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Dr. John Trapp
USNRC
Div. Waste Management, NMSS
Washington, D.C. 20555

January 30, 1986

Dear John:

Attached find a preliminary draft of my report on Potential Erosion at the Yucca Mountain nuclear waste site. All sections are included except for the list of references. Please read and convey any comments you may have.

I don't mention the Penrose conference in the report because it was basically no help in the specifics of the report. However the overall aspects of the conference were definitely applied when preparing the report.

Sorry I can't join you next week in the field. Catch you next time.

Sincerely,

Rus

Charles (Rus) Purcell

To be read by ...

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POTENTIAL EROSION
AT THE YUCCA MOUNTAIN
NUCLEAR WASTE SITE

1st DRAFT

prepared for: U.S. Nuclear Regulatory Commission

prepared by: Charles (Rus) Purcell

January 1986

INTRODUCTION

This report on rates of erosion in the Yucca Mountain region in light of expected climatic changes in arid and semiarid regions. is in response to a letter of authorization dated March 5, 1985 from the Nuclear Regulatory Commission.

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This study was totally restricted to evaluations made from previously published material and furthermore, to the more recent of the published data. The report should not be considered an all inclusive research of the literature pertaining to the titled subject but an evaluation based on the most recent and readily available data. No primary data were collected for this report.

The Background section of the report presents data on Paleoclimate of the desert areas of the southwesterm United States and Erosion studies pertinent to arid-semiarid regions. The section on Erosion Potential at the Neveda Test Site (NTS) discusses the applicability of the background climatic and erosion data to the proposed Yucca Mountain Site, evaluates the existing data at the site, and recommends future work necessary to complete the assessment of erosion potential for Yucca Mountain. The report concludes with a brief Summary and a References/References Cited section.

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BACKGROUND

Paleoclimate

Paleoclimate reconstruction has been an important area of interest in the geologic, biologic, and ecologic sciences for years. Various types of approaches to estimating changes in past climates have been used. These include evaluations based on hydrologic budgets, macrofossils, cryogenic deposits, and snowline changes to name a few. From these various approaches come predictions of past climates, most pertaining to the Quaternary and some extending back into the late Tertiary. As would be expected, the degree of compatibility is small. For this paper we will concentrate on the paleoclimate estimated on primarily full glacial and pluvial times, as this should represent the time of maximum conditions in the past and can best be used to estimate maximum future conditions.

As previously stated, this report is not intended to be all inclusive but will present the most modern and the entire range of possibilities applicable to the NTS. For detailed listings and discussions of past background studies on paleoclimate refer to the appropriate sections of Mifflin and Wheat (1979), Spaulding (1983), Spaulding and others (1984), Wells and others (1984), and Winograd (1980).

A few selected examples of paleoclimate reconstructions are presented here to support the conclusions of this report. Mifflin and Wheat (1979)in their work on pluvial lakes and pluvial climates estimated that full pluvial climates were not much different that today and predict a sufficient increase in precipitation could be brought about by lowering mean annual temperature no more than 3 C. Bradley (1985) agrees that the modern climate is closer to full glacial climate than interglacial times and calls for little or no increase in precipitation with cooler temperatures for the Great Basin. Spaulding (1983) and Mifflin and Wheat (1979) both suggest that modern climates in northern Nevada approximate the pluvial climatic conditions in south-central Nevada. Winograd (1980) predicts on a basis of hydrologic studies that the climate was significantly wetter during the Pleistocene and especially between about 10,000 to 40,000 years ago and feels this was due to some type of combination of increased precipitation and decreased temperature. Expanding into more recent time periods, Cole (1985) and LaMarche (1973) suggest a cooler and sometimes wetter climate in the late Holocene. Spaulding (1983) in his work on macrofossils (packrat middens) has described the climate of the last 45,000 years as follows: 45,000 years ago is similar to todays climate in northern Nevada, with average annual temperatures about 2 C less than today; 18,000 years ago average annual temperatures about 6-7 C less than today with summer temperatures 7-8 C lower and winter precipitation 70% greater. However, this still leads to a average annual precipitation rate of about 40% greater than present conditions.

