of the lava flow and the high density of archaeological structures (dwellings, platforms, plazas, pyramids; highlighted in blue). b) One of the 13 rectangular-shaped pyramids reported from the site. c) Typical square-shaped dwelling with central hearth. d) Front of the lava flow showing an extended terrace system. LiDAR 3D-view: Antoine Dorison; photos: Grégory Pereira.

Figure 28: Main pyramid of the Malpaís Prieto site. The southern part of the monument (to the right) still holds its original shape while the northern part (left) was heavily altered by a looter's trench. Photo Humberto Romero.

large platforms that supported squared buildings known from the 16th century sources to have been meeting houses for priests and warriors.

Stop 9: El Infiernillo lava flow and archaeological site (19°52'58.9", 101°50'06.5"; 2115 m)

This stop proposes a short walk across the archaeological site of El Infiernillo, located on the homonymous young lava flow (Figs. 29, 30). Like Malpaís Prieto, this settlement site forms part of the general urbanization process that took place on Holocene lava flows at the W margin of the Zacapu basin in the mid-13th century. However, unlike Malpaís Prieto, El Infiernillo was already significantly occupied by humans prior to the main urban phase that peaked in the 14th century.

Today, the area is covered by a sparse oak forest growing on the blocky andesitic lava flow that emanated from the Las Vigas cone (Fig. 30). This eruption was dated by paleomagnetic and radiocarbon means at ~1500 BC (1492-1379 BC, Mahgoub *et al.*, 2018; and 3200 ±30 y. BP = 1471 cal BC, Reyes-Guzmán *et al.*, 2018, respectively). El Infiernillo consists of two flow units (Fig. 29). The first and larger one extends northward and reaches 3.5 km from its source while the second flowed toward the E as far as 2 km. Together they form a 30 to 40 m-high, gently undulating plateau that covers ~400 ha, with a slight slope (<5°) that descends to the N. An area of ~160 ha of the flow's surface has been modified by human activity, mainly at its NW fringe, but also at its S limit.

Archaeological investigations at the site have been conducted sporadically, starting in the 1980s, then in 1994-1995, 2010, and following the acquisition of LiDAR data from 2015 until today. Excavations and ceramic typochronology have allowed to establish that the first phase of occupation took place around the 7th-8th century AD, on the western margin of the flow. The site's history is then marked by a hiatus of more than two centuries beginning in the 10th century, probably related to the effusive eruption of the nearby Malpaís Prieto. A second period of colonization began in the mid-13th century, with landscape modifications extending up to 1.5 km toward the interior of the flow's surface. The site was finally abandoned in the early 15th century. It is this second urban phase that was first identified by archaeologists. It is materialized by more than 1,400 square residential features built on locally levelled platforms, thus forming a very dense urban grid. From this, we estimate that the city could have accomodated nearly 8,000 inhabitants. It was punctuated by ~20 civic-ceremonial areas displaying a pattern similar to that described for the Malpaís Prieto. The whole site is interconnected by a well-developed network of pathways that allowed circulating with ease on the rugged terrain. During this urban phase, Infiernillo was in contact with the other cities of the region. They may have been allies in some aspects (e.g., defense against external threats) and competitors in others (e.g., day-to-day food production). The pre-urban occupation phase is characterized by larger open areas where residential features are harder to detect. Studies conducted in other parts of the region show that the ceremonial architecture of this earlier period was morphologically different. Few examples of such architecture have been detected at El Infiernillo, with the exception of two large ball courts—a typical Mesoamerican

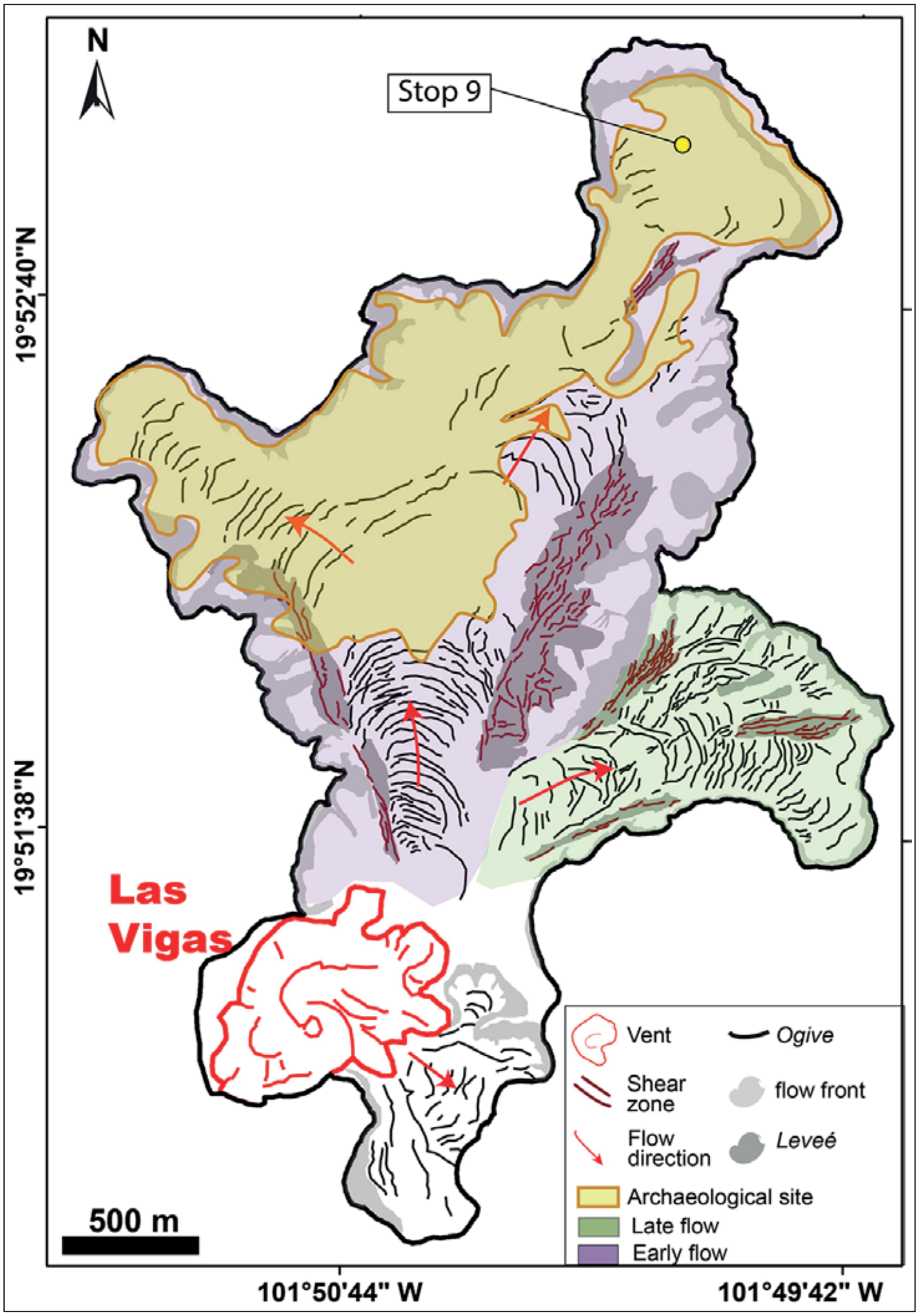

Figure 29: Sketch map showing main morphological features of the Infiernillo lava flow with the extent of the archaeological site. Modified from Reyes-Guzmán *et al.* (2021).

building—in the NW part of the site. This early colonization of the flow seems to correspond to the last expansion stage of a population cluster established as early as the 6th century to the NW, on the lower slope of the Las Flores dacitic dome, and the Malpaisillo and Las Minas flows.

Among the most striking features of El Infiernillo are the thousands of concavities (Fig. 31a) built by the systematic clearing and accumulation of andesite blocks from the flow's surface, whose function remains enigmatic. The smallest examples measure a few square meters (Fig. 31b, c) while the largest may cover almost a hectare. Ongoing investigations indicate that they were built during both phases of occupation of the site; the larger ones being characteristic of the earlier phase and the smaller ones, organized in parcel systems, being typical of the urban phase. Excavations suggest that these were dedicated to various domestic activities. A hypothesis, currently being tested, is that they may have been used for agricultural purposes. A geoscientific component of the ongoing research has demonstrated that a thin layer of soil formed from volcanic ash deposits covering the entire lava flow (Fig. 32). The mineralogy observable in thin sections under the microsope indicates that the ash probably resulted from a late explosive phase of the eruption (occurrence of olivine in the coarse tephra-clasts embedded in the soil). Thus, the anthropic concavities, apart from creating walkable areas, were also intended to concentrate soil derived from the ash. The systematic concentration, especially in areas where sediments and moisture tend to accumulate (between pressure ridges), shows that these pebbly soils were valuable to the builders of the site. Indeed, the agricultural exploitation of stony soils in pre-Hispanic times is mentioned in 16th century texts, but such practices have never been archaeologically documented. If this is the case at El Infiernillo, in-site gardening may thus have constituted another component of this pre-Hispanic city. However, this incredibly well-preserved testimony of the premises of the important pre-Hispanic Tarascan culture, is today gravely endangered by the desire to obtain short-term profits from uncontrolled wood exploitation, and agricultural developments that unfortunately, have already led to the irremediable destruction of the core of this magnificent archaeological site.

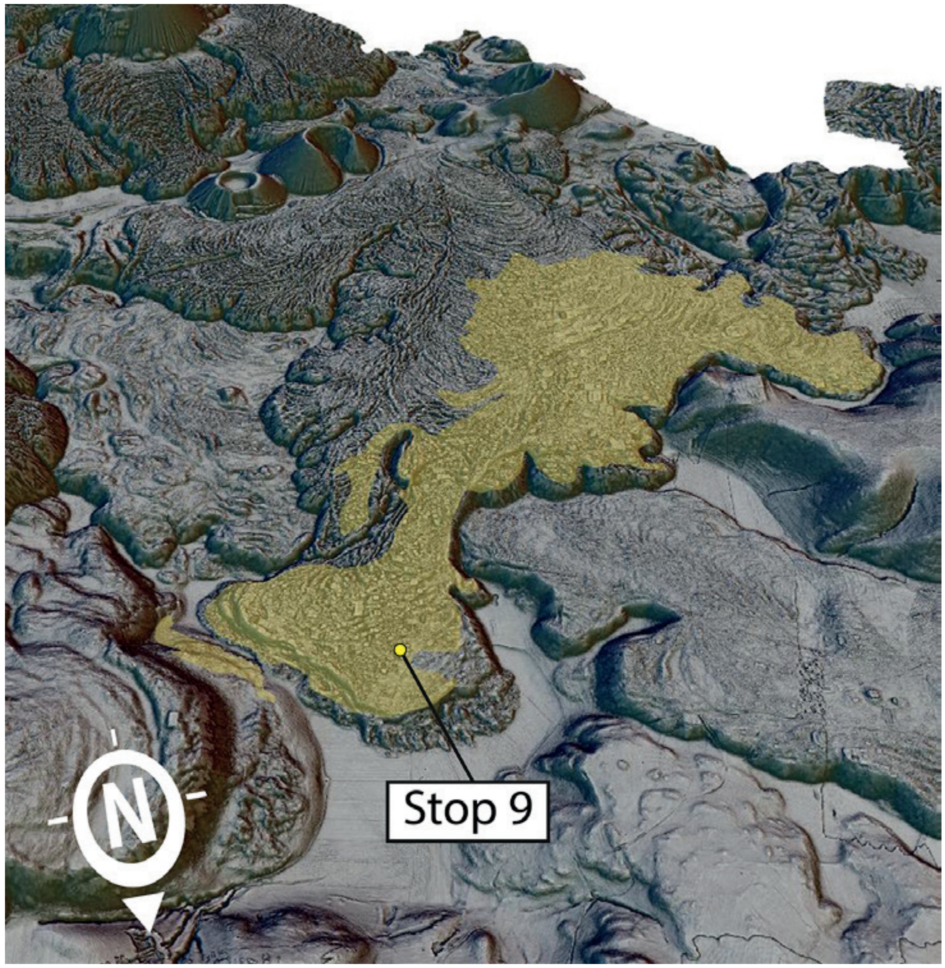

Figure 30: 3D-view of the Infiernillo lava flow with extent of the archaeological site. Generated from LiDAR data by Antoine Dorison.

