EVIDENCE FOR A WELDED TUFF IN THE RHYOLITE OF CALICO HILLS

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ABSTRACT

A welded pyroclastic deposit has been identified in the Rhyolite of Calico Hills near Yucca Mountain, Nevada, where only lava flows and nonwelded pyroclastic deposits were previously described. Field data from Fortymile Wash show that nonwelded, bedded tuff grades upward into partially welded massive tuff, and thence into densely welded vitrophyre. Petrographic data show a progressive decrease in inter- and intragranular porosity and amount of vapor-phase minerals, with increasing welding. Pumice fragments are first deformed, then develop diffuse boundaries which become increasingly obscure with progressive welding. The most densely welded rock is a perlitic vitrophyre. The origin of this welded tuff is not clear, as it could represent an ignimbrite or a tuff fused beneath a thick lava flow.

INTRODUCTION

The southern flank of the Timber Mountain Caldera complex in the Southwest Nevada Volcanic Field consists of voluminous, welded and nonwelded rhyolitic pyroclastic flows, lesser amounts of rhyolitic lava flows, and modest amounts of fallout and reworked tuffs. At Yucca Mountain, the thick sequence of volcanic rocks is broken into a series of north-striking, east-dipping fault blocks bounded by west-dipping normal faults. The surface and near-surface rocks of Yucca Mountain are composed primarily of the four major pyroclastic flow sheets of the Paintbrush Tuff. The oldest and thickest of these, the Topopah Spring Member, is a voluminous, densely welded ash-flow tuff which overlies the Rhyolite of Calico Hills, a formation composed largely of lava flows and nonwelded pyroclastic deposits. Provisional revisions to these stratigraphic names have been developed (D.A. Sawyer and others, written commun., 1993), elevating the Paintbrush members, the Rhyolite of Calico Hills, and other regional units to formation status (*Topopah Spring Tuff* or *Formation*) and elevating the Paintbrush Tuff to Paintbrush Group. The critical papers describing these stratigraphic name changes are in press, and the changes will be used here provisionally, for clarity and consistency with future work.

The type section of the Calico Hills Formation is located about 5 km east of Yucca Mountain, where it consists of two lava flows interstratified with three nonwelded pyroclastic deposits.[1] In upper Paintbrush Canyon north of Yucca Wash (see fig. 1),[2] it consists of five lava flows interstratified with bedded and massive nonwelded pyroclastic deposits.[3] Lava flows and thick, nonwelded pyroclastic deposits of the Calico Hills Formation are exposed in Yucca Wash and at Prow Pass, north of Yucca Mountain.[4,5] In boreholes in northern Yucca Mountain, the Calico Hills Formation is present as rhyolitic lava flows and zeolitized nonwelded tuffs, whereas in boreholes in central and southern Yucca Mountain, only the zeolitized tuffs are present.[6] Thin beds of nonwelded fallout and reworked tuff of the Calico Hills Formation are exposed at the north end of Busted Butte. Previous workers have noted the numerous lava flows and thick sequences of bedded and massive nonwelded tuffs, but welded tuffs are conspicuous by their absence.[1,4,5] Results from the present study, however, suggest that welded tuff occurs in the Calico Hills Formation in Fortymile Wash.

Yucca Mountain is being characterized as a potential site for the storage of high-level nuclear waste. Radioactive waste would be entombed within the thick, welded tuff of the Topopah Spring Tuff in the central fault block. The underlying, zeolitized tuffs of the Calico Hills Formation are anticipated to provide a natural barrier to radionuclides that might escape through the engineered barriers of the repository. The existence of welded tuff within the Calico Hills Formation could

