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# Earth Science Investigations for Environmental Restoration—Los Alamos National Laboratory Technical Area 21

Edited by
D.E. Broxton
P.G. Eller

Los Alamos
NATIONAL LABORATORY
Los Alamos, New Mexico 87545

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## Contents


Abstract 1

Introduction 1
*D.E. Broxton and P.G. Eller*

Geologic Map of Technical Area 21 7
*F. Goff*

Measurement and Analysis of Rock Fractures in the Tshirege Member of the Bandelier Tuff along Los Alamos Canyon Adjacent to Technical Area-21 19
*K. H. Wohletz*

Stratigraphy, Petrography, and Mineralogy of Bandelier Tuff and Cerro Toledo Deposits 33
*D.E. Broxton, G.H. Heiken, S.J. Chipera, and F.M. Byers, Jr.*

Geomorphic Studies at DP Mesa and Vicinity 65
*S.L. Reneau*

Preliminary Drilling Results for Boreholes LADP-3 and LADP-4 93
*D.E. Broxton, P.A. Longmire, P.G. Eller, D. Flores*

Fluorescein Dye Experiment at DP Spring and Sewage Outfall 111
*A. Adams, J. DeMuth, D. Counce, and F. Goff*

# GEOLOGIC MAP OF TECHNICAL AREA 21

by

F. Goff

***A geologic map of TA-21 was prepared by using color photographs of canyon walls as well as conventional field mapping (scale of 1:4200, or 1 in. = 350 ft), and the general bedrock relations were studied. Exposed bedrock geology consists of three stratigraphic units (bottom to top): (1) the Otowi Member, Bandelier Tuff (consisting primarily of nonwelded, lithic-rich, rhyolitic ignimbrite), (2) the Cerro Toledo interval (interbedded rhyolitic pyroclastic falls and epiclastic gravels of dominately dacitic composition), and (3) the Tshirege Member, Bandelier Tuff (nonwelded to welded rhyolitic ignimbrite). The Bandelier Tuff and fall deposits in the Cerro Toledo interval were derived primarily from explosive volcanic eruptions in the Valles caldera west of TA-21. In addition, the Tshirege Member is subdivided into five units because of the distinct boundaries caused by deposition of flow units, variations in welding, and variations in alteration. Bedrock units are partially covered by alluvium, terrace gravels, talus/colluvium, mesa top soils, and disturbed alluvium. Contacts between the three bedrock units are generally undulatory as a result of the periods of erosion between emplacement. However, thicknesses of most units, except for the bedded Cerro Toledo interval, are relatively constant. No faults were found in the map area in exposed bedrock units. One cold spring (DP Spring) was found in eastern DP canyon issuing from a contact between colluvial and valley fill deposits and Tshirege unit 1g. This spring discharges from the north cliff face about 20 ft above the canyon bottom.***

## INTRODUCTION AND PREVIOUS MAPPING OF TA-21 AND THE SURROUNDING AREA

This study presents a geologic map and cross sections of units at TA-21. The map supports RFI studies at TA-21 by showing the distribution and thickness of units. These data provide both a geologic framework for evaluating potential contaminant transport pathways and background information for evaluating various remediation alternatives.

TA-21 (also known as DP site) lies on the Pajarito Plateau, which is located on the east flank of the Jemez Mountains and the west margin of the Española Basin. The Pajarito Plateau is composed primarily of the slightly eroded Tshirege Member of the Bandelier Tuff, a large-volume, rhyolitic ash-flow tuff (ignimbrite) erupted from the Valles caldera

of the Jemez volcanic field (Smith and Bailey, 1966). All designated waste sites at TA-21 are built in the upper zones of this ignimbrite sheet or in overlying deposits. Discussions of the geology of the upper portions of DP Mesa and the history of disposal facilities can be found in several reports (Rogers, 1977; Nyhan *et al.*, 1984; Gerety *et al.*, 1989; Merrill, 1990; LANL, 1991).

