Technical Basis Report For Surface Characteristics, Preclosure Hydrology, And Erosion

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EXECUTIVE SUMMARY

This study presents a synthesis of information and interpretations relevant to surficial processes at the Yucca Mountain Site. The report is part of the technical basis which will be used to evaluate the suitability of Yucca Mountain, Nevada, as a site for a mined geologic repository for the permanent disposal of high-level radioactive waste and spent nuclear fuel. It provides a description of the surface characteristics, preclosure hydrology, and erosion at the Yucca Mountain Site. This report will provide the technical basis to evaluate three technical guidelines from the U.S. Department of Energy (DOE) siting guidelines, 10 CFR Part 960, *General Guidelines for the Recommendation of Sites for the Nuclear Waste Repositories*. These guidelines include: Surface Characteristics, Preclosure Hydrology, and Erosion.

The Yucca Mountain Site is located in southern Nevada about 160 km (100 mi) northwest of Las Vegas and is situated on land controlled by three Federal agencies: the U.S. Air Force, DOE, and the Bureau of Land Management. Yucca Mountain is in the southwestern Great Basin which is a subprovince of the Basin and Range physiographic province. The area is characterized by long, north to northwest-trending mountain ranges that are separated by intermontane sediment-filled, structural basins. Yucca Mountain is an irregularly shaped volcanic upland with elevations of about 1500 to 1930 m at the crest and about 650 m of relief. The mountain is composed of eastward dipping, volcanic and volcaniclastic strata broken into en echelon fault blocks. The climate of the Yucca Mountain area is considered arid with less than 10 inches of rain per year, and no perennial streams in the vicinity.

Information exists regarding surficial geology and surface drainage of the Yucca Mountain Site along with detailed topographic maps which will be used to evaluate if the surface facilities can be constructed on relatively flat and well-drained terrain given reasonably available technology (RAT). Currently planned locations for surface facilities are on alluvial surfaces and gently dipping bedrock surfaces located well above the ground-water table.

Documented occurrences of perched water in wells on or near the repository block are found at least 100 m below the current design level of the proposed repository. Small amounts of perched water near or in faults, fractures, or lithologic contacts may be encountered in the proposed repository. The currently planned portal and shaft sites are located outside of the flood-prone area for the probable maximum flood (PMF). Available data indicate that, to date, ground-water withdrawals have not impacted the water-level altitudes by causing any permanent drawdown. A modeling study also suggests that large quantities of ground water can be withdrawn without severely impacting ground-water level altitudes.

At the Yucca Mountain Site, the proposed repository can be located at least 200 m below the surface of the directly overlying ground surface. Studies of erosional processes at the Yucca Mountain Site suggest that the landscape at the Yucca Mountain Site has changed very little due to erosion during the past several hundred thousand years.

PREFACE

As part of the Program Approach developed by the DOE's Office of Civilian Radioactive Waste Management (OCRWM), the Yucca Mountain Site Characterization Project Office (YMSCO) intends on issuing a series of technical basis reports about the Yucca Mountain Site, of which the following document is the first. The Nuclear Waste Policy Act of 1982 (the Act) and its subsequent 1987 Amendment gave the OCRWM the responsibility to manage and provide for permanent disposal of the nation's spent nuclear fuel and high-level radioactive waste. In order to fulfill its mission, the OCRWM has been charged with evaluating and determining whether or not the Yucca Mountain Site is suitable for development of a permanent repository for waste disposal. The Program Approach has been developed by the OCRWM in part to ensure measurable progress toward evaluating and determining the suitability of the Yucca Mountain Site.

Each technical basis report on the Yucca Mountain Site will represent a synthesis of currently available site characterization data, analyses and technical interpretations on generally related technical topics and is part of the documentation related to the results of site characterization. The data and analyses intended to be presented in these reports have been selected by the YMSCO based on expected progress in the testing program, and facilitation of technical peer review. Peer review will be independently managed by the National Academy of Sciences for the OCRWM and is expected to build confidence in the YMSCO's technical investigations and interpretations. No single report is expected to cover all aspects of the site. However, the series of final peer-reviewed technical basis reports will provide a complete discussion of site characteristics necessary for a demonstration of compliance with the DOE siting guidelines.

The technical basis reports themselves, either singly or the series as a whole, do not constitute a demonstration of compliance with any regulation, nor is their final issuance by the YMSCO intended to imply compliance with any regulation. Each report is intended to support subsequent regulatory analyses to be performed by the YMSCO for the demonstration of compliance with one or more of the qualifying and disqualifying conditions contained in 10 CFR Part 960, which were developed following the consultation process required by the Act and promulgated on December 6, 1984. The regulatory analyses, referred to as guideline compliance assessments, are DOE staff analyses on whether compliance can be demonstrated. They will be issued in draft form for public review and comment prior to any regulatory decisions by the OCRWM Director. Regulatory decisions by the OCRWM Director will be relative to specific aspects of the site covered by the related qualifying or disqualifying condition and do not constitute a final agency action with regard to the Yucca Mountain Site.

Prior to any suitability determination or Secretarial recommendation of the Yucca Mountain Site for development as a repository, positive higher-level findings must be made by the OCRWM Director for each qualifying and disqualifying condition contained in 10 CFR Part 960. A series of technical basis reports and subsequent guideline compliance assessments will support these decisions. The total body of work must be complete to determine that the Yucca Mountain Site is suitable. In addition, the information required by Section 114 of the Act, including an environmental impact statement on the site, must be developed and provided with any site recommendation. Recommendation of the site by the Secretary is considered to be the final agency action.

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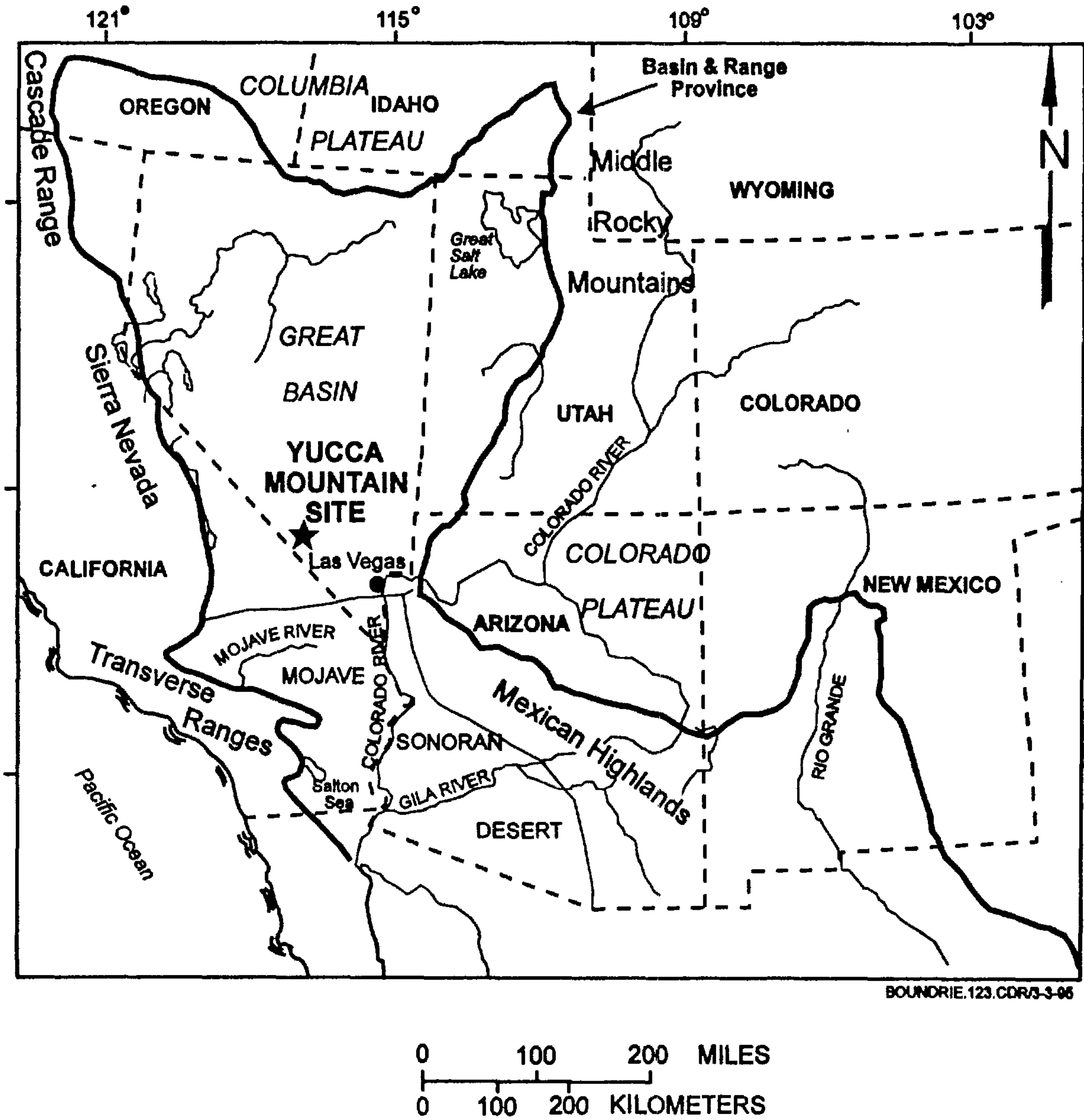


Figure 1.3-1 Boundaries and Larger Subprovinces of the Basin and Range Physiographic Province (after DOE, 1988)

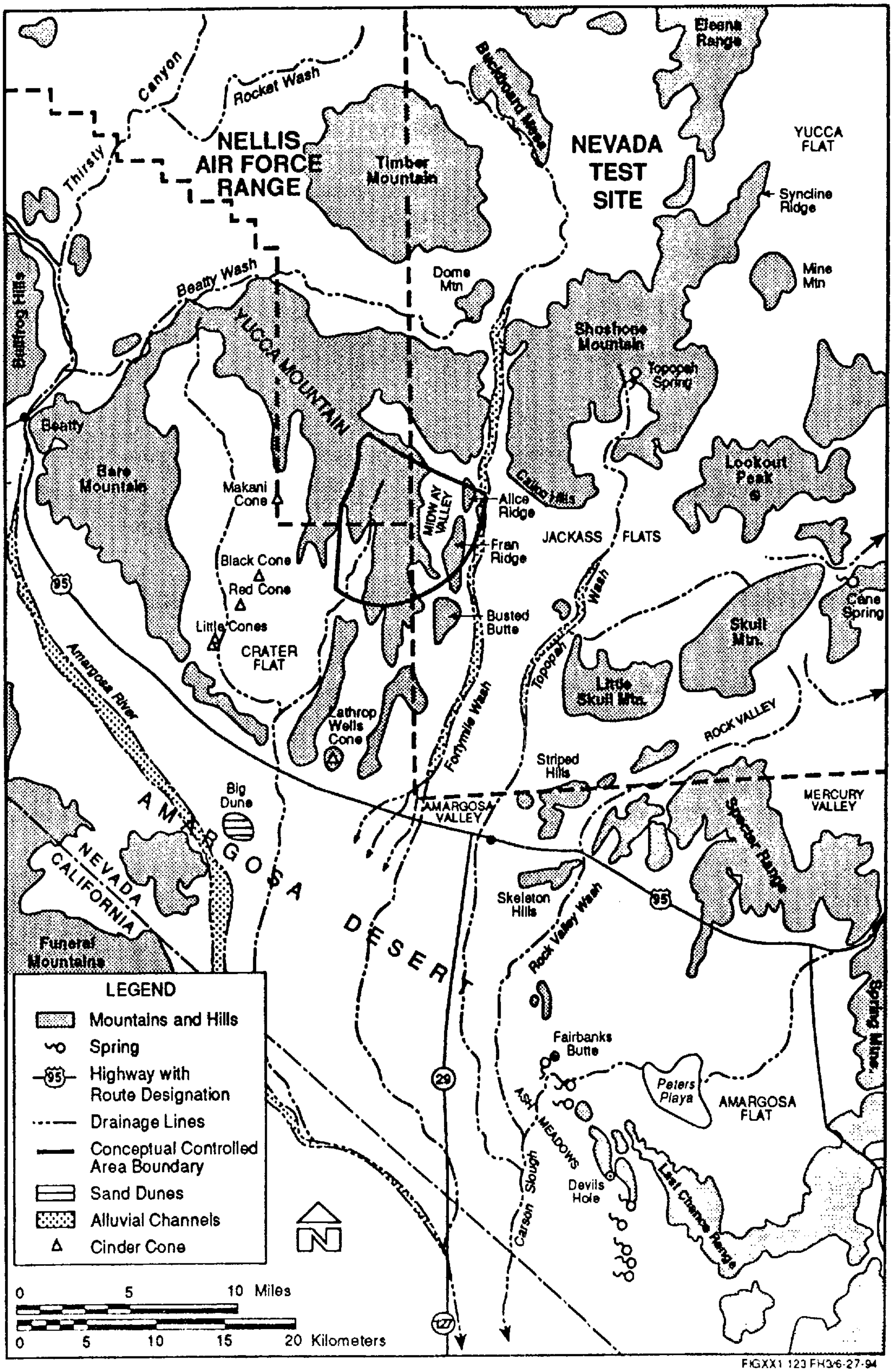


Figure 1.3-2 Location Map

(Figure 1.3-2) was much less voluminous than the tuffs of the Timber Mountain and Paintbrush groups (Sawyer et al., 1994). The Thirsty Canyon Group was mostly deposited to the north and west of the Timber Mountain resurgent dome and is not found at Yucca Mountain (Noble et al., 1984; Frizzell and Shulters, 1990). Subsequent volcanism in the region near Yucca Mountain occurred as small (<2 km^3) basaltic cinder cones and flows. Many of these eruptive centers and cones are now exposed at the surface, exposed as erosional roots, or are completely buried by alluvial deposits (Crowe et al., 1994).

2.0 SURFACE CHARACTERISTICS

2.1 INTRODUCTION

The surface characteristics at Yucca Mountain need to be sufficiently well understood to determine if the qualifying condition from 10 CFR Part 960 can be met.

Qualifying Condition [10 CFR 960.5-2-8(a)]: "The site shall be located such that, considering the surface characteristics and conditions of the site and surrounding area, including surface-water systems and the terrain, the requirements specified in 960.5-1(a)(3) can be met during repository siting, construction, operation, and closure." The cited section, 10 CFR 960.5-1(a)(3), states: *"Ease and Cost of Siting, Construction, Operation, and Closure.* Repository siting, construction, operation, and closure shall be demonstrated to be technically feasible on the basis of reasonably available technology and the associated costs shall be demonstrated to be reasonable relative to other available and comparable siting options."

No disqualifying condition is specified for this guideline, other than an inability to meet the qualifying condition. The intended scope of this guideline is indicated by the favorable conditions, which specify generally flat and well-drained terrain, and the potentially adverse condition, which addresses surface characteristics and existing or planned impoundments of water that could cause failure of the engineered components of the repository. Thus, the two concerns that need to be addressed are: whether areas that are sufficiently flat but well drained are available to accommodate operational facilities with the use of RAT, and whether areas that would not require engineered protection against flooding and erosion beyond that of RAT are sufficiently available at the site.

The Preclosure Hydrology section of this document discusses the information that provide the basis for assessing hydrologic hazards pertaining to the underground components and portals for access to the underground. Therefore, this evaluation of surface characteristics provides the information that will be used principally to assess (1) the topography and surficial geology of the site relative to options for siting surface facilities important to safety, considering the ease of construction, and (2) mitigating flooding hazards.

2.2 SURFICIAL GEOLOGY OF THE YUCCA MOUNTAIN REGION

Surficial deposits in the Yucca Mountain area for the most part overlie ash-flow tuffs of the middle to late Miocene southwestern Nevada volcanic field. Alluvium/colluvium locally overlies Paleozoic rocks on the flanks of Bare Mountain, the Calico Hills, and Rock Valley (Frizzell and Shulters, 1990). Figure 2.2-1 shows regional features. The basic elements of the present day landscape were in evidence approximately 11 m.y. ago, including the Amargosa River (Fox and Carr, 1989) and Fortymile Wash (Huber, 1988; p. 1; Lundstrom and Warren, 1994a). The Timber Mountain caldera area has been slightly modified by erosion and faulting since the eruption of the Thirsty Canyon Group, and constitutes a well preserved late Miocene landscape (Huber, 1988; p.1; Lundstrom and Warren, 1994a). Borehole data indicate that alluvium in the basins and flat-lying terrain east of Yucca Mountain reaches a maximum thickness of a few hundred meters in Jackass Flats and along Fortymile Wash.

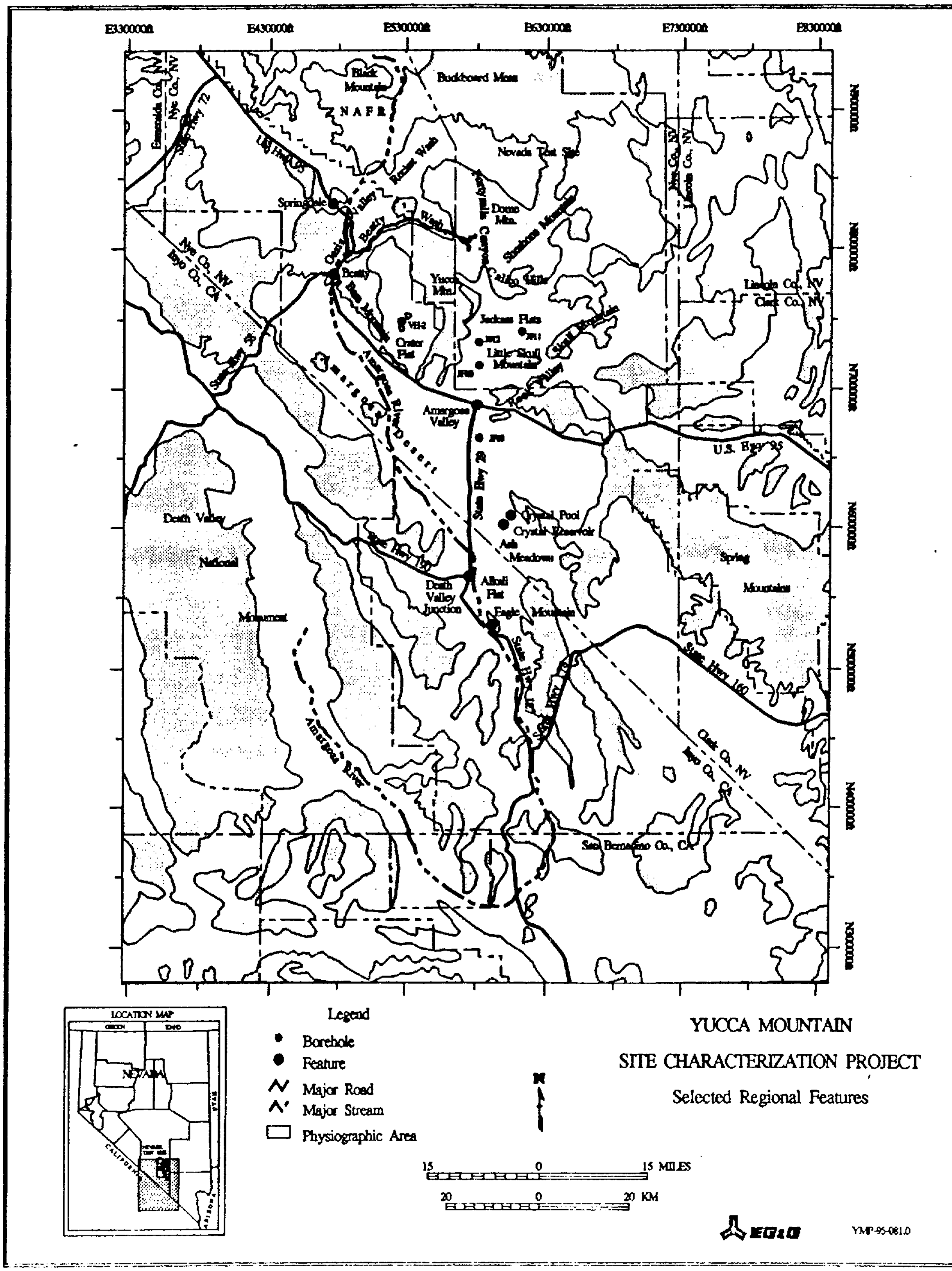


Figure 2.2-1 Selected Regional Features

Thick alluvium, overlying the Tiva Canyon Tuff, has been penetrated in four drillholes along the west side of Jackass Flats in the vicinity of Fortymile Wash. These deposits along Fortymile Wash may include late Miocene material near their base. Drillhole UE-25 WT#15 penetrated 64.0 m of alluvium composed of subrounded to rounded clasts of volcanic rock ranging in composition from rhyolite to basalt (Hayes, 1994). Drillhole UE-25 WT#13 penetrated 67.1 m of alluvium composed of subrounded to rounded clasts of volcanic rock ranging in composition from rhyolite to basalt, some of which were coated with caliche (Hayes, 1994). Average clast size ranged from 1.5 to 3.5 cm from 24 m below the ground to the contact with the Tiva Canyon Tuff. Well UE-25 J#13 penetrated 132.5 m of medium to very coarse sand, gravel and boulders composed of tuff and basalt (Thordarson, 1983). Drillhole UE-25 JF#3 penetrated 148 m of alluvium composed of mostly sand- to gravel-sized clasts of tuff and quartz that are angular to subrounded, with prevalent hematite. The thickest sequence of post-volcanic surficial deposits penetrated in Jackass Flats was in UE-25 J#11, located in the eastern flats, where 312 m of interbedded alluvium and colluvium were reported (Young, 1972; p. 5).

