THE SCORIA AT CHAN CHAN; NON-METALLURGICAL DEPOSITS

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Introduction

Chan Chan is one of the largest prehistoric settlements in South America. Situated in the Moche Valley on the north coast of Peru, the site spreads over a substantial area, and the central core of monumental architecture alone covers more than six square kilometers. The ruins contain a great range of archaeological phenomena. Noteworthy among these are several large concentrations of scoria that resulted from fairly high temperatures operating on inorganic material which partially melted and assumed a cinderlike appearance. It has long been supposed that the scoria accumulations at Chan Chan were the by-products of metal working. This view is not inconsistent with the fact that the Chimu who built the ancient city were productive and skillful metal workers. In terms of the quality and quantity of metal objects they produced, they rank high among the prehistoric craftsmen of the New World.

Ethnohistorical sources establish Chan Chan as the capital of the Chimu empire. The chronicles further relate that upon conquering Chan Chan, the Inca not only seized abundant treasure but transported some Chimu metalsmiths to Cuzco where they worked under their new rulers.[1] Thus there are grounds for believing that the working of metal did take place on a large scale at Chan Chan.

E. George Squier visited Chan Chan in 1865 and was among the first to interpret the scoria deposits as evidence of metal working.

> I have omitted reference, up to this point, to a remarkable sub-barrio, or enclosure, in one of the larger squares, notice of which now will naturally lead to a fuller consideration of what may be called the minor works of art of the ancient Chimus. This enclosure is very nearly of the dimensions of that last described, but with a different arrangement. It has a double row of buildings on its northern side, but along its southern wall is a succession of what were perhaps ancient furnaces or smelting-places, so much ruined as to prevent any clear understanding of their construction. Their thick walls were burned deep, and fragments of slag still clung to them, while in a large open space near by was heaped a great quantity of slag, or scoriae, which is proved by analysis to be mainly of copper and silver ores. We have here proofs of a certain proficiency of the Chimus in metallurgy, in addition to those furnished by their ornaments and other relics in gold, silver, and bronze. Here, too, we have further evidence of the hypothesis that the various great enclosures were occupied by

> artisans or mechanics of cognate pursuits, and the smaller divisions, by those who followed out the details of each pursuit--by those who reduced the metals from the ores, and those who wrought them into articles of use or ornament; by those who produced and cleansed the cotton from its seed, and those who spun, wove, and dyed it.[2]

In subsequent years other scholars have offered similar explanations, but the scoria and its archaeological associations have never received detailed study. If the major concentrations of scoria and their associated structures were related to metallurgy, Chan Chan would have the largest prehistoric facilities of this type yet discovered in the Andean area. A study of the remains would yield substantial information about the indigenous pyrotechnologies as well as contribute to the understanding of resource use, labor organization, and craft production. These considerations provided the rationale for undertaking a detailed investigation of the scoria. The program involved survey, excavation (carried out in May and June of 1970), and laboratory analysis (conducted at M.I.T. during 1971).

Overview

Evidence of localized burning is not uncommon at Chan Chan. Many of the major structures within the civic center have remains of roofed structures that were destroyed by fire. In most instances the burned buildings cannot be confused with metal working locations, and in all cases so far systematically examined the burning took place sometime after the structures had been abandoned. This study examines four locations within Chan Chan that are distinguished by the presence of large concentrations of scoria, burned earth, ash, and charcoal. At different times each concentration of material has been posited to be a metal working area. The four areas are located in different regions of the settlement (fig. 1). The first is inside the central sector of Ciudadela Gran Chimu. The second is in the central sector of Ciudadela Velarde. The third is situated immediately east of Ciudadela Tschudi, and is called the Tschudi Scoria. The fourth, and largest concentration, lies in an open area in the center of the site, and is called the Central Scoria.

Interpretations

The principal finding of the present study is that none of the four areas related to smelting operations or metal working activity. Analysis of the scoria demonstrates that it is not metallurgical slag but heat-altered soil of local derivation. Examination of the associated buildings provides no evidence that they were either designed for or used as metal processing installations. We conclude that the four principal concentrations of scoria at Chan Chan resulted from the burning of four separate buildings.

Although metal working was not carried out at these sites, we are faced with accounting for the types of structure that burned to produce such large accumulations of scoria and other burned materials, and why they were confused with smelters or foundries. The answers lie in investigation of the original nature of the buildings and their construction materials, the intended use of the structures, and the circumstances surrounding the fires.

The scoria deposits in Ciudadelas Gran Chimu and Velarde are the smallest and most easily dealt with. They are associated with types of buildings that occur unburned in other ciudadelas. These structures were high status mortuary complexes. In Gran Chimu and Velarde roofing timbers were ignited and burned with intense heat after the mortuary complexes had been abandoned and during a long period of sporadic but intensive looting.

The Tschudi and Central Scoria are the largest concentrations of burned materials in Chan Chan. Each is distinct, and neither has known counterparts at the site, either burned or unburned. Reconstructing the original nature of the two structures is, therefore, difficult. Although architecturally distinct, the Tschudi and Central Scoria share two important resemblances that suggest they were related in terms of certain construction techniques and materials. First, the fuel source for both burnings was the same, Tillandsia latifolia, a small plant native to the region. Second, the basic layering of both deposits of burned materials starts with scoria at the top, proceeds to fully combusted ash, then tillandsia charcoal, and ends with a fire reddened floor surface produced by oxidized burning. This sequence of layering is taken to mean that the fuel source (tillandsia as represented by ash, then charcoal) underlay the source material of the scoria (soil), but the fuel did not rest directly on the floor. If the fuel rested directly on the floor then the floor would reflect reduced rather than oxidized burning conditions.

We tentatively interpret the Central and Tschudi Scoria deposits to be the products of flat roofs that burned. The Central Scoria was a big ramada-like structure, and the Tschudi Scoria was a rectangular building with a roofed bench along the interior walls. Similarities in the make-up and layering of the two scoria deposits reflect similarities in the construction techniques and materials of the two roofs. The top of each was capped by a layer of soil laid down as mud. This rested on a thick bed of tillandsia, presumably supported by an open latticework of cane. The three-part roofs could have been held up by columns made of bundles of canes tied together and plastered over with mud. We do not know how either building was originally used.

Problems

Several problems arise from interpreting the Central and Tschudi Scoria deposits as products of burned roofs. First, the ash remains indicate that the tillandsia beds were quite thick. Second, tillandsia roofing has not been found elsewhere at Chan Chan. And third, the scoria deposits produced no identifiable remains of cane. This means our argument for cane columns and support structures rest on an analogy with roofing in Ciudadela Rivero where we have excavated this type of cane construction.

Archaeological Observations

Our investigation of the scoria deposits in Ciudadela Gran Chimu and Ciudadela Velarde was limited to surface observations, and the analysis of one sample of scoria from the latter area.

Ciudadela Gran Chimu

The scoria in Ciudadela Gran Chimu is not plentiful, but it is found with great quantities of intensely burned adobes. Most of the material lies within an area of 65 m. north-south by 50 m. east-west that is situated on and in front of a large platform built of adobes. The platform formerly contained deep internal cells that were roofed with wooden supports and then covered with bricks. The cells housed high status burials, and the grave goods promoted extensive looting of the structure after Chan Chan was abandoned. Burned soil and pieces of scoria are scattered throughout the looters' backdirt. The bulk of the material can be traced to four areas in and above former cells. Squier gives a plan showing one of these cells,[3] and although noting the presence of burned human bone near the cell, he nevertheless suggests that the structure was a metal working furnace.[4] Close inspection shows, however, that much of the floor of the room and sections of the lower walls were not burned. Evidence of intense heat is limited to the upper portions of the walls. A similar situation exists in the three other cells. Here the floors and 10 cm. to over 1 m. of the lower walls were unmodified by heat. The irregular nature of the burning as well as the mortuary context of the architecture removes the Gran Chimu scoria from the realm of metal working. Apparently the roofing materials in the four cells ignited sometime after the structures had been exposed by looters. The dirt and fill from the sacking operations covered and protected the lower walls and floors of the burial chambers during the course of the fire.

Ciudadela Velarde

Scoria in the Ciudadela Velarde is found in two contexts. The first is the backdirt of looters who sacked and completely destroyed a large platform built of adobes that formerly contained internal cells with burials. The scoria is not plentiful, but it does occur with substantial amounts of burned soil and adobes. The material is now out of its original context, and little can be said about it other than that it was once associated with the burial platform. The circumstances involved in its formation were probably similar to those in Ciudadela Gran Chimu. The second area of scoria occurs along the foot and northern face of a small rectangular structure that lies 20 m. to the west of the platform. The structure measures 15 m. north-south by 31 m. east-west. Within it there is one small room and two or possibly three cells that are T-shaped in plan. The great quantity of scoria and burned soil and adobes around the structure is impressive. This is apparently the area described by Squier in the introductory quotation. The structure cannot, however, be considered a metal working area for several reasons. First, burning is largely confined to the upper portions of the walls. The floor and from 10 to 40 cm. of the wall bases were covered with fill at the time of burning. Portions of the fill covered walls were unaltered by heat. Second, the cells inside the structure that Squier considered furnaces are T-shaped burial chambers. Prior to looting these chambers were completely sealed. Maintaining a fire within them would have been impossible. Although the situation is far from clear, the scoria probably resulted from the burning of a large roofed area along the north face of the structure. A small amount of hardwood charcoal and several pieces of fired clay plaster with cane impressions were found on the surface. These are probably roofing remains. In any case, it is evident that the Velarde scoria is found in a mortuary context and that the burning took place after a certain amount of looters' fill had accumulated on and around the building. After burning, renewed looting activity disturbed the burned deposits and scattered scoria over a wide area. As with Gran Chimu, there is no apparent association of the scoria with metal working.

Archaeological Excavation

Following a program of surface recording, excavations were conducted in areas of the Central Scoria and the Tschudi Scoria. Despite the fact that observations by Lechtman indicated metallurgical activity to have been highly unlikely at either site, the work was undertaken to elucidate something of the original nature of the areas; to determine the factors leading to the accumulation of the scoria deposits; and to dispel the long held notion that the Tschudi structure was a Chimu smelter.

The Central Scoria

The Central Scoria is a large oval deposit (about 55 m. in diameter) of scoria cinder lying more or less flush with the surrounding site surface. The cinder is abundant; the pieces are contiguous and form a level unit. In color the scoria is somewhat variegated, but the median hues tend to be browns to brown-blacks.

The deposit lies largely within the confines of what was once a rectilinear walled structure and occupies much but not all of the enclosed floor space. The structure is somewhat rhomboidal in plan. The wall lengths and orientations are: north wall, 78.0 m. at W 19 N; west wall, 72.0 m. at N 22 E; south wall, 71.6 m. at W 17 N; and the east wall, 68.0 m. at N 22 W. None of the walls now stands more than 50 cm. high, and most are less than half this height. Much of the east wall has been destroyed by a modern road. The walls were constructed of rectangular mold-made adobes. In some cases a gravel and pebble core was used. There is little brick fall, and the walls probably stood to an original height of less than 1.5 m. and did not support a roof.

Within the enclosure the scoria deposit lies slightly off center, abutting the north and west walls near the northwest corner.

Although scoria does not lie against the south and east walls, there is charcoal and ash in these regions, and some sections of floor contiguous to these walls show signs of heat alteration. Thus, there are indications of burning throughout the enclosure, but no indications of *in situ* burning outside the walls.

In investigating the scoria we stripped an area of 44 square meters in a shallow rectangular excavation measuring 22 m. (N 55 E) by 2 m. Later, a second set of excavations investigating different problems stripped an area in excess of twice the original cut. The additional work did not alter the conclusions drawn from the scoria study.

In the original cut, the stratigraphic profile had a relatively constant depth of about 24 cm. over the entire length of the excavation. It was composed of three even layers of material, each averaging 8 cm. in thickness. From top to bottom the layers were scoria, ash, and charcoal. The deposit was underlain by a burned surface of compact sandy silt.

The layer of scoria was composed of contiguous, tightly packed but unconsolidated pieces of cinder that are relatively homogeneous in size. The larger pieces were 7 to 9 cm. in maximum diameter and none exceeds 25 cm. Smaller fragments lay between the larger specimens, leaving little space unfilled. Some of the larger pieces of scoria contained within them either charred remains of *Tillandsia latifolia*, a small, fibrous, epiphytic plant that grows abundantly throughout the arid coastal region (see figs. 17 and 18), or casts of the plant retained in the once semimolten matrix.

In interpreting the scoria it is significant that the layer was compact and of constant thickness. This indicates that the original inorganic material from which the scoria derives was likewise uniform and of constant thickness prior to heat alteration. This material is presumed to have been local soil, and if correctly interpreted, the scoria derived from a layer of earth of even thickness. The tillandsia within the scoria could have been incorporated while the scoria was molten, but it might also have been an integral part of the soil layer prior to heat alteration.

The layer of ash beneath the scoria was loose, unconsolidated, and had the consistency of powder. It occurred in lenses of variegated colors: white, yellow, pink, and tan hues. The deposit was basically pure ash. Near the top, occasional small pieces of scoria were encountered; at the bottom of the layer, there were some flakes of charred tillandsia.

The ash layer is interpreted as a completely combusted source of flammable material. Because the overlying scoria contained remains of tillandsia and the underlying charcoal was likewise composed of tillandsia, it is assumed that the same plant was the ash source. Because the ash layer is of constant thickness, it is believed that combustion took place under relatively constant conditions consuming a uniform amount of fuel over the entire length of the stratigraphic profile.

The layer of tillandsia charcoal and charred tillandsia was compact but unconsolidated. The level contained only the remains of tillandsia; no other combustible material was recognizable. The deposit was pure, except for a small amount of ash that had filtered into the top of the level.

This layer is considered to be a partially combusted fuel source. Because of its constant thickness, relatively uniform conditions are implied. Since both the charcoal layer and the ash layer were of constant thickness, it is believed that, prior to burning, the deposit of tillandsia was of uniform thickness.

Underlying the deposit was a burned, but unscoriated, compact surface of sandy silt similar to other packed earth floor surfaces found at Chan Chan, with the exception of its color. The surface and the first few centimeters beneath tended to have reddish hues as a result of heating under oxidizing conditions, while below this depth there were dark brown to black hues from reduction heating. At approximately 20 cm. the color began to lighten towards a tan, unaltered soil. There was no surviving evidence of clay plaster on the burned surface. A small number of Chimu sherds was found on the surface and these had been badly burned.

The surface is interpreted as the floor of the structure enclosing the Central Scoria. The evidence of marked heat alteration is unequivocal and demonstrates local burning.

In summary, the stratigraphic profile is believed to represent: (1) an original use surface--the burned floor; (2) carbonized flammable material--the tillandsia charcoal; (3) fully combusted flammable material, presumably once tillandsia--the ash; and (4) heat altered inorganic material, presumably once soil--the scoria. Prior to burning, this sequence is presumed to represent a floor overlain by a bed of tillandsia of uniform thickness which in turn was covered by a soil cap of even thickness.

We can see no obvious connection of this site with metallurgy. Neither the structure housing the scoria nor the stratigraphic profile has characteristics one can expect of a furnace or metal working area. There are no indications that burning was, or could have been controlled. Nor can the remains be interpreted as a dump servicing a metal working area. The fire altered floor shows that intense burning took place locally, while the even stratification within the deposit is inconsistent with dumped material.

The stratigraphic evidence does imply that the Central Scoria resulted from a single hot fire. Tillandsia was the fuel, and it burned with sufficient intensity to scoriate an overlying layer of soil and to cause thermal alteration of the underlying floor surface.

The structural conditions allowing for such a fire are not entirely clear. It is doubtful that such intense and uniform burning could have taken place had the tillandsia lain directly on the floor with no soil cap immediately on top of the fuel. Direct superposition of the elements would have inhibited the free flow of air necessary to sustain a hot fire over a large area. If correct, this interpretation implies that there was originally some sort of vertical separation among the elements, allowing for good circulation of air. The situation is most easily explained in terms of a roofed structure. The roof cap would have been a thin, even layer of soil poured over the tillandsia as a thick mud, penetrating part of the way into the porous plant bed and solidifying there. Enough earth was poured to build up a thin slab above the bed, forming a fairly even and flat roof surface. When the structure burned, the soil cap was subjected to intense heat, melted and was transformed into the scoria deposit. In this reconstruction, tillandsia was the primary fuel source. Some 16 cm. of ash and charred plant remains survive in the profile. Prior to reduction and compaction by fire, the original plant layer may well have been at least twice this thickness.[5] Thus, a substantial quantity of fuel was present. It seems likely that the tillandsia was incorporated into the roof structure as a light weight, organic base held in place only in part by the soil mixed with it.[6]

While the origin of the Central Scoria is most conveniently explained in terms of the burning of a large roofed structure, there are serious _lacunae_ in our evidence for such an interpretation. Even if the poured earth penetrated sufficiently to hold some of the tillandsia plants together mechanically, it could not have been the sole means of horizontal support for the plant bed. Some web of reed or mat or cane had to have underlain the entire tillandsia layer. Yet we found no remains of such organic materials. Furthermore, in all the excavation programs conducted in the area, only one definite and three possible post molds were uncovered.

