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FIELD DESCRIPTIONS OF SEDIMENTARY AND DIAGENETIC FEATURES IN RED BEDS AND EVAPORITES OF THE NIPPEWALLA GROUP (MIDDLE PERMIAN), KANSAS AND OKLAHOMA

By

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**ABSTRACT**

"Red bed" siliciclastics and evaporites of the Guadalupian-Leonardian Nippewalla Group are exposed on the surface in south-central Kansas (Barber, Harper, Comanche, and Clark Counties) and nonhwestern Oklahoma (primarily Woods County and Alfalfa County). This paper describes the sedimentary and diagenetic features observed in the field and proposes a depositional and diagenetic history for these rocks.

Sedimentary structures such as cumulate and bottom-growth halite crystal casts, ripple marks. and cross-laminae suggest deposition in shallow saline surface waters. Associated prismatic mudcracks and curled mudchip intraclasts indicate that these water bodies underwent periods of desiccation. Subaerial exposure of adjacent sediments is confirmed by mudcracks and mudchip intraclasts, root features, *Microcodium* calcretes, and peds. Early diagenetic features including displacive halite, anhydrite nodules, anhydrite replacement of gypsum, halite cementation, meniscus cementation, and alveolar texture in calcretes suggest that saline groundwater played an important role in this environment.

Sedimentary and early diagenetic features in these red beds and evaporites suggest that they were deposited as ancient ephemeral saline lakes, mudflats, sand flats, and soils. They indicate that, during time of Nippewalla deposition, the midcontinent was probably covered by a low relief land surface with shallow saline lakes. This interpretation of a mid Permian saline pan environment may be useful in better defining paleogeographic maps. This paper offers a new interpretation of a continental paleogeographic setting in place of previous interpretations of a shallow mid-Permian sea for the midcontinent.

# INTRODUCTION

"Red bed" siliciclastics and evaporites make up the Guadalupian-Leonardian Nippewalla Group. These rocks are exposed on the surface in south-central Kansas (Barber, Harper, Comanche, and Clark Counties) and northwestern Oklahoma (primarily Woods County and Alfalfa County; Figure 1). The outcrop belt of the Nippewalla Group coincides with the Red Hills (or Gyp Hills) physiographic province of Kansas and Oklahoma. Differences in relative resistances to erosion of the red beds and anhydrite/gypsum beds have produced spectactular mesas, buttes, and canyons in this region (Figures 2 - 4). Drainage is provided by both perennial and ephemeral streams that now to the southeast. Sinkholes, caverns, and natural bridges are evidence of dissolution of the evaporite beds.

The thickness of the Nippewalla Group is greater than one hundred meters at the surface in southcentral Kansas and nonhern Oklahoma, but increases to several hundred meters in the subsurface of western Kansas. The general lithology of the Nippewalla Group differs from surface to subsurface. Anhydrite/gypsum beds and red bed shales, siltstones, and sandstones occur in outcrops. These surface exposures contain no halite. In the subsurface of western Kansas, the Nippewalla Group is composed of bedded halite, anhydrite, and red bed shales, siltstones, and sandstones. The detailed depositional environment and diagenetic history of the Nippewalla Group has not been resolved.

A major problem encountered in studies of evaporite rocks is determining their depositional environment. Traditionally, the view held is that all evaporites formed in restricted, shallow water marginal marine settings. Comparitive sedimentological studies in the 1970' s through the 1990' s have documented modem evaporite deposits forming in shallow water continental basins (Eugster, 1970; Handford, C.R., 1982: Hardie et al.. 1978: Lowenstein et al., 1989) and deep water stratified basins (Schreiber et al., 1976: \Veiler et al., 1974) as well as shallow water, marginal marine

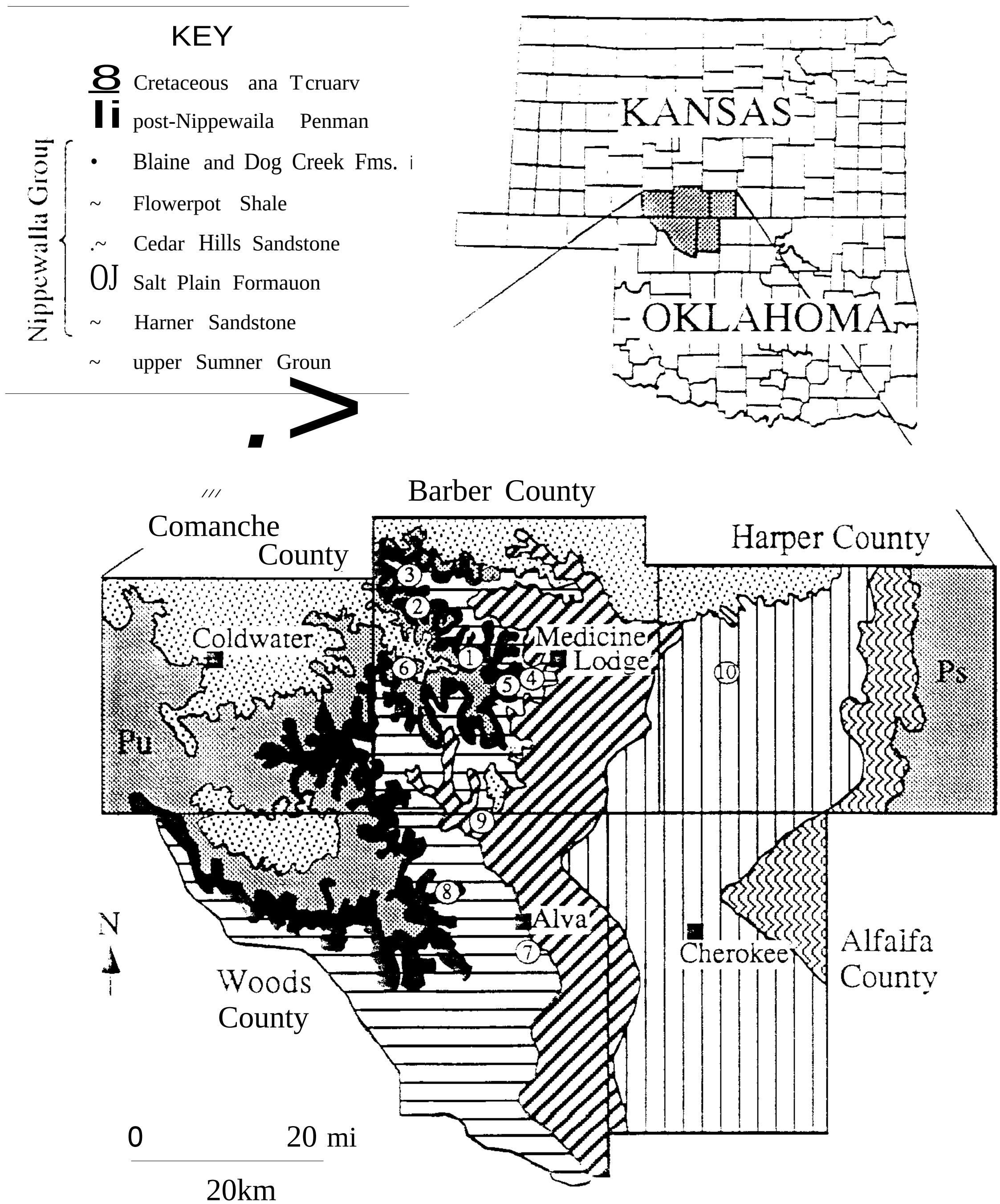


Figure 1.: General zeoloaicai man of the field area. Circled numbers refer to approximate outcrop locations ofmeasured sections in Appendix A. Modified after :\onon. 1939.

Figuc 2: Mesa of Flowerpot Shale; view looking north; Maria Ranch, Barber County, Kansas: SWI/4. NEI/4, Sec. 21, T32S, RI2W.

Figure 3: Mesas and buttes of Flowerpot Shale capped by Blaine Formation; view looking southeast from gate 2, Maria Ranch, Barber County, Kansas; NWI/4, NEI/4. Sec 20, T32S, R12W.

Figure 4: View of mesas and buttes, composed of uppermost Flowerpot Shale red beds capped by Blaine Formation gypsum, and valley floored by red beds of lowermost Flowerpot Shale and covered by grasses and salt cedars; note top of canyon in foreground and gypsum ledge in immediate foreground; view looking northeast from radio tower hill, inside gate 4, Maria Ranch, Barber County, Kansas; SW1/4, NE 1/4, Sec. 29, T32S, R12W.

environments (Hardie and Eugster, 1971: Presley, 1987). Criteria have been established to recognize ancient deep water evaporites from ancient shallow water evaporites (Lowenstein and Hardie, 1985; Warren, 1989). However, distinguishing between ancient evaporites formed in marine settings versus nonmarine settings is still problematic (Attia et al., 1995; Hardie, 1984; Warren, 1989). Recent work on modem evaporites has also concentrated on distinguishing primary sedimentary features from early diagenetic features (Casas and Lowenstein, 1989; Casas et al., 1992).

The purpose of this paper is to describe the sedimentary and diagenetic features of the Nippewalla Group and to propose a depositional and diagenetic history for these rocks. Although the author has conducted a preliminary petrographic study of core samples from the subsurface of western and southwestern Kansas, this paper will concern itself primarily with field data.

## STRATIGRAPHY

The stratigraphy of Permian red beds and evaporites in Kansas and Oklahoma is problematic. The Nippewalla Group maintains a consistent lithology in field exposures with few distinctive units or contacts. Similar lithologies have different stratigraphic names in the two states (Fay, 1964, Holdoway, 1975, 1978, Johnson, 1991, Kulstad et al., 1956, Norton, 1939, Scott and Ham, 1957). Various name changes have occurred since these rocks were first studied (Cragin, 1896, Holdoway, 1975, 1978, Myers et al., 1969, Norton, 1939, Swineford, 1955). "Lumping" versus "splitting" has produced myriad stratigraphic names. This has resulted in both: (1) the same rock unit having several different names in different locations, and (2) different rock units called by the same name.

Rapid erosion may complicate matters for today's geologists trying to locate outcrops described in the 1930's, 1950's, and 1960's. For example, a natural bridge used as a landmark in the 1930's collapsed in 1964. Another natural bridge

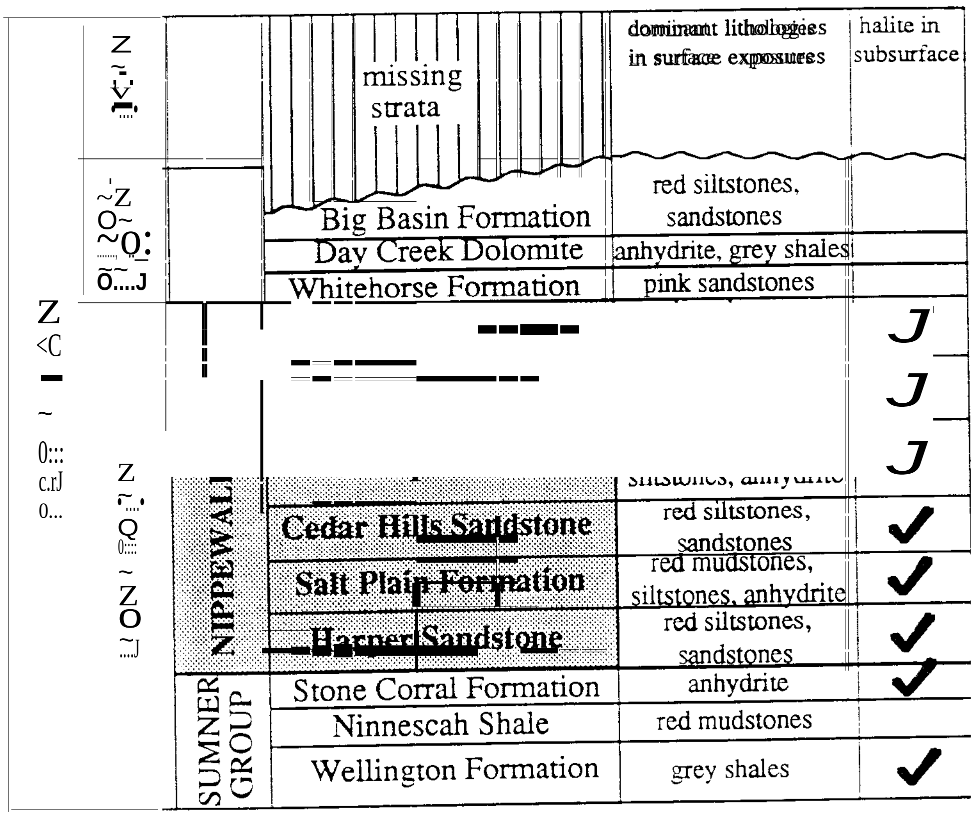


Figure 5: Stratigraphic setting of the Nippewalla Group; modified after Baars, 1990, Ham, 1960, Norton, 1939, and Swineford, 1955.

documented in the mid-1960's could be easily mistaken for the first one. The more recently described natural bridge can no longer be used as a landmark since it was destroyed by the landowner in the early 1990's. The similarity in appearance of many of the buttes in the field area has also hindered accurate location of previously described outcrops. Two buttes in different townships have both been referred to as Flowerpot Mound, the type locality of the Flowerpot Shale (Buchanan and McCauley, 1987, Norton, 1939). These inaccuracies in field locations have contributed to a confusing stratigraphy in this area.

Correlation has also been problematic in the study of the stratigraphy of the Nippewalla Group. Paucity of fossils renders biostratigraphic correlation impossible. Halite, present in abundance in the subsurface, is absent due to dissolution on the surface. This makes lithostratigraphic correlation between the surface and subsurface difficult. Even correlation among surface exposures may not be possible because many beds are laterally discontinuous at the outcrop scale.

