Oklahoma Geological Survey
Jeremy Boak, *Director*

Open-File Report 1-2019

Salt in Permian Flowerpot, Blaine, and Dog Creek Formations is dissolved to create salt plains in Childress, Hall, Cottle, and Motley Counties, Texas, and northern Harmon County, Oklahoma

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Oklahoma Geological Survey Open-File Report Disclaimer

Preface

This report is updated from one that was originally prepared for the Tulsa District Office of the U.S. Army Corps of Engineers (USACE) in 1974 to characterize the geology at and near major natural salt plains in parts of the Red River Chloride Control Project (RRCCP) in north-central Texas and southwestern Oklahoma. The RRCCP is designed to control natural-chloride-brine emissions at ten major source areas in this part of Texas and Oklahoma, and thus to improve water quality for municipal, industrial, and agricultural use downstream from the salt plains. Improvements that may help control brine emissions include construction of low-flow dams, pump stations, and diversion pipelines to impoundment facilities. The original 1974 report was titled: "Report on salt-bearing Permian rocks in portions of Red River Chloride Control Project Area, north-central Texas and southwestern Oklahoma."

The current report looks specifically at sites on the Pease River and Prairie Dog Town Fork Red River in Texas, and on Elm Fork Red River in Oklahoma. All of these tributaries feed into Red River (the boundary between southern Oklahoma and Texas), and the chloride emissions affect the quality of water in Red River and in Lake Texoma. The specific sites investigated include: sites on the North Pease and Middle Pease Rivers (designated "Area IX" by USACE), in Cottle County, Texas; sites on Jonah Creek and Salt Creek ("Area XIII" and "Area XIV," respectively), Childress County, Texas; and sites on Elm Fork Red River ("Area VI"), Harmon County, Oklahoma. A major product of this report is a series of maps and cross sections showing the distribution, thickness, and dissolution limits of various salt units in the Flowerpot, Blaine, and Dog Creek Formations. Subsurface dissolution of these salts creates the natural salt-water brines that come to the surface at the various salt plains.

Although the original report is now dated, there is continued interest in reducing the flow of chloride brines in the Red River and its tributaries. The original report had very limited distribution, and an electronic copy has not been available. Thus, in order to make the data more readily available to the geologic community, the Oklahoma Geological Survey is placing this updated version online as an Open-File Report.

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CONTENTS

ILLUSTRATIONS

Page

PLATES (All plates in pocket at back)

INTRODUCTION

Purpose and scope of investigation

Permian-age salt deposits underlie a vast area extending across western Oklahoma and adjacent states, and many natural salt plains and salt springs exist along the east side of this region in the watersheds of Red River and Arkansas River (Fig. 1). Because of the large amount of salt (halite, NaCl) entering these two major water ways, the Tulsa District of the U.S. Army Corps of Engineers has been tasked to investigate and reduce this natural contamination and improve water quality downstream from the salt plains. Efforts by the Corps are divided into studies of the Red River and the Arkansas River Chloride Control Projects.

The purpose of the original report to the Corps of Engineers, and this current report, is to evaluate surface and subsurface geologic features that bear upon the natural emission of brine at several sites within the boundaries of the Red River Chloride Control Project region. Field work and office studies for the original report were carried out in 1974, and those data were updated in 2018–19 for release of the current report.

The principal study area centers on Childress, Cottle, Hall, and Motley Counties, Texas. Within this four-county area of north-central Texas are six major sites of brine emission (Fig. 2): Pease River ("Area IX," as designated by the Corps of Engineers), Jonah Creek (Area XIII), Salt Creek (Area XIV), Little Red River (Area XV), Estelline Spring (Area V), and North Fork Wichita River (Area VII). Of these six sites, emphasis for this study was placed on determining geologic controls for emissions on the Pease River, Jonah Creek, and Salt Creek sites. In addition, two smaller studies were undertaken at the Elm Fork Red River brine-emission and brine-pond sites (Area VI) in Harmon and Beckham Counties, Oklahoma (Fig. 2).

All salt springs and salt plains within the region of the Red River Chloride Control Project occur where the bedrock is Permian in age. These sedimentary rocks are composed principally of reddish-brown shale, interbedded with layers of gypsum and dolomite on the outcrop, and also with layers of rock salt (halite, NaCl) in the subsurface. The current study has led to a better understanding of the regional geologic framework in the vicinity of the various salt plains, and has established the subsurface or down-dip distribution and depth of the various salt layers that probably are being dissolved to form brine that subsequently reaches the surface.

Methods of investigation

Procedures used in carrying out this investigation fall into two basic categories: 1) field work, in order to evaluate the surface geology and coordinate my efforts with those of the

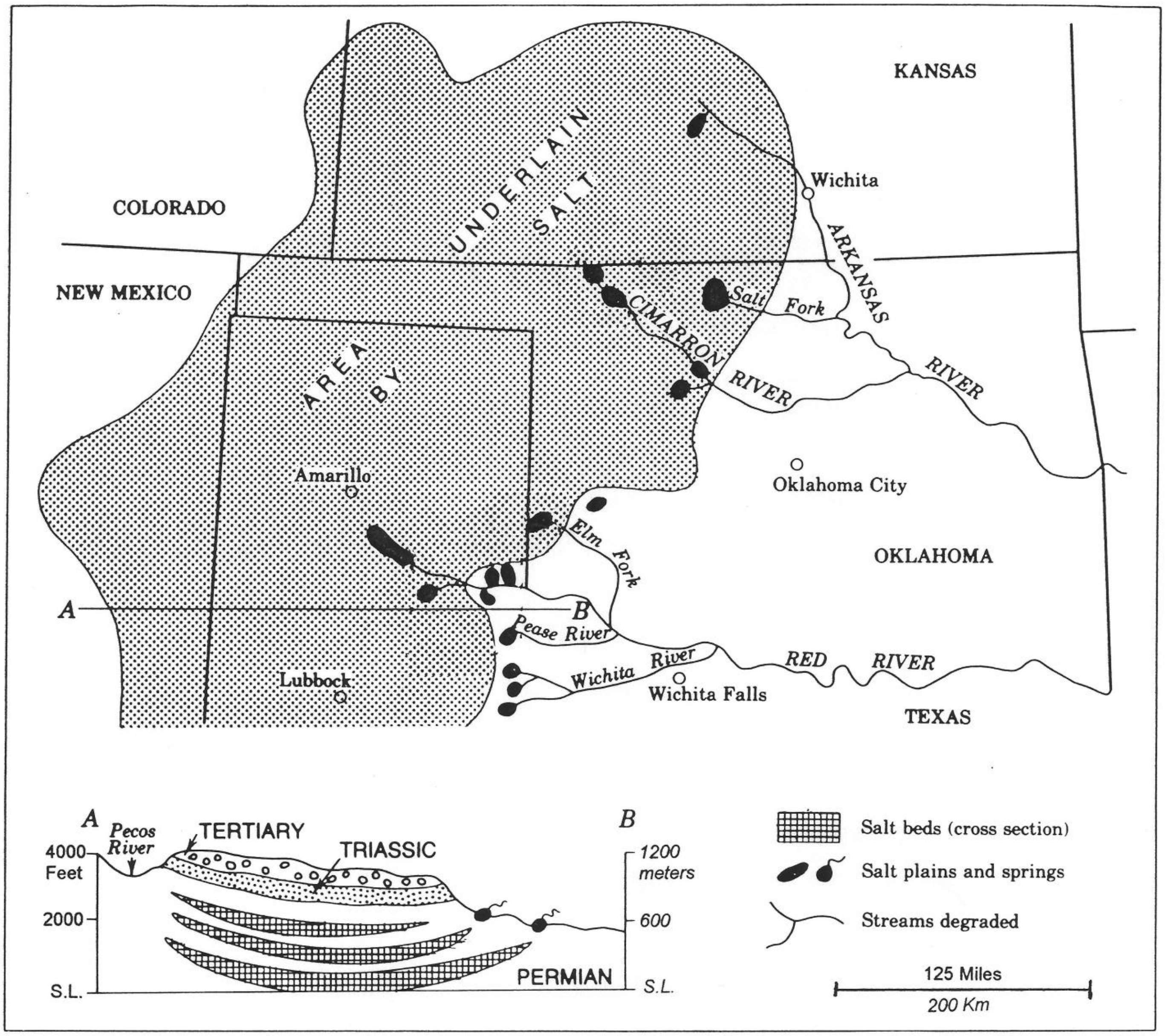

Figure 1. Map and schematic cross section showing distribution of Permian salts and salt plains in the Red River and Arkansas River watersheds of western Oklahoma and adjacent areas (Johnson, 1981).

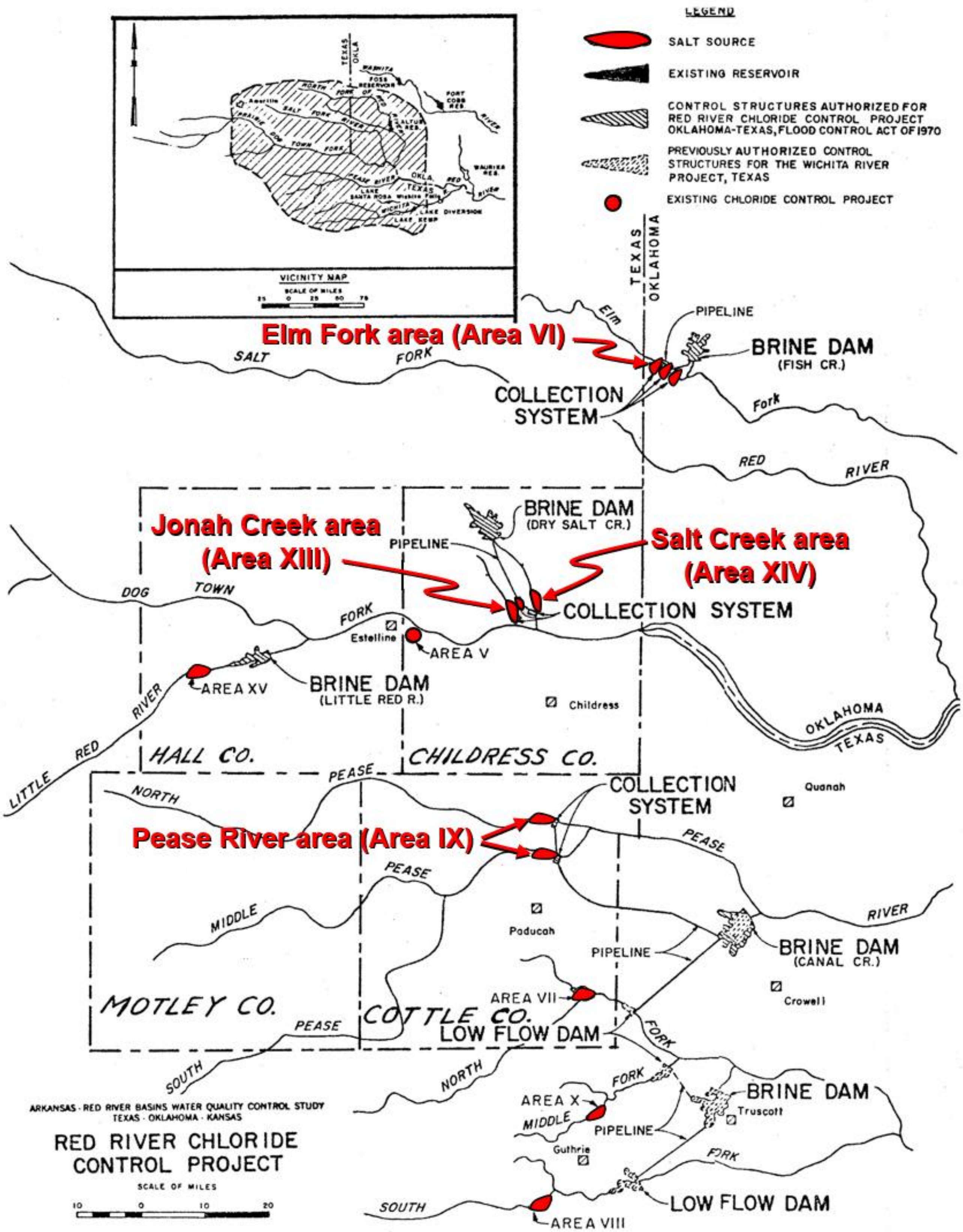

Figure 2. Location map showing brine-emission areas in the Red River watershed and the outline of Childress, Cottle, Hall, and Motley Counties, Texas.

geologic staff of the Corps of Engineers; and 2) office studies, which consisted mainly of studying subsurface data and relating those data to our outcrop investigations. In addition, a continuing search of the literature for books, maps, articles, and reports relating to the study area was made, and references to new publications were brought to the attention of various workers with the Corps of Engineers.

Field work helped to establish close liaison with Corps of Engineers personnel, and enabled me to provide continuing consultation on problems arising during field exploration. At least one trip was made each month in 1974 to field areas during the investigation. Conferences held in the field with Corps geologists and engineers were of great mutual value in developing basic geologic data. By working jointly with Wayne Wolfe and Melvin (Pete) Smith, we were able to establish the following: 1) a standard geologic column for the area; 2) stratigraphic correlations; 3) the outcrop area and extent of key beds; 4) the description of principal rock units on the outcrop and in continuous cores; and 5) the structural geology and dissolution phenomena that may affect the building of proposed structures within the project area.

