GEOLOGIC REVIEW OF PROPOSED AMARILLO AREA SITE FOR THE SUPERCONDUCTING SUPER COLLIDER (SSC)

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INTRODUCTION

In June 1987, the Texas National Research Laboratory Commission asked the Bureau of Economic Geology, The University of Texas at Austin, to review and briefly report on the geology of the proposed Amarillo area site for the Superconducting Super Collider (SSC) and to provide a surface geologic map of the site. An informal task force was organized, consisting of Jay A. Raney (Coordinator), Thomas C. Gustavson, and S. Christopher Caran of the Bureau of Economic Geology. This report accompanies the geologic map (Plate 1) of the proposed Amarillo area site in the Texas Panhandle.

REGIONAL SETTING

Structural Development

The proposed Amarillo site for the Superconducting Super Collider (SSC) lies west of the town of Happy, Texas, in the Texas Panhandle. The area is on the northeastern flank of the Palo Duro Basin, which is bounded by the Amarillo Uplift-Wichita Mountains trend on the northeast and by the Matador Arch-Roosevelt Uplift on the south. To the west the Palo Duro Basin is bounded by the Pedernal and

Sierra Grande Uplifts. These positive structural elements resulted from faulting and uplift initiated during the Paleozoic, perhaps as early as the late Cambrian.

During the Pennsylvanian and early Permian, tectonic movement along the Amarillo Uplift and Matador Arch controlled sedimentation and facies distribution in the Palo Duro Basin. Epeirogenic uplift during the Triassic resulted in the terrestrial basin that contains the Dockum Group. By Cretaceous time the region had subsided to below sea level. Epeirogenic movements continued into the Tertiary and resulted in uplift of Cretaceous marine strata in the study area to more than 940 m (3,100 ft) above sea level (Eifler, 1968; Gable and Hatton, 1983).

Nontectonic deformation, in the form of regional subsidence induced by extensive dissolution of Permian bedded salt, has occurred beneath all of the study area (Gustavson and others, 1980; Gustavson and Budnik, 1985; Gustavson and Finley, 1985).

Stratigraphy

In the eastern Texas Panhandle, episodes of deposition on shallow marine shelves alternated with periods of erosion during the early Paleozoic. Terrigenous clastics, informally called granite wash, were derived from and deposited near the Matador Arch and Amarillo Uplift during the Pennsylvanian and early Permian as a result of uplift of these features. Marine sedimentation during the Late Pennsylvanian and Early Permian was dominated by shelf-margin carbonates, while the deeper parts of the basin were being filled by fine-grained clastic sediments. During the middle and late Permian, a wide, low-relief marine shelf developed, and salt, anhydrite, dolomite, limestone, and red beds were deposited (Presley, 1979a, b, 1980a, b; McGillis and Presley, 1981; Hovorka and others, 1985; Fracasso and Hovorka, 1986).

Fluvial, deltaic, and lacustrine sandstones and mudstones of the Triassic Dockum Group unconformably overlie Permian strata (McGowen and others, 1979). Jurassic sediments are not preserved in the study area. In turn, the Lower Cretaceous Edwards Limestone and Kiamichi Formation unconformably overlie the Dockum Group. During the Late Cretaceous and early Tertiary, extensive erosion exposed both Triassic and Lower Cretaceous strata. Fluvial and eolian sediments of the Neogene Ogallala Formation overlie the Tertiary erosion surface (Seni, 1980; Winkler, 1985; Gustavson and Holliday, 1985). Locally, late Pliocene lacustrine sediments of the Blanco Formation, Cita beds, and the Rita Blanca Formation overlie the Ogallala Formation. The Quaternary Blackwater Draw Formation, which is composed primarily of eolian sediments, overlies the Ogallala Formation as well as the Pliocene lacustrine formations (Machenberg and others, 1985; Gustavson and Holliday, 1985). Lacustrine sediments of the Tule, Double Lakes, and Tahoka Formations are interbedded with the Blackwater Draw Formation.