In order not to be hampered by these stratigraphic problems, this paper will use only the most general five formation names for the Nippewalla Group (Baars, 1990, Holdoway, 1975, Merriam, 1963, Zeller, 1968; Figure 5) and the Norton's (1939) geological map (Figure 1).

## BACKGROUND

Most of the published work on the Nippewalla Group concentrates upon its stratigraphy (Cragin. 1896, 1897; Fay 1964, 1965; Fay et al., 1962; Ham, 1960: Merriam, 1963; Norton. 1939; Scott and Ham, 1957; Zeller, 1968) and the economic significance of its gypsum and anhydrite deposits (Fay, 1965; Fay et al., 1962; Kulstad et al., 1956; Scott and Ham, 1957). Cragin (1896, 1897) first divided these rocks into a detailed stratigraphic system. Norton (1939) mapped the Nippewalla Group in south-central Kansas and northern Oklahoma. The state geological surveys of both Kansas and Oklahoma published several compilations of measured sections in the 1950' sand 1960's (Fay, 1964: Fay et al., 1962; Kulstad et al., 1956: Scott and Ham, 1957), but these descriptions did not include most sedimentary structures and diagenetic features. A detailed petrographic study of the Sumner and Nippewalla Groups, as well as the post-Nippewalla Permian red beds, was conducted by Swineford (1955). This work focused on mineralogical and grain size analyses. Swineford concluded that the Permian red beds are composed mostly of quartz (approximately 80%) and onhoclase (approximately 15%) grains coated by hematite. Clay minerals, primarily illite, are also found in the finer-grained red beds. Holdoway (1975, 1978) used petrography and bromide analysis of core samples from the subsurface of western Kansas to interpret the depositional environment of the Nippewalla Group. She found that halite is abundant in the subsurface Nippewalla Group. For example, up to 85% of the Flowerpot Shale is halite. If all the halite in subsurface were removed, thickness of the Nippewalla Group would be approximately the same at depth as at the surface. Based on the low bromide content in halite and the association of red beds with evaporites, Holdoway claimed that the Nippewalla Group evaporites were deposited in a shallow, continental basin.

## METHODS

This paper concentrates upon sedimentary and diagenetic features observed in the field area of Barber, Harper, and Comanche Counties in Kansas, and Woods and Alfalfa Counties in Oklahoma. Field localities of previous workers have been examined, as well as some new localities.

Published descriptions of measured sections throughout the field area have already provided a lithologic and stratigraphic framework. Outcrops were described with detailed attention paid to sedimentary and diagenetic features. Several measured sections have been included in an Appendix in order to demonstrate general trends in stratigraphic locations of sedimentary and diagenetic features. Representative samples collected in the field were slabbed and thin sectioned for petrographic study.

## LITHOLOGY

The dominant lithologies in surface exposures of the the Nippewalla Group are: (1) hematitic mudstone, siltstone, and sandstone, and (2) anhydrite/gypsum beds. The more resistant, ledge-forming units are the Harper Sandstone, the Cedar Hills Sandstone, and the Blaine Formation. The less resistant, slope-forming formations are the Salt Plain Formation, the Flowerpot Shale, and the Dog Creek Formation (Figures 6 - 11).

The coarser-grained siliciclastic red beds are found in the Harper Sandstone and the Cedar Hills Sandstone. The Salt Plain Formation consists of silty and shaley red beds with thin resistant beds of anhydrite. The Flowerpot Shale is composed primarily of red bed shales and siltstones and less common thin anhydrite beds (Figures 12 and 13). The Blaine Formation is the most easily recognizable unit in the field area. It is composed of three thick, pale blue (5B9/1 and 5G8/1 on Munsell Color Chart) anhydrite and gypsum beds that cap most of the mesas and buttes in the Red Hills. The Dog Creek Formation, the uppermost unit of the Nippewalla Group, is similar to the Salt Plain Formation and Flowerpot Shale in lithology. It is composed of red bed siltstones, fine-grained sandstones, and thin resistant anhydrite beds. Red bed siliciclastics throughout the Nippewalla Group are characteristically 5YR5/6 and IOR6/6 in color on the Munsell Color Chan.

Neither red beds nor anhydrite beds are compositionally homogeneous. Red bed sediments are mostly quartz grains with hematite coatings and cement, but anhydrite grains are common as well. Rare, thin calcretes are also found in some red beds. Anhydrite units are composed mostly of detrital anhydrite grains, with some quartz grains and rare gray siliciclastic peloidal mudstone. Only the Blaine Formation

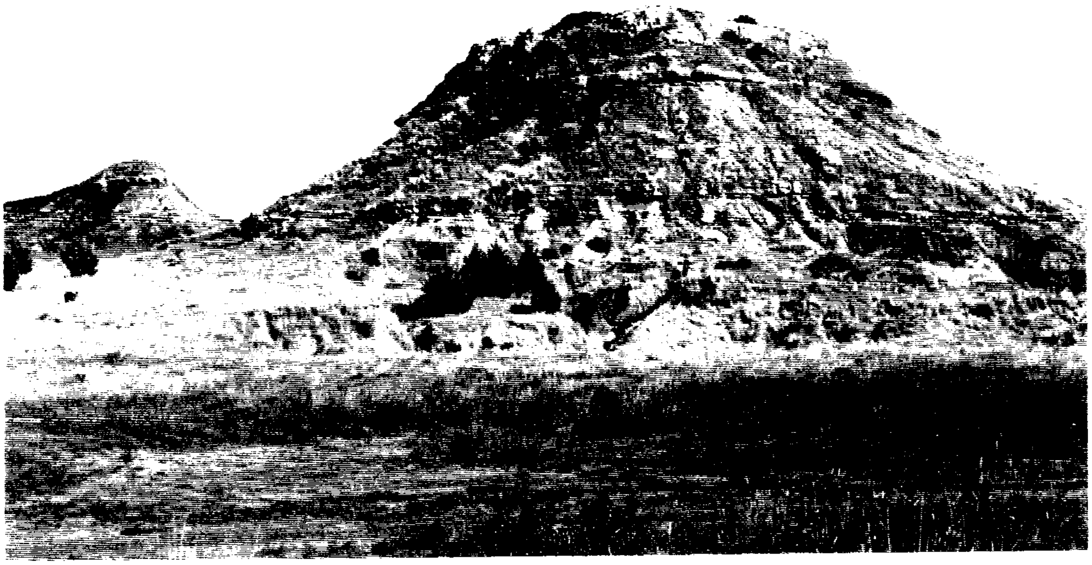

Figure 6: Butte of Flowerpot Shale capped by Blaine Formation; view looking north-west, Maria Ranch, Barber County, Kansas; SE 1/4, SWI/4, Sec. 20, T32S, R12W.

Figure 7: Radio tower hill; Flowerpot Shale capped by Blaine Formation; view looking west, Maria Ranch, Barber County, Kansas; SWI/4, NEI/4, Sec. 29, T32S, R12W.

Figure 8: Outcrop of Salt Plain Formation in front of dam at Great Salt Plains Reservoir; view looking southeast, Alfalfa County, Oklahoma; Sec. 1, T26N, RIIW.

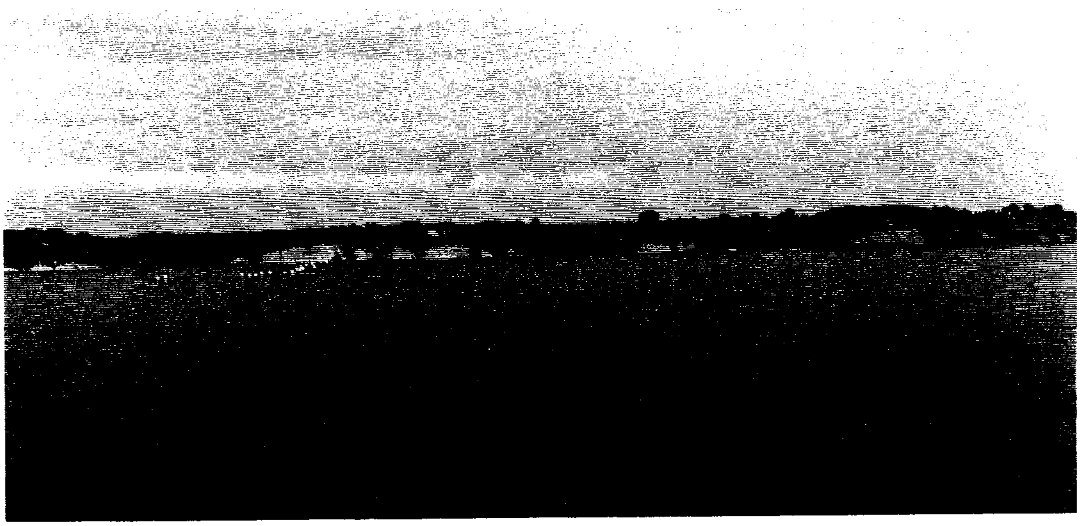

Figure 9: Cliffs of Salt Plains Formation and Cedar Hills Sandstone; view looking southwest across Great Salt Plains Reservoir, Alfalfa County, Oklahoma; Sec. 1, T26N, RllW.

Figure 10: Butte of mostly covered Flowerpot Shale capped by Blaine Formation; small exposure of Flowerpot Shale in foreground.Salt cedar trees indicate saline groundwater; view looking west from dirt road between Rte.160 and Sun City, Barber County, Kansas; SEl/4, NEl/4, Sec. 34, T31S, RI5W.

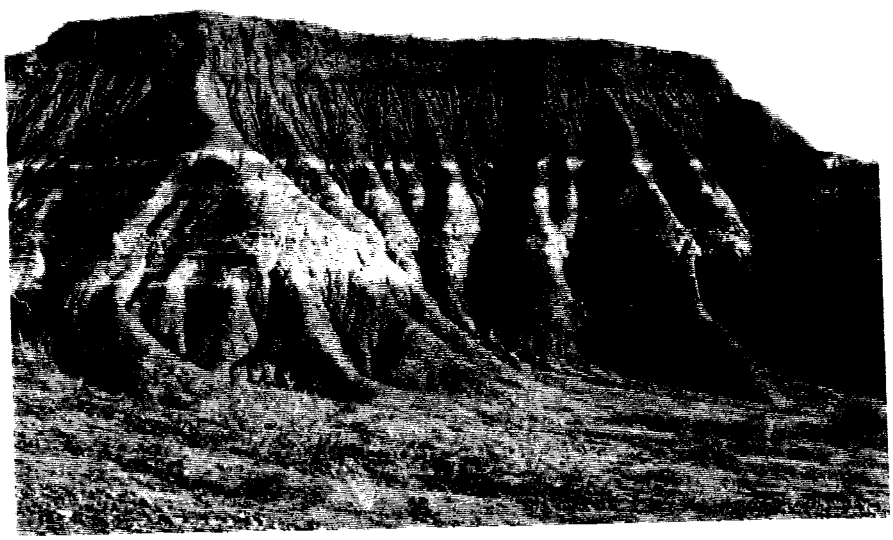

Figure 11: Flowerpot Shale capped by Quaternary sands and modem soil horizons; view looking east from dirt road southwest of Hardtner, Kansas, Woods County, Oklahoma; NWl/4, Sec. 15, T29N, R15 W.

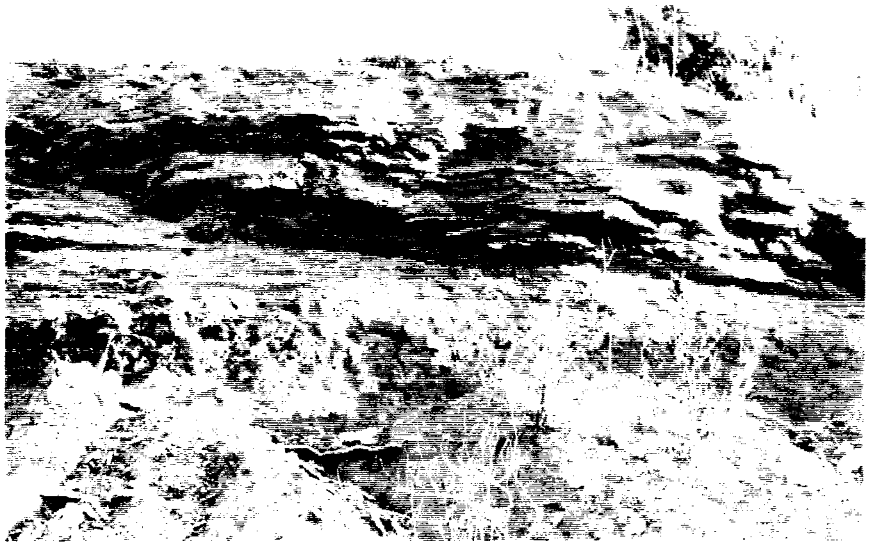

Figure 12: Outcrop of Flowerpot Shale showing anhydrite and quartz sandstone beds overlying red bed siltstones; note 32.5 em long hammer for scale in left center of photo; just inside gate 2, Maria Ranch, Barber County, Kansas; NWl/4, NEl/4, See. 20, T32S, R12W.

Figure 13: Profile view of same Flowerpot Shale outcrop shown above; note hammer for scale in center of photo, just under contact between sandstones and siltstones; hammer is 32.5 em long; just inside gate 2, Maria Ranch, Barber County, Kansas; NW1/4, NE1/4, Sec. 20, T32S, R12W.

contains a rather consistent composition in the form of anhydrite and gypsum.

By far the most common lithology in surface exposures of the Nippewalla Group are nearly uncemented quartz and hematite siltstones. These appear as crumbly, eroded, sloping, structureless red beds, held up only by resistant overlying units.

