Department of Energy
Salt Repository Project Office
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Hereford, Texas 79045

November 24, 1987

Mr. John J. Linehan
Section Leader, Salt Section
Repository Projects Branch
Division of Waste Management, MS 623-SS
U.S. Nuclear Regulatory Commission
Washington, DC 20555

Dear Mr. Linehan:

SUBJECT: TRANSMITTAL OF UPDATED VERSION OF SRP-SCP SECTION 5.2

Enclosed is an updated version of Section 5.2 of the Salt Repository Project's draft Site Characterization Plan. This revision was not available to be sent with our earlier transmittal of Revision 2. Please replace Section 5.2 transmitted with Revision 2 with the attachment.

Sincerely,

J.O. Neff

J.O. Neff
Project Manager
Salt Repository Project Office

SRPO:SLH:max:1271KW

Enclosure:
As Stated

cc: G. Appel, SRPO, w/o encl.
T. Baillieul, SRPO, w/o encl.
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5.2 LONG-TERM CLIMATIC ASSESSMENT

Long-term climatic assessment involves both reconstruction of late Cenozoic (past 23.7 million years) paleoclimate (Section 5.2.1) and projection of climate as much as one hundred thousand years into the future (Section 5.2.2). In this chapter, the Neogene (23.7 to 1.6 million years ago) and Quaternary (past 1.6 million years) paleoclimate of the Southern High Plains and adjacent regions is summarized, as is the record of global climatic changes throughout the Phanerozoic. Projection of future climate over geologically significant periods will require consideration of (1) very-long-term global trends; (2) the type, magnitude, and duration of late Cenozoic regional climatic variations; and (3) both deliberate and unintentional climatic changes induced by human activities. Application and development of global and regional climatic models (as referenced in Section 5.3.1.2) will allow projection of future climatic conditions for repository design and performance assessment.

5.2.1 PALEOCLIMATOLOGY

Throughout Phanerozoic time (past 570 million years), and even during the Precambrian (3.8 billion to 570 million years ago), global climate has undergone both periodic and episodic changes in response to large-scale variation in incident solar energy, tectonic evolution of the continents and ocean basins, alteration of atmospheric composition, volcanic activity, and perhaps rare events such as asteroidal or cometary impacts (Frakes, 1979). Hays et al. (1976) discussed the role of periodic orbital variations or "Milankovitch cycles" that produce long-term climatic changes. Cycles of different frequency may overlap and, when in phase, may be additive, producing marked perturbation. Climatic responses to these "orbital forcing functions" are complex; they are treated in greater detail in a collaborative volume edited by Berger and Pestiaux (1984). Orogenic and epeirogenic uplift and crustal plate movements (continental drift) have occurred in the region over tens of millions of years (Smith and Briden, 1977; Gable and Hatton, 1983; Budnik, 1987). These tectonic processes clearly have influenced global and regional climate, but the time required to effect these secular changes generally places them beyond the scope of the present investigation. So, too, are most of the major fluctuations of atmospheric chemistry described by Holland (1984). Volcanism operates on a time scale appropriate for consideration here; important contributions to the study of volcanic disturbance of climate have been made by Pollack et al. (1967), Bray (1977), and Rampino and Self (1982). Recently, attention has been focused on possible climatic and related effects of catastrophic collisions of astronomical bodies with Earth but the importance and inferred periodicity of such events is highly controversial (Kerr, 1985). Of these factors, several have implications for paleoclimatic reconstruction in the Southern High Plains and the candidate area and are discussed in the following sections.

5.2.1.1 Phanerozoic global climate

The reconstructed history of Earth's climate is discussed by Frakes (1979), Hambrey and Harland (1981), and Flohn and Fantechi (1984). Attainable chronologic resolution increases from the distant to the recent past, making direct comparisons difficult. Absolute extremes of temperature and precipitation throughout the Phanerozoic, particularly during the Cenozoic (past 66.4 million years), seem to fall within the modern global pattern; that is, the range of climatic conditions inferred from the stratigraphic record at any given location does not appear to exceed the range of existing climates over the planet as a whole. Yet, conditions in any given region clearly have fluctuated widely through time, exhibiting random and possibly nonrandom variation.

