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Geologic Evidence for Age of Deposits at Hueyatlaco Archeological Site, Valsequillo, Mexico

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Direct tracing of beds during excavation in May 1973, confirmed that the artifact-bearing layers at Hueyatlaco underlie 10 m of fine-grained, water-laid deposits that constitute part of the widespread Valsequillo gravels. Dissection of these deposits by the adjacent Río Atoyac has reached a depth of 50 m. The stratigraphic section at Hueyatlaco includes four distinctive tephra units. The oldest one occupies a small channel in a series of cut-and-fill stream deposits that have yielded bifacial tools. It lies more than a meter above flat-lying, fine-grained beds from which edge-retouched tools have been recovered. The three other tephra units occur higher in the section.

Fission-track ages on zircon phenocrysts from two of the younger tephra layers (370,000 ± 200,000 and 600,000 ± 340,000 yr, 2σ) agree with concordant uranium-series dates for a camel pelvis that was found associated with bifacial tools at Hueyatlaco (245,000 ± 40,000 yr by ^{230}Th and >180,000 yr by ^{231}Pa). These dates are compatible with the depth of burial and subsequent dissection of the Hueyatlaco deposits, as well as with the degree of hydration of volcanic glass shards and with the extent of etching of heavy-mineral phenocrysts from within the tephra layers.

These findings suggest to us that further search for archaeological remains in deposits as old as those at Hueyatlaco would be warranted.

INTRODUCTION

The Valsequillo area, a few kilometers south of Puebla, Mexico (Fig. 1), has long been famous among vertebrate paleontologists for its extinct Pleistocene fauna (Osborn, 1905). These remains have come from fluviatile deposits informally called the Valsequillo gravels (Aveleyra, 1962, pp. 54–56), which are well exposed in bluffs around the Valsequillo Reservoir. Remains of camel, horse, bison, mastodon, mammoth, four-horned antelope, peccary, tapir, sloth, glyptodon, short-faced bear, dire wolf, and saber-tooth cat are reported (Irwin-Williams, 1967; Kurtén, 1967; Guenther, 1968; Guenther *et al.*, 1973). The Valsequillo deposits, as first noted in 1959 by the Mexican prehistorian Juan Armenta Camacho, are also the source of artifacts made of flaked chert and bone (Armenta, 1959; Aveleyra, 1962, pp. 44–46; Armenta, 1978). The discovery of these indisputable artifacts and efforts to determine their geological age has led to this report.

During 1962, controlled excavation on the north shore of the Valsequillo Reservoir by Armenta and Cynthia Irwin-Williams (Irwin-Williams, 1967) uncovered four sites in which vertebrate fossils and stone tools were found together *in situ*: El Horno, El Mirador, Tecacaxco, and Hueyatlaco (Fig. 2). Excavation at Hueyatlaco continued in 1964 and 1966, and the artifacts were shown to compose a typological sequence ranging from edge-trimmed flake tools in the lower levels to well-made bifacial tools in the upper levels (Fig. 3; see also Szabo *et al.*, 1969, Fig. 3). At the same time, Clayton E. Ray, U.S. National Museum, undertook a search for fossil vertebrates, and Malde began field work on the local and regional geology. Steen-McIntyre began a study of the tephra deposits (layers of volcanic ash and pumice) in 1966. Further field work was done by Malde and Steen-McIntyre in 1968,

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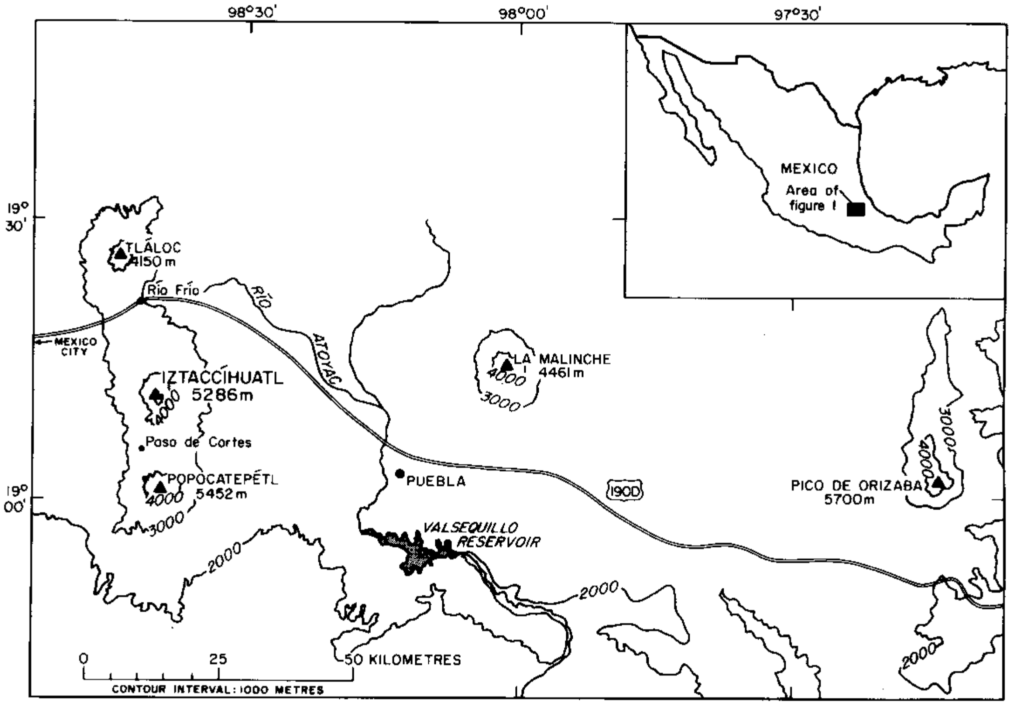

FIG. 1. Index map of the Puebla region showing the location of the Valsequillo Reservoir and the nearby volcanoes. (Modified from Tichy, 1968, Map 1.)

and by Malde in 1970. The stratigraphy at Hueyatlaco that we describe here was investigated in 1973. In addition, results of other stratigraphic work at Hueyatlaco are reported by Cornwall (1968, pp. 129–131; 1970, pp. 46, 47) and by Bunde (1973). Findings from an excavation that was made in 1965 by J. L. Lorenzo for the Instituto Nacional de Antropología e Historia, México, have not been published.

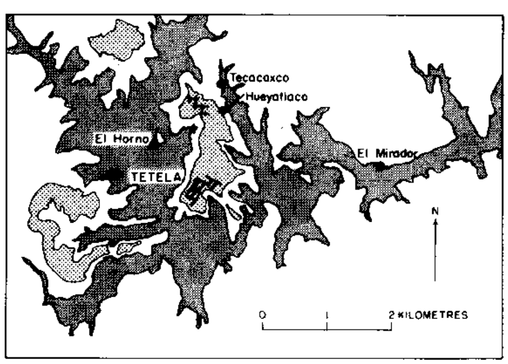

FIG. 2. Index map of the Valsequillo Reservoir and the Tetela Peninsula showing sites of stone tools associated with vertebrate fossils. El Horno, the lowest site, is now under water. Hueyatlaco is 10 m above El Horno and is above water during part of the year. The stippled areas are outcrops of a geologic unit informally named the Tetela brown mud.

This report summarizes our progress in finding geologic evidence for the age of the artifacts at Hueyatlaco, the site with the best-preserved sedimentary record and the one where most of the archeological work has been done (Fig. 4). We describe first the stratigraphic relations determined by excavation in 1973 and then explain the methods used to date particular deposits in the stratigraphic sequence.

