Oklahoma Geological Survey
Jeremy Boak, *Director*

Open-File Report 2-2019

Geology of salt plains on the Cimarron River in northwest Oklahoma: Big Salt Plain, Little Salt Plain, Salt Creek Canyon, and Okeene Salt Plain

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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 1975 to characterize the geology at and near major natural salt plains along the Cimarron River in parts of the Arkansas River Chloride Control Project (ARCCP) area in northwestern Oklahoma. The ARCCP is designed to control natural chloride-brine emissions at major source areas in northwestern 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 1975 report was titled: "Geology of salt plains on the Cimarron River, Arkansas River Chloride Control Project, northwest Oklahoma and southern Kansas."

The current report looks specifically at four sites in northwestern Oklahoma: Big Salt Plain (designated "Area II" by USACE), Little Salt Plain ("Area III"), Salt Creek Canyon ("Area IV"), and Okeene Salt Plain. Big and Little Salt Plains are the second- and third-largest salt plains in Oklahoma (Great Salt Plains is largest), and are located near the junction of Woods, Harper, and Woodward Counties. Salt Creek Canyon and Okeene Salt Plain are in Blaine County.

Although the original report is now dated, there is continued interest in reducing the flow of chloride brines in the Arkansas 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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INTRODUCTION

Purpose and scope of investigation

Permian-age salt deposits underlie a vast region 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 Arkansas River and Red 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 to improve water quality downstream from the salt plains. Efforts by the Corps are divided into studies of the Arkansas River Chloride Control Project and the Red River Chloride Control Project.

The purpose of my original report to the Corps of Engineers in 1975, and this current report, is to evaluate and summarize the surface and subsurface geologic features that bear upon natural emission of brine at several sites within the boundaries of the Arkansas River Chloride Control Project, with a focus on the Cimarron River in northwest Oklahoma. Along this stretch of Cimarron River are four principal sites of brine emission (Fig. 2): Big Salt Plain ("Area II," as designated by the Corps of Engineers), Little Salt Plain (Area III), Salt Creek Canyon (Area IV), and Okeene Salt Plain (a newly identified brine-emission site). These sites contribute about 4,600 tons of chloride per day to the Cimarron River (Fig. 3). I made investigations of the surface geology at each of these four emission sites and their surrounding area, and have related those data to the subsurface distribution of salt and to the ways in which brine emerges at the surface.

Field work and office studies for the original report to the Corps were carried out in 1975, and those data were updated in 2018–19 for release of this current report.

Permian strata are the bedrock for all salt springs and salt plains within the Arkansas River Chloride Control Project area. These Permian rocks consist mainly of reddish-brown shale, interbedded with layers of gypsum, siltstone, and sandstone; they also contain layers of rock salt (halite, NaCl) in the subsurface.

The current study has led to a better understanding of the geologic framework in the vicinity of the salt plains; it demonstrates that brine is being produced by dissolution of salt beds just back from the outcrop, and the brine then migrates a short distance to the surface.

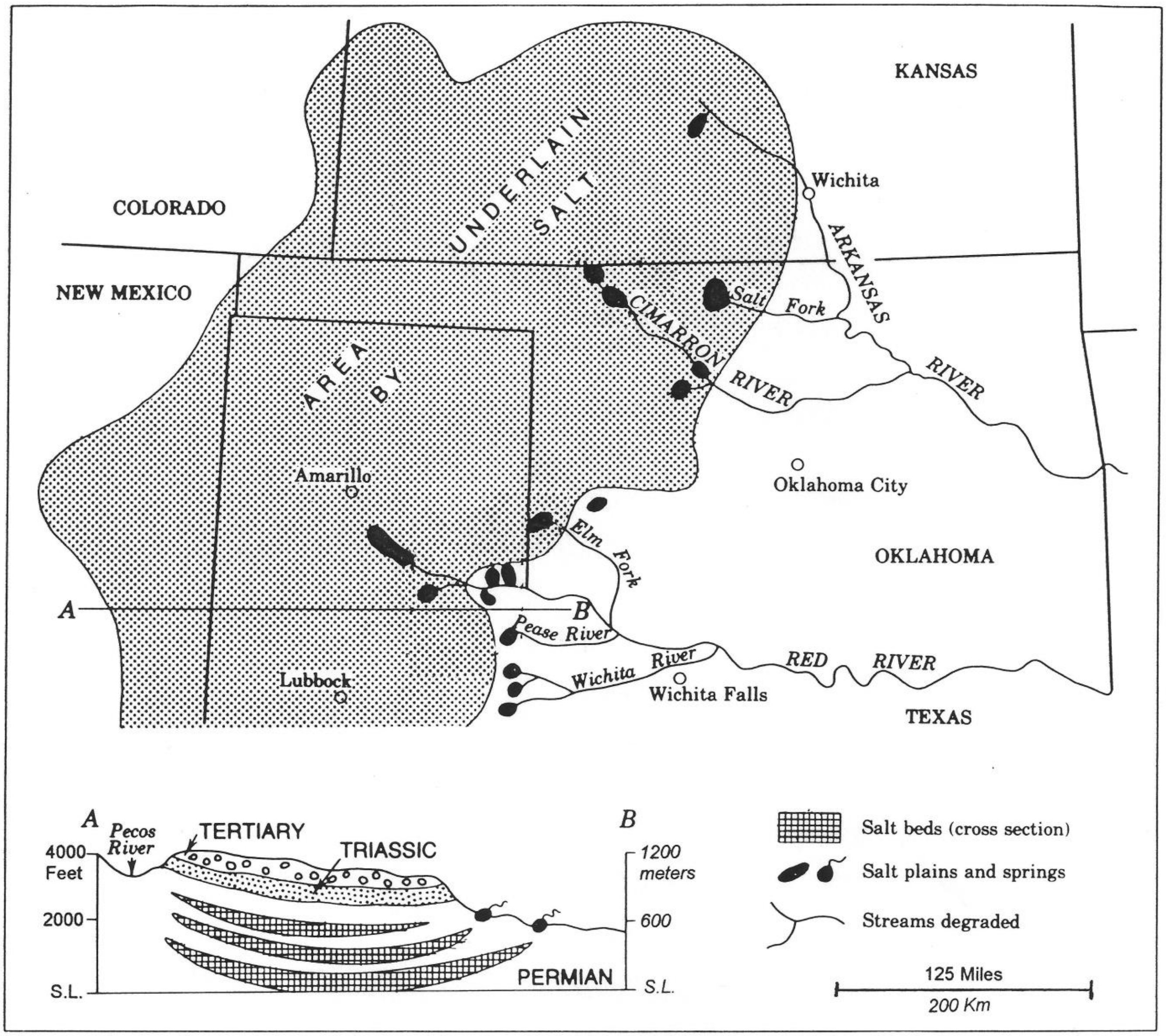


Figure 1. Map and schematic cross section showing distribution of Permian salts and salt plains in the Arkansas River and Red River watersheds of western Oklahoma and adjacent areas (Johnson, 1981).

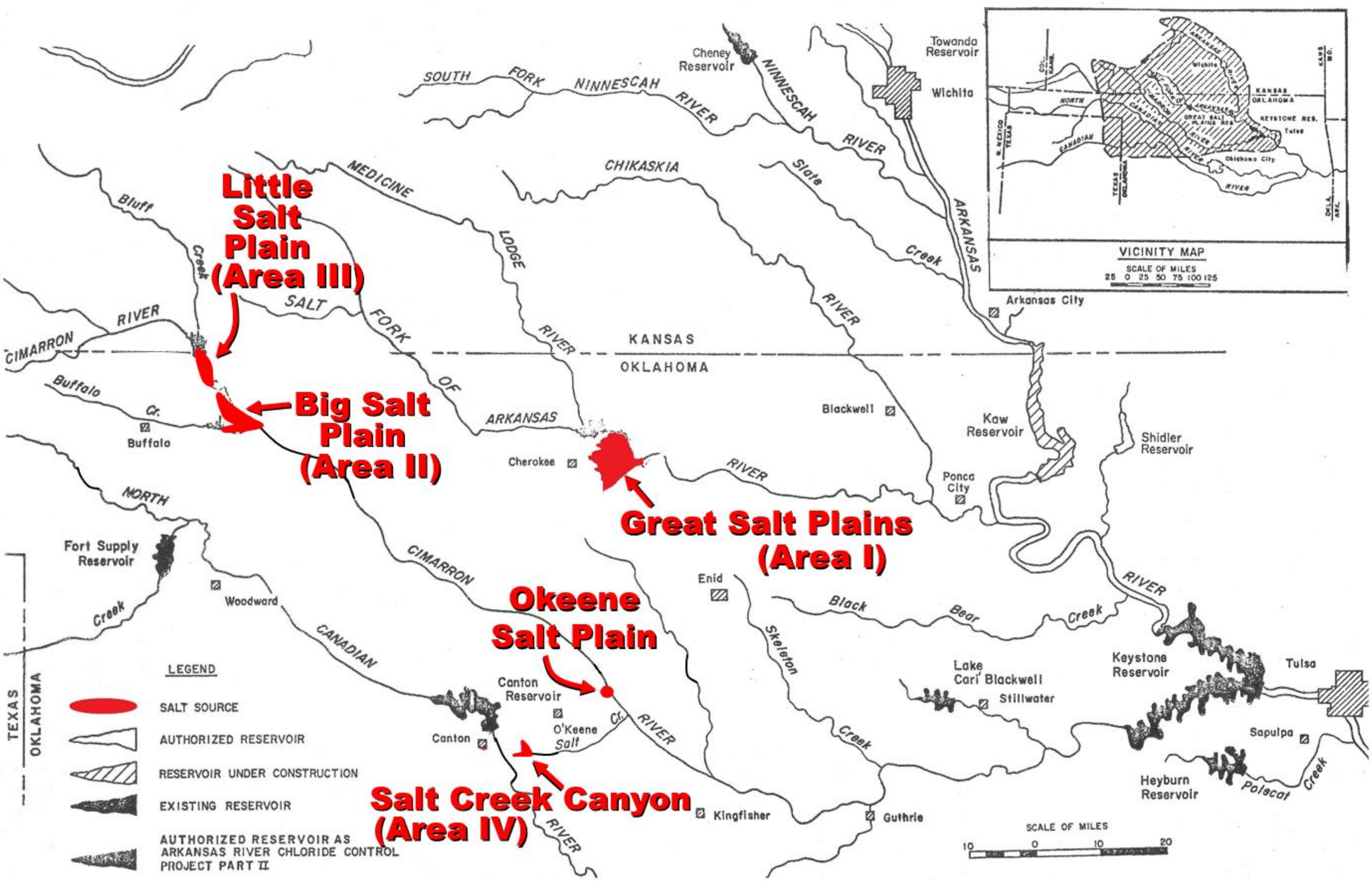


Figure 2. Location map showing brine-emission areas, reservoirs, and principal drainage of Arkansas and Cimarron Rivers in Oklahoma and Kansas.

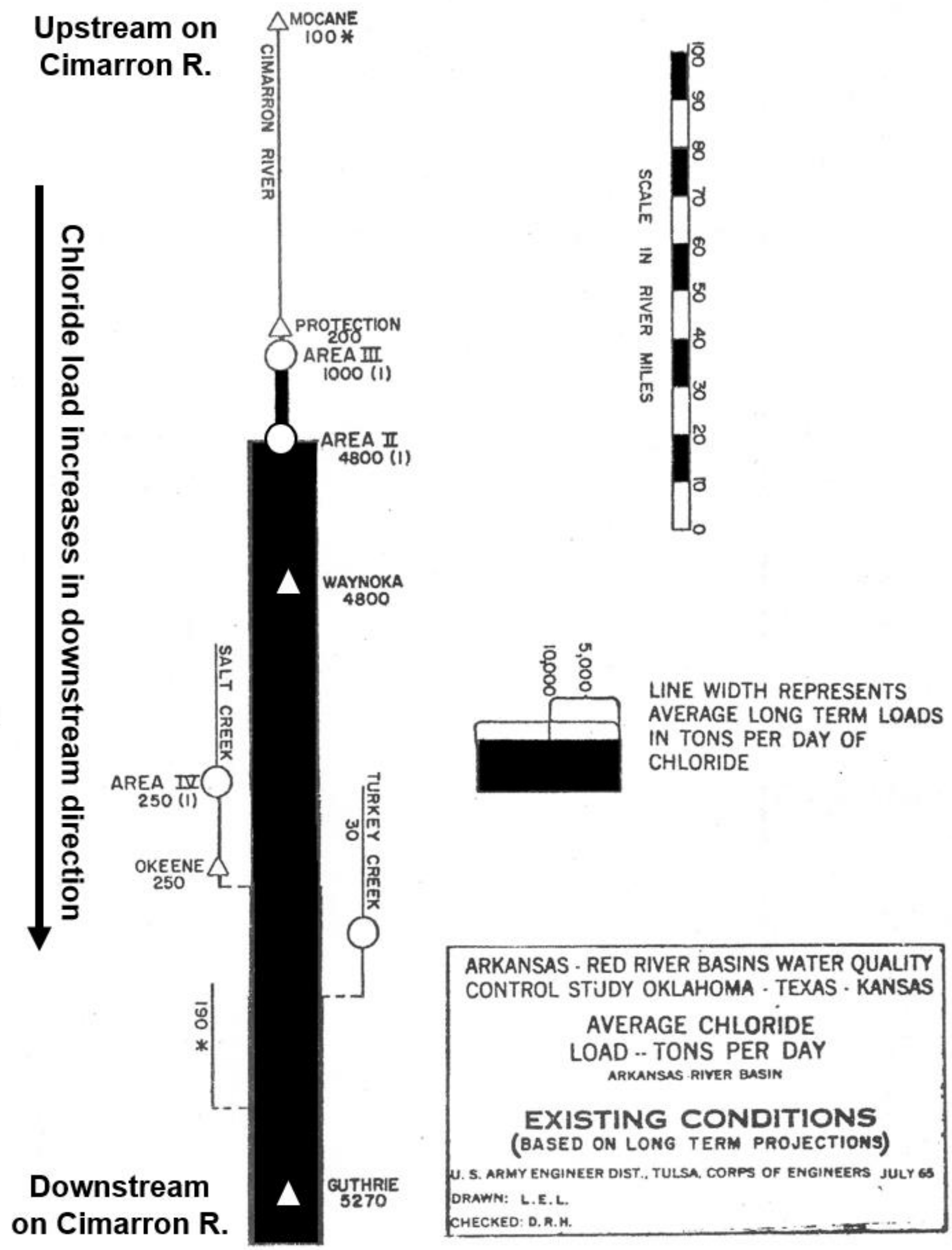


Figure 3. Chart showing average chloride load (in tons per day) of the Cimarron River in Oklahoma and Kansas. About 800 tons are added at Little Salt Plain (Area III), and about 3,800 tons are added at Big Salt Plain (Area II).

Methods of investigation

Procedures used in carrying out this investigation fall into two categories: 1) field work, in order to study and map the surface geology and coordinate my efforts with the geologic staff of the Corps of Engineers; and 2) office studies, which consisted mainly of studying subsurface data and relating them to outcrop investigations. In addition, a continuing search of the literature (books, articles, maps, and reports) relating to the study area was made, and these publications were brought to the attention of Corps personnel.

Field studies included mapping (at a scale of 1:24,000) the contacts between principal rock formations at, and in the vicinity of, each brine-emission area. Formations and units mapped include the Permian strata, as well as Quaternary alluvium, terrace deposits, and the salt plains (areas encrusted with salt). Field mapping was supplemented by examination of aerial photographs provided by the Corps of Engineers. Field studies also included examination and characterization of the lithology of each rock type in the emission areas.

Field work helped establish close liaison with Corps personnel, and enabled me to provide continuing consultation on problems arising during the field exploration. At least one trip was made each month in 1975 to field areas during the investigation. Field conferences with Corps geologists and engineers aided in developing basic geologic data. Additional field and office conferences were held with staff members of SYN-AN, Inc., and with John Dunlap, all of whom were doing contract work on hydrology in the vicinity of salt plains in northwest Oklahoma.

Office studies centered mainly on examination, interpretation, and correlation of electric logs, driller's logs, and core-hole logs throughout the Cimarron River drainage area, and relating these data to the results of field investigations. The logs of about 100 wells, most of them drilled for oil and gas, were examined in this study. Data from these logs, along with the description of cores drilled by the Corps of Engineers at each emission site and seismic profiles made by Geo Prospectors, Inc., at Big Salt Plain and Little Salt Plain, were valuable in determining the subsurface distribution of salt beds near the salt plains.

Acknowledgments

Assistance and cooperation were provided by members of the Corps of Engineers in making the field investigations for this report. Several field conferences were held with Tom Gay, and additional assistance was provided during orientation and review sessions in the field

with Tom Gay, Lawson Jackson, Wayne Wolfe, and Tom Purefort. Bob Brown and David Steele helped in obtaining aerial photographs, maps, seismic profiles, and other reports.

A number of field conferences, phone conversations, and office conferences were held with other A–E contractors: John Dunlap of Dallas, Texas; and Gale Billings, George Hoffman, and George Billings of SYN–AN, Inc., Socorro, New Mexico. We freely exchanged ideas and preliminary results of our respective investigations on salt-water contamination in the Arkansas River Chloride Control Project area, and these discussions helped considerably in our understanding of brine emissions.

GENERAL GEOLOGIC SETTING

Outcropping rocks throughout the Cimarron River region are strata of Permian age, and all the brine-emission sites are underlain by Permian bedrock. Therefore, the geology of Permian rocks in northwestern Oklahoma is key to understanding the salt deposits and brine emissions in the area. At many places, bedrock is overlain by a veneer of Quaternary alluvium and terrace deposits.

The study area is on the north shelf of the Anadarko Basin, a large east-west trending syncline extending across western Oklahoma and the Texas Panhandle. Outcropping Permian strata in the study area dip regionally to the southwest and south into the basin at about 10 to 20 feet per mile (about 0.1 to 0.2 degrees). Permian outcrops consist of shale, siltstone, sandstone, gypsum, and dolomite; they are interbedded with layers of salt (halite, NaCl) in the subsurface immediately below some of the salt plains, and they are also interbedded with salt in the subsurface to the south and southwest, where the salt layers are still preserved in deeper parts of the Anadarko Basin. Subsurface salts are being dissolved beneath and near the salt plains to form brine emitted at the salt plains, where the water (H_2O) is dissolved to leave a salt crust.

Permian stratigraphy

Principal outcropping rock units studied for this report are the Hennessey Shale (with Cedar Hills Siltstone Member at the top), Flowerpot Shale, and Blaine Formation—all of which are Permian in age (Figs. 4, 5). Also of special importance are the Upper Cimarron salt and the Flowerpot salt, which are subsurface equivalents of parts of the Hennessey Shale and the Flowerpot Shale, respectively (Figs. 6, 7). The following descriptions of rock formations are based upon surface and subsurface studies by several authors (Myers and others, 1959, 1969; Fay and others, 1962; Jordan and Vosburg, 1963; Fay, 1964, 1965; Johnson, 1972).

The Hennessey Shale consists of reddish-brown shale interbedded with reddish-brown, orange-brown, and light-gray siltstone and sandstone. Total thickness of the formation in outcrops is about 700 feet. The top 200 feet of the formation contains a number of siltstone layers, and it is referred to as the Cedar Hills Member of the Hennessey Shale. The Cedar Hills Member is the principal outcropping unit in the vicinity of the Okeene Salt Plain.