Additional field conferences were held with staff members of Engineering Enterprises, Inc., which was doing contract work on geohydrology in the vicinity of the salt springs. Their descriptions of logs and bedrock test holes aided greatly in the detailed geologic mapping of the Jonah Creek–Salt Creek area.

Office studies centered mainly on the examination, interpretation, and correlation of electric logs, drillers' logs, and core holes throughout the four-county area, and relating these data to the results of surface investigations. The logs of some 200 wells, most of them drilled for oil and gas, were examined in this study; each of the four counties contains about 50 of the well logs that were examined. Major results of this office study are: 1) a series of maps showing regional structure and the thickness, distribution, and depth of principal salt-bearing units in the area (Plates 1, 3–6); 2) a panel of cross sections showing geologic structures and the distribution of salt layers (Plate 2); and 3) a geologic map of the Jonah Creek–Salt Creek area (Plate 7).

Acknowledgements

Invaluable assistance and cooperation were provided by members of the Corps of Engineers in making both the surface and the subsurface investigations for this report. Wayne Wolfe and Melvin (Pete) Smith spent much time in the field with me discussing many aspects of the investigation; and both of them helped considerably with their knowledge of the area. In addition, discussions with Tom Gay in Tulsa, and previous field discussions (in 1970 and 1971)

with Wayne Wolfe, Pete Williamson, and Lawson Jackson helped provide background information for this investigation. Jerry Triggs assisted by providing some of the subsurface information and by discussions about his findings during drilling of a proposed salt-water-disposal well at the Jonah Creek site.

Field conferences and office conferences in Norman, Oklahoma, were held a number of times with John Fryberger and his staff of geologists and engineers working for Engineering Enterprises, Inc., Norman, Oklahoma. We freely exchanged ideas and preliminary results of our respective investigations, and I was provided with a set of logs from test holes they drilled in the Jonah Creek area.

GENERAL GEOLOGIC SETTING

Outcropping rocks throughout most of the four-county area are Permian in age, and all of the brine-emission sites are underlain by Permian bedrock. Therefore, the geology of Permian rocks in north-central Texas and surrounding areas is key to understanding the salt deposits and brine emissions in the area.

The study area is on the northeast shelf of the large Permian Basin of West Texas and southeast New Mexico. Outcropping Permian sedimentary rocks in these four counties dip regionally to the southwest into the basin at 5 to 50 feet per mile. However, outcropping rocks are locally disrupted and dip in various directions at angles of up to 20 to 40 degrees, due to dissolution of underlying salts. Outcropping layers of gypsum, dolomite, and shale are also interbedded with layers of salt in subsurface to the southwest, where salt layers are generally 500 to 800 feet below the present land surface.

Permian stratigraphy

Principal rock units involved in this investigation include the San Angelo, Flowerpot, Blaine, and Dog Creek Formations, all of which are Permian in age (Fig. 3). They are considered by various workers to be in either the upper Leonardian of lower Guadalupian part of the Permian System. These four formations have been placed in the Pease River Group of Texas (Roth, 1945; Pendery, 1963; Jones, 1971), and this is equivalent to the El Reno Group as recognized in southwest Oklahoma (Scott and Ham, 1957; Johnson 1967, 1990, 2018). Beneath the San Angelo Formation on the outcrop is the Clear Fork Group, at the top of which is the Choza Formation (Hennessey Shale in Oklahoma); the Merkel Dolomite and/or Anhydrite Bed is herein considered the contact between the Flowerpot Formation and the Clear Fork Group in subsurface where the San Angelo Sandstone is absent or cannot be recognized. Overlying the Dog Creek Shale are friable sandstones of the Whitehorse Group, near the base of which (commonly 5 to 15 feet above the base) is the Childress Dolomite Bed. The latest geologic mapping of the area is by Texas Bureau of Economic Geology (1967, 1968)

The San Angelo Formation consists of about 120 feet of interbedded sandstone and shale in outcrops just east of the study area, in Hardeman and Foard Counties. The sandstones grade laterally into shales of the overlying Flowerpot to the west throughout most of the four-county area. Inasmuch as sandstones of the San Angelo Formation were not deposited in the four-county area, the Flowerpot Formation rests directly upon the top of the Clear Fork Group.

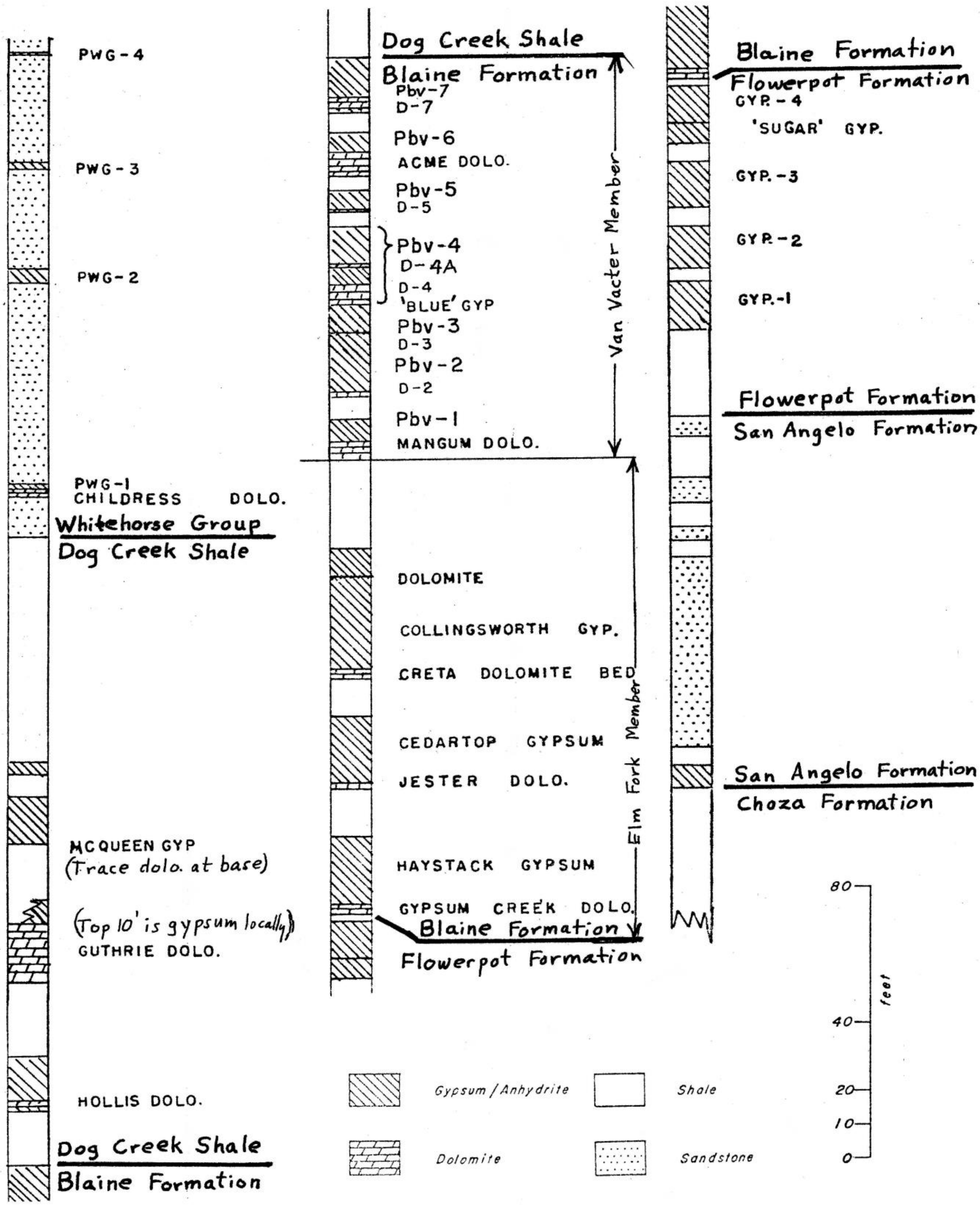

Figure 3. Standard geologic column of the Blaine Formation and associated strata near Pease River (Area IX) in north-central Texas. Modified from work by Wayne Wolfe in 1974 study of Corps of Engineers cores 1, 2, 3, and 3A.

Sandstones and interbedded shales of the San Angelo Formation at and near the outcrop are not known to contain any layers of salt or interstitial salt. Equivalent shales in the deep subsurface far to the west are interbedded with evaporites (including salt), but there they are considered part of the lower San Andres and Glorieta Formations (McGookey and others, 1988).

In outcrops and shallow subsurface of Hardeman and Foard Counties, the Flowerpot Formation comprises about 120 feet of reddish-brown shale interbedded with lesser amounts of gypsum, dolomite, and gray shale between the San Angelo and Blaine Formations. Gypsum and dolomite are more common in the upper part of the Flowerpot, and hence the unit may be subdivided into an upper gypsiferous member and a lower member that is almost entirely shale.

In subsurface of the four-county area, the San Angelo is missing. Thus, the Flowerpot Formation comprises all strata between the Merkel Dolomite/Anhydrite (top of the Clear Fork Group) and the overlying Blaine Formation. The Flowerpot is typically 250–350 feet thick in the east, where it does not contain salt interbeds, and is typically 350–450 feet farther west where it contains a considerable amount of salt in the upper part of the formation (Plates 2 and 3).

The upper gypsiferous member of the Flowerpot extends westward in subsurface across much of Childress and Cottle Counties, and the lower shale member increases in thickness greatly toward the west in eastern Childress and Cottle Counties, where the underlying San Angelo sandstone beds grade into shales of the Flowerpot.

The overlying Blaine Formation is generally 200 to 220 feet thick in outcrops and in shallow subsurface where it lacks salt layers. It comprises an interbedded sequence of gypsum beds (5 to 30 feet thick), dolomite beds (0.1 to 15 feet thick), and reddish-brown and greenish-gray shales (0.5 to 30 feet thick). These dolomite and gypsum beds are persistent marker beds that have been correlated with certainty over thousands of square miles, and some of the units have been traced a distance of some 400 miles from north-central Texas across western Oklahoma and into central Kansas. In subsurface of the four-county area, to the west and southwest of the outcrop, 20 to 40 feet of salt is present above the Collingsworth Gypsum Bed in the middle part of the formation (Plate 4), and salt may also be present as thin beds at other stratigraphic levels in the Blaine Formation; where salt is present above the Collingsworth Bed, the total thickness of the Blaine is typically about 250 feet.

The Dog Creek Formation ranges from 150 to 200 feet thick in outcrops and in shallow subsurface throughout most of the study area. It consists mostly of reddish-brown shale, although the lower part of the formation has several thick and persistent gypsum and dolomite beds. It is therefore divided into a lower gypsiferous member and an upper shale member. In the deeper subsurface to the west, where the unit is more than 500 to 800 feet below the surface, salt beds are present at a number of stratigraphic positions within the Dog Creek (see Plates 2, 5, and 6), and the formation is as much as 400 feet thick.

Permian paleogeography

During Permian time, north-central Texas was located on the east side of a broad, shallow sea that covered much of southwestern United States (Fig. 4). Because of slow but continual sinking of the earth's crust beneath this inland sea, a thick sequence of redbeds and evaporites (dolomite, gypsum, and salt) was deposited north of the major reefs and other marine carbonates of the Permian Basin of West Texas and southeast New Mexico. Normal marine water entered the Permian Basin from the open ocean to the southwest, and after passing over the reefs it entered the shallow sea or shelf areas where evaporation took place.

Permian shales and sandstones of the area were derived by erosion of land areas in eastern and central Texas. The principal source area was probably the Texas portion of the Ouachita Mountain chain, which is now deeply eroded and covered by younger sediments. The Wichita Mountains of southwest Oklahoma were almost completely covered by sediment at this time, and they contributed almost no sand and clay to the study area.

The study area, part of the northeast shelf of the Permian Basin, was near the sea shore during San Angelo, Flowerpot, Blaine, and Dog Creek times. At times it was above seal level, mainly when alluvial and deltaic sands of the San Angelo Formation were deposited in the east, but at most other times it was covered by the shallow sea and the shore was shifted farther east. Fresh and brackish water from the east mixed with marine and saline waters from the southwest: shales and sandstones were deposited from the former, whereas the evaporites were deposited from the latter.