## SEDIMENTARY FEATURES

Sedimentary structures are best preserved in the thin resistant anhydrite beds of the Salt Plain, Flowerpot, and Dog Creek Formations. Rare resistant siltstones within these formation also contain some sedimentary structures. These sedimentary features include halite crystal casts, ripple marks, planar laminae, mud cracks, curled mud chip intraclasts, root casts and traces, *Microcodium;* and peds.

### *HALITE CASTS*

Three types of halite crystal casts occur in the field area: (1) randomly-spaced and -sized cubic-shaped casts, (2) triangle-profile casts in a continuous lateral bed, and (3) displacive skeletal casts.

The random cubic-shaped casts range in size from 0.2 - 2.2 centimeters (Figures 14 - 19). Most are preserved as cubes composed of gypsum. anhydrite, and/or red siliciclastics, displaying flat cubic faces, but no internal structure (Figures 16 and 17). Some halite casts are "hoppers"; that is, they have an overall cubic shape with an inverted pyramid structure on cubic faces (Figure 18). These are the most common type of halite cast in the field area, occurring in abundant beds of the Salt Plain, Flowerpot, and Dog Creek Formations. These halite casts are randomly situated on bedding planes of thin anhydrite beds, immediately above ripple marks (Figures 1-1- and 15). This, along with their varying sizes, indicate that they probably grew at water's surface and then dropped down through the water column. If this halite had grown at the bottom of a water body, it would be preseved in the form of a continuous

Figure 14: Bedding plane of anhydrite with wave ripple marks and abundant cumulate halite casts; penny for scale is 1.9 em in diameter; Cox Ranch, Barber County, Kansas; NWI/2, NEI/4, Sec. 25, T30S, R15W.

Figure 15: Bedding plane of anhydrite with wave ripple marks and abundant cumulate halite; penny for scale is 1.9 em in diameter; Maria Ranch, Barber County, Kansas; NWl/4, NEl/4, Sec. 20, T32S, RI2W.

Figure 16: Bedding plane of anhydrite and quartz sandstone with abundant cumulate halite casts; dime for scale is 1.75 em in diameter; Cox Ranch, Barber County, Kansas; NWl/2, NEl/4, Sec. 25, T30S, R15W.

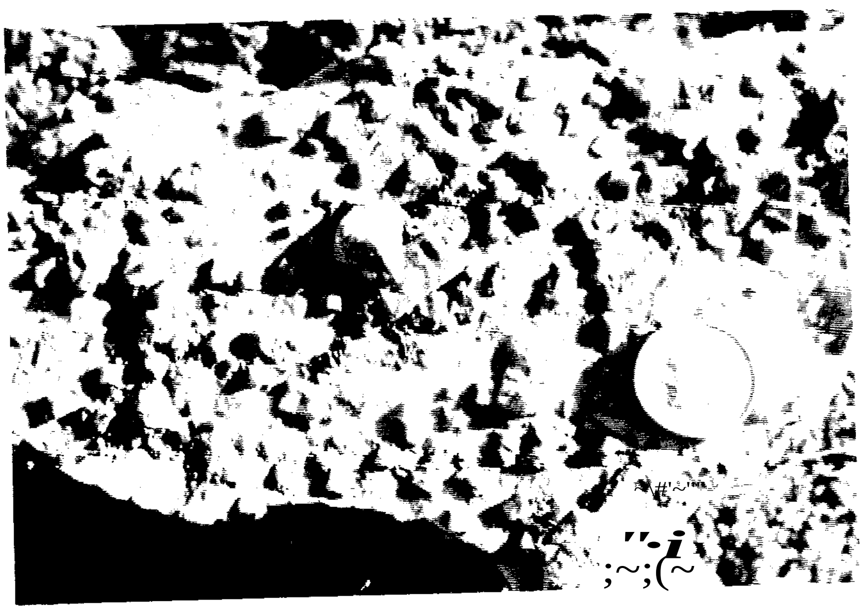

Figure 17: Bedding plane of anhydrite and quartz siltstone with cumulate halite casts; dime for scale is 1.75 em in diameter; Maria Ranch, Barber County, Kansas; NW1/4, NEl/4, Sec. 20, T32S, R12W.

Figure 18: Bedding plane of anhydrite and quartz fine sandstone with abundant cumulate halite casts; note inverted pyramid structure on faces of larger casts; penny for scale is 1.9 Col in diameter; Maria Ranch, Barber County, Kansas; NWl/4, NEI/4, Sec. 20, T~2S, R12W.

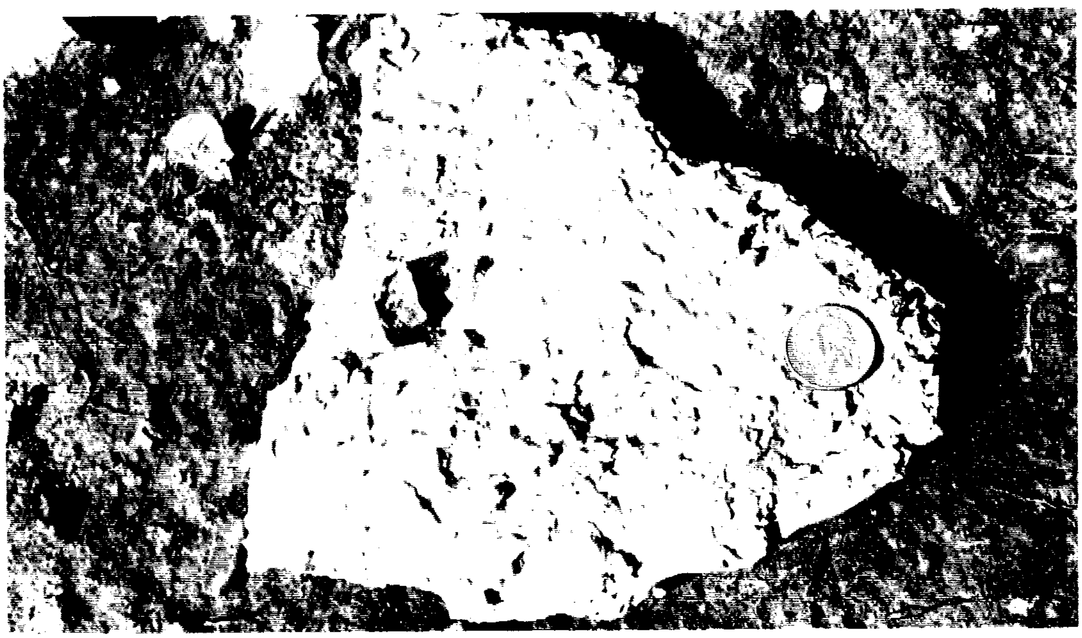

Figure 19: Bedding plane of anhydrite siltstone with cumulate halite casts and red red quartz sand; note large cast at left; quarter for scale is 2.4 em in diameter; Maria Ranch, Barber County, Kansas; NWl/4, NEl/4, Sec. 20, T32S, R12W.

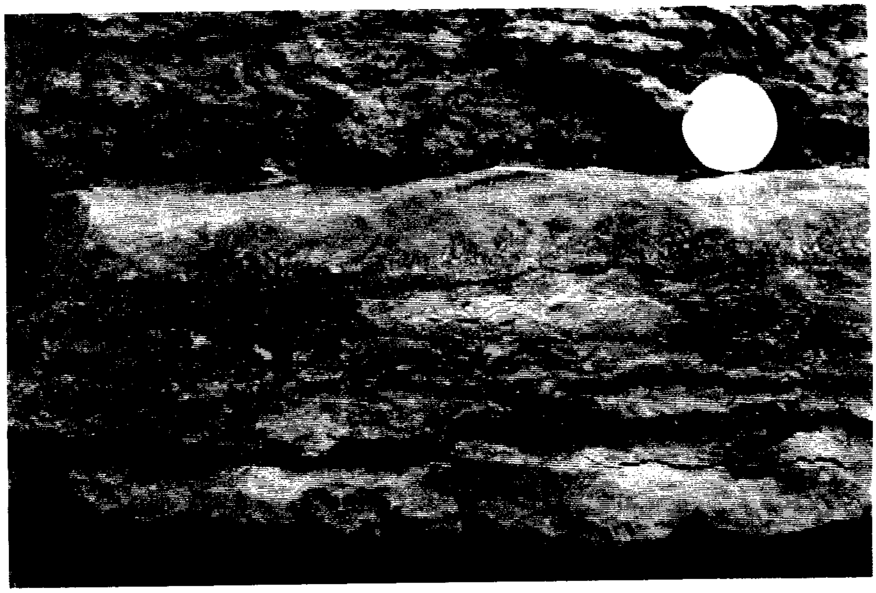

Figure 20: Pseudomorphs after bottom-growth chevron halite crystals; quarter for scale is 2.4 em in diameter; Cox Ranch, Barber County, Kansas; NWl/2, NEI/4, Sec. 25, T30S, R15W.

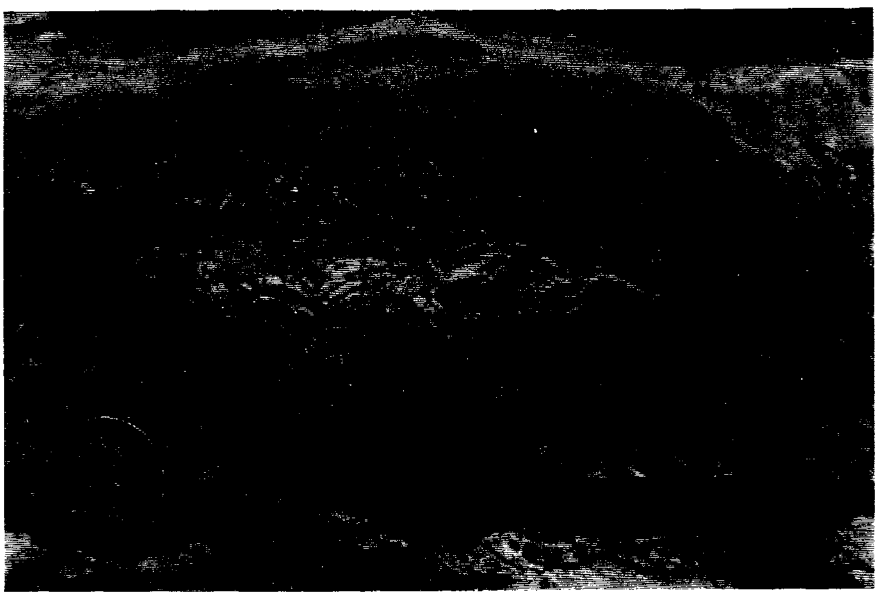

Figure 21: Pseudomorphs after bottom-growth chevron halite crystals; penny for scale is 1.9 em in diameter; Cox Ranch, Barber County, Kansas; NWl/2, NE1/4, Sec. 25, T30S, R15W.

bed of upward-oriented, elongated crystal remains. If it had grown displacively within in sediment, halite crystal casts would not be situated only on bedding planes, but would be found thoughout the thickness of beds. Therefore, these randomly-spaced and -sized cubic-shaped casts found on bedding planes are interpreted as the remains of cumulate halite crystals.

The second type of halite crystal casts are square to triangle-shaped, 1.0 - 1.6 centimeter casts which occur as a singular bed within an anhydrite-rich red bed unit in the Flowerpot Shale (Figures 20 and 21). These casts are actually gypsum and anhydrite pseudomorphs after halite. The base of this bed of halite casts is sharp and flat. The upward oriented halite casts are overlain by draping planar laminae with mudcracks and underlain by ripple marks and curled mud chip intraclasts (Figures 22 - 24). This halite type is interpreted as bottom growth crystals in shallow (no deeper than 4 meters; Friedman et al., 1976; Johns and Ludbrook, 1963; Lowenstein and Hardie, 1985) water based on: (1) its common, flat lower surface, (2) upward orientation of cubic crystals, and (3) associated sedimentary structures. Modern water deeper than centimeter-meter-scale that precipitates halite tends to be compositionally stratified. These deeper water halites are not associated closely with sedimentary features indicative of shallow water and desiccation, such as mudcracks, curled mud chip intraclasts, and ripple marks.

The final type of halite "casts" are actually pseudomorphs of displacive skeletal halite. They occur in red bed siltstones of the F1owerpot Shale, are randomly-spaced. and have 0.5 - 5.0 cm long pyramid and cubic shapes, and are situated randomly throughout thickness of beds. They are composed of alternating layers of microcrystalline anhydrite/gypsum and red bed silt within skeletal and cubic shapes. The anhydrite/gypsum is probably a replacement phase of halite while the alternating red bed silt layers may be primary sediment. This would suggest that these halite crystals incorporated silt as they grew. These halites may have grown displacively in soft silt at a shallow depth.

*RIPPLE MARKS*

Ripple marks are abundant in the Nippewalla Group. They occur in thin anhydrite beds in the Salt Plain, Flowerpot, and Dog Creek Formations and less commonly in red bed siltstones and fine-grained sandstones. Ripple marks are composed of silt- and sand-sized quartz and/or anhydrite grains.

Ripple marks are small; they measure approximately 1 centimeter or less in waveheight and between I and 2 centimeters in wavelength. They are symmetrical, with linear to wavy crests that are peaked or slightly rounded. Through the field area, ripple marks do not have a uniform direction of strike. For example, strikes of ripple crests measured from several beds within a 12 em thick unit of anhydrite included N85'E, N41 'E, N38'E, and N12CW.

Cross-lamination in these rippled beds show a structural dissimilarity of adjacent sets. Some sets are composed of symmetrical, oppositely-dipping laminae on either side of the wave crest. Some sets have unidirectional cross lamination. Some sets contain offshooting and draping of fore sets.

