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REGIONAL STRATIGRAPHY OF OLIGOCENE AND LOWER MIOCENE STRATA IN THE YUCCA MOUNTAIN REGION

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QUALITY OF DATA, ANALYSES, AND CODE DEVELOPMENT

DATA: CNWRA data contained in this report meet quality assurance requirements described in the CNWRA Quality Assurance Manual. Data used to support conclusions in this report taken from documents published by U.S. Department of Energy (DOE) contractors and supporting organizations were generated under the quality assurance program developed by the DOE for the Yucca Mountain Project.

ANALYSES AND CODES: Maps and related Geographic Information System (GIS) data were generated and plotted by the software ArcView GIS© Versions 3.1 and 3.2a, which are commercially available software codes that are maintained in accordance with CNWRA Technical Operating Procedure TOP–018.

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ESRI. "ArcView GIS©." Version 3.2a. Redlands, California: ESRI. 2000.

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EXECUTIVE SUMMARY

Yucca Mountain lies near the western edge of the Basin and Range Province of the North American Cordillera. The region's geology is characterized by complex interactions between strike-slip and extensional deformation that has been ongoing throughout most of the Cenozoic Era (last 65 Ma). This deformation produced a physiography that consists of an assemblage of exhumed crustal blocks separated by internally drained and alluvium-filled sedimentary basins. Exhumation of the ridges was accomplished by normal faults that bound the ranges. Ridges are also cut by numerous northwest-striking dextral and occasional east-northeast-striking sinistral strike slip faults. Ranges are up to several hundred kilometers long with elevations up to 2,000 m [6,700 ft] above the basin floors. Much of the surface faulting took place at the base of the ranges along normal faults that dip moderately (~60°) beneath the adjacent basins (generally defined as range-front faults), although complex faulting within the basins is also common.

The thick accumulation of sedimentary material within the basins provides much of the material through which groundwater flows in and around Yucca Mountain, especially south of Yucca Mountain as groundwater exits Fortymile Wash and enters the Amargosa basin. Evaluation of the stratigraphic architecture of the basins adjacent to Yucca Mountain is therefore important for accurate estimation of groundwater flow and transport of radioactive contaminants, especially in areas downgradient from Yucca Mountain.

To date, strata in basins proximal to Yucca Mountain have generally been modeled in groundwater flow and transport models and in performance assessment codes for the proposed Yucca Mountain repository as unconsolidated, homogeneous valley-fill alluvium. The actual stratigraphy of the basins has, however, not been extensively studied. The least studied strata in the basins are Oligocene and lower Miocene (36.6 to 16.6 Ma) age sedimentary, volcaniclastic, and volcanic deposits. Because the stratigraphy of the basinal strata is heterogeneous and well-stratified, groundwater flow and sorptive properties of the material are also likely to be inhomogeneous and anisotropic. Thus, a clearer understanding of these basinal deposits is necessary in order to develop more accurate and realistic models of groundwater flow and transport.

This report presents new outcrop and subsurface data that improve our understanding of the stratigraphy, structural configuration, and regional extent of the Oligocene and lower Miocene strata. Outcrops across the Nevada Test Site, Amargosa Desert, and in the Funeral Mountains reveal an extensive distribution of Oligocene and lower Miocene strata. Most published geologic maps of the region group these strata within the Oligocene and lower Miocene Horse Spring Formation and the lower Miocene Rocks of Pavits Spring. These two units may comprise more than 2,000 m [6,700 ft] of strata in the subsurface in and around the Yucca Mountain area.

To develop a stratigraphic framework for analyses of the alluvial and valley-fill strata in the subsurface, detailed stratigraphic sections were measured of similar-aged strata exposed in outcrop on the Nevada Test Site and in the eastern Funeral Mountains. New measurements in the Funeral Mountains show that the lowest parts of the stratigraphic sections are dominated by lithofacies of interbedded conglomerate and tuff. These grade into gastropod and stromatolite-rich limestone in the middle of the sections and conglomerate with quartzite and carbonate clasts, coarse sandstone, and minor volcaniclastic sandstone in the upper parts of the sections. On the Nevada Test Site, new measurements show that the lowest parts of the stratigraphic section are dominated by gastropod-rich and ostracod-rich limestone and siltstone. Higher in the section, coarse sandstone and conglomerate with quartzite and carbonate clasts are the dominant lithofacies. The heterogeneity of this stratigraphy leads to anisotropic hydraulic and sorptive properties both vertically through the stratal section and horizontally because of lateral facies changes within the basinal sediments.

To determine whether correlative subsurface strata are located in basins adjacent to Yucca Mountain, well cuttings from three wells, drilled as part of the Nye County Early Warning Drilling Program, were examined. Well cutting data correlate to strata within our measured sections in the Funeral Mountains and on the Nevada Test Site. The observation that the subsurface strata correlate to the surface outcrops is important because hydrologic and geologic rock property data that are appropriate surrogates to strata within the basins and alluvial aquifers can be now be obtained from the surface outcrop strata.

Based on these observations, the Horse Spring Formation and the Rocks of Pavits Spring were divided into three regional lithostratigraphic units: (i) a lower unit of white to brown limestone overlain by (ii) a middle unit of conglomerate and sandstone and (iii) an upper unit of volcanic tuff and volcaniclastic sandstone. Two cross sections utilizing the three-part stratigraphy show that the Horse Spring Formation and the Rocks of Pavits Spring were constructed to depict the subsurface geology of the region including Fortymile Wash and the Amargosa Desert. The cross sections show that the Oligocene and lower Miocene strata can be correlated at least 120 km [75 mi] from the Funeral Mountains, through the Yucca Mountain area to Frenchman Flat on the eastern side of the Nevada Test Site.

Recognition of thickness, extensive distribution, and heterogeneity of these Oligocene and lower Miocene strata within the sedimentary basins adjacent to Yucca Mountain is important to development of a more accurate depiction of the subsurface geology in and around Yucca Mountain, and ultimately to more realistic and reliable models of groundwater flow and transport from a potential repository to the compliance point in the Amargosa Desert.

1 INTRODUCTION

1.1 Purpose

Groundwater flow in the saturated zone of the Yucca Mountain region occurs in several aquifer systems, including the alluvium or valley fill strata, volcanic tuffs, and Paleozoic carbonate rocks (Winograd and Thordarson, 1975). For purposes of repository performance assessment, groundwater flow within the saturated zone is modeled within two generalized hydrostratigraphic aquifer units: a volcanic tuff aquifer and unconfined alluvium or valley fill aquifer (e.g., Mohanty and McCartin, 1998; CRWMS M&O, 1998a). Flow within the volcanic tuff aquifer occurs beneath and adjacent to Yucca Mountain. South of Yucca Mountain, groundwater flow transitions along a poorly defined boundary from the saturated volcanic tuffs into the unconfined alluvium or valley fill material. Properties of groundwater flow such as porosity, velocity, and sorption potential are considerably different within the two aquifer systems (e.g., Winterle, et al., 2000). As a result of these contrasting hydrologic properties, the structure and stratigraphy of the tuff and valley fill strata and the nature of the contact between the two are important to performance assessment calculations because these properties control both radionuclide mass and groundwater travel times from Yucca Mountain to compliance points located south of Yucca Mountain in the Amargosa Desert.

In current performance assessment models of the proposed Yucca Mountain high-level waste repository (CRWMS M&O, 1998a; Mohanty and McCartin, 1998), groundwater flow through the alluvium is one of the most critical factors to repository performance, specifically with regard to production zone thickness and dilution at the wellhead, groundwater travel times, and attenuation of radionuclides by interaction with valley fill minerals (NRC, 1998). In the performance assessment models, the simplifying assumptions of homogeneity and isotropy have been applied to the valley-fill alluvium, but no investigations have been completed to evaluate the potential significance of these assumptions. Moreover, these simplifying assumptions do not account for the observation that most natural sediments are heterogeneous, and that heterogeneities usually give rise to inhomogeneous and anisotropic hydraulic and sorptive properties.

The treatment of flow and transport in CRWMS M&O (1998b) was strongly criticized by the DOE Total System Performance Assessment Peer Review Panel (Whipple, et al., 1999). In particular, the Peer Review Panel noted a significant lack of subsurface geological and hydrological data along the projected saturated zone flow path from Fortymile Wash to the Amargosa Valley. Specific comments by the Peer Review Panel related to (i) the difficulty in estimating vertical flow and lack of an account of anisotropy and heterogeneity in both the volcanic tuff and alluvial aquifers, (ii) a lack of field data on which to base analyses of retardation and sorption, (iii) lack of an account for potential fast paths in the saturated zone and (iv) limited spatial resolution of the flow models (Whipple, et al., 1999). In response to the Peer Review Panel comments, the DOE noted improvements in the saturated zone modeling will include analyses and incorporation of geologic and hydrologic data acquired from the Nye County Early Warning Drilling Program (CRWMS M&O, 1999).

Similarly, the technical bases for the saturated zone flow models in the U.S. Nuclear Regulatory Commission (NRC) TPA Version 3.2 code (Mohanty and McCartin, 1998) and the DOE Total System Performance Assessment code models (CRWMS M&O,1998a) were criticized by its peer reviewers [Center for Nuclear Waste Regulatory Analyses (CNWRA) in Weldy, et al.

(1999)]. In particular Dr. Marsily of the External Peer Review commented that "available hydrogeological data were insufficient to justify the saturated zone flow and transport models." In reference to the valley fill aquifer, the peer review noted that (i) the relationship between the volcanic tuff and alluvium is not clear, so that the level of mixing is difficult to determine and the contact between the two rock types is poorly defined; (ii) the geometry of the alluvium is not well defined; (iii) flow in the alluvium cannot be modeled as an equivalent porous medium; and (iv) layering (stratigraphy) of the alluvium must be characterized to adequately determine dilution.

Because of these uncertainties in the geologic and hydrologic properties of the valley fill strata and their potential significance to repository performance, an adequate characterization of the valley fill aquifer has been the subject of prelicensing discussions between NRC and DOE. As a result of those discussions, DOE has agreed to provide additional information on the structure, stratigraphy, and hydrogeology of the valley fill aquifer as part of the formal agreements reached at the November 2000 Technical Exchange.[1] The DOE and NRC agreements include one in which DOE is to provide detailed geological cross sections that incorporate stratigraphic interpretations from the Nye County wells along U.S. Highway 95 and in Fortymile Wash.[2]

The purpose of this report is to provide the necessary technical bases for an independent evaluation of the stratigraphic and structural characterization of the valley fill strata. These technical bases will be used in assessments of DOE conclusions regarding the valley fill aquifer and its role in repository performance. In particular, the work described in this report defines the subsurface stratigraphy of the basins adjacent to Yucca Mountain through a correlation of well cuttings with outcrop data from the Horse Spring Formation and the Rocks of the Pavits Spring of the Funeral Mountains and the Nevada Test Site. Based on those correlations, a set of interpretative cross sections was drawn that describe the subsurface geology of these strata. Details of these cross sections provide additional input for updates to the three-dimensional structural model of the Amargosa Desert (Sims, et al., 1999).

1.2 Scope

This study considers the surface and subsurface stratigraphy in the sedimentary basins adjacent to Yucca Mountain with an emphasis on Oligocene and lower Miocene strata. Within the study area (Figure 1-1), the Oligocene-Miocene section consists of three sedimentary units, the Horse Spring Formation, the Titus Canyon Formation, and the Rocks of Pavits Spring (Hinrichs, 1968; Wright and Troxel, 1993; Barnes, et al., 1982). The Horse Spring Formation and equivalent strata mapped as the Titus Canyon Formation in the Funeral Mountains range in age from 38 to 16 Ma based on vertebrate fossils and $^{40}Ar/^{39}Ar$ radiometric ages (Stock and Bode, 1935; Reynolds, 1974). Two tuff beds in the Titus Canyon Formation yield $^{40}Ar/^{39}Ar$ isochron ages of 34.3 and 30.0 Ma (Saylor and Hodges, 1991). The oldest airfall tuff in the Horse Spring Formation produced a $^{40}K/^{39}Ar$ age of 30.2 Ma (Marvin, et al., 1970). The Rocks of

[1]Reamer, C.W. "U.S. Nuclear Regulatory Commission/U.S. Department of Energy Technical Exchange and Management Meeting on Unsaturated and Saturated Flow Under Isothermal Conditions (October 31–November 2, 2000)." Letter (November 17) to S. Brocoum, DOE. Washington, DC: NRC. 2000.

[2]Ibid.

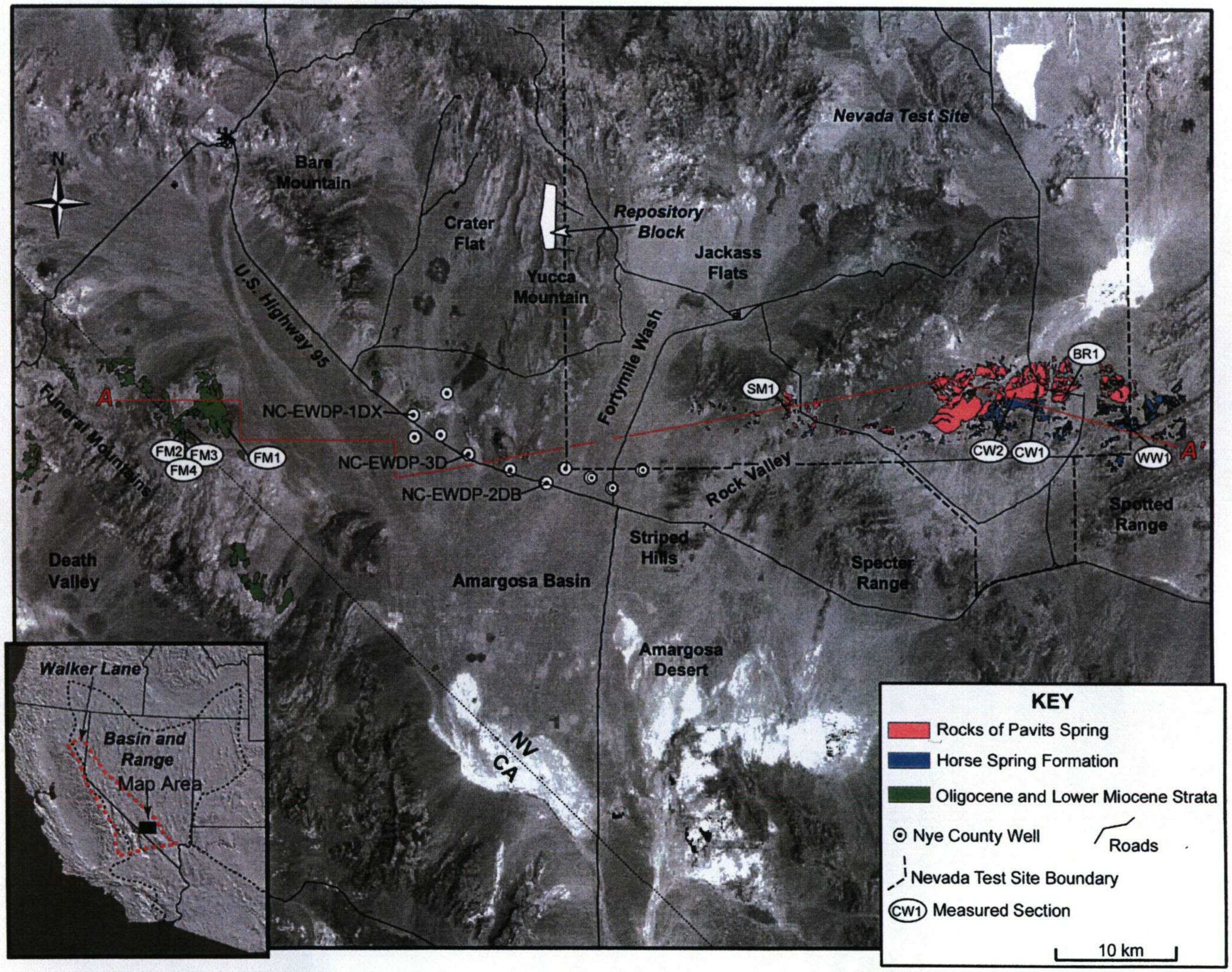

Figure 1-1. Satellite Image of the Yucca Mountain Region Showing Southwestern Nevada and Eastern California. Inset Is a Digital Elevation Model of the Western United States Showing the Location of the Basin and Range, Walker Lane, and Study Area. Map Data of the Horse Spring Formation and Rocks of Pavits Spring on the Nevada Test Site Are from Barnes, et al. (1982) and Hinrichs (1968). Map Data of the Oligocene and Lower Miocene Strata in the Funeral Mountains Are from Wright and Troxel (1993).