Overlying the Hennessey Shale is the Flowerpot Shale, consisting mainly of reddish-brown shale with thin layers of greenish-gray shale, gypsum, and dolomite. The formation is 200 to 300 feet thick in the northwest part of the study area (Big Salt Plain and Little Salt Plain),

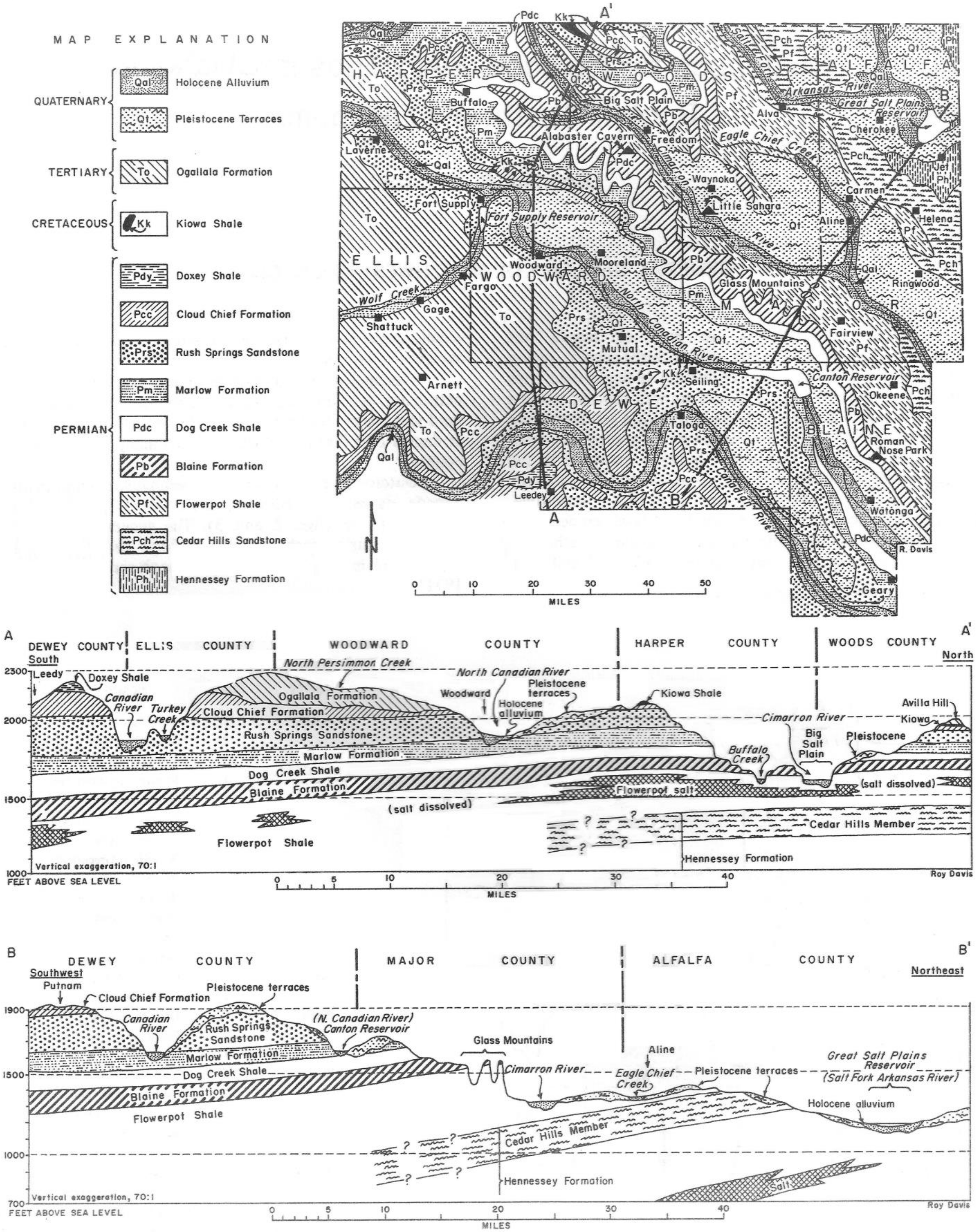


Figure 4. Generalized geologic map and cross sections of northwest Oklahoma (Johnson, 1972).

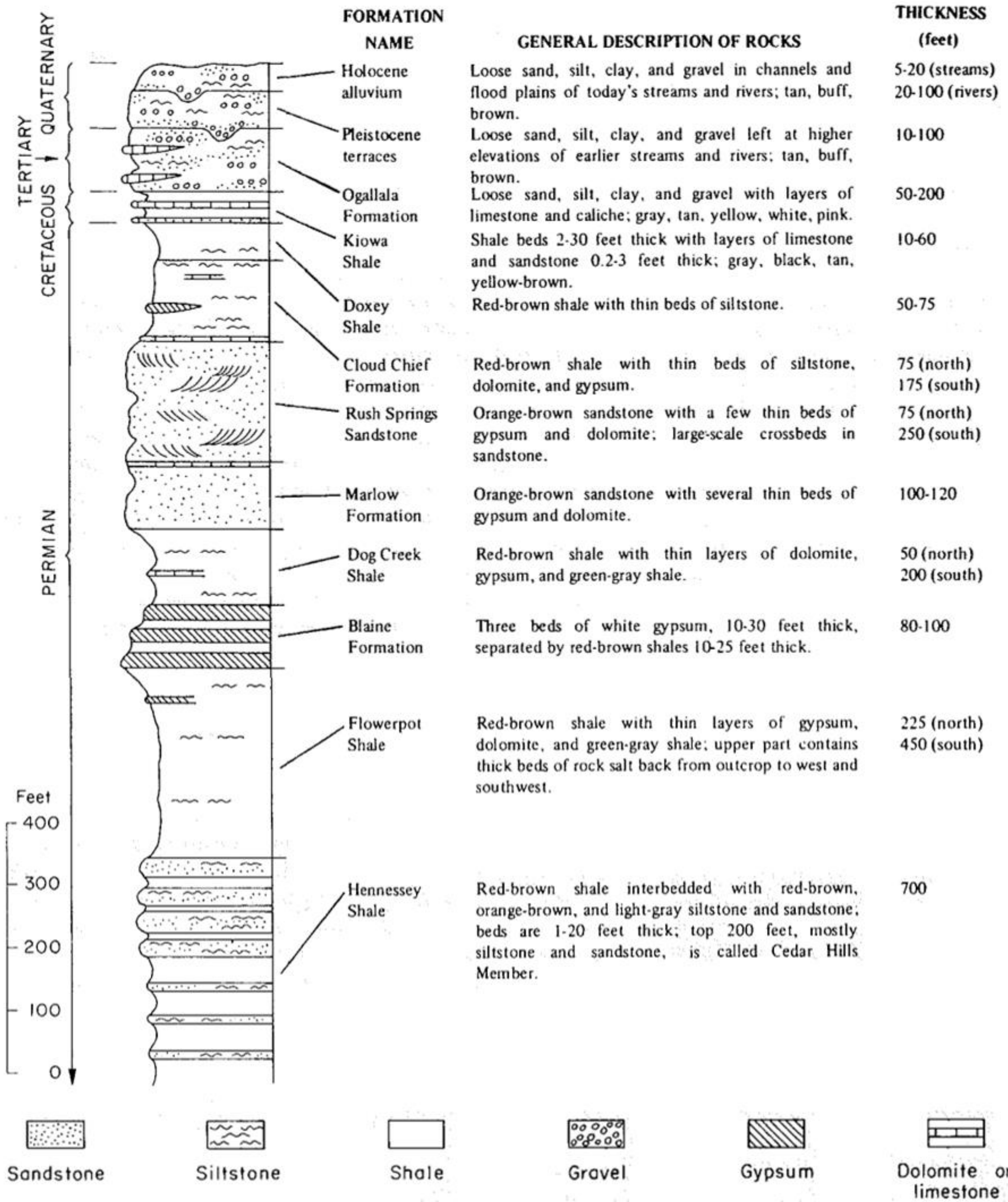


Figure 5. Generalized diagram and description of outcropping rocks in northwest Oklahoma (Johnson, 1972).

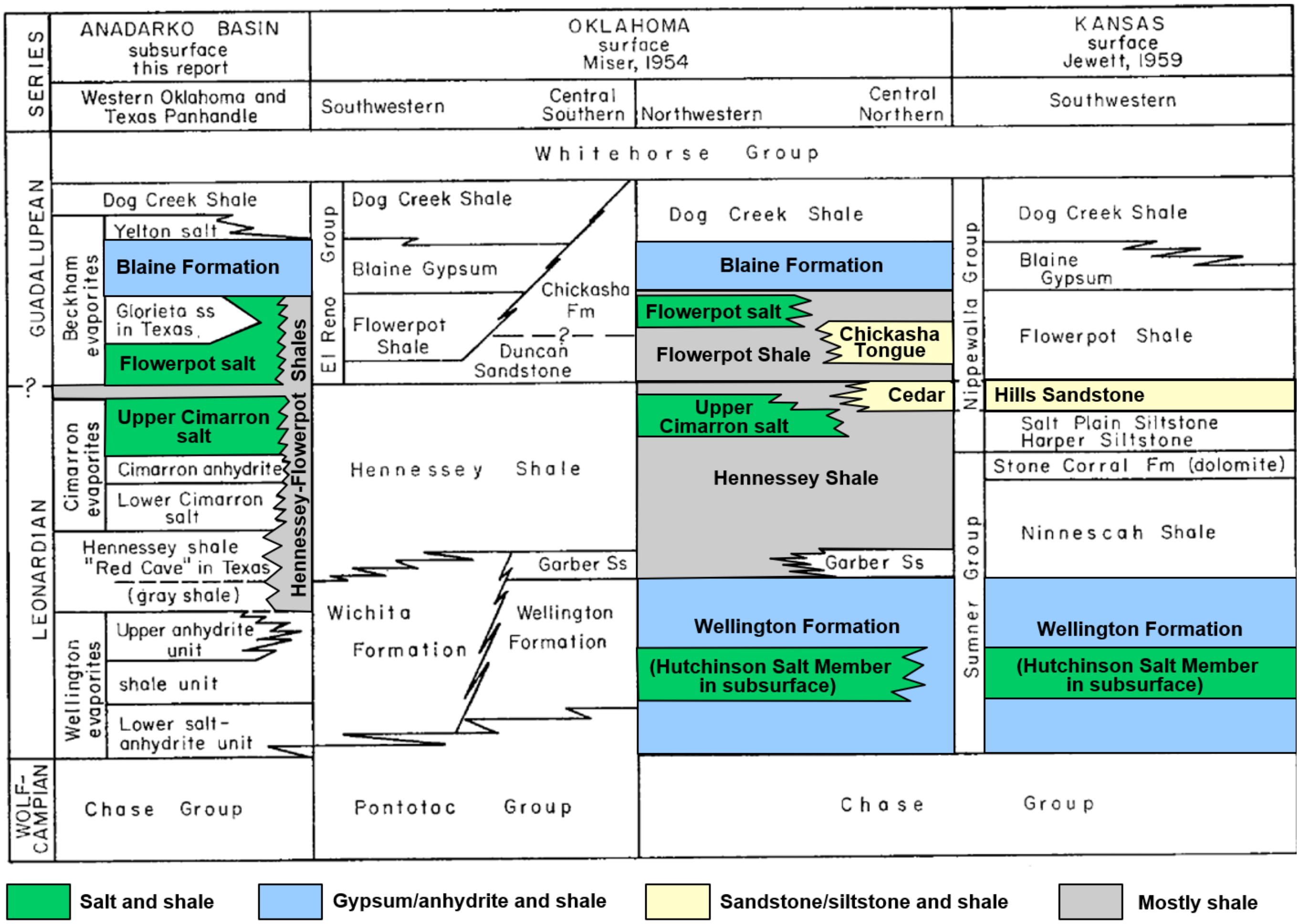


Figure 6. Stratigraphic nomenclature of Permian strata in outcrops and subsurface in northwest Oklahoma and nearby areas (Jordan and Vosburg, 1963). Rock units discussed in report shown in color.

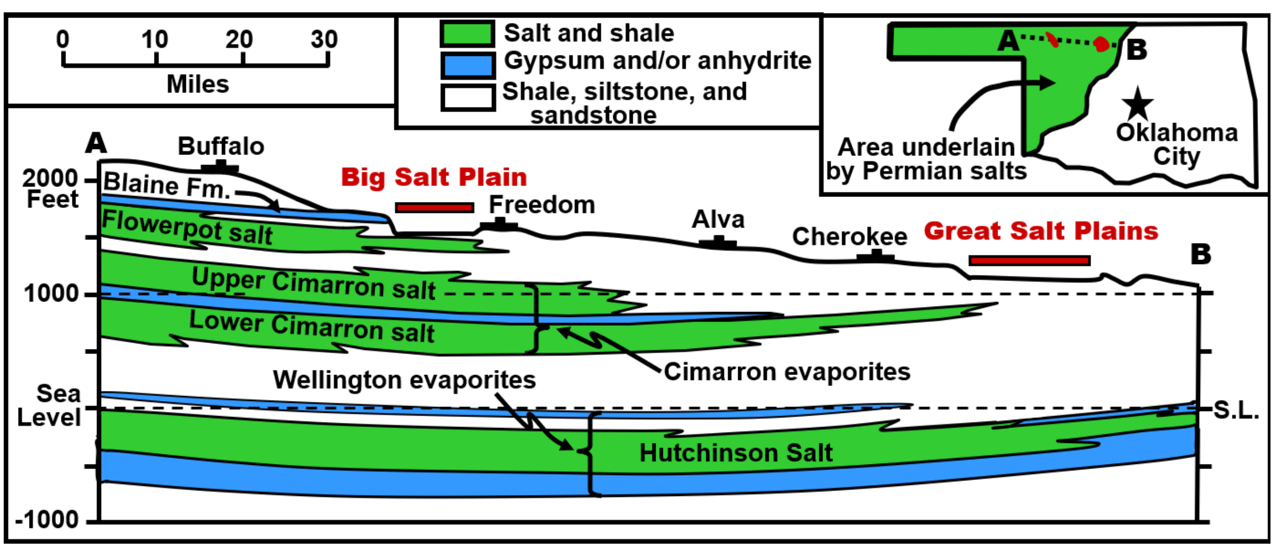


Figure 7. Generalized structural cross section of Permian strata in northwestern Oklahoma showing subsurface salt units and principal salt plains (modified from Jordan and Vosburg, 1963).

and is about 450 feet thick to southeast, at Salt Creek Canyon. A sequence of cross-bedded siltstones, sandstones, and shales in the middle of the formation are referred to as the Chickasha Tongue. The Chickasha Tongue is a northwest-thinning wedge of alluvial and deltaic sediments about 120 feet thick in the Salt Creek Canyon area; they grade into shale farther west and northwest of this site. The Chickasha Tongue is important inasmuch as it emits brine in the Salt Creek Canyon area, and the entire Flowerpot is important to the northwest where it contains salt and is the bedrock beneath Big Salt Plain and Little Salt Plain.

Above the Flowerpot Shale are the thick beds of white gypsum and shale comprising the Blaine Formation. The three principal gypsum beds of the Blaine Formation are typically 10 to 30 feet thick; they are separated by reddish-brown shales 10 to 25 feet thick, and each gypsum is underlain by a dolomite bed that is 0.1 to 2.0 feet thick. Total thickness of the Blaine Formation ranges from 80 to 100 feet. Resistant gypsum beds of the Blaine (especially the Medicine Lodge Gypsum Bed at the base) form the caprock above high escarpments of Flowerpot Shale in most parts of the study area.

The relationships of these outcropping rocks to other formations in the region are shown in Figures 4 and 7.

Permian paleogeography

During the Permian Period, northwest Oklahoma was located near the northeast end of a broad, shallow sea (the greater Permian Basin) that covered much of southwestern United States (Fig. 8). Because of slow but continual sinking of the earth's crust beneath this inland sea, a thick sequence of evaporites (dolomite, gypsum, and salt) and redbeds was deposited north of the major reefs and other marine-carbonate deposits 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, siltstones, and sandstones deposited in the study area were derived by erosion of land areas in eastern Oklahoma, eastern Kansas, and other areas farther to the east and northeast. Streams and rivers draining these land areas during Permian time carried mud and other fine clastic sediments into the shallow seas where they were deposited as layers alternating with salt, gypsum, and dolomite. Therefore, fresh and brackish water from the east mixed with marine and saline waters from the southwest: shales, siltstones, and sandstones were deposited from the former, whereas evaporites were deposited from the latter.

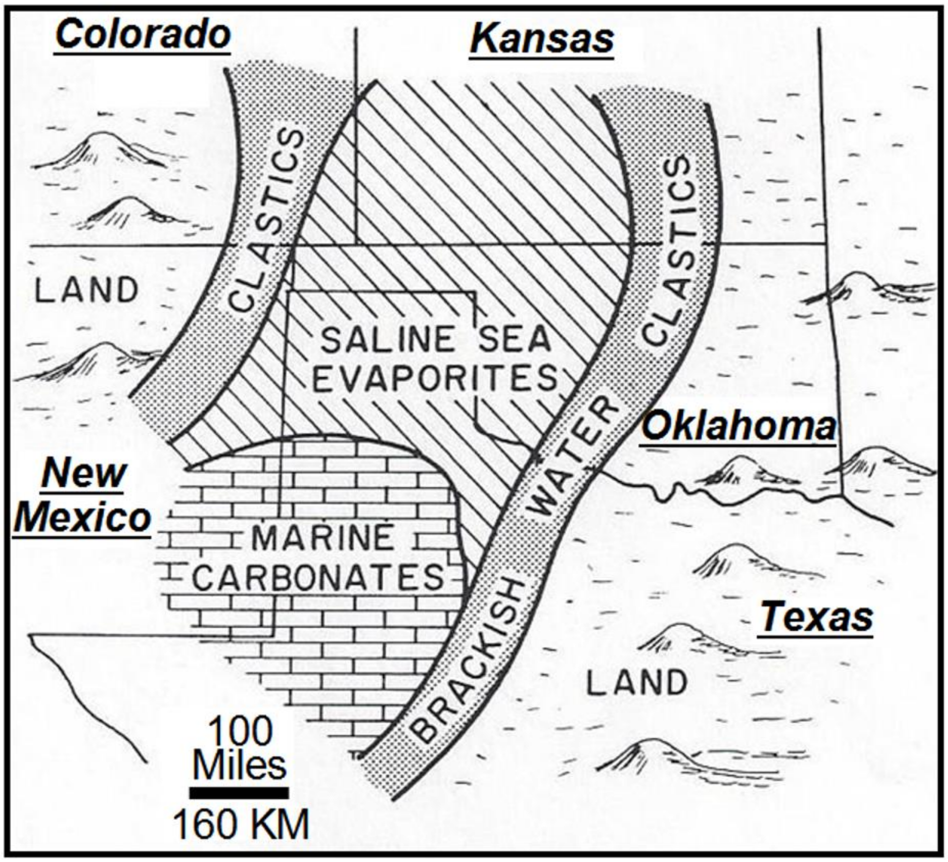


Figure 8. Paleogeography and principal facies of rocks deposited in the greater Permian Basin of southwestern United States during deposition of evaporites in the Flowerpot, Blaine, and Dog Creek Formations.

Deposition of salt and other evaporites

Evaporite deposition in the Hennessey–Flowerpot–Blaine sequence resulted from evaporation of sea water. Concentration of dissolved solids in the sea water was raised to the point where a series of “evaporite” minerals/rocks was precipitated on the sea floor, or in muds just below the sea floor. A typical complete cycle of evaporite precipitation began with deposition of a thin layer of dolomite (0.1 to 2.0 feet thick in the study area), followed by a massive layer of gypsum or anhydrite (5 to 30 feet thick), and finally a unit of salt (halite, NaCl) at the top (Fig. 9); the evaporite cycle typically ended when an influx of fresher water from the east and/or northeast caused deposition of shale/siltstone/sandstone.

For a number of reasons, the complete evaporite sequence is not found everywhere within the region: 1) evaporite precipitation may have been interrupted locally by an influx of less-concentrated water; 2) certain chemicals may have been depleted from the saline waters elsewhere (to the southwest), before precipitation of a particular salt could start in the study area; or 3) the more soluble units (salt, and sometimes gypsum) may have been deposited in some places, but were dissolved later. The best outcrop examples of the typical (partial) evaporite cycle in the study area is in the Blaine Formation: three thin dolomites are each overlain, successively, by a thick gypsum/anhydrite bed, and then by a fairly thick reddish-brown shale. Some of the Blaine gypsum/anhydrite beds are overlain by salt far to the south and southwest, in the deep Anadarko Basin (Johnson, 1967, 2017).

Salt beds in the Flowerpot and Upper Cimarron salt units do not have any significant amounts of gypsum, anhydrite, or dolomite associated with them in northwest Oklahoma. Therefore, these salts do not represent a typical vertical sequence of evaporite deposition. Far to the southwest, however, in north-central Texas and parts of the Texas Panhandle, gypsum and anhydrite make up a substantial thickness of strata deposited during this time (McGookey and others, 1988). It appears as if a horizontal cycle of evaporite deposition took place during Hennessey and Flowerpot time: saline water was depleted of its dolomite and gypsum/anhydrite chemical constituents in Texas, and it only had a significant concentration of NaCl in the water by the time it reached northwest Oklahoma.

