GEOLOGIC COMPONENTS OF SITE CHARACTERIZATION AND PERFORMANCE ASSESSMENT FOR A RADIOACTIVE WASTE MANAGEMENT FACILITY AT THE NEVADA TEST SITE

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ABSTRACT

The Radioactive Waste Management Site (RWMS), located along the eastern boundary of the Nevada Test Site, has been proposed as a location for a long-term, low-level radioactive waste management facility. The geologic setting of the RWMS requires a program with three major components: tectonism, volcanism, and surficial geology. Rather than treating these as independent activities, these components have been organized to construct a model of the late-Cenozoic landscape evolution of northern Frenchman Flat. To help identify faults that could impact the proposed facility, lineaments in the northern Frenchman Flat area were mapped using remotely-sensed data. To date, the only lineament confirmed by field evidence to be fault-related and associated with surficial deposits is 3.5 km northwest of the RWMS in the longitudinal valley of the Massachusetts Mountains; the faulting is late-Tertiary to Quaternary. No evidence of faulting was found during mapping of alluvium in pit walls at the RWMS proper. In the vicinity of Frenchman Flat, silicious volcanism ended about 10 million years ago (Ma) and basaltic volcanism ended 6.5 Ma. The hazard of volcanism at the RWMS within the 10,000-year regulatory period is considered very low due to the lack of evidence for post-Miocene volcanism in the vicinity of Frenchman Flat. Middle Miocene to Quaternary alluvium overlies the faulted middle Miocene rocks in northern Frenchman Flat, meaning that a proto-Frenchman Flat basin had formed by middle Miocene time. Drillhole investigations and pit wall mapping at the RWMS obtained detailed near-surface information about the Quaternary alluvium. Soils characterized by structural development and the accumulation of calcium carbonate are present throughout the exposures at the RWMS, indicating repeated periods of surface stability in the Quaternary. Large-scale (1:6,000) surficial geology maps are being made of northern Frenchman Flat. These will provide both fundamental data and the platform needed to reconstruct the Quaternary history of the area. At present, seven geomorphic surfaces are recognized, spanning from early Quaternary to historic time.

INTRODUCTION

The Radioactive Waste Management Site (RWMS) at the Nevada Test Site (NTS) has been proposed by the U.S. Department of Energy as a location for a long-term, low-level radioactive waste management facility. The siting of such a facility requires geologic investigations to satisfy criteria of the Resource Conservation and Recovery Act (40 CFR 264.18 "Location Standards" and 270.14 "Contents of Part B: General Requirements") and Low-Level Waste regulations (10 CFR 61.50), and to support the Greater Confinement Disposal (GCD) Program Performance Assessment (1) requirements in 40 CFR 191 "Environmental Radiation Protection Standard for Management and Disposal of Spent Nuclear Fuel, High-level and Transuranic Radioactive Wastes."

The RWMS is located in northern Frenchman Flat, a closed basin along the eastern boundary of the NTS. This basin is bound by mountains on the south and east consisting primarily of limestone and clastic rocks of Paleozoic age, and on the north and west by pyroclastic rocks of Miocene age (2). In northern Frenchman Flat, the Miocene volcanic and underlying pre-Tertiary rocks that demarcate the basin are broken by numerous normal faults, resulting in fault blocks that are gently to moderately tilted. Although regional Miocene tectonism began earlier, at least the northern portion of Frenchman Flat formed at some time after deposition of middle Miocene volcanic rocks about 11.5 million years ago (Ma) (3), but before intrusion of basaltic dikes along some of the faults about 8.5 Ma (4). This extension has continued into the Holocene as evidenced by movement along the Yucca Flat fault along the western margin of the basin and Rock Valley fault along the southern margin of the basin (5).

The geologic setting of the site requires a program with three major components: tectonism, volcanism, and surficial geology. Rather than treating these as independent activities, these components have been organized to construct a model of the late-Cenozoic landscape evolution of northern Frenchman Flat. The program first constructs a general landscape model for site characterization purposes, and then pursues detailed geologic studies as specific data needs for either site characterization or performance assessment arise. Such a program is flexible with regard to expansion of a particular component and allows ready incorporation of new information into the previous landscape model.

TECTONISM

To help identify faults of regulatory significance that could impact the proposed facility, lineaments in the northern Frenchman Flat area were mapped using remotely-sensed data. The purpose of this work was to identify non-cultural lineaments (i.e., lineaments not associated with roads, fences, or human disturbance) that may be related to the surface expression of faults. Tonal contrasts, linear drainages, alluvial and bedrock scarps, topographic saddles, and breaks-in-slope were all mapped. Some of these lineaments may not be

tectonic in origin. Field work is ongoing to evaluate these features.

