GEOLOGICAL NOTES ON THE RUINS OF MITLA AND OTHER OAXACAN SITES, MEXICO

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W. H. Holmes (1897:229) pointed out long ago that "Mitla is what it is largely because of the presence of inexhaustible supplies of superb and easily worked building stone." In great measure it is the geological setting of Mitla that has made possible the marvellous architectural forms and the beautiful mural mosaics with their intricate geometric designs for which the ruins are famous. Elaborate stone work of this kind would have been, for all practical purposes, impossible at the neighboring site of Monte Alban because the materials available there were mostly limestones, quite intractable and wholly unsuited to the fashioning of elaborate mosaics. At Mitla, however, there was not only abundant stone suitable for construction and sculpture, but also a copious supply of other stones ideal for use as cutting, scraping, polishing, and hammering tools. None can doubt that this fortunate combination accounts to a considerable extent for the excellence and beauty of the architecture and stone work at Mitla. Clearly, however, other important factors were involved, for at the neighboring site of Yagul the buildings and sculpture are decidedly inferior even though most of the materials for construction are similar.

The stone used at Mitla for facing walls, for lintels and door jambs, pillars, columns, and mosaics (pl. 5a, c) was referred to by Holmes as "a variety of volcanic lava known as trachyte." Any other competent geologist of his day would have said the same. The stone is, however, a kind of volcanic tuff, laid down probably during Middle Tertiary times by glowing avalanches. All tuffs produced by glowing avalances, no matter whether erupted from fissures or cones, are nowadays called ash flow tuffs or ignimbrites. Ignimbrites were used extensively as building stones not only at Mitla but in many parts of Latin America during Spanish colonial days, and are still being used extensively both there and in many other regions of the world. Because most archaeologists are probably not familiar with their nature and origin, our account of the particular ignimbrites used at Mitla is prefaced by an account of ignimbrites in general.

In 1912 devastating eruptions took place in the Valley of Ten Thousand Smokes in Alaska. Foaming magma rose to the surface through swarms of narrow fissures near the head of the valley. The effervescing, intensely hot liquid burst at once into incandescent spray, droplets, and bombs, all giving off large volumes of gas. The mass of ejecta did not rise high into the air but swept along the ground, rushing down the valley at incredible speeds as glowing, turbulent avalanches of ash and pumice. No less than 2.5 cubic miles of material were thus expelled, burying more than 40 square miles of the valley, in places to a depth of 700 feet. Indeed so much material was expelled that the central pipe of the adjacent volcano, Mount Katmai, was drained, leaving the summit without support. The mountaintop therefore collapsed, leaving in its place a vast caldera.

No one witnessed these Alaskan eruptions at close quarters; in fact it was not until four years later that Robert Griggs visited the region and was amazed when he discovered that what had been a verdant valley was now blanketed with hot ash and barren of all vegetation. Myriads of steam plumes rose from fumaroles in the ash deposits, and some of the fumaroles were still so hot that they ignited wood thrust into them. The basal and surficial parts of the ash deposits cooled quickly, but the thick inner parts remained extremely hot for many years. For that reason the constituent particles of volcanic glass in the interior of the deposits retained their plasticity for a long time so that they were flattened by the overlying load and were firmly annealed to each other. The larger pumiceous lapilli and bombs were also flattened into irregular discs. No wonder, therefore, that the streakily banded, welded tuffs look deceptively like many banded lava flows.

Subsequent studies have amply shown that similar glowing avalanches of ash and pumice have been erupted in many parts of the world, in all geological periods, often in colossal volumes, and usually from fissures rather than from the craters of cones. Vast areas formerly thought to be covered by lava flows are now known to be covered by ignimbrites. During Cenozoic times, for example, no less than 80,000 square miles of the Great Basin of Utah and Nevada were buried by ignimbrites, locally to a depth of 8,000 feet; more than 10,000 square miles of the North Island of New Zealand were buried in similar fashion; as were extensive areas in the plateau of Mexico; in Central America; and on the flanks of the Andes in Chile and Peru. In all these places the ignimbrites have long provided abundant, easily worked and durable materials for building and sculpture.