Some of the salt in northwest Oklahoma probably occurs as discrete beds and layers of rock salt interbedded with layers of reddish-brown shale and salty shale; however, much of the salt also occurs as isolated and/or intergrown crystals of halite, partially surrounded by red shale. These large crystals of halite probably developed and grew in the soft sediments just below the sea bottom shortly after deposition of the halite-encompassing mud or shale. Little is known

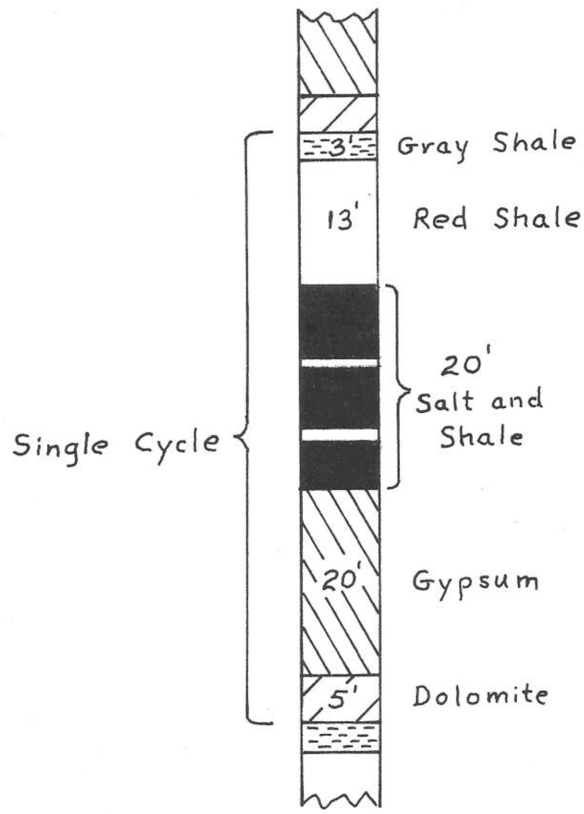


Figure 9. Idealized complete cycle of evaporite deposition in the Flowerpot, Blaine, and Dog Creek Formations of Oklahoma.

about the detailed character of these salts, because only the upper part of the Flowerpot salt has been cored in the vicinity of Big Salt Plain and Little Salt Plain, and the Upper Cimarron salt has not been cored in any part of the study area.

Subsurface distribution of salt

Salt is a highly soluble rock, more soluble than any other rock in the Permian sequence in this part of the State. Salt will be dissolved whether the water in contact with it is fresh or salty, so long as the water 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, 1961c; Johnson, 1976, 1981, 2017, 2019a, 2019b; Gustavson and others, 1980; 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. 10).

Data on the subsurface distribution of salt in western Oklahoma and the Texas Panhandle were presented by Jordan and Vosburg (1963), Johnson (1976, 1981, 2017), Johnson and Gonzales (1978), Gustavson and others (1980), and McGookey and others (1988). Of special interest are maps showing distribution of the Flowerpot salt and the Upper Cimarron salt: a modified, and much-simplified version of the Jordan and Vosburg (1963) maps is presented here (Fig. 11) to show the subsurface distribution of salt in comparison to known salt-emission sites.

Big Salt Plain and Little Salt Plain are located where the Flowerpot salt is at a relatively shallow depth (Figs. 4, 11). The Flowerpot salt is typically 50 to 125 feet beneath the land surface at both salt plains, and locally is just 30 feet below the surface. This salt is now being naturally dissolved by ground water circulating through salt beds at shallow depths, and the resultant brine is being emitted at these two salt plains.

Both Salt Creek Canyon and the Okeene Salt Plain are at least 30 miles east of any known Flowerpot salt, but they are located near the eastern limit of older salts in the Upper Cimarron salt (Fig. 11). Salty shale and salt beds of the Upper Cimarron salt are only about 300 feet below the bottom of Salt Creek Canyon, and are the lateral (down-dip) equivalent of rocks cropping out at the Okeene Salt Plain. I believe that ground water is dissolving parts of the Upper Cimarron salt in this area, and the resultant brine is migrating upward through fractures and joints to the surface in Salt Creek Canyon, and is migrating laterally (up-dip) in the Cedar Hills Member of the Hennessey Shale to be emitted at the Okeene Salt Plain.

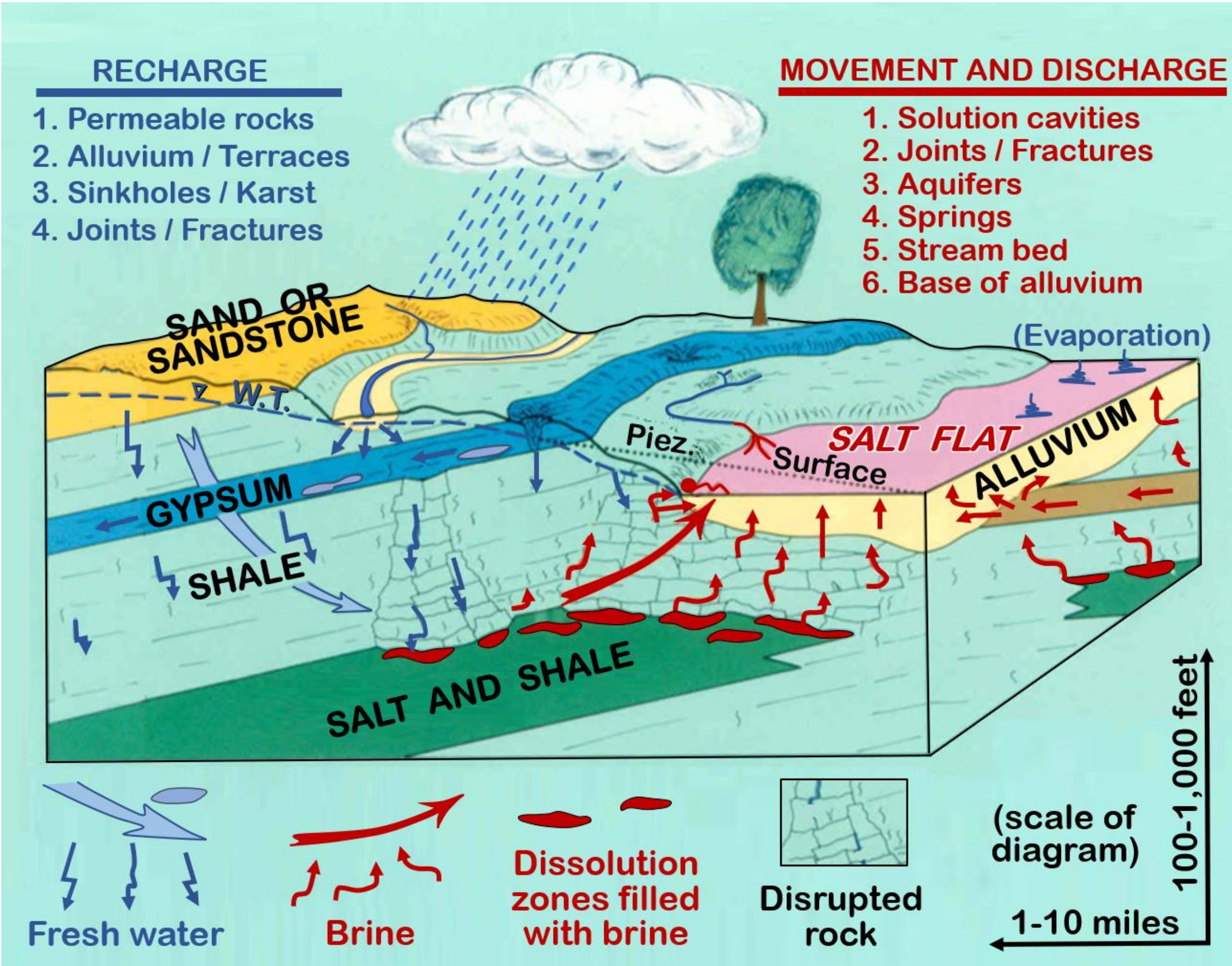


Figure 10. Schematic diagram showing circulation of fresh water and brine in areas of salt dissolution in western Oklahoma and north Texas (modified from Johnson, 1981).

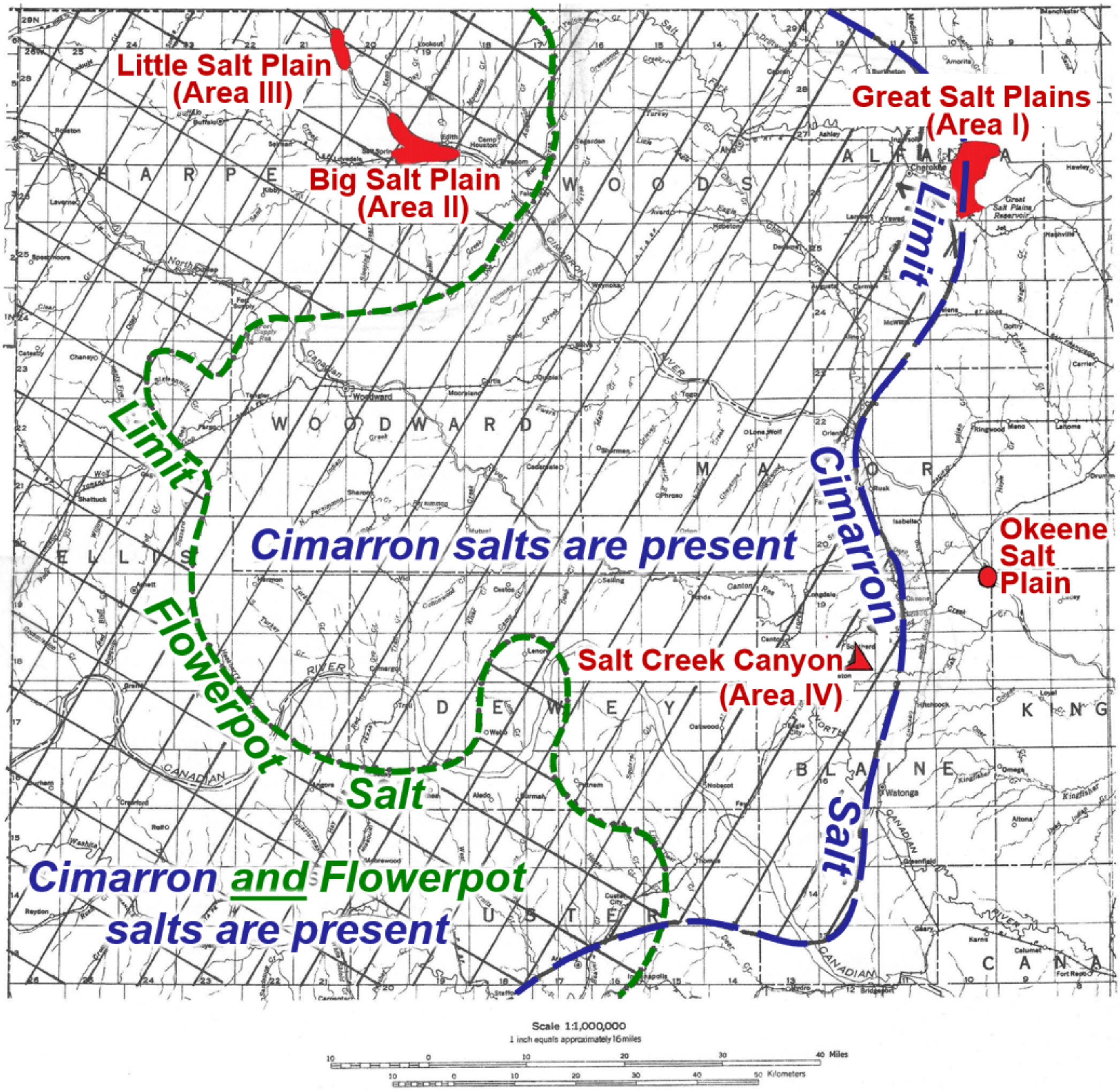


Figure 11. Distribution of Flowerpot salt and Upper Cimarron salt units in subsurface of northwestern Oklahoma. Modified from Jordan and Vosburg (1963, plate III).

A third principal salt unit, the Lower Wellington salt and anhydrite unit of the Wellington evaporites, is present beneath all of northwest Oklahoma (Fig. 7). However, it is at least 1,600 feet below the surface at all four salt plains, and clearly does not contribute brine at any of these emission sites. This salt unit in the Wellington is equivalent to the Hutchinson Salt Member of the Wellington Formation in central and south-central Kansas.

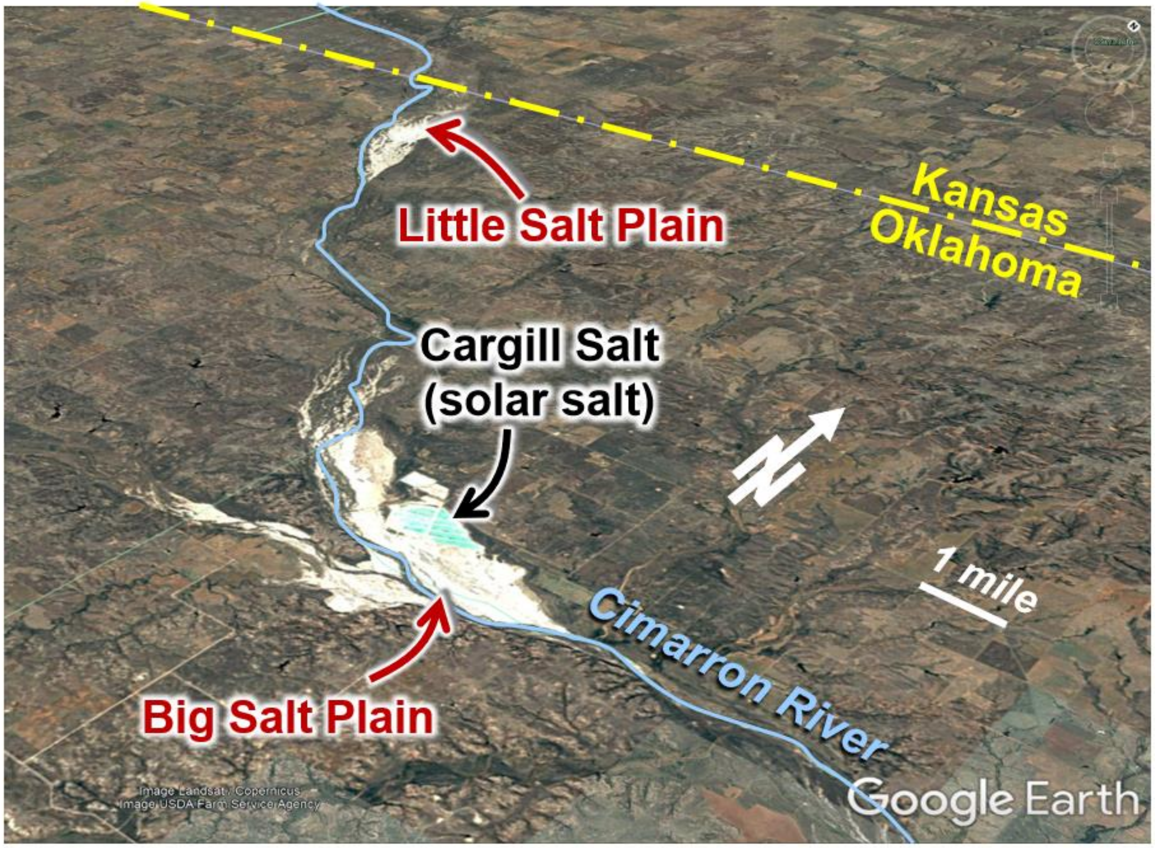
BIG SALT PLAIN (AREA II) AND LITTLE SALT PLAIN (AREA III)

Big Salt Plain and Little Salt Plain (Areas II and III, respectively) are the largest salt plains on the Cimarron River (Figs. 12, 13), and are the second and third largest salt plain, respectively, in Oklahoma (Great Salt Plains being the largest). Although they are two separate emission areas, they are discussed together here because of their proximity and similar geology. The average chloride (Cl) load entering the Cimarron River each day is about 3,800 tons at Big Salt Plain and about 800 tons at Little Salt Plain (Fig. 3): this amounts to about 7,200 tons of NaCl from the two salt plains together. High-salinity brine saturates the alluvium at both sites, with brine forming when ground water dissolves Flowerpot salt at shallow depths beneath and adjacent to the river: brine then seeps, because of hydrostatic pressure, up from the bedrock into the base of the alluvium. The top of the Flowerpot salt ranges from 30 to 200 feet below the surface of the salt plains. Dissolution of salt is more advanced beneath the river, and as a result the outcropping rocks are partly collapsed and drape (or dip) down toward the river.

The Corps of Engineers Survey Report plans for controlling fresh water and salt water in this area are shown in Figure 14, and a location map showing the outline of the area studied around both salt plains is shown in Figure 15.

Surface geology

Principal outcropping rock units around the two salt plains are the Flowerpot Shale and the overlying Blaine Formation (Plates 1 and 2). The Flowerpot consists chiefly of reddish-brown shale, but it also contains many thin beds of gray shale, brown siltstone, and gypsum or gypsum nodules. The formation is about 300 feet thick (Fay, 1965, reports 275 to 350 feet in outcrops of eastern Woods County), but the contact with the underlying Cedar Hills Member of the Hennessey Formation is not exposed in the study area, nor has it been cored in the vicinity of either salt plain. The top part of the formation is well-exposed in bluffs along Cimarron River adjacent to both salt plains, and as much as 100 feet of the formation can be examined just below the confluence of Cimarron River and Buffalo Creek (Plate 1). Farther northwest along Cimarron River (Plate 2), the top 60 feet of the Flowerpot is exposed north of U.S. Highway 64 bridge, and only the top 20 feet is exposed near the Oklahoma–Kansas border. Where red shales of this formation are interbedded with salt (back from the outcrop, and beneath the salt plains), the salt-bearing unit is called the Flowerpot salt (Fig. 4, cross section A–A’).



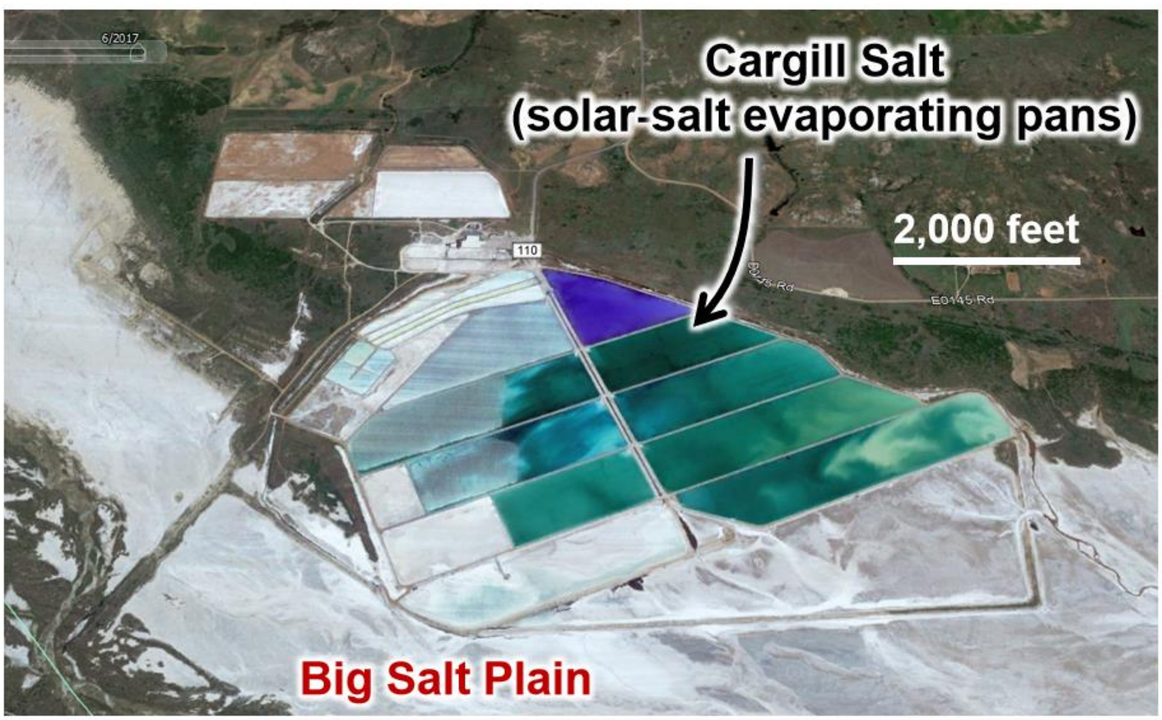


Figure 12. **Upper photo:** Google Earth photo of Big Salt Plain, Little Salt Plain, and Cargill Salt Co. solar plant on Cimarron River in northwest Oklahoma. **Lower photo:** Google Earth photo showing that Cargill Salt Co. has about 500 acres of evaporating pans on Big Salt Plain.

