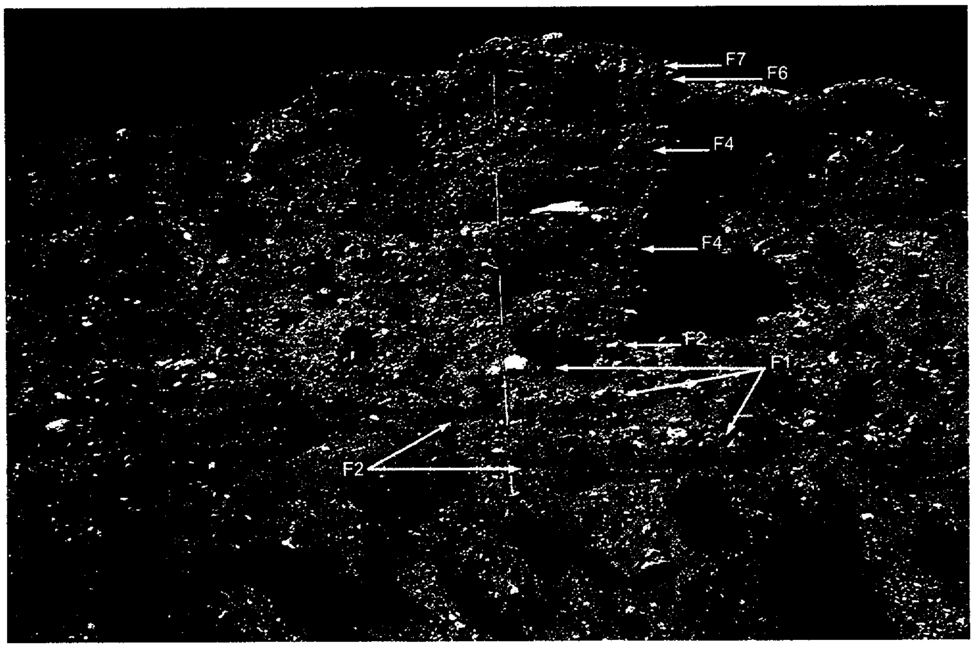
Figure 4-11. 40mPROX: The northernmost outcrop of the Fortymile Wash valley-fill. Arrows on the photograph highlight the facies present in the outcrop. The observable facies geometries are displayed in the illustration beneath the photograph.



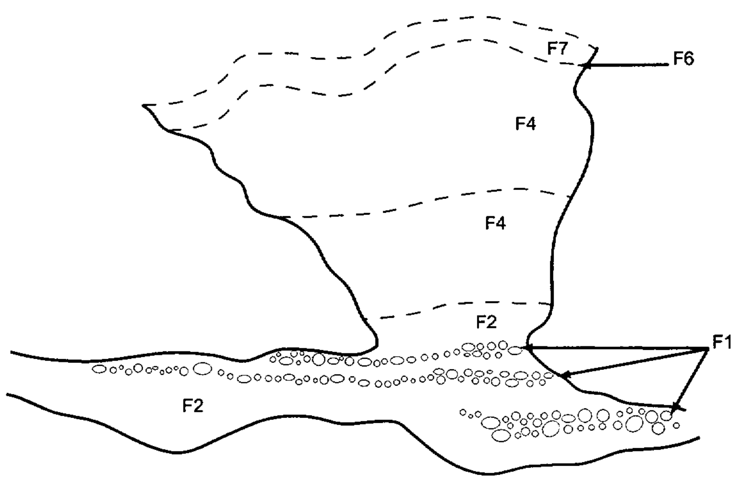


figure 4-11

Figure 4-12. Stratigraphic section measured from 40mPROX

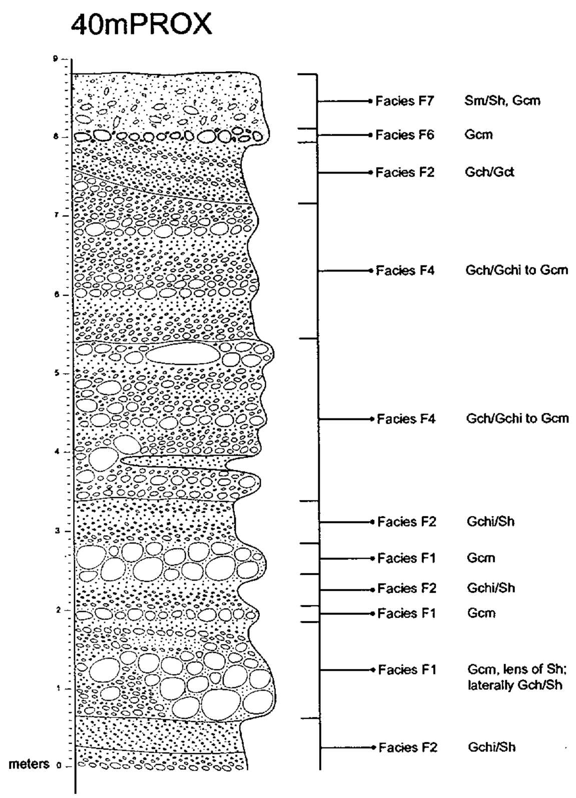
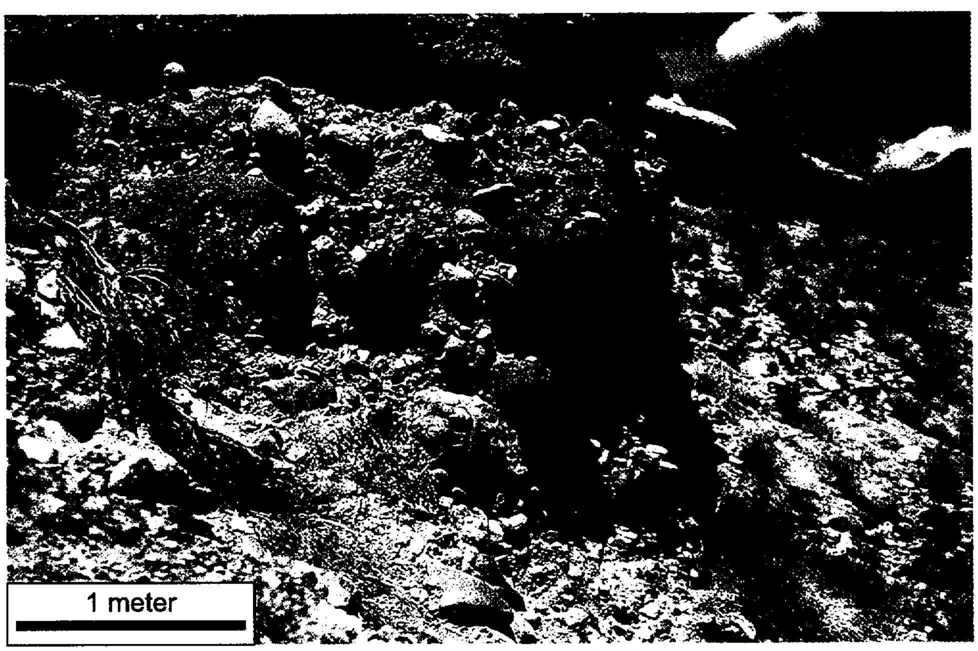

40mPROX
9
8
7
6
5
4
3
2
1
meters 0
Facies F7
Sm/Sh, Gcm
Facies F6
Gcm
Facies F2
Gch/Gct
Facies F4
Gch/Gchi to Gcm
Facies F4
Gch/Gchi to Gcm
Facies F2
Gchi/Sh
Facies F1
Gcm
Facies F2
Gchi/Sh
Facies F1
Gcm
Facies F1
Gcm, lens of Sh;
laterally Gch/Sh
Facies F2
Gchi/Sh

figure 4-12

Figure 4-13. Facies F4 in 40mPROX: (a) Upper exposure with crude to developed gravel couplets. Gravel becomes less stratified and more massive toward the left; (b) Lower exposure with coarser clast content and less developed stratification.

(a)



(b)

figure 4-13

outcrop. There may also be deposits farther to the east of 40mPROX, at the base of the ridge slopes. However, sediment gravity flow deposits may be limited in this locality of Fortymile Wash due to the lack of areas for these deposits to accumulate. At this locality—and becoming more prominent to the north—the narrow channel of Fortymile Wash is incised into the bedrock. Sediment gravity flows moving material any substantial distance would have deposited the material within the channel of Fortymile Wash where the sediment was incorporated into the sediment load of Fortymile Wash.

Below the exposures of Facies F4, Facies F2 and Facies F1 predominate (figure 4-11). The exposures of Facies F2 contain the characteristic gravel-sand couplets (figure 4-11). Facies F1 also is fairly common in 40mPROX, and its exposure in outcrop is typical of the facies. A characteristic exposure of Facies F7 is present at the top of 40mPROX. The facies extends laterally across the entire outcrop and does not appear to change in thickness. This upper surface is interpreted as the same terrace surface observed at the top of the other outcrops. A gravelly caliche layer (Facies F6) is developed beneath Facies F7. The gravelly caliche of Facies F6 and the strongly cemented Facies F7 form the resistive ledge at the top of the outcrop (figure 4-11).

Several substantial outcrops are available near the H-road crossing of Fortymile Wash, approximately 9 km south of 40mPROX (figure 4-10). These outcrops provide additional exposures of the valley-fill in the proximal reaches of Fortymile Wash. The large outcrop south of the H-road crossing of Fortymile Wash, on the west side of the entrenched channel of Fortymile Wash, is designated as 40mBIG. This outcrop provides an exposure of the alluvium approximately 500 m long and 20 m high. 40mBIG also is the locality where Lundstrom et al. (1998) dated buried soils and carbonate coats within the alluvium to constrain the timing of aggradation and incision in Fortymile Wash. The second outcrop chosen for investigation is located just north of the H-road crossing of Fortymile Wash and is designated as Portal 1. Portal 1 provides an exposure of the alluvium approximately 100 m long and 10 m in high oriented oblique to the orientation of 40mBIG.

The majority of the outcrops of alluvium are oriented parallel to the longitudinal axis of Fortymile Wash. Portal 1 is located near the confluence of Yucca Wash, a tributary to Fortymile Wash, and Fortymile Wash. Portal 1 is one of only a few outcrops that provides an exposure of the alluvium oblique to the flow direction of the wash. Facies present in Portal 1 include F1, F2, F5, F6, F7, and F8 (figures 4-14 and 4-15). Facies F2 is the dominant facies exposed in Portal 1. Of all the outcrops investigated, Portal 1 provides the best exposure of the cross-stratified gravel within Facies F2 because the outcrop is oriented oblique to the flow direction (figure 4-3). Facies F1 also is fairly common in Portal 1. The single exposure of Facies F5 is present in this outcrop. At this locality, the facies consists almost entirely of angular clasts of purple tuff, either Topopah Spring or Tiva Canyon. Portal 1 is located in close proximity to Fran Ridge, which is composed of Topopah Spring and Tiva Canyon tuff. The deposit is interpreted as a rock slide or debris flow that originated on the slopes of Fran Ridge (figure 4-10), based on the near monolithologic clast content of the deposit and the presence of modern and relict rockfalls on the slopes of Fran Ridge. Two exposures of Facies F7 are present in this locality. In both instances, Facies F6 lies beneath Facies F7, and a resistive ledge protrudes from the outcrop (figure 4-14). Both exposures of Facies F7 are laterally extensive across the entire outcrop (approximately 100 m). These exposures of Facies F7 are predominantly sand, but contain scattered gravel and cobbles and lack any identifiable sedimentary structure due to heavy bioturbation. Facies F7 is distinctively orange-red in color. Facies F8 is limited in exposure and volumetrically minor.

40mBIG is the largest outcrop of alluvium in Fortymile Wash. Nearly all the facies are exposed in this locality: F1, F2, F4, F6, F7, and F8 (figure 4-16 and 4-17). The exposures of channel geometry in

Figure 4-14. Portal 1: Outcrop of the Fortymile Wash valley-fill located near the confluence of Fortymile Wash and Yucca Wash (a tributary to Fortymile Wash). Arrows on the photograph highlight the facies present in the outcrop.