In summation, our work in the Central Scoria failed to demonstrate any connection of the site with metal working. The scoria resulted from a single hot fire for which tillandsia was the fuel. It is probable that what burned was a large roofed structure, but the evidence is not conclusive.

The Tschudi Scoria

The enclosure housing the Tschudi Scoria is a large, high walled structure situated in a relatively open area approximately 102 m. east of the Ciudadela Tschudi. An elevated earth platform abuts the east end of the building, and a second lower platform lies immediately to the north. Otherwise there are no adjacent constructions.

The accompanying plan (fig. 2) presents the layout, dimensions, and orientation of the Tschudi Scoria enclosure. Essentially, the building is a subrectangular enclosure measuring 70 m. by 25 m. There is no evident means of access. In the north wall there is a break several meters wide made in conjunction with a looting operation that took place in the center of the building. Perhaps the cut enlarged a former entrance, but there is no evidence to support this suggestion. Prior to excavation no internal structures or subdivisions were evident. Stripping revealed only a small, rectilinear structure of unknown function, situated on an elevated bench in the northwest corner of the building. A second small structure of unknown use was encountered in stripping the exterior southeast corner of the building. No other rooms or buildings were found.

The main adobe walls survive to an average height of 3.25 m. Originally they were somewhat higher. The walls taper, as is typical of most such structures at Chan Chan. They were laid in separate sections, each approximately 4 m. long. Although contiguous, the sections are not bonded to one another. The bricks used in construction are mold made, rectangular in plan, and trapezoidal in profile, the base being 2 to 3 cm. wider than the top. There is some variation in brick size, particularly between different wall sections. The most common brick dimensions are 25 cm. long, by 10 cm. wide, by 16 cm. high. These adobes are of a tan, compact, sandy silt and frequently contain pebbles and small stone inclusions. They were laid in alternating rows of runners and headers, but there is some variation in this pattern, particularly in the wall cores. Open spaces between the adobes are often chinked with pebbles and small stones. Earth mortar was applied to the horizontal joints; the vertical joints are not generally mortared. There is no surviving evidence of plaster on the wall faces.

The walls of the Tschudi Scoria are moderately eroded. On the exterior of the building there is some fill and wall wash banked against the wall base. In the interior of the building, wall faces are not visible. They are covered by fill that slopes down from the wall tops to the floor of the building. The center of the building is open and contains relatively little fill.

Scoria is visible both inside and outside the structure. All the burned material outside the walls is believed to have derived from within the building. Along the exterior of the south and east walls there are occasional pebble-sized pieces of scoriated cinder and small fragments of burned bricks and burned soil. Near the exterior of the northern wall, particularly in the west, there is relatively more material. Here the scoria and fragments of brick are of pebble and cobble size. Four to 8 m. beyond the central section of the north wall there is a large concentration of loose ash, burned soil and pieces of scoria, many of large size. This concentration represents backdirt hauled out of the enclosure from a looting operation inside the building.

Surface scoria, burned earth and adobes, ash, and charcoal are abundantly visible within the walls, particularly near the open center of the structure where there has been minimal burial by wall wash. The scoria is randomly distributed, but many pieces have been disturbed or moved from their original point of deposition. Disturbance is most evident in the west and west-central sections of the interior where huaquero looting took place. The pieces of scoria range in size from a few centimeters in diameter to irregular boulders in excess of 1.5 m. in length. The smaller pieces are the most frequent, but cobble- and boulder-sized blocks are not uncommon. The scoria varies in color from bright red-brown to brown-black, while some pieces are a yellow-brown color. When broken, most pieces are black in section. Often one or more surfaces of the blocks are glassy and lustrous in appearance, displaying signs of molten flow prior to solidification. In some cases the material twisted and slumped under its own weight while in a viscous, semimolten state. In other cases the scoria surfaces are highly porous with numerous holes made by escaping hot gases. The cinder is light in weight and of low density, although many examples contain inclusions. These inclusions are of three types: stones, charred tillandsia, and bones of small rodents. The inclusions are significant because of their implications concerning (1) the material that served as the source of the scoria, (2) the fuel that produced the scoria, and (3) the condition of the Tschudi Scoria building at the time the scoria was formed. These factors will be discussed later in greater detail.

We conducted two types of excavation at the Tschudi Scoria. The first was a simple stripping operation designed to check minor architectural details. For mapping purposes, all the corners of the building were partially cleaned. Some sections of wall tops were stripped to find roof supports, but none was encountered. In other areas wall tops were cleared to investigate the arrangement of the bricks. Where the bricks could be securely traced, they were plotted on the plan (fig. 2). The exterior and interior bases of several wall sections were stripped in an effort to locate the entrance to the building. Within the building we cleared a number of locations to search for floor features. This search proved disappointing, because it revealed only one small area of burned floor plaster, about 1 m. in diameter, and produced less than half a dozen floor contact sherds. These were all body sherds of Chimu domestic ware; all had been badly burned. Excavated areas are indicated by dashed lines on the plan (fig. 2).

The second type of excavation was a series of trenches designed to provide a north-south cross sectional profile through the building (figs. 3, 4, and 5). The trenches were originally aligned so as to utilize a large huaquero's pit in the center of the structure (fig. 2). The east face of the pit was straightened, and trenches were run off the pit to provide a continuous profile. Unfortunately, before the operation could be completed, a devastating earthquake struck the Peruvian north coast. One relatively insignificant casualty was our excavations, which collapsed. Subsequent work did produce a cross sectional, composite profile. It was not feasible to realign the trenches, however, and in some areas the excavations had to remain shallow because the quake had loosened unconsolidated deposits of gravel fill that kept collapsing, particularly due to continuing sharp after shocks that followed the earthquake. The composite profile is long and somewhat complicated. For convenience the description is presented in three sections: (1) the open interior of the building; (2) the deposits next to the interior wall faces; and (3) the deposits at the base of the exterior wall faces.

Where the profile followed the east face of the looters' pit (fig. 4) the archaeological deposit is thin, averaging 10 cm. or slightly less in depth. As the north and south walls are approached, the depth of material increases. In general, the deposit is composed, from top to bottom, of pieces of scoria, fine ash, tillandsia charcoal, and minor amounts of burned soil, and brick fragments. Because the materials are unconsolidated, the depth shallow, and looting had occurred, the stratigraphic sequence is not always uniform.

Scoria is not plentiful and appears only where the profile approaches the walls. The pieces are small, only a few centimeters in diameter. They never rest directly on the floor, but are always underlain by ash and/or charcoal. This situation repeats itself in all other areas where floor stripping was carried out. Even boulder-sized pieces of scoria lying in original position are always separated from the floor by at least a few centimeters of ash or charcoal.

The layer of ash is loose, unconsolidated and powdery. It is variable in color, ranging from white to yellow, pink, tan, and brown-black hues. The ash both surrounds pieces of scoria and underlies them. Because the scoria contains tillandsia inclusions, and because the charcoal at the base of the ash deposit is composed of the same plant, it is assumed that the ash derived from tillandsia.

The layer of charcoal and charred tillandsia is unconsolidated and loosely compacted. Only remains of tillandsia were encountered; no other combustible material was found. There is some blending or mixing with the overlying ash deposit, while at the base of the layer there is frequently loose burned soil or deteriorated adobes.

Underlying the charcoal deposit is a burned but unscoriated, compact surface of native soil. Red in color, this surface had been the floor at the time the Tschudi Scoria burned. No traces of plaster survive in the area of the profile, and no floor contact artifacts were found here. Below the surface is sterile sandy silt. This silt is compact, partially consolidated, and mixed with lenses of gravel. The soil is reddish-tan in color except close to the surface where it is dark brown to black.

The stratigraphic profiles next to the interior wall faces are complex. The profile of the south wall (fig. 5) shows a degree of consistency and will be described first. The deposit slopes at an angle of roughly 25 degrees. Adjacent to the wall the sequence of stratigraphic units is, from top to bottom: wall wash; scoria mixed with burned earth and ash; ash; charcoal; unconsolidated gravel; a slab of clay; and sterile soil. The wall wash is compact and tan in color. It has inclusions of burned and unburned bricks, and occasional small stones. The layer of burned earth mixed with scoria and ash is loose and not consolidated. The matrix of burned soil is bright red, indicating substantial heating. The deposit of ash and the underlying deposit of tillandsia charcoal are essentially the same as their counterparts described in the center of the building. The unconsolidated gravel is loose and extremely unstable. The stones are rounded and range in size from a few centimeters to cobbles about 15 cm. in maximum diameter. Domestic refuse is randomly mixed with the gravel, and includes numerous sherds of Chimu affiliation, occasional textile fragments, some metal artifacts, marine shells, mammal bone, and rare fragments of human bone. The refuse indicates that the gravels were derived from an area of human habitation. From the surface of the deposit to a depth of 5 to 10 cm. the layer shows red and black discoloration due to heat. Below this discolored area the deposit is tan to brown with no evidence of heat modification. The clay slab beneath the gravels is tan in color, compact, and consolidated. It represents a footing or foundation structure poured in place within a shallow cut extending out from the wall base. The sterile soil at the base of the deposit shows no evidence of heat alteration.

The stratigraphic situation changes in the section of profile lying between 2 and 4 m. out from the wall. The scoria and ash are unconsolidated, but closely packed. The larger pieces of scoria tend to interlock, and this gives stability to the deposit even though the ash matrix is loose and powdery. The underlying layer of burned soil is lightly compacted, and bright red in color. This material is generally the same as the burned soil described in the previous section of profile, however it lacks ash and scoria inclusions. Heavily burned adobes or brick fragments compose the bulk of the deposit. Several bricks at the top of the layer are partially scoriated, and their surfaces show signs of molten flow. Many of the burned bricks have partially disintegrated, and some of the loose soil matrix of the deposit derives from such bricks. The unconsolidated gravels are the same as in the previous section of profile. Near the top of the deposit, however, there is more red coloration as well as some mixing with burned disintegrated adobes, from the overlying stratigraphic unit. The mixing resulted from slumping of the loose gravels when the deposit was subjected to burning. The sterile soil at the base of this section of profile shows no heat modification on visual inspection.

Beyond about 4 m., the south wall profile resembles that described for the center of the building.

There are several important features to note about the interior face of the south wall. First, the bricks comprising the wall face and at least the first two courses of bricks behind them end about 2.25 m. above the level of the floor. This interior section of the wall rests on and is supported by the unconsolidated gravels. Second, all bricks in the wall face are heat altered. The exterior surfaces of some are scoriated. Other bricks are of substandard size. These apparently had scoriated faces that dropped off leaving the bricks thinner than usual.

The profile adjacent to the interior face of the north wall (fig. 3) is not as straightforward as its southern counterpart. This is due, in part, to the fact that the earthquake made it unfeasible to excavate either deeply or close to the wall. The stratigraphic profile slopes down from the wall top to the building floor at an angle of 30 degrees. The deposit is composed of many of the same elements found in the south wall profile. However, these elements tend to lack the relatively consistent ordering found in the south, and there are two points of difference. First, the wall wash lacks inclusions of burned brick. Second, a layer of gravel mixed with wash is not found in the south. This deposit has been loosely consolidated by the wall wash, but otherwise resembles the underlying gravels. It probably represents a simple washing of loose earth into the upper levels of the gravel layer.

The profile section from about 3.25 to 6.0 m. beyond the wall has elements similar to those described for the south wall profile. There are, however, several divergences. First, the deposit of burned soil is localized and thin. It lacks inclusions such as scoria or bricks, and rather than underlying a deposit of scoria it is banked against scoria and ash. Second, in the layer of scoria and ash there are some adobes. These bricks are purple in color, and their surfaces are glossy and scoriated in some instances.

The wall construction in the north is generally similar to that found in the south. Though not apparent in the illustrated profile, the interior wall face rests on and is supported by unconsolidated gravel fill. The wall faces show signs of heat alteration which was more evident in areas where the wall top was stripped than in the profile section.

The deposits banked against the exterior wall faces are variable in the amount of burned material they contain. The south wall sediments are shallow. From top to bottom the units are: wall wash; a few small pieces of scoria; ash; and tillandsia charcoal. These materials rest upon a lens of sandy silt. The sandy silt upon which the deposit rests represents a mixture of eolian sediments and wall wash. On the surface of this silt layer, where the tillandsia charcoal is relatively thick, there is a limited amount of heat induced discoloration. Below this silt deposit there is a footing structure in the form of used bricks and mud poured into a trench cut into sterile soil. Close to the base of the wall and over the footing structure, there is a foundation of coarse gravel in a loosely compacted soil matrix. This in turn is overlain by the lowest courses of the wall. All elements of the exterior north wall profile appear in one or the other of the previously described profiles. The wall resembles its southern counterpart except that the total deposit is much thicker, there is no footing structure, and the foundation gravels are relatively thicker.

To interpret the profile it is important first to reconstruct the nature of the building prior to the deposition of the scoria and burned materials, and then to reconstruct the events leading to the accumulation of burned materials.

As noted, the interior wall faces stop well above the floor of the building. The bricks rest upon and are supported by unconsolidated gravels. Because the gravels are loose and extremely unstable they could not have supported the walls had they not originally been contained and prevented from slumping into the building interior. The gravels must have once been held behind a restraining wall, which means that there was a gravel filled bench along the interior walls. The bench face was most likely of adobes and probably only one or two bricks thick with the base resting on a gravel foundation, like all other walls in the structure. The physical evidence for the bench face consists of the concentration of burned adobes situated in front of the gravel fill. In the south profile the bricks appear at a distance of 2.5 to 4.0 m. from the wall face. In the north profile they are found 3.5 to 4.0 m. beyond the wall.

Tillandsia in the form of charcoal is the only combustible material found in association with the Tschudi Scoria. The charcoal desposits are thickest adjacent to the walls and in the bench areas. This is also where the thickest deposits of ash appear. Deposits of scoria, burned clay, and burned bricks may be mixed with ash, but they are almost always underlain by layers of pure ash or beds of charcoal. In the center of the structure the burned floor is covered by charcoal. The bench fill gravels near both walls are generally covered by charcoal. This distribution of charcoal and ash indicates that an accumulation of tillandsia lay on, or was suspended above, the bench and floor prior to burning. Because there is substantially more ash and charcoal in the bench area, the original accumulation of tillandsia must have been greatest in these areas. Because the charcoal is overlain by scoria and burned soil, the bed of tillandsia is believed to have originally been overlain by a deposit of earth.

Thus, the pre-fire sequence of materials along the interior of the structure is postulated to have been: (1) the bench surface; (2) a substantial layer of tillandsia; and (3) a layer of earth. Since the free flow of air necessary for burning would have been at least partially hindered had these three elements been directly superimposed, vertical separation of the materials is postulated. Such separation is most easily accounted for in terms of a roof structure over the bench. The roof base was made of tillandsia, and the roof top was capped with earth. The roof structure may have projected beyond the edge of the bench. It did not, however, cover the interior of the building. In the center of the structure there is neither a substantial accumulation of ash or charcoal, nor a consistent scoria cap that would indicate a covering roof.

Thus, the structure enclosing the Tschudi Scoria is interpreted to have been an open building with benches against the interior walls before it burned down. The benches were covered by roofs which were built of a tillandsia base and a clay cap. Exactly how the roofs were suspended is open to question. If post supports were involved, as seems likely, they were probably nothing more than tightly bunched, parallel aligned, long reeds or cane. Judging from other Chan Chan structures, such supports of reeds would be bound spirally with cord, then plastered over to serve as a roof support. This type of roof pillar would account for the fact that no hardwood charcoal was found in the Tschudi Scoria. It should be noted, however, that we found no evidence of any horizontal supporting structure which would have been necessary to carry the tillandsia bed, quite apart from the vertical supports for the roof as a whole.