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Pavits Spring contain an airfall tuff near the base of the unit that has a $^{40}K/^{39}Ar$ age of 15.8 Ma.[3] The Horse Spring Formation and the Rocks of Pavits Spring are not exposed at the surface near Yucca Mountain (Figure 1-1), but they are well exposed in the nearby Nevada Test Site (Frizzell and Schulters, 1990) and equivalent strata are exposed in the Funeral Mountains (Wright and Troxel, 1993) (Figure 1-1). In addition, several wells adjacent to Yucca Mountain, recently drilled as part of the Nye County Early Warning Drilling Program (Nye County Nuclear Waste Repository Project Office, 2002), encountered unexpectedly thick sections of sedimentary strata between Miocene volcanic strata and Paleozoic limestone.

To assess the sedimentary strata between Miocene volcanic strata and Paleozoic limestone in the Nye County wells, and thereby define the subsurface stratigraphy of the Fortymile Wash and Amargosa basin, a three-task study was undertaken by the Structural Deformation and Seismicity Key Technical Issue group at the CNWRA. The three tasks consisted of (i) developing detailed stratigraphic profiles or stratigraphic sections of exposed Oligocene and lower Miocene strata in the Yucca Mountain region; (ii) examining the cuttings from the Nye County wells and correlating the well stratigraphy to outcrop data from the Horse Spring Formation and the Rocks of the Pavits Spring of the Funeral Mountains and the Nevada Test Site; and (iii) constructing two interpretative cross sections, one through the Nye County wells along U.S. Highway 95 and the other across the Nevada Test Site from the Funeral Mountains to the Spotted Range, including Fortymile Wash. This report documents the results of these three tasks.

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[3]Yount, J.C. Unpublished Data. 1989.

2 GEOLOGIC SETTING

Yucca Mountain is near the western edge of Basin and Range physiographic province within the Walker Lane Belt (Stewart, et al., 1968; Stewart, 1998), which is located in the Great Basin of the southwestern United States (Figure 1-1). The Basin and Range is characterized by subparallel mountain ranges alternating between elongate valleys formed through block faulting (Burchfiel, 1965; Stewart, 1988). Yucca Mountain consists of a series of north trending structural blocks, which were tilted to the east on west-dipping high-angle normal faults (Day, et al., 1998). Two structural basins bound Yucca Mountain, Crater Flat to the west and Jackass Flats to the east. Fortymile Wash, located in the western part of Jackass Flats, is a desert wash characterized by ephemeral flows (Ressler, et al., 2000). It lies adjacent to Yucca Mountain to the east (Figure 1-1). The Amargosa basin is a sedimentary basin located to the south of Yucca Mountain (Figure 1-1).

Stratigraphy of the Yucca Mountain region consists of thick accumulations of Cenozoic sedimentary and volcanic strata deposited on multiply deformed Paleozoic and Precambrian (older than 245 Ma) rocks (Figure 2-1). Mesozoic rocks (245–65 Ma) are not present, reflecting the active convergent tectonics that characterized the Cordillera at this time in addition to exhumation and erosion of the ranges that followed during Basin and Range extensional deformation in the Cenozoic.

Yucca Mountain itself consists of 1,830 m [6,000 ft] of volcanic tuff deposited on an irregular surface of eroded Paleozoic and Precambrian basement composed of highly faulted and folded sedimentary and metasedimentary rocks. These tuffs were erupted from a series of middle to late Miocene (15–9 Ma) calderas that collectively form what has been defined as the Southwestern Nevada Volcanic Field [see Sawyer, et al. (1994) for the most recent regional stratigraphy of the Miocene volcanic rocks in the Yucca Mountain region]. Rocks of the Paintbrush Group (Figure 2-1), principally Tiva Canyon Tuff (12.7 Ma), makes up the main surface exposures of Yucca Mountain, while the repository horizon is within the Topopah Springs Tuff (12.8 Ma). The Paintbrush Group Tuffs rest on a sequence of older tuffs (Figure 2-1), including the Prow Pass and Bullfrog Members of the Crater Flat Group. Younger tuffs related to the Timber Mountain Group are locally exposed at Yucca Mountain in topographic lows between large block-bounding faults.

Extensional deformation characteristic of the Basin and Range is manifest at Yucca Mountain by a sequence of north to north-northeast trending, fault-bound ridges crossed by northwest-trending, dextral strike-slip faults. Faults dip almost uniformly to the west and separate blocks of gentle to moderate east-dipping tuff strata. From north to south, both fault displacement and dip of bedding increase, indicating progressively greater extension of the Crater Flat basin southward (Scott, 1990). This pattern is most profound on the west flank of Yucca Mountain, which is defined by a series of left-stepping and north trending *en echelon* faults. The southward increase in fault offset is coupled with greater block rotation, both horizontal and vertical (Scott, 1990).

The thick accumulation of middle to late Miocene volcanic tuffs masks much of the older geologic history at Yucca Mountain. Older rocks are exposed elsewhere in the region, including Precambrian and Paleozoic sedimentary and metasedimentary strata (Figure 2-1) at Bare Mountain, the Funeral Mountains, the Specter Range, the Spotted Range, and the Striped Hills. Faulted Miocene and younger rocks indicate that extensional deformation at Yucca Mountain has been active since approximately 14 Ma. In other parts of the Basin and Range, older

System	Age Ma	Series	Stratigraphic Unit			Maximum Thickness Meters	Maximum Thickness Feet
Tertiary		Holocene to Pliocene	Valley Fill			610	2,001
	5.3	Miocene	Piapi Canyon Group	Timber Mountain Tuff	Ammonia Tanks	250	820
					Rainer Mesa	600	1,969
				Paintbrush Tuff	Tiva Canyon	120	394
					Pah Canyon	90	295
					Topopah Spring	350	1,148
			Calico Hills Formation			1,850	6,070
			Wahmonie Formation			4,000 1,700	13,123 5,577
			Sayler Formation			600	1,969
			Tuff of Crater Flat		Prow Pass Tuff	100	328
					Bullfrog Tuff	650	2,133
					Tram Tuff	250	820
			Belted Range Group		Grouse Canyon Tuff	150	492
					Lithic Ridge Tuff	275	902
					Rhyolite of Picture Rock	450	964
	16.6	Miocene and Oligocene	Rocks of Pavits Spring			1,200	3,937
	23.7	Oligocene	Horse Spring Formation			400	1,312
			Titus Canyon Formation			500	1,640
Permian Pennsylvanian	245		Tippipah Limestone			1,250	4,101
Mississippian Devonian	320		Eleana Formation			2,050	6,726
Devonian	360		Devil's Gate Limestone			420	1,378
Ordovician	438	Upper	Ely Springs Dolomite			150	492
		Middle	Eureka Quartzite			145	476
			Pognip Group		Antelope Valley Limestone	1,530	5,020
		Lower			Ninemile Formation	335	1,099
					Goodwin Limestone	900	2,953
Cambrian	505		Nopah Formation			720	2,362
			Bonanza King Formation			1,400	4,593
			Carrara Formation			470	1,542
			Zabriskie Quartzite			350	1,148
			Wood Canyon Formation			1,150	3,773
Precambrian	570		Stirling Quartzite			2,000	6,562
			Johnnie Formation			2,000	6,562

Figure 2-1. Stratigraphic Column of Rocks Exposed within the Study Area

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syndeformational Tertiary strata suggest active extensional deformation began much earlier, possibly in the early Cenozoic (e.g., Axen, et al., 1993).

The Funeral Mountains and the southern portion of the Nevada Test Site contain terrestrial deposits of Oligocene and lower Miocene strata including the Horse Spring Formation and the Rocks of Pavits Spring. Within the study area, the Horse Spring Formation consists of white to gray gastropod-rich limestone, and fluvial conglomerate (Barnes, et al., 1982). Interbedded white to gray airfall tuff is common near the base of the unit, and minor amounts of sandstone and siltstone are also present (Barnes, et al., 1982). The Titus Canyon Formation is an Oligocene unit mapped in the Funeral Mountains that is time-equivalent to the Horse Spring Formation. The Titus Canyon Formation consists of green tuffaceous sandstone and red conglomerate containing pebbles to boulders of quartzite and limestone. The Rocks of Pavits Spring (Barnes, et al.,1982) consist of gray tuffaceous sandstone, varicolored sandstone, conglomerate, minor ash-fall tuff and limestone.

3 OLIGOCENE AND LOWER MIOCENE STRATIGRAPHY

3.1 Outcrop Stratigraphy

3.1.1 Funeral Mountains

Four stratigraphic sections were measured in the eastern Funeral Mountains (Figure 1-1). The names and thicknesses of these sections are summarized in Table 3-1. Collectively these sections comprise 800 m [2,600 ft] of sedimentary and volcanic strata between Paleozoic carbonate deposits and Miocene volcanic strata. A key of the symbols used to illustrate the measured sections is shown in Figure 3-1. Correlation of the four sections to each other and to the Geologic Time Scale is shown in Figure 3-2. Details of sections FM-1, FM-2, and FM-3 are shown in Figures 3-3, 3-4, and 3-5.

The lower part of the Oligocene and lower Miocene strata in the Funeral Mountains is illustrated by the 0–200 m [0–650 ft] of FM-3 (Figures 3-2 and 3-3). It consists of tuff and disorganized and poorly sorted conglomerate. The conglomerate is generally matrix supported with clasts ranging in size from pebbles to boulders. The dominant clast type in the conglomerate is quartzite, with minor carbonate and occasional granite clasts. Bedding is massive, and average bed thickness is about 5 m [16 ft]. The siliceous airfall tuff units are fine grained with visible phenocrysts, generally devoid of sedimentary structures, and white to green in color. Bedding is massive and average bed thickness is about 3–5 m [10–16 ft].

The base of the section rests unconformably on dolomite beds of the Cambrian Wood Canyon Formation (Wright and Troxel, 1993). Near the top of FM-3 are distinctive green conglomerate beds with green and purple quartzite clasts (Figure 3-2). Similar conglomerate with distinctive green and purple quartzite clasts are also found near the base of section FM-2 (Figure 3-2).

Table 3-1. List of Measured Stratigraphic Sections of

Measured Section	Abbreviation	Interval Measured
Funeral Mountains 1	FM-1	171 m [561 ft]
Funeral Mountains 2	FM-2	352 m [1,155 ft]
Funeral Mountains 3	FM-3	212 m [695 ft]
Funeral Mountains 4	FM-4	64 m [210 ft]
Cave Wash 1	CW-1	370 m [1,214 ft]
Cave Wash 2	CW-2	177 m [581 ft]
Winapi Wash 1	WW-1	301 m [988 ft]
Burma Road 1	BR-1	213 m [699 ft]
Skull Mountain 1	SK-1	46 m [151 ft]

Legend For Stratigraphic Sections

Lithofacies Symbols:

- Gcm: Conglomerate, clast supported
- Gm: Conglomerate, matrix supported
- Sm: Sandstone, massive
- Sh: Sandstone, horizontal cross-stratified
- St: Sandstone, trough cross-stratified
- Fmm: Mudstone, massive
- Fsm: Siltstone, massive
- Fdm: Drilling mud and fine well cuttings
- Dl: Dolomite
- Lml: Limestone, laminated
- Lmb: Limestone, bedded
- Lma: Limestone, algal
- Lmf: Limestone, fossiliferous
- Lmm: Limestone, massive
- Sv: Volcaniclastic Sandstone
- Stv: Volcaniclastic Siltstone
- Tuff
- Ci: Covered Interval

Axes on Stratigraphic Measured Sections

X axis: Grain Size:
- S - Silt
- M - Medium grained sand
- P - Pebble
- B - Boulder

Y axis: Relative stratigraphic position within the measured section in meters (m).

Figure 3-1. Legend of Symbols and Nomenclature Used in the Measured Stratigraphic Sections

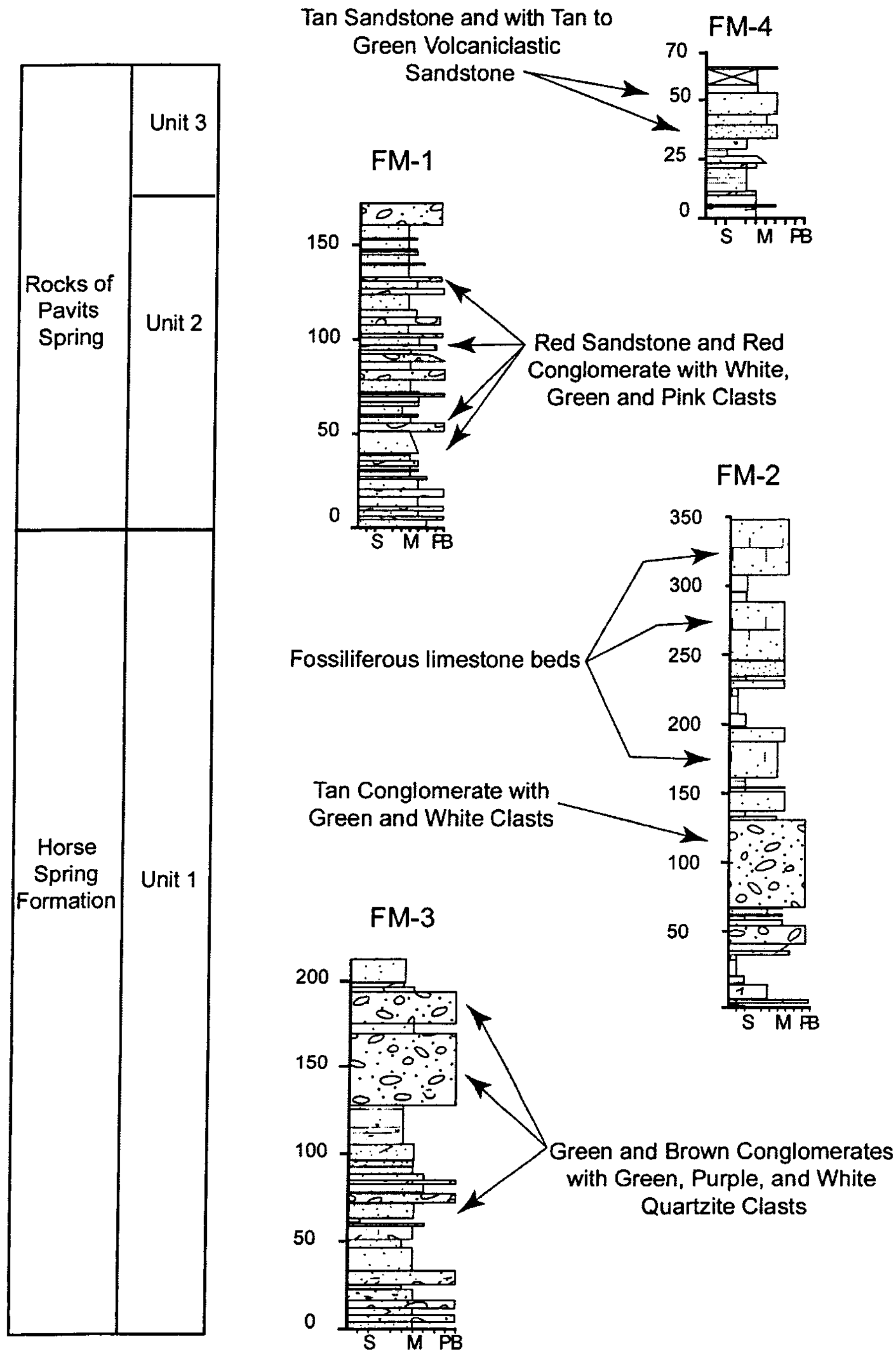

Figure 3-2. Summary Diagram Showing the Four Measured Sections from the Funeral Mountains and their Correlations to the Oligocene and Lower Miocene Horse Spring Formation and Rocks of Pavits Spring

