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U.S. Nuclear Regulatory Commission
ATTN: Mrs. Deborah A. DeMarco
Office of Nuclear Material Safety and Safeguards
Mail Stop 8 A23
Washington, DC 20555-0001

Subject: Submittal of Manuscript: Stratigraphy of Oligocene and Lower Miocene Strata—Yucca Mountain Region

Dear Mrs. DeMarco:

The purpose of this letter is to transmit the subject manuscript to NRC for programmatic review. This paper will be presented at the annual meeting of the International High-Level Radioactive Waste Management Conference in Las Vegas, Nevada, March 30 to April 2, 2003. The abstract for this talk was previously approved by NRC.

This manuscript documents a study of the Oligocene and lower Miocene sedimentary rocks in the Northern Amargosa Desert, Nevada. These rocks make up part of the deeper aquifer in the region south and southeast of Yucca Mountain.

Should you have any questions regarding this please contact Dr. John Stamatakos at (210) 522-5247 or Dr. Lawrence McKague at (210) 522-5183.

Sincerely,

B. Sagar
Technical Director

rae
Attachment

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STRATIGRAPHY OF OLIGOCENE AND LOWER MIOCENE STRATA—YUCCA MOUNTAIN REGION

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ABSTRACT

To develop a framework for analyses of the subsurface stratigraphy in the Yucca Mountain region, detailed stratigraphic sections of Oligocene and lower Miocene strata were measured in exposures on the Nevada Test Site and in the Funeral Mountains. Results show that the stratigraphy consists of three lithostratigraphic units: (i) a lower unit containing abundant gastropod- and ostracod-rich limestone; (ii) a middle unit dominated by conglomerate, coarse sandstone, and red siltstone; and (iii) an upper unit consisting mainly of volcaniclastic sandstone, tuffaceous sandstone, and tuff. These lithostratigraphic units correlate to similar strata in the subsurface that were identified from cuttings of three wells drilled as part of the Nye County Early Warning Drilling Program. The interpretation that the subsurface strata correlate to the surface outcrops indicates that there is broad lateral continuity of these strata across the Yucca Mountain region with substantial vertical anisotropy in rock and hydrologic properties within the basins. Moreover, continuity of this stratigraphy across the region and correlation between the outcrops and subsurface stratigraphy are important because hydrologic and geologic rock property data for the lower stratigraphy of valley fill aquifer within the basins can be obtained from surface outcrops.

INTRODUCTION

The geology of the Yucca Mountain region is characterized by complex strike-slip and extensional deformation that has been ongoing throughout the Cenozoic (last 65 Ma). This deformation produced a physiography of exhumed or remnant crustal blocks separated by internally drained and alluvium-filled sedimentary basins. The thick accumulation of sedimentary material within the basins provides much of the material through which groundwater flows in the vicinity of Yucca Mountain, especially south and east of Yucca Mountain as groundwater exits the fractured tuff aquifer and enters the alluvial aquifer of Fortymile Wash and the Amargosa basin [1]. Evaluation of the stratigraphic architecture of the basins adjacent to Yucca Mountain is therefore important for accurate representations of groundwater flow and transport of radioactive contaminants, especially in areas down gradient from Yucca Mountain.

To date, strata in basins proximal to Yucca Mountain have been represented in groundwater flow and transport models, and in performance assessments for the proposed Yucca Mountain repository, as unconsolidated, isotropic, and homogeneous valley-fill alluvium [2, 3, 4]. The actual stratigraphy of the basins has not been extensively studied, although analyses have recently been conducted to document the types of facies that occur within exposures of alluvium in Fortymile Wash [5]. 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.

Spengler and Chornack [6] recently developed stratigraphic cross sections based in part on analysis of cuttings from wells drilled as part of the Nye County Early Warning Drilling Program [7]. However, Spengler and

Chornack [6] designate the older strata in these wells as pre-Lithic Ridge and older volcanic tuff and sedimentary gravel, without consideration of whether the strata correlate to mapped rock units. This paper presents new outcrop and subsurface data that makes such a correlation, thereby improving our understanding of the Tertiary stratigraphy in the Yucca Mountain region.