Stop 10: Las Minas, a Pre-Hispanic mining complex of a dacite lava flow (19°52'28.3"; 101°51'38.3"; 2160-2200 m)

The Middle Pleistocene (1 Ma-100 ka) Las Minas lava flow is dacitic in composition (SiO_2 = 63-70 wt.%) and associated to the Las Flores dome complex dated at 0.92 ± 0.22 Ma (Reyes Guzmán *et al.*, 2018). In addition to Las Minas and Las Flores, another three nearby volcanoes with a dacitic composition were identified: La Guajolota, Cerro Vicente cone and its associated lava flow, and Las Milpillas Sur. All of them are Pleistocene in age and clustered in the NW sector of the Zacapu lacustrine basin (Reyes-Guzmán *et al.*, 2018). Although these five structures share several characteristics, each of them has its own peculiarities and only the Las Minas (Quezada and Darras, in press) and the nearby Cerro Vicente lava flows (Darras *et al.*, 2017) show evidence of pre-Hispanic mining activities (Figs. 15, 33).

The Las Minas lava flow is located ~25 km to the NW of the city of Zacapu and can be reached after driving ~4.5 km on an unpaved road from Caurio de la Rinconada, the nearest town. To the N, Las Minas is limited by the Malpaisillo lava flow, while its S slope faces the westernmost margins of the Holocene Infiernillo lavas (Fig. 33). The Las Minas lava flowed from W to E, forming a wide and elongated plateau with lobate fronts and steep marginal slopes (30°-45°). Given its age, the lava flow is covered by a clayey soil of variable thickness (<1 m). The thickest soil layer has formed along the entire length and width of the plateau, while on the lateral margins its thickness decreases. On the lobate steep lava flow fronts, the soil is particularly sparse and the underlying rocky lava blocks are extensively visible.

The Las Minas lava flow hosts two archaeological sites. On the northern plateau is La Mesa (Fig. 33), an Epiclassic (AD 550 to 900) site with monumental architecture, where civic, administrative, and ceremonial activities took place. La Mesa most likely played a key role in controlling the extraction of dacite.

On the SW margin of the flow is the second site, Las Minas (Figs. 33, 34), after which the lava flow takes its name. It consists of the remains of an ancient and important mining complex, where vitreous, dense, fine-grained dacite blocks were extracted. Here, the lava rocks display a very glassy matrix (49 vol.%, Reyes Guzmán *et al.*, 2018), an attribute that made this rock an ideal material for obtaining excellent cutting and carving edges.

The mines and workshops at the site testify to the continuous and organized exploitation of dacite by the human groups that occupied this territory from 100 BC to AD 1450. Over a period of fifteen centuries, the inhabitants of the Zacapu area used dacite as a raw material for making a range of lithic artefacts for subsistence, craft, ritual, and warfare activities (Fig. 35). Although dacite was exploited in the region over a long period, the intensity of exploitation varied over time, but between AD 600 and 850 the mining complex probably was at its peak of activity.

The Las Minas complex includes three sectors of different nature and functionality (Fig. 34). The first corresponds to the mining areas proper, where the extraction pits (Fig. 36A, B) are linked to other spaces such as dumps (Fig. 36 C, D) and places for the production of lithic artifacts. The second consists of a series of agricultural arrangements (cultivation terraces), and the third of two architectural complexes with uncovered esplanade-type spaces (Fig. 34), where possibly activities linked to the management of stone and agricultural resources were carried out.

The mines and workshops are irregularly distributed on a 1.2 km E-W strip along the southern slope of the lava flow, and mostly comprise open-pit mines. At the main sector are two, small tunnels (Fig. 36B), from which the dacite of the highest quality was extracted. The absence of weathering alteration rinds around dacite blocks, as well as the retention of humidity, were valued by the pre-Hispanic knapping artisans, as these qualities facilitated their work.

To date, the only dacite mining complexes reported and studied in Mesoamerican contexts are those located at the Cerro Vicente (Darras *et al.*, 2017) and Las Minas (Quezada and Darras, in press) sites in Michoacán. In addition, Las Minas is so far the only site in Mesoamerica where underground exploitation of a volcanic rock such as dac-

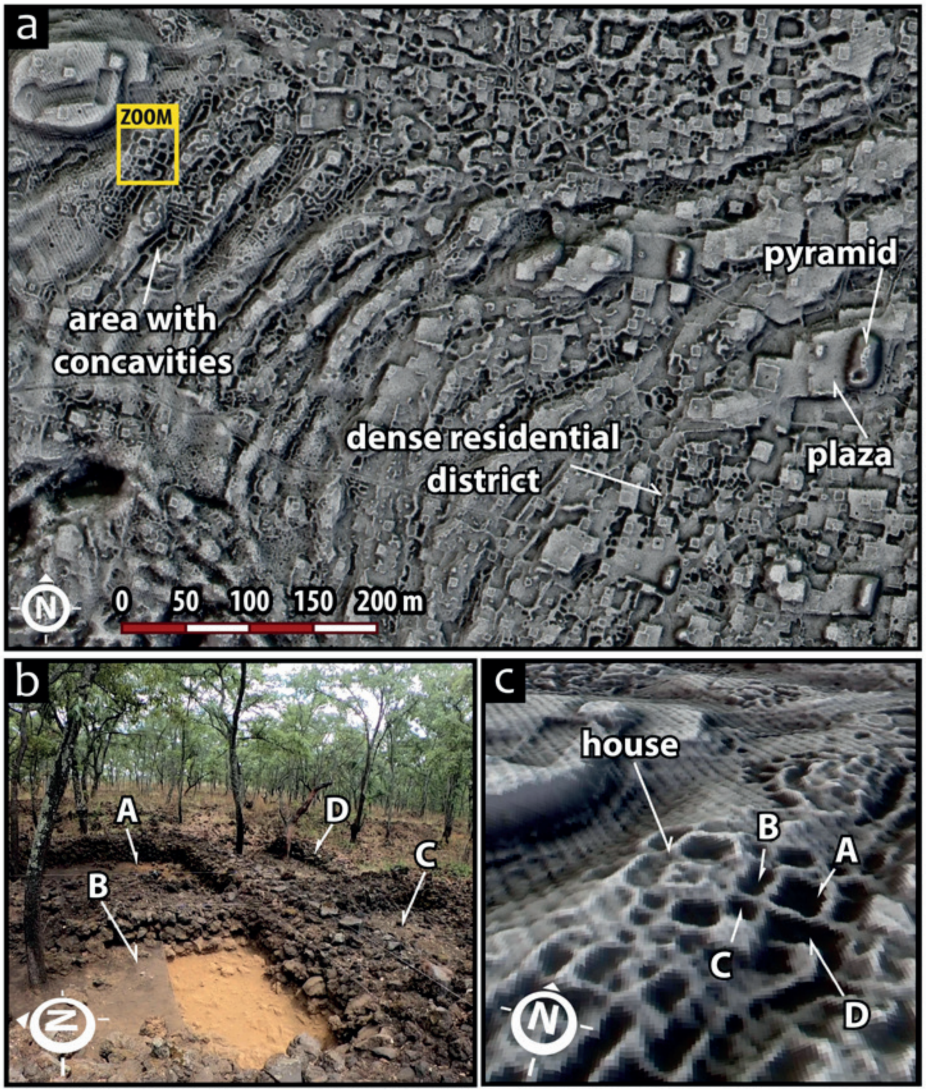

Figure 31: a) Lidar-derived visualization of the central-western part of the Infiernillo archaeological site showing the urban morphology of the settlement. b) Example of a cluster of anthropogenic concavities found during the excavation. c) LiDAR-derived 3D view of the same cluster shown in b). Images by Antoine Dorison.

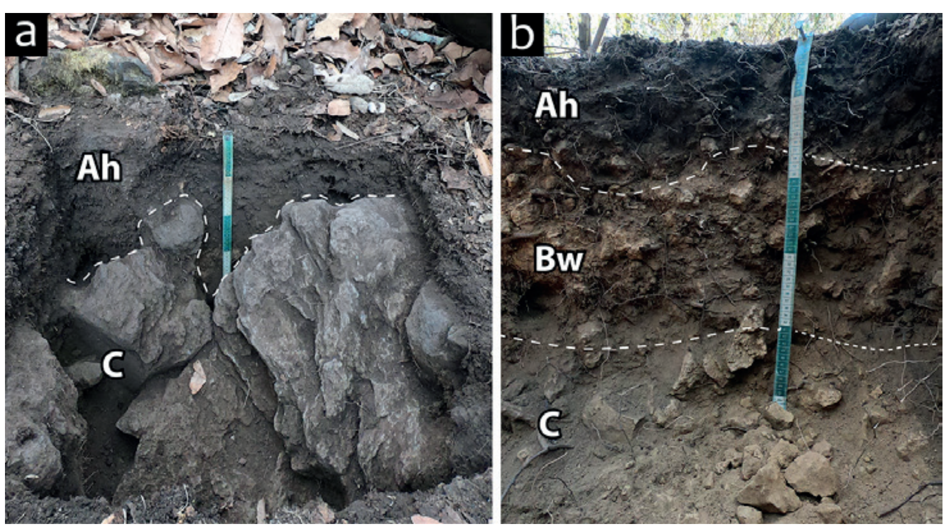

Figure 32: Typical horizon sequence of a volcanic ash soil on El Infiernillo lava flow a) without and b) with human modification. Photos by Antoine Dorison.

ite has been discovered. It should be noted that the underground extraction system is a method that in pre-Hispanic times had only been recognized for obsidian and minerals such as cinnabar. Undoubtedly, the exceptional quality of the dacite from Las Minas, given by its vitreous matrix and its homogeneity, made it an ideal raw material that motivated the development of a complex and well-organized mining process, which contributed to the economic development of the basin.

Stops 11 and 12: Las Cabras breached scoria cone

The Las Cabras scoria cone is located 10.5 km W of the Zacapu lacustrine plain in a tributary valley between two older volcanoes: The steep Late Pleistocene Cerro El Tecolote dome and the older (~0.11 Ma) Cerro El Tule basaltic-andesite shield (Reyes-Guzmán *et al.*, 2018). The latter shares the typical circular basal geometry and low-sloping flanks of other shields in the MGVF (Figs. 15, 37, 38). Although Las Cabras volcano is morphologically similar to many other young scoria cones in this area, its products display peculiar sedimentary and textural features that make it particularly interesting (Guilbaud *et al.*, 2021).

The eruption of the volcano included two main phases of activity: An explosive phase that built a ~170-m-high scoria cone and deposited thick ash-fallout exposed mainly to the N and NW of the cone, and an effusive phase that formed a >7 km long lava flow field that emerged from a major breach in the cone (Figs. 37, 38). The area covered by the flows and their volume were estimated at 18.2 km^2 and 0.6 km^3 respectively, while the volume of the cone is only 0.07 km^3. Radiocarbon dating of paleosols directly below the fallout deposits yielded ages ranging between 27,000 and 26,000 y. BP (Guilbaud *et al.*, 2021).