Regional Hydrology

Preliminary studies of the hydrology of the Palo Duro Basin indicate that an aquitard composed of upper Permian evaporites and salt-cemented carbonates and clastics separates the unconfined aquifer in the Ogallala Formation and a confined aquifer in the Dockum Group from a deeply buried aquifer containing brine in Wolfcampian rocks. Regional flow of ground water throughout the section reflects topographic and lithologic controls. Flow in the Wolfcampian aquifer beneath the northern part of the Southern High Plains is toward the northeast (Smith and others, 1983). Permeability of the evaporite aquitard is very low. The principal direction of ground-water flow through this unit is downward (Dutton and Orr, 1986). Ground-water flow in the unconfined Ogallala aquifer and in the confined Dockum Group aquifer is generally toward the east and southeast (Dutton and Simpkins, 1986). A preliminary model of ground-water movement suggests that along the Eastern Caprock Escarpment fresh water leaks from the Ogallala Formation and Dockum Group downward into the zone of salt dissolution and eastward through Permian formations beneath the Rolling Plains (Simpkins and Fogg, 1982). Numerous fresh-water springs, which mark discharge points of the Ogallala and Dockum aquifers, are present along the Caprock Escarpment at the base of the Ogallala and to a lesser extent at the base of sandstones in the Dockum Group (Brune, 1981). Springs discharging brines derived from dissolution of halite occur in several areas east of the escarpment (Richter and Kreitler, 1986).

Geomorphology and Physiography

The study area lies within the Southern High Plains, which are characterized by a flat, low-relief surface partly covered by small playa lake basins. Drainage of the High Plains is mostly internal into these lake basins. Widely separated linear draws with narrow drainage basins slope to the east and southeast. Adjacent draws do not share common drainage divides, but rather are separated by wide areas of numerous playa lake basins.

SURFACE AND NEAR-SURFACE STRATIGRAPHIC UNITS

All stratigraphic units cropping out within the construction area for the proposed Amarillo SSC site are of Cenozoic age, ranging from the Miocene-Pliocene Ogallala Formation to modern fluvial, eolian, and lacustrine (playa) deposits. Small outcrops of the Triassic Dockum Group are found along Tierra Blanca Creek just north of this corridor but within the area covered by areal geologic mapping for this study

(Plate 1). The Dockum Group and various Late Cretaceous formations lie at moderate depth beneath the Cenozoic cover but are unlikely to be encountered during construction of the proposed SSC. A representative vertical sequence of Cenozoic units is shown in Figure 1.

Ogallala Formation

The Miocene-Pliocene Ogallala Formation (Ogallala Group in parts of the Southern High Plains) is a complex lithostratigraphic body nearly coextensive with the Southern High Plains (Hawley, 1984). The Ogallala crops out locally within the Amarillo SSC site and underlies the entire area (Plate 1 and Figure 1). This formation constitutes a major fresh-water aquifer throughout most of the region and is hydrologically connected to Dockum and Cretaceous aquifer-bearing units in many areas, forming the High Plains aquifer (Nativ and Smith, in press). The Ogallala consists of stacked fluvial (gravel to silt and rare boulder beds) and eolian (coarse silt to very fine sand) deposits containing numerous paleosols. These paleosols generally include one or more prominent calcretes ("caliches") at the top and base of the Ogallala section (Gustavson and Holliday, 1985). Throughout the region, the name "Caprock caliche" traditionally has been applied to the most extensive and well-developed calcrete cropping out in a given area or encountered at shallowest depth during drilling. However, it is doubtful that all of these outcrops and well penetrations constitute individual occurrences of a single, widespread calcrete. Gustavson and Holliday (1985) have shown that two or more prominent calcretes (Stage V or VI in the classification proposed by Machette, 1985, table 1) are present in individual outcrops and the number and stratigraphic positions of these calcretes vary from place to place. In addition, calcretes of Stage IV or greater development are found in some outcrops of the overlying Quaternary Blackwater Draw Formation. For these reasons, neither