WORK DESCRIPTION

This study considers the surface and subsurface lithostratigraphy of Oligocene and lower Miocene strata in the sedimentary basins adjacent to Yucca Mountain (Figure 1). Within the region, the Oligocene-Miocene section consists of three mapped sedimentary units, the Horse Spring Formation, the Titus Canyon Formation, and the Rocks of Pavits Spring [8, 9, 10]. 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 [11, 12]. Two tuff beds in the Titus Canyon Formation yield $^{40}Ar/^{39}Ar$ isochron ages of 34.3 and 30.0 Ma [13]. The oldest airfall tuff in the Horse Spring Formation produced a $^{40}K/^{39}Ar$ age of 30.2 Ma [14]. The Rocks of Pavits Spring contain an airfall tuff near the base of the unit that has a $^{40}K/^{39}Ar$ age of 15.8 Ma. The Horse Spring Formation and the Rocks of Pavits Spring are not exposed at the surface near Yucca Mountain, but they are well exposed on the nearby Nevada Test Site [15] and equivalent strata are exposed in the Funeral Mountains [9]. In addition, several Nye County wells adjacent to Yucca Mountain [7] encountered unexpectedly thick sections of sedimentary strata between upper Miocene volcanic tuff and Paleozoic limestone.

To evaluate the sedimentary strata between Miocene volcanic strata and Paleozoic limestone in the Nye County wells, and thereby define the subsurface lithostratigraphy of the Fortymile Wash and Amargosa basin, detailed stratigraphic profiles of exposed Oligocene and lower Miocene strata in the Yucca Mountain region were developed. Similar stratigraphic profiles were developed for three of the Nye County wells (NC-EWDP-1DX,-2DB, and -3D). The outcrop sections were then correlated with the well strata based on stratigraphy, stratigraphic contacts, and lithology.

RESULTS

Stratigraphic Sections in the Funeral Mountains

Four stratigraphic sections were measured in the eastern Funeral Mountains (Figure 2). Collectively, these sections comprise 800 m [2,600 ft] of sedimentary and volcanic strata between Paleozoic carbonate deposits and Miocene volcanic strata of the Miocene southwestern Nevada volcanic field [16].

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 (Figure 2). It consists of tuff and organized and well-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 internal structures, and white to green in color. Bedding is massive and average bed thickness is about 0.1 m [0.3 ft].

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 (Figure 2). 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 Mountains is illustrated by the 0–171 m [0–560 ft] shown in FM-1 (Figure 2). These strata consist of red conglomerate with white, green, and pink quartzite and carbonate clasts and fine to coarse red sandstone (Figure 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 2). Near the very top of the Oligocene and lower Miocene section in the Funeral Mountains, illustrated by FM-4 (Figure 2), are tan sandstones and tan to green volcaniclastic sandstone.

Stratigraphic Sections on the Nevada Test Site

Five stratigraphic sections were measured on the Nevada Test Site in Frenchman Flat, in Rock Valley, and at Skull Mountain (Figure 3). Collectively these sections comprise 1,107 m [3,500 ft] of sedimentary and volcanic strata between Paleozoic carbonate deposits and middle to upper Miocene volcanic strata of the southwestern Nevada volcanic field [16].

The lower part of the Oligocene and lower Miocene strata on the Nevada Test Site is illustrated by the 0-300 m [0-1000 ft] shown on WW-1 (Figure 3). 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 are present in CW-1 (Figure 3). Key strata in both CW-1 and WW-1 are conglomerate beds with purple, white, and green quartzite clasts (Figure 3).

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 (Figure 3). Strata are dominated by brown to orange-red sandstone, tuffaceous sandstone, and conglomerate with white and purple quartzite and dark gray carbonate clasts. This middle part of the Oligocene and Miocene strata rests on a thick section of green tuffaceous sandstone, as shown in the top of CW-1 and the bottom of BR-1 (Figure 3).

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 (Figure 3). 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.

Lithostratigraphy

Based on these observations, the Oligocene and lower Miocene strata were divided into three regional lithostratigraphic units: (i) a lower unit containing abundant gastropod and ostracod-rich limestones; (ii) a middle unit dominated by conglomerate, coarse sandstone, and red siltstone; and (iii) an upper unit consisting mainly of volcaniclastic sandstone, tuffaceous sandstone, and tuff (Figures 2 and 3).

Stratigraphic Sections from the Nye County Wells

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 [17]. Characterization of cuttings from three wells provided a way to compare the well cutting sediments to surface outcrops.

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). 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 1.5 m [5 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.