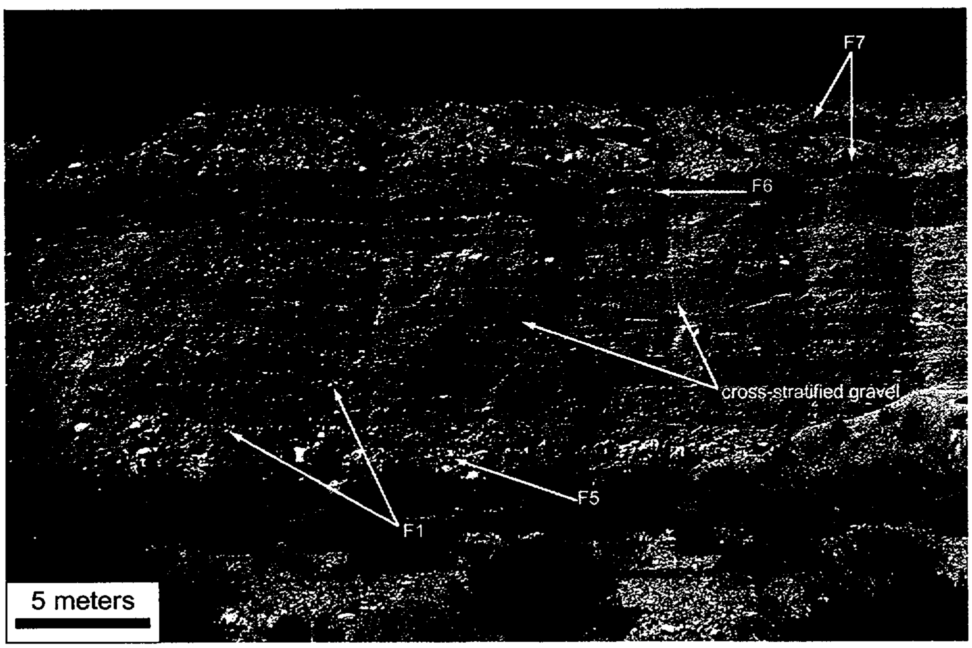
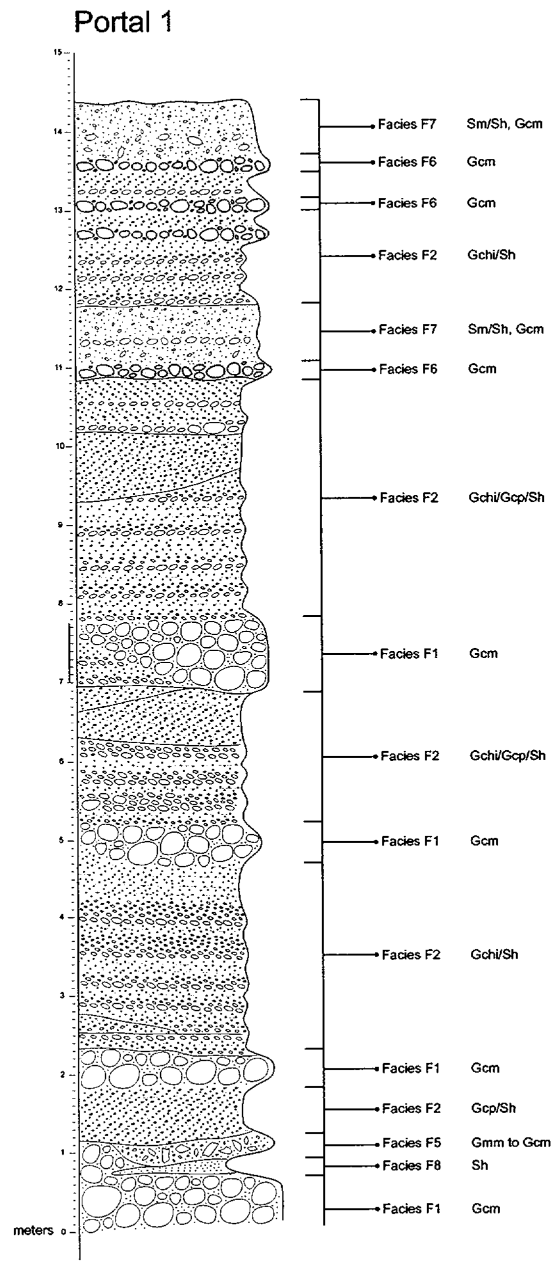


figure 4-14

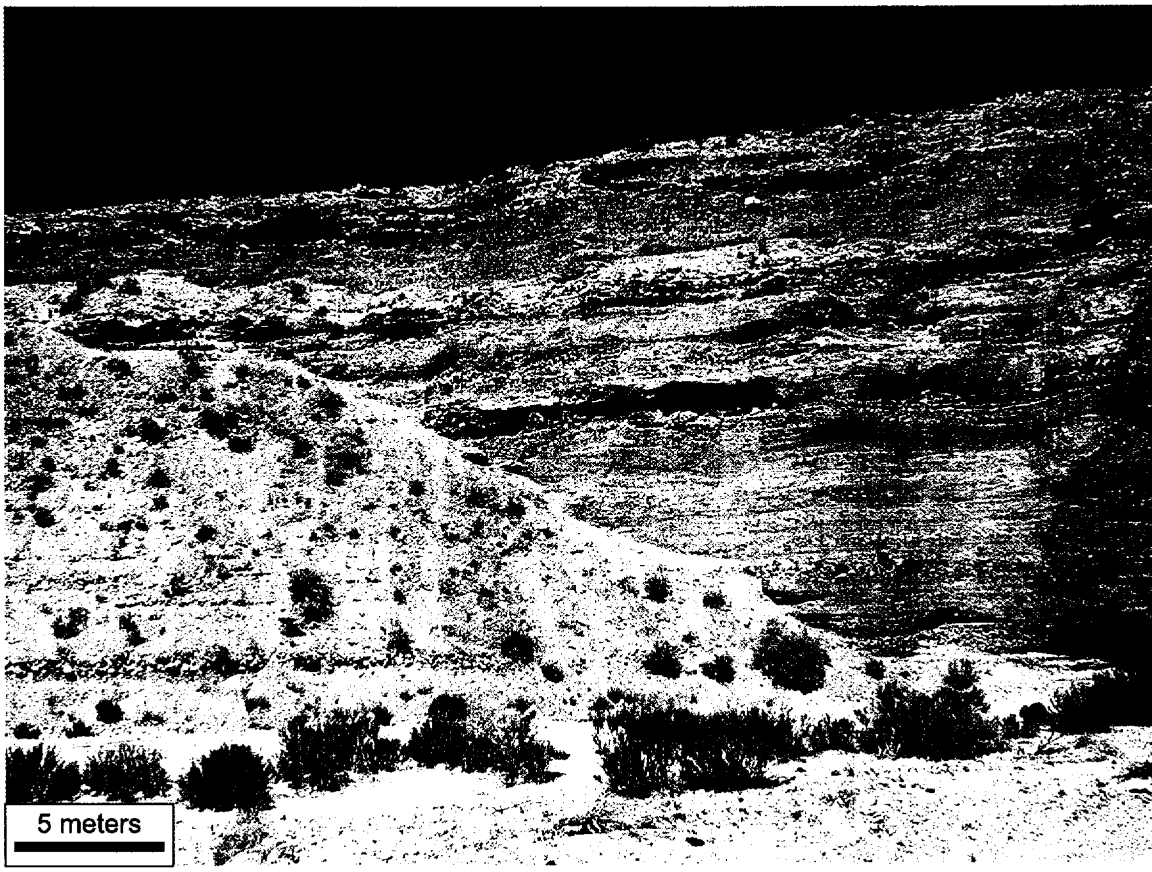
Figure 4-15. Stratigraphic section measured from Portal 1



Portal 1
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
meters 0
Facies F7 Sm/Sh, Gcm
Facies F6 Gcm
Facies F6 Gcm
Facies F2 Gchi/Sh
Facies F7 Sm/Sh, Gcm
Facies F6 Gcm
Facies F2 Gchi/Gcp/Sh
Facies F1 Gcm
Facies F2 Gchi/Gcp/Sh
Facies F1 Gcm
Facies F2 Gchi/Sh
Facies F1 Gcm
Facies F2 Gcp/Sh
Facies F5 Gmm to Gcm
Facies F8 Sh
Facies F1 Gcm

figure 4-15

Figure 4-16. 40mBIG: The largest outcrop of the Fortymile Wash valley-fill, located just south of the H-road crossing of Fortymile Wash