5.2.1.1.1 Sea level changes

Interpretation of Phanerozoic sea level changes (Haq et al., 1987) can be regarded as a surrogate climatic history. However, other processes such as tectonic evolution of the continental and oceanic plates and differential eustatic adjustments of the crust have affected sea level as well. Principal cycles of Triassic (208 to 245 million years ago) to Holocene (past 10,000 years) sea level variation have a reported periodicity on the order of 5 to 10 million years in the Mesozoic (66.4 to 208 million years ago) and Paleogene (66.4 to 23.7 million years ago) and 1 to 5 million years in the Neogene and Quaternary (Haq et al., 1987). An apparent increase in the frequency of cycles since the late Oligocene-early Miocene (approximately 24 million years ago) may be an artifact of improved resolution in this part of the stratigraphic section. The amplitude of individual cycles of late Cenozoic sea level fluctuation is comparable to that of longer-period cycles of the pre-Neogene.

Sea level lowstands during the Quaternary are correlative with intervals of extensive midlatitude, subalpine glaciation, and similar relations may have existed previously. However, only some of the pre-Pleistocene (before 1.6 million years ago) lowstands noted by Haq et al. (1987) can be tentatively correlated with stratigraphic evidence of past glaciation recognized by Hambrey and Harland (1981). Therefore, the history of transgression and regression cannot be linked to the glacial-interglacial record with certainty. Glaciation at high latitudes and high elevations in North America is indicated by tills and apparently ice-rafted material in strata at least as old as Miocene (23.7 to 5.3 million years ago) (Hambrey and Harland, 1981, p. 954). Mickelson et al. (1983) and Porter et al. (1983) present a chronology of late Pleistocene glaciation and deglaciation in the United States.

5.2.1.1.2 Late cenozoic climate

During the late Cenozoic, most of the Southern High Plains has remained an eolian depositional environment probably comparable to the semiarid prairie of today (Gustavson and Holliday, 1985, p. 26). Gustavson and Holliday (1985) studied eolian sediments and paleosols composing the Pleistocene-Holocene Blackwater Draw Formation (approximately 1.5 million years ago to present) and eolian facies of the underlying Miocene-Pliocene Ogallala Formation (approximately 11.5 to 3.4 million years ago). The Sand Hills described in

Section 1.1.1.1.3 are a region of partly vegetation-stabilized eolian sand sheets and dunes south of the proposed Deaf Smith County site. Most of these dunal features are Holocene (Gile, 1979). Arid conditions enhance development and expansion of eolian deposits although other factors (notably lack of vegetative cover in eolian source areas in the Pecos River Valley, owing to salinity of the alluvium) also are important. Deposits like these present few opportunities for direct paleoclimatic interpretation. In general, however, a dry continental climate has persisted since the middle Miocene, alternating with comparatively humid but still semiarid intervals, particularly since the late Pliocene (Wells et al., 1982; Van Devender, 1985). Such stability is not surprising in view of the major controls on regional climate: (1) westerly and southerly flows of moisture from distant (Pacific and Gulf of Mexico) sources and (2) orographic desiccation of air masses (rain-shadow effect) prior to arrival of the weather systems in the region (Haragan, 1976). Today there are numerous pluvial lakes (playas) and a few areally restricted, presumably ground-water-sustained ponds and marshes in draws of the Southern High Plains. Similar wetlands and extensive permanent lakes were common throughout the region during parts of the Pleistocene (1.6 million to 10,000 years ago), Pliocene (5.3 to 1.6 million years ago), and possibly late Miocene.