There are strong indications that the building burned during the daytime. There are two lines of evidence for this. First, there is little burned material outside the south wall, but abundant material outside the north wall. Second, within the structure, there is abundant ash but relatively little charcoal in the north while in the south the reverse is true; and in the south, charcoal is relatively more common. This state of affairs implies that detritus from the burning building was falling outside predominantly to the north, and that more complete combustion of flammable materials took place within the northern section of the building than within the southern. This situation is most easily accounted for in terms of the prevailing winds. At Chan Chan strong onshore winds blowing in a north-northwesterly direction arise between 9 and 10 o'clock in the morning. They gradually build up to velocities often in excess of 10 to 20 m.p.h. during the day and then die down in the evening. The stratigraphic profiles may, therefore, be said to indicate that the building burned at a time when there was a fairly substantial wind blowing in from the coast, and such winds are daytime winds.

Finally there is one line of evidence suggesting when, in the history of the building, burning took place. Some scoria deposits inside the structure contain osseous inclusions. The bones are of small rodents. They have not been identified by genus and species, but the remains appear to be those of indigenous field mice. The bones are mixed and do not occur in articulated anatomical position. Although fragmentary in the majority of cases, complete bones and intact mandibles and crania are frequently found. All the remains have been burnt. In addition to being imbedded in scoria some ash deposits surrounding the scoria contain large numbers of osseous inclusions.

The location of the scoria with osseous inclusions is important. The remains are restricted to scoria and ash deposits found along the interior of the walls, the south wall in particular. They are not encountered in the open center of the structure, nor were they encountered in the gravel fill underlying the scoria and ash, in the adobes of the wall, in the wall wash overlying the scoria and ash. Thus, the bones could not have derived from inclusions within the construction materials of the wall or bench. Rather, the location of the osseous remains indicates substantial accumulations of mouse bones on or above certain sections of the bench at the time the Tschudi Scoria burned.

Explaining the concentration and distribution of osseous inclusions is done most economically in terms of the nesting and eating habits of the coastal Burrowing Owl (<u>Speotyto cunicularia</u>). These birds are ground nesting, and they occupy burrows, pits such as old <u>huaquero</u> tunnels, or abandoned and partially collapsed structures with dark interiors. Such nesting areas are situated away from foci of human activity such as settlements or areas of cultivation. The birds feed upon insects and small rodents, such as mice. Because of certain physiological and anatomical features of owls, much of their food is not passed completely through the digestive tract. Rather, solid waste is eliminated by regurgitation in the form of loosely consolidated pellets about 1 cm. in diameter and between 1.5 and 2 cm. in length. The pellets are composed of bone, cartilage, hair, and other indigestible matter.[7] Around nesting areas there are quantities of owl pellets. With time the boluses break down and the lighter contents scatter, while heavier elements, such as bone, undergo less displacement. Around a long inhabited nest the process leads to sizeable accumulations of rodent remains.

The osseous remains found in the Tschudi Scoria can be interpreted as indicating the former presence of owl nesting on the bench inside the building. The high concentration of bones in the south may reflect the fact that being on the leeward side of the wall this was the most protected section of roofed bench. The northern bench faced the wind, was less protected, and made a less favorable nesting area.

If this interpretation is correct it carries important implications. The fact that local owls do not nest in areas of human activity suggests that the building was no longer in use when the mouse remains were deposited. The substantial accumulation of osseous material implies that the building had been abandoned for a considerable period of time prior to burning, though the length of time between abandonment and burning is not accurately known. Had sufficient time elapsed prior to burning the building and roofing over the bench could have fallen into disrepair. The proposed deterioration could have involved partial disintegration of the earth cap on the roof, bringing about a mixture of soil with the underlying tillandsia bed. This situation would be consistent with the technical analysis of the scoria (see pp. 156-157) which implies loose mixing of the roofing constituents at the time of firing.

If the building did burn after it had fallen out of use this could account for the paucity of floor contact artifacts. At the time other large structures at Chan Chan were abandoned their contents were systematically removed. A similar situation very likely took place at the Tschudi Scoria structure when it was vacated.

Reconstructing the sequence of events involved in the actual burning of the building is a difficult matter. The tillandsia roof bed must have ignited. As this material burned, charred and flaming plant material fell on the bench surfaces and on the floor. As these deposits accumulated, the upper surfaces where there was an abundant air supply, burned completely and turned to ash. As ash built up, it inhibited the combustion of the underlying plant material which burned only partially and was preserved as charcoal. As the heat increased, the interior wall faces burned. Some were subjected to sufficient heat to melt them, resulting in a facing of scoria and in some slumped scoria deposits. The roof cap of earth was also subjected to intense heat. Some of this material reached a molten state, while other sections of the cap simply collapsed forming deposits of heavily burned soil. With the collapse of the roofing, some of the upper wall sections also collapsed, mixing burned and scoriated adobes with the roof remains. In the south the roof fell inwards. In the north a considerable amount of material fell outside of the building. Sometime in the course of events the benches collapsed. This collapse probably occurred well after burning had started when the bricks in the bench face had already been heavily burned. Perhaps it was concomitant with the collapse of the roofs which would have placed added weight on the unconsolidated gravels. On the north side of the structure the bench face fell in toward the center of the structure. In the south, the base of the bench seems to have been pushed out by the weight of the gravels while the top caved in upon itself. When the roofing structures and the benches collapsed, they trapped and buried much of the combustible material, a situation that may have altered the nature of the fire from a hot flame to a long term baking heat.

Obviously, this is a general reconstruction and not equally applicable to all sections of the Tschudi Scoria. It does, however, account for the nature of the deposit as revealed in the stratigraphic profiles.

After burning, the structure was not reused. There was some late collapsing of loose gravels along the upper interior face of the north wall, and all the adobe walls were subjected to weathering, resulting in the accumulation of clay wash. Sometime well after burning the center was cut into by looters, but there are no indications that this was a productive huaquero operation. Otherwise, the building remained undisturbed until the 1970 excavations and earthquake.[8]

Pyrotechnological Considerations

Although Squier was apparently referring to the scoria remains associated with the Ciudadela Velarde at Chan Chan (see fig. 1 and p. 135) and not to the Tschudi site whose study forms the substance of our report, it is nevertheless true that for years most archaeologists have considered the Tschudi Scoria structure a metal smelting furnace. Thinking was influenced not only by V. F. Hollister's article,[9] which tended to substantiate Squier's claim by demonstrating the apparent metallurgical origin of the slags Hollister had analyzed from Chan Chan (see Table III, pls. XLI and XLII) but also by the certainty of Squier's early description coupled with his undocumented analyses of the scoria. Perhaps most convincing, though, was the evidence of one's own eyes, the impression gained when visiting the Tschudi Scoria site: its floor covered with large scoria boulders; its adobe walls reddened by a fire that had caused the inside surfaces to melt and flow; and its thick ash layer acting as a bed for the scattered scoria blocks. Dudley Easby, who visited Chan Chan briefly in 1951, described the site as "...the only known preconquest metallurgical and metalworking center on such a grand scale."[10] Junius Bird collected a sample of the scoria in 1966; Kenneth Rose collected another in 1967.[11] For those of us intent upon documenting the development of metallurgy in pre-Columbian South America, the Tschudi smelter at Chan Chan seemed a monument to the pyrotechnological skills of a complex society that was a prolific producer and user of metals and that, by the time of the Inca conquest, had developed virtually all of the alloys and metalworking techniques we recognize within the Peruvian tradition.[12]

The very size of the structure (roughly 70 m. by 25 m.) and the scale of the operations it supposedly housed were undoubtedly what proved most convincing, yet its dimensions alone ought to have been the first cause of skepticism. That a structure of this size could have been a single smelting furnace is almost out of the question. The amount of fuel necessary to operate it, the bulk of any single charge, and the volume of slag produced on each occasion would have made the operation unmanageable and probably dangerous. On the other hand, the structure could simply have acted as an enclosure for a series of smaller furnaces operated within its walls. Indeed, this is the impression given by Squier when he describes "...a succession of what were perhaps ancient furnaces or smelting-places..." at Ciudadela Velarde.[13] None of the excavations undertaken at various positions along the south, east, and west walls of the Tschudi Scoria enclosure, however, revealed any internal structural subdivisions that could have been the remains of such furnaces, hearths, or ovens (see fig. 2). Although we found abundant evidence of a hot and uncontrolled fire, as all the excavated areas revealed scoria and ash while the upper portions of the inner surfaces of the walls were also reddened and scoriated, we found none of the features one normally associates with the remains of a purposeful furnace operation: an earth floor markedly hardened through constant heating; plastered furnace walls that have been scoriated and relined a number of times to renew them; some means of creating enough draft to provide the air supply to the fuel; ash heaps somewhere near the furnace where excess ash, cleaned from the furnace, has been dumped; troughs into which molten slag can run when tapped from the furnace; slag heaps; remains of ore and of fuel; and occasional remains of won metal.

All the evidence, both in the field and in the laboratory, indicates instead that the structure in question burned down as a result of a hot but relatively brief fire to which it was subjected on one occasion only; that the carbonized vegetal material present in the debris was, in its unburned condition, the fuel for that fire; and that the ubiquitous scoria represents earth, originally from the wall bricks and possibly from a soil capped roof, that was heated up to and above its melting point, in some cases forming large masses of vitrified material. The only metal remains excavated at the site were occasional objects mixed in with the gravel fill and wall fall adjacent to the faces of the walls: a bead (2.5 mm. in diameter), a spindle whorl, a needle, and a small ornament, all of copper or a copper alloy; and the point of an iron spike.

The floor

Two large areas of the floor were uncovered by removing the scoria and ash that lay above it (see fig. 2). Little floor plaster remained, and the earth beneath was not particularly hard packed.

Nowhere had the floor been baked hard as is usual with furnace floors that are repeatedly subjected to high temperatures, resulting in the formation of a quasi-ceramic layer that can be 5 cm. or more in thickness. In such cases, one may expect to find some changes in the morphology of the individual clay particles in the heat affected zone, such as rounding of their edges as a result of partial sintering. Figures 6, 7, and 8 are photomicrographs of earth samples 7, 8, and 15 which were removed from the floor and at various locations beneath the floor (samples 7 and 8 were removed from the east face of the profile at a distance of 8.6 m. from the base of the interior south wall; sample 15 was 5.4 m. from the wall base; see figs. 4 and 5). Sample 7 was black in color and lay approximately 2.5 cm. below the floor surface; sample 8, which lay directly below sample 7, was 15 cm. beneath the floor surface at a depth where the soil, on the basis of its color alone, appeared unaffected by the heat; sample 15 lay approximately 6 cm. below the floor surface, was black in color, and contained tiny charcoal inclusions. The photomicrographs were taken with a scanning electron microscope at a magnification of 24,000. The clay particles of samples 7 and 15 appear identical with those of sample 8. Their edges are crisp and the angles sharp. They may be compared with similar particles in figure 9, a photomicrograph (X 14,000) of an earth sample removed from a depth of 27.5 cm. below the floor surface (well beneath the heat affected zones) and heated in the laboratory for one hour at 600°C. Note that in none of these particles has there been any thermally induced rounding of edges. By contrast, particles from the same earth sample which were heated for one hour at 1020°C. show considerable rounding from surface flow (fig. 10, X 1,500).

The photomicrographs of samples 7, 8, and 15 (figs. 6, 7, and 8) demonstrate that there has been no physical change in the particulate nature of the floor. The blackening of samples 7 and 15 is rather a chemical change caused by the heating of these zones under reducing conditions. Both samples lay beneath accumulations of ash or charcoal which restricted the amount of air reaching them during heating. Under such conditions, the iron oxides in these soils were reduced to Fe_3O_4, causing them to appear black. At other locations the floor had reddened under the influence of heat, but never to a depth greater than a few centimeters. That the earth floor was not more markedly affected by the fire is undoubtedly due to the presence of a thick layer of ash that accumulated on the floor during the early stages of the fire and served thereafter as an insulating and somewhat protective shield. Ash accumulations 10-15 cm. thick were not uncommon.

The walls

The individual adobes of the walls measure, on the average, 25 cm. long by 10 cm. wide by 16 cm. high. In the areas where the fire was hottest, the surface adobes on the interior face of a wall were affected by the heat throughout their depth, that is, for a distance of some 10 cm. The second layer of bricks, immediately behind the surface adobes, showed no signs of heat discoloration, however. Experiments with samples of unburned brick from the walls have shown that, when raised to a temperature of 500°C. in an oxidizing atmosphere, the clay turns a bright reddish-brown color. The bricks in the second layer could not have reached that temperature and probably were not heated much beyond 300° C.

A cross section of a typically scoriated brick from the interior surface of the south wall is shown in figure 11. The sample illustrated represents almost the total thickness of the original adobe, and the major heat induced changes have all occurred within these ten centimeters. The large number of stony inclusions is characteristic of all the adobes from the site. This particular brick was quite obviously heated from one side only, and the heat has completely scoriated the surface to a depth of 3 cm. (zones 1 and 2). Zone 1, 1.5 cm. in thickness, is highly porous as a result of the evolution of gases causing bubbles to form in the glassy matrix as its temperature was raised (see fig. 12). This vitrified surface zone was sufficiently viscous that it could move and indeed began to slide down the wall under the force of gravity. Large sheets of such slumped surface scoria can be seen on the exposed faces of the south wall. Zone 2, although vitrified and containing a few small bubbles (see fig. 13), did not reach the temperature at which much gas was formed, though it too, in its fused state, could creep slowly down the wall. The large crack in the brick between zones 2 and 3 was probably caused by the difference in thermal expansion between these two zones. It evidently represents the plane along which the scoriated zones could slough off.

Zone 3 exhibits a markedly different color, a dull brownish-black, and has undergone incipient fusion (see fig. 14). This portion of the adobe has not actually fused, but some slight sintering has occurred causing the matrix to glue the other particles together. This zone occurs between 3 cm. and 5 cm. from the surface. Below it, and throughout the remainder of the adobe, the clay is a bright reddish color, has undergone no fusion of any kind, and is consequently friable (see fig. 15).

Examination of the glassy portions of the adobe (zones 1 and 2) reveals that the tiny quartz crystals suspended in the glassy matrix have not reacted with that matrix. On prolonged or repeated heating at elevated temperatures, quartz particles will begin to react with the surrounding glass, breaking down at their surfaces and developing rounded edges. The absence of such reaction, together with the fact that the dimensions of such scoriated bricks are substantially the same as those of the unheated adobes, strongly suggest that the brick was heated on only one occasion. Since the inner surfaces of the walls of our structure were not replastered or renewed in any way, repeated scoriation of the brick as a result of furnace firings would have caused it to lose many centimeters of its original surface through slumping and gravitational flow. This has not occurred, however.

Samples of an unburned brick from the south wall were heated for one hour in an oxidizing atmosphere at temperatures increasing in intervals of roughly 100°C. to determine the temperatures at which the various zone characteristics apparent in figure 11 occur. The results of these experiments are tabulated in Table I.

TABLE I

Correlation between zone temperature and heat induced changes in a scoriated adobe

Zone	Fig. No.	Characteristics	Distance from surface [cm]	Temperature °C.
1	12	Black color; highly porous - large bubbles from gas evolution; expansion from gassing; melting of glassy matrix; flow and collapse at surface	0 - 1.5	$T_s \geqq 1320$
2	13	Black color; few and tiny bubbles; melting of glassy matrix	1.5 - 3	$T_1 \approx 1270$
3	14	Brownish-black color; no gas bubbles; slight sintering causing particles to stick together	3 - 5	T_2(crack) $\approx$ 1220 T_3(crack) $\approx$ 1130
4	15	Reddish color; no sintering; friable	5 - ...	$T_4 \approx 1050$

These results show that although glassiness, flow, and expansion from gassing began at about 1270°C., it is not until the surface has reached a temperature of approximately 1320°C. that collapse of the melt and rapid flow occur. Splitting of the clay and the formation of large fissures occur in the neighborhood of 1130°C., and this temperature may correspond to the upper temperature of zone 3 where the rather wide crack appears. Incipient fusion begins at approximately 1050°C. Below that, the adobe is oxidized but completely unfused. Perhaps the most significant result of these data is the rather surprising fact that the surface temperature of the interior walls of the structure was raised to 1300°C. and higher. The fire was extremely hot, though no evidence of any fuel save tillandsia was uncovered in the course of the excavations.