HUEYATLACO EXCAVATION, 1973

Purpose

Early in 1973, additional excavation at Hueyatlaco was deemed necessary to expose the stratigraphy more completely. The

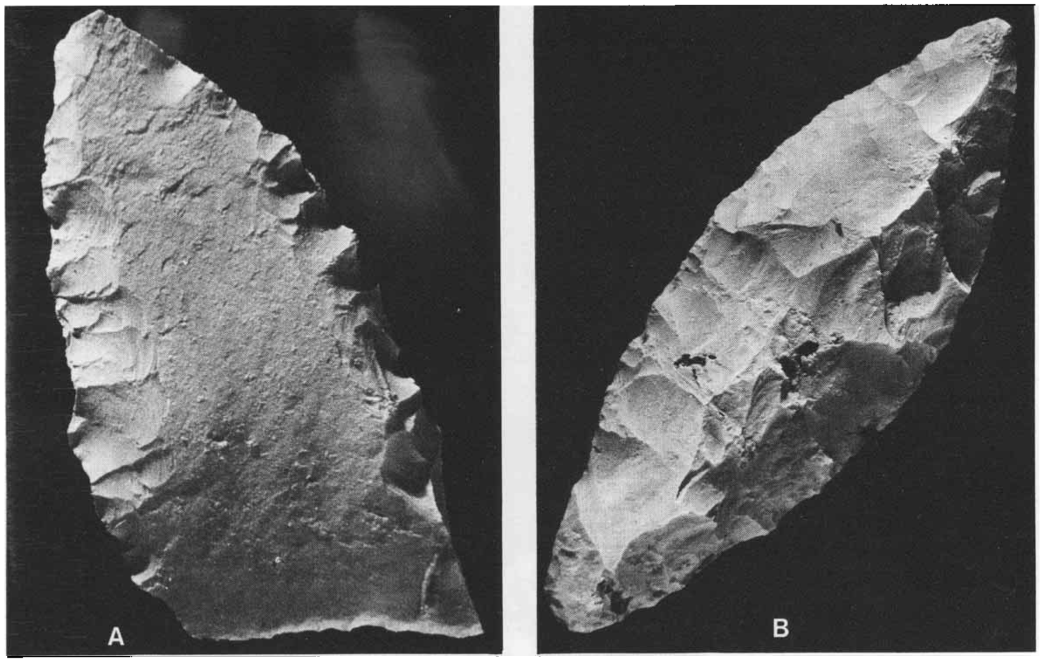

FIG. 3. Stone artifacts collected and described in stratigraphic context by Irwin-Williams (1967). (A) Edge-trimmed projectile point on a flake 38 mm long from unit II of Irwin-Williams. (B) Bifacial bipointed projectile point 89 mm long from unit 1E. For clarity, these artifacts have been fumed with ammonium chloride to eliminate differences due to color. Photographs by Harvey S. Rice, Washington State University, 1966.

stratigraphic relations, except where the deposits had been excavated for artifacts, had previously been inferred only from the field relations of existing outcrops, and we were concerned that the artifacts might lie in an erosional trough that had been cut into the Valsequillo gravels. If it could be shown that the layers with artifacts clearly underlie Valsequillo deposits exposed in the adjacent bluff, as the field relations imply, dating methods applied to the deposits would then provide minimum ages for the artifacts. To expose the stratigraphy, we proposed to dig a trench between the excavations made by Irwin-Williams in 1964 and 1966 and the excavation made by Lorenzo in 1965. The work was considered to be urgent because the site is periodically threatened by the seasonal rise and fall of water in the reservoir. The Instituto Nacional de Antropología e Historia approved our proposal for a geological excavation, the National Science Foundation supplied funds, and digging began in May.

Methods

The site was first resurveyed, using as reference points bench marks established in 1965 by Lorenzo and a corner preserved from the 1966 excavation of Irwin-Williams (Fig. 5). The previous excavations were cleaned, and a connecting trench was dug. Malde did surveying and photography. Fryxell drew the stratigraphic contacts directly on the trench walls and supervised the preparation and collection of stabilized columns of sediment. These columns, known as soil monoliths, preserve a complete record of all the stratigraphic units. Steen-McIntyre collected samples for petrographic work and dating and took photographs. When the beds were fully exposed, Fryxell and Steen-McIntyre mapped the stratigraphy of the 1965 trench and the new

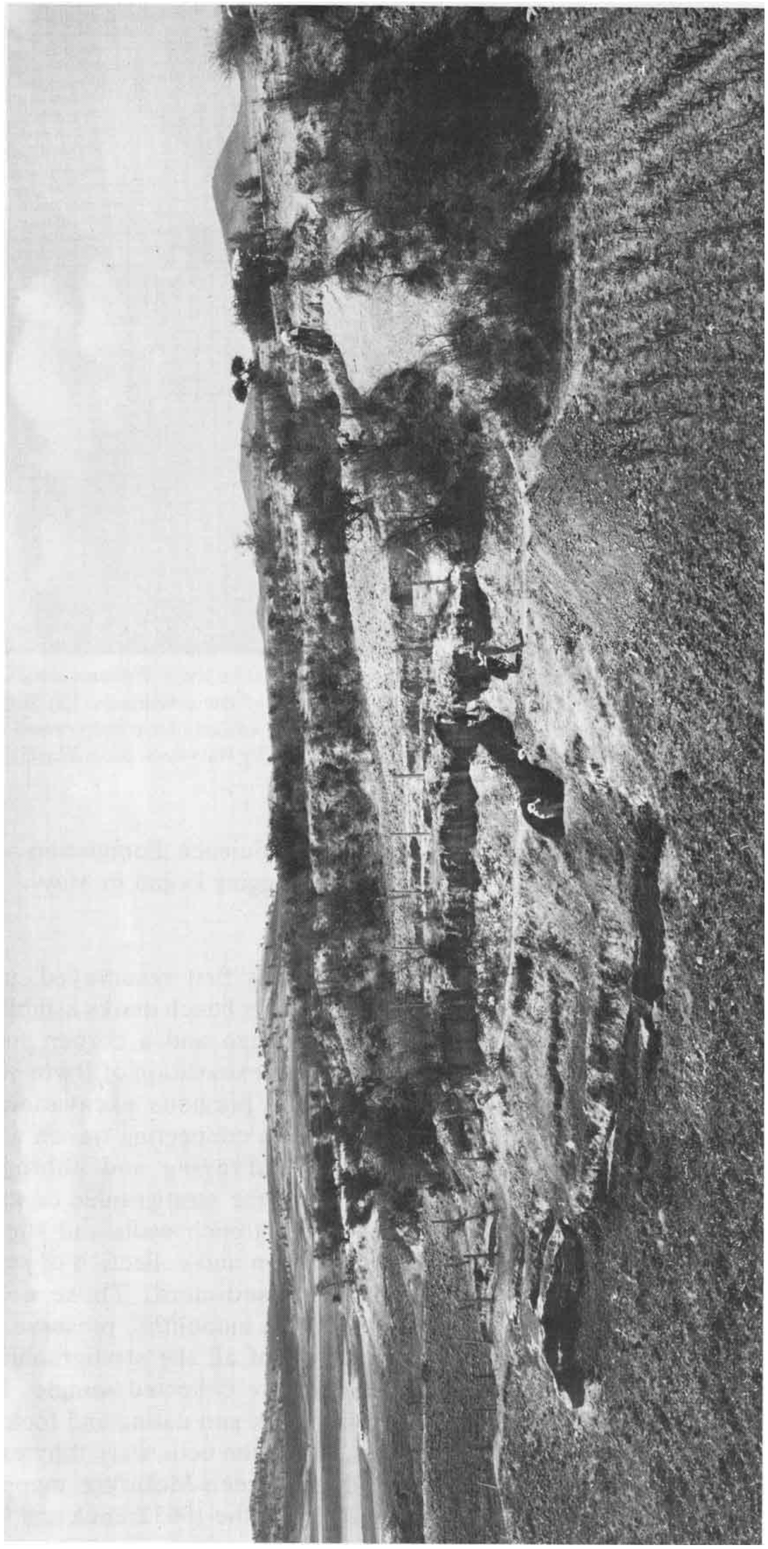

FIG. 4. View of Hueyatlaco from the northwest during excavation in 1973. A trench has been cut through a cliff-forming ledge of volcanic ash (center) informally called the Hueyatlaco ash. The man at the upper right kneels on a ledge formed by a mudflow informally named the Tetela brown mud. Outcrops of the overlying Buena Vista lapilli, another informal geologic unit, are beyond the field of view to the right (west).