5.2.1.2 Quaternary paleoclimatology of the candidate area

Several investigators have described the Quaternary paleoclimate of the Southern High Plains and adjacent areas. Work in this region includes some of the classic early studies of Paleoindian artifacts clearly associated with a late Pleistocene Rancholabrean megafauna. Other reports have been primarily devoted to paleoclimatic reconstruction based on inferred histories of pluvial lakes, alluvial terraces of intermittent drainages, and eolian deposits. Unfortunately, most of these pioneering efforts predated widespread application of modern stratigraphic concepts (depositional systems and genetic stratigraphy) and radiocarbon or other physical dating methods and, therefore, have limited applications. In addition, climatic fluctuations of the latest Pleistocene (Wisconsinan glacial stage) and early to middle Holocene were rapid, such that their record is partly obscured by lag responses of most physical and biological paleoclimatic indicators. Inherent difficulties in reconstructing the Quaternary paleoclimate necessitate rigorous interpretation of carefully dated stratigraphic sequences containing high-resolution records of appropriate indicators. There are, at present, few studies meeting these demanding criteria that directly pertain to the Southern High Plains. Recent reconstructions of Quaternary climate of the Southern High Plains (Holliday, 1985) and western Rolling Plains (Caran et al., 1985) are relatively well constrained, both stratigraphically and chronologically. These reports are broadly compatible with one another and with most modern studies conducted in the southwest and Great Plains; they are the basis of the following review of regional Quaternary paleoclimate.

5.2.1.2.1 Paleoclimate

Some of the most important stratigraphic and paleoenvironmental studies of Quaternary deposits in the Southern High Plains have been conducted at the Lubbock Lake archeological site in Lubbock County, Texas. Holliday (1985) summarized the archeologic and stratigraphic record of this site and its extensive radiocarbon-age data. He also presented a general discussion of paleoclimatic conditions that existed during the past 11,000 years. Beginning approximately 11,000 years before present, there was a gradual change from cool, wet conditions to a warmer, more arid climate (Holliday, 1985, Figure 7). Progressive warming and drying continued until almost 6,000 years before present, by which time conditions approximated those of the modern climate. Holliday (1985) reported two brief episodes of very dry and possibly very warm conditions in the middle Holocene: 6,300 to 5,500 and 5,000 to 4,500 years before present. He concluded that conditions during these intervals were more extreme than the modern warm, semiarid climate, but local evidence on which this interpretation is based is equivocal. Holliday (1985) stated that essentially modern conditions were reestablished by 4,500 years before present.

Many investigators, particularly palynologists working in the southwestern and southeastern United States, have inferred conditions like those described by Holliday (1985) during the middle Holocene or "Hypsithermal" (see summaries by Delcourt and Delcourt (1985) and Hall (1985)). But data from the western Rolling Plains (Caran et al., 1985) and other parts of Texas (Bryant and Holloway, 1985), as well as from other areas of the southwest (Markgraf et al., 1984; Van Devender et al., 1984), indicate progressive desiccation from the beginning of the Holocene until about 5,000 years before present, when the modern seasonal climatic range was attained. These conditions then persisted to the present, with only minor and temporary excursions.

Reconstruction of the latest Pleistocene and Holocene climate of the western Rolling Plains (southeastern Texas Panhandle; see maps presented in Sections 1 and 3) is based on interpretation of the diverse molluscan paleofauna and genetic stratigraphy of thick, laterally extensive Quaternary sediments composing the Lingos Formation (Caran et al., 1985; Caran and Baumgardner, 1987). The radiocarbon-dated record of the Lingos Formation for the past 30,000 years is closely constrained (based on more than 50 dates). For the lower half of the depositional sequence, radiocarbon dating is inconclusive, and only relative chronologic indicators are available. The climatic history of the Rolling Plains for the past 11,000 years is virtually identical to that of the Southern High Plains described by Holliday (1985). An exception is the record of the middle Holocene, as noted previously. During the middle Holocene, the Rolling Plains was not detectably warmer or drier than the present, and conditions like those of the present have persisted through the past 5,000 to 6,000 years.

The Lingos Formation also provides a record of late Pleistocene climate. When combined with genetic and paleoenvironmental studies of extensive late Miocene to middle Pleistocene lacustrine deposits in the Southern High Plains and adjacent areas, the complete Neogene and Quaternary paleoclimate of the region can be reconstructed. The stratigraphy of these deposits, which occupy discrete basins with partly asynchronous histories, is only now being investigated. When established, this stratigraphic model will provide the framework for further paleoclimatic investigations.