The fuel

Since the field studies made it quite evident that an uncontrolled, hot fire of major proportions had burned throughout the interior of the structure, a careful search was made for traces of any fuel that might have been associated with that fire. Neither hardwood charcoal, such as algarrobo which has been found at other sites in Chan Chan and which burns with a lasting hot flame, nor the remains of cane or any of the soft woods was found. Large quantities of completely carbonized Tillandsia latifolia were uncovered, however, in two conditions. When found near the walls and associated with wall fall or collapsed bench adobe-and-gravel, the tillandsia generally occurred in thick wads that measured as much as 20 cm. in thickness. These wads had no particular structure, being neither woven nor laminated in any regular way. Rather they were felted, matted together primarily by pressure, as were the original, unburned tillandsia plants that gave rise to the wads.

When found toward the center of the structure, however, this charcoal was often an integral part of the large blocks of scoria that lay scattered on the floor, embedded not only in their surfaces but intimately mixed with the fused interiors of even the largest boulders. Figure 16 shows one of the blocks from the east end of the structure. It measured 57 cm. by 27 cm. by 41 cm., exhibited free molten flow on two of its surfaces, and is shown split in two. The entire central portion of the scoria contains tillandsia charcoal. The outer shell of the block had access to much more air than the interior and could, therefore, sustain combustion, for the plant has burned to ash in this zone leaving large visible pores. The remarkable preservation of the stiff fibrous stems and leaves of this plant in the interior, however, is evident in figure 17, which shows such a stem embedded in the center of the block. Note the similarity to a modern specimen of the plant collected in the Moche Valley in 1972 (fig. 18).

The internal structure of these large scoria blocks is important, because it helps clarify several points concerning the pre-fired constitution of the boulders, the conditions under which vitrification could have occurred throughout such large volumes of material, and the original disposition of the tillandsia. Figure 19 illustrates a fragment of scoria with associated tillandsia charcoal that was removed from the interior of the block shown in figure 16. This fragment was located just inside the outer zone of high porosity, at a distance of roughly 16 cm. from the top, bottom and one end of the block. This fragment, typical of many areas within all of these boulders, shows clearly that considerable localized melting and flow occurred inside the block. Its surfaces are smooth and glassy, strongly resembling the once molten surfaces of the wall adobes described previously (zone 1 in fig. 11). Such surfaces are characteristic of molten material that has flowed, cooled, and solidified at a free and open surface. This evidence, combined with the high concentration of tillandsia throughout the block, demonstrates conclusively that the vegetal material and the earth or clay associated with it originally formed a loosely packed mixture with many internal air spaces resulting in high porosity. That porosity facilitated the flow of air to the interior of the mass, allowing combustion to take place internally once the fire started. As the individual lumps of earth became hotter and slowly melted, they shrank in size, creating even greater porosity and more open channels within the material. Since molten scoria does not wet charcoal, as is easily demonstrable in figures 17 and 19, and since there was not sufficient melting for the scoria to flow extensively, the tillandsia helped to hold the globules of scoriated earth apart preventing them from fusing into one solid mass. This separation also helped to maintain the open channels through which air could enter the block to sustain combustion. Once the viscous surfaces collapsed, however, free passage of air stopped and combustion ceased, leaving the charcoal _in situ_.

The loose mixture of tillandsia and earth or dried mud prior to firing explains the microstructure of the blocks as they now appear.[14] It also clarifies how a fire that caused scoriation of wall bricks to a depth of 3 cm. could, at the same time, uniformly scoriate a mass of material to depths of 30 cm. and more. We are assuming here, for lack of evidence to the contrary, that the fire burned reasonably uniformly throughout the structure, with no one area very much hotter than another. Even the fact that the bricks embedded in the walls were subject to heating from their outer surfaces only, while material in the center of the structure was undoubtedly heated from all sides, does not account for the vast difference in depth of scoriation between the blocks and the wall bricks. The explanation lies in the loose packing of tillandsia and earth which allowed combustion to occur throughout the volume of the material. Scoriation proceeded from many centers within a given volume, not from its surfaces alone.

If we are correct in our reconstruction of roofed areas within the structure, then the scoriated boulders provide some evidence for the nature of that roofing. Portions of the roof may have been constructed of tillandsia leaves and stalks loosely packed and held together with earth. On the other hand, it is also possible that the thick wads of tillandsia found buried near the walls served as a base layer over which a loose capping of earth was placed. With time, particles of earth may have filtered down into the tillandsia bed, mixing with it. When the structure caught fire and the roof burned, the tillandsia served as the primary source of fuel, quite apart from any other soft woods that may have been used to support the roof. Either of these modes of roofing is consistent with the present structure of the scoria blocks.

Tillandsia is a shrub of low density that burns rapidly, producing large quantities of ash. Ignited, it will quickly reach a high temperature, but will not sustain this temperature unless fuel is continually added. Assuming that the roof burned for some time before it collapsed and fell, the ash would have fallen and covered the floor, protecting it somewhat from the burning debris that later dropped from above.

The scoriated areas at Chan Chan are not the only evidence we have of the ability of tillandsia to support a fire hot enough to scoriate earth. One of us (MEM) has surveyed five areas in the Moche Valley where small flash fires, fueled by local stands of tillandsia, had caused the surrounding earth to melt, generate gases, and bubble. The earth at these sites is discolored, there is tillandsia charcoal scattered on the surface and a few centimeters below the surface, and the ground is covered with small round globules of scoria.

The scoria

Since the primary evidence for the existence of a smelter at the Tschudi site has seemed to be the presence of large quantities of scoria within its walls together with the reported metallic constituents of that scoria and other similar scoria deposits at Chan Chan,[15] it is perhaps ironical that chemical analyses of the scoria provide the final and conclusive data ruling out the smelting function of this structure.

Table III (pls. XLI-XLII) presents the analyses of Chan Chan scoria samples collected in the field and compares them with those published by Hollister and those made at the University of Trujillo.[16] These analyses of the Chan Chan material can profitably be compared with the data in Table II (pl. XL) which compiles several published analyses of copper smelting slags ranging from the Chalcolithic period roughly to the present time.

The internal analytical evidence of the Chan Chan scoria taken by itself demonstrates quite clearly that the scoria is not a metallurgical slag but rather the solidifed remains of once partly molten clay. The uniformity of analysis of all the samples, shown in Table III, regardless of their location at the site, is striking. Using the composition of an unburned adobe from the south wall of the structure (no. 427) as a standard of comparison, we note first that its composition is extremely close to that of the glassy portions of the two partly scoriated sherds (nos. 416 and 417) found on the floor of the structure. The sherds are made of basically the same clay as that from which the adobe was fabricated. If we turn to the analyses of the scoriated bricks that had fallen from the collapsed south wall (nos. 414, 418, and 419) as well as the slumped scoria still in situ on the surface of that wall (no. 415), they too are virtually identical with the analyses of the sherds. The scoriated brick surfaces cannot be distinguished from the two sherds on the basis of composition alone. Finally, the large scoria blocks that lie scattered over the floor of the structure (nos. 423, 424, 425, and 426) fail to distinguish themselves in any way from this general picture. The analyses of Lozano, who concluded as we do that the scoria was originally some form of clay, as well as those of Hollister, who attributed the scoria to the "...smelting of copper-silver ores,"[24] fit nicely with our determinations of the scoria composition at all three sites (Tschudi, Velarde, Central Scoria).

The scoria does not relate in any way to a metal bearing ore. The concentration of copper in the vitrified material is far too low for even the most efficient of metal winning processes.[25] Table II (pl. XL) gives a representative sample of copper smelting slag analyses from some of the earliest and least efficient operations to some of the latest and most proficient types. Lupu's published analyses of the products of the Chalcolithic smelter at Timna, Israel illustrate not only the inefficiency of the operation with large amounts of copper remaining in the slag (slags with 5-15% Cu content indicate a low extraction efficiency of less than 40-50%),[26] but also the variability one can encounter in the analysis of any particular batch of slag (cf. sample nos. 51 and 51B; or 58a, b, and c).[27] By the early Iron Age, the Timna smelters were able to regulate their metallurgical operations sufficiently to extract metal from the ore leaving only 0.98% CuO in the slag. The late Bronze Age and Roman slags from Cyprus also fall in this range, with concentrations of 0.91 and 0.70% Cu remaining in the slag. On the other hand, the slag from the presumed pre-Columbian huaira in Argentina in which chrysocolla, a copper-silicate ore, was smelted contained copper in a concentration not unlike that found in the earliest Timna operations (8.15% CuO). Finally, it is only in the modern period that the copper content of slags has been decreased appreciably from earlier levels of concentration (cf. Table II, pl. XL).

It seems clear that, on the basis of comparison with other copper smelting slags, the copper content of the Chan Chan scoria is far too low ($\leq$ 0.005%) to have originated from a copper bearing ore. Furthermore, the copper content of the unburned brick and of the two scoriated sherds is virtually identical with that in the other samples of scoria from the structure. They all originated from the same source, local soils.

The makeup of the scoria, quite apart from its lack of metallic constituents, is not slaglike. Again, looking at Table II, we note that in all cases fluxes were added to the copper ores in order to facilitate smelting by producing a more highly fusible material. These fluxes were generally oxides of iron which accounts for the high iron oxide concentrations in all of the slags analyzed. In the Chalcolithic slags from Timna the high MnO concentration in sample 58c (29.33%) probably indicates that manganese was used as a flux in that case. The elevated CaO content of some of these slags also suggests that limestone or a lime bearing clay was employed as a flux. By contrast, the Chan Chan scoria contains little iron, only that amount found in the brick itself. Most clays, in fact, contain iron in approximately this concentration. The elevated sodium concentration in all of the Chan Chan scoria is probably attributable to the nature of the clays in this desert region which are high in sodium salts.

Table IV (pl. XLIII) lists the temperatures at which the Chan Chan scoria were found to melt. Samples of the scoria were heated in a glo-bar furnace in an atmosphere of argon. The furnace was heated to approximately 800°C. before each sample was introduced. As the temperature of the sample was raised, visual inspection indicated the point at which slumping began (usually after 20 minutes or less), and that temperature, as well as the temperature at which the vitrified mass began to bubble and flow freely, were recorded. The lower free flow temperature recorded for samples 411-413, all from the Central Scoria, is probably related to their relatively higher sodium content. It is also interesting to note that the melting behavior of the unscoriated portions of sherd no. 416a, the unscoriated portions of brick no. 418a, and the unbaked brick no. 427 is almost identical, as would be expected.[28]

Finally, the physical nature of the scoria itself argues against its origin as a by-product of ore smelting. While quite small pieces of scoria melted completely, none of the larger chunks was ever entirely molten. Thus it would have been difficult at best for any silver or copper metal within the smelted ore to have gravitated through such a viscous mass of material and accumulate at the bottom of the furnace as won metal. The function of a fluxing agent is, of course, to lower the melting point of the slag so that it can run freely, enabling the metallic constituent of the ore to fall to the bottom where it can be collected after the slag has run off. As we have shown, no such flux is present in the scoria, and the internal structure of individual pieces of scoria reveals melting only at discrete sites within the porous matrix.

The ash

Given the presence of thick layers of tillandsia ash in both the Tschudi Scoria enclosure (accumulations of ash 10-15 cm. deep were not uncommon near the walls) and in the Central Scoria enclosure (a uniform layer approximately 8 cm. thick was uncovered), it was considered important to try to evaluate the thickness of the original tillandsia bed that gave rise to such ash accumulations. Specimens of tillandsia growing in the Moche Valley were collected and dried. The leaves were removed from some plants and were ashed to determine the change in volume between the individual dried leaves and their ashes. Entire plants including the leaves, stem, and bud were also ashed, again to determine the ratio between the original bulk volume of the plant and the volume of its ash. One plant was subjected to the amount of pressure it would have experienced had it been on the bottom of a pile of tillandsia about 50 cm. thick. The amount by which it was compressed was measured, and the change between its compressed volume and the volume of its ash determined. Two wads of tillandsia charcoal excavated at the Tschudi Scoria were also reduced to ashes.

The results of these experiments are given in Table V (pl. XLIV). Several points are immediately evident. First, most of the mineral content of the tillandsia is contained in the stem and buds, not in the leaves. This is clear from the extremely low weight percentage of the leaf ash as compared with that of the whole plant or of the charcoal, which can be assumed to have derived from whole plants. Second, it is equally clear that there is a large change in volume between the dried plant and its charcoal. In both charcoal samples, the change in volume from charcoal to ash was relatively small. The charcoal/ash volume ratios are approximately 2.5 and 3 as compared with 12 to 31 for the whole plant/ash or the leaves/ash ratios. Assuming that the properties of the modern plant are virtually those of the plants burned at the site, the Tschudi tillandsia charcoal/ash ratio cannot be used as the basis for approximating the volume of original material from which the ash derived. Such an approximation would give far too low a value. Instead, the actual ratio of the original volume of tillandsia to the volume of its compacted ash, as the ash present at both scoria sites was lightly compacted by virtue of the weight of the materials lying above it, should lie somewhere between the largest possible value (uncompressed whole plant/compacted ash) and the smallest possible value (individual leaves with no interstitial spaces/compacted ash). The experimentally determined ratios actually scatter around these two extremes, but the most reasonable value is probably the one associated with the whole plant that was subjected to pressure. It was compressed just as it would have been had it been within a bed of plants 50 cm. or more thick.

The data suggest that the ratio of the volume of the original tillandsia bed to the volume of its compacted ash lies somewhere between 12 and 20. When applied to the ash layers excavated at the Tschudi Scoria, such ratios indicate that the original tillandsia bed may have been between 1.2 and 3 m. thick. Although we argue elsewhere that the tillandsia which served as fuel for the Tschudi Scoria fire may have formed part of a roof above the bench near the walls, the ash data tend to cast doubt on that possibility. A roof composed of between 1 and 3 m. of plant material seems greatly in excess of what one might expect, particularly in view of the construction of other roofs for which we have evidence at Chan Chan (note 6). Cyril Stanley Smith, in a comment quoted earlier (see note 7) offers a possible alternative explanation.

Duration of the fire

We have argued at some length that all the evidence points to a single episode of intense burning that caused the destruction of the structure we have described, that the scoriated walls and the scoria blocks did not result from the repeated firings of any pyrotechnological operation, metallurgical or otherwise. An experiment designed to test this hypothesis has shown that a fire hot enough to melt the brick surfaces could readily have caused the internal heat induced changes we have encountered at the site had it burned for anywhere betwee sixteen and forty hours.

The experiment consisted of embedding a chunk of unburned brick from the south wall of the Tschudi Scoria structure in a wall of firebrick so that only one surface remained exposed. This surface was heated for seven hours at a constant temperature of 1320°C., simulating the unidirectional heating of the adobes in the Chan Chan wall. Two thermocouples monitored the temperature of the adobe at its front and back surfaces (6.7 cm. in depth).[29]

Figure 20 compares a cross section of the laboratory heated brick with that of the sample previously illustrated in figure 11. The microstructures of the two fragments are identical, as the same zones appear in the laboratory specimen as in the field sample. The difference lies only in the breadth of the experimentally induced zones, the narrowness of these zones resulting from insufficiently long heating, not from too low a surface temperature. Nevertheless, one can calculate the thermal diffusivity of the adobe from these experimental results, that is, the rate at which heat is conducted through this type of stone bearing soil. With this information, it is possible to return to the original field sample and to calculate the amount of time it would have taken for each of the zones to have reached the temperatures cited in

Table I, assuming that the surface temperature was held constant at 1320°C. Under these conditions, the temperature of incipient fusion ($\approx$ 1050°C.) was reached at the interface between zones 3 and 4 after approximately sixteen hours.[29] While it seems hardly likely that such an elevated surface temperature could have been sustained for that long with only tillandsia serving as fuel, even a far briefer exposure to this intense heat would have caused vitrification, bubbling, and flow within the first centimeter of the surface, while the changes induced at the greater depths could easily have resulted from the less intense but more constant heat of the slowly dying fire. In any case, the results are entirely in keeping with the archaeological evidence and are consistent with the hypothesis of a single intense burn.

Conclusions

Both field and laboratory studies show conclusively that the Tschudi Scoria structure at Chan Chan, generally considered to be a metallurgical smelter operated during the Chimu occupation, was not an ore smelting installation, though its function remains unknown. The structure was subjected to an intensely hot fire for a period of approximately 16 to 40 hours during which time it burned down, its presumed earth-capped roof and adobe walls melting to form the scoria that has characterized the structure ever since.