2.3 SURFICIAL GEOLOGY OF YUCCA MOUNTAIN VICINITY

Predominately east-draining ephemeral stream channels, tributary to Fortymile Wash, dissect the Tiva Canyon Tuff in central Yucca Mountain above the potential repository horizon. These drainages contain fluvial and debris flow deposits reaching a maximum thickness of a few tens of meters. East of Exile Hill, a small fault block of Tiva Canyon Tuff, the small structural basin called Midway Valley forms a flat-lying, undissected terrain underlain by a thicker section of late Cenozoic alluvial deposits. These surface characteristics led to the selection of the Midway Valley area as the potential site for both the Exploratory Studies Facility (ESF) and the repository surface facilities. Yucca Wash, one of the principal tributaries of Fortymile Wash, drains the northern part of Yucca Mountain.

Numerous borings in the vicinity of Yucca Mountain have penetrated thick post-volcanic surficial deposits. In the vicinity of Midway Valley, thick (46 to 52 m) surficial deposits that occur along the courses of Yucca, Drillhole and Sever washes probably are at least as old as Pliocene at the base, because Pliocene(?) to early Pleistocene Unit QTa deposits are mapped at the ground surface in northern Midway Valley (Swadley et al., 1984; Wesling et al., 1991).

2.3.1 Yucca Wash

Substantial thicknesses of alluvium were penetrated by two drillholes along Yucca Wash: 41.8 m in UE-25 WT#16, and 51.8 m in UE-25 WT#6. (Drillhole and site feature locations are shown on Figure 2.3-1). The alluvium overlies the Tiva Canyon Tuff at UE-25 WT#16 (Spengler, 1993a), and the Topopah Spring Tuff at UE-25 WT#6 (Spengler, 1993b, Hayes, 1994). The alluvium in UE-25 WT#16 consists of nonwelded to densely welded tuff fragments. The alluvium in UE-25 WT#6 consists of a mixture of nonwelded tuff, densely welded tuff, and rhyolitic lava fragments many of which are coated with caliche. The deposits in the bottom 3 m are characterized by an abrupt decrease in average grain size and roundness.

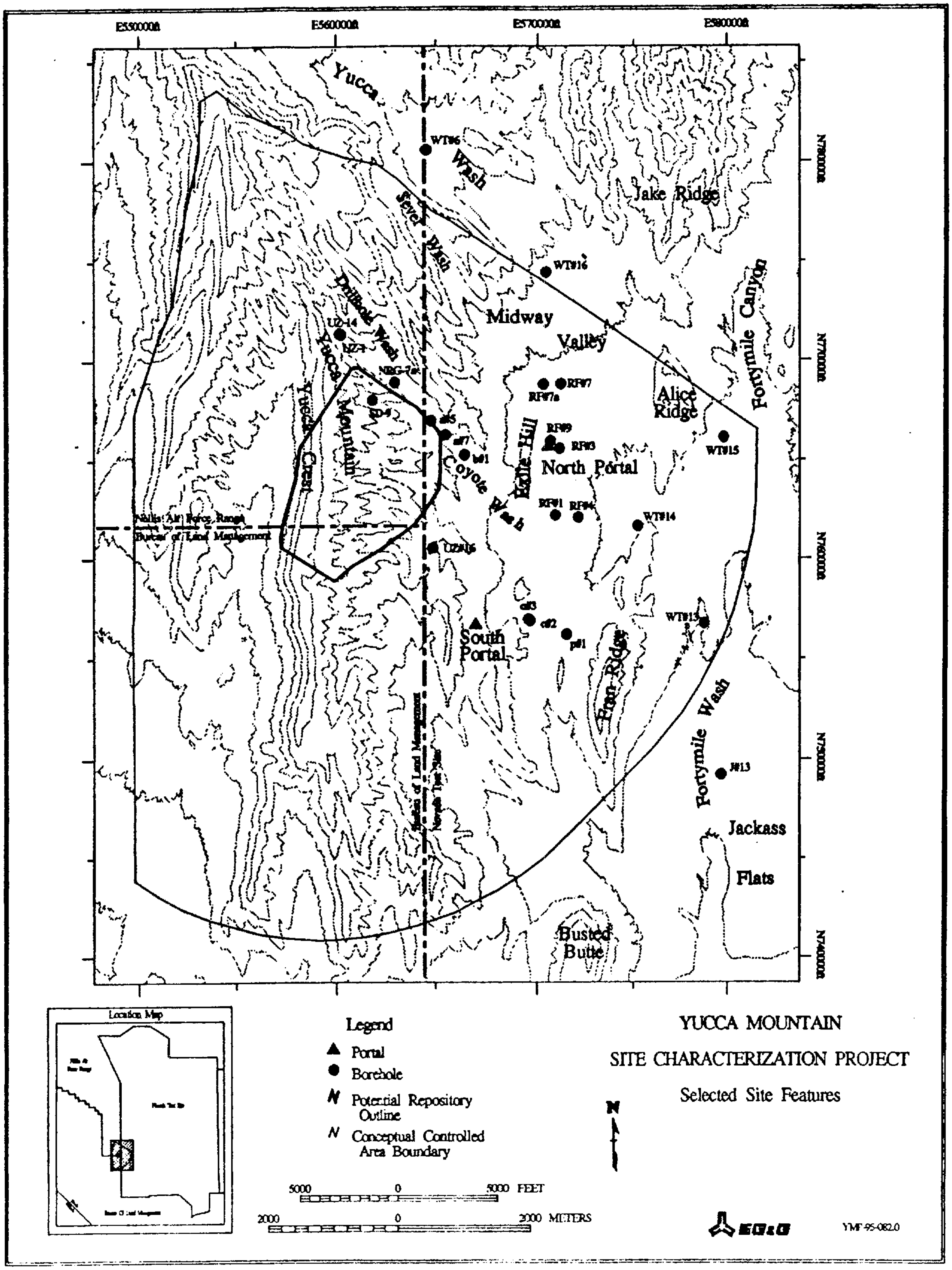


Figure 2.3-1 Selected Drillhole and Site Features

2.3.2 Midway Valley

In Midway Valley 36.6 m of alluvium were penetrated in drillhole UE-25 RF#1, 34.0 m in UE-25 RF#3, 32.0 m in UE-25 RF#3b, 45.7 m in UE-25 RF#4, 19.8 m in UE-25 RF#9, 36.6 m in UE-25 WT#14, and 39 m in UE-25 p#1 (Gibson et al., 1992). Two drillholes, UE-25 RF#7 and UE-25 RF#7a, did not reach volcanic bedrock; the thicknesses of alluvium penetrated at these locations are 45.7 and 46.6 m, respectively (Gibson et al., 1992). Drillhole UE-25 RF#l penetrated 36.6 m of bouldery alluvium that overlies the Tiva Canyon Tuff. Most of the unit consists of carbonate-coated clasts of welded Tiva Canyon Tuff that are more than 15 cm in diameter (Gibson et al., 1992).

2.3.3 Drill Hole Wash

Thick surficial deposits are present at Drill Hole Wash, which drains into Midway Valley from the west. Drillhole UE-25 b#1 penetrated 45.7 m of alluvium near the mouth of the wash (Lahoud et al., 1984). Farther west up Drillhole Wash, 42.7 m of alluvium/colluvium were penetrated in UE-25 a#7, and 27.4 m in UE-25 a#5 (Spengler and Rosenbaum, 1980).

2.3.4 Brain Wash Alluvial Fan

Drillholes UE-25 c#2 and UE-25 c#3, which are in the water gap at the north end of Bow Ridge, penetrated 21.3 and 24.4 m of alluvium, respectively, that overlies the Tiva Canyon Tuff (Geldon, 1993). Drillhole UE-25 RF#5, located upstream from the Bow Ridge watergap, penetrated 31.2 m of bouldery alluvium consisting of clasts up to 15 cm in diameter that are set in a matrix of tan calcareous sand. The unit overlies ash-flow tuff of Unit "X" of Gibson et al. (1992).

2.4 SURFICIAL DEPOSITS IN MIDWAY VALLEY

The ESF is currently under construction at Yucca Mountain. The North Portal for the ESF is located on the east side of Exile Hill in the densely welded ash flows of the Tiva Canyon Tuff. Surface facilities for the ESF are located immediately east of the portal in Midway Valley. Conceptual plans suggest that the surface facilities for the proposed repository would also be located here. Several surficial mapping studies are complete or in progress at Yucca Mountain. Describing the surficial geology of Midway Valley and establishing the location and recency of surface faulting with detailed mapping and trenching investigations were an early priority of the DOE site characterization activities. The preliminary results of these investigations are documented in a number of reports and maps, including Wesling et al. (1992), Wesling et al. (in press), Gibson et al. (1992), and Lundstrom et al. (in press). Final results of these studies are reported in Swan et al. (in press).

Investigations to determine geotechnical soil and rock properties data in Midway Valley were completed and are reported in DOI (1992). The soil investigations were accomplished by excavating test pits instead of boring or penetration testing as the soils are poorly graded silty sand and gravel with varying amounts of cobbles and boulders. The non-cohesive coarse-grained nature of the material precludes penetration testing as well as undisturbed sampling (DOI, 1992). Physical properties analyzed include unified soil classification, Atterberg limits, specific gravity, relative density, and gradation.

2.4.1 Surficial Geology of the North Portal Surface Facilities Site

A preliminary map of the surficial geology of Yucca Mountain at a scale of 1:6000 (Wesling et al., 1992) describes the areal extent and surface characteristics of Quaternary surficial deposits in the Midway Valley area. This mapping delineated ten surficial geologic map units based on landform morphology, relative geomorphic position, relative degree of preservation of surface morphology, relative soil development, distinctive drainage patterns and/or density and associated characteristics such as type and density of vegetation. Relative age data were collected to differentiate surfaces and assess their relative ages. Geochronologic data from thermoluminescence dates, tephrochronology, and U-series dates summarized by Paces et al. (1994) together with the relative age data and correlations of the Midway Valley soils to other desert chronosequences were used to establish ages ranging from Pliocene or early Pleistocene to Holocene for surficial deposits in Midway Valley (Swan et al., in press).

The prospective surface facilities site lies in the eastern portion of the Sever Wash Basin, an area characterized by alluvial fan aggradation and minor erosion in contrast to the area west of Midway Valley where narrow steep-sided valleys are incised in the east-dipping ash flow tuffs of Yucca Mountain (Wesling et al., 1992).

Lundstrom et al. (in press) map the surficial geology of the Midway Valley area. Footslope colluvium and alluvium (Holocene to early Pleistocene unit "cf" of Lundstrom et al., in press) are found on the east and west sides of Exile Hill and underlie the North Portal Pad location. These deposits are described as: "Interbedded colluvial and debris-flow diamictons grading to and interbedded with alluvium, generally on lower, concave-upward, and, in some cases, partially dissected portions of hillslopes. Angular gravel ranging in size from granules to boulders; generally supported by a matrix having variable proportions of sand, silt, and clay; matrix material inferred to be at least partly of eolian origin." These surficial materials overlie the Tiva Canyon Tuff bedrock.

2.4.2 Description of Surficial Geology near South Portal

Examination of the map prepared by Lundstrom et al. (in press) indicates that the location for the South Portal is on undivided colluvium (their unit "cu"). This unit is described as a thin mantle, generally less than 1 m thick of matrix-supported to clast-supported colluvial diamicton having angular gravel clasts composed of underlying resistant bedrock lithologies (Lundstrom et al., in press; p. 8). The underlying bedrock lithology at this location is composed of the Tiva Canyon Tuff (Scott and Bonk, 1984).

2.5 SURFACE DRAINAGE

The eastern slopes of Yucca Mountain drain to Fortymile Wash, and the northern slopes drain to Beatty Wash; these washes are major tributaries to the Amargosa River. The southern and western slopes of Yucca Mountain drain to the Amargosa River through a smaller unnamed drainage system.

The Amargosa River originates in Oasis Valley and continues southeastward through the Amargosa Desert past Death Valley Junction then southward another 75 km, where it turns northwestward and terminates in Death Valley (see Figure 2.2-1). The river carries flood waters following cloudbursts or intense storms but is normally dry, except for a few short reaches that contain water from springs (Walker and Eakin, 1963) in Oasis Valley between Springdale and Beatty (Malmberg and Eakin, 1962), in Ash Meadows northeast of Death Valley Junction, south of Alkali Flat near Eagle Mountain about 10 km south of Death Valley Junction, and near Shoshone, about 40 km south of Death Valley Junction. Base flow to these segments of the river is maintained by ground-water discharge during the winter, when evapotranspiration is at a minimum. During the summer, discharge from the springs is almost entirely lost by evapotranspiration (Walker and Eakin, 1963).

Throughout the region, perennial surface water comes only from springs, and it is restricted to some short reaches of the Amargosa River, to source pools at some large springs, and to some marshes around the edge of the salt pan in Death Valley (Hunt et al., 1966). One small lake, locally known as Crystal Reservoir, with a storage capacity of 2.27×10^6 m^3, occurs in the Ash Meadows area. The water for the reservoir is supplied via a concrete flume from a spring named Crystal Pool.

Inasmuch as the Yucca Mountain area is located inland and has no significant surface-water bodies or water-control structures located near the site, there is no potential for events such as surges, seiches, tsunamis, dam failures, or ice jams that could affect the site, nor is there any potential for future dam development. No evidence for past flooding induced by landslides in the vicinity of the site has been reported (USGS, 1984; p. 15; DOE, 1988; p. 1-32 to 1-33).

2.5.1 Evolution of the Fortymile Wash Drainage System

Yucca Mountain is located in the upper Amargosa River drainage basin. Most runoff from Yucca Mountain flows into small tributaries of Fortymile Wash, which drains 728 km^2 of the southern part of the Timber Mountain area located just north of Yucca Mountain. Timber Mountain is the remnant of a large volcanic caldera, of which the southeast rim was breached by Fortymile Canyon.

A regional study by Huber (1988) analyzes the late Cenozoic evolution of the upper Amargosa River drainage area based on a study of geologic and topographic maps, published reports, and aerial photographs. Huber indicates that the basic regional drainage pattern was established soon after collapse of the Timber Mountain caldera and has changed little in the last eleven million years. However, based on volcanic stratigraphy and sedimentary provenance, Lundstrom and Warren (1994a) suggest a major change in the Yucca Mountain region surface drainage pattern (see Figure 2.5.1-1). An eruption of the Thirsty Canyon Group (9.4 Ma) from the Black Mountain area is likely to have dammed counterclockwise drainage from the east moat of the Timber Mountain caldera. This resulted in a closed basin which infilled with sediment to the level of a new southward drainage. An older south-sloping canyon received the drainage and became the throughgoing Fortymile Canyon before 3 m.y. ago and probably by Miocene time. The 2.8 Ma basalt flows of Buckboard Mesa are emplaced with basal elevations parallel to slope and about 100 m above modern Fortymile Wash indicating that the drainage was well established in the Pliocene (Lundstrom and Warren, 1994a).

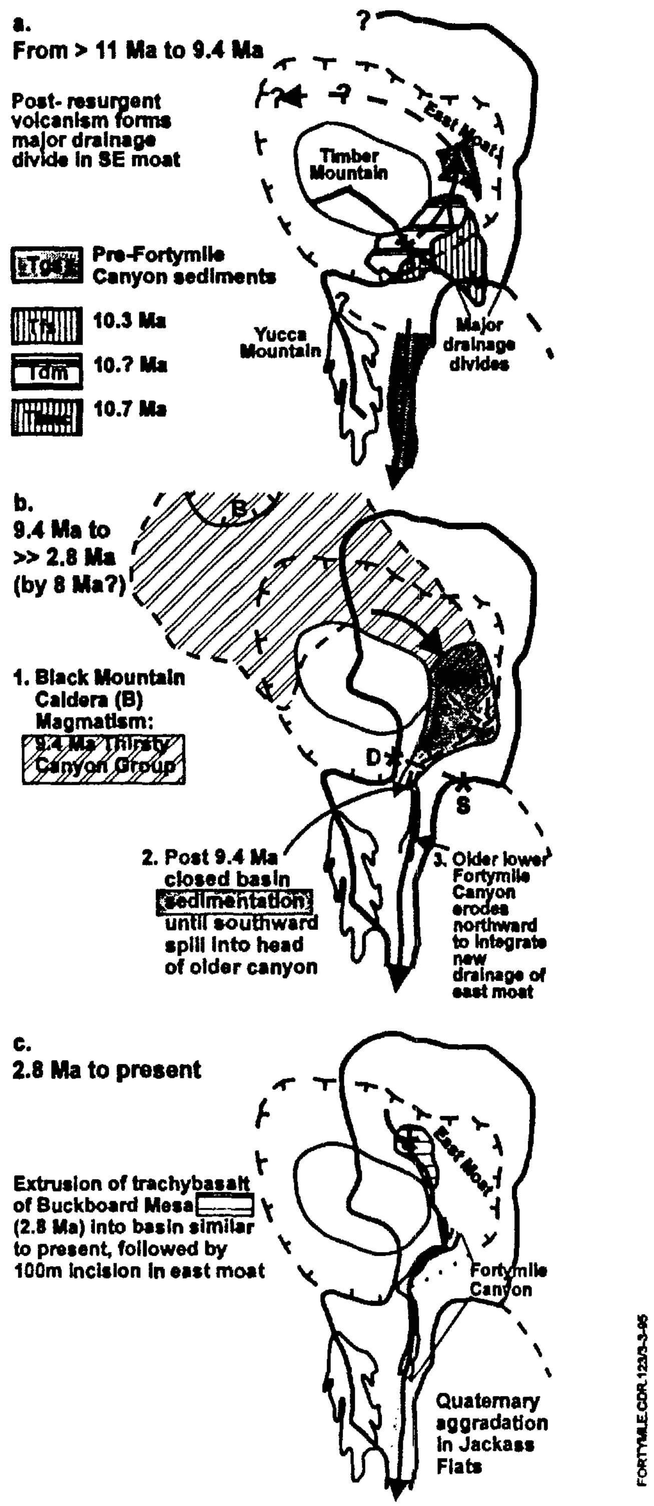


Figure 2.5.1-1 Evolution of the Fortymile Drainage System (from Lundstrom and Warren, 1994a)

Huber (1988; p.1) notes that a change in alluvial regimen is indicated by the end of alluvial-fan construction and the formation of incised washes through the process of fan-head erosion. General tectonic stability of the region is implied by the lack of significant changes in sub-basin geometry (Huber, 1988; p. 1). Huber (p. 22) prefers a climatic cause (as opposed to a tectonic cause) for the alluvial-regimen change. A climatic cause is indicated by the apparent synchroneity of the system-wide change in the entire Amargosa drainage.

Huber (1988; p. 23) suggests that the climatic change may be the increasing aridity proposed for the Yucca Mountain region by Winograd and Szabo (1986) due to the rise of the Sierra Nevada and the Transverse Range. Huber (1988; p. 23) notes that Fortymile Wash has apparently reached a state of near equilibrium with little aggradation or degradation at present and with the entire Fortymile drainage system adjusted to the baselevel of the main channel.

2.5.1.1 Run-off Characteristics and Duration

There are no perennial streams in or near the Yucca Mountain area. However, the many ephemeral stream channels, including the large drainage systems of Fortymile Wash and the Amargosa River, flow following significant regional or local storms. Although the region that includes Yucca Mountain has a generally arid to semiarid climate that includes high annual average potential evaporation (about 1,500 to 1,700 mm/yr; Kohler et al., 1959), low average annual precipitation (about 150 mm; Quiring, 1983), and infrequent storms, surface runoff does occur. Runoff results from regional storms that occur most commonly in winter and occasionally in autumn and spring, and from localized thunderstorms that occur mostly during the summer. Rugged relief, abundant bedrock exposed at the land surface, and sparse vegetal cover promote runoff, particularly during intense rainstorms.

The annual precipitation pattern usually follows a bimodal distribution, with greatest average amounts occurring during the winter storms and less during the summer (Quiring, 1983). Although runoff can result from severe winter storms, the sparse data available for the Great Basin suggest that peak discharges commonly result from summer storms. Precipitation and streamflow data for the Yucca Mountain vicinity are documented by Pabst et al. (1993) for the water years 1983 to 1985 and by Kane et al. (1994) for the years 1986 to 1990.

2.5.1.2 Channel Characteristics, Avulsion, and Migration

Fortymile Wash begins where Fortymile Canyon opens onto a low-gradient alluvial fan deposit. Near the fan apex, the wash is incised 15 to 20 m into the fan surface and the amount which the channel is incised shallows until the channel merges with the fan surface about 23 km south from the canyon mouth (Huber, 1988; p. 11). Huber (1988; p. 23) notes that Fortymile Wash has apparently reached a state of near equilibrium with little aggradation or degradation at present and with the entire Fortymile drainage system adjusted to the base-level of the main channel. This would include the ephemeral stream channels on the east flank of Yucca Mountain. The channels of Fortymile Wash and its tributaries are very straight and exhibit a low degree of sinuosity and meandering. This precludes much of the potential for avulsion. The present amount which the channel of Fortymile Wash and many of its tributaries are incised into fan surfaces precludes much of the potential for channel migration.