The remotely-sensed data used to construct the lineament map (Fig. 1) included color aerial photography (scales of 1:12,000 and 1:24,000), infrared aerial photography (scale of 1:6,000), and side-looking airborne radar images (approximate scale of 1:120,000). Many bedrock faults were mapped by Hinrichs and McKay (7) and Poole (8), and most are linear. However, only those faults having topographic expression (i.e, a scarp or slope break) were included on the lineament map. After the lineaments were compiled onto a base map they were classified (Fig. 1) according to a system used by Wesling *et al.* (9) in Midway Valley, 40 km to the west.

The field investigation of lineaments is an on-going component of both the surficial mapping and trench investigations. To date, the only lineament confirmed to be fault-related and associated with surficial deposits is located 3.5 km northwest of the RWMS in the longitudinal valley of the Massachusetts Mountains. The faulting is late-Tertiary to Quaternary in age. This interpretation is based on the faulting

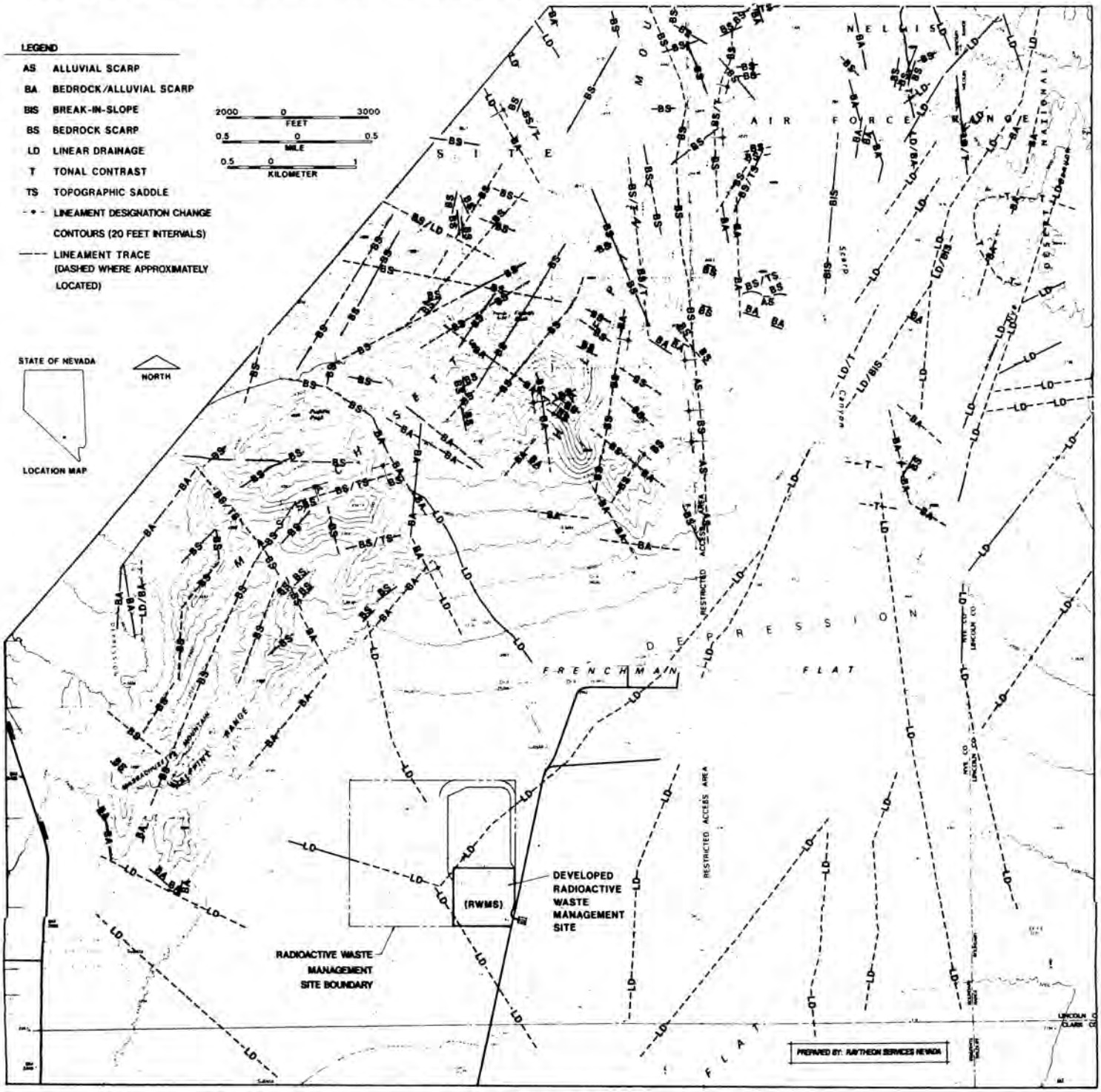

Fig. 1. Lineaments identified in northern Frenchman Flat, Nye, Lincoln, and Clark Counties, Nevada. Figure adapted from Miller et al. (6).

of conglomeritic alluvium, tens of meters thick, that overlies an ash deposit tentatively correlated with the Frenchman Flat Ash, which is estimated to be older than 2.9 Ma (10).

VOLCANISM

Volcanic activity was identified as one of the potentially disruptive scenarios at the GCD facility (11). RSN has undertaken a limited study of volcanic hazards at the RWMS. The main objectives of the study were to first summarize the literature as it applies to the study area, and second to obtain the most recent numerical age estimates of samples from Frenchman Flat, in support of the Performance Assessment scenario development.

The risk of volcanism in the NTS region includes future silicic and basaltic volcanic activity. However, the hazards of silicic volcanism are considered to be negligible because (4):

- Quaternary-age silicic volcanism is restricted to the eastern and western margins of the Great Basin.
- Silicic volcanism has been absent in the NTS region for the last 8.5 Ma.