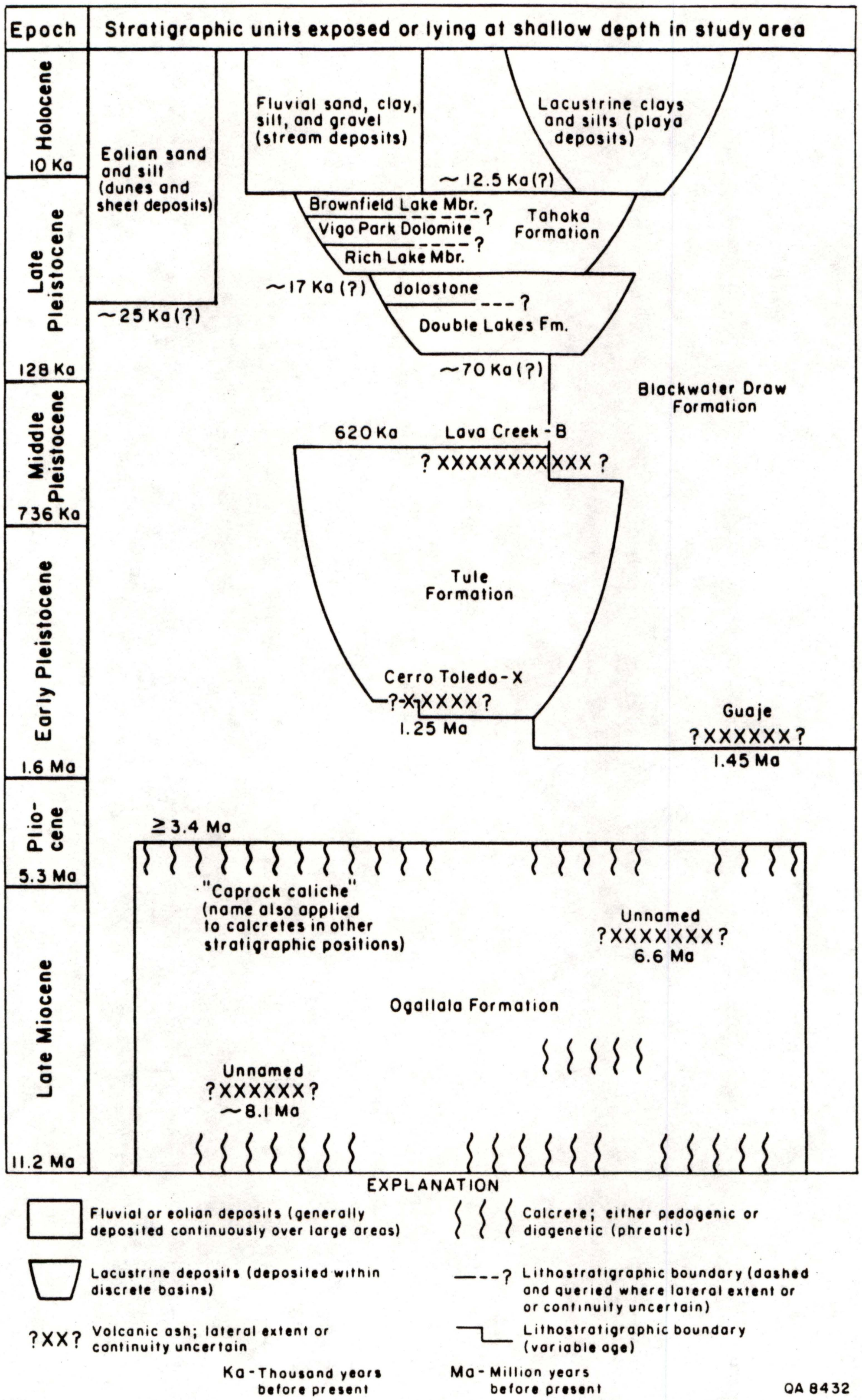

Figure 1. Cenozoic stratigraphy of the proposed Amarillo area SSC site near Happy, Texas (adapted from Caran, in press).

Table 1. Hypotheses on the formation of playa lake basins

Process	Reference
Differential compaction	Johnson (1901)
Deflation	Gilbert (1895), Patton (1935), Evans and Meade (1945), Havens (1961), Lotspeich and others (1971), and Reeves (1972)
Dissolution of evaporites	Johnson (1901), Baker (1915), Patton (1935) [Considered a minor or occasional factor by Evans and Meade (1945), Reeves and Perry (1969), and Reeves (1972)]
Buffalo wallows	Gould (1907)
Caliche karst	Price (1940) and Walker (1978)
Leaching of calcareous soil, cement, and deflation	Judson (1950) and Havens (1961)
Gentle subsidence from downward piping of fines, eluviation, and caliche dissolution	Osterkamp and Wood (1984) and Wood and Osterkamp (1984)

calcrete horizons nor any other recognized lithostratigraphic marker beds can be used for correlation within the Ogallala sections except on a local basis. Two unnamed volcanic ashes (6.6 m.y. and 8.1 [?] m.y. old) have been found in Ogallala sections in the Southern High Plains (Fig. 1). Biostratigraphic markers have been used in relating the relative ages of a few sections in which vertebrate remains have been found (Schultz, 1977; Winkler, 1985). However, the distribution of both tephrochronologic and biostratigraphic markers is uneven, and many Ogallala sections cannot be reliably subdivided or internally correlated.