Regional geologic maps that cover all or part of the Pajarito Plateau include those of Griggs (1964) for geohydrologic investigations centered around Los Alamos, Smith *et al.* (1970) for volcanologic investigations of the Jemez Mountains, and Kelley (1978) for tectonic investigations associated with the Rio Grande rift. Geologic maps of nearby areas that have bearing on the stratigraphic and tectonic context of the Pajarito Plateau in the greater regional picture have been published by Weir and Purtymun (1963), Baltz *et al.*, (1963), Galusha and Blick (1971), Aubele (1978), Dethier and Manley (1985), Goff *et al.* (1990), and Dethier (in press). Detailed geologic mapping and fracture measurements were completed for an area around TA-55 (Vaniman and Wohletz, 1990). Unpublished mapping was completed for large areas of US Department of Energy land on the plateau by M.A. Rogers. The most recent syntheses of geologic and tectonic studies on the Pajarito Plateau have been published by Dransfield and Gardner (1985) and Gardner and House (1987) as part of the Los Alamos investigation of the seismic hazard of faults within the region. The latter report includes recent detailed mapping along strands of the Pajarito fault zone.

## GEOLOGY OF BEDROCK UNITS

Stratigraphic units described within the Tshirege Member of the Bandelier Tuff follow the usage of Vaniman and Wohletz (1990). Estimates of the degree of welding in the Bandelier ignimbrites are based on hand-sample evaluations of pumice compaction. Detailed descriptions of lithologic and mineralogical variations are found in Broxton *et al.* (Sec. IV, this report). No mappable faults or folds cross the TA-21 site, although zones of intense fracturing correspond to the southern projections of mapped faults (Wohletz, Sec. III, this report). Descriptions of post-Bandelier alluvium, colluvium, landslides, terrace gravels, soils, and disturbed fill are given in Reneau (Sec. V, this report).

Because the cliffs along most of the south side of the TA-21 area (north wall, Los Alamos Canyon) are extremely steep, bedrock geology of this zone was mapped on a set of color photographs that will be available through the Environmental Restoration records processing facility. The geologic map (Plate 1 of this report) and cross-sections (Fig. 1) show the distribution of rock units at the site. The geologic map is a compilation of bedrock geology (this report) and post-Bandelier sedimentary deposits (Reneau, Sec. V, this report). The cross-sections use thicknesses obtained from the geologic map and from projected thicknesses from three nearby deep wells (Fig. 2). Representative photographs of rock units are displayed in Figs. 3 through 5.

### Otowi Member, Bandelier Tuff

The upper part of the Otowi Member of the Bandelier Tuff (1.50 Ma, Spell *et al.*, 1990; 1.61 Ma, Izett and Obradovich, 1994) is very poorly exposed in Los Alamos Canyon because of extensive cover by talus and colluvium (Plate 1). Better exposures occur in the mouth of DP Canyon. The base of the Otowi is not exposed but is described from cuttings taken in well Otowi-4 at the mouth of DP Canyon (Stoker *et al.*, 1992), in unpublished lithologic descriptions for EGH-LA-1 at Sigma Mesa, and from core recovered at hole SHB-1 at TA-55 (Gardner *et al.*, 1993).

Where exposed, the Otowi Member consists of white, massive, nonwelded, rhyolitic ignimbrite containing about 5% pumice clasts >2 cm in diameter and about 5% clasts of pre-Bandelier lithologies of sand to cobble size