FIG. 5. Hueyatlaco from the east at the start of excavation in 1973. Workers are removing water-hyacinth debris from the area excavated in 1966 by Irwin-Williams. Beyond them to the left is the southwest corner of the 1966 excavation. The conspicuous light-colored beds, units B and E of Irwin-Williams (1967), yielded vertebrate remains and bifacial tools in 1966.

excavation in profile at a scale of 1 to 20. At the end of the field season, the excavation of Irwin-Williams was backfilled, and arrangements were made to fence the remaining trenches.

Stratigraphy

The 1973 excavation at Hueyatlaco exposed for the first time the sequence of deposits extending upward from the layers with artifacts to the top of the adjacent bluff (Fig. 6). The only gap is a filled test pit made by Irwin-Williams in 1966, but this is easily bridged by matching flat-lying beds to the north and south. All the deposits are consolidated, although not cemented, and they become hard and durable when exposed to the air. A detailed description of the stratigraphy is planned for a later paper.

At the base of the section, in the area excavated in 1966, are the irregular alluvial deposits described by Irwin-Williams (1967). A layer of sand and fine gravel from which she obtained edge-trimmed tools occurs below other beds of sand and gravel that yielded various bifacial artifacts. The beds with bifacial artifacts thicken westward in the 1966 trench. Traced southward along the walls of the 1973 trench, the beds containing bifacial artifacts are cut out rather abruptly by a younger alluvial layer of sand and fine gravel (designated as "sand grading laterally to clay" on Fig. 6), which in turn is succeeded by Valsequillo deposits exposed in the bluff. In other words, the artifact-bearing beds that were excavated and described by Irwin-Williams pass beneath, and are thus older than, the Valsequillo sediments in the bluff above. Some aspects of the stratigraphic details are described in the captions for Figs. 7, 8, and 9.

Several layers in the stratigraphic sequence have provided material for age determinations, as described below. Near the base of the section, bone excavated by Irwin-Williams from the unit that yielded

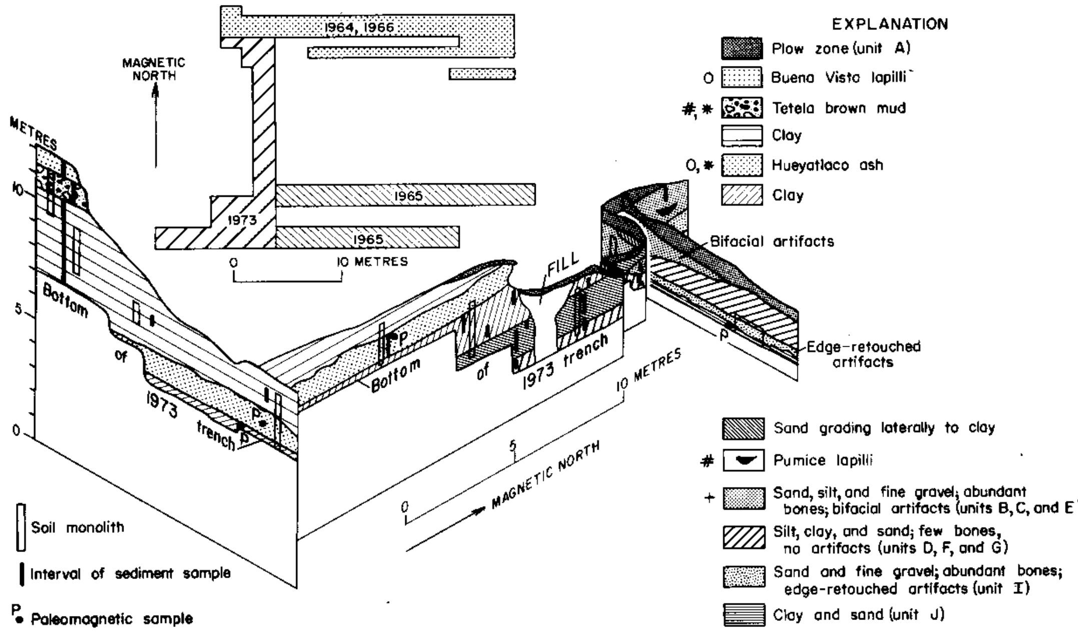

FIG. 6. Map of excavated areas of Hueyatlaco and fence diagram based on mapping done in profile in 1973 at a scale of 1 to 20. The east–west section along the 1964–1966 trench is generalized from an unpublished report by Irwin-Williams to the Departamento de Prehistoria, Instituto Nacional de Antropologia e Historia, México (INAH), dated November 17, 1966. Stratigraphic units identified by letter refer to units designated by her. Marginal symbols indicate methods of dating referred to in the text: #, mineral weathering; 0, hydration of volcanic glass; +, uranium-series dates; and *, fission-track ages. The positions of samples taken for sedimentary analysis and for paleomagnetic measurements are as marked. Only one set of soil monoliths is shown, but a duplicate set was taken for INAH.

bifacial tools has been used for uranium-series dating. The bone sample was a camel pelvis from "one of many articulated skeletons recovered during controlled excavation . . . and there is no doubt whatever about its association with artifacts" (Szabo *et al.*, 1969, p. 240). A channel deposit of pumice lapilli was also found within the unit containing bifacial artifacts, and it has provided information about mineral weathering. Some 4 m higher is the Hueyatlaco ash from which zircon phenocrysts have been concentrated for measurement of their fission-track age. (Phenocrysts are primary mineral crystals indigenous to a volcanic deposit.) The Hueyatlaco ash is a layer of silt-sized dacitic tephra 1 m thick that displays delicate laminar bedding indicative of primary deposition as an airfall in relatively quiet water (Fig. 10; Cornwall, 1968, p. 131). It is overlain by about 4 m of blocky clay, marked by flat-lying and continuously traceable bedding planes. On the clay, with an abrupt lower boundary, is the Tetela brown mud. This unit is thought to be an ancient mudflow, or lahar, because of its texture, volcanic constituents, lack of sorting, and certain features of its distribution in the Valsequillo area. The Tetela brown mud is crowded with large and small lumps of dacitic pumice up to several centimeters in size. Many pieces of the pumice have been examined, and all have the same distinctive set of petrographic characteristics. These characteristics are found in no other tephra beds in the Valsequillo area. This lack of mixing with the numerous other varieties of volcanic fragments that blanket the region suggests that eruption of the pumice was nearly contemporaneous with emplacement of the mudflow. Zircon phenocrysts from

FIG. 7. Hueyatlaco from the north before excavation in 1973, showing the southwest corner of the 1966 excavation and the higher cliff-forming ledge of Hueyatlaco ash beyond. The stratigraphic units are labeled as identified in 1966 by Irwin-Williams. Unit B, consisting of sand and silt, yielded a few remains of horse and camel but no artifacts. Unit E, which is a channel deposit of sand and fine gravel, yielded horse, camel, mammoth, and four-horned antelope, as well as several bifacial tools.

the pumice were used to determine a fission-track age for the brown mud, and heavy minerals from the pumice were examined for signs of *in situ* weathering. Directly on the Tetela brown mud 250 m northwest of Hueyatlaco is the Buena Vista lapilli. This is a pyroclastic unit of well-bedded coarse ash and lapilli that is thought to represent an airfall. Volcanic glass shards from this unit were used for tephra-hydration dating. Zircon phenocrysts are present in the Buena Vista lapilli, but they have not yet been dated.

AGE OF HUEYATLACO DEPOSITS

On the basis of an understanding of the stratigraphy determined by excavation in 1973, several lines of evidence now indicate that the deposits at Hueyatlaco are on the order of 250,000 yr old. To support this conclusion, we explain first some inferences about the relative age derived from local and regional physiographic relations and then discuss age determinations that depend on petrographic properties and radioactive methods. The dating methods used here do not include the potassium–argon method because of a lack of sanidine phenocrysts or other suitable materials. The bones are permineralized and are unsuitable for radiocarbon dating or for racemization (amino acid) dating (J. L. Bada, Scripps Institution of Oceanography, written communication, 1978). No charcoal was found at the site (Irwin-Williams, 1978, p. 18). The remanent magnetism of the paleomagnetic samples does not deviate much from the present geomagnetic field, according to J. C. Liddicoat, Lamont–Doherty Geological Observatory, and the measurements do not yet provide an independent means of dating these deposits.