2.5.2 Debris Flow Potential

In the region, hillslope erosion can occur during occasional summer convective thunderstorms if an individual storm cell stalls over a ridge crest long enough to saturate hillslope colluvium and initiate debris flows. Although debris flows are the primary mechanism for hillslope erosion in the Yucca Mountain region, they are infrequent events that occur when a geomorphic threshold is exceeded. For a debris flow to occur, debris and colluvium capable of being transported must have accumulated and a storm capable of initiating the flow and transporting the material must occur. That this is a rare event at Yucca Mountain is evidenced by the mantle of middle Pleistocene colluvium found on the slopes and by the lack of erosion scars. Additionally, once a debris flow occurs at a location, it can not occur at the same location until a new mantle of colluvium has developed.

Debris flows occurred on Jake Ridge, about 6 km northeast of Yucca Crest during an intense rainfall event that occurred on July 21 or 22, 1984. Pre- and post-erosional aerial photographs were used to evaluate the amount of the colluvial mass moved (Coe et al., 1995). Approximately 3640 m^3 of colluvial materials were eroded from a 39,800 m^2 hillslope area via debris flows. It is estimated that about 10 percent of the flow (by volume) was deposited on the slope as levees and splays, 35 percent deposited near the base of the slope, 40 percent was deposited in a tributary to Fortymile Wash with less than 15 percent flowing into Fortymile Wash. Thus, these episodic hillslope denudations can result in tributary/channel aggradation in the present climate. While the debris flows are capable of removing the colluvial mantle on hillslopes, it is not an effective process for eroding the unweathered bedrock that underlies the colluvium.

2.5.2.1 Debris Flow Deposits at Yucca Mountain

Swadley et al. (1984) describe their unit QTa as alluvium that ". . .consists of debris flows with sparse bedded fluvial sediments; it occurs as dissected fans and fan remnants that are adjacent to bedrock ranges and, less commonly, as isolated outcrops several kilometers from the ranges. Unit QTa typically is moderately indurated, coarse, angular, unsorted gravel with minor amounts of sand- to clay-sized particles. In most exposures, QTa is partly cemented with calcium carbonate."

Lundstrom et al. (in press) subdivide colluvial deposits based on surface characteristics more indicative of hillslope position, thickness, and origin rather than age. Footslope colluvium and alluvium (Holocene to early Pleistocene unit "cf" of Lundstrom et al., in press) is described as "Interbedded colluvial and debris-flow diamictons grading to and interbedded with alluvium, generally on lower, concave-upward, and in some cases, partially dissected. portions of hillslopes. Angular gravel ranging in size from granules to boulders; generally supported by a matrix having variable proportions of sand, silt, and clay; matrix material inferred to be at least partly of eolian origin." These deposits are found on the east and west sides of Exile Hill and underlie the North Portal Pad location. Unit cf deposits are also found around the base of most of Alice Ridge and on the west base of Bow and Fran ridges. In contrast to Swadley et al. (1984), Lundstrom et al. (in press) do not map debris flows away from bedrock ranges. Lundstrom et al. map the Mid Valley Wash fan surface as alluvium rather than debris flows as Swadley et al. (1984) did.

2.6 FLOODING POTENTIAL

Moderate to large floods in low-lying areas along the major drainages (drainage areas of several hundred square kilometers), such as the Amargosa River and Fortymile Wash, although rare, are usually the result of regional storm systems that most commonly occur during the winter and occasionally occur during autumn and spring. These extensive storm systems sometimes include areally restricted cells that discharge intense precipitation.

Flash floods of similar intensity and areal extent commonly occur as the result of summer thunderstorms. These summer floods usually do not cumulate to cause regional floods, but their intensive character renders them potentially destructive over limited areas. The summer storms are commonly the products of monsoonal air masses that invade southern Nevada and California from the general vicinity of the Gulf of California. The areally restricted storm cells are triggered by local convective lifting of the moist air or by cooler frontal systems that move through the region and intersect with the warmer monsoonal air mass.

In summary, although flooding can occur over an extensive area, intense floods are generally restricted to relatively small areas and occur as flash floods of short duration. Flash floods constitute a hazard throughout the Great Basin and specifically in southern Nevada. These floods and associated debris flows are among the most important geomorphic processes currently active in the region and local area. They play a major role in the development of alluvial fans, denudation of mountainous landscapes, and the evolution of drainage-channel morphology. Flash-flood discharges range in character from water-dominated mixtures of sediments and water to debris flows. The hazards posed by debris movement associated with flash floods may be of equal or greater importance with regard to destructive potential than that of the mobilizing water. The intensive rainfall and runoff of flash flooding may instigate debris avalanching on steep slopes.

2.6.1 Paleoflood Evaluation

Glancy (1994) discusses the geologic evidence found for paleofloods in Coyote Wash. Coyote Wash is an ephemeral stream channel on the east slope of Yucca Mountain which drains approximately 0.8 km^2. It had originally been considered for the location of the exploratory shafts as part of the *Site Characterization Plan*, DOE/RW-0199, (DOE, 1988). Trenches excavated both across and along the channel exhibit sediments indicative of multiple flood events including debris-flow deposits. Nineteen stratigraphic units were identified based on visual differences in textural characteristics. The oldest unit exhibits moderate induration and is differentiated from stratigraphically younger units which lack induration (Glancy, 1994; p. 1).

Glancy (1994; p. 29) also provides estimates of maximum flood events for Coyote Wash which are calculated based on empirically derived formulae. These estimates for the North Fork Coyote Wash range from 900 to 2,600 ft^3/s (25.5 to 73.6 m^3/s). An estimate of 2,500 ft^3/s (70.8 m^3/s) is derived by increasing Bullard's (1991) PMF calculation of 1,600 ft^3/s by an additional 55 percent to account for sediment and debris bulking. This value is similar to an estimate of 2,600 ft^3/s (73.6 m^3/s) derived from a runoff-area curve and an estimate of 2,400 ft^3/s (68 m^3/s) or more derived from a technique that calculates the discharge based on the size of boulders that the flow was capable of transporting. Based on similarities between the North Fork and South Fork of Coyote Wash, Glancy (1994; p. 29) estimates that the maximum combined flow in Coyote Wash would be about 5,000 ft^3/s (141.6 m^3/s).

2.6.2 PMF Determination

The results of a PMF study by the Bureau of Reclamation are documented in a study by Bullard (1991). Bullard used the PMF methodology primarily because it complies with American National Standards Institute, Inc. requirements that PMF technology be used in the design of nuclear related facilities and secondarily because the PMF analysis predicts the worst possible case flood scenario. However, Bullard describes only the clear water PMF calculations and neglects bulking factors for entrained air, debris, and sediment. Blanton (1992) re-evaluates the PMF for different locations at Yucca Mountain and includes a bulking factor. Based on field inspections and considering the natural ground cover within the small drainage basins and the steepness of the slopes, a multiplier of two was used to compensate for bulking in the PMF calculation.

Blanton's (1992) bulked PMF values for several valley section locations relevant to site characterization, and the proposed repository, are listed below:

Mid Valley Wash (Sites 1 to 3)	66,000 ft^3/s	(1868.9 m^3/s)
Mid Valley Wash (Sites 4 to 7)	67,000 ft^3/s	(1897.2 m^3/s)
Drill Hole Wash (Sites 1 to 3)	42,000 ft^3/s	(1189.3 m^3/s)
Coyote Wash (Sites 1 to 3)	6,600 ft^3/s	(186.9 m^3/s)
South Portal (Site 1)	3,460 ft^3/s	(98.0 m^3/s)
South Portal (Sites 2 and 3)	7,160 ft^3/s	(202.7 m^3/s)
South Portal (Site 4)	10,620 ft^3/s	(300.7 m^3/s)

The location of these sections and their relationship to the North Portal, South Portal, and shaft locations are shown in Figure 2.6.2-1. In all cases, the planned locations of the portals are located outside of the flood-prone area for the PMF. A portion of the existing North Portal Pad to support ESF operations is located in the flood-prone area (Figure 2.6.2-2). This will be further evaluated in the Guideline Compliance Assessment to ensure that RAT can mitigate potential hazards for the repository surface facilities.

2.6.3 Uncertainties in Calculating Magnitude and Frequency for Floods

Section 2.6.1 discusses investigations of paleoflood deposits and Section 2.6.2 discusses calculations of PMFs. Glancy (1994; pp. 28 and 29) also evaluates the estimates of flow for North Fork Coyote Wash which contributes approximately half of the discharge to Coyote Wash (estimates for the North Fork range from 900 to 2,600 ft^3/s [25.5 to 73.6 m^3/s]). Glancy notes that 900 to 1,000 ft^3/s (25.5 to 28.3 m^3/s) may represent the maximum flood to be expected from the North Fork. He also notes however, that estimating flood peaks for small basins in arid and semiarid environments is difficult with an acceptable degree of

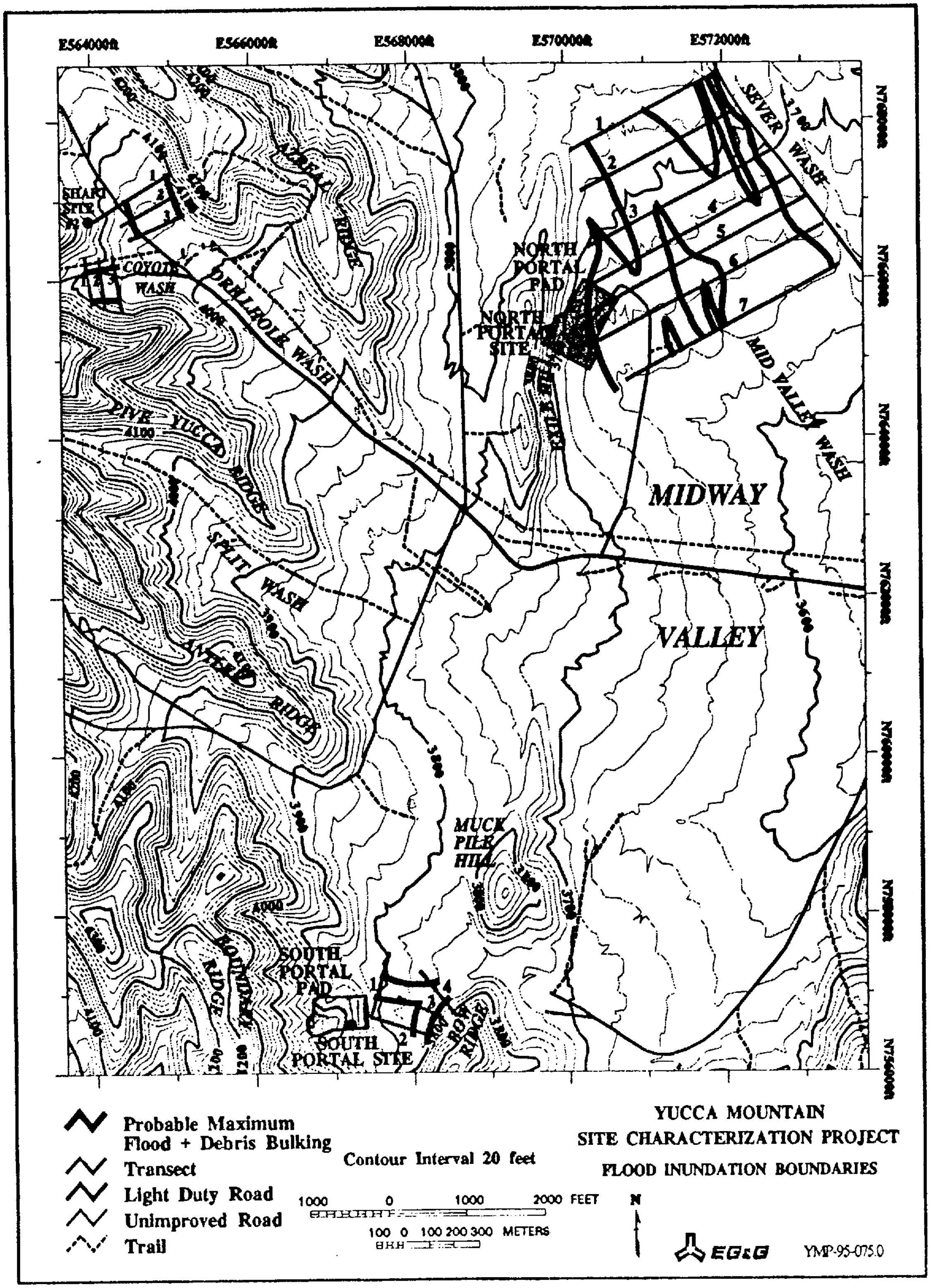


Figure 2.6.2-1 Probable Maximum Flood Inundation Boundaries (modified from Blanton, 1992)

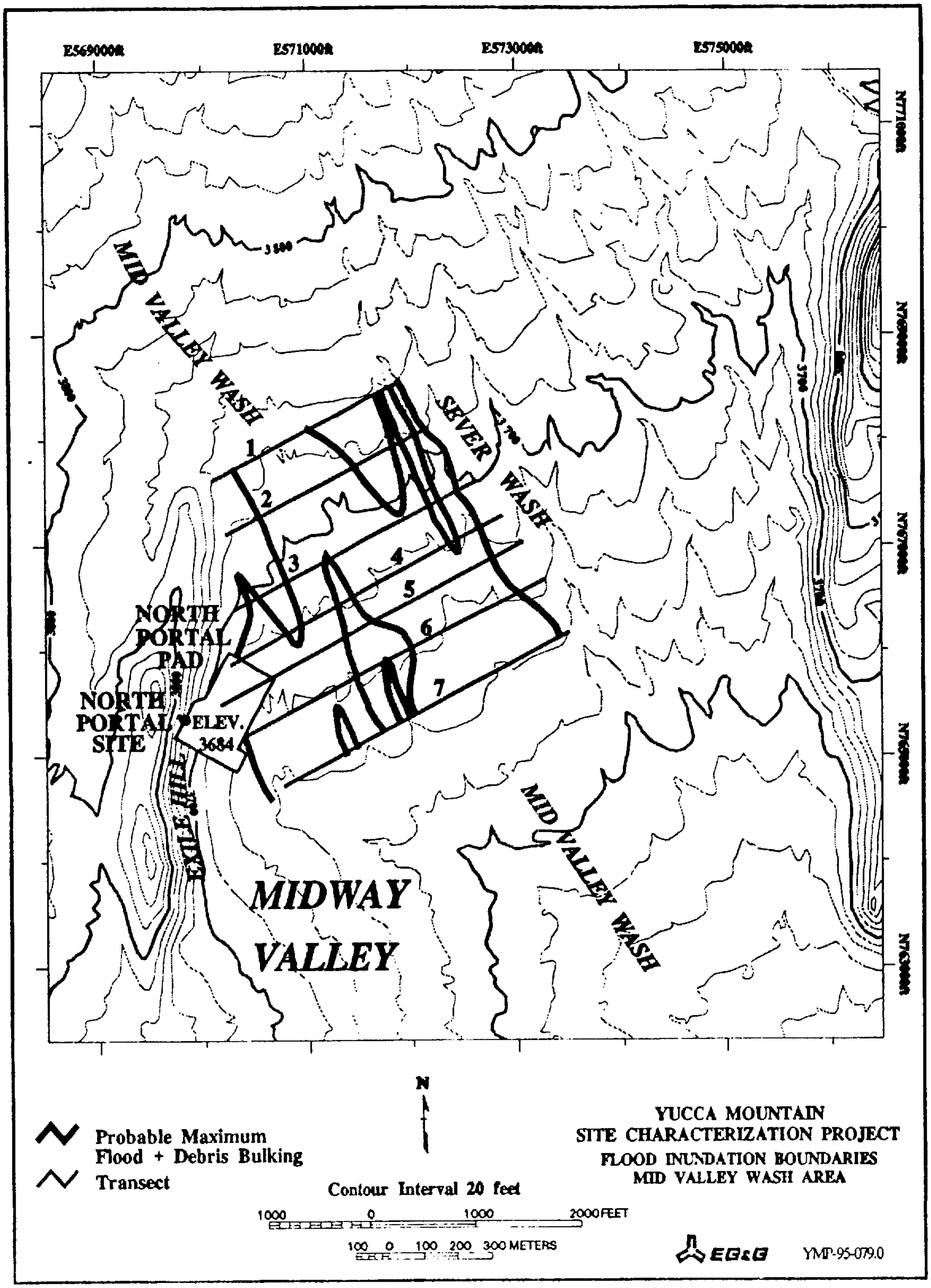


Figure 2.6.2-2 North Portal Pad Probable Maximum Flood Boundaries (modified from Blanton, 1992)

confidence. Thus, the paleoflood deposits investigations in Coyote Wash (Glancy, 1994; p. 29) have suggested that the most conservative value (i.e., the largest value) for the PMF for the combined North and South Forks based on geological evidence would equal about 5,000 ft^3/s (141.6 m^3/s), including a bulking factor for debris.

In all cases, the clear-water PMF calculated by Bullard exceeds the curve developed based on regional maximum floods and exceeds measured flood peaks at the Nevada Test Site (NTS) by more than an order of magnitude. The bulked PMF (Blanton, 1992), used for design purposes, with its discharge values double that of the clear-water PMF would exceed the regional maximum flood curve by a greater degree. Doubling of the discharge values for the bulking factor had the effect of raising the water surface elevation a maximum of 0.9 m (3.0 ft) (Blanton, 1992; Table 2).

The design PMF (Blanton, 1992) for this location, including a bulking factor which doubles the discharge, is 6600 ft^3/s (186.9 m^3/s). This value is 32 percent larger than Glancy's conservative value. Figure 2.6.3-1 is a plot of envelope curves adapted from Bullard (1991).

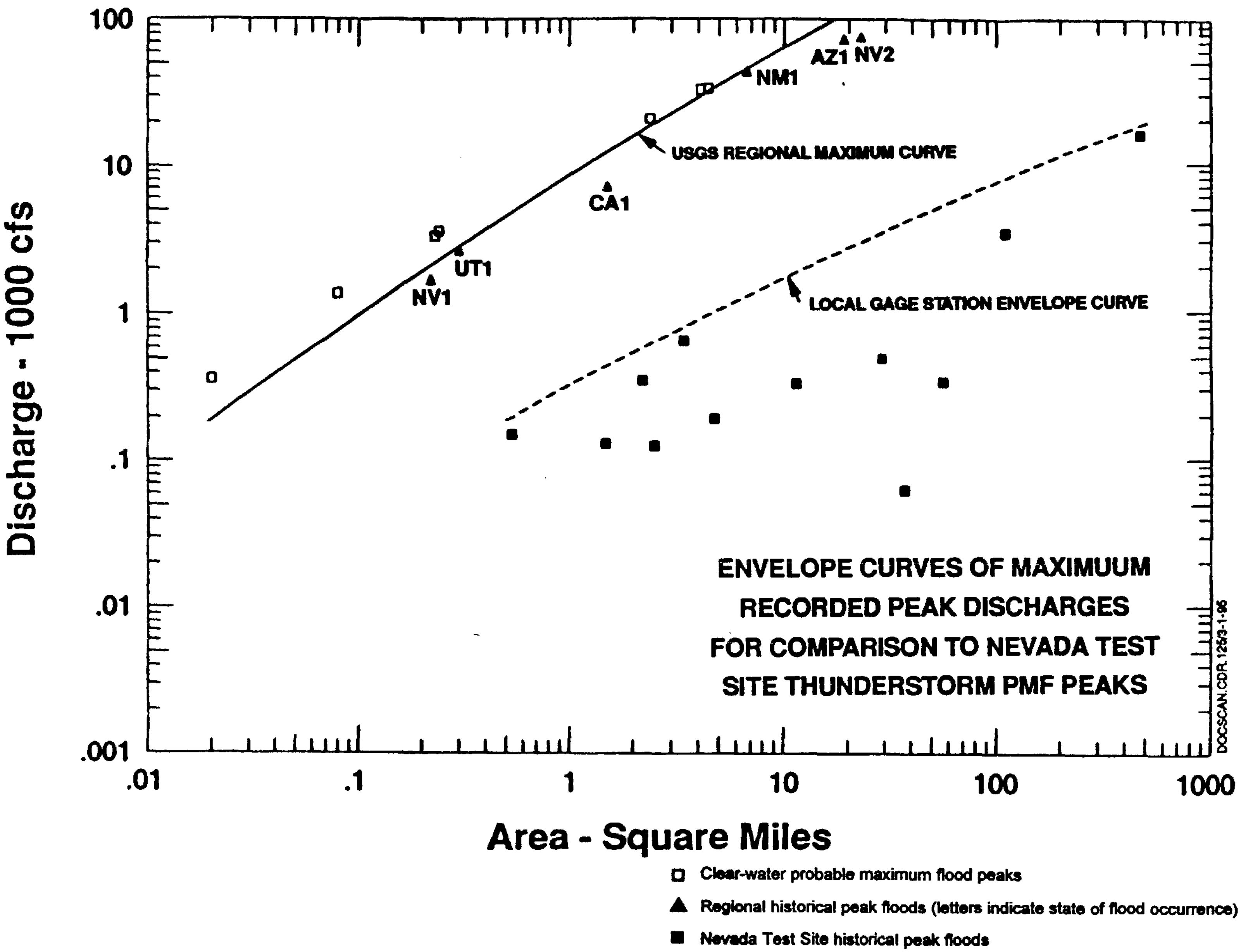


Figure 2.6.3-1 Envelope Curves - Maximum Peak Discharges (modified from Bullard, 1991)

3.0 PRECLOSURE HYDROLOGY

3.1 INTRODUCTION

The information pertaining to preclosure hydrology at Yucca Mountain needs to be sufficiently well understood to determine if the qualifying and disqualifying conditions from 10 CFR Part 960 can be met.

