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September 28, 2000
Contract No. NRC-02-97-009
Account No. 20.01402.471

U.S. Nuclear Regulatory Commission
ATTN: Dr. Philip S. Justus
Office of Nuclear Material Safety and Safeguards
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Mail Stop 7 C6
Washington, DC 20555

Subject: Transmittal of Intermediate Milestone—Preliminary Hydrostratigraphy of the Valley-Fill Aquifer in Fortymile Wash and the Amargosa Desert (IM 20.01402.471.060)

Dear Dr. Justus:

Enclosed is Intermediate Milestone 20.01402.471.060—Preliminary Hydrostratigraphy of the Valley-Fill Aquifer in Fortymile Wash and the Amargosa Desert. This preliminary report describes a detailed investigation of several laterally continuous outcrops of alluvium in the entrenched channel of Fortymile Wash, the results of field and laboratory tests, and some initial conclusions on the relationship between flow and stratigraphy in Fortymile Wash. This work is part of a planned joint study, with staff of the Unsaturated and Saturated Flow under Isothermal Conditions Key Technical Issue, to provide constraints on the parameters used to model flow in alluvium. Future work will include additional field work, further processing and analysis of stratigraphic and hydrostratigraphy data, correlations of alluvial layers with borehole logs, and synthesis and analysis of the field and borehole data into a conceptual model that can be used to model flow. The figures in the report are temporarily affixed to the pages and will be placed electronically in the document following NRC approval and any subsequent modifications.

If you have any questions or need clarification please call John Stamatakos at (210) 522-5247 or me at (210) 522-5183.

Sincerely,

H. Lawrence McKague
H. Lawrence McKague
Manager, Geology & Geophysics

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Enclosure

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PRELIMINARY HYDROSTRATIGRAPHY OF THE VALLEY-FILL AQUIFER IN FORTYMILE WASH AND THE AMARGOSA DESERT

Prepared for

Nuclear Regulatory Commission
Contract NRC-02-97-009

Prepared by

Center for Nuclear Waste Regulatory Analyses
San Antonio, Texas

September 2000

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September 2000

ABSTRACT

Information on the structural and stratigraphic controls of groundwater within the alluvium south and southeast of Yucca Mountain is needed for the groundwater models in performance assessment calculations used to independently evaluate the proposed nuclear waste repository at Yucca Mountain. Subsurface information characterizing the alluvium in the saturated zone is limited, and the collection of additional subsurface data is beyond the current scope of the project. The features observed in the nearsurface alluvium are presently the best analogs of the valley-fill material in the saturated zone. The modern entrenched channel of Fortymile Wash, a large desert wash located east-southeast of Yucca Mountain in southwestern Nevada, provides several laterally continuous, well exposed outcrops of alluvium suitable for study. A detailed investigation of the outcrops was completed to evaluate the sedimentary architecture and hydraulic properties of the alluvium. The outcrop investigations indicate that the alluvium of Fortymile Wash consists of predominantly conglomerate and sandstone. Conglomerates are clast-supported, and the majority of the alluvium is well organized and contains relatively small amounts of matrix fill material. Much of the alluvium displays weak to well developed horizontal or low angle planar stratification, and clast imbrication is common. Seven diagnostic sedimentary lithofacies were identified based on grain size, sedimentary features, and geometry. Laboratory permeability tests of alluvium samples were completed to investigate the variation in permeability between the different lithofacies. Preliminary results indicate that the permeability within the valley-fill varies two orders of magnitude, ranging from 10^{-3} to 10^{-5} cm/s. Gamma ray and density measurements were collected from the outcrops to develop simulated wireline logs for comparison to wireline logs from recently completed boreholes in Fortymile Wash. The outcrop density profiles were found to be a function of the clast content of the valley-fill. The results of the gamma ray analysis are not yet complete. These outcrop profiles can be used to constrain future interpretations of density wireline logs from wells in Fortymile Wash. These results will be used to develop a conceptual model of the hydrostratigraphy of the Fortymile Wash alluvium, which will subsequently be used to better constrain the models and uncertainties associated with saturated zone groundwater flow in the Fortymile Wash and Amargosa valley-fill aquifer.

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ACKNOWLEDGMENTS

This report was prepared to document work performed by the Center for Nuclear Waste Regulatory Analyses (CNWRA) for the U.S. Nuclear Regulatory Commission (NRC) under contract No. NRC-02-97-009. The studies reported here were performed on behalf of the NRC Office of Nuclear Material Safety and Safeguards, Division of Waste Management. The report is an independent product of the CNWRA and does not necessarily reflect the views or regulatory position of the NRC.

QUALITY OF DATA, ANALYSES, AND CODE DEVELOPMENT

Data: CNWRA-generated data contained in this report meet quality assurance requirements described in the CNWRA Quality Assurance Manual. Sources for other data should be consulted for determining the level of quality of those data.

Analyses and Codes: Maps of the Yucca Mountain region were generated by the software ArcView GIS©, Version 3.1, which is a commercially available software program. ArcView GIS©, Version 3.1 is currently undergoing the controls specified in Center for Nuclear Waste Regulatory Analyses Technical Operating Procedure 18.

1 INTRODUCTION

1.1 SATURATED ZONE GROUNDWATER FLOW IN THE VALLEY-FILL AQUIFER

One critical component in the evaluation of Yucca Mountain (YM) as a potential repository for safe disposal of high-level nuclear waste is groundwater flow in the saturated zone (SZ), from beneath the repository footprint to the critical group located 20 km down gradient in the Amargosa Valley (figure 1-1). Several important uncertainties remain in predicting the behavior of groundwater flow, including groundwater flow in the saturated alluvial or valley-fill aquifer down gradient from YM, near the proposed 20-km compliance boundary.

Site characterization data, principally from the Nye County drilling program (Nye County, 1999), indicate that all flow paths crossing the 20-km boundary within the predicted path pass through at least some portion of the saturated valley-fill aquifer. Estimates of the distance any potential flow paths might travel through alluvium are not well constrained. Geophysical data (gravity and electrical sounding) suggest that the valley-fill aquifer north of Amargosa Valley is thick. For example, a simple Bouguer anomaly map (Snyder and Carr, 1982) reveals a gravity low at Amargosa Valley that extends to the north-northwest across Fortymile Wash. This gravity low could be caused by a thick valley-fill aquifer beneath Fortymile Wash, extending at least 5 km north of Interstate 95. Oatfield and Czarnecki (1989) estimated that 5 km north of the town of Amargosa Valley, valley-fill may be more than 1,000 m thick.

Little is known about the bulk transmissivity or hydraulic conductivity of the SZ flow paths in the valley-fill aquifer. Short-duration tests in Nye County Wells 1S, three-dimensional (3D), and 9S yielded transmissivity estimates ranging 200–5,000 m^2/d, but these wells apparently produce water from a composite of valley-fill and volcanic tuffs. Additionally, these three wells are all west of the Lathrop Wells volcanic cone and do not intercept flow paths from YM. Nye County Wells 2D and Washburn1X are along potential flow paths but, based on preliminary testing,[1] groundwater production is insufficient for adequate determinations of transmissivity. Nye County Well 5S, on the eastern edge of the potential flow path area, had the lowest productivity of any of the Nye County Wells drilled to date. In fact, 5S was thought to be dry until water slowly rose within the wellbore, stabilizing at about 724 m. Well logs for 5S reveal a thick sequence of clay-rich valley-fill sediments, which may account for the low productivity (Nye County, 1999). Logs from local production wells in Amargosa Valley also indicate the presence of a subsurface clay layer beneath the Lathrop Wells area (along Interstate 95 near Fortymile Wash) at about a 110–120 m depth[2]. Water production from most of the local wells is from the water table aquifer in the unconsolidated alluvial sediments that overlie this clay layer. Additional knowledge of the thickness, continuity, and extent of this clay layer is required because SZ flow paths from YM may be diverted above, below, or around this low-permeability zone.

Estimates of groundwater velocities in the saturated valley-fill units located south of YM are necessary to assess the efficacy of these units as natural barriers to radionuclide migration. Current

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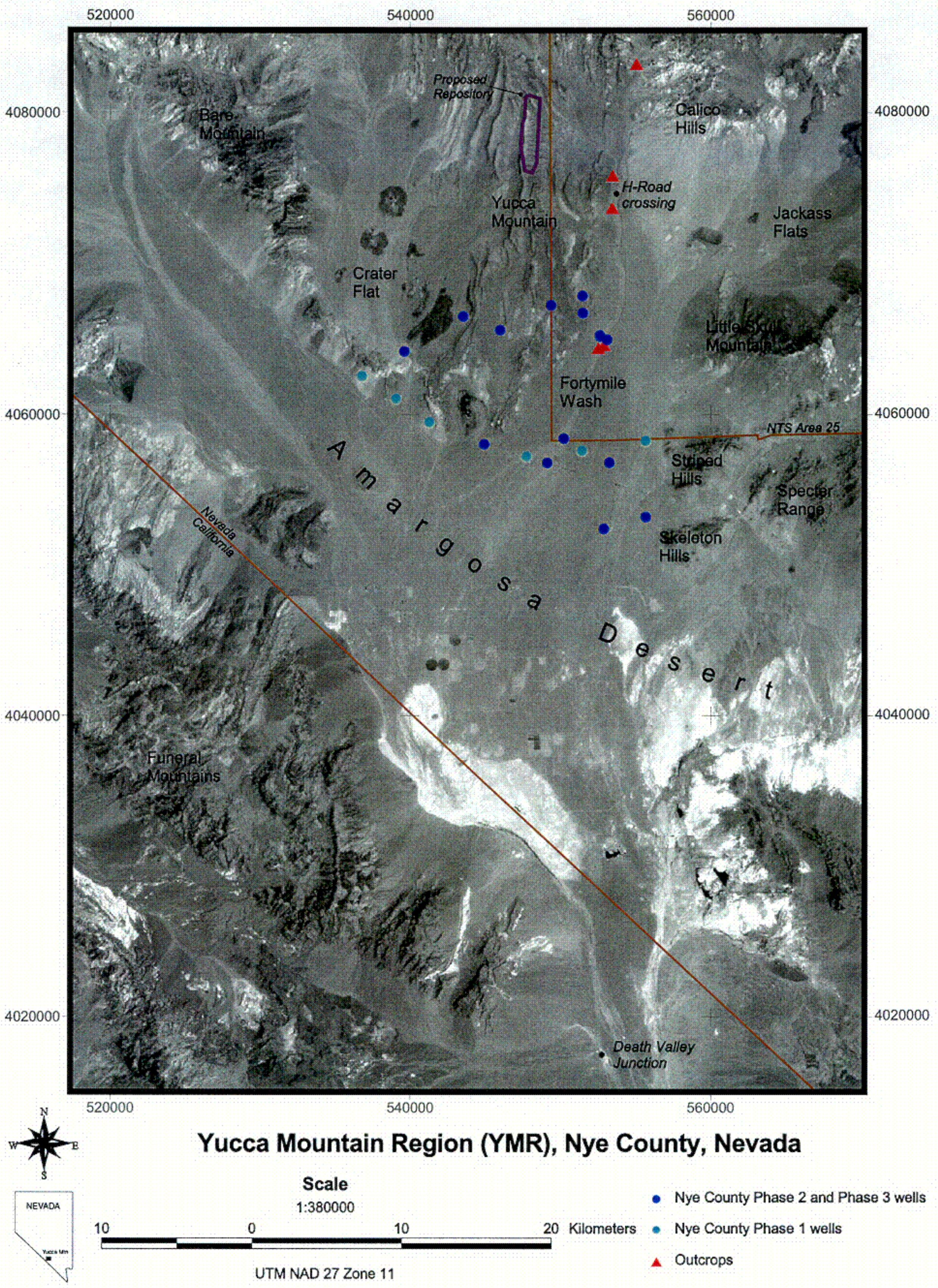
[1]U.S. Nuclear Waste Technical Review Board. *Repository Design and the Scientific Program.* Transcript of Summer Meeting. Beatty, NV: U.S. Nuclear Waste Technical Review Board. 1999.