It follows from what has been said that within any given sheet of ignimbrite—the product of a single avalanche—there is generally a pronounced vertical variation in the degree of induration. The quickly cooled top and bottom parts usually consist of loose, incoherent ash, unsuitable for building stone; the inner parts, on the contrary, because they remained hot for a long time, tend to be firmly compacted by annealing and welding of the fine particles of plastic glass, by crystallization (devitrification) and by deposition in pore spaces of silica minerals (tridymite and cristobalite) from fumarolic gases. In some sheets of ignimbrite, generally two-thirds to three-quarters of the distance from the top, annealing of the glass particles and flattening of the pumice lumps have progressed so far as to form extremely dense, black banded tuffs which are almost indistinguishable from finely banded flows of obsidian.

Some ignimbrites are strongly welded almost from top to bottom. Glowing avalanches may follow each other in such quick succession that the deposits of one are still partly incandescent when buried by the next, in which case no loose, quickly chilled ash is present at the bottom of the second sheet. Other ignimbrites are only moderately indurated and show litte vertical variation. Among these are the so-called sillars of Peru, the induration of which was caused mainly by crystallization of the glass and deposition of silica-minerals from hot gases. Sillars are particularly easy to cut and trim, and tend to harden as they dry. Intensely welded glassy tuffs, on the other hand, are difficult to fashion on account of their brittleness. Many ignimbrites, especially the firmly welded ones, develop beautiful columnar structures as they cool and solidify, and even sillars usually develop well-marked joints perpendicular to their tops and bottoms. It is not surprising, therefore, that the indurated parts of ignimbrite sheets commonly form cliffs which overhang the loosely consolidated basal parts. Large, plane-faced slabs and columns of indurated tuff break from the cliffs to accumulate below as talus, providing convenient materials for construction; moreover, the natural undercutting of the incoherent ash and the vertical jointing of the overlying tuff greatly facilitate quarrying operations.

Some of the lithological variations within ignimbrites are summarized in Figure 6a and b.

THE MITLA IGNIMBRITES

The southern end of the Valley of Oaxaca and much of the Valley of Mitla are bordered by mountains eroded in a thick succession of ignimbrites; to the north, on the contrary, the dominant volcanic rocks are flows of andesitic lava. Detailed studies would almost certainly reveal slight petrographic variations between the various sheets of ignimbrite, but our preliminary observations suggest that the principal ones by far are composed of biotite, rhyolite, or rhyodacite. They consist essentially of crowds of broken crystals—mostly of plagioclase feldspar and quartz, with a few of sanidine—accompanied by many flakes of brown biotite and a few prisms of green hornblende. In some ignimbrites these minerals are embedded in a matrix of ash particles and bits of pumice that are still glassy; in most, however, the once glassy matrix has been devitrified to micro- and crypto-felsite. Many ignimbrites are heavily loaded with small, angular fragments of older ignimbrites and of rhyolitic or rhyodacitic lava; others are almost devoid of such fragments. Debris of this kind was incorporated in the glowing avalanches either as they rose from the feeding fissures or during their swift passage over the surface. Careful microscopic examination would perhaps serve to identify the location of some of the particular ignimbrites quarried by the builders of Mitla, but our stay was too brief to permit us to locate any sources additional to those reported by Holmes.

Almost all of the worked stones at Mitla are of the sillar-type of ignimbrite; very few are of the intensely welded type. Noteworthy is the fact that many of the large lintel stones are of approximately the same length, that is to say about 3.8 meters; a few measure 4.5 meters in length and the largest measure about 6 meters (pl. 5b). It may well be that the length of these lintel stones was determined only in part by architectural requirements and mainly by the thickness of the more indurated portions of the sillars at the quarry sites. The following table gives the dimensions of some lintels at Mitla.

TABLE 1

Dimensions, Volumes, and Weights of Some Lintels at Mitla

	Length (m.)	Width (m.)	Thickness (m.)	Volume (m^3)	Weight (metric tons)
1.	3.82	1.00	0.62	2.37	5.45
2.	3.76	1.10	0.74	3.06	7.04
3.	4.74	1.62	1.00	7.68	17.70
4.	4.60	1.62	1.00	7.45	17.10
5.	6.00	1.59	1.17	11.23	25.80
6.	5.65	1.59	1.17	10.51	24.20
7.	4.46	1.00	1.55	6.91	15.90
8.	3.90	1.08	0.80	3.37	7.80
9.	4.42	1.17	0.80	4.15	9.50
10.	3.96	1.10	0.80	3.48	8.00

We visited the nearest quarry site to Mitla and saw the partially hewn block of sillar which Holmes (1897:282) described and illustrated. It lies at the base of an overhanging cliff on the north side of the valley, about two kilometers east of the ruins. This block, which measures a minimum of 4.0 m. in length, 1.15 m. in width, and 1.5 m. in thickness, clearly reveals some of the methods of the Mitla quarrymen.

