STATE OF NEW MEXICO
HEALTH & ENVIRONMENT department

MEMORANDUM

DATE: November 9, 1984

TO: Greg Mello, Environmental Scientist, Hazardous Waste Section

THRU: Karl Souder KCS, WRS III, Technical and Enforcement Section

FROM: Steve Cary KCS, WRS II, Technical and Enforcement Section

SUBJECT: Erosion potential and geomorphic stability on Mesita del Buey, Pajarito Plateau

TA-54

I have completed my rather cursory desk-top assessment of erosion potential and geomorphic stability on Mesita del Buey, site of LANL underground waste repositories. My major conclusions are as follows:

1. Barring some major near-future climatic change, natural erosion rates are very slow and probably of little concern;

2. Mesita del Buey will eventually be gone, but it may take 10^6 years;

3. Accelerated erosion due to land surface disturbance could cause waste repositories to be breached in less than 10^4 years.

KS:SC:egr

Enclosure: Report

TC

11204

ADM 031 Issued 6/78

Geomorphology and Erosion in the Mesita del Buey Area

I. Introduction

A. Purpose

The purpose of this report is to evaluate possible geomorphic threats to the integrity of underground waste repositories on Mesita del Buey. Mesita del Buey is a long, narrow, erosional remnant of the Pajarito Plateau in Los Alamos County, New Mexico. It is bounded on the north by Canada del Buey and its tributaries, and on the south by Pajarito Canyon. Principal geomorphic processes acting on Mesita del Buey are fluvial erosion and cliff backwasting. This study estimates the rates of these processes and evaluates the future integrity of waste repositories on the mesa.

B. Time Frame

Due to retention in the waste of long half-life radioactive materials, long-term estimates of geomorphic stability are desirable. Present erosion rates can be estimated with fair accuracy and then be used to predict future conditions. Such predictions will remain appropriate only as long as present climatic, tectonic, and land use conditions govern geomorphic processes at the site. Applicability up to several thousand years into the future can be provided; beyond about 10,000 years, however, stability in the driving factors of tectonism and climate cannot be assumed. Estimates of geomorphic stability are accordingly less reliable.

C. Scope

The scope of this study is restricted to information obtainable from published literature and maps. Unfortunately, the topic under study here has received only perfunctory treatment in the geologic literature. Field work was minimal and field checking of hypotheses was not done. Many of the conclusions and estimates provided herein therefore remain highly conjectural. Except for erosion rates, which have been estimated by other investigators, all strictly geomorphological conclusions are the author's.

D. Format

The body of this report has three parts. Part 1 summarizes the geologic past and presents the current geomorphic setting of the Pajarito Plateau. In Part 2 erosion rates are calculated. These rates will be derived using several examples, so that a regional picture of geomorphic processes will emerge. Accelerated erosion due to human activities will also be estimated. Finally, Part 3 will examine the future. General geomorphic evolution of the Pajarito Plateau will be discussed and the future integrity of Mesita del Buey will be forecast.

II. Geologic Past and Geomorphic Setting

A. Rio Grande Rift

The Pajarito Plateau occupies the western portion of the Espanola Basin, one of a north-south series of basins formed along the Rio Grande Rift in mid-Cenozoic time 30-40 million years (m.y.) ago. The Sangre de Cristo Mountains, which border the Espanola Basin on the east, provided sediments that began to fill the basin. These sediments were laid down in complex alluvial fan systems, indicating no large through-flowing drainage. The sediments, collectively termed the Santa Fe Group, are up to 2,000 feet thick and incorporate intermittent basalt flows.

B. Cerros del Rio Basalt

Extrusion of lava in the southern part of the basin intensified about 25 m.y. B.P. and gradually built the Cerros del Rio Volcanic Field. Cerros del Rio basalts filled in topographic lows in the area; the basalts now form a northwest-southeast trending dome that thins to the southwest and northeast. The last flows were apparently contemporaneous with the first ashfalls from the Jemez volcanic field. Any drainage from north to south in this area was probably diverted westward around the toe of the basalts.

C. Jemez Caldera

As volcanic activity declined in the Cerros del Rio area, it increased in the Jemez region in the western part of the Espanola basin. Repeated ash-falls, first from the Toledo caldera and finally from the Valles caldera, covered Santa Fe Group sediments and Cerros del Rio basalts with blankets of ash that thinned to the east. The last major ash-fall, now called the Tshirege Member of the Bandelier Tuff is about 1.1 m.y. old.