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. In this well, the stratigraphy of the interval between the Paleozoic strata and upper Miocene tuff also consists of three lithostratigraphic units characterized by (i) tan and brown limestone; (ii) conglomerate with multi-colored quartzite clasts and tan to red sandstone; and (iii) tuffaceous sandstone, volcaniclastic sandstone and volcanic tuff. This three-part lithostratigraphy corresponds to the lithostratigraphic units established from outcrop, both to the east and west. Because of this correspondence, the approximately 550 m (1300 ft) of strata in NC-EWDP-2DB is 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) the unconformable contact between Tertiary and Paleozoic carbonate strata, (ii) distinctive conglomerate clasts (multi-colored, especially green and purple) observed in both the outcrop strata and cuttings, (iii) relatively thick sections of limestone deposits, (iv) vertical gradational changes in lithology from limestone to sandstone, and (v) vertical changes in lithology from sandstone and tuffaceous sandstone to tuff.

In particular, the correlations between NC-EWDP-2DB and the outcrop stratigraphy are based on the following five observations:

(1) 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, 937–884 m [2,900–3,075 ft] depths from ground surface, the cuttings are dark gray and are interpreted to be Paleozoic dolomite. Above the gray dolomite, 884–866 m [2,840–2,900 ft] depths, 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, with significant limestone in section FM-2 (Figure 2).

(2) In FM-3 and low in FM-2 (Figure 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). In the well stratigraphy, these same green and purple quartzite clasts are present at depths between 815–866 m [2,675–2,840 ft] in Well NC-EWDP-2DB (Figure 3).

(3) In the Well NC-EWDP-2DB, drilling mud and very fine cuttings are present at depths from 753–815 m [2,470–2,675 ft] and at depths from 526–655 m [1,725–2,150 ft] (Figure 2). 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 interpreted to be equivalent to the numerous white and gray limestone beds in FM-2 (Figure 2), CW-1, and WW-1 (Figure 3).

(4) Above the limestone and conglomerate, the sedimentary section becomes dominated by clastic deposits. In outcrop sections FM-1 (Figure 2), BR-1 and CW-2 (Figure 3), 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, at depths between 400–526 m [1,312–1,726 ft] (Figure 3), 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.

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

Lithofacies Associations

The lithostratigraphic units of the Horse Spring Formation and the Rocks of Pavits Spring of southwestern Nevada and southeastern California are indicative of deposition in lacustrine, fluvial, alluvial fan, and volcanic depositional environments. The three lithostratigraphic units correspond to three lithofacies associations and are interpreted to represent three distinct depositional settings.

Lithofacies Association 1 is characterized by well-laminated algal-rich limestone and conglomerate with a sand-rich matrix and pebble to cobble-sized clasts of quartzite and carbonate. The limestone is indicative of deposition in a low energy freshwater lacustrine environment [18]. The matrix-supported conglomerate is indicative of deposition by streamflow processes in a braided stream [19].

Lithofacies Association 2 is characterized by poorly sorted, clast-supported conglomerate with pebble to boulder-sized clasts of quartzite and limestone and stratified fine-to-coarse-grained sandstone. These characteristics are indicative of deposition by streamflow in braided stream and alluvial fan environments [20].

Lithofacies Association 3 is characterized by tuff and volcaniclastic sandstone that are interpreted to represent sporadic local volcanism, and fluvial reworking of volcanic deposits.

CONCLUSIONS

The subsurface configuration of the Tertiary strata in basins adjacent to Yucca Mountain is lithologically highly complex. There are over 500 m (1,650 ft) and possibly up to 2,000 m (6,600 ft) of Oligocene and lower Miocene strata in the Yucca Mountain region. These strata, which were originally mapped as the Horse Spring Formation and Rocks of Pavits Spring, can be divided into three lithostratigraphic units: (i) a lower unit containing abundant gastropod and ostracod-rich limestone; (ii) a middle unit dominated by conglomerate, coarse sandstone, and red siltstone; and (iii) an upper unit consisting mainly of volcaniclastic sandstone, tuffaceous sandstone, and tuff. Cuttings from the three wells drilled in sedimentary basins adjacent to Yucca Mountain also suggest a three-part stratigraphy for the 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. Owing to the similarities in the stratigraphy of the outcrop and subsurface strata, we conclude that the three lithostratigraphic units can be correlated across the Yucca Mountain region, from the Funeral Mountains through Fortymile Wash and Jackass Flats to Frenchman Flat. Additionally, the three lithostratigraphic units corresponding to three lithofacies associations are interpreted to represent three distinct stages of extensional basin development.