5.2.1.2.2 Paleohydrology (surface water)

Regional studies by Caran et al. (1985) and Holliday (1985) indicate more constant rates of stream discharge and greater contributions of emergent ground water in the latest Pleistocene and early Holocene than at present. The wetter climate and reduced evaporation, due to lower temperatures, increased available moisture. Perennial or nearly permanent streams were created, and the water table, in many areas, probably stood tens of meters higher than it does today. The floors of some draws and subsidence basins were below the seasonal or permanent water table, which allowed ground water to emerge as springs, seeps, and diffuse discharge zones. Ground water probably sustained low-flow conditions in streams of the Southern High Plains. These streams had small surface drainage areas and, therefore, should have discharged only for short periods following moderate to heavy seasonal rains. But paleoenvironmental data presented by Holliday (1985) and Melteer and Collins (1987) provide limnologic evidence of sustained, low-velocity flow of a type related to ground-water discharge. Perennial discharge of ground water in streams and closed topographic basins on the Southern High Plains indicates the water table was significantly higher during much of the Pleistocene and Holocene than during historic times. However, paleohydrologic conditions are not yet known in sufficient detail for long-term performance assessment (see Section 5.3.3.2).

Several investigators have attempted to correlate the geomorphic history of streams in the area with Pleistocene sea level fluctuations caused by continental glaciation and deglaciation. Whether a precise chronology of either synchronous or lagging stream response can be developed is uncertain, but there is abundant evidence of global sea level changes in the Quaternary (see review by Butzer, 1983). Haq et al. (1987) presented a general model of sea level variation that encompasses the late Cenozoic, but their model lacks resolution needed for detailed correlation of the Quaternary record. Few investigations directly applicable to the detailed chronology of sea level changes in the Gulf of Mexico have been undertaken, although studies by Beard et al. (1982) and Lowrie (1986) provide some data. In general, the global pattern of lowstands during maximal extensions of continental ice is reasonably well understood and well dated. Butzer's (1983) discussion shows that the chronology of interglacial highstands is less reliable. The widely cited date of 18,000 years before present for the Wisconsinan Glacial maximum (CLIMAP Project Members, 1981) is compatible with stratigraphic evidence of cool, wet conditions at that time in the western Rolling Plains (Caran and Baumgardner, 1987). The record of pre-Wisconsinan glacial intervals in the region is inadequately understood and cannot now be reliably correlated.

5.2.1.2.3 Cryosphere

The timing and maximum extent of Quaternary continental glaciers and periglacial environments is the subject of current research by a number of investigators in the United States and elsewhere. Maps published by Flint (1971) remain useful, although details of his chronology have been modified by subsequent workers. Detailed reconstructions have been developed for the most recent major glaciation, the Wisconsinan. CLIMAP Project Members (1981) present a general overview of the extent of global ice as well as associated air and sea-surface temperatures 18,000 years before present. There is no recognized evidence of glaciation in the candidate area at any time during the Cenozoic (Hambrey and Harland, 1981). Alpine glaciers existed in the mountains of New Mexico and Colorado during most or all of the Quaternary (Richmond, 1965). Modern ice-cemented rock glaciers occur in the Sangre de Cristo Mountains of south-central Colorado at elevations as low as 2,570 m (Giardino et al., 1984), and Wisconsinan (?) rock glaciers were present at 2,420 m in Lincoln County, New Mexico (Blagbrough, 1984), less than 300 km southwest of the Deaf Smith County, Texas, candidate area. Frozen ground conditions occur seasonally in the Southern High Plains (Simpkins and Gustavson, 1987).

5.2.1.2.4 Influence of paleoclimate on recharge

Indirect evidence of rates of ground-water recharge in the past is found in the regional stratigraphic record. As noted in Section 5.2.1.2.2, climatic conditions during the Pleistocene and early Holocene produced elevated water tables in the Southern High Plains and Rolling Plains. Recharge was augmented by increased available moisture, resulting from a generally wetter climate and reduced evaporation owing to lower temperatures. Stratigraphic and paleoenvironmental evidence indicates the floors of many draws and closed topographic basins were inundated permanently or seasonally by emergent ground water (Section 5.2.1.2.2.). Aquifer discharge at the elevation of these depressions demonstrates that the water table in many areas was tens of meters higher than at present. To a large extent, higher water-table conditions reflect recharge greatly in excess of that occurring in the region today. Hydrologic properties of strata composing these aquifers and associated vadose zones have not changed significantly the Quaternary Epoch. Therefore, the rate of recharge appears to have fluctuated in direct proportion to moisture availability, a function of precipitation and temperature-driven evaporation.