[2]Tom Buqo, consultant to Nye County. Presentation to Nuclear Waste Technical Review Board, July 28–30, 1999.

Figure 1-1. Aerial photograph of the Yucca Mountain region showing the location of Fortymile Wash



Yucca Mountain Region (YMR), Nye County, Nevada

figure 1-1

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consensus between U.S. Department of Energy (DOE) and U.S. Nuclear Regulatory Commission (NRC) is that most of the attenuation in radionuclide concentration along the flow path will occur within the valley-fill units because of (i) significantly slower groundwater velocities compared to the tuff units up gradient, (ii) associated high mineral surface area to volume ratios, and (iii) advantageous mineral compositions within the alluvial units. Winterle et al. (2000) also suggest that matrix diffusion processes could contribute to further attenuation of radionuclide concentrations in the valley-fill units and that radionuclides might diffuse into pore spaces contained in large cobbles or clay lenses in which low permeability results in minimal advective mass transport.

1.2 PERFORMANCE ASSESSMENT

In current performance assessment (PA) models, groundwater flow through the alluvium is one of the most critical factors to repository performance, specifically with regard to production zone thickness and dilution at the wellhead, groundwater travel times, and attenuation of radionuclides by interaction with alluvium minerals (U.S. Nuclear Regulatory Commission, 1998). In the PA models, the simplifying assumptions of homogeneity and isotropy have been applied to the valley-fill alluvium, but no investigations have been completed to evaluate the significance of these assumptions. Moreover, these simplifying assumptions ignore the observation that most natural sediments are heterogeneous, and that heterogeneities usually give rise to inhomogeneous and anisotropic hydraulic and sorptive properties. No published studies have described the stratrigraphy of the valley-fill alluvium surrounding YM to the south and southeast, nor have any investigations attempted to characterize any heterogeneities within the alluvium resulting from the sedimentary structure of the alluvium. It is uncertain how heterogeneities resulting from the sedimentary structure within the valley-fill alluvium will affect groundwater flow, or at what scales the heterogeneity within the alluvium may be important for groundwater flow. These issues need to be addressed in order to properly represent the valley-fill alluvium in PA models of the proposed repository.

Currently, there are no YM site-specific data available for effective porosity in alluvium units. The most recent DOE model of SZ flow and transport (Civilian Radioactive Waste Management System Management and Operations Contractor, 2000), therefore, relies on a range of effective porosity values estimated by Bedinger et al. (1989) for alluvium within the southwest Basin and Range. For PA, the effective porosity of alluvium is sampled stochastically from a truncated normal distribution, with a mean value of 0.18 and a standard deviation of 0.05 (Civilian Radioactive Waste Management System Management and Operations Contractor, 2000). In addition, geophysical data (e.g., Oatfield and Czarnecki, 1989), well logs (neutron, caliper, and resistivity, in particular; see Nye County Early Warning Drilling Program, Phase 1–FY1999, Data Package), and drill cuttings indicate these deposits are composed of spatially varying thicknesses of sands, gravels, silts, clays, and cobbles. As a result, the hydrogeological properties of the valley-fill unit can be expected to show considerable spatial variability.

The NRC Total-system Performance Assessment (TPA) Version 3.2 code assumes that effective porosity follows a uniform distribution between 0.1 and 0.15 (Mohanty and McCartin, 1998). This range is based on crude estimates of specific yield provided by Walker and Eakin (1963). It should be noted that the Walker and Eakin values are not based on data from the valley-fill sediments south of YM, but are instead based on estimates from other sites they considered reasonable analogs. Total porosity measurements from near-surface valley-fill sediments (composed of varying quantities of sands and silts), located at the low-level radioactive waste site near Beatty, Nevada, range between 0.25 and 0.45 (Fischer, 1992). These measurements suggest values of effective porosity that appear to exceed measurements of Walker and Eakin

(1963). Because these sediments have undergone little compaction, the high porosity values may not be representative of porosities in the valley-fill deposits below the water table south of YM.

The technical bases for the SZ flow models in the NRC TPA Version 3.2 code (Mohanty and McCartin, 1998) and the DOE TSPA models (Civilian Radioactive Waste Management System Management and Operating Contractor, 1998) were criticized by the External Peer Review of the TPA Version 3.2 Code (Weldy et al., 1999). In particular, Dr. Marsily of the review committee commented "available hydrogeological data were insufficient to justify the SZ flow and transport models." In reference to the valley-fill aquifer, the committee noted that (i) the relationship between the volcanic tuff and alluvium is not clear, so the level of mixing is difficult to determine and the contact between the two rock types is poorly defined; (ii) the geometry of the alluvium is not well defined; (iii) flow in the alluvium cannot be modeled as an equivalent porous medium; and (iv) layering (stratigraphy) of the alluvium must be characterized to adequately determine dilution.

1.3 SCOPE

To evaluate uncertainties associated with flow and transport of groundwater in the valley-fill aquifer, the Structural Deformation and Seismicity Key Technical Issue (KTI) and Unsaturated and Saturated Flow under Isothermal Conditions KTI began a joint project in 1998 as part of the Structural Effects on Groundwater Flow Working Group. The goal of the project was to refine concepts about structural and sedimentological controls on groundwater flow in the valley-fill aquifer, which will underlie independent assessments of DOE data and analyses regarding performance of the proposed repository. The work focused on investigations of valley-fill deposits exposed in Fortymile Wash, specifically to: (i) delineate sedimentary structure in the nearsurface alluvium; (ii) determine if the nearsurface alluvium can be used as an analog of the alluvium in the SZ; (iii) estimate values for the hydraulic properties and the distribution of these hydraulic parameters within the alluvium; and (iv) develop a 3D conceptual model of the stratigraphic and structural framework.

Several well exposed outcrops of nearsurface alluvium are located in the entrenched channel of Fortymile Wash. These exposures provide information on the types of sediment and the sedimentary architecture within the alluvium. The features observed in the nearsurface alluvium are presently the best analogs of the valley-fill material in the SZ because subsurface information about the alluvium in the SZ is limited, and the collection of additional subsurface data is beyond the current scope of the project.

This report describes preliminary results of the investigations in Fortymile Wash, specifically, (i) field observations regarding the sediment types composing the valley-fill of Fortymile Wash, (ii) the subdivision of the valley-fill into facies, (iii) the interpreted depositional processes responsible for the different facies, (iv) the distribution of these facies within Fortymile Wash, (v) permeability estimates for sediment samples from various facies, and (vi) nearsurface to subsurface comparisons of the valley-fill. This project is a work-in-progress, thus, some sections of the report are incomplete and will be appended, modified, or both based on future work.

2 SETTING

2.1 PHYSIOGRAPHY AND GEOLOGY

YM is located in southwestern Nevada in the Great Basin, of the Basin and Range Province of the North American Cordillera. YM is an associated group of north to north-northeast-trending, fault-bound ridges crossed by occasional northwest-trending strike-slip faults. The block-faulted ridges of YM extend from Pinnacle Ridge southward into the large northwest-trending alluvium-filled basin of the Amargosa Desert (figure 1-1). YM and the surrounding region remain tectonically active as indicated by numerous Quaternary faults (including faults with demonstrable Holocene activity), historic seismicity (including the 1992 Little Skull Mountain earthquake), and late Quaternary volcanism.

YM consists of a thick accumulation of volcanic tuff deposited on an irregular surface of eroded and deformed Paleozoic and Precambrian rocks. These tuffs were erupted from a series of Middle to Late Miocene (15–9 Ma) calderas that collectively form the Southwestern Nevada Volcanic Field (Sawyer et al., 1994). Rocks of the Paintbrush Group, principally ash flows of the Topopah Spring Tuff and Tiva Canyon Tuff, make up the main surface exposures of YM. Bounding YM is the Solitario Canyon Fault and the associated down-faulted Solitario Canyon to the west and Fortymile Wash to the east. Flanking YM farther to the east and west are the alluvium-filled basins of Crater Flat and Jackass Flats (figure 1-1). Like that of the rest of the Great Basin, YM is underlain by a thick unsaturated zone, up to 750 m thick (Robinson, 1984).

Fortymile Wash is the largest tributary of the upper Amargosa River and is one of the largest alluvial systems in the Southern Basin and Range Province (Lundstrom et al., 1998). The ephemeral channels of Fortymile Wash drain southward from the headwaters in Eastern Pahute Mesa to the juncture with the Upper Amargosa River in the Amargosa Desert just north of Death Valley Junction (figure 1-1). The drainage basin of Fortymile Wash is approximately 1,036 km^2, with nearly 1,676 m of relief (Glancy and Beck, 1998). The upper reaches of Fortymile Wash, referred to as Fortymile Canyon, pass through the east half of the Timber Mountain caldera, located within the Southwestern Nevada Volcanic Field (Lundstrom et al., 1998). Fortymile Wash extends south-southwest from YM into the Amargosa Desert and is rimmed in its upper reaches by smaller transverse fans emerging from the surrounding uplands (figure 1-1). The active wash channel is entrenched to depths exceeding 20 m, and gently grades into a wide alluvial plain within the Amargosa Desert just north of Interstate 95 (Lundstrom et al., 1998, Figure 2).