We also saw crudely worked rectangular blocks along and at the base of a ridge which projects into the valley about four kilometers east of Mitla, close to the trail used as a short cut to Santo Domingo and San Lorenzo. These blocks measure 1.9 x 2.23 x 0.6 m., and 1.8 x 2.1 x 0.4 m. (pl. 6a, b). Worked blocks are also to be seen, so we were told, still farther east, at much higher elevations, in a quarry where stone for a nearby cruciform tomb was extracted.

Holmes described and illustrated large blocks of ignimbrite at a quarry site nearly 300 meters above Mitla and at least 10 kilometers to the north. Some of the blocks at this site were already detached while others had been left partly cut out or only outlined. The larger blocks, Holmes said, measure "12 feet or more in length by 5 or 6 wide, and from 2½ to 3 feet thick" and they weigh perhaps 15 short tons, which is about the weight of the heaviest lintel stones at Mitla (cf. pl. 6c, d). It was Holmes' opinion that the quarrymen probably planned to haul the blocks to Mitla by a roundabout route, following gentle slopes rather than dragging them directly down the mountainsides. According to Holmes, there are at Mitla "upwards of fifty lintel stones, ranging from 10 to 20 feet in length and from 2 to 4½ feet in each of the other dimensions, their weight varying from 10 to 15 [short] tons." Some of the cylindrical columns, which were used mainly to support roof timbers in the wider chambers, measure about 11 feet above ground and perhaps 15 or 16 feet in full length; their diameters diminish as they rise from the floor where they measure 30 or 36 inches to 20 or 24 inches at the top; their weights approximate 6 to 8 tons.

The Mitla tuff is fairly durable, but shafts as long as 6 meters, if dragged over uneven ground, might snap in two. It seems very probable, therefore, that these large slabs were lashed to rigid wooden sledges whose runners would absorb the strains imposed by the irregularities of the ground surface so that the block itself was not subjected to undue strain. No such sledges, nor pictured representations of them, have ever been found, but there is good evidence at Mitla that solid wooden beams 9 inches square and over 12 feet long were used for rafters in some of the buildings. Timbers of this size would have served very well for sledge construction.

Using Barber's formula (1900:41; cf. Heizer and Williams 1963:97), the largest lintel at Mitla, which weighs about 25 metric tons (55,000 pounds), could have been dragged on a sledge with ropes by about 366 men.

No certain evidence of the use of ropes has been found at Mitla, but we believe that they were almost certainly used as aids in transporting the multiton ignimbrite blocks from the quarries to the site. Today there is a large amount of maguey grown locally, and according to what we heard, larger amounts were grown here in earlier times. In the earth fillings of the Mitlan walls are large numbers of "push-planes" or "scraper-planes" which show wear on the sharp basal edge. Holmes (1897: 286, pl. XLII) described and illustrated these, and we provide additional illustrations (pl. 7) of this type of implements, which show evidence of having been used to work some relatively soft material. We suggest that these tools served to express the pulp from the pounded maguey leaf during the process of fiber extraction carried out in the same general fashion as described by Lothrop (1929) for Guatemala, except that in Guatemala the handled wooden scraper rather than the stone push-plane was used. The large numbers of scraper-planes at Mitla can therefore be accounted for by assuming that large amounts of rope were made here for use in the construction activities.

Stone Tools

Holmes thought that the tools—hammerstones, picks, flakes, and scrapers—used at Mitla were made from "roundish masses or waterworn boulders of the harder varieties of volcanic lava" and from a "coarse, yellowish striped flint or flinty quartzite." These materials, he said, are found "in great numbers in the adobe mortar used in hearting the walls and pyramids of the great buildings at Mitla," and he correctly surmised that they must occur in the neighborhood "in bodies sufficient to be quarried or in surface masses so numerous as to be collected in considerable quantities." He found abundant flaked stones as shop refuse on the spur of the Fortified Hill about two kilometers west of Mitla. Here, he said, the "ground was filled with broken flint, generally of a grayish hue, and wholly distinct from the yellowish flinty rock worked elsewhere." Finding only a single imperfect hammerstone, he concluded that only blades were made at this locality.