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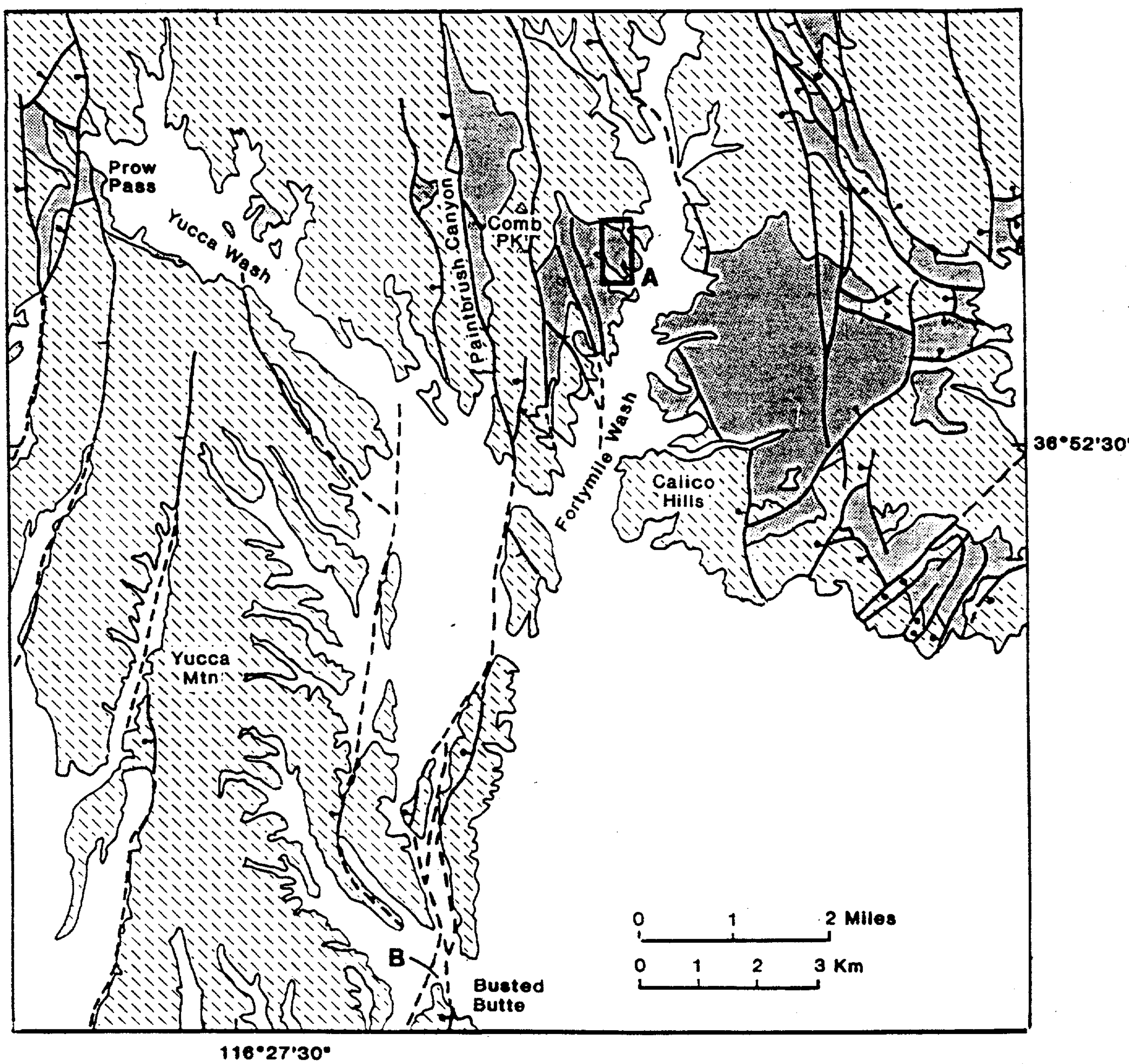

Figure 1. Regional geologic map of Yucca Mountain and the Calico Hills, Nevada. The dashed pattern represents non-Calico Hills Formation bed rock, and the dark pattern represents exposures of the Calico Hills Formation. Box labeled "A" in Fortymile Wash is the area of figure 2. "B" marks the location of thin beds of nonwelded tuff of Calico Hills Formation. The remainder of the map area is Quaternary alluvial fill. Modifications after Frizzell and Schulters.[2]

affect fluid flow within the saturated and unsaturated zones in this formation. The distribution of zeolitic alteration may be affected by the lateral variability associated with welded pyroclastic flows within the Calico Hills Formation. Additionally, determination of whether this unit represents a welded tuff or a tuff fused beneath a thick lava flow may address questions of areal extent of the unit and its impact on fluid movement. Despite its importance to repository design, little detailed study of the Calico Hills Formation has been undertaken. Most detailed mapping and stratigraphic analysis has been focused south of Yucca Wash in the potential site area, where these rocks are not exposed.[5]