Specifically, the laboratory studies show that:

1. The concentration of metals other than iron in the scoria is far too low for the scoria to be considered an ancient metallurgical slag.
2. The composition of the scoria is virtually identical with that of the unburned brick of the walls and of sherds that were scoriated during the fire. There is no evidence in the scoria of the usual fluxes added to a charge of ore and fuel to facilitate smelting.
3. No heat induced physical changes were found in the earth of the floor as might be expected in a furnace floor subjected to high temperatures on repeated occasions.
4. The scoria has a melting point of about 1320°C. A fire at least this hot existed within the structure and was brought to this temperature by an abundance of burning tillandsia.
5. A study of the ashing properties of modern samples of tillandsia collected in the Moche Valley indicates that the thickness of the original tillandsia bed that served as fuel for the fire may have been between 1 and 3 m.
6. Partial simulation in the laboratory of the heating conditions presumed to have occurred during the course of the fire demonstrated that the heat induced changes in the adobe walls could have taken place as a result of a hot fire (ca. 1320°C.) blazing for a period of from 16 to 40 hours.

Summary

Our investigation of the four principal scoria deposits within Chan Chan shows no relationship with metal working activities. All the

accumulations of burned materials are associated with buildings that were incompatible with pyrotechnological activities in terms of structural design, layout, and construction materials. Laboratory analysis demonstrates the composition of the scoria to be virtually identical with that of unburned soil and adobes found in the surrounding architecture.

The four scoria deposits fall into two groups. The first group is made up of the Gran Chimu and Velarde examples. Here the roofs of high status burial cells burned after exposure by looting. The second group of deposits is represented by the Central and Tschudi Scoria. These were products of the burning of thick layers of tillandsia. The tillandsia may once have been part of roof structures composed of a soil cap overlying a bed of tillandsia, supported by a horizontal lattice of cane held up by columns of cane.

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NOTES

[1]Cieza de León [1553], 1967, cap. LIX, p. 195.

[2]Squier, 1877, p. 164.

[3]Squier, 1877, p. 136.

[4]Squier, 1877, p. 141.

[5]See the section describing the ashing properties of tillandsia on pp. 160-161 and Table V.

[6]The general roofing pattern at Chan Chan is one of a clay cap resting upon an organic base. These base structures, however, are almost without exception mat, reed, and/or cane, and not tillandsia.

[7]For brief descriptions of this phenomenon, see Thomson, 1964, pp. 608-609; Reed and Reed, 1928.

[8]When reading a preliminary draft of this paper, the authors' colleague, Cyril Stanley Smith, noticing the extraordinarily high ratio

of fuel to clay involved in the "event" at the Tschudi Scoria, suggested that,

> instead of the simple burning of a building in which combustible material had been used structurally, the structure might have been merely an area for the storage of fuel, without roof but walled to prevent theft. Perhaps some earth from the surrounding desert had been windborn and deposited in intermixture with the fuel. Once ignited such a pile would burn at a rate controlled only by the amount of air that had access to it. No mere roof would yield anything like the amount of ash observed. The layer of ashes (about 10 cm. thick) that was observed corresponds to nearly two metres of solid hardwood, or several metres of shrub such as Tillandsia latifolia which, though of high ash content, would pile in a mass of relatively low density. This material would be more or less felted as stacked in the store, whereas any structural or weatherproofing use of it would almost certainly involve the detachment of the leaves and, if not active interweaving, at least the laying of them in compact form, no evidence for which was found on the site. In fact, the preservation of a plant section (as in fig. 17) not broken into leaves virtually proves that it was stored, not prepared for mechanical use.
>
> The use of similar desert shrubs as fuel for a pottery kiln, continually fed in small amounts to maintain a uniform fire, is described by Hans Wulff (The Traditional Crafts of Persia, Cambridge, Mass. 1966, pp. 116-117) who says that "these shrubs burn with a long and intensely hot flame."

While Professor Smith's argument does provide an alternate explanation for the quantity of ash found at the Tschudi Scoria (see our section "The ash" beginning on p. 160) and could account for the absence in our excavations at both the Tschudi and Central Scoria of supporting devices for a roof, such as vertical posts or some form of horizontal structure to bear the weight of the tillandsia and soil cap, it nevertheless fails to explain other significant features at these sites:

a. The presence of gravel, sherd, and osseous inclusions in the scoriated soil at both the Tschudi and Central Scoria sites. These inclusions, intermixed with the soil before it underwent heat alteration, could not have been windborne. The size and weight of the stone inclusions particularly preclude this possibility.

b. The uniformity of the charcoal, ash, and scoria strata across the entire section of the Central Scoria. This suggests that the original "structure" giving rise to these deposits was itself quite uniform, consisting of a layer of tillandsia beneath a layer of earth. We wonder if a mere store of tillandsia would exhibit such uniformity of thickness and why, if it were stored, a layer of soil was placed on top of the plants. That the soil was not simply windborne is attested to by its evenness and by the nature of the associated inclusions discussed in (a) above.

c. The presence of considerably more tillandsia upon the "benches" of the north and south walls of the Tschudi Scoria structure with concomitantly more intensive burning at these locations. If the Tschudi Scoria were a store for tillandsia plants, why was there a greater amount of the plant material stored all along the bench tops and near the walls than in the open center of the structure?

d. The heavy burning that occurred outside the north wall of the Tschudi Scoria. If the tillandsia were stored wholly within the walls of the structure, how may we account for the fire spreading outside and to the north unless the plant material were elevated high enough so that the wind blowing from the south could carry the burning debris beyond the north wall? Presumably stockpiling of the tillandsia atop the benches or its presence in a roof above the benches would account for the fire damage it caused on the exterior of the north wall. Mere piling of the plant in the interior of the structure is unlikely to have caused the burning revealed there upon excavation.

Given the nature of the monumental sector of Chan Chan in the midst of which all the scoria sites are located, there is also the question of whether the Chimu elite occupying this area would have stockpiled a plant, that grows abundantly in the region and is easy to collect, in the middle of an otherwise highly restricted zone of the city. That they used tillandsia for fuel is certain, but that the Central and Tschudi Scoria sites are fuel repositories is not at all clear. Professor Smith's suggestion is a strong alternative to our reconstruction, but it does not answer many of the problems presented by these two sites.

[9]Hollister, 1955.

[10]Caley and Easby, 1959, p. 64.

[11]The analyses of both these samples appear in Table II.

[12]Only one technique, metal-in-metal inlay, was introduced later by the Inca, as well as copper-tin bronze.

[13]Squier, 1877, p. 164.

[14]Parenthetically, it could be argued that the scoria boulders are the remains of a mixture of tillandsia charcoal and ore that formed the charge for the smelter. In view of the analyses of this material, however, which show no evidence of metal in other than faint trace amounts, this hypothesis seems hardly likely.

[15]Squier, 1877; Hollister, 1955.

[16]In 1948, Olga Lozano presented a thesis for a degree in industrial chemistry in the School of Chemical Engineering for the National University of Trujillo. It was entitled, "Aporte químico a la arqueología peruana" and consisted of a chemical study of some of the scoria from the structure described in our article. Her conclusion was that the scoria, which she found contained no metal, did not originate from a metallurgical operation, but was fused ceramic. Hollister published two sets of her analyses in his article (samples 6 and 7) but mistakenly published the analyses of two Chan Chan potsherds she had included in her study. The results of her scoria analyses are given correctly in our Table III (pls. XLI-XLII).

[17]Lupu, 1970. Of 20 analyses reported, only one contained Cu in as low a concentration as 0.024%. The next highest concentration was 0.73%. Of the remaining 18 samples, 11 fell between 1 and 5% Cu, 4 between 5 and 10% Cu, 3 between 10 and 20% Cu.

[18]Tylecote, 1968.

[19]Taylor, 1952.

[20]Boman, 1908, t. II, p. 539.

[21]Lozano, 1948.

[22]Hollister, 1955, p. 34.

[23]Hofman, 1924, pp. 128-129.

[24]Hollister, 1955, p. 36.

[25]We do not understand why Hollister's figures for the copper content of the scoria are as high as they are. Note, however, that neither the copper nor the iron content is high enough to warrant the claim that the slag might have come from a metal smelting operation.

[26]Lupu, 1970, p. 23.

[27]In this case, the variation may have been due to the presence of small droplets of copper in one part of the batch and their absence in another.

[28]Lupu reports the melting range of the Timna slags as 1180-1350°C.

[29]A furnace utilizing four glo-bars arranged as a half cylinder with their axes parallel was placed against the fire brick wall containing the unburned adobe sample. The wall, built of K-30 firebrick, lay on a diameter of the cylinder, so that the bars were between 2.5 and 6 cm. from the surface of the adobe. The furnace temperature was raised

to 1320°C. before it was positioned against the wall and was continually held at that temperature for the duration of the experiment. After 5 minutes, the surface temperature of the adobe had reached 1096°C.; after 1 hour, 1263°C.; 2 hours, 1306°C.; 2 1/2 hours, 1322°C. The furnace was removed after a total of 7 hours when the back surface of the adobe had reached 800°C. Using a value of 1.83 g/cc as the bulk density of the adobe (experimentally determined using a piece of the unburned adobe which was fired for one hour at 1010°C.), the thermal diffusivity α of the clay was calculated as 0.00316 cm^2/sec. (The equation used to determine α was that which describes the transient heat flow in a semi-infinite solid. See Holman, 1967, pp. 79-81.) By contrast, the thermal diffusivity of some fireclays at 1000°C. is about 0.00302 cm^2/sec. (See Searle and Grimshaw, 1959, p. 856, Fig. XIV.3.) Kreith (1962, p. 534) reports a value of 0.005 cm^2/sec. as the diffusivity of fireclay brick at 392°F. The unexpectedly low value of diffusivity of the adobe may result from the high porosity in the gassy surface layer at these elevated temperatures. A careful measurement of α for the adobe at various temperatures and, therefore, at various porosities would probably give a somewhat higher value. These calculations are only approximations but are close enough to give a good feeling for the circumstances that probably prevailed. With a surface temperature of approximately 1320°C. and a thermal diffusivity of 0.00316 cm^2/sec., the interface between zone 3 and zone 4 of the adobe illustrated in figure 11 would have reached 1050°C. in 15.8 hours (see Table I, p. 155). Under the same conditions, the interface between zone 2 and zone 3, at the position of the crack, would have reached 1220°C. after 40 hours.

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KEY TO ILLUSTRATIONS

Plates XLI and XLII

Table III. The following samples were analyzed by MIT: 315, 317, 318, 411, 412, 413, 414, 415, 416, 417, 418, 419, 422, 423, 424, 425, 426, 427. All MIT analyses were conducted by the Central Analytical Laboratory of the Department of Metallurgy and Materials Science. Each sample was ground to a fine powder; average sample size was 2.7 g. The copper determination was obtained colorimetrically using diethyldithiocarbamate. The figures reported for the copper concentration are accurate to ± 0.0005.

The following sample was analyzed by Olga Lozano at the Universidad de Trujillo: Velarde scoria (?). The analyses were performed on dried samples that contained 1.5% water.

The following samples were analyzed by the Northern Peru Mining Co., Assay Office, Quiruvilca: Tschudi scoria nos. 1, 2, 3. In addition to the elements and oxides listed in this table, Au, Pb, and Zn were searched for but not detected in any of the three samples. Iron was reported as Fe, and silver was reported in oz/ton.

Plate XLIX

Fig. 6. Tschudi Scoria. Scanning electron micrograph of soil particles 2.5 cm. beneath the floor surface. (Sample 7) 24,000 X.

Fig. 7. Tschudi Scoria. Scanning electron micrograph of soil particles 15 cm. beneath the floor. (Sample 8) 24,000 X.

Plate L

Fig. 8. Tschudi Scoria. Scanning electron micrograph of soil particles 6 cm. beneath the floor. (Sample 15) 24,000 X.

Fig. 9. Tschudi Scoria. Scanning electron micrograph of soil

particles 27.5 cm. beneath the floor surface; heated in an oxidizing atmosphere for one hour at 600°C. No rounding of edges has occurred. 14,000 X.

Fig. 10. Tschudi Scoria. Soil particles from the same location as those in figure 9; heated for one hour at 1020°C. Slight surface flow has rounded the edges, and the particles have begun to stick together. 1,500 X.

Plate LI

Fig. 11. Tschudi Scoria. Polished cross section of a portion of a fired and surface-scoriated adobe from the south wall. Sample is mounted in wax. The temperatures T_s - T_4 at which major heat-induced changes occurred are given in Table I. Scale in centimeters.

Plate LIII

Fig. 16. Tschudi Scoria. Large block of scoria shown split in two. The interior is filled with carbonized tillandsia stalks and leaves.

Fig. 17. Tschudi Scoria. Detail of a charcoal tillandsia stalk from the interior of the block shown in figure 16.

Fig. 18. A specimen of *Tillandsia latifolia* collected from the Moche Valley in 1972.

Fig. 19. Tschudi Scoria. Detail of a scoria-and-charcoal fragment removed from a depth of 16 cm. within the block shown in figure 16. Its smooth, glassy appearance indicates molten flow and subsequent solidification at an open surface.

Plate LIV

Fig. 20. Tschudi Scoria. Comparison of the cross section shown in figure 11 with a similar section of an unburned adobe from the south wall, heat treated in the laboratory. Samples are mounted in wax. All four zones occur in both specimens; differences in zone thickness result from differences in duration of heating, except for the surface zone which is free to expand from gas evolution.

TABLE II COMPARISON OF ANALYSES OF COPPER SMELTING SLAGS

A. CHALCOLITHIC
Timna, Israel (after Lupu)[17]

Chemical Composition
%, by weight

Slag No.	Cu	SiO_2	Al_2O_3	FeO	MnO	CaO	MgO	K_2O	Na_2O
51	2.48	39.22	11.11	37.31	0.32	6.39	–	N.D.	N.D.
51 B	0.024	28.10	21.00	20.99	0.10	23.66	1.77	N.D.	N.D.
52	5.04	48.42	1.43	22.84	0.27	13.6	2.56	N.D.	N.D.
58 a	15.12	34.25	–	21.69	–	22.13	1.62	N.D.	N.D.
58 b	16.60	45.92	17.13	14.20	–	8.80	2.22	N.D.	N.D.
58 c	0.73	30.11	–	30.35	29.33	12.17	0.98	N.D.	N.D.
64	8.36	16.26	0.37	43.12	0.16	20.80	0.23	N.D.	N.D.
72 a	2.64	36.77	0.98	34.91	0.80	12.10	1.42	4.04	1.36

B. EARLY IRON AGE
Timna, Israel (after Tylecote)[18]

%, by weight

CuO	SiO_2	Al_2O_3	FeO	Fe_2O_3	MnO	CaO	MgO	K_2O	Na_2O	P_2O_5	BaO(SrO)	H_2O	CO_2
0.98	41.75	2.69	24.94	13.7	1.59	10.18	1.57	0.77	0.49	0.82	0.29	0.16	0.05

C. LATE BRONZE AGE; ROMAN; MODERN
Apliki, Cyprus (after Taylor)[19]

%, by weight

	Cu	SiO_2	Al_2O_3	FeO	Fe_2O_3	Mn	CaO	MgO	S
L.B.A.	0.91	21.30	7.80	30.47	34.77	T	1.14	T	1.14
ROMAN	0.7	28.8	3.95	8.0	35.07	8.6	4.24	3.53	1.28
MODERN (1939)	0.3-0.4	–	+CaO +MgO 10-16	36-44 (FeO + Fe_2O_3)		–	+MgO +Al_2O_3 10-16	+Al_2O_3 +CaO 10-16	1.2

D. PRE-COLUMBIAN
Slag from a huaira
Diaguita region, Cobres, Argentina (after Boman)[20]

%, by weight

CuO	SiO_2	Al_2O_3	FeO	Fe_2O_3	CaO	MgO	PbO
8.15	40.82	0.33	49.00		1.50	0.13	T

E. MODERN

(1) Reverbatory slag
La Oroya, Peru - 1948 (after Lozano)[21]

Cu	SiO_2	Al_2O_3	FeO	CaO	MgO	Pb	ZnO
1	35	4	45	6	–	1	3

(2) Garfield smelter, Utah - 1955 (after Hollister)[22]

Cu	SiO_2	Al_2O_3	FeO	Fe_3O_4	CaO	MgO	Pb	ZnO
0.4	38.5	6.0	44.0		10.0	–	–	–

(3) Blast furnace slag - 1924 (after Hofman and Hayward)[23]

	Cu	SiO_2	Al_2O_3	FeO	CaO	MgO	S
Granby smelter, British Columbia	0.24	37.7	7.2	42.9	7.4	2.5	1.7
Tennessee Copper Co., Tenn.	0.31	34.2	4.0	40.0	6.9	–	2.00
Braden Copper Co., Caletones, Chile	0.51	36.3	14.6	41.5	1.7	–	0.7
Calumet and Arizona, Ariz.	0.44	34.6	8.9	38.7	9.3	–	1.3
Mt. Lyell Mining & R'way. Co., Queenstown, Tasmania	0.35	33.0	8.10	46.5	6.75	–	0.45

LEGEND

–	Not reported
N.D.	Not detected
T	Trace

Plate XL. Table II.