Our observations suggest that almost all of the hammerstones and picks used at Mitla were made from firmly indurated ignimbrites, fragments of which were available in vast quantities on the sides of the valley and in the stream beds to the east. Most of the flakes and scrapers, on the other hand, were made from silicified tuffs and tuffaceous sediments, the principal, though probably not the sole, source of which was along the base of the Fortified Hill.

The Fortified Hill itself is composed of a series of cliff-forming ignimbrites which dip northward at low angles. Near the base of the hill, on the southern and eastern sides, these massive ignimbrites are underlain by a greenish, altered ignimbrite which is interbedded with much thicker layers of well stratified, whitish tuffs and tuffaceous muds and silts. These very fine-grained, airborne and fluviatile deposits are extensively silicified and in many places are veined and replaced by chalcedony. Close to the spring near the western base of the hill a few steeply dipping and vertical veins of chalcedony, up to about 30 cm. thick, cut the thinly bedded tuffs; not far away thin lenses of chalcedony conform to the bedding of the tuffs.

Silicification of the tuffs and tuffaceous sediments as well as the development of greenish clay (montmorillonite?) in the interbedded ignimbrite were caused by moving groundwaters enriched in silica and other constituents through alteration of the overlying ignimbrites. That is why greenish ignimbrites are invariably found close to the floors of the valleys of Mitla and Oaxaca. The ignimbrite used in construction of the cathedral and several churches in Oaxaca comes from quarries near the floor of the valley, a short distance southeast of the city. Only rarely are the ignimbrites on the valley sides silicified or discolored by alteration; it was the older, fine-grained airborne and waterlaid tuffs and tuffaceous sediments which were especially susceptible to such changes, particularly where groundwater was plentiful.

The gently undulating slopes adjoining the Fortified Hill are thickly strewn with angular fragments of chalcedonic flint. To the east of the spring, as Holmes noted, the flints are almost all pale to dark gray in color; to the west, however, there are abundant yellow, brown, and orange colored flints similar to those present in profusion among the ruins of Mitla. In our opinion this was probably the main source for the scrapers and flakes. The notable scarcity of chalcedonic debris in the bed of Río Mitla to the east of the ruins indicates that very little flint came from the upper parts of the valley, where most of the hammerstones and picks were obtained. Holmes suggested (1897:287) that the flint outcrop and workshop at the base of the Fortified Hill "was occupied by a people distinct from the builders of Mitla, or possibly by the Mitlan stock at an earlier period in its history." This statement is an interesting one in that it illustrates Holmes' keen awareness of assessing archaeological situations and his willingness to propose time differences in American prehistory at a time when his colleagues in archaeology were almost completely unaware of even the possibility of making temporal distinctions between different sites.

Holmes' geological training no doubt was responsible for his ideas on this matter. We did not make any special study of this workshop area and do not have any opinion on whether it may be older than the Mitla site proper.

The ignimbrites on the valley sides near Mitla vary, as we have pointed out, from brittle, dense, glassy types to soft sillar types; hence they provided materials not only for construction and sculpture but also for a wide variety of other uses, such as hammering, picking, scouring, and polishing. But for cutting and scraping, use was made of the silicified tuffs, especially of those completely replaced by chalcedony. It was this juxtaposition of abundant materials for tools of many kinds with abundant and easily worked building stones that particularly favored the peoples of Mitla.[1] Perhaps they first worked the soft sillars along and close to the valley floor, and then went farther afield in search of more strongly indurated and crudely columnar sillars from which they fashioned their huge lintels and jambs. Why else would they have gone ten kilometers to the north, climbing 300 meters, to quarry the slabs described by Holmes?

Use of Andesite

Our impression is that along the floor of the valley between Mitla and Oaxaca and in the adjacent mountains the ignimbrites are generally underlain by andesitic lavas and thinly bedded tuffs and tuffaceous sediments. Apart from the beautiful green ignimbrite in the roadside quarries near Oaxaca, most of the volcanic rocks extending along both sides of the valley between the city and Tlacolula are andesites. As far as we know no andesites are exposed close to Mitla and none seem to have been carried there for construction. At Yagul, on the other hand, waterworn boulders of andesite are about as common as those of ignimbrite.