Qualifying Condition [10 CFR 960.5-2-10(a)]: "The site shall be located such that the geohydrologic setting of the site will: (1) be compatible with the activities required for repository construction, operation, and closure; (2) not compromise the intended functions of the shaft liners and seals; and (3) permit the requirements specified in 960.5-1(a)(3) to be met."

Disqualifying Condition [10 CFR 960.5-2-10(d)]: "A site shall be disqualified if, based on expected ground-water conditions, it is likely that engineering measures that are beyond reasonably available technology will be required for exploratory shaft construction or for repository construction, operation, or closure."

The cited section, 10 CFR 960.5-1(a)(3), states: *"Ease and Cost of Siting, Construction, Operation, and Closure.* Repository siting, construction, operation, and closure shall be demonstrated to be technically feasible on the basis of reasonably available technology and the associated costs shall be demonstrated to be reasonable relative to other available and comparable siting options." Therefore, this synthesis of preclosure hydrology characteristics provides the information that will be used principally to assess: (1) the potential effects of ground water on the construction and sealing of shafts, ramps, and other underground openings, including the repository itself; and (2) the availability of water for repository construction and operation. The potential for flooding of the surface portals or the underground facilities by surface water is discussed in Section 2.6.

3.2 GROUND-WATER CONDITIONS IN THE UNSATURATED ZONE

The main technical issue with ground-water conditions at a repository site involves the design, construction, and operation of underground facilities and sealing components, considering the likely ground-water conditions (Younker et al., 1992). The current design (M&O, 1994) places the proposed repository block in the unsaturated zone, approximately 300 m above the regional water table. No contact with the regional water table except with boreholes is planned during site characterization and, if licensed, during repository construction and operation (DOE, 1988). The total thickness of the unsaturated zone at Yucca Mountain ranges from 500 to 700 m and existing boreholes demonstrate that no aquifers exist between the surface and the regional water table. Within the unsaturated zone, capillary tension holds moisture in the pores, preventing saturated flow from the rock into excavated openings. The only ground-water condition, therefore, that could interfere with underground operations is perched zones of saturation within the unsaturated strata. The Environmental Assessment (DOE, 1986) suggests that these ground-water conditions will not require complex engineering measures and that shafts and boreholes can be sealed using RAT.

3.2.1 Unsaturated Zone Hydrostratigraphy

The stratigraphy at Yucca Mountain can be divided into three general groups: Paleozoic sedimentary deposits, Tertiary volcanics, and Quaternary alluvium. The top of the uppermost regional aquifer occurs in the lowest part of the volcanics, the Crater Flat Group and the Calico Hills Formation. The volcanics at Yucca Mountain dip to the east through a water table that is nearly level under the site. The proposed repository horizon is in the Topopah Spring Tuff of the Paintbrush Group, which overlies the Calico Hills Formation.

Montazer and Wilson (1984) describe the unsaturated zone hydrostratigraphy and recognize six units (Figure 3.2.1-1). The critical differences between these units are the degree of welding, which largely determines the matrix permeabilities, and the fracture density, which introduces secondary permeabilities that may be much greater than the values for the matrix alone. Direct flow through fractures can be much faster than percolation through the unsaturated matrix but the fractures also increase the matrix surface area and can slow flow through imbibition on the fracture walls. The six unsaturated zone hydrostratigraphic units are described briefly below:

Quaternary Alluvium (Qal) consists of irregularly distributed deposits of alluvium and colluvium. The Qal ranges up to 30 meters thick in the washes that incise Yucca Mountain, but alluvium is thin or nonexistent over much of the site. The alluvium is composed of very poorly sorted granular material with small effective hydraulic conductivities, large effective porosities compared to the volcanics. Precipitation may infiltrate into the upper few meters but then be lost again to evaporation before percolating deeper into the unsaturated zone.

Tiva Canyon Welded Unit (TCw) is the uppermost volcanic unit and forms much of the caprock on Yucca Mountain and the peripheral ridges. These moderately to densely welded tuffs are 0 to 150 m thick. Although this unit may be densely fractured, moisture infiltrating along fractures may be absorbed into the rock matrix before percolating into the underlying units. Weeks and Wilson (1984) estimated the saturated matrix hydraulic conductivity on the order of 10^{-11} m/s.

Paintbrush Nonwelded Unit (PTn) consists of the non- and partially welded base of the Tiva Canyon Tuff, the Yucca Mountain Tuff, the Pah Canyon Tuff, the non- and partially welded upper Topopah Spring Tuff, and associated bedded tuffs. Within the central block, the Paintbrush Nonwelded is composed of thin, nonwelded ashflow sheets and bedded tuffs that range from 20 to 100 m thick. Weeks and Wilson (1984) determined saturated hydraulic conductivities on the order of 10^{-7} m/s and obtained similar values from air permeability tests, indicating that fracture permeability within this unit is significant. The low matrix conductivities of the underlying Topopah Spring unit may divert percolating soil moisture laterally.

Topopah Spring Welded Unit (TSw) is the host rock for the potential repository. The Topopah Spring Tuff is the thickest and most extensive ash-flow tuff of the Paintbrush Group, ranging from 290 to 360 m thick in the central block. The unit consists of a thick central zone of densely welded, devitrified ash-flow sheets bounded by upper and lower vitropheres. The saturated matrix hydraulic conductivity in on the order of 10^{-11} m/s

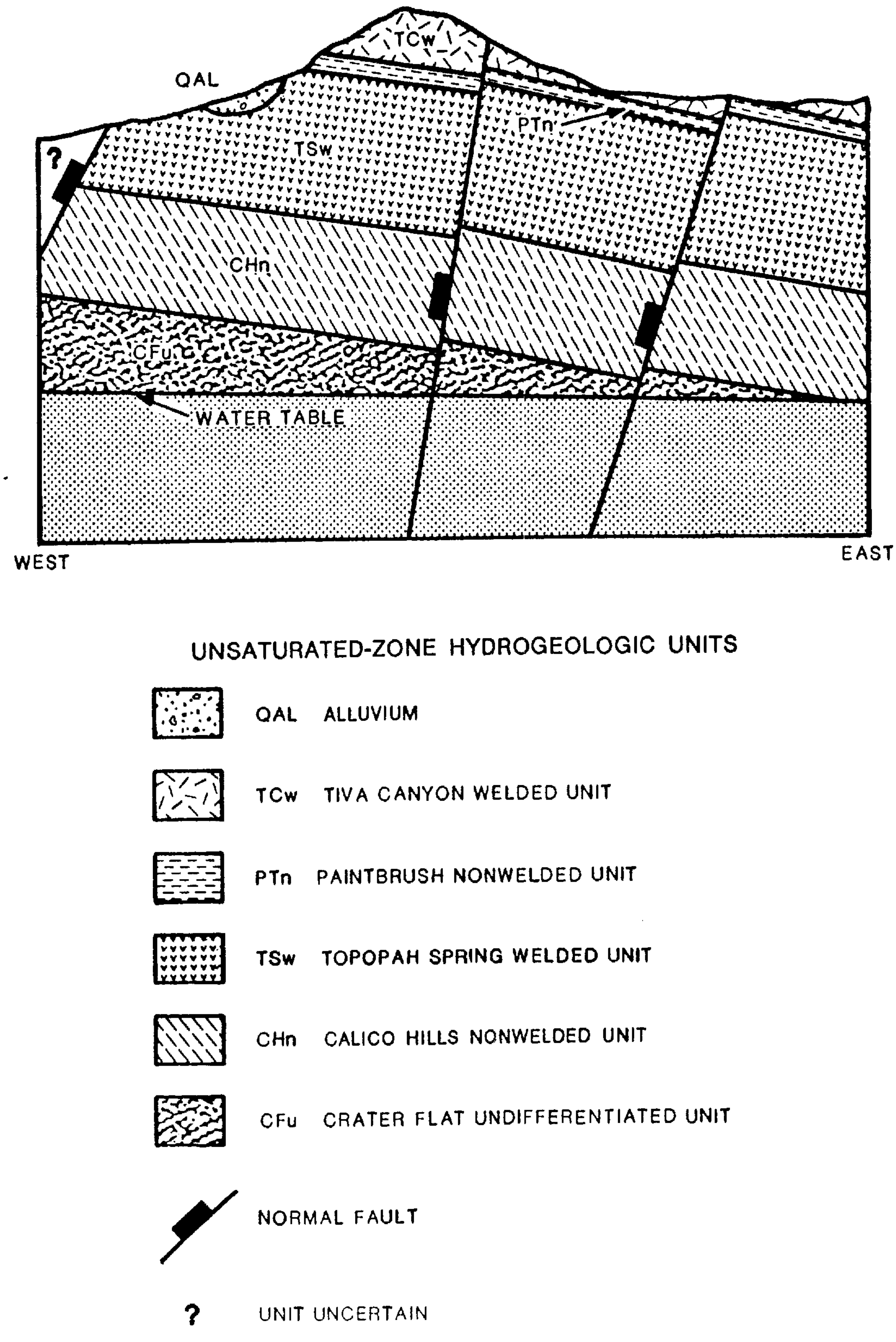


Figure 3.2.1-1 Conceptual east-west hydrogeologic section through the unsaturated zone at Yucca Mountain (modified from Montazer and Wilson, 1984)

(Montazer and Wilson, 1984) but bulk conductivities may be higher due to fracturing. Thordarson (1983) conducted tests in well J-13 and measured a horizontal saturated conductivity on the order of 10^{-5} m/s. Matrix porosities are low, however, the central and lower portion of this unit contain abundant lithophysal cavities. Air may become trapped in these cavities by capillary barriers, decreasing the unsaturated hydraulic conductivity and the effective porosity.

Calico Hills Nonwelded Unit (CHn) underlies the host rock and intersects the water table under the northern half of the proposed repository block. The Calico Hills is sequence of non- to partially welded ash-flow tuffs 100 to 400 m thick, and includes the unsaturated parts of the lowermost Topopah Spring Tuff, the Calico Hills Formation, and the Prow Pass and Bullfrog Tuffs of the Crater Flat Group.

Parts of the Calico Hills unit has been devitrified and altered to zeolites, clays, and calcite so that Montazer and Wilson (1984) distinguished two subunits: vitric (CHnv) and zeolitized (CHnz). The subunits have similar porosities (37 percent and 31 percent) and are approximately 90 percent saturated. The difference between the vertical saturated conductivities on the order of 10^{-8} m/s in the vitric subunit and 10^{-11} in the zeolitized subunit is attributed to argillization in the zeolitized tuff. Montazer and Wilson (1985) report a mean saturated conductivity in the zeolitized subunit on the order of 10^{-9} m/s, noting the anisotropy between the vertical and horizontal conductivity values.

Crater Flat Undifferentiated Unit (CFu) is the lowermost unsaturated unit under the southern half of the proposed repository block. The unsaturated thickness ranges from 0 to 160 m and the unit is saturated under the northern half of the block. The Crater Flat unit comprises the welded and nonwelded sections of the Bullfrog Tuff of the Crater Flats Group. Hydraulic conductivities in this unit are highly variable due to the lack of differentiation of the tuffs.

3.2.2 Perched Water

Perched water is a localized zone of saturation hydraulically not directly connected to the static water table (Freeze and Cherry, 1979). Perched zones may form where a hydrostratigraphic unit overlies or abuts a unit of lower hydraulic conductivity (Fetter, 1988). At Yucca Mountain, water can perch where nonwelded tuff overlies more densely welded tuff, such that there is a contrast in the matrix permeabilities, or where a highly fractured, densely welded unit overlies a nonwelded unit and the bulk permeability of the overlying unit is greater due to the fracture permeability. Permeability contrasts can form across lithologic contacts or where two units are juxtaposed by faulting (Burger and Scofield, in prep.).

Burger and Scofield (in prep.) report an examination of perched water that has been encountered in four boreholes in the vicinity of Yucca Mountain (USW UZ-1, USW UZ-14, USW NRG-7/7A, and USW SD-9). In all holes, the perched water was encountered 100 m above the water table, which is fairly flat with an elevation of about 730 m above sea level. Video borehole logs in USW UZ-14 and USW SD-9 indicate water enters these holes via discrete fractures, suggesting that fracture density and permeability have a strong influence on the occurrence of perched water.

3.3 WATER RESOURCE POTENTIAL

Water resources in the Jackass Flats area of the NTS were first developed in the late 1950s and early 1960s to provide water for the Nuclear Rocket Development Station (Young, 1972). Well-construction information can be found in Thordarson et al. (1967), Young (1972), Claassen (1973), and Thordarson (1983).

Well UE-25 J#11 was drilled in 1957 in eastern Jackass Flats and produced water from the Basalt of Kiwi Mesa and the welded-tuff aquifer. After the casing corroded and production declined, an attempt was made in 1962 to reperforate the casing which resulted in rupturing the casing. Because of this and relatively poor quality of water, UE-25 J#11 was abandoned (Young, 1972; p. 17).

Well UE-25 J#12 was drilled in 1957 along Fortymile Wash to a depth of 270 m (887 ft) and produces water from the Topopah Spring Tuff (equated with the welded-tuff aquifer). Well head elevation is 953.8 m (3128.4 ft) and depth to water was 226.0 m (741.4 ft) on January 27, 1960 (Young, 1972). Young (1972; p. 17) reports that UE-25 J#12 had been placed on standby status with all water for the Nuclear Rocket Development Station being obtained from UE-25 J#13.

Well UE-25 J#13 was completed in 1963 to a depth of 1063 m (3488 ft). It is north of UE-25 J#12 along Fortymile Wash and also produces water from the Topopah Spring Tuff (Young, 1972; p. 10). The Topopah Spring Tuff is fully penetrated at depths of 207.3 to 449.6 m.

Wells UE-25 J#12 and UE-25 J#13 have been pumped intermittently since their completion with UE-25 J#13 being used as the main water supply well for the Nuclear Rocket Development Station and, as such, it was pumped nearly continuously for many years. Between December 1962 to April 1969, the depth to water in UE-25 J#13 increased from 282.5 m to 283.3 m; however, the static water level had recovered to 282.4 m by 1980 due to decreased pumping (Thordarson, 1983). Young (1972; p. 12) estimated that for a constant pumping rate of 63 L/s (1000 gal/min or 1610 acre-feet/year) it would take between 380 to 76 years to dewater the aquifer, assuming a specific yield that varied between 5 to 1 percent and no recharge. Given the recovery of the static water level with decreased pumping, the assumption of no recharge to the aquifer is questionable.

Before 1968, UE-25 J#12 was pumped at rates in excess of 2,000 m^3/day. After the wellbore was cleaned and deepened in 1968, production capabilities exceeded 4,500 m^3/day. Well UE-25 J#13 has been shown to be capable of producing in excess of 3,800 m^3/day of water (Claassen, 1973). The specific capacity of the well underwent a slight decline in 1964 shortly after completion. Claassen (1973) hypothesized that the well was not fully developed during the 1964 tests. Subsequent pumping tests performed in 1969 support this hypothesis, and a specific capacity of 540 m^3/day/m is considered the most reliable measurement.

Pumping tests performed after 1968 on UE-25 J#13 produced draw-downs of less than 7 m with pumping rates in excess of 3500 m^3/day. Even with UE-25 J#13 in continuous service, declines in the water level have been minimal. This suggests that the short-term effects of pumping on the regional potentiometric surface are probably negligible and the system is experiencing recharge on a regional scale.

USW UZ-1 was drilled to a depth of 387 m or about 961 m above sea level. Drilling was stopped at this depth when a possible perched-water zone was encountered. The perched water was found in or just below the Topopah Spring Tuff in a zone that is less fractured than the overlying rock. Chemical testing showed that the water was contaminated with water used to drill USW G-1, a hole less than 300 m away (Whitfield et al., 1990, p.6).

USW UZ-14 was drilled to a depth of 678 m and encountered perched water at a depth of 383 m or an altitude of about 965 m. The first occurrence of perched water was located near the upper contact of the basal vitrophyre of the Topopah Spring Tuff. This borehole is located less than 30 m for USW UZ-1. As the perched water in USW UZ-1 was encountered at approximately the same level, it may indicate that the zone was a true perched-water zone with a connection to USW G-1.

USW NRG-7/7A was drilled to a depth of 461 m. Perched water initially was thought to have been encountered at a depth of about 458 m, at an elevation of 824 m. This is just below the contact of the bedded tuff below the partially welded pyroclastic flow at the base of the Topopah Spring Tuff. Over time, the water level rose to 15 m above the bottom of the hole, so it is possible that the original water had entered the borehole above the depth of 458 m.

USW SD-9 was drilled from an elevation of 1301 m to a depth of 663 m. Water was encountered at a depth of 452 m, but a borehole video log showed water slowly seeping into from a fracture into the hole at 413 m, or an altitude of about 888 m.

According to the current design, the elevation of the drifts at the north end of the repository is above 1000 m. Perched water in USW UZ-1 and USW UZ-14 was encountered at an altitude below the minimum repository elevation, and both boreholes are located about one kilometer to the north of the proposed repository. Known perched water in wells on or near the proposed repository block is more than 100 m below the level of the current design for the proposed repository, so extensive perched water is not expected during construction of the ESF. The possibility exists of encountering small amounts of perched water near faults, fractures, or lithologic contacts in the repository, but this is not expected to impede construction. Details of the design are likely to have small changes in the future, but these changes are not expected to result in construction of the repository below the levels where large amounts of perched water have been encountered or below the level of the water table.

3.2.3 Subsurface Flooding Potential

If perched water were to be encountered, it is not expected that it would pose construction problems requiring other than standard engineering measures. Drifts have been constructed in volcanic tuffs on the NTS in environments with higher matrix and fracture saturation than at Yucca Mountain. Tunnels have been constructed in Rainier Mesa that did not require complex engineering measures. Even though they were above the water table, tunnels in Rainier Mesa had perched-water flow from fractures after excavation (Thordarson, 1965). The flow eventually ceased, most within a few weeks or months, but some fractures dripped for two years or more (Thordarson, 1965). Extraordinary methods for stopping water influx were not needed.

Other drillholes exist near the site but are pumped only periodically to obtain hydrologic and hydrochemical information. These test holes have not been used to supply water.

Younker et al. (1992; page 3-78) conclude that the preclosure hydrology issues are not expected to constitute serious problems and can be accommodated using standard engineering control measures and RAT. Additional tests and design analyses were suggested to continue as confirmatory measures.

Since Younker et al. (1992) was published, UE-25 JF#3 has been drilled as a monitoring well and a monitoring program has been established to ensure that water withdrawals for the Yucca Mountain Site Characterization Project do not impact endangered species at Ash Meadows or Death Valley. Well pumpage at UE-25 J#13 has been monitored and reported to the State Engineer.

La Camera and Westenburg (1994) report estimates of total ground-water withdrawals in Jackass Flats and tabulate measured water levels for the Yucca Mountain region. Figures 3.3-1, 3.3-2 and 3.3-3 graph annual estimates of ground-water withdrawal and compare these estimates to measured water-level altitudes in wells in Jackass Flats. These data suggest that, to date, the ground-water withdrawals have not impacted the water-level altitudes by causing any permanent drawdown.

Czarnecki (1991) describes simulations of the effects of ground-water withdrawals in the Yucca Mountain area which were made using a two-dimensional, subregional, finite-element model of the flow system. Czarnecki (1991) used the same subregional model configuration which was used in Czarnecki (1985) and used the current version of the computer code MODFE to simulate ground-water flow. Steady-state simulations with no withdrawals were done to obtain steady-state values of hydraulic head which were verified. Various withdrawal rates were simulated for a period of ten years to evaluate the effects of different stresses on the system. For each withdrawal rate, simulations were performed with the model values of specific yield set at 0.001, 0.005, and 0.01. 0.001 and 0.005 are considered extremely conservative estimates of specific yield and 0.01 may be considered a conservative minimum value. Thordarson (1983, page 18) reports estimates of effective porosity ranging from 2.8 to 8.7 percent, and Young (1972, p. 12) indicates that the specific yield is closer to 0.05 than 0.01.

Figure 3.3-1 indicates that since 1983, the largest estimated water withdrawal was 70,000,000 gallons per year in Jackass Flats during 1983. This amount is equivalent to an average withdrawal rate for the entire year of about 133 gallons per minute. The simulations showed that for a specific yield of 0.01, the maximum drawdown was less than two feet after 10 years of withdrawal at a combined rate of 177 gallons per minute for wells J-13 and J-12 (Figure 3.3-4a). As an extreme case, if both J-13 and J-12 were pumped at their maximum capacity for 10 years (630 and 760 gal/min), the maximum drawdown calculated for a specific yield of 0.01 was only slightly more than 10 feet (Figure 3.3-4b).

