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Geology, Drilling, and Some Hydrologic Aspects of Seismic Hazards Program Core Holes, Los Alamos National Laboratory, New Mexico

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GEOLOGY, DRILLING, AND SOME HYDROLOGIC ASPECTS OF SEISMIC HAZARDS PROGRAM CORE HOLES, LOS ALAMOS NATIONAL LABORATORY, NEW MEXICO

by

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ABSTRACT

As part of the Los Alamos National Laboratory's Seismic Hazards Investigations Program, we have cored four holes, as follows: SHB-1 at TA-55 to 700 feet; SHB-2 at TA-3 to 200 feet; SHB-3 at TA-16 to 860 feet; and, SHB-4 at TA-18 to 200 feet. In that the near-surface seismic velocity structure of the holes is the subject of other reports, we describe here the lithologies, general aspects of drilling, and some hydrologic implications of the core holes.

All four holes penetrated variably welded Tshirege Member of the Bandelier Tuff. The two deeper holes encountered thick sequences of epiclastic sands and gravels, with minor interbeds of Cerro Toledo Rhyolite, on top of the dominantly nonwelded Otowi Member of the Bandelier Tuff. Beneath the Otowi was basalt at TA-55 and Puye Formation sands and gravels at TA-16. Two of the core holes (SHB-3 at TA-16 and SHB-4 at TA-18) appear to have encountered groundwater.

The holes were all continuously cored with conventional wireline diamond coring techniques. Maintaining high percentage core recovery in nonwelded tuff and loose formations with air as the circulating fluid proved impossible. Light muds, however, improved recovery in these zones considerably. A variety of bits were tested, but none yielded consistent results in the alternating hard and soft rock conditions found beneath the Laboratory.

I. INTRODUCTION

As part of the Laboratory's Seismic Hazards Program, four holes have been cored for the primary purpose of determining near-surface seismic velocity structure at key Laboratory facilities. While the velocity structure studies are the subject of other reports (Redpath, 1992; Wong, in preparation), we present in this report some notable characteristics of the drilling, geology, and some hydrologic aspects of the holes. After completion of the velocity structure studies, the core holes and cores will be available for sampling, experiments, and study by other interested persons.

The general locations of the core holes are shown in Figure 1. Figures 2 through 5 show the location of each hole on more detailed technical area maps modified from the Facilities Engineering Division's report "Structure Location Maps." Figures 6 through 9 are generalized graphic logs of the core holes.

II. STRATIGRAPHY AND NOMENCLATURE

Throughout this report, the estimates of the degree of welding in the ignimbrites of the Bandelier Tuff are based on hand sample evaluation of the degree of flattening of pumices. Generally, nonwelded tuff contains equant, undeformed pumice; moderately welded tuff contains pumice that exhibits some degree of flattening; and densely welded tuff is a dense grey rock with pumice flattened to thin wispy fiamme. Although the welding process has imparted a first order control on the degree of lithification, and for that matter other physical properties, of the tuff, it is important to remember that just because the tuff is well-indurated it is not necessarily welded. Other processes, such as vapor phase alteration and/or crystallization, can cause induration of the tuff.

The general stratigraphic and lithologic relations that we rely on are discussed in detail by Gardner et al. (1986). Geologic maps of the Los Alamos area also provide extremely relevant relations (Griggs, 1964; Smith et al., 1970; Goff et al., 1990). We have also employed recently obtained radiometric dates. or age constraints, of units reported in Gardner et al. (1986), Goff et al. (1990), and Spell et al. (1990).

The core holes penetrate mostly the Bandelier Tuff, which is dominantly a complicated sequence of welded to nonwelded ignimbrites that were erupted from the Valles-Toledo caldera complex (see Smith and Bailey, 1966). The nomenclature we employ for the Bandelier Tuff was defined by Griggs (1964) with revisions of Bailey et al. (1969) and Smith et al. (1970). The Bandelier Tuff beneath the Pajarito Plateau consists of two members: the Tshirege (formerly "upper") Member (1.13 Ma) and the Otowi (formerly "lower") Member (1.5 Ma). At the base of each member there may be a pyroclastic fallout or Plinian deposit. Within the Pajarito Plateau, the basal fallout deposit of the Tshirege Member is called the Tsankawi, which consists of well sorted ash or pumice lapilli; the basal fallout deposit of the Otowi Member is called the Guaje, which consists mainly of well sorted pumice lapilli.

Griggs (1964) and Smith et al. (1970) recognized a sequence of pyroclastic deposits between the two members of the Bandelier Tuff. These pyroclastic deposits represent part of the Cerro Toledo Rhyolite, erupted from the caldera that was formed as a result of Otowi Member volcanism (see Heiken et al., 1986).

In two of the core holes (SHB-1 and SHB-3, see below), a sequence of alluvial sands and sandy gravels with interbeds of Cerro Toledo Rhyolite pyroclastic deposits was encountered between the Otowi and Tshirege members. Much literature dealing with geology of the Laboratory apparently calls these sedimentary deposits "Tsankawi." Clearly this is a misuse and potentially confusing application of the nomenclature because the Tsankawi is defined as the pyroclastic fallout deposit at the base of the Tshirege Member. Heiken et al. (1986) included epiclastic deposits at this horizon as part of the Cerro Toledo Rhyolite; however, their descriptions and our field reconnaissance in the areas where they worked indicate the epiclastic deposits that Heiken et al. (1986) included as part of Cerro Toledo Rhyolite are derived directly from volcanic deposits of that formation. At this time, we can see no stratigraphic assignment for the sands and gravels penetrated in SHB-1 and SHB-3 because there is no defined unit to which they temporally and lithologically belong. Although lithologically these sands and gravels are very similar to Puye Formation deposits, they are too young to be assigned to that formation as it is defined (see definitions and discussions of Bailey et al., 1969, and Gardner et al., 1986).

Three formations lie beneath the Bandelier Tuff of the Pajarito Plateau, as follows: the Puye Formation, Cerros del Rio basalts, and Tschicoma Formation (Dransfield and Gardner, 1985). One of the