We saw no ignimbrites at the Monte Alban site, and only a little andesite, almost the sole building stone there being local limestone. In a ruin group east-northeast of the principal group of buildings designated as Tumba 105 by Caso (1938:83-95, Plano No. 18) there is a doorway built of slabs of purplish, porphyritic, and vesicular pyroxene andesite, one of which measures approximately 4.2 x 1.6 x 0.6 m. and weighs more than four metric tons (pl. 5d). These andesite slabs were probably transported at least ten kilometers from the high range that separates Tlacolula from Ocotlan (map 4).

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[1] A similar situation exists at the site of Copán and we will report separately on this site.

Sources of Lime

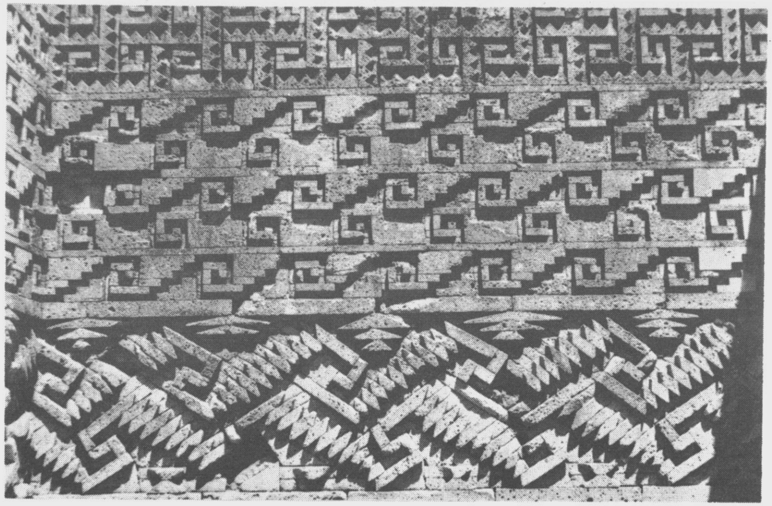
Holmes said that the source for the lime used at Mitla for plaster, cement, and mortar was unknown. The ignimbrite blocks were so carefully cut and precisely fitted that little mortar was required and perhaps the small amount of lime that was needed came from the outcrops of Cretaceous limestone on the north side of the valley, about 20 kilometers northwest of Mitla, although some may have been obtained to the east, near Santo Domingo, where deposits of travertine occur.

DENSITIES OF CERTAIN ROCKS

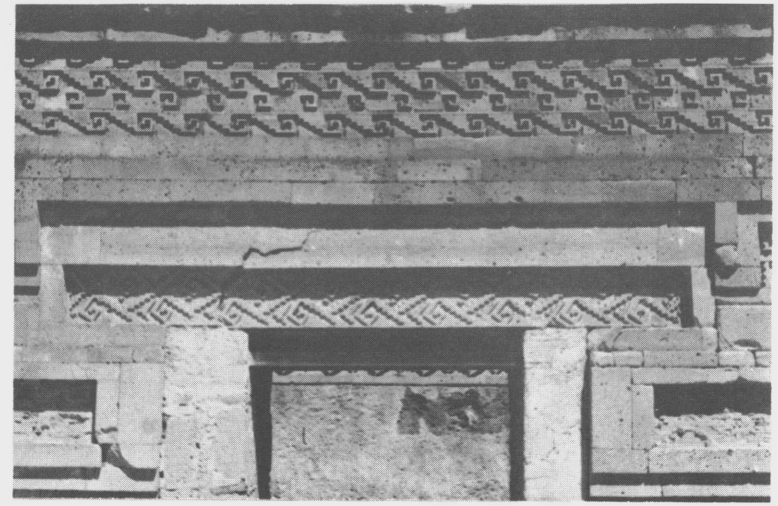
Because the information may be useful to others, we give here our determination of densities of certain rocks at Mitla and Monte Albán.