SAMPLE	SITE OF SAMPLE	COLLECTED BY	WET CHEMICAL												
			SiO_2	Al_2O_3	Fe_2O_3	MnO	CaO	MgO	K_2O	Na_2O	P_2O_5	S	TiO_2	Cu	Ag
315	Velarde scoria	MEM:1969	66.2	17.9	6.28	–	2.16	1.56	2.73	1.65	0.41	0.006	0.98	<0.004	–
317	Tschudi scoria	Kenneth Rose: 1967	58.7	16.1	3.1	–	6.2	3.65	3.0	5.3	–	–	0.79	<0.004	–
318	Tschudi scoria	Junius Bird: 1966	62.3	15.0	6.10	–	4.35	2.92	2.37	5.1	0.80	0.039	0.88	<0.004	–
411	Central scoria	HL, MEM: 1970	58.6	14.9	6.3	–	5.0	2.6	2.2	10.2	–	–	–	0.003	–
412	Central scoria	"	58.4	14.9	6.1	–	4.3	3.0	2.2	10.0	–	–	–	–	–
413	Central scoria	"	58.8	15.5	6.4	–	4.3	3.0	2.2	10.8	–	–	–	–	–
414	Tschudi: scoriated adobe, S. wall	"	62.0	13.4	6.1	–	4.5	2.6	2.3	7.7	–	–	–	–	–
415	Tschudi: scoriated S. wall surface	"	61.4	14.7	6.6	–	4.5	2.6	2.2	7.7	–	–	–	0.002	–
416	Tschudi: scoriated sherd	"	62.0	14.9	6.4	–	4.5	3.0	2.9	7.5	–	–	–	0.004	–
417	Tschudi: scoriated sherd	"	62.0	15.1	6.1	–	4.8	3.2	2.3	7.8	–	–	–	0.003	–
418	Tschudi: scoriated adobe, S. wall	"	64.0	15.1	6.1	–	4.9	3.0	2.4	7.5	–	–	–	–	–
419	Tschudi: scoriated adobe, S. wall	"	63.5	15.1	6.0	–	5.6	3.0	2.4	7.4	–	–	–	–	–
422	Tschudi: sheet of scoria on floor	"	62.5	15.3	6.0	0.36	4.7	2.8	–	4.7	0.66	–	0.72	0.005	–
423	Tschudi: scoria block, W. end	"	63.5	14.7	5.7	0.35	4.1	2.5	–	5.1	1.04	–	0.67	0.003	–
424	Tschudi: scoria block, E. end	"	61.7	14.7	6.0	0.41	4.5	2.7	–	5.3	0.54	–	0.69	–	–
425	Tschudi: scoria block, E. end	"	61.9	15.1	6.1	0.25	4.1	2.3	–	5.8	0.84	–	0.55	0.004	–
426	Tschudi: scoria block, E. end	"	62.7	14.9	7.1	0.33	3.2	1.8	–	6.0	1.25	–	0.73	–	–
427	Tschudi: unbaked adobe, S. wall	"	65.2	15.1	6.3	0.30	1.5	1.1	–	2.7	1.90	–	0.30	0.004	–
–	Velarde scoria ?	? 1948	63.4	13.0	8.5	–	1.6	1.5		6.0	–	–	–	N.D.	–
1	Tschudi scoria	V.F. Hollister: 1955	59.44	16.98	7.9	–	4.3	–	–	–	–	0.16	–	0.05	0.0001
2	Tschudi scoria	"	57.40	17.90	6.2	–	4.6	–	–	–	–	0.22	–	0.12	0.0001
3	Central scoria	"	59.42	17.20	8.0	–	4.7	–	–	–	–	0.84	–	0.05	0.0004

Plate XLI. Table III, left half. Analysis of Chan Chan scoria; percent, by weight. See Key to Illustrations.

SPECTROGRAPHIC (QUALITATIVE)

Cu	Ag	B	Ba	Be	Co	Cr	Ga	In	Mn	Ni	P	Pb	Sn	Sr	Ti	V	Zn	Zr
VFT-FT	N.D.	N.D.	FT-T	VVFT	VFT	FT	VFT	VFT	FT-T	FT	N.D.	VFT	N.D.	FT	L	FT-T	N.D.	N.D.
VFT-FT	N.D.	FT	FT	N.D.	N.D.	N.D.	VFT-FT	VFT	T	N.D.	T	N.D.	FT-T	FT	T	FT	N.D.	FT
VFT-FT	N.D.	FT	FT	N.D.	N.D.	VFT	VFT	VFT	FT-T	N.D.	T	N.D.	N.D.	FT	T	FT	N.D.	FT-T
VFT-FT	VVFT	FT	FT	VVFT	N.D.	FT	VFT	N.D.	T	N.D.	T	N.D.	N.D.	FT	T-L	FT-T	N.D.	N.D.
VFT-FT	VVFT	FT	FT	VVFT	N.D.	FT	VFT	N.D.	T	N.D.	T	N.D.	N.D.	FT	T-L	FT-T	N.D.	N.D.
VFT-FT	VVFT	FT	FT	VVFT	N.D.	FT	VFT	N.D.	T	N.D.	T	N.D.	N.D.	FT	T-L	FT-T	N.D.	N.D.
VFT-FT	VVFT	FT	FT	VVFT	N.D.	FT	VFT	N.D.	T	N.D.	T	N.D.	N.D.	FT	T-L	FT-T	N.D.	N.D.
VFT-FT	VVFT	FT	FT	VVFT	N.D.	VFT	VFT	N.D.	T	N.D.	T	N.D.	N.D.	FT	T-L	FT	N.D.	N.D.
VFT-FT	VVFT	FT	FT	VVFT	N.D.	VFT	VFT	N.D.	T	N.D.	T	N.D.	N.D.	FT	T-L	FT	N.D.	N.D.
VFT-FT	VVFT	FT	FT	VVFT	N.D.	VFT	VFT	N.D.	T	N.D.	T	N.D.	N.D.	FT	T-L	FT	N.D.	N.D.
VFT-FT	VVFT	FT	FT	VVFT	N.D.	VFT	VFT	N.D.	T	N.D.	T	N.D.	N.D.	FT	T-L	FT	N.D.	N.D.
VFT-FT	VVFT	FT	FT	VVFT	N.D.	VFT	VFT	N.D.	T	N.D.	T-L	N.D.	N.D.	FT	T-L	FT	N.D.	N.D.
FT-T	N.D.	VFT	FT	VVFT	N.D.	FT	N.D.	N.D.	L	N.D.	L	N.D.	N.D.	N.D.	L-M	FT	N.D.	T
FT-T	N.D.	VFT	FT	VVFT	N.D.	FT	N.D.	N.D.	L	N.D.	L	N.D.	N.D.	N.D.	L-M	FT	N.D.	T
FT-T	N.D.	VFT	FT	VVFT	N.D.	FT	N.D.	N.D.	L	N.D.	L	N.D.	N.D.	N.D.	L-M	FT	FT	T
T	N.D.	VFT	FT	VVFT	N.D.	FT	N.D.	N.D.	L	N.D.	L	N.D.	N.D.	N.D.	L	FT	N.D.	T
FT-T	N.D.	VFT	FT	VVFT	N.D.	FT	N.D.	N.D.	L	N.D.	L	N.D.	N.D.	N.D.	L	FT	N.D.	T
FT-T	N.D.	VFT	FT	VVFT	N.D.	FT	N.D.	N.D.	T	N.D.	L	N.D.	N.D.	N.D.	L	FT	N.D.	T

LEGEND

VVFT	< 0.0001	%	—	Not reported
VFT	0.0001 - 0.001			
FT	0.001 - 0.01		N.D.	Not detected
T	0.01 - 0.1			
L	0.1 - 1.0			
M	1.0 - 10.0			

Plate XLII. Table III, right half. Analyses of Chan Chan scoria; percent, by weight. See Key to Illustrations.

TABLE IV

Melting points of Chan Chan scoria

Sample No.	Slumping Temp. °C.	Free flow Temp. °C.
411	1113	1184
412	1102	1187
413	1093	1188
414	1139	1201
415	1118	1249
416 (scoriated portion of sherd)	1140	1274
416a (unscoriated portion of sherd)	1292	1348
417	1059	1293
418 (scoriated portion of brick)	1156	1307
418a (unscoriated portion of brick)	1290	1368
419	1244	1343
422	1172	1312
423	1155	1218
424	1165	1289
425	1167	1291
426	1137	1246
427 (unburned brick)	1237	1376

Plate XLIII. Table IV.

Table V

Ashing Properties of Tillandsia Latifolia

Summary of Experimental Results

	LEAVES*		PLANT**		CHARCOAL***	
	Sample A	Sample B	Uncompressed	Compressed to Half Thickness Under Pressure of 70g/cm^2	Sample A	Sample B
Weight of original sample [g]	4.52	2.75	10.92	10.92	7.3	5.23
% by weight of ash	8.8	2.9	50.7	50.7	58.6	53.7
Specific volume of original sample [cc/g]	5.75	4.56	11.7	5.17	2.04	1.75
Specific volume of ash [cc/g]	6.75	14.9	1.01	1.01	1.75	1.96
Specific volume of ash, compacted [cc/g]	4.5	5.0	0.83	0.83	1.17	1.35
Ratio of volume of original sample to volume of its compacted ash	14.4	31.2	27.8	12.1	2.98	2.42

* Individual leaves; no interstitial space

** Whole plant, including leaves, stem and bud; volumes are bulk volumes

*** Tillandsia charcoal wads excavated at Tschudi Scoria; volumes are bulk volumes

Plate XLIV. Table V.

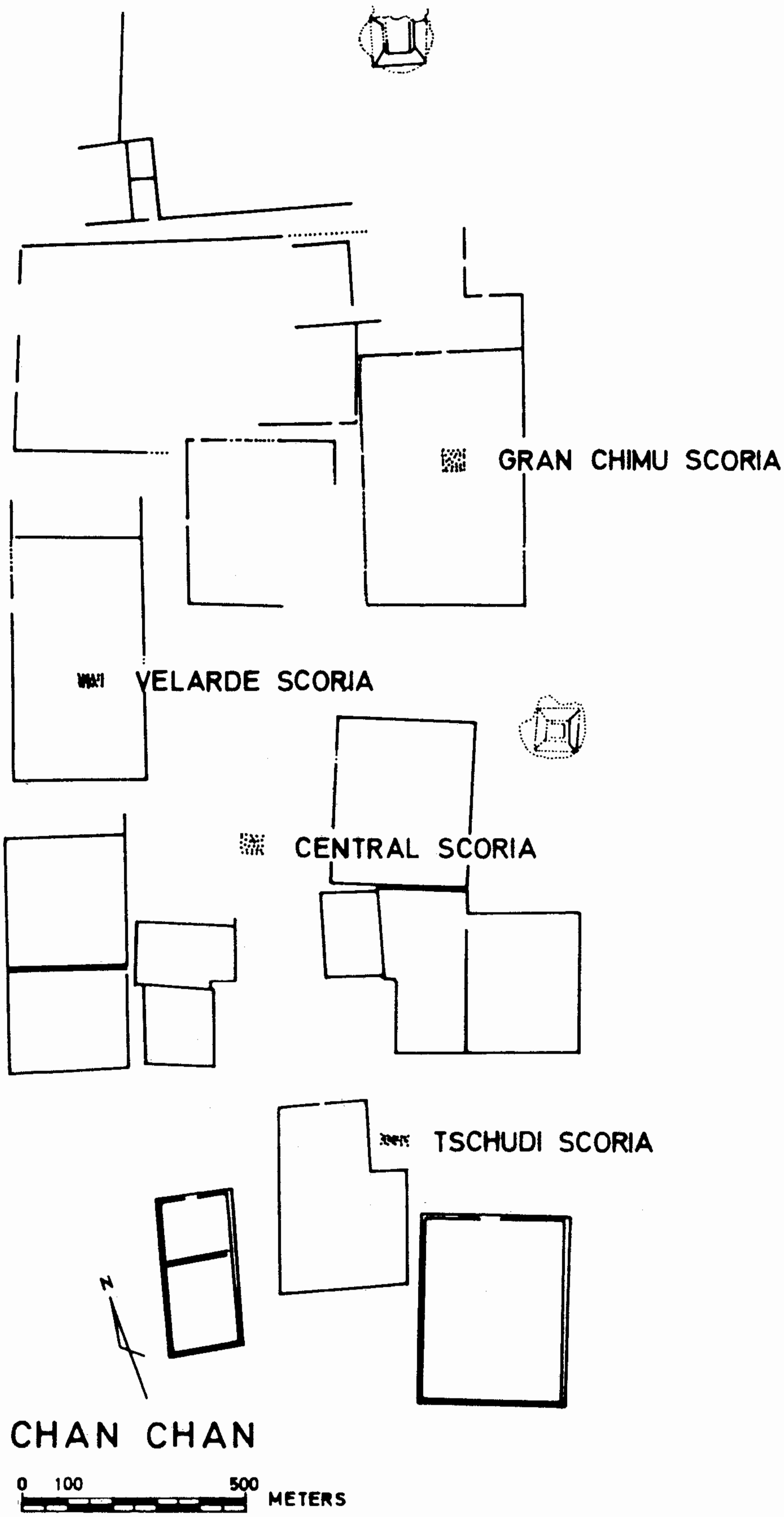


Plate XLV. Fig. 1, the four major scoria areas at Chan Chan.