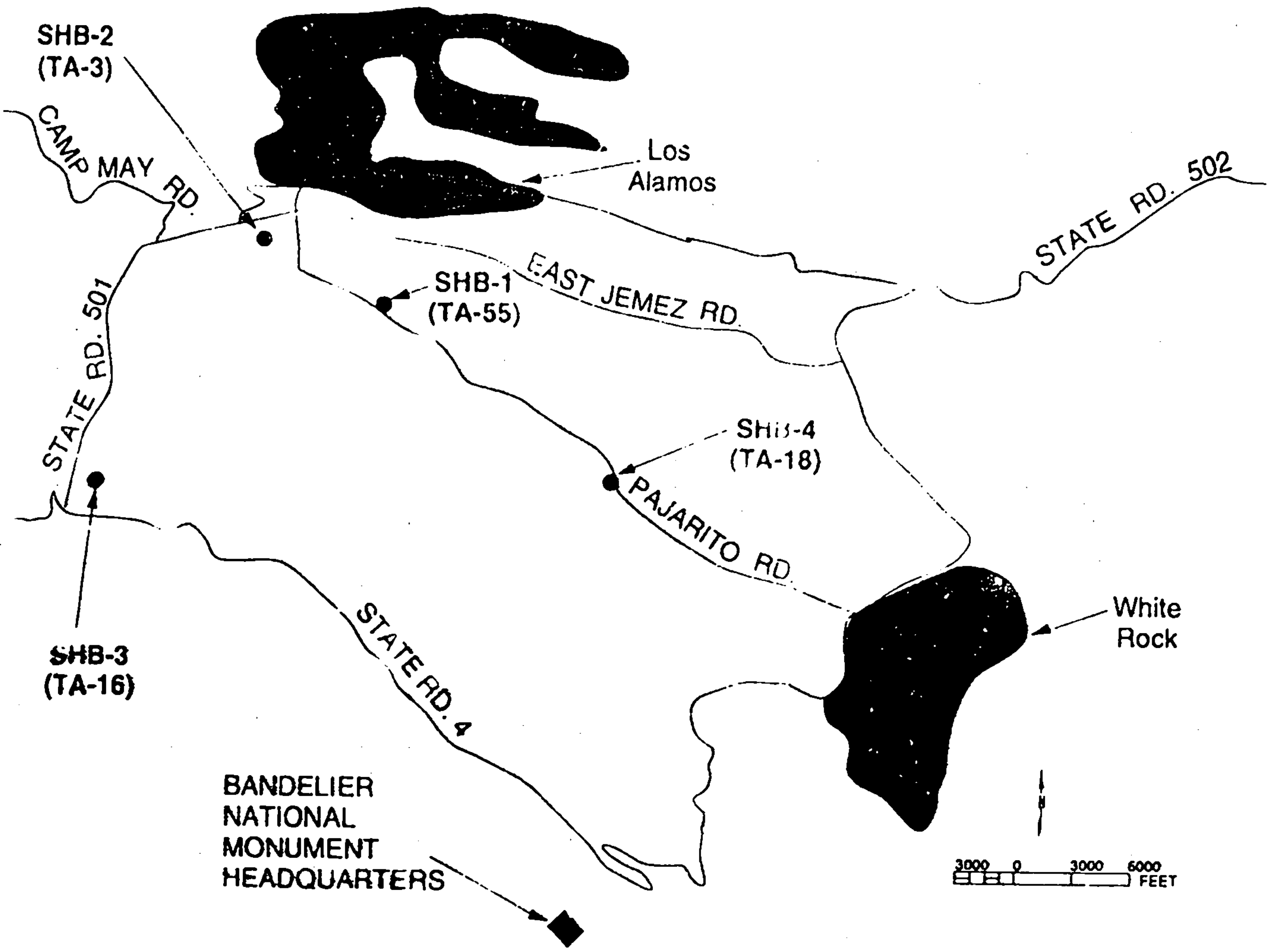


Figure 1: Map of Los Alamos National Laboratory area showing main roads, residential/commercial areas (shaded), and general locations of the Seismic Hazards Program core holes.

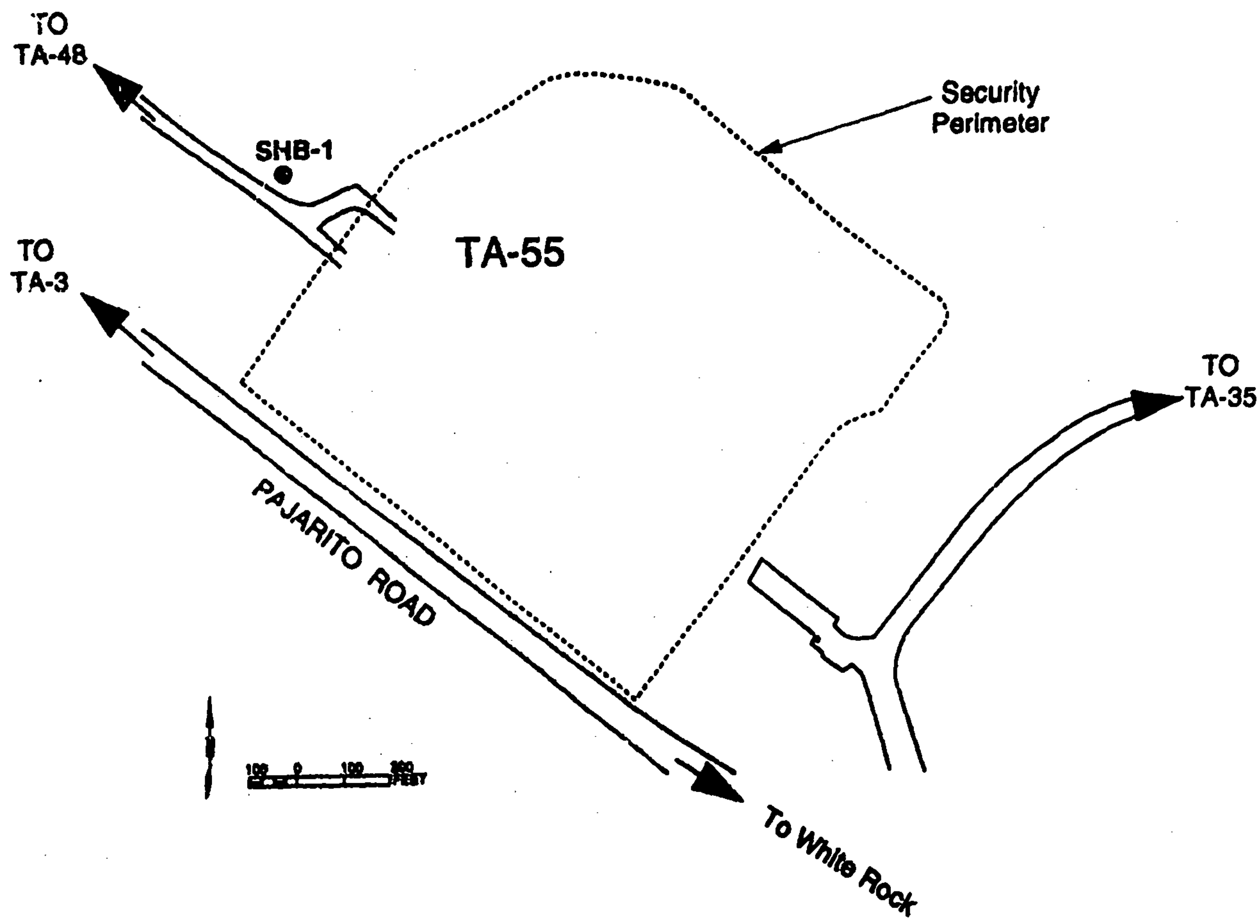


Figure 2: Map of the TA-55 area showing main roads, security perimeter, and location of core hole SHB-1.