Juvenile products (scoria clasts and lavas) vary from basaltic andesite to andesite (54–62 wt.% SiO_2). The mineralogy is similar for lava and scoria samples: Both contain olivine and plagioclase phenocrysts (<1-3 mm) in a matrix rich in plagioclase microlites. Samples from the upper tephra unit (late tephra) span this whole range, while lavas and samples from the lower tephra unit (early tephra) spread over a more restricted range (57-61 wt.%). Samples with light-grey Bt-bearing material are dacitic (63-67 wt.% SiO_2) and their SiO_2 content

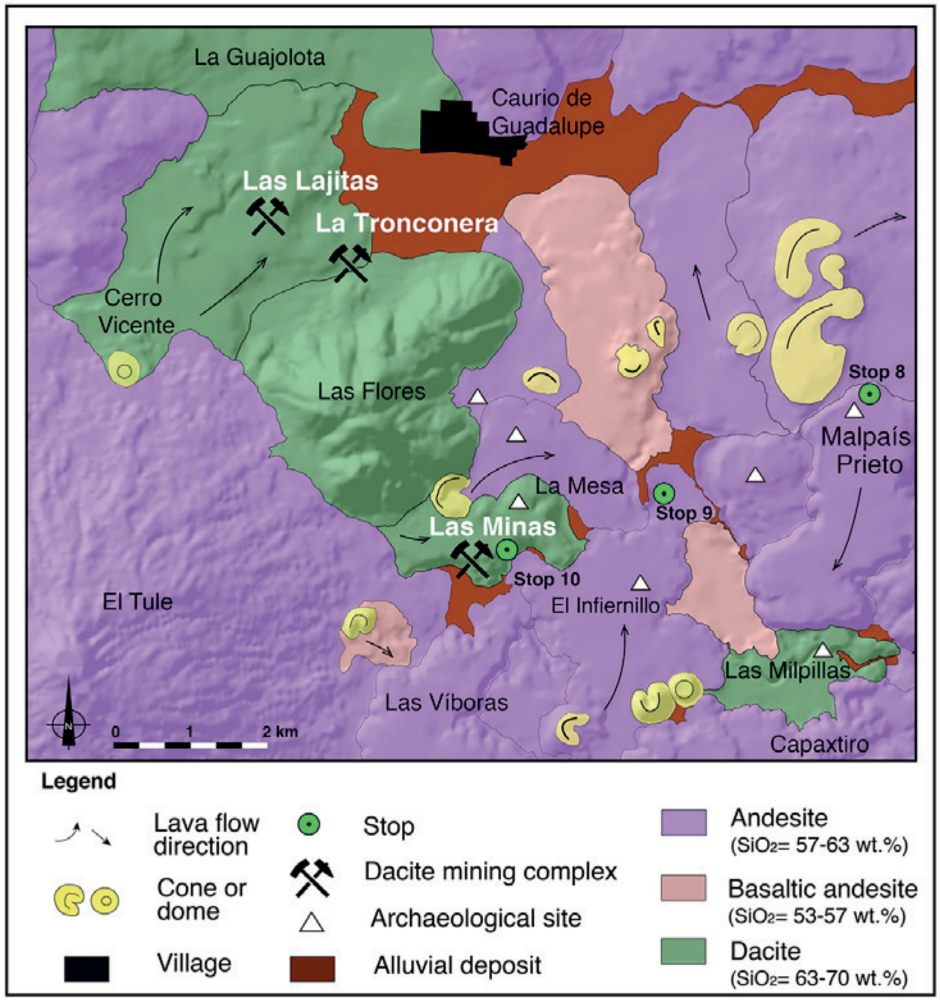

Figure 33: Map indicating archaeological sites of dacite extraction and rock compositions of the different volcanoes and lava flows. Drawn by Osiris Quezada and Nanci Reyes.

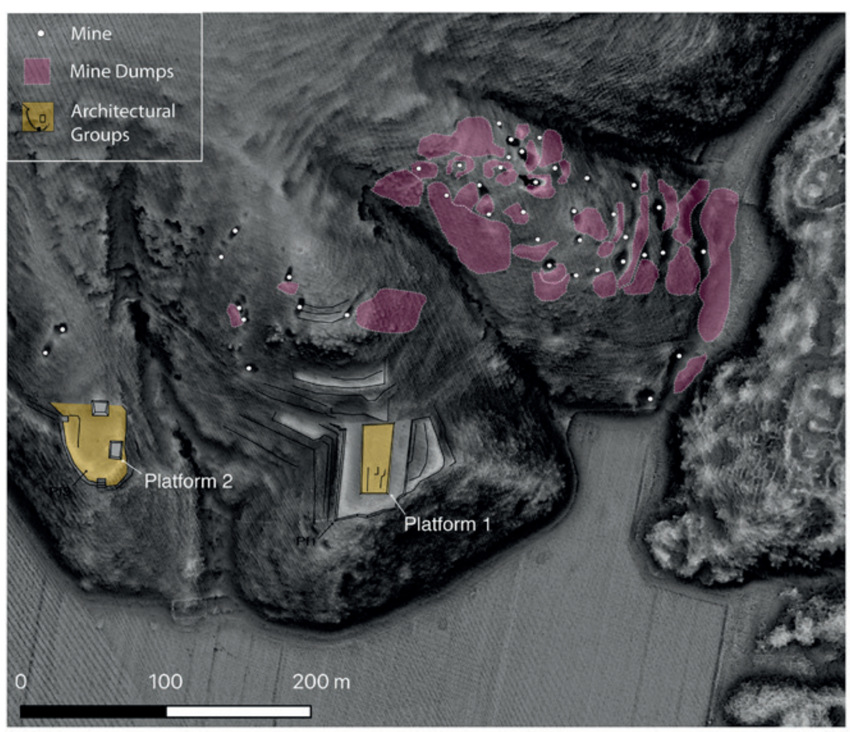

Figure 34: Map showing the core of the Las Minas mining pit area where the majority of extraction sites is located. Associated architectural features are also indicated. Drawn by Osiris Quezada.

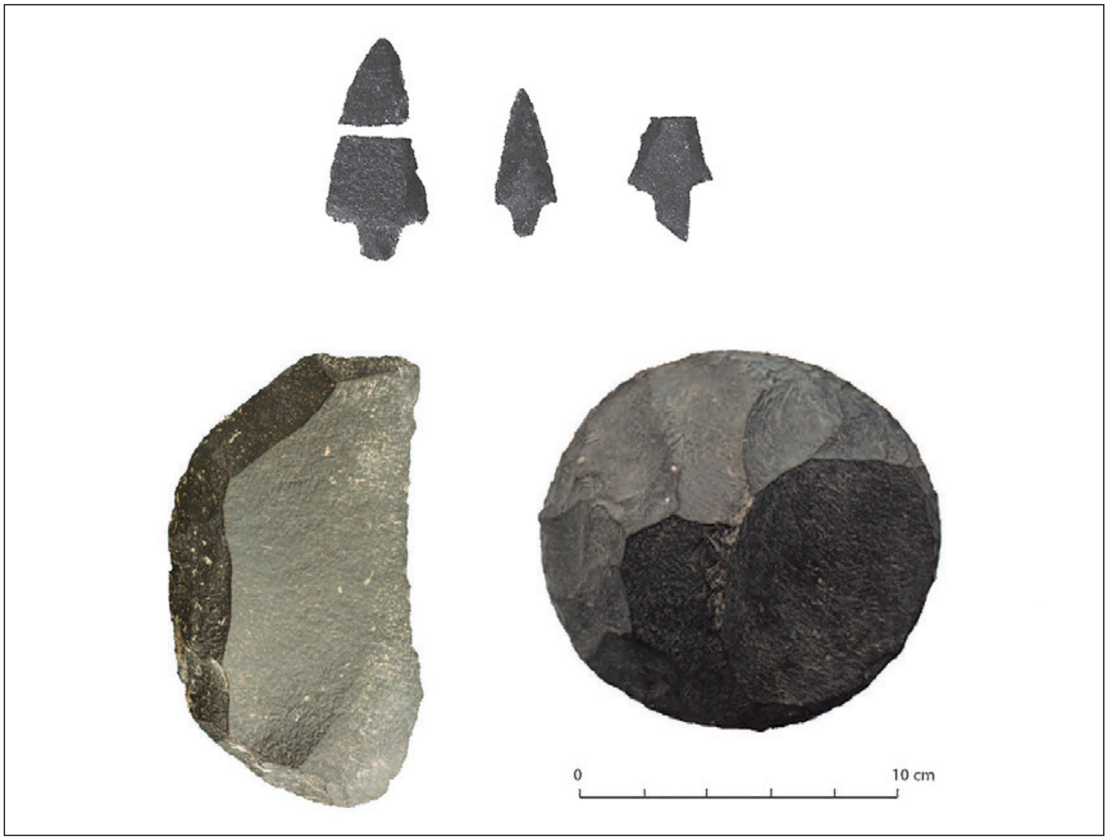

Figure 35: Examples of dacite artifacts (half-moon shaped knives and projectile points) found at the Epiclassic sites of Potrero de Guadalupe and Rincón de las Flores, situated in the Las Lomas area and to the NW of El Malpaís, respectively. Photo Osiris Quezada.

Figure 36: a) Front of an external extraction pit that serves as an entrance to tunnel UEx-2. b) Interior of tunnel UEx-1. c) and d) Views of an accumulation (dump) of flaking debitage at an artifact workshop. Photos Osiris Quezada.

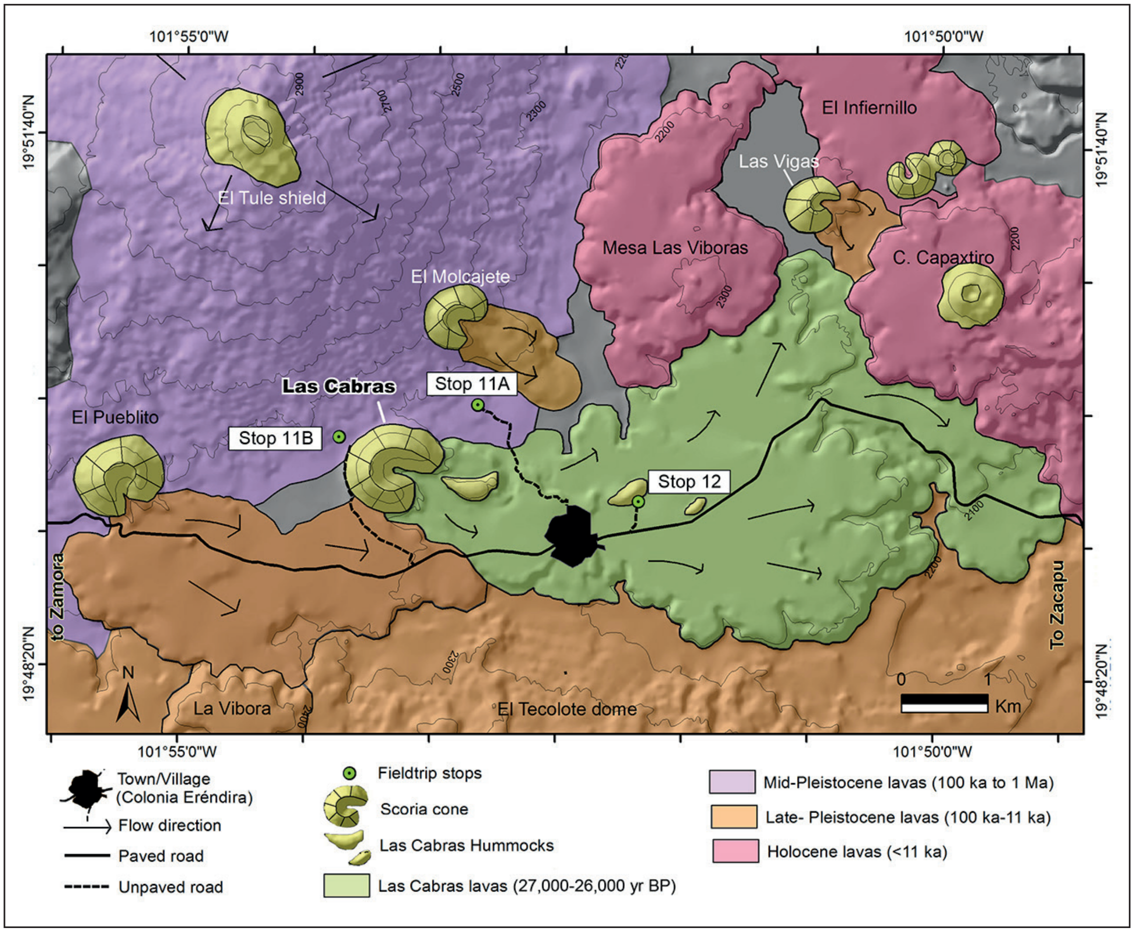

Figure 37: Geological sketch map of Las Cabras cone and associated lava flows indicating location of Stops 11A and 11B (fallout deposits) and Stop 12 (hummock). Taken from Siebe *et al.* (2014) and drawn by Athziri Hernández.