DESCRIPTION OF WORK

Recent geologic mapping has focused on the region north of Yucca Wash and west of Fortymile Wash in an effort to understand further the stratigraphy beneath Yucca Mountain (fig. 1). During this mapping, we identified an unusual deposit that may be a welded tuff within the Calico Hills Formation. Four buttes capped by vitrophyre, on the west side of Fortymile Wash, 1 km east of Comb Peak, were previously mapped by Christiansen and Lipman as part of a lava flow.[4] Perhaps significantly, Christiansen and Lipman also documented fused pyroclastic deposits beneath the thick lava flows of Comb Peak in Fortymile Wash, near the present study.[7] The four buttes of the present study were mapped in detail (fig. 2), two stratigraphic sections were measured (figs. 3 and 4), and nine samples were collected from the deposit. A third section was partly measured and sampled (six additional samples), and the available data corroborate the data of the first two measured sections. A petrographic study of thin sections made from these samples has been completed.

FIELD OBSERVATIONS

The pyroclastic deposit of this study is composed of a lower bedded tuff, a discontinuous massive tuff, and a capping vitrophyre. The bedded tuff has a maximum thickness of 31.7 m (fig. 3) and forms a modest cliff beneath three of the four vitrophyre-capped buttes. It consists of a series of parallel beds that are vertically gradational. Individual beds are commonly defined by changes in lithic and pumiceous clast abundance, size, composition, and sorting. Most beds contain both rhyolitic lithic fragments and pumice fragments, though one type commonly predominates locally over the other, and the dominant clast type varies from bed to bed. Clast size averages from 1 to 3 cm and reaches a maximum of 7.5 cm. Pumice clasts are commonly equal in size to or slightly larger than lithic clasts from the same bed. Most beds are matrix-supported and poorly sorted to moderately well-sorted. Some beds are defined only by a color change. The bedded tuff does not contain well-sorted, clast-supported beds typical of fallout deposits, nor does it contain the cross-bedded, normally graded, cut-and-fill structures common to reworked deposits. There are no sharp contacts within the bedded tuff to suggest a break in deposition or change in depositional process. The bedded tuff is nonwelded.

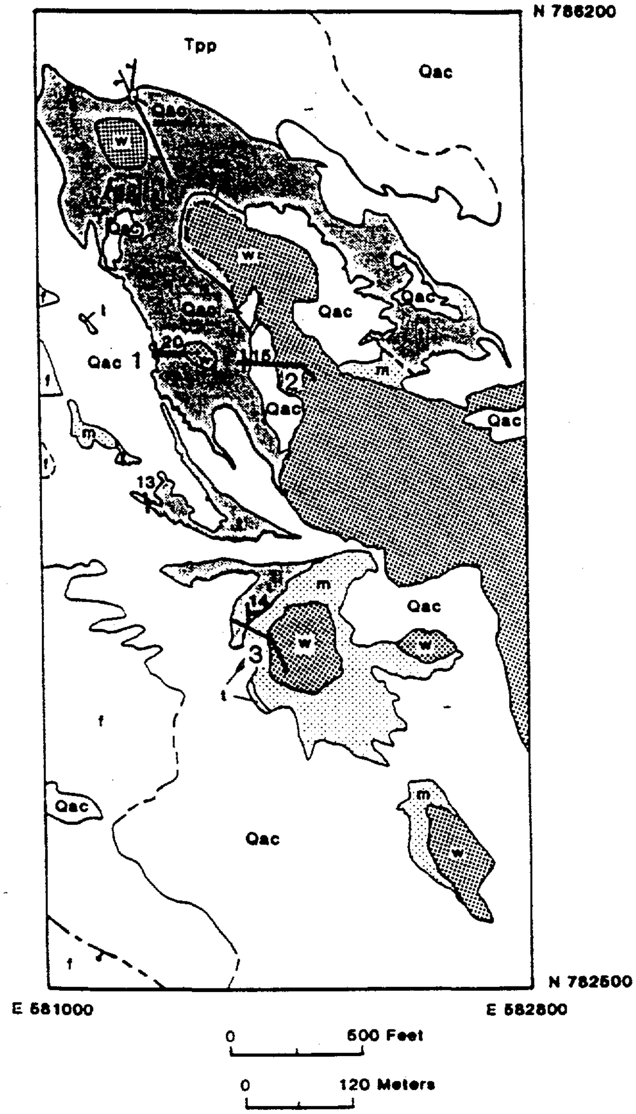

Figure 2. Detailed geologic map of the welded ash-flow tuff within the Calico Hills Formation, in Fortymile Wash. Coordinates are from the Nevada State Coordinate System. Qac = Quaternary alluvium, colluvium, and rock fall deposits; Tpp = Pah Canyon Tuff of the Paintbrush Group; f = lava flow, Calico Hills Formation; t = bedded tuff, Calico Hills Formation; m = massive tuff, Calico Hills Formation; and w = vitric welded tuff, Calico Hills Formation. 1 = measured section 1; 2 = measured section 2; 3 = measured section 3.