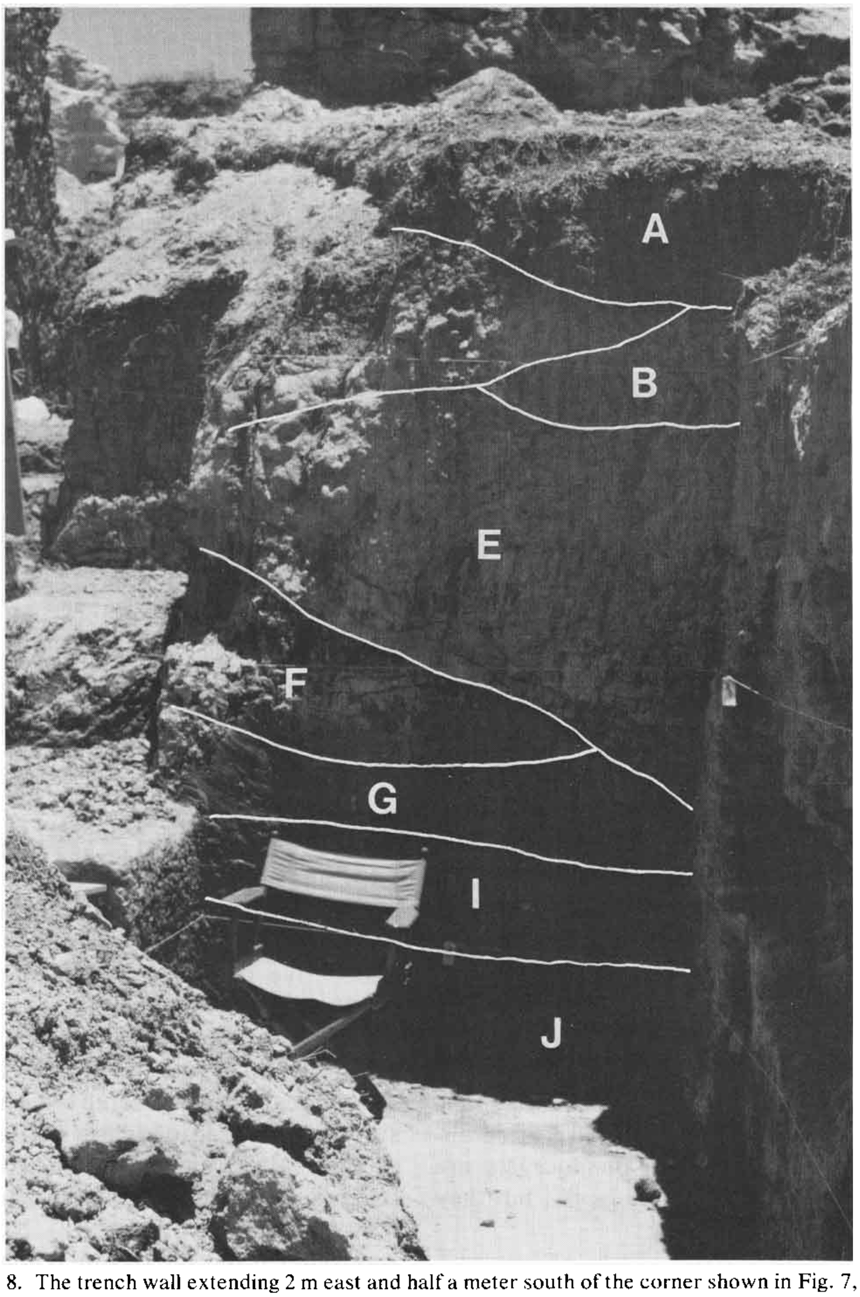

FIG. 8. The trench wall extending 2 m east and half a meter south of the corner shown in Fig. 7, as it appeared after excavation in 1973. The stratigraphic units are labeled as identified by Irwin-Williams in 1966. Unit I, the lowest layer with artifacts, yielded abundant vertebrate remains and edge-trimmed unifacial tools. An unlabeled layer above unit B and below unit A (the plow zone), which was first exposed in 1973, is designated on Fig. 6 as "sand grading laterally to clay." Its further extent to the south is shown in Fig. 9.

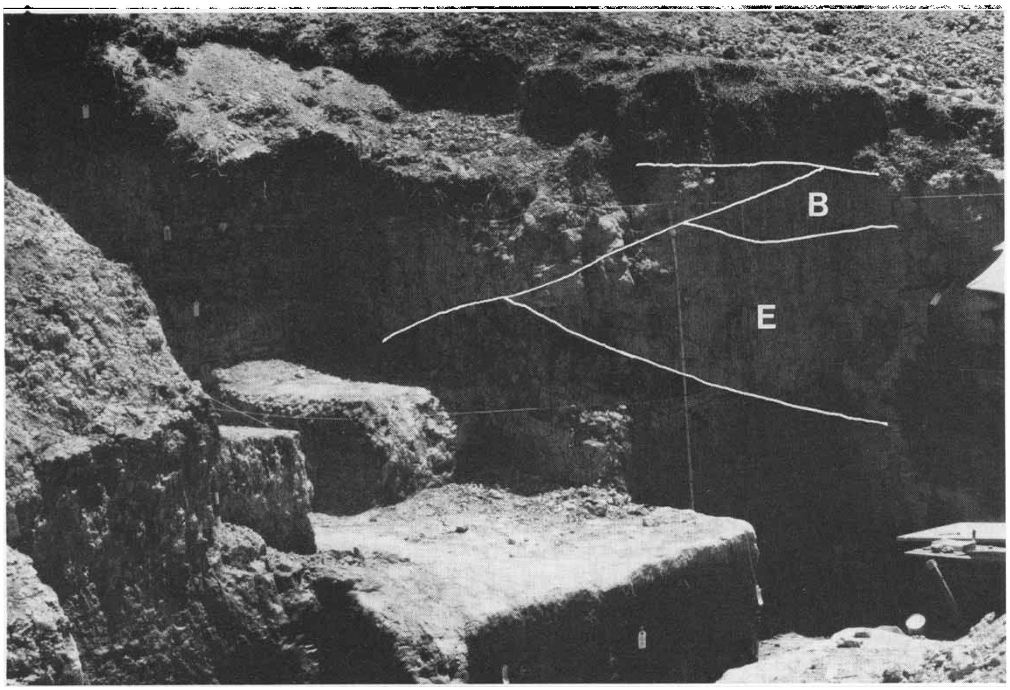

FIG. 9. View southwestward of the corner at the left of the wall in Fig. 8. Cutting units B and E is the unlabeled layer designated as "sand grading laterally to clay" on Fig. 6. Southward-dipping beds in this layer grade from sand to silty clay and flatten beneath higher stratigraphic units.