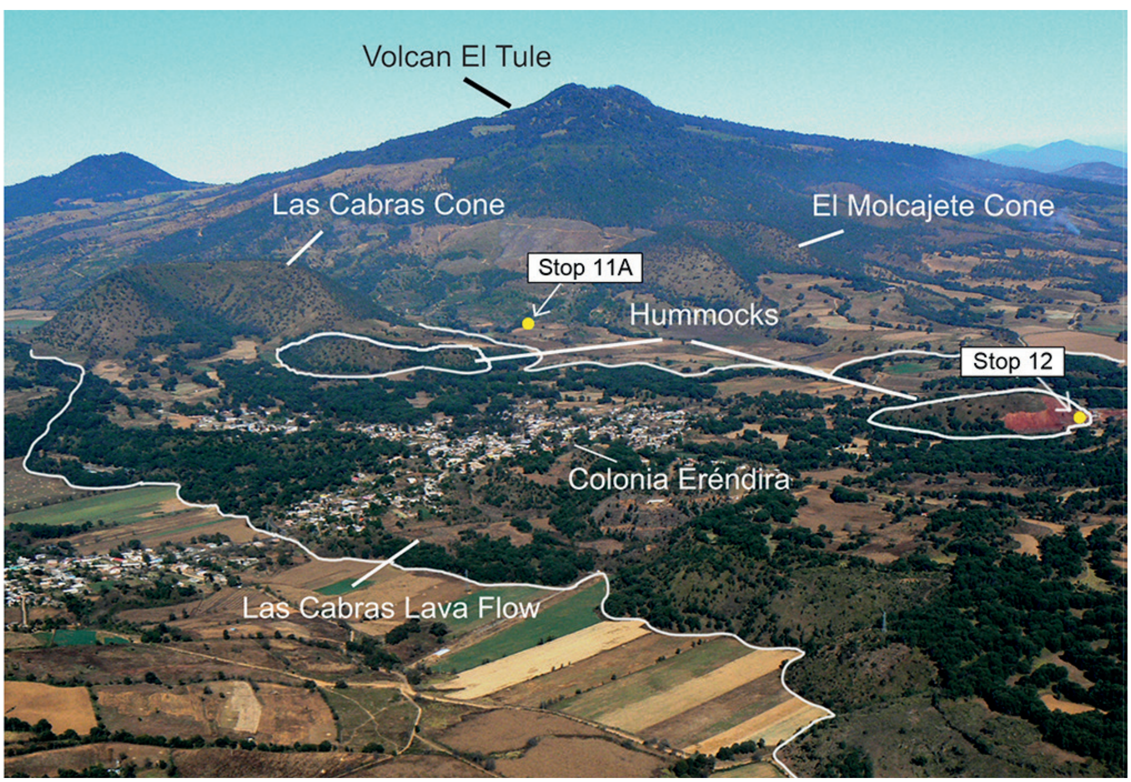

Figure 38: Aerial photograph from the SE of Las Cabras scoria cone and proximal deposits (hummocks, thick andesite lava flows). Note red color of scoria agglutinates exposed in quarry of hummock to the right (Stop 12). Taken from Siebe *et al.* (2014).

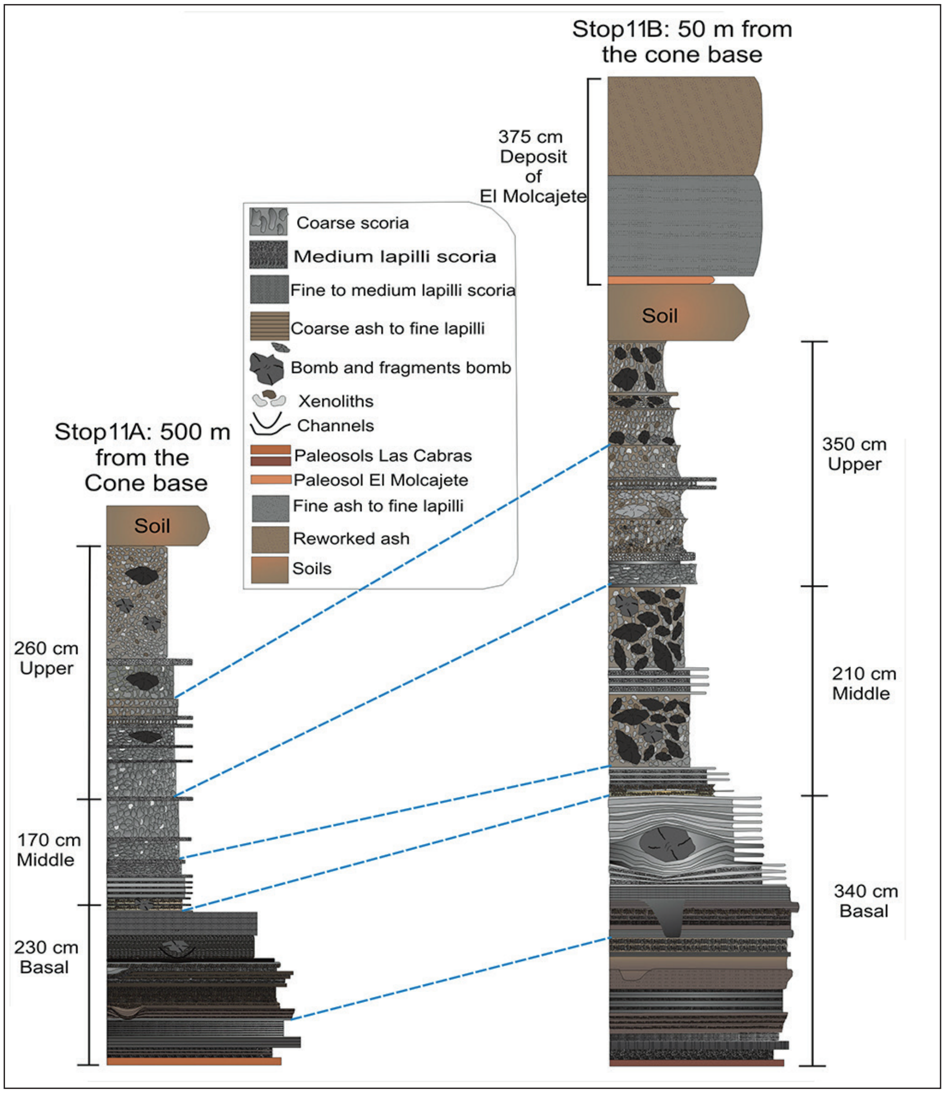

Figure 39: Stratigraphic sections of Las Cabras fallout deposits at Stop 11A located 500 m and another quarry (Stop 11B) located 50 m from the base of the cone. The different parts of the sequence (basal, middle, upper) described in the text are indicated. Layers at the most proximal quarry are thicker, richer in bombs, and contain larger bombs in the upper part. Taken from Siebe *et al.* (2014) and drawn by Athziri Hernández.

increases linearly with the proportion of xenolithic material in them (Guilbaud *et al.*, 2021). A total of three nearby quarries will be visited. The first two (Stops 11A and 11B) superbly expose the Strombolian scoria fallout deposits, while the third (Stop 12) shows the interior of a large hummock that belongs to the debris avalanche deposit produced toward the end of the eruption.

Stops 11A and 11B: Quarries displaying Las Cabras fallout deposits with evidence for syn-eruptive rain and magma mingling (11A: 19°50’00.2”, 101°53’10.5”; 2265 m; 11B: 19°49’47.0”, 101°53’51.7”; 2324 m)

Proximal tephra fallout deposits at Las Cabras can be divided into three main parts: a) A basal indurated part dominated by thin fine-grained (ash and fine lapilli) layers and sporadic bombs, b) a middle part consisting of increasingly thicker (6-50 cm) and coarser grained (4-16 mm in size) layers, and c) an upper, friable part characterized by thick (10-100 cm) layers, coarse clasts (16-64 mm), and large bombs (Fig. 39). Layers forming the basal part consist of a mixture of highly-vesicular and dense juvenile clasts, while accidental lithics first appear in the middle and get more abundant toward the upper part, where juveniles are mostly of the highly-vesicular type.

Noteworthy at these locations is the exposure of various sedimentary structures in the fine-grained basal part that are diagnostic of the occurrence of torrential rain during the eruption (Fig. 40). The most notorious are asymmetric erosion channels that are 10-18 cm deep, 30-40 cm wide, and display a near constant horizontal separation interval of 80-100 cm (Fig. 40a). They affect mostly the finest, most indurated layers of the sequence and are concentrated in two stratigraphic levels. Impact-sag structures that were produced by large bombs causing ductile and brittle deformation of the underlying layers (Figs. 40b, c) are also well exposed. In addition, bombs in the upper part of the sequence display peculiar characteristics. Many of them are dense and glassy, almost obisidian-like. Others show marked flow-banding (Fig. 40d) indicating mingling of two types of magma prior to explosive eruption. Interestingly, these peculiar bombs are petrographically distinct from the others since they bear phenocrysts of biotite (<4.1 mm), in addition to the usual olivine and plagioclase crystals.

Stop 12: Large hummock (Las Cabras debris avalanche deposit) with coarsely stratified deposits rich