Blackwater Draw Formation

Overlying the Ogallala Formation in many sections is the early Pleistocene to Holocene Blackwater Draw Formation (Holliday and Gustavson, in press). The Blackwater Draw is the surficial unit across most of the proposed SSC study area. Areal extent of the Blackwater Draw is at least as great as that of the Ogallala, and both the Ogallala and High Plains aquifers receive significant recharge through the Blackwater Draw Formation. The Blackwater Draw contains eolian silt to medium sand and incorporates a variable number of stacked paleosols. Vertebrate remains and other fossils are rare (Schultz, in preparation). Both the Lava Creek-B and Guaje volcanic ash beds (620,000 and 1,450,000 yr old, respectively) have been found in a few probable Blackwater Draw sections (Fig. 1). Like the underlying Ogallala Formation, the Blackwater Draw includes well-developed calcic horizons and calcretes (to Stage IV or greater) at some sites. However, the lateral extent of these and other pedostratigraphic markers is unknown, and there is at present no reliable basis for correlating most widely separated sections or for subdividing the unit.

Tule Formation

The Early to Middle Pleistocene Tule Formation consists of lacustrine clays, silts, and sands containing the widespread Lava Creek-B volcanic ash (620,000 yr old) and, in at least one locality, the Cerro Toledo-X volcanic ash (approximately 1,250,000 yr old) (Fig. 1). Locally, the Tule and Blackwater Draw Formations appear to interfinger. Tule Formation sediments accumulated in discrete lacustrine depositional basins, but both tephrochronologic and biostratigraphic evidence indicates that several of these basins coexisted across the region (Caran, in press). During field work connected with the SSC siting study, a previously unreported sequence of lacustrine deposits (probably correlative with the Tule Formation) was found along Tierra Blanca Creek north of the primary study area. Deposits at this locality include a previously reported bed of Pearlette family (?) volcanic ash (Izett and Wilcox, 1982, loc. TX24), possibly the Lava Creek-B ash. Although no exposures or subsurface records of the Tule Formation were logged in core from drill holes along the corridor of the SSC, this unit could be encountered at shallow depth during construction.

Double Lakes and Tahoka Formations

Both the Double Lakes and overlying Tahoka Formations consist of Late Pleistocene noncalcareous to calcareous and gypsiferous clays, sands, and dolostones (Reeves, in press) (Fig. 1). These formations are exposed or known from drilling at numerous sites in the southern part of the Southern High Plains. Chronologic control is afforded by radiocarbon dates and the presence of archeological materials and diagnostic fossil vertebrates. Neither formation is known to occur in the Amarillo SSC study area, but Reeves (in press) has noted that the Tahoka and, less commonly, the Double Lakes are encountered by drilling within the basins of some existing playas south of this area. Therefore, either or both of these formations might be found at shallow depth at the proposed Amarillo SSC site but were not encountered in any of the test holes.

Fluvial, eolian, and lacustrine (playa) deposits

Fluvial deposits of variable thickness and texture line most draws in the study area. The sand, clay, silt, and gravel composing these deposits include one or more paleosols, some of which can be used in correlating local sections. In most areas, the fluvial deposits are partly saturated with shallow, perched ground water. Eolian sands and silts form broad sheets and discrete dunes at the edges of some playas. Although most are stable and include at least incipient paleosols, there is no clear basis for correlating individual sections through these eolian deposits. Throughout the study area, lacustrine clay and silt deposits of similar composition but varying thickness are found in shallow basins known as playas. The history of playa development is complex. At many sites, modern playa basins are inset into older lacustrine deposits, indicating possible genetic cyclicity. Several mechanisms may be involved in creating and maintaining playas, and many individual playas may be polygenetic.

Playa Lake Basins

Many investigators have attempted to explain the origin of the numerous, shallow, generally circular, ephemeral lake basins known as playas. Playas have been a source of controversy; Table 1 summarizes some of the principal arguments. Most playas have at least the following characteristics in common: (1) topographic depression with a low but variable ratio of depth to diameter; (2) internal drainage (unless the basin margin has been breached by a through-going drainage channel); and (3) lacustrine fill discretely related to that basin (note, however, that at some sites, playas also form over or through the fills of older, generally larger basins). In almost all modern playas, sedimentary deposits are aggrading; this indicates that the playa basins are either being infilled and will eventually disappear as depressions or that some concurrent process is operating to cause the basin floor to subside, thereby allowing for continued filling while maintaining the playa as a depression. Wood and Osterkamp (1984) recognized a subsidence mechanism contributing to playa development in the Southern High Plains. They found that Ogallala calcretes underlying a test playa had undergone karstification, permitting piping of overburden. Sediment reaches the playas by eolian transport and by centripetal runoff from drainage basins generally only a few times larger in areal extent than the playa floor.