Fortymile Wash is referred to both as an alluvial fan and as a desert wash in published literature and maps. Fortymile Wash displays some of the morphologic features of an alluvial fan, but lacks some defining characteristics. An alluvial fan is a gently sloping, conical or fan-shaped accumulation of detrital sediment deposited as a stream emerges from upland to lowland. This typically occurs along mountain fronts, usually as a stream emerges from an incised canyon onto a plain or valley floor. The term desert wash, widely used in the arid southwestern U.S., refers to a broad, gravelly intermittent stream that is occasionally swept by torrential flood flows. Much like an alluvial fan, Fortymile Wash is located where channelized flow draining an upland emerges from a mountain. Alluvial fans tend to have a fan-shaped geometry with a radial slope. Many of the fans rimming Fortymile Wash have this geometry, as well as the small fan below the intersection point of Fortymile Wash (figure 1-1). Fortymile Wash itself has a more elongate geometry, lacking a well defined radial slope, which may be the result of its location in a fault bounded half graben structure. The incised channel and small radial fan beneath an intersection point are also characteristic of fan morphology.

The slope of Fortymile Wash (and the terraced surface of Fortymile Wash) is substantially less than that expected of alluvial fans. In the proximal reaches of Fortymile Wash (and in the mountain uplands before its emergence), the slope of Fortymile Wash does not exceed 1, and the slope grades to approximately 0.5 at the intersection point just north of Interstate 95. Alluvial fans typically have radial slopes of 2 to 20; gravelly fluvial systems, on the other hand, have slopes typically 0.5 (Blair and McPherson, 1994). The slope of Fortymile Wash is closer to the range expected of gravelly fluvial systems than that expected of alluvial fans. In light of these observations, Fortymile Wash should be considered as a proximal gravelly fluvial system, rather than an alluvial fan.

2.2 CLIMATE AND HYDROLOGY

The climate in the vicinity of Fortymile Wash ranges from semiarid in the upper basin to arid in the lower basin with a mean annual precipitation of 35 cm and 15 cm, respectively. The coarse sediment of Fortymile Wash and the arid climate of the basin result in significant downstream channel losses of the few channel flows that occur. Accordingly, significant downstream sediment deposition occurs as stream flow infiltrates and evaporates, resulting in gradation of the entrenched channel of Fortymile Wash in the upper basin to the wide braided plain in the Amargosa Desert (Glancy and Beck, 1998).

Fortymile Wash, much like the Amargosa River, flows only ephemerally in response to intense rainfalls and rapid melting of a thick snow pack. Glancy and Beck (1998) compiled the available historical records (quantitative) of surface water flow for the Upper Amargosa River and for Fortymile Wash to gain some insight into the runoff and stream characteristics. The objective of the study was to determine if flows from Fortymile Wash ever reached the Amargosa River and ultimately Death Valley. Although the majority of stream flow records do not document whether the flow observed in Fortymile Wash or in the Amargosa River reached Death Valley, several observed events provide evidence that this can indeed occur. Simultaneous stream flow through both Fortymile Wash and the Amargosa River to its terminus in Death Valley was visually observed during a storm event on March 11–12, 1995, and on February 22–23, 1998. In total, surface water flow in Fortymile Wash has been observed only six times during the past 15 yr, with the flows lating less than 1–2 d (Glancy and Beck, 1998).

The ephemeral flow activity in Fortymile Wash ranges from torrential, high discharge floods that occupy the entire entrenched channel to low discharge channelized flow in a braided pattern within the entrenched channel. As is evident in the preceding paragraph, due to the remote location of Fortymile Wash, documentation of flow activity and any resulting deposits are scant. One visually documented event occurred on February 24, 1969. An Nevada test site (NTS) security guard observed wall-to-wall flow in the entrenched channel of Fortymile Wash, near the H-road crossing of Fortymile Wash (figure 1-1), that completely submerged the 240–275 m wide floor of the entrenched channel to an estimated depth of 1.2 m. The NTS security guard described the flow as highly turbid with frothing waves on the flow surface (Glancy and Beck, 1998; personal communication of C.E. Finch to P.A. Glancy). An estimated peak discharge of 566 m^3 (Squires and Young, 1984) traveling at a velocity of 1.68–1.94 m/s (Glancy and Beck, 1998) passed through the entrenched channel of Fortymile Wash during this flood at this locality.

3 METHODS

3.1 FACIES ANALYSIS

Subsurface and outcrop information regarding the alluvial aquifer, especially the alluvium at depth, is limited to sample observations and geophysical measurements from a small number of widely distributed wells. Consequently, other methods of analysis in addition to direct measurement were applied to characterize the heterogeneity present within the alluvium. Many of the methods used for developing descriptive and quantitative models of alluvial heterogeneity are described by Koltermann and Gorelick (1996) and Webb and Davis (1998). Many of the methods use some form of depositional analysis to assist in the characterization of heterogeneity (e.g., Davis et al., 1993, 1997; Galloway and Sharp, 1998a, 1998b; Miall, 1985, 1988). The premise of these methods is that geologic processes deposit bodies of sediment or associations of deposits with characteristic geometries and properties that give rise to geological heterogeneity. These methods have been extended by other investigators to develop hydrostratigraphic models in which the hydraulic properties of each element (i.e., the deposits or associations of deposits) are measured and analyzed; subsequently, characteristic properties or geostatistical models of the properties are applied to each element. The results of such an application are documented in recent studies by Davis et al. (1993, 1997).

In this study, predictions on the structure of the alluvium were made using field observations and facies models of similar depositional environments. This is not to say that a facies model will be chosen and applied to the site; rather, the existing facies models will be analyzed in conjunction with the field evidence available from the site. Facies models are a collection of observations and information regarding a particular environment or system based on investigations of modern and ancient examples of that particular environment. Walker (1984) succinctly notes that facies models should serve four basic purposes: as a norm for purposes of comparison in related studies, a framework and guide for future observations, assist in predictions in new geologic situations, and a foundation for interpretation of the environment it represents.

The nearsurface exposures of the valley-fill were investigated to determine the types of sediment present within and to delineate the different deposits composing the valley-fill based on grain size, sedimentary features, and deposit geometries. Using geological and sedimentological principles, interpretations were made regarding the processes responsible for the different deposits observed. These interpretations are important because depositional processes yield sedimentary deposits with characteristic geometries and hydraulic properties. The proper interpretation of the process(es) responsible for a particular sediment deposit provides the geologist with a conceptualized 3D geometry of the deposit. The critical assumption of the analysis lies in the subsequent application. In the current models, it is assumed that similar processes controlled sedimentation in Fortymile Wash since significant sediment accumulation began there, probably in the late Tertiary. It is acknowledged that Fortymile Wash has evolved through time, as is evident by the modern processes, but the data sets needed for interpreting the evolution of Fortymile Wash are not yet available. The nearsurface exposures of the alluvium are proposed as the best analog of the alluvium in the SZ that is currently available. A future goal is to use geophysical work on the outcrops (see sections 3.1 and 5.2) to assist in interpretation of the deeper alluvium once the needed data sets regarding the deeper alluvium become available.

3.2 WIRELINE LOGS AND OUTCROP PROFILES

Lithologic and geophysical logs from boreholes within Fortymile Wash provide the only tangible source of information regarding the valley-fill at depth. These limited logs provide a useful summary of the valley-fill, but cannot provide much information on the sedimentary structure within the alluvium, the processes responsible for sediment deposition, or the geometry of the deposits. To facilitate correlations between the nearsurface and subsurface valley-fill, profiles of density and gamma radiation (i.e., simulated wireline logs) were developed from outcrops of the nearsurface valley-fill. The importance of the outcrop profiles lies in the ability to correlate a measured density or gamma ray response with a visually observable facies in outcrop. The use of outcrop profiles is widely documented and accepted method of analyses in reservoir characterization projects (Batzle and Smith, 1992; Aigner et al., 1995, 1996, 1999; Ahmadi and Coe, 1998; Thomas, 1998). Such a methodology can also be applied in aquifer characterization.

Several of the Nye County Early Warning Drilling Program (NC-EWDP) Phase 1 wells are located within Fortymile Wash (2D, 5S, and Washburn 1X). These wells provide lithologic and geophysical logs of almost the entire thickness of the alluvium. Available data consist of mud logs, cuttings, and geophysical wireline logs. Partial to complete neutron, density, and gamma ray logs are available for all these wells, and electric logs, caliper, and deviation are variably available. Due to problems with borehole collapse, the neutron, density, and gamma ray logs were run in the drill string so complete logs would be obtained. Additional logs were run after the removal of the drill string but only to provide partial logs due to borehole collapse. The logs available for the NC-EWDP wells in Fortymile Wash are provided in table 3-1.

3.2.1 Density Logs

Density values for the valley-fill were obtained using a small, hand-held ultrasonic velocity probe developed by Batzle and Smith (1992). The instrument operates much like a borehole sonic probe: it emits a *P*-wave (compressional wave) and records the arrival time of the *P*-wave at two locations separated by a known distance. The velocity of the *P*-wave propagation through a formation depends on the rock (or sediment) and the contained fluids. A detailed explanation of the hand-held velocity probe is provided in Batzle and Smith (1992). An apparent bulk density value was obtained from the velocity values using a velocity-density model (Mavko et al., 1998).

Outcrop density profiles were developed following the methodology of Ahmadi and Coe (1998); except that, whereas, Ahmadi and Coe obtained the point bulk density measurements from laboratory analyses of rock samples collected from outcrop, the density measurement in this study was 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 not 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 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 readings).