5.2.2 FUTURE CLIMATIC VARIATION

A hypothetical model of natural and human-influenced climatic variation in the candidate area over the next 10 to 100 millenia is discussed by Caran (1985). However, available projections of future climate at the site are not sufficiently detailed to permit meaningful long-term analyses and planning. Extensive atmospheric modeling will be required prior to investigation of the impact of future climate on an underground nuclear waste repository. Possible considerations are (1) the global history of climatic variation during the Phanerozoic, particularly the Quaternary; (2) the regional Miocene to late Holocene paleoclimate; (3) possible effects of inadvertent human activities, especially atmospheric contamination by carbon dioxide and particulate matter; (4) probable deliberate human manipulation of regional climate; and (5) essentially random occurrences such as prolonged, widespread, or particularly violent volcanic (caldera) eruptions, asteroidal impact, or other large-magnitude events that have affected climate on a regional to global scale in the geologic past (Caran, 1985).

5.2.2.1 Expectation for natural climatic changes

Imbrie and Imbrie (1979) proposed an instructive concept of the relationship between natural and human-induced climatic variations over geologically significant periods. They conclude that the human-induced greenhouse effect would reinforce and possibly prolong interglacial conditions, creating a "superinterglacial" period, and would partly offset glacial cooling to produce a subdued full glacial period (Figure 5-7). The appropriateness of this concept cannot be judged without additional, extensive climatic modeling. However, it is highly unlikely that the same pattern of response would be seen worldwide. Buildup of heat in a high-CO_2 atmosphere might enhance vertical atmospheric instability by increasing convection. Differences in latitude, altitude, and proximity to oceans cause marked meteorologic gradations that would not be completely eliminated and might be exaggerated locally. In addition, rotation of the Earth causes large-scale motion of the atmosphere that ensures regional variability. For these and other reasons, the future climatic scenario discussed by Imbrie and Imbrie (1979) cannot adequately provide information required for assessment and planning in the candidate area.

Plausible estimates of future climatic conditions will depend on implementation of a broad-based assessment strategy involving both global and regional modeling efforts. A global perspective is essential for recognition of the possible range and chronology of future meteorologic extremes. Climatic trends over periods of 10 to 100 millenia can be projected on the basis of general circulation models of the global atmosphere and, subsequently, the coupled global system of ocean, atmosphere and ice. Scenarios reflecting the local range of climatic extremes during the Quaternary (glacial and interglacial episodes), as well as possible human-induced conditions of the future, may be addressed through development of a specific regional ("mesoscale") climatic model. This model would be linked to the global models but verified by close comparison with the regional paleoclimatic record and projected local effects of human-induced climatic change.

Figure 5-7 goes here

Although climatic fluctuations in the geologic future (10^4 to 10^6 years) cannot now be projected in detail or with certainty, we can characterize the two most likely conditions: one based on natural recurrent variations alone, the other based solely on anthropogenic effects like those now occurring. The two projections are diametrically opposed, and neither can be accepted or rejected with confidence. The correct answer may lie between these extremes or perhaps in another direction entirely, but evidence at hand favors one or both of the alternatives discussed here.

5.2.2.1.1 Theoretical discussion

Effects of cyclical changes in Earth's orbital parameters on insolation (incidental solar radiation) have been discussed by Hay et al. (1976), Denton and Hughes (1983), Wright (1984), and by Berger and Pestiaux (1984). Climatic responses to large-scale perturbations of insolation are inferred to have caused, or significantly contributed to, global glacial-interglacial oscillations, although Moore et al. (1982) have shown that this relation is more complex and variable than many have supposed.

Properties of the atmosphere combine with planetary orbital characteristics to regulate the amount and distribution of heat and moisture. This, in turn, influences "secondary" climatic controls, such as the areal extent of high-albedo ice cover, which inversely proportional to that of climate-moderating ocean waters. These and other factors interact to affect atmospheric circulation, seasonality, and the position of climatic zones. Of the several orbital cycles shown to influence climate, those of 400,000, 100,000, 40,000 and 20,000 years ago have been most significant during the late Cenozoic Era (Moore et al., 1982). Denton and Hughes (1983) have explained the roughly 100,000-year late Pleistocene full glacial/interglacial cycle in terms of combination of orbital parameters that periodically reinforce one another. If this relationship persists, the next full glacial episode would be expected in 80,000 years, or approximately 100,000 years after the Wisconsinan Glacial maximum 18,000 years before present (CLIMAP Project Members, 1981). Several intermediate glacial advances during relatively cool periods are likely to occur within those 80,000 years (Denton and Hughes, 1983).