Some playas lose part of their accumulated sediment, possibly seasonally. Recognizable eolian deposits are present on the eastern or southeastern sides of certain playas in the Southern High Plains, indicating deflation from the basins and contiguous (lee-side) deposition in either crescentic dunes, broad mounds, or sheets of sand and silt. The sediment composing these deposits generally is reworked lacustrine fill, not the older eolian deposits (Blackwater Draw Formation) that underlie and surround most playa deposits (Fig. 1).

SALT DISSOLUTION

The Permian upper Seven Rivers and Salado Formations contain the shallowest bedded salt in the interior Palo Duro Basin. The upper Seven Rivers Formation, the shallowest salt beneath the SSC proposed site, lies approximately 1,300 ft below the surface. Thickness maps of the upper Seven Rivers and Salado Formations show that both units thin toward the basin margins (Gustavson and others, 1980; Gustavson and Finley, 1985). Thinning may be attributed to both updip facies change and salt dissolution processes. Regional post-depositional dissolution in the interior of the Palo Duro Basin including the area of the Amarillo SSC site is evidenced by core studies of the collapse breccias and insoluble residues overlying the uppermost salt in 11 wells drilled for the U.S. Department of Energy (Hovorka and others, 1985). Rapid thinning of the Salado Formation in the southern Palo Duro Basin beneath the extreme southeastern area of the Amarillo SSC site is indicative of dissolution rather than facies change (McGillis and Presley, 1981; and DeConto and Murphy, 1986).

An episode of local dissolution in an area along the Briscoe-Swisher county line approximately 35 mi east-southeast of the Amarillo SSC site was interpreted to be Triassic by DeConto and Murphy (1986) or late Tertiary to early Quaternary by Gustavson and Budnik (1985). This area of dissolution is overlain by a broad structural basin filled with lacustrine sediments of the Quaternary Tule Formation. An area of preferentially thinned upper Seven Rivers Formation has been documented in Deaf Smith, Randall, Parmer, and Castro Counties adjacent to the northwestern margin of the proposed Amarillo SSC site (Gustavson and Budnik, 1985). On the basis of structural, stratigraphic, and geomorphic data, Gustavson and Budnik (1985) hypothesized that dissolution-induced surface subsidence occurred along Tierra Blanca Creek during late Tertiary or early Quaternary time. During field work connected with the SSC siting study, a previously unreported sequence of lacustrine beds occupying a structural depression within the valley of Tierra Blanca Creek was recognized. These sediments contain a bed of Pearlette family (?) ash (late Tertiary-Quaternary). DeConto and Murphy (1986) also addressed the thinning of upper Seven Rivers and argued against a Tertiary-Quaternary dissolution episode.

Numerous Quaternary alkaline lake basins on the Southern High Plains south of the proposed site have been related to dissolution of underlying Permian salt beds (Reeves and Temple, 1986). Alkaline lake basins should not be confused with playa lake basins. Alkaline lake basins are commonly an order of magnitude larger than playa lake basins and irregular in shape. Playa lake basins are nearly circular in plan. No alkaline lake basins are present in the Amarillo SSC site area.

Playa lake basins have also been attributed to dissolution and subsidence (Baker, 1915; Gustavson and others, 1980) among other causes (Table 1). Gustavson and others (1980) described evidence of salt dissolution beneath two large playa basins near Pampa, Texas, approximately 90 mi north of the SSC site. They also described a large playa lake basin in eastern New Mexico that had no evidence of salt dissolution below it.

Lack of recent surface subsidence beneath most of the Southern High Plains suggests that salt dissolution there is inactive or very slow. Data from test wells in salt-dissolution zones in Deaf Smith, Donley, and Swisher Counties confirm that ground waters in salt-dissolution zones move downward from the overlying Dockum Group and Ogallala aquifers (Dutton, in press). Dutton (in press), comparing salinities of ground water, concluded that dissolution of the uppermost salts under the Southern High Plains is slow relative to dissolution rates under the Rolling Plains.