- During the last 10 to 20 Ma there has been a dramatic decrease, and in most areas a cessation, of silicic volcanism within the central and southern parts of the Great Basin.

There are no Pliocene or younger silicic centers within a 50-km radius of the RWMS. No site-specific data at or near Frenchman Flat has been found in the literature or through field investigations that would alter the above interpretation of silicic volcanism near the RWMS.

A transition from predominantly silicic volcanism to predominantly basaltic volcanism occurred approximately 10 Ma (12). Hazards of basaltic volcanism at the NTS have been judged through research approaches combining hazard appraisal and risk assessment. The most likely values of the probability of magmatic disruption of the proposed waste repository at Yucca Mountain, 45 km west of the RWMS, are less than 1 in 10,000 in 10,000 years (13). Field investigations and drillhole studies suggest shallow basalt intrusions are rare in the geologic record of the southern Great Basin. Based on the analysis of previous basaltic volcanism in the NTS region, there is no evidence of evolution toward either an increase in the volcanic rate or the development of a large-volume volcanic field (14).

The youngest basalt exposed at the land surface nearest the RWMS is that of Nye Canyon, an older post-caldera basalt (13). The Nye Canyon basalt consists of at least five centers (Fig. 2). Three of the surface basalts in Nye Canyon were described through detailed field investigations and chemical analyses (14). The three centers are the oldest basalt units (6.5 Ma) in the Yucca Mountain region that show a northeast structural trend (13, 15).

In Frenchman Flat, basalt was intersected beneath about 290 m of alluvium in drillholes UE-5i and UE-5k, which are located approximately 2 km north and northeast of the RWMS, respectively (Fig. 2). The numerical age of this basalt flow, presumably from a local center underlying Frenchman Flat, is 8.6 Ma (16). The Paintbrush and Timber Mountain Tuffs northeast of the RWMS were intruded by two small plugs of probably related age (Fig. 2).

A regional hiatus in volcanic activity occurred after eruption of the basalts of Nye Canyon. No volcanic rocks of the NTS region have yielded numerical ages in the range of 6.5 to