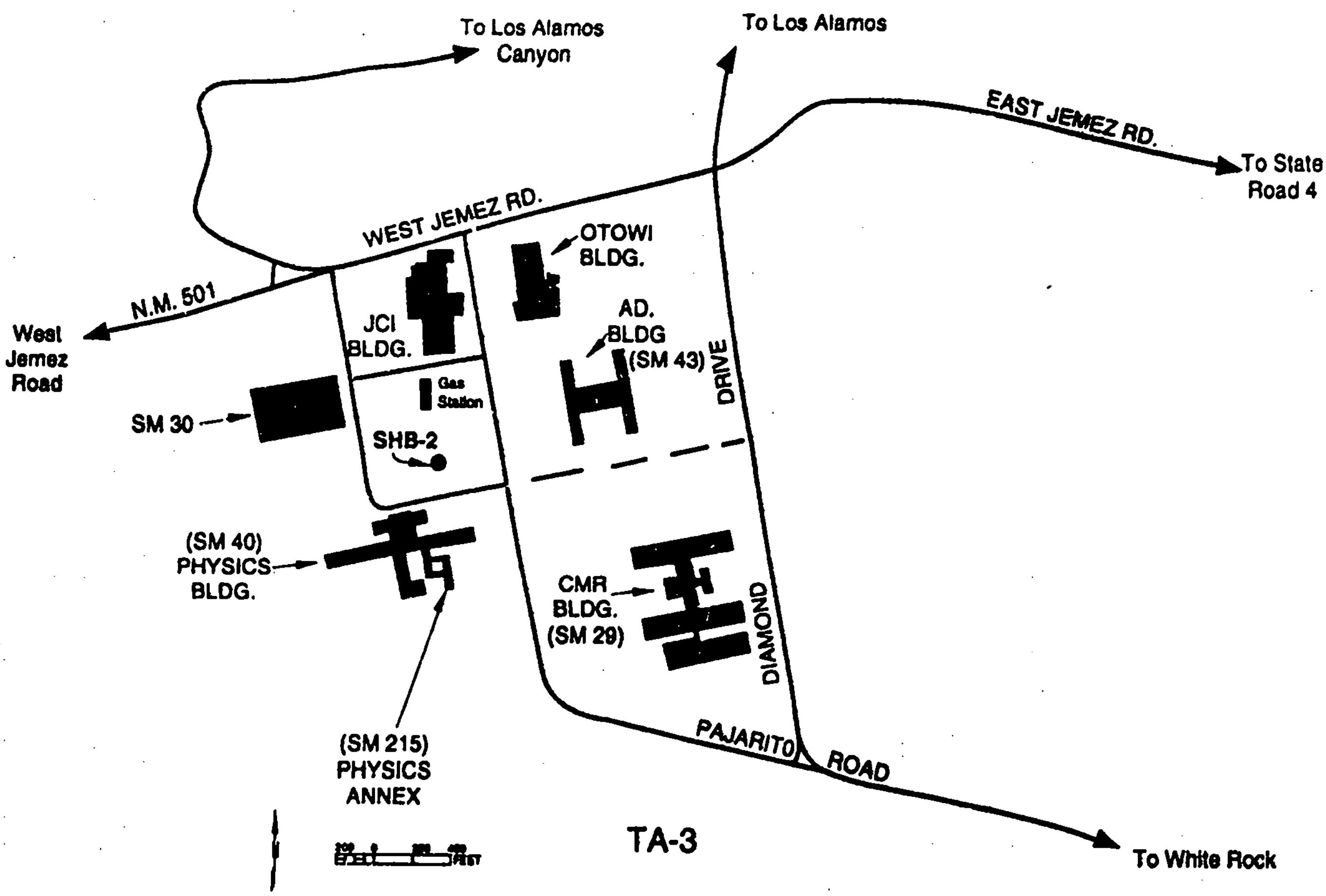


Figure 3: Map of the TA-3 area showing main roads, selected buildings, and location of core hole SHB-2.

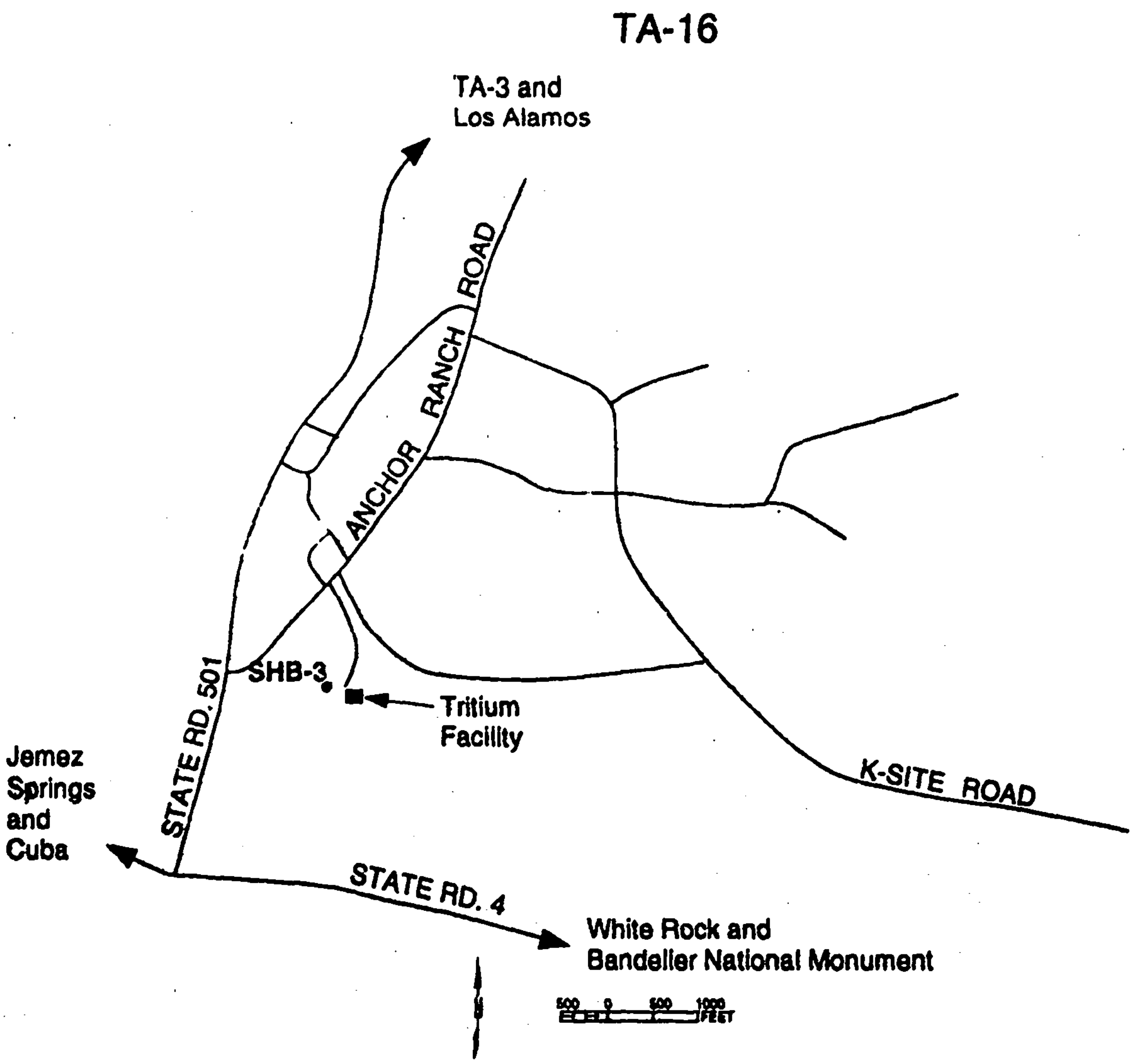


Figure 4: Map of the TA-16 area showing main roads, the Tritium Facility, and location of core hole SHB-3.