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REFERENCES

Baker, C. L., 1915, Geology and underground waters of the Northern Llano Estacado, Texas: Austin, University of Texas Bulletin No. 57, p. 46-49.

Brune, Gunnar, 1981, Springs of Texas, vol. I: Fort Worth, Texas, Branch Smith, Inc., 566 p.

Caran, S. C., in press, Late Cenozoic stratigraphy, southern Great Plains and adjacent areas, in Morrison, R. B., ed., Quaternary nonglacial geology, conterminous United States: Geological Society of America, Decade of North American Geology v. K-2, plate.

DeConto, R. T., and Murphy, P. J., 1986, Dissolution of the Upper Seven Rivers and Salado salt in the interior Palo Duro Basin, Texas: Columbus, OH, Battelle Memorial Institute, prepared by Stone & Webster Engineering Corporation for Office of Nuclear Waste Isolation, ONWI/SUB/86/E512-05000-T45.

Dutton, A. R., and Orr, E. D., 1986, Hydrogeology and hydrochemical facies of the San Andres Formation in eastern New Mexico and the Texas Panhandle: The University of Texas at Austin, Bureau of Economic Geology Report of Investigations No. 157, 58 p.

Dutton, A. R., and Simpkins, W. W., 1986, Hydrogeochemistry and water resources of the Triassic Lower Dockum Group in the Texas Panhandle and eastern New Mexico: The University of Texas at Austin, Bureau of Economic Geology Report of Investigations No. 161, 51 p.

Dutton, A. R., in press, Hydrogeologic and hydrochemical properties of salt-dissolution zones, Palo Duro Basin, Texas Panhandle--preliminary assessment: The University of Texas at Austin, Bureau of Economic Geology Geological Circular 87-2.

Eifler, G. K., Jr., 1968, Geologic atlas of Texas, Plainview sheet: The University of Texas at Austin, Bureau of Economic Geology (scale 1:250,000).

Eifler, G. K., Jr., and Reeves, C. C., Jr., 1977, Geologic atlas of Texas, Clovis sheet: The University of Texas at Austin, Bureau of Economic Geology (scale 1:250,000).

Evans, G. L., and Meade, G. E., 1945, Quaternary of the Texas High Plains: Austin, University of Texas, in Texas Mineral Resources, Publication 4401, p. 485-507.

Fracasso, M. A., and Hovorka, S. D., 1986, Cyclicity in the Middle Permian San Andres Formation, Palo Duro Basin, Texas Panhandle: The University of Texas at Austin, Bureau of Economic Geology Report of Investigations No. 156, 48 p.

Gable, D. J., and Hatton, T., 1983, Maps of vertical crustal movements in the coterminous United States over the last 10 million years: U.S. Geological Survey, Miscellaneous Investigations Map I-1315.

Gilbert, G. K., 1895, Lake basins created by wind erosion: Journal of Geology, v. 3, p. 47-49.

Gould, C. N., 1907, The geology and water resources of the western portion of the Panhandle of Texas: U.S. Geological Survey, Water-Supply and Irrigation Paper No. 191.

Gustavson, T. C., Finley, R. J., and McGillis, K. A., 1980, Regional dissolution of Permian salt in the Anadarko, Dalhart and Palo Duro Basins of the Texas Panhandle: The University of Texas at Austin, Bureau of Economic Geology Report of Investigations No. 106, 40 p.

Gustavson, T. C., and Budnik, R. T., 1985, Structural influences on geomorphic processes and physiographic features, Texas Panhandle: technical issues in siting a nuclear waste repository: Geology, v. 13, no. 3, p. 173-176.

Gustavson, T. C., and Finley, R. J., 1985, Late Cenozoic geomorphic evolution of the Texas Panhandle and northeastern New Mexico: case studies of structural controls of regional drainage development: The University of Texas at Austin, Bureau of Economic Geology, Report of Investigations No. 148, 42 p.

Gustavson, T. C., and Holliday, V. T., 1985, Depositional architecture of the Quaternary Blackwater Draw and Tertiary Ogallala Formations, Texas Panhandle and Eastern New Mexico: The University of Texas at Austin, Bureau of Economic Geology, OF-WTWI-1985-23, 60 p.

Handford, C. R., and Dutton, S. P., 1980, Pennsylvanian-Early Permian depositional systems and shelf margin evolution, Palo Duro Basin, Texas: American Association of Petroleum Geologists Bulletin, v. 64, no. 1, p. 88-106.