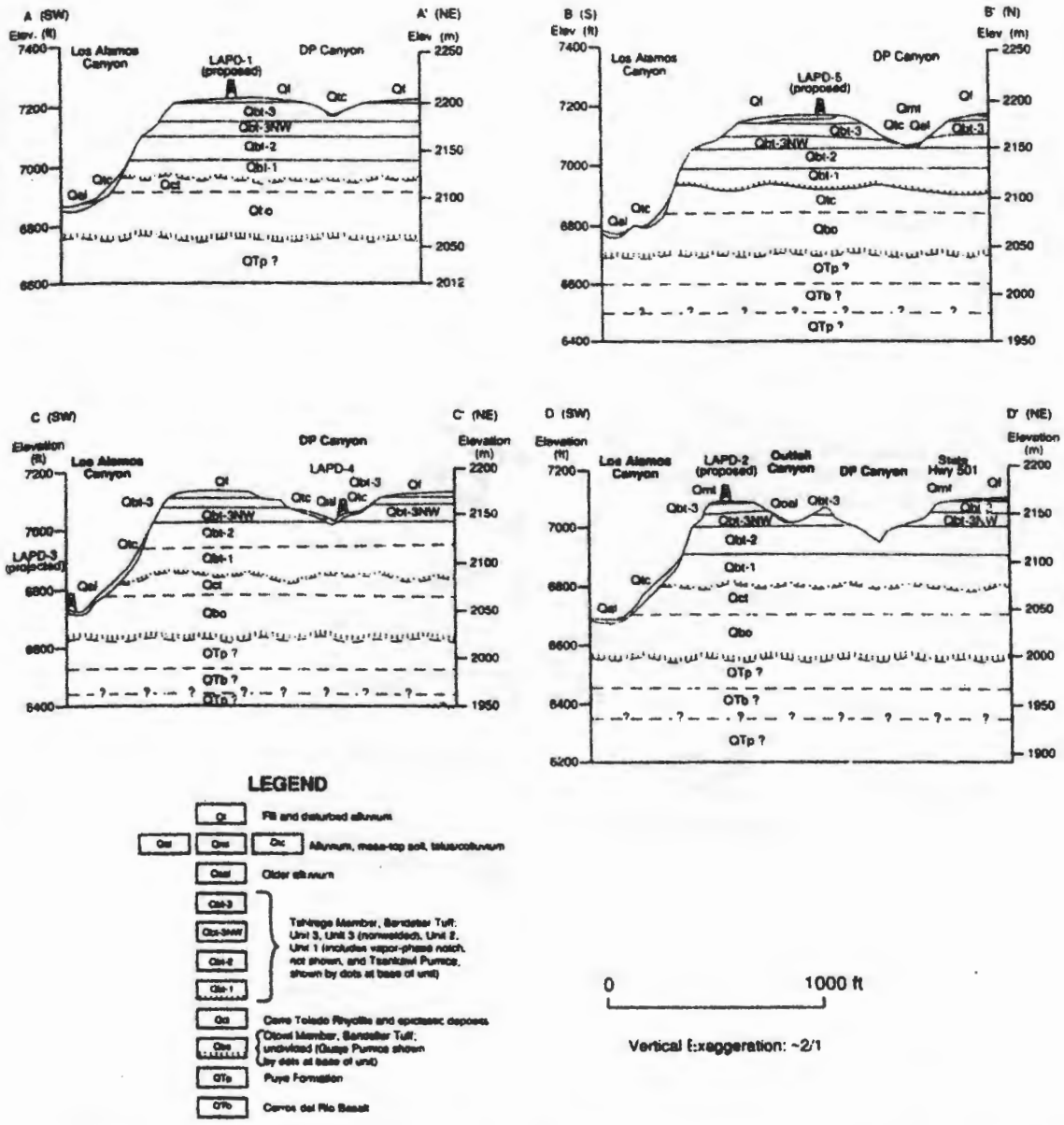


***Fig. 1. Cross sections for geologic map of TA-21. Line of cross sections shown on geologic map (Plate 1, pocket inside back cover of this report). These cross sections are vertically exaggerated and reduced. Units Qtp and Qtb are not exposed at the surface in the map area; thus, their depth and thickness are approximate.***

(mostly intermediate-composition volcanics). The ignimbrite matrix consists of poorly sorted ash, pumice, crystal, and lithic fragments. Phenocrysts in pumice clasts consist of quartz (~20%) and sanidine (~80%). Tiny black phenocrysts of clinopyroxene are rare and difficult to see in hand specimens. No flow-unit boundaries are observable in the few outcrops of Otowi found within the map area.