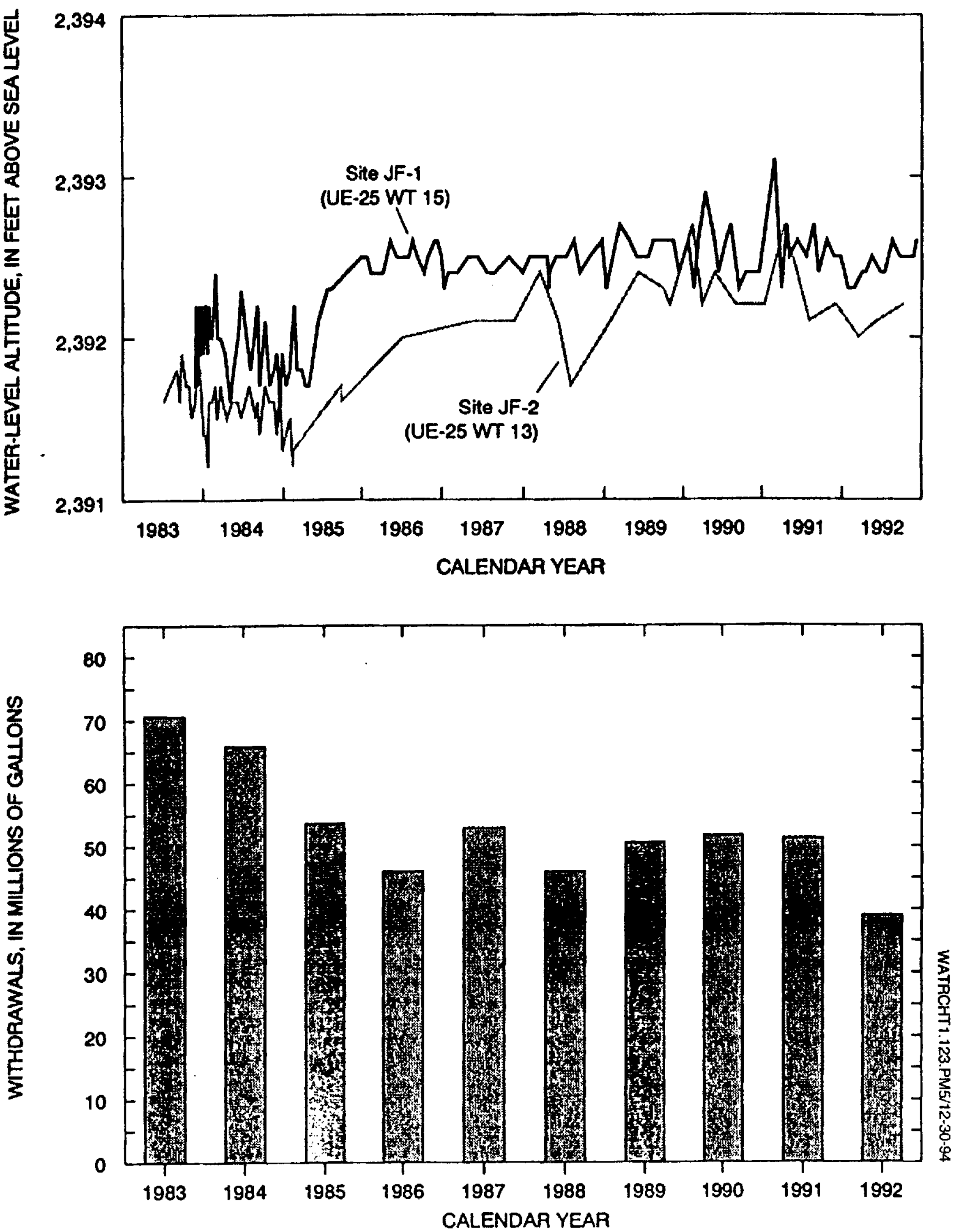


Figure 3.3-1 Water-level altitudes in wells JF-1 and JF-2 and estimated ground-water withdrawals from Jackass Flats, 1983 through 1992. Bar height equals sum of withdrawals from water-supply wells J-13 and J-12. (from La Camera and Westenburg, 1994)

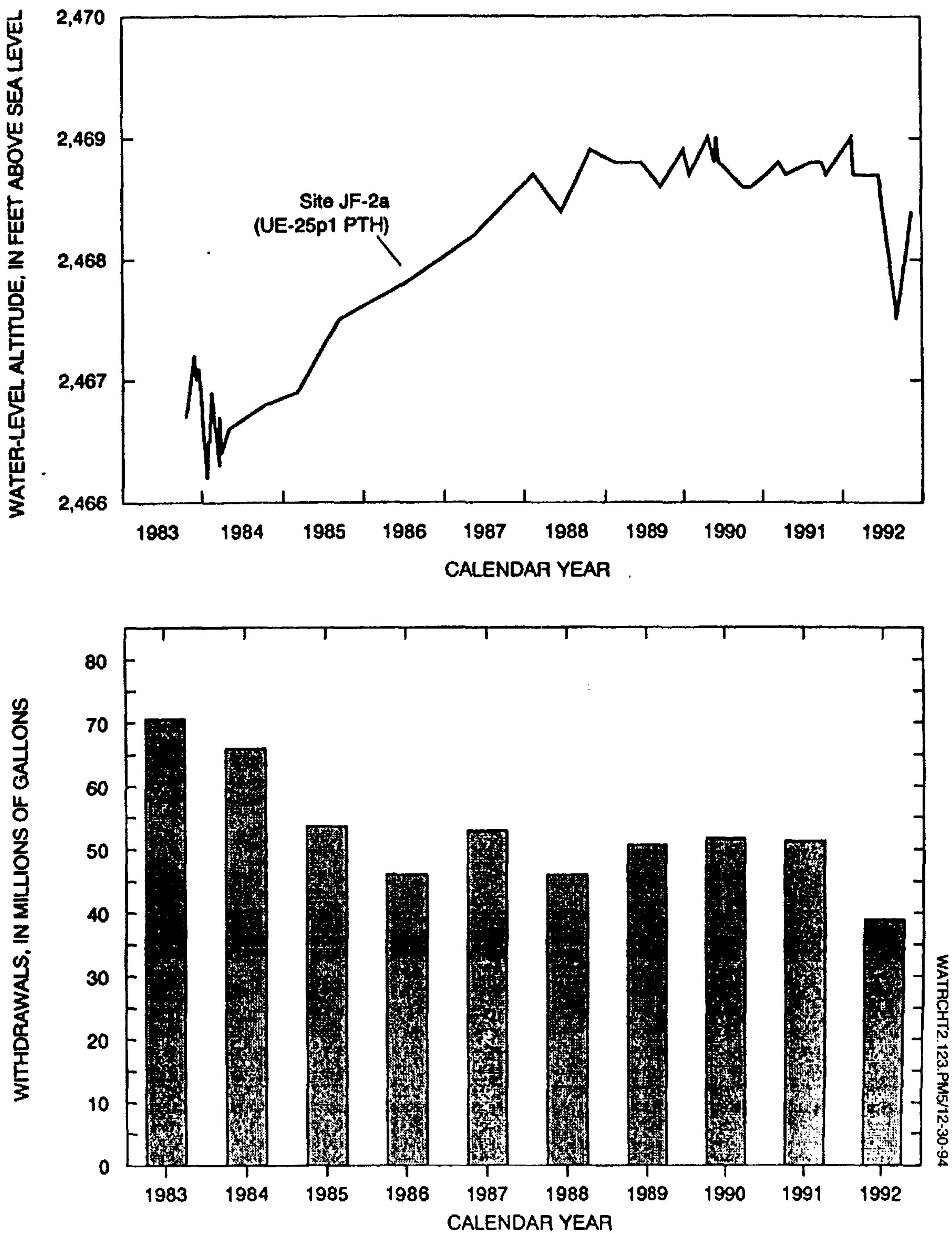


Figure 3.3-2 Water-level altitude in well JF-2a and estimated ground-water withdrawals from Jackass Flats, 1983 through 1992. Single measurement on November 7, 1983, has been excluded, as that measurement may represent transient conditions at the site. Bar height equals sum of withdrawals from water-supply wells J-13 and J-12. (from La Camera and Westenburg, 1994)

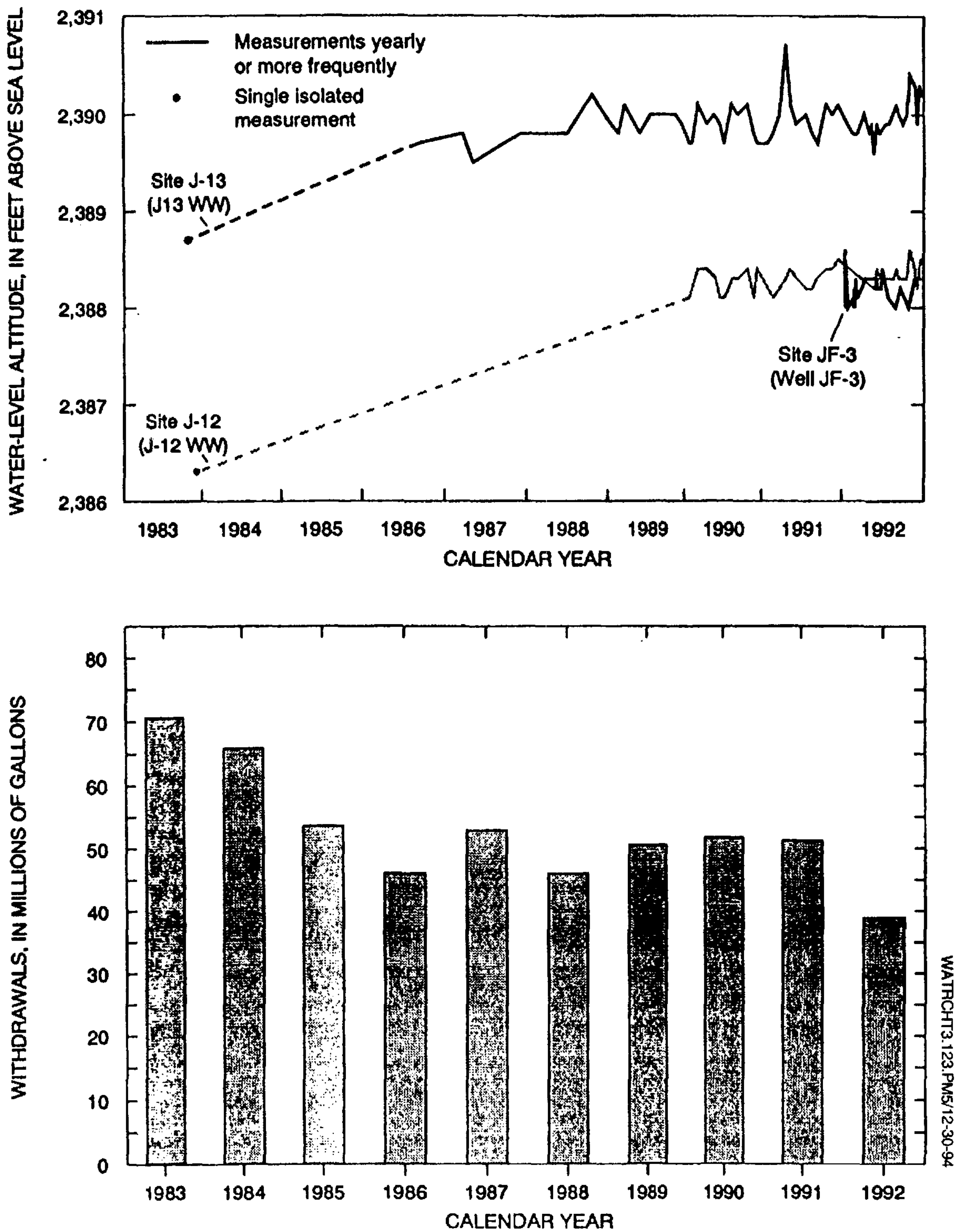
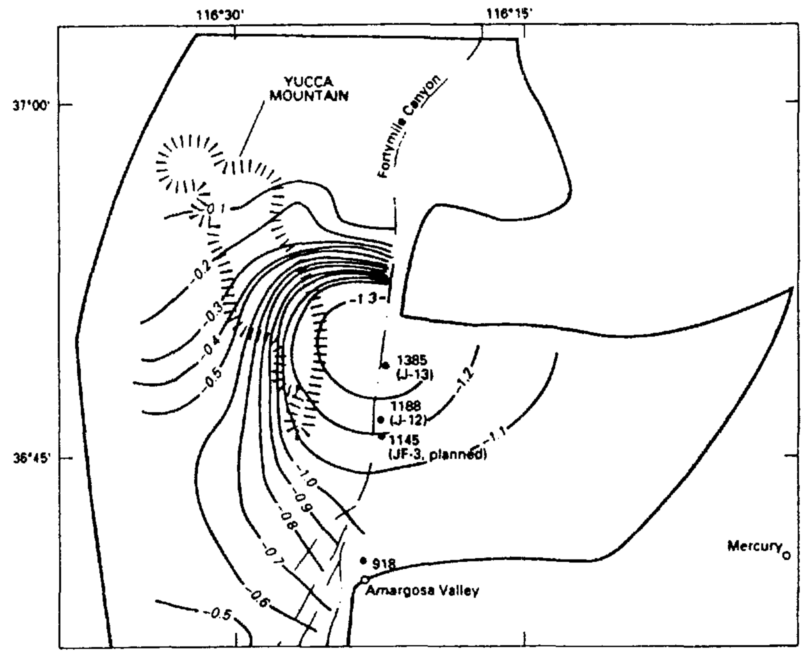
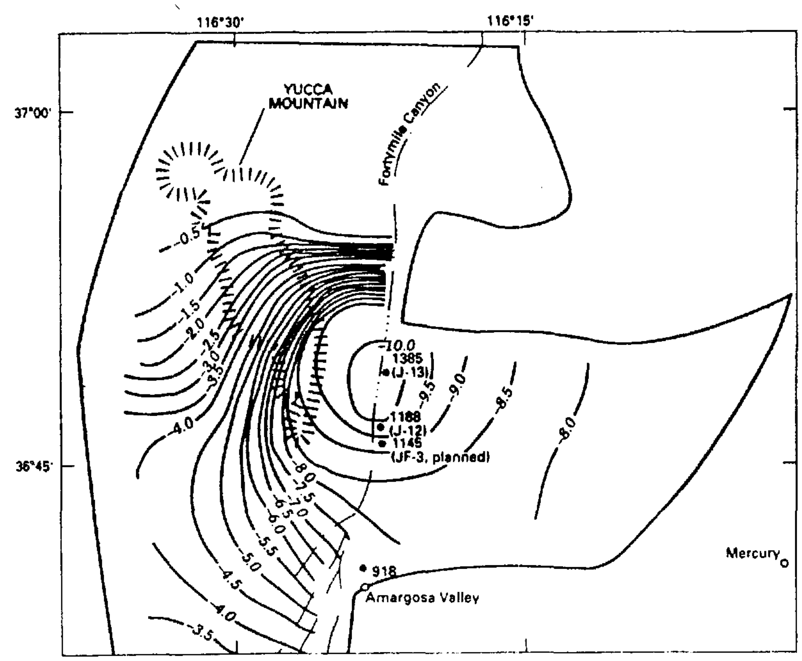


Figure 3.3-3 Water-level altitudes in wells J-13, J-12, and JF-3 and estimated ground-water withdrawals from Jackass Flats, 1983 through 1992. Bar height equals sum of withdrawals from water-supply wells J-13 and J-12. (from La Camera and Westenburg, 1994)



(a) Simulated water-level decline caused by well J-13 pumped at 138 gal/min and well J-12 pumped at 39 gal/min for 10 years.



(b) Simulated water-level decline caused by well J-13 pumped at 630 gal/min and well J-12 pumped at 760 gal/min for 10 years.

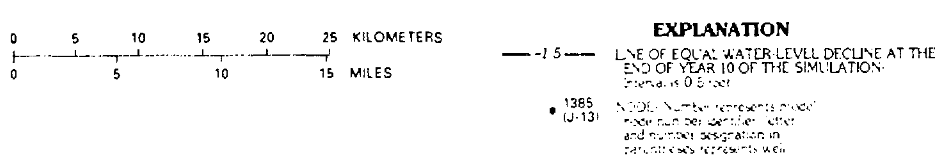


Figure 3.3-4 Simulated Drawdowns From Pumpage at Wells J-12 and J-13 (from Czarnecki, 1992)

4.0 EROSION

4.1 INTRODUCTION

Erosion at Yucca Mountain needs to be sufficiently well characterized to determine if the qualifying and disqualifying conditions from 10 CFR Part 960 can be met.

Qualifying Condition [10 CFR 960.4-2-6(a)]: "The site shall allow the underground facility to be placed at a depth such that erosional processes acting upon the surface will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in Section 960.4-1."

Disqualifying Condition [10 CFR 960.4-2-6(d)]: "The site shall be disqualified if site conditions do not allow all portions of the underground facility to be situated at least 200 m below the directly overlying ground surface."

The cited section, 10 CFR 960.4-1, states: "(a) *Qualifying Condition.* The geologic setting at the site shall allow for the physical separation of radioactive waste from the accessible environment after closure in accordance with the requirements of 40 CFR Part 191, Subtitle B, as implemented by the provisions of 10 CFR Part 60. The geologic setting at the site will allow for the use of engineered barriers to ensure compliance with the requirements of 40 CFR Part 191 and 10 CFR Part 60 (see appendix I of this Part)." Thus, the objective of the Erosion Guideline is to ensure that erosional processes will not degrade the waste-isolation capabilities of the repository site. The site should allow the underground facility to be placed deep enough to ensure that the proposed repository will not be uncovered by erosion or otherwise adversely affected by surface-degradation processes. To this end, estimates of erosion rates will be calculated based on measurements of incision of dated geologic units.

4.1.1 Thickness of Overburden

Figure 4.1.1-1 shows the thickness of the overburden above the current design depth of the proposed repository. All segments of the proposed repository are more than 200 m below the ground surface.

4.1.2 Erosional Processes

An unusually long Quaternary record is preserved in the Yucca Mountain landscape. The evidence indicates that the Yucca Mountain landscape has changed very little during the past several hundred thousand years (DOE, 1993). This evidence includes:

1. Early and middle Quaternary hillslope and basin alluvial deposits are common, while late Quaternary deposits are generally confined to the present washes. The preservation of these deposits, which range to over one million years in age, indicates an unusual geomorphic stability has existed on these hillslopes and basin surfaces during the Quaternary. This stability has existed because of low rates of tectonic activity in this area and small fluctuations in climate during the Quaternary.

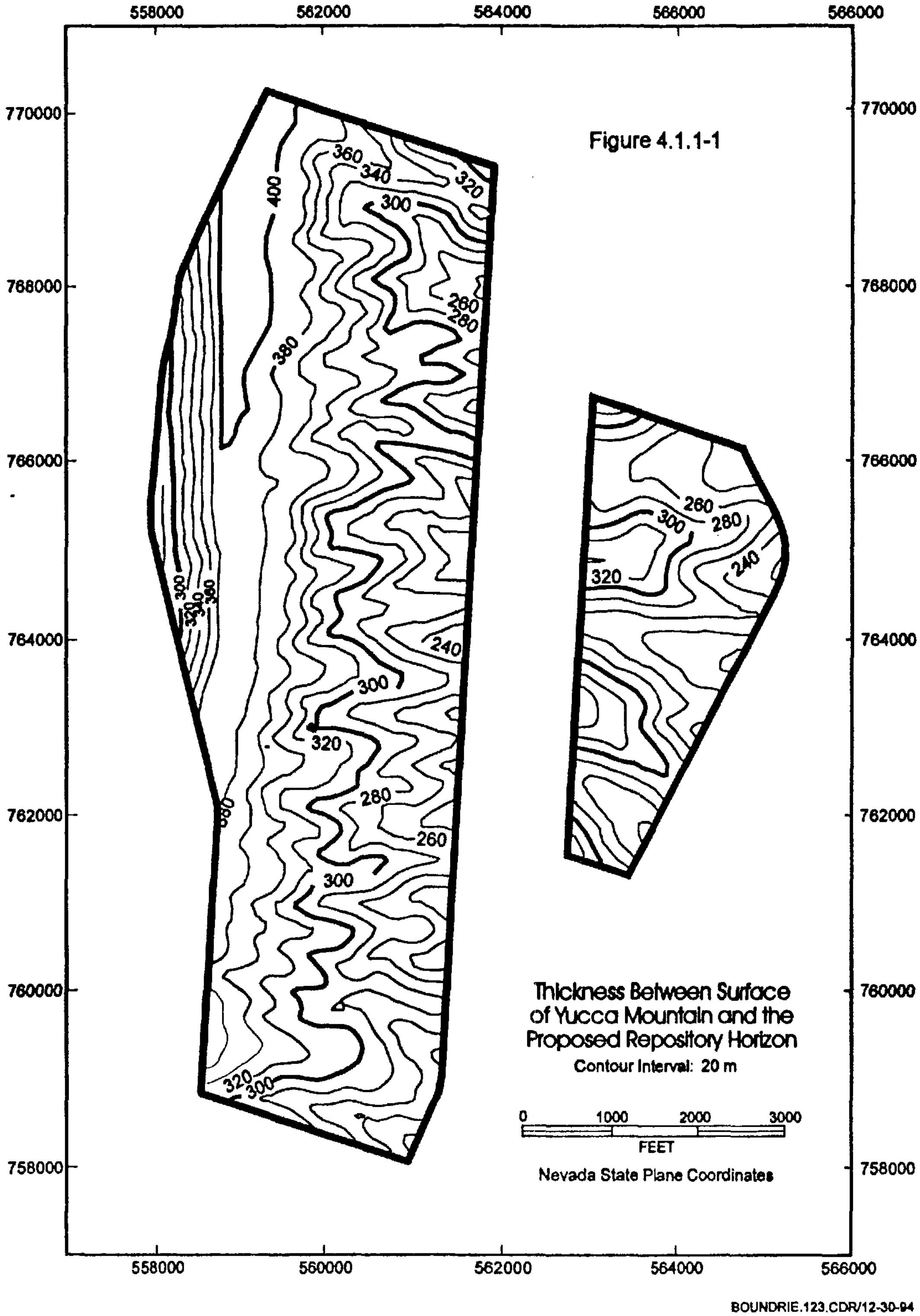


Figure 4.1.1-1 Thickness Between Surface of Yucca Mountain and the Proposed Repository Horizon

2. The evolution of Fortymile Wash indicates that the overall process in this drainage system during the Quaternary has been aggradation, not downcutting. The original valley floor formed during Miocene time, over nine million years ago, has not been subsequently re-exposed by stream incision during the past few million years.