Havens, J. S., 1961, Preliminary results of test drilling in depressions on the High Plains, Lea County, New Mexico: Geological Survey Professional Paper 424-B.

Hawley, J. W., 1984, The Ogallala Formation in eastern New Mexico, in Whetstone, G. A., ed., Proceedings, Ogallala Aquifer Symposium II: Lubbock, Texas Tech University, Water Resources Center, p. 157-176.

Holliday, V. T., and Gustavson, T. C., in press, Quaternary geology of the Southern Great Plains, in Morrison, R. B, ed., Quaternary nonglacial geology, conterminous United States: Geological Society of America, Decade of North American Geology v. K-2.

Hovorka, S. D., Fisher, R. S., and Nance, H. S., 1985, Petrography and geochemistry of the Artesia Group, Palo Duro Basin, Texas Panhandle: The University of Texas at Austin, Bureau of Economic Geology, OF-WTWI-1985-43, p. 58-65.

Izett, G. A., and Wilcox, R. E., 1982, Map showing localities and inferred distributions of the Huckleberry Ridge, Mesa Falls, and Lava Creek ash beds (Pearlette family ash beds) of Pliocene and Pleistocene age in the western United States and southern Canada: Washington, D. C., Geological Survey Miscellaneous Investigations Series Map I-1325 (scale 1:4,000,000).

Johnson, W. D., 1901, The High Plains and their utilization: U.S. Geological Survey 21st annual report, part 4, p. 701-705.

Judson, Sheldon, 1950, Depressions of the northern portion of the Southern High Plains of Eastern New Mexico: Geological Society of America Bulletin, v. 61, p. 253-274

Lotspeich, F. B., Lehman, O. R., Hauser, V. L., and Stewart, B. A., 1971, Hydrogeology of playa near Amarillo, Texas: Bushland, TX., U.S. Department of Agriculture, Southwestern Great Plains Research Center, Technical Report 10.

Machenberg, M. D., DuBar, J. R., Gustavson, T. C., and Holliday, V. T., 1985, A depositional model for post-Ogallala sediments on the Southern High Plains (abs.): Geological Society of America Abstracts with Programs, v. 17, p. 165.

Machette, M. N., 1985, Calcic soils of the southwestern United States, in Weide, D. L., ed., Soils and Quaternary geology of the southwestern United States: Geological Society of America Special Paper 22, p. 1-21.

McGillis, K. A., and Presley, M. W., 1981, Tansill, Salado, and Alibates Formations: Upper Permian evaporite/carbonate strata of the Texas Panhandle: The University of Texas at Austin, Bureau of Economic Geology, Geological Circular 81-8, 31 p.

McGowen, J. H., Granata, G. E., and Seni, S. J., 1979, Depositional framework of the lower Dockum Group (Triassic), Texas Panhandle: The University of Texas at Austin, Bureau of Economic Geology Report of Investigations No. 97, 60 p.

Nativ, Ronit, and Smith, D. A., in press, Hydrogeology and geochemistry of the Ogallala aquifer, Southern High Plains: Journal of Hydrology.

Osterkamp, W. R., and Wood, W. W., 1984, Playa Lakes of the Southern High Plains - geologic evidence for origin and development (abs.): Geological Society of America Abstracts with Programs, v. 16, no. 6, p. 615.

Patton, L. T., 1935, Some observations on the so-called "lakes" of the Llano Estacado of Texas (abs.): Proceedings of the Geological Society of America for 1934, p. 451.

Presley, M. W., 1979a, Upper Permian evaporite and red beds in Dutton, S. P., and others, Geology and geohydrology of the Palo Duro Basin, Texas Panhandle, a report on the progress of nuclear waste isolation feasibility studies (1978): The University of Texas at Austin, Bureau of Economic Geology Geological Circular 79-1, p. 39-49.

_______ 1979b, Salt deposits, in Dutton, S. P., and others, Geology and geohydrology of the Palo Duro Basin, Texas Panhandle, a report on the progress of nuclear waste isolation feasibility studies (1978): The University of Texas at Austin, Bureau of Economic Geology Geological Circular 79-1, p. 50-56.

_______ 1980a, Upper Permian salt-bearing stratigraphic units, in Gustavson, T. C., and others, Geology and geohydrology of the Palo Duro Basin, Texas Panhandle, a report on the progress of nuclear waste isolation feasibility studies (1980): The University of Texas at Austin, Bureau of Economic Geology, Geological Circular 80-7, p. 12-23.