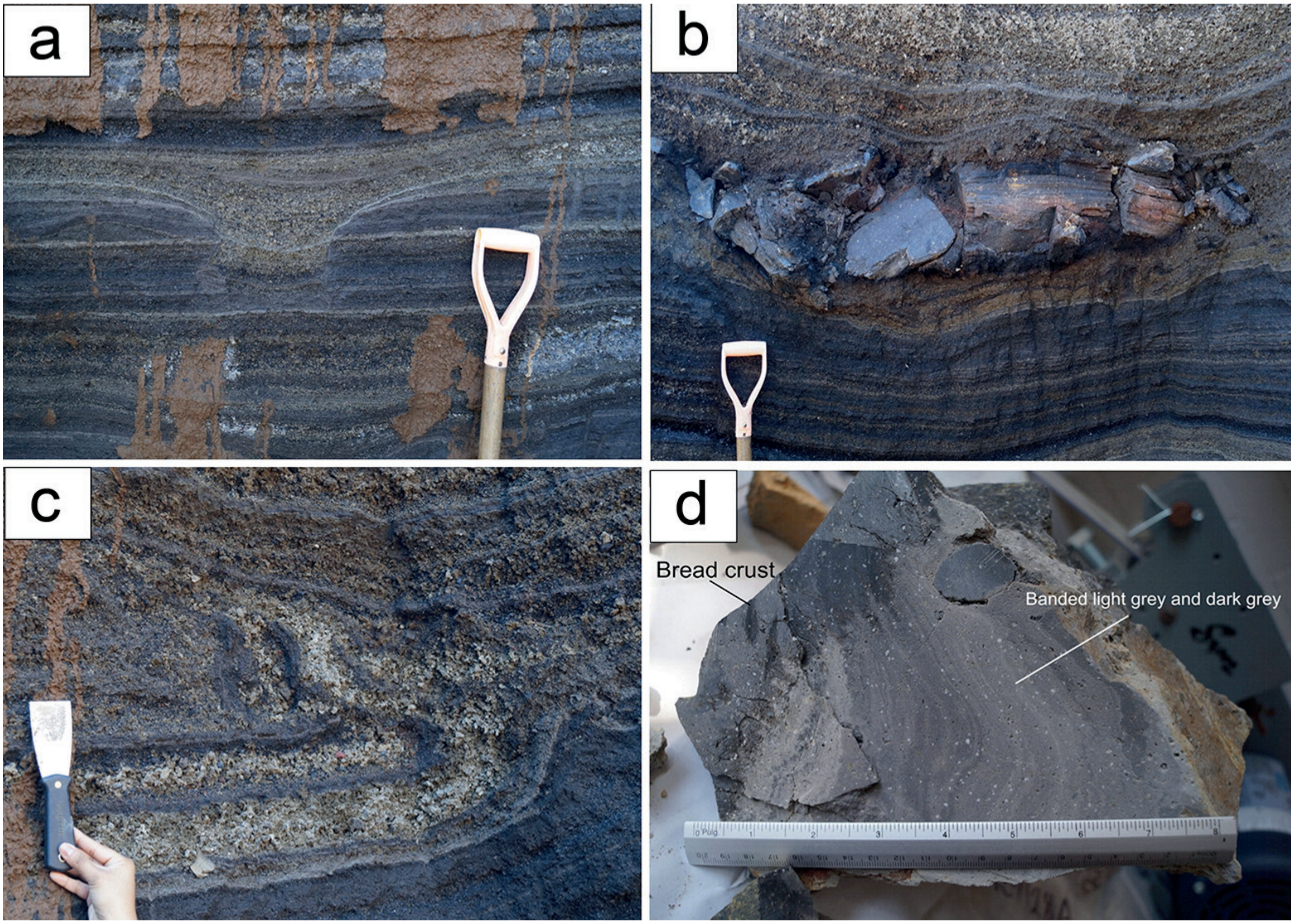

Figure 40: a) Erosion channels are 10-18 cm deep, 30-40 cm wide and affect mostly the finest and most indurated layers of the sequence (basal sequence at Stop 11A). b) Large bomb fragmented due to impact (2.11 m long, 0.43 m wide) observable in the basal part of the stratigraphic section (Stop 11A). c) Ductile deformation (folded layers) produced by ballistic impact (Stop 11A). d) Fragment of bread-crust bomb with outer dark glassy rind and distinct interior displaying parallel flow-banding. Layers of micro-vesicular light-grey material alternate with denser dark-grey layers. Larger xenolithic enclaves (<2 cm) surrounded by bands are common. All layers contain micro-phenocrysts of plagioclase (~2 mm), olivine (~1.5 mm), and biotite (~1 mm). The crust is richer in Plag than the core, but the core is richer in biotite (Stops 11 and 12). Taken from Siebe *et al.* (2014).

in bread-crust bombs (19°49'25.8", 101°51'58.5"; 2252 m)

The lava surface displays a few peculiar elongated mounds or hummocks (Figs. 37, 38). This quarry exposes the interior of one of the largest (420-m-long, 200-m-wide, 15-m-high) hummocks in the area, revealing coarsely stratified, partly-welded fallout products rich in scoriaceous spatter-bombs and large bread-crust bombs (~1-2.5 m in size) (Fig. 41). The bombs have been piled up on site due to their non-utility for road construction and hence are particularly well exposed at this location. They nicely display internal concentric vesicular zoning and stretched and cracked outer glassy skins (bread-crust surface textures).

These features are typical for proximal andesite scoria-cone deposits hence, the hummocks must have originally been part of the cone. The hummocks probably formed as a result of the breaching of the eastern flank of the cone by the lava flow that then rafted parts of the detached cone down the flow. The elongation of the hummocks in the direction of the flow (Fig. 37) suggests that after detachment from the cone, these were carried on top of the lava flow.

Stop 13: Zacapu city (19°48'50", 101°47'25.5"; 2002 m)

The modern city of Zacapu (~55,000 inhabitants) is located on the SW margin of the basin. It is the head of a municipality that encompasses the SW portion of the lacustrine basin and its surrounding volcanic reliefs, including the Malpaís de Zacapu. This important regional commercial and industrial hub (chemical factories on the NE outskirts) is built on a relatively flat terrain wedged between the Capaxtiro lava flows and the Laguna de Zacapu pond, within the area that was formerly the shore of the dried-up lake.

The center of Zacapu is on a hill on which the church and former cloister of Santa Ana stand (Fig. 42). The colonial city was founded in 1548 by Fray Jacobo Daciano, a Franciscan missionary of Danish descent, who arrived in New Spain in 1542 and participated in the evangelization of Michoacán. Today, the church opens toward the recently remodeled Plaza Morelos, where the *Casa de la Cultura* (municipal cultural center) is located. A walkway connects this area with the nearby main square of Zacapu, which is flanked by the city hall and the Los Portales building, a notable vestige of traditional colonial architecture, that originally surrounded the entire square. From there, it is

Figure 41: Exposure of the interior of a hummock at Stop 12 showing coarsely stratified deposits rich in bread-crust bombs. The largest bombs were left behind by quarrying activities forming piles at the base of the hummock. Photo taken January 29, 2014 by Claus Siebe.

Figure 42: Santa Ana church and adjacent former cloister in Zacapu city. Photo courtesy of the Zacapu city council.

Figure 43: Chinampa-type orchard at the shore of the small Laguna de Zacapu. Photo Grégory Pereira.

Figure 44: *Bicentenario monument*, inaugurated in 2021. Photo Grégory Pereira.

possible to take a short walk to the La Zarcita springs (to the NW) and the nearby shore of the Laguna, a small natural pond that survived the desiccation of the main lake at the beginning of the 20th century. An ancient cultivation system with canals and artificial islets, known in Mexico as *chinampas*, can still be observed on its shore (Fig. 43). In 2021, as part of the bicentennial festivities of the independence from Spain (initiated in AD 1810), the municipal authorities inaugurated the *Bicentenario monument* (Fig. 44), a peculiar building that at first glance resembles the famous *Arc de Triomphe* in Paris. It is located in the central island of a roundabout at the road exit towards Pátzcuaro. The eclectic sculpted decoration of this monument illustrates not only the main episodes of the region's history, from pre-Hispanic and colonial times to the current COVID-19 pandemic, but also highlights other themes such as the current inhabitant's love for cycling.

DAY 3: VISIT OF EL PALACIO-LA CRUCITA SITE (NEAR ZACAPU) AND DRIVE TO THE PATZCUARO LAKE BASIN (TZINTZUNTZAN AND ANGAMUCO ARCHAEOLOGICAL SITES)

During the third day, we will first visit the archaeological site of El Palacio-La Crucita (Stop 14), located on a distal El Capaxtiro lava flow at the NW outskirts of the city of Zacapu. From there, we will head SE towards the basin of Pátzcuaro on highway No. 15 to Quiroga (Fig. 50) at the NE margin of the Pátzcuaro lake. There we continue SW and arrive at Tzintzuntzan and its archaeological site (Stop 15), the former capital of the Tarascan empire. After inspecting the ruins and the colonial buildings in the center of the present town, we continue to the city of Pátzcuaro, located at the S margin of the lake and visit its main square (Stop 16) with its colonial buildings. In the afternoon, we drive back to Morelia on freeway 14D and en route visit the arcaheological site of Angamuco (Stop 17), built on the distal lava flows of Rancho Seco volcano. The trip will end at the conference venue near the square of Morelia.

Itinerary: Exit Naranja to the NW and at the *roundabout (Bicentenario monument) follow the signs to the center of Zacapu. From the Santa Ana church go W along Zaragoza Street and at Luis Moya turn left until reaching the junction with La Crucita alley and park the car. Continue on foot along a walking path that ascends to La Crucita (a large Christian cross) which is at the core of the El Palacio site (Stop 14). From here inspect a few nearby places of interest and enjoy the panoramic view over the city and lacustrine plain beyond. After walking back down to the parking lot, drive on the shortest route to Tzintzuntzan at the shores of Pátzcuaro lake (total of ~47 km/60 Mins.). First, drive to the roundabout (Bicentenario monument) and exit Zacapu on highway 15 toward the SE. After passing Naranja and climbing the mountainous volcanic range that separates the Zacapu from the Pátzcuaro basin, arrive at the town of Comanja (~14 km/20 Mins.), located a few hundred meters beyond the highest topographical point on the drainage divide (*Fig. *50). From here, on the left side, the Calabaza scoria cone dated at ~20,000 y. BP can be seen. Shortly afterwards, the road crosses the Holocene lava flows of the Mazcuta scoria cone dated at ~8,000 y. BP (Ramírez-Uribe et al., 2019). Continue descending until you arrive at the small town of Santa Fe de la Laguna (~22 km/26 Mins.) at the shore of Lake Pátzcuaro. This traditional town holds one of the oldest colonial churches in Michoacán. Drive another ~4 km (~10 Mins.), arrive at Quiroga and at the junction with highway No. 120 turn right toward the SW and after ~8 km (~15 Min.), arrive at Tzintzuntzan. Follow the signs to the archaeological site (Stop 15) that overlooks the present town. After inspecting the ruins, return to the center of town at the foot of the hill and visit the colonial edifices (church and cloister). From Tzintzuntzan continue on highway No. 120 southward and after ~19 km (~30 Mins.) arrive at Pátzcuaro's main square (Stop 16) with its numerous restaurants under the surrounding colonial arcades. In the afternoon and after lunch, take tollroad 14D back to Morelia (total distance ~57 km, ~60 Mins.). After the tollbooth, drive another ~5 km (~5-10 Mins.) and near a bridge, park the car on the right side of the road on a meadow. From here walk ~100 m to the N to the forested distal margin of a lava flow that emanated from the Rancho Seco volcano. This is the archaeological site of Angamuco (Stop 17), a major urban complex that remains largely hidden under the forest cover. Return to the car and follow the signs to the center of Morelia, where the trip ends near the main square.*

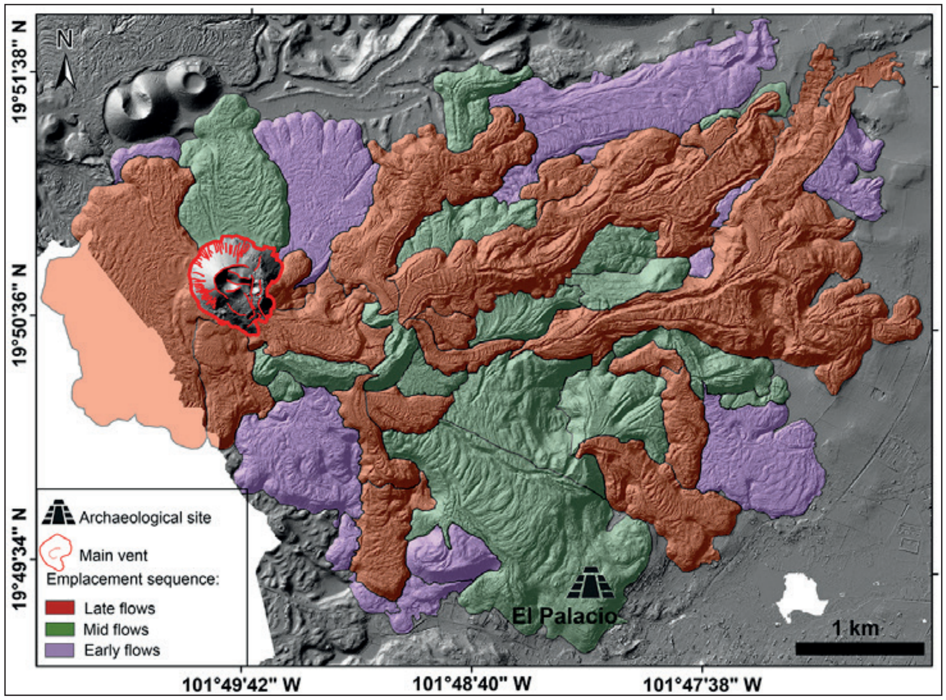

Figure 45: Hill-shaded DEM showing the emplacement sequence of the Capaxtiro lava flows. Modified after Reyes-Guzmán *et al.* (2021).