Although Spaulding (1983) and Mifflin and Wheat (1979) are in basic agreement on the pluvial climate of south-central Nevada being similar to modern nothern Nevada, their climatic reconstructions differ significantly with overall change in mean annual temperature and precipitation. Mifflin and Wheat (1979) estimated a temperature change about 3 C and increased mean annual precipitation of about 70%. Spaulding (1983) estimated 6-7 C increase in temperature and increase in mean annual precipitation of no more than 40%.

From this comparison it becomes obvious that quite a range exists in paleoclimate reconstructions. Mifflin and Wheat (1979) reviewed 27 references on pluvial climates and noted that only 2 works called for less than 3 C decrease in temperature while all the others called for changes in temperature greater than 5-6 C. Ranges from the literature predict mean annual temperature changes from as little as 2 C (Van Devender, 1973) to as much as 11 C (Galloway, 1970, 1983) with basically the entire range covered. Associated with the range of mean annual temperatures is the estimated range of increase of mean annual precipitation from

0mm (Brackenridge, 1978) to 250mm (Leopold, 1951) and estimates of from -20% (Galloway, 1970, 1983) to 100% (Antevs, 1952) of present precipitation.

Spaulding (1983) has divided the many studies of paleoclimatic reconstruction into three basic categories of pluvial climates: 1) mild-pluvial, 2) cold-dry, and 3) cold-pluvial (Table 1). Further variations can also be interpreted between the maximum pluvial and the present. Morrison (1964) suggests there is evidence, primarily based on paleopedologic data, suggestive of not only cool-moist periods but cool-dry and warm-moist conditions.

All the above paleoclimate reconstructions are based on climatic response to the volume of polar ice. Recently, based on his work in Searles Lake and the marine oxygen isotope record, Smith (1984) has suggested that some sort of global phenomena is responsible for climatic changes but not necessarily one that systematically affected the volume of polar ice. He suggests that the 413,000 year orbital eccentricity cycle may cause cyclical variations in global temperatures that could be partly expressed by changes in surface temperatures in all oceans and that these cycles influence the amount of precipitation reaching mid-latitude areas.

Whatever theory is preferred is presently unimportant. The importance of the reconstructions is best presented by Wells and others (1984) when they summarize by saying that whatever the specifics, there is general agreement that there was definitely a higher effective moisture in late glacial, pluvial, and Holocene time, than today.

Table 1 --*Paleoclimatic reconstructions for the Wisconsin maximum in the American West*
[$-\Delta T_a$, change, in degrees Celsius, in annual temperature; $-\Delta T_s$, change, in degrees Celsius, in summer temperature; $-\Delta T_w$, change, in degrees Celsius, in winter temperature; ΔP, change, in millimeters (mm), in annual precipitation; percent P, ΔP/modern P × 100]

Reference	Study area	Methods	$-\Delta T_a$	$-\Delta T_s$	$-\Delta T_w$	ΔP (mm)	Percent P
			Mild-pluvial reconstructions				
Antevs, 1952	Lake Lahontan, Nevada.	Hydrologic budgets	2.5 to 3	---	---	+80 to +160	+50 to +100
Broecker and Orr, 1958.	Lake Lahontan, Nevada.	Hydrologic budgets	5	---	---	+200	+80
Mifflin and Wheat, 1979.	Nevada, statewide.	Hydrologic budgets	3	---	---	---	[1]+68
Snyder and Langbein, 1962.	Spring Valley, Nevada.	Hydrologic budgets	[2]5	[3]7.2	---	+200	+67
Van Devender, 1973.	Western Arizona	Packrat middens	2 to 4	---	---	+120 to +220	---
			Cold-dry reconstructions				
Brakenridge, 1978.	Montana to Arizona (lat 45°40' N. to 33°22' N.).	Relict cirques and cryogenic deposits.	[4]8	[4]8	---	0	0
Galloway, 1970, 1983.	Southwestern United States.	Cyrogenic deposits	10 to 11	---	---	---	-20
			Cold-pluvial reconstructions				
Leopold, 1951	Lake Estancia, New Mexico.	Hydrologic budgets and snowline changes.	6.6	9	2.8	+180 to +250	+50 to +70
Spaulding, 1983a	Southern Great Basin.	Packrat middens	6 to 7	7 to 8	[5]6	---	+30 to +40

[1]Statewide average.
[2]Extrapolated by Morrison (1965) and Schumm (1965).
[3]Extrapolated by Schumm (1965) and Brakenridge (1978).
[4]Recalculated by Smith and Street-Perrott (1983).
[5]Minimum estimate.