Figure 13. **Upper photo:** approaching Cargill Salt Co. evaporating pans from the north. **Lower photo:** view of brine pouring (on right) into one of the evaporation pans, and in the background are large piles of high-purity solar salt that has been harvested and is ready for market.

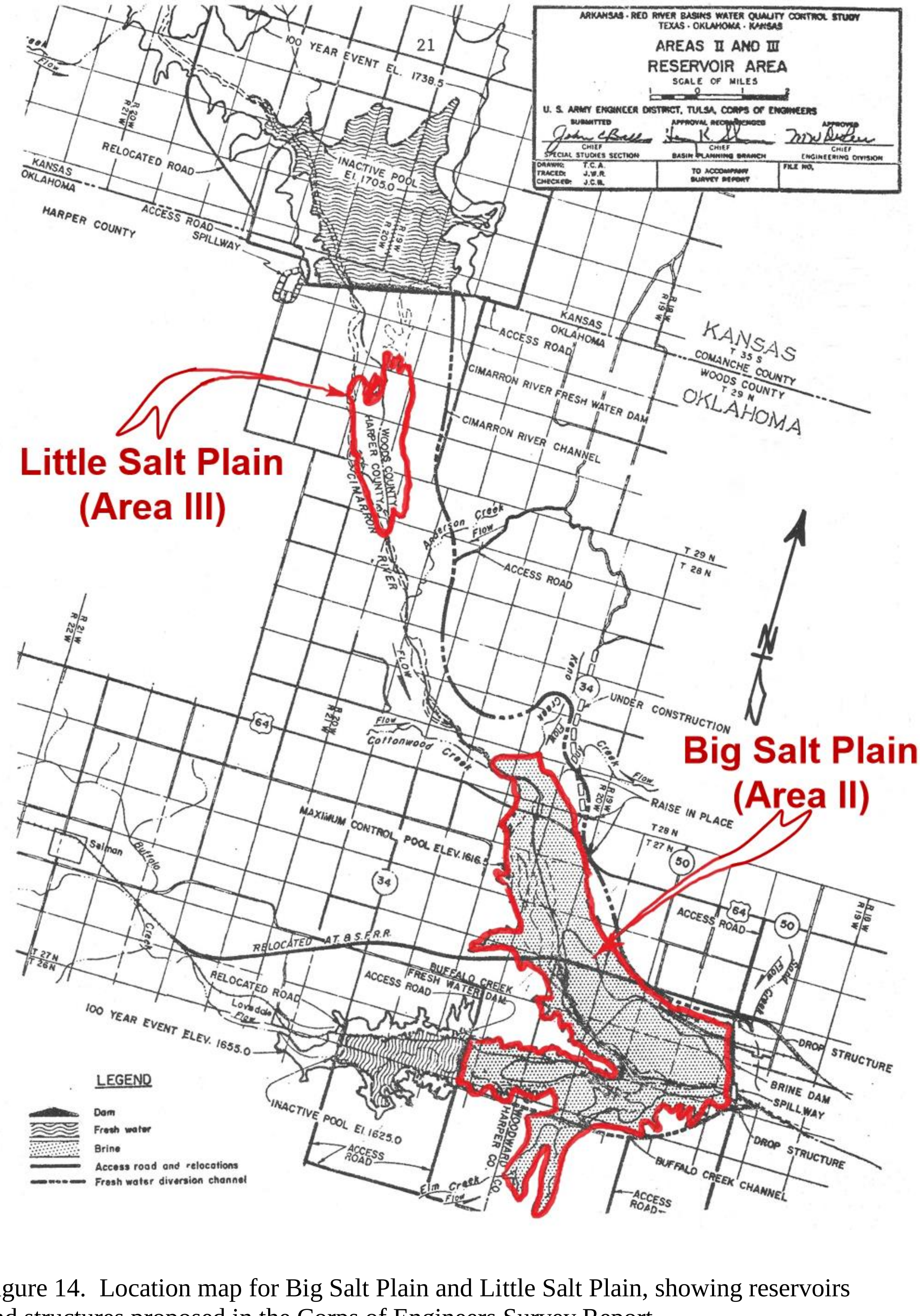


Figure 14. Location map for Big Salt Plain and Little Salt Plain, showing reservoirs and structures proposed in the Corps of Engineers Survey Report.

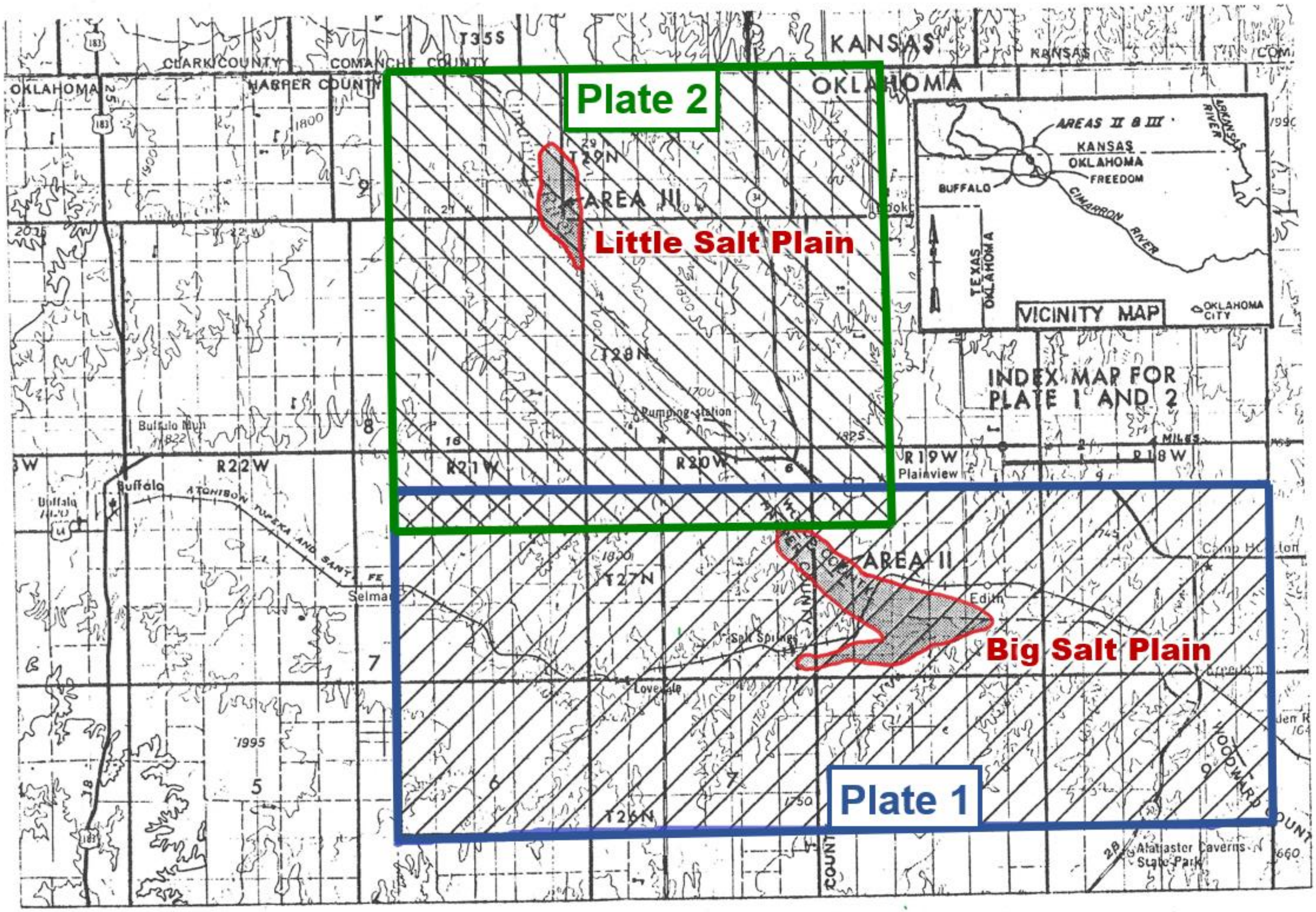


Figure 15. Map showing location of Big Salt Plain (Area II) and Little Salt Plain (Area III), and outline of areas mapped on plates 1 and 2.

The overlying Blaine Formation is 85 to 95 feet thick and consists of white gypsum interbedded with reddish-brown shale and thin layers of greenish-gray shale and dolomite. It has three main gypsum beds, each 10 to 25 feet thick, with the most conspicuous being the Medicine Lodge Gypsum Bed at the base. Individual gypsum beds of the Blaine are abnormally thin at a number of places, and locally one or more of the gypsum beds is completely missing: this results from some gypsum beds having been dissolved at an earlier time. In many places, a brown silty or clayey sediment was deposited in Quaternary time to fill original caverns and void spaces that resulted from dissolution of the gypsum.

The Medicine Lodge Gypsum Bed, at the base of the Blaine Formation, is the best marker bed for structural mapping in the area (Plates 1 and 2). South of Highway 64, the Medicine Lodge generally forms a good escarpment; north of Highway 64, however, in many places it is partially or completely dissolved, but the immediately underlying dolomite and gray shale (each about 2 feet thick) comprise a distinctive zone of light-gray or off-white rock that marks the base of the Blaine.

Overlying the Blaine Formation are several other formations locally seen in outcrops. The Dog Creek Shale, immediately above the Blaine, consists of 40 to 50 feet of mostly reddish-brown shale, and above the Dog Creek are orange-brown sandstones of the Marlow Formation (the lower part of the Whitehorse Group).

Quaternary terrace deposits consist chiefly of sand and gravel deposited along the former courses of Cimarron River and Buffalo Creek. Typically, they are well above Cimarron River on the south side of the salt plains, but they extend down to, and are in contact with, alluvial deposits on the north side of river. Terrace deposits range from 1 to 50 feet thick.

The youngest sediments in the area are Quaternary and Recent sand, silt, clay, and gravel that comprise alluvium along the flood plains of Cimarron River, Buffalo Creek, and their principal tributaries. These youngest sediments are typically 10 to 70 feet thick on Cimarron River, and are 20 to 60 feet thick on Buffalo Creek. Detailed information concerning thickness of the alluvium is available from bore holes drilled by the Corps of Engineers, and from seismic profiles made by Geo Prospectors, Inc., during an earlier stage of investigation (Plates 1 and 2).

Outcropping rocks throughout the area are essentially flat-lying, except for the gentle dip (20 to 40 feet per mile) into Cimarron River and Buffalo Creek (Plates 1 and 2); the Blaine Formation (and the upper part of the Flowerpot Shale) forms a definite synclinal structure along the two principal rivers in the area. This dip or drape of the rocks towards the rivers results from underground dissolution of salt in the upper part of the Flowerpot salt; dissolution is more advanced directly beneath Cimarron River and Buffalo Creek, and thus the amount of collapse and drape of overlying rocks is greatest in these areas.

Almost all outcropping strata on both sides of Cimarron River are disturbed as a result of dissolution of Flowerpot salt. Disruption is the rule in the Flowerpot, Blaine, Dog Creek, and Whitehorse strata, especially north of Highway 64. One area that is highly chaotic is in sections 3, 4, and 10, T. 28 N., R. 21 W., just west of Cimarron River (Plate 2). In this area, the logs of two oil wells show there is a difference in elevation of 35 feet at the base of the Blaine, and outcropping rocks between these two wells are chaotic blocks that dip 20 to 30 degrees in various directions, as a result of being dropped into underlying dissolution cavities. Similar dissolution-and-collapse features near Big Salt Plain (Plate 1) are in sec. 19, T. 27 N., R. 19 W., in sec 21, T. 27 N., R. 19 W., in sec. 4, T. 26 N., R. 19 W., in sec. 22, T. 27 N., R. 21 W., and several other places where the base of the Blaine has been dropped more than 10 or 20 feet.

Subsurface salt deposits

Flowerpot salt is at shallow depths beneath Big Salt Plain (Johnson, 1981), Little Salt Plain, and adjacent areas, and the total thickness of Flowerpot salt here is about 150 to 175 feet (Johnson, 1976, see his Plate 6). It consists of reddish-brown shale interbedded with transparent to translucent layers, crystals, and veins of salt. Commonly the salt is reddish in color, due to shale impurities, and in many layers it is intimately intermixed with shale. Stratigraphic zones containing salt are typically 2 to 10 feet thick (based upon core holes drilled in 1960–1961 by the Corps of Engineers), and halite appears to comprise about half of the entire Flowerpot salt unit. The full thickness of the salt unit has not been cored, but as much as 60 feet of salt and interbedded shale was cored by the Corps down to a depth of 118 feet in their hole no. II–20, in sec. 21, T. 27 N., R. 19 W.

The top of the Flowerpot salt commonly is 100 to 200 feet below the top of the Flowerpot Shale, but the upper surface is irregular as a result of dissolution of the salt by ground water; this irregularity is well displayed in the seismic profiles on Plates 1 and 2 (see also Johnson, 1981). Ground water dissolves the salt principally from the upper part of the unit beneath Cimarron River and Buffalo Creek. In some boreholes there is a solution cavity, or a “zone of lost circulation,” at the top of the salt unit: this probably represents the zone in which dissolution is now most actively taking place, and/or the zone that is transmitting high-salinity brine away from the salt beds. The top of the Flowerpot salt is only 50 to 100 feet below the top of the formation at some localities several miles from Cimarron River, such as in two oil-well tests drilled in secs. 4 and 10, T. 28 N., R. 21 W. (Plate 2).

The depth to the top of salt beds beneath Big Salt Plain is generally 50 to 100 feet, and beneath Little Salt Plain it is 100 to 125 feet. The salt is closest to ground level in sec. 21, T. 27 N., R. 19 W., where it was encountered only 30 feet below the surface in the Corps hole no. II–50. The top of the salt is at slightly greater depths to the northwest and west of that location, but it drops off to a considerable depth (about 175 feet below the surface) eastward along the east line of sec. 21 (Ward, 1961c; Johnson, 1981).

Further evidence suggesting dissolution of Flowerpot salt near Big Salt Plain is the "Freedom Gas Blowout," as described by Johnson (2003). In 1980, natural gas erupted from alluvium in the Cimarron River floodplain about 2 miles east of Big Salt Plain and created a 20-foot-wide crater from which mud was ejected to a height of 60 feet. Other nearby craters were up to 30 feet wide and 10.6 feet deep. An estimated 20 million cubic feet of gas was emitted daily from the larger vents. Johnson (2003) summarized that apparently a mechanical failure in a deep gas well, drilled 10 miles to the southwest, allowed high-pressure natural gas to enter a "lost-circulation zone" (an open, probably cavernous zone) at a depth of 177 feet in the well; a depth that is within the Flowerpot salt in that area. The data suggest the following (Johnson, 2003): 1) high-pressure gas from the well entered dissolution cavities in the Flowerpot salt; 2) the gas then migrated laterally 10 miles to the northeast through dissolution cavities in the Flowerpot salt; and 3) then reached the land surface through fractured Flowerpot shales that underlie Cimarron River alluvium just east of Big Salt Plain.

Other salt units are also present beneath Big Salt Plain and Little Salt Plain (Jordan and Vosburg, 1963; Johnson 1976), but they are too deep to be making any contribution to the flow of brine at the surface. Salty shale is present in the Upper Cimarron salt at a depth of 500 feet below both salt plains, and massive beds of salt in the Lower Cimarron salt are present about 800 to 900 feet below the salt plains. In addition, thick salts in the Lower Wellington salt and anhydrite unit are at least 1,700 feet below both salt plains.

Brine emission

Clearly, brine is forming in the shallow subsurface by dissolution of halite beds in the Flowerpot salt, and it is coming to the surface through alluvial deposits in Cimarron River and Buffalo Creek. The brine is saturated with respect to sodium chloride: brine wells of Blackmon Salt Co. (now Cargill Salt, see Figs. 12, 13) on Big Salt Plain contain 205,000 grams of chloride per liter (about 160,000 ppm) (Johnson, 1970). Also, an artesian brine well on the south side of Buffalo Creek (Corps hole no. II–31, in sec. 33, T. 27 N., R. 19 W.) has salt encrusted over the surface pipe, because salt is precipitated from saturated brine immediately upon coming to the surface.

Brine is present in bedrock under a hydrostatic head that causes it to rise above ground level in artesian flow. This is seen both in Blackmon's original wells and in the artesian well south of Buffalo Creek. With this hydrostatic head, brine is forced into the base or the sides of the alluvial deposits and is then forced upwards to the surface of the alluvium. At the surface, water (H_2O) is evaporated from the brine, and salt is precipitated as a crust on the salt plain.

Some of the brine flows in the subsurface through dissolution cavities at and near the upper surface of the Flowerpot salt. Much of the brine probably is entering the base of alluvium through joints and fractures formed in part by collapse of overlying Flowerpot strata when salt is dissolved, although some brine may be entering alluvium through thin aquifers in the Flowerpot Shale (Fig. 10).

In general, water wells drilled on the north and east side of Cimarron River are in terrace deposits: they provide fairly good- to good-quality fresh water, and often they are flowing wells. Ground water here results from infiltration of precipitation falling on the terrace deposits. Wells drilled on the west and south side of the river (particularly north of Highway 64; Plate 2) can obtain small yields of fresh water from the terrace deposits, but when drilled into bedrock they typically encounter salty water. This results from precipitation infiltrating the Permian rocks and dissolving some of the Flowerpot salt (Fig. 10). The difference in ground-water quality between the northeast (terrace deposits) and southwest (bedrock) side of the Cimarron River is seen at many places farther downstream, such as in the Okeene Salt Plain area.

Alluvium near, and downstream from, the salt plains is undoubtedly saturated with high-salinity brine; a water well drilled in 50 feet of alluvium in NW¼ sec. 6., T. 28 N., R. 20 W., yielded water with about 60,000 ppm chloride at a rate of more than 100 gallons per minute (the well supplied drilling water for a nearby oil test).

Solar evaporation of brine has supported commercial recovery of salt on Big Salt Plain since the 1920s. Although native Americans and early settlers traditionally harvested salt from Big Salt Plain, Blackmon Salt Co. established and carried out a small salt business from the 1920s (Johnson, 1970). In 1984, Cargill Inc. acquired the Blackmon lands and constructed about 500 acres of solar ponds that could produce 150,000 to 200,000 tons of salt annually (Figs. 12, 13). Joachims (1999) describes Cargill's operation thus: 1) saturated brine is pumped to the surface from cavities in the Flowerpot salt beneath the salt plain; 2) the brine is placed in about 500 acres of earthen pans surrounded by earthen embankments; 3) evaporation of H_2O from the brine is enhanced by lots of summer sunshine and strong winds, and thus salt is precipitated in the earthen pans; and 4) high-purity salt (99.5 to 99.8% NaCl) is harvested from the earthen pans in the fall of the year and is marketed for water-softening, industrial, and agricultural (livestock feed) uses, as well as for de-icing of roads in the winter.

Recommendations for future studies

1. Set up a program for drilling cores and other test holes to obtain additional geohydrologic information, such as the types and number of aquifers, and how the brine is transmitted through the Flowerpot from the salt beds to the alluvium (fractures and joints? and/or permeable strata?). Also, establish the water table, the flow pattern of brine movement, and the piezometric surface for brine in the vicinity of both salt plains.

2. A test hole should be drilled in the vicinity of the right abutment of the Survey-Report axis for the brine pool on Cimarron River to determine the depth to Flowerpot salt at this site, as well as the thickness and character of the salt unit.

3. Test holes should be drilled in the area of the Survey-Report axis for the fresh-water dam on Buffalo Creek to determine the depth to the Flowerpot salt, and also the thickness and character of the salt at this site. The same data are needed at the Survey-Report axis for the fresh-water dam on Cimarron River near the Oklahoma–Kansas border, above Little Salt Plain.