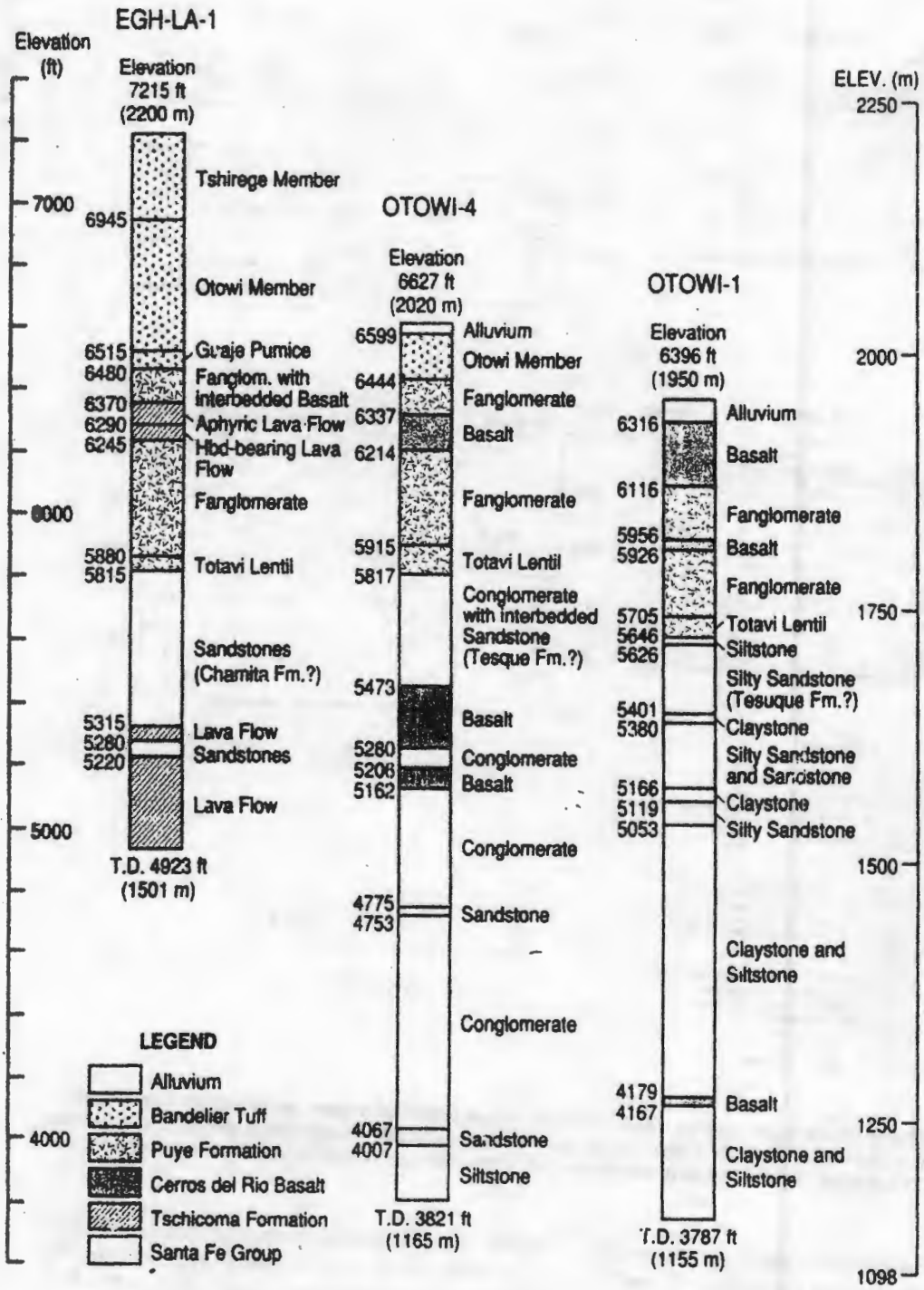


***Fig. 2. Lithologic logs of well EGH-LA-1 (Sigma Mesa) and wells Otowi-1 and Otowi-4 (Pajarito and Los Alamos Canyons); lithology from C. Potzick (unpublished data), Stoker et al. (1992), and Purtymun et al. (1993). Elevations at left of columns are in feet.***

The Otowi Member is relatively soft and easily eroded. An exposure in the bottom of Los Alamos Canyon along the dirt road (site C-1, Plate 1) reveals several feet of massive Otowi ignimbrite overlain by a small remnant of older alluvium (Qoal) composed primarily of dacitic rocks from sources upstream. The older alluvium is ≤3 ft thick (too small to show on the map) and is overlain by colluvium of mostly Tshirege Member, Bandelier Tuff.

Near the mouth of DP Canyon (sites C-2 and C-4, Plate 1), the top of the Otowi Member consists of an irregular erosional surface overlain by either bedded tuffs and epiclastic sedimentary rocks of the Cerro Toledo interval or by older alluvium (Qoal, too small to show on map) and recent talus and colluvium (Qtc).