(From Spaulding, 1984)

Erosion

Estimates of potential erosion at a specific location or site must consider a large number of variables. Included in this list of variables are climate (temperature and precipitation), vegetation cover, slope, type of surface material, baselevel factors (uplift and/or subsidence), and how is man modifying the area of concern. The literature pertinent to the subject matter covers two basic types of studies, erosion/denudation/degredation rates, and deformation and uplift rates. This report treats the terms erosion, degredation, and denudation as synonyms and interchanges the terms based on the reference material being discussed. When basically unreferenced data is discussed, erosion will be used.

Winograd (1974) summarized the literature on denudation and slope retreat rates in arid and semiarid climates. His average rate is 9-18 cm/1000yr. Dohrenwend and others (1984) have reported average degredation rates in their work in the Cima Volcanic Field in the Mojave Desert. The rates are based on the relation between the average pediment height above the modern surface and the K-Ar age of the basalt flow capping that remnant pediment. At the Cima Volcanic field, rates ranging from 0.9 to 4.6cm/1000 yr have been determined. This data gives an average denudation rate of about 2.1cm/1000yr and is basically applicable over the last 4 million years. Figure 1 and Table 2 present the data that support these dates. For contrast, the Cima rates were compared to other general published erosion rates. The data at the Cima field basically are very similar to rates presented by Hamblin and others (1981) for the western margin of the Colorado Plateau (2.5cm/1000yr). The Cima rates are about 2 to 4 times less than the tectonically active area along the Hurricane Fault (Hamblin and others, 1981) while they are 2-10 times

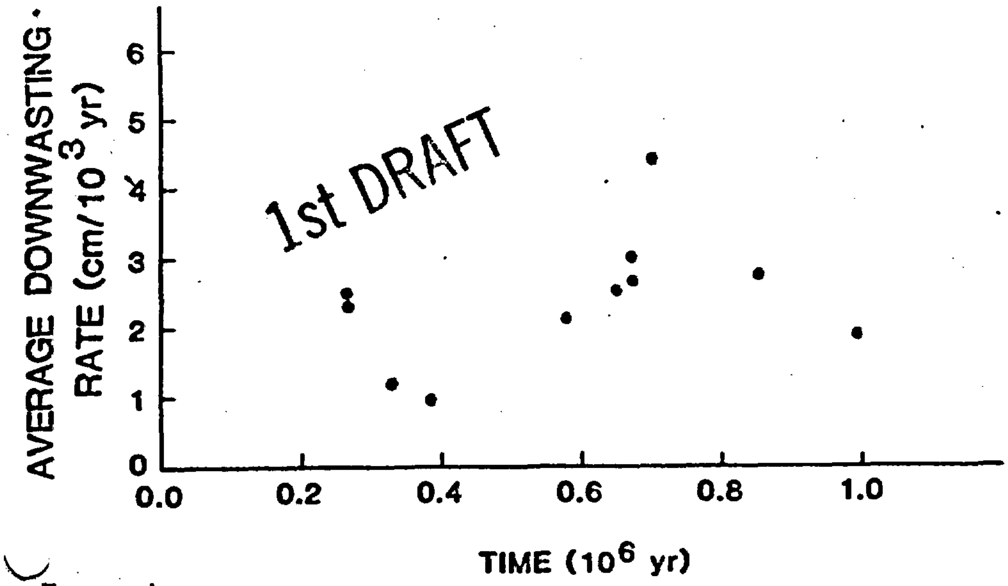

Figure 1

Average pediment downwasting rates through time. Downwasting has varied locally from 0.9 to 4.6 cm/10^3 yr but has averaged 2.1 cm/10^3 yr through time. (From Dohrenwend, 1984)

