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Paleoindian sites from the Basin of Mexico: Evidence from stratigraphy, tephrochronology and dating

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We the undersigned declare that this manuscript is original, has not been published before and is not currently being considered for publication elsewhere.

We confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed. We further confirm that the order of authors listed in the manuscript has been approved by all of us.

We understand that the Corresponding Author is the sole contact for the Editorial process. He/she is responsible for communicating with the other authors about progress, submissions of revisions and final approval of proofs.

Signed by all authors as follows:

Silvia Gonzalez, David Huddart, Isabel Israde Alcantara, Gabriela Dominguez Vazquez and James Bischoff

*Cover Letter

Dear Editors for the Special Volume

For Quaternary International

Francisco Javier Aceituno and Miguel Eduardo Delgado

Present

Liverpool John Moores University 26 September 2013

Dear Francisco and Miguel

Thank you very much for the invitation to submit this paper for your special volume. Sorry that took so long but finally is finished.

The paper includes new stratigraphic, teprochronology and dates regarding the most important Paleoindian sites for the Basin of Mexico together with their evaluation and Interpretation. The impact of volcanic activity is a very important factor also the potential if controversial YD Meteorite impact for which we have found evidence in the basin.

Best regards

Prof Silvia Gonzalez

Prof of Quaternary Geology and Geoarcheology

Liverpool John Moores University

Paleo-Indian Sites from the Basin of Mexico: Evidence from stratigraphy, tephrochronology and dating.

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Abstract

We present new data on the stratigraphy, dating and tephrochonology at the most important Paleoindian sites in the Basin of Mexico. These include: a) Peñon Woman III, with the oldest directly radiocarbon dated human remains (10,755± 75 yr BP); b) Tlapacoya, with two human crania dated to just over 10 ka BP; c) Tocuila, an important mammoth site with incorporation of fossils and suggested bone tools within the Upper Toluca Pumice (UTP) lahar (volcanic mudflow). The Tocuila site also includes potential evidence for a layer associated with the Younger Dryas meteorite airburst, with charcoal, iron microspherules, micro-tektites (melted glass) and volcanic ash, dated to 10,800 ± 50 yr BP and d) the Santa Isabel Iztapan mammoths I and II with lithics of Scottsbluff, Lerma and Angostura types and obsidian prismatic blades but lacking the characteristic fluted Clovis type points normally associated with mammoth kills and butchering and dated after the Pumice with Andesite (PWA) layer ~14,500 BP, to 10, 900 yr BP, before the Younger Dryas interval. These results show that these lithic traditions in Central Mexico are older than in the Great Plains of USA. Several tephra markers are recognised in the sites that help to constrain the stratigraphy and dating of the archaeological sequences. However tephra reworking in marginal lake sites is present and has been carefully considered, especially for the PWA tephra.

Keywords: Late Pleistocene, Mexico, tephra, dating, mammoths, Paleoindians.

1.Introduction

The main objectives of this paper are to present and discuss the complexities of the sedimentology, tephrostratigraphy and dating related to the most important Paleoindian sites in the Basin of Mexico: Peñon Woman III, Tlapacoya, Tocuila Mammoths and Santa Isabel Iztapan I and II Mammoths. The overall aim is to investigate the influence of volcanic processes and a potential meteorite airburst event on the development of human and animal populations during the Late Pleistocene/ Early Holocene.

The sites are located at around 2240m a.s.l. in the flat-floored, Basin of Mexico, which has been a closed hydrographic system for the past 700 ka. Magnetic polarity stratigraphy does not give tight constraints but suggests a Brunhes age (Urrutia and Martin del Pozzo 1993). The basin contained a large lake approximately 1000 km^2 in area, extending within a series of sub-basins (Figure 1), prior to artificial recent drainage. The basin limits to the east are the volcanoes of the northern Sierra Nevada (Tláloc and Telapon). Pyroclastic flows, ashes, block-and-ash flows, lahars and fluvial sediments make up an extensive volcaniclastic piedmont linking these volcanoes to the lake basin. Other potential sources of volcaniclastic sediment are from the monogenetic volcanoes in the basin and the strato-volcano Nevado de Toluca from which a Plinian eruption produced the extensive Upper Toluca Pumice (UTP) and the strato-volcano Popocatépetl, the source of the Pumice with Andesite (PWA), south-west and south-east respectively (Figure 1). The basin climate today is subtropical with summer rainfall predominant (c.500-1000 mm), but around the basin the mountains provide a wide range of temperature, rainfall and vegetation environments. Climatic change in the last 50,000 ka has driven large fluctuations in vegetation and lacustrine environments in the basin (e.g. Lamb *et al.*, 2009).

2. Description and interpretation of studied Paleoindian sites

2.1 Peñon Woman III Paleoindian Skeleton:

The volcano "Peñon de los Baños" was situated within the former Lake Texcoco and today is located by the northern side of the International Airport in Mexico City (Figure 1). Hot spring activity during the Late Pleistocene-Early Holocene produced layered travertine occurring as a conspicuous "platform" around the volcano. This hill was an important Preceramic locality in the basin, with at least 4 human skeletons reported to have been found in the area, 3 skeletons embedded in the travertine deposits and one (Peñon Woman III) below the travertine deposits. These skeletons are now part of the Preceramic human collection at the National Museum of Anthropology . All these skeletons were found by chance and there is no information available as to how they were incorporated into the sediments. They include:

Peñon I: Found in 1884 comprising mineralized and fragmented human ribs and a femur in travertine (Barcena and del Castillo, 1887, Newberry, 1887).

Peñon II: Found in June 1957 in the Colonia Peñon de los Baños, comprising a mineralised human skull embedded in travertine, (Figure 2a) (Romano, 1964, 1970). Radiocarbon dating of the skull by the authors was unsuccessful due to lack of collagen.

Peñon Woman III (Catalogue number: 6-07-1959/DAF INAH): This is a very important skeleton found in1959 in Colonia Peñon de los Baños. It is a semi-complete, well preserved, adult female human skeleton (Figure 2b). The postcranial skeleton was fragmentary (missing parts included both femurs and tibias and the right perone).The mandible is well preserved showing almost all the teeth except the left lateral incisor and all the upper and lower teeth show strong wear. The height was estimated at 1.51 m. Both cranial and postcranial evidence indicates a female with an age at death about 25 years. The skeleton was found below a 2 m. travertine sequence in sediments “with volcanic tuff characteristics” (Aveleyra de Anda, 1964). The skeleton age was estimated to be Late Pleistocene because it was found below the UTP ash (Mooser and Gonzalez-Rul, 1961). The deposit yielded no pottery, but “threads of natural fibres” were attached to the pelvis (still preserved today), and a polished bird bone and a root fragment with sediments were collected at the time of the discovery. The skull had very “primitive characteristics” (Romano, 1974). Later Gonzalez *et al*. (2003) directly dated a sample from the left humerus using AMS C^{14} to 10,755 ± 75 yr BP, (OxA-10112), confirming a Late Pleistocene age. **(*All the dates in this paper are uncalibrated*).** Detailed descriptions of the physical anthropology are included in Jiménez-López *et al*. (2006).

Peñon IV: Fragments of travertine mixed with human bone including a human skull, found in 1962, with no archaeological control.

2.1.2.Stratigraphy of Peñon Woman III:

The stratigraphy for Peñon III is re-drawn here from Mooser and Gonzalez-Rul (1961), including our own field observations at the site (Figure 3). The stratigraphic position of the skeleton is below the UTP ash layer, derived from a Plinian eruption of Nevado de Toluca volcano, radiocarbon dated to 10,445 ± 95 yr BP (Arce *et al.*2003).

We have also studied sediment samples found attached to the foot of the skeleton, taken at the time of the discovery, which consist of a mixture of organic material, molluscs, ostracods, diatoms, phytoliths, quartz crystals and volcanic ash grains, including small pumice clasts. They represent a saline and alkaline shallow lake/marsh environment surrounding the island of El Peñon at the time.

2.1.3.Importance

Peñon Woman III is the oldest directly dated skeleton from Central Mexico. The potential association of its pelvis with natural fibres is intriguing and unique to Paleoindian populations of this age and requires urgent investigation. This Paleoindian woman was living during the Younger Dryas cold chronozone.

The skull is dolicocephalic, with a cranial index of 70.05, which reinforces the view that older Paleoindian populations in the Americas were different from modern Amerindian populations which are generally brachycephalic, with cranial indices of ≥ 80. Attempts have been made to extract ancient DNA from this skeleton, but despite good bone preservation, with high collagen content (50.3 mg/g), no results have been replicated.

2.2 Tlapacoya

Here we re-assess evidence for early human occupation based on previous excavations at Tlapacoya Hill (Mirambell, 1967, 1978; Lorenzo and Mirambell, 1986a) in the SE of the basin (Figure 1) and present new stratigraphy, tephrochronology and AMS C^{14} dates for the sediment sequence.

2.2.1. Previous Work at Tlapacoya

The Tlapacoya site was discovered during motorway construction in the 1960s. Tlapacoya is an andesitic, Miocene volcano which was at times a peninsula or an island within Lake Chalco depending on lake levels. Construction work exposed sediment layers that contained fragmentary animal bones and reddish areas thought to be associated with burning. This led to an excavation programme at eighteen localities between 1965-1973, concentrated mainly around the SE hill base, Figure 4 (Lorenzo and Mirambell, 1986a). The most significant evidence for establishing the antiquity of early human occupation was found in trenches Tlapacoya I, Alpha, Beta and Tlapacoya XVIII. Excavations in Tlapacoya I produced Late Pleistocene animal bones (black bear and cervids) in association with pebbles and what were interpreted to be hearths and artefacts (Lorenzo and Mirambell, 1986a). Radiocarbon dates of 24,000 ± 4,000 yr BP (A 794b) and 21,700 ± 500 yr BP (I 4449) were obtained on humic extracts from charcoal in trench Alpha and one of 22,000 ± 2,600 yr BP (A 790 A) for a layer containing a supposed quartz scraper in trench Beta. Tlapacoya II, on the NW hillside, produced similar stratigraphy and a swamp cypress trunk (*Taxodium mucronatum*), with a C^{14} date of 23,150 ± 950 yr BP (GX 0959) from beneath which was recovered an obsidian blade.

A fragmentary human cranium was found in a horizon dated to 9,920 ±250 yr BP (I 6897) in trench Tlapacoya XVIII (Mirambell, 1986a). No details are given of the precise stratum in which the cranium was found and no stratigraphic section is reported for this trench. However, Garcia-Bárcena (1986) lists the date as obtained on unspecified material from the base of the UTP. The absence of stratigraphy for Tlapacoya XVIII and the lack of details related to the cranium’s recovery make this find frustrating for later researchers.

In 1968 archaeologists were informed of an earlier discovery of another human cranium that had been re-buried. The original location of the cranium lay 50m to the north of trench Beta (Mirambell, 1986a). Mirambell points out that the specimen shows features unlike those generally encountered in Mexican crania and Romano (1974) listed the cranium as dolicocephalic (cranial index of 67.17). This specimen has now been directly AMS radiocarbon dated to 10,200 ± 65yr BP (OxA-10225) and is known as Tlapacoya I skull, Figure 5 (Gonzalez *et al*. 2003).

Lithic materials found in trenches Alpha, Beta and Tlapacoya 1were reported as evidence of very early human activity on a lake beach by Lorenzo and Mirambell (1986a). Other interpretations are more plausible. The C^{14} dates for these levels suggest human activity considerably older than the age of the cranium from trench XVIII. The suggested artefacts provide the "cultural" evidence based on a lithic assemblage composed of 2,500 andesite flakes. The flakes are of the same local bedrock lithology that fractures naturally into very sharp flakes. They occur abundantly on today's surface. There were three obsidian flakes and two small bone fragments, claimed to be worked. From a poor photo (Mirambell, 1986b) the bone fragments appear appear to be a distal second phalanx from an ungulate and a small flake of longbone. The phalanx was suggested by Mirambell to be a whistle and the flake as a point but both are probably simply broken bones, selected from the total sample of over 100 bones in the vicinity of the "hearths" in Tlapacoya I Alpha. Most of these bones appear to be cervids and a single black bear (*Ursus americanus*), along with a small number of coyote (*Canis latrans*) and racoon (*Procyon lotor*). Alvarez (1986) emphasises the complete absence of any traces of cut marks, or deliberate breakage of the bones.

The interpretation of Tlapacoya Alpha sediments as a lake beach depends on assumptions about former lake levels and on the deposition of what were described as "smooth stones, pebbles and gravels" actually representing a beach (Mirambell, 1978). Many of the deposits in all of the Tlapacoya trenches were recognised as volcanic, mainly tephra falls into the lake, interbedded with diatomites. Diatom recovery and interpretation was less than optimum (Bradbury, 1986, 1989) and species from deposits associated with, or close to, the supposed beach hearths were those of brackish conditions (Bradbury, 1971). There were occasional lake high stands, but much of the diatom accumulation took place in smaller, alkaline pools. This impression is derived from paleoenvironmental interpretations from the former Lake Chalco deposits (Caballero-Miranda, 1997; Urrutia-Fucugauchi *et al.*, 1995) that characterise the Late Pleistocene lake as variable in depth, oscillating between fresh and saline water. As for the suggested beach deposits, it is hard to see how even full lake levels of around 20m would produce wave action to form beach pebbles and these pebbles would be rounded. It is more likely that the coarse, angular gravel layers found in the trenches represent weathered scree carried down the Tlapacoya Hill slopes to accumulate at the slope-break below the steep face. That the andesite flakes found had rounded edges is unsubstantiated by shape analyses in Mirambell (1978) and doubted by Gonzalez and Huddart (2008).

The Tlapacoya environment during the formation of these deposits was not the pleasant lakeside locality as represented by Lorenzo and Mirambell, (1986a). Much of the Late Pleistocene in the area was interupted by frequent and often heavy ash falls, as major volcanic eruptions took place. Yet despite the obvious impact of such major volcanic eruptions on the environment and human and animal populations, this caused little comment from the archaeologists at the time of the excavations. Hence there is uncertainty from the previous work as to the stratigraphy, its environmental interpretation and the true age of any human presence.We have therefore taken the opportunity to re-investigate the Tlapacoya stratigraphy, refine its dating by obtaining new AMS radiocarbon dates and analyse further the volcanic ashes. Three new trenches were excavated to re-study the Tlapacoya sequence in detail and are reported here.

2.2.2 New Excavated Trenches at Tlapacoya

Three new stratigraphic trenches were excavated (A, B, C) by the authors (Figures 6a and 6b). The aim was to locate them as close to those excavated in the SE part of the hill (Trenches Alpha and Beta) reported by Lorenzo and Mirambell (1986a). This proved impossible because of the large population and settlement growth in the area that has completely altered the appearance from that shown in the photos in Lorenzo and Mirambell (1986a). Ironically whilst settlement growth has reduced the choice of possible excavation areas it did provide a ready-made trench in undisturbed deposits from a proposed septic tank, in approximately the same position as Tlapacoya I. This is designated as trench Lake Margin B in Figure 6b. A roadway cut into the hillslope exposed trench Hillside A and the third trench, Lake C was excavated in open ground midway between the trenches Tlapacoya XVIII and Tlapacoya I of the original excavations.