Rare, tiny (wavelength of 1 em and waveheight of 0.2 cm) ladder-type asymmetrical ripples are within the troughs of some of the main ripples. These ladder-type ripples are oriented normal to the main ripples. They probably formed either as (1) water drained from the troughs of the larger, host ripples, or (2) wind blew the water and sediment within the troughs of the larger ripples.

These ripple marks are closely associated with halite cumulate casts (Figures 14 and 15), shallow desiccation cracks, and, less commonly, curled polygonal mudchips (Figure 22). These ripple marks and cross-laminae are interpreted as wave ripples. They probably formed in a shallow subaqueous environment by oscillatory motion caused by wind-generated waves.

*CROSS-STRATA*

Cross-lamination is preserved in rare thin beds of red bed siltstones and fine

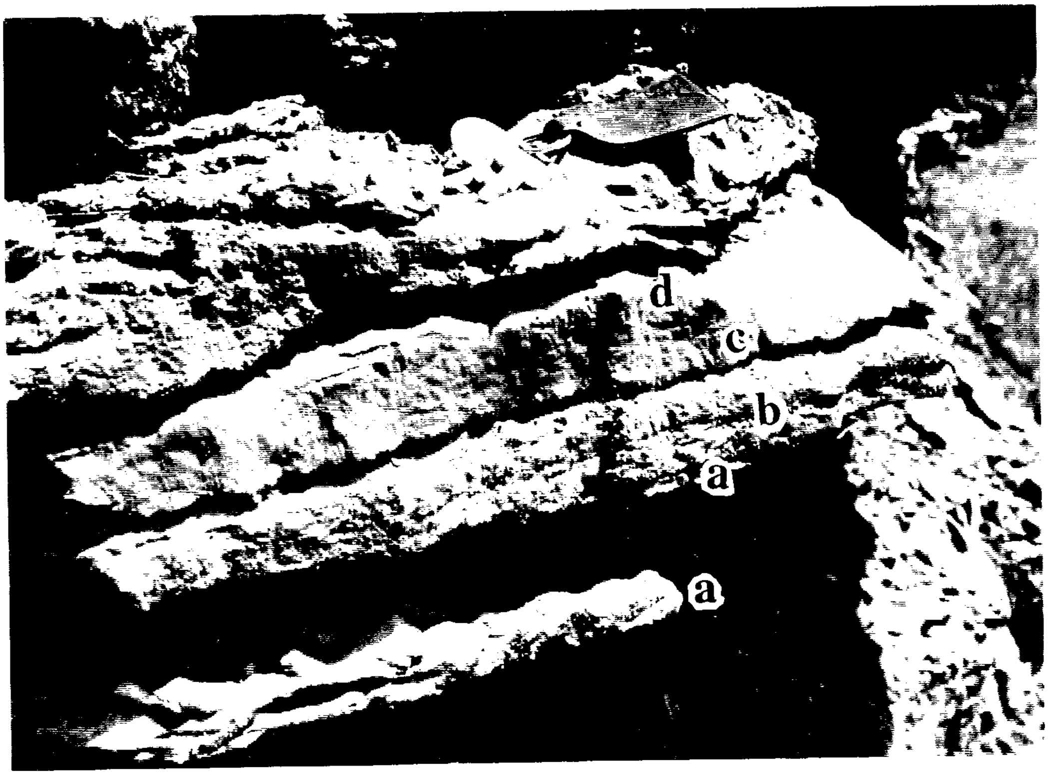


Figure 22: Anhydrite and fine quartz sandstone at Cox Ranch, Barber County, Kansas; small-scale cyclic strata contain: (a) ripple marks with cumulate halite casts, overlain by (b) pseudomorphs after bottom-growth halite crystals, (c) planar laminae, and (d) mudcracks and mud chip intraclasts; keys for scale; leather key ring tag is 9 ern long; Cox Ranch, Barber County, Kansas; NWI/2, NEI/4, Sec. 25, T30S, R15W.

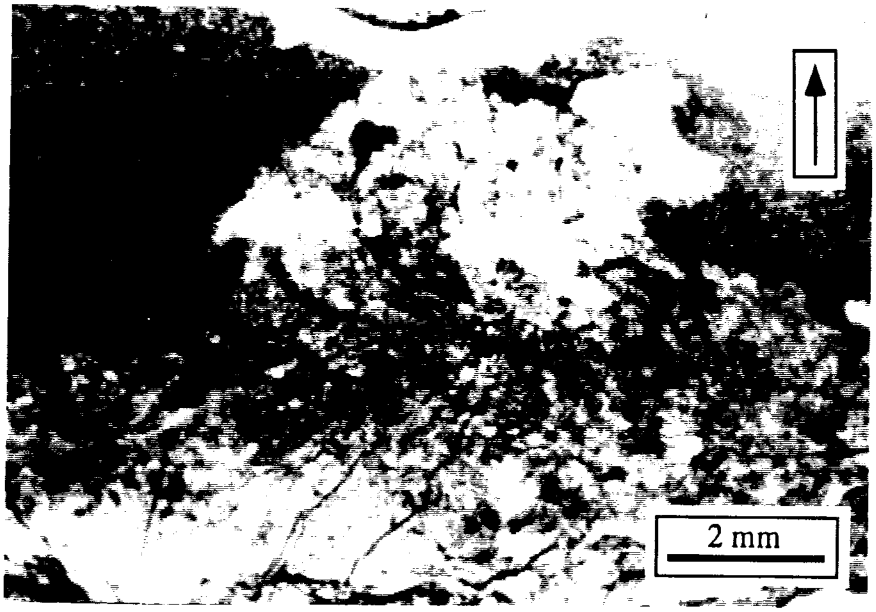


Figure 23: Photomicrograph of anhydrite/gypsum pseudomorph after bottom-growth chevron halite crystal; note dark draping mud lamina; boxed arrow indicates stratigraphic up; Cox Ranch, Barber County, Kansas; NWI/2, NEl/4, Sec. 25, T30S, RI5W.

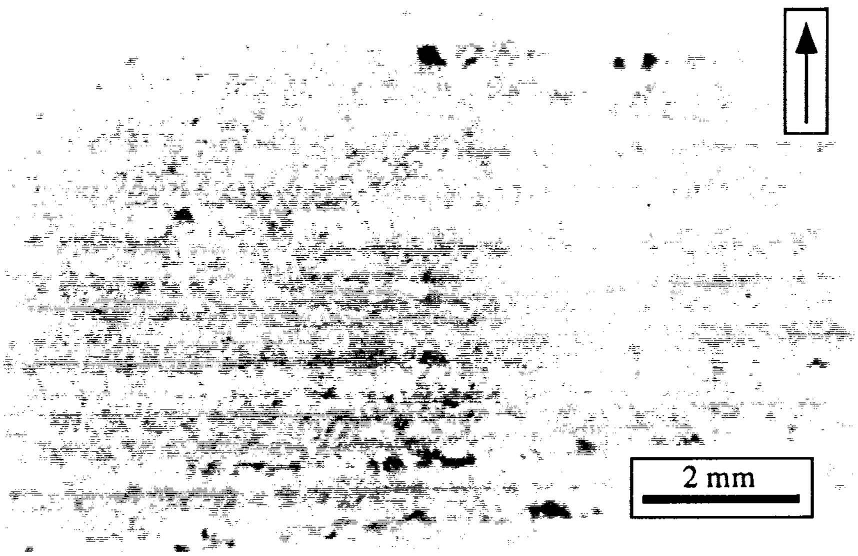


Figure 24: Photomicrograph of alternating laminae of quartz silt (white laminae) and anhydrite silt (pale grey laminae); boxed arrow indicates stratigraphic up; Cox Ranch, Barber County, Kansas; NWI/2, NEl/4, Sec. 25, T30S, RI5W.

sandstones throughout the Nippewalla Group. These cross-strata occur as small-scale (0.5 em high sets), very low angle (approximately 51 planar foresets. Coarser grains, commonly fine sand-sized, rounded quartz grains, are concentrated at the top of each foreset. *Microcodium* and root features overprint some of these cross-strata. These cross-laminae are interpreted as the remains of aeolian sand sheets.

*PLANAR LAMINAE*

Planar laminae are found most commonly in thin quartz and anhydrite beds in the Flowerpot and Dog Creek Formations. This bedding type consists of alternating thin laminae of dark grey micrite and light colored coarse silt composed of quartz and anhydrite grains (Figure 24). Contacts between laminae are not sharp, but gradational. Planar laminae are found overlying wave ripples and cumulate and bottom-growth halite casts. The tops of many laminated beds are penetrated by desiccation cracks.

*MUD CRACKS AND MUD CHIPS*

Mud cracks and mud chips are common in the Nippewalla Group. They are located in association with wave ripples, planar laminae, and halite cumulate and bottom-growth casts.

Mud cracks are formed most commonly in red bed mudstone and siltstones overlying halite cumulate casts that settled out of the water column onto wave rippled sediment. These mudcracks are shallow (0.2 to 0.5 em depth) and straight. The resulting red mud chips have polygonal shapes and slightly upcurled edges. Most mud chips have remained *in situ*, but some can be seen as intraclasts in the bases of overlying wave rippled beds.

Less commonly mudcracks are at the top of planar laminated beds. These cracks are deeper (0.5 to 1.0 em deep), wider, and filled with red bed sand or silt.

Both types of mud cracks are interpreted to have formed upon wetting and drying of the sediment since they are straight and associated with shallow water depositional features, such as halite cumulate and bottom-growth crystal casts and wave ripples. They are therefore referred to as desiccation cracks.

*PEDS*

Peds are stable aggregates of soil material that are bounded by voids or clay cutans. Columnar and prismatic peds are recognized in some outcrops of the Nippewalla Group. The peds here are vertically elongated clumps of red bed siltstone or mudstone. Some have a rounded, cylindrical shape with a domed top and are interpreted as columnar peds. Others have a polygonal (in cross-section) shape with a flat top. These latter types are interpreted to be prismatic peds. These ped types form by wetting and drying of a soil.

*ROOT FEATURES*

*ROOT CASTS*

Several root casts have been identified in outcrops of the Flowerpot Shale. They have a cylindrical shape that tapers downward. Smaller casts branch and taper downward and laterally. The largest root cast seen in the field is 12 em long and 4 em in diameter at its top (Figure 25). Root casts are hosted by red bed siltstones and sandstones, some with a mottled texture, and filled with fmer-grained red siltstone and mudstone.

Some smaller straight vertical tubes filled with finer grained material than the host rock are also interpreted as root casts. These are abundant in some red siltstones.

*MICROCODIUM-RICH CALCRETES*

*Microcodium* are sand-sized spherulitic aggregates of calcite grains that have been documented in Tertiary and Recent calcareous soils (Gluck, 1912; Klappa, 1978) and, less commonly, in more ancient paleosols (Goldstein, 1988). Although their origin is controversial, it has been argued that they may form by the calcification of plant root cells and fungi (Klappa, 1978).

Figure 25: Root cast in massive mottled red sandstone overlain by red mudstone with blue anhydrite; keys for scale; silver key is 6 em long; Cox Ranch, Barber County, Kansas; NWl/2, NEl/4, Sec. 25, T30S, R15W.

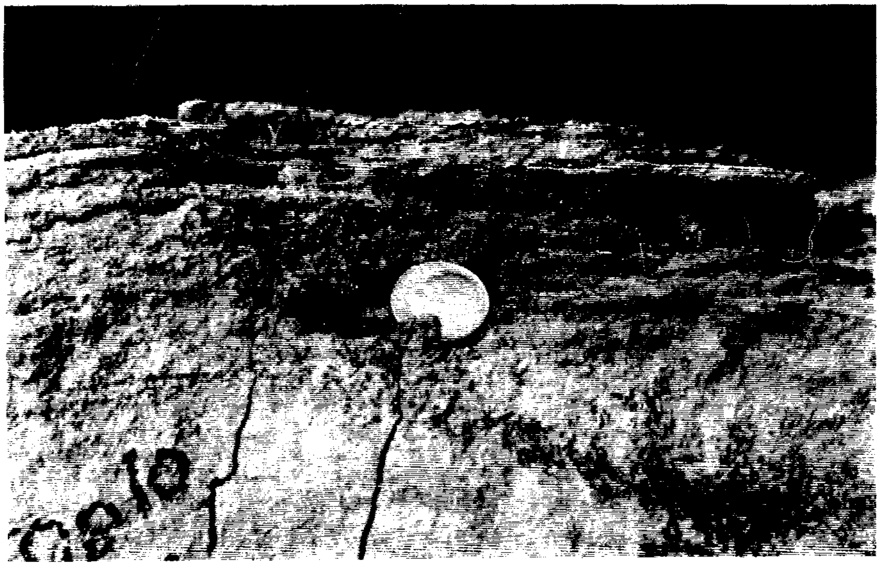

Figure 26: Calcrete composed of thin layers of *Microcodium.:* dime for scale is 1.75 em in diameter; Cox Ranch, Barber County, Kansas; NWl/2, NEl/4, Sec. 25, T30S, R15W.

Figure 27: Bedding plane view of *Microcodiumcalcrete;* dime for scale is 1.75 em in diameter; Cox Ranch, Barber County, Kansas; NWl/2, NEl/4, Sec. 25, T30S, R15W.