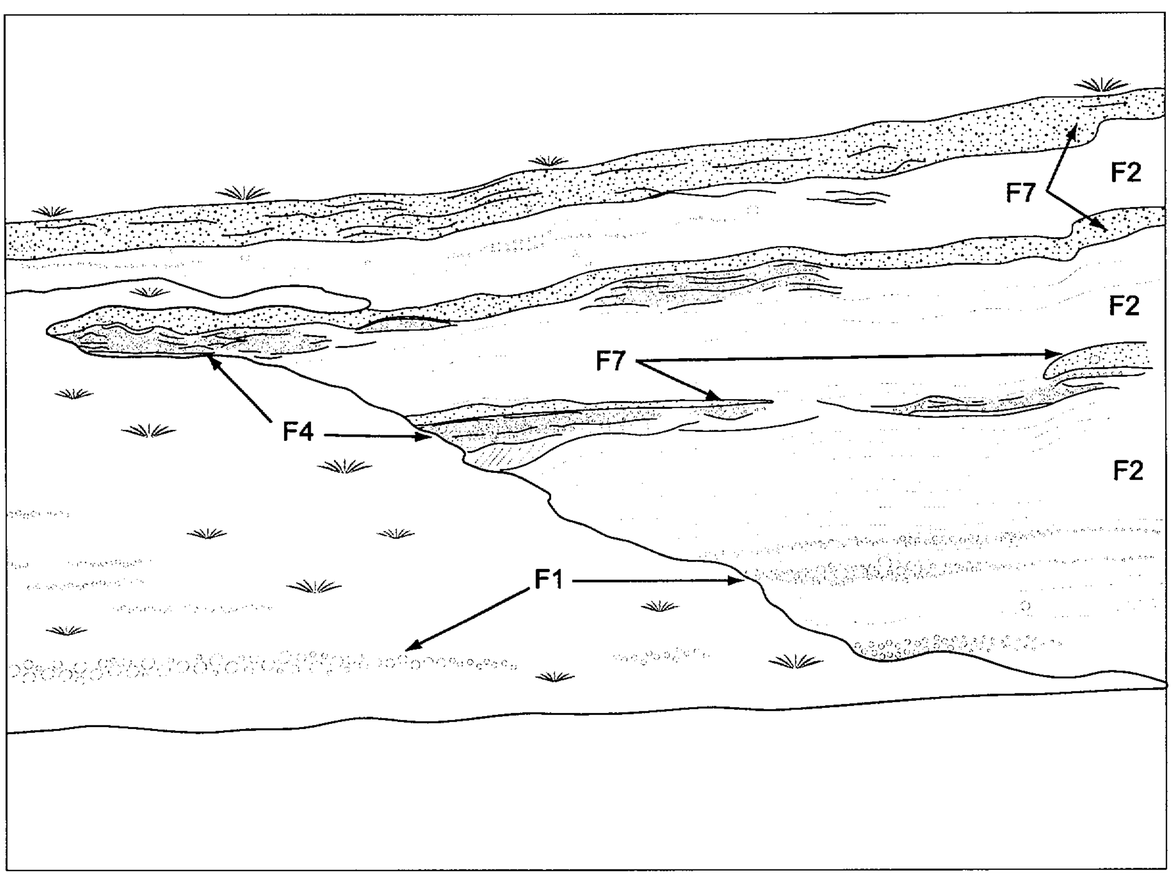


figure 4-16

Figure 4-17. Stratigraphic section measured from 40mBIG

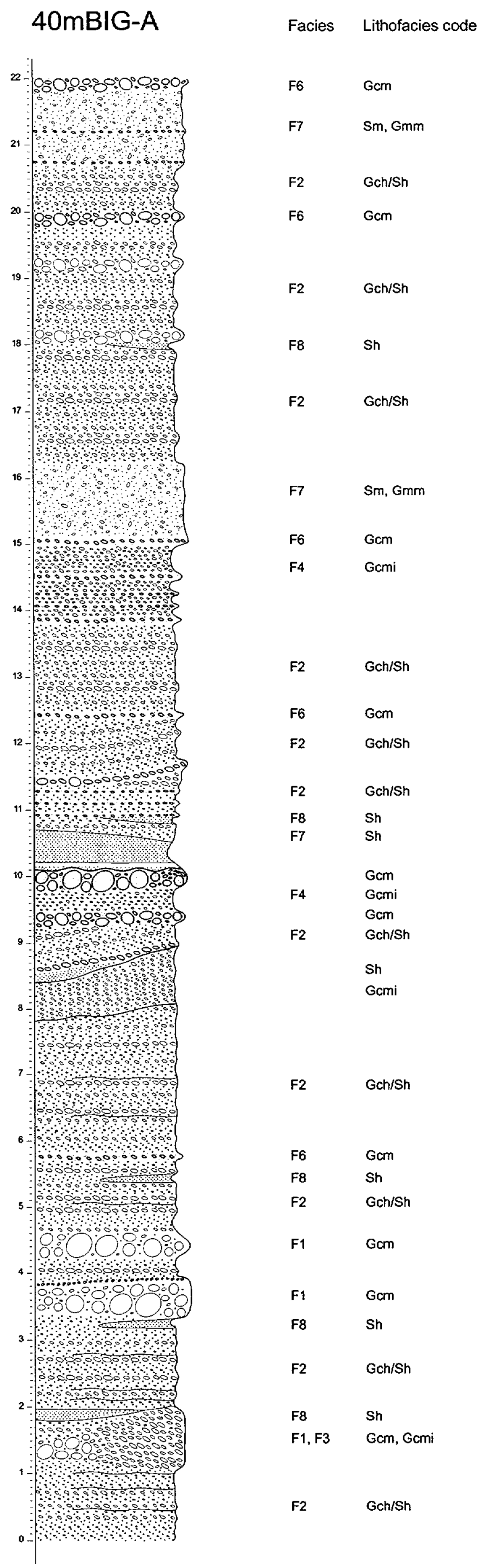

40mBIG-A
Facies
Lithofacies code
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
F6 Gcm
F7 Sm, Gmm
F2 Gch/Sh
F6 Gcm
F2 Gch/Sh
F8 Sh
F2 Gch/Sh
F7 Sm, Gmm
F6 Gcm
F4 Gcmi
F2 Gch/Sh
F6 Gcm
F2 Gch/Sh
F2 Gch/Sh
F8 Sh
F7 Sh
Gcm
F4 Gcmi
Gcm
F2 Gch/Sh
Sh
Gcmi
F2 Gch/Sh
F6 Gcm
F8 Sh
F2 Gch/Sh
F1 Gcm
F1 Gcm
F8 Sh
F2 Gch/Sh
F8 Sh
F1, F3 Gcm, Gcmi
F2 Gch/Sh

figure 4-17

Facies F2 as seen in Portal 1 are not as visible as in 40mBIG. There are several definable lenticular limits of cross-stratified gravel within Facies F2, but for the most part the lenticular units are not visible. This is not surprising because the outcrop is oriented parallel to the flow direction of Fortymile Wash. As in the other outcrops, Facies F2 dominates. Facies F6 is common in 40mBIG and its appearance is typical of the facies. Facies F8 is also common in the outcrop, although volumetrically it is a minor component.

Several exposures of Facies F7 are present in 40mBIG. Two of these are similar in appearance and stratigraphic position to those seen in 40mPROX and Portal 1. The first is at the top of the outcrop, and the second is approximately 6 m below the top of the outcrop. These two exposures of Facies F7 are laterally extensive across the entire outcrop (approximately 500 m) and are approximately 1 m thick. These units contain scattered gravel and cobbles and are heavily bioturbated. As in the other outcrops, Facies F7 and the underlying Facies F6 form a resistive ledge that protrudes from the outcrop. The top of this outcrop has been dated as a Pleistocene terrace of Fortymile Wash with an age of 53 ± 2 ka (Lundstrom et al., 1998). Several smaller, lenticular units of Facies F7 are exposed in 40mBIG (figure 4-18). The units are 10–40 m in length and are approximately 1 m thick. These units consist of medium to coarse sand displaying horizontal to subhorizontal stratification, containing little to no scattered gravel (figure 4-8a). The sand contains numerous burrows and has an orange-red coloration. These lenticular units are interpreted as remnants of a paleosol. There are caliche layers between these paleosol remnants, but the paleosol appears to have been extensively eroded by subsequent flows leaving only remnants of the original paleosol. The bioturbation and reddening of the sediment took place while the sediment was exposed at the surface and free from subsequent burial.

4.2.4 Medial Alluvium

The entrenched channel of Fortymile Wash begins to grade into a wide braidplain 1.5 km north of Interstate 95 (figure 4-10). The southernmost outcrop in Fortymile Wash that provides a useable exposure of the valley-fill characteristic of the medial parts of Fortymile Wash is located in the entrenched channel of Fortymile Wash approximately 6.5 km north of where the entrenched channel disappears (figure 4-10). This outcrop, hereafter referred to as 40mDIST, provides an exposure of the alluvium approximately 100 m long and 9 m high. The wide braidplain of Fortymile Wash extends into the Amargosa desert, but only small exposures typically less than 50 cm in height exist.

40mDIST is located on the east side of the entrenched channel. The outcrop provides one of the better exposures of the alluvium in this part of the wash. Facies F2, F4, F6, F7, and F8 are exposed in outcrop (figures 4-19 and 4-20). Facies F4 is the dominant facies exposed in outcrop. Two separate exposures of Facies F4 are present in the outcrop. The upper exposure predominantly consists of gravel to cobbles and contains little sand. Crude gravel couplets are developed in some portions of the facies, while in other portions, the facies appears massive (figure 4-4). The lower exposure of Facies F4 is notably more coarse and sandy, with grain sizes ranging from sand to boulders (figure 4-19). Facies F2 is present, but limited to one approximately 2-m exposure near the middle of the outcrop and a small exposure capping Facies F4 near the top of the outcrop (figure 4-19). Facies F2 is notably finer grained, but retains the gravel-sand couplets indicative of the facies. A characteristic exposure of Facies F7 is present at the top of the outcrop. As in the other exposures of this facies, the unit is distinctively orange-red in color (figure 4-19). At this locality, Facies F6 does not underlie Facies F7, and there is a distinctive Facies F6 above Facies F7, which forms the resistive ledge characteristic of the facies. Facies F8 is limited to a single, volumetrically minor exposure near the bottom of the outcrop.

Figure 4-18. 40mBIG: Inset provides a closeup of a portion of the outcrop in which the paleosol horizons (Facies F7) are highlighted by arrows

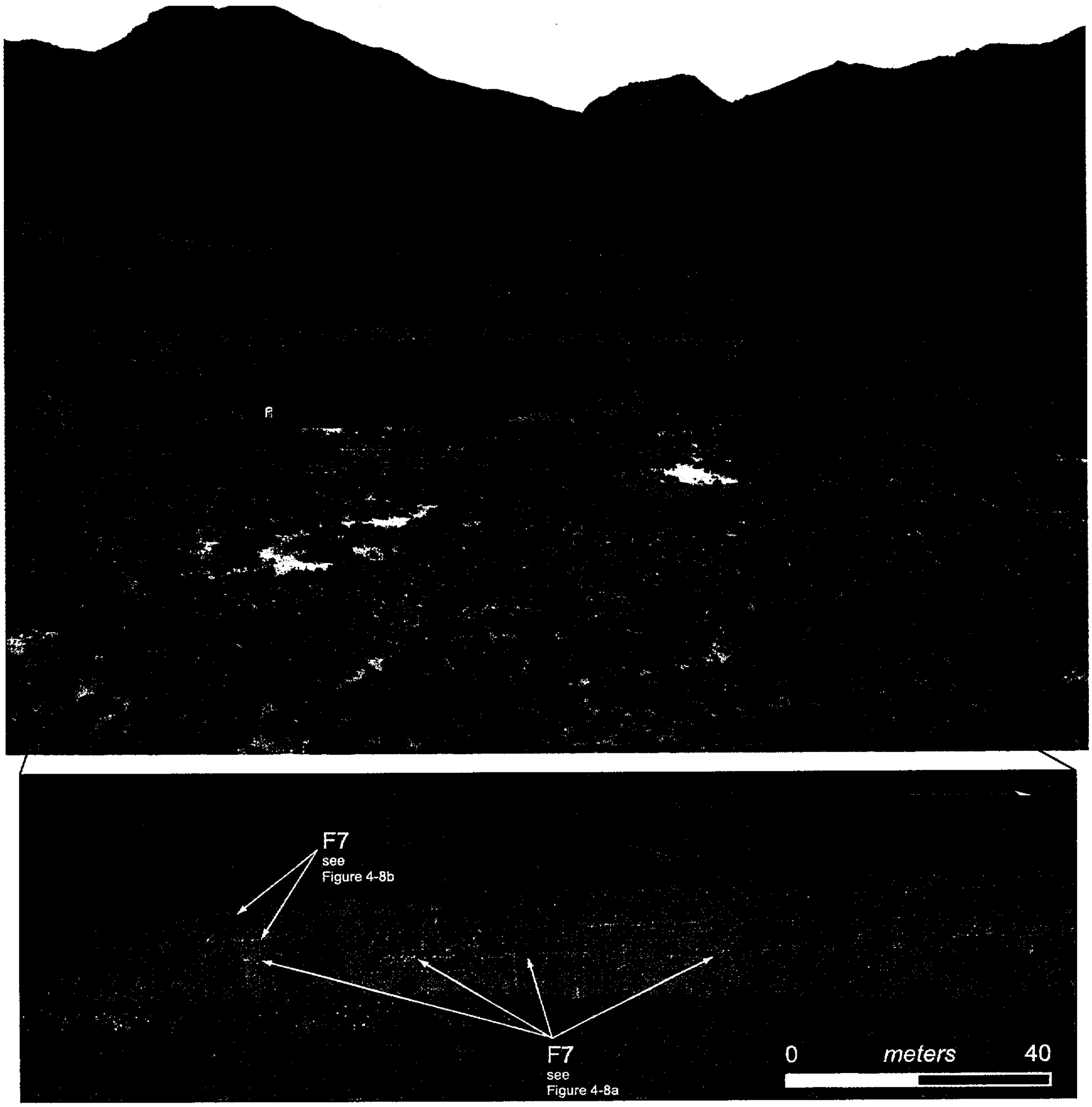


figure 4-18

Figure 4-19. 40mDIST: One of the southernmost outcrops of the Fortymile Wash valley-fill. Arrow A indicates sand to gravel lens within Facies F4. Arrow B indicates channelized sand to gravel atop Facies F4.

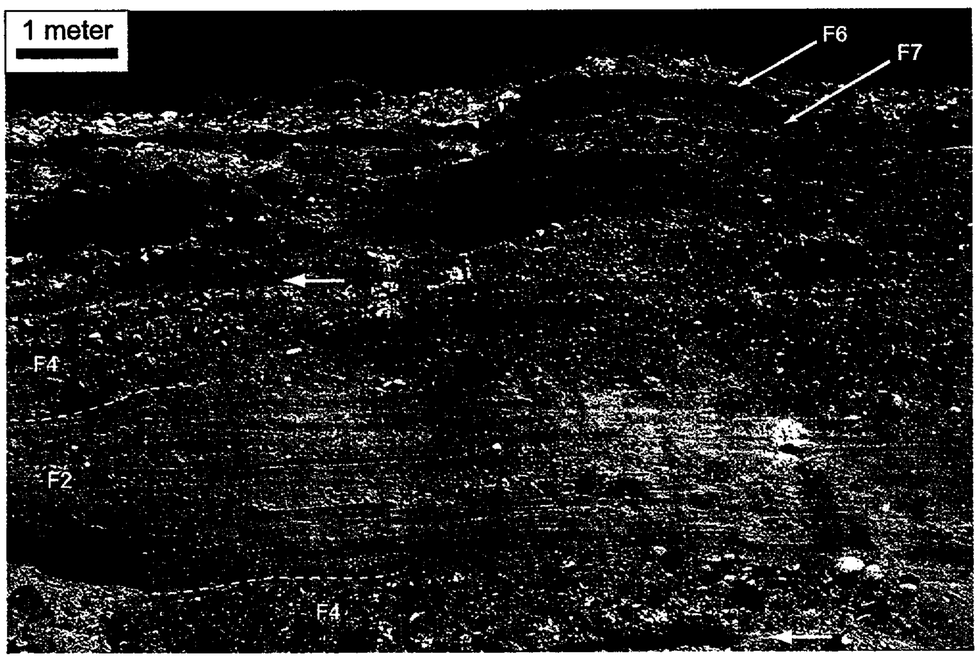
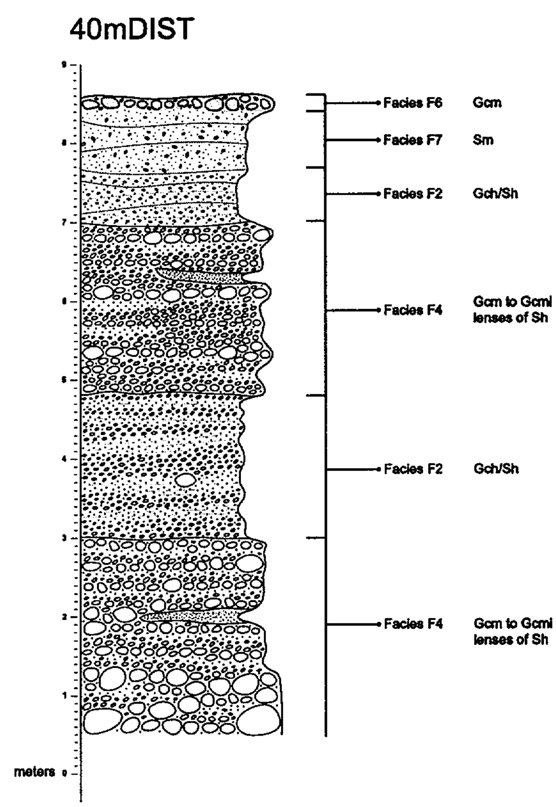