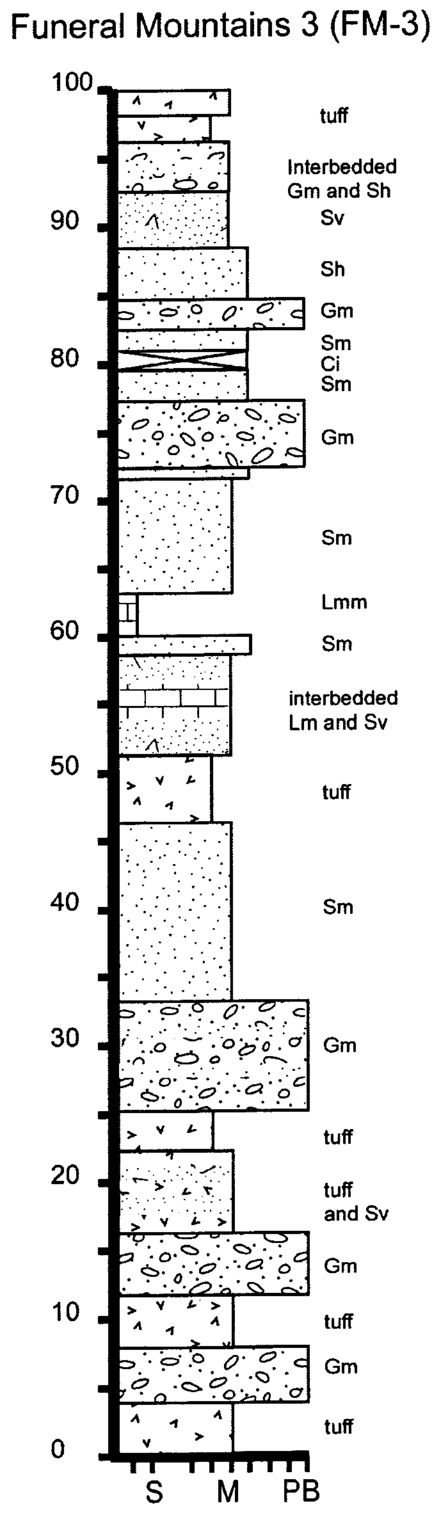

Figure 3-3. Measured Stratigraphic Section of the Lower 100 m [330 ft] FM-3. See Figure 3-1 for the Lithofacies Codes and Descriptions.

Funeral Mountains 2 (FM-2)

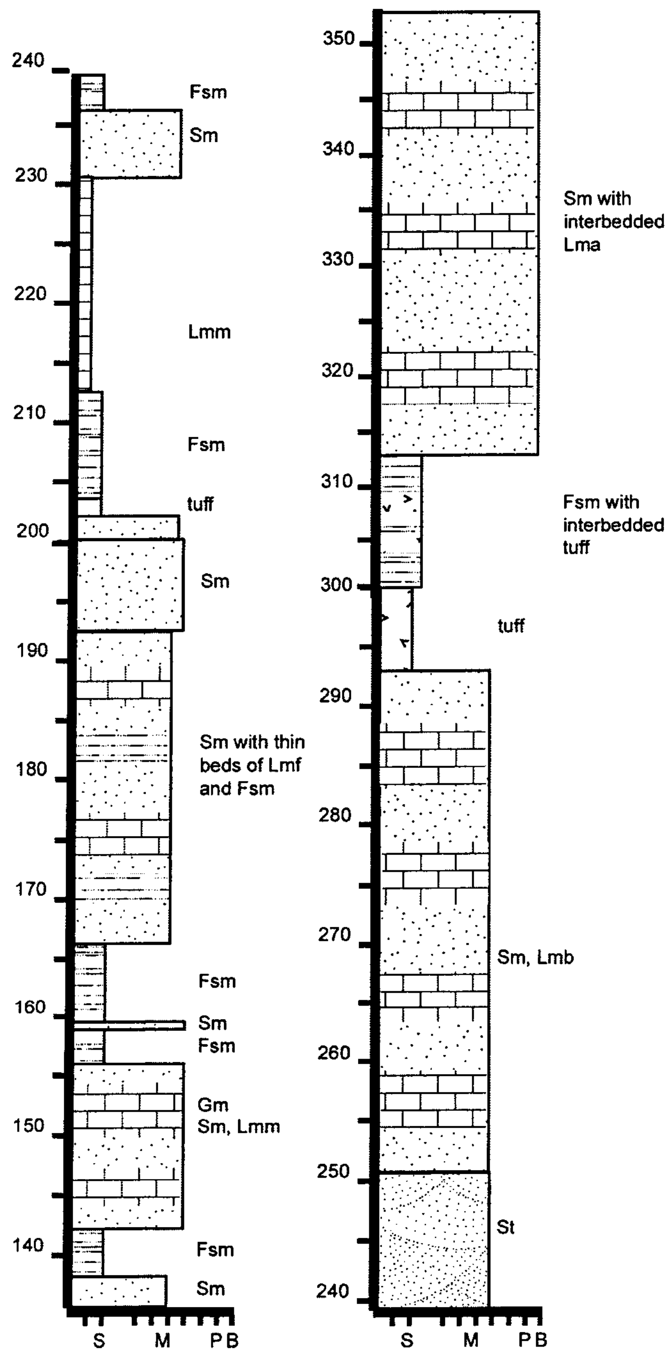

Figure 3-4. Measured Stratigraphic Section of the Middle 217 m [712 ft] of FM-2 from 135–325 m [321–1,066 ft]. See Figure 3-1 for the Lithofacies Codes and Descriptions. See Figure 3-2 for the Entire F-2 Section.

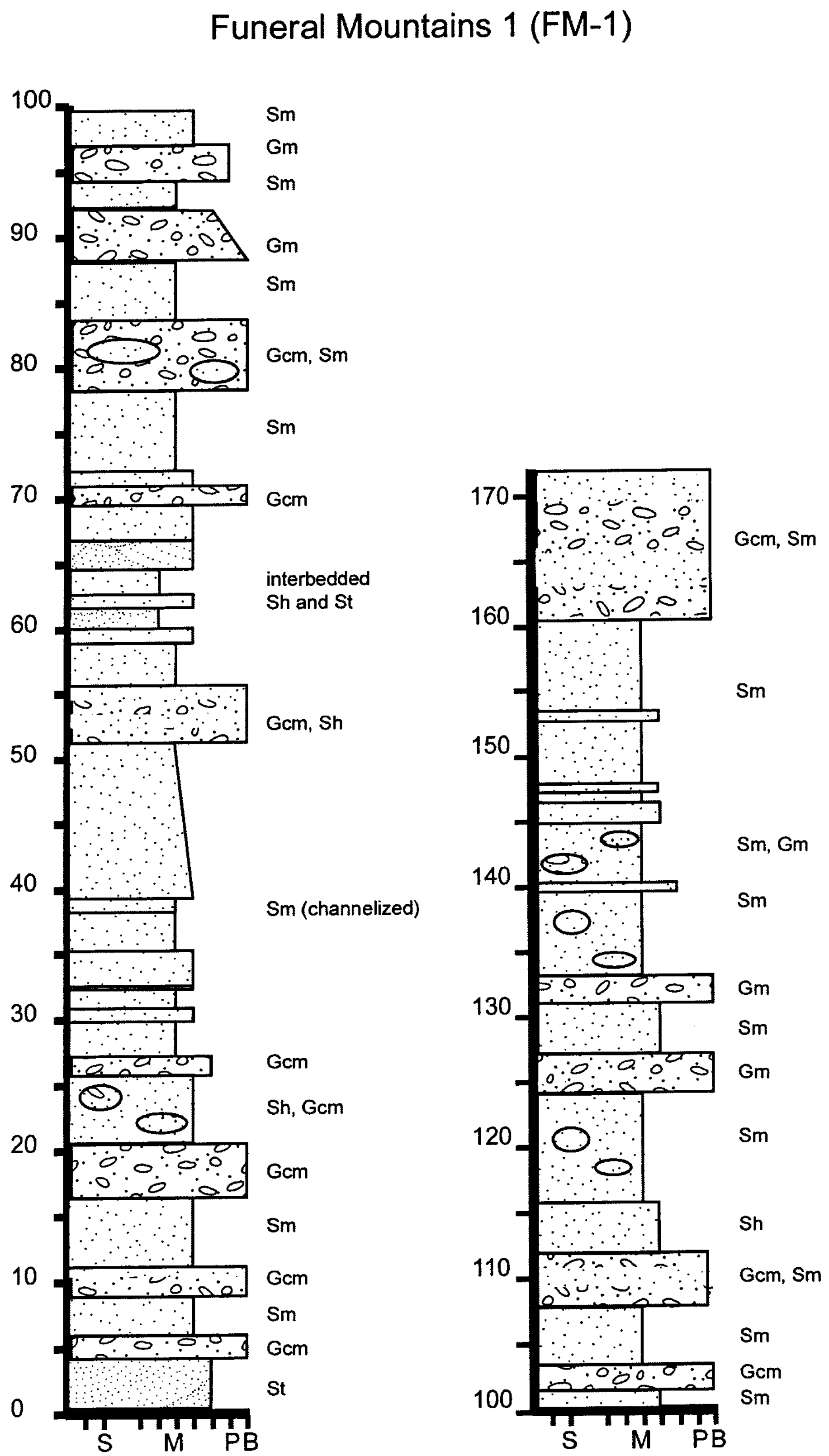

Figure 3-5. Measured Stratigraphic Section of FM-1. See Figure 3-1 for the Lithofacies Codes and Descriptions.

The middle part of the Oligocene and lower Miocene strata in the Funeral Mountain is illustrated by the 150–350 m [490–1,150 ft] shown in the FM-2 (Figures 3-2 and 3-4). Stratigraphically, FM-2 is directly above FM-3. In this part of the stratigraphy, the dominant lithology is fine-grained limestone, including a tan stromatolitic limestone and a white laminated gastropod-rich limestone. The limestone units are thinly bedded, generally less than 1 m [3 ft] thick, and they are frequently interbedded with fine-grained siltstone and sandstone.

The upper part of the Oligocene and lower Miocene strata in the Funeral Mountain is illustrated by the 0–171 m [0–560 ft] shown in FM-1 (Figures 3-2 and 3-5). These strata consist of red conglomerate with (white, green, and pink) quartzite and carbonate clasts and fine to coarse red sandstone (Figure 3-2). Sandstone in the higher part of the section contains planar cross stratification, trough cross stratification, horizontal stratification, and channelized bases. Minor volcaniclastic sandstone units are interbedded within the sandstone at the top of the measured stratigraphic section (Figure 3-5). Near the very top of the Oligocene and lower Miocene section in the Funeral Mountains, illustrated by FM-4 (Figure 3-2), are tan sandstones and tan to green volcaniclastic sandstone.

3.1.2 Nevada Test Site

Five stratigraphic sections were measured on the Nevada Test Site in Frenchman Flat, in Rock Valley, and at Skull Mountain (Figures 1-1 and 3-6). The names and thicknesses of the measure sections are summarized in Table 3-1. Collectively these sections comprise 1,034 m [3,500 ft] of sedimentary and volcanic strata between Paleozoic carbonate deposits and middle to upper Miocene volcanic strata. A key of the symbols used to illustrate the sections is shown in Figure 3-1. Correlation of the four stratigraphic sections to each other and to the Geologic Time Scale is shown in Figure 3-6. Details of the measured sections are shown in Figures 3-7, 3-8, and 3-9.

The lower part of the Oligocene and lower Miocene strata on the Nevada Test Site is illustrated by the 0–200 m [0–660 ft] shown on WW-1 (Figures 3-6 and 3-7). Strata are dominated by white laminated gastropod-rich limestone with minor interbedded layers of tan stromatolite-rich limestone. Minor deposits of fine siltstone and conglomerate with quartzite and carbonate clasts are also present. Similar thick sections of white fossiliferous and brown algal limestone is present in CW-1 (Figure 3-6). A key part of the stratigraphy in both CW-1 and WW-1 are conglomerate beds with purple, white, and green quartzite clasts (Figure 3-6).

The middle part of the Oligocene and lower Miocene strata at the Nevada Test Site is illustrated by the 65–210 m [215–690 ft] on BR-1 and the 40–170 m [130–560 ft] on CW-2 (Figures 3-8 and 3-9). Strata are dominated by brown to orange-red sandstone, tuffaceous sandstone, and conglomerate with white and purple quartzite and dark gray carbonate clasts.

The top of the Oligocene and lower Miocene strata at the Nevada Test Site are dominated by tuff and tuffaceous sandstone. This part of the section is illustrated by the 0–50 m [0–165 ft] shown on SM-1 (Figures 3-8 and 3-9). The tuff is white to red, fine-grained, and some beds have channelized bases. The tuffaceous sandstone is generally white to tan and medium grained. Some beds contain sedimentary structures including planar stratification, channelized bases and raindrop impressions. This middle part of the Oligocene and Miocene strata rest on a thick section of green tuffaceous and green sandstone, as shown in the top of CW-1 and the bottom of BR-1 (Figure 3-6).