Figure 46: 3D-view of the Capaxtiro volcano lava flows with location of El Palacio-La Crucita site and other nearby sites. Generated from LiDAR data by Antoine Dorison.

Stop 14: The Capaxtiro lava flows and the El Palacio-La Crucita archaeological site (19°49'24.5", 101°48'06.9"; 2112 m)

The Capaxtiro eruption occurred between 200 and 80 BC (Mahgoub *et al.*, 2018) and is the most voluminous of the Malpaís de Zacapu eruptions. The emitted lava field (Figs. 15, 45) includes at least 28 partly overlapping flows, covers an area of ~21 km^2 with a total volume of ~3.1 km^3 (Reyes-Guzmán *et al.*, 2021), and extends just NW of the present city of Zacapu. The emission vent, located ~4 km NW of Zacapu, is a topographically-high cone formed by fragments of dense to vesicular lava agglutinated during the periodic explosive expulsion of magma. The lavas produced by Capaxtiro flowed mainly to the E, with a maximum distance of ~5 km reaching the shores of the ancient lake. Some lavas also spread to the N and W with wide lobate fronts, while the lavas to the E flowed in a more channeled manner, i.e., their flows were narrower and with more abrupt and defined fronts. Due to the complexity of Capaxtiro's lava field, the precise chronological order of the emplacement of the various flows (Fig. 45) was difficult to reconstruct, but they have been grouped into three temporal categories: early, middle, and late lavas (Reyes-Guzmán *et al.*, 2021). Early lavas correspond to the first part of the eruption and are generally partially covered by later flows. They are only visible to the N and S of the lava field, while the middle-stage flows, that cover the early ones, are more visible and are covered by lavas which correspond to the late stage and whose surface can be observed practically complete. These latter lavas have an average thickness that varies between 25 and 50 m. However, because they are superimposed, the area has been considered to have an average thickness of 150 m. The superposition of lava flows (Fig. 46) generated a stepped morphology in the lava field with multiple fronts that form steep, abrupt slopes on the edges of the lava field, and that can be observed from the central square of the city of Zacapu.

All Capaxtiro lava samples include phenocrysts and micro-phenocrysts of augite, hypersthene, and plagioclase. In samples from early flows rare olivine crystals were found, while in a sample from the late flows, hornblende crystals were identified. From petrological and morphological analyses (Reyes-Guzmán *et al.*, 2021) it was possible to calculate lava viscosities and other rheological parameters. Results indicate that the eruption temperatures were ~1000 °C and that the emplacement of all lava flows took ~27 years.

The archaeological site of El Palacio-La Crucita (Figs. 45, 46, 47) occupies the SE margin of a secondary flow that runs from NW to SE. In this area, the front of the lava flow shows an abrupt slope which is ~100 m in height (Fig. 47). From the upper edge the view dominates the modern city as well as the ancient lake basin and surrounding mountains (Figs. 48, 49). At the foot of the lava flow is the important La Zarcita spring that feeds the Laguna de Zacapu pond.

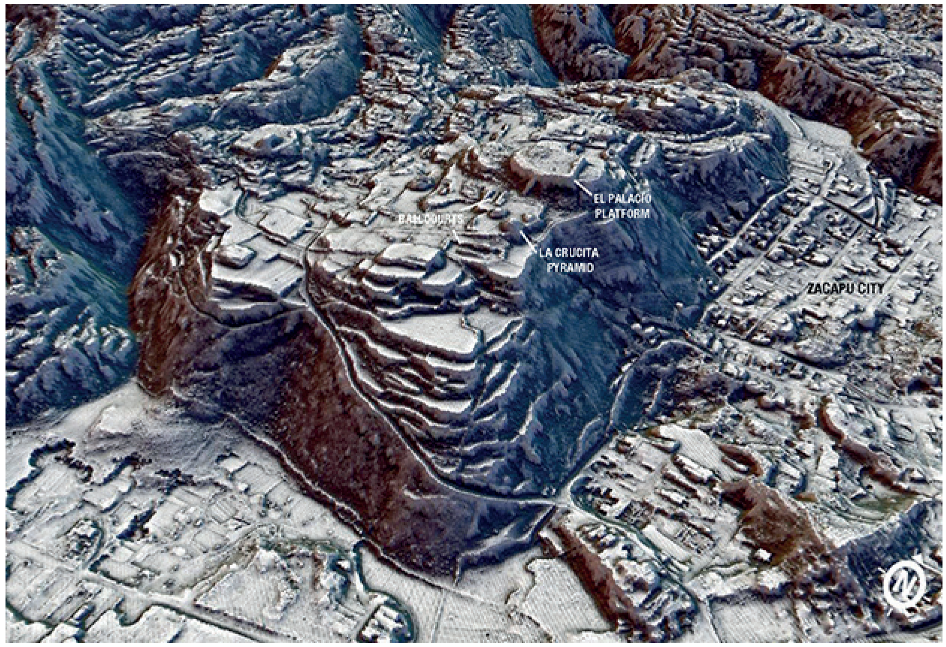

Figure 47: 3D-view of El Palacio-La Crucita site showing the massive pre-Hispanic modifications of the distal end of the lava flow. Generated from LiDAR data by Antoine Dorison.

Figure 48: La Crucita pyramid complex. Photo Marion Forest.

Figure 49: Panoramic view of Zacapu City from the El Palacio site. Note the Santa Ana church in the middle of the city, La Zarcita springs and La Laguna lake to the left side of the photo and the flat plain in the background of the desiccated lake. Photo Grégory Pereira.

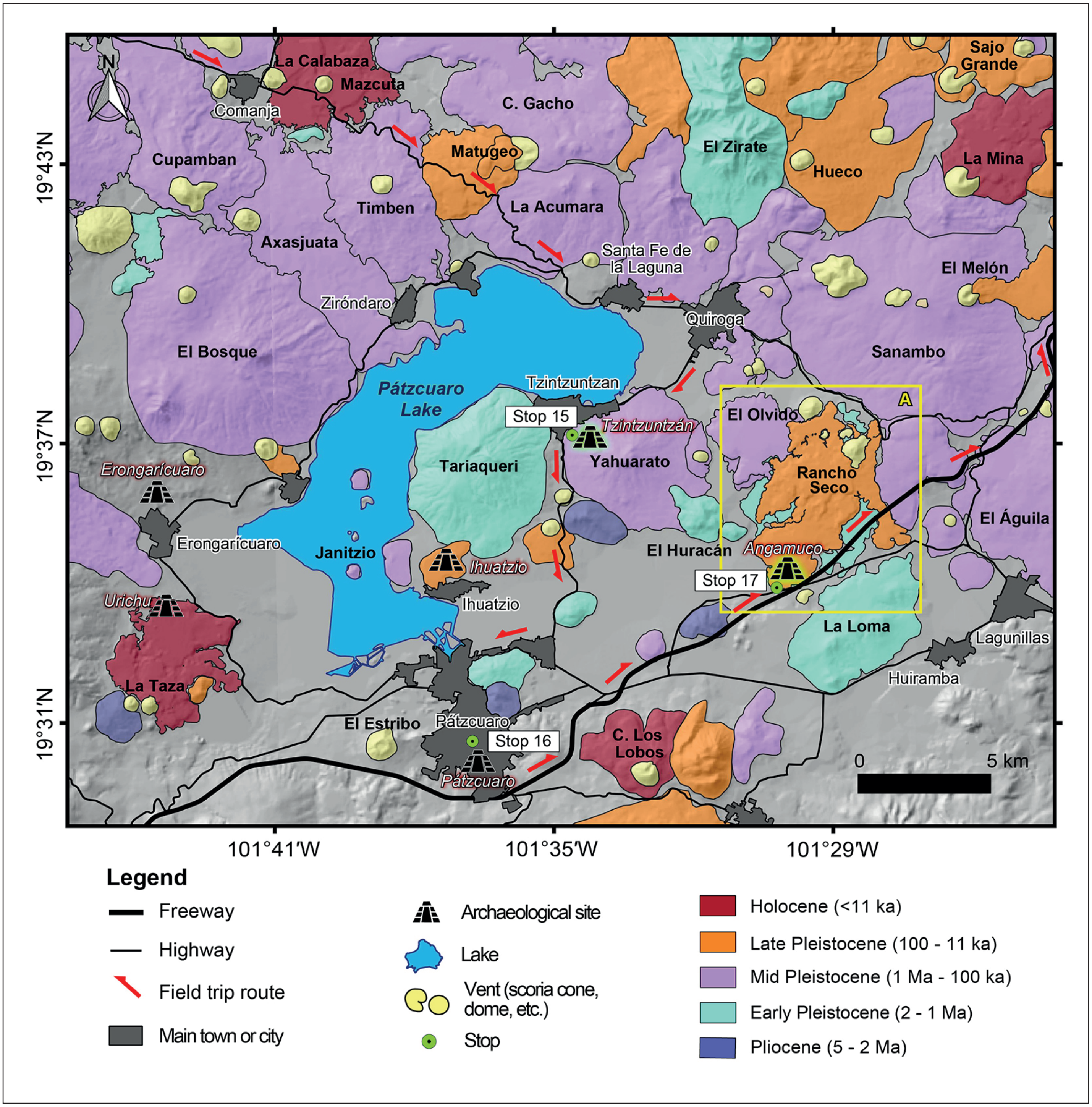

Figure 50: Simplified geologic map of the Pátzcuaro lake basin (based on Osorio-Ocampo *et al*., 2018, Pérez-Orozco *et al*., 2018, and Ramírez-Uribe *et al*., 2019) showing travel route (red arrows) and Stops 15 to 17 to be visited during the last part of the excursion. Yellow rectangle A denotes area covered in detailed map in Fig. 52. Map by Israel Ramírez.

The site itself occupies an area of ~50 ha corresponding to the upper part of the lava flow front. Because of its proximity to the city, the site attracted early attention from explorers and archaeologists. Since the end of the 19th century, occasional explorations have revealed archaeological ruins and, especially, bone remains that awakened greater interest in this settlement (Lumholtz, 1902; Lumholtz y Hrdlicka, 1898; Caso, 1930; Pereira, 2005). Unfortunately, the site has also been the target of looting and degradation linked to the modern agricultural use that has been given to it.

It probably corresponds to the pre-Hispanic city of *Zacapu Tacanendan* mentioned in the *Relación de Michoacán* from the 16th century (Alcalá 2000 [1541]), a city described as an important political and religious center.

Archaeological investigations carried out during the last decades (Fernández Villanueva, 1992; Michelet, 1998; Jadot and Forest, 2020; Forest, 2020) allow us to better understand its history and organization. The initial occupation of the site was limited and dates back to the end of the Epiclassic (~AD 800). During the Early Postclassic (AD 900-1200), the settlement grew and reached an area of ~20 ha including several ceremonial

Figure 51: One of the five pyramids (yácatas) of Tzintzuntzan (a) and schematic reconstruction of the monument (b). Drawing by S. Eliès.

buildings: the plaza with square pyramids of La Crucita and two ball courts. Several spaces were leveled but the later occupation and modern destructions do not allow to define clearly their functions. Excavations indicate that, during this period, the inhabitants of El Palacio maintained connections with the Toltec civilization of central Mexico, and particularly with the site of Tula (present state of Hidalgo).