The massive tuff of this report (fig. 2) was originally mapped as a "tuff breccia" by Christiansen and Lipman and described as "vesicular glass blocks in a zeolitized shard-and-pumice matrix".[4] Surface exposures

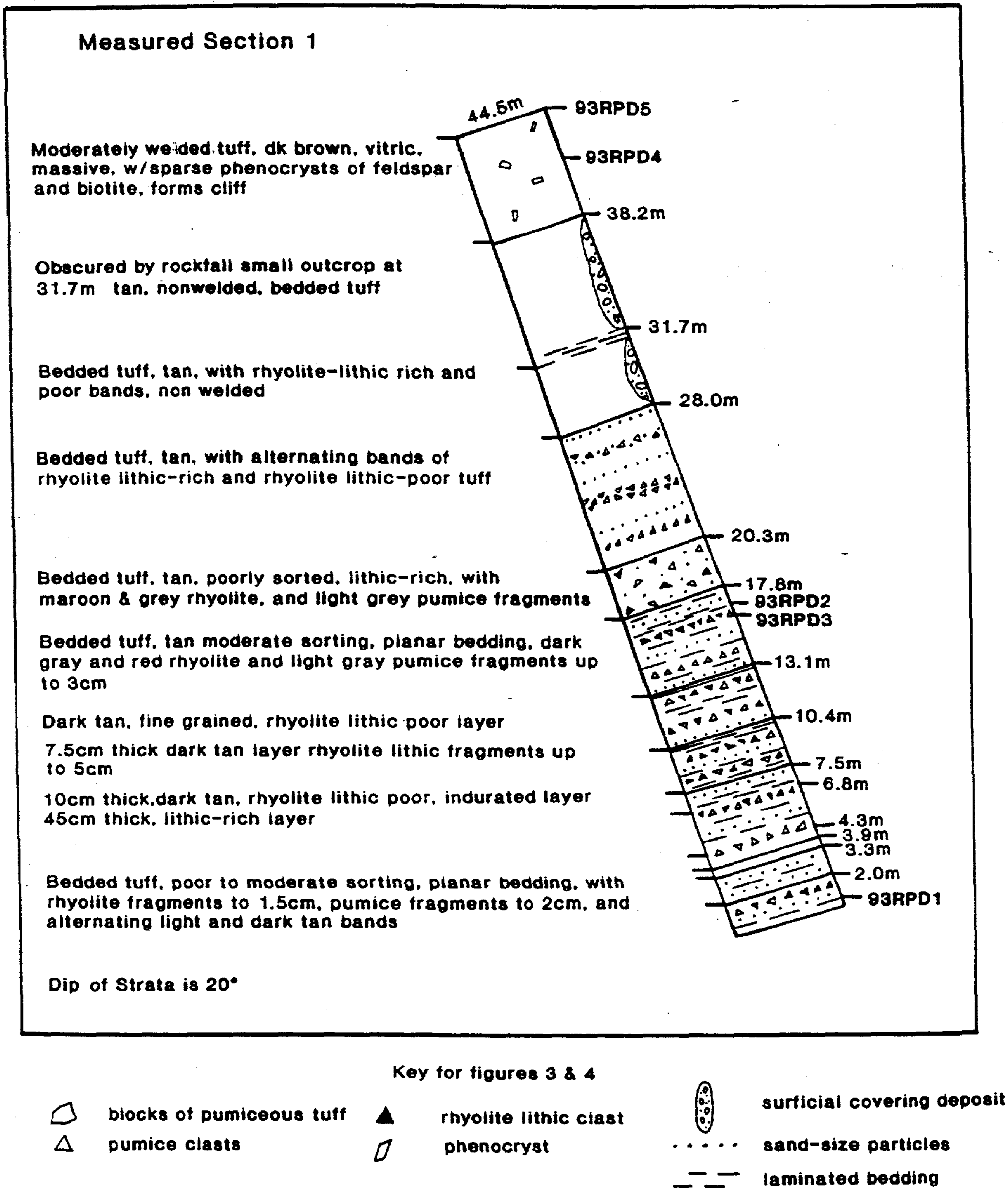

Figure 3. Measured section 1, oriented to show actual stratigraphic thickness and local dip of the strata. Actual topographic expression of section 1 is different. Sample locations are indicated by labels of the form **93RPDx**.

