CHAPTER V

GEOLOGIC FACTORS IN THE ISOLATION OF NUCLEAR WASTE: EVALUATION OF LONG-TERM GEOMORPHIC PROCESSES AND EVENTS

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In this report the rate, duration, and magnitude of changes from geomorphic processes and events in the Southwest and the Gulf Coast over the next million years are projected. The projections were made by reviewing the pertinent literature; evaluating the geomorphic history of each region, especially that during the Quaternary Period; identifying the geomorphic processes and events likely to be significant in the two regions of interest; and estimating the average and worst-case conditions expected over the next million years. The results of the analysis are presented in Table V-1.

DESCRIPTION OF THE STUDY AREAS

Existing Geomorphic Environment

Gulf Coast

The Gulf Coast, which is within the Coastal Plains Physiographic Province, is characterized by rolling uplands with young to mature coastal plains. The flood plain and delta of the Mississippi River are the major geomorphic features of the area.

Southwest

The Southwest area extends over four physiographic provinces: Basin and Range, Colorado Plateau, Southern Rocky Mountains, and Great Plains. The Basin and Range Province (Nevada, western Utah, southern Arizona, and New Mexico) is characterized by dissected fault-block mountains with associated large alluvial fans and bajadas. The Colorado Plateau (eastern Utah, northern Arizona, northwestern New Mexico) is generally a well-dissected structural

TABLE V-1. Summary of Projected Rates for Geomorphic Processes

	Rate		Total Erosion after 10^6yr	
	Average ($m/10^3$ yr)	Maximum ($m/10^3$yr)	Average (m)	Maximum (m)
Denudation				
Gulf	0.05	0.15	50	150
Southwest	0.10	0.30	100	300
Entrenchment				
Gulf Coast				
Mississippi River near mouth	50[a]	75[b]	100[c]	150[c]
200 km upstream	6[a]	20[b]	30[c]	40[c]
Southwest[d]	0.20	1.0	200	1,000
Ashfalls[e]				
Gulf Coast[f]	x101	x102	Unknown	Unknown
Southwest[f]	x102	x103	Unknown	Unknown

(a) Assumes 5,000 years for entrenchment period.
(b) Assumes 2,000 years for entrenchment period.
(c) Erosion occurring during each full glacial period. A period of aggradation follows entrenchment and tends to replace the removed sediment.
(d) Assumes uplift comparable to Late Mesozoic.
(e) Other catastrophic events considered were landslides and floods.
(f) These figures represent the order-of-magnitude increases in denudation expected.

plateau. The Southern Rocky Mountain Province in north-central New Mexico has steep, precipitous mountains (Sangre de Cristo Range) and open, grassy valleys (San Luis Valley). The Great Plains in eastern New Mexico are comprised of rolling hills and high plateaus with some entrenched streams. The Colorado is the major river basin in the Southwest.

Quaternary Geomorphic History

Significant geomorphic changes have occurred during the Quaternary Period (1,800,000 years B.P. to present). The changes have been reviewed to provide a basis for predicting future conditions.

Gulf Coast

Widespread Pleistocene glaciation was accompanied by a eustatic fall in sea level that led to entrenchment and valley deepening of the Mississippi River near the Gulf of Mexico. The maxiumum depth of entrenchment probably was approximately 120 m.

Maximum aggradation of the Lower Mississippi Valley occurred in the waning stages of the last Wisconsin glaciation and lasted no more than a few thousand years. The Mississippi River altered from braided to meandering when the ratio of sediment to water decreased sufficiently to begin degradation. The deltaic plain of the Mississippi River was structurally active during the Quaternary.

During the Holocene (10,000 years B.P. to present), little change has occurred in the Lower Mississippi Valley. Deltaic deposition in Louisiana occurred as the sea level rose. In the last few thousand years, the Mississippi River has continued slowly to aggrade its flood plain and to build its delta across the continental shelf.