3. Minor episodes of Quaternary downcutting (superimposed on the overall aggradation) in Fortymile Wash have not migrated upstream into Yucca Mountain tributaries; thus, incision on Fortymile Wash has had a very minor effect on stream incision in small canyons on Yucca Mountain.

4. Canyon cutting on Yucca Mountain has averaged only 0.8 cm/ka for the past 12 million years.

5. Erosion on Yucca Mountain hillslopes, determined by measuring degradation below dated deposits, is very low. The average degradation rate for the last several hundred thousand years is measured to be 0.19 cm/ka. This rate is lower than, although comparable to, those rates measured in nearby regions. Because the erosion rates in this report are based on rock-varnish surface exposure ages of boulder deposits, they are therefore somewhat overestimated (this is more fully discussed in Section 4.3.2.1).

Degradation over the whole United States ranges from 2 to 15 cm/ka and averages about 4 cm/ka. Degradation at Yucca Mountain, as expected for a region averaging less than 250 mm of rainfall per year, is more than an order of magnitude less than the average for the whole United States.

4.2 DESCRIPTION OF HILLSLOPE EVOLUTION

Hillslope erosion can occur during occasional summer convective thunderstorms if an individual storm cell stalls over a ridge crest long enough to saturate hillslope colluvium and initiate debris flows. Although debris flows are the primary mechanism for hillslope erosion in the Yucca Mountain region, they are infrequent events. This is evidenced at Yucca Mountain by the mantle of middle Pleistocene colluvium found on the slopes and by the lack of erosion scars.

At Yucca Mountain, the Tiva Canyon Tuff forms the ridge-crest bedrock that is the source of coarse bouldery debris on Yucca Mountain hillslopes (Scott and Bonk, 1986; Sawyer et al., 1994), while basalt is the bedrock source on Skull and Little Skull mountains and on Buckboard Mesa (Sargent and Stewart, 1971; Maldonado, 1985). Physical weathering, by freezing of water at considerable depth, along joints and fractures in welded tuffs and basalts produced boulders and smaller clasts that become colluvial boulder deposits. Whitney and Harrington (1993) suggest that this boulder-forming process took place during colder and wetter parts of the Pleistocene, and is no longer operative. Bull (1991; p. 160) indicates that the small grain size of these rock types (welded tuff and basalt) causes them to chemically weather more slowly than their coarse-grained counterparts (granite and gabbro, respectively). Bull (1991; pp. 159 and 160) notes that the erodability of hillslope weathering products is largely a function of abundance of boulders and that basalt and tuff are insensitive to a climatic change from semiarid (250 to 500 mm of rainfall/year) to arid (50 to 250 mm of rainfall/year) because unfractured blocks between cooling joints weather slowly to fine materials in semiarid and arid climates. Large forces are required to move boulder lag deposits downslope (Bull, 1991; p. 160). In southern Nevada, colluvial boulder deposits are noticeably absent on hills composed of limestone, sandstone, and coarse-grained igneous rocks that are susceptible to solution or grain-to-grain physical weathering. In short, colluvial boulder deposits are most commonly found in parts of the southern Great Basin where resistant, fine-grained volcanic rocks comprise most of the hillslope bedrock (Whitney and Harrington, 1993).

Several conditions contribute to the long-term preservation of these hillslope deposits:

1. Boulders in the hillslope deposits are erosionally resistant volcanic rocks.

2. Rock varnish coatings on the surface of boulders inhibit weathering, and the large boulder sizes are difficult to move by modern hillslope processes.

3. Incision of hillslope channels isolates colluvial boulder deposits by topographic inversion and removes them from the zone of most active erosion by runoff.

4. Debris flows, although effective in removing bouldery colluvium from upper slopes, are generally restricted to active channels on middle and lower hillslopes and rarely strip debris from non-channelized areas.

4.3 QUATERNARY GEOCHRONOLOGY

Quaternary deposits at the NTS and the Yucca Mountain area have been dated by a variety of geochronologic methods since the late 1970s. Radiocarbon has been used to date suitable materials when available (see, for example, Swadley et al., 1988). Uranium-series methods have been used to date carbonates in faults, spring deposits, drill cores and soils (Szabo and Sterr, 1978; Szabo et al., 1981; Knauss, 1981; Szabo and O'Malley, 1985; Szabo and Kyser, 1990; Paces et al., 1993). Rosholt pioneered the uranium-trend method for dating soil carbonates (Rosholt, 1980; Rosholt, 1985) and used this method to date NTS deposits (Rosholt et al., 1985). Potassium-argon and argon-argon methods have been used with varying success to date Tertiary and Quaternary basalts (Sinnock and Easterling 1983; Champion, 1991; Turrin and Champion, 1991; Crowe et al., 1992). Thermoluminescence has been used for dating fault movements (Whitney et al., 1986) and eolian silts (Whitney and Harrington, 1993). Methods for dating cosmogenic isotopes have recently been employed (Whitney and Harrington, 1993; Harrington et al., 1994).

For the purpose of evaluating erosion at Yucca Mountain, a dating technique was needed capable of dating deposits with a broad range in ages covering the Quaternary Period. Such techniques as radiocarbon, uranium series, and uranium trend dating have applicable ranges too short to span the time period of interest in dating of hillslope deposits (see Pierce, 1986). Additionally, because the intent was to calculate long-term erosion rates, the dating of deposits having a wide range in ages was required, rather than the dating of very young (<100 ka) deposits with a high degree of accuracy.

It was recognized that the best age control on the hillslopes would result from the dating of colluvial boulder deposits because these deposits were common on Yucca Mountain and other regional hillslopes, they had been stabilized on the hillslope for a long period of time, and they could be used to reconstruct the form of the paleohillslope. Thus, the dating technique had to be appropriate for the dating of deposits with large clasts. A variety of Quaternary dating techniques are useful for dating fine-grained deposits, but are not useful in dating deposits composed of large boulder-sized clasts. Additionally, the surface exposure age of the deposit was needed to calculate erosion rates rather than the age of the rocks of which the boulders consisted (i.e., the age of the deposit, not the time that the basalt or tuff was formed). Thus, techniques such as K-Ar and Ar-Ar that are commonly used to date the formation of lava flows were not useful in dating features formed at a later time from boulders broken from the lava flow. Soils-dating techniques and isotopic techniques such as uranium-series dating of soil carbonates were not considered because they provide only a minimum limiting age for the hillslope surface and may not closely reflect the true age of the surface. After careful consideration of relevant factors (see Section 4.3.1) rock varnish cation-ratio dating of the boulder deposits was identified as an acceptable technique, because it satisfied the criteria for selection (i.e., it provided surface exposure ages of hillslope features), it was able to date 100 ka to 2000 ka deposits, it could date bouldery deposits, and it was useable on any fine-grained volcanic rock such as basalts and tuffs.

4.3.1 Criteria for Selection of a Dating Methodology

Cation-ratio dating of rock varnish was utilized to provide the dating of hillslope surfaces rather than other Quaternary dating techniques for a number of reasons:

1. It was recognized that the best age control on the hillslopes would result from the dating of boulder deposits because these deposits were common on Yucca Mountain and other regional hillslopes, they had been stabilized on the hillslope for a long period of time, and they could be used to reconstruct the form of the paleohillslope. Thus, the dating technique had to be appropriate for the dating of deposits with large clasts. A variety of Quaternary dating techniques such as radiocarbon, uranium trend, and amino acid racemization dating, and thermoluminescence, are useful for dating fine-grained deposits, but are not useful in dating deposits composed of large boulder-sized clasts.

2. The direct dating of hillslope surfaces is necessary to define the time that a specific paleohillslope existed, rather than the dating of some hillslope aspect that can often only be generally related to the age of the hillslope surface. For this reason, soils-dating techniques and isotopic techniques such as uranium series dating of soil carbonates were not considered because they provide only a minimum limiting age for the hillslope surface and may not closely reflect the true age of the surface.

3. Boulder deposits consist of basalt or tuff boulders and the dating technique utilized had to be appropriate to both lithologies. A variety of techniques including several of the cosmogenic techniques could not be used to reliably date both quartz rich tuff and basalt boulders and were eliminated from consideration for this reason.

4. The surface exposure age of the deposit was needed to calculate erosion rates rather than the age of the rocks of which the boulders consisted (i.e., the age of the deposit, not the time that the basalt or tuff was formed). Thus, techniques such as K-Ar and Ar-Ar that are commonly used to date the formation of lava flows were not useful in dating features formed at a later time from boulders broken from the lava flow.

5. The dating technique needed to be able to date deposits with a broad range in ages covering the Quaternary Period. Such techniques as radiocarbon, uranium series, and uranium trend dating have applicable ranges too short to span the time period of interest in dating of hillslope deposits (see Pierce, 1986). Additionally, because the intent was to calculate long-term erosion rates, the dating of deposits having a wide range in ages was required, rather than the dating of very young (<100 ka) deposits with a high degree of accuracy.

6. The technique needed to be one unaffected by the possibility that boulders in the deposit may have been exposed as part of a rock outcrop for some long time period prior to being broken apart and incorporated into a boulder deposit. Thus, cosmogenic techniques were problematic in that cosmogenic isotopes could have accumulated in the rock in the outcrop and retained this dose throughout the depositional process, leading to an erroneously old age for the deposit.

4.3.2 Rock Varnish Cation-Ratio Dating Technique

The rock varnish cation-ratio dating technique is one of a large number of calibrated dating techniques, such as lichenometry, amino acid racemization, and obsidian hydration that can be used for dating Quaternary deposits and events (see Pierce, 1986, for a discussion of Quaternary dating methods).

4.3.2.1 Rock Varnish

Rock varnish is a black to red brown manganese-rich coating that accretes on stable rock surfaces in arid and semiarid regions. Rock varnish cation-ratio dating is a method used to estimate the exposure age of a surface or deposit (Dorn, 1983) and is based on the premise that a ratio of minor elements within the varnish systematically decreases with increasing exposure age (Dorn, 1983; Dorn et al., 1986; Harrington and Whitney, 1987; Reneau et al., 1992). The complex depositional and diagenetic processes by which successively accreted layers of varnish, are in general, progressively more depleted of a variety of these minor cations is not yet completely understood (Reneau et al., 1992; Dorn and Krinsley, 1991; Reneau and Raymond, 1991). Thus, rock varnish ages for surfaces are estimated from empirical curves that calibrate the decreasing trend of the cation ratio with time, using independently dated geomorphic surfaces within the study region for the calibration (Dorn, 1983; Dorn et al., 1986; Harrington and Whitney, 1987; Pineda et al., 1988).

Rock varnish dating provides the means by which the exposure age of boulder deposits on Yucca Mountain region hillslopes can be estimated. Figure 4.3.2.1-1 displays examples of varnished colluvial boulder deposits. Rock varnish begins to form on the surface of boulders after they have been deposited as part of the hillslope debris. To obtain a rock varnish surface exposure age that most closely approximates the age of the deposit, the oldest varnish on the boulder deposit would have to be sampled and analyzed. There is a time lag of uncertain duration between the deposition of the boulders and the beginning of varnish accumulation on the surface of the boulder which occurs after the deposit surface is

Figure 4.3.2.1-1 Colluvial boulder deposits on the southwest flank of Skull Mountain. Boulders originally mantled the entire slope and were weathered from a basalt flow that caps the mountain. Note the overlapping and lighter color of the deposits of younger boulders that have been deposited on top of the older (darker) boulders in the large boulder deposit in the center of the picture (arrow).

stabilized and no material is in transport across the surface. This usually occurs when incision or dissection begins and channel incision around the deposit starts the varnish clock. Thus, rock varnish dating provides only a minimum age for the boulder deposit (see Figure 4.3.2.1-2 for detail of boulder deposits). Using the age of the rock varnish as a proxy for the age of the boulder deposit will therefore result in underestimating the time over which the process has been operative. Additionally, if the varnish sampled from the boulder deposit is not the oldest formed on the deposit, or if some event on the hillslope occurs after the deposition of the boulders and results in either the stripping of varnish from the clasts or in the overturning of the clasts on the deposit, then any new varnish forming on the clast surface would yield an erroneously young varnish age for the deposit. Thus, the use of any varnish, other than the oldest occurring on the deposit, to calculate the deposit age results in the age being erroneously underestimated and the process rate calculated being overestimated. The erosion rates calculated in this report, because they are based on rock varnish surface exposure ages of the boulder deposits, are therefore somewhat overestimated.

A basic assumption in the use of rock varnish dating to obtain age estimates of the relict hillslope boulder deposits is that the upper surface of boulders within these deposits possessed no pre-existing rock varnish when the boulder deposits were initially formed. The likelihood that this assumption is valid for the vast majority of boulders in the dated hillslope deposits is very high because:

1. Most boulders were broken out of rock outcrops on the upper hillslope, then fell, toppled, or rolled onto steep slopes (gradients of 28 to 31 degrees) and were subsequently transported tens to hundreds of meters downslope as part of the bouldery hillslope debris to the place of deposition on the mid-to-lower hillslope.

2. To retain rock varnish on the upper surface of the boulder following deposition, each clast would have to arrive on the upper steep hillslope, after being broken from the rock outcrop, with the upper surface of the rock on the hillslope having the same orientation as it initially possessed in the outcrop. This would necessitate delivery of the boulder onto the hillslope with no tipping or rotation of the clast during movement from the outcrop to the hillslope.

3. Finally, the rock clast would have to undergo tens of meters of downslope transportation and deposition as part of the bouldery debris moving down the hillslope without upper varnished rock surfaces being either broken or overturned during impacts with other boulders. Additionally, this soft and easily eroded rock varnish on the rock surface would have to withstand degradation during the transportation and deposition process.

The DOE concludes that the probability is low that this scenario would occur for large numbers of clasts. This conclusion provides a high degree of confidence in the validity of the assumption that the upper surface of boulders selected for rock varnish analysis possess only rock varnish that has formed on the rock surface after deposition of the boulder deposit.

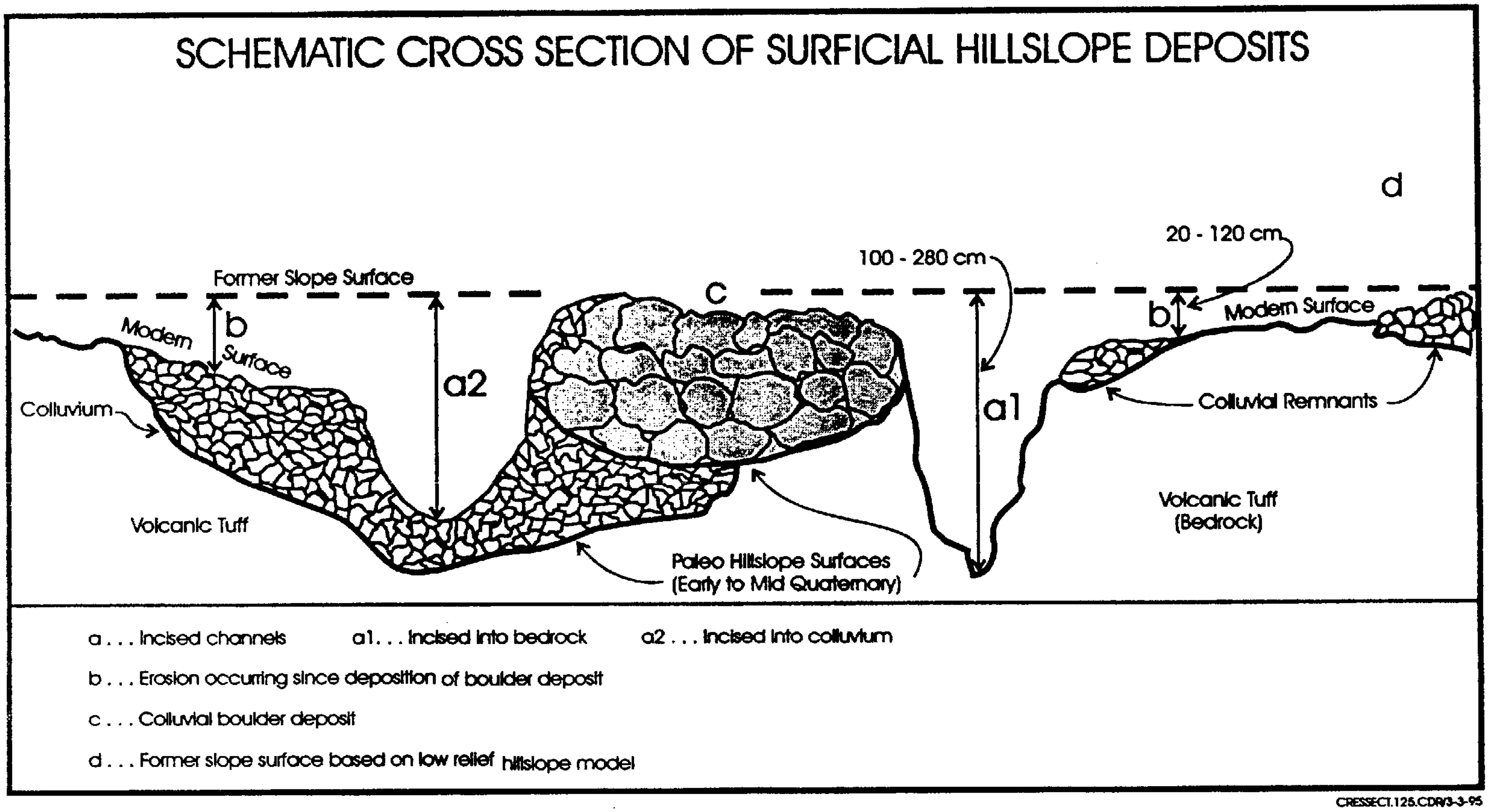


Figure 4.3.2.1-2 Schematic Cross Section of Surficial Hillslope Deposits

Lastly, to ensure that cation ratios of rock varnish represent the ages of deposits formed on boulder surfaces after deposition, conclusions need to take account of anomalous clasts. If the varnish chemistry from one clast is anomalous compared to that from the other clasts and the majority of varnished clasts possess a consistent varnish chemistry (see Section 4.3.2.5), then the analyses from the anomalous clast are disregarded during calculation of the cation ratio for that deposit.

After consideration of the temporal window for which a geochronology needed to be established and the variety of techniques available, their advantages, disadvantages, utility and limitations, the inherent uncertainties, and aspects of techniques that were not well constrained (e.g., production rates for some of the cosmogenic isotopes and the nature of their calibration), rock varnish cation-ratio dating of the boulder deposits was identified as an acceptable technique, because it satisfied the criteria for selection (i.e., it provided surface exposure ages of hillslope features), it was able to date 100 ka to 2000 ka deposits, it could date bouldery deposits, and it was useable on any fine-grained volcanic rock such as basalts and tuffs.

4.3.2.2 Calibration of the Cation-Ratio Dating Technique

Cation-ratio dating is a calibrated technique that uses the chemistry of rock varnish formed on geologic features of known age to establish a calibration of varnish chemistry to varnish age. Rock varnish formation involves complex depositional and diagenetic processes that result in stratigraphic variations in rock varnish chemistry (Reneau et al., 1992). Other calibrated techniques commonly used in Quaternary studies, include soils-dating techniques such as the Harden Index, carbonate accumulation in soils, and techniques that utilize the sequential development of a feature or set of geomorphic features through time.