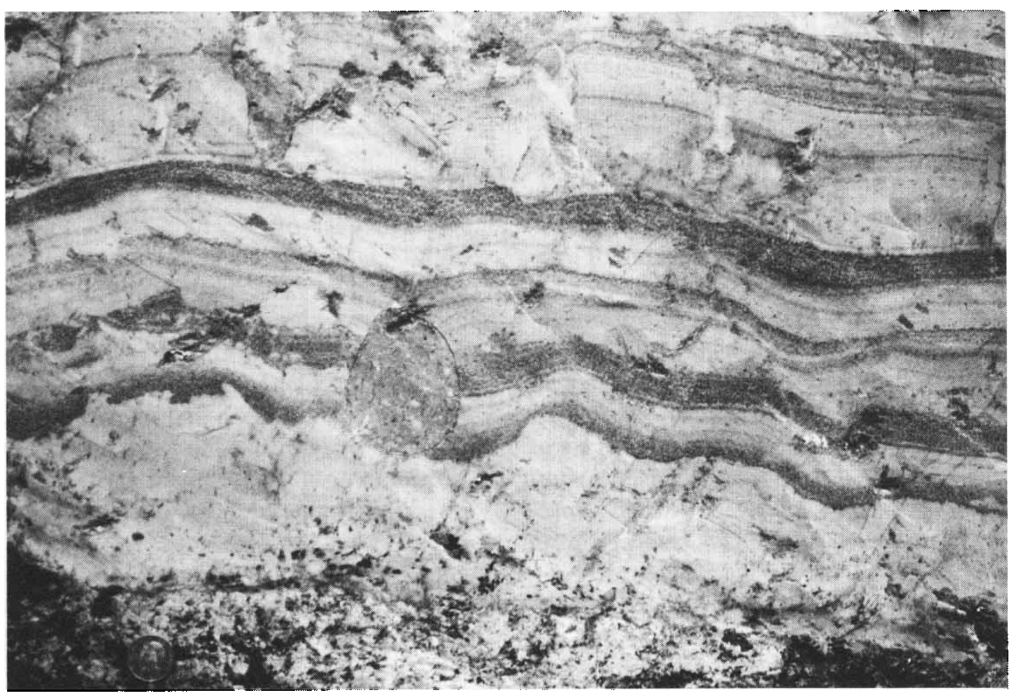

FIG. 10. Lower part of the Hueyatlaco ash showing graded laminar bedding resulting from deposition in water under relatively tranquil conditions. The diameter of the coin is 25 mm. The lack of mixing with nonvolcanic detritus suggests that this layer represents an airfall, preserved essentially as it was deposited in the Valsequillo sediments. The egg-shaped area is an animal burrow.

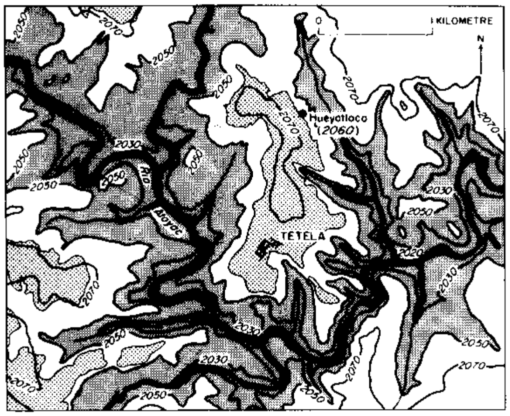

FIG. 11. Contour map of the Valsequillo area showing the drowned topography beneath the reservoir and the former course of the Río Atoyac. The area flooded by the reservoir during the season of low water is shown in gray. Outcrops of Tetela brown mud are stippled. (Adapted from a map prepared by Secretaria de Recursos Hidráulicos, 1936.)

Depth of Burial

The artifact-bearing layers at Hueyatlaco are buried by more than 10 m of Valsequillo deposits, which include several zones of soil development (Cornwall, 1970, pp. 46, 47, 53). These detrital layers are largely an array of alluvial sediments, mostly fine grained, but they culminate in about 2 m of material that is probably subaerial (Tetela brown mud and Buena Vista lapilli). Judging from still thicker accumulations of subaerial deposits preserved in protected sites elsewhere in the Puebla Valley, but absent at Hueyatlaco, it seems likely that the Hueyatlaco artifacts were once buried by several additional meters of sediment. Subjectively, therefore, although the rate of buildup of the Valsequillo deposits is not known, the length of geologic time represented by deposits above the artifacts seems long.

Extent of Dissection

After the sediments at Hueyatlaco were deposited, the Valsequillo area became greatly dissected. Figure 11 shows the dissected topography as it existed before the reservoir was filled. At Tetela, the Atoyac River flowed at an altitude of 2020 m, some 50 m below the Tetela brown mud. Outcrops of Tetela brown mud north and south of the river demonstrate the presence of this unit before downcutting began.

If the Río Atoyac and its tributaries are visualized as a simple V-shaped valley, 50 m of downcutting at the center amounts to an average lowering of 25 m. Assuming a high annual rate of erosion, equal to that in the area drained by the Colorado River (namely, 17 cm/1000 yr; Judson and Ritter, 1964), the 25 m eroded at Valsequillo would represent 150,000 yr. Assuming a slow rate of erosion—for example, the average rate of 3 cm/1000 yr for the United States as a whole—the dissection at Valsequillo would represent 800,000 yr.

To this must be added whatever time was required to bury the artifacts to a depth of 10 m or more, and whatever time passed before erosion by the Río Atoyac began. Quite obviously, these factors of additional time, together with the actual rate of erosion, are unknown. Nonetheless, if the limiting rates of erosion used in this calculation can be regarded as reasonable, the amount of dissection at Valsequillo suggests that the Hueyatlaco site is geologically old.

The Search for Volcanic Sources

A large part of the field work at Valsequillo has been a search for sources of the volcanic units interbedded in the Valsequillo deposits. If even one of these sources could be identified, geologic evidence at the volcano itself could be used, and additional means of dating might then be available. For this purpose, Malde has collected over 500 tephra samples from the Valsequillo area and from stratigraphic sections exposed on the nearby volcanoes. Steen-McIntyre has made a preliminary petrographic examination of most of them. The work has been both tantalizing and frustrating: tantalizing because deposits have been found on the volcanoes in datable sequences; frustrating because apparent correlations between deposits on the volcanoes and those at Valsequillo have tumbled as samples have been examined in greater detail. At this writing, none of the correlations previously suggested (Malde, 1965, 1967; Steen-McIntyre, 1968; Steen-McIntyre and Malde, 1970) can be supported (Steen-McIntyre, 1977, pp. 109–114).

Still, much has been learned. Pumice cobbles from the Tetela brown mud and pumice lapilli associated with the bifacial tools, although individually distinct, have petrographic characteristics generally similar to coarse tephra on the flanks of Popocatépetl and Iztaccíhuatl. In contrast, the Buena Vista lapilli has a clear affinity with tephra deposits on the volcano La Malinche. The Hueyatlaco ash is also petrographically similar to coarse tephra on La Malinche, although its thickness and fineness of grain would be compatible with a large-scale eruption from a more distant source.

The apparent lack of deposits on La Malinche that are specifically correlative with volcanic units at Valsequillo seems significant because exposures in barrancas (deep ravines) on the volcano are excellent. Indeed, numerous volcanic units are found in a sequence extending downward through a buried soil dated by radiocarbon at about 25,000 yr B.P. (samples W-1911, W-2570, and W-2571; Kelley *et al.*, 1978), and the petrography of these units has been studied in detail (Steen-McIntyre, 1977, pp. 114–117). Having failed to identify any volcanic unit on La Malinche exactly correlative with a tephra layer at Valsequillo, Steen-McIntyre now believes that the source deposits on La Malinche are still deeply buried. If so, the Valsequillo deposits at Hueyatlaco are older than any now exposed on La Malinche.

Mineral Weathering

Weathering of hypersthene, an orthopyroxene mineral, provides another clue to the age of volcanic units at Hueyatlaco. Hypersthene occurs as phenocrysts within pumice from two tephra units: the Tetela brown mud and the pumice lapilli found with the bifacial tools. Pumice from the brown mud is partly altered, and freshly broken surfaces have a marblelike texture consisting of swirls of waxy brown clay interleaved with fresh pumiceous glass. Hypersthene crystals enclosed in the fresh glass are unaltered, but adjacent crystals protruding into the waxy clay are strongly etched, giving a "picket-fence" profile (Figs. 12 A and B). Hypersthene phenocrysts from the pumice lapilli 9 m lower in the section are even more deeply etched (Fig. 13).

Etching of hypersthene has been discussed with P. W. Lambert, U.S. Geological Survey, who has studied the sediments at Tlapacoya, an archeological site near Mexico City in a climatic environment similar to Valsequillo. At Tlapacoya, the oldest tephra units range in radiocarbon age from about 22,000 to 24,000 yr B.P. (Lambert, 1979). Etching of hypersthene is rare and incipient in these deposits and is entirely lacking in the younger units (Lambert, oral communication, 1973). By this analogy, although conditions of weathering at Valsequillo and Tlapacoya may have been significantly different in the past, weathering of hypersthene phenocrysts seems to indicate an age for the Hueyatlaco sediments greatly in excess of 24,000 yr.