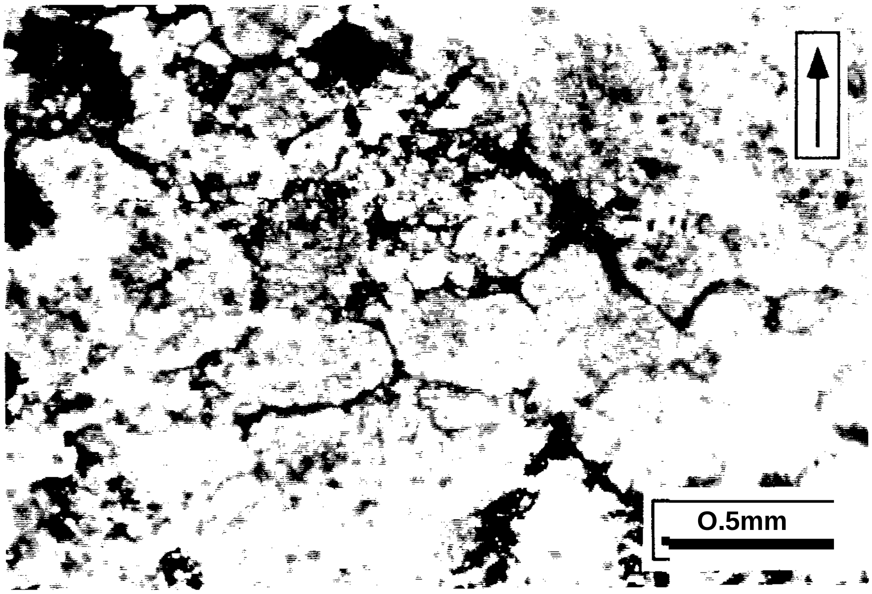


Figure 28: Photomicrograph of *Microcodium;* boxed arrow indicates stratigraphic up; Cox Ranch, Barber County, Kansas; NWI/2, NEI/4, Sec. 25, T30S, R15W.

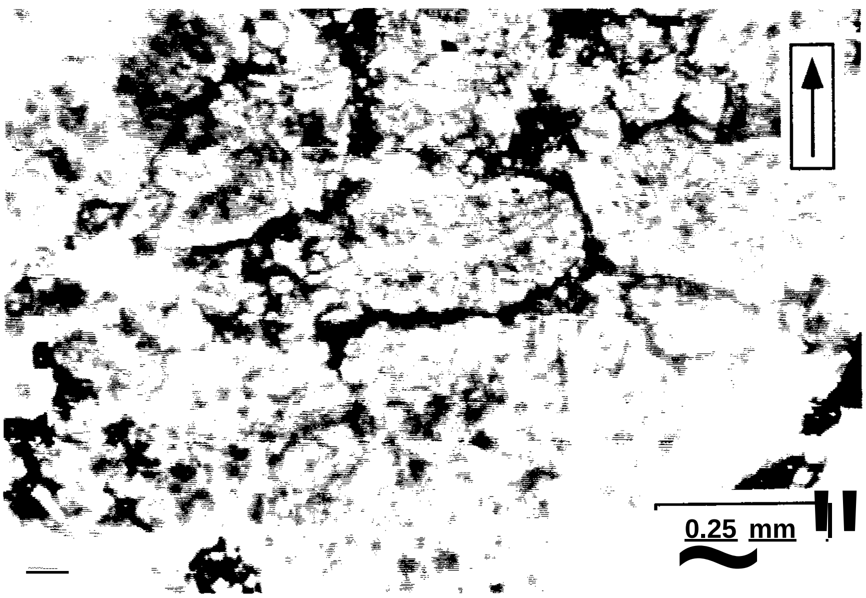


Figure 29: Photomicrograph of *Microcodium* (close-up of plate 26); elongated spherule in center of photo is similar in appearance to typical "epis de mais", or "com on the cob", *Microcodium.:* boxed arrow indicates stratigraphic up; Cox Ranch, Barber County, Kansas; NWI/2, NEI/4, Sec. 25, T30S, R15W.


Figure 30: Photomicrograph of two large *Microcodium* spherules; note dark donut shape with clearer center and rim, and cross-cutting fibrous and bladed calcite crystals (arrow); boxed arrow indicates stratigraphic up; Cox Ranch, Barber County, Kansas; NWI/2, NEI/4, Sec. 25, T30S, R15W.

Ancient Microcodium tend to differ slightly in structure from true Recent and Tertiary Microcodium. This may be due to different plant and fungi species in soils of the past or simply to diagenesis. For this reason, Goldstein (1988) uses the term "possible Microcodium" to describe these calcitic spherules in Pennsylvanian paleosols.

The *Microcodiwn-rich* calcretes occur as 1 to 8 centimeter thick beds within thick, unresistant and poorly cemented red bed siltstones of the Flowerpot Shale. These calcretes are composed of several hard, resistant, thick laminae (0.2 -0.3 em thick; Figures 26 and 27). Each lamina is made entirely of small (0.1 to I mm) rounded spherule-shaped aggregates of calcite crystals that closely resemble *Microcodium* (Figures 28 - 30). Each *Microcodia* has a cloudy brown donut shape with a thin clear rim and a clear core. The cloudy donut and clear rim are composed of radiating bladed or fibrous calcite crystals (Figure 30). The dark donut may be composed of the remains of plant cells. Some are isodiametric shape. Some are elongated shapes that look like corn on the cob, or "epis de mais" *Microcodium* (Figure 29). These have an thin, elongated clear core. Some *Microcodium* are accumulated as single layers that may represent laminar colonies. *Microcodium* probably formed in situ since they overprint a low-angle planar cross-stratified red bed siltstone.

## DISCUSSION OF SEDIMENTARY FEATURES

The sedimentary features observed in the outcrops of the Nippewalla Group suggest that deposition was dominated by shallow saline surface waters, subaerial exposure, and saline groundwaters.

Evidence of saline shallow surface water deposition is attributed to the association of ripple marks, cross-laminae, cumulate and bottom-growth halite crystal casts, and desiccation cracks. The small-scale wave ripple marks and cross-lamination indicate that water was shallow and was affected by winds. The abundant halite cumulate casts and less common halite bottom-growth casts that are superimposed upon the ripple marks suggest saline surface waters. Host rock lithology of anhydrite and some quartz detrital grains also supports this interpretation of deposition by saline surface waters. Associated prismatic mudcracks and mud chips indicate periods of drying. Stratigraphic relationships among these sedimentary features on a small-scale (8 - 18 em thick) suggest mini shallowing-up cycles. Commonly, wave ripples are overlain by halite casts, overlain in turn by some planar laminae and abundant mudcracks. This pattern suggests that deposition took place in shallow surface waters that underwent periods of flooding and desiccation.

Subaerial exposure at the time of Nippewalla Group deposition is confirmed by mudcracks and mudchips, root features, and peds. Mudcracks are abundant and indicate wetting and drying of the sediment. Prismatic, curled up mudchips that directly overlie mudcracks formed by extensive drying. Some planar cross-strata may have formed by winds. Root features, such as root casts and *Microcodium*, as well as peds are suggestive of paleosols. The peds observed in the Nippewalla Group, prismatic and columnar peds, are fanned by wetting and drying of a soil. Domed columnar peds, in particular, are characteristic of modern soils saturated with saline groundwater in marginal marine salt marshes and desert soils around salt pans (Retallack, 1988). Another indicator of saline saturated groundwater is the presence of skeletal halite pseudomorphs in red bed siltstones. The random orientation of these halite remains throughout the thickness of beds and the incorporation of silt suggests that the halite grew displacively in the sediment, These sedimentary features indicate that the sediments of the Nippewalla Group underwent subaerial exposure for various periods of time, some long enough to form soils.

Carbonates are noticably absent in outcrops of the Nippewalla Group. In fact, the only carbonate mineral found was calcite in the form of *Microcodium* calcretes. Fossils, aside from root features, are also lacking in these rocks. The lack of fossils and carbonates is not indicative of any sedimentary environment, but may be used as evidence against a marine or marginal marine depositional setting. One would expect to observe carbonate muds in abundance in an evaporative marine environment. Although hypersaline environments are hostile to most organisms, some invertebrates, such as certain species of gastropods, commonly live in modern restricted marine settings. If these rocks had been deposited adjacent to the sea, one might expect to fmd classic shallow marine carbonate rocks with marine fossils interbedded with the Nippewalla Groups' evaporite beds and siliciclastic red beds. But this is not the case. While the absence of evidence should never be considered evidence of absence, the lack of carbonates and fossils in the Nippewalla Group may be considered more suggestive of a nonmarine depositional setting than of a marine depositional setting.

The collection of sedimentary features, along with lithologic types, observed during field study of the Nippewalla Group in southcenrral Kansas and northern Oklahoma suggests that deposition most likely took place in shallow saline lakes surrounded by mudflats, sandflats. and soils.

## DIAGENETIC FEATURES

Most diagenetic features in the Nippewalla Group are related to the precipitation, replacement, or dissolution of evaporite minerals. The following summarizes the diagenetic features observable in the field.

### *EARLY DIAGENETIC FEATURES*

Many early diagenetic features have been dissolved or replaced over time. However, it is possible to describe a likely early history based upon field observations from southcentral Kansas and northern Oklahoma and preliminary study of subsurface samples from western Kansas.

#### *EARLY ANHYDRITE REPLACEMENT OF GYPSUM*

There is abundant anhydrite/gypsum in outcrop, some of which is composed of beds of rounded sand-sized anhydrite detrital grains. But much of the sulfates are in the form of large (1 to 4 em long) interlocking, anhedral gypsum crystals with random orientation that are probably the result of recrystallization and replacement (Figures 31 and 32). By comparison, in core samples, there are two types of bedded anhydrite: (1) anhydrite pseudomorphs after gypsum swallowtail crystals, and (2) rounded, sand-sized anhydrite grains. The beds of gypsum swallowtail pseudomorphs show competitive growth, with upward-increasing crystal size, suggesting that they grew at the bottom of a water body. The gypsum crystal shape, as well as the many tiny anhydrite crystals within each gypsum crystal pseudomorph, suggests that anhydrite replaced gypsum. In modern evaporative environments, bottom-growth gypsum crystals like these are replaced by anhydrite very early. Some of these crystals in the Nippewalla Group may were probably broken, either before or after replacement by anhydrite. The broken fragments were reworked by wind and shallow waters and deposited as rounded, sand-sized anhydrite or gypsum grains. This scenerio probably occurred in the rocks of the field area as well as those preserved better in the subsurface. The early transition from gypsum to anhydrite explains the origin of the bedded anhydrite seen in surface exposures.

*GREY REDUCTION SPOTS*

Pale grey spots are common in some red bed siltstones and sandstones. These spots are round and range in size up to 1.1 em in diameter. Most are a uniform pale grey, but some have a dark grey or black central nucleus. These pale grey spots overprint bedding. The only change seen across the boundary between grey spot and red bed host rock is a change in color. Similar grey spots have been observed in red beds of various ages from around the world (Blodgett et al., 1993). The spots in the Permian Ninnescah Shale (which underlies the Nippewalla Group) probably formed as decaying organic matter caused reduction, bringing $Fe^{+3}$ and Mn+4 to $Fe^{+2}$ and Mn+2. This reduction allowed the $Fe^{+2}$ and Mn+2 ions to be transported out of these localized reducing zones by groundwater, causing sediment color to fade from red to pale grey

(Daily and Angino, 1990). The similarity of the grey spots in the Nippewalla Group to those in the Ninnescah Shale suggest that localized reducing conditions also occurred in the Nippewalla Group.

*DISPLACIVE HALITE GROWTH IN SEDIMENT*

**The** displacive skeletal halite crystal pseudomorphs described previously in the sedimentary features section of this paper are also included here since they probably formed early, while sediment was still uncemented. The random orientation of these halite remains throughout the thickness of beds and the incorporation of silt suggests that the halite grew displacively in the sediment.

*ANHYDRITE NODULES*

Rare anhydrite nodules exist in the subsurface in planar laminated anhydrite and fine quartz sandstones. These are white to pale blue and range in size from 0.2 to 1.0 em in diameter. An altered form of anhydrite nodules is found in surface exposures. These are "snowball concretions", fist-sized, rounded masses offme, crumbly white microcrystalline gypsum that probably originated as anhydrite nodules that grew displacively soon after deposition of the sediment.

*CALCITE CEMENTATION*

Calcite cement is restricted to the *Microcodium-rich* calcretes of the Nippewa11a Group. Meniscus cement is composed of clear calcite crystals located between *Microcodium* spherules. Most of the meniscus cement is equant, but some is bladed. The calcite cement crystals are approximately 0.01 to 0.15 mm long. Meniscus cements precipitate from vadose zone waters that cling to grains by surface tension. They are diagnostic of subaerial exposure.

Another early cement seen only in the calcretes is aveolar texture. This feature is found in rounded pores that have been crossed by thin bridges of micrite. The area between the micrite bridges is filled with clear equant calcite cement. Aveolar texture is considered a remnant of root growth or decay and, thus, is common in paleosols and rocks that have been subaerially exposed.

### *RED BED FORMATION*

Red hematitic clay coats detrital grains in the Nippewalla Group, giving the rocks their red color. It is difficult to determine whether these grains were deposited as red beds or if hematitic coatings formed after deposition. However, petrographic observation of subsurface samples show that the hematitic coatings preceeded halite cementation. Thus, red beds were either deposited red or became so soon after deposition.

### *HAUTE CEMENTATION*

Halite cement is another probable early diagenetic feature that is difficult to prove by field observations alone. In the subsurface, clear halite cements all detrital grains. This halite cement can be seen in core samples from a depth of 1300 feet to 2000 feet Rancher and gypsum mine geologists have esimated that some halite exists at shallow depths of only 50 feet in the field area. This information is supported by high NaCl content in local well water and by halite in shallow cores taken at local gypsum mines (T. Hanson, pers. comm.; P. Cox, pers. comm.). At the surface, red beds are poorly cemented. This may be due to late dissolution of an early pervasive halite cement

## *LATE DIAGENETIC FEATURES*

Late diagenetic features are abundant and easily recognizable at outcrops of the Nippewalla Group. They can be seen on the individual grain-scale as well as the landscape-scale. None of these late diagenetic features have been observed in core samples; they are exclusive to surface exposures. They have been formed primarily by interaction with meteoric water at or close to the earth's surface.