figure 4-19

Figure 4-20. Stratigraphic section measured from 40mDIST



40mDIST
meters
0
1
2
3
4
5
6
7
8
9
Facies F6
Gcm
Facies F7
Sm
Facies F2
Gch/Sh
Facies F4
Gcm to Gcml
lenses of Sh
Facies F2
Gch/Sh
Facies F4
Gcm to Gcml
lenses of Sh

figure 4-20

4.2.5 Transverse Fan Deposits

Fortymile Wash is rimmed in its upper reaches by fans emerging from the surrounding uplands that are transverse to the main channel of Fortymile Wash. Smaller fans arise from the western margin of Fortymile Wash, Busted Butte, Fran Ridge, Alice Ridge, and Jake Ridge (figure 4-10). Larger fans arise from the Calico Hills and the Striped Hills to the east of Fortymile Wash (figure 4-10).

Several minor exposures of the fans to the east of Fortymile Wash are available. One small outcrop in an alluvial fan beneath Jake Ridge is shown in figure 4-21. The alluvium is much coarser, poorly sorted, poorly organized, and is matrix rich compared to the alluvium of Fortymile Wash. The alluvium also lacks the horizontal stratification and tractive transport features present in the Fortymile Wash alluvium. The geometries of the deposits are difficult to discern due to the limited size of the outcrop, but appear to be roughly tabular beds. These deposits are interpreted as debris flow deposits based on these observations and the fact that modern debris flow processes are currently active on nearby hillslopes (Coe et al., 1997).

Several outcrops of alluvium were located in the larger fans (relict and modern) adjacent to the Calico Hills and east of Fortymile Wash. One of these outcrops provides a particularly good exposure of the Calico Hills alluvium (figure 4-22). The Calico Hills alluvium is notably more angular than that of Fortymile Wash; and although the alluvium is less organized, it does have horizontal stratification and tractive transport features. Similar facies to those observed in the Fortymile Wash alluvium are present in the Calico Hills alluvium. The Facies F2 consisting of gravel-sand couplets and the Facies F6 consisting of gravelly caliche layers were observed in the Calico Hills alluvium.

4.3 PERMEABILITY

To examine the K variations within the nearsurface alluvium, representative sediment samples of the alluvium were collected for laboratory permeability tests. Three different repacked test specimens were created from each sediment sample and tested to determine the consistency of the test results and of the variation between repacked specimens created from the same sediment sample.

No large deviations were observed between the permeabilities calculated for the three test specimens created from each of the sediment samples. The mean K_{sat} of all test runs for each sediment sample, along with the 95-percent confidence interval for the mean K_{sat}, are presented in table 4-5. These preliminary permeability test results indicate that the saturated hydraulic conductivity within the nearsurface alluvium varies for two orders of magnitude ranging 10^{-3}–10^{-5} cm/s. Of the alluvium samples tested, 40mBIG-P1, fine to medium gravel with little to no sand, was found to be the most permeable with a mean K_{sat} of $2.24 \times 10^{-3} \pm 4 \times 10^{-5}$ cm/s ($K_{sat} \pm 2\sigma$). This sediment sample was collected from a layer of open framework gravel within Facies F2. Several alluvium samples of slightly different grain sizes but consisting of a mix of sand and gravel were found to have intermediate K_{sat}s within the range of 10^{-4} cm/s. The least permeable sediments were found to be clayey cross-stratified medium to coarse sand (40mBIG-P3), clayey medium sand (40mBIG-P7), and paleosols (40mBIG-P12) with K_{sat}s in the range of 10^{-5} cm/s.

Figure 4-21. Alluvial deposits in a small fan beneath Jake Ridge. Note the more coarse, poorly sorted, poorly organized, and matrix rich nature of these sediments compared to those observed in Fortymile Wash.

figure 4-21

Figure 4-22. Relict and modern fans emerging from Calico Hills along the eastern margin of Fortymile Wash. Note that the younger fan is emerging from an entrenched channel within the older fan deposits. Inset displays an outcrop of the older alluvium from Calico Hills. Note the similarity of the alluvium to Facies F2 of Fortymile Wash.

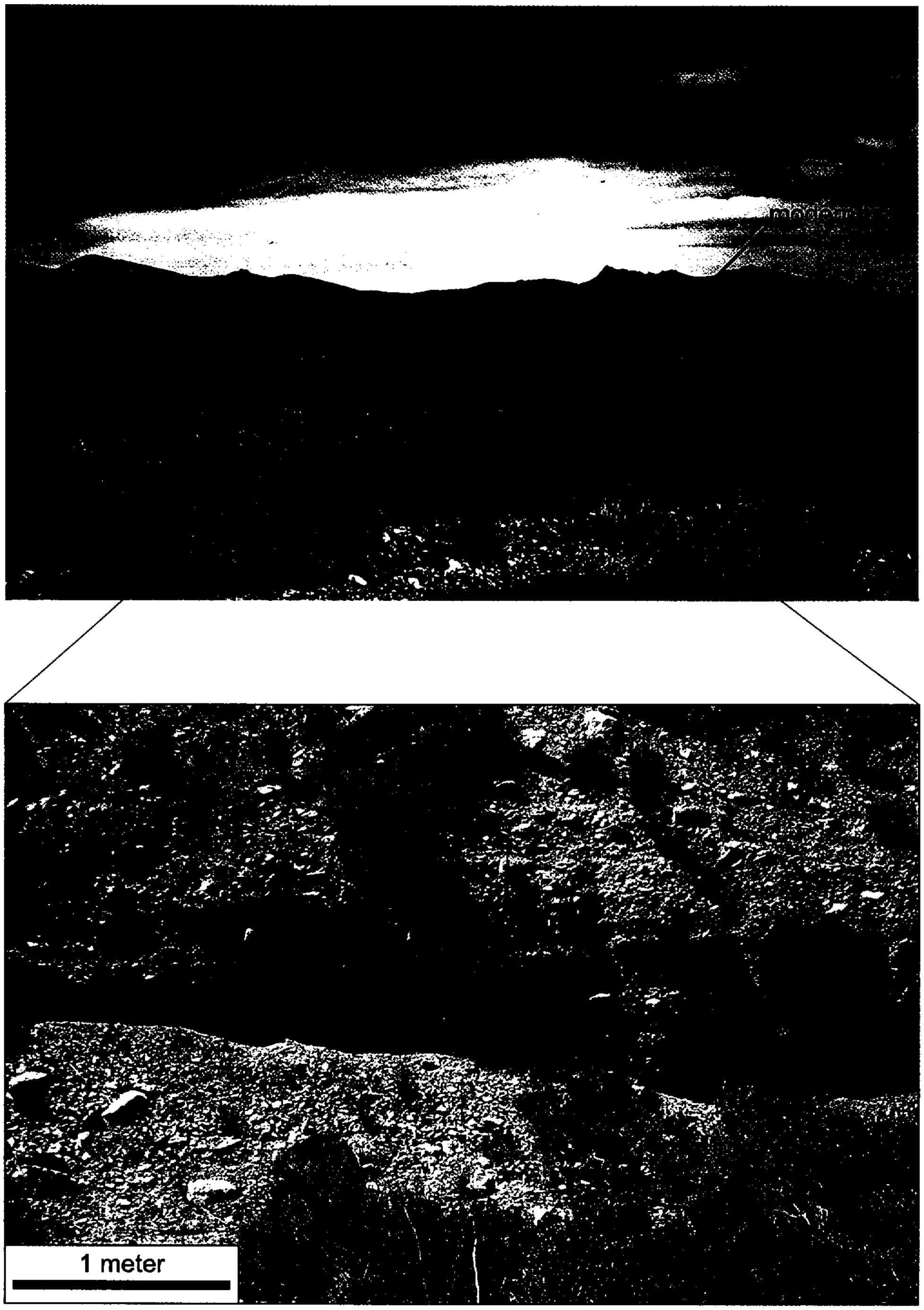


figure 4-22

Table 4-5. Results of laboratory permeability tests completed to date

Sediment Sample	Mean K_{sat} (cm/s)	95% Confidence Interval	Facies	Sediment Description
40mBIG-P1	2.24×10^{-3}	$\pm 4.16\times10^{-5}$	F2	fine to medium gravel with little to no sand
40mBIG-P2	1.67×10^{-4}	$\pm 6.43\times10^{-5}$	F2	fine to medium gravel with sand
40mBIG-P3	3.59×10^{-5}	$\pm 7.16\times10^{-6}$	F8	crossbedded medium to coarse sand
40mBIG-P5	7.16×10^{-4}	$\pm 8.58\times10^{-5}$	F2	fine to medium gravel with sand
40mBIG-P6	3.56×10^{-4}	$\pm 3.33\times10^{-5}$	F2	coarse sand to fine gravel
40mBIG-P7	3.23×10^{-5}	$\pm 1.33\times10^{-5}$	F7	clayey medium sand
40mBIG-P8	7.23×10^{-4}	$\pm 1.60\times10^{-4}$	F2	fine to medium gravel
40mBIG-P9	4.69×10^{-4}	$\pm 1.10\times10^{-4}$	F4	fine to medium gravel with little sand
40mBIG-P12	2.32×10^{-5}	$\pm 4.25\times10^{-6}$	F7	paleosol

These preliminary permeability tests were conducted on disturbed samples of the alluvium, thus the grain arrangement, cementation, and density differ from the *in situ* state of the alluvium. These permeability values most likely overestimate the true permeability of the nearsurface alluvium because of the method of permeability sampling. The removal of disturbed sediment not only disrupts cementation of the grain but also causes grain rearrangement. Even if the field bulk density is achieved during the repacking of the sediment, the test specimens are still different from the undisturbed sediment present in outcrop. However, these results provide some insight into the range of permeabilities present within the alluvium, uncertainties in permeability values, and how permeability is distributed within the alluvium. Additional and more rigorous sampling of the alluvium needs to be completed before any firm conclusions can be made regarding the range of permeabilities present within the nearsurface alluvium.

Currently, only one other dataset of permeability and porosity values is available for the alluvium to the southeast of YM. Guertal et al. (1994) provide some estimates of porosity and hydraulic conductivity for the nearsurface alluvium of Fortymile Wash based on ponding experiments conducted near the H-road crossing of Fortymile Wash (figure 4-10) and based on grain-size analyses of alluvium samples. Guertal et al. (1994) determined porosity values using neutron and density logs completed in a borehole adjacent to the infiltration ring during and following the ponding experiments. Subsequent use of these porosity values should be approached with caution, as a density value for the alluvium ($\rho_s = 2.55$ g/cm^3) had to be assumed in the development of the porosity values. These density values reliably illustrate relative variations in the porosity, but may not provide absolute values reflective of the true porosity of the alluvium. Guertal et al. (1994) provide additional porosity values and hydraulic conductivity values based on sieve analyses of alluvium samples. As discussed in section 4.1, Guertal et al. (1994) subdivided a 19-m sequence of the alluvium near 40mBIG (figure 4-10) into nine units. A single alluvium sample was collected from each of the nine units, providing only a single porosity and hydraulic conductivity estimate for each of the nine units, which varied

from 0.3 to 4.5 m in thickness. The sieve analysis based porosity and hydraulic conductivity values thus provide only an average value for each of the nine delineated units. Further, the correlation of the porosity and hydraulic conductivity values provided by Guertal et al. (1994) with the facies delineated in the current study will difficult if possible at all. As with the disturbed permeability tests completed in the current study, the sieve analysis based porosity and hydraulic conductivity values cannot truly represent the *in situ* character of the alluvium. The results of the sieve analyses found that porosity ranged from 27–39 percent and that K_{sat} ranged from 3.8×10^{-4} to 1.1×10^{-1} cm/s (Guertal et al., 1994). The K_{sat} values are higher than those calculated in the current study, but show a similar magnitude of variation between the maximum and minimum values.