2.2.3 Tlapacoya New Stratigraphy and Tephrochronology studies.

The motorway construction removed the top Holocene sequence around the SE of Tlapacoya Hill. The new excavated stratigraphy (Figure 6b) is complex and consists of diatomites, lake sediments, ash falls, reworked tephra, clays, organic-rich sediment and slope deposits. No bones, hearths or artefacts were recovered.

In the roadcut cut, Hillside A the sequence is dominated by volcanic ashes, some *in situ* (e.g. samples A5 and A2), whilst others were reworked downslope. The coarse gravel unit towards the base is composed of sub-angular/angular rock fragments, up to 20cm “b” axis, embedded in grey/beige, sandy ash. Ashes A2, A3, A5 contain white pumice up to 5cm “b” axis. The unit A6 consists of topsoil and angular gravel up to 10cm “b” axis, with pumice fragments in a sandy matrix.

The basal organic deposits in trench Lake margin B have been radiocarbon dated from 22,610 ± 100 yr BP to 20,960 ± 130 yr BP (See Table 1) and consist mainly of peat, alternating with diatomites and silts/clays, all associated with a shallow, freshwater lake. The middle of the section is dominated by diatomites but B11 is a grey-black ash, with thin layers of brown silt and diatomite, whilst B15/16 are grey/black ashes with some diatoms. Layers B18/19 are composed of a rounded to sub-angular gravel, up to 30cm “b” axis, embedded in a dark grey, sandy ash matrix, with few diatoms and pumice fragments. Above is a grey, sandy-silty ash (B20), with occasional lenses of black ash (B21). The sequence is capped by grey, sandy silts, with pumice lenses up to 10cm across and gravel fragments, with some animal burrows.

The basal unit in Trench C is a black peat, above 2cm silty, grey ash. The peat was radiocarbon dated to 13,030 ± 70 yr BP (See Table 1). Above are thin ashes, some with pumice and all showing diatoms and one white, silty diatomite with charcoal fragments. The thick unit above (C6, C7 and C8) is composed of gravels and sands, matrix-supported, occasionally organic-rich, with some caliche lenses, sub-rounded and rounded pumice, up to 3.5cm “b” axis and angular rock fragments, up to 8 cm “b”axis. In C6 there are diatoms and wood fragments. Units C9, C10 and C11 are units of white/grey, silty-sandy ash, with few diatoms. The uppermost layer (C12) is a sandy-silty, brown soil, with many roots and pumice fragments, up to 7 mm “b” axis.

Many of the volcanic ashes found were mixed and reworked with lake sediments. The only way to study their true chemical composition was by obtaining their major oxide geochemistry in single grain microscopic tephra, using a Cameca SX100 Electron Probe Microanalyser. The tephra major element geochemistry obtained is given in the Supplementary Data and summarised in Table 2.

2.2.4 Interpretation of the new Tlapacoya Stratigraphy

Trench Hillside A:

The sequence is dominated by ashes that have been reworked downslope, although A5 and A2 are in situ, and depending on the supply source there is usually a mixture of PWA (59 to 63% $Si0_2$) and UTP tephra (~ 69.9% $Si0_2$).. In the lowest sample A0 there are again two tephra populations, one with a mean of 61% $Si0_2$ (PWA) and the other with a rhyolitic composition (mean of 73% $Si0_{2,}$) which is considered to be reworked from a tephra from Tlaloc volcano. There is similar reworking of tephra populations from Lake Texcoco marginal areas in the Tepexpan Paleoindian and Tocuila Mammoths sites (Gonzalez and Huddart, 2007; Lamb *et al*., 2009; Gonzalez *et al.*, 2014) . The 10cm unit of sub-angular andesite gravels in an ash matrix is interpreted as reworked hillside scree, incorporated with ash by hillslope processes, such as insolation weathering and then slopewash, or solifluction and is not a beach as interpreted by Lorenzo and Mirambell (1986a).

Trench Lake side B:

The lowest 2.50m of this section is dominated by marginal lake sediments (diatomites, silts and silty sands) and thin organic layers, the lowest 85cm dated by radiocarbon dating between 22,610 ± 100 and 20,960 ± 130 yr BP. There are thin volcanic ashes interlayered throughout this sequence. Samples B1 and B3 associated with the oldest radiocarbon date obtained from wood, have two tephra populations with mean values between 60 to 61% $Si0_2$ (andesitic) and 69 to 71% $Si0_2$ (rhyolitic). Probably the andesitic composition is derived from an eruption of Popocatépetl Volcano that is known at this period. Tephra TB11 is 14cm thick and has only one tephra population, with a mean of 59% $Si0_2$ and is interpreted here as the PWA deposited as airfall into the lake. In the basin it has a thickness range from 5-30cm and can be traced to Popocatépetl, with an age of around 14,500 BP (Mooser, 1967; Garcia-Barcena, 1986 and Ortega-Guerrero and Newton, 1998). This is followed by lake sediments (diatomites and silts) below the 22cm thick gravel unit in a sandy ash matrix, with pumices and diatoms (samples B18 and B19). As in trench Hillside A this unit is interpreted here as a slopewash deposit into the marginal lake, or close to the shoreline from Tlapacoya Hill. It cannot be a lake beach gravel as the gravels are too angular and there is inadequate fetch to produce a beach gravel. Immediately above this unit is a 2-3cm irregular, organic horizon, interpreted as a subaerial palaeosol, capped by a cream, massive, silty-sandy ash, with pumice and gravel clasts up to 5 cm “b” axis. Within this unit are lenses of black ash up to 2cm thick. Sample B21 from this latter unit is dominated by a basaltic-andesitic geochemistry ($Si0_2$ of 57%), This tephra is likely to have been derived from a local monogenetic, cinder cone from the Santa Catarina Range.

Trench Lake C:

This sequence is constrained by a radiocarbon date of 13,030 ± 70 yr BP from the base of the trench, unit C0, which is made of charred vegetation. Above there is a thin sequence of coarse pumice C1, with a bulk chemical composition of 59.% $Si0_2$, C2 is a silty-sandy black ash, with many diatoms and thin diatomites. C2 is interpreted as marginal lake reworking of PWA, along with an unknown tephra. For example C2 has two mean tephra populations of 60.9% $Si0_{2,}$ interpreted as PWA and 66% SiO_2. C5 has only one population, with mean SiO_2 of 65%. The thickest unit in this trench is the 1.03m, hillslope deposit dominated by reworked PWA pumice and ash. C7 has a tephra population with a mean $Si0_2$ of 63%, is a gravelly matrix-supported sand, with rock fragments between 5-8cm "b"axis, some caliche lenses, diatoms, fish scales, and occasional wood fragments. It is capped by a 13cm palaeosol. The top of the sequence is dominated by 30cm white to grey, tripartite, silty-sandy ash, (mean $Si0_2$ of 69.92%), interpreted as the UTP *in situ.* This unit is important because it is in this layer that the "stratified" human cranium was excavated from Trench XV111 (Lorenzo and Mirambell, 1986a). This tephra at Tlapacoya was C^{14} dated to 9,920 ± 250 yr BP (I-6897), for the base of the ash sequence, correlating more or less with the AMS date obtained directly for the unstratfied human cranium.

2.2.5 Tlapacoya Radiocarbon Dates

Samples for C^{14} dating were taken from animal bones obtained from the original excavations described in Lorenzo and Mirambell, (1986a). Two phalanges of *Ursus americanus* (DP-958 and DP-957) were selected because of their association with the "hearth" in Trench Alpha. Since at the time we were unable to locate the fragmentary *in situ* human cranium from trench XVIII , the third sample was taken from the second, unstratified human cranium, number 10-1961-DAF/INAH. Unfortunately neither bear phalange gave a date, because of poor collagen preservation, but the cranium was dated to 10,200 ± 65 yr BP (OxA-10225). This is one of the oldest directly dated humans currently known from Central Mexico (Gonzalez *et al*.2003). Organic materials were selected from the new trenches and AMS radiocarbon dated (Table 1), providing reliable dates (with low error values) and those from trench Lake margin B are in stratigraphic order.

2.2.6 Tlapacoya I Human Cranium, 10-1961-62-DAF/INAH

The dated unstratified cranium (Figure 5) is well preserved, with collagen content of 10.9 mg/g but has lost all of its facial and palatal bones, together with the basilar and condylar parts of the occipital. A portion of the left squamous part of the occipital was removed for the radiocarbon AMS determination. The cranium is dolicocephalic (Gonzalez *et al.* 2003) and the parietal eminences are well-developed. On the basis of size, robusticity and sutural fusion it appears to be a mature, adult male, with a marked glabella and well developed supraorbital tori, external occipital region and mastoid process. The occipital region is prominent and has several wormian bones, while the frontal bone is centrally ridged and bears a small depression near bregma that may have been produced by a trauma earlier in life. Further possible evidence of early trauma is seen in slight depressions either side of the sagital suture close to lamda, and only the right parietal foramen is present in this area. The right orbit has a supraorbital notch whilst the left has two foramena, the more medial one larger than the lateral. Slight pitting (criba orbitalia) may be seen in the frontal bone surface within the orbits, a condition indicative of anaemia (Roberts and Manchester, 1997), but there is no evidence of pathology of the tempromandibular articulation in either the mandibular fosase, or the articulareminences. There is no obvious evidence of deliberate perimortem, or immediately postmortem activity, such as cutting. The endocrania is covered by a sediment layer and it has not been possible to describe its morphology.

2.2.7. Importance of Tlapacoya.

The claims for early human occupation at this site from supposed hearths associated with Pleistocene vertebrate bones and obsidian blades on beach gravels remain controversial and we did not find any evidence to support the claims. However the two fragmentary human skulls, found during the original excavations, have now been dated, one directly by radiocarbon AMS and the other indirectly by stratigraphy. It is unfortunate that they lack associated artefacts. The fact that one of the human skulls was found associated with the UTP tephra is important. We have found other Paleoindian human remains associated with this volcanic layer (Metro Man and Chimalhuacan Man, see section 3), that confirms that there was a Late Pleistocene human population living on the shores of Lake Chalco at the time of this major volcanic eruption. during the Younger Dryas period, with different cranial morphology to Modern Amerindians. These human skeletons associated with ash from the eruption, were buried quickly, which allowed their preservation. We do not know if the eruption killed these humans.

We have found that by studying the detailed geochemistry of individual volcanic glass in the Tlapacoya sequence and other Paleoindian sites in the basin, we were able to recognise reworking and mixing of the ash layers.

We found no sedimentological evidence for the presence of coarse gravel, “Late Pleistocene beaches” as interpreted by Lorenzo and Mirambell, (1986a) and we propose that instead they are angular scree deposits derived from the hillslopes.

3. Metro Man and Chimalhuacan Man Tephra Dating

Commonly human and animal bones of presumed Late Pleistocene age found around the lake sites in the basin and other Central Mexico lakes are highly mineralised, heavy and display a distinctive “black” coloration. Examples include the Metro Man and Chimalhuacan Man skulls (Figure 7). When we attempted direct AMS radiocarbon dating on them, we found that there was almost no collagen preserved, making C^{14} dating impossible. During detailed examination inside these two human crania, sediment samples were collected and analysed using electron microprobe studies. Their major element geochemistry was then compared against known volcanic ashes that were deposited during the Late Pleistocene-Early Holocene in the Basin to try to date the specimens using tephrochronology.

3.1. The Metro Man skull was found in 1970 at 3.10 m depth, during construction of the Metro Balderas station in Mexico City centre, embedded in the UTP ash (Mooser, 1967). Volcanic ash taken from the skull gave results of 63 to 71.2% SiO_2 showing some mixing (Table 4), but mainly associated with the UTP tephra.

3.2. The Chimalhuacan Man skeleton was found in 1984, in Colonia Embarcadero, Mexico State (Pompa y Padilla, 1988) but there are no published records of the stratigraphic context. Sediment from inside the skull was a mixture of lake sediments, diatoms and volcanic ash. The electron microprobe analysis of the ash indicate SiO_2 values between 62 to 77%, indicating a mixture of ashes, with the latest probably corresponding also to the UTP eruption (Table 4). For this reason we interpret that the skull has an indirect date of around 10,500 BP and not 33,000 BP as suggested previously using obsidian hydration dating (Pompa y Padilla, 1988).

4. Tocuila Mammoths Site

Tocuila is located in a western Texcoco suburb, in sediments of a former near-shore, Late Pleistocene, higher level of Lake Texcoco (Figure 1). A review of detailed recent stratigraphic work and a re-interpretation of the sedimentology, dating and origin of the Tocuila Late Pleistocene mammoths site has been reported by Morett *et al.*(1998) and more recently by Gonzalez *et al.* (2014). The main objectives were to understand the stratigraphic complexities and tephra sequence at the site and to describe a newly recognised layer that may represent the Younger Dryas meteorite impact event (Israde *et al*. 2012). This layer is between 6-10 cm thick, and consists of a mixture of lake-fall volcanic ash, magnetic Fe microspherules, micro-tektites (melted glass), charcoal and diatoms. If the interpretation is correct the occurrence extends the geographic range of this Younger Dryas event to the Basin of Mexico. Here we present a short summary of the results and conclusions derived from this recent work because of the importance and relevance of the site for the interpretation and understanding of the paleoevironment in the Basin of Mexico during the Late Pleistocene-Early Holocene transition.

4.1 Tocuila previous work

In 1996 the remains of at least seven mammoths (*Mammathus columbi)* were excavated, see Figure 8 (Morett *et al.*, 1998) and evidence for the presence of worked mammoth bones in the bone assemblage was presented (Arroyo Cabrales *et al.* 2001). Subsequently sedimentological and tephrochronological work from the deposits was reported by Siebe *et al.* (1999) and Gonzalez and Huddart (2007).

4.1 New stratigraphic work at Tocuila

The stratigraphic sequence at Tocuila is complicated, (See Figure 9) but it can be explained in terms of a lake marginal sequence that is cut by a channel infilled with lahar (volcanic mudflow) sediments (Gonzalez *et al*. 2014). It is in the channel infill where the mammoth bones were found, embedded in the lahar. The stratigraphy in Figure 9 shows the channel wall cut in the marginal lake sequence, with the basal sequence composed of grey clays and a black, indurated, sandy basaltic andesitic ash.

The channel base is eroded into a 55cm layer of brown clay, with root casts. Incorporated into this unit there are lenses (4cm x 5cm) of sandy ash (Sample A-5a), which shows two tephra populations. One has a mean SiO_2 of 55 % and the other a mean SiO_2 of 74 %. This is unconformably overlain by a conspicuous unit, 6-10cm, of laminated, black, reworked silty ash, waterlaid, with large amounts of charcoal, micro-tektites (siliceous glass spherules), diatoms and magnetic iron spherules (see location of sample Toc-6 in Figure 9). This layer shows two populations of tephra shards (means of 55 % and 67 % SiO_2). This is overlain by 45cm of sandy silt, with root casts and diatoms. There are also pumice clasts, up to 1.0cm in diameter in this silt, which grades transitionally into a further silt unit, with pumice clasts and root casts. This is overlain by silty clay, with no root casts in contrast to the units below. It is followed by 9cm of pale-grey, silty ash, which becomes lighter coloured towards the top of the unit. This unit has two shard populations with mean SiO_2 values of 66 % and 74 %. This grey-white ash is overlain by 8cm of dark grey, laminated, silty clay with diatoms. The sequence is topped by 45cm of sandy clay and grey-brown, silty clay, with gastropod shells throughout.