D. Rio Grande Evolution

The succession of thick ash falls caused repeated impoundment of drainage north of the Cerros del Rio basalts. The final outlet for this water was across a low point on the northwest limb of the Cerros del Rio basalts. Incision of the Rio Grande down through those basalts cut what is now White Rock Canyon, 1000 feet deep. Incision proceeded from south to north, gradually lowering the basalt dam until the ponded water to the north was completely drained. Downcutting probably began about 1.1 m.y. ago; it probably proceeded rapidly at first because of the steep initial gradient, but incision undoubtedly slowed as the trench was cut. Exactly how the present Rio Grande system evolved upstream of the study area is not known, but it is thought that significantly more water now flows through the Espanola Basin than 2-3 m.y. ago.

E. Drainage Evolution on the Pajarito Plateau

Eastward drainage from the Jemez Mountains flows across the Pajarito Plateau into the Rio Grande. The latter served as base level when the plateau was formed. Prior to Rio Grande incision, slopes north of what is now Mesita del Buey drained east into the lake(s) behind the ash/basalt

dam. Slopes south of Mesita del Buey drained east and south into the Rio Grande. Pajarito Canyon and Canada del Buey drained directly toward the highest part of the underlying basalt-cored dam.

As the Rio Grande began to incise through the dam, base level was lowered first for streams draining the southern part of the plateau, such as Capulin, Alamo, and Frijoles Canyons. Base level was then successively lowered for Ancho and Water Canyons. Because of the resistant character of the basalt and apparent stream incompetence, however, several drainages were not able to incise with the Rio Grande. Water courses in Fence, Potrillo, and Pajarito Canyons, as well as Canada del Buey and Mortendad Canyon were stranded by the Rio Grande and are graded to the erosion-resistant Cerros del Rio basalt that formed the dam.

Incision of the Rio Grande caused dissection of the Pajarito Plateau by several competent Rio Grande tributaries. As canyon incision worked its way up each drainage system, the headwaters of each tributary underwent headward downcutting; this resulted in expansion of drainage areas. Those southernmost watercourses that incised first began to capture drainage area that once belonged to a neighboring watercourse, usually one to the north. Carried to its logical conclusion, capture of drainage area can result in capture of whole streams.

Topographic evidence of former stream capture is abundant on the plateau. One well preserved capture can be seen in the north-central part of the Frijoles, NM (1952) 7.5' quadrangle, where Water Canyon captured Canon del Valle from Potrillo Canyon. Many other probable captures are readily seen, and in almost all cases the drainage area transfer is to the more southerly of two adjacent watercourses. Several cases of incipient capture are also evident. Drainage areas are thus expanding northward, resulting in major canyons whose watersheds are truncated on the south.

III. Erosion Rates

A. Introduction

Erosion on the Pajarito Plateau must be viewed from several perspectives: erosive agents or mechanisms, variation over time, and natural versus anthropogenic. Erosive agents to be considered include running water and freezing/thawing; both are clearly water and climate related. As climate has varied over time, so have erosion rates. The relative importance of fluvial erosion and cliff backwasting is evaluated. Also important are man-caused modifications of the land surface and subsequent changes in erosion by flowing water. The primary focuses of the analysis below is on rates of mesa decay, that is, how fast is the mesa top being diminished in size?

B. Cliff Backwasting

The steep cliffs separating mesa tops and valley floors are prominent features of plateau physiography; so too are the piles of boulders that have accumulated at the cliff bases. While these features are glaring evidence of vertical backwasting of mesa edges, I do not think cliff backwasting is the major erosion process of concern.

Backwasting of vertical rock walls occurs by rockfall, which is brought about by a combination of biological, chemical, and physical processes. Qualitatively, these processes include root penetration, chemical degradation of rock material, and freezing/thawing of water in cracks and crevices. Slowly, these processes loosen and disloge rock material.

Such dislodged rocks will fall only if there is a steep vertical face, however. Vertical faces and steep slopes were brought about on the plateau by fluvial erosion. Vertical downcutting by streams combined with resistance of the ash to erosion and weathering created the steep mesa walls. Streams also played an important part in maintaining the steep faces by removing fallen rubble. Without periodic removal of fallen rock material, the cliff face would eventually be eliminated by the accumulation of fallen rocks. Thus, it is my conclusion that cliff backwasting is not a primary erosional process on the Pajarito Plateau. It is merely an artifact of and is dependent on fluvial erosion.

Along some mesa edges, where there are no stream channels or arroyos of any size, cliff backwasting is the only ongoing erosional process. It is thus possible to estimate a rate for it. However, the calculated rates are quite slow. Over recent geologic time, cliff backwasting is not a major factor in reducing the total upland area. Nevertheless, cliff backwasting rates are estimated below.