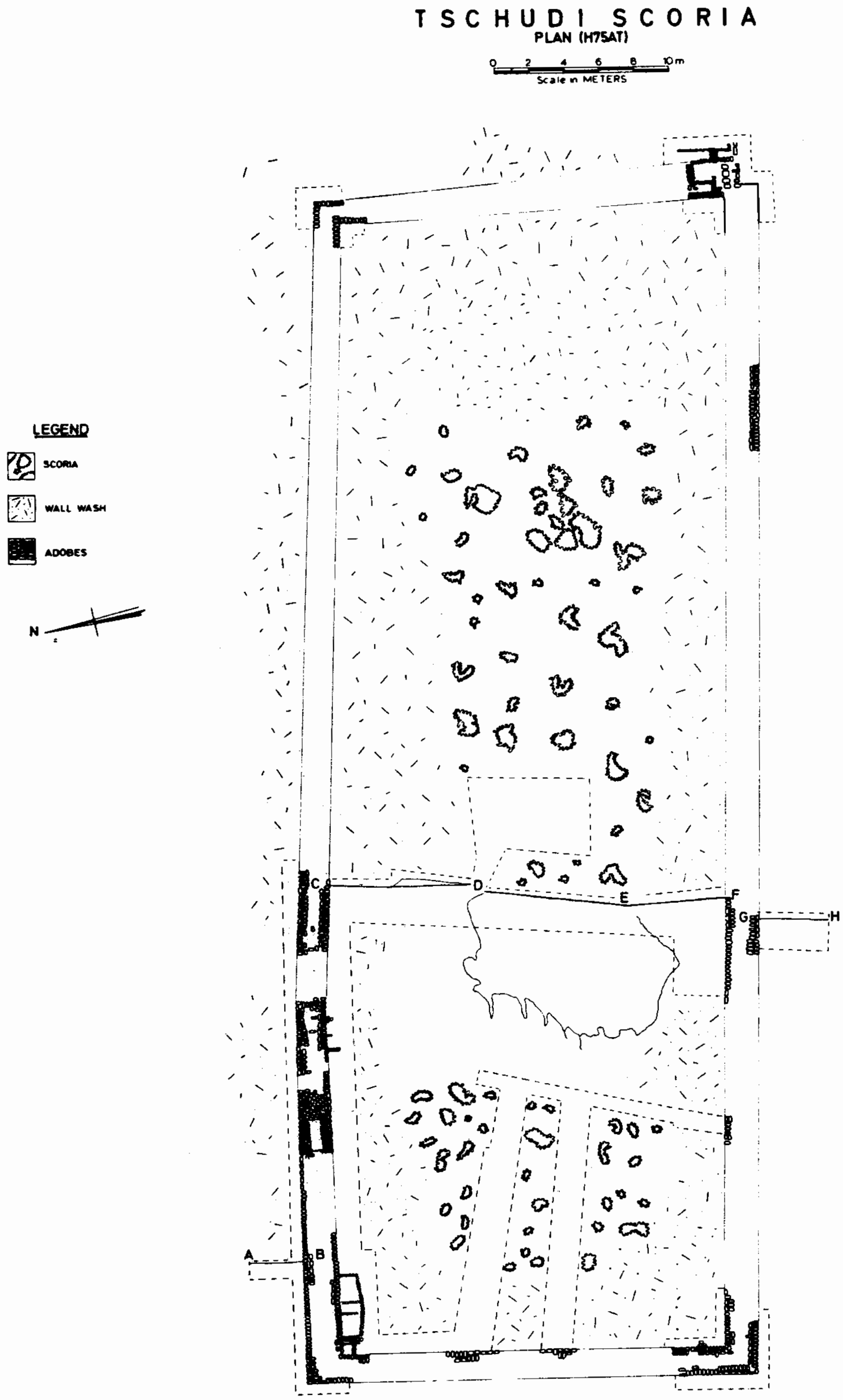
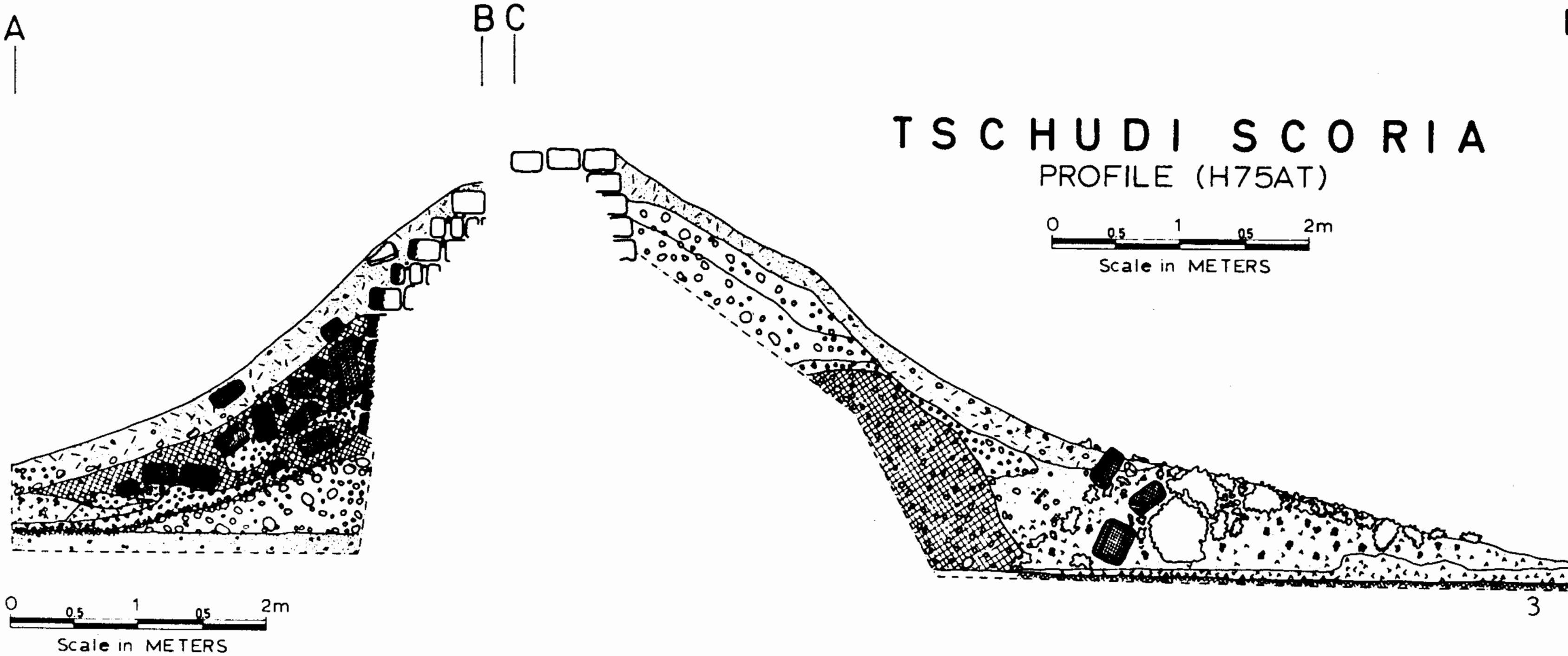
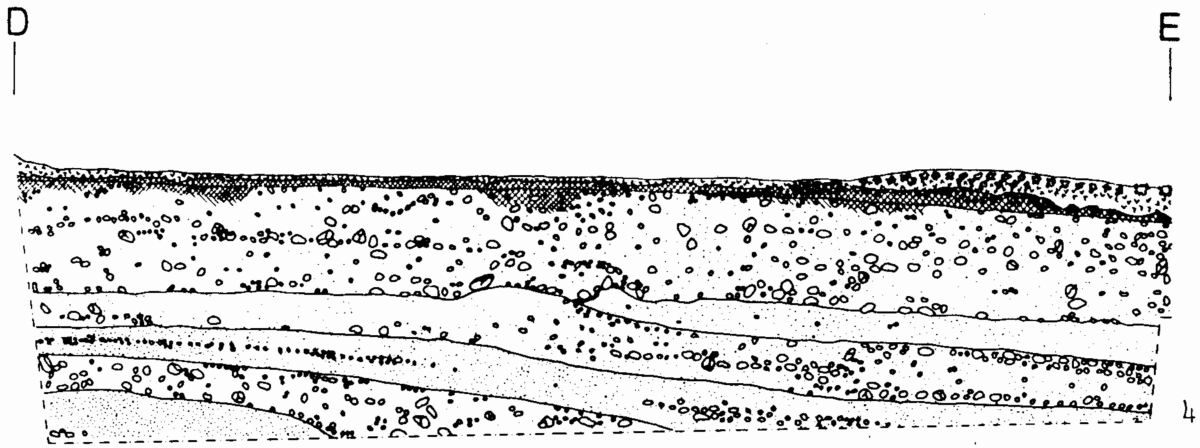


Plate XLVI. Fig. 2, plan of the Tschudi Scoria.

Plate XLVII. Figs. 2 and 3. For caption see Plate XLVIII.





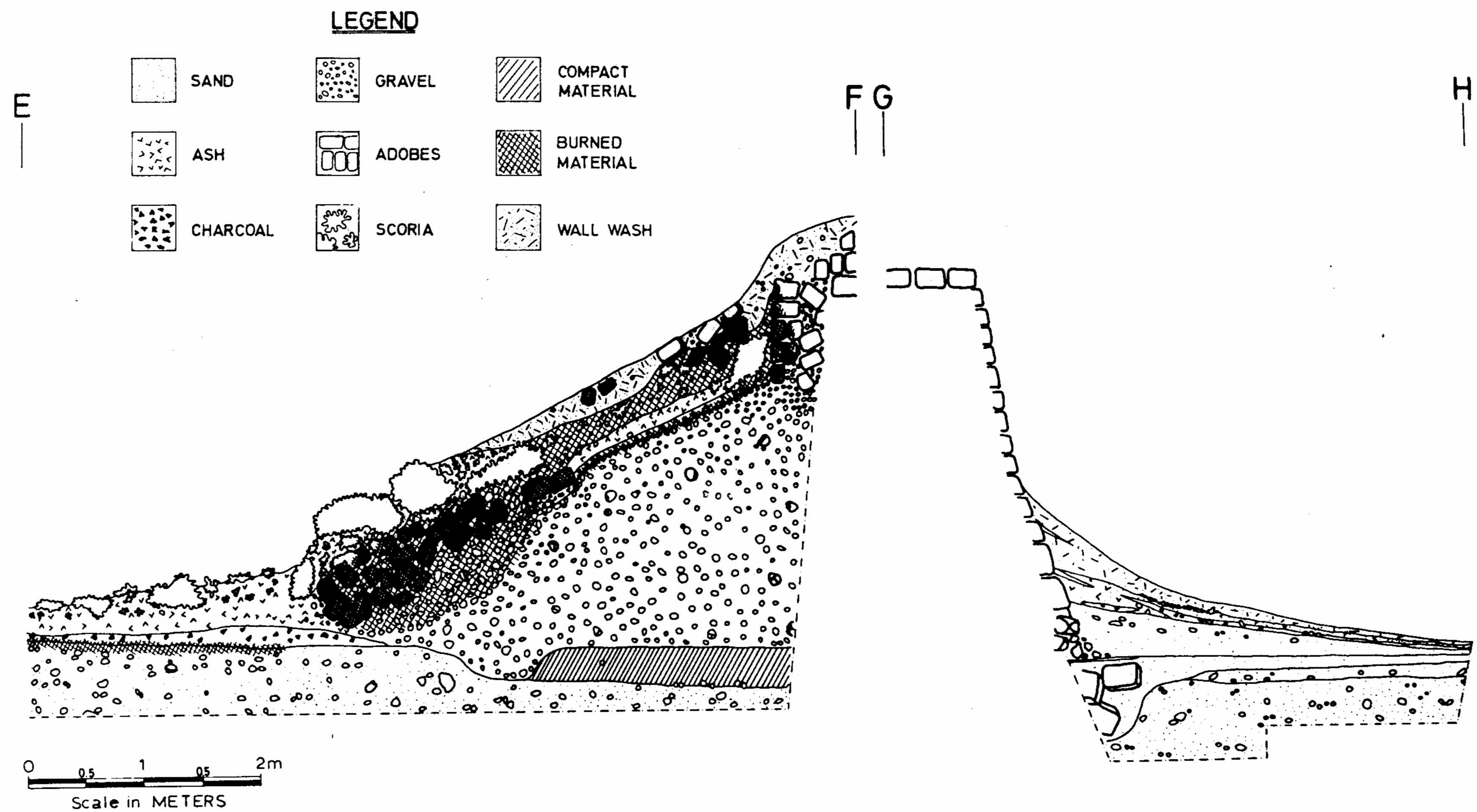
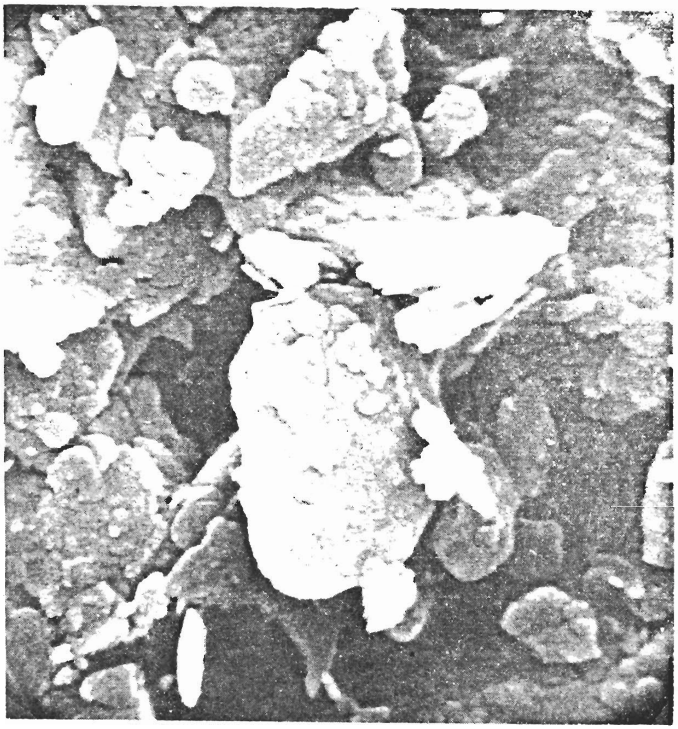


Plate XLVIII. North-south profile through the Tschudi Scoria (see location on plan, fig. 2): North section (fig. 3); Central section (fig. 4); South section (fig. 5).



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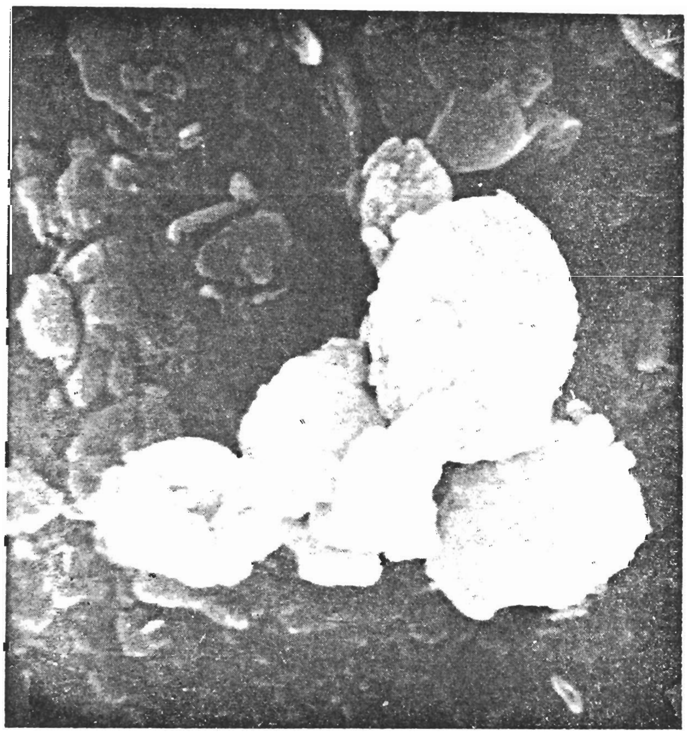

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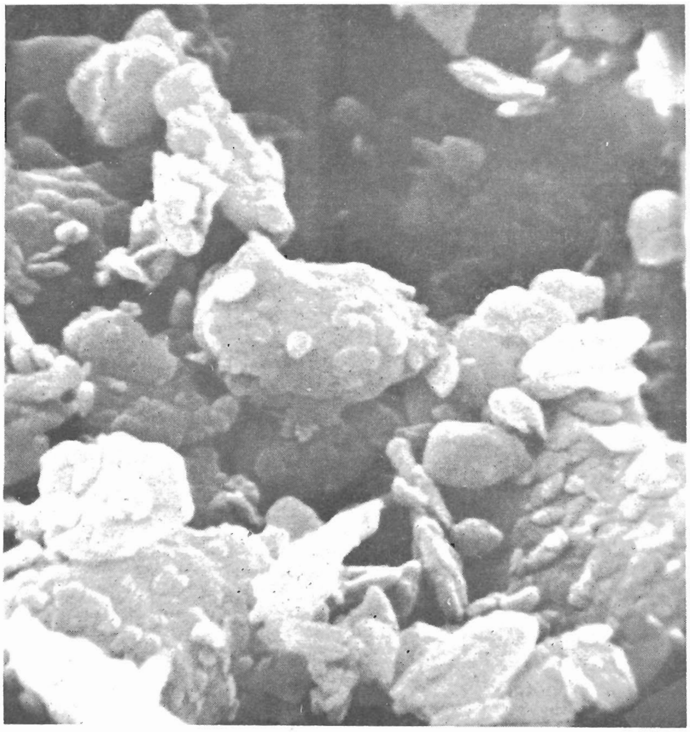
Plate XLIX. Scanning electron micrographs of soil particles from beneath the floor of the Tschudi Scoria. See Key to Illustrations.