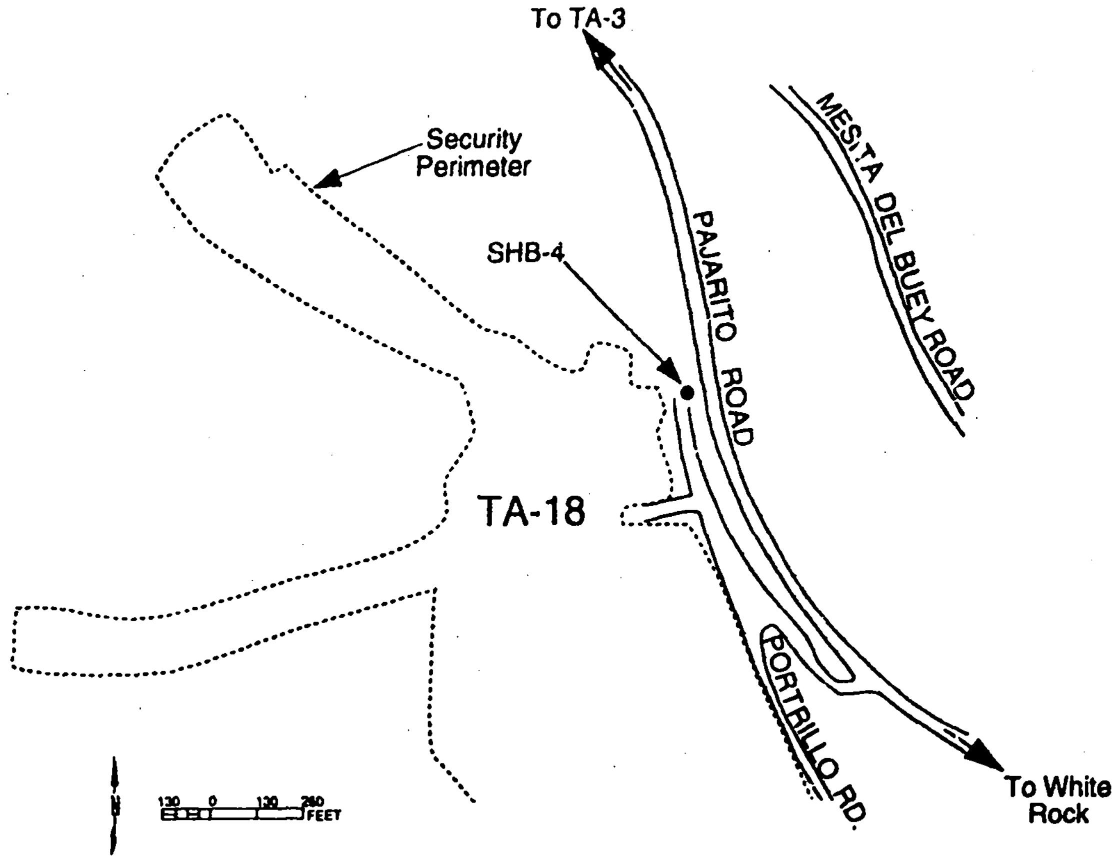


Figure 5: Map of the TA-18 area showing main roads, security perimeter, and location of core hole SHB-4.

core holes (SHB-1) penetrates basalts and related sediments of the Cerros del Rio, and another (SHB-3) penetrates sands and gravels that must, because of their lithology and stratigraphic position, be considered part of the Puye Formation.

We have avoided, in this report, use of the subdivisions of the Tshirege Member of previous workers (for example, Wier and Purtymun, 1962; Baltz et al., 1963; Crowe et al., 1978; Vaniman and Wohletz, 1990). We have done this for two main reasons: first, the units used in the aforementioned works are inconsistent; and, second, we note that the sub-units are useful only within localized areas, and without geologic mapping between these areas correlations are dubious at best. Thus, we make only the most general stratigraphic correlations, and emphasize descriptions of the rocks and deposits. Another difference in our nomenclature from that of some previous workers at the Laboratory is in our use of the term surge. Surges are a kind of pyroclastic flow that leave deposits of sorted pyroclasts which commonly exhibit bedforms typical of high energy flow regimes, such as plane beds or low-angle cross-beds. Previous workers (for example, Wier and Purtymun, 1962; Purtymun and Stoker, 1987) have called the surges of the Pajarito Plateau fluvial sandstones. However, in that the surges of the Bandelier Tuff are rather famous in the earth science community (for example, Fisher, 1979; Fisher and Schmincke, 1984), their description as sandstones should be discontinued.

III. DRILLING

All four of the holes were drilled by conventional wireline, diamond coring techniques using an Ingersoll Rand TH-60 drill, during the winter of 1991-1992 (October through January). PC Exploration, of Salt Lake City, Utah, was the drilling contractor. For each hole H core (2.5 inches in diameter) was taken to total depth, then the hole was reamed to about 6 inches in diameter. Schedule 80 PVC (about 2.8 inches inner diameter) casing was set with grout. A cap is on the bottom of each casing string, and each hole was left with the casing filled with water.

Both deep core holes (SHB-1 and SHB-3) were drilled mostly with mud, but both shallow holes (SHB-2 and SHB-4) were drilled with air. Although all holes were continuously cored, core recovery was extremely variable. We found that core recovery in nonwelded tuff was dismal while using air, but light muds (water and bentonite) improved core recovery from nonwelded zones remarkably (see Figures 6 through 9). It is also worth noting that every time we went to mud systems we almost immediately lost circulation and never got it back.

Another problem in nonwelded zones was extreme bit wear. A variety of drill bits were used during the Seismic Hazards Drilling Program. The results were mixed and difficult to assess (Table I). Core recovery for given bits ran from a low of 13% to a high of 72%. Acceptable core production was achieved using diamond as well as carbide bits, however consistency varied. Longyear Stratipak bits with two rows of chisel-shaped, carbide teeth and Christiensen surface-set, diamond bits performed well in nonwelded through densely welded tuff (SHB-2 and SHB-3). Longyear green, diamond impregnated bits, also performed well in tuff with mixed strength.

Variability in the degree of welding and/or lithification within the Bandelier Tuff probably contributed to the wide ranging and fluctuating core recovery. Variability in rock strength also made it difficult to select a bit that would consistently yield satisfactory core production. In general, however, core recovery increased with both diamond and carbide bits with some consistency in holes with greater amounts of welded tuff (Figs. 7 and 8).

Table I: Summary of core bit performance.

	Borings							
	SHB1		SHB2		SHB3		SHB4	
Coring Bit	%Rec	Feet	%Rec	Feet	%Rec	Feet	%Rec	Feet
1) Punch core tube, spring loaded	31	20	68	25				
2) Stratipak, spoon-shaped carbide, single row	36	315						
3) Stratipak, chiesel-shaped carbide, step-fence, double row			62	175	56	64	17	107
4) Diamond impreg, Series 6	29	27						
5) Diamond impreg, Longyear green	47	165			72	288		
6) Diamond impreg, step-face surface set	13	80					13	93
7) Longyear Series 2	65	64						
8) Christiansen surface set					64	496		

IV. SHB-1 (TA-55)

SHB-1 was drilled immediately west of TA-55 (Figures 1 and 2) to a total depth of 700 feet. Core recovery on this hole was poor, with a total of less than 40%. Approximately 70% of the entire section penetrated by SHB-1 is nonwelded tuff and unconsolidated sediments (Figure 6). Rather than core, recovery from nonwelded tuff was more commonly powder.

The Tshirege Member of the Bandelier Tuff in SHB-1 extends from the surface to 310 feet. It mainly consists of multiple sequences of non- to densely welded units, and approximately 60% of the Tshirege section is nonwelded tuff at this locality. The Tshirege contains a probable surge bed between 80 and 85 feet. The thickness of this surge bed is uncertain due to poor recovery through this zone. From about 250 to 270 feet the tuff is prominently vapor phase altered with dark purple pumice lumps. The bottom 30 feet of the Tshirege ignimbrite sequence is notably pumice rich. The base of the Tshirege is marked by a fallout deposit of white ash over tan to light brown pumice (up to several centimeters in diameter) between about 302 and 310 feet. This fallout deposit is, or at least is equivalent to, the Tsankawi pumice. The true thickness of this fallout deposit is uncertain due to erratic recovery through this interval.

Beneath the Tshirege Member is a thick (from 310 to 447 feet) package of dominantly epiclastic sediments that lithologically resemble the older Puye Formation. The sediments are fluvial deposits of poorly sorted sands and gravels derived mostly from the dacite highlands to the west. Some of the gravels are very coarse with cobbles ranging up to boulder size (greater than 30 cm in diameter). Understandably, the alternating soft, unconsolidated sands and extremely hard dacite boulders provided nightmarish drilling conditions. Interbedded with the epiclastic sediments are two probable pyroclastic fallout deposits. These deposits are thin (less than 0.5 foot) and consist of coarse ash at about 369 feet and pumice lapilli at about 395 feet. These pyroclastic interbeds are probably part of the Cerro Toledo Rhyolite.