1. White, loosely coherent, sillar-type ignimbrite, 2.01
2. White, loosely coherent, sillar-type ignimbrite, 1.80
3. Dense, firmly welded ignimbrite, 2.46

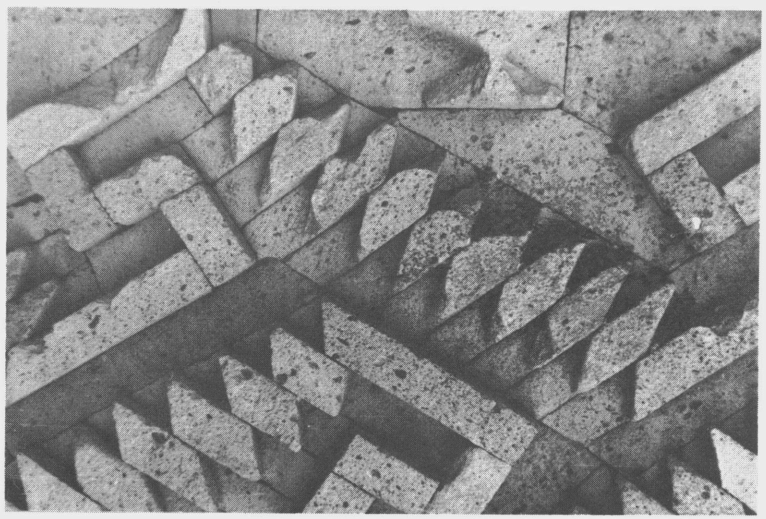
In general it can be said that the Mitla lintels and jambs are composed of moderately welded ignimbrite and range in density from 2.20 to 2.30. At Monte Albán the andesite used for jambs and the lintel at Tumba 105 has a density of 2.38. This is a relatively low value and is probably explainable as due to the microporous and minutely vesicular character of the lava.



a. Detail of "mosaic" facade at Mitla



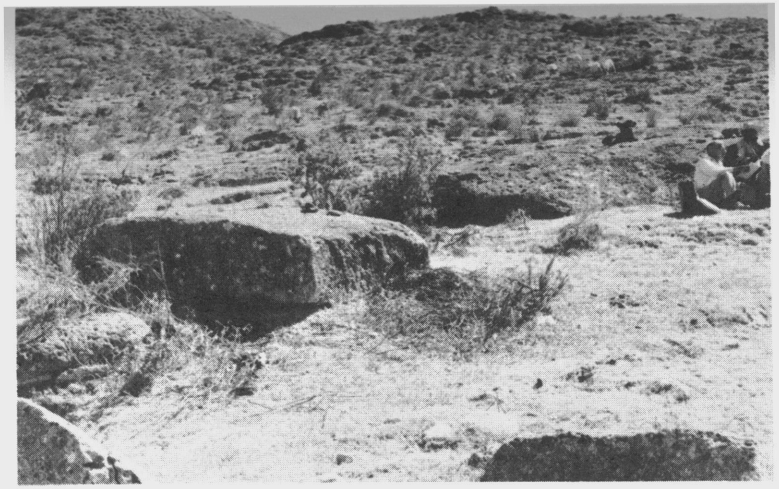
b. Strain-cracked lintel in Quadrangle of the Grecques, Mitla



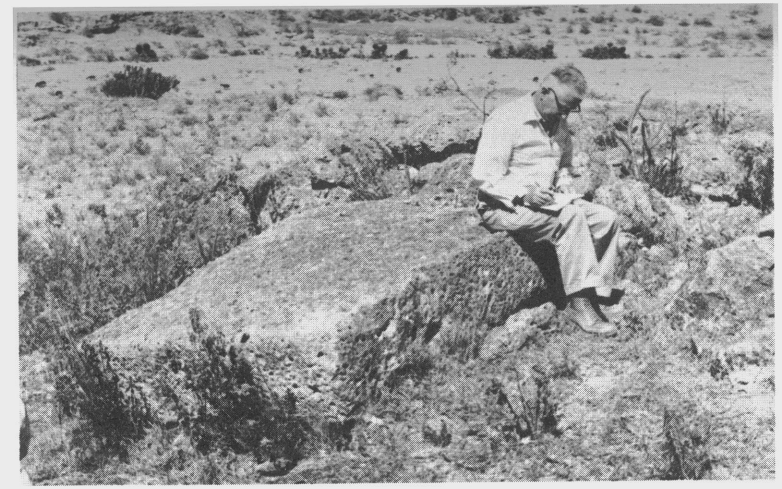
c. Detail of "mosaic" at Mitla (cf. Holmes 1897, pl. XXX A-B