The lahar channel sequence is dominated by an ungraded, poorly sorted unit, 1.75m thick which has a silty-sand, ash matrix. It includes rounded silt balls up to 1cm in diameter, pumice lapilli clasts, up to 3.5cm in diameter and andesitic lithic clasts. The clasts show a macrofabric indicating SE-NW transport. This unit contains charcoal fragments throughout which have been dated by AMS radiocarbon dating. Towards the base of this unit there is a concentration of over 1000 animal bones. Over 90% belong to *Mammuthus columbi*, including three almost complete skulls, two incomplete skulls and four mandibles (Morett *et al.*1998). The skeletons are disarticulated and elongated bones tend to be subhorizontal and aligned in the same direction as the clasts, suggesting flow alignment. Excavation has yielded other animal species, including fragments of horse, bison, duck, goose, flamingo, rabbit, camel, turtle and tortoise (Morett *et al*. 1998).

The erosional channel margin shows small lenses of reworked PWA ash. The lahar deposits are composed of four units (Figure 9); units 1, 2 and 3 have small, basal, erosional channels that are infilled with convoluted, brown, clayey silt.

4.2 Interpretation of the Tocuila stratigraphy

The overall sequence is interpreted as a transition from deeper water lake to a more nearshore facies. The lowest black basaltic-andesitic ash is laminated, has diatoms and it is interbedded with lake sediments. It is correlated with the Great Basaltic Ash (GBA) or Tlahuac ash, dated by Mooser (1997) to 28,600 ± 200 yr BP.

Overlying the GBA are uniform, lacustrine, grey clays, with white root casts, although in between there is one conspicuous dark grey tephra unit 6-10 cm thick (Sample Toc-6) that has a mixed andesitic and rhyolitic ash compositions. In this layer are microscopic magnetic iron spherules, tektites (melted glass) and large amounts of charcoal (Figure 10), dated by AMS radiocarbon to 10,800 ± 50 yr BP, contemporaneous with the Younger Dryas

Boundary Layer (YDB). This unit possibly contains material from the controversial YDB Meteorite Airburst layer but further detailed geochemical work is now underway to test this hypothesis**.** The YD Meteorite Airbust Layer has been recognised in other important mammoth/ Paleoindian sites in SW America, e.g. Murray Springs, Blackwater Draw, Topper, Arlington Springs, and it is associated there with black organic mats, nanodiamonds and elevated iridium concentrations in bulk sediments (Firestone *et al*. 2007; Kennett *et al*. 2009). It has been suggested that this impact is associated with the megafuna extinction and the onset of the Younger Dryas cold interval (Firestone *et al.* 2007). However the interpretation is still controversial and there are other possible interpretations for the presence of large amounts of magnetic Fe microspherules, such as derived from spores or from volcanic processes. This layer however has been identified in Lake Cuitzeo sediments in Central Mexico (Israde *et al*. 2012) with Fe microspheres and nanodiamonds but Tocuila could be potentially the first site in the Basin of Mexico. However we emphasize that the Tocuila bone assemblage is not the result of the meteorite airburst event, the mammoth bones were incorporated into the lahar sequence produced after the UTP ash deposition, after ~10,500 BP (see discussion below).

On top of the lacustrine clays there is a thicker, coarse ash, composed of subrounded pumice and lithics with a mixed andesitic and rhyolitic tephra composition and it is interpreted as reworked PWA tephra. Above this reworked PWA tephra there is another lacustrine sequence of clays or silts, with root casts.

Outside the main mammoth trench above this lake sequence was found a series of three, *in situ*, rhyolitic ashes, correlated with the UTP tephra (Figure 1), dated by Bloomfield and Valastro (1977) to about 11,600 BP. However, Arce *et al.* (2003) dated this tephra to around 10, 500 BP. The thickness in Tocuila of 44 cm is slightly thicker than the reported UTP deposits at Tlapacoya between 30-37 cm (Gonzalez *et al*. 2001, Gonzalez and Huddart, 2008).

4.3 Age of the Tocuila Deposits: Radiocarbon Dating

The lahar deposits in the Mammoth Trench have been previously radiocarbon dated by Siebe *et al*. (1999); Morett *et al*. (1998b) and Arroyo Cabrales *et al.* (2003). The value of these dates has been discussed by Gonzalez and Huddart (2007) as they are not in stratigraphic sequence. It is not surprising to find such variability in a lahar deposit that is by its nature a reworked deposit. An average date of about 11,188 BP has nevertheless been given for this deposit by Morett *et al*. (1998) and Arroyo Cabrales *et al*. (2003), but we do not consider this procedure appropriate because the deposit is mixed.

From our stratigraphic observations and C^{14} results we interpret the lahar sequence at Tocuila with the mammoth remains to be associated with the deposition and rapid reworking of the UTP tephra shortly after 10,500 years BP.

4.4 The Tocuila bone assemblage interpretation

The excavated area in the lahar has produced approximately one thousand bones, mostly of the Columbian mammoth (*Mammuthus columbi).* These represent at least seven individuals ranging from young to adults. The skeletons were not complete, but some show articulation indicating that they have not been transported far. It has been argued by Arroyo-Cabrales *et al.* (2001) and Johnson *et al.* (2001) that the presence of humans is indicated by dynamic impact fracturing on mammoth long bone segments and fracture debris. The small assemblage includes a bone core with a prepared platform and scars from the removal of a number of large cortical flakes and a cortical bone flake with remnant platform preparation. The cortical flake conjoins with the central flake scar on the bone core. The assemblage is interpreted as mammoth bone quarrying to produce cores for transport elsewhere. This is not a subsistence activity but a technological one aimed at securing raw material shaped into a transportable, useable form. It could be an activity occurring together with butchering of a mammoth, or an independent activity but is a specialised activity requiring fresh mammoth bone.

How the mammoth bones became incorporated into the lahar sediments has been debated: A) were they previously deposited in the channel either as the result of attritional accumulation or a catastrophic event (meteorite burst?) and covered subsequently by the lahar? or B) were the bones transported into the channel with the lahar? It seems unlikely that the UTP lahars killed the mammoths, because two direct AMS dates on their bones gave dates of 11,100 ± 80 yr BP and 11,255 ± 75 yr BP, indicating that they were already dead when incorporated into the UTP distal lahars and concentrated in the lahar channels in the lake nearshore (Morett *et al*.1998; Siebe *et al*.1999). The time gap between the mammoths' death and their incorporation into the lahar means that the skeletons were lying around the lake shore for several hundred years. The fact that bone quarrying requires fresh bone means that humans killed, or scavenged the bones for tool production well before the skeletons and bone tools were incorporated into the UTP lahars.

5. Santa Isabel Iztapan Mammoths

5.1 Site description

Santa Isabel Iztapan (Fig. 1and Fig.11) has two of the most important mammoth sites because of the indisputable association with lithic points (Martinez del Rio, 1952; Aveleyra Arroyo de Anda and Maldonado-Koerdell, 1952, 1953; Aveleyra Arroyo de Anda, 1955, 1956; Wormington, 1957; Gonzalez *et al*. 2006). The mammoths in the Basin of Mexico have been described by Reyes (1923), Lorenzo and Mirambell (1986b), Carballal-Staedtler (1997) and Gonzalez *et al*. (2006) and most are found around the marginal fringes of the former Lake Texcoco. Into this former lake a series of currently ephemeral steams fed as part of the low-angled delta of the Rio San Juan in the Santa Isabel and Tepexpan area but the lake at the time of the deposition of the mammoth bones must have been no more than 70cm in depth.

The lithics found associated with the two mammoths are interesting because they are not fluted, or Clovis type (Fig. 11a and Fig.11b). Haynes (2002) discussed three important mammoth sites in North America with associated artefacts that are typologically not Clovis, that included the Santa Isabal Iztapan mammoths lithics indicating that there was no date for the finds. The uncertainty regarding the typology and dating of lithics at Santa Isabel Iztapan was also mentioned by Tankersley (2002). This is not exactly true because Mooser and González-Rul (1961) interpreted the mammoths' stratigraphic position as below the PWA ash at both Santa Isabel Iztapan I and II (Figure 12).

As Mooser (1967) dated peat under the PWA with an age of 14,700 ± 280 yr BP and Lozano-Garcia *et al*. (1993) also published a second date of 14,450 ± 100 yr BP it was possible that the mammoths were killed around these Pre-Clovis dates. Pichardo (2000) concluded that it was imperative that a detailed re-examination of the stratigraphy of the Tepexpan, Iztapan and Peñon sites be made to confirm the tephra sequence proposed by Mooser and Gonzalez-Rul in 1961. In a new trench excavated as close as possible to the same location of the Santa Isabel Iztapan II site, Gonzalez *et al.* (2006) reported that "even now the real age of the mammoth is not very clear, but further tephrochronology studies are underway to clarify the chemical composition of the volcanic ashes found in the sequence." This new work is reported here to clarify further the age and significance of this site and its associated mammoth remains and lithics. The lithic assemblage lacks fluting (Fig. 11a and Fig. 11b) and includes Scottsbluff , Lerma (laurel-leaf) and Angostura type points that have been reported in the USA associated with bison bones. For this reason they are thought to be younger than Clovis points (Wormington, 1957). The Mexican assemblage has been given dates from older than the PWA (~14,500 yr BP) (Mooser, 1967) to around 9000 yr BP (Krieger, 1964), to as young as 7000-9000 yr BP (Armillas, 1964). It is important to stress that although the Basin of Mexico is very rich in terms of mammoth finds, no Clovis points have been found in the area so far.

5.2 Previous Work at Santa Isabel Iztapan Mammoths

Santa Isabel Iztapan I: In March 1952 following a chance find by workers opening a drainage ditch close to Santa Isabel Iztapan, a mammoth skeleton was excavated by the Instituto Nacional de Antropologia e Historia (INAH). It was completely embedded in green clays (Aveleyra de Anda and Maldonado-Koerdell, 1952, 1953). The mammoth bones were disarticulated and appeared to have been butchered *in situ.* Six lithic points (Figure 11a) were found in direct association with the skeleton. The other artefacts included a scraper, a knife and a fine prismatic blade, all composed of obsidian and an endscraper and a retouched flint blade. One of the mammoth femurs was a short distance from the remaining bones as if pulled aside for butchering and approximately 80% of the total bones were recovered.

Santa Isabel Iztapan II: In May 1954 the construction of another ditch resulted in a second mammoth "kill" site, approximately 350m south of Santa Isabel Iztapan I. Here too lithic points had been used during mammoth butchering. In this case one of the posterior legs of the animal was found in anatomical position, showing that it had probably been trapped in the lake clay (Aveleyra de Anda, 1955, Aveleyra de Anda and Maldonado-Koerdell, 1956). The skull and tusks of an adult animal that had reached maximum growth were overturned during butchery and some of the bones had deep cut marks. The skeleton was incomplete and was lacking sections of the mandible, both humeri, the right ulna, both radii, the left femur and the right scapula. All the bones were displaced from their correct anatomical position, apart from the leg bone. Of interest is that the cranium was inverted, possibly for ease of brain extraction. The skull of another mammoth excavated by Arellano (1946) close to Tepexpan was in a similar position. The Iztapan mammoth was found at depths from 1.80 to 2.25m from the surface which was at 2238 m.Three lithics were found in direct association with the mammoth bones (Figure 11b).

5.3 New Santa Isabel Iztapan II stratigraphy and tephrochronology:

The new trench stratigraphy is presented in Figure 13, showing a sequence of lacustrine sediments, with abundant ostracods, interbedded with several volcanic ash layers.The tephra geochemistry is given in Table 3. The lowest tephra (Sample Santa 2) is 17.0cm fine sand black ash with a mean SiO_2 of 56% (with a uniform, basaltic-andesitic composition). This is interpreted here as the GBA (Mooser, 1967) or Tlahuac ash (Ortega and Newton, 1998). Between 260-270cm there is a light grey sandy ash (Sample Santa 10) that is chaotically mixed with lake sediments. This tephra has a mean SiO_2 of 67% and currently its source is unknown. When comparing its geochemistry we conclude that it was neither the PWA nor UTP tephra markers (Table 4). Within the green lake clay at around 220cm in the new trench section there is a layer with pockets of ash, pumice and clay up to 2.2cm across with a mixed tephra shard population (samples Santa 12 and 13) with values of SiO_2 of 58%, 64% and 71%. Associated with this horizon are mud balls. The mixed tephra population and the mud balls indicate reworking of tephra populations, including the PWA and lake sediments into the marginal, nearshore lake environment.
There appears to be no *in situ* PWA in this trench as originally described by Mooser and Gonzalez-Rul (1961), See Figure 12, but without detailed tephra geochemistry and radiocarbon dating , which was not available at the time, the most obvious feature in the layer would have been the presence of pumices. The lack of *in situ* PWA tephra has also been noted at the Tepexpan (Lamb *et al*. 2009) and Tocuila sites (Gonzalez *et al.* 2014), in similar marginal lake locations. The youngest tephra (Sample Santa 16) is a 7cm dark grey/black basaltic ash with abundant ostracods, dominated by tephra with a mean SiO_2 composition of 58%, although there a few shards of rhyolitic composition. We interpret this ash as probably equivalent to layer Toc-6 in Tocuila due to its composition and stratigraphic position, although we need more data to confirm this conclusion. This layer was dated at Tocuila at ~ 10,800 ± 50 yr BP (Gonzalez *et al*. 2014). A sample taken from a mammoth molar from Santa Isabel Iztapan 2 (bone DP-412) could not be radiocarbon dated because of low collagen content.

5.4 Significance of the results

The Santa Isabel Iztapan I and II Mammoth sites are important because of the undoubted association of unfluted lithics and mammoths. It was proposed previously that both were below the PWA tephra marker with dates older than 14,500 yr BP but our new work has shown that there is no PWA tephra *in situ* in our new trench and that in the stratigraphic layer (Samples Santa 12 and 13) where there were pumice fragments, they are reworked. The layer is a mixed tephra horizon with PWA and other ashes in a marginal lake environment.

However on top of the Santa Isabel Iztapan II mammoth there is also a basaltic-andesitic tephra (sample Santa 16) that was dated at the Tocuila site at ~10,800 yr BP. This means that the age of both the mammoths and associated lithics are after 14,500 yr BP to 10,800 yr BP, before the onset of the Younger Dryas, overlapping in time with the Clovis lithic tradition in the USA and perhaps even older. This timing suggests that the Scottbluff, Lerma and Angostura lithics are likely to have originated first in Central Mexico, before spreading to the Great Plains of USA.

6. Discussion and Conclusions

In the American Continent there are very few directly dated Paleoindians; examples include Buhl Woman, Idaho 10,675 ± 95 yr BP; Spirit Cave Man, 9,415 BP; Wizards Beach Man 9,225 BP and Kennewick Man at 8,410 ± 60 yr BP. So far the oldest human in the Basin of Mexico is the Peñon Woman III skeleton dated to 10,755 ± 75 yr BP but there are also human remains found in submerged caves in the Yucatan peninsula with comparable dates between 9-11,000 BP (González González *et al.* 2006). The Tlapacoya I cranium with a date of 10,200 ± 65 yr BP is also important for any discussion of humans in the New World. There are also indirectly dated human skulls from the basin using tephrochronology: Chimalhuacan Man and Metro Man dated by association with the UTP tephra at ~ 10,500 BP.