Table 2. Downwasting rates in the Cima volcanic field

Flow Designation	Flow Age (m.y.)[a]	Maximum Height Above Modern Surface (m)	Approximate Downwasting Rate (cm/10^3yr)
z_1	0.27 ± 0.11	6.5	2.4
t_2	0.27 ± 0.05	6.6	2.5
j'_1	0.33 ± 0.03	4.0	1.2
m_3	0.39 ± 0.08	3.5	0.9
s_x	0.58 ± 0.16	12	2.1
s_2	0.64 ± 0.05	17	2.6
		11 (t_2)[b]	3.0[b]
z_3	0.67 ± 0.13	18	[illegible]
		10.5(z_1)[c]	2.6[c]
r_2	0.70 ± 0.06	32	4.6
r_3	0.85 ± 0.05	25	2.9
k_3	0.99 ± 0.07	19	1.9
Tv	3.88 ± 0.09	120	3.1

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[a] Radiometric ages from Turrin et al. (this volume); ± values are 2 sigma error ranges.
[b] Difference in height between the base of flow s_2 and the base of flow t_2; dissection rate for the period 0.64 to 0.27 m.y.
[c] Difference in height between the base of flow z_3 and the base of flow z_1; dissection rate for the period 0.67 to 0.27 m.y.

(From Dohrenwend, 1984)

greater than rates reported for the tectonically quiet area on the east flank of the Great Dividing Range in New South Wales, Australia (Young, 1983). In contrast to the rates of pediment degredation, Dohrenwend and others (1984) also noted canyon downcutting in localized areas capped by lava flows has proceeded at rates a high as 20cm/1000yr; nearly an order of magnitude greater than the pediment areas (Figure 2).

Another study by Dohrenwend and others (1985) estimates erosion rates for different parts of the erosion system on the Revielle Range, Nye County, Nevada. He estimates erosion rates based on comparisons of paleosurfaces separated by K-Ar dated basalt flows and finds: 1) maximum erosion in upper reaches (i.e. crestal and upper flank areas) and approximate equilibrium in midpiedmont regions and 2) accelerated erosion during early phases of range dissection followed by less erosion during later phases. Erosion rates in the upper reaches range from 1.6 to 3.1cm/1000yr. In the lower flank and upper piedmont reaches, the erosion rates range from 5.8cm/1000yr (from 5.9 to 3.8myBP) to 1.6cm/1000yr (since 3.9myBP), while the central and lower piedmont reaches are essentially undissected. Damon and others (1978) estimate an erosion rate around 0.03cm/1000yr for areas of the lower Colorado River for the last 3.8myBP.

Schumm and Chorley (1983) have compiled an excellent document on the role of geomorphic hazards, including erosion, and their application to the management of nuclear waste. In this document they discuss some general erosion rates, the complex response of streams to baselevel changes, rates of valley incision, hillslope erosion, and escarpment retreat. Although none of their examples directly covers the NTS area, important relationships are summarized.