5.2.2.1.2 Empirical discussion

The stratigraphic and paleoecologic record of the latest Pleistocene and early Holocene in the Texas Panhandle is a valid indicator of regional paleoclimate. As discussed previously in Section 5.2.1.2.1, relatively cool, wet conditions persisted throughout the region during most or all of the Wisconsinan glaciation until at least the early Holocene (perhaps as recently as 6,000 years before present). By the middle Holocene, conditions had approached those of the modern warm, dry climate with its marked annual and seasonal variations. The Southern High Plains may be as warm and dry today as at any time in the Quaternary Period. The climate of the future could stabilize to conditions like those of the present, but this probably would require a substantial increase in atmospheric carbon dioxide or other anthropogenic effects. Predicted solely on the basis of the late Cenozoic paleoclimatic record, the regional climate is most likely to grow wetter and cooler in coming millenia, although there may be significant departures from this overall trend. Just when this might occur has been widely debated (Kukla et al., 1972; Mitchell, 1972), and no firm conclusions have been reached.

5.2.2.2 Expectation for human-induced climatic change

Humans may influence future climate through both incidental and deliberate activities. Many investigators have discussed individual examples of human impact on climate. Notable among these effects is the demonstrated increase in atmospheric carbon dioxide that results from combustion of fossil fuels and from certain industrial and agricultural processes (Liss and Crane, 1983). Carbon dioxide, together with water vapor and ozone, selectively absorbs infrared energy radiated from the ground as well as vagrant heat from manufacturing and other activities. This causes an increase in atmospheric heat, the "greenhouse effect," which may produce global warming and associated climatic changes. The extent and timing of warming is the subject of active research (Blasing, 1985).

Humans have unintentionally affected climate in many different ways. Large reservoirs, irrigation programs, manufacturing processes, and internal combustion engines add substantial quantities of moisture to the atmosphere (Lyons, 1974; Stidd et al., 1975). Intensified land use and manufacturing change the surface albedo over vast areas and generally increase atmospheric dust (Flohn and Fantechi, 1984). Urban centers produce sufficient heat to create "heat islands" that modify normal climatic systems in their vicinities (Griffiths, 1976, p. 125-129). Some of these effects may influence regional climate, and could conceivably influence global climate, but their importance is not fully understood.

In addition to inadvertent effects, deliberate modification of weather is being attempted in many parts of the world and may increase in the future. Literature pertaining to this topic, particularly rain and snow inducement and hail suppression, is extensive. Most modification efforts to date have been largely experimental, and results are mixed. However, demands for weather modification for agriculture and other purposes are likely to increase if large-scale manipulation becomes technologically feasible and predictable. Eventually there might be a pressing need for remedial, although technologically challenging, measures to offset adverse climatic conditions, such as the greenhouse effect produced by increased concentration of atmospheric carbon dioxide (Laurmann, 1983). The alternative could be gradual desiccation of much of the planet, including more than half of North America as far as the southern Great Plains (Kellogg, 1983). Deliberate weather modification may be commonplace in the future; regional augmentation of rainfall could affect recharge and thus may conceivably influence an underground repository in the candidate area.

5.2.2.3 Implications of climatic changes

Effects of climatic change are linked to the nature, geographic scope, and duration of that change. Possible consequences of such changes were discussed by Caran (1985), although any such appraisal is necessarily uncertain. Two scenarios of future climatic conditions are proposed in this chapter. One reflects only natural, cyclical variation (Section 5.2.2.3.1), and the other is solely dependent on human-induced climatic changes of the kinds experienced today (Section 5.2.2.3.2). These alternatives address the most likely extremes of future climate, but they are intended to convey only a general impression of conditions that may occur in the region. Detailed climatic modeling will produce better estimates for long-term planning and assessment.