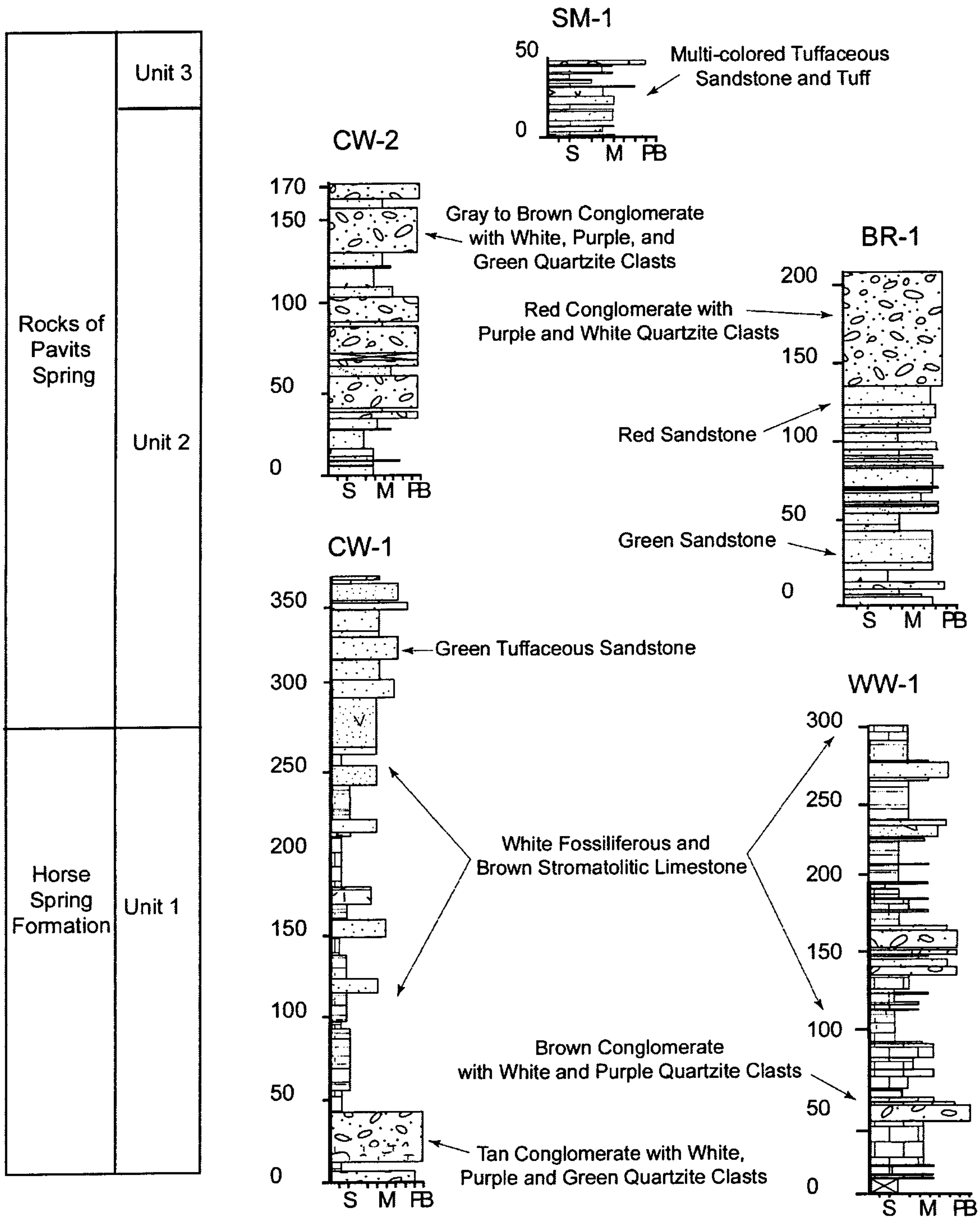

Figure 3-6. Summary Diagram Showing the Four Measured Sections from the Nevada Test Site and their Correlations to the Oligocene and Lower Miocene Horse Spring Formation and Rocks of Pavits Spring. See Figure 3-1 for Lithofacies Codes and Descriptions.

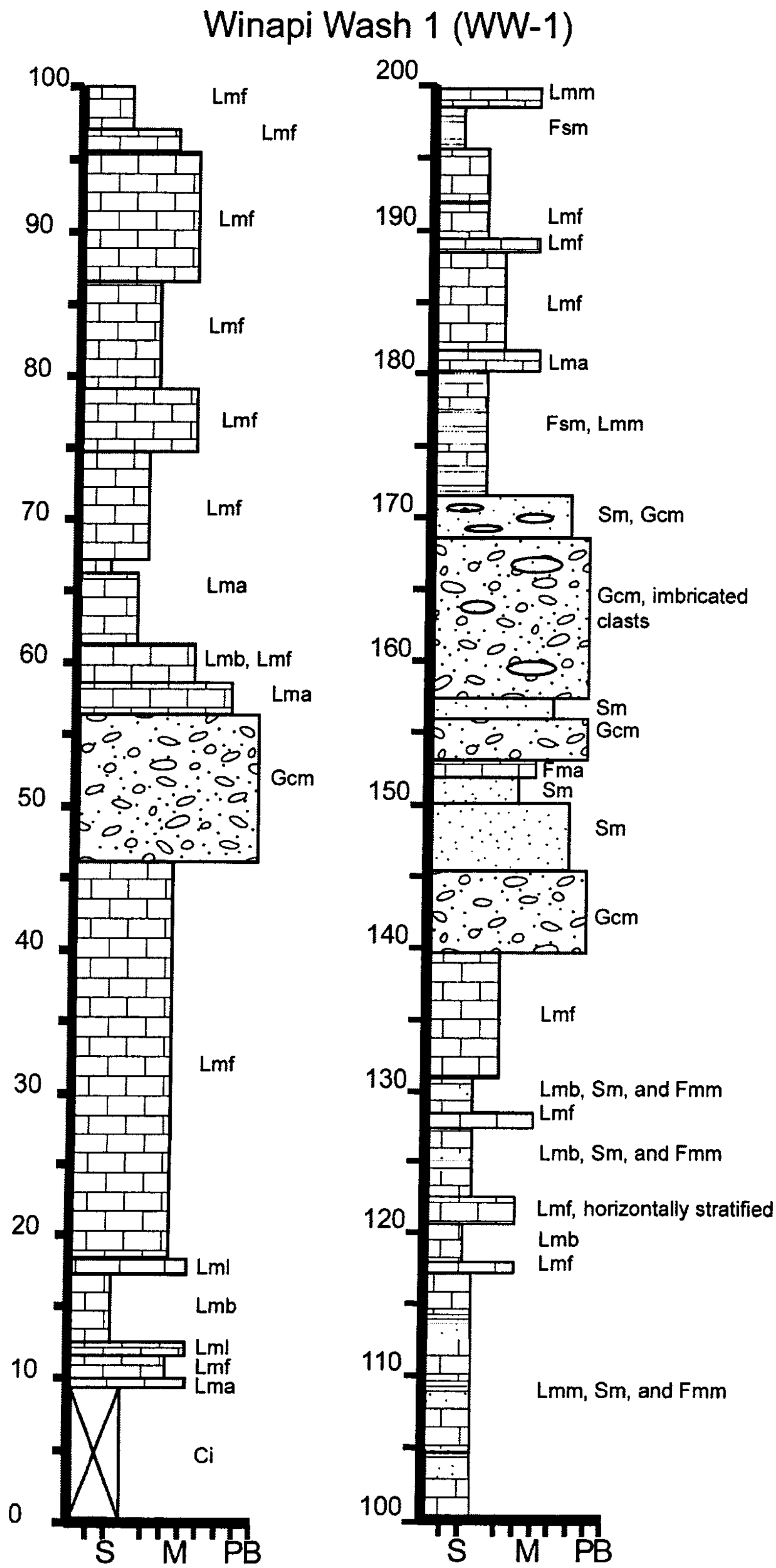

Figure 3-7. Measured Stratigraphic Section of WW-1. See Figure 3-1 for the Lithofacies Codes and Descriptions.

Burma Road 1 (BR-1)

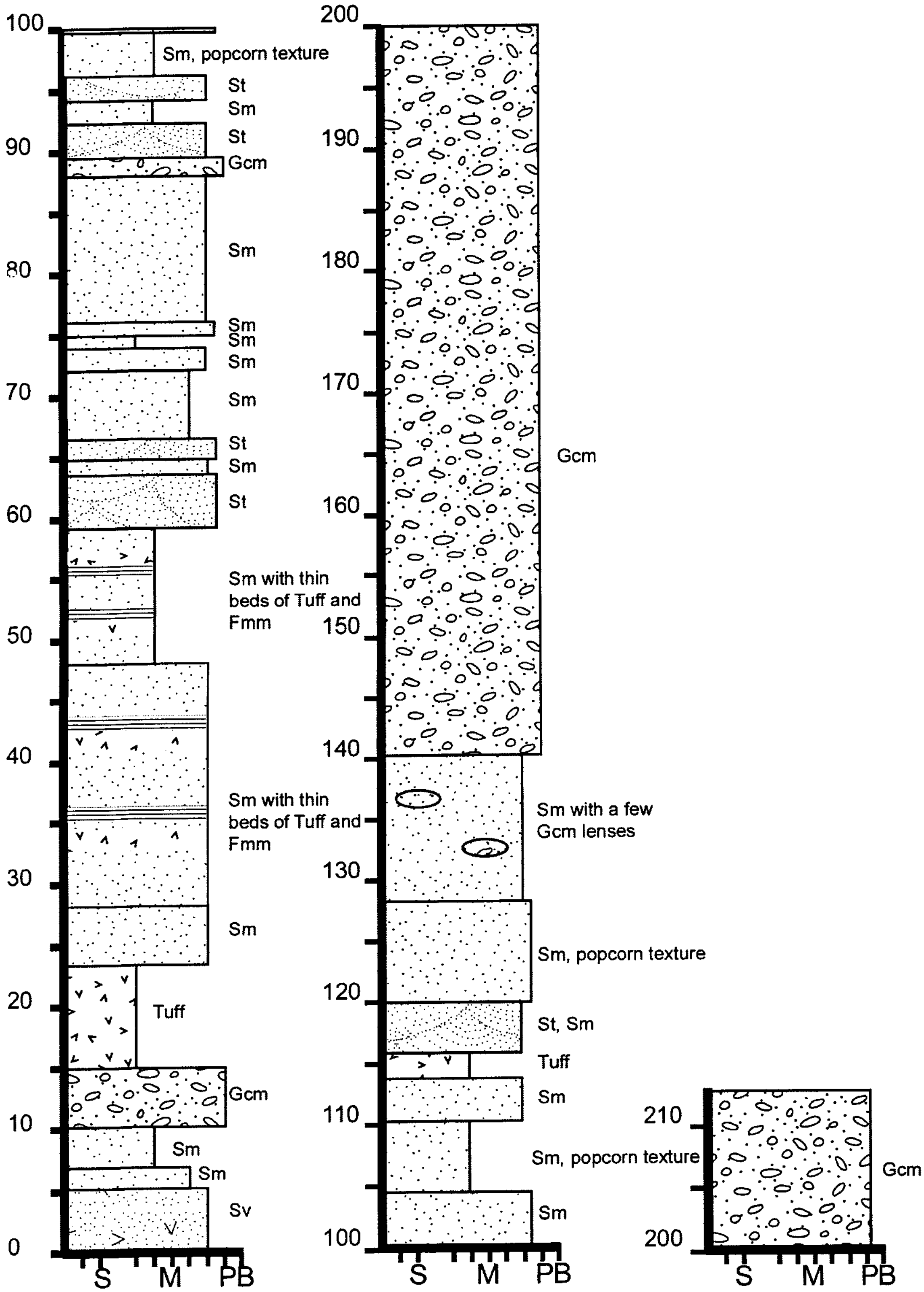

Figure 3-8. Measured Stratigraphic Section of BR-1. See Figure 3-1 for the Lithofacies Codes and Descriptions.

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Skull Mountain 1 (SM-1)

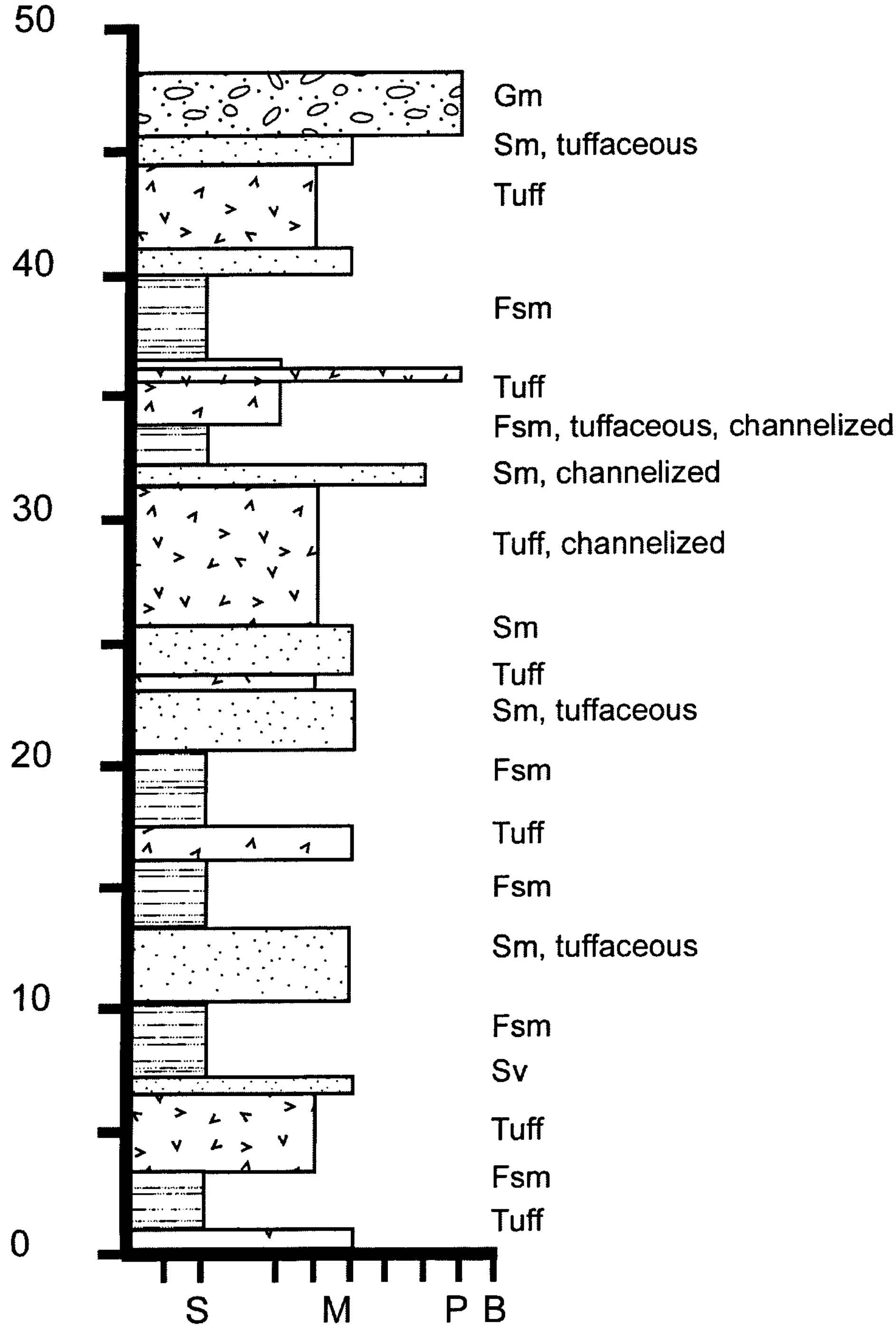

Figure 3-9. Measured Stratigraphic Section of SM-1. See Figure 3-1 for the Lithofacies Codes and Descriptions.

3.1.3 Oligocene and Lower Miocene Lithostratigraphy

Based on detailed stratigraphic analyses of the Funeral Mountain and Nevada Test Site stratigraphy, strata of the Horse Spring Formation and Rocks of Pavits Spring can be divided into three distinctive lithostratigraphic units (Table 3-2). The lowest lithostratigraphic unit, labeled Unit 1, is characterized by white to brown gastropod and stromatolite-rich limestone. This unit corresponds to the Horse Spring Formation (Figures 3-2 and 3-6). Unit 1 lies unconformably above Paleozoic carbonate strata. Unit 2 is dominated by conglomerate with pebble to boulder sized clasts of quartzite and carbonate, and fine to coarse tan to red sandstone. Individual conglomerate beds can be greater than 30 m thick. This unit corresponds to the lower part of the Rocks of Pavits Spring (Figures 3-2 and 3-6). Volcanic deposits, including bedded tuff, airfall tuff, volcaniclastic sandstone, and tuffaceous sandstone characterize Unit 3. This is the highest unit in the section, and it corresponds to the upper part of the Rocks of Pavits Spring (Figures 3-2 and 3-6).