The base of the Otowi Member contains a pyroclastic fall unit named the Guaje Pumice Bed (Griggs, 1964; Bailey *et al.*, 1969), which is not exposed in the map area but is found in nearby wells. It is shown diagramatically on the cross sections of Fig. 1.

### Cerro Toledo Interval

Many discontinuous exposures of the Cerro Toledo interval can be observed in the lower slopes and cliffs of Los Alamos Canyon and near the mouth of DP Canyon. Complete sections occur only in DP Canyon (Plate 1). The Cerro Toledo interval in the map area consists of at least five pyroclastic eruption sequences of the Cerro Toledo Rhyolite interbedded with epiclastic deposits of mostly fluvial origin (Fig. 3). Cross-cutting relations, pinch-outs of beds, and the channeling of fluvial and sheet-wash deposits into underlying pyroclastic beds are commonly observed characteristics. Locally, old soils are preserved within the unit. Tuffaceous deposits associated with the Cerro Toledo Rhyolite are described by Griggs (1964), Bailey *et al.* (1969), Heiken *et al.* (1986), Gardner *et al.* (1986), and Stix *et al.* (1988). Heiken *et al.* (1986) and Gardner *et al.* (1993) also describe epiclastic sediments associated with the Cerro Toledo interval.

Pyroclastic sequences consist of 1.7- to 5.0-ft-thick beds of white fine ash, pumice, and pumice lapilli and contain up to 5% lithic clasts of pre-Bandelier volcanic units (Heiken *et al.*, 1986; Stix *et al.*, 1988). Most pyroclastic beds are normally graded. Phenocrysts are rare in pumice clasts of the Cerro Toledo Rhyolite (usually <2%). Most phenocrysts consist of quartz and sanidine but may include trace amounts of pyroxene, biotite, hornblende, and opaque oxides; thus, Cerro Toledo Rhyolite

***Fig. 3. Photo of the Cerro Toledo Interval, eastern DP Canyon in the general area of site C-4 (Plate 1). The Cerro Toledo Interval consists of several layers of pyroclastic falls interbedded with layers and lenses of fluvial sands and gravels. The Cerro Toledo Interval overlies the massive ignimbrite of Otowi Member, Bandelier Tuff, and underlies Tsankawi Pumice Bed and unit 1g ignimbrite of Tshirege Member, Bandelier Tuff.***

pumice is usually distinct from Bandelier Tuff pumice because the latter has abundant quartz and sanidine and sparse mafic phenocrysts.

Epiclastic deposits display tremendous variations in thickness, cobble size, and sorting. An outcrop in Los Alamos Canyon (site C-8, Plate 1) exposes the upper part of a poorly sorted bed of boulders (diameters ≤ 3 ft) overlain by a series of pyroclastic deposits. In lower DP Canyon, several poorly sorted epiclastic deposits (≤ 10 ft thick) show channeling into relatively soft pyroclastic layers (Fig. 1). Cobble sizes are mostly <1.7 ft in diameter but can be as large as 3 ft in diameter. Epiclastic clasts are dominantly composed of dacitic-to-andesitic rocks from sources to the west, but the finer grained matrix between fragments contains some rhyolitic ash and pumice. These epiclastic beds resemble many of the deposits of the older Puye Formation because the sources of materials (dacitic rocks to the west) and mechanisms of deposition are similar.

The thickness of the Cerro Toledo interval is variable. Although Gardner *et al.* (1993) report about 140 ft at TA-55, the maximum thickness in DP Canyon is about 66 ft, but the thickness decreases to the east to as little as 13 ft. Exposed thickness on the west side of the map area (site C-12, Plate 1) near Omega East is about 50 ft. Some top and bottom contacts of the Cerro Toledo interval are irregular, although most contacts appear planar. The Cerro Toledo interval is overlain by the Tsankawi Pumice Bed of the Tshirege Member. In lower DP Canyon near site C-4 (Plate 1), the Cerro Toledo interval is overlain by ≤3 ft of older alluvium (too small to show on the map) that post-dates the Tshirege Member.