Tephra Hydration Dates

Tephra-hydration dating is a method of estimating the age of rhyolitic or dacitic tephra by measuring the thickness of hydration rinds in volcanic glass and the amount of water taken up by enclosed bubble cavities (Steen-McIntyre, 1973, 1975, 1981a). The method is applicable provided that something is known about the chemical composition of the volcanic glass and the environment of deposition and preservation. Tephra-hydration dating stems from research on obsidian-hydration dating (Friedman and Smith, 1960; Friedman and Long, 1976; Ross and Smith, 1955) and from studies of liquid water in pumice vesicles (Roedder and Smith, 1965; Roedder, 1970).

Two of the tephra deposits at Hueyatlaco—the Hueyatlaco ash and the Buena

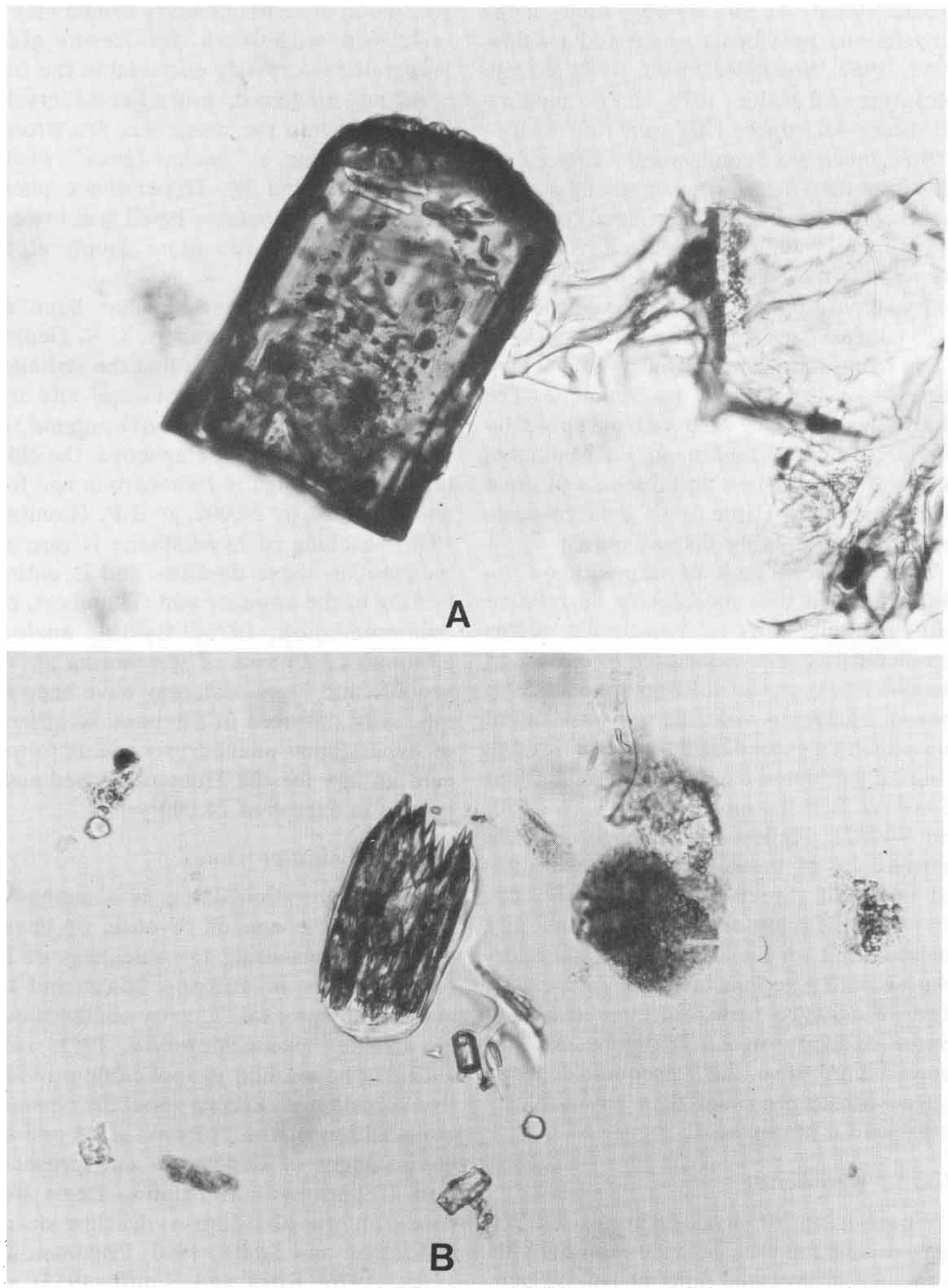

FIG. 12. Photomicrographs by R. B. Taylor, U.S. Geological Survey, of hypersthene phenocrysts in pumice from Tetela brown mud at Hueyatlaco, showing differences in etching caused by weathering. (A) Unaltered hypersthene crystal 0.15 mm long from an area of fresh volcanic glass. (B) Altered hypersthene crystal 0.1 mm long showing a picket-fence profile produced by etching.

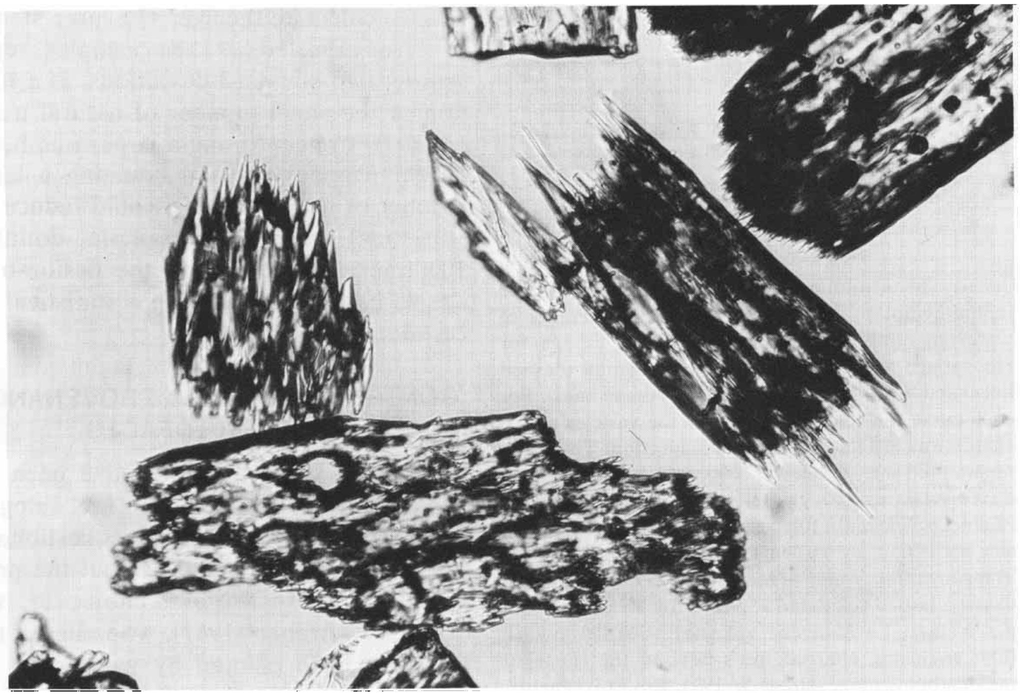

FIG. 13. Photomicrograph by R. B. Taylor, U.S. Geological Survey, of altered hypersthene crystals 0.1–0.15 mm long from the pumice lapilli associated with bifacial tools and found 9 m below Tetela brown mud. Etching is more advanced here than in pumice from the Tetela brown mud (Fig. 12) and has formed delicate needlelike shapes.