Deposition of salt and other evaporites

Evaporite deposition in the Blaine Formation and associated strata resulted from evaporation of sea water. The concentration of dissolved solids in sea water was raised by this evaporation to the point where a series of "evaporite" minerals/rocks was precipitated on the sea floor. The cycle of evaporite precipitation in this area begins with formation of 0.5 to 15 feet of dolomite, followed by 5 to 30 feet of gypsum or anhydrite, and, at some stratigraphic intervals, finally 5 to 40 feet of salt (halite, NaCl). For a number of reasons, the complete evaporite

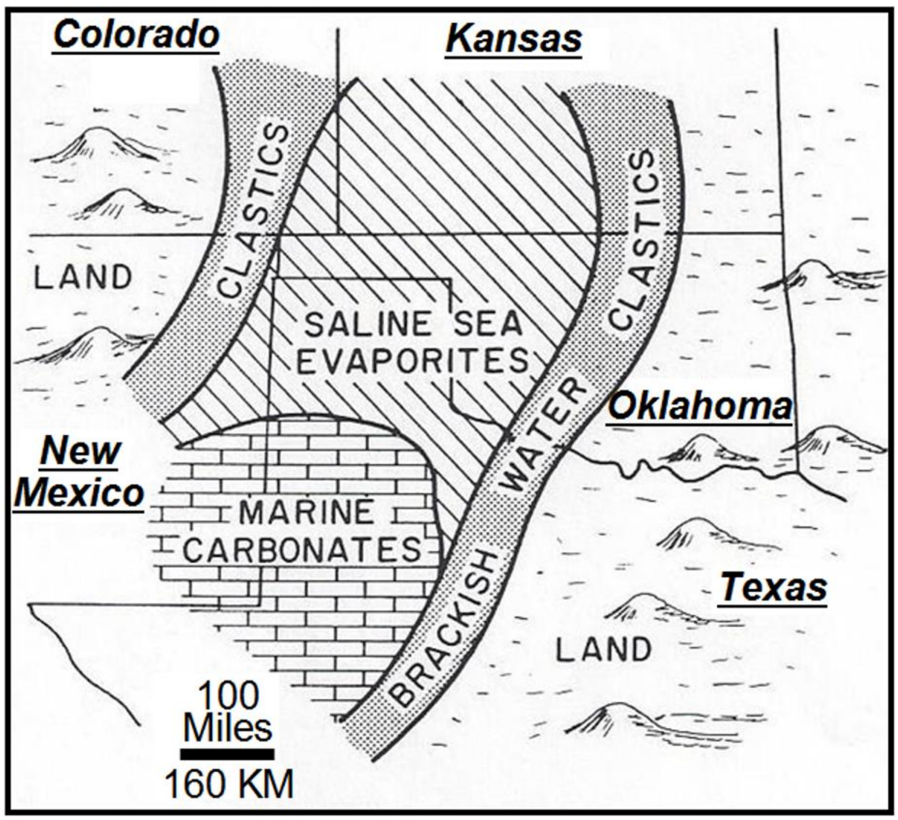

Figure 4. Paleogeography and principal facies of rocks deposited in the greater Permian Basin of southwestern United States during deposition of evaporites in the Flowerpot, Blaine, and Dog Creek Formations.

sequence is not found everywhere within the region: 1) precipitation may have been interrupted locally by an influx of less-concentrated water; 2) certain chemicals may have been depleted from the sea before precipitation of a particular evaporite mineral could start; and/or 3) the more soluble units (mainly salt, and sometimes gypsum or even dolomite) may have been deposited in places, but were later dissolved.

Typically, above each gypsum or salt bed is 2 to 30 feet of reddish-brown shale that is, in turn, overlain by 1 to 3 feet of greenish-gray shale. The complete cycle consists of dolomite, gypsum and/or anhydrite, salt (in subsurface), red-brown shale, and green-gray shale (Fig. 5). Ham (1960) attributes this cyclicity to transgression of the sea through periodic eustatic rise of sea level. This caused deposition of gray shale, followed by deposition of carbonates, sulfates, and salt through evaporation of sea water. Subsequent regression caused displacement of saline water by brackish water, with the result that red shale was deposited to close the cycle.

Subsurface dissolution of salt

Salt is a highly soluble rock, more soluble than any other rock in the Permian sequence in this part of the State. Therefore, if ground water comes into contact with a sequence of interbedded shale, dolomite, gypsum, and salt, it is the salt that is dissolved first. This is true whether the water is fresh or salty, so long as it is not a brine already saturated with respect to salt (NaCl). Regional and detailed studies have shown that natural dissolution of bedded rock salt occurs at shallow depths at many places in western Oklahoma and adjacent areas on the east side of the greater Permian Basin (Ward, 1961a, 1961b; Johnson, 1976, 1981, 2013, 2019a, 2019b; Gustavson and others, 1980; Richter and Kreitler, 1986; McGookey and others, 1988). Fresh and saline ground water moves laterally through aquifers, such as sandstone or cavernous gypsum, dolomite, or salt, and water also moves vertically through sinkholes, fractures, and collapse features (Fig. 6).

Dissolution of salt can occur by development of a system of subsurface caverns and dissolution channels through which ground water flows. As the water flows through the dissolution channels, salt is dissolved from the walls of the cavities and the water becomes more saturated with sodium chloride. When the water becomes fully saturated with sodium chloride, it will no longer dissolve salt. With continual replenishment of unsaturated water to the cavern system, the caverns can become sufficiently large, so that overlying rock units can collapse into the underground openings.

Another way in which salt may be dissolved is by widespread removal of relatively thin intervals (for example, several inches to several feet) of salt at the top or the bottom of an individual bed; the saturated brine that is formed escapes through subjacent of superjacent layers that are somewhat permeable, or it eventually enters a pre-existing dissolution channel. Where

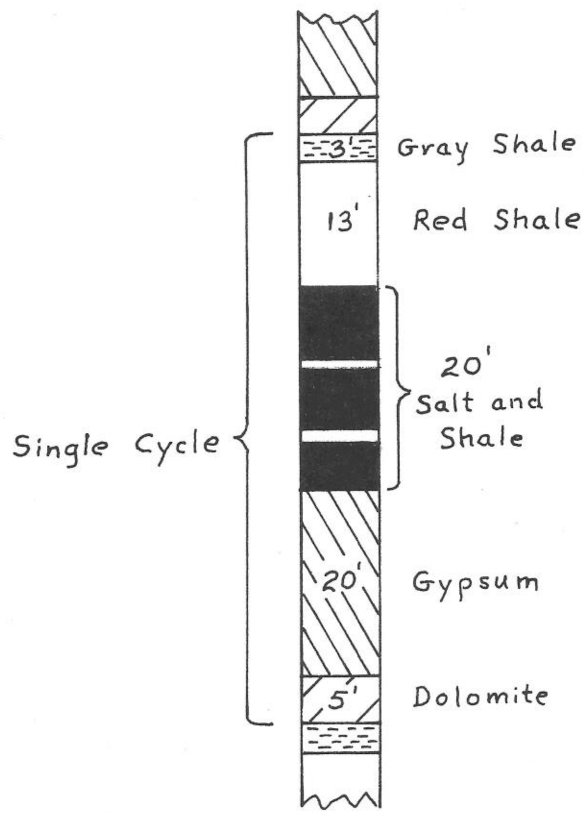

Figure 5. Idealized complete cycle of evaporite deposition in the Flowerpot, Blaine, and Dog Creek Formations of north-central Texas.

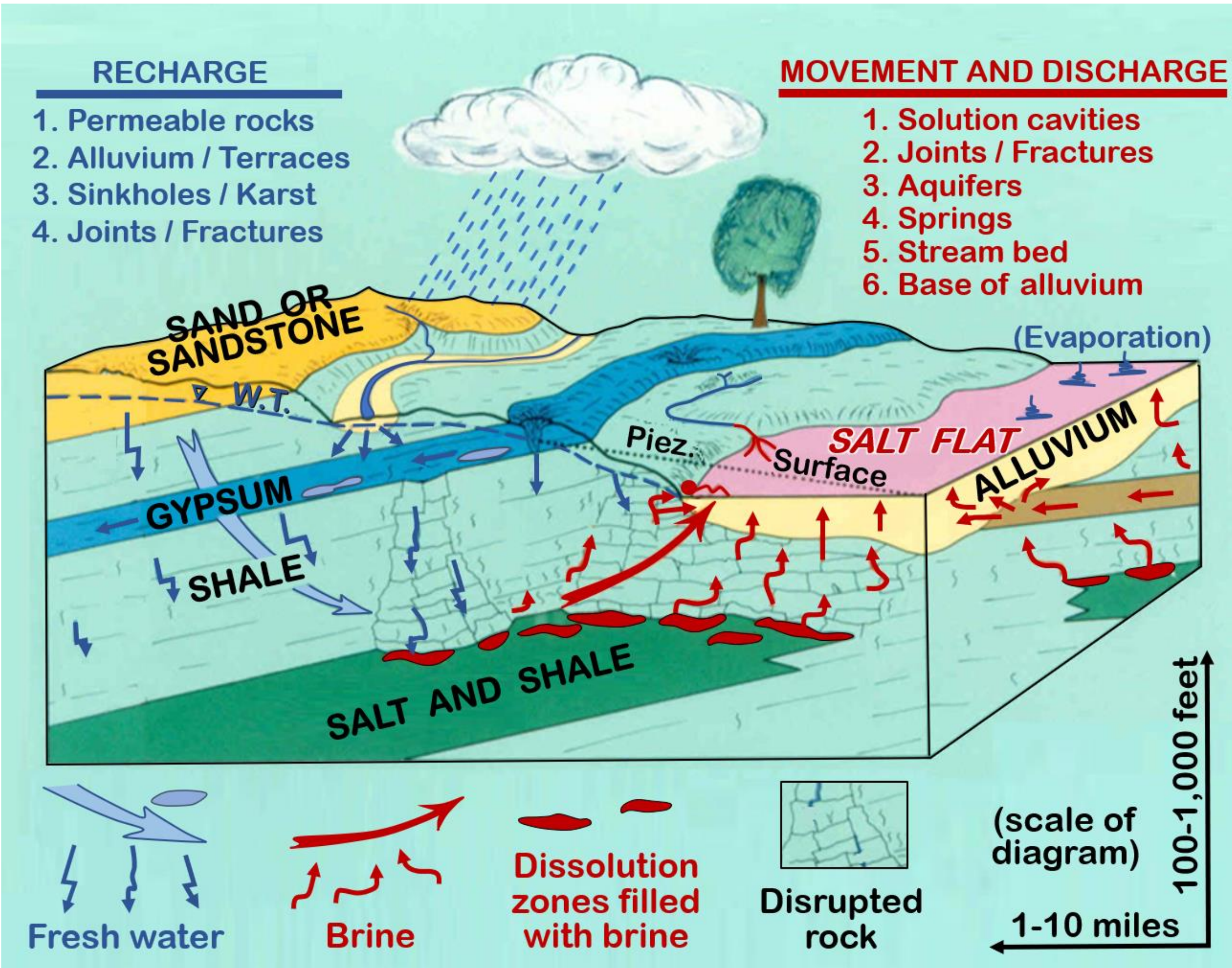

Figure 6. Schematic diagram showing circulation of fresh water and brine in areas of salt dissolution in north Texas and western Oklahoma (modified from Johnson, 1981).

this type of dissolution occurs, which may be likened to sheet-like dissolution or erosion, overlying strata are more gently let down into small caverns with less disruption of the overlying rock.

Salt is also disseminated as discrete and separate crystal within layers of shale or other rock. Circulating unsaturated ground water can dissolve the salt crystals; this will increase the porosity and permeability of the rock, and will help accelerate the further removal of salt.

Saturated and unsaturated brines now are being produced by one or a combination of these natural processes, and the brine is reaching the surface chiefly through interconnected gypsum and dolomite aquifers in the Flowerpot, Blaine, and Dog Creek Formations. Brine either is being emitted from outcrops of Permian bedrock, or is seeping from bedrock into the base or sides of alluvial and terrace deposits along rivers and streams.

Gypsum (and even dolomite) also can be dissolved, though not as readily as salt. There are many examples of dissolution features developed in gypsum beds in outcrops and shallow test holes in the four-county area, and these attest the relative ease with which gypsum can be dissolved. In many places, some of the gypsum has been dissolved from one or several of the key beds; caverns in gypsum may still be open, may be filled by rock collapsed from overlying layers, or may be filled with clays or other debris deposited from ground water that coursed through the caverns. Even entire gypsum beds 15 to 20 feet thick have been removed locally by dissolution, with the cavity thus formed often being later filled with clays or with collapse blocks from overlying rock units.

Several lines of evidence point to subsurface dissolution of salt in the study area:

1) The present northern and eastern margins of the salt deposits in subsurface are too abrupt and too irregular to be considered depositional limits. Similar studies of redbed-evaporite series elsewhere in the Permian basin (Jordan and Vosburg, 1963; Johnson, 1967, 1976, 2013; Johnson and Gonzales, 1978; Gustavson and others, 1980; McGookey and others, 1988) have found that such abrupt and irregular boundaries result from dissolution of the salt.

2) Collapse features, such as slumped and contorted strata, are common throughout much of the area (Fig. 7). The nature of disruption of these surface rocks is not typical of true geologic structures; instead it attests the removal or dissolving of some underlying rock unit with resultant chaotic collapse of overlying strata. Although locally it is clear that some of the collapse features are related to dissolution of an underlying gypsum bed,

Figure 7. Collapse blocks of gypsum where underlying layers of rock salt have been dissolved. **Upper photo** is in Jonah Creek area. **Lower photo** is along Prairie Dog Town Fork Red River.

in most cases the disruption is so severe and of such great extent that the widespread removal of a thicker and much more soluble rock (salt) must be appealed to. Also, a full and complete normal sequence of gypsum, dolomite, and shale has been drilled into beneath many sites where the surface rocks are highly chaotic; thus, only the salt, which is believed to have been deposited originally, is now missing from the sequence. The collapse of surface rock units above areas where salt has been dissolved is identical to what was seen in areas studied in detail near the central part of the Anadarko Basin and in the Hollis Basin of Oklahoma (Johnson, 1967, 2013).