Table 2

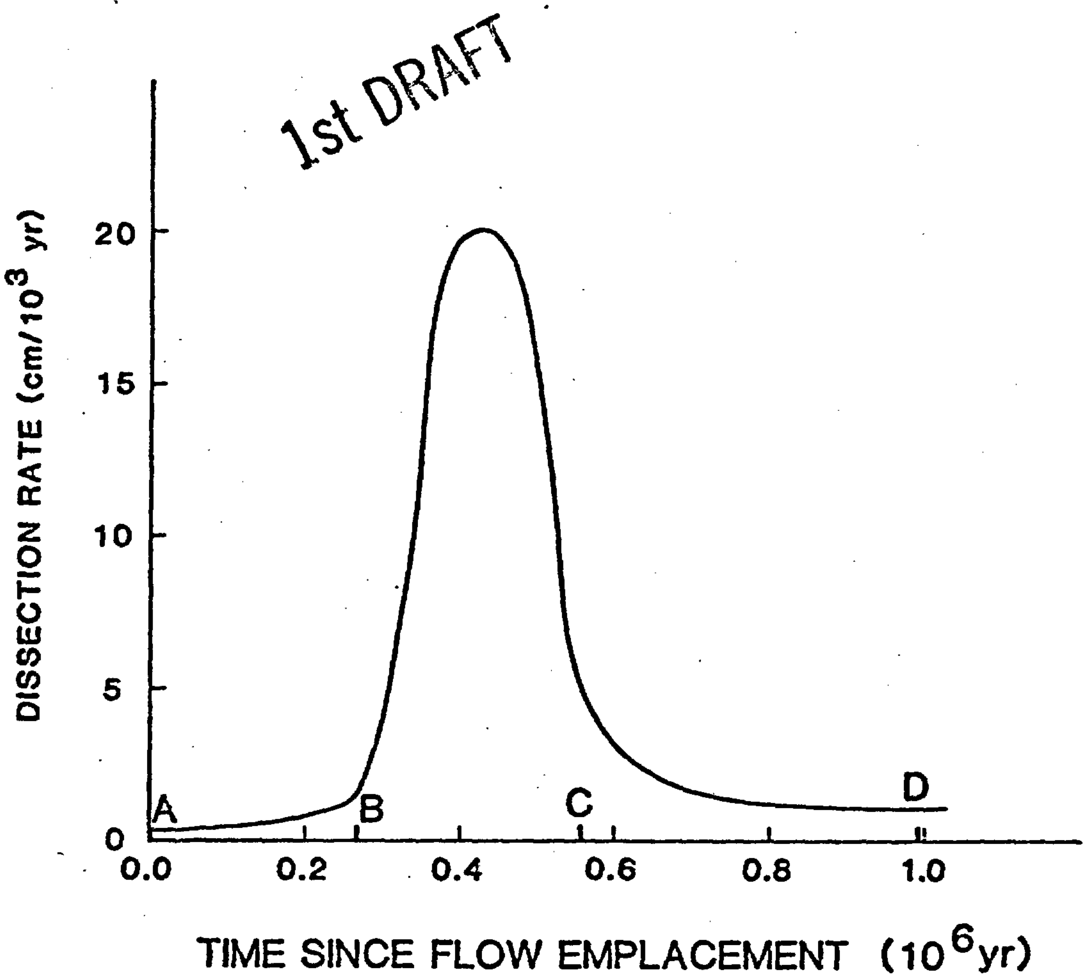

Figure 2 Canyon development through time in areas capped by lava flows. Canyons have been formed by relatively rapid and short-lived pulses of erosion. After emplacement of the lava flows (time A), little dissection occurs for at least 0.2 to 0.3 m.y. Canyon cutting then proceeds at rates ten to twenty times greater than average pediment downwasting rates (time B to time C). As equilibrium is approached (time C), dissection rates drop precipitously to the average downwasting rate of the surrounding pediment. Time D = 1984.

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(From Dohrenwend, 1984)

Table 3 is a general compilation of regional denudation rates throughout the world. These estimates range from 1.6cm/1000yr on the Thames River to 100cm/1000yr in the Himalayas, and basically demonstrate the large range of active rates.

Schumm and Chorley (1983) also discuss the differences and uniquenesses of valley incision, hillslope erosion and escarpment retreat. These three separate aspects play a cumulative role, when combined with uplift rates and sediment yield data, in the total evaluation of the potential erosion at a specific site. Valley incision rates, based on rock types and location, range from 2.6cm/1000yr on limestone and basalt in Utah to 30cm/1000yr on sedimentary rocks in Colorado (Table 4). Hillslope erosion rates based on climate range from a low of 20cm/1000yr to a high of 82cm/1000yr in semiarid regions (Table5). The process of hillslope erosion uses water as its dominant agent and is dependent on sheetwash and rill erosion, slope angle and length, inherent soil erodibility, vegetation cover, and surface management practices. Typical estimates of hillslope erosion are made by applying the Universal Siol Loss Equation (USLE). This equation was developed primarily for croplands in the midwest but modifications to the equation have helped expand its geographic applicability. Still, great care is necessary in determining the equation parameters for an arid to semiarid environment. Refer to U.S. Department of Agricluture (1977) for an expanded discussion of the USLE in the midwest states. Rates of scarp or escarpment retreat, based on rock type and climate, range from 20cm/1000yr for sandstone in a semiarid climate to 200 to 1300 cm/1000yr for shales in a semiarid climate (Table 6). Escarpment retreat is primarily a function of mechanical weathering and rock type.