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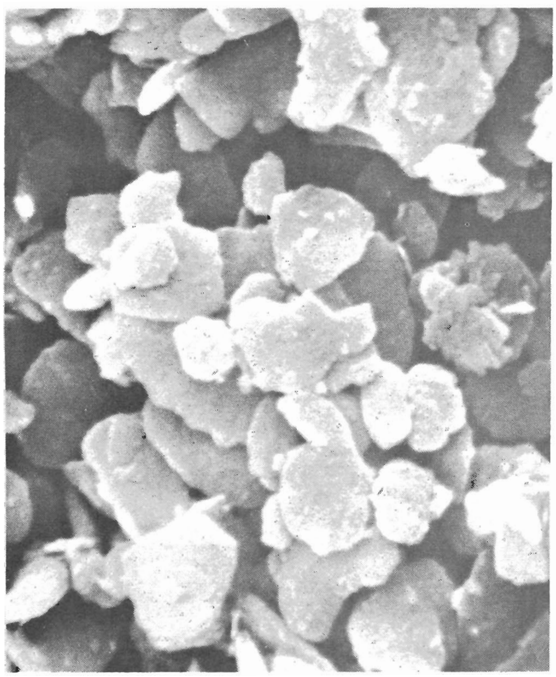

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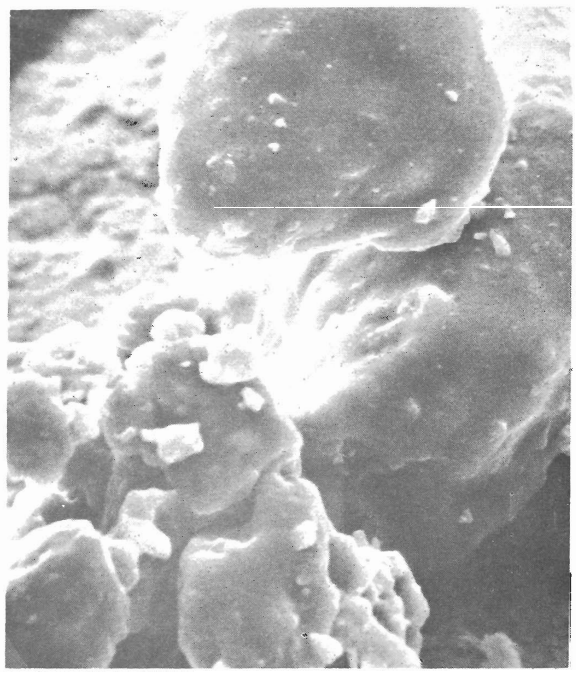


Plate L. Soil particles from beneath the floor of the Tschudi Scoria. See Key to Illustrations.

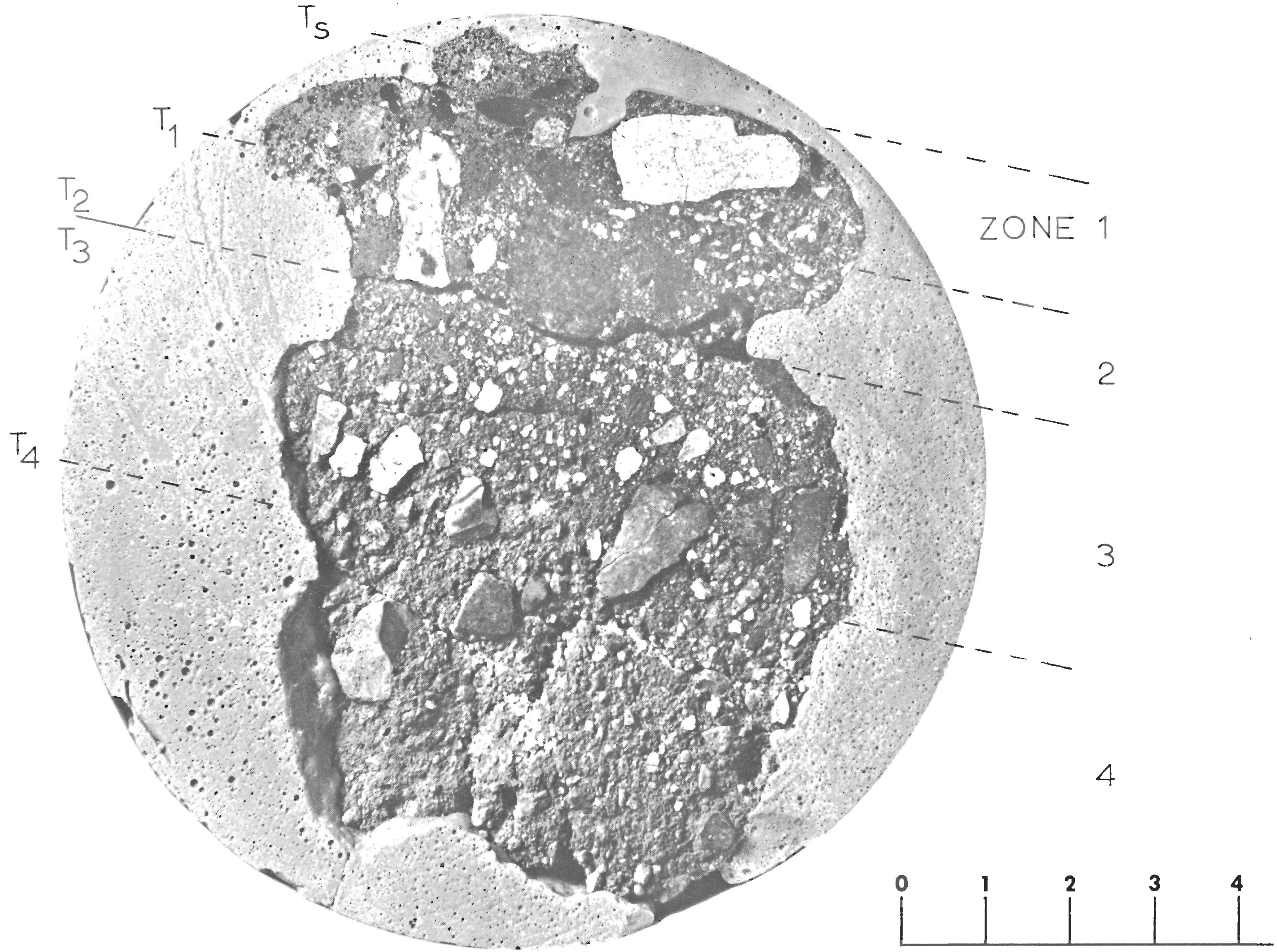
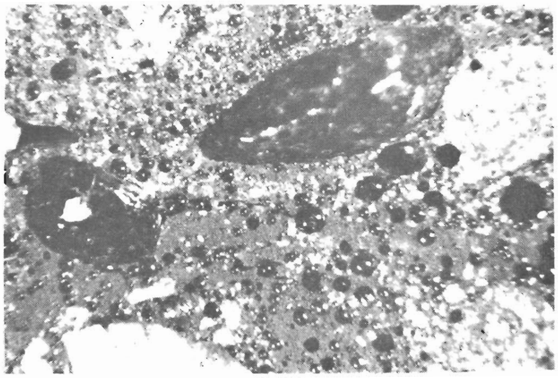


Plate LI. Fig. 11, Tschudi Scoria. Polished cross section of a portion of a fired and surface-scoriated adobe from the south wall. See Key to Illustrations.



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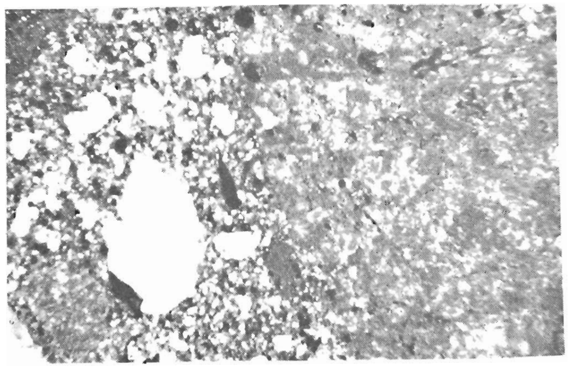

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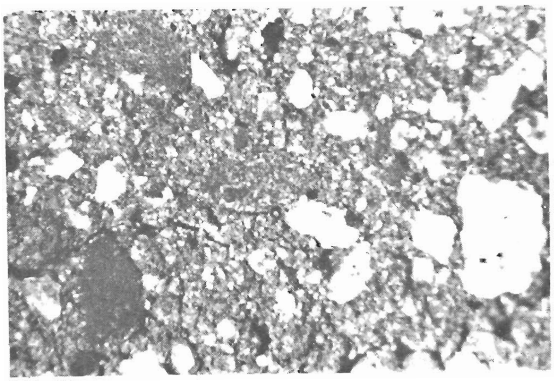

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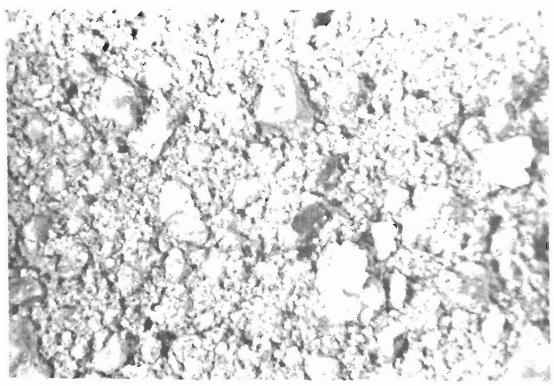

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Plate LII. Tschudi Scoria. Details of the microstructure of the adobe in each of the four zones demarcated in fig. 11: Zone 1 (fig. 12); Zone 2 (fig. 13); Zone 3 (fig. 14): Zone 4 (fig. 15).


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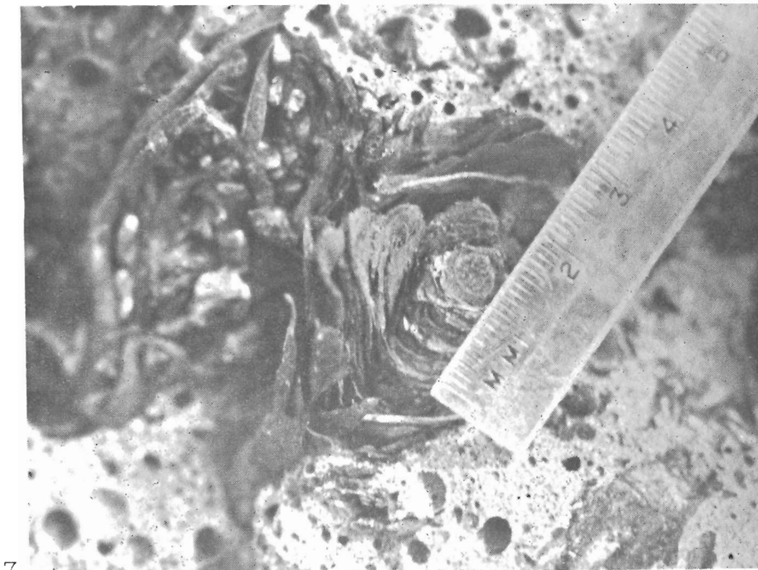
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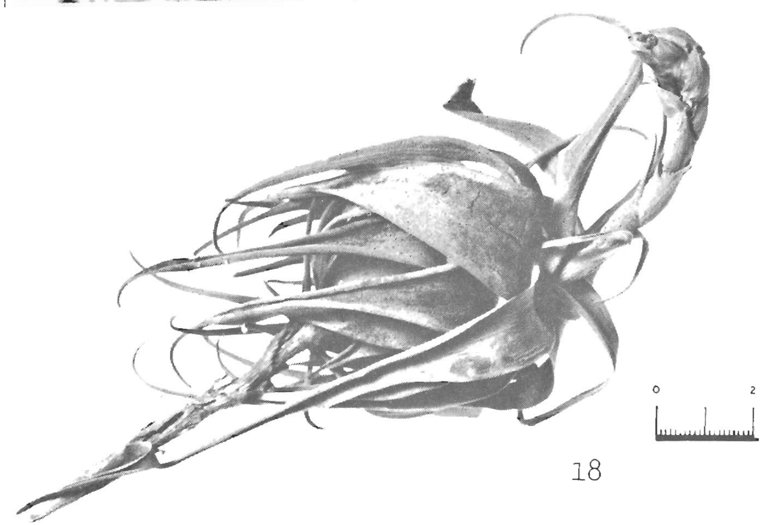
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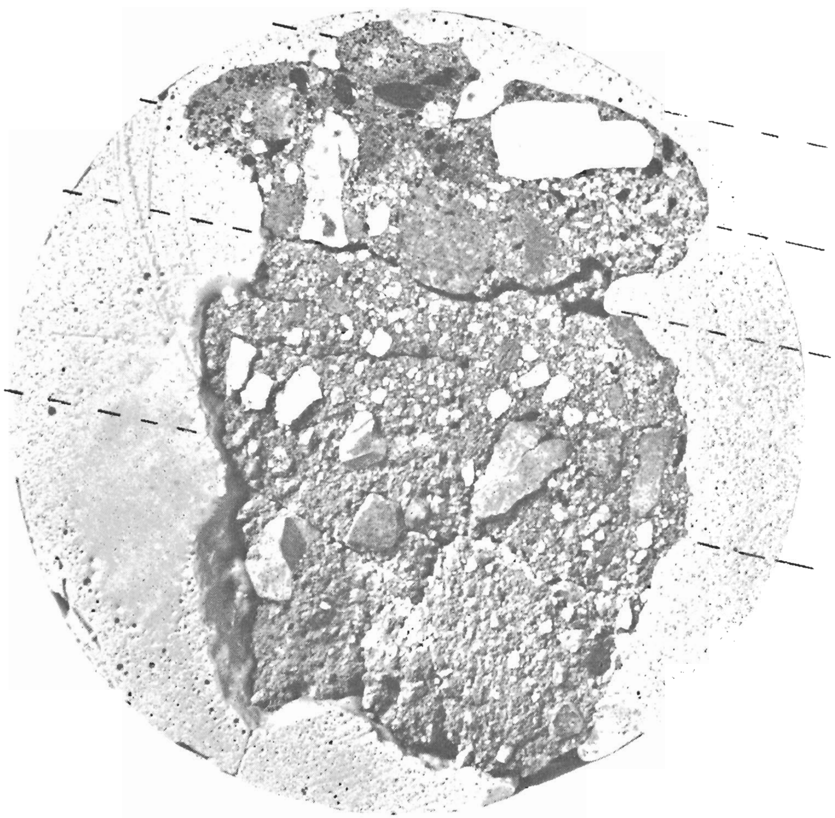
Plate LIII. Scoria block filled with carbonized tillandsia remains (fig. 16); detail of tillandsia stalk from block in fig. 16 (fig. 17); modern tillandsia from Moche Valley (fig. 18); detail of scoria and charcoal fragment taken from block in fig. 16 (fig. 19). See Key to Illustrations.



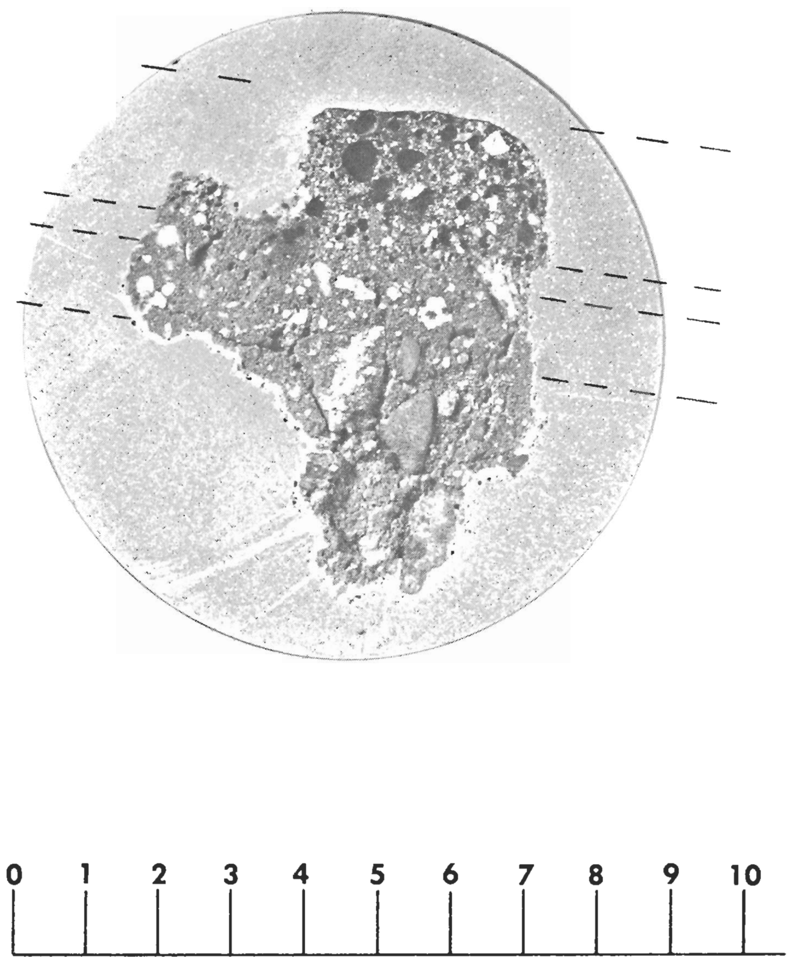


Plate LIV. Comparison of cross section in fig. 11 with similar section of unburned adobe from south wall of Tschudi Scoria, heat treated in laboratory. See Key to Illustrations.