Our new stratigraphic work at Tlapacoya has produced no further evidence to support early humans at 24,000 years BP. However, it is clear that the locality is an important Paleoindian site, because one of the two human crania found previously has produced a direct radiocarbon date of Late Pleistocene age. As both human skulls are dolicocephalic, it means that there was a Paleoindian population before 10,000 years BP in Central Mexico with different cranial morphologies from Modern Amerindian populations. This Paleoindian population includes also the long skulls found associated with the UTP ash at Chimalhuacan and El Metro sites.

We emphasize the importance of volcanic eruptions and volcanic hazards with early human presence in the Basin of Mexico. We know that humans were suffering the consequences of major Plinian volcanic eruptions during the Late Pleistocene. This major environmental control and the implications for human and animal populations living at the time has only been recently been incorporated into archaeological interpretations in Central Mexico during Paleoindian times (e.g. Gonzalez and Huddart, 2007).

The period between 15,000-10,000 yr BP in the Basin of Mexico was characterised by extensive volcanic ash falls. There are two main tephra markers, the PWA and the UTP that have been identified at the El Peñon Woman III, Tlapacoya, Tocuila and Santa Isabel Iztapan Mammoth II sites. However for the PWA ash there is also evidence for multiple phases of deposition and considerable thicknesses in the basin because there is extensive reworking and redeposition of this ash on the hill slopes and into the margins of the Texcoco and Chalco Lakes. Thus, great care is required when interpreting volcanic ashes in marginal lake sites, where only by using detailed geochemistry studies of single tephra grains, detailed dating and good vertical and horizontal exposure of the stratigraphic layers is it possible to identify those tephras which are truly *in situ*, or reworked (Lamb *et al.* 2009; Gonzalez *et al.* 2014).

At Tlapacoya the evidence is unconvincing for a true lithic assemblage. We postulate that the andesite flakes recovered from the original excavations are geofacts derived from the local bedrock that fractures into naturally sharp flakes. The small number of obsidian flakes from the original excavations were likely introduced by rodent burrowing from above and the two “worked” bone fragments seem to be simply broken bone. The proposed Pleistocene lake beach gravels and “hearths” from the original excavations appear to us as simply local angular pebble-gravel, scree and burnt vegetation. The UTP layer was *in situ* in our Trench C. It is in this layer that the “stratified” human cranium was reported to be embedded. This layer has been dated to 9,920 ±250 yr BP (Garcia Barcena, 1986) and which agrees more or less with the AMS C^{14} date for the other unstratified human cranium at 10,200 ± 65 yr BP (Gonzalez *et al*. 2003).

The shallow marginal Lake Texcoco at the Tocuila Mammoths site contains possible evidence for a thin Younger Dryas meteorite airburst layer, mixed with volcanic ash, dated to approximately 10,800 BP. Three hundred years later (~ 10,500 BP) the large UTP Plinian volcanic eruption also severely disrupted the basin ecosystem. The large volume of tephra caused partial damming and change in the drainage and the input of flood and lahar deposits into the lakes. The timing of these later events seems synchronous or post-dates the age of the UTP eruption occurring within the Younger Dryas period. Into the lahars was incorporated a vertebrate assemblage that included mainly mammoth (*Mammuthus columbi*) skeletons and a few bone tools. The UTP ash has been found associated with other Paleoindian skeletons in the Basin of Mexico and it seems likely that both the potential meteorite airburst and the UTP Plinian eruption caused widespread environmental disruption of the ecosystem, the death of humans, and the death of megafaunal populations, that were already weakened by human predation and climate change during the Younger Dryas period. There is little evidence for megafauna presence after this large Plinian eruption in the Basin of Mexico and the possible meteorite airburst. Afterwards, there seems to be a gap in the basin archaeological record, with a discontinuity in the hunter-gatherer, Late Pleistocene Paleoindian populations. This hiatus in human occupation and changes in site use have been proposed for several sites around the world at 10.8 ka (Wittke *et al*., 2013).

Evidence for re-occupation in the basin is not observed until approximately 4,500 B. This is from the dating of the Preceramic site of San Vicente Chicoloapan, showing a site with incipient agriculture and food processing (metates) (Gonzalez, *et al.* 2003). There is an urgent need to establish if this archaeological gap is real or apparent as perhaps we have been looking in the wrong lake locations. The problem is that the Preceramic occupation sites on the shores of the early Holocene lakes in the basin are likely to be buried today at depths between 2 to 3 meters under sediments, ashes and soils.

The new tephra dates given to the mammoths from Santa Isabel Iztapan I and II (between 14,500 to 10,800 BP) indicates that the fossil finds were probably butchered during the Clovis time period but by a culture lacking Clovis points. This suggests that the Lerma and Scottsbluff lithic types found in Central Mexico are likely to be older than those from cultures in the USA, found with bison kill sites.

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Figures

Fig. 1. Basin of Mexico: Location of studied Paleoindian sites and main tephra markers: GBA, Great basaltic-andesitic ash; PWA, Pumice with Andesite and UTP, Upper Toluca Pumice. The black arrows indicate the dispersion axes for the tephras and the volcanoes that produced them; dashed black arrow = inferred dispersion axe for GBA tephra.

Fig. 2. Peñon Hill humans: a) Peñon II Skull found in travertine. B) Peñon Woman III skull, oldest directly dated human from the Basin of Mexico.

Fig. 3. Stratigraphic sequence at Peñon Woman III (modified from Mooser and Gonzalez Rul, 1961); S= Position of the human skeleton.

Fig. 4. Tlapacoya Hill: location of previous archaeological trenches (after Lorenzo and Mirambell, 1986a). Also marked with a star is the location of the three new stratigraphic trenches (A + B + C) reported in here (See Figure 6a).

Fig. 5. Tlapacoya I (10-1961-62-DAF/INAH), radiocarbon dated crania, Age: 10,200 ± 65 yrs BP, scale in cm.

Fig. 6a Tlapacoya, location of studied stratigraphic trenches (A + B + C) in a profile from the hill side to the lake.

Fig. 6b Tlapacoya new trenches stratigraphy, showing the position of samples taken and with black stars the position of the new AMS radiocarbon dates obtained in organic materials (See Table 1).

Fig. 7a. Metro Man skull showing intense mineralisation. Figure 7b. Chimalhuacan Man skull. Both skulls were dated indirectly using tephrochronology methods, see the text.

Fig. 8. Photograph showing the Tocuila mammoths trench in 2013.

Fig. 9. Tocuila mammoths general stratigraphy in the main mammoth trench (Museum), after Gonzalez *et al.*, 2014.

Fig. 10. Location of possible Meteorite airburst layer in the channel wall at Tocuila. a) Example of typical microscopic Fe magnetic spherule, scale= 30 microns (Sample Toc- 6); b) Chemical analysis from the Fe micro-spherule using the scanning electron microscope.

Fig. 11. Lithics from the Santa Isabel Iztapan Mammoths.

11a) Lithics from Santa Isabel Iztapan Mammoth I, after Wormington, 1957:

1. Dark grey, flint projectile point with a white patina. 60mm long plus 1-15mm because of the break, 27mm wide; thin and delicate due to fine flaking, no medial ridge. Extremely fine pressure retouching along the edges. Conforms to general features of Scottsbluff type in shape, proportions and flaking technique, but much thinner. In Great Plains always less than 8,000 BP and associated with fossil bison.

2. Two edged scraper of black obsidian, with chipped parallel edges worked by fine, although irregular, pressure retouching. 36mm long and maximum width 27mm.

3. Flake obsidian knife, 50mm long and 24mm wide, one edge crudely pressure retouched to form a scraping edge in a wide arc whilst the other bears three concentric arcs, the central one being the deepest serving as a spokeshave.

4. Fine-grained grey flint, roughly triangular in outline. One face pressure flaked into a steep bevel and classified as an end scraper, 43mm long and 35mm wide.

5. Prismatic obsidian flake knife, 59mm long and 17mm maximum width. Both edges pressure-retouched.

6. Clear, grey flint blade, 54mm long and 19mm maximum width, extremely fine marginal retouching.

11b) Lithics from Santa Isabel Iztapan Mammoth II, after Wormington, 1957:

1. A red dacitic/andesitic, lanceolate point without shoulders, symmetrical shape, the base slightly concave; length 80.2mm, width 27.4mm and thickness 8.5mm. Fine pressure flaking over all the basal edges. Originally defined as an Angostura point by Aveleyra de Anda (1955), although Wormington (1957) disagrees with this designation.

2. Brown flint, leaf-shaped projectile point; lacks the distal extremity. The chipping is bifacial, with scars of irregular flakes over both sides and fine pressure flaking along the edges, maximum length 61.3mm, maximum width 24.4mm, maximum thickness 8.1mm.
3. Light coloured, chert, biface knife; percussion completely over both faces and secondary retouching on some small sectors of the edges. Probably originally had a laurel-leaf form; length 67.2mm, width 34.9mm and 9.3mm thick.

Fig. 12. Tephra markers from the Santa Isabel Iztapan Mammoth II, Peñon Woman III and Tepexpan Man, modified after Mooser and Gonzalez- Rul, (1961). PWA= Pumice with Andesite and UTP= Upper Toluca Pumice. FH: Fossil human, F: Mammoth Find, S: Soils, SA: Archaeological soils, T: Travertine, C: Caliche layer, AC: Consolidated sands, B: Bentonite clays.

Fig. 13. Stratigraphy in new trench, Santa Isabel Iztapan Mammoth II, showing the position of samples taken and with "M" the position of the mammoth.

Tables:

Table 1. Tlapacoya Uncalibrated AMS radiocarbon results in organic materials. For location of samples see Figure 6b.

Table 2. Summary of Geochemistry results for Tlapacoya tephra layers, using the Electron Scanning Microscope on tephra shards (see Figure 6b).

Table 3. Summary of Santa Isabel Iztapan Tephra Shard Geochemistry (see Figure 13)

Table 4. Comparison of Main Tephra Markers Geochemistry in the Basin of Mexico

Table 1. Tlapacoya Uncalibrated AMS C^{14} results in organic materials. (See Figure 6b)

Sample	Laboratory Number	Description	C^{14} yr BP	Type of Analysis	$\delta\ ^{13}C$
Tlapacoya I	OxA-10225	Human cranium	10,200 ± 65	AMS	-16.1
Trench C, Layer C0	Beta-131855	Burned vegetation	13,030 ± 70	Standard	-25.0
Trench B: Layer B8	Beta-131856	Peat	20,960 ± 130	Standard	-25.0
Trench B: Layer B6	Beta-131857	Peat	21,800 ± 190	Standard	-25.0
Trench B: Layer B3	Beta-131854	Wood fragment	22,610 ± 100	AMS	-27.0

Table 2. Summary of Geochemistry of Tlapacoya Tephra samples (see Figure 6b)

Tlapacoya	**N**	**mean SiO_2 %**	**S.D.**	**Variance**	**Range**
Trench A:					
A0	5	61.0	3.90	15.2	56.75-65.44
A0	3	73.41	0.33	0.11	73.13-73.78
A1	6	62.25	2.94	8.63	58.69-64.87
A1	8	69.36	3.37	11.37	66.35-75.28
A2	11	59.07	2.17	4.71	56.73-60.89
A3	9	59.40	2.76	7.64	56.12-63.91
A3	3	69.39	3.38	11.44	66.70-73.19
A4	12	63.09	1.70	2.9	60.05-65.53
A5	14	61.46	2.17	4.71	58.60-65.73
A5	5	69.99	1.96	3.86	68.67-73.24
Trench B:					
B1	7	60.14	3.27	10.67	54.16-63.75
B1	5	69.83	2.36	5.58	67.50-73.66
B3	4	70.78	1.47	2.16	69.21-72.75
B3	6	61.16	3.95	15.6	56.90-65.16
B11	11	59.88	2.79	7.78	53.62-63.17
B16	4	71.50	0.73	0.54	70.69-72.15
B16	1	54.52			
B16	1	64.3			
B21	10	57.39	0.53	0.29	56.58-58.25
B21	1	66.15			
Trench C:					
C2	6	60.95	3.32	11.03	56.43-65.49
C2	4	66.93	0.57	0.33	66.33-67.66

C5	15	65.08	2.38	5.67	58.43-68.78

Table 3. Summary of Santa Isabel Iztapan II Tephra Shard Geochemistry

Sample	n	Mean SiO_2 %	S.D.	Variance	Range
Santa 2	17	56.61	0.74	0.54	54.17-57.35
Santa 10	16	67.87	1.83	3.33	64.2-70.91
Santa 13 Santa 13	4 4	58.04 63.99	0.98 1.37	0.96 1.87	56.92-58.95 62.36-65.71
Santa 16 Santa 16	3 11	72.60 57.92	2.54 1.86	6.47 3.45	69.75-74.63 53.44-60.28

Table 4. Comparison of Geochemistry of Main Tephra Markers in the Basin of Mexico

Santa Isabel Iztapan, Santa 10, n=16

SiO_2 mean 67.87%, SD 1.83, variance 3.33, range 64.20-70.91%

FeO mean 2.45%, SD 1.47, variance 2.16, range 1.38-5.68%

MgO mean 0.53%, SD 0.16, variance 0.03, range 0.32-0.84%

CaO mean 2.64%, SD 0.81, variance 0.66, range 1.37-4.46%

Tocuila, Toc A1C, Tlahuac (GBA), n=18,
SiO_2 mean 57.00%, SD 1.24, variance 1.54, range 54.62-59.33%