The ability to correlate units in outcrop in the Funeral Mountains and the Nevada Test Site to units in the subsurface is useful to refine modeling of fluid flow and contaminant transport in sedimentary basins adjacent to Yucca Mountain. First, there appears to be broad lateral continuity of the Oligocene and lower Miocene strata across a wide area of the Yucca Mountain region. Second, the three-part lithostratigraphy suggests substantial vertical anisotropy in rock and hydrologic properties. Third, because the outcrops are analogs for the subsurface strata, rock and hydrologic parameters such as porosity and permeability for the basin fill in sedimentary basins adjacent to Yucca Mountain can be obtained from correlative strata in the Funeral Mountains and on the Nevada Test Site.

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The study was carried out by Ms. Danielle Murray as part of her masters thesis at Purdue University. Ms. Murray was supervised by Dr. Kenneth Ridgway, also at Purdue University and working under a consulting contract to the CNWRA.

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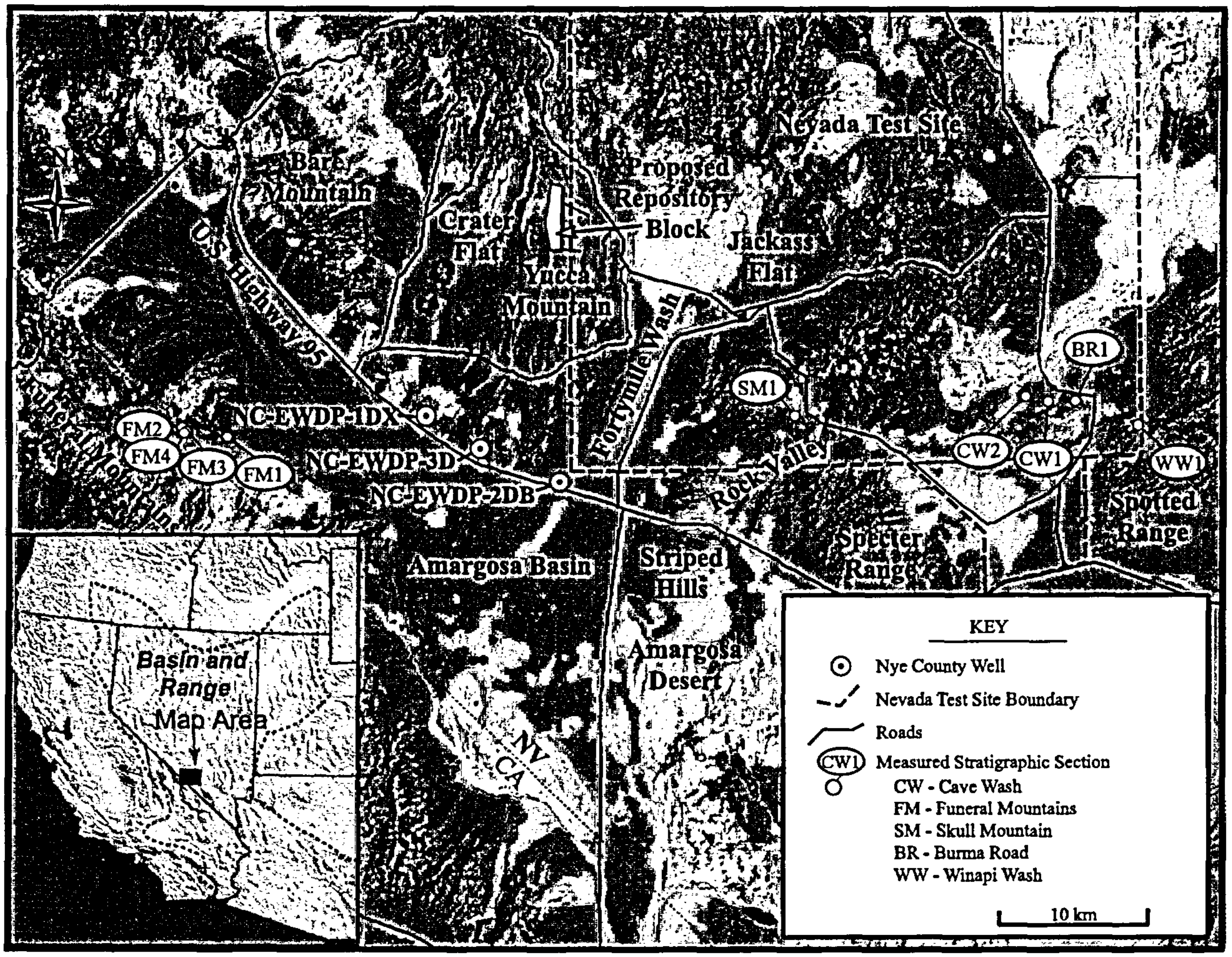

Figure 1. Satellite image of the Yucca Mountain region showing the location of measured stratigraphic sections and Nye County Early Warning Drilling Program wells. Inset is a digital elevation model of the western United States showing the location of the Yucca Mountain region relative to the Basin and Range physiographic province.