The site underwent a new stage of expansion during the Middle/Late Postclassic period (AD 1200-1450) when it reached its maximum extension. For this period the site has 17 pyramids and new residential areas built on terraces in the western and northern part of the settlement. This remarkable population increase coincides with the urbanization phase observed in other parts of the malpaís, in sites such as Las Milpillas, El Malpaís Prieto, and El Infiernillo, and is contemporary with the arrival of the Chichimecas Uacúsecha in the region. It is known from written sources (visit of Antonio De Caravajal in 1523-1524) that the site was still occupied when the Spaniards arrived but was subject to the Comanja lordship that dominated the S and SE of the Zacapu basin. By this time, the urban center had lost much of its population, but it was still a sacred place where the *irecha* ("king" in Purépecha language) of the Tarascan kingdom made an annual pilgrimage to make an offering in a temple dedicated to the Curicaueri god.

Today, the inhabitants of Zacapu continue performing religious ceremonies and climb in procession to the site on May 3 (Holy Cross' day) and on October 4 (Saint Francis' day).

Stop 15: Tzintzuntzan, last capital of the Tarascan empire (19°37'23.0", 101°34'24.5"; 2057 m)

Tzintzuntzan (*place of hummingbirds,* in Purépecha language), the last capital city of the Tarascan empire, is located on the northern shore of a peninsula that breaks off from the eastern shore of Pátzcuaro lake (Fig. 50). The modern town extends over a narrow flat area between the lake and the base of two shield volcanoes: Tariaqueri to the SW and Yahuarato to the SE (Fig. 50) formed during the middle and early Pleistocene, respectively (Osorio-Ocampo *et al.*, 2018). The archaeological site open to the public is to the SE of the present town, on the lower slope of the Yahuarato shield. According to archaeological ground surveys (Pollard, 1977) and LiDAR-image analysis (Punzo Díaz and Navarro Sandoval, 2022), the pre-Hispanic city occupied an area of ~9 km^2 with an estimated population of ~30,000 inhabitants at the beginning of the 16th century. The distribution of archaeological remains reveals areas inhabited by nobles and common people, but also many craft workshops (Pollard, 1977). In this regard, the *Relación de Michoacán* indicates that the craftsmen were organized in corporations directed by a representative subordinate to the king. They produced high-quality polychrome pottery, instruments, and jewelry made of obsidian, turquoise, feathers or metal. The metallurgy of copper, gold, and silver was particularly developed among the Tarascans who worked these metals to produce jewelry as well as utensils (axes, chisels, needles, etc.).

Today, the most distinct feature of the site is the main ceremonial center. It consists of a monumental terrace of ~400 x 200 m overlooking the lake. A large rectangular plaza can be seen at the top, limited to the NW by a row of five large *yácatas* ("temple", in Purépecha). These are stepped pyramids formed by the combination of a rectangular

Figure 52: 17th century church of our Lady of Solitute in Tzintzuntzan as seen from the atrium with centuries-old olive trees. Photo Claus Siebe.

Figure 53: Main square of Pátzcuaro surrounded by arcades and colonial buildings (Stop 16). Photo Claus Siebe.

and a circular base. A sanctuary dedicated to the gods was originally erected on the circular base, while a stairway on one side of the rectangular base provided access from the great plaza (Fig. 51). The central yácata was probably dedicated to the main deity of the Tarascans, Curicaueri, the god of fire. Excavations carried out since the 1930s (e.g., Rubín de la Borbolla, 1939) have revealed that these monuments went through several successive construction stages. The last of them occurred shortly before the arrival of the Spaniards and it is distinguishable by an ornamental cover of volcanic rock formed by well-cut angular blocks (*janamu*, in Purépecha) that were carefully adjusted to the walls. Interestingly, several of these blocks were decorated with petroglyphs. To the NW of the plaza, some smaller constructions can be distinguished such as Building B or Palace, a structure consisting of several rooms and a patio surrounded by columns that may have served as a residence or government building.

After the conquest, the shrines were destroyed and stony materials were extracted to build the Santa Ana convent and the adjacent churches of San Francisco and Our Lady of Solitude (Fig. 52), which conformed the new religious center of the colonial city. Built in the XVI and XVII centuries, this complex shows a plateresque and baroque architecture and has an extended atrial garden planted with centennial olive trees (supposedly the oldest on the American continent). The colonial walls integrate stones carved with pre-Hispanic petroglyphs suggesting that they were extracted from the yácatas.

Today, Tzintzuntzan continues to be an important Purépecha town that maintains artisanal traditions such as pottery, woodwork, and the work with aquatic plants from the lake.

Stop 16: Pátzcuaro (19°30'48.5"; 101°36'33.0"; 2160 m)

Pátzcuaro, located on the southern shore of the lake with the same name (Figs. 1, 50), is certainly one of the most charming cities of Mexico. Its colonial architecture (especially edifices built during the 18th century) includes religious buildings (churches and monasteries) as well as luxurious civil mansions with beautiful interior patios of extraordinary artistic value. In addition, traditional markets, museums, and surrounding picturesque villages are worth visiting and could easily fill an itinerary of several days. The main square (Plaza Vasco de Quiroga) with its surrounding arches (Fig. 53) is an ideal starting point for a reconnaissance tour of the central part of town.

Pátzcuaro was the first capital of the Tarascan kingdom before it was moved to Tzintzuntzan, also located near the lake, but further to the north (Fig. 50). Its temperate climate was considered healthy (mean annual Temp. = 16.4°C). In 1534, shortly after the Spanish conquest, Vasco de Quiroga was appointed the first bishop of the province of Michoacán, which was initially seated at Tzintzuntzan, the center of the former Tarascan kingdom and most densely populated area in the region. He decided to move the seat of the bishopric from Tzintzuntzan to nearby Pátzcuaro in 1538 and there he constructed the first cathedral on top of the old Tarascan temples (Warren, 1985). A few decades later, the silver mines of Guanajuato to the N were discovered. Since Pátzcuaro was somewhat off from the main road between the cities of Mexico and Guanajuato, Valladolid (now Morelia) located closer, started to gain in importance as a center of food supplies, etc. for the new mining operations in the northern part of New Spain. As a result, the seat of the bishopric was moved to Valladolid in 1574 and Pátzcuaro lost the cathedral. In addition, during epidemic diseases of 1576-1578, Pátzcuaro lost a substantial percentage of its Indian population. Nonetheless, due to its strategic geographic position at the southern margin of the Mexican high plateau and gate to the *Tierra Caliente* to the S, Pátzcuaro recovered and benefited from trading with this vast area that included the port of Acapulco, which received goods from China (e.g., textiles, porcelain, and spices) and Perú (quicksilver). Although the *Tierra Caliente* was considered unhealthy and was, hence, sparsely populated, it did produce important commodities such as sugar, cotton, copper, etc. that were in high demand in the highlands. The economic bonanza in the silver-mining districts of Guanajuato and Zacatecas also had repercussions in Pátzcuaro, which experienced a construction boom between 1740 and 1760. Most of the baroque private mansions at the main square were built during this period and many religious and public buildings refurbished.

Stop 17: Angamuco archaeological site on the lavas of Rancho Seco volcano (19°34'06.5"; 101°30'00.5"; 2100 m)

The archaeological site of Angamuco is located on the most distal lava flow (malpaís) of the Rancho Seco scoria cone (Fig. 54). By analysing LiDAR images, Fisher and Leisz

(2013) determined that the site displays urban features and estimated that there are more than 20,000 remains of different types of buildings (mostly foundations) covering the area. Based on identifiable patterns buildings include commoners and elite residences, as well as ceremonial buildings (altars and temples), *yácata*-style pyramids (very characteristic of the region, such as those observed in nearby Tzintzuntzan), cultivation terraces, granaries, ball-courts, channels, and a vast network of roads (Fisher *et al.*, 2017; Solinis-Casparius, 2022). The name "*Angamuco*" was taken from the colonial map of Beaumont (1932) of the Pátzcuaro lake basin by archaeologists (e.g., Bush, 2012), although this might not be the original name of the site. This uncertainty arises because it is not further mentioned in historical records (Urquhart, 2015). Today, farmers living in the vicinity of the site refer to the area as "*Los Corrales*" (farmyards in Spanish), probably because of the abundance of massive walls made of loose lava blocks that are still visible under the oak forest. Preliminary results from excavations indicate that during much of the Post-Classic period (AD 900-1521), Angamuco should have dominated the eastern portion of the Pátzcuaro Lake Basin, and sustained a large population. The variety of resources offered by the lake, the low/medium slopes and the forests on top of the hills, made the Pátzcuaro lake region a propitious place for the installation of human groups, which undertook important modifications to the landscape in pre-Hispanic times (Pollard and Gorenstein, 1980; Migeon, 2016; Fisher, 2005).

Although the exact benefits for choosing the malpaises, seemingly unattractive sites, as major building grounds remain enigmatic, one reason could be the fact that they provide large *in situ* quarries for construction materials utilized in diverse architectural elements. By building cities on top of the lava flows that served as a source of most of the heavy building materials, a substantial amount of energy (work hours) could be saved by avoiding long transportation distances (Ramírez-Uribe *et al.*, 2019). Also, the site selection was probably motivated by their close proximity to the Pátzcuaro lake and its natural resources. In addition, the lava flows represent topographically elevated areas with respect to the lake level, allowing a better visibility over the wide lake area. This would represent a strategic advantage

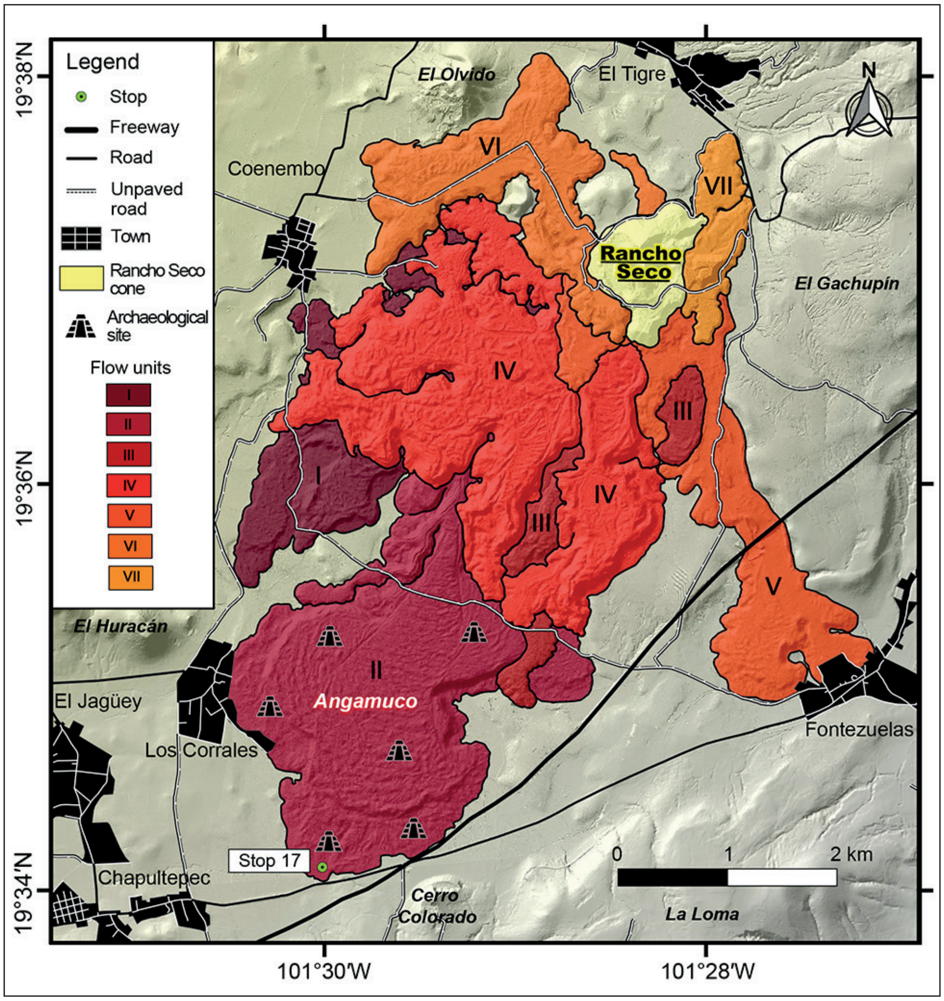

Figure 54: Geological map of Rancho Seco volcano (Stop 17) with LiDAR-based digital elevation model, showing the sequence of its different lava flows (I-VII) and the Angamuco archaeological site to be visited during the 3rd day of the excursion. Taken from Ramírez-Uribe *et al.* (2021).

that could also be useful as a defense in war times (Ramírez-Uribe *et al.*, 2019).