From the distribution and thickness of these three units, it appears that this part of southwestern Nevada was a loci of active basin development and deposition during the Oligocene and early Miocene. The measured sections comprise nearly 2,000 m [6,562 ft] of Oligocene and lower Miocene deposits (given maximum stratigraphic thickness). Preliminary tectonic-stratigraphic interpretation is that the lower limestone-rich unit represents initiation of extension that resulted in the ponding of existing fluvial drainages along the axes of newly developed extensional basins. The middle conglomerate-rich unit represents active extension and the development of regional through-going fluvial drainage systems. Once the drainage networks were established, the basins accumulated thick deposits of these clastic rocks, mainly conglomerate with quartzite clasts and coarse sandstone. These quartzite clasts and sands were derived from the eroding Precambrian and Paleozoic quartzite strata recently exposed in the exhumed footwall ranges during Oligocene to early Miocene extensional faulting. The upper volcanic-rich unit represents the late phase of extension, when attenuation of the crust resulted in widespread regional volcanism to the north of this area.

3.2 Subsurface Stratigraphy

The subsurface stratigraphy of the basins was examined through the detailed analysis of well cuttings from wells drilled as part of the Nye Early Warning Drilling Program. Characterization of cuttings from three wells provided a way to compare the well cutting sediments to surface outcrops.

Table 3-2. Oligocene and Lower Miocene Lithostratigraphic Units

Lithostratigraphic Unit	Description
Unit 1	Tan stromatolitic limestone and white gastropod rich limestone with minor conglomerate containing quartzite and carbonate clasts
Unit 2	Coarse to fine brown to red sandstone and brown to red conglomerate with clasts of quartzite and carbonate
Unit 3	Multi-colored sandstone, tuffaceous sandstone, volcaniclastic sandstone, and tuff

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Nye County Wells NC–EWDP–1DX, NC–EWDP–3D, and NC–EWDP–2DB lie along a west to east transect between the Funeral Mountains and the Nevada Test Site (Figure 1-1). These cuttings were studied because the wells contain thick sections of sedimentary and volcaniclastic strata that are layered between Paleozoic limestone and Miocene volcanic strata. The deepest of the three wells, NC–EWDP–2DB, also contains the thickest record of the sedimentary strata sections. The study interval in each well included all samples between the total depth of the well, and the base of the Miocene volcanic strata. The top of the sedimentary section was determined based on a lithology transition from sedimentary to volcanic flow lithologies. The well cuttings were examined in 5-m [16-ft] intervals with a petrographic microscope, and each interval was characterized by lithology. Lithologic types found in the three wells included conglomerate, fine to coarse-grained sandstone, limestone, mudstone, tuff, and tuffaceous sandstone. Analyses presented herein are restricted to sedimentary strata.

3.2.1 Nye County Well NC–EWDP–1DX

Well NC–EWDP–1DX was examined in the interval between 358–762 m [1,175–2,500 ft]. In the examined section, the well contained a lower package of interbedded sandstone, siltstone, and tuffaceous sandstone between 383–762 m [1,256–2,500 ft], a middle package of pink tuff between 364–383 m [1,194– 1,256 ft], and an upper package of siltstone between 358–364 m [1,174–1,194 ft] (Table 3-3 and Figure 3-10).

Table 3-3. Lithology of Examined Section of Nye County Well NC–EWDP–1DX

Distance Below Surface	Lithology
358–364 m [1,175–1,195 ft]	Siltstone
364–383 m [1,195–1,255 ft]	Tuff
383–425 m [1,255–1,395 ft]	Interbedded sandstone and siltstone
425–488 m [1,395–1,600 ft]	Tuffaceous sandstone gray, medium-fine grained
488–501 m [1,600–1,645 ft]	Sandstone, medium to coarse
501–591 m [1,645–1,940 ft]	Tuffaceous sandstone, gray, medium-fine grained
591–613 m [1,940–2,010 ft]	Sandstone, gray, medium grained
613–633 m [2,010–2,075 ft]	Tuffaceous sandstone, gray, medium-fine grained
633–663 m [2,075–2,175 ft]	Sandstone, gray, medium grained
663–701 m [2,175–2,300 ft]	Tuffaceous sandstone
701–728 m [2,300–2,390 ft]	Siltstone
728–762 m [2,390–2,500 ft]	Sandstone gray, fine grained

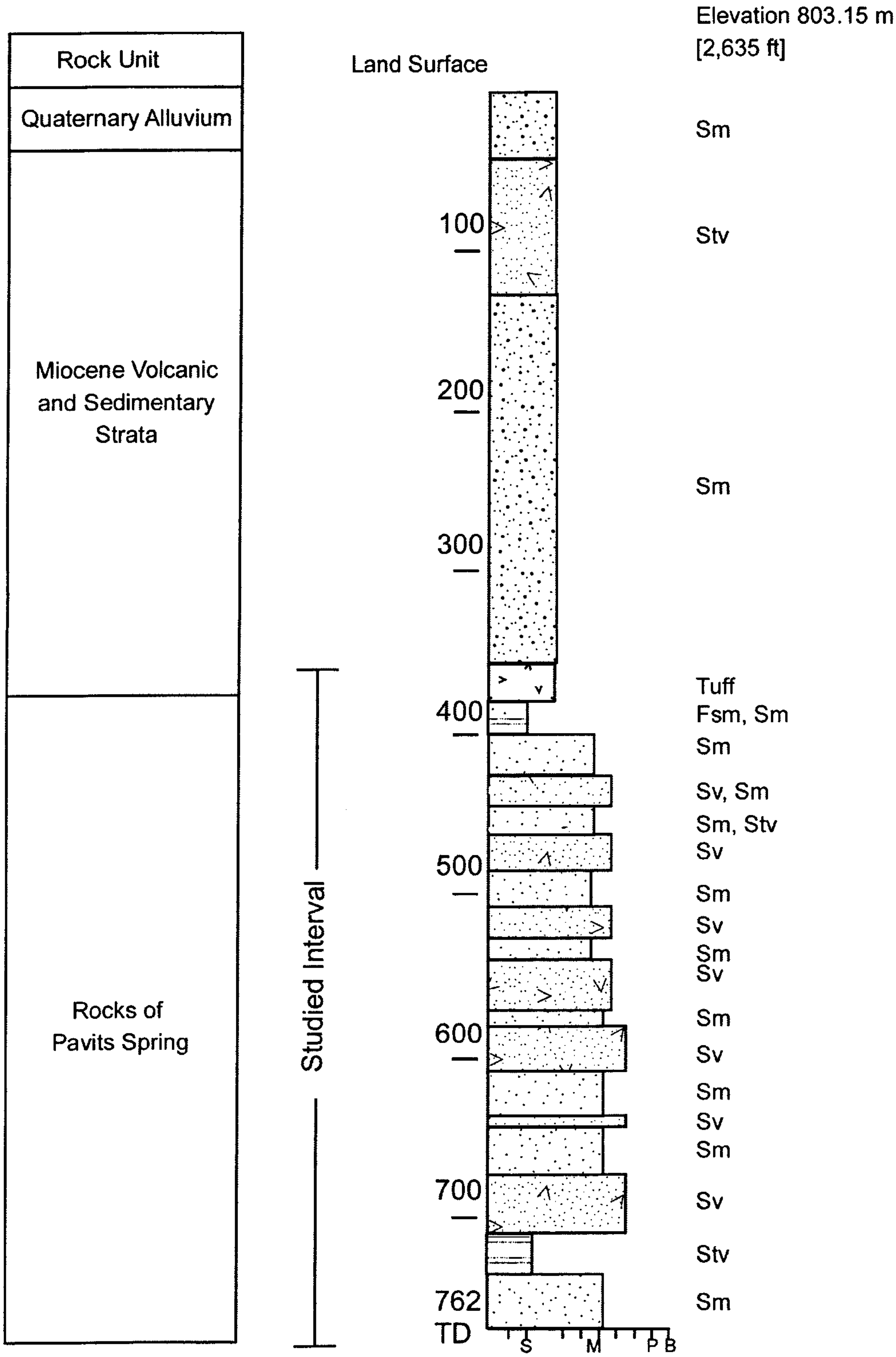

Figure 3-10. Stratigraphic Column of Well Cuttings in Well NC–EWDP–1DX Correlated to Tertiary Units. Lithologies for Unstudied Intervals Were Obtained from Nye County Nuclear Waste Repository Project Office (2002). See Figure 3-1 for the Lithofacies Codes and Descriptions.

3.2.2 Nye County Well NC–EWDP–2DB

Well NC–EWDP–2DB was examined in the interval between 358–937 m [1,175–3,075 ft]. In the examined section, the well contained a lower package of dark gray limestone between 884–937 m [2,900–3,073 ft], a tan limestone between 866–884 m [2,840–2,768 ft], a middle package of interbedded coarse to fine grained sandstone, conglomerate, and mudstone between 399–866 m [1,309–2,840 ft], and an upper package of volcanic strata between 358–399 m [1,174–1,308 ft] (Table 3-4 and Figure 3-11). Large sections of this well included drilling mud and fine well cuttings that could not be clearly identified.

Table 3-4. Lithology of Examined Section of Nye County Well NC–EWDP–2DB

Distance Below Surface	Lithology
358–399 m [1,175–1,310 ft]	Interbedded tuffs and volcaniclastics
399–405 m [1,310–1,330 ft]	Conglomerate
405–415 m [1,330–1,360 ft]	Sandstone
415–424 m [1,360–1,390 ft]	Conglomerate
424–477 m [1,390–1,565 ft]	Sandstone, very coarse to coarse
477–491 m [1,565–1,610 ft]	Conglomerate
491–526 m [1,610–1,725 ft]	Sandstone, coarse to medium
526–556 m [1,725–1,825 ft]	Mudstone, loosely consolidated, likely drilling mud
556–564 m [1,825–1,850 ft]	Siltstone
564–639 m [1,850–2,095 ft]	Mudstone, loosely consolidated, likely drilling mud
639–646 m [2,095–2,120 ft]	Sandstone, coarse
646–655 m [2,120–2,150 ft]	Mudstone, loosely consolidated, likely drilling mud
655–730 m [2,150–2,395 ft]	Sandstone, coarse to fine
730–736 m [2,395–2,415 ft]	Conglomerate
736–753 m [2,415–2,470 ft]	Sandstone, coarse to fine
753–815 m [2,470–2,675 ft]	Mudstone, loosely consolidated, likely drilling mud
815–866 m [2,675–2,840 ft]	Conglomerate contains limestone and quartzite clasts
866–884 m [2,840–2,900 ft]	Tan limestone
884–914 m [2,900–3,000 ft]	Dark gray limestone
914–919 m [3,000–3,015 ft]	Red siltstone
919–937 m [3,015–3,075 ft]	Dark gray limestone

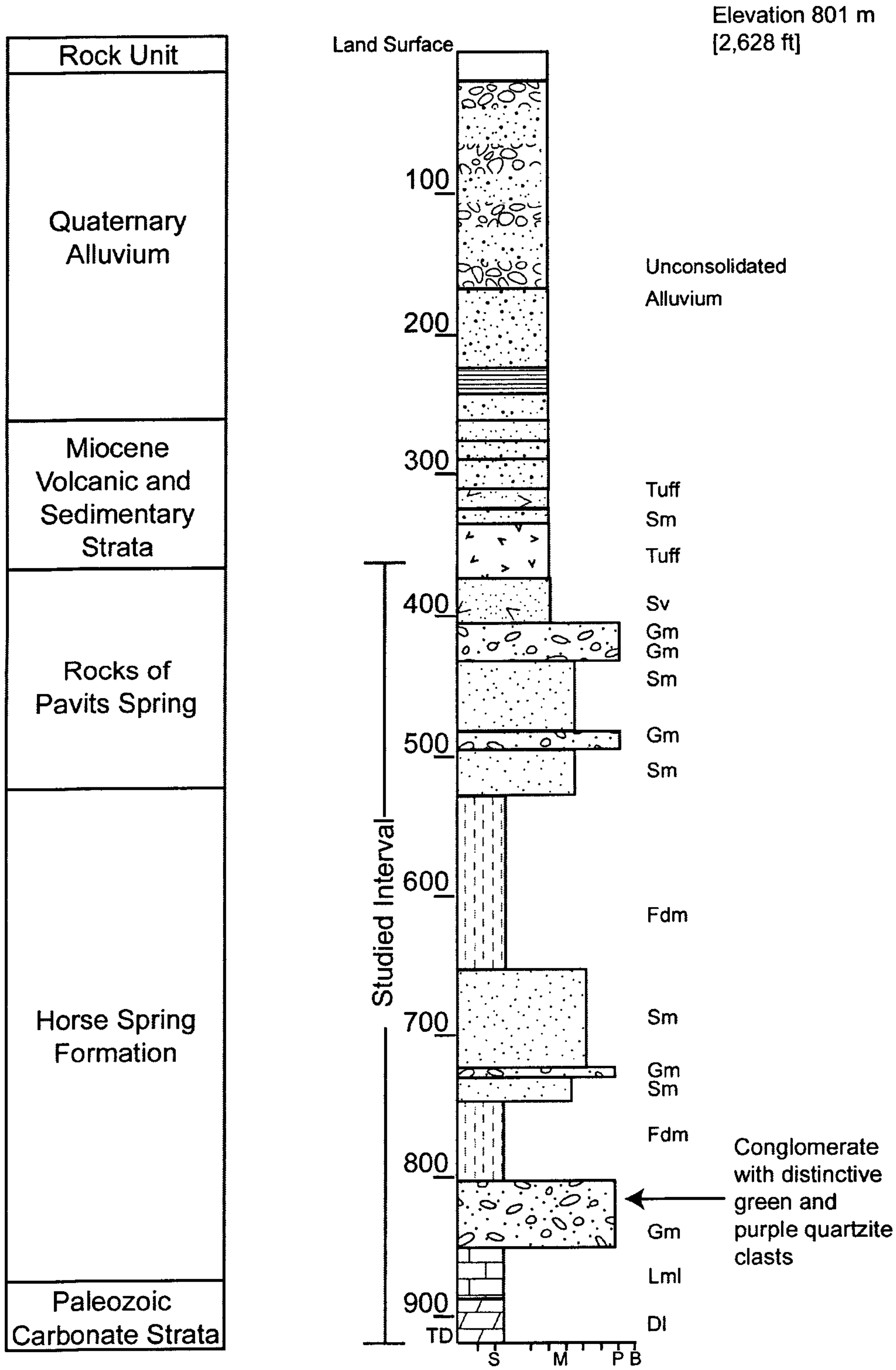

Figure 3-11. Stratigraphic Column of Well Cuttings in Well NC–EWDP–2DB Correlated to Tertiary Units. Lithologies for Unstudied Intervals Were Obtained from Nye County Nuclear Waste Repository Project Office (2002). See Figure 3-1 for the Lithofacies Codes and Descriptions.

3.2.3 Nye County Well NC–EWDP–3D

Well NC–EWDP–3D was examined in the intervals from 107–229 m [350–750 ft] and 351–762 m [1,150–2,500 ft]. In the examined sections, the well contained a lower package of sandstone and siltstone between 559–762 m [1,834–2,499 ft], a middle package of tuff and altered tuff with minor siltstone between 162–559 m [531–1,834 ft], and an upper tuff unit between 107–162 m [351–531 ft] (Table 3-5 and Figure 3-12).