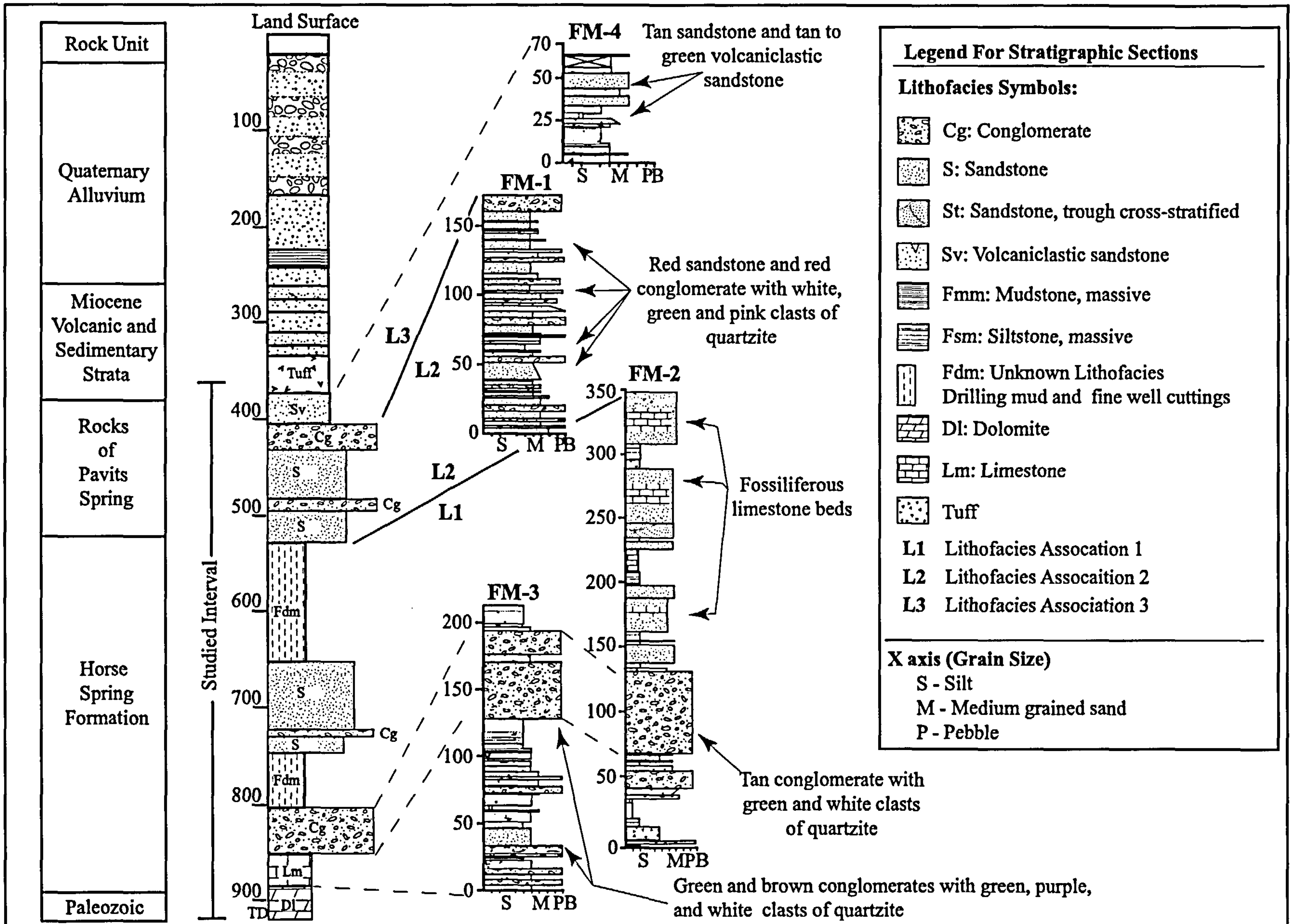

Figure 2. Correlation of Oligocene and lower Miocene strata from the Nye County, Well NC-EWDP-2DB to measured stratigraphic sections from the Funeral Mountains. Note that the outcrop and well sections are drawn with different vertical scales. Stratigraphic sections were measured in meters perpendicular to layering.