d. Jambs and lintel, Tumba 105, Monte Albán

Plate 5



a. Abandoned building blocks along trail about 4 km. east of Mitla



b. Same as a

c. Large fallen lintel in front of Hall of Columns (No. 2 in Table 1), weight ca. 7 metric tons

d. Large lintel of ignimbrite at Mitla

Plate 6

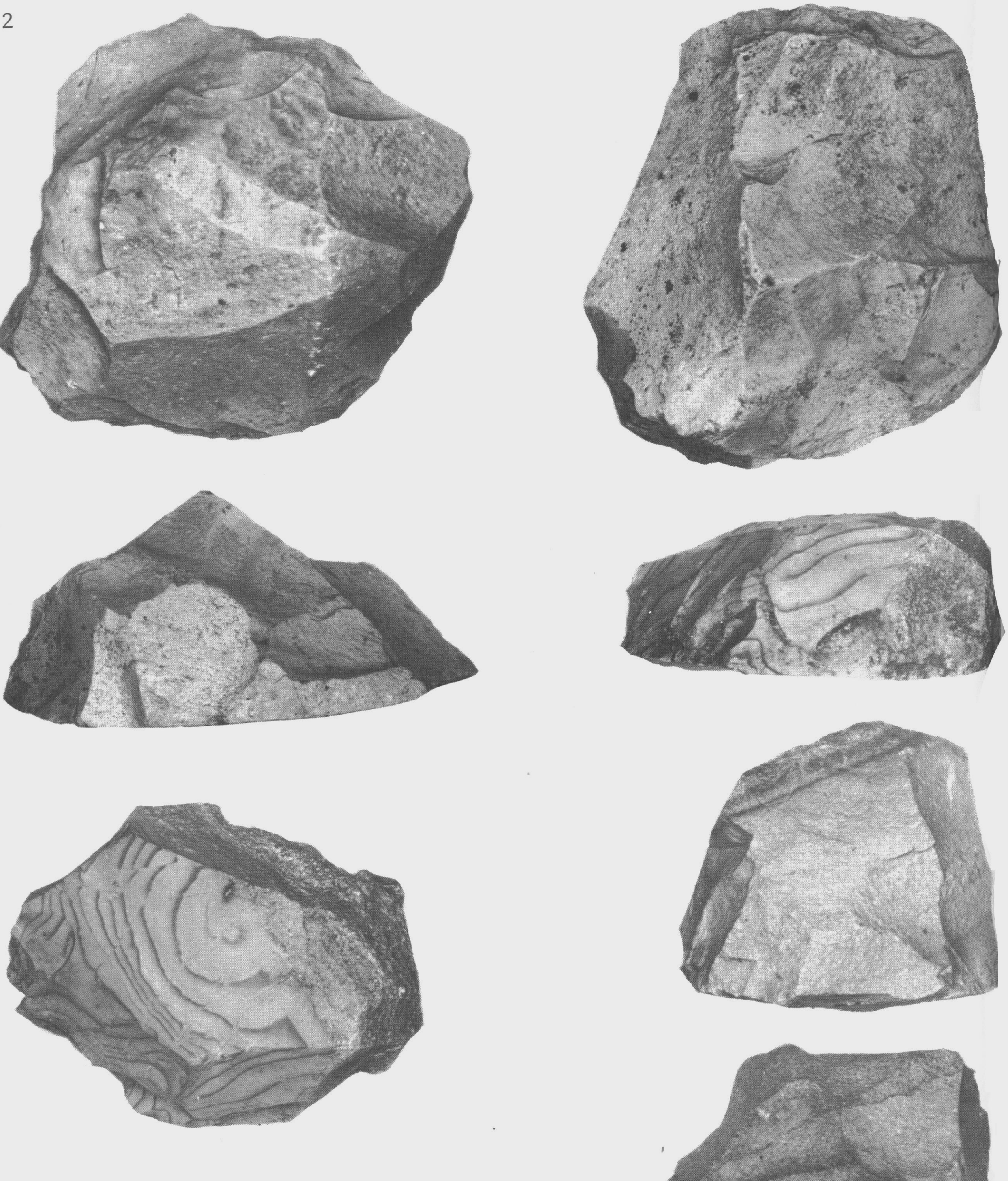


Plate 7

Scraper-planes from Mitla (actual size)