4. Test-hole data are needed at several places downstream from the Survey-Report axis (brine pool) on Cimarron River to see if brine is flowing downstream in aquifers below the alluvium, and is entering Cimarron River below the proposed axis in significant quantities.

5. Shallow test holes should be drilled in Traders Creek, and perhaps other creeks farther downstream, to see if brine is entering the base of alluvium in the tributary creek(s) and moving as a subsurface flow into Cimarron River alluvium. The same types of data may be useful in studies of principal tributaries entering Cimarron River near Little Salt Plain.

6. Shallow test holes are needed in the alluvium near the Survey-Report axis (fresh water) on Cimarron River to establish the upstream limits of brine associated with Little Salt Plain. This also will show if the proposed axis will impound fresh water on top of brine-saturated alluvium.

SALT CREEK CANYON (AREA IV)

Salt Creek Canyon is one of the two known salt-emission areas in Blaine County (Figs. 8, 16). Outcropping rocks in the area are the Permian Flowerpot, Blaine, and Dog Creek Formations, with brine emissions coming from siltstone and sandstone beds of the Flowerpot Shale exposed in the floor of Salt Creek Canyon (Fig. 17). Brine apparently forms by dissolution of salt beds in the Upper Cimarron salt unit, which is about 300 feet below the canyon floor (Fig. 18), and the brine migrates laterally and upward through fractures and joints until it reaches the surface in the canyon. It appears as if almost all of the chloride load entering Salt Creek is being emitted within the confines of the canyon itself, and thus it may be desirable to attempt trapping and retaining the brine at the mouth of the canyon. An estimated 250 tons of chloride enters the Cimarron River from Salt Creek Canyon (Fig. 3).

Surface geology

The rock unit of principal importance is the Flowerpot Shale (Plate 3). It consists mainly of reddish-brown shale, with some thin layers of gray shale, gypsum nodules, siltstone, and sandstone. The formation is about 450 feet thick in the area, but only the top 130 to 150 feet are exposed in canyon walls adjacent to the salt plains. Older Flowerpot strata are exposed farther east along Salt Creek.

The floor of Salt Creek Canyon consists mostly of interbedded siltstone, sandstone, and mudstone layers of the Chickasha Tongue, which is part of the Flowerpot Shale (Fay and others, 1962). Strata in the Chickasha Tongue exhibit large-scale cross bedding that dips generally to the west, and cross beds represent the foreset beds of a deltaic sequence (the land area at that time lay to the east). Cross-bedded deltaic sands are reddish brown and greenish gray, and they contrast with overlying layers of orange-brown and reddish-brown shale and mudstone. Deltaic strata exposed in the floor of the canyon are the youngest deposits of the Chickasha Tongue in this area, and they probably are equivalent to unit Pf-4, as described by Fay and others (1962). The base of the deltaic sequence is not exposed in the canyon area, but the full thickness of the Chickasha Tongue is believed to be about 120 feet.

Overlying the Flowerpot Shale are interbedded thick gypsums and shales of the Blaine Formation. Resistant gypsum beds cap high escarpments in the area, and the thicker gypsums are being mined by U.S. Gypsum Co. on north of Salt Creek Canyon (Fig. 17). The Blaine Formation is 80 to 90 feet thick in the area, and individual gypsum/anhydrite beds are 5 to

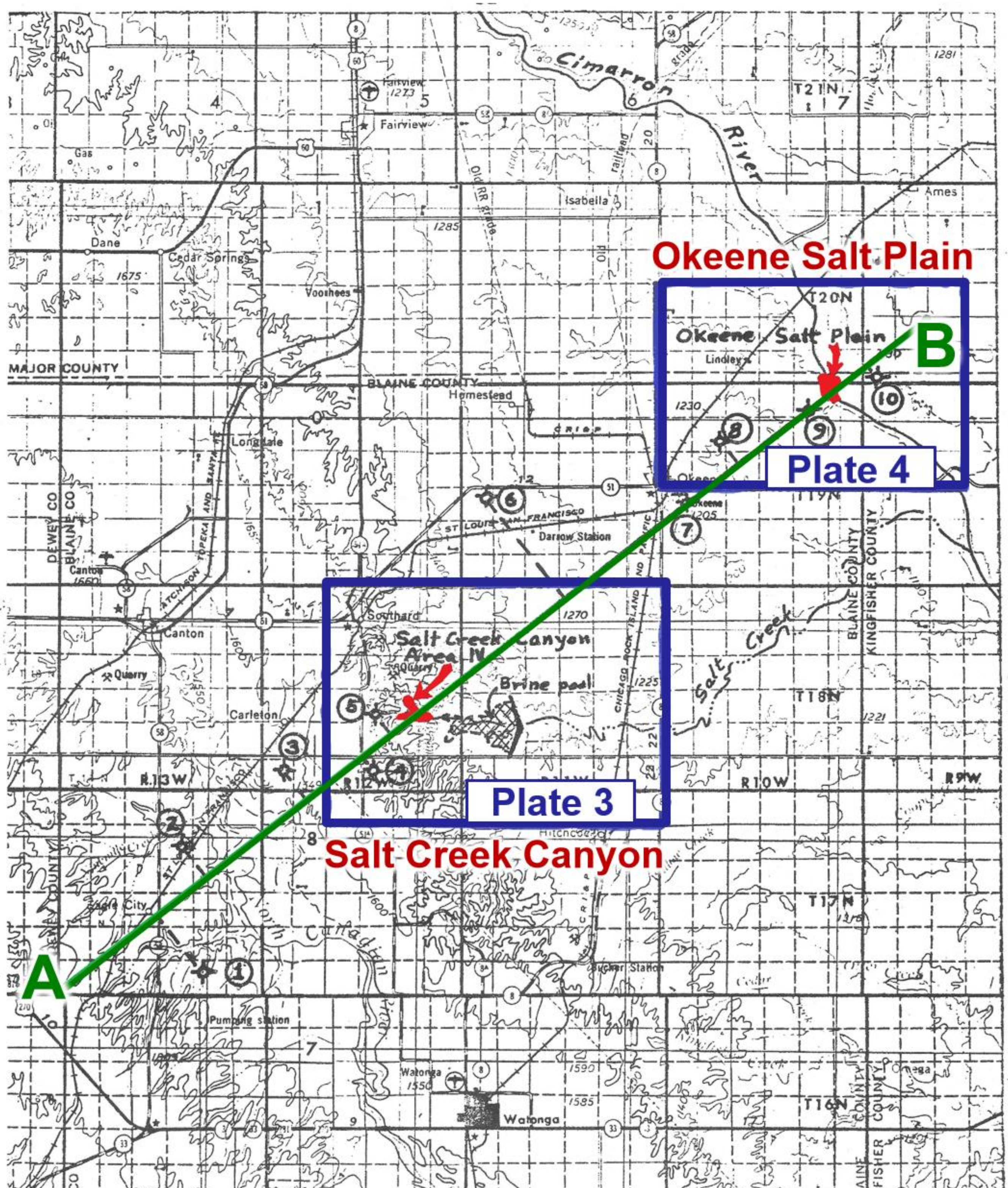
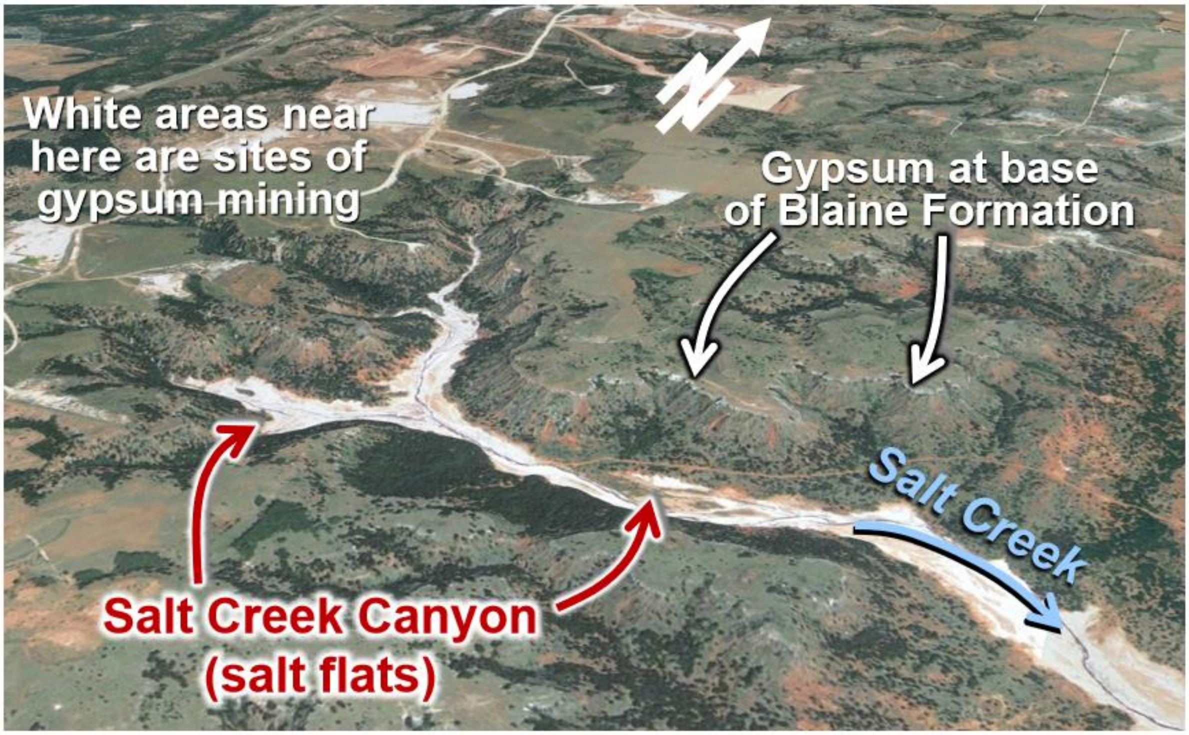


Figure 16. Map showing location of Salt Creek Canyon and Okeene Salt Plain in Blaine County, Oklahoma. Also shown is the location of control wells 1 through 10 for cross section A—B (see Figure 18 for cross section), and outline of areas mapped on Plates 3 and 4.



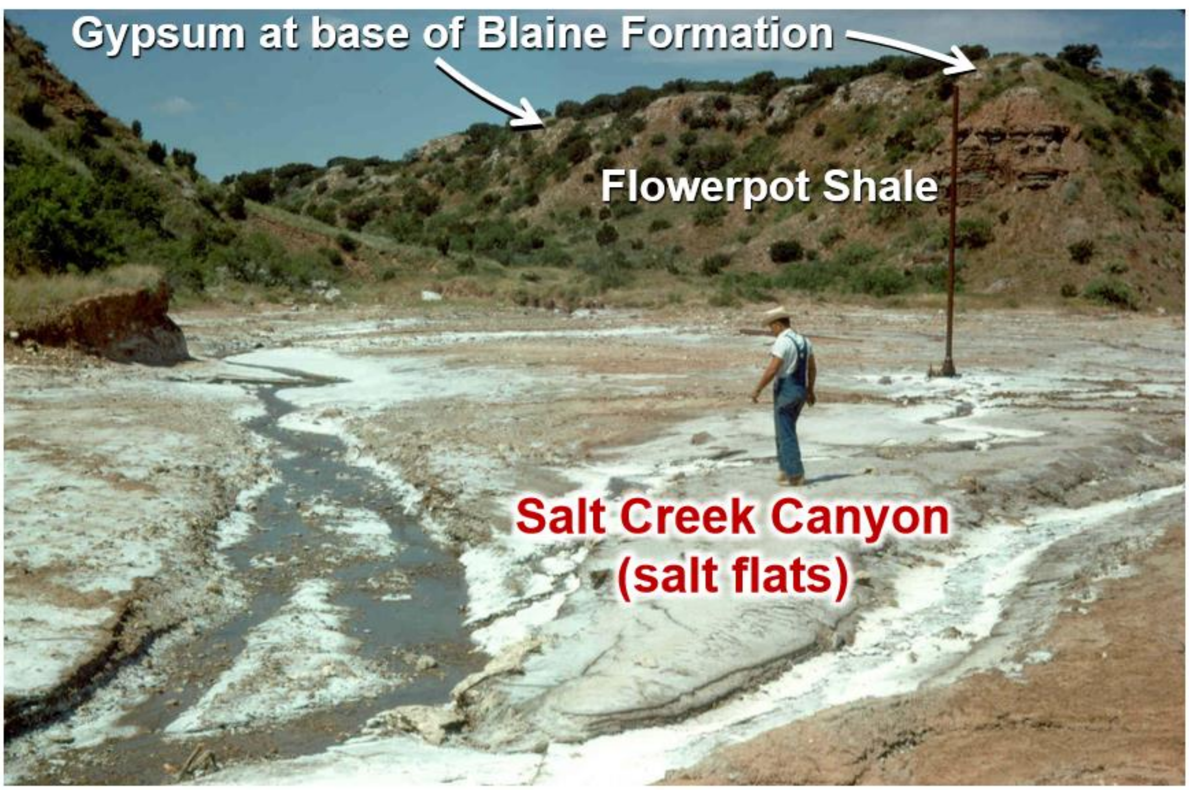


Figure 17. **Upper photo:** Google Earth photo of Salt Creek Canyon showing salt crust on the canyon floor. **Lower photo:** ground view of Salt Creek Canyon with salt crust formed by evaporation of high-salinity brine emitted from the canyon floor.

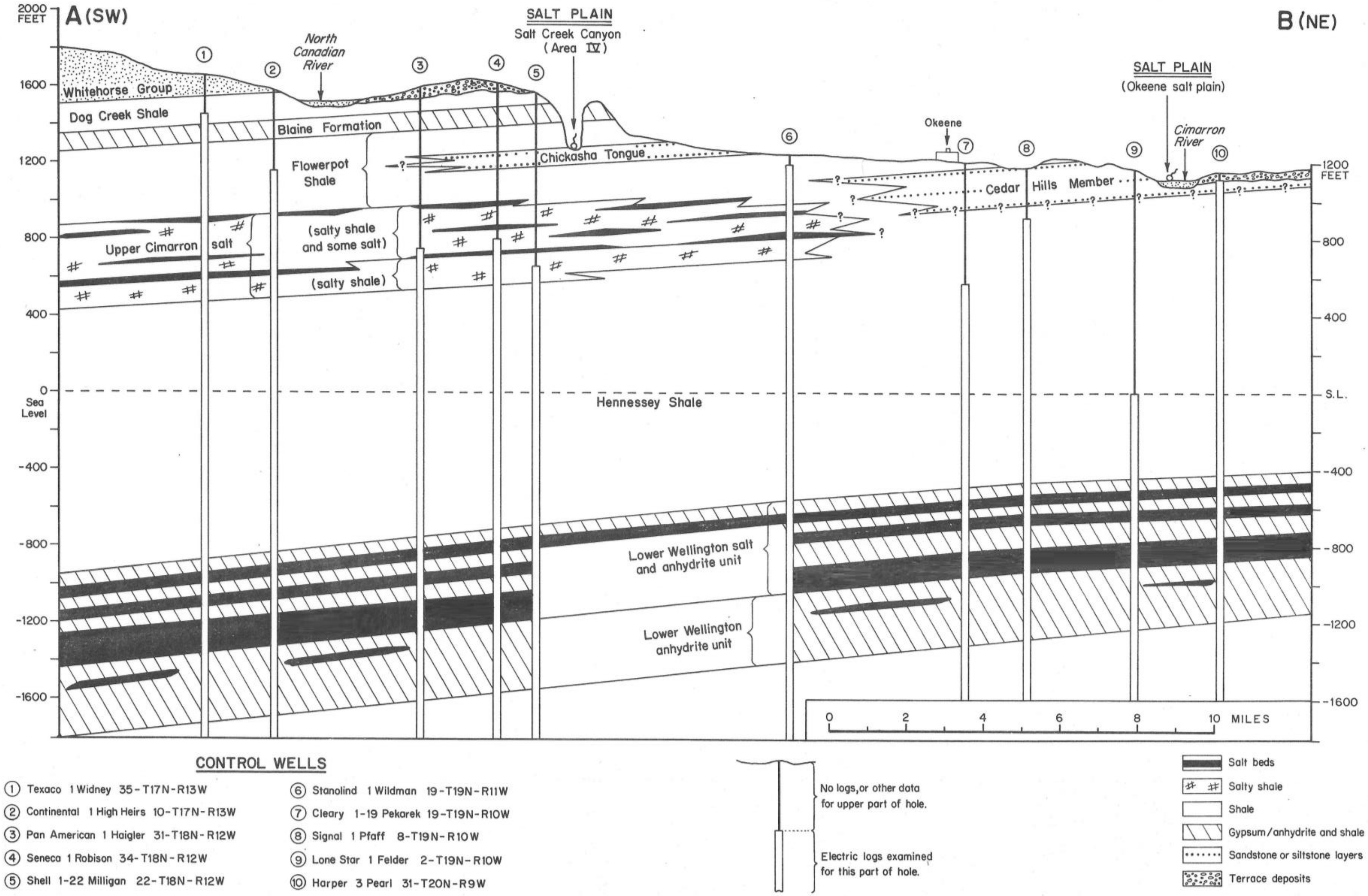


Figure 18. Southwest-northeast cross section through Salt Creek Canyon (Area IV) and Okeene Salt Plain on Cimarron River, Blaine County, Oklahoma. Brine forms by dissolution of salt layers in Upper Cimarron salt, and it reaches the surface through siltstone and sandstone aquifers in the Chickasha Tongue (Flowerpot Shale) and Cedar Hills Member of the Hennessey Shale. See figure 16 for location of cross section.

15 feet thick. At the base of the Blaine is the Medicine Lodge Gypsum Bed, which is 5 feet thick. Structure mapping of the base of the Blaine Formation (Plate 3) shows that outcropping rocks dip to the southwest at a rate of only 15 to 20 feet per mile (about 0.15 to 0.2 degrees), and that there is no evidence of faults or folds.

Overlying the Blaine Formation is the Dog Creek Shale, which comprises 50 to 100 feet of reddish-brown shale. The formation also contains several thin beds of siltstone and dolomite. At all places near Salt Creek Canyon, the top of the formation is eroded and it is overlain by Quaternary terrace deposits.

Terrace deposits consist mostly of sand and gravel deposited along the former courses of North Canadian River: they are as much as 60 feet thick. Their high permeability makes them an excellent medium for trapping precipitation and allowing it to percolate down into the ground-water system.

Quaternary alluvium is present along Salt Creek below the mouth of Salt Creek Canyon (Plate 3). It is commonly 3 to 4 feet thick just downstream from the mouth of the canyon, in sec. 24, T. 18 N., R. 12 W. Alluvium is 5 to 14 feet thick about 3 miles farther downstream from Salt Creek Canyon, along the Corps of Engineers Survey-Report axis (based upon bore holes drilled in 1962 along the proposed axis). Within Salt Creek Canyon, bedrock is exposed in the creek bottom at most places, or it is covered by no more than 1 to 2 feet of alluvium.

A clear understanding of the stratigraphic sequence of upper Flowerpot, Blaine, and Dog Creek strata in the area is provided in the Southard core, drilled by the Corps of Engineers 0.3 mile west of the SE corner sec. 21, T. 18 N., R. 12 W. (Fig. 19; Plate 3). Minor amounts of salt occur in the Blaine Formation in the core: scattered small crystals and veins of salt make up 1 to 2 percent (or less) of some of the gypsum/anhydrite layers, and all the shales and siltstones of the Blaine have a taste of salt. There is no evidence of similar minor amounts of salt either in the overlying Dog Creek Shale or in the top 50 feet of the Flowerpot Shale in the Southard core.