Table 3-1. Geophysical logs for available Nye County Early Warning Drilling Program wells located in Fortymile Wash

Well	Total Depth (ft)	Logs Available	Logged Interval (ft)
2D	1618	neutron density gamma	0–440 0–440 0–440
5S	1200	neutron density gamma e-logs caliper deviation	0–1160 0–1160 0–1160 500–950 500–690 0–1160
Washburn 1X	658	neutron density gamma e-logs deviation	0–657 0–657 0–657 340–511 0–657

3.2.2 Gamma Logs

The outcrop gamma ray measurements were collected using an Exploranium GR–256 spectrometer with a GPS–21 detector. The GPS–21 uses a thermally insulated and ruggedized 21-in.^{3} sodium iodide (NaI) crystal coupled with a photomultiplier tube for gamma ray detection. The spectrometer uses a small radioactive reference source (Cs 137 at 0.5 μCi) for automatic gain stabilization (i.e., the frequency peak of the reference isotope is kept at the proper channel of the spectrometer) to correct for temperature and humidity effects. Count rates collected included total counts, potassium, uranium, and thorium. The gamma ray spectra were collected because they may provide additional details regarding the gamma ray response of the valley-fill.

It should be noted that the count rate obtained by this particular instrument is not an absolute rate, rather it is a relative rate dependent on (i) the size of the crystal in the detector, (ii) the distance between the detector and the gamma ray source, (iii) the angle between the detector and the gamma ray source (Ward, 1982), (iv) the sampling volume of the instrument, and (v) the background radiation setting of the instrument. However, as gamma ray logs measure relative changes in gamma radiation, these differences do not hinder comparisons.

Natural radioactivity in igneous rocks primarily arises from the contained potassium, mainly in the form of feldspar. In sedimentary rocks, the highest natural radioactivity is associated with clays, specifically the radioactive elements present in the crystal lattice of the clay (Ward, 1982). In the study area, a change in gamma ray response is assumed to be related to these two components (i.e., the contained clasts of igneous provenance and the clays contained in the matrix).

The use of outcrop gamma ray profiles as simulated wireline logs is better established in published literature than are outcrop density profiles. Aigner et al. (1995), Thomas (1998), and Ahmadi and Coe (1998) provide published examples of how outcrop gamma ray profiles are developed and Aigner et al. (1996, 1999) demonstrate how gamma ray profiles can be used in outcrop analog studies to assist in formation characterization. Further references to additional studies using outcrop gamma ray profiles are provided in these cited papers.

The method for developing the outcrop gamma ray profiles is much simpler than that used in the construction of density profiles. Unlike density sampling, gamma ray sampling is not restricted by outcrop quality for sample placement. Thus, measurement can be taken at any chosen sampling interval, simplifying the later construction of the outcrop gamma ray profile. The outcrop gamma ray profile was generated by plotting the gamma ray measurements at the stratigraphic interval at which they were recorded. Overlapping of the gamma ray measurements imparts a moving average effect on the results; consequently, a moving average filter was not applied to the developed gamma ray profiles.

3.3 PERMEABILITY MEASUREMENTS

To examine the hydraulic conductivity (K) variations within the nearsurface alluvium, representative sediment samples of the alluvium were collected for laboratory permeability tests. As the majority of the exposed alluvium is poorly cemented and consists of large clast sizes, the removal of undisturbed sediment samples proved difficult. A preliminary phase of sediment sampling and permeability testing has been completed. Only disturbed sediment samples were collected and used in this phase of testing. The goal of this phase of sediment sampling was to provide an overview of the permeability variations within the alluvium; consequently, sediment samples representing each type of sediment composing the alluvium were collected. The sampling locations were dictated by accessibility to the outcrop. A subsequent phase of sediment sampling is planned, during which additional sediment samples will be collected to better characterize each of the delineated facies. These latter results will be used to both guide development of independent NRC/Center for Nuclear Waste Regulatory Analyses (CNWRA) models and to evaluate models proposed by DOE.

The laboratory test specimens were repacked to the appropriate in-field bulk density using a field estimate of the bulk density. The in-field bulk density was estimated from the mass of sediment removed from the outcrop and the volume of the space created by removal of the sediment. A detailed description of how the test specimens were prepared and how the permeability tests were completed is provided in the appendix to this report. Laboratory permeability tests were completed using a constant pressure permeameter. Three different repacked test specimens were created from each sediment sample and tested to examine the consistency of the permeability test results and of variation between repacked specimens created from the same sediment sample. For those test specimens that could not be repacked to the in-field bulk density, the total (dry) mass of sediment packed into the test cylinder was measured after completion of the permeability test for subsequent calculation of the achieved bulk density. Permeability tests were completed on nine samples of alluvium. In most circumstances, two duplicate sets of test runs were performed on each repacked specimen at the following pressure cell specifications: confining pressures = 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) (appendix). This low-confining pressure was considered appropriate for testing 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 the timely completion of the permeability tests.

4 NEARSURFACE ALLUVIUM

4.1 PREVIOUS INVESTIGATIONS

Previous investigations regarding the alluvium surrounding YM to the south and southeast are limited in number. Lundstrom et al. (1995) described the development of alluvial soils in the YM region (YMR) using soil pit and surface observations, and mapped the surficial alluvial units of the YMR based on surface features and soil morphology. Age control for the mapped surficial units was established from geochronologic studies predominantly based on thermoluminescence (TL) of eolian material incorporated into the alluvial soils and uranium series ages on pedogenic carbonate and silica (Paces et al., 1994).

Further age dating of the alluvium using TL and ^{230}Th in a subsequent study by Lundstrom et al. (1998) was used to interpret rates and timing of the aggradation and incision occurring in Fortymile Wash. Lundstrom et al. (1998) documented several fine sand-dominated horizons (in addition to the top surface of the outcrop) in investigations of the nearsurface alluvium of Fortymile Wash. The sand-dominated horizons were interpreted as resulting from eolian sand deposition incorporated into freshly deposited alluvium. These horizons are interpreted by Lundstrom et al. (1998) as buried soils on the basis of the increase fine grain size content, the redder color of these horizons, the carbonate/silica cemented gravel layers at the base of the horizon, and the lateral continuity of these horizons. Lundstrom et al. (1998) completed TL and ^{230}Th dating of a total of four buried soils (in addition to the top surface of the outcrop) in a large outcrop of the alluvium. Observations and descriptions of this particular outcrop were made during this study and are discussed in a subsequent section. TL dates were obtained for two of the buried soils were considered by the authors as reliable. ^{230}Th dates for the Pleistocene terrace surface (40–60 ka at this location) were regarded as acceptable, but ^{230}Th dates on the buried soils were suspect and were in discordance with TL dates. Based on the surface ^{230}Th dates and the TL dates of the buried soils, 13 m of fan aggradation and formation of four buried soils are constrained between 140 and 50 ka. If only ^{230}Th dates are used (even the suspect dates), the 13 m of fan aggradation is constrained from 500–50 ka. Based on ^{230}Th dating of the oldest inset terrace within the entrenched channel, the period of fanhead entrenchment is constrained to have occurred by 24–36 ka. Lundstrom et al. (1998) found no record or evidence indicating incision or aggradation within the entrenched channel from 24 ka to the present.

Guertal et al. (1994) provide a brief description of a vertical sequence of the alluvium exposed in the west entrenched channel wall of Fortymile Wash just south of the H-road crossing of Fortymile Wash (figure 1-1). The 19-m vertical sequence of alluvium was subdivided into nine major horizons, which were interpreted as episodic depositional and erosional cycles (Guertal et al., 1994). Sieve analyses of collected alluvium samples were used to estimate hydraulic conductivity values for each of the nine major horizons. Guertal et al. (1994) conducted ponding experiments behind the cliff wall to determine vertical movement of water in the alluvium. A borehole directly behind the outcrop was used to monitor the downward movement of water during the ponding experiments, as well as to complete wireline logs for comparisons to the wetting front movement and to the observations of the alluvium from the cliff face. Guertal et al. (1994) found that the downward movement of water was strongly retarded by petrocalcic (caliche or calcrete) horizons present within the alluvium. Guertal et al. (1994) also suggest that the large discrepancy in the mass balance between the volume of water added to the alluvium and that detected during the ponding experiment was due to substantial horizontal movement of the water atop the caliche horizons.

Few previous investigations addressing depositional processes in Fortymile Wash have been completed. Coe et al. (1997) described debris flow events occurring on Jake Ridge. Modern sediment gravity flow processes are currently active, although infrequent, on the small fans rimming Fortymile Wash. In late July 1984, an intense rainfall event triggered a debris flow on the southern hillslope of Jake Ridge (Coe et al., 1997) that resulted in approximately 7,000 m^3 of sediment distributed downslope. Of the mass of sediment transported by the debris flow, 65 percent was deposited on the lower slopes of Jake Ridge and the remaining 35 percent was deposited in the tributary to Fortymile Wash, with only minor amounts reaching Fortymile Wash itself (Coe et al., 1997).

4.2 LITHOFACIES

4.2.1 Nomenclature

A lithologic code system similar to that described by Miall (1978) was used in the field descriptions and stratigraphic sections (table 4-1). The code system differs slightly due to the coarse nature of the investigated alluvium. All the alluvium is either gravel or sand, so a more detailed code system was used to describe the sediments. The first capital letter indicates the grain size, in reference to this study: G = gravel and S = sand. The following lower case letters indicate sedimentary structures that are present. In the gravel grain size, the second letter indicates if the sediment is clast (c) or matrix (m) supported. The grain-size scheme used in the descriptions and discussions of the investigated sediments is provided in table 4-2.

The sediments observed in outcrop are poorly to well-cemented, with the degree of cementation varying horizontally and vertically. The in-field degree of cementation of the sediments was described by the amount of sediment able to be removed by hand abrasion on the outcrop exposure of the sediment (table 4-3). Observations collected and recorded in the stratigraphic sections included grain size, sedimentary structure, sorting, cementation, caliche development, and lateral continuity of the delineated sedimentary units.

4.2.2 Facies Descriptions

On the basis of grain size, sedimentary structure, and geometry of the investigated alluvial deposits, the alluvium was divided into distinct lithofacies. The following paragraphs provide a detailed description of each of the facies including grain size, sedimentary structure, interpreted process of deposition, and observed or interpreted facies geometry. A summary of the delineated facies is provided in table 4-4.

4.2.2.1 Facies F1 (Gcm to Gcmi)

Facies F1 is characterized by clast-supported, well sorted cobble to boulder conglomerate with a matrix of well-cemented medium to coarse sand (figure 4-1). This facies typically has a distinct bimodal grain size consisting of cobbles to boulders, and medium to coarse sand. Some clasts are imbricated. Scattered outsized boulder clasts in the range of 60 cm occur. This facies has lenticular geometries with lengths of 10–50 m. Facies F1 occurs as isolated lenses within Facies F2. The lenticular geometries are best developed perpendicular to the longitudinal axis of the wash (perpendicular to the flow direction). Facies F1 is common in occurrence and remains fairly consistent in character in the investigated outcrops.