FeO mean 6.45%, SD 2.11, variance 4.46, range 1.14-8.72%

MgO mean 2.37%, SD 1.07, variance 1.14, range 0.2-5.36%

CaO mean 1.82%, SD 0.15, variance 0.02, range 1.51-1.95

Tocuila, Toc D2 (UTP) n=15

SiO_2 mean 70.29%, SD 1.19, variance 1.41, range 68.76-73.26%

FeO mean 1.802%, SD 0.21, variance 0.45, range 1.22-2.09%

MgO mean 0.39%, SD 0.06, variance 0.004, range 0.18-0.45%

CaO mean 1.72%, SD 0.39, variance 0.153, range 0.74-2.46%

Tocuila, Toc D3 (UTP reworked) n= 9,

SiO_2 mean 70.96%, SD 2.13, variance 4.52, range 69.52-76.09%

FeO mean 1.62%, SD 0.034, variance 0.11, range 0.95-1.87%

MgO mean 0.35%, SD 0.95, variance 0.009, range 0.17-0.44%

CaO mean 1.59%, SD 0.53, variance 0.28, range 0.45-1.93%

Metro Man Skull (UTP) n=13

SiO_2 mean 68.21%, SD 3.11, variance 9.67, range 63.06-71.86%

FeO mean 2.89%, SD 1.84, variance 3.39, range 0.3-5.35%

MgO mean 1.10%, SD 1.19, variance 1.43, range 0.01-2.09%

CaO mean 2.37%, SD 1.16, variance 1.35, range 0.21-4.42%

Chimalhuacan Man (UTP, reworked?) n=11,

SiO_2 mean 68.69%, SD 4.59, variance 21.02, range 62.25-77.66%

FeO mean 3.19%, SD 1.82, variance 3.32, range 0.53-5.46%

MgO mean 0.95%, SD 1.36, variance 1.86, range 0.09-2.10%

CaO mean 2.85%, SD 1.36, variance 1.86, range 1.29-4.94%

Tlapacoya C9 (UTP *in situ*) n=7,

SiO_2 mean 69.62%, SD 0.56, variance0.31, range 68.62-70.38%

FeO mean 1.76%, SD 0.01, variance 0.01, range 1.61-1.92%

MgO mean 0.41%, SD 0.03, variance 0.001, range 0.37-0.45%

CaO mean 1.82%, SD 0.15, variance 0.02, range 1.51-1.95%

Tlapacoya A2 (PWA), n= 11,

SiO_2 mean 59.07%, SD 2.17, variance 4.71, range 56.73-60.89%

FeO mean 6.97%, SD 1.13, variance 1.28, range 5.51-9.42%

MgO mean 3.12%, SD 1.39, variance 1.94, range 1.75-6.92%

CaO mean 5.33%, SD 0.83, variance 0.69, range 4.13-6.69%

Tephra 11 (UTP) from Chalco Lake (Ortega-Guerrero and Newton, 1998) n=10,

SiO_2 mean 71.2%, SD 1.27, variance 1.60, range 69.71-74.24%

FeO mean 1.86%, SD 0.13, variance 0.02, range 1.62-2.11%

MgO mean 0.39% SD 0.043, variance 0.002, range 0.32-0.43%

CaO mean 1.74%, SD 0.2, variance 0.04, range 1.46-2.04%

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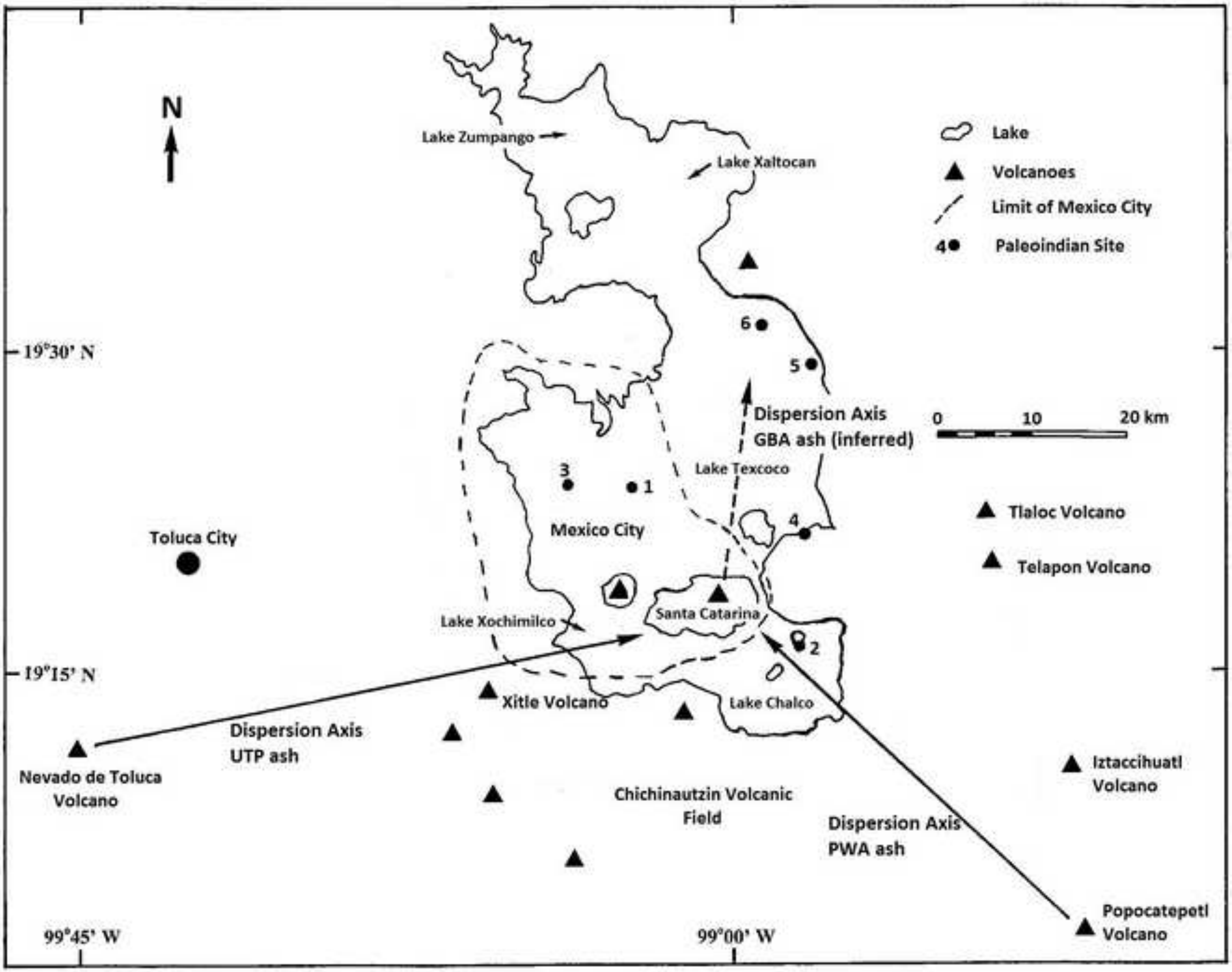

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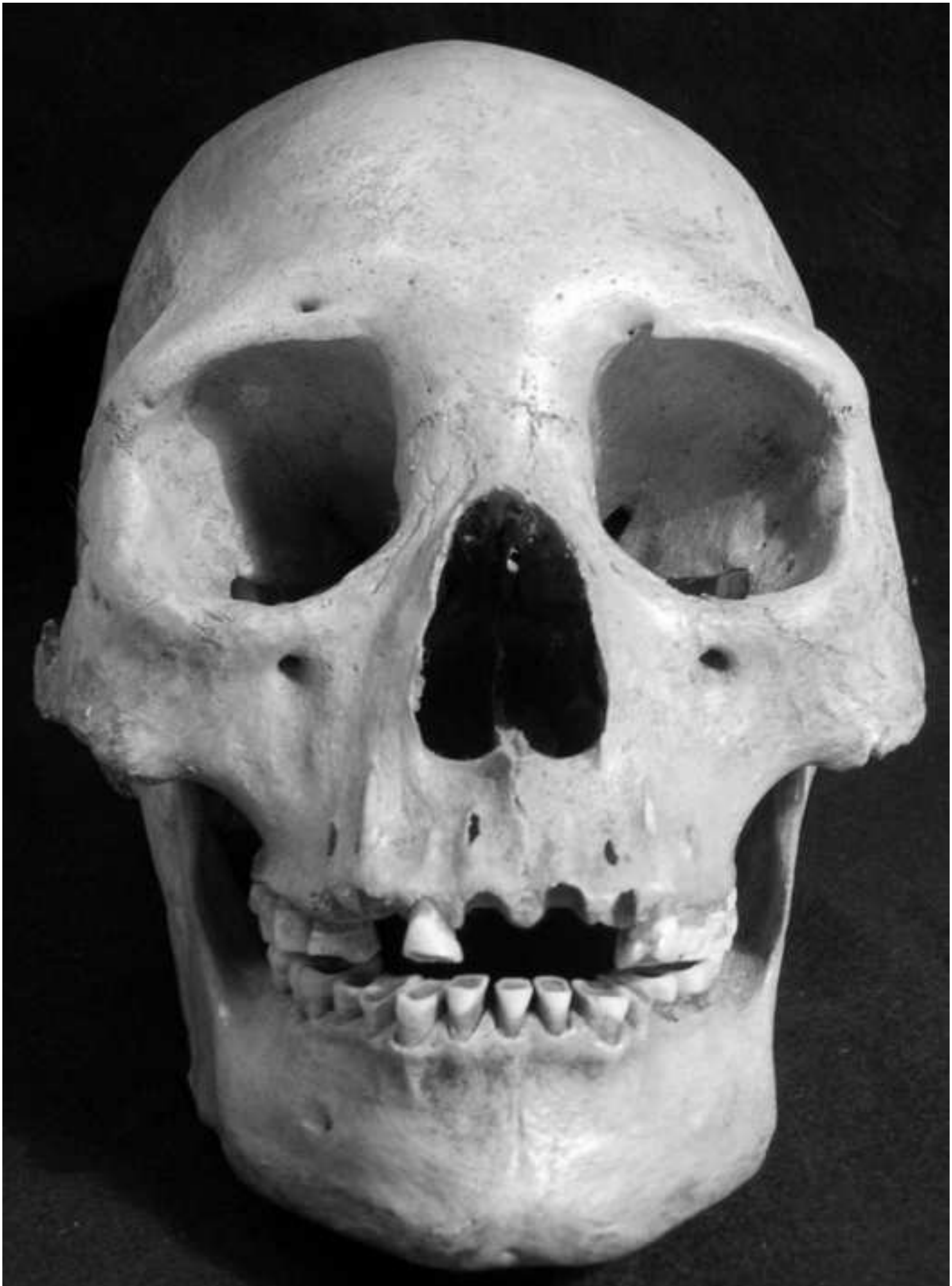

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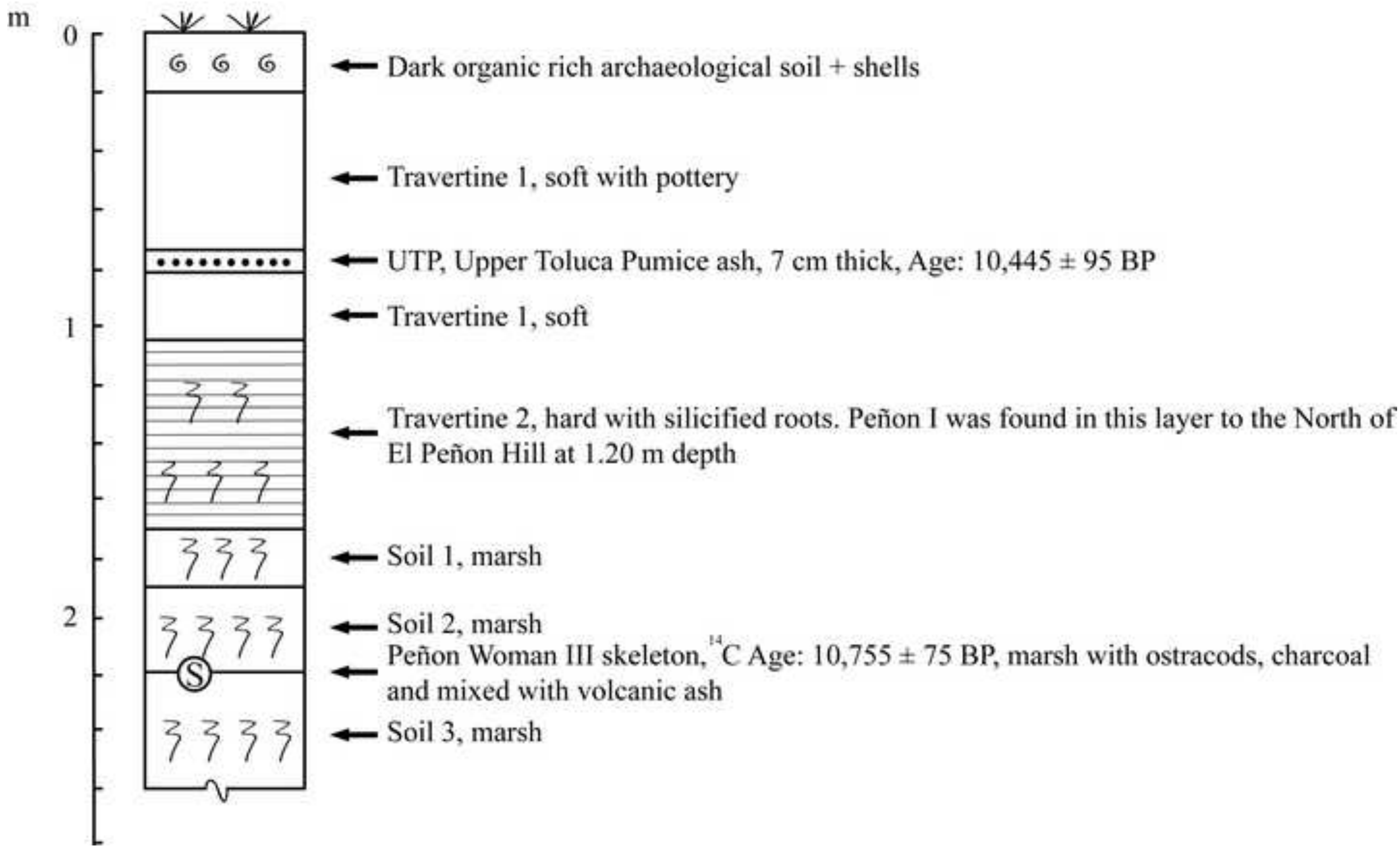

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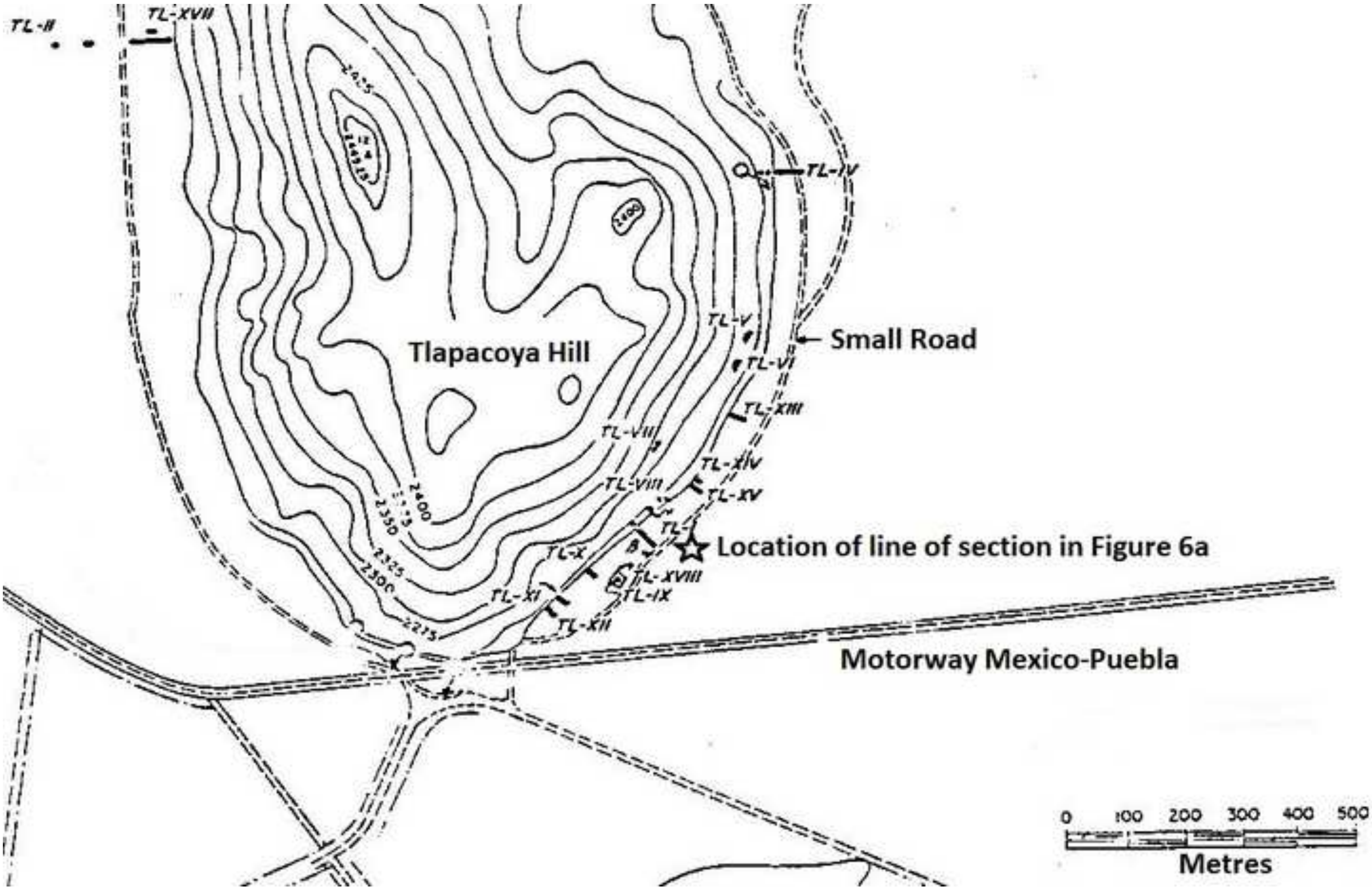