### *DISSOLUTION AND REPLACEMENT OF HALITE*

All inferred forms of halite, including halite cumulate and bottom-growth depositional crystals, displacive halite crystals, and halite cement, were altered close to the earth's surface by meteoric water. Although most of the halite was dissolved, some, including some displacive halite and bottom-growth crystals, were replaced by anhydrite and gypsum. Indirect evidence oflate dissolution close to the surface is: (1) poorly cemented red mudstones, siltstones, and sandstones at the surface, and (2) the presence of pervasive halite cement at depth, but none at the surface. Pseudomorphs of halite bottom-growth and displacive crystals composed of anhydrite and gypsum that are found only in surface exposures are suggestive of late replacement near the earth's surface.

*REPLACEMENT OF ANHYDRITE BY GYPSUM*

It appears that recent transitions between anhydrite and gypsum are common in surface exposures. Many of the bedded sulfates are composed of gypsum, but show no traces of bottom-growth crystals or detrital grains, and only very faint traces of bedding. In fact, some gypsum in the Blaine Formation looks more like a metamorphic rock than a sedimentary rock; it is composed of a mosaic of 1 to 4 em long, interlocking, anhedral gypsum crystals (Figures 31 and 32). Some faint "ghosts" of laminae can be traced through multiple crystals. The large gypsum crystals, mosaic texture, and laminae ghosts are evidence of replacement and recrystallization. Some massive units of replaced and recrystallized anhydrite have been identified within this gypsum (T. Hansen, pers. comm.). Comparison with subsurface anhydrites that contain only depositional and early diagenetic features suggests that diagenetic events such as replacement of anhydrite to gypsum, recrystallization, and replacement oflate gypsum to anhydrite occurred late and close to the earth's surface.

Other features are also the result of hydration of anhydrite to gypsum. "Snowball concretions" are fist-sized, rounded masses offme, crumbly white gypsum found in anhydrite and quartz fme sandstones. These snowball concretions probably originated as anhydrite nodules that grew displacively in the sediment soon after deposition. The anhydrite was altered to gypsum at or close to the earth's surface late in the history of these rocks.

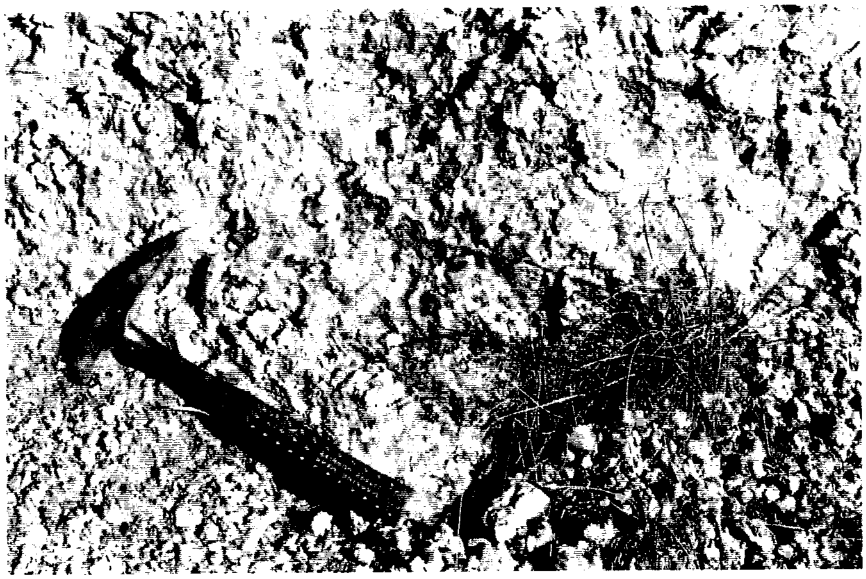

Figure 31: Blaine Formation gypsum in outcrop; hammer for scale is 32.5 em long; Woods County, Oklahoma; Sec. 14, T29N, R15W.

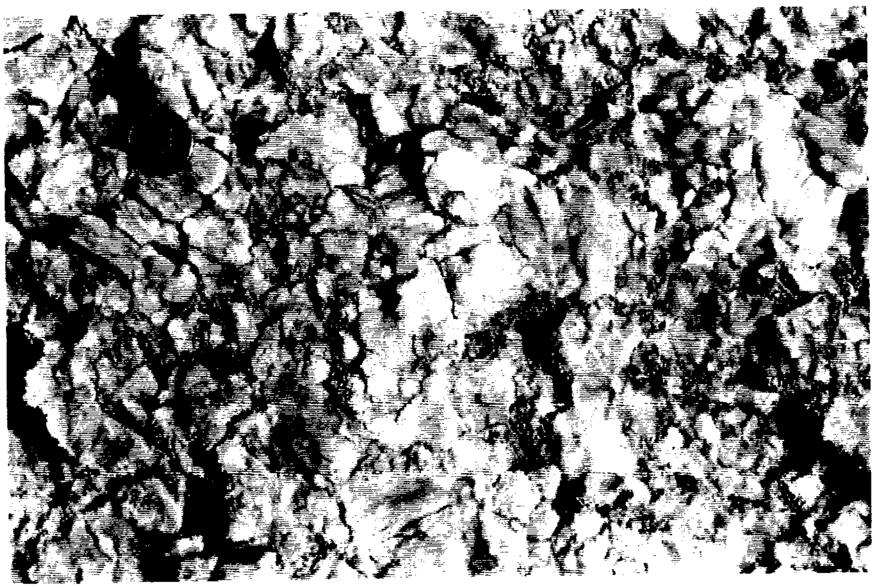

Figure 32: Blaine Formation gypsum; penny for scale is 1.9 em in diameter; Woods County, Oklahoma; Sec, 14, T29N, R15W.

Figure 33: Hollow mound in Blaine Formation gypsum caused by dissolution; note large recrystallized gypsum crystals at base of mound (arrow); hammer for scale is 32.5 em long; Radio tower hill outcrop, near gate 4, Maria Ranch, Barber County, Kansas; SWl/4, NEl/4, Sec. 29, T32S, R12W.

Figure 34: Solution enlarged vertical fracture in Blaine Formation gypsum; hammer for scale is 32.5 em long; Radio tower hill outcrop, near gate 4, Maria Ranch, Barber County, Kansas; SWI/4, NEI/4, Sec. 29, T32S, R12W.

Figure 35: Dissolution collapse feature in Dog Creek Formation; north side of Rte. 160, approximately 14.5 miles west of Medicine Lodge, Barber County, Kansas; SCl/2, SWl/4, Sec. 6, T32S, R14W.

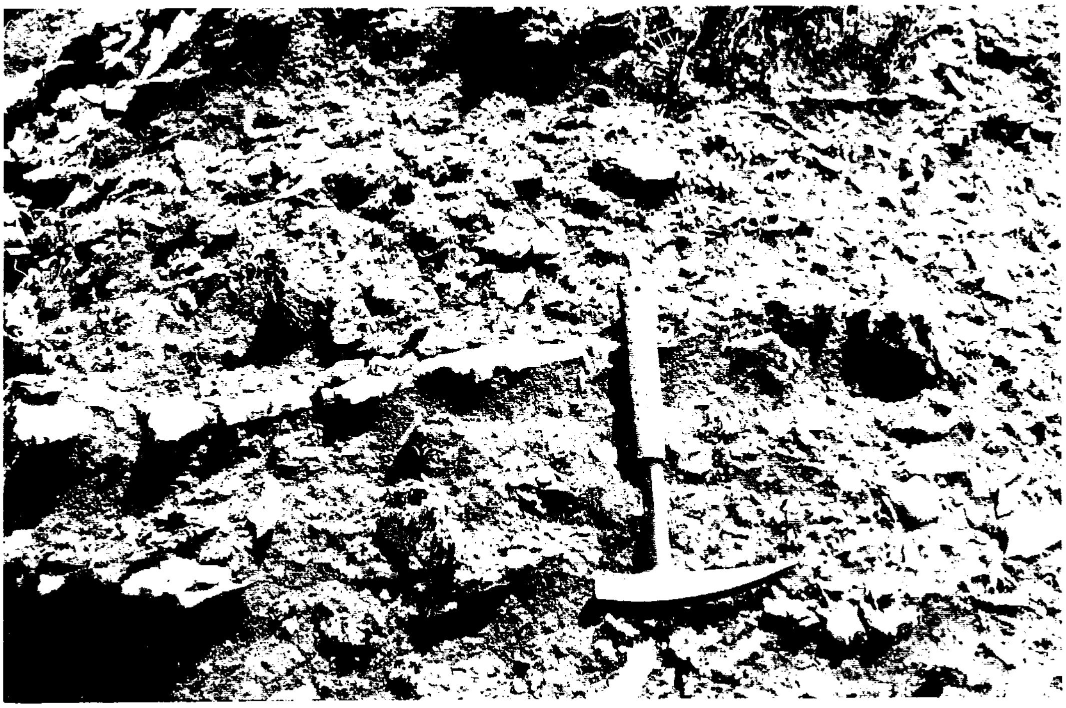

Figure 36: Late-stage satin spar "stringers" and selenite crystals in red siltstone; hammer for scale is 32.5 em long; Overlook View butte, Rte. 160, Barber County, Kansas; SE1/4, Sec. 1, T32S, R14W.

Figure 37: Late-stage satin spar "stringers" in red anhydrite and fine-grained quartz sandstone; quarter for scale is 2.4 em indiarneter; (}yp Hills Scenic Drive, Barber County, Kansas; NEl/4, SW1/4, Sec. 20, T32S, R12W.

*DISSOLUTION OF GYPSUM/ANHYDRITE*

The gypsum and anhydrite at and just below the surface are undergoing dissolution. This sulfate mineral dissolution, along with probable dissolution of halite beds at shallow depths, has resulted in a karst topography in southcentral Kansas and northern Oklahoma. Sinkholes (mostly dry), collapsed blocks, caverns, and natural bridges exist in the field area. On a smaller scale, hollow mounds (Figure 33) and solution enlarged fractures (Figure 34) are abundant in the Blaine Formation gypsum and anhydrite. One can hear a hollow sound when stomping on some of this gypsum. Recent collapse features are common in the Dog Creek Formation (Figure 35), indicating that the underlying Blaine Formation gypsum is undergoing dissolution.

*DISPLACIVE GYPSUM GROWTH IN SEDIMENT*

Two forms of late-stage gypsum crystals are found in the red beds throughout the field area: (1) selenite crystals and (2) satin spar veins.

Euhedra1 transparent selenite crystals ranging from 2 to 5 em long are abundant. They are scattered in the red bed mudstones, siltstones, and fine sandstones (Figure 36). They probably grew displacively in the sediment at the surface by meteoric waters that had leached calcium and sulfate from beds of anhydrite and gypsum.

White fibrous satin spar veins, or "stringers", are also found in red bed mudstones, siltstones, and fine sandstones (Figures 36 and 37). Satin spar stringers are 0.5 to 1.75 em thick and up to several meters long. Many stringers are oreinted subparallel to bedding, but some are perpendicular to bedding. These veins probably formed as satin spar precipitated by meteoric water rich in calcium and sulfate moving through fractures in the red beds.

## DISCUSSION OF DIAGENETIC FEATURES

Diagenetic features observed in the field suggest that alterations in the Nippewalla Group happened either quite early after deposition or quite late. Most diagenetic features appear to have been formed by the dissolution, precipitation, or replacement of evaporite minerals by meteoric waters at or close to the earth's surface.

Early diagenetic events include growth of displacive halite in sediment, and growth of anhydrite nodules in sediment, anhydrite replacement of gypsum, localized reduction of organic matter, halite cementation, meniscus cementation and alveolar texture formation in calcretes, and perhaps red bed formation. Many of these events probably occurred syndepositionally. The remainder occurred soon after deposition.

Late diagenetic events include dissolution of halite cement, replacement of anhydrite by gypsum, recrystallization of gypsum/anhydrite, dissolution of gypsum/anhydrite, and displacive gypsum growth in sediment. These features are all exclusive to surface and near surface exposures. It is most likely that these diagenetic features formed late in the history of the Nippewalla Group by interactions between the rocks and meteoric water.

The Nippewalla Group's evaporites and red beds seem most vulnerable to meteoric waters and surface conditions. Based on study of both core and outcrop samples, it can be hypothesized that sediments were altered soon after deposition while still at or near the earth's surface. Upon burial, no significant diagenesis occurred. When these rocks were exposed again at the surface, millions of years later, they were again subjected to diagenetic alteration.

## PROPOSED MODEL FOR DEPOSITIONAL AND DIAGENETIC HISTORY OF THE NIPPEWALLA GROUP

The assemblage of sedimentary features observed in the field indicates that the Nippewalla Group rocks were deposited under shallow saline waters and subaerial exposure. Sedimentary and early diagenetic features, along with lithologic types. suggest that deposition most likely took place in halite-dominated ephemeral saline lakes surrounded by saline mudflats, sandflats, and soils. Evaporation, desiccation, flooding, and wind played significant roles in the depositional environment. The Nippewalla Group red beds and evaporites are representative of a saline pan deposit.

Saline pans are bedded evaporite deposits found in shallow, low relief depressions in arid climates. The saline pan itself is an ephemeral lake that is usually dry, except when flooding transforms it into a shallow saline lake. Evaporative concentration leads to precipitation of evaporite minerals, most notably halite, gypsum, and/or anhydrite, until eventual desiccation of the lake. Therefore, saline pan deposits are dominated by flooding-evaporative concentration-desiccation cycles (Lowenstein and Hardie, 1985).