3.3 Correlation of Well Stratigraphy to Outcrop Exposures

A correlation between the outcrops of the Horse Spring Formation and the Rocks of Pavits Spring in the Funeral Mountains and the Nevada Test Site was developed and compared to the subsurface strata in Fortymile Wash south of Yucca Mountain. This correlation was made on the basis of lithology and stratigraphic contacts. The sampling interval for the well cuttings is 1.5 m [5 ft]. Due to sample mixing, we believe that maximum resolution of the cuttings is 3–5 m [9.7–16 ft].

Table 3-5. Lithology of Examined Section of Nye County Well NC–EWDP–3D

Distance Below Surface		Lithology
107–145 m	[350–417 ft]	Tuff, yellow/green
145–162 m	[417–530 ft]	Tuff, white/gray
162–213 m	[530–700 ft]	Siltstone, brown
213–229 m	[700–750 ft]	Tuffaceous sandstone, very coarse to medium
351–392 m	[1,150–1,285 ft]	Siltstone, brown
392–419 m	[1,285–1,375 ft]	Tuffaceous sandstone
419–520 m	[1,375–1,705 ft]	Tuff, black and white
520–529 m	[1,705–1,735 ft]	Interbedded tuffaceous sandstone and siltstone
529–544 m	[1,735–1,785 ft]	Altered tuff
544–552 m	[1,785–1,810 ft]	Tuffaceous sandstone
552–559 m	[1,810–1,835 ft]	Tuff, gray/white
559–581 m	[1,835–1,905 ft]	Sandstone, fine, gray/brown
581–722 m	[1,905–2,370 ft]	Siltstone, brown, possible fossils
722–731 m	[2,370–2,400 ft]	Sandstone, gray, fine to medium grained
731–742 m	[2,400–2,435 ft]	Interbedded sandstone and tuffaceous sandstone
742–762 m	[2,435–2,500 ft]	Tuffaceous sandstone, gray/white

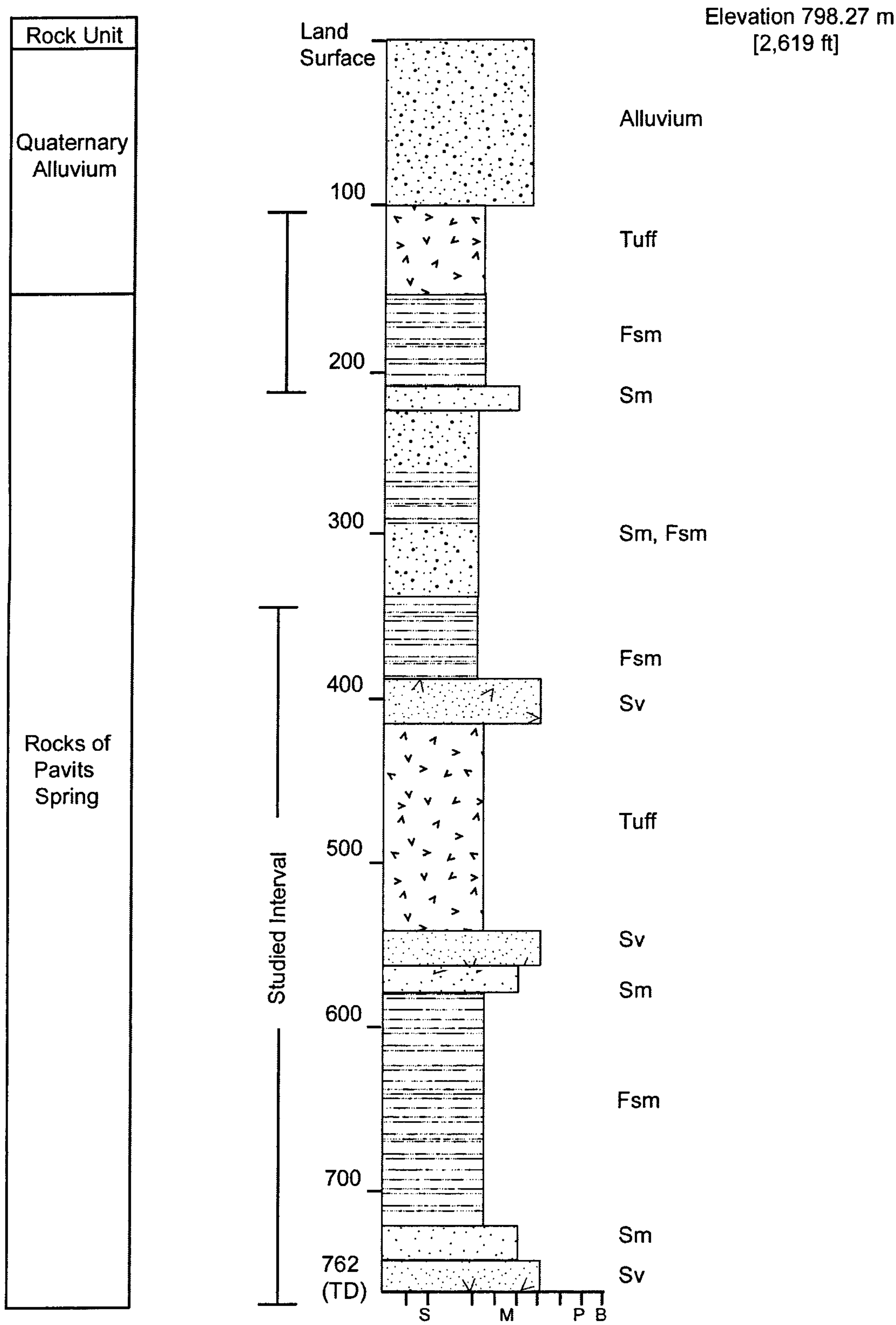

Figure 3-12. Stratigraphic Column of Well Cuttings in Well NC–EWDP–3D. Lithologies for Unstudied Intervals Were Obtained from Nye County Nuclear Waste Repository Project Office (2002). See Figure 3-1 for the Lithofacies Codes and Descriptions.

3.3.1 Nye County Well NC–EWDP–2DB

Nye County Well NC–EWDP–2DB was the only well drilled through the entire valley fill section and into Paleozoic strata. Thus, this well provides the most complete subsurface sedimentary record of strata deposited between the Paleozoic and late Miocene in the Amargosa Basin. As described in Section 3.2.2, the stratigraphy of the interval between the Paleozoic strata and upper Miocene tuff consists of a three unit lithology of (i) tan and brown limestone overlain by (ii) conglomerate with quartzite and carbonate clasts and tan to red sandstone overlain by (iii) tuffaceous sandstone, volcaniclastic sandstone and volcanic tuff. This three-part lithology corresponds to the lithostratigraphic units (Table 3-2) established for the strata of the Horse Spring Formation and Rocks of Pavits Spring from the outcrop exposures in the Funeral Mountains and on the Nevada Tests Site. Because of this correspondence, the approximately 550 m (1300 ft) of strata in NC–EWDP–2DB is herein interpreted to be Oligocene and lower Miocene sedimentary strata correlative to the Horse Spring Formation and Rocks of Pavits Spring.

Details of the correlations between the measured Oligocene and lower Miocene sections in outcrop and the subsurface stratigraphic record from Nye County Well NC–EWDP–2DB further support this interpretation. Key features that establish the correlation are (i) unconformable contact between Tertiary and Paleozoic carbonate strata, (ii) distinctive conglomerate clasts observed in both the outcrop strata and cuttings, (iii) relatively thick sections of limestone deposits, (iv) changes in lithology from limestone to sandstone, and (v) change in lithology from sandstone and tuffaceous sandstone to tuff.

In particular, the correlation between NC–EWDP–2DB and the outcrop stratigraphy are based on the following:

- Near the base of Well NC–EWDP–2DB, there is a distinctive change in color of the carbonate strata. At the base of the well (Figure 3-11), 937–884 m [2,900–3,075 ft], the cuttings are dark gray and are interpreted to be Paleozoic dolomite. Above the gray dolomite, from 884–866 m [2,840–2,900 ft], the cuttings are light tan and are interpreted to be Oligocene and lower Miocene limestone. In outcrop on the Nevada Test Site, the Oligocene and lower Miocene strata, consisting of thick sections of white to brown fossiliferous limestone rest unconformably on gray Paleozoic dolomite and limestone. In the Funeral Mountains, the lowermost part of the section is dominated by sandstone and conglomerate and tuff. The first appearance of limestone is at 55 m of section FM-3 (Figure 3-3), with significant limestones in section FM-2 (Figure 3-4).

- In FM-3 (Figure 3-2) and low in FM-2 (Figure 3-2), conglomerate beds with distinctive green and purple quartzite clasts are present. Similar green and purple quartzite clasts are also present on the Nevada Test Site in CW-1 and WW-1 (Figure 3-6). In the well stratigraphy, these same green and purple quartzite clasts are present between 815–866 m [2,675 ft–2,840 ft] in Well NC–EWDP–2DB (Figure 3-11).

- In the Well NC–EWDP–2DB (Figure 3-11), drilling mud and very fine cuttings are present from 753–815 m [2,470–2,675 ft] and from 526–655 m [1,725–2,150 ft]. These cuttings are generally obscured by the drilling mud or are too small for an accurate lithologic description. Because the limestone and fine sandstone strata are much more susceptible to the mechanical abrasion of drilling than coarse sandstone and quartzite clasts, however, these fine cuttings are herein interpreted to be equivalent to the numerous white and gray limestone beds in FM-2 (Figure 3-2), CW-1, and WW-1 (Figure 3-6).

- Above the limestone and conglomerate, the sedimentary section becomes dominated by clastic deposits. In outcrop sections FM-1 (Figure 3-2), BR-1 and CW-2 (Figure 3-6), there is a middle unit of clastic deposits consisting of coarse red sandstone and conglomerate with carbonate clasts and white, purple, and green quartzite clasts. In Well NC–EWDP–2DB between 400–526 m [1,312–1,726 ft] (Figure 3-11), there is a distinctive change in lithology from drilling mud and fine grained deposits to red sandstone and conglomerate with white, purple, and green quartzite clasts.

- Above the sandstone and conglomerate there is a distinctive lithology change from clastic strata to volcanic strata. In the FM-4 section (Figure 3-2), the deposits consist of tan to green volcaniclastic sandstone interbedded with tan sandstone. In the SM-1 section (Figure 3-6), multi-colored tuff and tuffaceous sandstone are the dominant lithology. In Well NC–EWDP–2DB (Figure 3-11), there is a distinctive lithology change at 358 m [1,174 ft]. Red tuffaceous sandstone is present between 358–400 m [1,174–1,312 ft].

Therefore, the similarity of the strata in Well NC–EWDP–2DB and the exposures in the Funeral Mountains (FM-1, FM-2, FM-3, and FM-4) indicate that the two stratigraphic sections can be closely correlated (Figure 3-13). This correlation is made based on lithologic similarities discussed above. In general in both the Funeral Mountains outcrops, and in Well NC–EWDP–2DB, the deposits grade upward from white to tan limestone and conglomerate with carbonate and distinctive quartzite clasts into red sandstone and conglomerate with distinctive quartzite clasts, and finally into multi-colored sandstone and tuffaceous sandstone.

As noted, low in the Oligocene and lower Miocene stratigraphic section in the Funeral Mountains, below the stromatolite and gastropod-rich limestone, many interbedded tuff and conglomerate beds are observed. These occur between 0–200 m [0–670 ft] in the FM-3 (Figures 3-2 and 3-3). These lithologies are not observed in Well NC–EWDP–2DB (Figure 3-11). In NC–EWDP–2DB, tan-gray limestone lies directly above the dark gray limestone interpreted as Paleozoic carbonate rocks. Based on the map pattern of these lowermost outcrops (Wright and Troxel, 1993), it appears that these basal clastic strata were deposits in small local fault-bound basins that were cut into the Paleozoic bedrock. Thus in the very earliest stages of extension, deposition occurred in small isolated basins. As extension progressed and the drainages matured, the basins interconnected to form one larger basin.

The similarity of the Nevada Test Site outcrops (WW-1, BR-1, CW-1, CW-2, and SM-1) to Well NC–EWDP–2DB indicates that the two stratigraphic sections can also be correlated (Figure 3-14). In both the Nevada Test Site measured sections and in Well NC–EWDP–2DB (Figure 3-14), white to tan limestone beds lay stratigraphically above the dark gray limestone interpreted as Paleozoic. The base of the Nevada Test Site section is characterized by limestone with minor amounts of interbedded sandstone and conglomerate with carbonate and distinctive quartzite clasts. Above the limestone and minor sandstone and conglomerate in Well NC–EWDP–2DB and in the outcrops, the deposits consist of fine to coarse sandstone and conglomerate with carbonate and distinctive quartzite clasts. Volcaniclastic deposits are present at the top of the sedimentary section in Well NC–EWDP–2DB and in the Nevada Test Site outcrops.

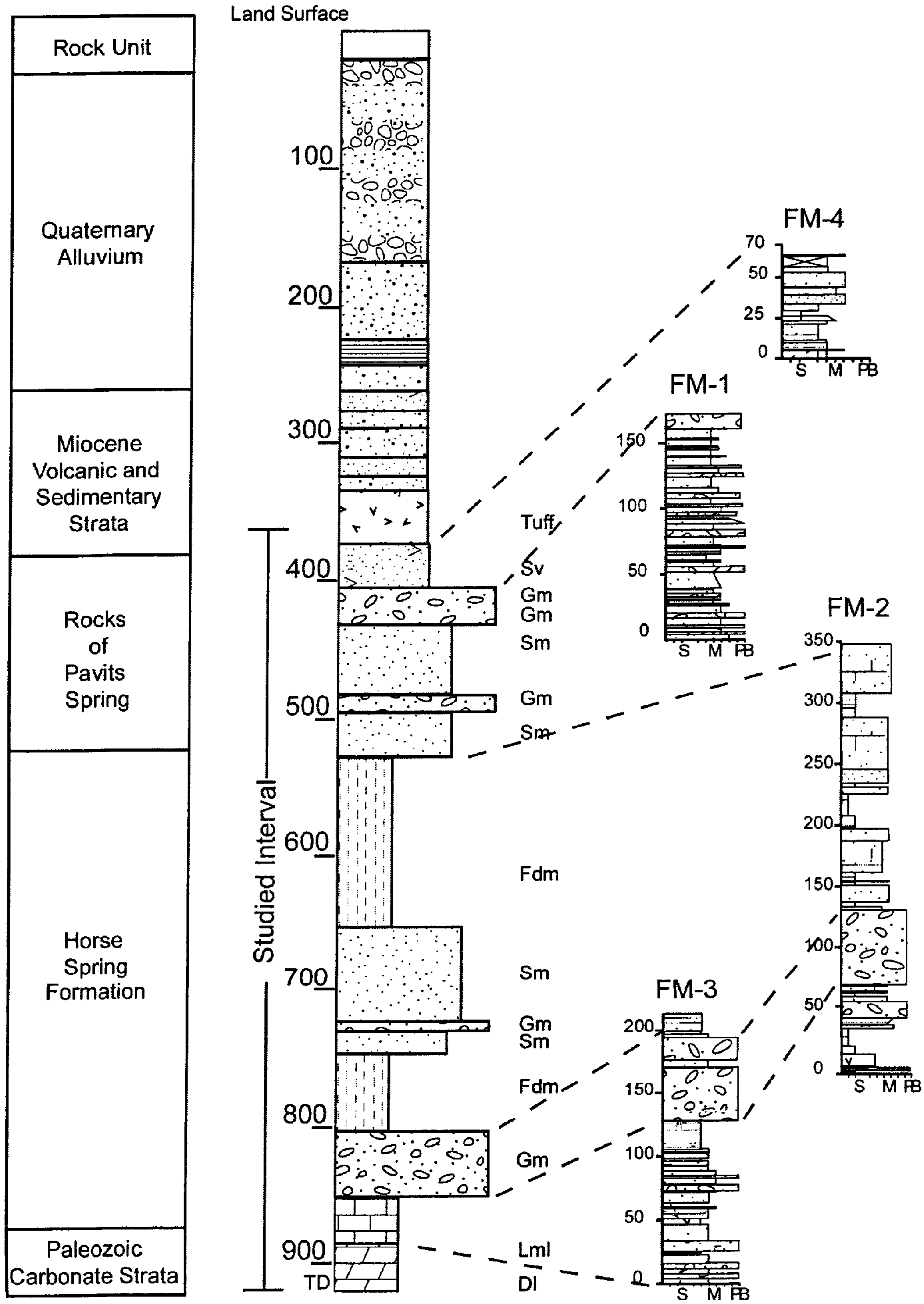

Figure 3-13. Correlation of Stratigraphy of Oligocene and Lower Miocene Strata from the Nye County Well NC–EWDP–2DB to the Measured Stratigraphic Sections from the Funeral Mountains. See Figure 3-1 for the Lithofacies Codes and Descriptions.