Subsurface source of brine

The most probable source of brine in this area is subsurface dissolution of salt in the Upper Cimarron salt unit, followed by migration of that brine to the surface through permeable beds of the Chickasha Tongue. Although data on the shallow subsurface beneath Salt Creek Canyon are meager, I believe that salty shale and salt beds of the Upper Cimarron salt are about 400 feet thick, and the top of the unit is about 300 feet below the canyon floor (Fig. 18). Several miles west of Salt Creek Canyon, where ground level is much higher, the top of the salt is about

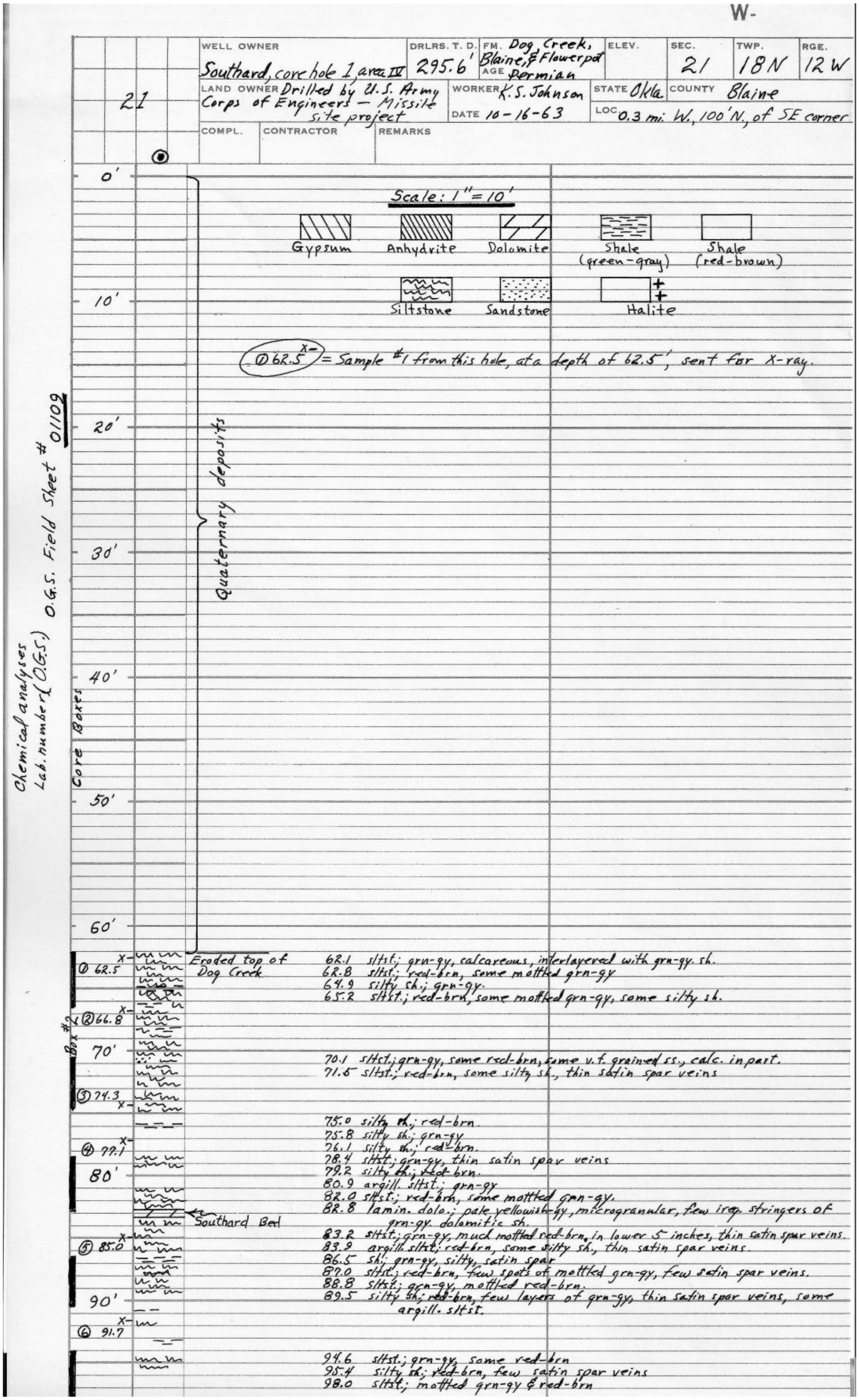


Figure 19. Geologic log of Corps of Engineers core hole #1, Area IV ("Southard Core") in sec. 21, T. 18 N., R. 12 W.; examined by K.S. Johnson. Description continued on next 2 pages.

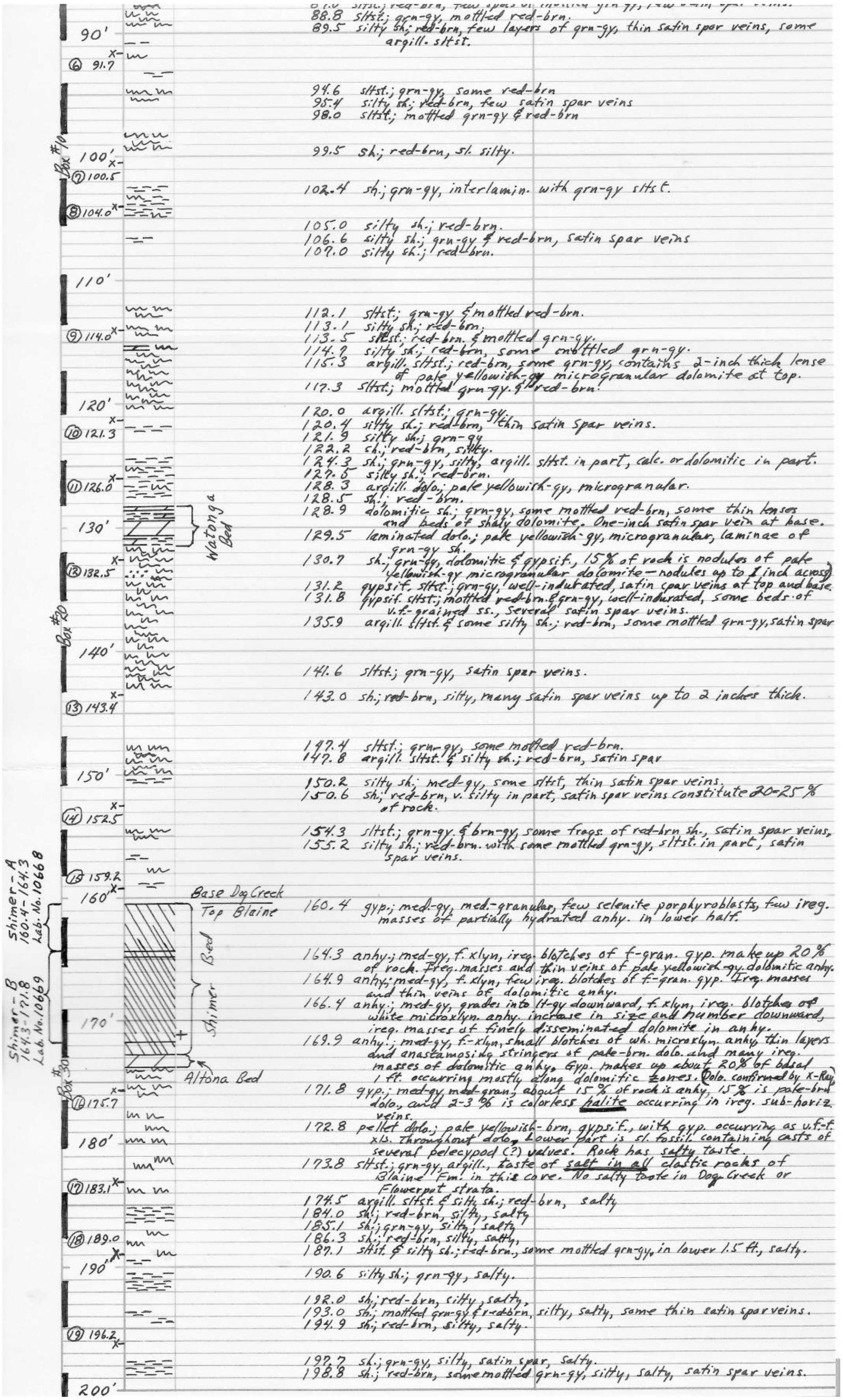


Figure 19 (continued).

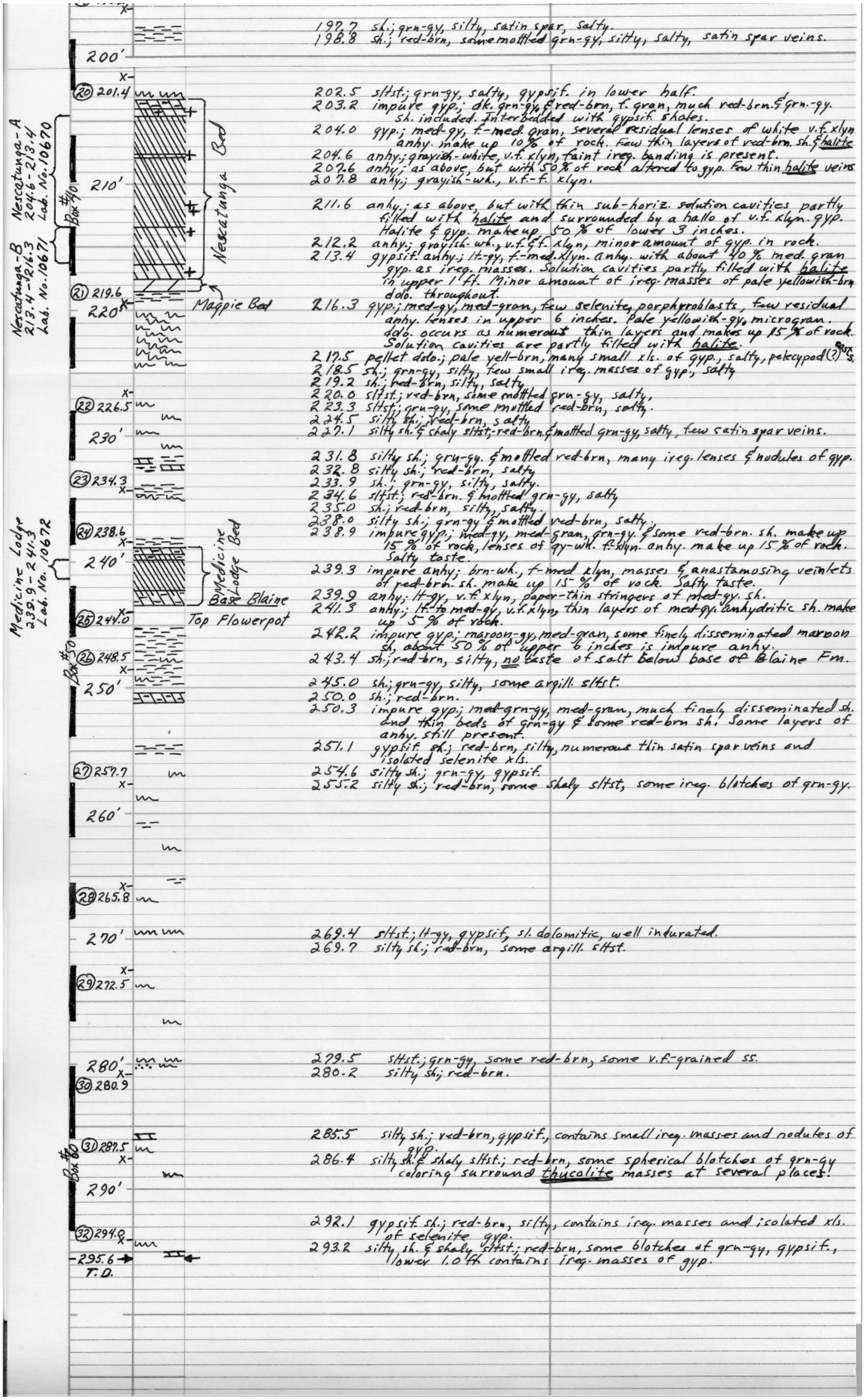


Figure 19 (continued).

600 feet deep. Dissolution of this salt undoubtedly is taking place beneath or just west of the canyon, where salt is in this range of 300 to 600 feet below the surface.

The Upper Cimarron salt is the only salt-bearing unit present here in the shallow subsurface: the nearest Flowerpot salt, which is stratigraphically equivalent to rocks cropping out in Salt Creek Canyon, is about 30 miles west and southwest of the area (Fig. 11); and salt in the Wellington evaporites is about 2,000 feet below the surface at Salt Creek Canyon. Thus, neither the Flowerpot salt or the Wellington salt can be making any contribution to brine emissions in this area.

Upper Cimarron salt has not been cored here, and thus it is impossible to give an accurate description of the unit. However, it probably consists mostly of reddish-brown salty shale with some layers of rock salt (halite). Salt probably makes up only about 10 to 25 percent of the unit, and the remainder is almost entirely shale.

Brine emission

Emission of brine appears to be restricted to the bottom of Salt Creek Canyon in sec. 23, T. 18 N., R. 12 W. (Fig. 17). Bedrock from which brine is emerging in all parts of the canyon is the Chickasha Tongue. As shown on Plate 3, only water flowing in the north and west branches is salty, whereas surface flow in the northwest and south branches is fairly fresh. All chloride concentrations shown on this map were determined by using Quantab Titrators.

The flow of water in upper reaches of all branches of Salt Creek Canyon is relatively fresh, ranging from 200 to 500 ppm chloride. When fresh water reaches the bottom of the canyons in the north and west branches, it mixes with high-salinity brine coming from fractures and joints in the bedrock. Within a distance of only 5 to 10 feet along the canyon floor, the stream salinity increases sharply to 33,000 to 45,000 ppm chloride; and where the north and west branches converge in SE¼ sec. 23, the water is 71,000 ppm chloride (Plate 3).

Brine is introduced only in the floor of the canyons from rocks cropping out at elevations below 1,290 feet (in the north branch) and 1,275 feet (west branch). Brine-contributing beds are interbedded siltstone, sandstone, and mudstone of the Chickasha Tongue, and the top of the unit is 130 to 150 feet below the base of the Medicine Lodge Gypsum (base of the Blaine Formation).

Brine emissions in the upper reaches of the north canyon are coming from joints or fractures in the bedrock; one set of joints strikes east-west, and the other set of joints strikes N 35º E. In the west canyon there are no distinct sets of joints or fractures where the brine first enters the steam. I believe that brine coming to the surface in both branches is nearly saturated with salt (perhaps 140,000 to 160,000 ppm chloride?), but it mixes with larger amounts of fresh water and was quickly diluted to 33,000 to 45,000 ppm chloride on the day of my measurements. However, additional highly saturated brine enters the north and west streams from the floor of the canyon within the next several thousand feet and increases the concentration to 71,000 ppm chloride; it probably remains at about 71,000 ppm chloride across the southern half of sec. 24, because no tributaries enter Salt Creek within this stretch. The concentration is then reduced to 22,000 ppm chloride in sec. 29, and to 7,800 ppm chloride in sec. 21, because of the influx of large amounts of fairly fresh water from Ruby Mill Canyon, Bitter Creek, and other smaller tributaries (Plate 3).

Principal tributaries entering Salt Creek downstream from the mouth of the canyon have a relatively low chloride content. The largest stream is Bitter Creek, with 840 ppm chloride, and the other principal flow comes from the creek in Ruby Canyon, with 1,800 ppm chloride (sec. 25, T. 18 N., R. 12 W.). Other tributaries entering Salt Creek have less water and range from 400 to 1,000 ppm chloride.

Several outcrops along the banks of Salt Creek (downstream from the canyon), and along tributaries to Salt Creek, have encrustations of a white mineral. At many places this mineral does not have the taste of halite, but instead it is bitter and may be a sodium-sulfate mineral that forms through evaporation of mineralized water present in some of the siltstone beds in the area.

Recommendations for future studies

1. Cores and other bore holes should be drilled in the floor of Salt Creek Canyon and the immediately surrounding area to determine geohydrologic characteristics of the bedrock, especially of the Chickasha Tongue. Data to be gathered about the Chickasha Tongue include the following: 1) the thickness, number, and characteristics of sandstone and siltstone beds; 2) presence of aquifers; 3) permeability of strata; 4) the role of joints and fractures in transmitting water to the surface; 5) quality and quantity of water in the aquifers; 6) piezometric surface of the brine; and 7) identification of areas where brine is seeping to the surface.

2. Determine if brine is entering alluvium from bedrock downstream from the mouth of Salt Creek Canyon.

3. Drill at least one deep hole about one mile west of Salt Creek Canyon to penetrate the Chickasha Tongue where it is 200 to 300 feet deep, and determine the following: 1) does it contain salt; 2) does it contain brine; 3) what is the composition and concentration of the water; and 4) what is the hydrostatic pressure of the ground water?

4. Examine the feasibility of building a structure at the mouth of Salt Creek Canyon (SW¼ sec. 24, T. 18 N., R. 12 W.) to trap high-concentration brines emitted within the canyon. A single structure here should contain about 90 percent of the chlorides entering surface waters at and near this salt plain.

5. Study the feasibility of intercepting fresh water in the four branches of the canyon before it mixes with high-salinity brines. Perhaps fresh water can be diverted around the salt-emission areas in the canyon, or can be impounded behind fresh-water dams in the northwest and south branches of the canyon. By diverting the fresh water, a dam at the mouth of Salt Creek Canyon would need to contain only brine emissions and the precipitation and run-off from about 500 acres of land within and adjacent to the canyon.

OKEENE SALT PLAIN ON CIMARRON RIVER

A newly recognized salt plain was called to my attention by John Dunlap as a result of his study of chloride emissions on Cimarron River between Okeene and Orienta (Dunlap, 1975). This salt plain is herein referred to as the "Okeene Salt Plain." The main part of the salt plain is in the northeast corner of Blaine County, in secs. 1 and 2, T. 19 N., R. 10 W. (Fig. 20 and Plate 4), but brine is also entering the river for about 4 miles upstream and downstream from the salt plain. Mr. Dunlap discovered, by talking with residents of the area, that the salt plain had once been more conspicuous and well developed, until a flood in the 1920s caused the river to shift its position and cut through the middle of the salt plain. Since then, it has been more difficult to recognize the area as a salt plain, probably because of repeated flush-outs by the fresher Cimarron River water.

The Okeene Salt Plain area contributes about 250 tons per day of chloride to Cimarron River (Fig. 3), and thus is an important source of contamination. Brine probably enters the base of alluvium at this site from the underlying Cedar Hills Member of the Hennessey Shale (Plate 4). The brine apparently forms by ground water dissolving some of the Upper Cimarron salt in subsurface, to the west and southwest of the outcrop.

Surface geology

The principal outcropping rock unit in the area is the Cedar Hills Member, at the top of the Hennessey Shale. It consists of reddish-brown shale interbedded with light-gray and reddish-brown siltstone beds that commonly are 1 to 5 feet thick. Total thickness of the Cedar Hills Member is about 200 feet, but only the top 100 feet is exposed within the map area (Plate 4). The Cedar Hills dips gently to the west at about 10 feet per mile, and it grades laterally into part of the Upper Cimarron salt in subsurface southwest of Okeene (Fig. 18). The lower part of the overlying Flowerpot Shale is also exposed in the study area, several miles southwest of the salt plain.