Southwest

Tectonism and volcanism resulting from movements of crustal and oceanic plates continued into the Quaternary. The Colorado Plateau was uplifted nearly 1,500 m during the late Tertiary and early Quaternary, and some uplift of the Colorado Plateau is still occurring. In the Basin and Range Province, normal faulting and volcanism, which began in the Tertiary, continued into the Quaternary. However, volcanism in the western United States appears to have been less intense in the late Pleistocene than during the late Tertiary and early Pleistocene.

The major geomorphic feature in the Southwest is the Grand Canyon. The canyon has had a complex history of uplift, downcutting, and volcanism that began sometime in the Tertiary.

PROBLEM FORMULATION

Geomorphic processes are influenced by many variables. Geomorphologists tend to evaluate these processes and variables over periods that are generally less than 100 years. Little research has addressed the problems associated with estimating long-term erosion and landform development.

Given the number of variables contributing to the development of landforms over time, the paucity of the research is not surprising. However, the key element to remember is time. When the time frame is expanded, the number of independent variables is reduced. For example, when the time frame is expanded from 10 years to 1,000 years, the number of independent variables is reduced from seven to four.

Because the number of independent variables is reduced as the time frame expands, somewhat cruder measures can be used in place of specific analytical measurements to represent long-term, basin-wide changes in morphology. Denudation rates are one such measure. Commonly presented as the number of meters a basin is lowered in a one thousand-year period, denudation rates afford a reasonable long-term estimate that tends to smooth out pulses in the system.

LONG-TERM ESTIMATES OF CONTINUOUS GEOMORPHIC PROCESSES

Denudation

At any given time, a basin is undergoing net storage or flushing of sediment. For example, sediment will be stored until a geomorphic threshold is passed; at that time erosion (or flushing) begins. Consequently, erosion rates represent a normal, yet unstable period, in the history of a basin. Denudation, on the other hand, occurs over longer periods, and this lengthy duration tends to even out short-term anomalies. Although in some cases man has increased rates of erosion by a factor of seven or eight since European settlement, denudation rates that are based on data gathered in the last 100 years should provide a reasonable compromise between short-term (<100 years) erosion in localized areas and long-term (>1,000 years) evaluation of a drainage basin.

Calculations of denudation rates are usually based on data obtained from the dissolved and suspended sediment load of streams. Climate and tectonic environment have a significant influence on the estimated rates; for example, the Kosi River Basin, which receives sediment eroded from Mt. Everest, has an estimated denudation rate 20 times higher than that estimated for the Gulf Coast.

Maximum denudation rates occur when effective precipitation ranges from 25-38 cm. Maximum rates are therefore expected in the Southwest, where effective precipitation ranges from 20-30 cm. However, the Gulf Coast's effective precipitation ranges from 63-127 cm, indicating that estimated denudation rates should be lower there.

Although the Southwest and the Gulf Coast have tectonically active areas, the associated rates of uplift and subsidence are very slow. From the data available, it appears clear that uplift and isostasy are much faster than denudation. Therefore, to evaluate a worst case, denudation could be assumed to equal uplift (or subsidence). Estimates of maximum and average denudation rates have been made. These estimates assume that any uplift or subsidence that occurs will be quite slow.

Entrenchment

In addition to overall lowering of the basins by denudation, entrenchment of streams is another possible mechanism that could result in a breach of the geologic containment. Entrenchment is the process by which streams cut through geologic materials.

Gulf Coast

A simple way to estimate maximum entrenchment rates for the Mississippi River or other coastal streams is to assume that entrenchment will keep pace with lowering of sea level during a glacial period. Estimates of the maximum lowering of sea level during the Pleistocene full glacial intervals vary from 80-140 m. The coastline during a full glacial interview, however, would be several hundred kilometers south of its present location. For a worst case, entrenchment at the present mouth of the Mississippi River could be assumed to equal maximum sea-level lowering. Rates are estimated by assuming that a full-glacial interval will last from 10,000 to 20,000 years, and that maximum entrenchment (coinciding with maximum sea-level lowering) will occur over a period of 5,000 years or less.