Vista lapilli—are composed of silica-rich volcanic glass, and their approximate age by this method is 250,000 yr (Fig. 14). Glass from pumice in the Tetela brown mud and from lapilli associated with the bifacial tools, on the other hand, proved to be unsuitable for dating by this method.

Uranium-Series Dates

Several uranium-series dates on bone from the Valsequillo area have been determined by B. J. Szabo, U.S. Geological Survey (Szabo *et al.*, 1969). The results for samples from Hueyatlaco, El Horno, and Atepitzingo, a vertebrate locality that has yielded many species of the Valsequillo fauna, are summarized in Table 1. They indicate an age of about 250,000 yr. The dates determined at Hueyatlaco by measurement of the ^{230}Th and ^{231}Pa isotopes are independent.

Isotopic measurements by Szabo indicate that the samples from Hueyatlaco and El Horno formed a closed system during the last 180,000 and 165,000 yr, respectively, in the sense that uranium and its decay products did not demonstrably migrate either in or out of the samples during this time. Thus, these samples are at least as old as the respective ^{231}Pa dates and are more exactly dated by the ^{230}Th dates, as listed. On the other hand, isotopic measurements show that the sample from Atepitzingo does not conform with a closed system, and this sample is dated by an open-system model.

Fission-Track Ages

Fission-track ages for zircon phenocrysts from two of the tephra units at Hueyatlaco have been determined by C. W. Naeser, U.S. Geological Survey, giving results comparable to the dates determined by the uranium-series method (Table 2). This method depends on counting the tracks

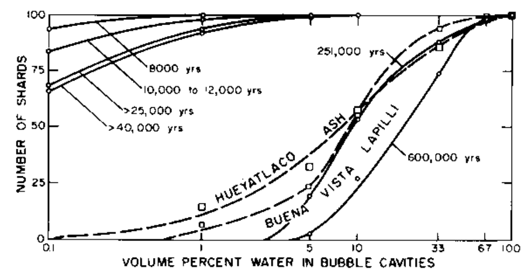

FIG. 14. Cumulative curves obtained by the tephra-hydration method, showing the percentage of water in bubble cavities with respect to age for Hueyatlaco ash and the Buena Vista lapilli (dashed lines) and for some dated tephra units (solid lines). For each curve the amount of water in the vesicles of 100 shards was estimated by visual inspection. The dated tephra units are as follows: 8000 yr (ash on buried soil dated 8240 ± 300 yr B.P., sample W-1909, La Malinche volcano); 10,000 to 12,000 yr (a distinctive ash identified by P. W. Lambert, 1979, from the Tlapacoya site, Valley of Mexico); >25,000 yr (pumice below a buried soil dated 25,920 ± 1000 yr B.P., sample W-1911, La Malinche volcano); >40,000 yr (ash flow enclosing charred trees beyond the range of radiocarbon dating, sample W-1995, Río Frío, Puebla, Mexico); 251,000 yr (pumice, Yellowstone National Park, dated by J. D. Obradovich, U.S. Geological Survey, using the K–Ar method on sanidine phenocrysts); and 600,000 yr (volcanic glass, Wascana, Saskatchewan, dated by J. A. Westgate, University of Toronto, using the fission-track method).

produced in a mineral crystal by fast-moving atomic particles that result from radioactive decay (Naeser *et al.*, 1980). The tracks are first counted as the sample comes from the ground. The sample is then irradiated in a nuclear reactor to produce a large number of induced tracks. The numbers of natural and induced tracks are then used to calculate the age. The large statistical error reported for these samples, representing two standard deviations, is a function of the small number of natural tracks counted. Concentrating a larger number of zircon phenocrysts and counting a larger number of natural tracks would reduce the statistical error. For example, counting 100 tracks would permit the fission-track age to be determined with a statistical uncertainty of 10%.

CONTROVERSY OVER PROVENANCE OF THE ARTIFACTS

Some 40 stone artifacts have been obtained from Hueyatlaco, and archeologists agree that these objects are unquestionably man-made. A controversy about the provenance of these artifacts, however, was raised by Lorenzo (1967), who alleged that they had been planted by workers at the site. This charge was refuted in detail by Irwin-Williams (1968?), and she later published written testimony by R. S. MacNeish, F. A. Petersen, and H. M. Wormington to the effect that artifacts and bones had been examined by them *in situ* in 1962, embedded in deposits that were then being excavated (Irwin-Williams, 1969). Irwin-Williams argued that fragile artifacts of chert could not have been forcibly driven into the hard, consolidated deposits without breaking, and without producing signs of disturbance. Malde was present when some of the artifacts were being excavated in 1964 and 1966 and agrees that the artifacts

TABLE 1. URANIUM-SERIES DATES ON FOSSIL BONE, VALSEQUILLO AREA, PUEBLA, MEXICO

Sample No.	Location	Material	^{230}Th date (yr)	^{231}Pa date (yr)	Open-system date (yr)
M-B-3	Hueyatlaco, with bifacial tools	Camel pelvis (articulated skeleton)	245,000 ± 40,000	>180,000	
M-B-8	El Horno	Tooth fragment (butchered mastodon)	>280,000	>165,000	
M-B-4	Atepitzingo	Horse metapodial			260,000 ± 60,000

Source: Szabo *et al.*, 1969.

TABLE 2. FISSION-TRACK AGES FOR 10 ZIRCON PHENOCRYSTS FROM EACH OF TWO TEPHRA UNITS AT THE HUEYATLACO SITE

Sample No.	Unit	Number of natural tracks	Number of induced tracks	Age (2σ)
73-SM-2	Tetela brown mud	12	603	600,000 ± 340,000 yr
73-SM-13,14	Hueyatlaco ash	13	1055	370,000 ± 200,000 yr

Note. Determined by C. W. Naeser, U.S. Geological Survey.

could not have been planted in the manner alleged by Lorenzo. Archeological evidence explained by Irwin-Williams, particularly the occurrence of the artifacts in proper archeological sequence, makes planting even more implausible. For the other archeological sites at Valsequillo (El Horno, El Mirador, and Tecacaxco), no charge of planting has been made.

CONCLUSION

The evidence outlined here consistently indicates that the Hueyatlaco site is about 250,000 yr old. We who have worked on geological aspects of the Valsequillo area are painfully aware that so great an age poses an archeological dilemma (Szabo *et al.*, 1969). If the geologic dating is correct, sophisticated stone tools were used at Valsequillo long before analogous tools are thought to have been developed in Europe and Asia. Thus, our colleague, Cynthia Irwin-Williams, has criticized the dating methods we have used (Irwin-Williams, 1978, pp. 18–23), and she wishes us to emphasize that an age of 250,000 yr is essentially impossible.

The climate of archeological thought, however, is changing. Ages for Early Man in America substantially older than the tenth millennium B.C.—the date conventionally set for the time of the first immigrants—are being increasingly contemplated (see, for example, MacNeish, 1976; Bryan, 1978; and Steen-McIntyre, 1981b).

In our view, the results reported here widen the window of time in which serious investigation of the age of Man in the New World would be warranted. We continue to cast a critical eye on all the data, including our own. Still, direct tracing of continuously exposed beds places the artifact-bearing layers at Hueyatlaco beneath the Hueyatlaco ash and, in turn, beneath the Tetela brown mud, both of which have been dated. The stratigraphy of the layers with artifacts seems equally clear and was reviewed by Irwin-Williams and Malde while archeological excavations were in progress.

Fortunately, further findings can be expected from study of geological samples brought back from Valsequillo. In storage in Denver and awaiting examination (after several years of delay in transit) is a ton of specimens and sediment columns that represent the complete stratigraphic section at Hueyatlaco. A detailed study of this material, especially with regard to weathering effects, mineralogy, and other physical properties, should yield useful additional information.

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LETTERS TO THE EDITOR

Reply to Comments by C. Irwin-Williams: Archeological Site, Valsequillo, Mexico

The comments of Irwin-Williams are based in part on her earlier, more detailed criticism of the dating methods and her related conclusion that only radiocarbon dates from deposits on a tributary to the Valsequillo Reservoir (Barranca de Caulapan) are archeologically significant (Irwin-Williams, 1978). Our reply is directed to both the earlier and present comments.