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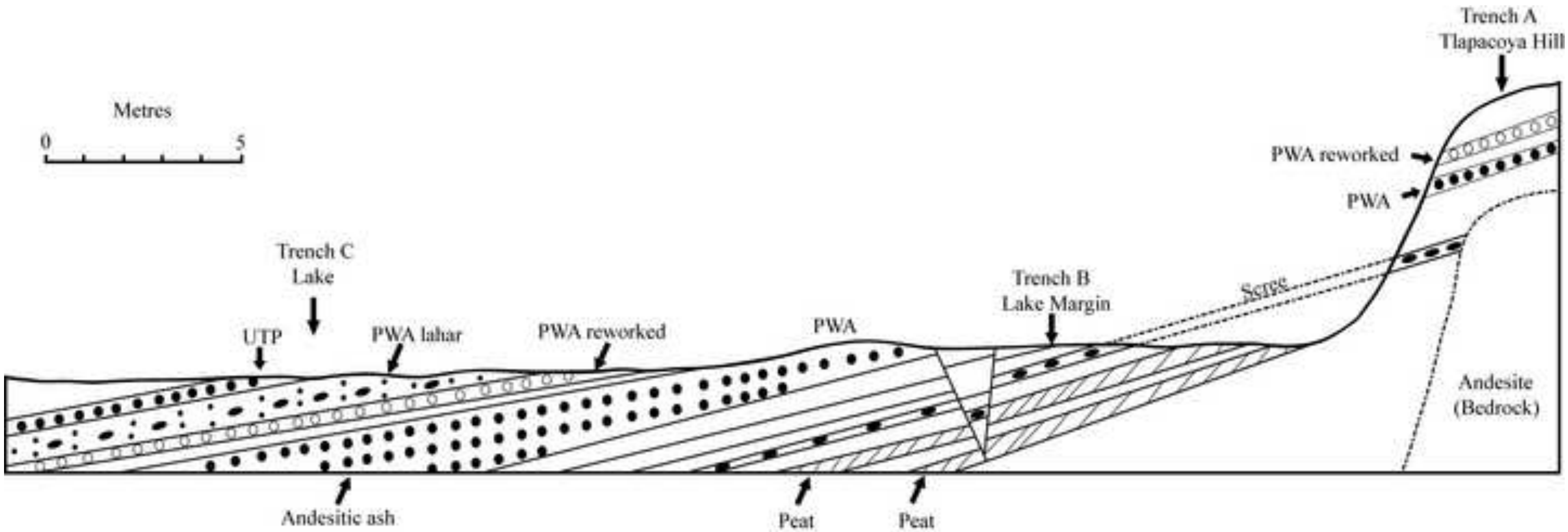

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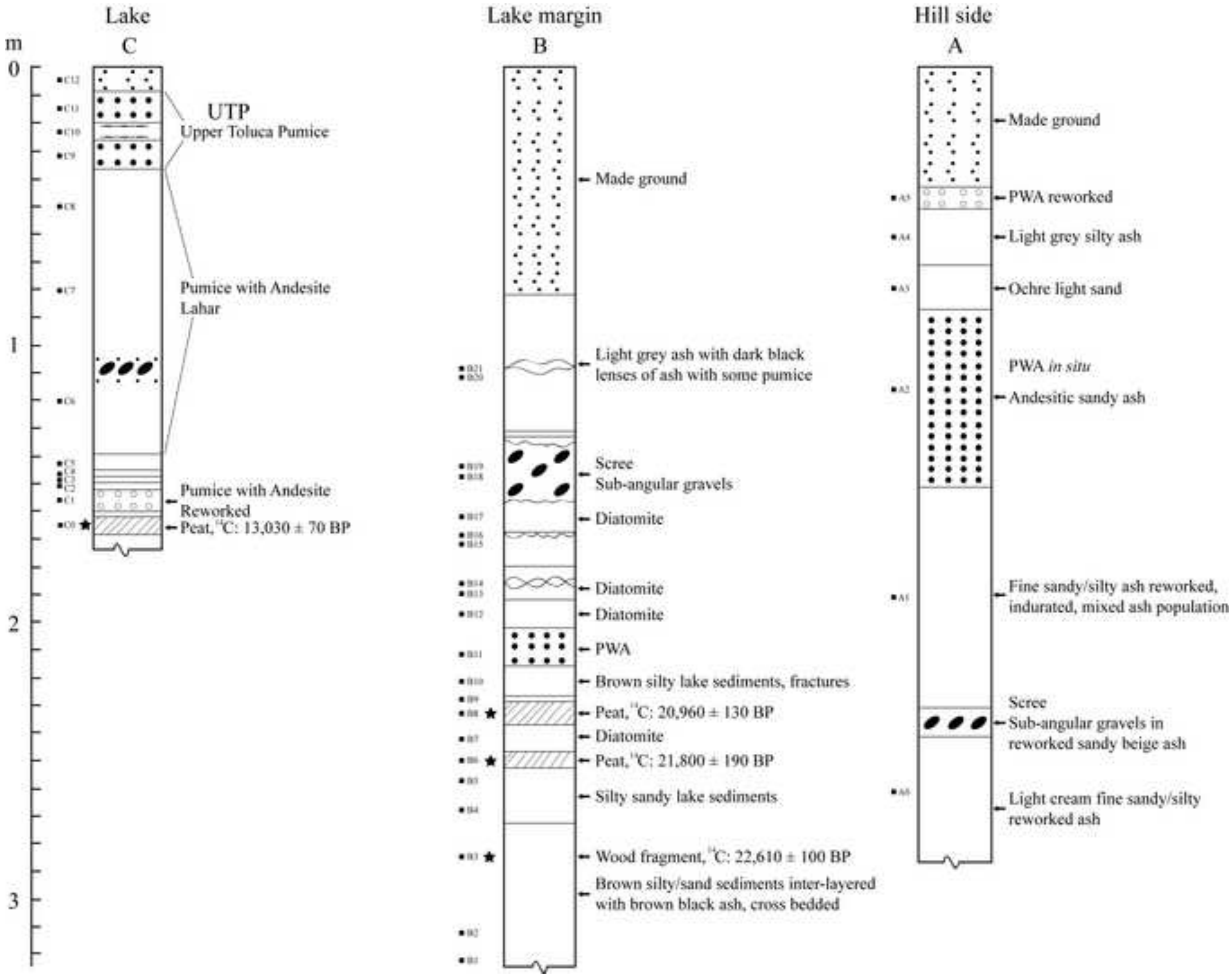

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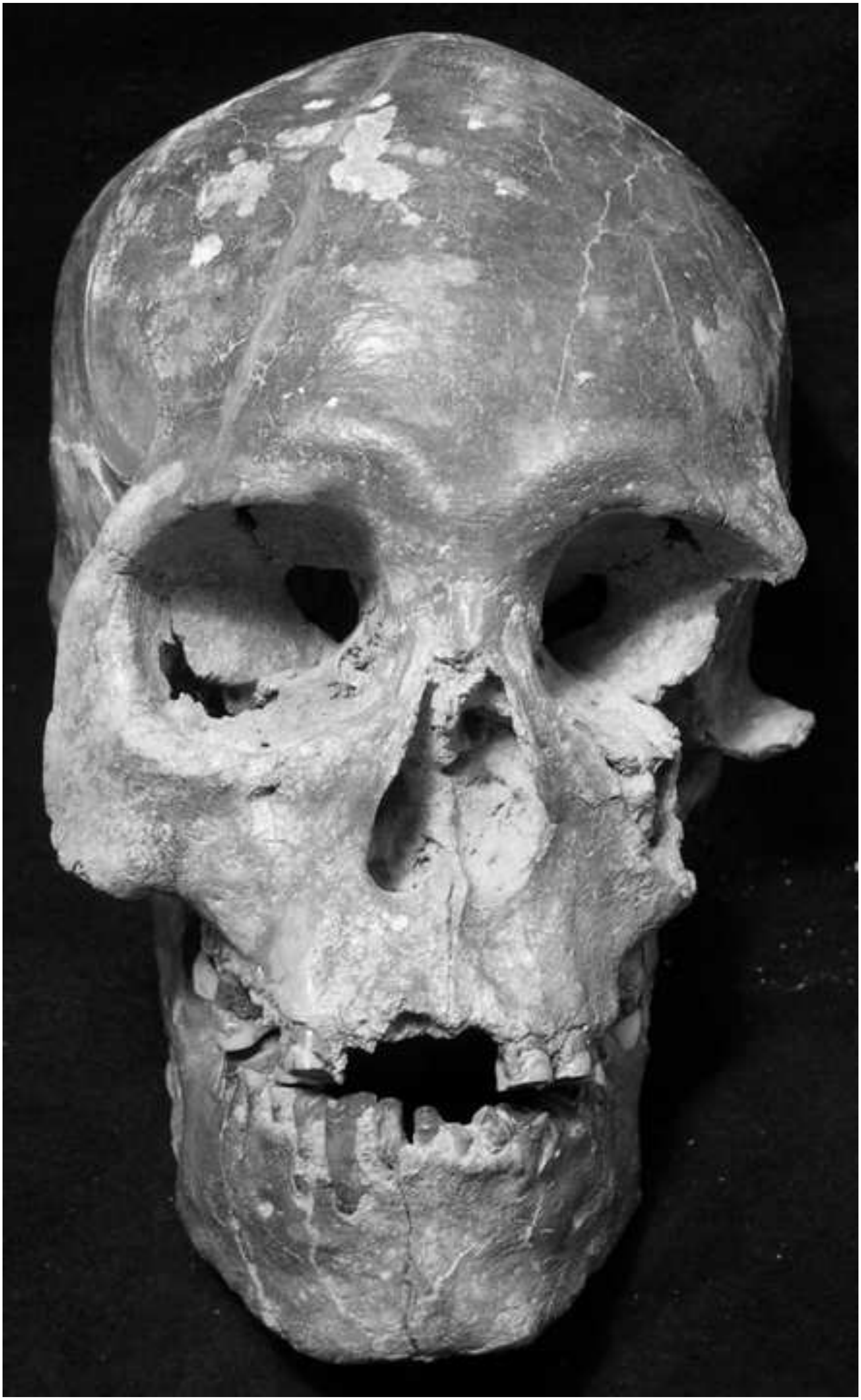

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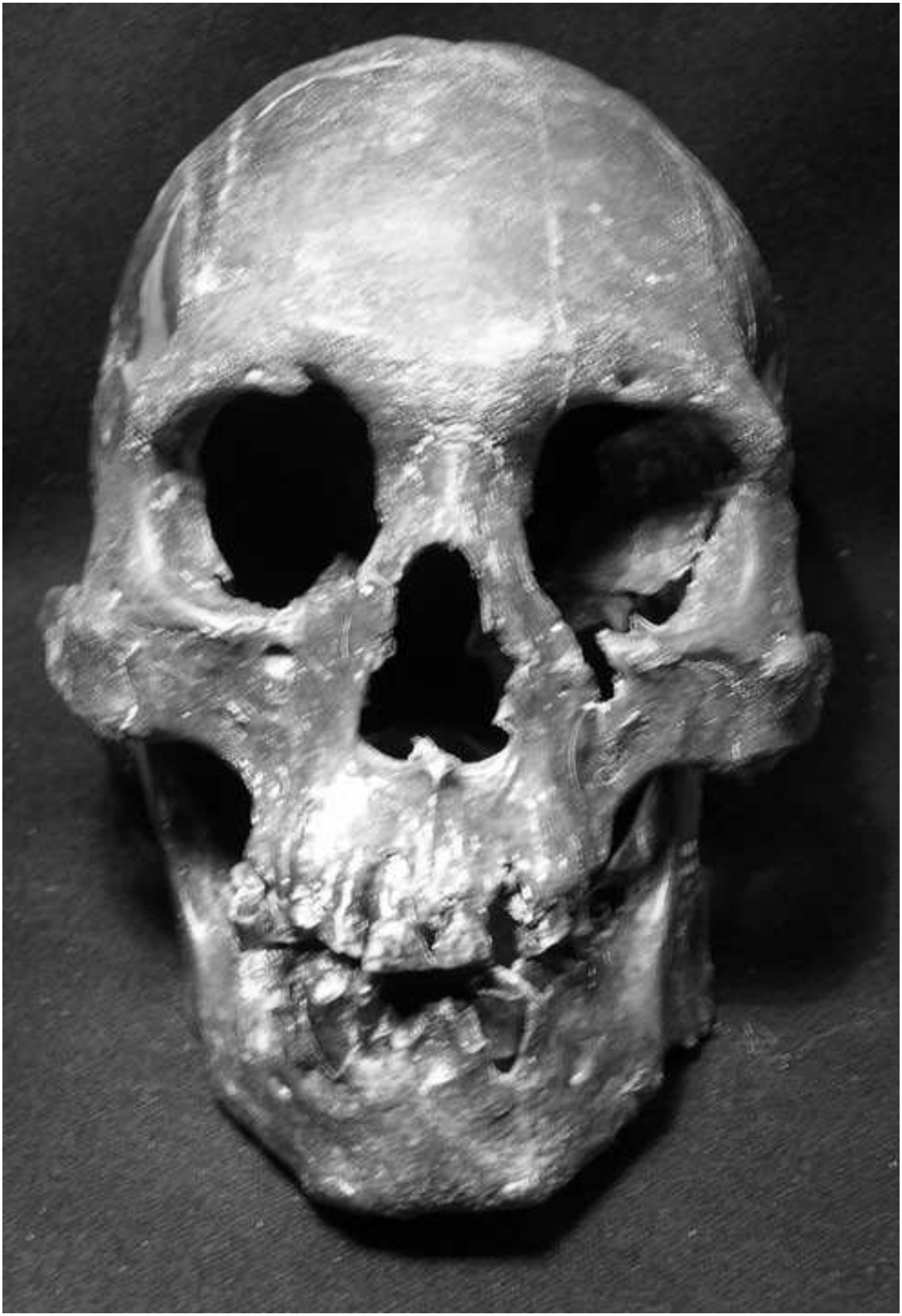