For the rock varnish dating curve for the Yucca Mountain area, surfaces dated by other techniques provide the necessary calibration (Harrington and Whitney, 1987). Lava flows in Crater Flat with K-Ar ages in excess of 500 ka were used to calibrate the older part of the rock varnish dating curve. The K-Ar dating technique (see section by Damon, in Rosholt et al., 1991), yields the time of lava flow formation, and the chemistry of rock varnish that has formed on exposed lava flow rock surfaces is calibrated to this K-Ar age of lava flow formation. Volcanic features less than 500 ka were not used for calibration because of the controversy as to the reliability of K-Ar ages determined for younger volcanic features in the Yucca Mountain area (Crowe et al., 1992). Uranium-trend ages (see Szabo and Rosholt, 1991, for details of the uranium-trend dating method) of alluvial surfaces were used for calibrating that part of the curve within the period from 40 to 500 ka. The uranium-trend dating technique yields the time of carbonate deposition in the sedimentary material. Uranium-trend ages were used for calibration only where the deposits had been dated more than once with resultant comparable ages being obtained.

Rock varnish age estimates have been evaluated within the geologic context and constraints of two study areas, the Española basin in New Mexico (Dethier et al., 1988) and the Yucca Mountain area. In the Española basin, the rock varnish age estimates were compared to amino acid racemization ages of deposits underlying the rock varnish covered surfaces and were found to be comparable and slightly younger than the ages of the underlying deposits. Additionally, a rock varnish age estimate of 550 ka (Dethier et al., 1988) was obtained for an alluvial fan surface in the Española basin overlying deposits containing the Lava Creek B tephra (620 ka) and therefore representing an event happening more recently than deposition of the volcanic ash. This also supports the contention that the rock varnish age estimates are geologically reasonable.

In the study area in southern Nevada, similar geologic comparisons were made and it was noted that varnish thickness is greatest on the deposits that yield the oldest age estimates and that the thickest carbonate soil horizons are likewise noted in the deposits with the oldest estimated ages (Whitney and Harrington, 1993). Finally, rock varnish on a surface in Las Vegas Wash yields a 600-ka age estimate and is underlain by deposits that contain the Lava Creek B tephra (620 ka) at a depth of 2 m (DOE, 1993). Thus, it is believed that the Yucca Mountain rock varnish age estimates are reasonable when placed within the geologic constraints of the area. There are no noted examples where geologic constraints conflict with rock varnish age estimates.

4.3.2.3 Age Estimates of Varnished Boulder Deposits

Twelve colluvial boulder deposits were sampled for cation-ratio dating on the north, east, and west flanks of Yucca Mountain, the southwest flank of Skull Mountain, and the northeast flank of Little Skull Mountain and on Buckboard Mesa. Colluvial boulder deposits sampled on Yucca Mountain include: one about 100 m above the base of the slope on the north flank (YMN-1) (see Figure 4.3.2.3-1); one 50 m below the ridge crest (YMW-1); two laying 20 to 40 m above the base of the west flank (YMW-2 and YMW-3); one near the crest of the east flank (YME-1); and one about 15 m above the base of Boundary Ridge (YME-2), a ridge spur projecting from the east flank. A colluvial boulder deposit was also sampled in Skull Mountain Pass 20 m above the base of the slope comprising the northeast flank of Little Skull Mountain (LSM-1). Three additional deposits were sampled along the lower slope on the south and southwest flank of Skull Mountain (SKM-1, SKM-2, SKM-3, and SKM-3A). Sample SKM-3 was collected from the toe and SKM-3A from the upper part of a large boulder deposit of more than 50 m in length. A boulder deposit was also sampled on the lower slopes of Buckboard Mesa north of Yucca Mountain (BM-1). Sample preparation and analysis are discussed in Harrington and Whitney (1987), DOE (1993), and Whitney and Harrington (1993).

The estimated age of a boulder deposit is obtained by plotting the scanning electron microscope-derived cation ratio on the Y-axis (ordinate) and then using the rock varnish dating curve to establish the corresponding geologic age estimate on the X-axis (abscissa) (Table 4.3.2.3-1). The range in age, representing the estimated age uncertainty (last column, in brackets, Table 4.3.2.3-1) is calculated by first, subtracting the cation ratio uncertainty from the cation ratio for a deposit (yields minimum age) and secondly, adding the cation ratio uncertainty to the deposit cation ratio (yields maximum age) and plotting these values on the cation-ratio dating curve for Yucca Mountain. A conservative approach has been incorporated in the use of age estimates and in calculation of erosion rates because the minimum age of the age range (last column, in brackets, Table 4.3.2.3-1) is used in the calculation of erosion rates. Because the oldest boulder deposits most closely reflect the maximum age of the surface, these oldest deposits were dated to ensure that the age of the

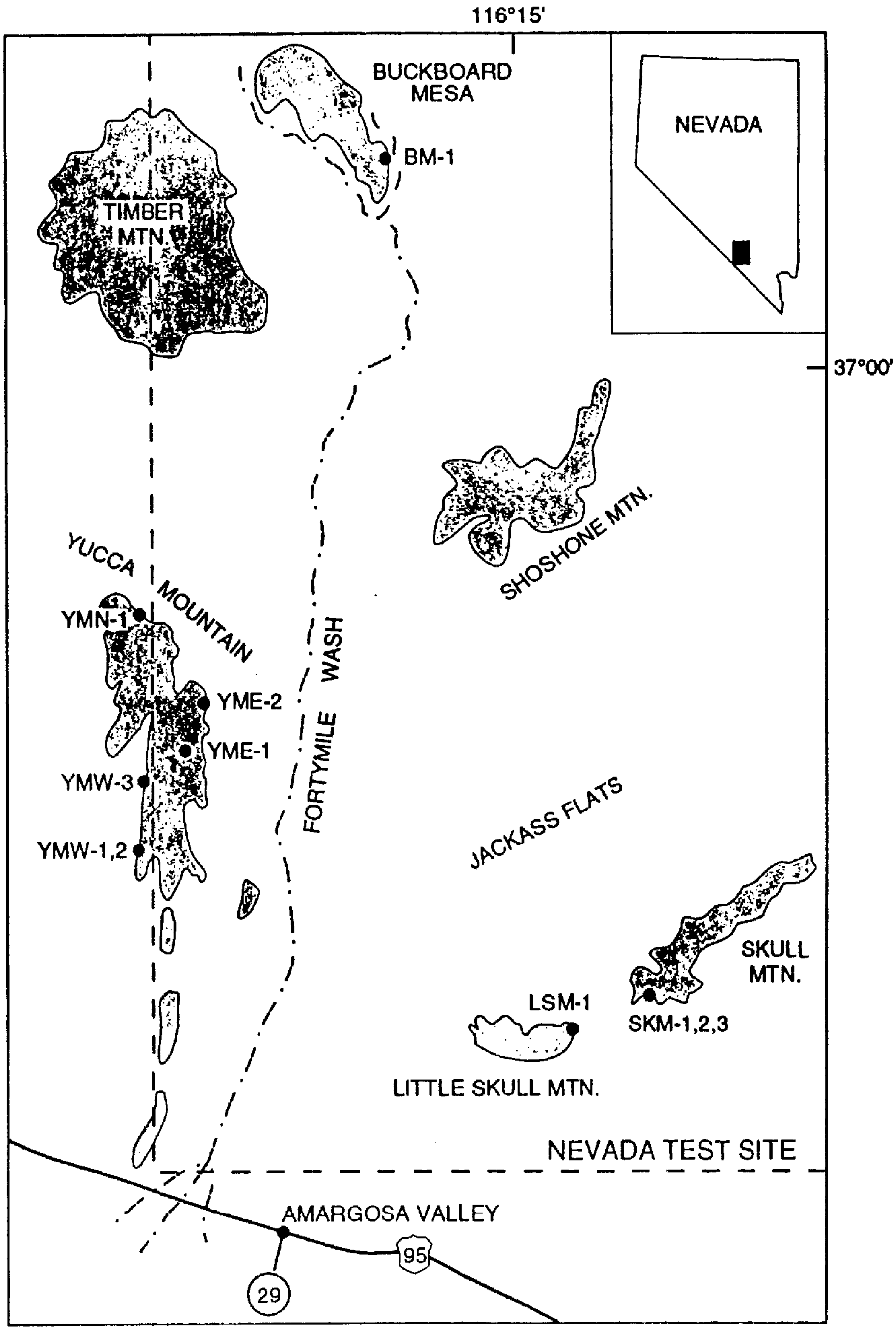


Figure 4.3.2.3-1 Location map of boulder deposit sample site locations

Table 4.3.2.3-1 Varnish Cation Ratios and Estimated Ages of Colluvial Boulder Deposits of the Yucca Mountain Area (after DOE, 1993)

SAMPLE LOCATION	SAMPLE NUMBER	NUMBER OF ANALYTICAL SITES (n)[1]	CATION RATIO	CALCULATION OF UNCERTAINTY 1 Scr[2]	95%CL[3]	ESTIMATED AGE (ka) AND AGE UNCERTAINTY
Yucca Mountain						
East Flank	YME-1	55	2.99	0.19	0.05	640[610-970]
Boundary Ridge	YME-2	80	4.52	0.55	0.12	170[140-180]
West Flank (1)	YMW-1	55	3.34	0.47	0.13	465[400-515]
West Flank (2)	YMW-2	40	2.97	0.08	0.03	645[630-660]
West Flank (3)	YMW-3	65	2.88	0.19	0.05	710[680-740]
North Flank (1)	YMN-1	40	2.79	0.27	0.09	760[710-820]
Little Skull Mt.	LSM-1	160	2.52	0.21	0.03	960[930-990]
Skull Mountain						
Skull Mountain (1)	SKM-1	45	2.74	0.21	0.06	800[760-830]
Skull Mountain (2)	SKM-2	30	2.68	0.16	0.06	830[800-880]
Skull Mountain (3)	SKM-3	35	2.28	0.26	0.09	1180[1110-1270]
Skull Mountain (3A)	SKM-3A	50	2.49	0.11	0.03	990[960-1030]
Buckboard Mesa	BM-1	40	2.09	0.35	0.11	1380[1260-1510]

NOTES:

1. (n) = Number of SEM analytic sites per geomorphic surface.
2. Scr = Standard deviation calculated for the mean cation ratio for a surface.
3. 95%CL = 95% Confidence level for the mean cation ratio for a geomorphic surface calculation using formula of Bierman et al., 1991.

surface was not underestimated. However, to ensure conservatism in the erosion rate calculations, minimum ages, from the range of estimated ages (i.e., the youngest of the oldest), were used.

The estimated ages derived from the varnish cation ratios in Table 4.3.2.3-1 indicate that colluvial boulder deposits on hillslopes in the Yucca Mountain area have considerable antiquity. The estimated ages of boulder deposits in this study range in age from early to middle Pleistocene, the oldest being nearly 1.4 Ma. This deposit is the oldest dated hillslope deposit in the southwestern United States. The range in ages of these boulder deposits (170 ka to ~1400 ka) spans at least 75 percent of the Quaternary Period and is the longest Quaternary hillslope geologic record yet constructed for areas in the southwestern United States.

The oldest dated deposits on the slopes of Yucca Mountain range from 640 ka on the east slope to about 760 ka on the north flank. Older deposits occur on steeper slopes (up to 31°) at Skull Mountain and Buckboard Mesa. The antiquity of these bouldery deposits indicates that even on the steepest slopes of the Yucca Mountain area, hillslope erosion has been remarkably ineffective at removing hillslope colluvium during the Quaternary.

The youngest episode of colluvial boulder stabilization identified in this study (YME-2; see Figure 4.3.2.3-1 for sample locations) is estimated to have occurred near the end of the middle Pleistocene at about 170,000 years ago. Varnish cation ratios of older deposits on the east and west flanks of Yucca Mountain (YME-1, YMW-2, and YMW-3) are remarkably similar, and indicate that these deposits may have stabilized during one period at around 650,000 years ago. Varnish cation ratios of two colluvial boulder deposits on Skull Mountain (SKM-1 and SKM-2) closely correspond and are nearly the same as that for the deposit on the north flank of Yucca Mountain (YMN-1), indicating that these three deposits formed during an earlier episode of colluvial boulder deposition around 800,000 years ago. Similarity of varnish cation ratios for two even older deposits on Skull (SKM-3) and Little Skull (LSM-1) mountains could represent a fourth episode of stabilization about 1 Ma. A fifth and earlier episode of hillslope deposit stabilization is indicated, at about 1.3 Ma, by the similarity of varnish cation ratios for the oldest boulder deposits on both Skull Mountain (SKM-3A) and Buckboard Mesa (BM-1).

Rock-varnish dating indicates that extensive bouldery hillslope mantles are composed of colluvial boulder deposits of varying age. The varnish cation ratios from the Skull Mountain boulder deposit (SKM-3 and SKM-3A) suggest that the toe of the deposit was emplaced earlier than the clasts that now form the upper part of the deposit. Sample YMW-1 is situated about 35 m upslope from, and has a higher cation ratio than, sample YMW-2 on the west slope of Yucca Mountain. Although too few deposits have been dated to demonstrate it statistically, the clustering of the boulder deposit age data indicate that the processes of boulder production and stabilization are episodic and that boulder deposits have formed at several and probably many times during the Quaternary Period.

4.3.3 Corroborative Quaternary Dating Evidence

Whitney and Harrington (1993, p. 1014) also sampled three darkly varnished boulders from the toe of the Buckboard Mesa varnish cation ratio-dated colluvial boulder deposit (site BM-1 on Figure 4.3.2.6-1) for surface exposure dating using cosmogenic ^{36}Cl. This method is discussed by Phillips et al. (1986). Whitney and Harrington's estimated ages range from 600 ka (+71/-59 ka) to 310 ka (+26/-22 ka) for the samples. However, they note that the ^{36}Cl accumulation in rocks is calibrated in radiocarbon years which when adjusted will increase calculated ages by about 10 percent. Additionally, the oldest sample has a measured ^{36}Cl content of greater than 92% of the saturation value. Because this sample is close to the theoretical saturation, the sample may represent the highest maximum ^{36}Cl concentration effectively measurable. The age estimate may represent the practical upper limit of this dating technique and not closely limit the age of the deposit (Whitney and Harrington, 1993, p. 1014). It should be noted however, that even if the 310 ka age estimate were to be accurate for the Buckboard Mesa deposits, when this value is factored with the maximum channel incision of 0.3 m, it results in a calculated long-term channel incision rate of slightly less than 0.1 cm/Ka.

Additional corroborative investigations using cosmogenic dating techniques are in progress.

4.3.4 Corroborative Geomorphic Relationships

Another indication of low erosion rates in the Yucca Mountain vicinity is provided by the Lathrop Wells cinder cone. Wells et al. (1990) document that the Lathrop Wells cinder cone has undergone little erosional modification. They state ". . .the Lathrop Wells cone has the maximum cone slope, apparently no apron development and shows no erosional modification of the cone flanks and crater. . ." and "Very shallow discontinuous rills occur on the southwestern cone flank and within the crater, whereas the older cones of the Crater Flat area display deep gullies with inset fills, integrated channel networks, and aprons with well-developed soils." The age of the Lathrop Wells volcanic deposits is the subject of current debate. Based on the geomorphic evidence and comparison of the cone with others in the Cima volcanic field, the Lathrop Wells cone has been estimated as being less than 20 ka (Wells et al., 1990; Crowe et al., 1988). However, some studies have indicated that the cone may not have been formed by polycyclic eruptions (Champion, 1991) and may be 130 ka (Turrin and Champion, 1991). Whether the cone is less than 20 ka or approximately 130 ka, the minor amount of degradation that it has undergone accentuates how minor erosion is in the Yucca Mountain area.

An evaluation of the age of scarps along the southern part of the Solitario Canyon and northern Windy Wash fault traces has been carried out (Harrington et al., 1994). These scarps have been found to be exhumed bedrock fault scarps dating back at least to the latest Pleistocene and are not the result of recent tectonism. These scarps separate faulted bedrock from hillslope colluvium, have slope angles of 70 to 80°, and range in height from <0.5 m to 2.5 m (Harrington et al., 1994). A minimum age for these scarps was determined using cosmogenic ^{14}C to date rock samples collected from near the top and at the base of the scarp face at four sites along each scarp. Additional samples were collected from the middle of the scarps at sites where scarp height was greater than 1 m. Results of analyses indicate that nearly all samples are saturated with respect to cosmogenic ^{14}C. Since saturation is achieved at approximately 20 ka, the scarps have a surface exposure age greater than 20 ka. Both scarps each had one basal sample which yielded ages significantly younger than 20 ka, suggesting that localized erosion at the base of the scarp occurred at these sites during the Holocene. The samples at the base of the scarp at the three other scarp sites on both the Solitario Canyon and Windy Wash faults yielded saturated ^{14}C values which led Harrington et al. (1994) to conclude that the scarps have not been enhanced by coseismic surface rupture during the last 20,000 years. Study of the geomorphic field relationships along the scarps supports the conclusions reached through cosmogenic dating, that differential hillslope erosion was responsible for exposure of the scarps by exhumation of siliceous Tertiary fault breccias (Harrington et al., 1994). These data are supportive of conclusions that bedrock hillslope erosion rates at Yucca Mountain are among the lowest in the world. The basis for this conclusion is that the cosmogenic isotopes indicate that the tuffaceous bedrock scarps have been exposed at the surface for greater than 20,000 years and exhibit little geomorphic modification.

4.3.5 Analytical Uncertainty in the Quaternary Geochronologic Framework

Bierman et al. (1991) note that the uncertainty in a calculated mean cation ratio for a geomorphic surface is a function of the number of analyses that are used to calculate the mean cation ratio. Cation ratios that incorporate fewer than five analyses have a significantly higher uncertainty than that of one standard deviation calculated for a cation ratio. In the analyses of colluvial boulder deposits between 30 and 160 varnish sites for each deposit being dated have been analyzed. The magnitude of the uncertainty at a 0.95 probability in calculated cation ratios varied from a maximum of 0.127 (compared to one standard deviation of 0.47 calculated for the same cation ratio) to a minimum of 0.026 (compared to one standard deviation of 0.08). In this study, the uncertainty in the estimated ages of boulder deposits (Table 4.3.2.6-1) is reported using the technique of Bierman et al. (1991), because it is a more accurate measure of the true uncertainty of a calculated cation ratio than the uncertainty measured as one standard deviation. The age estimates and uncertainties are calculated using the cation-ratio curve for Yucca Mountain (Whitney and Harrington, 1993).

Although more data points might reduce the curve uncertainty to a minor degree, the concentration of data points is adequate to establish a calibration curve. Most age estimates for the boulder deposits in this report are derived from within the calibrated interval of the dating curve (11 of 12 deposits). The remaining point lies in immediate proximity to the calibrated interval. Any additional reduction in the uncertainty of the curve that could be obtained with the addition of a greater number of calibration points would not affect any of the technical conclusions in this report that are based on the dating curve.

4.4 EROSION RATES AT YUCCA MOUNTAIN

4.4.1 Methodology to Calculate Erosion Rates

To establish erosion rates at Yucca Mountain, it is first necessary to establish the age of those landscape features to be used in determining erosion rates. Any geomorphic rate can then be calculated using the following standard formula:

Process Rate(R) = Process Magnitude(M)/Time Process Operative(T)

Thus, to calculate erosion rates (R) a dated surface must be available to provide the time (T) over which the process has been operative. The magnitude of erosion (M) can be measured as the distance between this dated surface and the present surface.

4.4.2 Hillslope Erosion Rates at and near Yucca Mountain

For deposits on mid to lower hillslopes, long-term Quaternary erosion rates have been calculated for the hillslopes on which the colluvial boulder deposits occur. The surface of the oldest dated boulder deposit on a hillslope was used to define the topography that existed when the boulders were deposited and rock varnish began forming. The erosion that has occurred on the hillslope since that time was measured as the perpendicular distance between the modern hillslope and the top of relict hillslope deposits. The level of the paleohillslope was assumed to be represented by the surface of the relict boulder deposit and incision or degradation was measured below this surface. Because colluvial boulder deposits commonly possess a lenticular cross-section shape, it is believed that these colluvial deposits were deposited in and filled topographic lows and hollows, and spilled over onto adjacent slopes; this assumption maximizes the erosion rate. At present, these boulder deposits form slight topographic highs, commonly 0.5 to 1 m above bedrock (or thinly mantled) hillslopes. Amounts of erosion were measured in channels on mid and lower hillslopes which are areas of maximum hillslope erosion. Data from upper hillslopes, areas in which no evidence of erosion was found, were excluded from erosion rate calculations. As the channels are zones of maximum erosion, measurements of process magnitude made in these channels ensured that rate calculations were likely to overestimate the amount of overall slope degradation and were, therefore, conservative.

Measurements were made of depth of maximum incision in drainage channels marginal to these deposits and the average hillslope degradation was measured over the slope, 50 m to each side of the deposit. The 50 m distance was chosen to: (1) incorporate a large enough area so as to minimize the effect of incised channels marginal to the deposit and other local hillslope irregularities; and (2) not extend into the zone of effects of adjacent deposits or associated incised channels. The calculated rate of degradation does not factor in upper hillslope deposits where little, if any, erosion has occurred and may therefore overestimate the amount of hillslope degradation when averaged over the entire hillslope. General hillslope degradation on Yucca, Skull, and Little Skull mountains and Buckboard Mesa averages less than 1 m below colluvial boulder deposits that range from 170 ka to more than a million years old, attesting to the very low rates of hillslope erosion that has occurred in the Yucca Mountain area during the Quaternary Period.