### Tshirege Member, Bandelier Tuff

The Tshirege Member of the Bandelier Tuff (1.13 Ma, Spell *et al.*, 1990; 1.22 Ma, Izett and Obradovich, 1994) is well exposed in the map area and forms most of the spectacular cliffs throughout the Pajarito Plateau. Thick sections are observable at several locations along Los Alamos Canyon and near the mouth of DP Canyon. Because of variations in both welding and devitrification textures and in distribution of flow units and cooling units, other workers (Baltz *et al.*, 1963; Weir and Purtymun, 1963; Crowe *et al.*, 1978; Vaniman and Wohletz, 1990, 1991) have subdivided the Tshirege member into mappable units whose continuity across the Pajarito Plateau is not yet demonstrated. The basic unit subdivisions of Vaniman and Wohletz are used for this report and map (Plate 1) because their recent map overlaps with the TA-21 map area and because their subunits are based on the physical property of erodability—a property easy to recognize in the field.

According to Vaniman and Wohletz (1990; 1991), the Tshirege Member on the Pajarito Plateau consists of five units of ignimbrite and a basal pyroclastic fall unit named the Tsankawi Pumice Bed (Bailey *et al.*, 1969). For the purposes of this report, the Tsankawi pumice is described separately but, because it is ≤3 ft thick, the Tsankawi is included at the bottom of the lowermost ignimbrite unit in the map and cross-sections.

#### *Tsankawi Pumice Bed*

The Tsankawi Pumice Bed is roughly 1.7 to 3 ft thick in the map area (Fig. 4) and consists of a distinct package of ashfalls composed of bedded ash, crystal-rich ash, pumice and <5% lithic fragments (Bailey *et al.*, 1969). Tsankawi pumice contains "sparse phenocrysts of quartz and sanidine and rare black specks of oxides and ferromagnesian minerals" (Bailey *et al.*, 1969). The Tsankawi Pumice Bed also contains rare (0 to 10%) hornblende dacite pumice that is quite distinctive because of its contrasting grey color and phenocryst assemblage (Bailey *et al.*, 1969). In addition, the Tsankawi Pumice Bed commonly rests on a poorly developed soil in the uppermost pyroclastic fall of the Cerro Toledo interval. This

*Fig. 4. Photograph of 3-ft-thick Tsankawi Pumice Bed on nose of DP Mesa (site C-6, Plate 1). The Tsankawi Pumice Bed overlies soil at top of the Cerro Toledo interval (next to lower half of hammer handle) and underlies unit 1g massive ignimbrite, Tshirege Member, Bandelier Tuff.*

soil horizon is often damp or erodes differentially. In spite of these features, there is some argument about assignment of individual beds to the Tsankawi Pumice Bed or the Cerro Toledo Rhyolite based on chemical and petrographic criteria (Self *et al.*, 1986; Heiken *et al.*, 1986; Stix *et al.*, 1988). For the purposes of the maps and cross sections, in this report, the original definition of Bailey *et al.* (1969, p.14) is used.

### *Tshirege Unit 1 Ignimbrite*

Unit 1 Ignimbrite is divided into units 1g (glassy) and 1v (vapor phase) in Fig. 5 and by Vaniman and Wohletz (1990 and 1991), but it is shown only as unit 1 on the geologic map (Plate 1). Units 1g and 1v are separated from each other by a persistent and mappable pink-colored, erosional notch, in which the pumices are extremely "soft" (Vaniman and Wohletz, 1990). Pumice clasts at this horizon fall apart with the touch of a finger, and they have a distinctive greyish-purple color. This notch, also described by Crowe *et al.* (1978), is referred to as the vapor-phase notch (Fig. 5). Vaniman and Wohletz (1991) and Broxton *et al.* (Sec. IV, this report) include the vapor-phase notch as the lowermost part of unit 1v.

Unit 1g rests on the Tsankawi Pumice Bed (Fig. 4) and underlies the vapor-phase notch. It consists of ≤83 ft of white-to-gray nonwelded tuff that weathers to pale orange. Although the ignimbrite is soft, unit 1g generally forms cliffs where it is not covered by talus and colluvium. Unit 1g commonly contains abundant holes ≤ 5 ft in diameter arranged in vertical tiers that give a "swiss-cheese" appearance to the unit (Fig. 5). These holes are caused by preferential erosion of pumice clasts in the ignimbrite.