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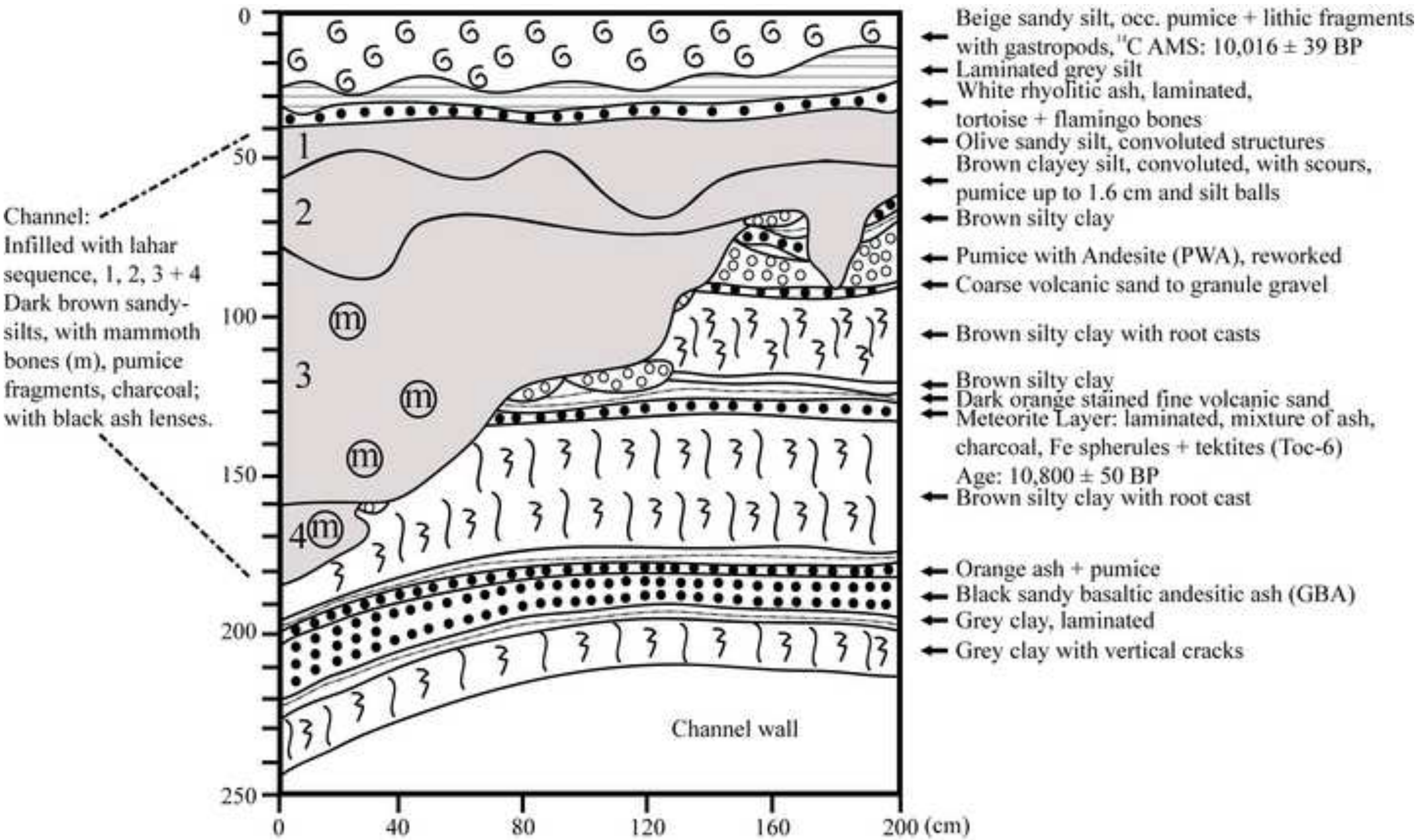

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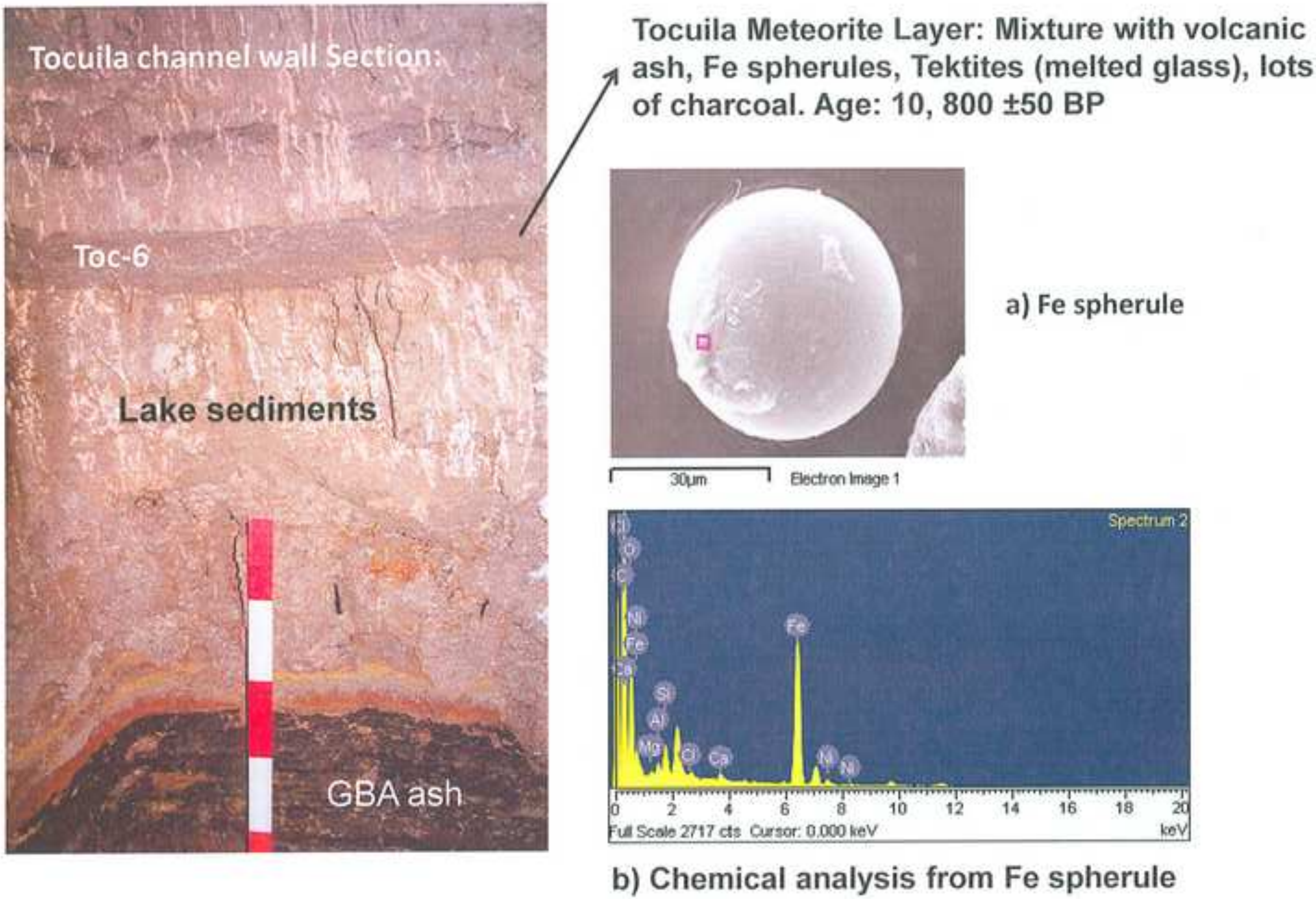

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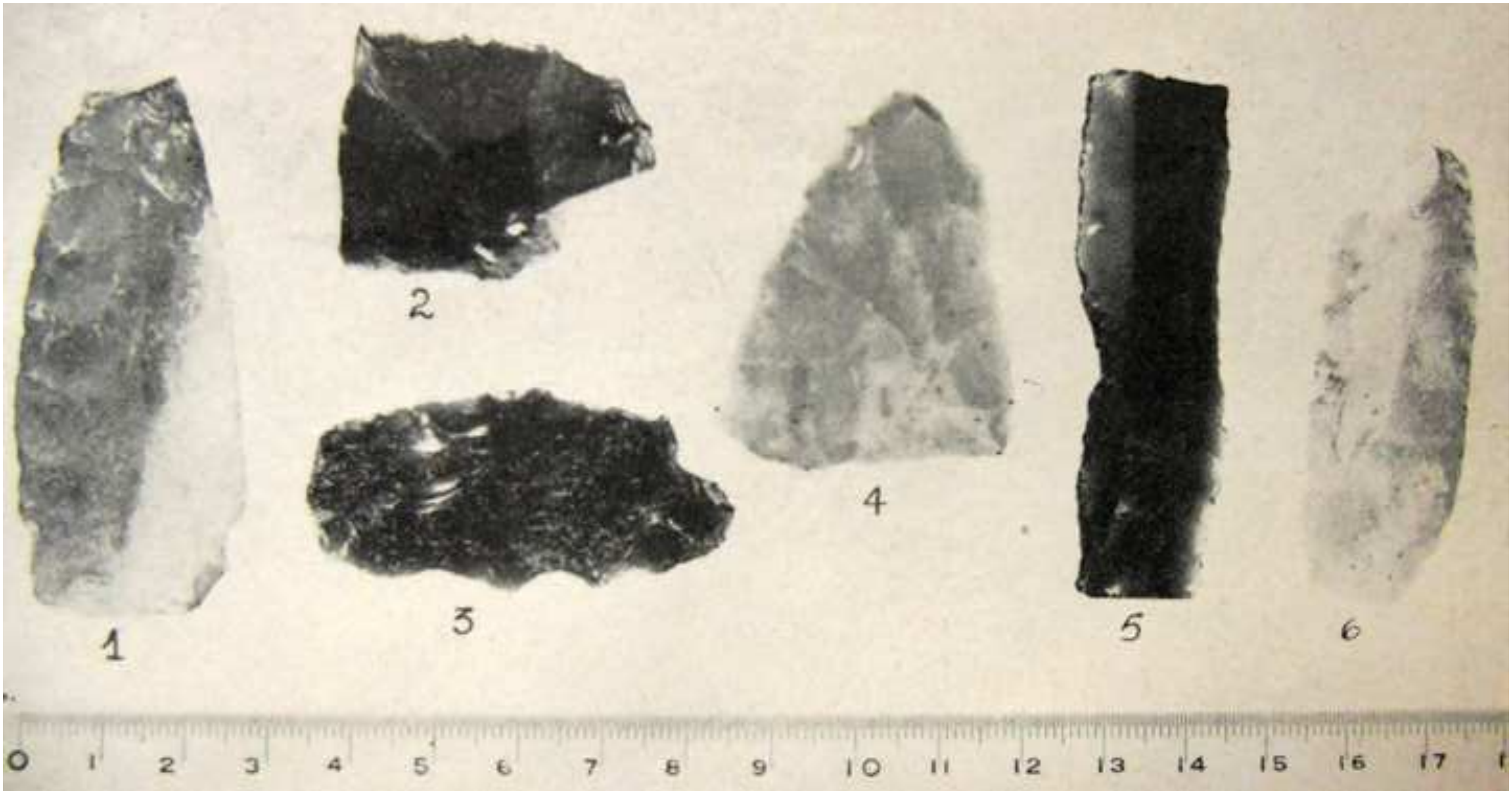

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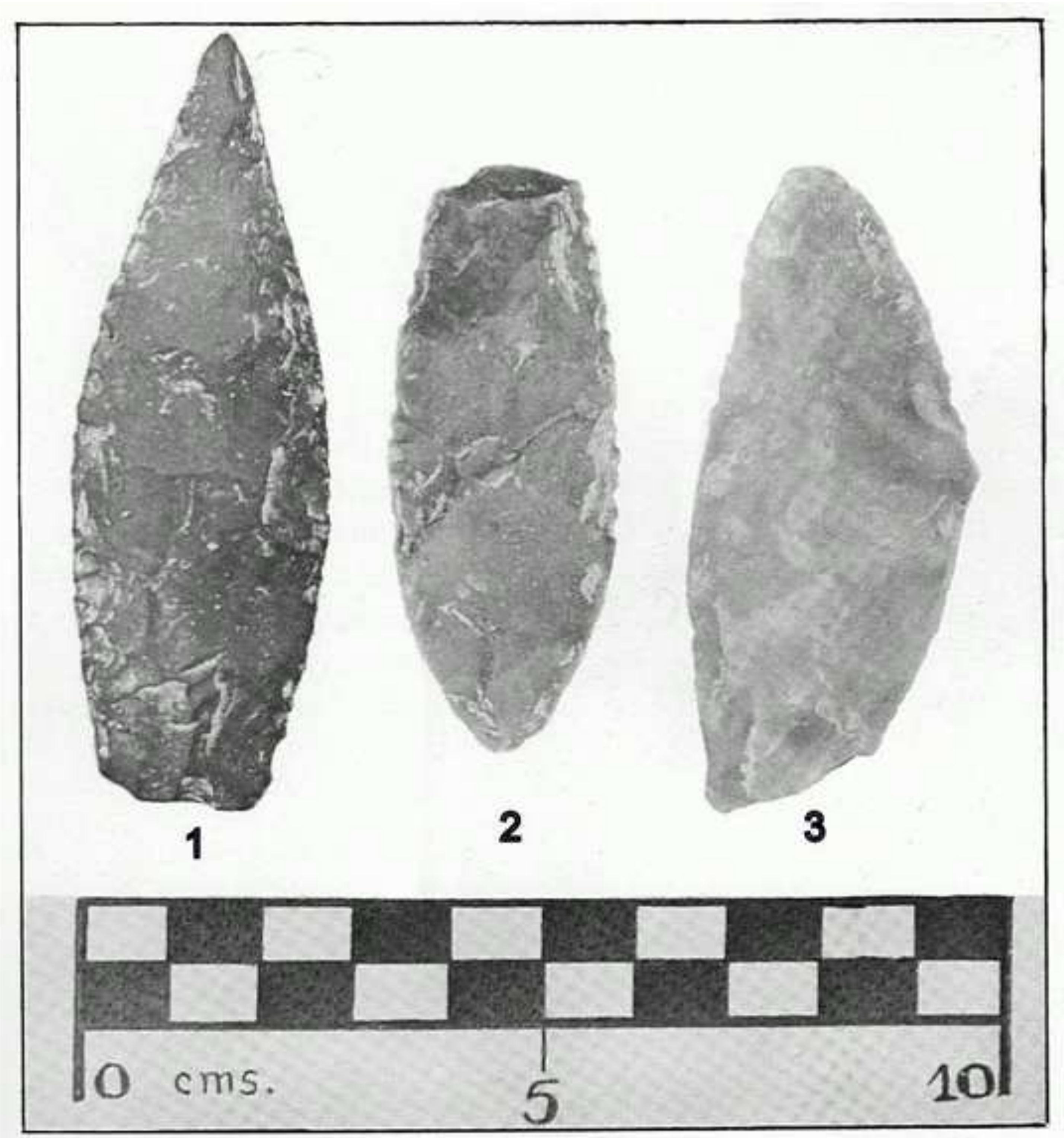