The Rancho Seco monogenetic volcano (19°37'03"N, 101°28'21"W), a scoria cone with associated lava flows situated at the eastern margin of the Pátzcuaro basin (Figs. 50, 54), was dated at 27,845 +445/-425 y. BP (Ramírez-Uribe *et al.*, 2019). It has a maximum elevation of ~2520 m a.s.l. and a height of ~200 m above surrounding ground with an almost circular base and a diameter of ~880 m. Today, the initial crater is practically unrecognizable due to intensive quarrying of the cone (Fig. 55). The cone flanks have been almost completely obliterated and only the crater floor and underlying neck (exposing crater-fill and dikes) remain in place. Lava flows associated with this volcano radiate away from the base of the cone (Fig. 54) mainly towards the SW, where they reach distances of up to 6.4 km; shorter lavas extend towards the NW (3.5 km) and NE (1.5 km). The Rancho Seco lava flows are essentially of the 'A'ā type, cover an area of 21.3 km^2, and their entire volume was estimated to be 0.72 km^3. Despite being covered by an oak/pine forest, the lava morphology of Rancho Seco lavas is remarkably well-preserved.

Rancho Seco's composition is andesitic (58.5-60.6 wt.% SiO_2), sub-alkaline, and shows a medium-K calc-alkaline trend (1.5-1.9 wt.% K_2O). Rancho Seco samples are remarkably homogeneous in composition, which contrasts with the wider evolutionary patterns displayed by other monogenetic volcanoes in the TMVB, e.g., in the Sierra Chichinautzin (Siebe *et al.*, 2004), but also in the MGVF, where the best studied example is Paricutin volcano, whose SiO_2-contents range between 53 and 60 wt.% (Wilcox, 1954; Cebriá *et al.*, 2011; Larrea *et al.*, 2019).

Rancho Seco volcano lavas show aphanitic and occasionally trachytic textures. Mineral phases in all lavas include mainly plagioclase and orthopyroxene, minor clinopyroxene and opaques (generally ilmenites), and rare

Figure 55: Aerial view of Rancho Seco volcano with its diverse lava flows and peripheral topography. Note extreme degradation of the cone by intense recent quarrying. Photo taken by Claus Siebe from the E in November, 2011.

quartz xenocrysts. Quartz xenocrysts display marked dissolution embayment textures and occasionally thin coronas of hypersthene and plagioclase microlites.

Rancho Seco volcano products have relatively narrow variations of SiO_2 and other major and trace elements which indicate that they may have been derived from a single batch of magma that was gradually erupted. According to stratigraphy, the Rancho Seco eruption followed a pattern of activity that was similar to that observed at Paricutin volcano (e.g., Luhr and Simkin, 1993): Initial stages of violent-Strombolian activity (effective degassing of the magmatic system) produced fallout of scoria, bombs, and ashes around the crater, which resulted in the rapid construction of a cone and were followed by a largely effusive stage that successively formed a lava-flow field (Ramírez-Uribe *et al.*, 2019). During this late stage, the Strombolian activity (well-bedded ash fallout) had greatly diminished and occurred only intermittently, since most lava flows lack an ash cover. From the effusion rates and the emplacement times obtained for high viscosity lava flows, a rough notion of the approximate total duration of the Rancho Seco volcano eruption could be obtained (Ramírez-Uribe *et al.*, 2021). Accordingly, the successive emplacement time of Rancho Seco volcano's lava flows probably took between 2 and 6 years.

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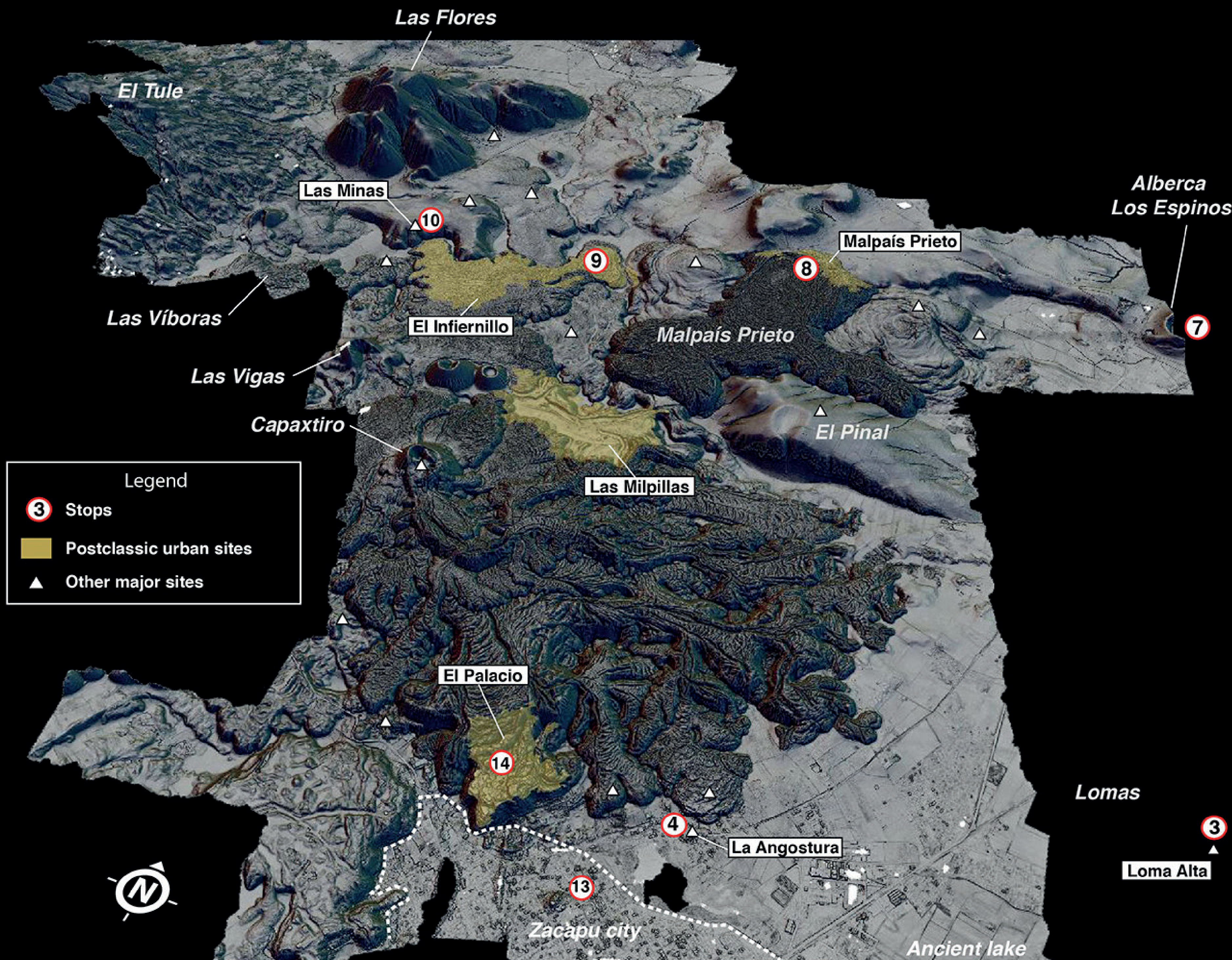
Notes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Archaeology and recent volcanism in the Zacapu lacustrine basin (Michoacán, Mexico)

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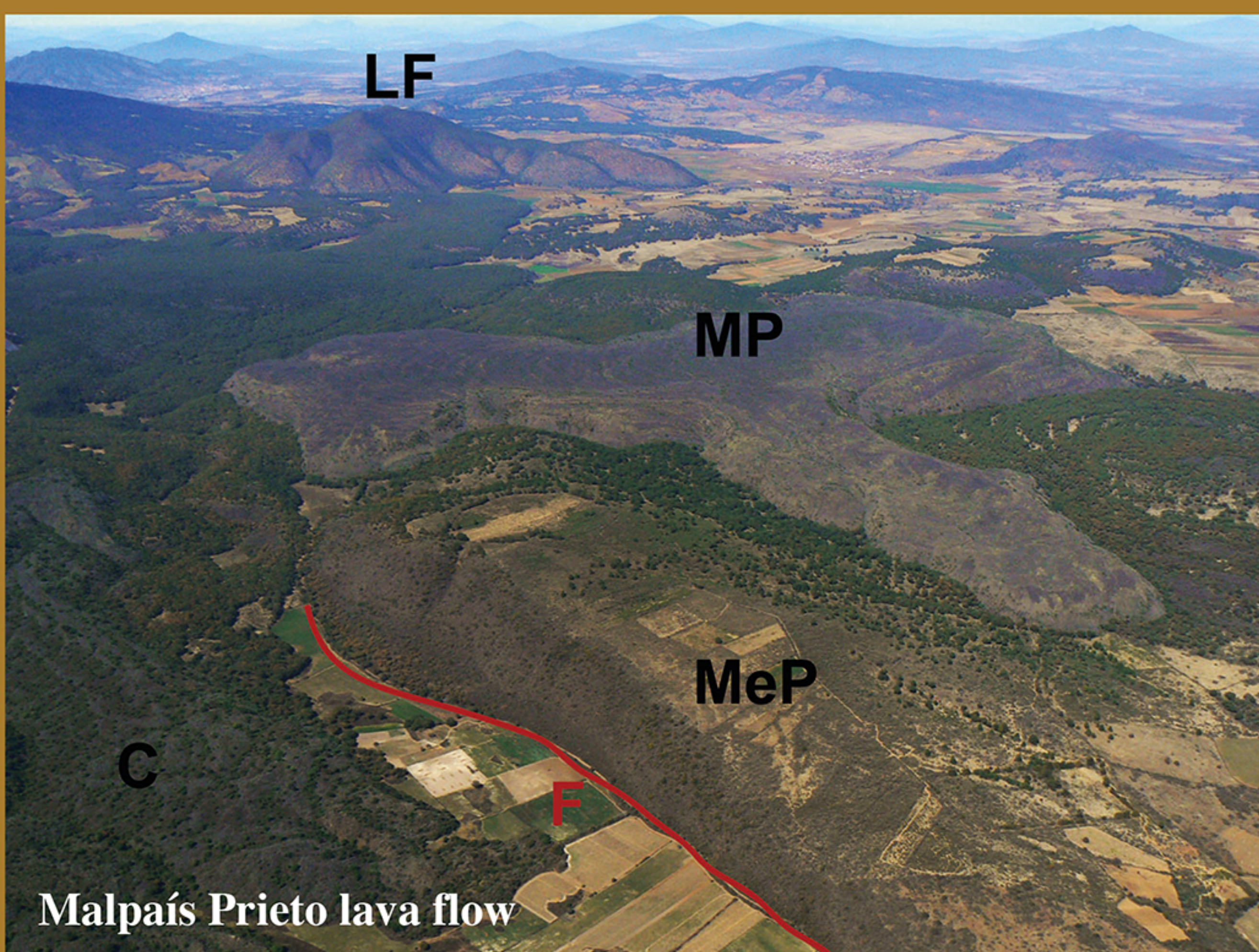
Capaxtiro lava flow field


LF
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Malpaís Prieto lava flow

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