For Pajarito Canyon, the valley width at disposal area "L" is approximately 950 feet. I assume this area was excavated in about 1.1 million years, resulting in a gross rate of 0.000864 ft/yr of lateral erosion. Of that figure, about half (4.32×10^{-4} ft/yr) would occur on each side. (The rate would be slightly faster on south-facing walls than on north-facing walls.) This translates to 1 foot of cliff retreat every

2,000-2,500 years. For Canada del Buey: 525 ft/1,100,000 yrs = 0.000477 ft/yr, x ½ = 0.000239 ft/yr. This translate to about 1 foot in 4,000-4,500 years. These rates would cause 50 feet of cliff retreat in 100,000-125,000 years for the south face of Mesita del Buey and 200,000-225,000 years for the north face. These rates assume that cliff faces are maintained. Moreover, these rates represent 1.1 million year averages. Under the present environment (no rock removal, semi-arid climate) rates are probably much slower.

C. <u>Fluvial Erosion</u>

Of far greater significance to mesa stability is headcutting of surface drainages into the mesa edge. At the study area, it is clear that flowing water has been the most effective geomorphic agent. Fluvial erosion is directly responsible for the numerous canyons, steep cliff faces, and mesa remnants. Rates of drainage extension by headcutting are estimated below.

For two ravines heading on Mesita del Buey and draining to Pajarito Canyon 2 to 2.5 miles west of White Rock:

1. Ravine length = 1,400 ft (measured from mesa top to middle of Pajarito Canyon)

   Time = 1.1 million years

   1,400 ft/1,100,000 years = 0.00127 ft/yr

2. Ravine length = 1,200 ft

   Time, as above

   1,200 ft/1,100,000 yrs = 0.00109 ft/yr

A more conservative approach, using only 1.0 m.y. gives rates of 1.4×10^{-3} and 1.2×10^{-3} ft/yr. These rates translate into 1 foot in 800 years and 900 years respectively, or 50 feet in 40,000 and 46,000 years, respectively.

Thus, fluvial erosion can be expected to eat into the top of Mesita del Buey at much faster rates than simple cliff backwasting. Also note that while cliff retreat rates would be aproximately uniform along the entire mesa edge, fluvial erosion would be concentrated in ravines draining the top of the mesa. It is therefore at ravine heads that erosion rates will be greatest.

Fluvial erosion involves dislogement, entrainment, and downstream transport of mineral grains. These processes are governed by many other environmental factos. Of greatest significance are channel slope, drainage area, and resistance of basin materials to erosion. These factors ensure that those ravines with the steepest slopes and largest watershed areas will have the greatest headcutting rates in areas of uniform geologic material, assuming comparable climatic influences.

D. Variation in Erosion Rates Over Time

Erosion estimates covering the last million years are only gross averages because climate, which strongly influences erosion, has varied widely. I suspect that most erosion that has occurred in the area took place during the one or more glacial/pluvial episodes that occurred in Pleistocene times. In the study area, an assumed greater abundance of moisture would have supported more streamflow. With the steep gradients to the Rio Grande, more flow would cause more fluvial erosion, both downcutting and lateral widening, which in turn would facilitate faster cliff retreat. It would probably be fair to say that 95 percent of all the erosion that has ever occurred on the plateau took place during pluvial climates. How much time these climates represented is not known. However, fluvial erosion rates at mesa edges of 1-2 feet per 100 years during pluvial episode would not be surprising.

Present natural erosion rates are probably almost negligible. The region's semi-arid climate produces little precipitation in excess of evaporation. Runoff from the mesa top occurs only after the most intense

summer storms. At other times, most rain or snow infiltrates shallowly and eventually evaporates. Thus, there is not enough runoff to maintain perennial streams or to support fluvial erosion. Such erosion is probably at a virtual standstill, with present rates almost nil. With the onset of glacial/pluvial conditions in the future, erosion rates would again increase.

E. Accelerated Erosion Caused by Man

Although present erosion rates are quite low under natural, well-vegetated conditions, land disturbance by construction activity can greatly alter erosion characteristics on Mesita del Buey. Removal of plant cover, compaction of soil by heavy equipment traffic, and terrain alteration through earth moving can cause dramatic increases in such processes as particle dislodgement through raindrop impact, rill development, gullying, particle entrainment, runoff, and sediment delivery rates. Decreases occur in precipitation interception, infiltration, and runoff detention. The combined effect of these many factors is greater runoff and greater erosion.