Tectonic activity, uplift and/or subsidence play an important role in

Table 3 Regional Denudation Rates

Region	Present Denudation Rate (mm/1000 yrs) mean	range
Himalayas	1000	
N. Alps	610	
French & Swiss Alps	379	287-518
Colorado River	165	58-
Utah	130	82-177
Hawaii	130	
California	91	
W. Gulf (Texas)	53	16-
Mississippi River	51	
S.E. U.S.A.	41	28-
N.E. U.S.A.	38	27-48
Columbia River	38	
Thames River	16	

(From Schumm and Chorley, 1983)

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Table 4 Rates of Valley Incision

Rate (mm/1000 yrs)	Rock Type	Location	Source
240	granite	SE Australia	Brittlebank, 1900
96	basalt	SE Australia	Brittlebank, 1900
95	conglomerate	Arizona	Rice, 1980
248	shale and	Arizona	Rice, 1980
300	sedimentary rock	Colorado	Larsen et al., 1975
70	metamorphic rock	Colorado	Scott, 1975
370	limestone and basalt	Utah	Hamblin et al., 1981
26	limestone and basalt	Utah	
87		Sierra Nevada, CA	Huber, 1981

(From Schumm and Chorley, 1983)

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Table 5 Rates of hillslope erosion (Young, 1972).

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Climate	Ground Lowering mm/yr	Volumetric Movement, cm3/cm/yr
Temperate	--	0.08
Temperate	0.005	--
Temperate	0.005	--
Temperate	0.03	--
Temperate	--	0.09
Temperate	0.01-0.06	--
Temperate montane	0.01	--
Warm temperate	0.05-0.10	--
Mediterranean	0.09	--
Semi-arid	2.0	--
Semi-arid	6.40-8.20	--
Savanna	0.039*	--
Rainforest	5.0-15.0	--

(From Schumm and Chorley, 1983)

[redacted]

Table 6 Rates of Scarp Retreat (from Young, 1972).

Rock Type	Climate	Recession mm/yr
Shale	Semiarid	2 - 13
Granite, Gneiss	Rainforest	2 - 20
Sandstone	Humid Temperature	0.5
Sandstone	Semiarid/Arid	0.6
Sandstone	Semiarid/Arid	0.2

(from Schumm and Chorley, 1983)

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effecting erosion rates because of the ability to change baselevels. Uplift is typically rapid and of short duration allowing for little erosion before ending. However, they point out that you can find situations where both are nearly equal. Not only are uplift rates important in assessing erosion potential but the type of uplift may have a distinct effect on where or how the responding erosion takes place. For example, tilting will increase erosion throughout the tilted region while near vertical uplift will concentrate incision along the margins of the uplifted area.

Carr (1984) suggests uplift rates from 1cm/1000yr near Crater Flats to 180cm/100yr at the Coso Range in California. Winograd (1980) presents uplift rates from 10-40cm/1000yr and favors the lower end of the range for the NTS area. Gable and Hatton (1980) present uplift rates of 20-60cm/1000yr increasing southwestwardly across the NTS. Carr (1984) suggests Gable and Hattons data is much too high for the NTS area and discusses his reasons as well as presenting data on approximate rates of relative vertical tectonic adjustment or burial in the SW Great Basin during the late Neogene and Quaternary (Table 7). Hoover and others (1981) discusses 25-100m of erosion of stratigraphic unit QTa (0.9to 1.1my old) above the present surface. These data give an erosion rate of about 10cm/1000yr. The U.S. Geological Survey lists 2.2 to 8.2 cm/1000yr as the maximum rates of stream incision in Tertiary and Quaternary surfaces in the Yucca Mountain area (Table 8), and less than 10cm/1000yr during the last 300,000 years on Forty Mile Wash. The Department of Energy (1984) presents a mean, maximum stream incision rate of 5cm/1000yr and suggests that the rate has been less than 10cm/1000yr for the last 300,000 years.

As with the paleoclimate data, the compatibility of the types of data and rates presented is highly variable. Data presented for the NTS area are

Table 7.--Approximate rates of relative vertical tectonic adjustment or burial at selected locations in the southwestern Great Basin during the late Neogene and Quaternary