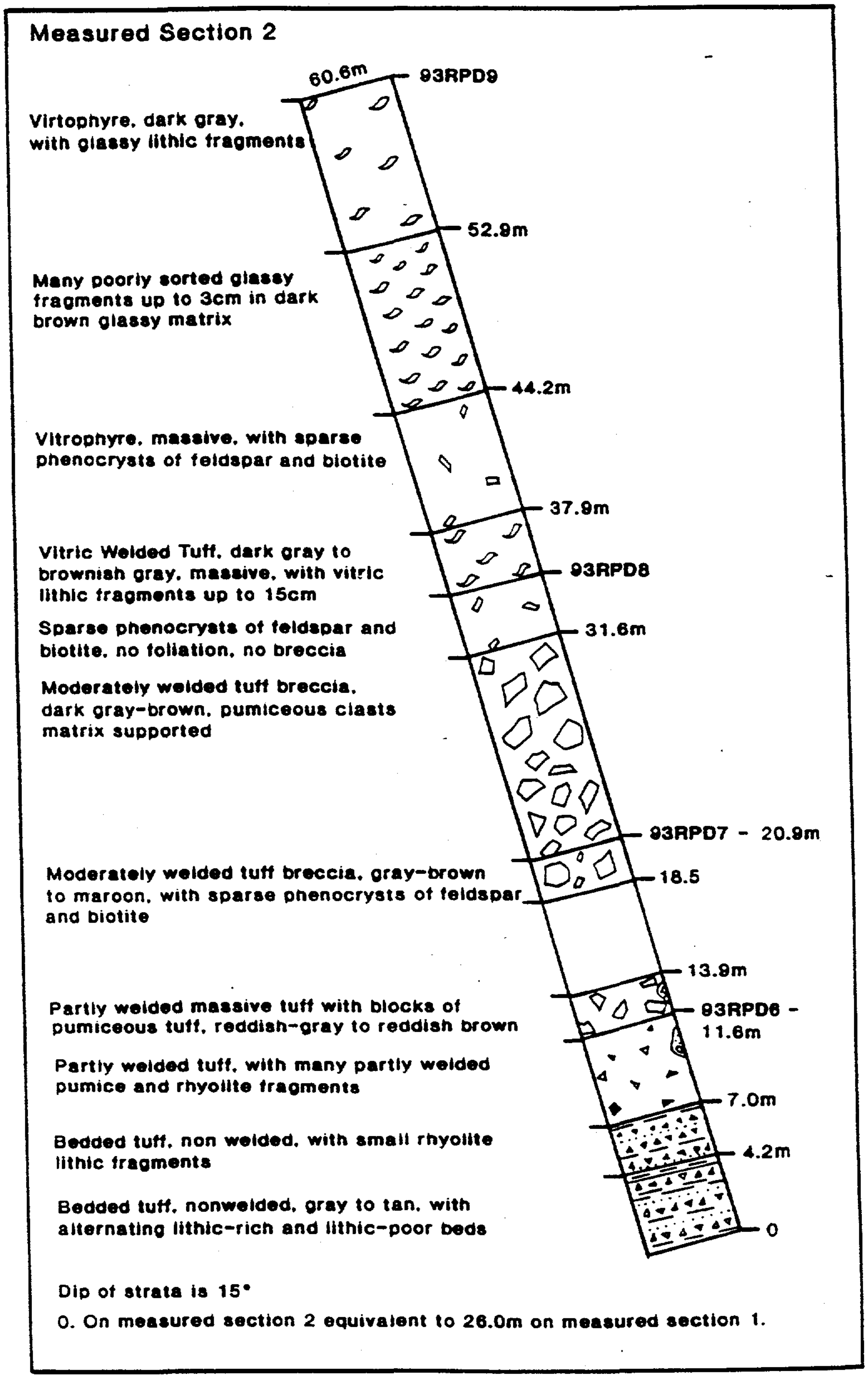

Figure 4. Measured section 2, oriented to show actual stratigraphic thickness and local dip of the strata. Actual topographic expression of section 2 is different. The zero (0) m point on section 2 correlates to the 26.0 m point on section 1. The 60.6 m mark correlates to the highest point of the highest butte. Sample locations are indicated by labels of the form **93RPDx**.