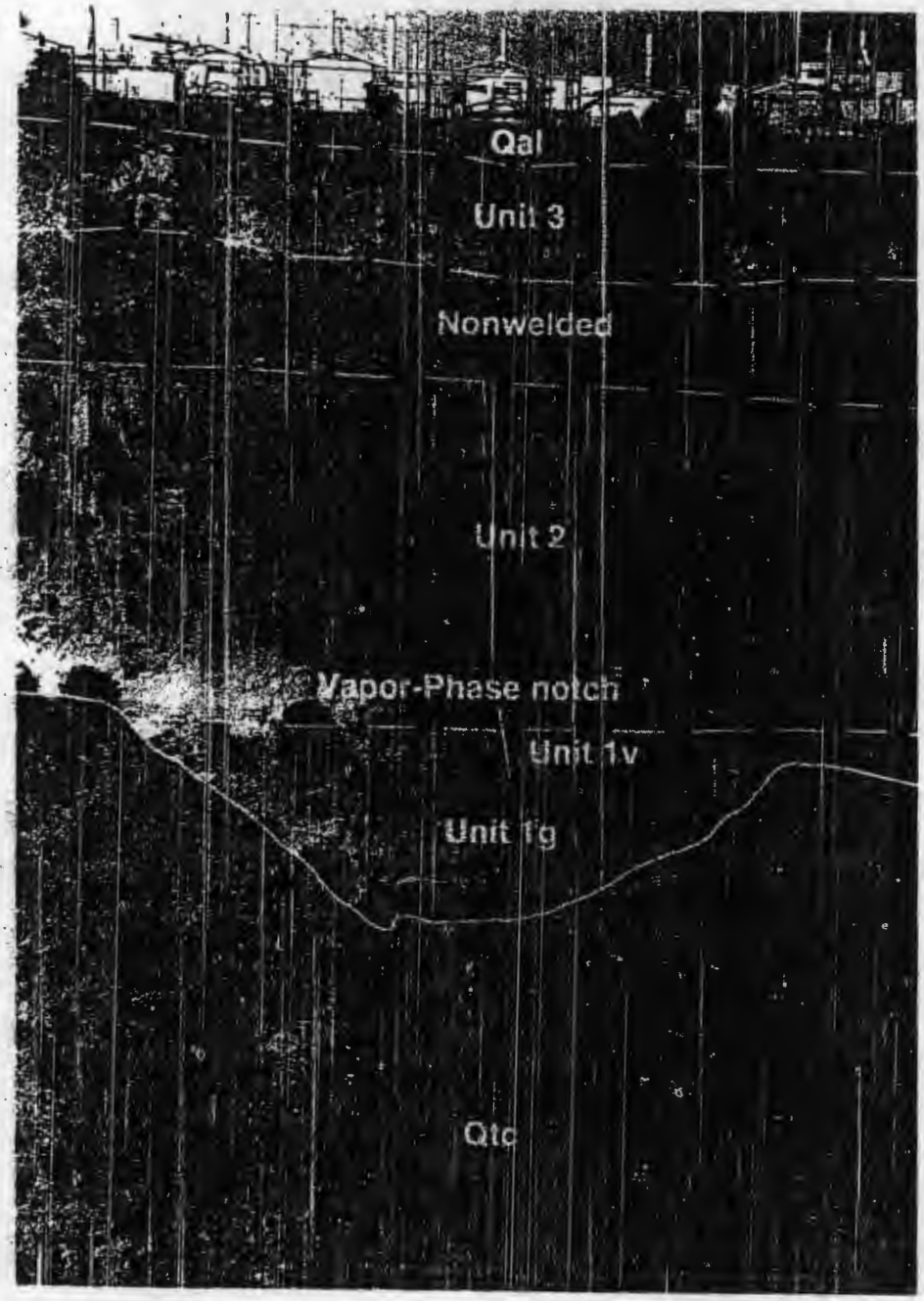


*Fig. 5. Representative photograph of the south wall of DP Mesa (north wall of Los Alamos Canyon); locations of photographs are shown on geologic map (Photo 2/5, Plate 1). Symbols: Unit 1g, Unit 1v, Unit 2, Unit 3-Nonwelded, and Unit 3 are various subdivisions of the Tshirege Member, Bandelier Tuff; vpn = vapor-phase notch; Qtc = post-Bandelier talus and colluvium; Qal on photos refers to post-Bandelier mesa top soils, alluvium, and disturbed fill shown as Qmt and Qf on geologic map and cross sections. Buildings of TA-21 are visible at the top of the mesa.*