3) The northern and eastern limits of the various salt units in the study area (see Plates 2–6) are generally 500 to 800 feet below the present land surface (salt is generally missing at shallower depths). This depth range is the same as what was observed in the closely studied area of salt dissolution in the Anadarko Basin (Johnson, 1967, 2013). It appears, therefore, that ground water has been able to dissolve and largely flush out interbedded salt in the Flowerpot, Blaine, and Dog Creek Formations at depths generally less than 500 to 800 feet below the surface.

4) The map showing distribution of salt in the Flowerpot–San Angelo interval (Plate 3) shows a striking example of an outlying mass of salt that has not yet been dissolved. At this location, in the upper reaches of Jonah Creek in northeast Hall County, the upper part of the Flowerpot has a thickness and an apparent salt content similar to that of the main area of Flowerpot salts about 10 miles to the south. Between these two areas, however, salt appears to be totally absent, and the thickness of the upper Flowerpot is abnormally thin near the present drainage way of Prairie Dog Town Fork Red River. Clearly, the once-continuous salt beds beneath the river have been dissolved, thus separating these two areas that still contain salt.

5) Salt casts and molds, in the form of cubic and hopper-shaped voids, impressions, and fillings in the rock, are present at some outcrops in the area. These casts and molds are evidence of the former presence of salt in the rock, and they show that the salt has been removed by dissolution. They are best seen in some of the dolomite beds, which are capable of retaining the delicate impressions of the salt crystals,

SURFACE INVESTIGATIONS

Field investigations of the four-county area were closely coordinated with the work carried out by Wayne Wolfe and Pete Smith. The nature of investigations carried out in the Pease River area and in the Jonah Creek–Salt Creek area were somewhat different, mainly because of the vastly different size of the two areas. Pease River area is large and contains a number of widely scattered emission sites, and therefore regional stratigraphic and structural information seemed to be of greater need. In contrast, the Jonah Creek–Salt Creek area is relatively small, and its smaller size seemed to justify a more detailed program of geologic mapping, structural mapping, and stratigraphic work.

Limited field studies were also carried out in the vicinity of the Elm Fork brine-emission and brine-pond sites in Harmon and Beckham Counties, Oklahoma.

Pease River area (Area IX)

Studies in the Pease River area consisted mainly of examination of rock units and stratigraphic correlation of Blaine and Dog Creek strata at key locations in northern Cottle County. Valuable information on the stratigraphy, structure, and dissolution characteristics in the rock were gained through examination of continuous cores drilled by the Corps of Engineers, and by discussion of the results of this drilling with Wayne Wolfe and others involved in the project. Information from these cores on the characteristics of rock in the shallow subsurface was one of the key factors in being able to extend geologic studies into the deeper subsurface throughout the region.

A companion field study in the Pease River area was structural mapping on a number of key beds on the surface and in shallow subsurface. Coordinating photogeologic and field work done by Mr. Wolfe and myself enabled us to determine elevations on marker beds in many of the inaccessible areas. These data points have been provided to the Tulsa District office as part of the total information they are compiling.

Jonah Creek–Salt Creek area (Areas (XIII and XIV)

The study in the Jonah Creek–Salt Creek area was a more detailed investigation owing to its smaller size (about 40 to 50 square miles). The abundance of good rock exposures in this area, and the relatively good access, made it possible to map the bedrock of the entire area with a minimum of effort (Plate 7). Photogeologic and field examinations were essential in this work, and also the work was greatly facilitated by the availability of shallow-subsurface information at a number of critical points through drilling programs of the Corps of Engineers and of Engineering Enterprises, Inc. Basic geologic information gained in this detailed study was immediately put to use in the hydrologic studies being carried out concurrently by John Fryberger and Engineering Enterprises, Inc.

One of the principal results of this detailed investigation is the realization that the geologic structure of the area is much more complicated than it appears. The area is on the south flank of the Hollis Anticline (see Plate 1), but it contains three fault–flexure systems, as well as several structural depressions and structural highs. Whether these small-scale structural features are the result of dissolution and collapse, or whether they represent the surface expression of deeper structural features in not clear. Regardless of the cause for the fault-flexures, however, they are closely associated with known brine-emission sites on both Salt Creek and Jonah Creek. Fault–flexure A (see Plate 7) is one mile northeast of the salt plains on Jonah Creek, and fault-flexures B and C are about one mile southwest of emission sites along Salt Creek. These fault-flexure zones probably are zones of broken and fractured rocks, and thus they may be acting as conduits through which brines can flow more easily to the surface.

At some locations in the Jonah Creek area, outcropping strata are disrupted due to dissolution of underlying salt beds (Fig. 7).

It is possible that the structural high that is centered about one mile north of the Jonah Creek Salt Plain may represent an area where surface rocks are arched over a residual patch or mass of salt (20 to 40 feet thick?) that has not been dissolved from the upper part of the Flowerpot Formation. If this is so, then this residual or outlying patch of salt may be one of the principal contributors of brine in the immediate area.

Elm Fork area (Area VI)

Elm Fork Red River contains three principal brine-emission areas in northern Harmon County, Oklahoma (Fig. 2). Brine is emitted near the mouths of three canyons (Kiser, Robinson, and Salton [or Chaney] Canyons) on the south side of Elm Fork (Fig. 8), and forms three salt plains that each has an area of between 2.5 and 9 acres. A study of the general geology, brine composition, and potential for commercial solar-evaporation of the brine to produce salt at these salt plains is given by Johnson and Denison (1973), and they note that brine is produced from dissolution cavities in salt at depths of 30 to 40 feet. Field study of the area was conducted to relate outcrop information with core and other shallow-subsurface data that

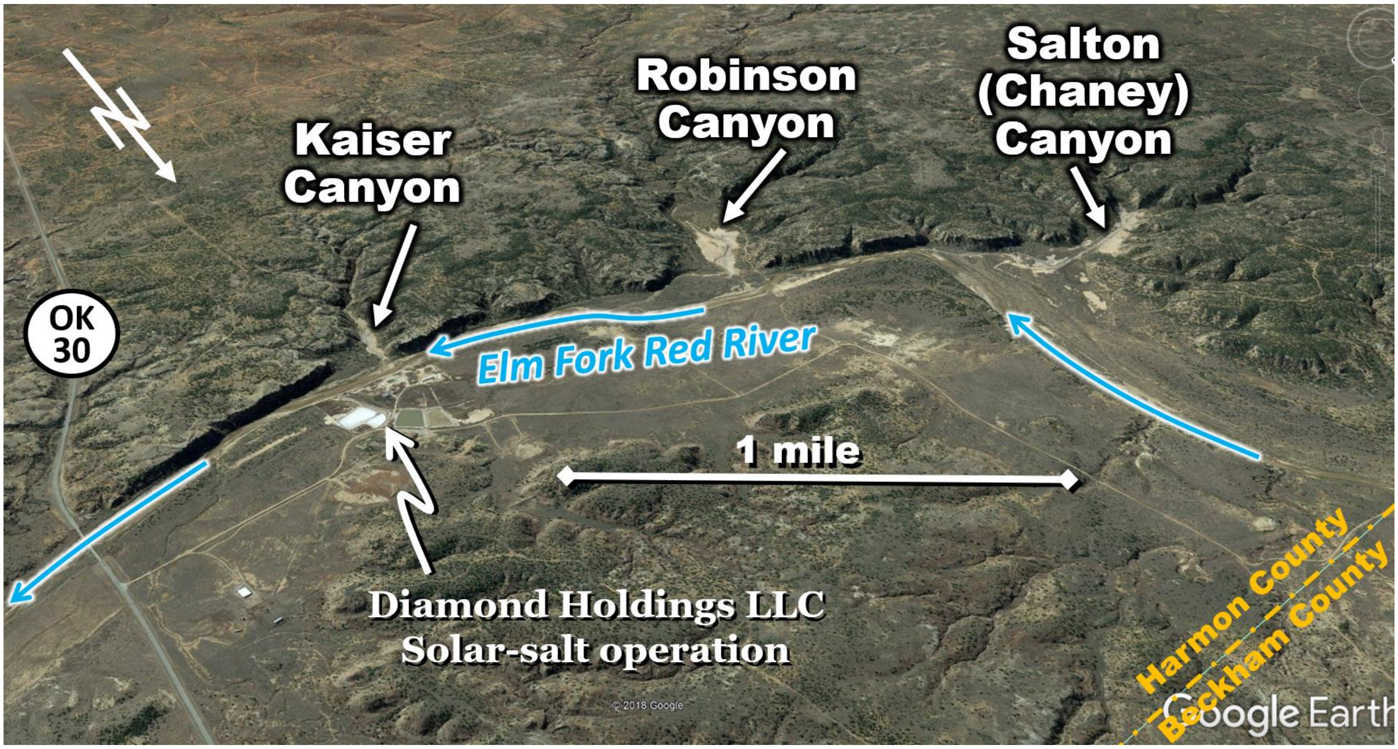

Figure 8. Aerial view (looking toward the southwest) of three brine-emission areas and salt plains in canyons adjacent to Elm Fork Red River in northern Harmon County, Oklahoma (Google Earth imagery, November 2014). Brine emissions occur near mouths of the three canyons and degrade fresh water in Elm Fork that enters the area upstream of Salton (or Chaney) Canyon. Diamond Holdings LLC is the latest of several companies that have commercially produced solar salt by pumping brine from salt plains in the canyons to evaporating pans on the more-suitable flat land on the north side of Elm Fork.

had been obtained previously. The result is a generalized cross section through the Salton (or Chaney) Salt Plain showing the inferred subsurface distribution of salt and its relation to the brine springs (Fig. 9).

Stratigraphy of the Flowerpot and Blaine Formations here is similar to what it is in the four-county study area of north-central Texas. The Haystack Gypsum Bed is the basal unit of the Blaine, and it is overlain by a normal sequence of Cedartop Gypsum, Collingsworth Gypsum, and Mangum Dolomite. The upper Flowerpot is not as gypsiferous here as in north-central Texas: only the Kiser and Chaney Gypsum Beds are conspicuous here, and their precise correlation with gypsum beds in Texas is not yet established.

Reconnaissance field work was also done in the vicinity of the proposed brine-holding pond (for Area VI) along Fish Creek in Beckham County, Oklahoma (Fig. 10). I hoped to establish whether any of the massive (and possibly cavernous) gypsum beds of the Blaine Formation would be beneath the maximum pool level. By coordinating field study and photogeologic study, and comparing these data with advance-copy 1:24,000 topographic maps (10-foot contour interval) for the area, it appears that at all places along Fish Creek the base of the Blaine Formation will be more than 20 to 25 feet above maximum pool level (Fig. 10). Only the Flowerpot Formation, with several gypsum beds 0.5 to 2.0 feet thick, will be below maximum pool level.