From 447 to 631 feet is the Otowi Member of the Bandelier Tuff. It is mostly nonwelded ignimbrite which becomes very pumice rich near the base. The ignimbrite exhibits prominent vapor phase alteration at about 550 feet. Beneath the ignimbrite is possibly as much as 41 feet of pumice fallout which is clearly correlative to the Guaje pumice.

Under the Bandelier Tuff in SHB-1 is a sedimentary interval from 631 to 644 feet. The deposits are siltstone, pebbly sandstone, and conglomerate all derived from a basaltic source material. Much of the siltstone appears to be water-worked and altered basaltic ash, and pebbles and cobbles in the coarser deposits are variably altered basalt clasts.

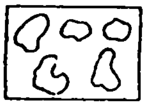
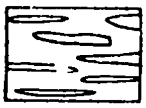
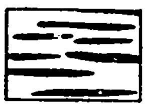
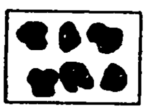
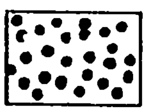
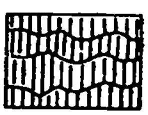
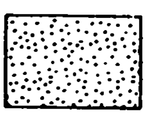
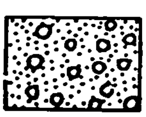
The bottom 56 feet of SHB-1 (from 644 to 700 feet) penetrates a series of olivine basalt flow units. The flow units are thin and vesicular, with extreme oxidation at unit boundaries. These basalts are part of the Cerros del Rio basalt field.

Faults, and associated fractures, are evident throughout the core hole. Prominent faults, showing cataclastic brecciation and shearing, have been noted at 155-160 feet, 174 feet, 638 feet, and 656 feet. Faults and fractures are commonly lined with smectite, as identified by X-ray diffraction (S. Chipera, written communication, 1992). The abundance of faults encountered in this core hole provides confirmation of the fault zone mapped by Vaniman and Wohletz (1990) at this locality.

V. SHB-2 (TA-3)

SHB-2 was drilled north of SM-40 (Physics Building) in TA-3 between two large parking lots (Figures 1 and 3) to a total depth of 200 feet. Apparently because only about 45% of the section penetrated was nonwelded tuff (Figure 7), core recovery was about 65% using air as the circulating fluid. Several non- to moderately or densely welded units of the Tshirege Member were penetrated. The hole bottomed in densely welded ignimbrite. Approximately the top 20 feet of the hole appears vapor phase altered.

Table II: Explanation of symbols for Figures 6-9.

Symbol	Explanation
	NON WELDED IGNIMBRITE
	MODERATELY WELDED IGNIMBRITE
	DENSELY-WELDED IGNIMBRITE
	VAPOR PHASE ALTERATION
	PYROCLASTIC FALLOUT DEPOSIT
	BASALT
	SANDS
	SANDS AND GRAVELS

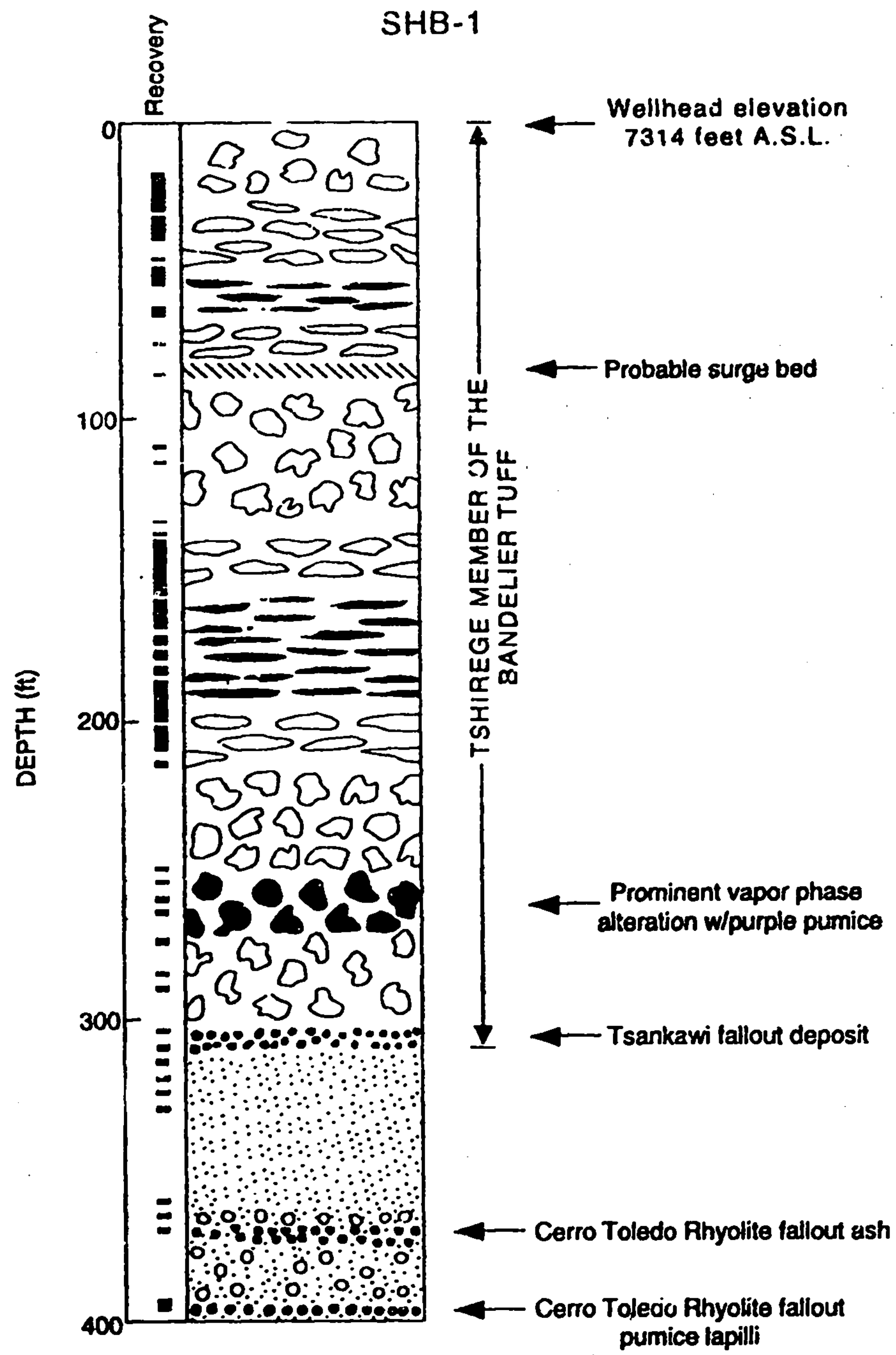


Figure 6a: Graphic lithology log for core hole SHB-1. Log is continued on next page. Black marks in recovery column indicate where core was recovered. See Table II for explanation of symbols.