4.3.1 Permeability Variations

The available permeability estimates indicate permeability variations between several of the delineated facies. The sand-dominated facies, Facies F7 and Facies F8, were found to be the least permeable. Variation in the permeability of Facies F7 is expected due to the range of grain sizes, clast content, and degree of cementation that are present in different exposures of the facies. Variation within Facies F2 is also expected due to grain size variations, amount of sand content or lack thereof (open framework), and the degree of cementation. The measurement on this facies indicate a high permeability value for the open framework gravels, but do not indicate a wide variation in permeability between the sediments consisting of varying proportions of sand and gravel (table 4-4). Some of the open framework gravel can be significantly coarser than the collected sample; thus, permeability may surpass this estimated value. These open framework gravels are likely the highest permeability sediment within the observed valley-fill. Groundwater flow within these open framework gravels could be extreme, though the interconnectedness of the open framework gravel and Facies F2 will be important in accessing the impacts on larger scale flow.

On a larger scale, the interlayering and intergradation of facies in the alluvium will be important in assessing implications for groundwater flow. The low permeability of Facies F7 (paleosol horizons) and the large aerial extent over which this facies can exist suggest that this facies will impart a strong stratification within the alluvium, with implications for vertical and horizontal groundwater movement. Results of previous investigations conducted in the Fortymile Wash alluvium support this conclusion. During infiltration investigations conducted near 40mBIG (figure 4-10), Guertal et al. (1994) found that the downward movement of water was strongly retarded by petrocalcic (caliche or calcrete) horizons present within the alluvium. These petrocalcic horizons described by Guertal et al. (1994) include the pedogenic calcrete layers and the paleosols described in the current investigation as Facies F6 and Facies F7, respectively. Guertal et al. (1994) also suggest that the large discrepancy in the mass balance they obtained between the volume of water added to the alluvium and that detected during the ponding experiments was due to substantial horizontal movement of the water atop the caliche horizons. This observation, along with the low permeability calculated for these horizons ($2.32\times10^{-5}\pm4.25\times10^{-6}$ cm/s in the current study and 3.8×10^{-4} cm/s in Guertal et al., 1994), indicates that Facies F6 and Facies F7 impart a strong vertical stratification within the alluvium with respect to permeability and water movement.

Additional observations regarding permeability variations can be made based upon the conceptualized depositional model for Fortymile Wash developed from the outcrop investigations during the current study. The sedimentary deposits and structures observed in outcrop indicate a history of more perennial flows in Fortymile Wash as compared to the modern processes, at least for the stratigraphic interval of time exposed in outcrop. A braided stream depositional model is proposed for the Fortymile Wash alluvium (the details of

which are discussed further in section 6). In a braided stream environment, the active channel consists of braid channels and intervening bars. This active channel zone of the river was the site for the accumulation of Facies F1, F2, F4 and F8. Laterally bounding the active channel zone of the river were areas bypassed by active sedimentation (i.e., floodplains), which are reflected in the stratigraphic record by paleosols (Facies F7 and F6). Accordingly, more rapid changes between facies should be expected perpendicular to the flow direction of Fortymile Wash than parallel to the flow direction, thus producing an anisotropy in the hydraulic properties of the alluvium. The lateral shift of the active channel through time leads to the interlayering of active channel deposits with laterally bounding paleosols, imparting a distinct stratification to the alluvium. Facies F7 may laterally extend for great distances, where not scoured by subsequent flows. As discussed in the preceding paragraphs, permeability estimates and ponding experiments demonstrate that the hydraulic properties of Facies F7 and Facies F6 are lower than those of the active channel deposits (except for Facies F8). This has important implications for groundwater flow. Facies F7 and F6 may create vertical flow barriers in the alluvium. Additional vertical complexity is developed by the interlaying of larger flood flows with those of lower discharge flows. Facies F2, F1, and F8 are considered to represent deposits of the normal flows occurring within Fortymile Wash, at least during the stratigraphic time period exposed in outcrop. Facies F4 is interpreted as resulting from larger flood flows that periodically occur. The distinct stratification developed by the interlayering of the larger flood flows with lower discharge flows is clearly demonstrated in 40mDIST (figure 4-19). In general, the grain size of the alluvium in Fortymile Wash becomes finer toward the Amargosa Desert (figure 4-10), which is as expected in fluvial systems. At 40mDIST (figure 4-10), finer grained accumulations of Facies F2 are interlayered with the much coarser grained Facies F4, which imparts a strong stratification (figure 4-19). If Facies F4 indeed represents periodic, larger magnitude flood deposits, additional stratification similar to that observed in 40mDIST will be present in deeper alluvium not exposed in outcrop. These different layers within the alluvium may have different flow properties that will need to be assessed for the proper representation of the valley-fill in groundwater flow models. In addition to interlayering of deposits in Fortymile Wash, deposits of sediment gravity flows arising from the ridges that rim Fortymile Wash likely interfinger with the deposits of Fortymile Wash along its margin. Small alluvial fans transverse to the flow direction of Fortymile Wash rim the upper reaches of Fortymile Wash (figure 4-10). The fan deposits consist of coarse, angular, poorly organized deposits that may have significant matrix. A small-scale example in the Portal 1 outcrop demonstrates the interfingering of debris flow deposits with the deposits of Fortymile Wash (figure 4-6). The hydraulic properties of these alluvial fan deposits likely differ from the more stratified deposits of Fortymile Wash.

4.3.2 Additional Permeability Sampling

Insufficient hydraulic data have been collected during the current investigation and during previous investigations to characterize these potential variations in the valley-fill alluvium. More rigorous permeability sampling is needed at the outcrop scale to accurately characterize the hydraulic properties of the individual facies and to evaluate the differences in hydraulic properties between the different facies. To help address these issues, intact blocks of the alluvium were collected by CNWRA staff for laboratory permeability tests on undisturbed columns of the alluvium. The results of these analyses are not yet available. Attempts were made to collect samples from each of the facies in several localities in Fortymile Wash; unfortunately, due to time constraints and the difficultly in removing intact samples, not all of the facies were equally represented in the collected samples. If successful, the undisturbed column permeability tests offer a more accurate means of assessing the *in situ* permeability of the alluvium.

Larger scale hydraulic tests utilizing the Nye County Wells in Fortymile Wash are currently being completed by Nye County and the U.S. Geologic Survey (USGS). The results of the investigation discussed in the present report should be considered in planning these larger scale hydraulic tests. The possible presence of vertical variations in hydraulic properties due to the stratification within the alluvium, and horizontal variations perpendicular to the flow direction of Fortymile Wash need to be considered. If properly conducted, these wells tests can be used to assess how the layering in the alluvium affects larger scale flow.

5 SUBSURFACE ALLUVIUM

5.1 PREVIOUS INVESTIGATIONS

Information about the alluvium within the SZ is limited to drilling mud logs, cuttings, and borehole wireline logs from the NC-EWDP, from several DOE installed wells, and from a number of shallow groundwater pumping wells in the Amargosa Farms Area (located 8–11 km south of Interstate 95; figure 1-1). The DOE wells (UE–25 UZN#85, UE–25 J–13, UE–25 J–12, JF–3, and WT#16) have only limited lithologic and geophysical data available regarding the alluvium, because the purpose of the wells was to investigate the volcanic and sedimentary rocks at depth. The usefulness of these wells for evaluating subsurface alluvium characteristics has not yet been determined. The NC-EWDP Phase I wells were installed by the Nye County Nuclear Waste Repository Project Office during November 1998–January 1999. Three of the eight completed NC-EWDP Phase I wells (NC–EWDP–2D, NC–EWDP–5S, and NC–Washburn–1X) are located in the alluvium of Fortymile Wash and penetrate the alluvium to depths of 493.2 m, 355.7 m, and 200.6 m, respectively. The base of the alluvium was not encountered in any of these wells. The remaining five NC-EWDP Phase I wells are located just west of Fortymile Wash along the confluence of YM and the Amargosa Desert. Nye County intends to install additional monitoring wells during 2000 (Phase 2) and 2001 (Phase 3), several of which will be located within Fortymile Wash (figure 1-1). To date, several of the Phase 2 wells have been completed, but the data were not yet available when this report was written.

Previous investigations regarding the stratigraphy subsurface alluvium surrounding YM to the south and southeast are limited in number. Few studies have attempted to describe the stratigraphy of the valley-fill (Guertal et al., 1994; Lundstrom et al., 1998, and Taylor et al., 1999). Guertal et al. (1994) and Lundstrom et al. (1998) only provide brief descriptions of the alluvium at particular locations and primarily describe buried soil horizons within the nearsurface alluvium. Taylor et al. (1999) have complied the logs from the shallow groundwater wells in the Amargosa Farms Area to develop a stratigraphic model of the alluvium in the Amargosa Desert, but the results of this work are not yet available.

Previous studies investigating the hydraulic properties of the alluvium surrounding YM are equally limited. Currently, there are no YM site-specific data available for effective porosity in the alluvium units in the SZ. Current models of groundwater flow within the alluvium utilize effective porosity values based on studies in other areas that are considered reasonable analogs to the alluvium surrounding YM (section 1.2). Guertal et al. (1994) provide some estimates of porosity and hydraulic conductivity for the nearsurface alluvium of Fortymile Wash based on ponding experiments conducted near the H-road crossing of Fortymile Wash (figure 4-10) and based on grain-size analyses of alluvium samples (section 4.3). Limited hydraulic data is available from short-duration tests in Nye County wells 1S, 3D, and 9S; unfortunately, these wells do not intercept the conceived flow paths from YM and apparently produce water from a composite of valley-fill and volcanic tuffs. Currently, Nye County and the USGS are conducting tracer and well tests in newly completed wells in Fortymile Wash to improve estimates of the hydraulic properties of the alluvium. Results of this work are not yet available.

5.2 OUTCROP TO SUBSURFACE COMPARISONS

5.2.1 Data Sources

Currently, the Nye County drilling program and the DOE are conducting extensive subsurface hydrologic tests in the recently drilled wells in the Amargosa Desert and Fortymile Wash. Comparisons of the outcrop descriptions to the subsurface will be updated once the data from the Nye County and DOE field experiments are provided.

In this preliminary report, limited lithologic and geophysical logs from three completed NC-EWDP wells located within Fortymile Wash (NC–EWDP–2D, NC–EWDP–5S, and NC–WASHBURN–1X) were compiled to investigate the character of the alluvium at depth (figure 4-10). Lithologic data on the subsurface alluvium are limited to drill return logs and cuttings. Available geophysical data consist of wireline logs with gamma, density, and neutron for all wells in addition to caliper, resistivity, and spontaneous potential for some wells (table 3-1). The following information regarding the NC-EWDP wells was personally communicated to T. Ressler by R. Federwisch of Geophysical Logging Services.[1] The NC-EWDP Phase I wells were drilled using dual wall reverse circulation and dual wall hammer rigs. Although these methods are excellent for sample recovery, these methods did not leave open holes when the drill string was removed, complicating subsequent geophysical logging. All geophysical logging used fully down hole digital logging equipment produced by Mount Sopris Instruments and was completed by Geophysical Logging Services. The deviation, moisture, density, and natural gamma geophysical logs were run in the drill string. There are not any methods to compensate for the dual wall drill string and other borehole conditions necessary to convert the density or moisture logs to quantitative values, so only the qualitative counts per second are currently available. Cuttings taken from the boreholes are being analyzed to develop quantitative porosity, density, and moisture logs, but the results of this work are not yet available. The electric logs (8-, 16-, 32-, 64-inch normal resistivity), spontaneous potential, SPT res, fluid temperature, resistivity, and sonic velocity spinner logs were completed in the open boreholes after removal of the drill string. Unfortunately, due to the drilling methods used, the borehole collapsed complicating completion of this logging, and complete logs were not obtained for all wells.