Two possible saline pan types are: (1) a playa system, consisting of inland ephemeral saline lakes surrounded by saline mudflats, dry mudflats, and sand flats, or (2) a salina system, composed of coastal ephemeral lakes or restricted lagoons influenced by seawater, bounded on its seaward side by saline mudflats, tidal flats, and possibly reefs and on its landward side by saline and dry mudflats, sand flats, and sand dunes (Figure 38).

It is difficult to differenciate between these two possible depositional settings (Hardie, 1984, Lowenstein and Hardie, 1985). Both settings are characterized by: (1) cumulate and bottom-growth halites, (2) clear halite cements, and (3) displacive halite growth in the sediment. Many of the same sedimentary and diagenetic features are observed in both modern playas and salinas. There are some slight differences. Salinas at both Salina Omotepec, Baja California, and Bonaire, Netherland Antilles are hosted by limestone and contain abundant carbonate mud (Casas, 1987, Handford, 1990). Besides carbonates, marine or marginal marine evaporite settings commonly, but not always, include algal mats and stromatolitic laminites (Handford, 1990, Hardie and Eugster, 1971), flat pebble conglomerates (Hardie and Eugster, 1971), a small assemblage of tolerant organisms such as gastropods, forams, and brine shrimp (Handford, 1990, Hardie, 1984), and halite ooids and pisoids (Handford, 1990,

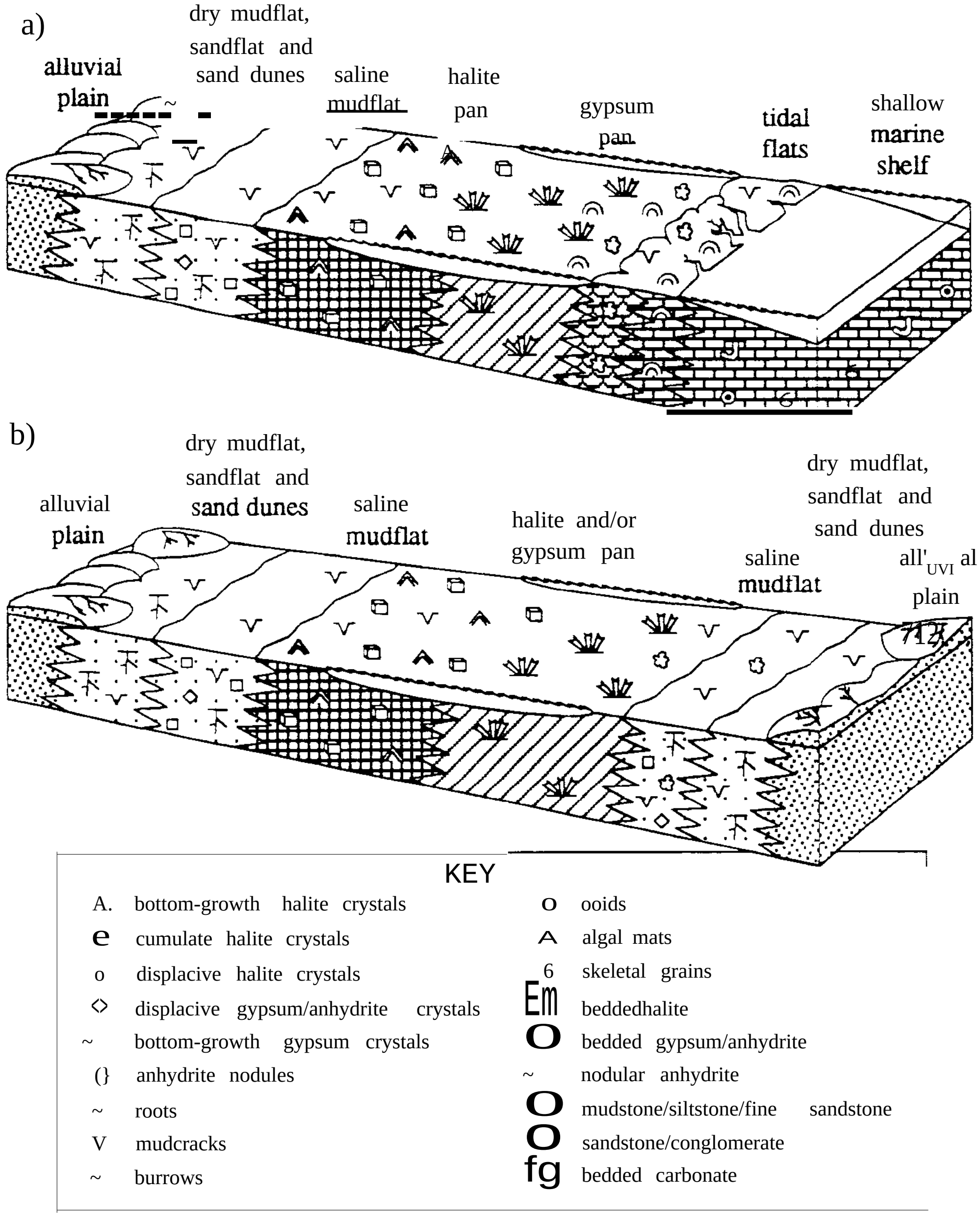


Figure 38: Schematic block diagrams of the two types of saline pan environments - the coastal salina setting (a) and the inland playa setting (b). These diagrams show generalized subenvironments and their respective lithofacies and key sedimentary and early diagenetic features. This field study indicates that the Penman Nippewalla Group was deposited in either a salina- or a playa-type saline pan; however, it is slightly more suggestive of a playa.

Weiler et al., 1974).

Alternately, modem playas may have abundant siliciclastics and little carbonate (Brown, 1995, Casas, 1987, Handford, 1982, Lowenstein et al., 1989, Roberts et al., 1994). Fewer organisms have been reported in playas than in salinas; they include ostracodes and lungfish. Some evaporite minerals characteristic of non-marine waters may be found in playa deposits.

Hardie (1984) gives specific criteria for making distinctions between marine and non-marine evaporites. These criteria are: (1) kinds of fossils, (2) sedimentology of the associated non-saline facies, (3) kinds of and association of primary evaporite minerals, and (4) trace element, isotope, and fluid inclusion geochemistry of primary evaporite minerals. These criteria are difficult to apply in this field study because fossils have not been found and accessory primary evaporite minerals have most likely been lost to dissolution, as has halite. This leaves the sedimentology of associated non-saline facies to serve as the most useful criteria in distinguishing between salina and playa deposition in the field exposures of the Nippewalla Group.

Many of the sedimentary features seen in the field are characteristic of both inland playa and coastal salina saline pan systems. However, field evidence is slightly more suggestive of an inland continental playa deposit due to: (1) lack of near shore carbonates characteristic of marine or marginal marine evaporites, and (2) lack of restricted marine fossils found in many modem analogous environments. The assemblage of sedimentary features in outcrops of the Nippewalla Group clearly indicate saline lakes, saline mudflats, and saline soils, but there is no solid evidence for marine shoreline environments.

Early diagenetic features also support an inland playa depositional setting over a marginal marine salina. Cements were more likely precipitated by meteoric waters than by seawater. The only carbonate cements present are confined to calcretes. No marine carbonate cements have been found. Displacive halite crystals and halite cement suggest hypersaline groundwaters typical of modem saline mudflats in closed basins.

Modem settings that may be good analogs for the Permian depositional environment of the Nippewalla Group include Bristol Dry Lake (Handford, 1982), Saline Valley (Casas, 1987), and Death Valley (Brown, 1995, Roberts et al., 1994), all in California, and Quidam Basin, western China (Lowenstein et al., 1989). These are all halite-dominated saline pans hosted by siliciclastic sediments. All are situated inland in closed basins and are underlain by up to several hundred meters of bedded salt.

The interpreranon of an inland saline pan depositional setting for the Nippewalla Group agrees withHoldoways (1975, 1978) conclusions. Based on petrographic study and bromide analysis of one core, she claimed that these rocks were deposited in a continental, closed basin environment. Extremely low bromide values of less than 5 ppm from halite samples suggested either non-marine precipitating waters or recrystallized halite. Although sampling for bromide analyses was performed using whole rock samples and some of the displacive halite may actually have resulted from recrystallization, much of the bedded cumulate and bottom-growth halite is well-preserved with intact growth bands in chevron and cumulate crystals. So the low values for bromide may indeed reflect deposition by non-marine waters. Holdoway's other evidence for continental deposition was abundance of red bed siliciclastics. Although presence of red beds are not indicative of depositional setting, those found in the Nippewalla Group contain sedimentary and early diagenetic features suggestive of aeolian and paleosol deposition. This field study has documented sedimentary and diagenetic features that support and better define Holdoway's initial intetpretations.

This study has also demonstrated that field observations of ancient evaporite deposits can indeed yield valuable sedimentological information.

Further study of well-preserved subsurface samples of the Nippewalla Group from western Kansas may provide more evidence to better interpret depositional environment Identification of any accessory primary minerals and geochemical analyses of primary evaporite minerals may give valuable information on parent water geochemistries. This will allow a more definitive answer to the marine vs. nonmarine problem encountered in these rocks.

## CONCLUSIONS

Field observations of the mid Permian Nippewalla Group have documented sedimentary features that help clarify the depositional and diagenetic history of these rocks. Depositional features include halite cumulate and bottom-growth crystal casts, ripple marks, planar laminae, mud cracks, curled mud chip intraclasts, root casts and traces, *Microcodium;* and peds. These features suggest that the depositional environment was dominated by ephemeral saline lakes, saline mudflats, sand flats, and saline soils.

Early diagenetic features include growth of displacive halite in sediment, growth of anhydrite nodules in sediment, anhydrite replacement of gypsum, localized reduction of organic matter, halite cementation, meniscus cementation and alveolar texture formation in calcretes, and perhaps red bed formation. These early diagenetic features also suggest an inland playa setting.

These depositional and early diagenetic features are quite similar to those found in core samples. Therefore, the depositional system probably covered an area ranging at least from westernmost Kansas to central Kansas.

Late diagenetic events include dissolution of halite cement, replacement of anhydrite by gypsum, dissolution of gypsum/anhydrite, and displacive gypsum growth in sediment These features are all exclusive to surface and near surface exposures. They formed late in the history of the Nippewalla Group, probably very recently, by interactions between the rocks and meteoric water.

The red beds and evaporites of the Nippewalla Group were deposited during the mid Permian in an inland saline pan system that may have covered a large portion of the midcontinent region. This interpretation of a mid Permian environment may be useful in better defining paleogeographic maps and making paleoclimatic interpretations.

## ACKNOWLEDGMENTS

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# KEY TO MEASURED SECTIONS

## LITHOLOGIES

- quartz and gypsum sandstone
- red siltstone
- recrystallized anhydrite
- bedded anhydrite
- red mudstone/ siltstone
- recrystallized gypsum
- red mudstone

## DEPOSITIONAL AND DIAGENETIC FEATURES

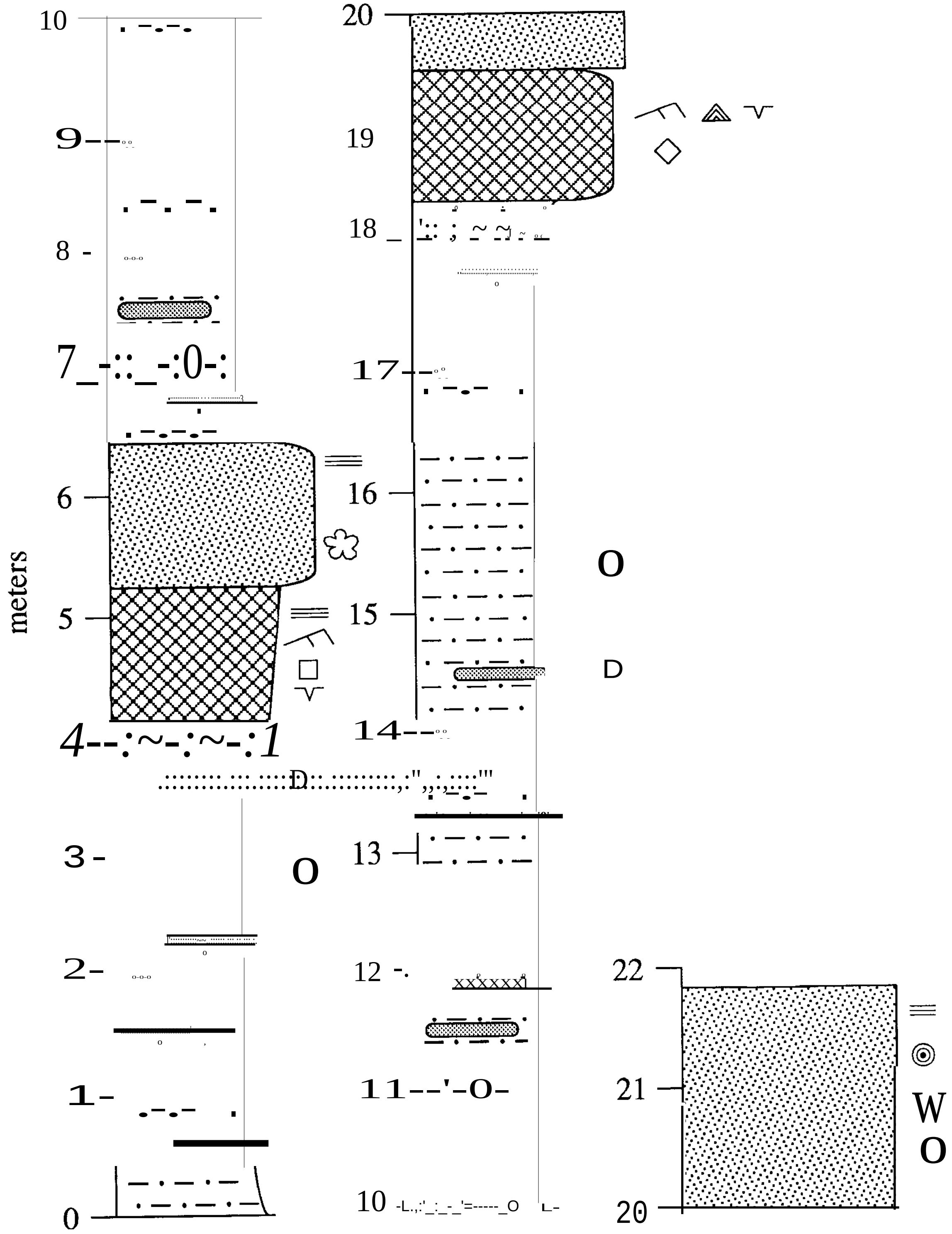
- planar laminae
- intraclasts
- wave ripple marks
- root casts and traces
- cumulate halite crystal casts
- *Microcodium*
- chevron halite crystal casts
- anhydrite nodules
- displacive skeletal halite crystal casts
- late-stage gypsum crystals and "stringers"
- desiccation cracks
- reduction spots
- columnar and prismatic peds

Note: The measured sections on the following pages are numbered. These numbers correspond to outcrop locations on the field map shown in Figure 1.