Location	Rate, m/1000 yr (mm/yr)	Comment
S. Amargosa Desert valley[1]	[2]<0.01	Based on an ash bed in lake deposits about 5 m below the surface; "Ewing" clay pit, just north of Ash Meadows
Crater Flat, central	[2]<0.01	Basalt dated by K-Ar at 1.2 m.y. (Crowe and others, 1983) is at the present surface and has not been deformed or subsided into the basin
Crater Flat, eastern	[2]<0.01	Based on an offset in alluvium at trench 1 (allowing for 0.6 m of erosion) of 3.0 m in 1.1 m.y.[3] Swadley and Hoover, 1983
Crater Flat, southeastern	<0.02	Offset of alluvium in trench 3 in a minimum time of 40,000 yr. Actual time was probably closer to 260,000 yr (Swadley and Hoover, 1983)
Crater Flat, USW VH-2 drill hole	0.03	Burial of basalt about 11 m.y. old (R. F. Marvin. U.S. Geol. Survey, written commun., 1983)
Yucca Mountain	0.03	Based on maximum of 460 m of offset of Tiva Canyon Member in last 12.8 m.y. For the Quaternary, a very conservative estimate is <0.01 m/1000 yr, based on maximum credible amount of displacement (10 m) in Quaternary time (see text)
N.W. Frenchman Flat[1]	0.06	Burial of ash bed at depth of 195 m in drill hole UE5n; not in most active part of the Frenchman Flat basin

Table 7--Approximate rates of relative vertical tectonic adjustment or burial at locations in the southwestern Great Basin during the late Neogene and Quaternary--Continued

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Location	Rate m/1000 yrs (mm/yr)	Comment
S. Yucca Flat	0.16	Based amount of displacement of a basalt in drill holes UE1h and UE6d (fig. 11); basalt is 8.1 m.y. old from K-Ar date (R. F. Marvin, U.S. Geol. Survey, written commun., 1980)
Searles Valley[1]	0.22	Burial of ash bed in core at depth of 691 m
Death Valley-foot of of Black Mountains	0.3	Based on displacement of Artist's Drive Formation, which is 6-8 m.y. old according to Fleck (1970a). Estimated here to be about 1,525 m (5,000 ft) in 5 m.y.
Sierra Nevada-Owens Valley-White-Inyo Mountains	0.4	Average of 9 estimates (range 0.2-1.0 m/1000 yr) from various sources[4]. Quaternary rate is probably higher
Coso Range-Rose Valley	1.8	Offset of 2.5 m.y.- old lava flow (Roquemore, 1980; Healy and Press, 1964).

[1] Relative rate of subsidence or burial is based on an ash bed that occurs at these three locations, and is believed to correlate (Izett, 1981; Sarna-Wojcicki and others, 1980; R. L. Hay, written commun., 1979); the ash is dated at about 3 m.y. by paleomagnetic, stratigraphic, K-Ar and fission-track techniques (Liddicoat and Smith, 1979).

[2] Maximum rate; figures using additional decimal places are considered to imply unrealistic accuracy.

[3] The age of 1.1 m.y. assumes that basalt ash in the fault in this trench came from one of four centers in Crater Flat of this age (Crowe and others, 1983). Logic supports this conclusion (Swadley and others, U.S. Geological Survey, written commun., 1984), but does not rule out the possibility that the ash came from the 0.3 m.y.-old Big Dune Center. If the latter is the case, the rate becomes 0.01 m per 1,000 yr.

[4] Owens Valley--Bachman (1978); central Sierra Nevada--Curry (1971), and Huber (written commun., 1980); Mono Lake basin--Gilbert and others (1968).

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(From Carr, 1984)

TABLE 8

MAXIMUM DEPTH AND RATES OF STREAM INCISION
IN TERTIARY AND QUATERNARY SURFACES IN THE YUCCA MOUNTAIN AREA

Surface of Unit[a]	Approx. Age (Years)	Maximum Depth (m)	Maximum Rate[b] ($m/10^3$ Years)	Location
Q2b	1.6×10^5 [c]	8.5	0.053	Fortymile Wash
Q2c	3×10^5 [d]	25.9	0.082	Fortymile Wash
Tpc	10×10^6 [e]	218.2	0.022	Western Yucca Mountain

Notes:

a) For meaning of unit designations, see Hoover and others, (1981).

b) Corrections for differences in slope, topographic relief, or drainage basin area have not been made in calculating the maximum rates of stream incision. All such corrections would tend to decrease the rates.

c) Q2b age is maximum determined by U-Th disequilibrium method.

d) Q2c age is average of two U-Th disequilibrium ages.

e) Tpc (Tiva Canyon Member of the Paintbrush Tuff) uplift age is determined from two minimum K-Ar ages for the Rainier Mesa Member, which overlies the traces of faults along which blocks of the Tiva Canyon Member were uplifted.

greatly limited and inadequate to support the overall conclusions as presented in the Department of Energy (1984) Environmental Assessment.