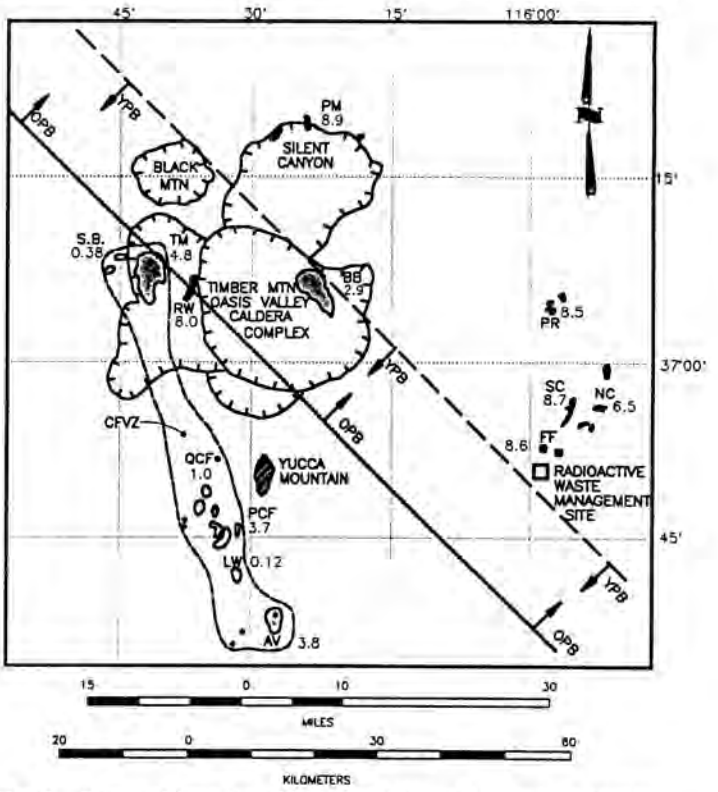

Fig. 2. Post-caldera basalts of the Yucca Mountain region. Shaded areas are the Older Post-Caldera Basalt (OPB) including: basalt of Frenchman Flat (FF), which were intersected in drillholes; basalt of Nye Canyon (NC); basalt of Pahute Mesa (PM); basalt of Rocket Wash (RW); basalt of Scarp Canyon (SC). Stippled areas are the Younger Post-Caldera Basalt (YPB) including: basalt of Amargosa Valley (AV); basalt of Buckboard Mesa (BB); basalt of Lathrop Wells (LW); Quaternary basalt of Crater Flat (QCF); Pliocene basalt of southeast Crater Flat (PCF); basalt of Sleeping Butte (SB); basalt of Thirsty Mesa (TM). Asterisks mark aeromagnetic anomalies identified as potential buried basalt centers or intrusions (18, 14). Dashed line encloses the area of the Crater Flat Volcanic Zone (CFVZ). Numbers associated with the symbols for the volcanic units of the OPB and YPB are the age estimates in millions of years (Ma). Figure adapted from Crowe (12).

4.8 Ma (Fig. 2). The younger post-caldera basalt (YPB) includes all volcanic rocks younger than the basalt of Nye Canyon (13). The nearest Pliocene-Quaternary basalt to the RWMS is the basaltic andesite of Buckboard Mesa, 40 km northwest of the RWMS, with numerical ages of about 2.9 Ma (Fig. 2). Crowe and Perry (17) defined a narrow northwest trending zone called the Crater Flat Volcanic Zone that encompasses all the YPB centers, with the exception of the basalt of Buckboard Mesa (Fig. 2).

Crowe (13) concurred with established predictions of the nature of future volcanic activity in the Yucca Mountain region, as to the most likely composition and type of volcanic activity. He concluded:

- The highest probability of a near-term event is the recurrence of a small volume eruption at the Lathrop Wells or Sleeping Butte volcanic centers, 50 to 75 km to the west of the RWMS. These eruptions would

probably be analogous to the last eruptions at these centers. This prediction is based on the concept of polycyclic basalt eruptions.

- The formation of a new volcanic center or cluster of centers has a finite probability of occurring at the NTS, with the most likely area of formation being in the Crater Flat Volcanic Zone.

Local and regional studies of volcanic risk indicate that major changes in regional volcanic activity within the next 10,000 years are not likely. Thus, based on the Miocene ages of the Nye Canyon basalt (6.5 Ma) and the basalt center underlying Frenchman Flat (8.6 Ma), and the lack of evidence for post-Miocene volcanism in the vicinity of Frenchman Flat, the hazard of basaltic volcanism at the RWMS within the 10,000-year regulatory period is very low and not physically reasonable.

SURFICIAL GEOLOGY

Subsurface Investigations

Middle Miocene to Quaternary alluvium overlies middle Miocene rocks in northern Frenchman Flat. Cuttings from 12 drillholes in northern Frenchman Flat have been examined to determine sediment provenance, thus lending insight into basin evolution. The basalt flows estimated at 8.6 Ma in drillholes UE-5k (Fig. 3) and UE-5i overlie older alluvium in each hole. The accumulation of sediment prior to 8.6 Ma suggests that at least a proto-Frenchman Flat basin was present at this time and was accumulating sediment. The occurrence of the basalt at a similar depth in drillholes 2 km apart suggests either the basalt layer is on a single fault block or that minimal fault activity has taken place since emplacement in middle Miocene time.