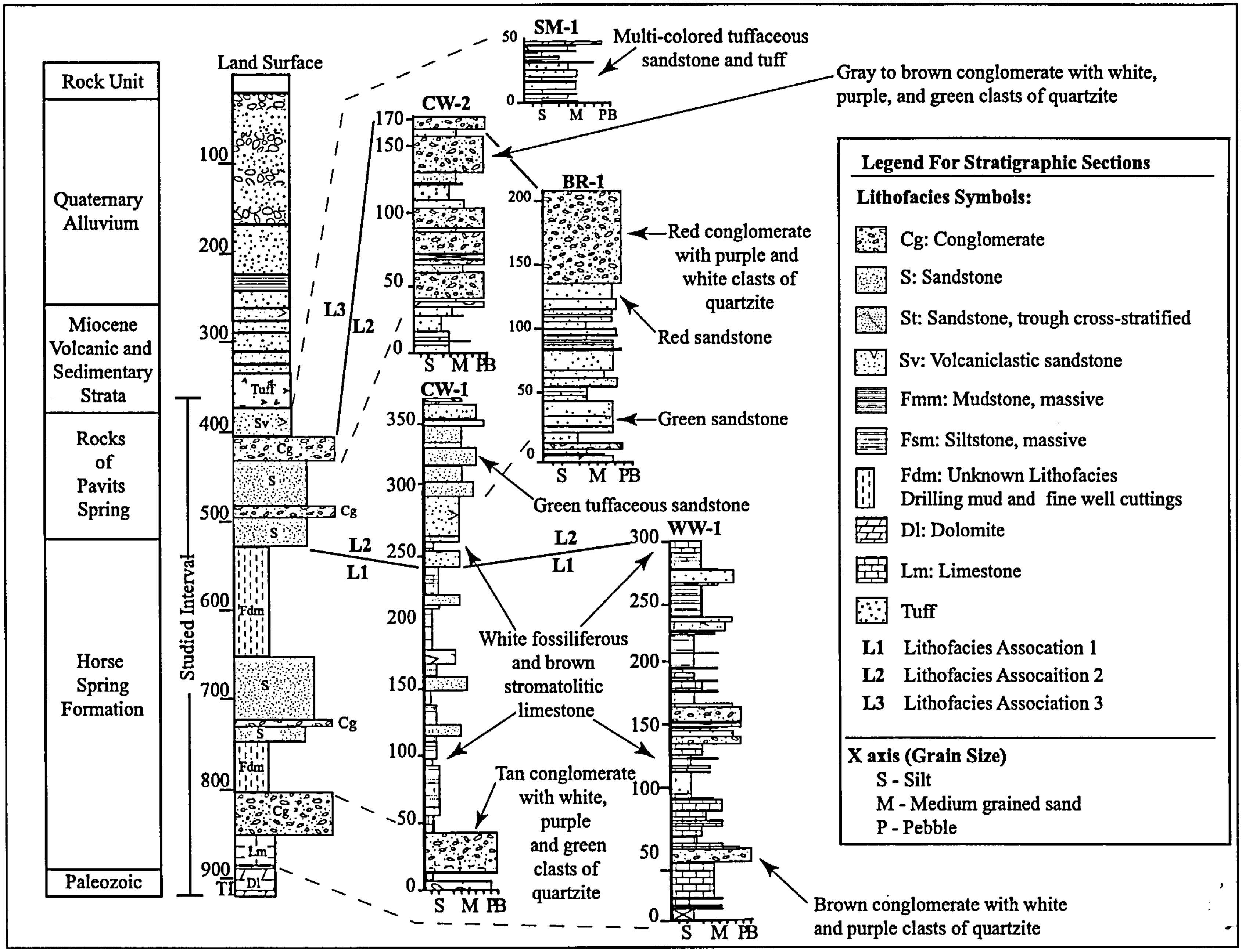

Figure 3. Correlation of Oligocene and lower Miocene strata from the Nye County Well NC-EWDP-2DB to measured stratigraphic sections from the Nevada Test Site. Note that the outcrop and well sections are drawn with different vertical scales. Stratigraphic sections were measured in meters perpendicular to layering.