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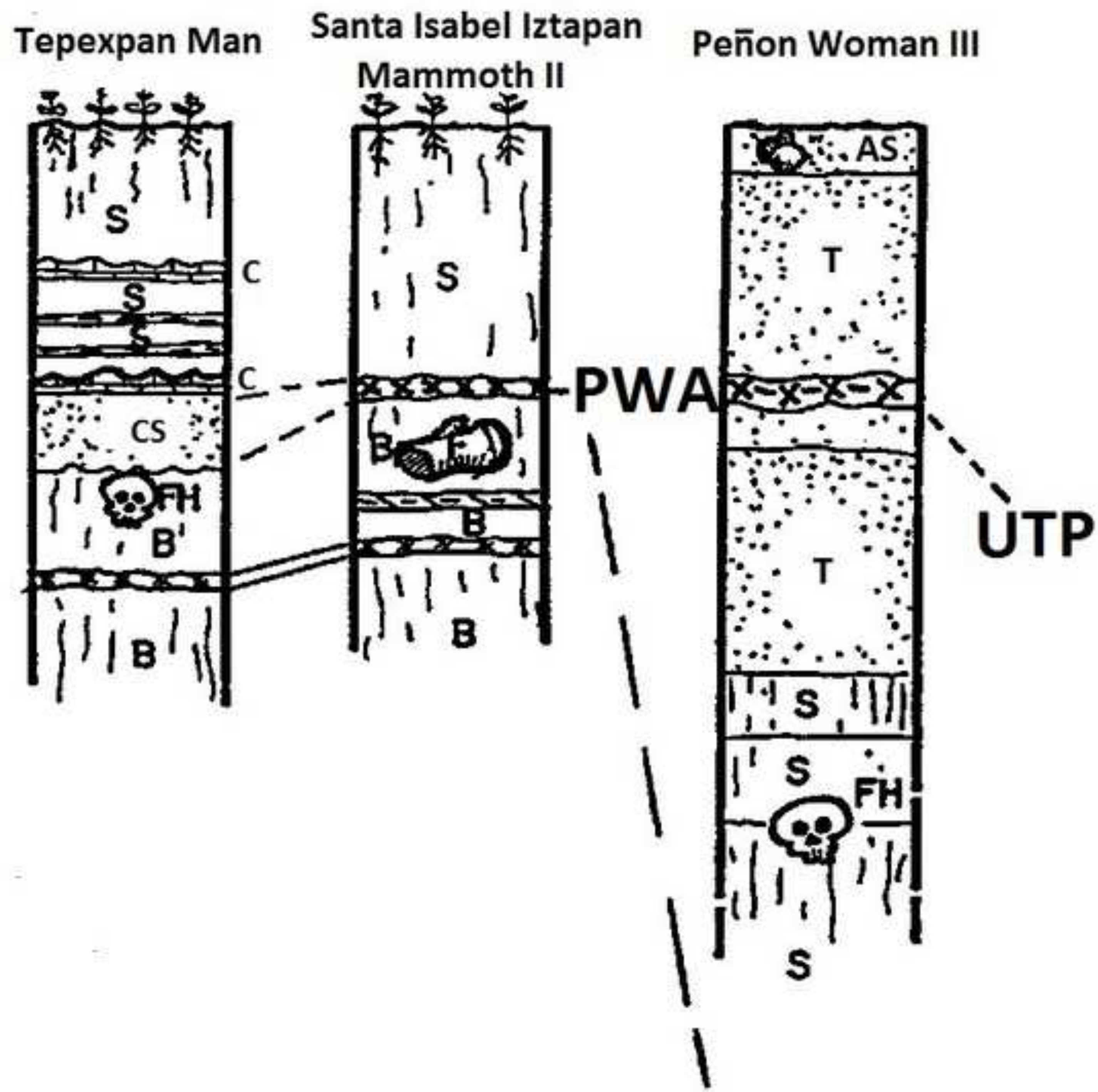

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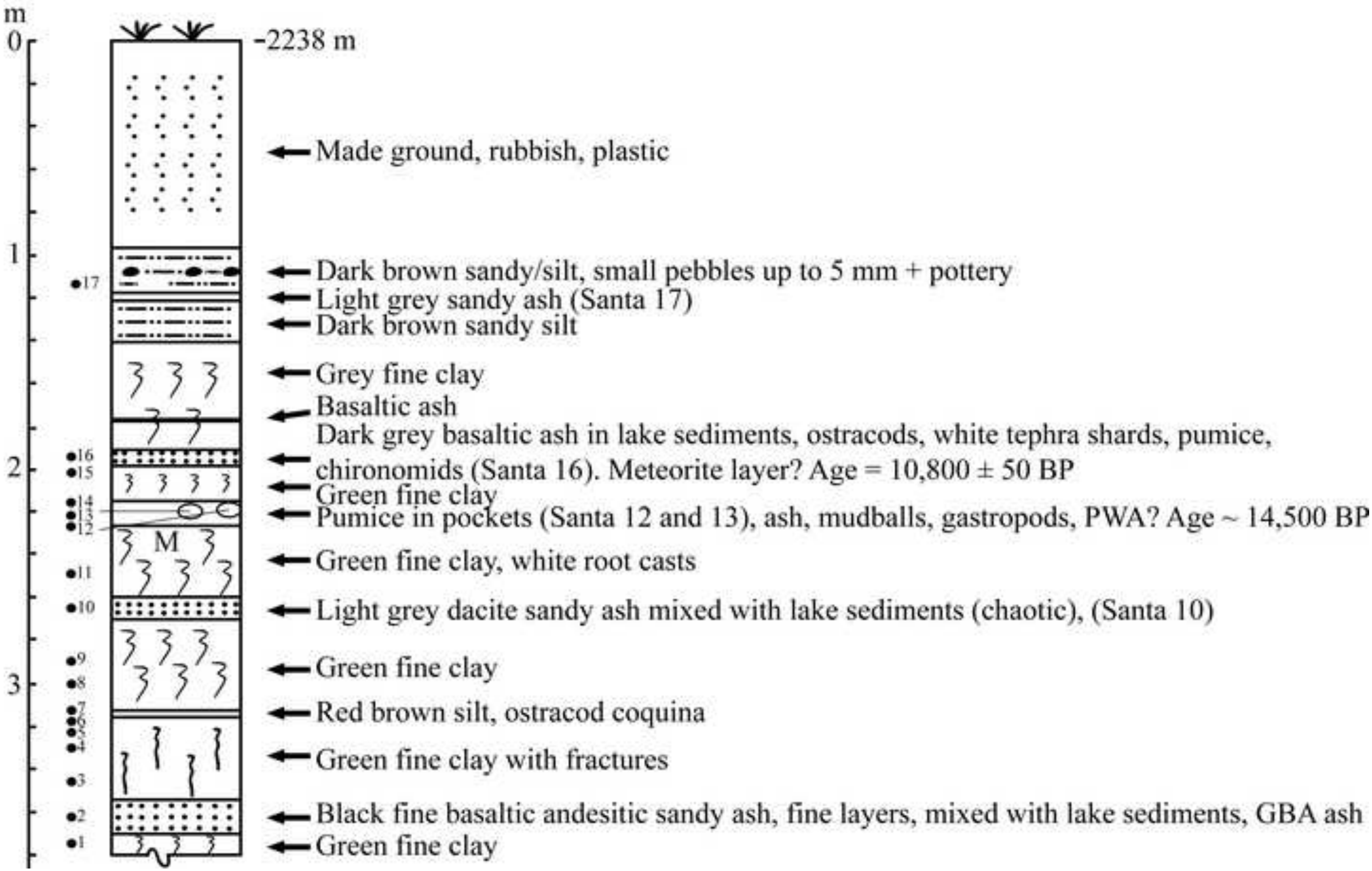

Liverpool John Moores University 24 February 2014.

Editors for the Special Volume

For Quaternary International

Francisco Javier Aceituno and Miguel Eduardo Delgado

Dear Francisco and Miguel

Paper: "Paleo-Indian Sites from the Basin of Mexico: Evidence from Stratigraphy, Tephrochronology and Dating", by Silvia Gonzalez, David Huddart, Isabel Israde-Alcántara, Gabriela Dominguez-Vazquez, James Bischoff and Nicholas Felstead.

I enclose here the new revised version of our paper for the Special Volume for Quaternary International. We have followed the advice of the referees' comments as follows:

Reviewer 1 Comments in black bold, followed by our response in blue:

1) The description and interpretation of the new trenches at Tlapacoya contributes to a better comprehension of the whole chronological sequence and correlation among stratigraphic units, but in my opinion this part is very long and could be shortened, as well as the supplementary data files with geochemical information (11 pages).

We have shortened the description of the stratigraphic units from Tlapacoya to ease understanding, but we would like to keep the Supplementary data files (11 pages) because they support our interpretation and they are only available ONLINE, so we feel that they don't interfere with the reading of the paper.

2) **A direct radiocarbon dating on bones is essential for providing a reliable chronology to the paleoindian human remains and it is another valuable contribution of this paper. The inclusion of human bones in tephra layers of known age as the UTP ash may be also a good chronological indicator, however, I think it requires a discussion of taphonomic aspects. How human bodies were incorporated in the layers?, by a violent death during catastrophic volcanism?, or by cultural practices of burial? In the last case the body is intrusive in a stratum, and careful sedimentary and stratigraphic analyses must be done to evaluate such possibility.**

The 2 skeletons embedded in volcanic ash, Metro Man and Chimalhuacan Man reported in this paper were discovered by chance and there is no archaeological information available at the time of the finds, to be able to say if they were burials or if they were killed and incorporated into the deposit violently during the volcanic eruption. The skulls look well preserved but with a very dark colour, there are no

other marks on them. We have made this clear in the paper explaining that they where found by chance, with no controlled archaeological information

3)The same is valid for the Peñon Woman III, how the authors suppose this skeleton was incorporated to the marsh sediments? I suggest a brief consideration about taphonomic processes for human remains in the manuscript.

Peñon Woman III was also discovered by chance in 1959 and there is no archaeological information available in terms of being a burial or by chance deposition of the skeleton in the marsh sediments. We have made this clear in the paper.

4) In the case of the Tocuila Mammoths Site there is an aspect of the interpretation that should be considered. The channel was produced by the lahar? It seems to be the case considering the macrofabric of clasts and the presence of aligned bones in the deposit, but if it is so, how articulation persisted in some reworked skeletons of Mammuthus which died several centuries earlier?

The mammoths were incorporated in the lahar deposits that were emplaced in a channel, but the evidence is that they were not transported very far at all, hence there is no surprise that some body parts (mainly leg bones) were preserved articulated. We have explained this in the paper more.

5) At Tocuila the evidence of a possible meteorite layer is still under analyses, and in this manner should be referred to in the text (including the Abstract) and conclusions. It is still a controversial hypothesis that has scientific literature for and against.

We have included a paragraph with a discussion in the paper saying that the work on the potential meteorite layer is still ongoing and that this interpretation is still controversial. However there is definitely the presence of microscopic Fe spherules and tektites, so an explanation is required to understand why they are in a layer of Younger Dryas age? However we don't believe that the meteorite impact was responsible alone for the extinction of the megafauna. We have explained all these facts in the paper now.

6) Some other minor suggestions are included in the pdf manuscript.

We have made all these suggested changes now in the manuscript.

Reviewer 2 Comments in black bold, **followed by our responses in blue:**

1) **The text can be shortened to make the arguments easy to follow and the number of figures reduced. Comments are penciled in the manuscript, which is here attached for consideration of authors.**

   We have shortened the paper, in particular the Tlapacoya section. We have followed and made all the suggested changes in the text.

2) **In the text, consider shortening reference to additional not directly related information to the site or material descriptions. For example reference to international airport, description for Peñon II, etc (see comments on manuscript).**

   We have made all these suggested changes in the manuscript.

3) **The text is a bit long and at times difficult to follow the arguments. Consider including an appendix with the relevant information for the sites.**

   The bulk of the tephra geochemical data are included now in the Supplementary Information which is only available Online and doesn't interfere with the reading of the paper.

4) **Part of the descriptions is repeated; for example pag 5 on Peñon site about the saline and marsh setting. At some parts, it is not clear when new descriptions and findings are reported, and if they modify or support previous information. The section on 2.2.3 Tlapacoya new stratigraphy and tephrochronology, perhaps can be deleted and part combined with following section 2.2.4 on interpretations of these new findings in the Tlapacoya trenches. The two sections contain some repetition and not clear how to separate the new findings.**

   We have re-written the paper and tried to avoid repetition as much as possible in the sections mentioned above.

5) **The dates are reported as conventional dates BP and not as calibrated dates. Check non radiocarbon dates, and delete BP; e.g., page 2 reference to 700 ka BP, page 3 reference to 50,000 ka BP (50 ka?). It will be good to standardize to yr BP and provide whenever possible reference to the laboratory identification number and the analytical uncertainties.**

   We have made all the changes suggested and now all the dates are reported in the same format; we have also included Table 1, with all the information regarding the dates.

6) **Figures are not legible and require re-drawing with labels and symbols translated, particularly those taken from previous works. Consider deleting some of them and make reference in text to the figure in the paper; i.e., figure 4.**

   We have re-drawn all the figures with the stratigraphic sections (Figures 3, 6a, 6b and Figure 13) and have now translated into English the Figure 4. All the figures are referenced in the text.

7) **Figure captions for Figs. 11 a and 11 b can be reduced and the caption information added in table form (that related to the description of materials). The caption description includes some discussion contents, e.g., "in Great Plains always less than…", "Originally defined as an Angostura point, although …disagrees…"**

   We have left the captions the same as before because we think that it is important to have the descriptions together with the images. We consider this a very important part of this paper.

8) **Check the reference list and include some referred in the text and not included.**

   We have checked all the references in the text and in the references list and they are now correct.

9) **About the chronological information, in addition to the radiocarbon dates and thephrochronology there is limited magnetostraigraphic data for the Chichinautzin and age estimates for the closure of the basin drainage by volcanic activity, which occurred in the Brunhes chron. There is also some data on the Santa Catarina range and Cerro Tlapacoya, which might be interesting to consider in the discussion.**

   We have now incorporated in the paper a brief discussion on the magnetostratigraphic data for the Chichinautzin Formation related to the closing of the Basin to the South; we have added the following reference as well: Urrutia-Fucugauchi, J. Martin del Pozzo, A.L., 1993. Implicaciones de los datos paleomagnéticos sobre la edad de la Sierra de Chichinautzin, cuenca de México. *Geofísica Internacional* 32, 523-533.

Also please notice that we have added **another author, Nicholas Felstead** that has contributed new work on the study of the proposed meteorite layer at Tocuila.

Best regards

Prof Silvia Gonzalez

Prof of Quaternary Geology and Geoarcheology

Liverpool John Moores University, Byrom Street, Liverpool, L3 3AF, United Kingdom