Alluvium in this area consists of sand, silt, clay, and gravel deposited by Cimarron River; it is as much as 40 feet thick, based upon water-well information. Cimarron River alluvium rests upon shales and siltstones of the Cedar Hills Member in most of the study area, and elsewhere it is in contact with terrace deposits. The terrace deposits are mostly sand and gravel deposited along the former courses of Cimarron River. Terraces are generally 40 to 80 feet thick and

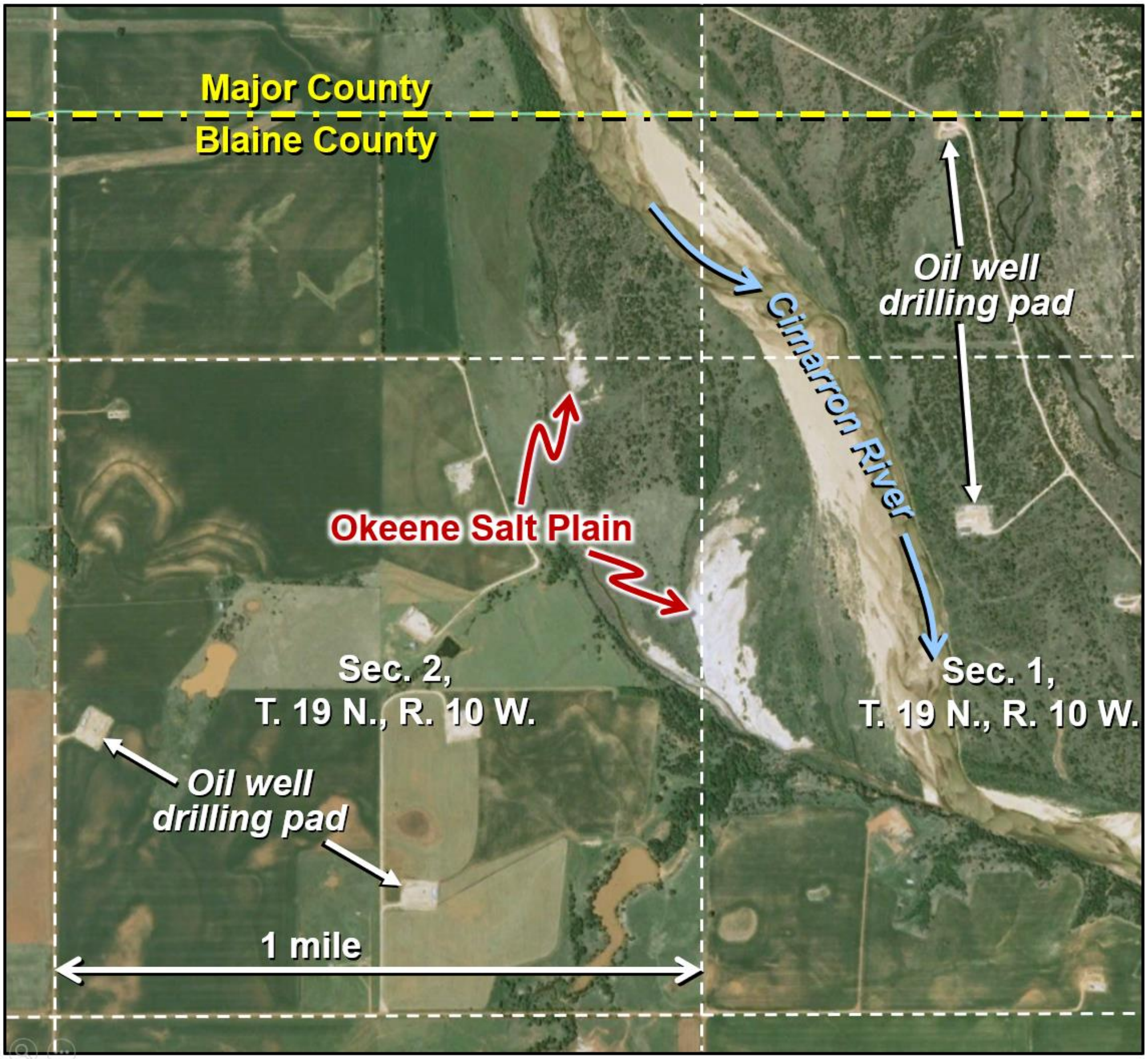


Figure 20. Google Earth photo (April, 2010) showing location of Okeene Salt Plain developed on the alluvial plain of Cimarron River.

continuous on the northeast side of the river, whereas southwest of the river they typically are much thinner and are scattered.

Subsurface source of brine

Salt beds believed to be responsible of brine emission at and near Okeene Salt Plain are in the Upper Cimarron salt. This salt unit is present in shallow subsurface just west (perhaps 8 to 10 miles west) of the salt plains (Figs. 11, 18). There are no cores of the Cimarron salt here, and there is no detailed description of it any place in the study area. The Upper Cimarron salt probably is mostly salty shale with some interbeds of salt (halite).

Thick salt sections of the Lower Wellington salt and anhydrite unit are about 1,600 feet below the surface at the salt plains (Fig. 18), and thus are so deep that they clearly make no contribution to the flow of brine at the surface.

Brine emission

Brine coming to the surface in the Okeene Salt Plain area is seeping into alluvium from the bedrock, and is probably under hydrostatic pressure in the bedrock. Aquifers carrying brine to the base of alluvium are siltstone beds of the Cedar Hills Member of the Hennessey Formation, and they are laterally equivalent to the Upper Cimarron salt unit farther to the west (Fig. 18). I believe that ground water southwest of the river circulates downward, where it dissolves the salt and becomes brine; the brine then moves up dip, and perhaps upward across fractures and joints, to emerge at the base of the alluvium. No brine was seen coming directly out of bedrock in this area.

Water-well drillers in the area (Wade and Charles Ewbank of Ewbank Drilling, Co., Fairview) report encountering brine at depths ranging from 70 feet to as much as 300 feet southwest of the river in the Orienta-Fairview-Isabella-Okeene region. Typically, the brine is 200 to 300 feet below the surface in the west, and it is at successively shallower depths to the east, toward Cimarron River. Just west of Cimarron River, the brine is about 100 feet below the surface. Wade and Charles Ewbank say that at some places they recover salt water, and at yet other places they encounter a "zone of lost circulation," which they assume is salt water. This zone of lost circulation may be a highly porous bed in the Cedar Hills Member that is carrying brine to the east, or a zone of salt dissolution in the Upper Cimarron salt. There may be several aquifers carrying brine eastward to the surface; in this way, it is similar to movement of brine through aquifers at Great Salt Plains (Area I) in Alfalfa County (Johnson, 1972, 2013, 2019).

Data reported by John Dunlap (1975) indicate there is a significant contribution of chlorides to Cimarron River near Okeene Salt Plain; that is, within 8 miles upstream of Highway 51 bridge (Plate 4). Based upon measurements made by him on a single day, or consecutive days, along this part of the river, the following increases in total chloride load were determined: 1) on May 22-23, 1974, the load increased from 878 tpd (tons per day) to 1,447 tpd (an increase of +569 tpd) from mile 8 down to the bridge; 2) on August 1, 1974, the load increased from 49 tpd to 180 tpd (+131 tpd) from mile 7 to mile 1; and 3) on January 1, 1975, the load increased from 4,159 tpd to 6,234 tpd (+2,075 tpd) from mile 7 to the bridge. Dunlap's work clearly shows a major influx of brine along the 8 miles upstream from Highway 51 bridge: in these three measuring periods, the increase ranged from 131 to 2,075 tpd, and averaged 925 tpd. These data show a much higher contribution of chlorides here than the 250 tpd estimated by the Corps of Engineers (Fig. 3).

Dunlap's data also show there is no significant influx of brine upstream from mile 8, up to the Highway 60 bridge at Orienta. Inasmuch as the Na/Cl ratio of Cimarron River water during these measurements was commonly 0.62 to 0.66, Dunlap properly concludes that this influx results from subsurface emission of natural brine formed by dissolution of salt alone (see also Leonard and Ward, 1962). It is certainly possible that more brine is entering Cimarron River downstream from Highway 51 bridge.

Water wells drilled into thick terrace deposits northeast of the river encountered fresh water in almost all cases. It is clear that ground water in these terrace deposits results from precipitation on the northeast side of the river, and there is little or no seepage of brine from bedrock into these terrace deposits. However, influx of natural salt water into terrace deposits farther downstream near Dover is reported by the Oklahoma Water Resources Board (1975).

Recommendations for future studies

1. Monitor the discharge, concentration, and total salt load of Cimarron River water for 8 miles upstream from Highway 51 bridge for an extended period (6 to 12 months) to obtain complete data on the amount and significance of the chloride load introduced near Okeene Salt Plain.

2. Carry out a similar program for about 5 or 10 miles (or more, if warranted) downstream from Highway 51 bridge to see if additional brine is entering the river in significant amounts.

3. Carry out a drilling program in the Cedar Hills Member to identify certain geohydrologic properties: 1) thickness and number of aquifers; 2) porosity and permeability; 3) ground-water-flow patterns and piezometric head; 4) quality and quantity of ground water; 5) areas underlain by salt water; and 6) the means of subsurface brine movement, either laterally through aquifers, or perhaps at some places vertically through fractures and joints.

4. Carry out a program of test drilling in alluvium to determine its thickness and the concentration of brine at the known emission sites; also, identify any other sites where brine is entering the alluvium, and carry out the same testing programs at those sites.

CONCLUSIONS

1. Working closely with Corps of Engineers geologists and other A–E contractors has helped establish the basic geologic framework of the region and the detailed geology of the four principal brine-emission areas on Cimarron River. Results of core drilling into bedrock were invaluable in all phases of geologic study, and such information is needed for any additional studies here, or similar studies in other problem areas.

2. Salt layers are widespread in the subsurface beneath, and/or to the west and southwest of, the four salt plains. The Flowerpot salt is being dissolved to produce brine at Big Salt Plain and Little Salt Plain (Areas II and III), and the Upper Cimarron salt is being dissolved to produce brine at Salt Creek Canyon (Area IV) and Okeene Salt Plain.

3. The Wellington evaporites also contain an important salt unit (the Hutchinson Salt Member, of Kansas terminology), but they are at least 1,600 feet below the salt plains and are not believed to be making any contribution to these salt plains.

4. Salt apparently occurs only as halite (NaCl); there is no evidence of potash or any other type of salt in the Flowerpot salt or Upper Cimarron salt.

5. Some of the salt probably occurs as discrete beds and layers of rock salt interbedded with layers of reddish-brown shale and salty shale. However, much of the salt also occurs as isolated and/or intergrown crystals of halite, partially surrounded by reddish-brown shale.

6. Salt units in northwest Oklahoma are being dissolved locally at depths of 30 to 600 feet below the land surface. At Big Salt Plain and Little Salt Plain the top of salt is 30 to 125 feet deep, whereas in Blaine County the top of the Upper Cimarron salt is being dissolved where it is 300 to 600 feet below the surface.

7. Salt is present at depths as shallow as only 30 feet beneath Big Salt Plain.

8. Brine being emitted at these four salt plains is formed by ground water dissolving salt in the Flowerpot and Upper Cimarron salts units. The brine then migrates laterally and upward through interconnected aquifers and enters the base or sides of alluvial deposits. Joint systems and fractures (formed due to collapse of rocks where underlying salt deposits are being dissolved) are probably the principal means for vertical movement of brine. Brine rises to the land surface, where H_2O is then evaporated from the brine; this leaves a salt crust on the surface of the salt plains. 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 Cimarron River drainage area.

9. Brine is emitted through joints and fractures in the floor of Salt Creek Canyon.

10. Gypsum beds of the Blaine Formation are above the level of the brine pool proposed at Big Salt Plain.

11. The Medicine Lodge Gypsum Bed, at the base of the Blaine Formation, is an excellent marker bed for structural mapping at Big Salt Plain, Little Salt Plain, and Salt Creek Canyon.

12. Regional dips in all four areas are only 10 to 20 feet per mile (about 0.1 to 0.2 degree) to the south and southwest, towards the axis of the Anadarko Basin. But near Big Salt Plain and Little Salt Plain, subsurface dissolution of salt has caused overlying rocks to collapse and dip (at a rate of 20 to 40 feet per mile—about 0.2 to 0.4 degree) towards Cimarron River, Buffalo Creek, and local structural depressions.

13. Evidence of subsurface dissolution of salt near the salt plains includes: 1) some salt plains are directly above shallow salt deposits, whereas others closely overlie the eastern limit of salt deposits; 2) suspected salt layers are at a fairly shallow depth beneath or near salt plains; 3) brine is saturated (or nearly saturated) with respect to NaCl, indicating undoubted contact of water with salt deposits; 4) Na/Cl ratios of brines are typically about 0.64, which is to be expected when brine is derived solely by dissolving salt (halite, NaCl); 5) brine-filled cavities were encountered in boreholes at Big Salt Plain; 6) zones of "lost circulation" at or near the tops of salt beds are believed to be cavities or cavernous rock resulting from dissolution of salt; 7) collapse structures are present at, and adjacent to, Big Salt Plain and Little Salt Plain, and they represent sites where subsurface salt has been dissolved; 8) outcropping strata drape (dip) down from both river banks towards Cimarron River and Buffalo Creek at Big Salt Plain and Little Salt Plain, because dissolution of salt is more advanced beneath and adjacent to these principal waterways; and 9) the upper surface of the Flowerpot salt is quite irregular at Big Salt Plain and Little Salt Plain (based upon seismic profiles), due to irregular salt dissolution at the top of the Flowerpot salt.

14. Inasmuch as it appears that about 90 percent of the chloride load at Salt Creek Canyon enters the stream within the canyon itself, it may be desirable to attempt trapping and containing the brine at the mouth of the canyon. Perhaps fresh water entering Salt Creek Canyon can be diverted around the salt-emission areas, or be ponded behind fresh-water structures in the northwest and south branches of the canyon.

15. Between 131 and 2,075 tons (an average of 925 tons) of chloride are emitted each day to Cimarron River in the vicinity of the newly identified Okeene Salt Plain, according to measurements by John Dunlap. Additional data are needed to determine the average chloride load at this important site, which probably is between 500 and 1,000 tons per day. Brine is emitted along the entire 8 miles of river upstream from Highway 51 bridge (not just at Okeene Salt Plain), and there may be more emissions downstream from that bridge.

16. Additional geologic and geohydrologic studies are needed at each of the salt plains on the Cimarron River, and specific recommendations have been made at the conclusion of each chapter in this report.

17. Detailed field work should be carried out in the vicinity of any other brine-emission sites that are discovered. Such work should result in maps and cross sections showing the major rock types, key beds, structure contours, and distribution and depth of salt beds within several miles of each site. Best results are obtained by combining field work and photogeologic study with data from cores, shallow test wells, electric logs from petroleum or other test holes, and seismic profiles.

18. A study such as this one should be carried out on Great Salt Plains (Area I) in order to more fully evaluate surface and subsurface geologic features that bear upon brine emission. See Johnson (2019) for results of such a study, as well as a later summary of geologic studies at Big Salt Plain and Little Salt Plain.

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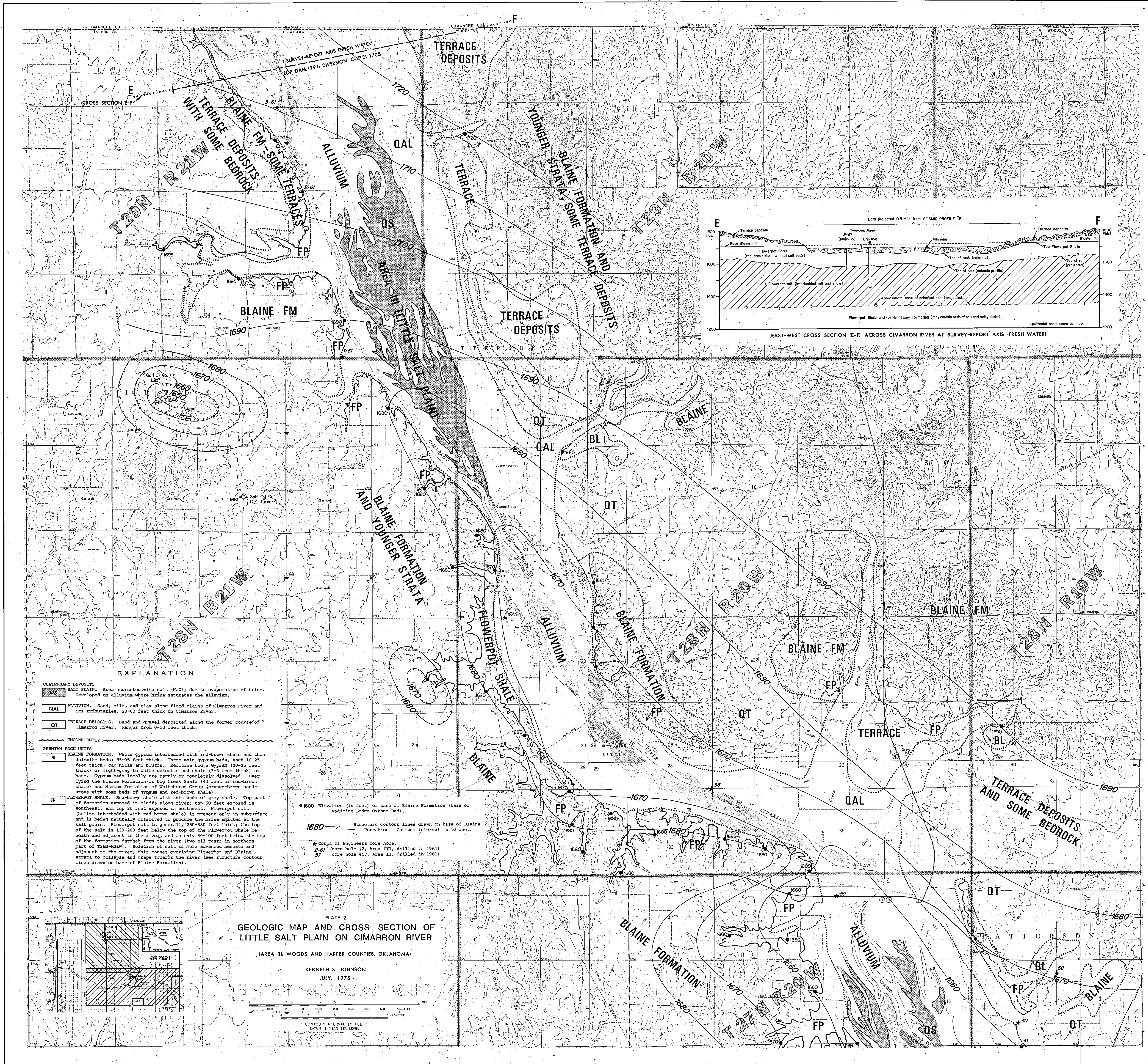
GEOLOGIC MAP AND CROSS SECTIONS OF BIG SALT PLAIN
ON CIMARRON RIVER AND BUFFALO CREEK
(AREA II: WOODS, WOODWARD, AND HARPER COUNTIES, OKLAHOMA)
KENNETH S. JOHNSON
JULY, 1975
1 MILE
7000 FEET
1 KILOMETER
CONTOUR INTERVAL 20 FEET
DATUM IS MEAN SEA LEVEL
A
B
Pure Oil Co.
B.A. Brown #1
Bend in section
Data from SEISMIC PROFILE "G"
Terrace deposits
2-75
1-75
2-60
Base of Blaine Formation
Cimarron River
Base of Blaine
Top of Flowerpot Shale
Alluvium
Flowerpot Shale
(red-brown shale without salt beds)
No electric log
Top of rock (seismic profile)
Top of salt (projected)
Top of electric log
Flowerpot salt (interbedded salt and shale)
Top of salt (seismic profile)
Base of principal salt
Base of principal salt (projected)
Flowerpot Shale and/or Hennessey Formation (may contain beds of salt and salty shale)
Horizontal scale is same as map
1800 feet
1600
1400
1200
1000
NORTH-SOUTH CROSS SECTION (A-B) ACROSS CIMARRON RIVER AT SURVEY-REPORT AXIS (BRINE)
AREA II
(BIG SALT PLAIN)
TOP DAM 1640
SPILLWAY 1616
BLAINE FM
FLOWERPOT SHALE
ALLUVIUM
TERRACE
CROSS SECTION C-D
T 27 N R 21 W
T 27 N R 20 W
T 27 N R 19 W
T 27 N R 18 W
T 26 N R 21 W
T 26 N R 20 W
T 26 N R 19 W
T 26 N R 18 W
C
D
Data from SEISMIC PROFILE "S"
6
(projected)
Drill hole
Buffalo Creek
Base of Blaine Formation
Flowerpot Shale
(red-brown shale without salt beds)
Flowerpot Salt
(interbedded salt and shale)
Top of salt (seismic profile)
Base of principal salt (projected)
Flowerpot Shale and/or Hennessey Formation (may contain beds of salt and salty shale)
Horizontal scale is same as map
NORTH-SOUTH CROSS SECTION (C-D)
ACROSS BUFFALO CREEK AT SURVEY-REPORT AXIS (FRESH WATER)
HARPER CO.
WOODWARD CO.
1640 Elevation (in feet) of base of Blaine Formation (base of Medicine Lodge Gypsum Bed).
1640 Structure contour lines drawn on base of Blaine Formation. Contour interval is 10 feet.
Corps of Engineers core hole.
2-75 (core hole #2, drilled in 1975)
38 (core hile #38, drilled in 1960-1961)
QUATERNARY DEPOSITS
QS SALT PLAIN. Area encrusted with salt (NaCl) due to evaporation of brine. Developed on alluvium where brine saturates the alluvium.
QAL ALLUVIUM. Sand, silt, and clay along flood plains of Cimarron River and Buffalo Creek (and their tributaries); 10-70 feet thick on Cimarron River and 20-60 feet thick on Buffalo Creek.
QT TERRACE DEPOSITS. Sand and gravel deposited along the former courses of Cimarron River and Buffalo Creek. Ranges from 0-50 feet thick.
UNCONFORMITY
PERMIAN ROCK UNITS
BL BLAINE FORMATION. White gypsum interbedded with red-brown shale and thin dolomite beds; 85-95 feet thick. Three main gypsum beds, each 10-25 feet thick, cap hills and bluffs. Medicine Lodge Gypsum (20-25 feet thick) at base. Gypsum beds locally are partly or completely dissolved. Overlying the Blaine Formation is Dog Creek Shale (40 feet of red-brown shale) and Marlow Formation of Whitehorse Group (orange-brown sandstone with some beds of gypsum and red-brown shale).
FP FLOWERPOT SHALE. Red-brown shale with thin beds of gray shale. Top part of formation exposed in bluffs along river and streams; top 100 feet exposed just below confluence of Cimarron River and Buffalo Creek. Flowerpot salt (halite interbedded with red-brown shale) is present only in subsurface and is being naturally dissolved to produce the brine emitted at the salt plain. Flowerpot salt is generally 150-250 feet thick, and the top of the salt is about 150-200 feet below the top of the Flowerpot Shale. Solution of the salt is more advanced beneath and adjacent to the rivers; this causes overlying Flowerpot and Blaine strata to collapse and drape towards the rivers (see structure contour lines drawn on base of Blaine Formation).