Southwest

The Colorado River provides a dramatic example of entrenchment where it flows through the Grand Canyon. Rates of downcutting have ranged from a high of 0.3 m/10^3 years during the Pliocene to a low of 0.01 m/10^3 years at present. Although these rates are much slower than those estimated for the Gulf Coast during a full glacial interval, it must be remembered that the duration of downcutting in the Grand Canyon extends over several million years rather than over several thousand years as in the former case.

Aggradation

Gulf Coast

The alluvial valley of the lower Mississippi is a broad lowland varying from 40 to 200 km in width. More than 100 m of alluvium has been deposited in some parts of the valley. Rates of aggradation in large part depend on rates of sea-level rising. During the most rapid phase of deglaciation, from about 10,000-7,000 years B.P., sea level may have risen at a rate of 1 cm/year.

A simple way to account for aggradation in a model of a geologic system is to assume that the trenching which occurs during the simulated glacial interval is entirely compensated by deposition of alluvium during the waning stages of glaciation. Therefore, whether or not a breach in the geologic containment occurs will depend on the maximum lowering of sea level and the associated entrenchment of the river. Following entrenchment, aggradation will occur and the cycle will be repeated during the next glacial interval. No evidence exists to suggest that aggradation following entrenchment results in a net lowering of the river valley over and above that accomplished by denudation. However, if uplift operates concurrently with entrenchment, net lowering could occur.

Southwest

Aggradation similar to that associated with periglacial environments is not expected to occur in the Southwest within the next million years.

However, aggradation in the form of alluvial fans will occur. Although alluvial fans and bajadas (coalescing fans) are important local geomorphic features, they are not expected to affect estimated rates of denudation and entrenchment substantially. Therefore, aggradation in the Southwest need not be included in the simulation model.

LONG-TERM ESTIMATES OF CATASTROPHIC EVENTS

Landslides

Mass movement in the form of landslides is an important mechanism in the weathering process in certain regions of the United States. Although small localized landslides, primarily earth slides, may occur in the Gulf Coast, no major landslides are expected to occur in that region in the next one million years. The Southwest, however, has known occurrences of fairly large landslides, especially debris flows.

Although a landslide releases significant energy, most of the energy is absorbed in breaking up the mass of material. No known cases exist of a landslide triggering seismic activity.

Landslides do not account for substantially larger volumes of sediment than do normal rates of denudation. The author recommends that landslides not be included in the long-term simulation model.

Flooding

Catastrophic floods have been responsible for rapid movement of large volumes of sediment. The erosive power of such events greatly supersedes that of landslides.

There are no known cases of catastrophic flooding in the Gulf Coast or the Southwest. Although the catastrophic release of Lake Bonneville occurred close to the area of study, existing and probably future drainage conditions make it highly unlikely that flooding to the south will occur. Volcanic activity in portions of northern Arizona and New Mexico could conceivably initiate small-scale catastrophic flooding during a glacial period; however, the overall erosive effect would be minimal. Therefore, the potential for a catastrophic flood in the areas of study during the next million years is remote and should not be included in the long-term simulation model.

Ashfall

Ashfall may result from widespread (or long-term) volcanic activity and may denude the landscape. Erosion rates would be affected by two factors: removal of vegetation and changes in the characteristics of the top layer of erosive material.

Removal of vegetation has been shown repeatedly to increase erosion significantly by reducing infiltration, by increasing runoff velocity and volume, and by decreasing land surface stability. The deposition of a layer of ash on the land surface, however, could have a countering effect. The ash may impart special properties of superior strength and chemical resistance that significantly reduce its ability to erode. Nevertheless, where slopes are moderately steep and precipitation occurs in intense, convectional storms (as in a semiarid climate), sheet wash erosion and gullying would take place. A worst case would occur if the ash was assumed to have no counterbalancing effect on the denudation of vegetation. In that case, erosion rates in the Southwest could be expected to increase by as many as three orders of magnitude, whereas rates in the Gulf Coast would increase by as many as two orders of magnitude.