of this unit are grayish-tan, altered, and without discernible internal structure. The unit is locally breccia-like and contains numerous, irregular blocks (up to 20 cm) of altered pumiceous tuff and altered vesicular glass in a matrix of altered or devitrified ash. The massive tuff is less resistant than the bedded tuff to erosion and forms low-angle slopes that are commonly covered by rock-fall deposits. The thickness of this unit and the size and number of pumiceous blocks it contains increase to the south within the mapped area. In measured section 2 this unit is nearly 20.0 m thick (fig. 4), and it is 40.4 m thick in section 3. The contact between the bedded tuff and the massive tuff is gradational. The onset of welding occurs near the top of the massive tuff as it is mapped here.

The vitrophyre forms gray to chocolate brown, steep-sided buttes. There are no flow foliations, lithophysae, autobreccia, banded devitrification textures, or spherulites within the vitrophyre. The color of the vitrophyre darkens from the base to the top of outcrops. Lithic clasts are visible on weathered and fresh surfaces, but pumiceous clasts are discernible only on weathered surfaces. The lithic clasts appear similar to those found in the underlying massive tuff and bedded tuff. At the southern-most vitric butte in the mapped area (fig. 2), the vitrophyre contains glassy blocks similar to those found in the breccia-like parts of the massive tuff. The vitrophyre attains a maximum measured thickness of 22.7 m in section 2 (fig. 4). The contact between the vitrophyre and the underlying massive tuff is gradational but is marked locally by an abrupt change in slope.
The onset of welding appears at different stratigraphic levels in different locations but is always within the massive tuff. In measured section 1, the onset of welding occurs 12 to 15 m above the top of the bedded tuff, but it is within 4 m of the top of the bedded tuff in measured section 2. A gradual upward increase in welding is accompanied by gradual darkening of the color of the rock. A sudden change in the slope angle and an abrupt color change occur at the base of the buttes, marking the transition from partially welded to densely welded. Examination of pumice-clast deformation and glassy texture in hand samples, however, reveals this welding transition to be gradational, despite the sharp geomorphic break. The color and vitric texture of the rocks forming the buttes change gradually upward, to a black, glassy vitrophyre occurring at the top of the highest buttes.

The regional extent of these units is incompletely understood. The tuffs and vitrophyre dip eastward at 13° to 20° (fig. 2) and are exposed for 1070 m from the northwesternmost exposures to outcrops in Fortymile Wash southeast of measured section 2. Beyond this point, the vitrophyre is covered by younger alluvium. Northeast of the vitrophyre there are scattered exposures of lava flows more typical of the Calico Hills Formation. These rocks exhibit parallel and contorted flow foliations, autobreccias, spherulites, banded devitrification textures, and irregular lithophysae. Regional dip suggests that these lava flows are stratigraphically above the welded tuff, but there are no exposures that demonstrate this relationship.

PETROGRAPHY

The tuffs can be subdivided petrographically into nonwelded tuff, partially welded tuff, densely welded tuff, and vitrophyre. Microscopic examination of thin sections reveals that the tuff contains rhyolitic lithic fragments, pumiceous lithic fragments, and phenocrysts of quartz, plagioclase, sanidine, and biotite. Opaque minerals are observed locally around biotite phenocrysts or aligned parallel to compaction foliation. Pumice-rich layers and lithic-rich layers in the tuff responded differently to the welding process. Lithic fragments are unaffected by welding, whereas pumice fragments are progressively deformed and more completely fused. Within this suite of samples, all changes in porosity, vapor-phase mineralization and zeolitic alteration, pumice compaction, and development of vitric and perlitic textures are gradational and progressive.

The nonwelded tuff contains pumice fragments with distinct margins and planar internal foliation. Pumice fragments are deformed only slightly or not at all and are randomly oriented. The matrix consists of fine-grained volcanic ash, and clay and zeolites derived from altered ash. Ash shards have all been devitrified or altered to zeolites. The ashy matrix does not appear compacted. The nonwelded tuff is characterized by intergranular porosity in the matrix and intragranular porosity within pumice fragments. Axiolitic crystals are more abundant within pores of the nonwelded tuff than in any of the welded tuffs. These minerals are probably the result of zeolitic alteration, vapor-phase crystallization, or both.