5.2.2.3.1 Cool, wet conditions

If the geologic record of the Quaternary is a reliable model, a major glacial episode could occur within 80,000 years. There is no evidence to suggest that continental glaciers would extend as far south as the Texas Panhandle, nor would sea level rise resulting from interglacial melting cause a marine transgression over the area. In the Southern High Plains and adjacent areas, a Wisconsinan-type glacial stage would be characterized by conditions significantly cooler and wetter than at present. An absolute increase in precipitation during the warm seasons, coupled with reduced evaporation as a result of cooler mean tempertures, would heighten discharge through drainages and cause additional impoundment in poorly drained areas. Finley and Gustavson (1980) stated that erosion by running water under present climatic conditions may approach a maximum theoretical rate defined by Schumm (1965). Although additional runoff should intensify erosion, increased moisture generally would increase erosion-retarding vegetative cover as well in areas not otherwise disturbed. Erosion in the Southern High Plains might diminish under these circumstances. Yet, at least in some areas, interplaya drainage might increase, thereby promoting headward stream incision and downcutting. Along the margins of the plains, Permian (245 to 286 million years ago) evaporites are widely exposed and tend to retard plant growth. Schumm's (1965) theoretical relationship would not apply there, and additional runoff probably would exaggerate erosion.

In addition, increased rainfall almost certainly would increase recharge and reduce dependence on withdrawal of ground water, both of which would cause a rise in the water table. Deep circulation of geochemically unsaturated ground water driven by increased hydraulic head might enhance subsurface dissolution of evaporites, resulting in subsidence and lower regional geomorphic base levels along the escarpments. In these areas, discharge of ground water also would increase spring sapping (Gustavson, 1983). All these effects would accelerate escarpment retreat and drainage extension.

5.2.2.3.2 Warm, dry conditions

An entirely different scenario would result from a prolonged or permanent shift to warm, dry conditions that would suppress natural cyclical variations. This might occur if anthropogenic effects, especially an increase in atmospheric carbon dioxide, were to continue unabated. However, natural processes and large-scale corrective measures probably could prevent, delay, or partly offset an occurrence of this kind (Laurmann, 1983; Liss and Crane, 1983). If the regional climate did stabilize to conditions as dry and warm as those of today (or even slightly more extreme), geomorphic processes might be largely unaffected. Denudation, incision, and mass wasting would continue to be important, particularly during intermittent, and perhaps less frequent, periods of intense rainfall. Deflation would continue, especially on disturbed (cultivated and overgrazed) uplands, at modern or somewhat greater rates. Spring sapping along the escarpments would essentially terminate, but the importance of this process has already declined from historic levels because of overpumping of the Ogallala aquifer (Gustavson, 1983). Reduced availability of surface water would further increase demands on the aquifer. Drier, warmer conditions might accentuate deflation relative to erosion by water under ordinary circumstances, but effects of extreme rainfall events might not differ from those under existing conditions. The findings of Finley and Gustavson (1980) and Machenberg and Caran (1984) indicate modern erosion by water and wind may approach maximum potential rates. Moisture available for recharge would diminish and the water table would decline, but a falling potentiometric surface would enhance deep penetration of available recharge and could produce piping in the shallow subsurface as the thickness of the unsaturated zone increased. Piping could adversely affect the surface, particularly along canyons and the escarpments.

5.2.3 SITE PALEOCLIMATIC INVESTIGATIONS

Paleoclimatic investigations at the site will be conducted in tandem with studies of late Cenozoic stratigraphy, geomorphic processes, and relevant characteristics of playas. These efforts must be closely integrated if they are to achieve meaningful results in a timely manner. Relevant findings will supplement those of the site paleoclimatic investigation, which, in turn, will augment other site studies. Core and outcrop samples of sediment from playas, Pleistocene lacustrine basins, paleosols, and other Cenozoic deposits will be characterized for possible correlation with comparable deposits elsewhere and for paleoclimatic interpretation. Relative and absolute age determinations will be made on any diagnostic or datable materials found. A paleoclimatic summary developed in the course of site investigations will be compared with similar data from off site and with a regional late Cenozoic paleoclimatic model that synthesizes information from many sites throughout the region.

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