Long-term, average hillslope erosion rates have been calculated for the Yucca Mountain area from the dated hillslope boulder deposits. These rates range from less than 0.1 to 0.6 cm/ka and average less than 0.12 cm/ka (Table 4.4.2-1). Erosion rates for the hillslopes on Yucca Mountain are also very low, averaging less than 0.19 cm/ka (Table 4.4.2-1). This rate is considered to be a maximum rate because in situ boulder deposits are found on several Yucca Mountain ridges that are well varnished and show no signs of significant movement resulting from hillslope erosion since they were formed.

4.4.3 Channel Erosion Rates

4.4.3.1 Stream Incision Rates on Fortymile Wash

Fortymile Wash continues south from Timber Mountain along the east side of Alice and Fran Ridges and Busted Butte, and across this section is incised 15-20 m into a low-gradient alluvial fan complex derived primarily from the Calico Hills. The channel shallows

Table 4.4.2-1 Hillslope Degradation Rates and Characteristics of Colluvial Boulder Deposits in the Yucca Mountain Area (from DOE, 1993)

DEPOSIT	SLOPE OF DEPOSIT (degrees)	EXPOSED DEPOSIT THICKNESS (meters)	MAXIMUM CHANNEL INCISION (meters)	AVERAGE HILLSLOPE DEGRADATION (meters)	ESTIMATED AGE (1000 years) [age range]	LONG-TERM AVERAGE HILLSLOPE DEGRADATION RATE[4] (cm/ka)
Yucca Mountain						
East Flank Yucca	21-28	1.4	<0.4[2]	<0.2	640[610-970]	0.033
Boundary Ridge	23	>0.5	1.0[2]	0.8	170[140-180]	0.571
West FlankYucca (1)	31	0.4	<0.3[2]	0.2	465[400-515]	0.050
West FlankYucca (2)	28	2.4	1.3[3]	1.1	645[630-660]	0.175
West FlankYucca (3)	27-31	0.6-2.1	2.8	1.1	710[680-740]	0.162
North FlankYucca	25	>1.6	1.6[1]	≤1.0	760[710-820]	0.141
Little Skull Mt.	15	0.9	0.9	0.3	960[930-990]	0.032
Skull Mountain						
Skull Mountain (1)	32	1.6	2.0[3]	≤1.0	800[760-830]	0.132
Skull Mountain (2)	31	0.8	1.8	<0.5	830[800-880]	0.063
Skull Mountain(3)	30	0.7	2.8	<0.3	1180[1110-1270]	0.027
Skull Mountain (3A)	19	1.0	1.5[1]	≤0.5	990[960-1030]	0.052
Buckboard Mesa	32	1.2	0.3	<0.2	1380[1260-1510]	0.016

Average rate for Yucca Mountain ≤ 0.19 cm/ka
Average rate for Yucca Mountain region ≤ 0.12 cm/ka

1 Channel not cut into bedrock
2 Channel poorly defined or non-existent
3 Maximum depth of "stairstep" channel; maximum depth is not continous
4 Rate calculated = average hillslope degradation divided by the youngest estimated age. Age estimates are based on varnish cation ratios.

downstream from Busted Butte until it merges with the alluvial fan surface 23 km to the south of Busted Butte. Inset below the alluvial fan surface are several alluvial fills that underlie stream terraces that formed along this section of the wash in response to major Quaternary climate changes. Evolution of the Fortymile Wash drainage system is discussed in Section 2.5.1.

Fluvial activity since the middle Quaternary (<128,000 years ago) in Fortymile Wash and its principal tributaries has been limited to aggradation and re-entrenchment through its own alluvial fill. During the past half million years, four stream terraces have formed in Fortymile Wash. Remnants of this terrace sequence are preserved east of Alice Ridge. The ages of these deposits are discussed in Hoover (1989) and Taylor (1986).

Dating of the alluvial materials that directly underlie these terrace surfaces indicates that maximum aggradation of Fortymile Wash that occurred during Quaternary time culminated in the formation of the highest terrace along the wash (28 m above the modern valley floor; see Figure 4.4.3.1-1). Deposits that underlie this oldest terrace have been correlated to other deposits dated at about 430 ka (see Szabo and Rosholt, 1991). Since the formation of the highest (oldest) terrace surface, two other terraces have been formed, each as a result of channel incision and some amount of subsequent aggradation. Deposits that directly underlie the main, or most extensive, terrace surface (25 m above the valley floor) correlate to deposits dated at about 270 ka (see Szabo and Rosholt, 1991). The next younger terrace is about 10 m above the present channel and is underlain by alluvium that correlates to deposits dated at about 150 ka. The lowest (youngest) terrace is situated just above the active floodplain/channel of the wash and is of Holocene age. The depth of the alluvial fill below the modern channel of Fortymile Wash, as measured at UE-25 J#13 (Thordarson, 1983) across from Busted Butte, is 108 m, although the number, thicknesses and ages of the fills that comprise this sequence are unknown. Therefore, the depth from the 270 ka terrace surface to the bottom of the alluvial fill as measured at UE-25 J#13 is 133 m.

Long-term (average) stream incision rates on Fortymile Wash can be calculated by: (1) comparing the differences in elevation of the dated terrace surfaces along the wash; and (2) comparing the terrace surfaces to the base of valley alluvium as defined in boreholes. Wells UE-29A#l and UE-29A#2 are located in Fortymile Canyon about 15 km upstream from Fran Ridge. These wells were drilled to bedrock from the surface of the main, 270,000 year old alluvial fill. The thickness of this fill is only about 20 m and no younger alluvial terrace is present at this locality. If the downcutting assumption is made that incision of the 20 m of fill occurred in half the time interval from 270,000 years ago to present and aggradation of the new younger fill occurred during the other half of this time interval, then Fortymile Wash would have a long-term average incision rate of about 15 cm/ka in this upstream segment of Fortymile Canyon.

About 30 km downstream, near Highway 95, the channel of Fortymile Wash merges with the general alluvial plain of the Amargosa Desert. No canyon or record of Quaternary downcutting exists at this locality; thus, the lower reaches of Fortymile Wash appear to have been primarily in a state of aggradation for much of the Quaternary Period.

Two scenarios can be hypothesized for the Quaternary evolution of the terraces along the middle section of the wash from Fran Ridge downstream to Busted Butte, and the implication for incision rates along the wash. These scenarios are graphically represented in

Figure 4.4.3.1-1. A theoretical maximum incision scenario proposes that between the formation of any two sequentially dated terraces (e.g., the 430,000-year-old and the 270,000-year-old terrace, or the 270,000-year-old and the 150,000-year-old terrace), Fortymile Wash first incised to the base of the alluvial fill before aggrading back to the next younger terrace level. A minimum incision scenario for valley evolution hypothesizes that each episode of incision was to a level below, but not far below, the next lower terrace and the subsequent aggradation resulted in only a thin (3-8 m) new fill underlying each terrace surface. Use of the theoretical maximum incision for valley evolution results in the calculation of maximum possible incision rates for Fortymile Wash, whereas utilization of the minimum incision scenario would result in significantly lower incision rates calculated for Fortymile Wash east of Fran Ridge.

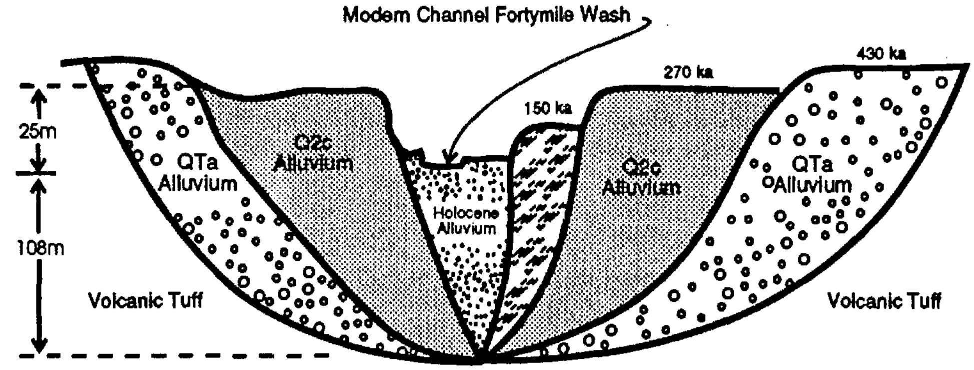
A maximum, long-term average downcutting rate on Fortymile Wash was calculated for the time interval between formation of the main terrace at 270,000 years ago and the formation of the lower terrace at 150,000 years ago, by assuming the wash cut down to the base of the valley fill (a total depth of 133 m) before aggradation filled the valley back to the 150,000 year old terrace level. It was further assumed, for the worst case assumption, that the downcutting took place during the first half of that time interval (270,000 - 150,000 years ago) and aggradation of the channel occurred during the second half of the time interval. Therefore, Fortymile Wash would have downcut 133 m in 60,000 years, or at an average incision rate of 222 cm/ka. A slightly lower incision rate is obtained if the terraces used in the worst case scenario are either the 150,000-year-old and Holocene terraces or the 430,000 and the 270,000-year-old terraces.

Several arguments suggest that the maximum incision scenario is not feasible. Cross-channel geometry of the existing terraces suggests that the banks would become oversteepened by incising a channel 133 m deep into Fortymile Wash. The major tributaries of Fortymile Wash are accordant junctions, currently entering at grade. If the main channel of Fortymile Wash had incised 133 m deeper, this would have lowered the base level for the tributaries. A lowered base level for the tributaries would have accentuated erosion in the tributaries and their tributaries. Current evidence of such a previous episodic erosional event (e.g., headcuts, knickpoints, stripping of surface alluvium/colluvium) is not observed. Evidence indicates that Fortymile Wash has been aggrading during the Quaternary. Although this maximum incision scenario is recognized as apparently not being feasible, this scenario is included as a maximum bounding calculation.

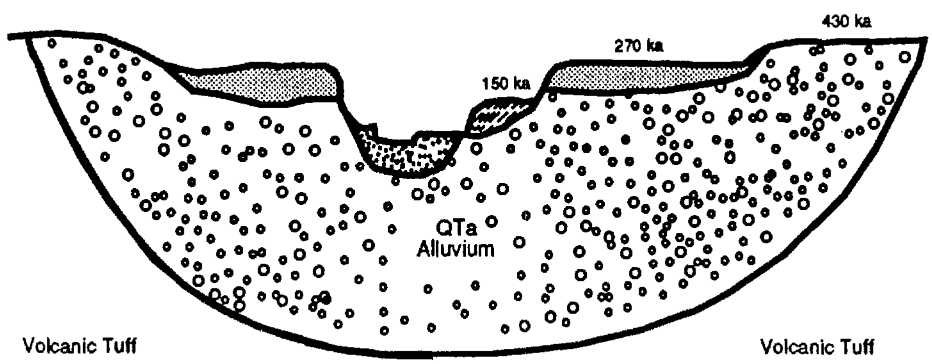
If the minimum incision scenario is used and if: (1) incision is assumed not greatly to exceed the vertical distance between sequentially developed terrace surfaces; and (2) incision occurred during half of the time interval between terrace formations, then a minimum incision rate of 42 cm/ka (25 m in 60,000 years) is calculated.

The low rates of channel incision calculated for the wash both upstream and downstream from the Fran Ridge-Busted Butte segment of the wash support a downcutting history through the midsection of the wash that closely approximates the minimum calculable incision rate scenario. Additionally, the well-defined incision along this middle segment of Fortymile Wash did not migrate upstream to the tributaries on Yucca Mountain located above the proposed repository block. In fact, only minor incision is observed in Midway Valley west of the Fortymile Wash terraces. Therefore, incision rates on Fortymile Wash cannot be used to describe or predict stream incision in small canyons on Yucca Mountain.

Stream Incision Scenario For Fortymile Wash



A maximum incision scenario assumes Fortymile Wash incised from the 270 ka terrace to the base of the valley fill (133m) in 60,000 years, before aggrading to the 150 ka terrace level.



A minimum incision scenario implies the basic alluvial fill was deposited before 430 ka and episodic downcutting since then has not resulted in the formation of any subsequent thick fills.

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Figure 4.4.3.1-1 Stream incision scenario for Fortymile Wash (from DOE, 1993)

That long periods of protracted downcutting at high incision rates have not occurred in Fortymile Wash is proven by the fact that Fortymile Wash has not excavated down to its former valley floor of nine million years ago. Assuming our theoretical high incision rate of 222 cm/ka, the wash could potentially have cut down to its former valley floor (at a depth of 178 m) in about 80,000 years. As stated above, the primary process occurring along Fortymile Wash during the Quaternary has been aggradation, not degradation.

4.4.3.2 Other Channel Erosion Rates

Lundstrom and Warren (1994a) suggest that the 2.8 Ma basalt flows of Buckboard Mesa are emplaced with basal elevations parallel to slope and about 100 m above modern Fortymile Wash. This indicates that the Fortymile Wash drainage system was well established in the Pliocene, and Lundstrom and Warren (1994b) suggest an average bedrock incision rate of 3.6 cm/ka along Fortymile Canyon based on incision of 100 m in 2.8 million years..

Several narrow canyons exist on the land surface within the boundaries of Yucca Mountain. These canyons descend east from the main ridge of Yucca Mountain and contain small first and second-order streams that drain into Midway Valley, which in turn drains into Fortymile Wash. The bedrock surface into which these small canyons were incised is formed of the 12.7-Ma Tiva Canyon Tuff. The canyons decrease from 100 m to 60 m deep eastward, which translates into a maximum average canyon-cutting rate of about 0.8 cm/ka through bedrock.

4.6 COMPARISON OF YUCCA MOUNTAIN EROSION RATES WITH OTHER SEMIARID ENVIRONMENTS

Rates of hillslope erosion are related to local relief, climate, the type of rock undergoing erosion, and its degree of resistance to the erosional process. Fine-grained igneous rocks are more resistant to erosion and chemical weathering in dry environments than other common rock types. In contrast, areas that are formed on: (1) unconsolidated or lacustrine sediments; (2) shale, siltstone or poorly cemented sandstones; and (3) limestones, especially in more humid environments, are generally not resistant to erosion. DOE (1993) tabulates hillslope degradation rates from several regions around the world (Table 2 in DOE, 1993) and from different climatic environments within the United States (Table 3 in DOE, 1993).

The lowest hillslope erosion rates are found in areas that possess a combination of several favorable characteristics: (1) a dry climate, because there will be a lack of surface runoff and insufficient water for effective physical and chemical weathering to occur; (2) rocks that are resistant to erosional processes, most commonly this means that quartz-rich rocks or fine-grained volcanic rocks like tuff or basalt are present; and (3) areas with low rates of tectonic activity, because tectonism will increase the local relief and increase the effectiveness of erosional processes that are enhanced by gravitational forces. Yucca Mountain possesses several of the conditions that favor low erosion rates. These are: (1) a dry climate with less than 250 mm/year of rainfall; (2) fine-grained, quartz-rich volcanic tuffs, strengthened by welding of many of the tuff units; and (3) low rates of tectonic activity during the Quaternary. Therefore, long-term, low rates of hillslope erosion are an anticipated characteristic of the Yucca Mountain area.

The lowest erosion rates noted for various areas around the world are in the tectonically stable Australian shield region. This region also possesses a dry, semiarid climate and erosionally resistant quartz-rich rocks. Erosion rates from this region of Australia (0.2-0.3 cm/ka) are nearly the same as hillslope erosion rates at Yucca Mountain (0.19 cm/ka, Table 4.4.2-1).

Long-term average erosion rates for the United States, including a variety of climates and diverse rock types are 2.5-15 cm/ka. Hillslope erosion rates at Yucca Mountain (0.19 cm/ka, Table 4.4.2-1) are at least two orders of magnitude lower than this average. Published long-term erosion rates for areas of New Mexico and California that possess dry climates, range from 1.0-4.3 cm/ka on hillslopes underlain by resistant rock types. Hillslope erosion rates at Yucca Mountain are an order of magnitude lower than rates in these areas. Erosion rates similar to Yucca Mountain (less than 0.8 cm/ka) have been calculated in the arid southern Mojave Desert (Oberlander, 1972 and 1974) on quartz-rich, granitic terrain.

The preservation of middle Quaternary deposits on Yucca Mountain indicates that there has been insufficient runoff during interpluvial climates to remove bouldery colluvium from hillslopes. The lack of young bouldery colluvium on these slopes also suggests that pluvial climates during the late Quaternary have not been cold enough to physically produce large volumes of debris. Thus, the low rates of erosion are in part due to relatively small fluctuations in climate at Yucca Mountain during the late Quaternary.

The field measurements made to calculate the amount of hillslope degradation reported in Table 4.4.2-1 assume that the top of the measured hillslope deposits represent the average land surface position at the time they were emplaced. Alternative hillslope erosion rates can be calculated from hypothetical models that assume the general hillslope surface may have possessed two to three times greater relief than the low-relief model assumed in this study. There is, however, no field geomorphic evidence to support a hypothesis of such an increase in hillslope relief during the early to middle Quaternary. Boulder-mantled hillslopes probably possessed less relief than that on the modern hillslope because boulder deposits formed during periods of hillslope aggradation would result in reduction of general hillslope relief by filling in the drainage channels on the hillslope.

If it is assumed that the ancient land surface had two to three times greater relief than the modern hillslope, then the hillslope degradation rates would still increase to no more than 0.6 cm/ka (three times the average degradation rate of 0.19 cm/ka calculated for Yucca Mountain hillslopes), and this still constitutes a very low erosion rate.

4.7 SUMMARY OF YUCCA MOUNTAIN EROSION RATES

Long-term, average erosion rates have been calculated from dated hillslope deposits. These rates range from less than 0.1 cm to 0.6 cm/ka for hillslopes in the Yucca Mountain area. Erosion rates on Yucca Mountain hillslopes are very low, averaging 0.19 cm/ka. This average rate is only this high because the erosion rate determined for the Boundary Ridge location is much higher than the individual rates determined from all other locations sampled. This rate is considered to be a maximum rate because in situ boulder deposits are found on several Yucca Mountain ridges that are well varnished and show no signs of significant movement by hillslope erosion since they were formed. The degradation rate for slopes in the Yucca Mountain area is slightly lower than for hillslopes on Yucca Mountain, averaging

0.12 cm/ka, because older deposits were found on hillslopes north and east of Yucca Mountain.

Two types of stream incision rates were calculated for the Yucca Mountain area alluvial deposits. Minimum and maximum hypothetical downcutting rates were constructed for Fortymile Wash on the basis of stream terrace elevations above the modern channel and the total thickness of alluvium in the valley. A minimum downcutting rate is about 42 cm/ka and the maximum is 222 cm/ka. The true long-term downcutting rate for the present incised wash is believed to be closer to the minimum rate because: (1) it is highly unlikely that the wash incised to bedrock during each downcutting episode; (2) headcutting from the main wash did not migrate upstream into Yucca Mountain tributaries; and (3) the overall behavior of Fortymile Wash during the Quaternary has been aggradation, not degradation.

Bedrock channel incision rates have been evaluated at Yucca Mountain and in Fortymile Canyon. Several small canyons are located above the potential repository block on Yucca Mountain. Each of these canyons is cut 60-100 m into 12.7 m.y. old volcanic tuff and they shallow eastward toward Midway Valley into which the canyons drain. Thus, the long-term incision rate for the first-order streams that cut the small canyons on Yucca Mountain is 0.8 cm/ka or less. The drainage system of Fortymile Wash and its tributaries was established in Miocene time and has changed little in basic plan since then with an average bedrock incision rate of 3.6 cm/ka along Fortymile Canyon and aggradation along Fortymile Wash during the Quaternary.

5.0 SUMMARY

The information on surficial geology and surface drainage of the Yucca Mountain Site along with detailed topographic maps will be used to evaluate if the surface facilities can be constructed on relatively flat and well-drained terrain given RAT. Currently planned locations for surface facilities are on alluvial surfaces and gently dipping bedrock surfaces located well above the ground-water table.

Documented occurrences of perched water in wells on or near the repository block are found at least 100 m below the current design level of the proposed repository. Small amounts of perched water near or in faults, fractures, or lithologic contacts may be encountered in the proposed repository. The currently planned portal and shaft sites are located outside of the flood-prone area for the PMF. Available data indicate that, to date, ground-water withdrawals have not impacted the water-level altitudes by causing any permanent drawdown. A modeling study also suggests that large quantities of ground water can be withdrawn without severely impacting ground-water level altitudes.

At the Yucca Mountain Site, the proposed repository can be located at least 200 m below the surface of the directly overlying ground surface. Studies of erosional processes at the Yucca Mountain Site suggest that the landscape at the Yucca Mountain Site has changed very little during the past several hundred thousand years due to erosion.

APPENDIX A

REFERENCES

APPENDIX A

REFERENCES

NOTE: Unless otherwise stated, refer to the latest revision or interim change of the referenced document.

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APPENDIX B

ACRONYMS AND ABBREVIATIONS

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DOE	U.S. Department of Energy
ESF	Exploratory Studies Facility
NTS	Nevada Test Site
OCRWM	Office of Civilian Radioactive Waste Management
PMF	probable maximum flood
YMSCO	Yucca Mountain Site Characterization Office