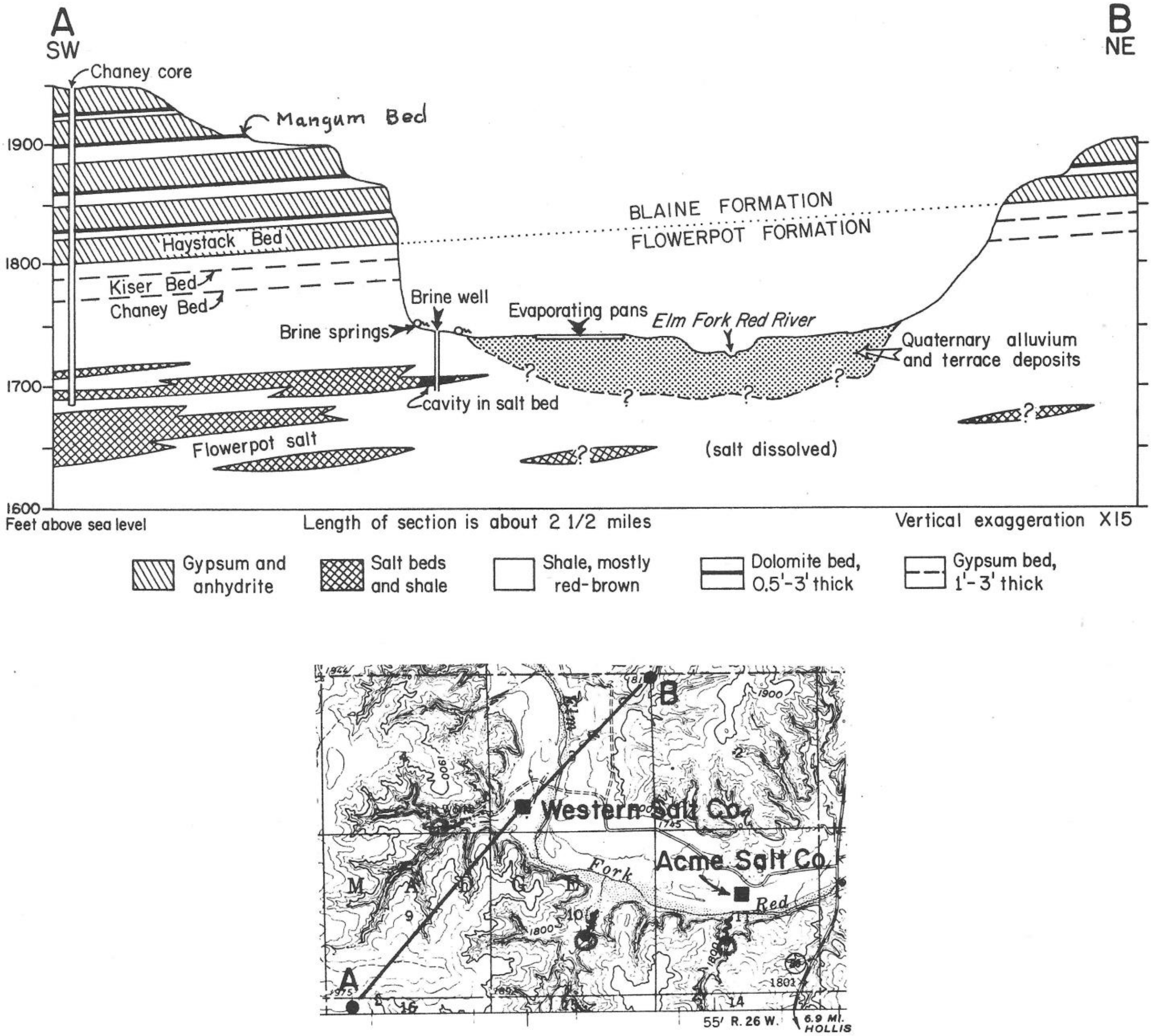

Figure 9. Generalized cross section (above) and location map (below) showing salt layers, brine springs, and stratigraphy in the vicinity of Salton (or Chaney) Salt Plain on Elm Fork Red River (from Johnson and Denison, 1973). In 1973, two companies (Western Salt Co. and Acme Salt Co.) were producing solar salt from evaporating pans on the Elm Fork alluvial plain.

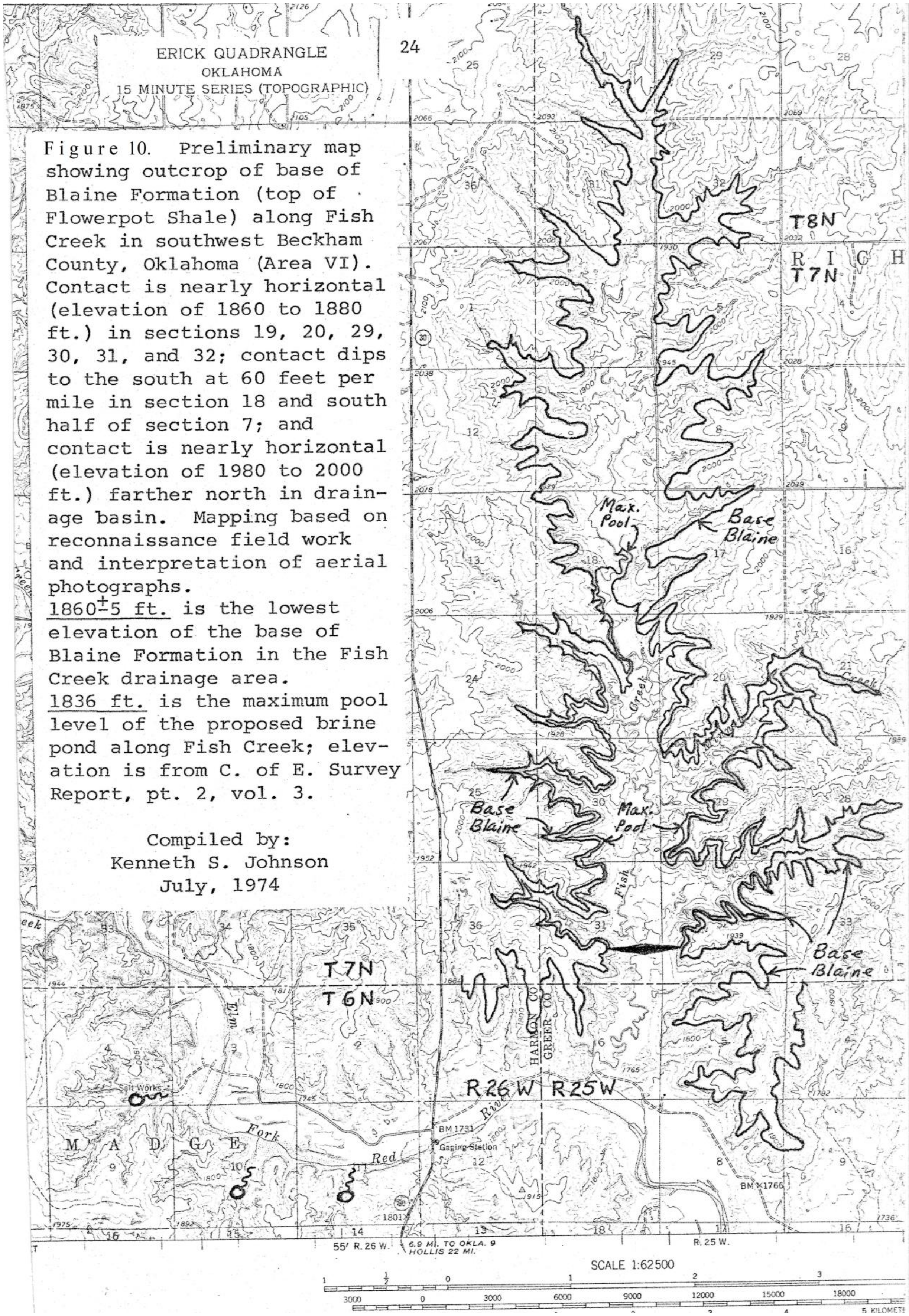

Figure 10. Preliminary map showing outcrop of base of Blaine Formation (top of Flowerpot Shale) along Fish Creek in southwest Beckham County, Oklahoma (Area VI). Contact is nearly horizontal (elevation of 1860 to 1880 ft.) in sections 19, 20, 29, 30, 31, and 32; contact dips to the south at 60 feet per mile in section 18 and south half of section 7; and contact is nearly horizontal (elevation of 1980 to 2000 ft.) farther north in drainage basin. Mapping based on reconnaissance field work and interpretation of aerial photographs.

1860±5 ft. is the lowest elevation of the base of Blaine Formation in the Fish Creek drainage area.

1836 ft. is the maximum pool level of the proposed brine pond along Fish Creek; elevation is from C. of E. Survey Report, pt. 2, vol. 3.

Compiled by:
Kenneth S. Johnson
July, 1974

STRUCTURAL GEOLOGY

Regional investigations, combining the results of both surface and subsurface study, have produced a good understanding of the structural geology of the four-county area. The results are presented here as a structure-contour map of the four-county area (Plate 1), and a panel of generalized cross sections (Plate 2).

Structure-contour map (Plate 1)

Regional dip in the four-county area is generally towards the southwest, and ranges from about 10 to 50 feet per mile (Plate 1). The datum for the structure-contour map is the base of the Mangum Dolomite in the middle of the Blaine Formation. The dolomite is typically 1 to 4 feet thick in outcrops and in shallow subsurface in the eastern half of the area. Farther west, in deeper subsurface, the lithology and thickness are not discernible from the various electric logs available, but its stratigraphic position can be picked with certainty, based upon correlation of adjacent gypsum marker beds on the electric logs. Individual salt layers in the Flowerpot, Blaine, and Dog Creek Formations are subparallel to the Mangum Dolomite, so this structure-contour map also indicates the direction and rate of dip of the various salt beds under study. Structural contouring shown on this map greatly simplifies the complexity that one finds through detailed structural mapping within the area (for example, see the detailed structural map of the Jonah Creek–Salt Creek area, Plate 7).

Along the south side of the map area is the prominent Matador Arch. This major structural feature extends several hundred miles, with an east–west trend across north-central Texas. Although the Matador Arch had its principal development during the Pennsylvanian Period, it remained a semi-positive structure that had at least minor influence on subsequent Permian sedimentation. Later, gentle movements along the Matador Arch have caused uplift of Permian strata over the arch.

The second major structural high in the area is the Hollis Anticline, which extends across the northeastern part of the study area and continues another 15 miles into southwestern Oklahoma. Other smaller features are the Baker Anticline, which is a poorly defined arch extending north-northwesterly across the North and Middle Pease Rivers, and the Plaska Dome, which is a pronounced domal or anticlinal feature south of Memphis, in northeastern Hall County. Several other small areas that seem to be structurally high or low (because of the closure of a single contour line around one control point) may also have structural significance, or they may be local dissolution-and-collapse features resulting from dissolution of salts.

The four above-named arches, anticlines, and domes are true structural features: they are the surface and near-surface reflections of deep-seated structures in early Paleozoic and perhaps Precambrian rocks.

Structural cross sections (Plate 2)

Lines of the three cross sections (Plate 2) were selected to show the regional southwest dip of Permian rocks and the principal structural features in the area. The present-day distribution of salt units is largely controlled by surface drainage systems and the depth to the salt layers. As seen in the cross sections, near-surface salt beds have been dissolved beneath, and up-dip from the following rivers and creeks: 1) Prairie Dog Town Fork Red River and Salt Creek in cross section A–B; 2) Turtle Creek, North Pease River, and Prairie Dog Town Fork Red River in cross section C–B; and 3) Turtle Creek in cross section C–D.

It is clear from the cross sections that salt beds are now limited to depths greater than about 500 to 800 feet below the ground surface, and at shallower depths the salt beds have been dissolved by ground water. I have tried to indicate the collapse and disruption of rock layers that overlie dissolved salt beds only in the vicinity of the present dissolution boundaries on Plate 2, although field studies have shown that the area of collapse and disruption extends far to the north and east of these boundaries.

SUBSURFACE DISTRIBUTION OF SALT

Although layers or masses of rock salt have not been cored, or knowingly drilled into during the present investigation by the Corps of Engineers, it is certain that layers of rock salt are present at depths greater than 500 to 1,450 feet in much of the western part of the four-county area (Johnson, 1976; Gustavson and others, 1980; McGookey and others, 1988).

Principal salt-bearing intervals are located: 1) in the upper part of the Flowerpot Formation; 2) in the middle part of the Blaine Formation (above the Collingsworth Gypsum); 3) in the lower part of the Dog Creek Formation (above the Pbv-7, the Hollis, and the Guthrie Gypsum Beds); and 4) in the upper part of the Dog Creek Formation (see Plate 2 for positions of these principal salt intervals).

Salt maps accompanying this report (Plates 3–6) show the thickness and distribution of each of the principal salt-bearing units: they also show the depth below land surface to the top of each salt-bearing interval, or to the top of stratigraphically equivalent shale layers where the salt has been dissolved.

I believe that, in the past, all parts of the four-county area under study were underlain by salt beds in one or more of the various salt-bearing intervals cited above. This belief is based upon interpretations of the following: 1) the present-day thickness and distribution of remaining salt beds; 2) the disrupted and chaotic character of outcropping strata throughout the area (Fig. 7); and 3) previous studies of the original distribution of salt in these same rock formations in southwestern Oklahoma and other parts of the Permian Basin (Jordan and Vosburg, 1963; Johnson, 1967, 1976, 2013; Gustavson and others, 1980; McGookey and others, 1988).

<u>Salt in the Flowerpot–San Angelo interval (Plate 3)</u>

The Flowerpot Formation contains the greatest thickness of salt-bearing strata at relatively shallow depths within the study area: the Flowerpot typically is 350 to 450 feet thick in the west half of the area where it contains salt. The upper half of this interval contains the principal salt deposits and ranges from 90 to 271 feet thick: the greater thicknesses are in the west, where salt makes up a substantial part of the interval, and the lesser thicknesses are in the north and east where the salt has been partially or completely dissolved.

Salt beds in the upper part of the Flowerpot generally make up 30 to 40 percent of the aggregate thickness of all strata in the unit in those parts of Hall County where the salt is still present. Eastward, in Childress County, salt makes up about 20 percent of the unit, where the salt is still present. To the south, in Motley and Cottle Counties, salt decreases progressively to 20 percent and then 10 percent of the unit, towards the depositional limit near Matador.

Salt has definitely been dissolved beneath, and north of, Prairie Dog Town Fork Red River, where the top of the Flowerpot is generally 200 to 500 feet deep. The residual mass of salt in a well 10 miles southeast of Memphis may be preserved because it is located in part of the shallow structural depression between the Hollis Anticline and the Plaska Dome (Plate 2, cross section A–B). The areal extent of this residual salt may be greatly exaggerated on the map (Plate 3), as it may possibly only underlie one or two square miles, or an even smaller area. It does demonstrate, however, that such residual masses of salt can exist in areas where the salt has generally been removed by dissolution, and there may be other similar salt areas unknown at the present time. It is also possible that the structural high just north of Jonah Creek Salt Plain (Plate 7) may reflect such a residual mass of some 20 to 40 feet of salt in the upper part of the Flowerpot.