Table 4.1. Lithologic codes used in sediment descriptions and stratigraphic sections

Lithologic Code	Description
Gravel and Coarser	
Gcm	clast-supported, massive
Gcmi	clast-supported, massive, imbricated
Gch	clast-supported, horizontal stratification
Gchi	clast-supported, horizontal stratification, imbricated
Gcp	clast-supported, planar cross-stratification
Gct	clast-supported, trough cross-stratification
Gmm	matrix supported, massive
Sand	
Sm	massive
Sh	horizontal stratification
Sp	planar cross-stratification
St	trough cross-stratification

Table 4-2. Grain-size system used in alluvium descriptions (modified Wentworth scale)

Sediment Grain Size	Size Range (mm)
clay	$<{}^{1}/_{256}$
silt	${}^{1}/_{256}$–${}^{1}/_{16}$
sand	${}^{1}/_{16}$–2
gravel	2–64
cobble	64–256
boulder	>256

Table 4-3. In-field degree of cementation

Degree of Cementation	Description
well	No significant amount of sediment grains are removed by hand abrasion of outcrop
moderately well	Small amounts of sediment are removed by hand abrasion of outcrop, but sediment is mostly solid
moderate	Small amounts of sediment are removed by hand abrasion of outcrop
poor	Large amounts of sediment grains are removed easily upon touch

Facies F1 is interpreted as channel deposits that formed between longitudinal bars in a braided stream system (Miall, 1977). Facies F1 is always found in close association with Facies F2 and both facies are interpreted to have formed by similar depositional processes.

4.2.2.2 Facies F2 (Gch/Sh to Gchi/Sh)

The most common facies within the alluvium is horizontally stratified gravel and sand, which is here defined as Facies F2. The characteristic feature of the facies are gravel-sand couplets (figure 4-2). The coarse component consists of clast-supported medium gravel to fine cobble. In some exposures, the coarse component has a distinctive bimodal grain size content consisting of gravel to fine cobble and medium to coarse sand; whereas in other exposures, portions of the coarse component have open framework. The fine component of the gravel-sand couplets consists of interlayered medium to coarse sand and fine gravel. The sand layers tend to be more strongly cemented than the gravelly layers and stand out in relief, highlighting the stratification. These gravel-sand couplets vary in thickness, but are typically less than 50 cm. Imbrication of clasts is common, and is particularly evident in the coarser, elongate clasts. Numerous thin (millimeters in thickness) but laterally extensive sandy caliche layers are commonly present in this facies and are characteristically separated by intervals of tens of centimeters. These thin caliche layers are concentrated in the sandier component of the facies, and commonly cap the gravel-sand couplets. Facies F2 was consistently observed throughout the various outcrops, though the grain size varied slightly. In proximal regions of Fortymile Wash, the grain size is more coarse but the couplets of coarser and finer clast sizes are still clearly observable. In the same manner, Facies F2 has a finer grain size content in distal outcrops, but retains the other sedimentary features of the facies. Lenticular units of cross-stratified gravel are locally present within the horizontally stratified gravel. The lenticular units are on the order of 5–15 m in length. Stratification within the lenticular units varies from stratification parallel to the base of the lens, to cross-stratification that is tangential to the base, to more planar cross-stratification. A coarse gravel to cobble lag is commonly developed along the base of the lenticular unit (figure 4-3).

Table 4-4. Facies delineated within the alluvium of Fortymile Wash from outcrop studies

Facies	Lithologic Codes	Sedimentary Features	Observable Geometries	Interpreted Depositional Environment
F1 *figure 4-1*	Gcm to Gcmi	• clast-supported • bimodal grain size consisting of cobbles to boulders and m-c sand	• occurs as lenses within Facies F2 • lenticular for lengths of 10–50 m; 10–50 cm thick; coarser units tend to be thicker	channel deposits between longitudinal bars
F2 *figure 4-2, figure 4-3*	Gch/Sh to Gchi/Sh	• clast-supported, imbrication • sand to cobble • primarily horizontally stratified gravel and sand, characterized by gravel-sand couplets • coarse component of gravel-sand couplets may have bimodal sediment content; open framework gravels variably contained within couplets	• most common and volumetrically significant facies • gravel couplets 10–50 cm thick	gravel-sand couplets formed by migration of submerged gravel bars
	Gch, Gcp, or Gct	• clast-supported • gravel to cobble • lens-shaped units of cross-stratified gravel; internal stratification varies from base parallel stratification to cross-stratification that is planar or tangential to the base	• occurs as lenses within horizontally stratified gravel • 10–15 m in length; ≤ 2 m in thickness	pool scours at convergence of two braid channels
F4 *figure 4-4, figure 4-5*	Gcm to Gcmi, Gch, and Sh	• clast-supported; poorly sorted, poorly organized; imbrication • sand to boulders, coarse gravel to cobbles predominating • crude stratification to massive • crude gravel couplets • variably contains small lenses of sand • channelized gravel and sand commonly present at top of facies	• gravel couplets are 40–50 cm thick • lenses of sand < 30 cm thick • facies are 2–3 m thick	deposits of turbulent flood flows

Table 4-4. Facies delineated within the alluvium of Fortymile Wash from outcrop studies (cont'd)

Facies	Lithologic Codes	Sedimentary Features	Observable Geometries	Interpreted Depositional Environment
F5 *figure 4-6*	Gmm to Gcm	• matrix-supported, nearing clast-supported in some instances; disorganized • angular clasts; predominant monolithologic clast content • distinct bimodal sediment content consisting of coarse gravel to boulders and m-c sand	• laterally extensive for 10–15 m; variable in thickness, but ≤ 50 cm [Note: based only on a single exposure] ⋆ this facies is expected to be volumetrically larger in proximity to the mountain slopes rimming Fortymile Wash	sediment gravity flow; most likely debris flow or rock fall
F6 *figure 4-7*	Gcm	• gravel to boulders • calcrete horizons	• 5–30 cm in thickness; laterally continuous for 100s of meters, though facies may be discontinuous of that length	pedogenic carbonate associated with paleosols
F7 *figure 4-8*	Sm to Sh	• matrix-supported, in some instances nearing clast-supported; mild to heavy bioturbation common • medium to coarse sand, with varying concentrations of gravel to cobbles • distinctive reddish coloration and strong caliche development • internal structure complex	• thickness ranges from 50 cm to 2 m; laterally extensive for 10–100s of meters	paleosols
F8 *figure 4-9*	Sh	• horizontal stratification to massive • dominantly well-sorted, m-c sand; some scattered fine gravel clasts • mild bioturbation in some exposures	• commonly found in association with bimodal gravel units (Facies F1 or Facies F2) • < 30 cm thick; laterally continuous ≤ 1 m	concentrations of finer sediment deposited during waning flow

The formation of gravel-sand couplets common in Facies F2 (sometimes referred to as gravel couplets) is attributed to the migration of gravel bars. These gravel-sand couplets have been attributed to the migration and destruction of antidunes (Blair, 1987) in sheetflood flows on alluvial fans and the bar-front migration of submerged gravel bars in braided stream environments (Carling and Glaister, 1987; Carling, 1990). The bar-front migration mechanism of Carling and Glaister (1987) is favored for the interpretation of the gravel-sand couplets in Facies F2. This mechanism not only accounts for the gradation of grain size, but also the bimodal sediment content of the coarse fraction and the open-framework gravels observed within the gravel-sand couplets.

Figure 4-1. Facies F1: Elongate to lenticular units of clast-supported, well sorted pebble to boulder conglomerate with a matrix of medium to coarse sand

figure 4-1

Figure 4-2. Facies F2: Alternating layers of gravel and coarse sand with fine gravel, forming gravel-sand couplets. Arrows highlight a single gravel-sand couplet. Numbers correspond to position on stratigraphic section 40mBIG.

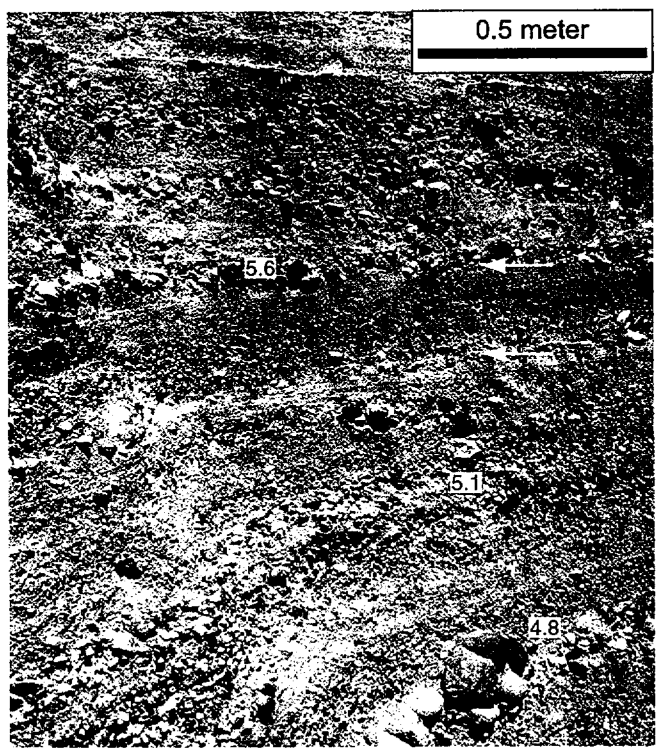
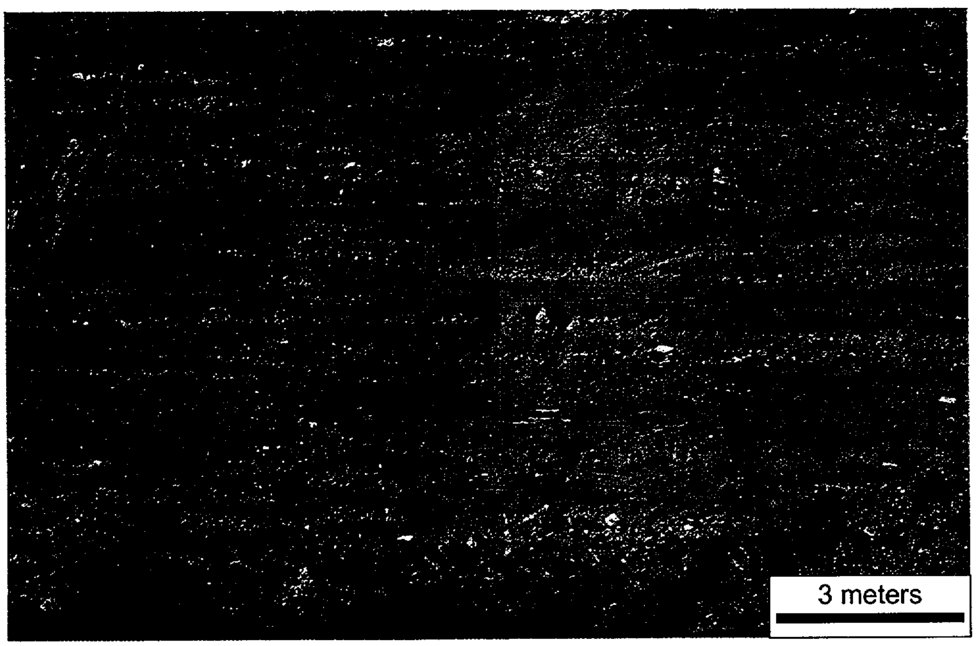


figure 4-2

Figure 4-3. Lenticular units of cross-stratified gravel within horizontally stratified gravel; interpreted as scour pools at the confluence of two braid channels.