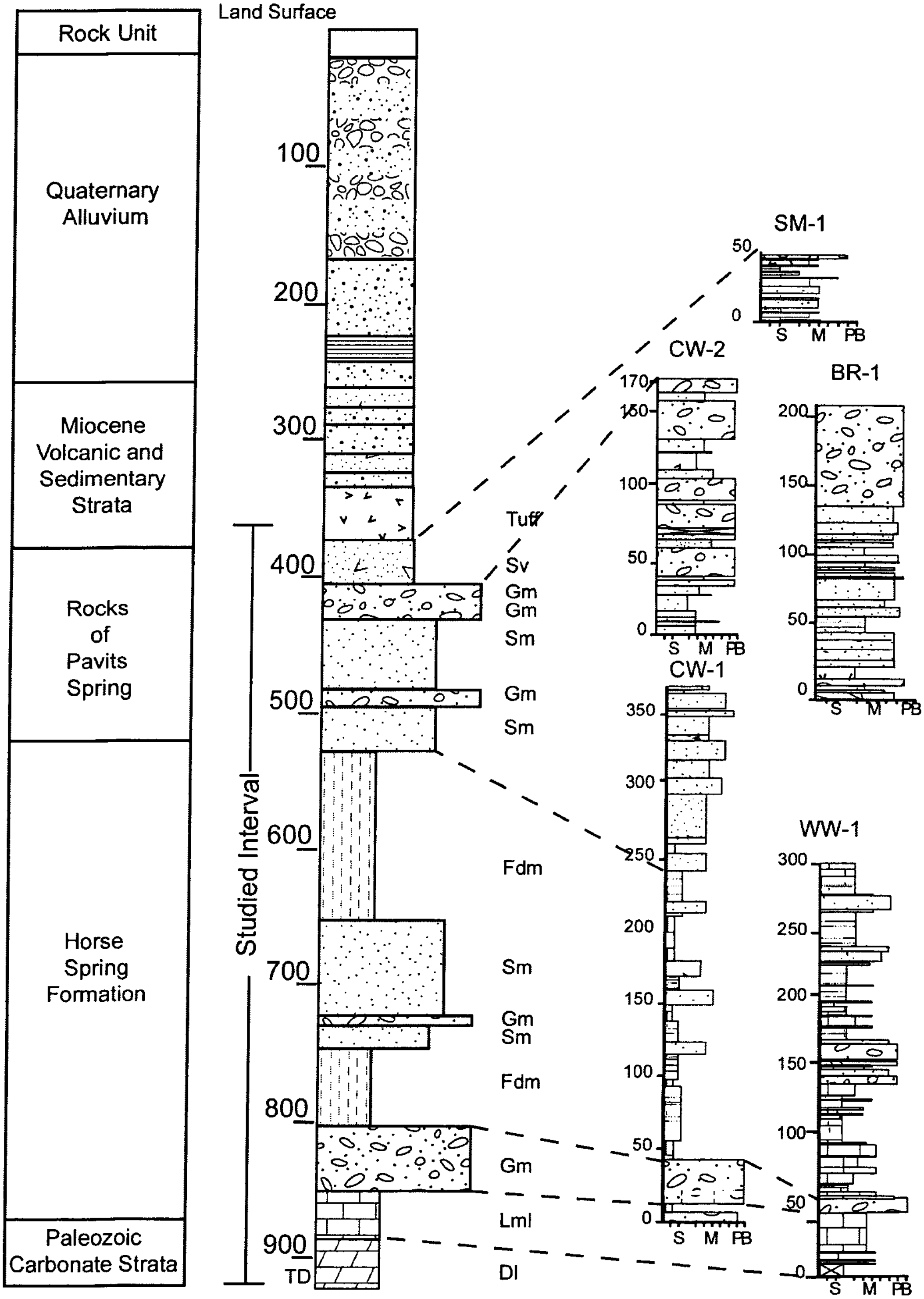

Figure 3-14. Correlation of Stratigraphy of Oligocene and Lower Miocene Strata from the Nye County Well NC–EWDP–2DB to the Measured Stratigraphic Sections from the Nevada Test Site. See Figure 3-1 for the Lithofacies Codes and Descriptions.

Based on the above correlation (Figures 3-13 and 3-14), and the previous description of the Horse Spring Formation and the Rocks of Pavits Spring, the limestone, mudstone, and conglomerate strata that occur between 526–884 m [1,725 ft– 2,900 ft] in Well NC–EWDP–2DB are interpreted to be equivalent to the Horse Spring Formation and the siltstone, sandstone, and conglomerate strata that occur between 390–526 m [1,280–1,725 ft] in NC–EWDP–2DB are interpreted to be equivalent to the Rocks of Pavits Spring (Figure 3-11). The volcanic unit that constitutes the upper part of the examined section in the well is equivalent to the overlying strata of the Miocene volcanic section, and it may correlate to the Tram Tuff.

3.3.2 Nye County Well NC–EWDP–1DX

Well NC–EWDP–1DX contains sandstone, tuffaceous sandstone, and siltstone between 383–762 m [1,255 ft–2,500 ft] (Figure 3-10) that is similar to observed strata of the Rocks of Pavits Spring, which also consist of gray tuffaceous sandstone and varicolored sandstone and siltstone. Thus, Well NC–EWDP–1DX appears to have penetrated 379 m [1,243 ft] of the Rocks of Pavits Spring. The absence of limestone and conglomerate in the well cuttings from NC–EWDP–1DX indicate that this well did not penetrate strata equivalent to the Horse Spring Formation. Based on this correlation of the well strata to strata of the Rocks of Pavits Spring, the red fine-grained tuff in the interval of Well NC–EWDP–1DX between 364–383 m [1,195–1,255 ft] appears to represent the oldest tuff in the overlying Miocene volcanic section, either the Tram Tuff or an older tuff.

In Well NC–EWDP–1DX, the lower strata deposits become finer grained toward the base of the well (Figure 3-10). This observation suggests that the base of the well strata may be quite close to the contact with the fine-grained limestone and siltstone of the Horse Spring Formation. In the outcrop on the Nevada Test Site, deposits are finer grained near the base of the Rocks of Pavits Spring outcrops, for example in the interval between 285–370 m [941–1,214 ft] in CW-1 (Figure 3-15) and in the interval between 0–40 m [0–131 ft] in CW-2 (Figure 3-6). This correlation suggests that the contact between the Rocks of Pavits Spring and the Horse Spring Formation may be just a few meters below the total depth of the well at 762 m [2,500 ft].

3.3.3 Nye County Well NC–EWDP–3D

Well NC–EWDP–3D contains siltstone, sandstone, and tuffaceous sandstone in the interval between 162–762 m [530–2,500 ft]. As stated previously, the Rocks of Pavits Spring consist of gray tuffaceous sandstone and varicolored sandstone and siltstone. As in Well NC–EWDP–1DX, this interval of Well NC–EWDP–3D is interpreted to be equivalent to the Rocks of Pavits Spring (Figure 3-12). The absence of limestone and conglomerate in the cuttings from this well suggest that the well did not penetrate strata equivalent to the Horse Spring Formation.

The tuff strata encountered in this well appear to be different than the tuff units in NC–EWDP–1DX and NC–EWDP–2DB. Two tuff units were encountered in this well, one in the interval between 107–162 m [530 ft–350 ft] and one in the interval between 419–559 m [1,361–1,834 ft] (Figure 3-12). The higher tuff unit is interpreted to represent a Miocene tuff unit younger than the Miocene tuff present in Wells NC–EWDP–1DX and NC–EWDP–2DB. This interpretation is based on the observation that the tuff units in this well are gray to yellow/green and medium grained, while the tuffs in Wells NC–EWDP–1DX and NC–EWDP–2DB are red and fine grained. The lower tuff unit is interpreted to represent part of the Rocks of Pavits Spring unit. This interpretation is based on the observation that the Rocks of Pavits Spring

Cave Wash 1 (CW-1)

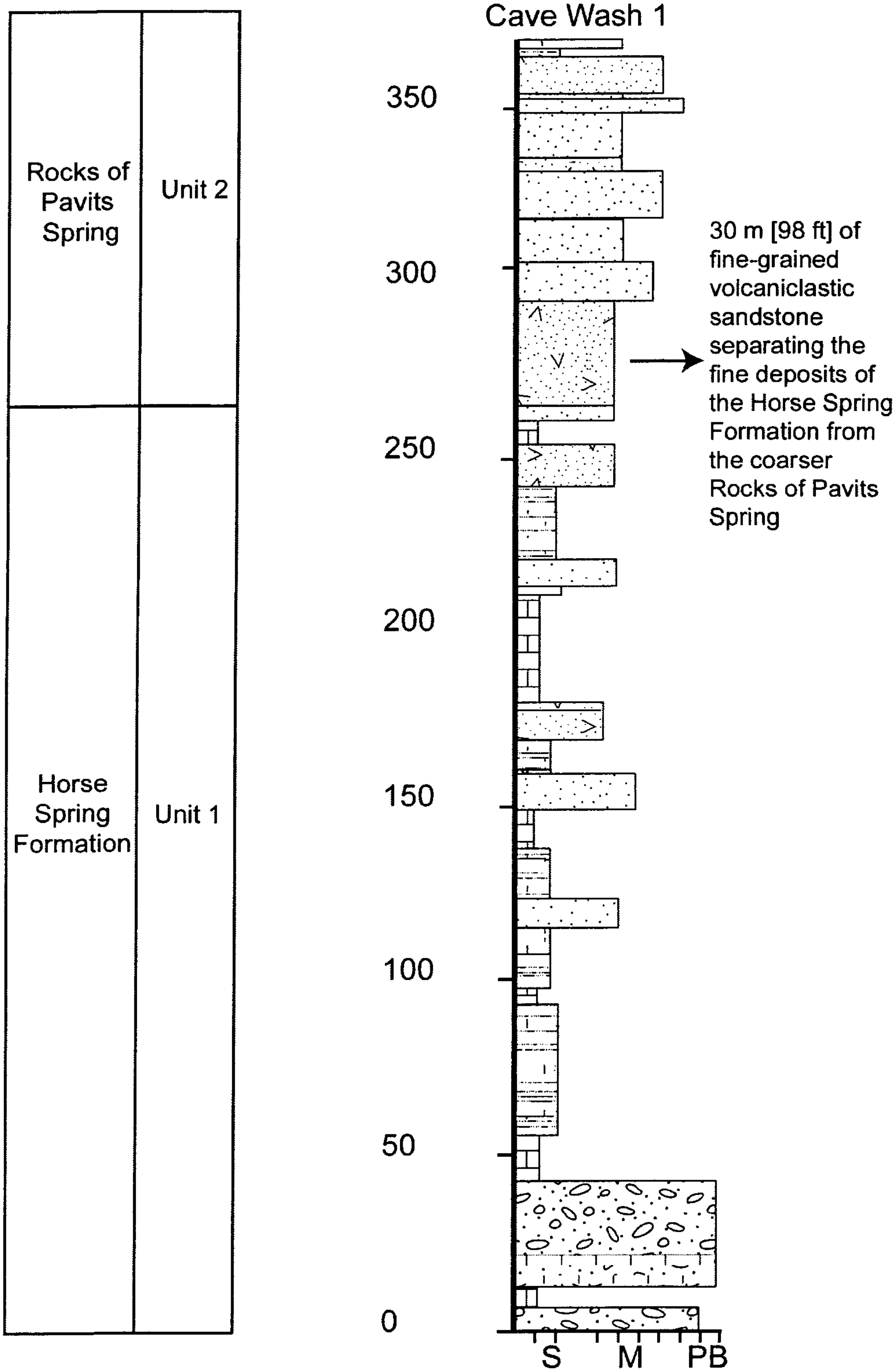

Figure 3-15. Measured Stratigraphic Section of CW-1. See Figure 3-1 for the Lithofacies Codes and Descriptions.

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contain interbedded tuff deposits (Hinrichs, 1968). In addition, sediments above and below this tuff unit are considered to be equivalent to the Rocks of Pavits Spring based on color and lithology.

Through correlation with outcrop strata, the stratigraphic level of the base of the Rocks of Pavits Spring can be estimated. In Well NC–EWDP–3D, the sediment at the base of the well consists of medium-grained sandstone and tuffaceous sandstone, indicating that the base of the well is not near to the finer-grained deposits of the Horse Spring Formation. Using a correlation to the CW-1 measured section (Figure 3-15) for reference, the minimum depth for the base of the Rocks of Pavits Spring in this well is estimated to be at least 30 m [100 ft] deeper than the current well bottom. This 30 m [100 ft] estimate is derived from the stratigraphy at CW-1 (Figure 3-15), in which approximately 30-m [100-ft] of volcaniclastic sandstone were deposited between the coarse sandstone near the base of the Rocks of Pavits Spring and the fine sandstone and siltstone near the top of the Horse Spring Formation. Well NC–EWDP–3D did not penetrate volcaniclastic sandstone, fine sandstone, or siltstone at its base, indicative of the Horse Spring Formation.

4 CROSS SECTIONS

4.1 Regional Cross Section

Using the information from the measured outcrop sections, well data, and existing map data, an east-west regional cross section was constructed (Figure 4-1). The regional cross section spans 120 km [75 mi] from the eastern Funeral Mountains to the Spotted Range on the Nevada Test Site. The cross section includes information from geologic maps, (Barnes, et al., 1982; Hinrichs, 1968; Sargent and Stewart, 1971; Sargent, et al., 1970; Swadley and Carr, 1987; Swadley, 1983; Wright and Troxel, 1993) outcrop data presented in this report, and stratigraphic data from wells NC–EWDP–2DB and NC–EWDP–4PA. Stratigraphic units on the cross section include rock units that range from Precambrian metamorphic rocks to Quaternary alluvium, however, the focus of the cross section is to illustrate geological relationships of the Tertiary sedimentary strata.

The most important result from this report, and illustrated in this cross section (Figure 4-1), is the recognition that the sedimentary basins in Fortymile Wash and the Amargosa Desert contain more than 500 m [1,650 ft], and possibly 1,000–2,000 m [3,281–6,562 ft] of these deposits (given maximum stratigraphic thickness) buried beneath younger Neogene and Quaternary volcanic and basin fill strata. This observation is important to groundwater flow and performance assessment models, because it implies additional complexity in the stratigraphy of the subsurface, complexity that could lead to greater vertical or lateral anisotropic and inhomogeneous flow and transport parameters such as permeability, porosity, retardation, and sorption. As a result, groundwater flow and transport and performance assessment models used in support of or review of a license application for the high-level waste repository at Yucca Mountain will need to account for the presence of the Oligocene and lower Miocene strata within Jackass Flats, Fortymile Wash, and the Amargosa basin.