In southwest Childress County and northwest Cottle County, the eastward limit of salt in the Flowerpot cannot be drawn with certainty, nor is it certain whether the eastern limit is depositional or due to dissolution. The absence of a zone of abrupt thinning in the unit suggests that there is no major dissolution zone in the area, so I believe that the eastward thinning of the unit and the disappearance of the salt is a result of the combined effects of depositional thinning of salt modified by some dissolution of salt. The limit line shown on this part of the map is drawn through the area where there is a slight increase in the rate of thinning of the unit.

The southern limit of the Flowerpot salt, in the vicinity of Paducah and the area south of Matador, appears to be a depositional limit. Interpretation of electric logs in this area shows no evidence of salt in the upper Flowerpot to the south, and I believe this may be related to facies changes in Flowerpot deposition because of the Matador Arch: the Matador Arch was probably a gentle but positive feature on the sea floor during Flowerpot time, and the shoaling of water across the arch may have influenced deposition of salt in the slightly deeper basin north of the arch, while keeping the arch free of salt deposition.

Salt above Collingsworth Gypsum (Plate 4)

The stratigraphic interval immediately above the Collingsworth Gypsum Bed and below the Mangum Dolomite Bed is the principal position at which salt is found within the Blaine Formation throughout the Texas Panhandle and western Oklahoma. This condition also exists in the four-county study area (Plate 4), and in fact layers of salt have not been found at any position in the Blaine Formation in the study except just above the Collingsworth Gypsum. Where salt is present, the interval is typically 20 to 40 feet thick and consists of interbedded salt and shale layers, each generally 1 to 10 feet thick. The interval appears to comprise 50 to 75 percent salt and 25 to 50 percent shale and gypsum. Westward, salt beds in this interval are thicker and shale interbeds are thinner: thus, the percentage of salt in this unit is greatest in the far west. Throughout the area, this salt is immediately overlain by 15 to 20 feet of shale that lacks salt interbeds, and this in turn is overlain by the Mangum Bed.

The northern and eastern limits of present-day salt distribution clearly result from dissolution of salt that once was more widespread. The complete absence of salt from a salt-shale interval 30 to 40 feet thick within a distance of only two miles at many places along this irregular limit can best be explained as a dissolution phenomenon, when it is compared to the normal depositional limit of salt units (a more gradual rate of thinning) in other parts of the Permian Basin. In general, the salt above the Collingsworth Gypsum is restricted to those areas where it is more than 500 to 700 feet below the present land surface.

Salt above Hollis Gypsum (Plate 5)

Salt above the Hollis Gypsum Bed, in the lower part of the Dog Creek Formation, is 5 to 25 feet thick, with the greater thickness in the far west (Plate 5). It appears to consist of one massive bed of rock salt, although there probably are some thin shale layers that could make up about 10 to 15 percent of the unit. Its present limit in Hall County is clearly a result of dissolution. Based upon the rate of eastward thinning to the west of the dissolution front, it seems likely that salt above the Hollis Gypsum was originally restricted to Hall and Motley Counties, and it was not deposited in any parts of Childress or Cottle Counties.

The present distribution of salt above the Hollis Gypsum is generally restricted to areas where it is more than 500 to 800 feet below land surface.

Salt above Guthrie Gypsum (Plate 6)

The salt-bearing unit above the Guthrie Gypsum Bed, in the lower part of the Dog Creek Formation, ranges from 28 to 42 feet thick and is restricted to parts of Hall and Motley Counties (Plate 6). It appears to be a single, nearly massive unit of rock salt, but probably has thin layers or irregular masses of shale making up perhaps 10 percent of the unit. The present northern and eastern limits of this salt clearly result from dissolution of the salt. The unit thickens toward the east, and it probably was originally present throughout much of Cottle County, and perhaps even into parts of Childress County.

The present distribution of this salt is limited to areas where it is more than 700 to 800 feet below the land surface.

Salt at other stratigraphic levels

Salt also occurs in the lower part of the Dog Creek Formation just above Pbv-7 at a few scattered places in Hall County, principally in the area between the town of Turkey and Little Red River. This salt is typically 5 to 10 feet thick, and it appears to be massive salt with only minor amounts of shale.

A major sequence of interbedded salt and shale occurs in the upper part of the Dog Creek Formation in the deeper subsurface of Motley County (see Plate 2, cross sections C–B and C–D). Typically, strata in the upper Dog Creek (from the top of the McQueen Gypsum Bed to the base of the Whitehorse Group) are 80 to 100 feet of reddish-brown shale with thin layers of gypsum and dolomite. Where this interval contains salt in subsurface, it is 200 to 240 feet thick and layers of rock salt make up about 50 to 60 percent of the total thickness. Individual salt and shale interbeds in this sequence are commonly 1 to 10 feet thick. I believe that some of these salt beds originally extended across all of Motley County and much (if not all) of Hall and Cottle Counties, and perhaps even much of Childress County. These salts, as well as those in the lower part of the Dog Creek, are in the same stratigraphic position as the 285 feet of interbedded salt and shale (the Yelton salt) that make up almost the entire Dog Creek Formation in the deeper part of the Anadarko Basin in Oklahoma (Jordan and Vosburg, 1963; Johnson, 1967, 2013).

SUMMARY AND RECOMMENDATIONS

1. Working closely with Corps of Engineers geologists has helped establish the basic geologic framework for the region. Results of core drilling and test holes drilled into bedrock were invaluable in all phases of geologic study, and such information is needed for similar investigations of other problem areas.

2. The geologic structure in the area is more complicated than it appeared initially. Regional dips are generally 10 to 50 feet per mile towards the southwest, but faults, flexures, and local structural highs and depressions are common. These faults, flexures, and local structures may have an influence on brine migration and emissions.

3. Fault-flexure zones of broken rock may be conduits through which brines can flow more readily to the surface. Fault-flexure zones are closely associated with brine-emission sites at Jonah Creek and Salt Creek.

4. Salt is present in subsurface in the Flowerpot, Blaine, and Dog Creek Formations. The salt apparently occurs only as halite (NaCl): there is no evidence of potash or any other type of salt.

5. Salt layers are widespread in the subsurface to the west and southwest. They occur mainly at the following stratigraphic levels: 1) in the upper Flowerpot; 2) above the Collingsworth Gypsum; 3) above the Pbv-7 gypsum; 4) above the Hollis Gypsum; 5) above the Guthrie Gypsum; and 6) in the upper Dog Creek, above the McQueen Gypsum. Salt also is disseminated as crystals in shale and other rocks.

6. Salt was originally more widespread that it is today. I believe that all parts of the four-county study area probably were originally underlain by salt at one or more stratigraphic levels in the Flowerpot, Blaine, or Dog Creek Formations.

7. Salt layers are now largely dissolved at depths less than 500 to 800 feet below the land surface. Some dissolution of salt took place long ago, but some of it is certainly taking place now.

8. Salt beds in stratigraphically lower units now extend farther to the north and east than overlying salts. This is to be expected, because the upper salts (where they would be less than 500 to 800 feet below the land surface) have already been dissolved, and the lower salts are still protected at depth.

9. Evidence for subsurface dissolution of salt includes: 1) abrupt thinning and irregular boundaries of salt beds; 2) collapse and disruption of strata above areas where salt is believed to have been dissolved; 3) the depth to the top of most remaining salt units (500 to 800 feet) is consistent with observations in other areas of western Oklahoma and north Texas; 4) the presence of an outlying mass or patch of Flowerpot salt 10 miles north of the main salt deposits; and 5) the presence of salt casts in dolomites and other rocks in the area.

10. The structural high located one mile north of Jonah Creek Salt Plain may be underlain by a residual mass of salt that has not been dissolved.

11. Brine forms by ground water dissolving salt in the Flowerpot, Blaine, and Dog Creek Formations. The brine then migrates laterally and upward through interconnected aquifers to the surface. Joint systems, fault-flexure zones, sink holes, and collapse features are probably the pathways for major vertical movement of brine. This process has been going on intermittently or continuously for a long time, perhaps several hundred thousand years, with brine being emitted at different sites as the salt was being dissolved in various parts of the four-county area.

12. Salt is now being dissolved at shallow depths (as shallow as 30 feet below the surface) along Elm Fork Red River (Area VI), and brine is being discharged through several springs in three canyons along the river in northern Harmon County, Oklahoma.

13. The Flowerpot and lower Blaine stratigraphy at the Elm Fork Red River brine springs is similar to that seen in north-central Texas.

14. Massive gypsum beds of the Blaine Formation are all at least 20 to 25 feet above maximum pool level at the proposed brine-holding pond on Fish Creek, near the brine springs on Elm Fork Red River.

15. Detailed mapping should be carried out in the vicinity of other brine-emission sites in the Red River Chloride Control Project area. This should result in maps showing the major rock types, key beds, and structure contours within a 2-mile radius of these sites. Maximum results are obtained by combining field work, photogeologic study, and data from shallow test holes and cores drilled at key locations.

16. A detailed study should be made of the surface geology of the Fish Creek area, the location proposed to hold brines from Elm Fork Red River emission sites. This will establish whether the gypsum beds in the upper Flowerpot might allow leakage of brine from the pond, and also determine if there are small-scale structures that might affect the pond.

17. A down-dip subsurface study of the region to the west of Little Red River (Area XV) is needed. This brine-emission site is near the eastern limit (a dissolution limit) of salt beds in the Dog Creek Formation, and there are references in the literature to thick salt deposits in the overlying Whitehorse Group farther to the west. The distribution, thickness, depth, and limits of these various salt units should be determined in Briscoe and northeast Floyd Counties, Texas.

<u>18.</u> Based on hydrogeologic data, freshwater-recharge areas near brine-emission sites should be identified: once identified, these areas should be studied in detail to fully understand the geologic and hydrologic controls on the flow of ground water into, through, and out of the subsurface salt deposits.

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PLATE - 1

STRUCTURE - CONTOUR MAP

CHILDRESS, COTTLE, HALL, and MOTLEY COUNTIES, TEXAS

Contoured on base of Mangum Dolomite Bed in middle of Blaine Formation (Permian age)

Contour Interval, 50 feet (datum is sea level)

Kenneth S. Johnson
July, 1974

0 5 10 miles
Scale, 1 : 250,000

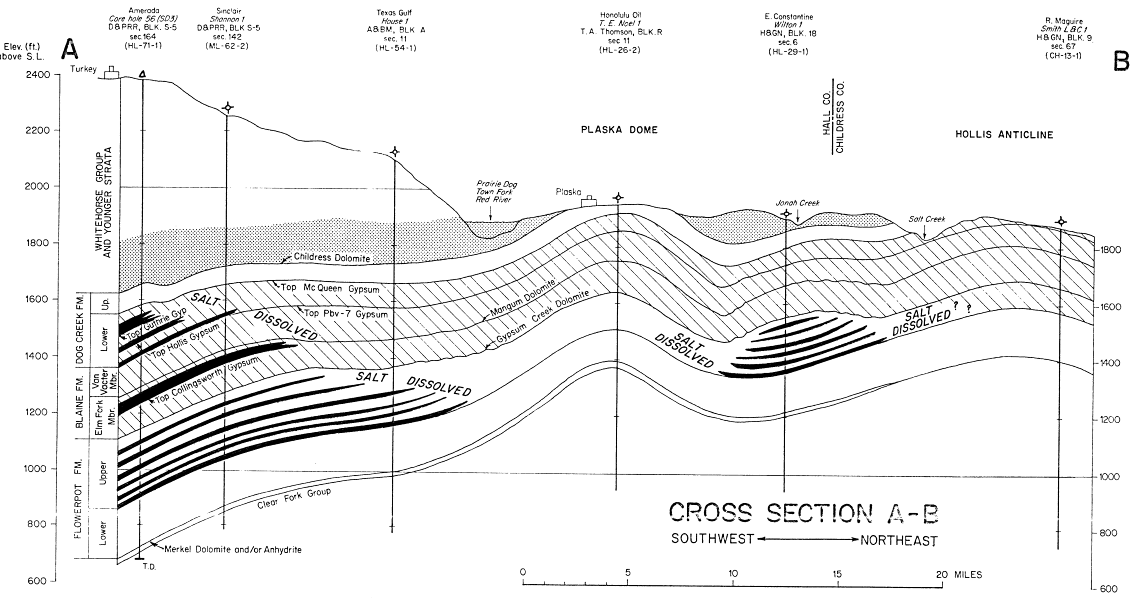
Bore Holes and Symbols

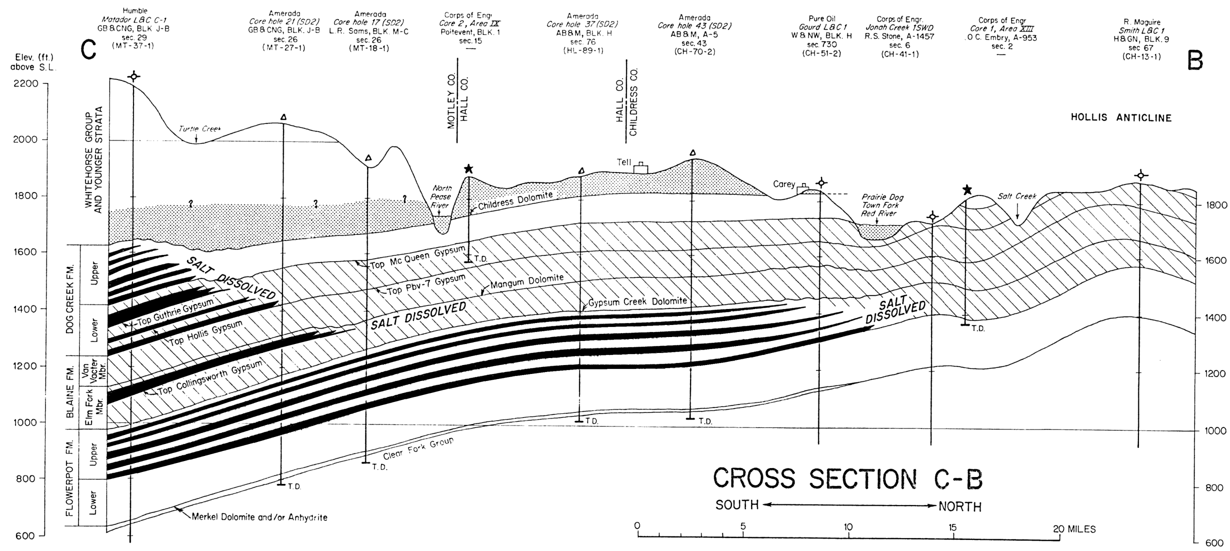
1525 ● Oil and Gas test (electric log)
1486 ▲ Stratigraphic test (electric log)
1588 ☆ Corps of Engrs. (core)