Preliminary analysis of the lithology logs from the NC-EWDP wells indicate the alluvium at depth generally shows similar sediment types and bed thickness to those sediments observed in outcrop: predominantly sand and gravel with some intervals of increased/decreased gravel, sand, silt, or clay content. Based solely on lithologic data, the types of sediment present at depth not observed in outcrop were reworked tuff (or bedded tuff or fine sandstone) in NC–EWDP–5S at 750 m and 728 m average mean sea level (AMSL), and several thin intervals (< 1 m) of predominantly clay in NC–EWDP–2D at 739 m AMSL and in NC–EWDP–5S in the interval 744–751 m AMSL. A more detailed description of the subsurface alluvium can be developed by augmenting the available lithology logs with interpretations made from the geophysical wireline logs. Due to the problems discussed previously, only portions of the geophysical logs are available for this task (section 3.2). To assist in the interpretation of the geophysical logs, simulated density and gamma ray wireline logs (i.e., outcrop profiles of density and gamma radiation) were developed at several of the exposed outcrops. The purpose of the outcrop profiles is to investigate whether particular facies have a

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[1]R.H. Federwisch. Personal communication to T. Ressler. San Antonio, TX: Geophysical Logging Services. February 18, 2000.

distinctive geophysical response or signatures that can be used to further constrain lithologic interpretations of the Nye County wells.

5.2.2 Outcrop Density Profiles

The outcrop density profiles were developed following the methodology of Ahmadi and Coe (1998), except that Ahmadi and Coe (1998) obtained point bulk density measurements from laboratory analyses of rock samples removed from outcrop. In the current investigation, the density measurements were collected using a hand-held ultrasonic velocity probe. The density profile of the outcrop was generated by plotting the measured densities at the stratigraphic interval at which they were sampled. The raw density profile was then adjusted to compensate for the limited number of density measurements that could be collected from each bed and for beds that sampled. These adjustments consisted of: (i) assigning the single density measurement for a particular bed to the entire bed thickness, (ii) assigning an average density value determined from the measurements made within a particular bed to the remainder of the bed thickness that was not sampled, and (iii) assigning an average density (typical for the particular sediment) to beds that had no density measurements. Ahmadi and Coe (1998) suggest the application of a moving average filter to the developed density box curve to account for the moving average effect of wireline density logging (i.e., consecutive readings overlap a portion of the sampling volume of the previous reading).

In figure 5-1, the raw density profile, the density box curve, and the converted apparent density curve are plotted against the stratigraphic section of Portal 1 from which the measurements were obtained. The apparent density curve was developed to illustrate the density variations in a more intuitive set of units. The apparent density values were calculated using Gardner's velocity/density model (Mavko et al., 1998):

$$\rho_b = a^* V_p^2 + b^* V_p + c \qquad (5\text{-}1)$$

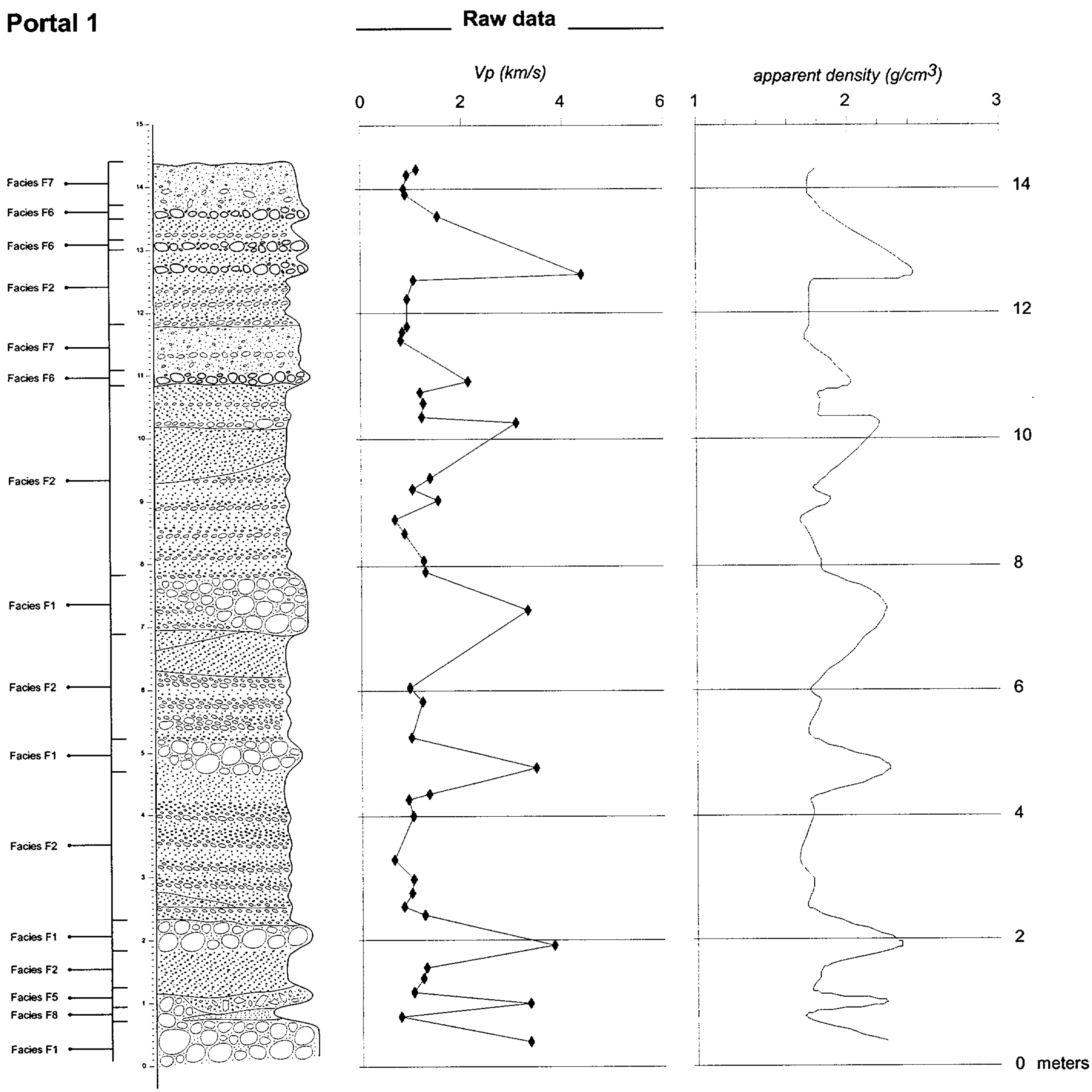
where,

ρ_b	—	bulk density (g/cm^3)
V_p	—	*P*-wave velocity (km/s)
a, b, c	—	empirical coefficients

The sandstone model was chosen for the velocity-density calculations because the observed *P*-wave velocities ($0.6 \le V_p \le 6.4$ km/s) closely approximated the model V_p range ($1.5 \le V_p \le 6.0$ km/s). The empirical coefficients for the sandstone model are $a = -0.0115$, $b = 0.261$, and $c = 1.515$ (Mavko et al., 1998).

The variations in density observed in the alluvium are given in figure 5-1. The coarse units have higher densities than the finer grained units. This difference arises from the larger clasts contained in the coarser units. An average density range for the volcanic rocks in the area is 1.8–2.45 g/cm^3 (Brocher et al., 1998), and an average bulk density range for sand is 1.44–2.40 g/cm^3 (Carmichael, 1989). The large cobbles and boulders in the coarse units have a higher density than a sand or a sand and fine gravel unit; consequently, a unit containing a large percentage of large clasts should have a higher bulk density than a sand or sand and fine gravel unit. The density values obtained in the current investigation compare favorably with values used by Brocher et al. (1998) for the alluvium in Crater Flat (1.8–2.2 g/cm^3). An outcrop density profile was also developed from 40mDIST, displaying similar facies responses as seen in the Portal 1 density profile (figure 5-2).

Figure 5-1. Outcrop density profile of Portal 1



Portal 1
Raw data
Vp (km/s)
0
2
4
6
apparent density (g/cm3)
1
2
3
Facies F7
Facies F6
Facies F6
Facies F2
Facies F7
Facies F6
Facies F2
Facies F1
Facies F2
Facies F1
Facies F2
Facies F1
Facies F2
Facies F5
Facies F8
Facies F1
14
12
10
8
6
4
2
0 meters

figure 5-1

Figure 5-2. Outcrop density profile of 40mDIST

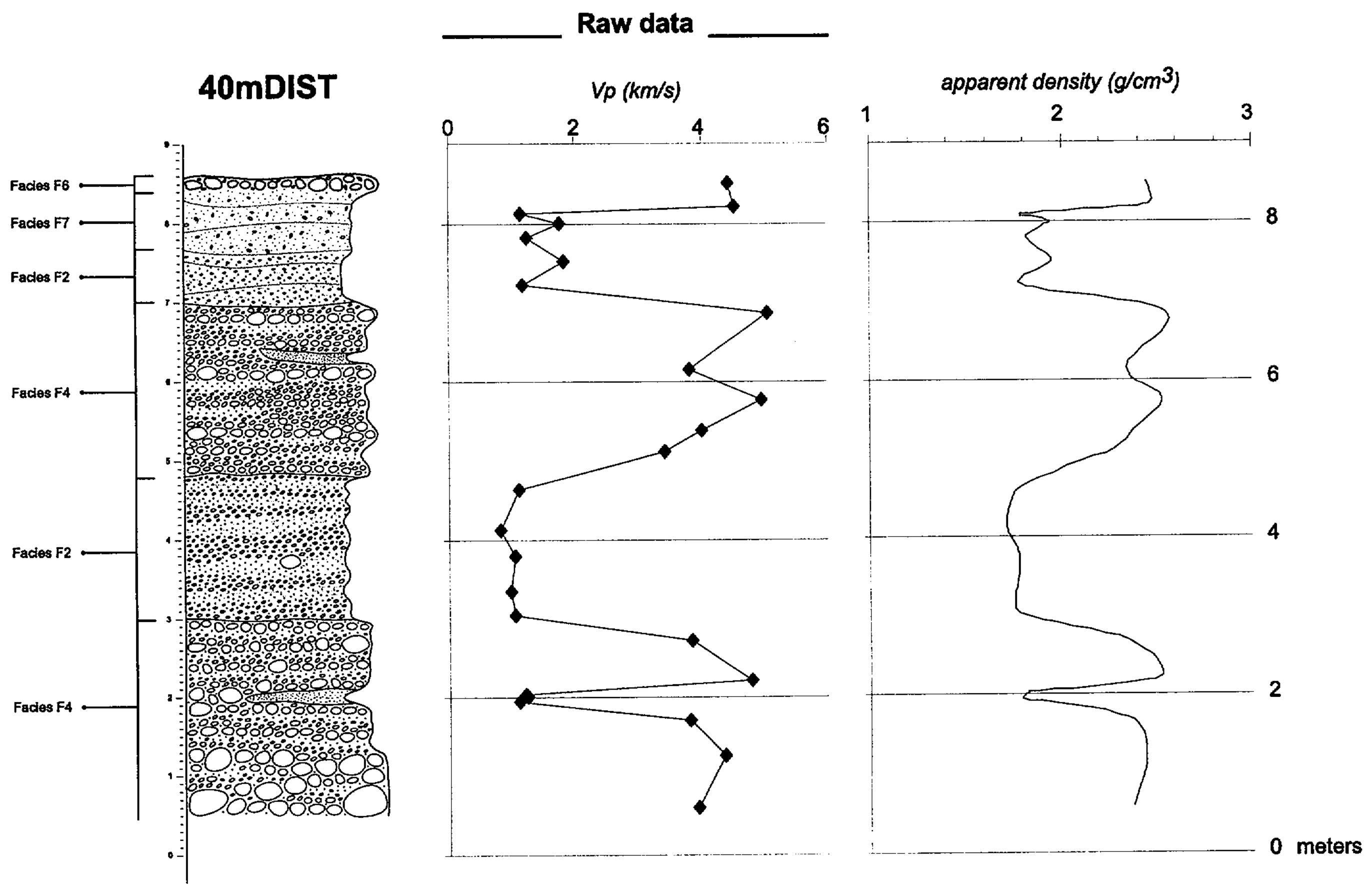

Raw data
40mDIST
Vp (km/s)
apparent density (g/cm3)
Facies F6
Facies F7
Facies F2
Facies F4
Facies F2
Facies F4
0
2
4
6
1
2
3
8
6
4
2
0 meters

figure 5-2

Limited success was obtained in identifying unique geophysical signatures for the different delineated facies. The outcrop density profiles were found to be primarily a function of the clast content of the valley-fill. The profiles clearly identify the cobble and boulder layers: Facies F1, Facies F4, Facies F6, and, in some instances, the coarse fraction of the gravel-sand couplets in Facies F2.