4.2 Local Cross Sections Through Nye County Early Warning Drilling Program Wells

A more detailed local cross section was also constructed, using stratigraphic data from the 18 Nye County wells along U.S. Highway 95 (Figure 4-2). The cross section incorporated the Nye County Well data by projecting well stratigraphy onto the line of section. Unlike the regional correlation of the Oligocene and lower Miocene units, which is based on a lithostratigraphic correlation using the three-part lithology, the detailed bed-to-bed correlation between these wells is difficult because (i) only cuttings were recovered from the wells, (ii) most of the wells are quite shallow {less than 200 m [660 ft]} and do not penetrate diagnostic lithologies, (iii) the wells are all located near the distal pinch-outs of many of the Miocene volcanic deposits (Carr, et al., 1986), and (iv) geologic data from the surface (e.g., Swadley and Carr, 1987; Simonds, et al., 1995) suggests that numerous north-south faults exist between many of the wells. Nevertheless, analyses of the subsurface data and the cross section reveal that several interesting trends can be deduced from the cross section.

First, thicknesses of stratigraphic units vary greatly between wells. For example, in Nye County Well NC–EWDP–1DX, the upper most tuff in the well stratigraphy was encountered at approximately 50 m [164 ft] depth and is 80 m [262 ft] thick. In Well NC–EWDP–3D, the

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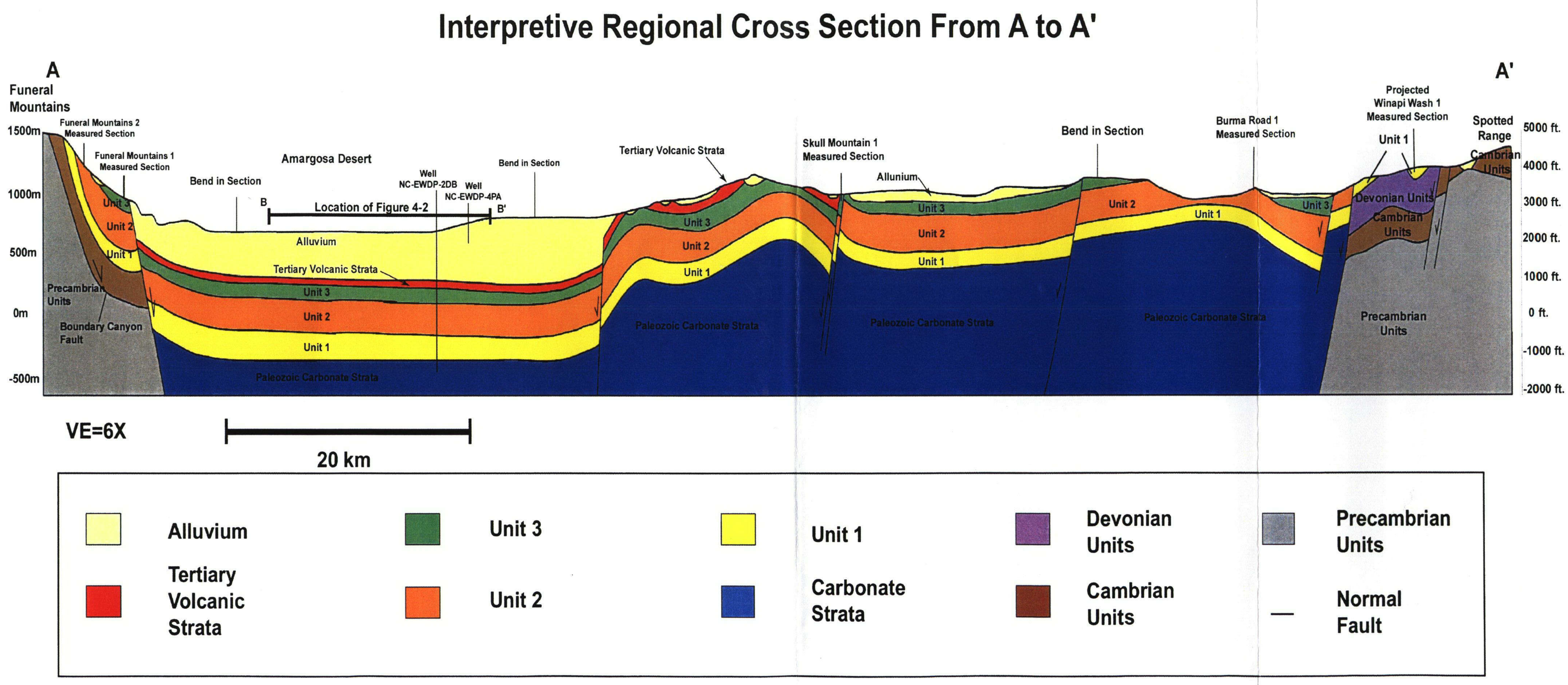

Figure 4-1. Geologic Cross Section through the Study Area from the Funeral Mountains to the Spotted Range on the Nevada Test Site. Location of the Section Line A to A' is Shown on Figure 1-1.

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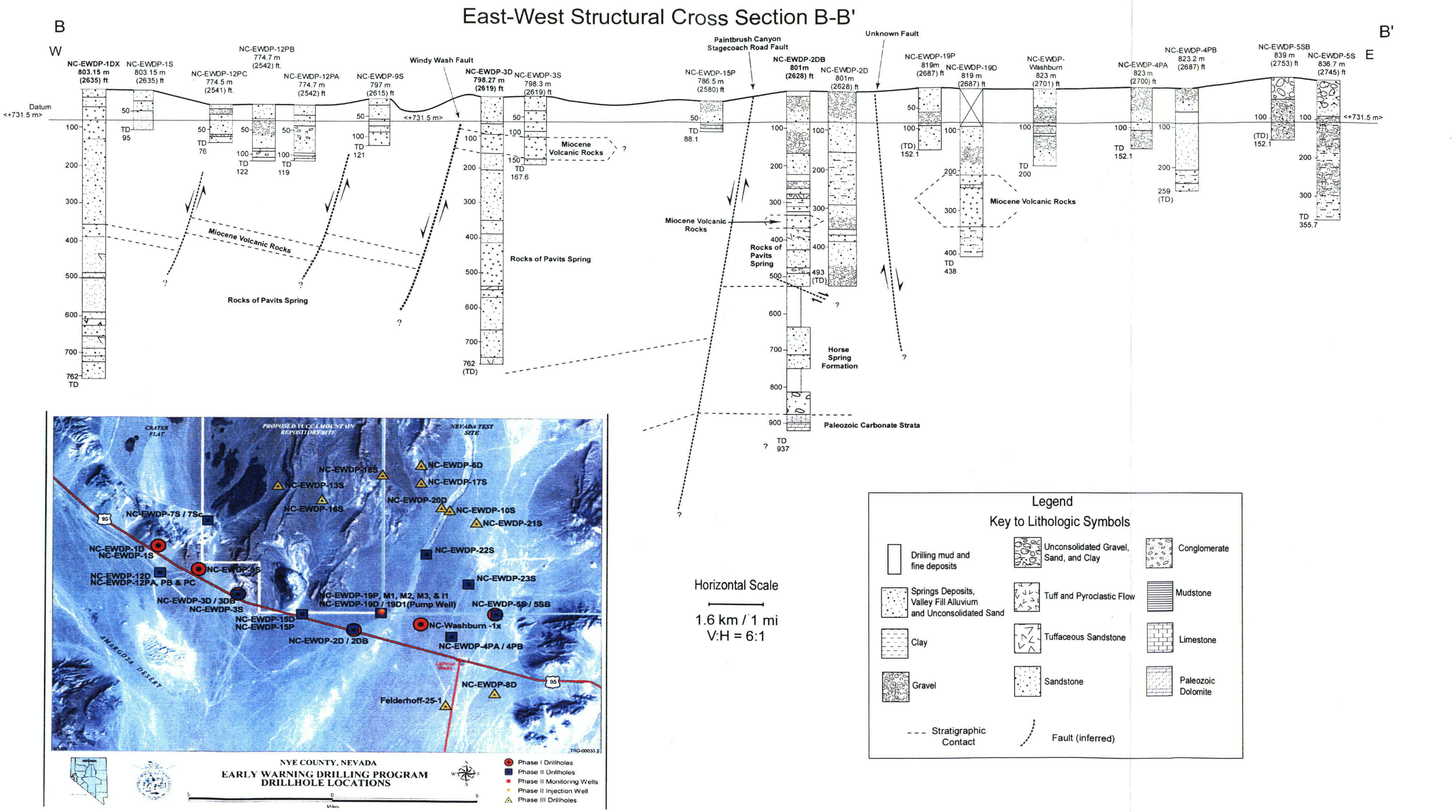

Figure 4-2. Geologic Cross Section through 18 Nye County Wells. Stratigraphic Data and Location Map Are from Nye County Nuclear Waste Repository Project Office (2002).

uppermost tuff, the section was encountered at 100 m [328 ft] depth and is approximately 55 m [131 ft] thick. These changes in thickness can be abrupt and occur over relatively short lateral distances. For example, Wells NC–EWDP–3D and NC–EWDP–3S are less than 1 km [0.6 mi] apart. In the upper 200 m [660 ft] of Well NC–EWDP–3D, there is one tuff unit (Figure 4-2), which occurs in the interval between 105–150 m [344–492 ft]. In contrast, at the same structural level in Well NC–EWDP–3S, two tuff units are present (Figure 4-2), one between 45–80 m [147–262 ft] and one between 100–150 m [328–494 ft]. The three wells also contain a different thickness of the Rocks of Pavits Spring. We estimate that Wells NC–EWDP–1DX and NC–EWDP–2DB contain 379 m [1,243 ft] and 136 m [446 ft] of the Rocks of Pavits Spring, respectively, while Well NC–EWDP–3D contains 600 m [1,968 ft] of the Rocks of Pavits Spring. In Well NC–EWDP–3D, the top of the Rocks of Pavits Spring is structurally higher than in the other two wells. The unit is encountered at 162 m [530 ft] in Well NC–EWDP–3D and at approximately 400 m [1,300 ft] in Wells NC–EWDP–1DX and NC–EWDP–2DB.

Second, there is a distinct change in lithology from west to east along the cross section. On the west side of the cross section, tuff is present in all but the shallowest well, NC–EWDP–12PC. On the eastern side of the cross section, out of ten wells, only four contain tuff. There are three tuff units present in the deepest well, NC–EWDP–2DB. In Well NC–EWDP–19D, two tuff units are present, and in Wells NC–EWDP–2D and NC–EWDP–15P, only one tuff unit is present. The difference in tuff content between wells implies that (i) the tuffs are more deeply buried in Fortymile Wash, (ii) the tuffs may have been removed from the section through faulting and erosion, or (iii) the wells intersected the complex distal edge of the tuff deposits.

Third, it is worth noting that the average thickness of the alluvium on the western side of the cross section is about 45 m [150 ft]. On the eastern side of the cross section, the average thickness is about 200 m [660 ft]. This thickness difference implies that the basin is asymmetric. If the eastern side of the basin was subsiding more rapidly than the western side, the result would be thickened alluvium on the east side.

The three observations discussed above—marked thickness changes, discontinuous units, and abrupt change in lithologies from west to east—indicate that several faults, complex depositional contacts, and lateral facies changes are present in the subsurface along the cross-section line. Most notable is the thick accumulation of the Rocks of Pavits Spring in Well NC–EWDP–3D compared to the thickness of this unit in Well NC–EWDP–2DB.

Based on these lateral variations, several faults have been drawn in the cross section (Figure 4-2). One normal fault is inferred between Well NC–EWDP–3D and Well NC–EWDP–2DB based on substantial lithologic differences between the two wells (Figure 4-2). This inferred fault is down-to-the-west as it displaces the contact between the Horse Spring Formation and the Rocks of Pavits Spring below the 762 m [1,184 ft] total depth of Well NC–EWDP–3D. The location and displacement of this fault is consistent with a southward projection of the Paint Brush Canyon-Stagecoach Road fault (e.g., Simonds, et al., 1995).

A second down-to-the-east fault is inferred just east of Well NC–EWDP–2D in order to explain the relatively thicker sections of alluvium and tuff in wells east of Well NC–EWDP–2D. No such fault is currently mapped along the western margin of Fortymile Wash, but one may be surmised in order to explain the juxtaposition of Miocene tuff and thick accumulation of alluvium and valley fill material. An alternative is that the changes in thickness of alluvium east of Well NC–EWDP–2D and in Fortymile Wash reflect deposition over an originally irregular topography such as the basement high shown in the three dimensional model of Sims, et al. (1999).

Several down-to-the-west normal faults are also inferred in the westernmost part of the section between NC–EWDP–1DX and NC–EWDP–3D. These faults are down-to-the-west, as they displace the Miocene volcanic rocks to relatively deep stratigraphic levels in Well NC–EWDP–1DX. The location and displacement of this fault is consistent with a southward projection of the Windy Wash fault system (e.g., Simonds, et al., 1995).

5 CONCLUSIONS

The Horse Spring Formation and the Rocks of Pavits Spring in the Funeral Mountains and on the Nevada Test Site can be divided into three lithostratigraphic units. These consist of a lower unit composed of stromatolite and gastropod-rich limestone, a middle unit composed of sandstone and conglomerate with quartzite and carbonate clasts, and an upper unit composed primarily of tuff and volcaniclastic strata. Cuttings from the three wells drilled in sedimentary basins adjacent to Yucca Mountain also suggest a three-part stratigraphy for units that we interpret as correlative with the Horse Spring Formation and the Rocks of Pavits Spring. The subsurface data from the well with the most complete section, Well NC–EWDP–2DB, consists of a lower package of limestone, a middle package of sandstone and conglomerate, and an upper package of volcaniclastic deposits. The stratigraphy of other wells that did not penetrate the complete Horse Spring Formation and Rocks of Pavits Spring sections can be inferred based on correlation with outcrop stratigraphy. Owing to the similarities in the stratigraphy of the outcrop and subsurface strata, we conclude that the three lithostratigraphic units can be correlated across 120 km [75 mi] across the Yucca Mountain region, from the Funeral Mountains through Fortymile Wash and Jackass Flats to the eastern border of the Nevada Test Site, just north of the town of Mercury, Nevada.

The subsurface configuration of the Tertiary strata in basins adjacent to Yucca Mountain is highly complex, both lithologically and structurally. There are over 500 m [1,650 ft] and possibly up to 2,000 m [6,600 ft] of probable Oligocene and lower Miocene strata between the Miocene volcanic strata and the Paleozoic carbonate strata. Our study indicates that the Oligocene and lower Miocene strata are an important component of the stratigraphic package of basins adjacent to Yucca Mountain.

The ability to correlate units in outcrop in the Funeral Mountains and the Nevada Test Site to units in the Early Warning Drilling Program wells is useful to refine modeling of fluid flow and contaminant transport in sedimentary basins adjacent to Yucca Mountain. The outcrops are analogs for the subsurface strata, so hydrologic parameters such as porosity and permeability for the basin fill in sedimentary basins adjacent to Yucca Mountain may be determined using the Horse Spring Formation and the Rocks of Pavits Spring in the Funeral Mountains and the Nevada Test Site.

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