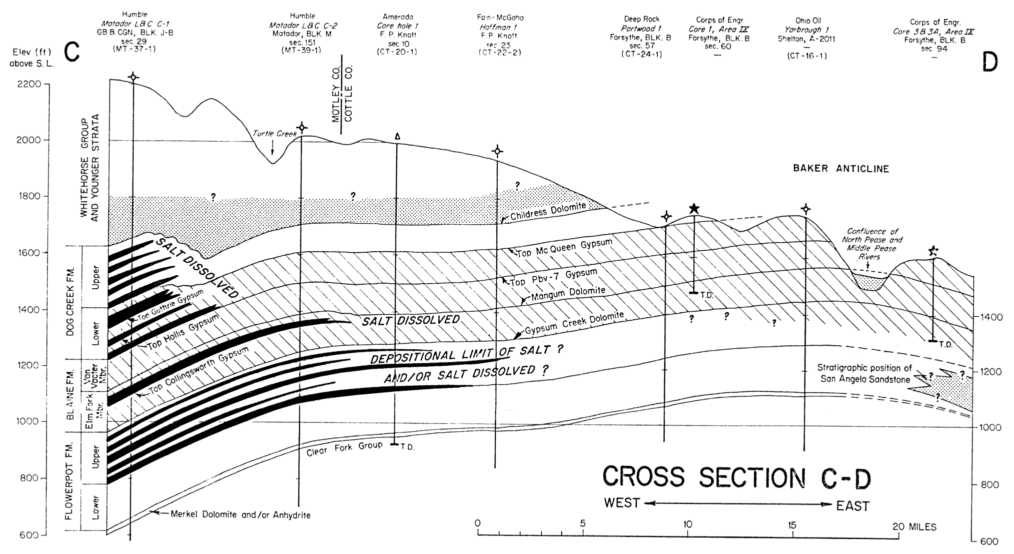
Number next to bore hole symbol is elevation (in feet) of base Mangum Dolomite above sea level. Underlined number (1569) is elevation projected from another marker bed.

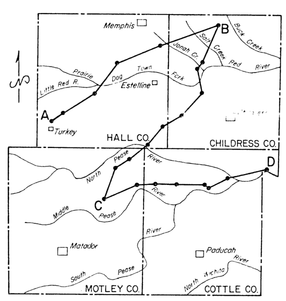
1500
Contour line showing where Mangum Bed is 1500 feet above sea level

A———B———C———D
Lines of cross sections (A-B, C-B, C-D,)









Location Map Showing Lines of Cross Sections

EXPLANATION

Mostly sand and/or sandstone

Mostly gypsum interbedded with shale and dolomite

Unit of interbedded salt and shale

Mostly shale

Lithologies and stratigraphic correlations based on:

(1) Continuous cores drilled by U.S. Army Corps of Engineers (★)

(2) Outcrop studies made with Corps of Engineers geologists

(3) Interpretation of electric logs of bore holes drilled for oil and gas (✧) or for stratigraphic/structural information (△)

PLATE-2

GENERALIZED STRUCTURAL CROSS SECTIONS SHOWING SALT-BEARING STRATA IN FLOWERPOT, BLAINE, AND DOG CREEK FORMATIONS

CHILDRESS, COTTLE, HALL, AND MOTLEY COUNTIES, TEXAS

Kenneth S. Johnson

July, 1974

PLATE - 3

THICKNESS OF SALT-BEARING STRATA IN UPPER PART OF FLOWERPOT-SAN ANGELO INTERVAL

CHILDRESS, COTTLE, HALL, and MOTLEY COUNTIES, TEXAS

Contour Interval, 20 feet (of thickness)

Kenneth S. Johnson

July, 1974

0 5 10 miles

Scale, 1:250,000

Bore Holes and Symbols

198
522 ⚬ *Oil and Gas test (electric log)*

220*
627 ▵ *Stratigraphic test (electric log)*

☆ *Corps of Engrs. (core)*

Top number is thickness (in feet) of the salt-shale unit in the upper Flowerpot: the unit extends from top of Flowerpot down to persistent marker in middle of Flowerpot - San Angelo interval. A star (*) means salt is not present within the unit. Bottom number is depth below ground level to top of salt-shale unit.

180

Contour line showing where salt-shale is 180 feet thick.

•••••••••••••••

Approximate limit of salt in unit due to salt being dissolved.

Assumed depositional limit of salt in unit.

A———B———C———D

Lines of cross sections (A-B, C-B, C-D)

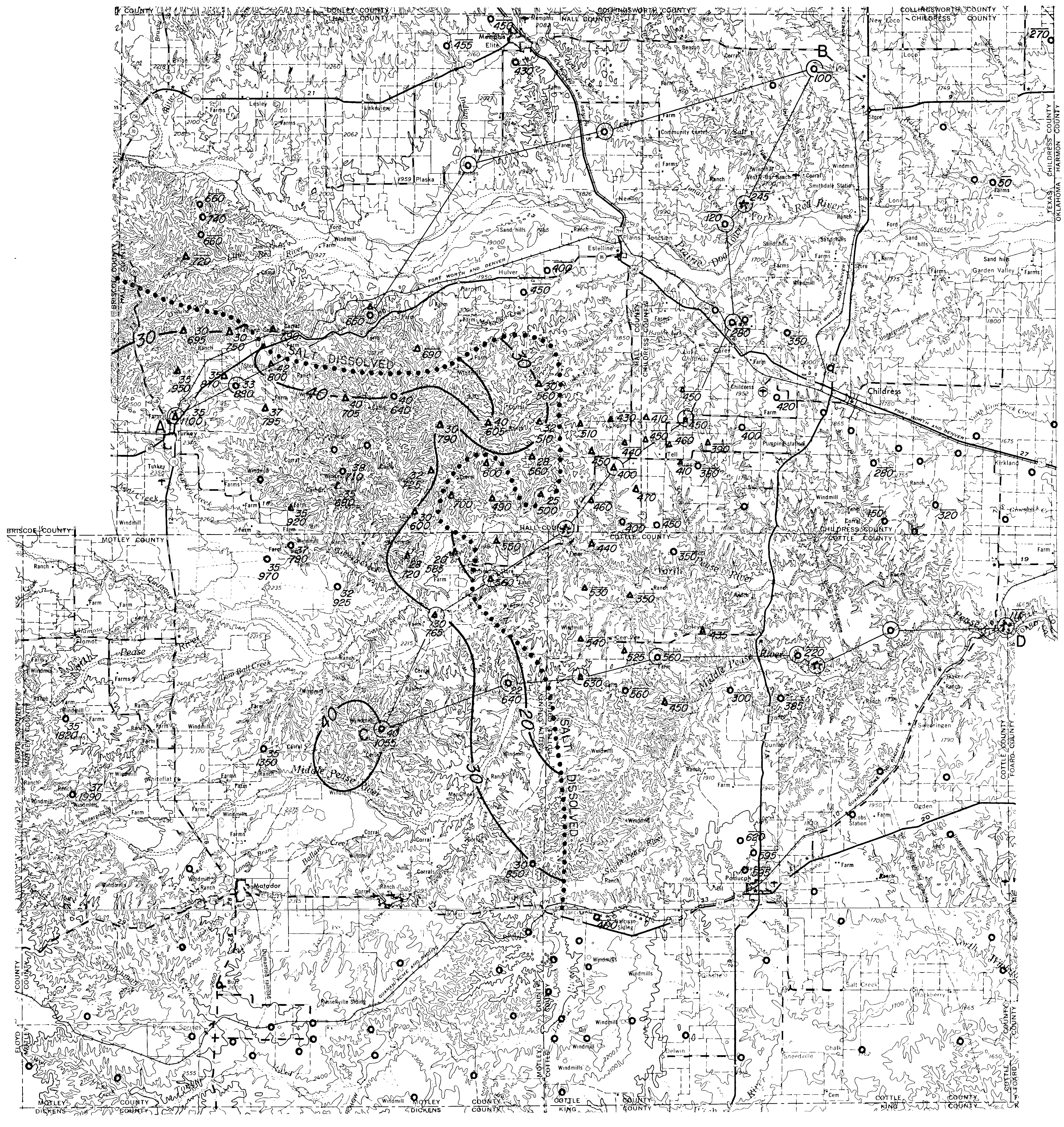


PLATE - 4

THICKNESS OF SALT-BEARING STRATA ABOVE COLLINGSWORTH GYPSUM BED IN BLAINE FORMATION

CHILDRESS, COTTLE, HALL and MOTLEY COUNTIES, TEXAS

Contour Interval, 10 feet (of thickness)

Kenneth S. Johnson

July, 1974

0 5 10 miles

Scale: 1:250,000

Bore Holes and Symbols

$\frac{30}{765}$ o *Oil and Gas test (electric log)*

$\frac{32}{725}$ Δ *Stratigraphic test (electric log)*

$\frac{—}{245}$ ☆ *Corps of Engrs. (core)*

Top number is thickness (in feet) of the salt-shale unit above Collingsworth Bed; a dash (—) means salt is not present. Bottom number is depth below ground level to top of salt-shale unit.

30

Contour line showing where salt-shale unit is 30 feet thick.

•••••••••••••• *Approximate limit of salt in unit.*

A———B———C———D

Lines of cross sections (A-B, C-B, C-D)

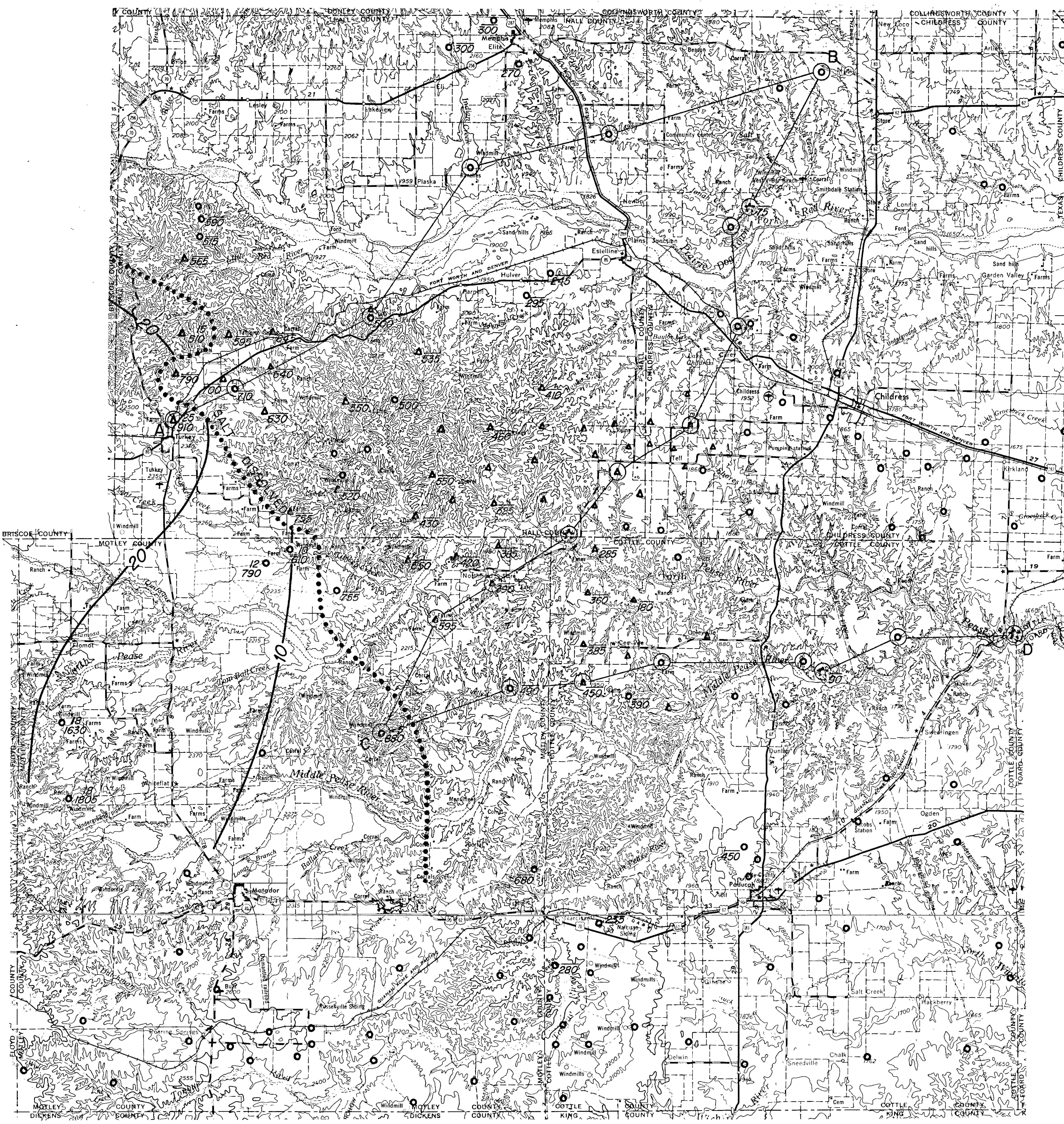


PLATE - 5

THICKNESS OF SALT-BEARING STRATA ABOVE HOLLIS GYPSUM BED IN DOG CREEK FORMATION

CHILDRESS, COTTLE, HALL, and MOTLEY COUNTIES, TEXAS

Contour Interval, 10 feet (of thickness)