5.2.3 Outcrop Gamma Profiles

Two outcrop gamma ray profiles were collected at 40mDIST and Portal 1. Processing of this data is not complete, so these results are not available at this time.

6 SUMMARY

6.1 DEPOSITIONAL ENVIRONMENT

Fortymile Wash is referred to both as an alluvial fan and a desert wash in published literature and maps. In light of the observations made during the current investigation, referring to Fortymile Wash as an alluvial fan could lead one to associate attributes of Fortymile Wash that are inconsistent with the observed sedimentary deposits and structure. The modern Fortymile Wash is indeed a desert wash characterized by ephemeral flows, though the older deposits exposed in outcrop indicate a flow history characterized by more perennial flows. In regards to the deposits and sedimentary architecture observed in outcrop, Fortymile Wash is best considered as a proximal fluvial system dominated by gravel.

The modern entrenched channel of Fortymile Wash is largely inactive except during large flood events. Only a few active channels occupy a small fraction of the entire entrenched channel width. The smaller active channels that carry the lower discharge flow events form a braided morphology within the entrenched channel. The intervening portions between these active channels are heavily vegetated and eolian sand addition is widespread, especially in the southern portion of the entrenched channels. Within the active channels, smaller braided like channels exist. Various erosional and depositional bars result from this channel configuration.

Although the modern channel morphology is the product of ephemeral flows, the older deposits exposed in outcrop indicate a history of perennial flows within a network of active braid channels and intervening bars. The active channel zones resulted in the accumulation of Facies F1, F2, F4 and F8. The repetitious gravel couplets of Facies F2, for example, are interpreted as deposits of migrating gravel bedforms. The lack of well-preserved channel geometries observed in outcrops is a common trait of gravelly braided stream deposits (Miall 1985). Limited cross-stratified gravel is locally present within the horizontally stratified gravel of Facies F2. This cross-stratified gravel commonly occurs in lenses, with the cross-stratification being planar, tangential to the base of the lens, or almost paralleling the curvature of the base of the lens (figure 4-3). These lenses of cross-stratified gravel are interpreted as pool scours located at the convergence of two channels. Siegenthaler and Huggenberger (1993) provide a simple model for the formation and migration of these pools with time: the different cross-stratification observed in pool scours results from the orientation of the outcrop with respect to the pool. Isolated, lenticular units of clast-supported cobbles to boulders with medium to coarse sand (figure 4-1) within Facies F2 are interpreted as channel deposits that formed between longitudinal bars (Miall, 1977). The volumetrically small sandstone drapes of Facies F8, found in association with Facies F2 and Facies F1, are interpreted as concentrations of finer sediment deposited during waning flows. Based on the large volume and predominance of Facies F1, F2, and F8 in the outcrops, perennial flows has likely been the 'normal' flow regime in Fortymile Wash during the depositional history reflected in outcrops.

Other facies in the valley-fill indicate large-magnitude flows. For example, the Facies F4 deposits have coarser clasts and are notably less stratified and organized. Crude stratification and imbrication of clasts are present, indicating water transport. There appears to be a gradation, rather than a distinct textural break, between these deposits and the finer-grained deposits of Facies F2. In some exposures of Facies F4, crude gravel couplets resembling those of Facies F2 (except for the grain size differences) are present. Significant exposures of Facies F4 were observed in the proximal reaches of Fortymile Wash (40mPROX) just south

of Fortymile Canyon (figure 4-10). Large exposures of Facies F4 were also observed in the southern most outcrop (40mDIST). At this location, Facies F4 was found in association with much finer-grained deposits of Facies F2 (figures 4-5 and 4-19). Facies F4 is thus interpreted as deposits of larger-magnitude flood flows. These larger-magnitude flows transported large cobbles and boulders significant distances down stream.

Laterally bounding the active channel zones were areas bypassed by active sedimentation (i.e., floodplains), reflected in the stratigraphic record by Facies F7 and Facies F6 paleosols. The presence of paleosols in the valley-fill indicates that parts of Fortymile Wash experienced prolonged periods of subaerial exposure, during which the deposited alluvium became bioturbated and oxidized (reddened) by pedogenic processes. The variation in stratification and grain size of these paleosols reflects the different sediment deposits upon which soil development took place. The paleosols reflect areas of the floodplain bypassed by active flows. Subsequent deposition, and in some instances scouring of the paleosols, indicates channel reactivation in these areas of the floodplain. Layers of pedogenic carbonate (Facies F6) are developed beneath and in the paleosols (figure 4-7). The varying degree of bioturbation and caliche development in the paleosols reflects different time lengths of exposure for pedogenesis.

Deposits of debris flows or other sediment gravity flows are limited in exposure within the outcrops of the Fortymile Wash alluvium. The lack of debris flow deposits may be due to the location of outcrops near the center of Fortymile Wash, as opposed to the margins of Fortymile Wash where relict deposits are present and where modern sediment gravity flow processes are active. The single exposure of debris flow or rock slide deposits (Facies F5) found in association with the 'normal' flow deposits of Fortymile Wash is in Portal 1 (figure 4-6 and figure 4-10). The deposits consist almost entirely of angular clasts of purple tuff, either Topopah Spring or Tiva Canyon. Portal 1 is located in close proximity to Fran Ridge, which is composed of Topopah Spring and Tiva Canyon tuff. This deposit is interpreted as a rock slide or debris flow that originated on the slopes of Fran Ridge, based on the near monolithologic clast content of the deposit and the presence of modern and relict rock falls on the slopes of Fran Ridge. The small proportion of rounded clasts of differing lithologies are likely clasts within Fortymile Wash that were entrained by the rock slide.

Other coarse, angular deposits of disorganized cobbles and boulders were also observed in outcrops on the slopes beneath Jake Ridge (figures 4-10 and 4-21). These deposits illustrate the sediment input of the smaller fans that rim Fortymile Wash. Upon deposition, these deposits are reworked by subsequent waterflows in Fortymile Wash. This process is illustrated in the exposure of Facies F5 in Portal 1. Scattered angular clasts identical to those found in Facies F5 are found incorporated within subsequent deposits of Facies F2 (figure 4-6). Toward the margins of Fortymile Wash, these types of deposits (e.g., Facies F5) will likely become more abundant.

A conceptualized depositional model of the Fortymile Wash alluvium has been developed based on outcrop observations of the nearsurface alluvium. Additional observations regarding the lateral extent and geometries of the different facies are needed for the development of a conceptual 3D block model of the alluvium that displays the facies geometries and/or features important for groundwater flow. For example, the lateral correlation scale of Facies F7 is important, as the low K_{sat} values suggest it may influence larger-scale flow. The internal geometry within Facies F2, especially the interconnectedness of the open framework gravels, also needs to be addressed. Given that the majority of outcrops are oriented parallel to the flow direction of Fortymile Wash, direct observation of the geometries of the different facies in different orientations is not possible. Thus far, the geometries of the different facies are based solely on the two-dimensional outcrop exposures and geologic interpretation.

Geophysical methods may prove helpful in establishing geometries of the different facies. Huggenberger (1993), for example, successfully utilized ground penetrating radar to map lenses of cross-stratified gravel on the order of 10 m and the individual cross-strata within the lens in coarse-grained braided-river deposits. Since the majority of available outcrops are oriented parallel to the flow direction of Fortymile Wash, this technique may provide a noninvasive method for examining the sedimentary structure in other orientations. This may be especially important in assessing the lateral extent of Facies F7 (paleosol horizons).

6.2 PERMEABILITY AND IMPLICATIONS FOR GROUNDWATER FLOW

Sediment samples were collected from outcrop to examine the variation in permeability between the different identified facies. Although repacking sediment samples into columns for permeability tests results in differences from the *in situ* state, the results do provide insight into variations in permeability in the valley-fill sediments. These permeability tests indicate that permeability varies over two orders of magnitude ranging from 10^{-3} to 10^{-5} cm/s. A sample consisting of predominantly fine to medium gravel was found to be the most permeable: K_{sat} of $2.24\times10^{-3} \pm 4\times10^{-5}$ cm/s ($K_{sat} \pm 2\sigma$). This sediment sample was collected from a layer of open framework gravel within Facies F2. Several additional samples were collected from Facies F2 that consisted of slightly differing gravel sizes and sand. These samples were found to have K_{sat} in the range of 10^{-4} cm/s (table 4-4). Samples collected from Facies F8 and from Facies F7 were found to be the least permeable: in the range of 10^{-5} cm/s (table 4-4).

These results indicate permeability differences between several of the delineated facies. The sand-dominated Facies F7 and Facies F8 were the least permeable. Additional variation in the permeability of Facies F7 is expected due to the range of grain sizes, clast content, and degree of cementation. Variation within Facies F2 is also expected due to grain size variations, amount of sand content or lack thereof (open framework), and the degree of cementation. The alluvium sample from the open framework gravel in Facies F2 was found to have the highest permeability, but the sediments consisting of varying proportions of sand and gravel within the facies were found to have similar permeabilities in the range of 10^{-4} cm/s (table 4-4). Some of the open framework gravel can be significantly coarser in grain size than the collected sample; thus, permeability may exceed this estimated value. These open framework gravels are likely the highest permeability sediment within the observed valley-fill. Because they can accommodate large groundwater flows, the interconnectedness of the open framework gravel and Facies F2 is important in assessing larger-scale hydraulic conductivity.

On a larger scale, the interlayering and intergradation of the facies in the alluvium has important implications for groundwater flow. For example, the low permeability of Facies F7 (paleosol horizons) and its typically large areal extent suggests this facies can impart a strong stratification that could affect vertical and horizontal groundwater movement. Results of ponding experiments conducted by Guertal et al. (1994) in the Fortymile Wash alluvium support this conclusion. During infiltration investigations conducted near 40mBIG (figure 4-10), Guertal et al. (1994) found that the downward movement of water was strongly retarded by petrocalcic (caliche or calcrete) horizons present within the alluvium. These petrocalcic horizons described by Guertal et al. (1994) include the pedogenic calcrete layers and the paleosols described in the current investigation as Facies F6 and Facies F7, respectively. Guertal et al. (1994) also presented evidence of substantial horizontal movement of water atop the caliche horizons. This observation, along with the low permeability calculated for these horizons ($2.32\times10^{-5} \pm 4.25\times10^{-6}$ cm/s in the current study and 3.8×10^{-4} cm/s

in Guertal et al., 1994), indicates the strong vertical stratification of permeability imparted by Facies F6 and Facies F7 can affect water movement.

Lateral shifts of the Fortymile Wash active channel through time leads to the interlayering of active channel deposits with laterally bounding paleosols, imparting a distinct stratification to the alluvium. Where not scoured by subsequent flows, Facies F7 may laterally extend for great distances. Because permeability estimates for Facies F6 and F7 are generally lower than most active channel deposits, they may create resistance to vertical flow in the alluvium. Additional vertical complexity is developed by the interlaying of larger flood flows with those of lower discharge flows. The distinct stratification developed by the interlayering of the larger flood flows with lower discharge 'normal' flows is clearly demonstrated in 40mDIST (figure 4-19).

Additional observations regarding permeability variations can be made based on the conceptualized depositional model for Fortymile Wash developed from the outcrop investigations made during the current study. In a braided stream environment, the active channel consists of braid channels and intervening bars. Laterally bounding the active channel zone of the river were floodplain areas that were bypassed by active sedimentation. Accordingly, more rapid changes between facies should be expected perpendicular to the flow direction of Fortymile Wash than parallel to the flow direction, thus producing a bulk horizontal anisotropy in the hydraulic properties of the alluvium. In other words, long, continuous channels of high-permeability sands and gravels can result in preferential flow parallel to the present Fortymile Wash channel.

Another factor to consider is that, in general, the grain size of alluvium in Fortymile Wash becomes finer toward the Amargosa Desert (figure 4-10). At 40mDIST (figure 4-10), finer grained accumulations of Facies F2 are interlayered with the much coarser grained Facies F4, imparting a strong stratification (figure 4-19). If Facies F4 indeed represents periodic, larger magnitude flood deposits, additional stratification similar to that observed in 40mDIST can be expected in deeper alluvium. In addition to interlayering of deposits within Fortymile Wash, deposits of sediment gravity flows arising from the ridges that rim Fortymile Wash likely interfinger with the deposits of Fortymile Wash along its margin. The fan deposits consist of coarse, angular, poorly organized deposits that may have significant matrix. A small-scale example in the Portal 1 outcrop demonstrates the interfingering of debris flow deposits with the deposits of Fortymile Wash (figure 4-6). The hydraulic properties of these alluvial fan deposits likely differ from the more stratified deposits of Fortymile Wash.