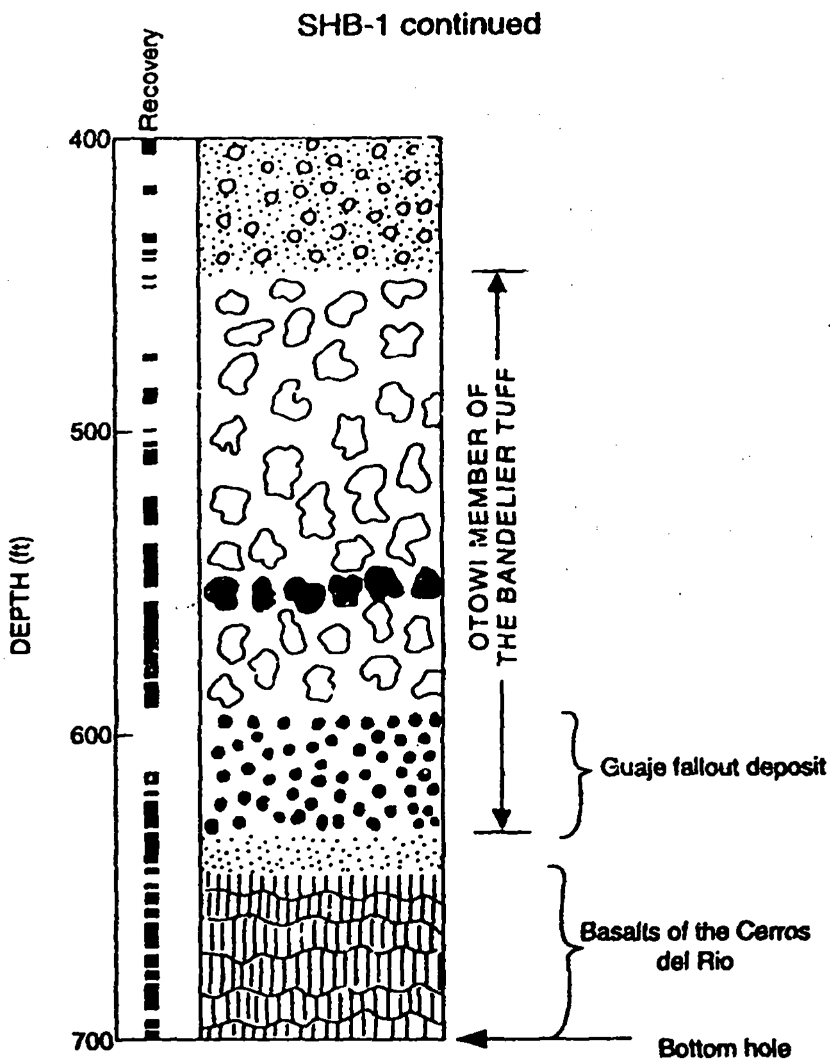


Figure 6b: Graphic lithology log for core hole SHB-1. Black marks in recovery column indicate where core was recovered. See Table II for explanation of symbols.

VI. SHB-3 (TA-16)

SHB-3 was drilled west of the new tritium facility in TA-16 (S-site) (see Figures 1 and 4) with a total drilled depth of 848 feet and an accessible depth of 860 feet (the depth discrepancy is explained below). In spite of the fact that about 70% of the section penetrated consisted of nonwelded tuff and unconsolidated sediments (Figure 8), core recovery from SHB-3 was nearly 70%, indicating both the advantages of drilling with mud and the results of lessons learned during the drilling of SHB-1.

After the hole was cored to 848 feet, the reaming operation proceeded to 790 feet with the use of a down-hole air hammer. At this point there was a breakdown on the rig and the hammer was pulled up about 40 feet to 750 feet while repairs were made. After about 45 hours from last air injection, air was resupplied to the reaming hammer to resume operations. Within a minute of the resupplying of air to the hammer, SHB-3 erupted a spout of water at least 40 feet into the air (40 feet is the height of the derrick on the drill rig). The spout lasted for less than 10 seconds, and, while air was supplied to the down-hole hammer for the remainder of the reaming operation, SHB-3 continued to make water at a rate of about 10 to 15 gallons per minute. Reaming proceeded without further incident to 852 feet where air was supplied for about 10 more minutes after reaming to remove sand and other loose material from the hole. By this time, the discharging water was clear; furthermore, the discharge water never appeared to contain bentonite or other drilling mud additives. When the PVC casing was inserted into the core hole, it dropped to 860 feet. Apparently, the loose bottom hole material (see below) was extensively eroded during the flowing of the hole.

From the surface to about 335 feet, SHB-3 penetrates the Tshirege Member of the Bandelier Tuff. The Tshirege at this locality, closer to the caldera source, is over 95% welded tuff, most of which is densely welded (Figure 8). Cooling breaks are few, with one in the top 60 feet of the hole and another around 230 feet. From about 320 to about 335 feet core recovery was poor, but this interval apparently includes the nonwelded base of the ignimbrite and an unknown thickness of Tsankawi fallout pumice.

From roughly 335 to 424 feet is a sequence of unconsolidated sands and sandy gravels very similar to the sequence between the Tshirege and Otowi members encountered in SHB-1. Lithologically identical to the older Puye Formation, these epiclastic sediments represent alluvium shed off of the Sierra de los Valles dacite highlands to the west. Interbedded with this epiclastic sequence at about 385 to 388 feet is a coarse sand-sized pumice fall deposit. Some of the pumice contain obsidian fragments. It is likely that this pyroclastic interbed is related to the Rabbit Mountain tuff of the Cerro Toledo Rhyolite (Goff et al., 1990).

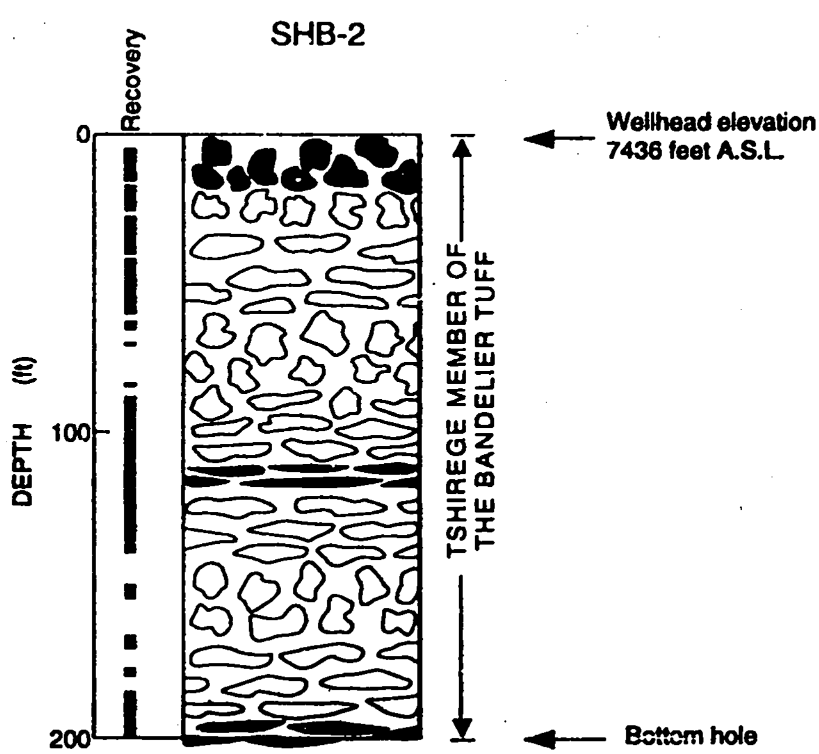


Figure 7: Graphic lithology log for core hole SHB-2. See Table II and Figure 6 for explanation of symbols.