CROSS SECTION E-F
SURVEY-REPORT AXIS (FRESH WATER)
TOP DAM 1791; DIVERSION OUTLET 1705
TERRACE DEPOSITS
BLAINE FM, SOME TERRACES
TERRACE DEPOSITS WITH SOME BEDROCK
ALLUVIUM
QAL
QS
AREA III LITTLE SALT PLAIN
TERRACE
YOUNGER STRATA, SOME TERRACE DEPOSITS
BLAINE FORMATION AND
BLAINE FM
FP
QT
BL
T 29 N
R 21 W
R 20 W
T 28 N
R 19 W
T 27 N
BLAINE FORMATION AND YOUNGER STRATA
FLOWERPOT SHALE
BLAINE FORMATION
BLAINE FM
TERRACE
TERRACE DEPOSITS AND SOME BEDROCK
BLAINE
E
F
Data projected 0.5 mile from SEISMIC PROFILE "R"
Terrace deposits
Cimarron River
3-61 (projected)
Drill hole
Alluvium
Base Blaine Fm.
Blaine Fm.
Top Flowerpot Shale
Flowerpot Shale (red-brown shale without salt beds)
Top of rock (seismic)
Top of salt (projected)
Top of salt (seismic profile)
Flowerpot salt (interbedded salt and shale)
Approximate base of principal salt (projected)
Flowerpot Shale and/or Hennessey Formation (may contain beds of salt and salty shale)
Horizontal scale same as map
1800 FEET
1600
1400
1200
EAST-WEST CROSS SECTION (E-F) ACROSS CIMARRON RIVER AT SURVEY-REPORT AXIS (FRESH WATER)
EXPLANATION
QUATERNARY DEPOSITS
QS SALT PLAIN. Area encrusted with salt (NaCl) due to evaporation of brine. Developed on alluvium where brine saturates the alluvium.
QAL ALLUVIUM. Sand, silt, and clay along flood plains of Cimarron River and its tributaries; 20-60 feet thick on Cimarron River.
QT TERRACE DEPOSITS. Sand and gravel deposited along the former course of Cimarron River. Ranges from 0-50 feet thick.
UNCONFORMITY
PERMIAN ROCK UNITS
BL BLAINE FORMATION. White gypsum interbedded with red-brown shale and thin dolomite beds; 85-95 feet thick. Three main gypsum beds, each 10-25 feet thick, cap hills and bluffs. Medicine Lodge Gypsum (20-25 feet thick) or light-gray to white dolomite and shale (3-5 feet thick) at base. Gypsum beds locally are partly or completely dissolved. Overlying the Blaine Formation is Dog Creek Shale (40 feet of red-brown shale) and Marlow Formation of Whitehorse Group (orange-brown sandstone with some beds of gypsum and red-brown shale).
FP FLOWERPOT SHALE. Red-brown shale with thin beds of gray shale. Top part of formation exposed in bluffs along river; top 60 feet exposed in southeast, and top 20 feet exposed in northwest. Flowerpot salt (halite interbedded with red-brown shale) is present only in subsurface and is being naturally dissolved to produce the brine emitted at the salt plain. Flowerpot salt is generally 250-350 feet thick; the top of the salt is 130-200 feet below the top of the Flowerpot Shale beneath and adjacent to the river, and is only 50-100 feet below the top of the formation farther from the river (two oil tests in northern part of T28N-R21W). Solution of salt is more advanced beneath and adjacent to the river; this causes overlying Flowerpot and Blaine strata to collapse and drape towards the river (see structure contour lines drawn on base of Blaine Formation).
1680 Elevation (in feet) of base of Blaine Formation (base of Medicine Lodge Gypsum Bed).
1680 Structure contour lines drawn on base of Blaine Formation. Contour interval is 10 feet.
Corps of Engineers core hole.
2-61 (core hole #2, Area III, drilled in 1961)
57 (core hole #57, Area II, drilled in 1961)
PLATE 2
GEOLOGIC MAP AND CROSS SECTION OF LITTLE SALT PLAIN ON CIMARRON RIVER
(AREA III: WOODS AND HARPER COUNTIES, OKLAHOMA)
KENNETH S. JOHNSON
JULY, 1975
1 MILE
7000 FEET
1 KILOMETER
CONTOUR INTERVAL 10 FEET
DATUM IS MEAN SEA LEVEL

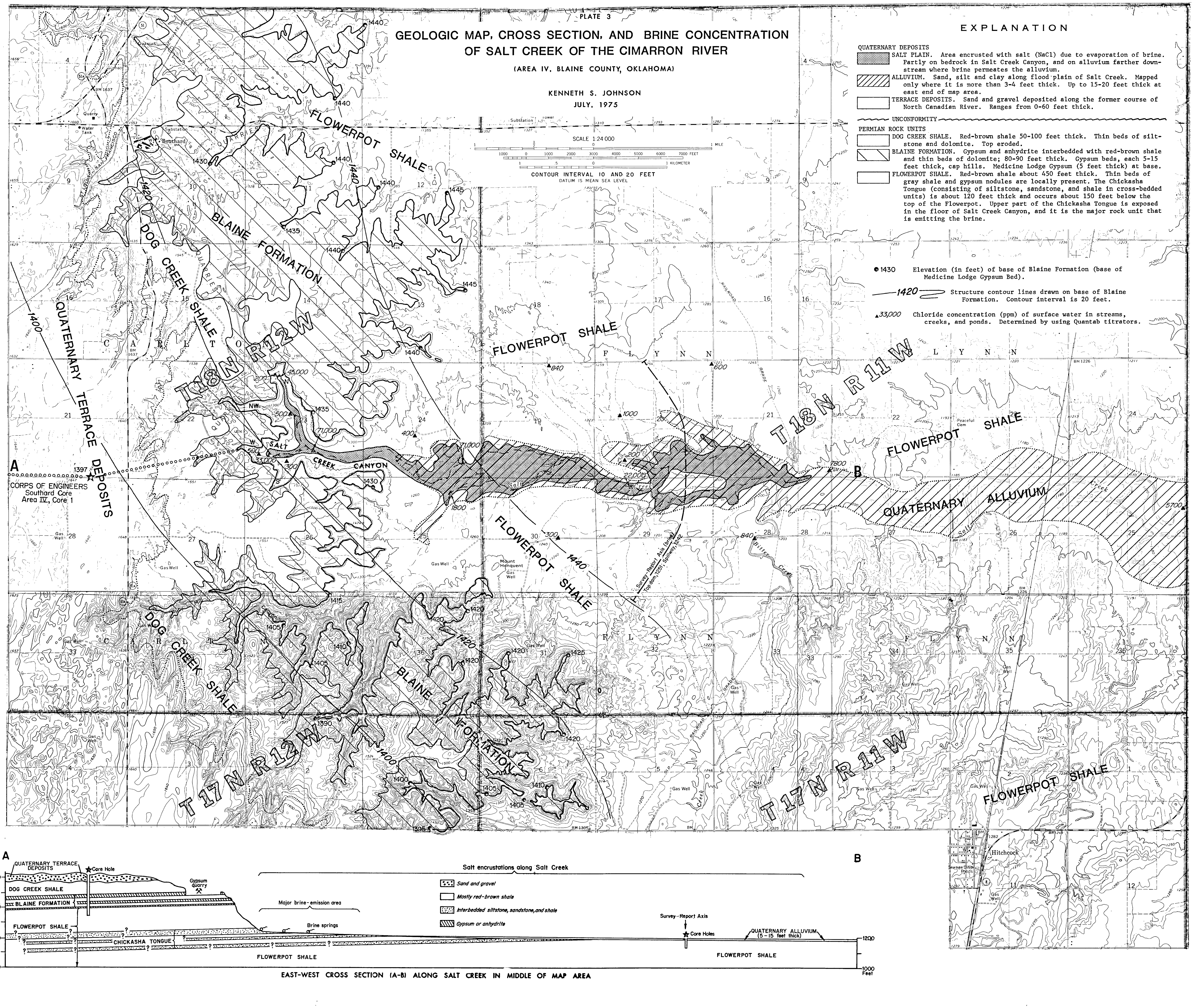


PLATE 3
GEOLOGIC MAP, CROSS SECTION, AND BRINE CONCENTRATION OF SALT CREEK OF THE CIMARRON RIVER
(AREA IV, BLAINE COUNTY, OKLAHOMA)
KENNETH S. JOHNSON
JULY, 1975
SCALE 1:24 000
CONTOUR INTERVAL 10 AND 20 FEET
DATUM IS MEAN SEA LEVEL
EXPLANATION
QUATERNARY DEPOSITS
SALT PLAIN. Area encrusted with salt (NaCl) due to evaporation of brine. Partly on bedrock in Salt Creek Canyon, and on alluvium farther downstream where brine permeates the alluvium.
ALLUVIUM. Sand, silt and clay along flood plain of Salt Creek. Mapped only where it is more than 3-4 feet thick. Up to 15-20 feet thick at east end of map area.
TERRACE DEPOSITS. Sand and gravel deposited along the former course of North Canadian River. Ranges from 0-60 feet thick.
UNCONFORMITY
PERMIAN ROCK UNITS
DOG CREEK SHALE. Red-brown shale 50-100 feet thick. Thin beds of siltstone and dolomite. Top eroded.
BLAINE FORMATION. Gypsum and anhydrite interbedded with red-brown shale and thin beds of dolomite; 80-90 feet thick. Gypsum beds, each 5-15 feet thick, cap hills. Medicine Lodge Gypsum (5 feet thick) at base.
FLOWERPOT SHALE. Red-brown shale about 450 feet thick. Thin beds of gray shale and gypsum nodules are locally present. The Chickasha Tongue (consisting of siltstone, sandstone, and shale in cross-bedded units) is about 120 feet thick and occurs about 150 feet below the top of the Flowerpot. Upper part of the Chickasha Tongue is exposed in the floor of Salt Creek Canyon, and it is the major rock unit that is emitting the brine.
1430 Elevation (in feet) of base of Blaine Formation (base of Medicine Lodge Gypsum Bed).
1420 Structure contour lines drawn on base of Blaine Formation. Contour interval is 20 feet.
33,000 Chloride concentration (ppm) of surface water in streams, creeks, and ponds. Determined by using Quantab titrators.
FLOWERPOT SHALE
BLAINE FORMATION
DOG CREEK SHALE
QUATERNARY TERRACE DEPOSITS
QUATERNARY ALLUVIUM
T 18 N R 12 W
T 18 N R 11 W
T 17 N R 12 W
T 17 N R 11 W
SALT CREEK CANYON
CORPS OF ENGINEERS
Southard Core
Area IV, Core 1
A
B
Hitchcock
EAST-WEST CROSS SECTION (A-B) ALONG SALT CREEK IN MIDDLE OF MAP AREA
QUATERNARY TERRACE DEPOSITS
Core Hole
Gypsum quarry
DOG CREEK SHALE
BLAINE FORMATION
FLOWERPOT SHALE
CHICKASHA TONGUE
Salt encrustations along Salt Creek
Major brine-emission area
Brine springs
Survey-Report Axis
Core Holes
QUATERNARY ALLUVIUM (5-15 feet thick)
Sand and gravel
Mostly red-brown shale
Interbedded siltstone, sandstone, and shale
Gypsum or anhydrite
Feet

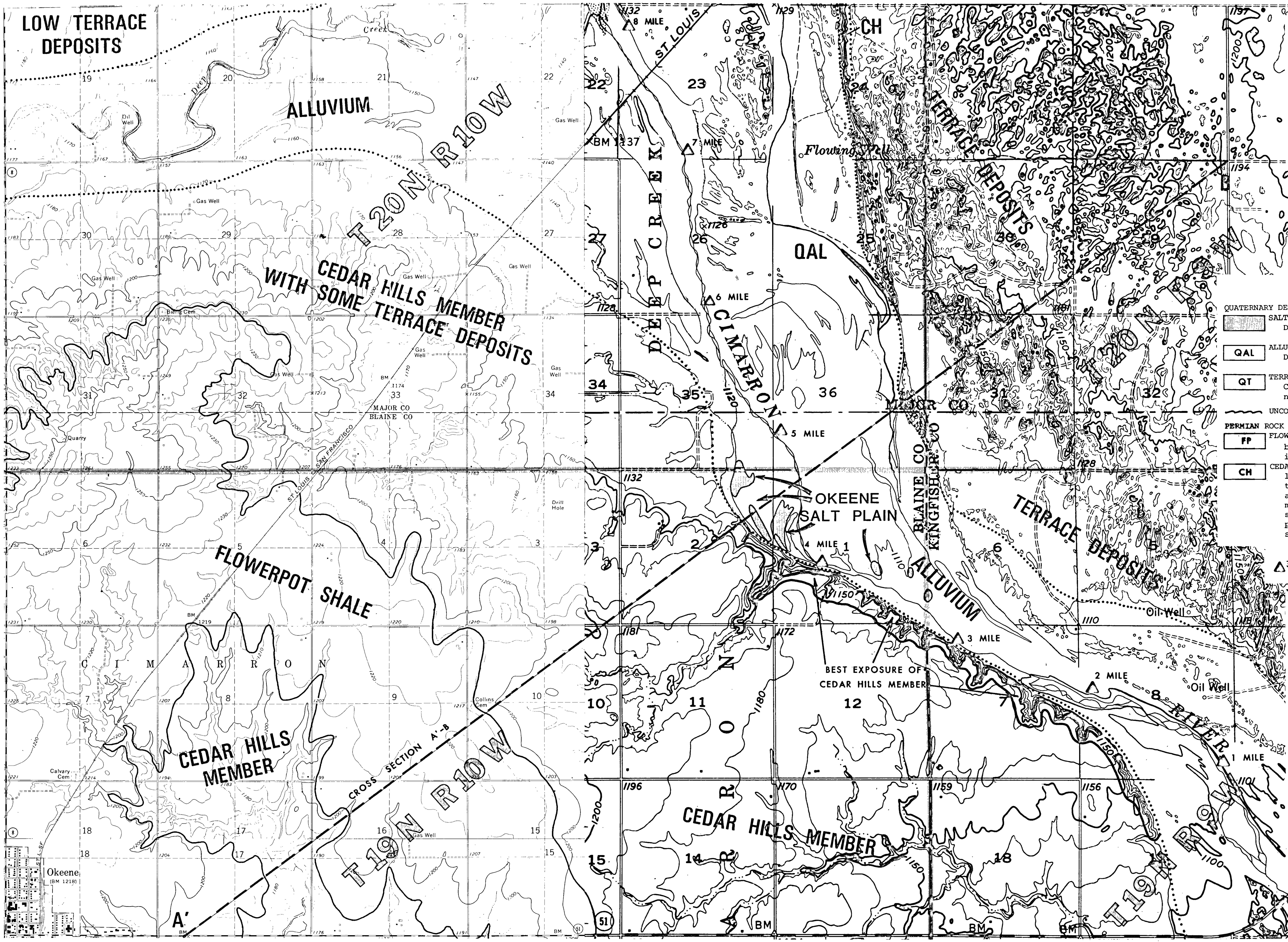


PLATE 4

GEOLOGIC MAP AND CROSS SECTION OF OKEENE SALT PLAIN ON CIMARRON RIVER

(NORTHEAST CORNER OF BLAINE COUNTY, OKLAHOMA)

KENNETH S. JOHNSON

JULY, 1975

SCALE 1:24 000

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 MILE

1 .5 0 1 KILOMETER

CONTOUR INTERVAL 10 FEET
DATUM IS MEAN SEA LEVEL

EXPLANATION

QUATERNARY DEPOSITS

SALT PLAIN. Area encrusted with salt (NaCl) due to evaporation of brine. Developed on alluvium where brine saturates the alluvium.

QAL — ALLUVIUM. Sand, silt, and clay along flood plains of Cimarron River and Deep Creek; up to 40 feet thick on Cimarron River.

QT — TERRACE DEPOSITS. Sand and gravel deposited along former courses of Cimarron River and Deep Creek. May be as much as 75-100 feet thick northeast of Cimarron River.

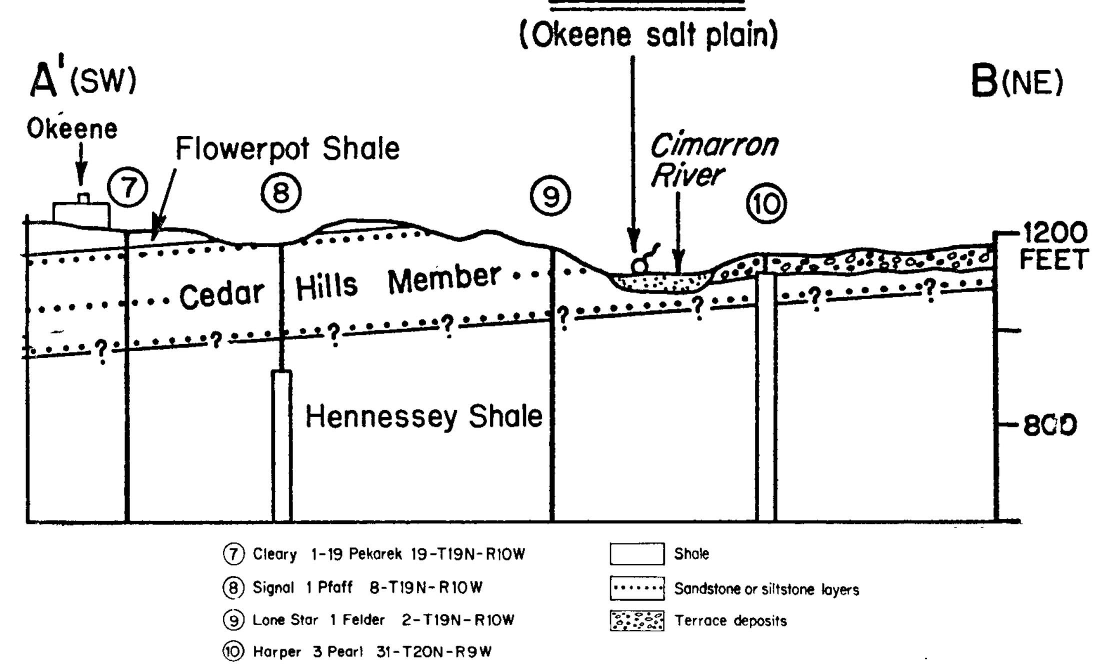
UNCONFORMITY

PERMIAN ROCK UNITS

FP — FLOWERPOT SHALE. Red-brown shale. Total thickness is 450 feet, but only bottom 50 feet exposed within map area. Mapped contact with underlying Cedar Hills Member is modified from mapping by R. O. Fay (1962).

CH — CEDAR HILLS MEMBER OF HENNESSEY SHALE. Red-brown shale interbedded with light-gray and red-brown siltstone beds that are commonly 1-5 feet thick. The Cedar Hills Member (at the top of the Hennessey Shale) is about 200 feet thick, but only the top 100 feet are exposed within the map area. Grades laterally into part of the Upper Cimarron salt in subsurface southwest of Okeene (see cross section), and this salt is probably being naturally dissolved to produce the brine emitted at the salt plain.

△3 MILE River mile above Highway 51 bridge (approximate).



CROSS SECTION A'-B ACROSS OKEENE SALT PLAIN
(THIS IS A PORTION OF CROSS SECTION A-B SHOWN IN FIGURE 12)