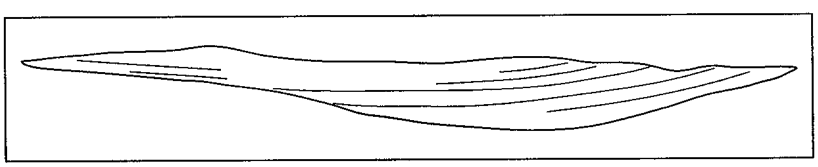


figure 4-3

Figure 4-4. Facies F4: Poorly sorted, coarse alluvium displaying crude horizontal stratification. Arrows to the left of the Jacob staff highlight coarse layers in crude gravel couplets. The single arrow to the right highlights a small lens of fine gravel and sand within the facies.

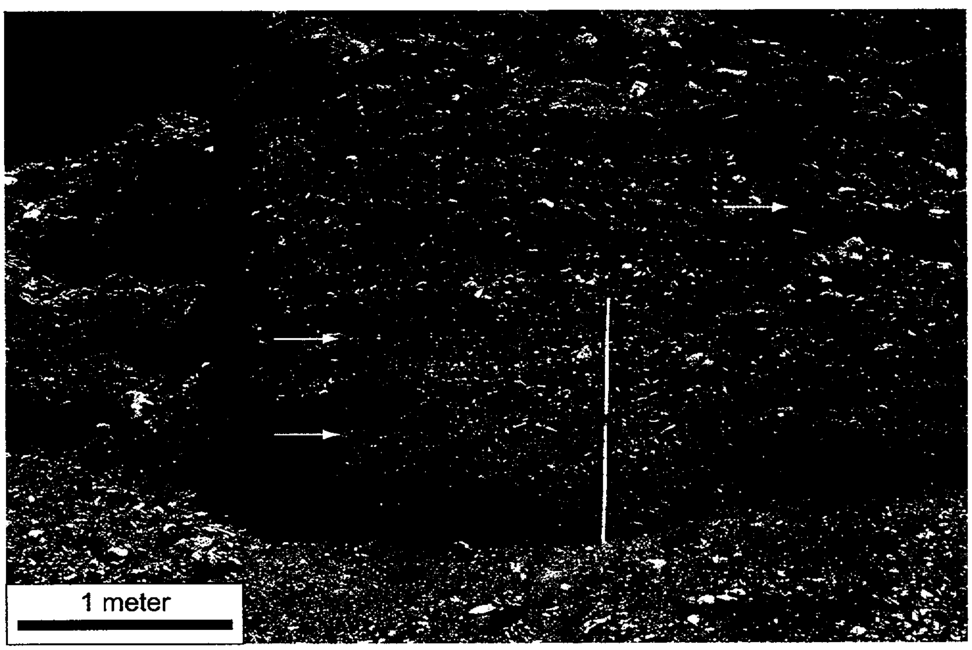


figure 4-4

Figure 4-5. Channelized fine to medium gravel and sand at the top of Facies F4, indicated by arrow. The bottom and top of Facies F4 are indicated by the dashed lines.

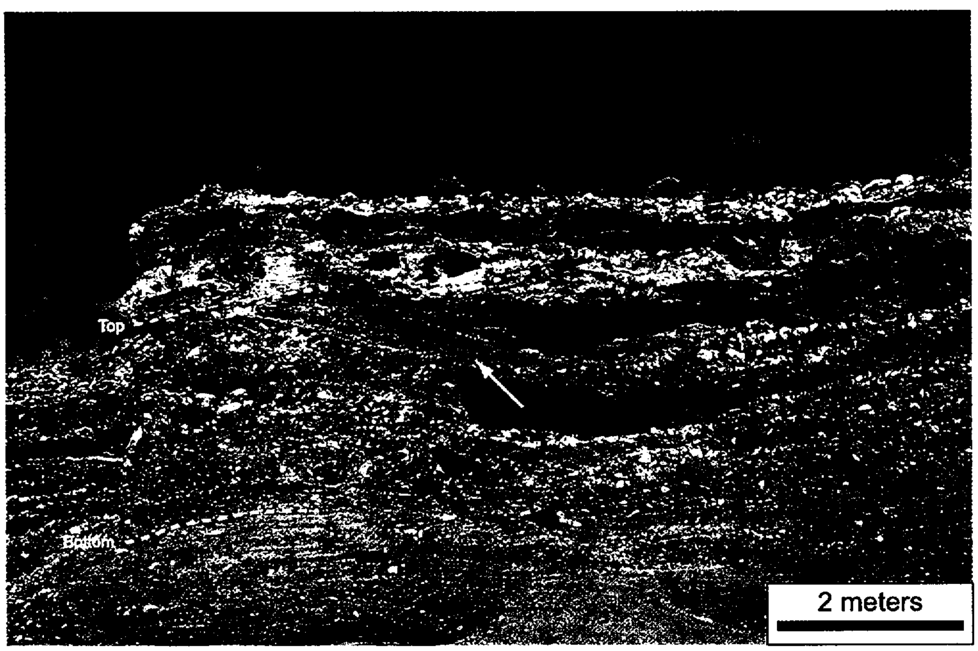


figure 4-5

Figure 4-6. Facies F5: Clast-supported, distinctly disorganized deposit consisting of dominantly monolithologic angular gravel to boulders with a matrix of medium to coarse sand. Note the incorporation of angular clasts identical to those observed in Facies F5 into subsequent deposits of Facies F2.

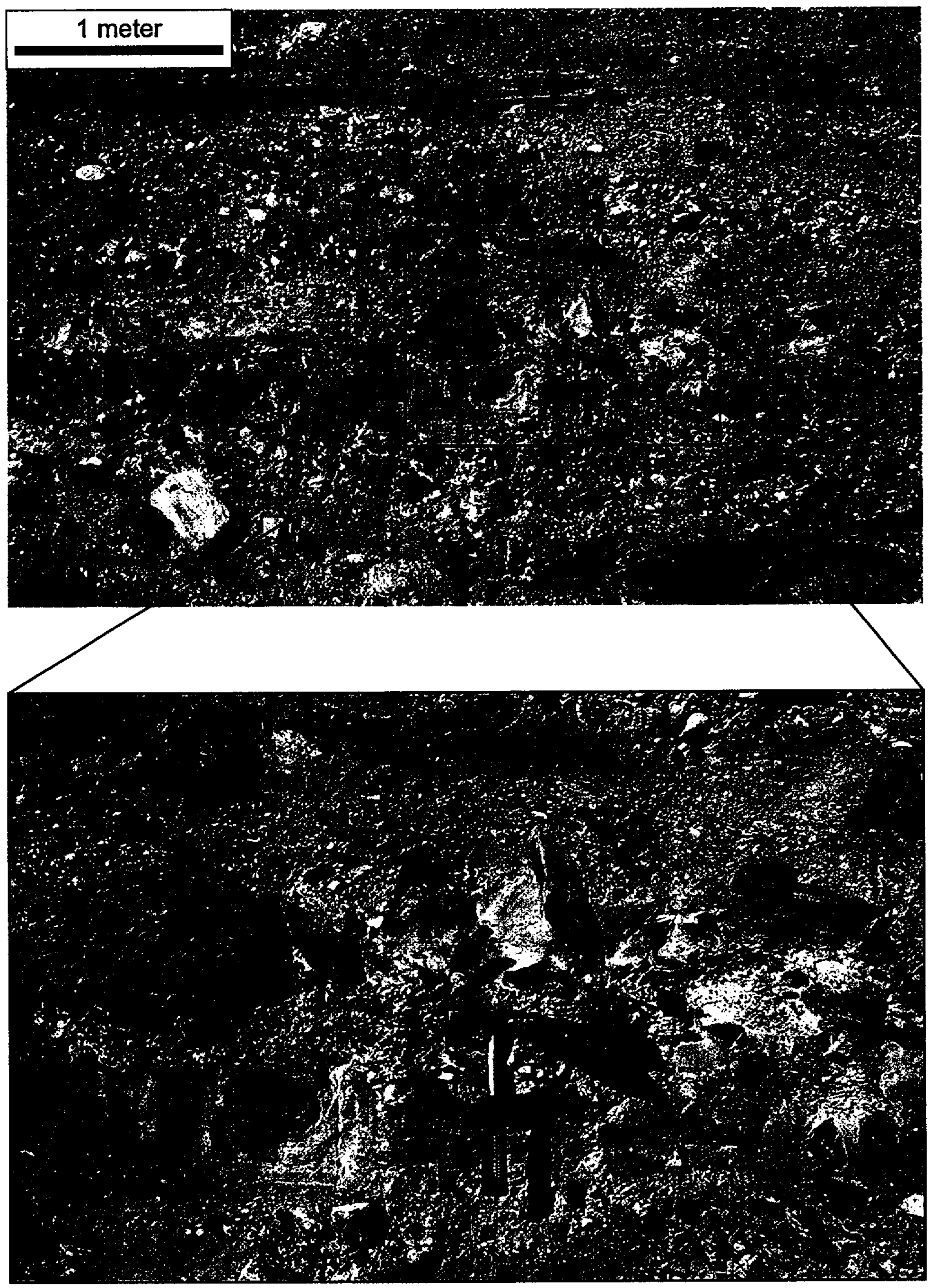


figure 4-6

Figure 4-7. Layers of Facies F6 developed beneath a paleosol. Arrows highlight individual gravelly calcrete horizons.