Kenneth S. Johnson

July, 1974

0 5 10 miles

Scale: 1:250,000

Bore Holes and Symbols

$\frac{12}{790}$ o *Oil and Gas test (electric log)*

$\overline{325}$ Δ *Stratigraphic test (electric log)*

$\overline{90}$ ☆ *Corps of Engrs. (core)*

Top number is thickness (in feet) of the salt-shale unit above Hollis Gypsum; a dash (—) means salt is not present. Bottom number is depth below ground level to top of salt-shale unit.

—20—

Contour line showing where salt-shale unit is 20 feet thick.

•••••••••••••• *Approximate limit of salt unit.*

A———B———C———D

Lines of cross sections (A-B, C-B, C-D)

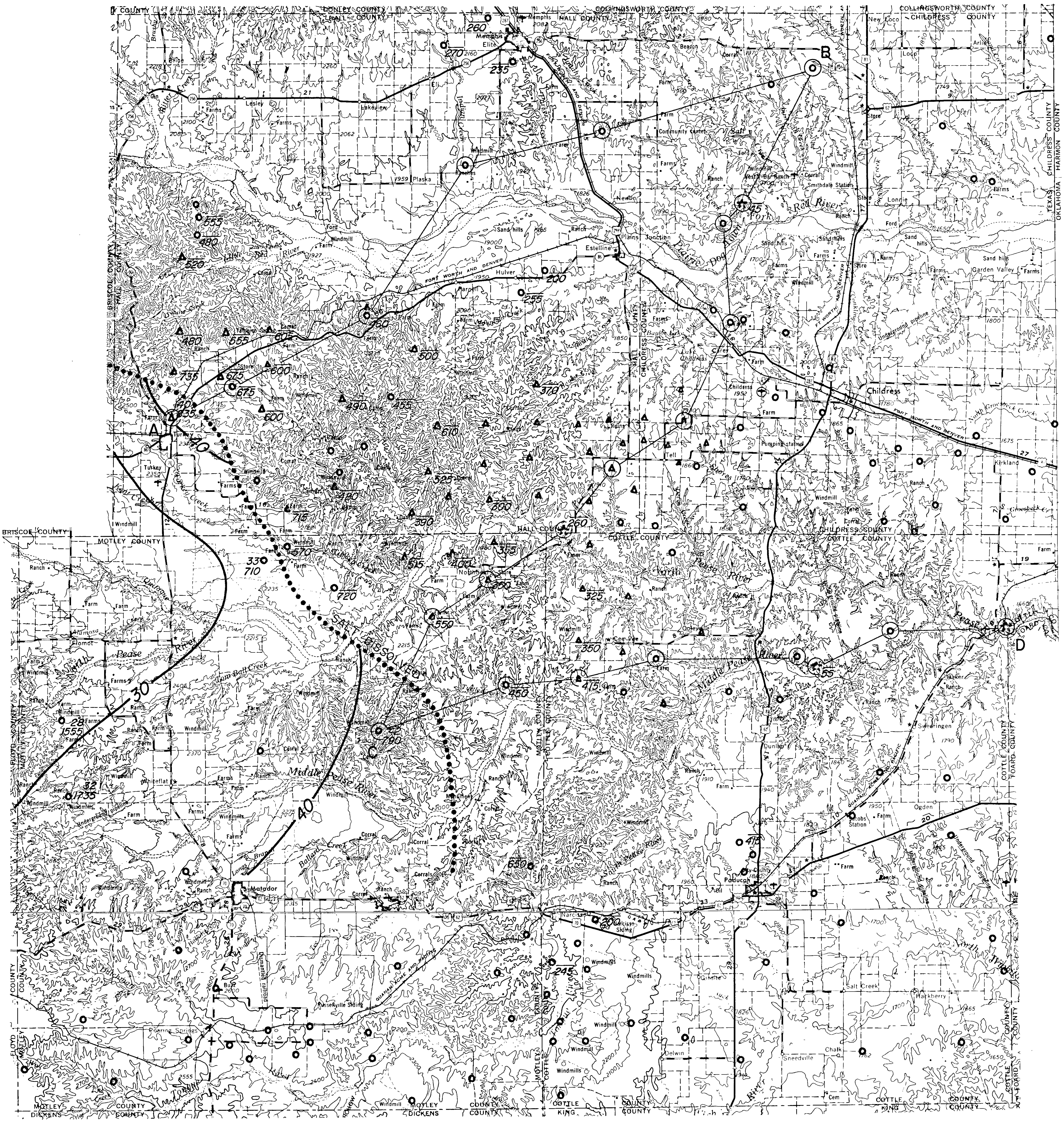


PLATE-6

THICKNESS OF SALT-BEARING STRATA ABOVE GUTHRIE GYPSUM BED IN DOG CREEK FORMATION

CHILDRESS, COTTLE, HALL and MOTLEY COUNTIES, TEXAS

Contour Interval, 10 feet (of thickness)

Kenneth S. Johnson

July, 1974

0 5 10 Miles

Scale: 1:250,000

Bore Holes and Symbols

42/790 o *Oil and Gas test (electric log)*

525 Δ *Stratigraphic test (electric log)*

260 ☆ *Corps of Engrs. (core)*

Top number is thickness (in feet) of the salt-shale unit above Guthrie Gypsum; a dash (—) means salt is not present. Bottom number is depth below ground level to top of salt-shale unit.

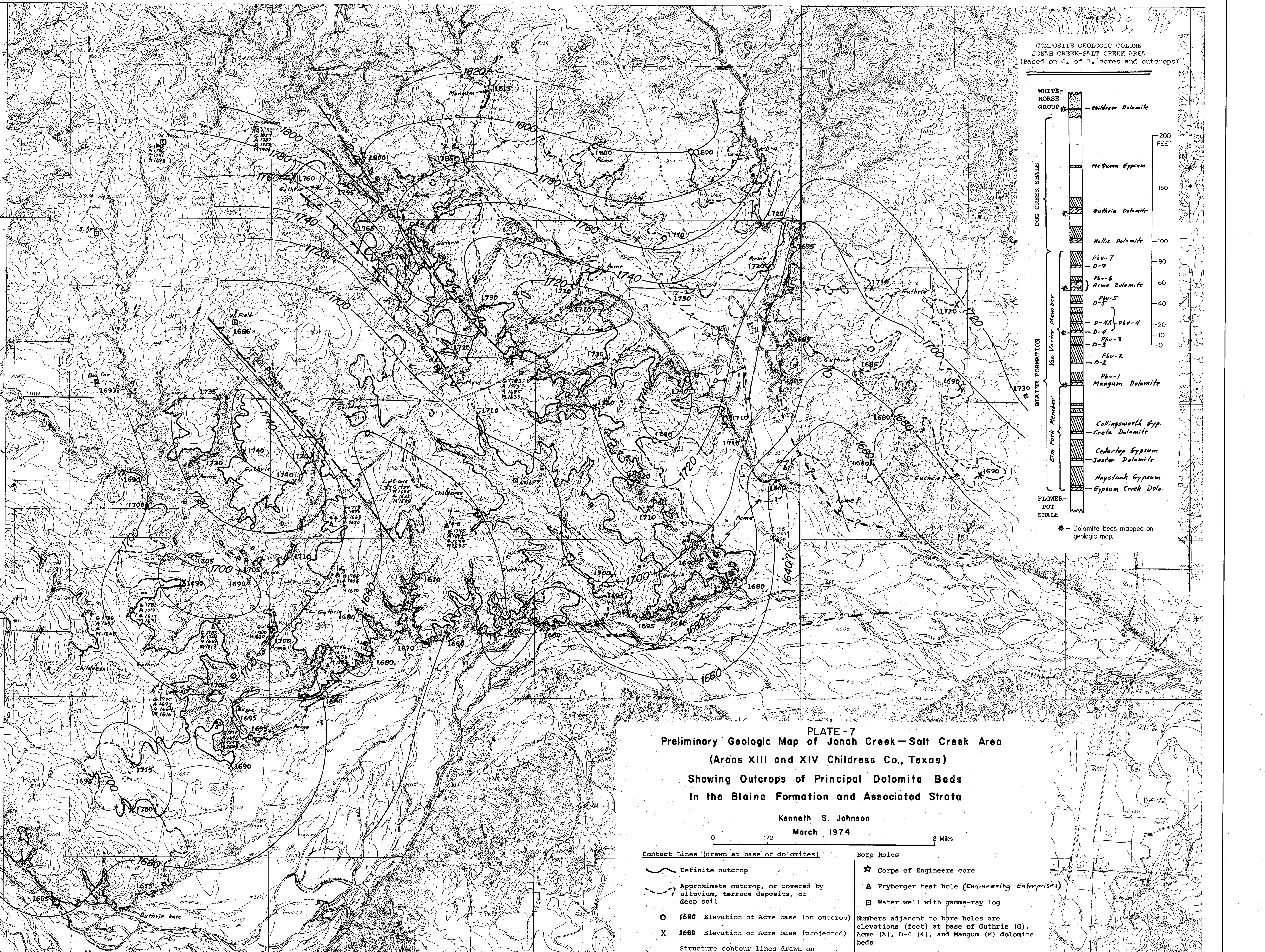
30

Contour line showing where salt-shale unit is 30 feet thick.

•••••••••••••• *Approximate limit of salt unit.*

A ———— B ———— C ———— D

Lines of cross sections (A-B, C-B, C-D)


COMPOSITE GEOLOGIC COLUMN
JONAH CREEK-SALT CREEK AREA
(Based on C. of E. cores and outcrops)
WHITE-HORSE GROUP
Childress Dolomite
DOG CREEK SHALE
McQueen Gypsum
Guthrie Dolomite
Hollis Dolomite
BLAINE FORMATION
Van Vacter Member
Pbv-7
D-7
Pbv-6
Acme Dolomite
Pbv-5
D-5
D-4A
Pbv-4
D-4
Pbv-3
D-3
Pbv-2
D-2
Pbv-1
Mangum Dolomite
Elm Fork Member
Collingsworth Gyp.
Creta Dolomite
Cedartop Gypsum
Jester Dolomite
Haystack Gypsum
Gypsum Creek Dolo.
FLOWER-POT SHALE
200 FEET
150
100
80
60
40
20
10
0
✱ – Dolomite beds mapped on geologic map.
Fault-Flexure C
Fault-Flexure B
Fault-Flexure A
PLATE - 7
Preliminary Geologic Map of Jonah Creek — Salt Creek Area
(Areas XIII and XIV Childress Co., Texas)
Showing Outcrops of Principal Dolomite Beds
In the Blaine Formation and Associated Strata
Kenneth S. Johnson
March 1974
0
1/2
1
2 Miles
Contact Lines (drawn at base of dolomites)
Definite outcrop
Approximate outcrop, or covered by alluvium, terrace deposits, or deep soil
1680 Elevation of Acme base (on outcrop)
X 1680 Elevation of Acme base (projected)
Structure contour lines drawn on base of Acme Dolomite Bed. (Contour interval, 20 feet)
Bore Holes
Corps of Engineers core
Fryberger test hole (Engineering Enterprises)
Water well with gamma-ray log
Numbers adjacent to bore holes are elevations (feet) at base of Guthrie (G), Acme (A), D-4 (4), and Mangum (M) dolomite beds