Uranium-series dates. Irwin-Williams refers to Seitz and Taylor (1974) in suggesting that leaching of uranium could lead to anomalously old uranium-series dates. Seitz and Taylor do not propose a specific model for evaluating the effect of a loss of uranium on dates calculated from the $^{230}Th/^{234}U$ and $^{231}Pa/^{235}U$ activity ratios. Rather, they are primarily concerned with the uranium concentrations in five teeth from Olduvai Beds I through III/IV, Tanzania, as a function of their age. The teeth are 0.5–1.9 million yr old and, accordingly, are much beyond the range of uranium-series dating (Ku, 1976). Seitz and Taylor find that the uranium concentrations do not vary systematically with age, but the concentrations are generally greater in the older teeth. However, because the uranium concentrations in the dentine of three teeth from 1.6 to 1.9 million yr old decrease with increasing age, Seitz and Taylor discuss leaching of uranium after an initial period of uranium precipitation. For uranium-series dating, gains or losses in uranium or its decay products can be tested by measuring the ^{230}Th and ^{231}Pa dates themselves. For samples up to about 180,000 yr old, which is the approximate upper limit for ^{231}Pa dating, concordant dates imply that the sample has been closed to migration of uranium and its decay products during the time calculated from the respective activity ratios. That is, the amounts of the daughter elements ^{230}Th and ^{231}Pa are supported by the amounts of their respective radioactive parents, ^{234}U and ^{235}U. Leaching of uranium, on the other hand, would be shown either by excess ^{230}Th and ^{231}Pa with respect to the uranium isotopes, or by discordant dates in the sense that the activity ratios would be altered nonuniformly. For the El Horno and Hueyatlaco samples, the activity ratios show that the amounts of ^{230}Th and ^{231}Pa are not excessive, and the samples evidently have been closed to losses of uranium during the last 165,000 and 180,000 yr, respectively (Szabo *et al.*, 1969). Thus, the calculated ^{230}Th dates seem to be reliable. A further consideration about possible gains or losses of uranium, where migration of uranium in fossil bone can be inferred, is that the apparent uranium-series dates are consistently younger, not anomalously older, than ages established by radiocarbon dating and by various other geological methods of dating (Szabo, 1980). On the other hand, when suitable samples have been selected, many uranium-series dates are considered to be consistent with other determinations of geological age.

Fission-track ages. Irwin-Williams refers to the ages determined for zircon from the Hueyatlaco ash and the Tetela brown mud without recognizing the associated ranges of analytical uncertainty. When the reported ranges in the ages are considered, the ages overlap for the interval from 260,000 to 570,000 yr. The apparent reversal in the ages with respect to the actual

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sequence of the deposits is perhaps accounted for by the small number of tracks that were counted and the resulting ranges of statistical uncertainty. As mentioned in the text, concentrating a larger number of zircon crystals and counting more tracks would reduce the analytical uncertainty. The effort required, although laborious, could yield results that might explain the existing discrepancy.

Tephra hydration. Irwin-Williams emphasizes the uncertain variability of the rate of hydration of volcanic glass as a function of its chemical composition and particle shape and the conditions imposed by differing temperatures and the chemistry of the ground water. The uncertainties related to these variables, and several others, have been widely discussed and are openly recognized (see the references cited on this subject in Steen-McIntyre *et al.*, 1981). Irwin-Williams requires that the hydration rate for a given set of conditions be calculated on samples of known age, thus providing a basis for estimating the ages of similar samples preserved under a comparable environment. This set of requirements, of course, underlies the tephra-hydration method, although truly equal conditions can hardly be expected in nature. Even so, Pearlette type O tephra from Utah, Kansas, and Saskatchewan, which is 600,000 yr old, has a consistently high (but variable) extent of hydration (Steen-McIntyre, 1975). Also, five samples of Glacier Peak tephra from various environments in eastern Washington, which represent an eruption dated at about 12,000 yr, consistently have a low (but appreciable) extent of hydration (Steen-McIntyre, 1981), comparable to the hydration found in the younger samples described by us from Mexico. Of the samples from the neighborhood of Hueyatlaco, the 8000-yr-old tephra, the pumice older than 25,000 yr, the Hueyatlaco ash, and the Buena Vista lapilli are chemically similar, as indicated by their phenocrysts and by the refractive index of the hydrated glass. The present mean annual temperature from the youngest to the oldest tephra localities ranges from 4° to 16°C (Lauer, 1978, map), which is approximately the range of temperatures for the Pearlette type O tephra and the Glacier Peak tephra. Thus, the extent of hydration in the tephra samples from the neighborhood of Hueyatlaco cannot be expected to be more affected by temperature than is found in tephra deposits from other regions that have been studied thus far.

Burial and dissection. Our observations on deposition and erosion at Valsequillo are intended to provide perspective on these geologic processes, and we point out that the actual rates of sedimentation and erosion are uncertain. Irwin-Williams, by referring to burial and dissection of archeological sites in the American Southwest, seems to have in mind the geologic record of alluviation and arroyo cutting in confined alluvial valleys that are characteristic of the region. We trust that our description of Valsequillo, although brief, does not misleadingly imply a basis for directly comparing the Valsequillo area with alluvial valleys in the Southwest. The Valsequillo gravels extend across a broad basin from 3 to 5 km wide (von Erffa *et al.*, 1977, geologic map), and the 50 m of downcutting by the Atoyac River has formed not a steep-walled arroyo but a mature dendritic system with a central valley generally more than 1 km across. Moreover, the lower story of the valley is cut in comparatively resistant lacustrine deposits and volcanic tuff that underlie the Valsequillo gravels. In short, the features of burial and dissection at Valsequillo are not at all comparable to the geological environment of archeological sites reported from the Southwest.

Vertebrate fauna. We are aware that vertebrate fossils collected by C. E. Ray, J. Armenta, and Irwin-Williams from the Hueyatlaco site, as well as from the surrounding region, are being studied by R. W. Graham, but Graham has not yet published his findings. Also, knowledge of the provenance of the fossils from Hueyatlaco depends on records of their stratigraphic position, which are also not yet available in the open literature. Thus, we believe that comment by us on Graham's study would be premature.

Radiocarbon dates from Caulapan. For dating archeological discoveries at Valsequillo, Irwin-Williams relies on two radiocarbon dates from Barranca de Caulapan, a tributary of the Valequillo Reservoir 6 km northeast of Hueyatlaco, and on the resemblance of the artifacts to archeological assemblages at nearby Tehuacan, Mexico, and at Pikimachay Cave, Peru. Molluscan fossils midway in the Caulapan section, about 12 m above the base, which is a place where Irwin-Williams and J. Armenta found a single flake scraper, are dated by radiocarbon at 21,850 ± 850 yr (Kelley *et al.*, 1978, sample W-1895). A proboscidean vertebra from the same locality has an average ^{230}Th and ^{231}Pa age of 21,000 ± 1500 yr (Szabo *et al.*, 1969; Szabo, 1980, sample B-6). Mollusks at the top of the Caulapan deposits are dated by radiocarbon at 9150 ± 500 yr (W-1896). Mollusks near the bottom of the section give radiocarbon dates of about 30,000 yr or older (30,000 ± 1000 yr, W-2189; >29,000 yr, W-1975; and >35,000 yr, W-1898), and an associated proboscidean tusk gives an inconsistently young average ^{230}Th and ^{231}Pa age of 18,500 ± 1500 yr, perhaps because dentine is not a suitable material for uranium-series dating (Szabo *et al.*, 1969; Szabo, 1980, sample B-5). The mollusks and the dates support the interpretation that stream flow was perennial under a moister and cooler climate 20,000 yr ago but had become markedly seasonal by about 9000 yr ago (Taylor, 1967). We have not found a geological basis by which the relation of the Caulapan deposits to Hueyatlaco can be determined. However, based on analyses of heavy minerals, Bunde (1973) correlates the beds younger than 22,000 yr with the Valsequillo deposits at Hueyatlaco (his Profile 103).

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