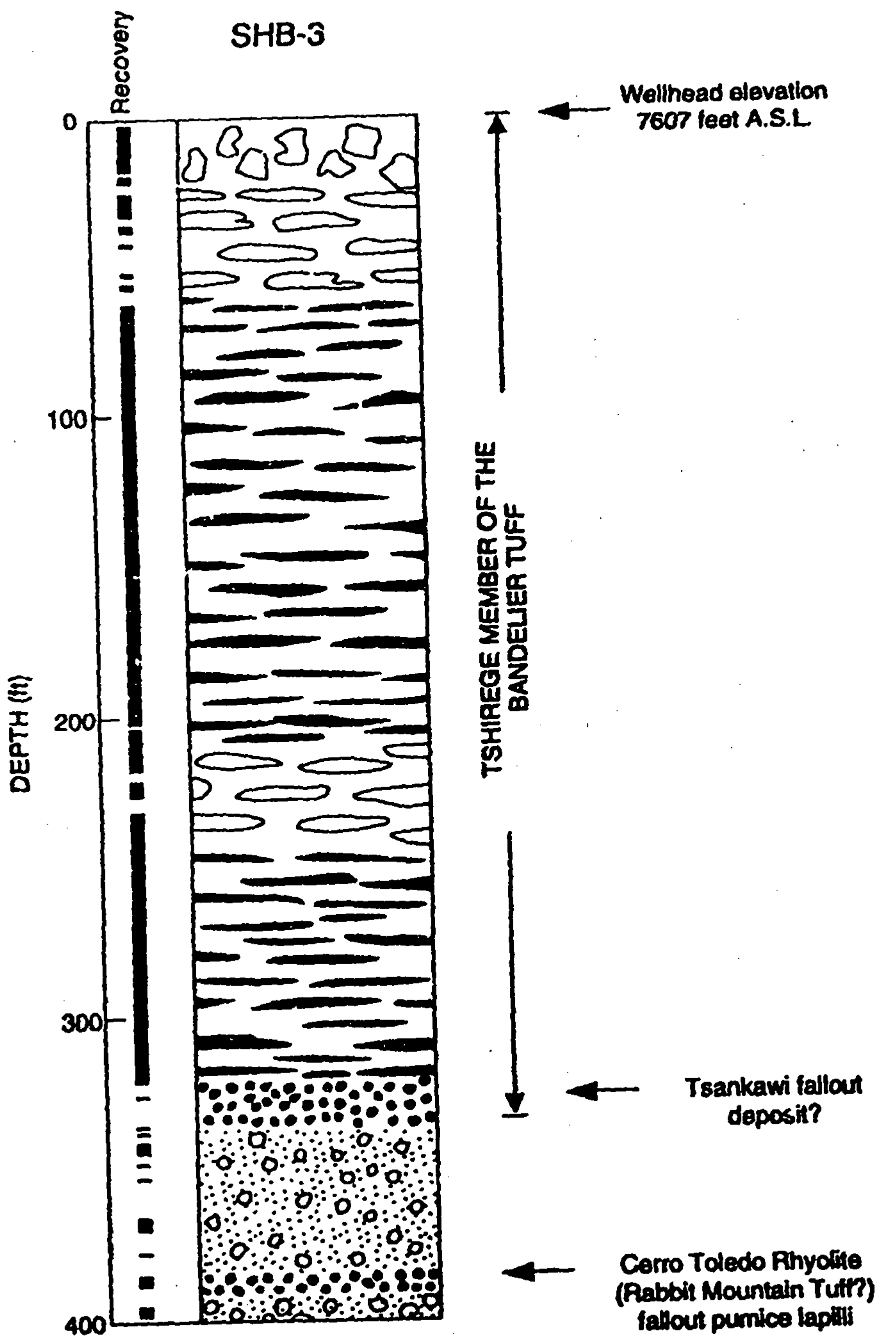


Figure 8a: Graphic lithology log for core hole SHB-3. Log is continued on next page. See Table II and Figure 6 for explanation of symbols.

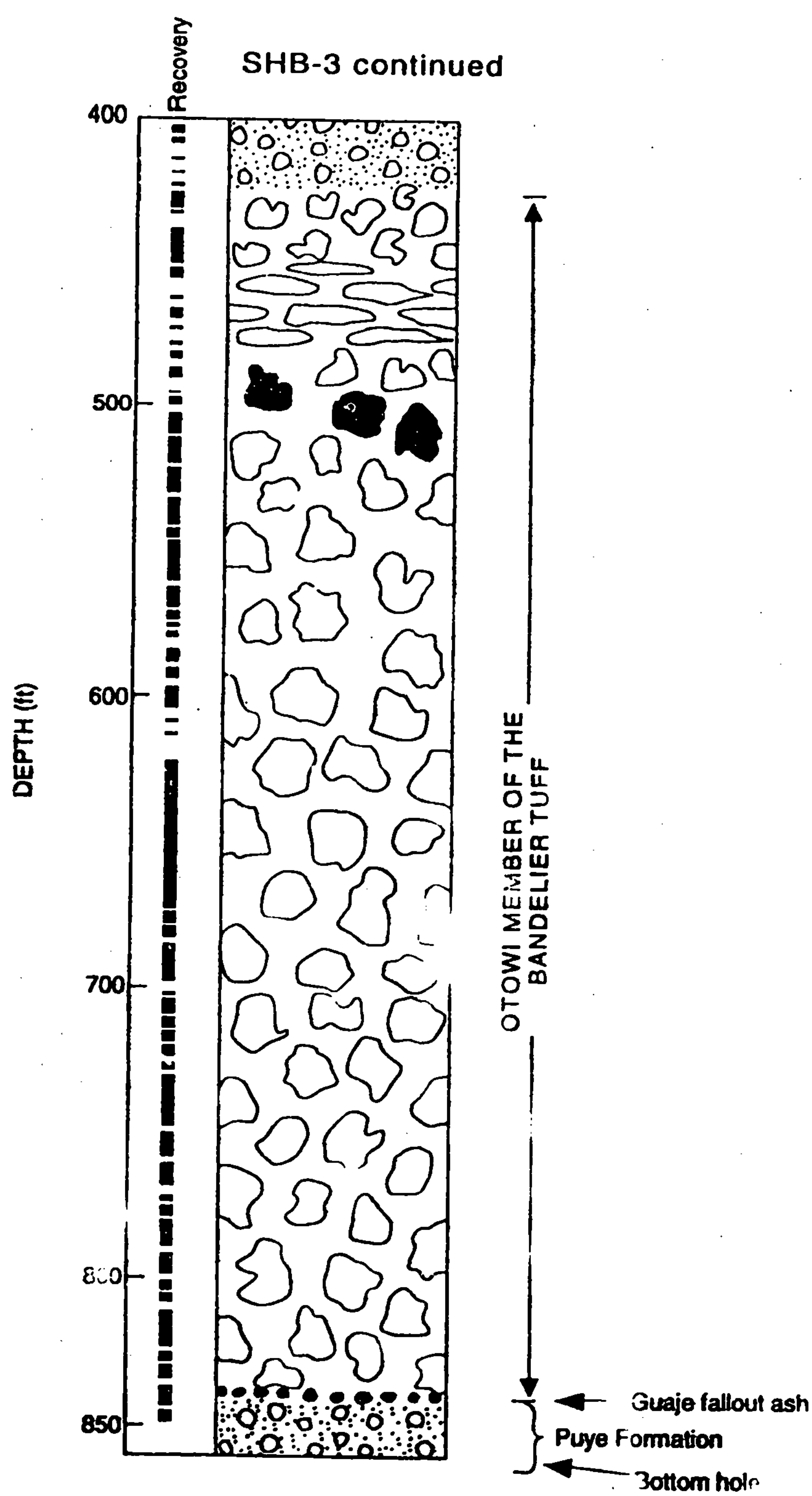


Figure 8b: Graphic lithology log for core hole SHB-3. See Table II and Figure 6 for explanation of symbols.