Conditions observed at one disposal area during a site visit on October 2, 1984, were qualitatively consistent with the above conditions. The site was cleared of soil and vegetation and a small gully (approximately 1 foot wide, 1 inch deep) had developed draining off the site to the north. Nearby undisturbed areas showed no evidence of runoff. Thus, man-caused disturbances can artificially elevate runoff and erosion. Actual rates would depend on many factors, but a safe assumption would be that the accelerated erosion could be of the same magnitude as erosion under a pluvial climate. There is abundant evidence, in fact, that brief intense rainfall on an unvegetated surface in a semi-arid environment produces more erosion than abundant precipitation on a well-vegetated landscape.

IV. Prospects for the Future

Near-future erosion will be minimal under natural conditions. As long as climate remains as it is now, rates of cliff retreat will be negligible and stream headcutting will be slow. This can be expected to continue for several thousand years.

The greatest near-future geomorphic threat to the integrity of disposal areas on Mesita del Buey is accelerated erosion caused by land surface alteration. If this potential problem remains unaddressed, then headcutting of ravines into the mesa could cause disposal areas to be breached in less than 5,000 years (0.015 ft/yr with 50 ft setback). This is an order-of-magnitude estimate. I recommend that measures be taken to limit runoff at disposal sites.

The far future is even more conjectural that the near future, but potentially important events are tectonic, climatic, and geomorphic in character. Renewed volcanism and base-level change in the Rio Grande are hypothetical tectonic events that would affect erosion on the plateau.

Climatic events are less hypothetical, but the future is still unpredictable. Another pluvial episode would not surprise me, but my guess is that it is at least 10,000 years away. When, and if, it occurs, eroision will speed up on Pajarito Plateau.

Another likely consequence of regionally-accelerated stream erosion is increased incidence of stream capture on the plateau. While the basalt remnant has prevented deep incision of Canada del Buey and Pajarito Canyon to date, it is only a matter of time before these perched drainages are captured, possibly setting off one or more geomorphic events that are also difficult to predict. However, the following scenario seems reasonable to me.

Examination of the topography 2-4 miles west and southwest of White Rock reveals several major watercourses that are vulnerable to piracy. For example, the divide between Fence Canyon and Water Canyon along State Road 4 appears to be only about 20 feet high. A south-flowing, ephemeral arroyo tributary to Water Canyon parallels State Road 4 and has as its drainage area part of the valley floor of Fence Canyon. During the next episode of wet climate, I would expect this tributary to rapidly expand its watershed northward, eventually capturing all but the lower reaches of the Fence Canyon drainage. Stream capture is also foreseeable in the following locations: an ephemeral tributary to Potrillo Canyon near State Road 4 could capture Pajarito Creek by extension across a low divide of 10-20 feet; an equally insignificant divide separates Pajarito Canyon from Canada del Buey, also at State Road 4. Thus there are at leat three sites at which stream piracy could occur in the study area.

The impacts of these events on local physiography are best understood in an extended time frame and on a regional scale. The drainages on the plateau are attempting to make the most efficient trip from uplands eastward to the Rio Grande. Incision of the Rio Grande through the basalts at White Rock Canyon led to incision of those tributaries able to follow suit, that is, those north and south of the basalt high.

Several drainages, especially Pajarito Canyon, remain perched on and graded to the Cerros del Rio basalt. Neighboring drainages to the south, because they are graded to the Rio Grande up to 900 feet lower, have steeper channel gradients and are thus more effective erosion agents. These streams are geomorphically aggressive, extending their drainage areas to the north by capturing slopes from the less competent drainages perched by the basalt. While Pajarito Creek and Canada del Buey may be the last of the plateau drainages to be pirated, their capture is inevitable, given time and the proper climate.

Stream capture generally results in incision of the winner and alluviation of the loser. The pirating system gains drainage area and streamflow, resulting in a stream system with more competence in a valley system sized for a smaller system. The piracy therefore causes increased erosion as the enlarged stream system readjusts its channel and floodplain to the new conditions. The impact is usually greatest on the captured area. For example, when Fence Canyon is captured by Water Canyon, Fence Canyon will

be regraded to a new base level about 150 feet lower, and the once ephemeral tributary that does the capturing will have much more flow. these conditions will cause deep incision of the captured part of Fence Canyon and will rejuvenate its tributaries as well. Potrillo Canyon and lower Fence Canyon will lose drainage area and flow. They will become less competent and may alluviate slightly. They will become good candidates for capture by the rejuvenated Water Canyon system to the south.

Eventually, stream piracy will affect Pajarito Canyon and Canada del Buey, causing accelerated incision and rejuvenation of tributaries. This will increase the rates of headcut extension calculated earlier, eventually hastening the dissection of Mesita del Buey and the penetration of the disposal pits and shafts. These events are in the far future, awaiting the appropriate climatic trigger.

SC:egr

N