_______ 1980b, Salt depth and thickness studies, in Gustavson, T. C., and others, Geology and geohydrology of the Palo Duro Basin, Texas Panhandle, a report on the progress of nuclear waste isolation feasibility studies (1979): The University of Texas at Austin, Bureau of Economic Geology, Geological Circular 80-7, p. 33-40.

Price, W. A., 1940, Caliche karst (abs.): Geological Society of America Bulletin, v. 51, p. 1938-1939.

Reeves, C. C., Jr., and Parry, W. T., 1969, Age and morphology of small lake basins, Southern High Plains, Texas and Eastern New Mexico: The Texas Journal of Science, v. 20, no. 4, p. 349-354.

Reeves, C. C., Jr., 1972, Tertiary-Quaternary stratigraphy and geomorphology of West Texas and Southeastern New Mexico, in Kelley, C. V., and Trauger, F. D., eds., Guidebook of East-Central New Mexico, 23rd Field Conference, New Mexico Geological Society, p. 108-119.

Reeves, C. C., Jr., and Temple, J. M., 1986, Permian salt dissolution, alkaline lake basins, and nuclear-waste storage, Southern High Plains, Texas and New Mexico: Geology, v. 14, no. 11, p. 939-942.

Reeves, C. C., Jr., in press, Alkaline lakes, southern Great Plains, in Morrison, R. B., ed., Quaternary nonglacial geology, coterminous United States: Geological Society of America, Decade of North American Geology, v. K-2.

Richter, B. C., and Kreitler, C. W., 1986, Geochemistry of salt-spring and shallow subsurface brines in the Rolling Plains of Texas and southwestern Oklahoma: The University of Texas at Austin, Bureau of Economic Geology Report of Investigations No. 155, 47 p.

Schultz, G. E., 1977, The Ogallala Formation and its vertebrate faunas in the Texas and Oklahoma Panhandles, in Schultz, G. E., ed., Guidebook, field conference on Late Cenozoic biostratigraphy of the Texas Panhandle and adjacent Oklahoma: Canyon, West Texas State University, Killgore Research Center Special Publication No. 1, p. 5-104.

________ in preparation, Biostratigraphy of the Ogallala and Blackwater Draw Formations, Central and Southern High Plains, in Gustavson, T. C., ed., Proceedings, Symposium on the Late Tertiary Ogallala and Quaternary Blackwater Draw Formations: The University of Texas at Austin, Bureau of Economic Geology.

Seni, S. J., 1980, Sand-body geometry and depositional systems, Ogallala Formation, Texas: The University of Texas at Austin, Bureau of Economic Geology Report of Investigations No. 105, 36 p.

Simpkins, W. W., and Fogg, G. E., 1982, Preliminary modeling of ground-water flow near salt dissolution zones, Texas Panhandle, in Gustavson, T. C., and others, Geology and geohydrology of the Palo Duro Basin, a report on the progress of nuclear waste isolation feasibility studies (1981): The University of Texas at Austin, Bureau of Economic Geology Geological Circular 82-7, p. 130-137.

Smith, D. A., Bassett, R. L., and Roberts, M. P., 1983, Potentiometric surface of the Wolfcampian aquifer, Palo Duro Basin, in Gustavson, T. C., and others, Geology and geohydrology of the Palo Duro Basin, a report on nuclear waste isolation feasibility studies (1982): The University of Texas at Austin, Bureau of Economic Geology Geologic Circular 83-4, p. 94-96.

Walker, J. R., 1978, Geomorphic evolution of the Southern High Plains: Waco, TX, Baylor University, Baylor Geological Studies Bulletin No. 5.

Winkler, D. A., 1985, Stratigraphy, vertebrate paleontology, and depositional history of the Ogallala Group in Blanco and Yellowhouse canyons, northwestern Texas: The University of Texas at Austin, Ph.D. dissertation, 243 p.

Wood, W. W., and Osterkamp, W. R., 1984, Playa lakes of the Southern High Plains - geochemical and hydrologic evidence for development (abs.): Geological Society of America, Abstracts with Programs, 1984, v. 16, p. 700.

Wood, W. W., and Osterkamp, W. R., 1984, Recharge to the Ogallala aquifer from playa lake basins on the Llano Estacado--an outrageous proposal?, in Whetstone, G. A., ed., Proceedings, Ogallala Aquifer Symposium II: Lubbock, Texas Tech University, Water Resources Center, p. 337-349.