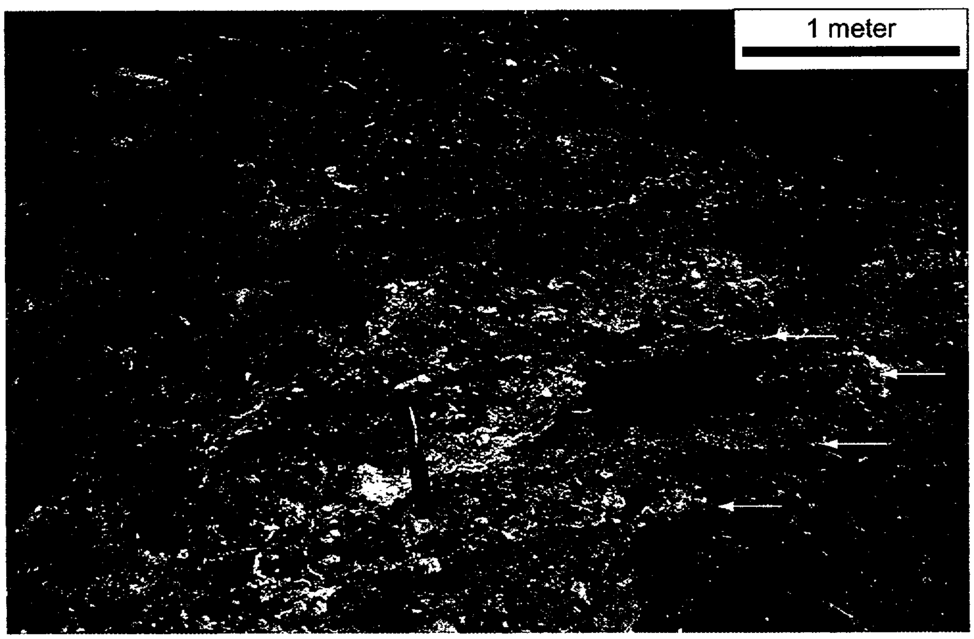
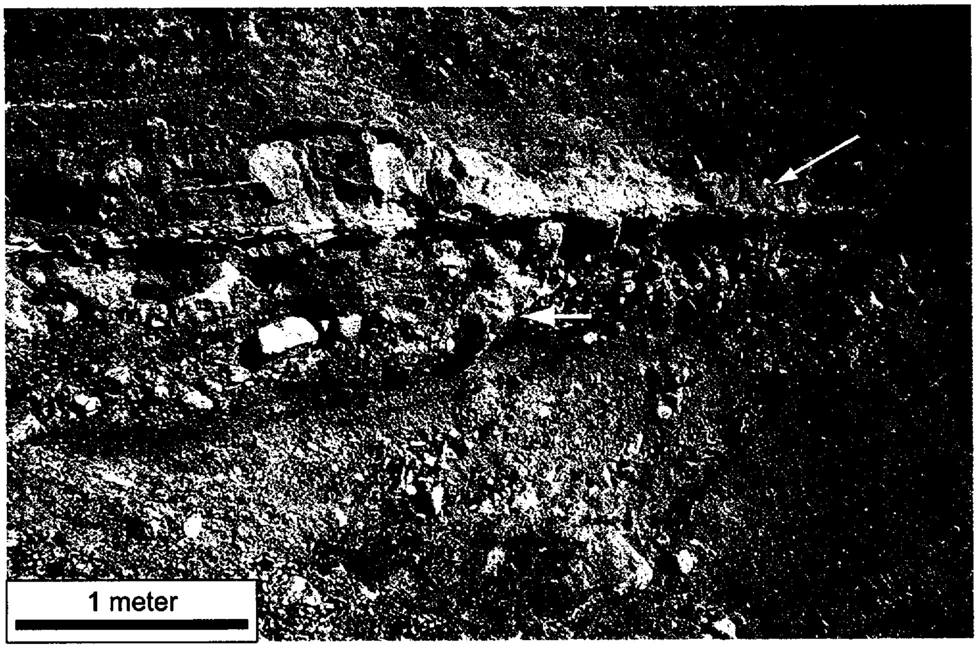
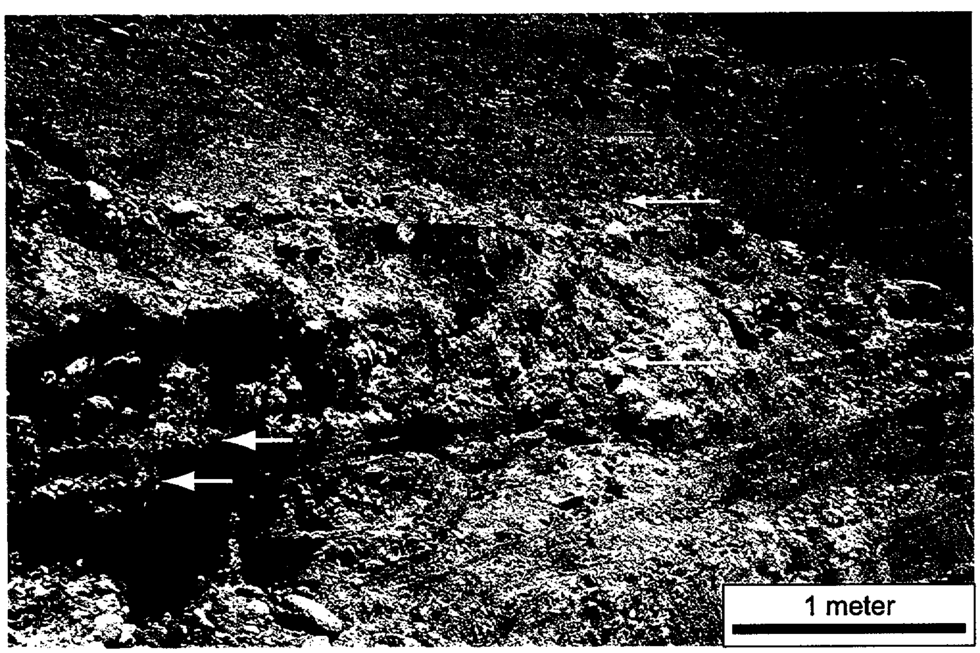


figure 4-7

Figure 4-8. Facies F7: Paleosols in various stages of development. (a) Lenticular shaped sand body consisting of medium to coarse sand. Sand is bioturbated, calcite cemented, and has a distinctive orange-tan color. Thick, short arrows indicate gravelly caliche layers. (b) Laterally extensive, heavily bioturbated coarse sand with scattered gravel and cobbles to boulders. Thin, long arrows highlight top and bottom of the paleosol. Thick, short arrows indicate gravelly caliche layers.



(a)



(b)

figure 4-8

Figure 4-9. Facies F8: Lenticular shaped sandstone drapes composed of well sorted, medium to coarse sand

figure 4-9

The cross-stratified to channelized gravel locally present within the horizontally stratified gravel is similar to structures observed by Siegenthaler and Huggenberger (1993) in their investigations of Pleistocene braided stream deposits in Switzerland. These lens shaped units of cross-stratified gravel were interpreted by Siegenthaler and Huggenberger (1993) as scour pools developed at the convergence of two channels. A simple geometric model of pool migration with time and orientation of cross-sectional view (i.e., orientation of outcrop) provides an explanation for the differing styles of cross-stratification observed within the lens shaped units (Siegenthaler and Huggenberger, 1993, Figure 12). Near identical cross-stratified features were observed in the lens shaped gravel units within Facies F2 (figure 4-3). Currently, the cross-stratified gravel is included in Facies F2, though this sediment association may be later subdivided as a separate facies (Facies F3).

4.2.2.3 Facies F4 (Gcm to Gcmi, Gch, and Sh)

Facies F4 consists of poorly sorted, clast-supported conglomerate that contains a wide range of clast sizes ranging from sand to boulders, with coarse gravel to fine cobbles predominating. Imbrication of clasts is common. The facies exhibits crude horizontal to subhorizontal stratification due to partitioning of coarser and finer grain sizes into crude gravel couplets 40–50 cm thick (figure 4-4). The finer portions consist of sand to gravel, and the coarser portions consist of sand and cobbles. In some exposures the cobble layers are strongly cemented and may have significant caliche development. These coarse layers stand out in relief within the facies. Small lenses of sand to fine gravel, typically less than 30 cm thick, are variably present within the facies. The available exposures of Facies F4 are limited, but the facies appears to exist as laterally continuous tabular units on the order of 1–2 m thick. Channelized fine to medium gravel and sand are commonly present at the top of the facies (figure 4-5).

The poor sorting and organization of the facies indicates a more turbulent depositional process than that which deposited the other facies. The crude stratification and clast imbrication indicate tractive transport processes. This facies is interpreted as deposits of turbulent flood flows containing extremely high sediment concentrations. Similar poorly sorted and poorly organized deposits have been described by Nemec and Steel (1984) and attributed to fluvial sediment flows. Terminology regarding these deposits and this realm of fluid flow is not well defined, and, according to Nemec and Steel (1984), these types of flows also have been referred to as hyperconcentrated flows, intermediate-type flows, streamfloods, and sheetfloods. The channelized gravel and sand commonly present atop the facies are interpreted as erosion and deposition by lower discharge channelized flows following the flood flow.

4.2.2.4 Facies F5 (Gmm to Gcm)

Facies F5 is a clast-supported, disorganized deposit consisting of angular gravel to boulders with a matrix of medium to coarse sand (figure 4-6). The facies has a distinct bimodal sediment content, and the angularity of the particles strongly contrasts with the predominant rounded to well-rounded nature of the majority of the alluvium. The facies is distinctively almost monolithologic in clast content. Some clasts of differing lithology are present in the deposit, although in minor amounts, and have the more rounded texture characteristic of the Fortymile Wash alluvium. Only a single exposure of Facies F5 was observed within the Fortymile Wash valley-fill, in Portal 1. In this exposure, the facies is variable in thickness but always less than 50 cm and laterally extensive for 10–15 m.