The suite of thin sections collected from the partially welded tuff demonstrates a progressive loss of intergranular porosity within the matrix and diminished intragranular porosity within pumice fragments. The matrix appears compacted, more dense, and darker in color than in the nonwelded tuff. Individual shards are typically indistinguishable in the matrix due mainly to pervasive zeolitic alteration. Some pumice fragments in the partially welded tuff maintain a distinct boundary between the pumice clast and the ash and clay of the matrix; other pumice fragments exhibit a more diffuse margin. In pumice-rich layers, the pumice fragments are more flattened, exhibiting a pronounced parallel compaction foliation that locally wraps around phenocrysts. Vitric texture partially replaces the compaction foliation within some pumice fragments. Secondary mineral growth is less common than it is in the nonwelded tuff. Such minerals occur both as axiolitic needles and equant crystals coating flattened pores within pumice fragments, and they probably represent vapor phase crystallization and zeolitic alteration.

In the densely welded tuff, all porosity has been destroyed, and vapor-phase minerals were not observed. The margins of pumice fragments locally become very obscure. In pumice-rich layers, the compaction foliation has been overprinted by a dense glass; relict foliation is preserved locally as lineations of opaque minerals within the glass. Perlitic cracks are developed in some glassy pumice fragments but not in the matrix. The matrix appears as dense, dark, irregular patches between glassy, welded, pumice fragments.

The vitrophyre, which exhibits the highest degree of welding, is dominated by vitric texture with widespread development of perlitic cracks. Phenocrysts of feldspar, quartz, and biotite, and rhyolitic lithic fragments occur in similar abundances to those of the underlying tuff. The margins of pumice fragments are very obscure, and individual pumice fragments are difficult to recognize petrographically. Most traces of compaction foliation are absent but are locally preserved as parallel lineaments of very small opaque mineral grains. Interestingly, weathered outcrop exposures from this same stratigraphic interval show the faint outline of discrete pumice fragments. The matrix has largely been converted to perlitic glass that contains irregular dark patches. There is no visible porosity, and vapor-phase minerals are completely absent.

CONCLUSION

A sequence of bedded tuff, massive tuff, and vitrophyre occurs within the Calico Hills Formation in Fortymile Wash. This sequence lacks the sharp contacts, layers of autobreccia, flow foliations, banded devitrification textures, spherulites, and lithophysae that are characteristic of lava flows within the Calico Hills Formation in Fortymile Wash, Paintbrush Canyon, and Black Glass Canyon. Petrographic data from this study show a continuum of welding phenomena that are progressive from nonwelded tuff to vitrophyre. This continuum is particularly well-illustrated by the pumice fragments, which progress from undeformed and randomly oriented, to deformed in parallel alignments, to vitric, to perlitic. Such observations are consistent with the features of welded tuffs.[8,9] It is not presently known what rocks existed stratigraphically above the vitrophyre. More of this sequence probably exists beneath younger surficial deposits where the unit dips to the east (fig. 2).

Current data are not sufficient to determine if this unit represents a welded ignimbrite or a tuff fused beneath a thick lava flow.[7] Christiansen and Lipman have demonstrated the fusion of tuff to a maximum depth of 75 m into the pyroclastic deposits beneath the thick lava dome on Comb Peak near these exposures of the Calico Hills welded sequence. Those fused tuffs are locally indistinguishable from ignimbrites.[7]

The existence of welded tuffs within the Calico Hills Formation could have a bearing on fluid flow within these rocks in the unsaturated zone, as well as on the amount and distribution of zeolitized tuff within this formation. Determination of whether this unit represents a welded tuff or a tuff fused beneath a thick lava flow has important bearing on its extent. If the welded tuff of this study represents a tuff fused beneath a lava flow, then the extent of such welded units would be dependent upon the distribution of thick lava flows. If this unit represents a welded pyroclastic flow, however, then welded tuffs could appear in the Calico Hills Formation independently of the distribution of lava flows. The lateral variability of lava flows and pyroclastic deposits within the Calico Hills Formation will have a direct bearing on the type of rocks can realistically be expected to occur beneath Yucca Mountain. Further detailed geologic mapping in Fortymile Wash may determine the significance of this welded tuff to the internal stratigraphy of the Calico Hills Formation and the larger questions of hydrologic flow beneath Yucca Mountain.

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