The overall effect of the juxtaposition of different facies within the alluvium needs to be assessed for the proper representation of the valley-fill in groundwater flow models. The observations reported in this investigation provide an important first step toward understanding the necessary level of complexity for groundwater flow and radionuclide transport models used to assess performance of the proposed nuclear waste repository at YM. At present, however, more rigorous permeability sampling is needed to assign hydraulic properties to the individual facies and to understand the variations in permeability between facies.

To help address these issues, intact blocks of the alluvium were collected for laboratory permeability tests on undisturbed columns of the alluvium, but the results of these analyses are not yet available. Attempts were made to collect samples from each of the facies in several localities in Fortymile Wash; unfortunately, due to time constraints and difficulty removing intact samples, not all of the facies were equally represented in the collected samples. If successful, the undisturbed column permeability tests offer a more accurate means of assessing the *in situ* permeability of the alluvium. Another possibility is to collect actual *in situ*

measurements of permeability in the field using an air minipermeameter[1]. This may require some special preparation, as conventional minipermeameters are not designed to handle such coarse grain size as is contained in the Fortymile Wash valley-fill alluvium.

Larger scale hydraulic tests utilizing the Nye County Wells in Fortymile Wash are currently being completed by Nye County and the USGS. The results of the investigations described in this report should be considered in the planning of these larger scale hydraulic tests. The potential vertical and horizontal variations in facies with different hydraulic properties within the alluvium need to be considered. If properly conducted, these wells tests can be used to assess how the stratification in the alluvium affects larger scale flow.

6.3 NEARSURFACE TO SUBSURFACE COMPARISONS

To assist in the interpretation of the geophysical logs, simulated density and gamma-ray wireline logs (i.e., outcrop profiles of density and gamma radiation) were developed at several of the exposed outcrops. The purpose of the outcrop profiles was to investigate whether particular facies have a distinctive geophysical response or signature, which can be used to further constrain lithologic interpretations of the Nye County wells. Limited success was achieved in identifying unique geophysical signatures for the different delineated facies. The outcrop density profiles were found to be a function of the clast content of the valley-fill. The profiles clearly identify the cobble and boulder layers (Facies F1, F4, F6), and in some instances the coarse fraction of the gravel-sand couplets in Facies F2. Two outcrop gamma ray profiles were collected at 40mDIST and Portal 1. Processing of this data is not complete, so these results are not available at this time. The outcrop investigation of the density response of the different facies can be used to constrain subsequent interpretations of density wireline logs from wells within Fortymile Wash.

Future work will include review of geophysical logs, stratigraphic logs, and hydraulic testing data emerging from the recently completed NC-EWDP wells. It is hoped that sufficient data will be available to assess the vertical distribution of differing hydrologic facies and a comparison can be made to the conceptual model developed in this report for the sedimentary structure of Fortymile Wash.

6.4 CONCEPTUAL MODEL INTEGRATION WITH FLOW MODELS

The current investigation demonstrates that the alluvium is heterogeneous, consisting of several different types of sedimentary deposits, some of which have substantially different hydraulic properties. Further work will be needed to incorporate these observations, interpretations, and permeability values into groundwater flow models to better constrain SZ groundwater flow in the Fortymile Wash and Amargosa valley-fill aquifer.

The conceptual model for the sedimentary structure of the valley-fill underlying Fortymile Wash will provide a basis for developing geostatistical descriptions of the distribution of hydrologic facies within zones of similar sedimentary geomorphology. Such descriptions can be used to assess whether flow and transport models for the region appropriately account for the effects of the heterogenous flow system. Such effects include confinement of flow between low-permeability strata and channelization of flow in high-permeability

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[1] An air minipermeameter operates by injecting air into a rock or sediment and measuring the resulting rate of air flow into the rock or sediment, which can be related to permeability.

paleostream channels. Scaling relationships can be developed to assess whether flow and transport models use values of effective porosity, hydraulic conductivity, and dispersion coefficients that are appropriate for the grid-scale used in the numerical flow and transport models.

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APPENDIX

PERMEABILITY TESTS

This appendix describes, in detail, how the *in situ* density measurements were made and how the disturbed sample permeability tests were conducted. No ASTM standards were found that were applicable for the work completed on vertical outcrops. No CNWRA Technical Operating Procedures (TOPs) were developed for the procedures used, as this was the first time the procedures were applied. If the procedures are used again, appropriate TOPs will be developed.

Laboratory permeability tests were completed using a constant pressure permeameter. All sediment samples tested were disturbed sediment samples and, therefore, had to be packed for testing. A split-barrel mold was used to create test specimens. Each test specimen was repacked to its approximate in-field bulk density. The methodology for the removal of the sediment sample and the estimates of in-field bulk density follow. A portion of sediment was removed from the outcrop face using a masonry trowel and a collection container beneath the excavation. The sediment was carefully removed so no significant excavated sediment was lost. The sediment was troweled from the outcrop face in as near to a rectangular shape as possible. The volume of the created rectangular void in the outcrop (from the removal of the sediment sample) was then estimated. Because the mass of sediment removed came from this volume of space in the outcrop, the field bulk density of the sediment can be estimated. This estimated field bulk density was used to constrain repacking of the sediment for laboratory permeability tests; thereby reducing the uncertainty associated with the permeability test results. The test specimen can be repacked to its in-field bulk density using the estimated in-field bulk density and the known volume of the split-barrel mold used to create the test specimen.

The procedure for creation of test specimens from unconsolidated sediment is as follows (refer to permeameter schematic provided in figure A-1). A 5.08×20.32 cm latex membrane was attached to the base pedestal of the bottom plate of the permeameter. The membrane was doubled over on itself, just enough for two layers along the height of the base pedestal. An O-ring was then placed over the latex membrane, fitting into the grove around the circumference of the base pedestal. A 5.08-cm diameter, two-piece cylindrical mold was placed around the latex membrane and base pedestal, resting on the bottom plate of the permeameter. The rigid mold was used to allow the unconsolidated sediment to be packed into the latex membrane. The excess latex membrane extending above the mold was rolled down around the top of the mold. A vacuum was applied via a small pressure valve on the side of the mold to pull the membrane tightly against the inside of the mold.

Because the permeability of the collected sediment samples was anticipated to be quite high, a 5.08-cm diameter sandwich of filter paper, fine mesh screen, and filter paper was used in place of a porous stone between the sediment and the base pedestal and between the sediment and the top cap. The appropriate amount of sediment (to achieve the desired bulk density) was added to the mold a little at a time in between which the sediment in the mold was moistened with water and tamped 10–15 times with a 1733 gram stainless steel cylinder. For those test specimens that could not be repacked to the in-field bulk density, the test specimens were packed as dense as possible; the density achieved was determined as described next. After the permeability test was completed, the sediment from the test cylinder was carefully emptied into a sample tray and placed in an oven at 32 °C to dry. The achieved density of the test specimen was determined using the total (dry) mass of sediment that was packed into the test cylinder.

Figure A-1. Schematic diagram of constant pressure permeameter used in laboratory permeability tests of alluvium samples

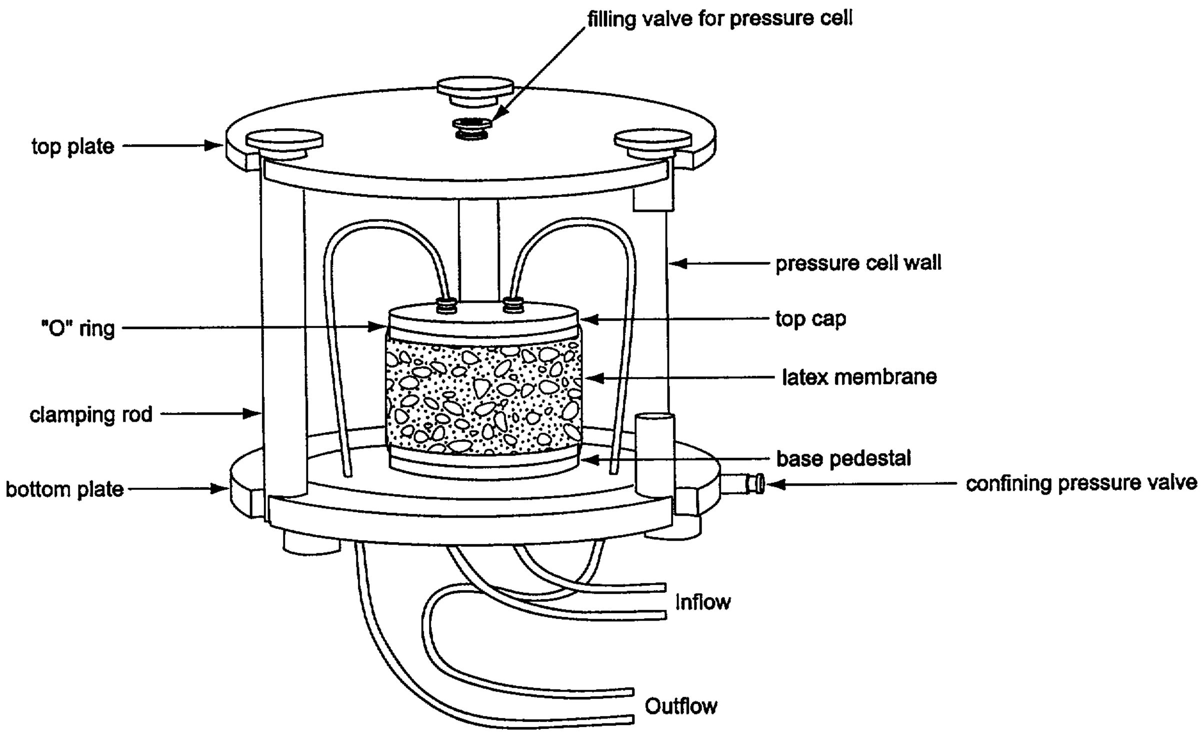
filling valve for pressure cell
top plate
pressure cell wall
"O" ring
top cap
latex membrane
clamping rod
base pedestal
bottom plate
confining pressure valve
Inflow
Outflow

figure A-1

Another 5.08 cm diameter sandwich of filter paper, fine mesh screen, and filter paper was placed between the packed sediment and the top cap. The latex membrane that was rolled down around the top of the mold was rolled up around the top cap. An O-ring was fixed around the top cap in a similar fashion to the base pedestal. The excess latex membrane extending above the top cap was rolled down over the O-ring and top cap. Vacuum grease was applied to the grooves on the bottom and top plates of the permeameter. The cell wall cylinder was inserted into the groove on the bottom plate and the top plate was placed in a similar fashion onto the top of the cell wall cylinder. The top and bottom plates and the cell wall cylinder are clamped together with the clamping rods. A 0.01 percent solution of degassed sodium hypochlorite was used to saturate the specimen and was used in the permeability tests. The mild solution of sodium hypochlorite kept any organisms from growing in the permeameter tubes.

Three different repacked test specimens were created from each sediment sample and tested to examine the consistency of the permeability test results and the variation between repacked specimens created from the same sediment sample. In most circumstances, two duplicate sets of test runs were performed on each repacked specimen at the following pressure cell specifications: confining pressure = 20 psig, outflow pressure = 2 psig, and inflow pressure = 6, 7, and 8 psig. The confining pressure of 20 psig is equivalent to the pressure exerted by a 6.1-m vertical column of alluvium (overburden) assuming an average density of 2.3 g/cm^3 for the alluvium. This low confining pressure was considered appropriate for the testing of nearsurface unconsolidated sediment samples. Several of the more impermeable sediment samples were run with higher inflow pressures (8, 9, and 10 psig each at two times) to facilitate timely completion of the permeability tests. The saturated hydraulic conductivity (K_{sat}) is calculated using Darcy's Law. The average K_{sat} for each of the repacked specimens was compared to that of the other specimens for the particular sediment sample; thereby, evaluating some of the variability possible between test specimens repacked to approximately the same bulk density.

Repacked sample permeability tests also were completed on portions of the undisturbed sediment samples collected, namely 40mBIG-P7 and 40mBIG-P12. The bulk density of the undisturbed samples was estimated by determining the mass and volume of a small piece of the undisturbed sample following the clod method described by Blake and Hartge (1986). Once the bulk density of the sediment was determined, the appropriate mass of sediment to be packed into a test specimen was obtained and repacked into a test specimen for testing. Any intact pedosols were broken up prior to repacking.