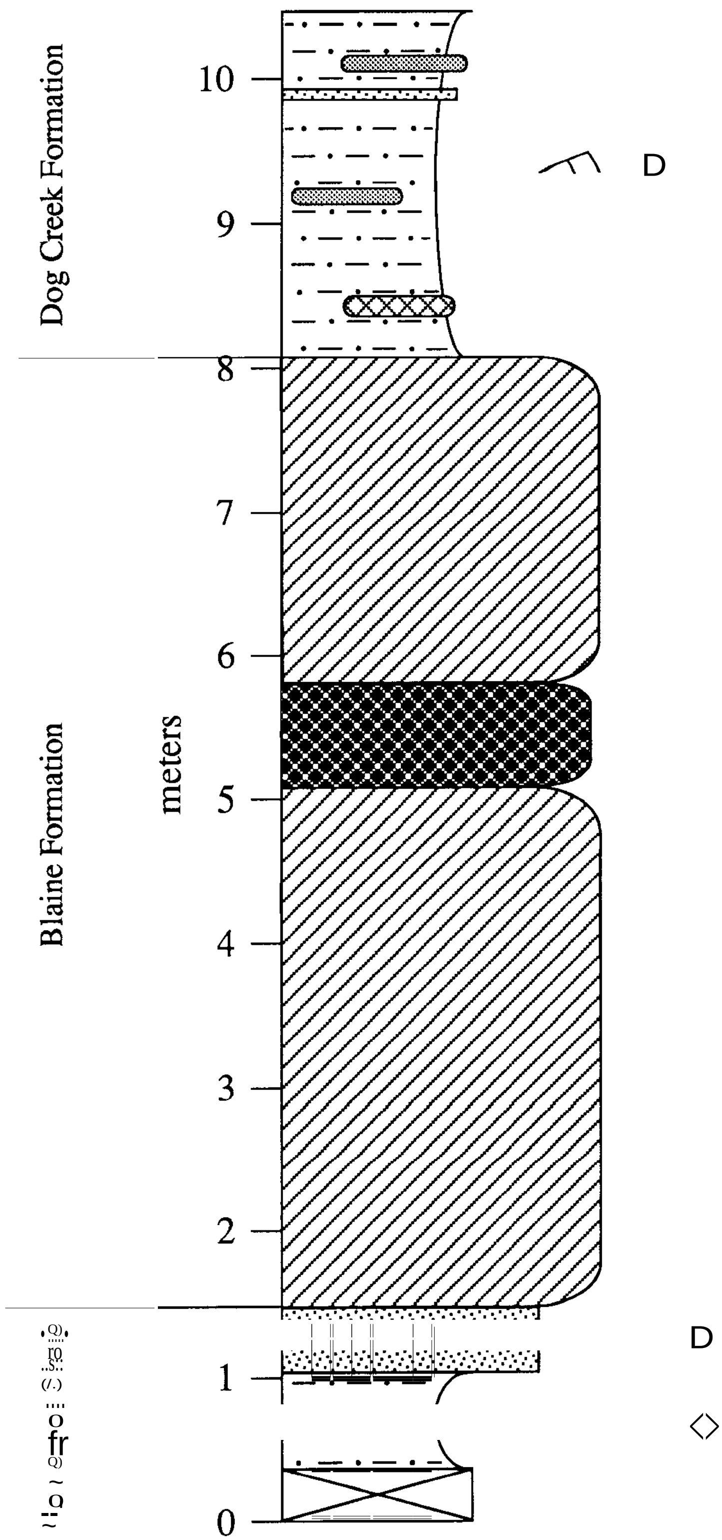
# APPENDIX A:

# MEASURED SECTIONS

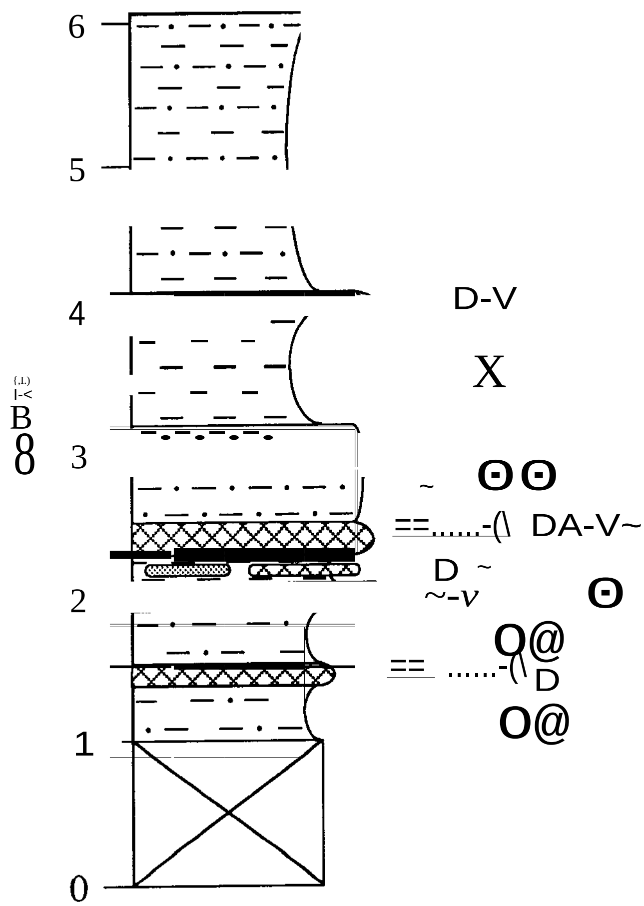
1) "Scenic Overlook" butte, SE1/4, Sec. 1, T32S, R14W
north side of Rte. 160, approximately 10 miles west of Medicine Lodge,
west central Barber County, Kansas
Flowerpot Shale



2) National Gypsum Mine, NWl/4, NEl/4, SWl/4, Sec. 11, T31S, R15W approximately 1 mile southwest of Sun City, northwest Barber County, Kansas uppermost Flowerpot Shale, Blaine Formation, and lowermost Dog Creek Formation

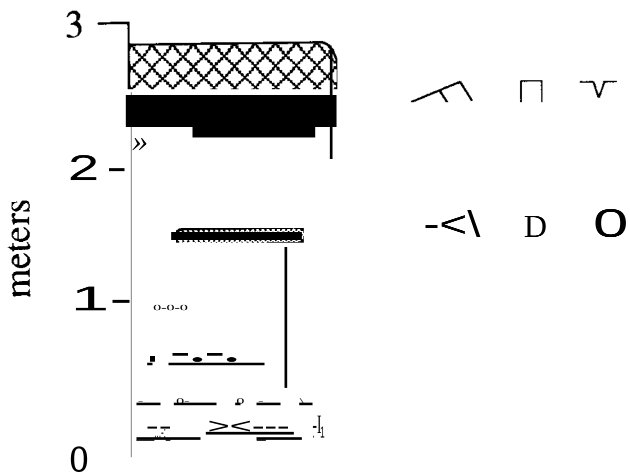


3) Cox Ranch, NWl/2, NEl/4, Sec. 25, T30S, R15W
east side of paved road 2.5 miles north of Sun City
northwest Barber County, Kansas
Flowerpot Shale



4) Maria Ranch, gate 2, NW1!4, NEl/4, Sec. 20, T32S, R12W

Gyp Hills Scenic Drive Road, 2 miles south of Rte 160
central Barber County, Kansas
uppermost Flowerpot Shale

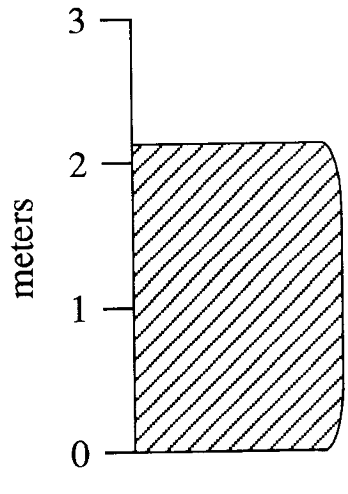


5) Maria Ranch, gate 4, top of radio tower hill, SWl/4, NEl/4, Sec. 29, T32S,R12W

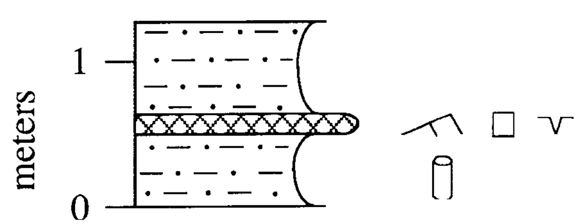
Gyp Hills Scenic Drive Road, 2.4 miles south of Rte 160

central Barber County, Kansas

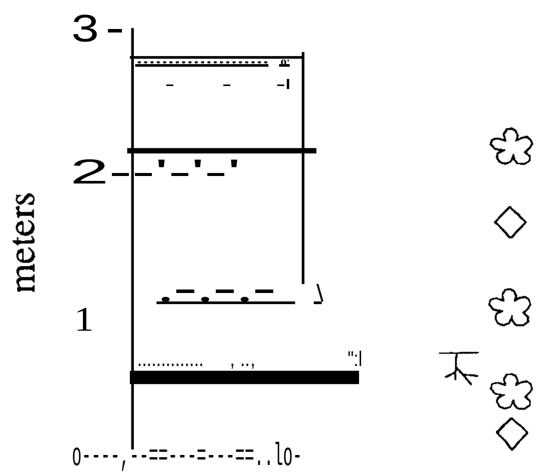
Blaine Formation



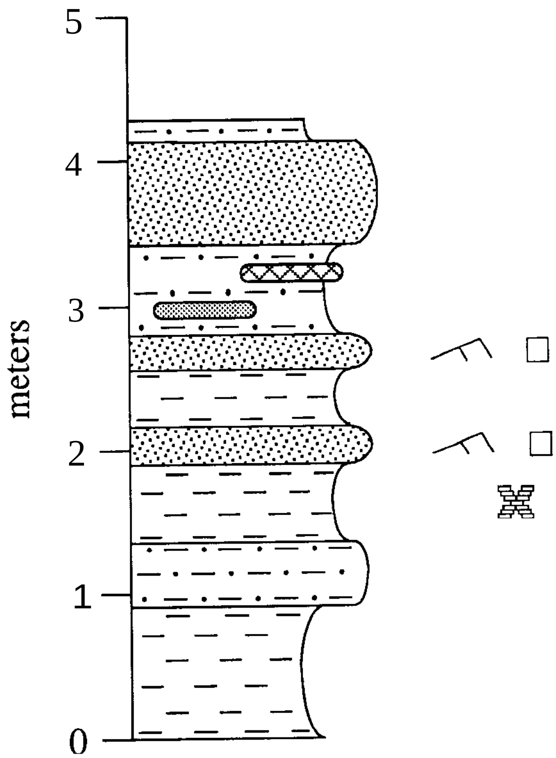
10) North side ofRte 160, *S1/2, SE1/4,* Sec. 14,
T32S, R9W
1.7 miles west of Attica
west central Harper County, Kansas
Salt Plain Formation



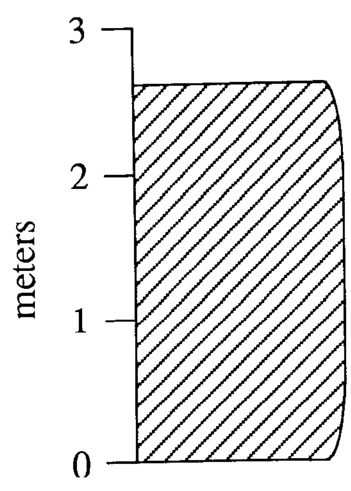
7) Small canyon next to paved road, Sec. 30, T28N, R14W
approximately 2 miles west of Avard
north central Woods County, Oklahoma
Cedar Hills Sandstone



6) Collapse structure roadcut, SC1/2, SWl/4, Sec. 6,
T32S, R14W
north side of Rte 160, 14.5 miles west of medicine Lodge
west central Barber County, Kansas
Dog Creek Formation



8) Roadcut along paved road, Sec. 14, T29N, R15W
approximately **1.5** miles north of Rte. 64 Gust northwest
of junction of Rte. 64 and 14)
north central Woods County, Oklahoma
Blaine Formation



9) Roadcut along paved road, at curve in road, Sec. 2, T29N, R15W
north of Rte. 64 (just northwest of junction of Rte. 64 and 14)
north central Woods County, Oklahoma
Flowerpot Shale