Analysis of cuttings from UE-5k and several other drillholes identify the post-basalt period as a time when the alluvium was dominated by volcanic lithologies (Fig. 3), suggesting the dominant source area was the Massachusetts Mountains and Halfpint Range directly to the west and north. Below the basalt layer there is an abrupt increase in proportion of Paleozoic carbonate and quartzite, with the most probable source being Nye Canyon to the north and east. The implications for basin development continue to be analyzed.

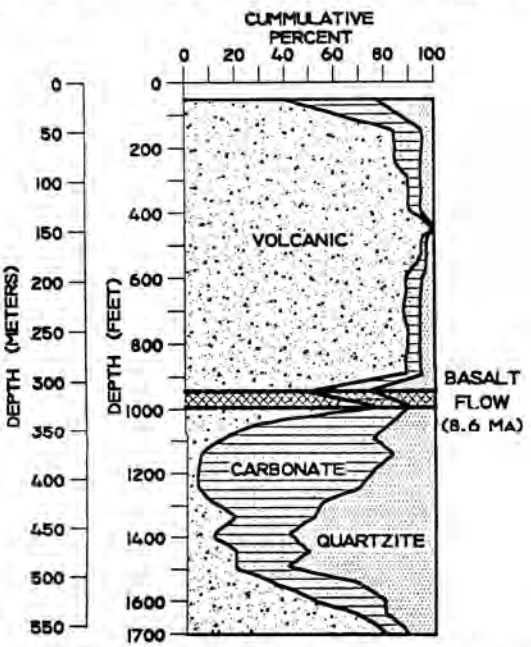

Fig. 3. Proportion of rock lithologies in drillhole UE-5k in northern Frenchman Flat. Age estimates of basalt from Turrin (16).

In addition to the drillhole investigation, the walls of four excavations (a total of 425 m) at the RWMS were mapped and sampled to obtain detailed near-surface information about the Quaternary alluvium and to check for faults (19). In the 425 m of exposure mapped to a depth of about 10 m, the alluvium consists of conglomeritic to fine-grained sediment, which represents deposition on the lower–middle portion of the largest fan complex issuing into Frenchman Flat from the north. Alluvium exposed in the pit walls displays characteristics typical of lower-middle to distal alluvial fan deposition, including sheet-flood, stream channel, and thin debris flows. Although present, debris flows are only a minor component compared with the other two. Provenance analysis shows that the source area contains a mixture of pyroclastic volcanic, quartzite, carbonate, and minor amounts of other sedimentary rocks. This information, combined with paleoflow measurements, indicates deposition predominantly from the northeast, meaning the Scarp Canyon-Nye Canyon fan complex and associated watersheds are the source for most of the sediments.

Six allostratigraphic units (20), informally named Unit A1 (lowermost) through A6 (uppermost), were identified and mapped in the four excavations. The sediments were also segregated into nine lithofacies based on such features as grain size, sorting, clast abundance, and bedding. Whereas the allostratigraphic units are remarkably laterally continuous, both within pit walls and among the pits, the lithofacies often grade into one another both laterally and vertically within an allostratigraphic unit. The lithofacies are more laterally continuous in exposures oriented nearly parallel to paleoflow than those perpendicular to paleoflow, which display abundant channel scours.

Soils characterized by structural development and the accumulation of calcium carbonate are present throughout the exposures at the RWMS, indicating repeated periods of surface stability in the Quaternary. Soils have overprinted much of the original sedimentological character throughout Units A6, A5, and A3, and are conspicuous at the top of Unit A4 and portions of Unit A1. The loose, bedded sedimentary structure in the C horizons passes to massive structure in the transitional BC horizons, and ultimately to weak subangular blocky structure in most B horizons. Calcium carbonate has accumulated in the B and BC horizons as coatings on clasts with pendants of pebbles and sand beneath, and as common filaments and masses in the matrix, stage I and I+ following Birkeland (21) as modified from Gile *et al.* (22). Associated with this carbonate accumulation is the progressive etching of paleocarbonate coatings from clasts with increasing pedogenic development.