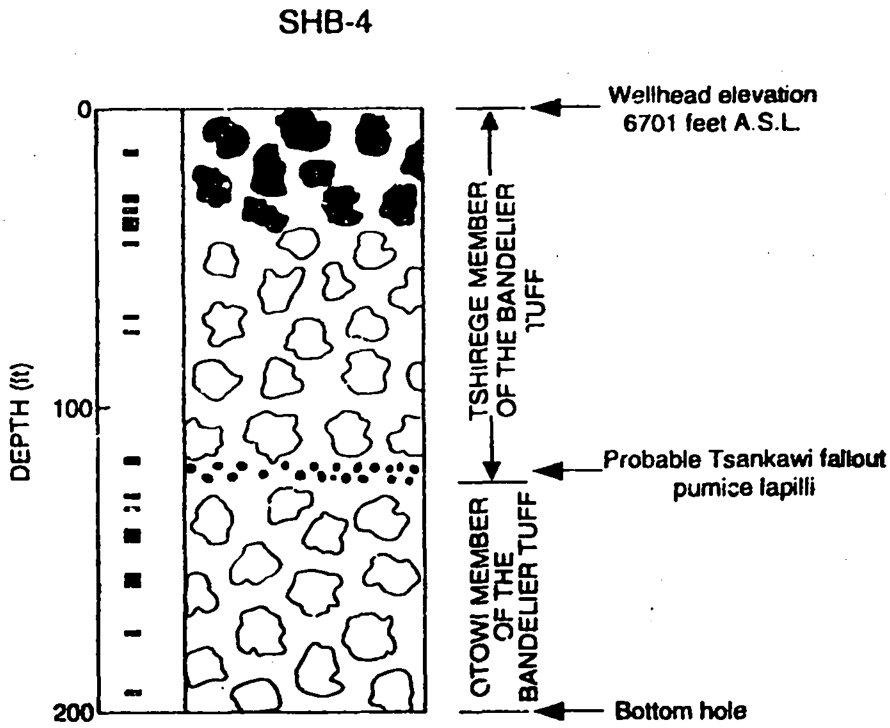


Figure 9: Graphic lithology log for core hole SHB-4. See Table II and Figure 6 for explanation of symbols.

The Otowi Member of the Bandelier Tuff extends from about 424 to 839 feet in SHB-3. It is almost entirely nonwelded tuff with a zone of slightly flattened pumices from about 450 to 480 feet.

Beneath the Otowi in SHB-3 is a sequence of sands and boulder-rich gravels that must be correlative to the Puye Formation (see Discussion, below). The cobbles and clasts of these epiclastic, alluvial deposits are dominantly dacite lithologies that can be found exposed in the Tschicoma Formation in the Sierra de los Valles immediately west of the drill site. As with the similar epiclastic deposits encountered between the Otowi and Tshirege members higher in SHB-3 and in SHB-1, the alternating unconsolidated sands and hard dacite boulders caused very difficult drilling conditions.

VII. SHB-4 (TA-18)

SHB-4 was drilled exclusively with air, north and east of entrance road to TA-18 in Pajarito canyon (see Figures 1 and 5), to a total depth of 200 feet. Core recovery was only about 12.5%, so our interpretations of stratigraphy must be considered to be constrained speculation (see Figure 9).

The top 40 feet of SHB-4 appears to penetrate nonwelded, vapor phase altered ignimbrite of the Tshirege Member. Spotty recovery from 40 to about 117 feet suggests this interval consists of nonwelded ignimbrite. At about 117 feet, the samples recovered were discrete pebble-sized pumices, which may represent a fallout deposit equivalent to the Tsankawi pumice. From about 120 to 200 feet, the remainder of SHB-4 appears to have penetrated nonwelded ignimbrite of the Otowi Member.

Cuttings and core samples from 32 to at least 125 feet came out of SHB-4 damp and moist. The core tube and rock samples from about 125 feet and 145 feet came out of the hole wet. From about 55 feet to total depth SHB-4 would steadily discharge air while drilling was stopped.

VIII. DISCUSSION

It is important to note that while, in a very general sense, the Bandelier Tuff may form blanket-like deposits beneath the Pajarito Plateau there is good reason to expect irregular geometries and distributions of all stratigraphic units. The Otowi Member of the Bandelier Tuff was erupted over a rugged topography (see Dransfield and Gardner, 1985). Given this, the Otowi Member will have a variable thickness, not only because of thinning to the east with increasing distance from the source, but also depending on the paleotopography of a given site (compare SHB-1 and SHB-3, Figure 6 and Figure 8). In addition, significant incision and sedimentation occurred between eruption of the Otowi and Tshirege members as evidenced by the epiclastic sequences at this horizon in SHB-1 and SHB-3. Puye-like sedimentation, forming alluvial fans off the eastern front of the Sierra de los Valles, not only preceded the Bandelier Tuff, but occurred during the major hiatus in ignimbrite eruptions and, in fact, continues today.

The Guaje and Tsankawi fallout deposits also have variable thicknesses and textures, and should not necessarily be expected to be present everywhere beneath the Pajarito Plateau. These deposits are thickest along the axes of their dispersal plumes (Self et al., 1986). For example, the Guaje fallout deposit is as much as 41 feet of very coarse pumice in SHB-1, but it is represented by only one foot of ash in SHB-3. These relations are consistent with SHB-3 being farther from the axis of the northeastern dispersal plume for the Guaje. These relations also strongly suggest that the 91 feet of Guaje pumice reported for DT-5A (Wier and Purtymun, 1962), less than three miles southeast of SHB-3, may be in error.

Of the four holes drilled for the seismic hazards program, only SHB-4 was drilled in proximity to a pre-existing well. SHB-4 is approximately 1000 feet north-northwest of water supply well PM-2. A first comparison of the logs for the two drill holes (Figure 9 and Cooper et al., 1965) appears to indicate a total lack of correlation between the holes. However, after examination of the PM-2 lithology logs, Reneau (written communication, 1992) indicated that PM-2 penetrates first Tshirege Member, not Otowi, beneath the near-surface alluvium, and he inferred the Tshirege-Otowi contact to be at a depth of around 100 feet. Reneau's re-interpretation of the original logs is in very close agreement with the stratigraphy of SHB-4.

The water encountered in SHB-3 is groundwater based on the observations of no drilling additives in the fluid; however, how this groundwater relates to the main aquifer (for example, Purtymun, 1984) will remain uncertain until further tests are performed. Operating pressures for the compressor delivering air to the hammer were 100 to 150 pounds per square inch (psi). Simple calculations, using these operating pressures and a hydrostatic pressure gradient of 0.4333 psi/ft, indicate that the top of the groundwater column filling SHB-3 could have been no deeper than 346 feet in order for the compressor to be capable of lifting the fluid and stimulating flow. This implies that the groundwater system has sufficient head to force water up natural conduits such as faults and fractures, with a potential for forming perched aquifers.

Wet samples and equipment were repeatedly extracted from SHB-4. While the discharge of air from the hole during breaks in drilling and some of the moisture on core and equipment could well be attributed to atmospheric effects, the wet samples and core tube can not be explained in similar fashion. The variations in weather conditions were the same during the drilling of all four core holes, and at least portions of all four holes were drilled with air. Thus, if the water on/in the samples and the core tube from SHB-4 was, for example, condensation, then the effect should have appeared at the other holes as well. Furthermore, samples and equipment from 125 to 145 feet were truly wet. Instead, the wet samples and equipment retrieved from SHB-4 may suggest that shallow, alluvial aquifers in Pajarito Canyon have some vertical and lateral continuity into the tuffs beneath the mesas and canyons.

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