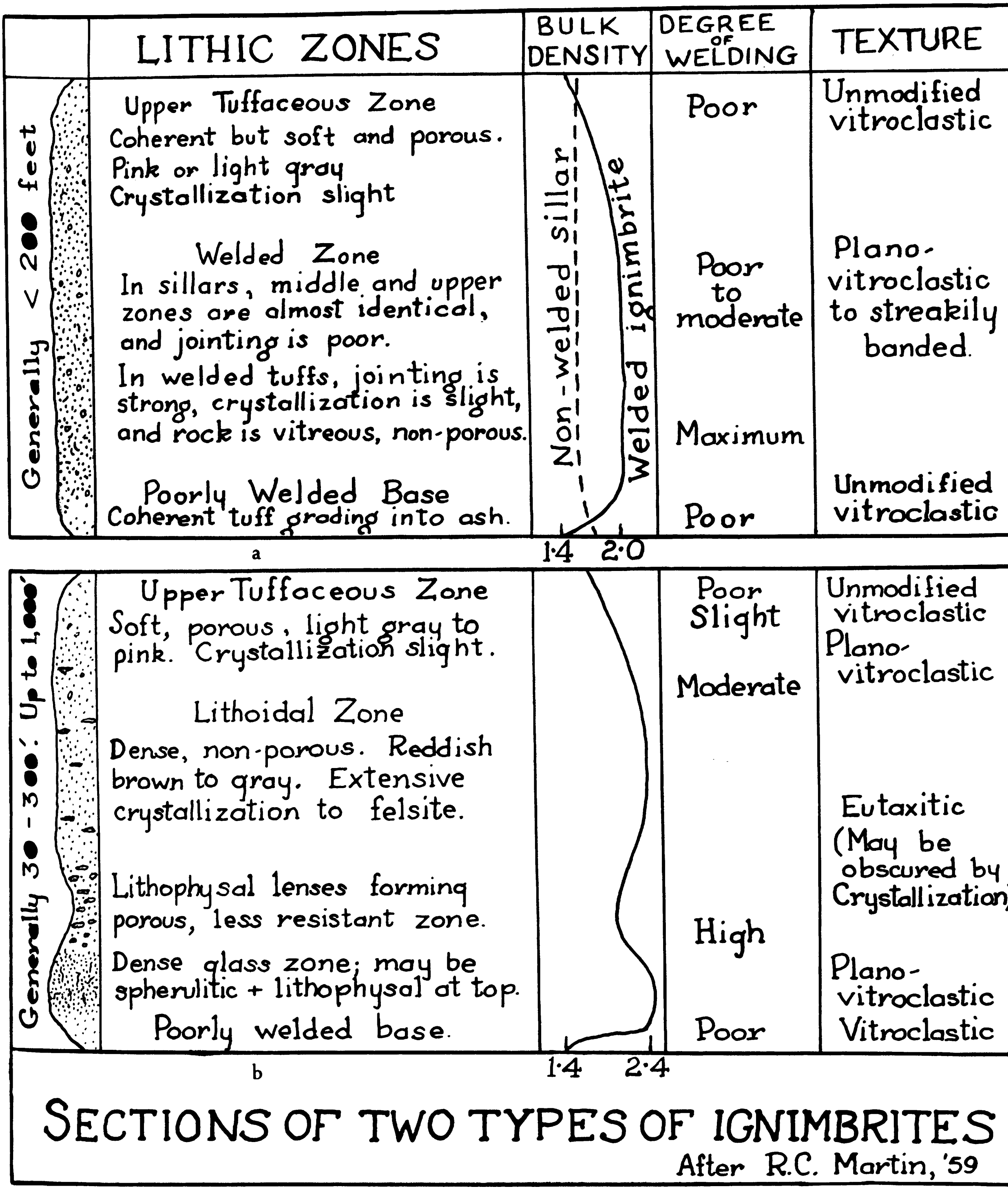


Figure 6. Vertical variations in ignimbrite sheets

<u>a</u>. Poorly zoned type

<u>b</u>. Strongly zoned type

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