Surficial Mapping

Large-scale (1:6,000) surficial geology maps that include geomorphic surfaces and surficial deposits are being made of northern Frenchman Flat. This work will provide both fundamental data and the platform needed to reconstruct the late-Cenozoic history of the area. This mapping uses color and color-infrared aerial photographs and field verification of map unit composition and boundaries. Criteria for defining the map unit composition of geomorphic surface units are

based on relative geomorphic position, landform morphology, and degree of preservation of surface morphology, like that used by Gibson *et al.* (23) and Wesling *et al.* (9) in Midway Valley. A preliminary photo-interpretive map at a scale of 1:12,000 of geomorphic surfaces has been prepared (24) and provides a framework for detailed mapping. At present, seven geomorphic surfaces are recognized, spanning from early Quaternary to historic time (about 1 million years).

Another goal of this mapping is to extend or correlate the allostratigraphy of the RWMS pit walls to the surficial deposits mapped. This is being aided by detailed mapping of four trenches north of the RWMS. Trench 1 will be used as an example. Trench 1 is the nearest of the four trenches to the RWMS, located at the northwest corner of the RWMS and transverse to a drainage lineament (Fig. 4). Two allostratigraphic units are recognized in Trench 1, Unit A5 and Unit A6, which has subunits A6[1], A6[2], and A6[3]. The bounding discontinuity between Units A5 and A6 is approximately 1 m below the surface. Because the boundary is not traceable from the pits to Trench 1, the boundary placement is based on a relative-age correlation of the truncated paleosol in Unit A5 between the pits and Trench 1. In this trench, as in the pits, Units A5 and A6 are considered different lithostratigraphic units because they differ significantly in their proportion of Paleozoic clasts, 3 and 19 percent, respectively.

CONCLUSIONS

The geologic setting and regulatory requirements for a proposed low-level radioactive waste management facility at Frenchman Flat require a flexible site characterization program consisting of three areas of geologic investigation: tectonism, volcanism, and surficial geology. These components have been organized to construct a late-Cenozoic landscape evolution model of the study area. The model begins with the deposition of pyroclastic rocks of Miocene age over a landscape dominated by limestone and clastic rocks of Paleozoic age. Subsequent faulting between about 11.5 and 8.6 Ma apparently opened a proto-Frenchman Flat basin. Local evidence of continued fault activity into the late-Tertiary or Quaternary is present in the Massachusetts Mountains, 3.5 km northwest of the proposed facility; field checking of a lineament map found evidence of faulting in alluvium.

An analysis of local and regional volcanic studies found that in the area around Frenchman Flat, silicious volcanism ended about 10 Ma and basaltic volcanism ended 6.5 Ma. Thus, the risk of volcanism within the next 10,000 years is very low and volcanism can be eliminated from scenario development in the GCD Performance Assessment because it is not physically reasonable.

Although evidence of faulting is present near the RWMS, no such evidence was found during mapping of pit walls at the RWMS proper. Six allostratigraphic units were traced without evidence of faulting and readily correlated within and between the pits. This stratigraphy is being extended as part of the surficial mapping effort, which includes geomorphic surfaces and surficial deposits. It will provide both fundamental data and the platform needed to reconstruct the late-Cenozoic history of the area. At present seven geomorphic surfaces are recognized, spanning from the early Quaternary to historic time.

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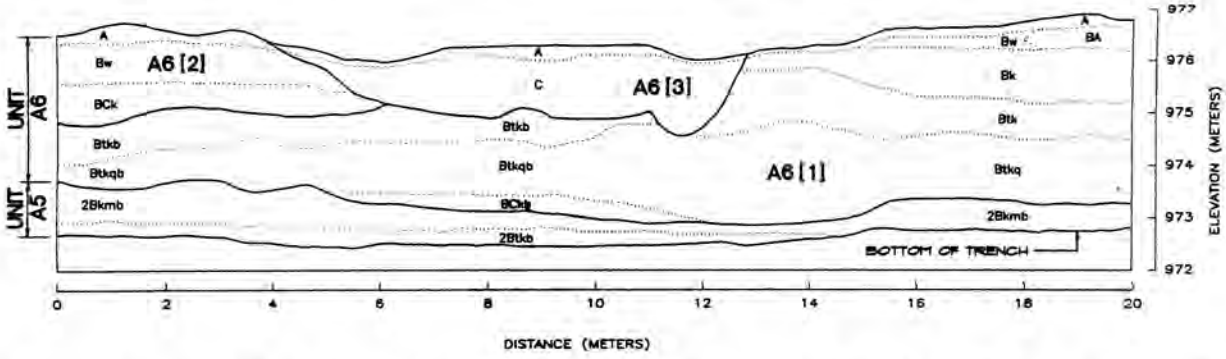

Fig. 4. Stratigraphy and soil horizons of south wall in soil trench 1, northern Frenchman Flat, southern Nevada.

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