Unit 1v overlies unit 1g. Within the map area, unit 1v is consistently ≤40 ft in thickness. It consists of white-to-pink nonwelded to slightly welded tuff that weathers to pale orange. Vapor-phase alteration of individual pumice fragments is pervasive and distinctive because of the color and textural changes described above. Although the ignimbrite is soft, unit 1v also forms cliffs. The top of unit 1v is often defined by a thin bench, but the actual contact between units 1v and 2 is not sharp. More often than not, the contact is defined by a change in color (orange to white ascending) and erodability.

### *Tshirege Unit 2 Ignimbrite*

Unit 2 ignimbrite, further subdivided into welded and nonwelded units by Vaniman and Wohletz (1991), is described as one unit and shown as one unit on the geologic map in this report. The contact between welded and nonwelded units is gradational in the map area. Unit 2 ignimbrite consists of ≤100 ft of white-to-orange-to-brown nonwelded (bottom) to moderately welded (top) tuff. Both pumice and groundmass of moderately welded tuff are dense and hard. The nonwelded base weathers white-to-pale-pink and generally forms a steep slope, whereas the moderately welded top weathers dark-brown-to-orange and forms broadly jointed cliffs. The bottom contact of unit 2 ignimbrite often forms a thin erosional bench with unit 1v. The top of unit 2 forms a wide bench below the mesa top, extending along the entire length of the north wall of Los Alamos Canyon within the map area (Fig. 5).

### *Tshirege Unit 3 Ignimbrite*

Unit 3 ignimbrite is divided into welded and nonwelded units by Vaniman and Wohletz (1991). These units are shown separately on the west and central parts of the geologic map (Plate 1) but are undivided on the eastern part of the map because the units thin and become indistinguishable eastward.

The nonwelded unit is ≤50 ft thick where subdivided on the map and consists of white-to-gray pumice-rich ignimbrite that weathers to pale pink. The nonwelded unit forms broad slopes that are generally covered with talus, brush, and scattered trees.

Unit 3 ignimbrite is nonwelded to partially welded tuff that is ~50 ft thick on the east side of the map area but as thin as 26 ft in the central map area. Differences in relative thickness were noted in north-south directions, as shown in the cross sections. Where partially welded, the ignimbrite consists of gray tuff that weathers to a pale orange and forms broadly jointed, low cliffs that can be climbed at numerous locations. The upper surface of unit 3 ignimbrite is covered with mesa top soil and alluvium or with disturbed alluvium from construction of roads and buildings (Reneau, Sec. V, this report).

## CONCLUSIONS

Bedrock geology of TA-21 consists primarily of Otowi and Tshirege Members of the Bandelier Tuff. The thickness of the Tshirege Member is rather constant over the map area, but thickness of the Otowi Member is only known approximately. In contrast, the Cerro Toledo interval, which lies between the two members of the Bandelier Tuff, varies from 13 to 66 ft in thickness. The Cerro Toledo interval deposits display large-scale variations in lithologic properties both vertically and laterally. No obvious surface expression of faults was found in the map area. One cold spring (DP Spring), found in eastern DP Canyon, issues from a contact between colluvial and valley-fill deposits and Tshirege unit 1g.

The geologic map presented in this report and the detailed stratigraphic and lithologic descriptions (Broxton *et al.*, Sec. IV, this report) complete the geologic characterization of bedrock geologic units in the upper vadose zone for the TA-21 RFI work plan. Additional work is under way to characterize the fracture mineralogy of these bedrock units; results of

these studies will be reported at a later date. The data in this report provide a geologic framework for evaluating potential subsurface transport pathways and will be particularly useful for understanding the distribution of contaminants when characterization boreholes for the MDAs are completed. The map accompanying this report shows the thickness and distribution of geologic units in the upper part of the vadose zone and will support the interpretation of subsurface geologic units penetrated by planned boreholes at TA-21.

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