On the basis of the extreme angularity of the clasts, the dominant monolithologic clast content of the sediment, and the disorganized arrangement of the clasts, Facies F5 is interpreted as a rock slide or debris flow deposit. The more rounded clasts of differing lithologies contained in the facies are interpreted as Fortymile Wash alluvium entrained by the sediment gravity flow. The monolithologic clast content of Facies F5 is thought to be characteristic of the facies, but the lithology of the clasts in a particular exposure of the facies is dependent on the sediment source of the sediment gravity flow. The facies is limited in outcrop exposure and is volumetrically minor in the areas of the wash where outcrops are available. However, this facies is interpreted to be more expansive and volumetrically larger toward the margins of Fortymile Wash where mountains rim the wash—localities with steep slopes where these types of flows commonly occur and where relict deposits are present. On deposition, Facies F5 is reworked by subsequent water flows in Fortymile Wash, which is illustrated by the incorporation of scattered angular clasts (identical to those observed in Facies F5) into subsequent deposits of Facies F2 (figure 4-6). Deposits similar to Facies F5 were observed in outcrop in the slopes beneath Jake Ridge (figure 4-10). These deposits, also interpreted as deposits of sediment gravity flows, are poorly sorted, poorly organized, and consist predominantly of angular monolithologic clasts (section 4.2.5).

4.2.2.5 Facies F6 (Gcm)

Facies F6 consists of gravel to boulder conglomerate with well developed calcrete cement (figure 4-7). The facies varies from 5–30 cm in thickness, though typically not exceeding 20 cm. The facies is laterally extensive for hundreds of meters, but with that length the thickness varies, and in some cases the facies is discontinuous. Facies F6 is commonly present stratigraphically below paleosols (Facies F7). These gravelly calcrete horizons stand in relief and form resistive ledges in outcrop.

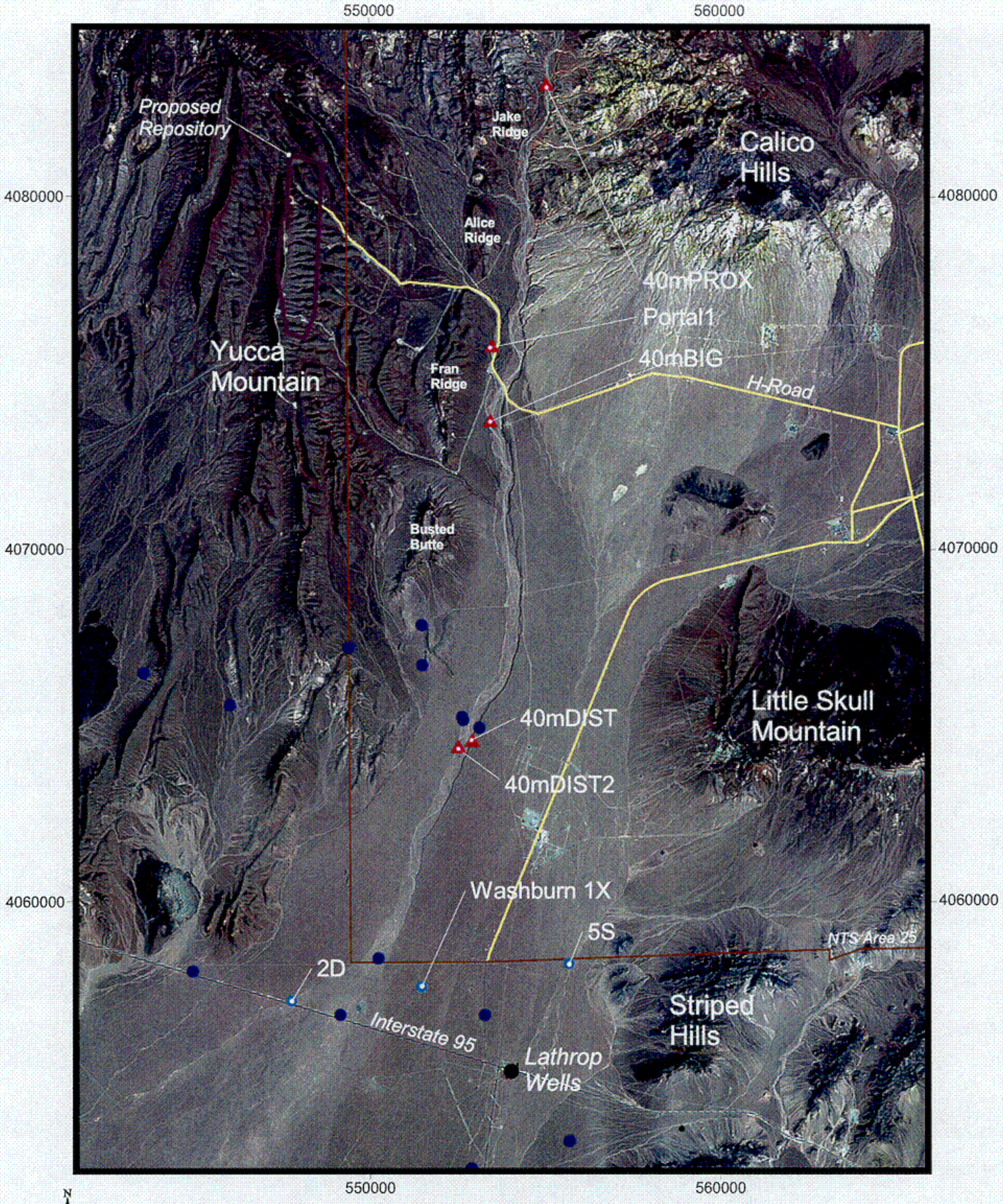
Facies F6 is commonly developed beneath paleosols. These calcrete horizons are interpreted as pedogenic carbonate associated with paleosols.

4.2.2.6 Facies F7 (Sm to Sh)

Facies F7 consists of medium to very coarse sand with well developed calcite cement. The facies contains varying concentrations of gravel to cobbles, is mildly to heavily bioturbated, and commonly has small caliche layers within the unit as well as an exposure of Facies F6 at its base. The internal stratification of the facies is complex. In many exposures, the internal stratification resembles that of one of the other delineated facies except for the increased sand content, increased cementation and caliche formation, and the reddish coloration. In other exposures, the facies appears more massive. Bed thickness typically range from 50 cm–2 m, and the facies may be scoured out by overlying units. This facies is often 1–2 m thick and laterally for hundreds of meters. In other areas, this facies consists of discontinuous lenses 50 cm–1 m thick and laterally continuous for 10–40 m that occur at the same stratigraphic position throughout the exposure (figure 4-8a). In general, thicker units tend to be highly bioturbated, completely homogenized (no stratification), and contain scattered gravel clasts (figure 4-8b). In some instances, the facies contains outsized cobble and boulder clasts. A gravelly caliche layer (Facies F6), typically 10–30 cm thick, is commonly developed near the base of the unit.

The increased fine component content, intensive caliche development, bioturbation, and orange-red coloration are consistent with formation by pedogenic processes. This facies is interpreted as paleosols in

Figure 4-10. Location of investigated outcrops within the entrenched channel of Fortymile Wash



Yucca Mountain Region (YMR), Nye County, Nevada

Scale

1:175000

4 0 4 8 Kilometers

UTM NAD 27 Zone 11

NEVADA

- Nye County Phase 2 and Phase 3 wells
- Nye County Phase 1 wells
- Outcrops

figure 4-10

C02

various stages of development. The varying internal stratification and grain size content of this facies reflect the different sediment deposits in which soil development occurred.

4.2.2.7 Facies F8 (Sh)

Facies F8 is the only sand dominated facies present in the alluvium. This facies consists of well-sorted, medium to coarse sand that variably contains scattered fine gravel clasts (figure 4-9). The sand typically displays horizontal stratification, but appears almost massive in some exposures. In some instances, the sand is mildly bioturbated, limited mostly to scattered burrows. Facies F8 occurs as lenticular shaped sandstone drapes, typically found in association with bimodal gravel units (Facies F1 or coarse fractions of gravel couplets in Facies F2). The facies is typically less than 30 cm thick and laterally continuous for approximately 1 m. Facies F8 is not volumetrically significant within the outcrops investigated.

The sand composing Facies F8 appears similar to the sand found in the matrix of Facies F1 and the coarse fraction of the gravel couplets in Facies F2. The fine grain size content of this facies stands in contrast to the predominantly coarse grain size content of the alluvium. Facies F8 is interpreted as concentrations of finer sediment deposited during waning flow.

4.2.3 Proximal Alluvium

The thickness of the alluvium thins toward the apex of the wash at Fortymile Canyon (Lundstrom et al., 1998, Figure 2), where Fortymile Wash is incised into bedrock. Here, outcrops of bedrock abut the alluvium. The most proximal outcrop of alluvium, referred to as 40mPROX, is located near the southern end of Fortymile Canyon (figure 4-10). 40mPROX is a fairly small outcrop compared to the others that will be discussed, but nonetheless provides a useable exposure of the proximal deposits of alluvium (figure 4-11). A stratigraphic section of the proximal alluvium is provided in figure 4-12.

Facies present in the 40mPROX include F1, F2, F4, F6, and F7 (figure 4-11). The sediment composing several of these facies is notably more coarse than in exposures of the facies downstream of 40mPROX, but retains the sedimentary features and structure indicative of the facies. Facies F4 and Facies F2 volumetrically dominate the proximal alluvium (figure 4-11 and figure 4-12). Two distinct and separate exposures of Facies F4 are present in 40mPROX. The first exposure is near the top of the outcrop, stratigraphically beneath the soil horizon (Facies F7). The other exposure of Facies F4 is stratigraphically beneath the former, clearly separated by an erosional surface and by slightly differing sediment textures. In both exposures, the facies appears to occur as laterally continuous beds 2–3 m thick (figure 4-11). In the upper exposure, the grain size varies from sand to boulders and crude to developed stratification is present. The stratification reflects portioning of coarser and finer material, forming crude gravel couplets. Laterally, this portioning of clast sizes becomes less distinct and the facies is more massive in appearance, although clast imbrication is still common (figure 4-13a). The lower exposure of Facies F4 is notably more coarse in clast content; but the portioning of clast sizes is locally present within the exposure, although much more crude than in the upper exposure of the facies. Clast imbrication is also evident, although less common, within this exposure of the facies (figure 4-13b). These deposits, delineated as Facies F4, are interpreted as deposits of turbulent flood flows. The upper exposure of the facies was likely deposited by a lower magnitude and less turbulent flow (as compared to the lower exposure of the facies), as indicated by the better developed stratification and clast imbrication. No deposits of sediment gravity flows (Facies F5) were observed in this