EROSION AT THE NEVADA TEST SITE

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How does all this relate to the NTS? Two of the works previously cited are worth quoting here. The quotes reflect 1) the incompleteness of data on the total degredation at the NTS and 2) the need for a complete, highly detailed geomorphic study to adequately assess the erosion potential of the NTS.

> 1) "Stream incision rates are only one measure of the total Quaternary erosion that has occurred in the Site Vicinity. No data are yet available for rates of hillslope erosion, deflation by wind, or sediment yield. These are the principal measurements necessary to characterize total Quaternary degradation at the Site." (U.S. Geological Survey, 1984, p.16), and
>
> 2) "If the required geomorphic, climatic, tectonic and hydrologic data are not available at a perspective site, as is usually the case, geomorphic stability must then be determined by a complete geomorphic evaluation of the site based on the most conservative assumptions." (Schumm and Chorley, 1983, p. iii).

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To adequately address the potential erosion at the proposed Yucca

Mountain site, data pertinent to all the aspects of climate and erosion, as presented in the previous sections of this report, are necessary. Estimates of the climatic reconstruction variables, mean annual temperature, and mean annual precipitation, have been presented. The average annual precipitation ranges from 6cm at the lowest elevations to about 50cm at the highest elevations with an average between 10 to 25cm (Squires and Young, 1984). However, theories presented to explain the paleoclimate data are varied. Therefore, as Schumm mentioned, the most conservative approach must be taken. In this case, analyses should at least be based on pluvial climate interpretations that call for the maximum amount of increased precipitation, or 100% (Table 1) over present conditions.

Likewise, estimates of potential erosion need to be totally conservative. The Department of Energy (1984) has formally presented an erosion rate, less than 10cm/1000yr or 10m/10,000yr, primarily based on the work of Hoover and others (1981). These data are quite in agreement with the published literature presented earlier in this report. However, as was previously noted by this author during review of the Department of Energy (1984) publication and in alletter to Ben Rice of the NRC, dated March 5, 1985, these rates are derived from a maximum of three data points (Table 8). In no way can these data be adequate to base comments regarding favorable and adverse conditions and qualifying and disqualifying conditions. Much additional data is necessary to even form a preliminary understanding of the erosion potential at the NTS.

Further investigaions of stream incision on Fortymile Wash and probably Yucca Wash are important to understanding the past erosional history of these major drainages. Most likely the U.S. Geological Survey (1984) is correct in assuming some of the increase in channel incision along Fortymile Wash was initiated when it captured Beatty Wash. However, much more data is necessary to support this contention.

Estimates of hillslope erosion are necessary, especially as they relate to the eastern slopes of Yucca Mountain and the Drill Hole Wash area. Attempts to apply the USLE and to adequately choose the appropriate variables to the equation are necessary. Presently, with no available data on hillslope erosion, if one used the data presented on Table 5, you could produce estimates ranging from 2 to 8.2 mm/yr which converts to 200 to 820m/10,000yr. Likewise, with no data presented regarding escarpment retreat along the west face of Yucca Mountain, estimates based on Table 6 could range as high as 20 to 60m/10,000yr. Although these rates are based on sandstone in a semiarid/arid environment, they have to be considered to be in the general range of potential escarpment retreat for Yucca Mountain.

Both the estimates presented on hillslope erosion and escarpment retreat are considered intuitively excessive, but are used to demonstrate the need for detailed, site specific evaluations.

SUMMARY

In summary, paleoclimate reconstructions applicable to the NTS area are numerous and varied. Because of these discrepancies, only the most conservative estimates of pluvial conditions, decreased temperature about 10 to 11 C and increased present precipitation about 100%, should be applied for future predictions of paleoclimate and erosion potential. The erosion rates presented for the Yucca Mountain Site are quite in agreement with published rates in the literature. However, the data base for these rates is inadequate and numerous additional types of erosion, especially hillslope rates and escarpment retreat, need to be studied. By applying theoretical, tabulated data to the Yucca Mountain Site, unfavorable rates can be estimated. Although the intuitive suggests erosion should not be a critical problem at the Yucca Mountain Site, further data need to be generated to confirm these intuitions.