G. DAVID STEELE

SLIDES AND DESCRIPTIONS OF GEOLOGICAL FEATURES OF THE ARKANSAS AND RED RIVER CHLORIDE CONTROL PROJECT IN OKLAHOMA, TEXAS, AND KANSAS

BY

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INTRODUCTION

The purpose of this report is to provide a series of slides which show the major geological features related to natural emission of brine at several sites within the boundaries of the Arkansas and Red River Chloride Control Projects. Each slide is accompained by a written description of the significant geological features that it protrays. Data presented in these slides and descriptions summarizes the large amount of information that has been gathered, and the important geologic interpretations that has been made by Corps of Engineers geologists, engineers, and consultants.

This project called for preparation of 13 slides covering geologic aspects of Areas I, II, and III, on the Salt Fork Arkansas River and Cimarron River in northwest Oklahoma and southwest Kansas. Three of these slides (nos. 1-3) are of a regional nature and serve to introduce the slides of specific areas. Five slides (nos. 4-8) deal with the geologic framework, salt deposits, brine movement, and emissions at Area I (Great Salt Plains). Five slides (nos. 9-13) show the geology, salt deposits, brine movement, and emissions at various sites in Areas II and III (Big and Little Salt Plains).

Several years earlier I had prepared some slides relating to studies carried out with the Corps of Engineers on brine-emission areas on Red River in north-central Texas. Inasmuch as these slides have proven especially useful in introducing the geologic setting for the chloride-control problems on both the Red River and the Arkansas River, I am including copies of these slides and descriptions of the slides in this report. Three of these slides (nos. 14-16) are useful in showing the origin of the Permian salt beds and how the regional distribution, depth, and dissolution of these salts relates to the Chloride Control Project. The other two slides (nos. 17-18) show the general geology, salt deposits, and emissions along Red River and its tributaries in north-central Texas (Areas V, VII, IX, XIII, XIV, and XV).

Slide 1

Schematic Diagram Showing Circulation
of Fresh Water and Brine near Salt Plains

This slide shows in a simplified manner the apparent movement of ground water and the origin of the brine emitted at the salt plains on the Arkansas River. Fresh ground water (shown by blue arrows) migrates downward and laterally to the salt beds, which are 50 to 400 feet below the surface, and it dissolves the salt to form brine. The brine (shown by red arrows) then is forced laterally and upward by hydrostatic perssure through aquifers or through joints and fractures until it is emitted at the surface. Upon reaching the surface, the brine is evaporated and a crust of salt (NaCl) is built up on the salt plain.

There are 4 (some slides show 5) principal ways whereby the fresh ground water is recharged. 1. Water seeps into the ground through permeable rocks and soils, such as those areas where sandstone (ss.) is at the surface. 2. It enters the bedrock through highly permeable alluvium and terrace deposits along and near the major streams and rivers. 3. It enters through sinkholes and other karst features in areas where gypsum, limestone, or dolomite are at the surface. 4. It enters through joints and fractures present in the rocks, particularly where underlying salt beds are partly dissolved and the rock is more fractured due to collapse. (Some slides show a fifth recharge method, but this is not known to be important near the salt plains. Omit #5 if it is not shown on the slide.) 5. And it may, in some areas, enter through breccia pipes, which are vertical cylinders of broken rock or rubble that result from collapse into a cavern far back from the dissolution front (breccia pipes have not yet been identified near the salt plains, but they are known in other parts of western Oklahoma and may still be found during later studies).

After the water has dissolved some of the salt and has become brine, there are 6 principal ways whereby it moves underground and is discharged. The driving mechanism in all cases appears to be the hydrostatic head created in the recharge areas, with brine moving laterally and upward toward the piezometric surface. 1. Brine moves through solution cavities in the salt or other soluble rocks. 2. It moves through joints and fractures, particularly where the rock is broken over dissolution cavities. 3. It moves through aquifers consisting of sandstone, siltstone, or other permeable rocks (see brown layer on right side of diagram). 4. It can be emitted at point sources as a spring of salt water. 5. It can be emitted along a stream bed and become part of the surface waters. 6. And it can enter the base of the overburden where it will be forced upward by hydrostatic pressure and then drawn upward by capillary action as the brine is evaporated.

Regional Geologic Cross Section
Showing Permian Evaporites in Northwest Oklahoma

As a result of evaporite deposition in the shallow inland sea during Permian time, 3 principal salt units were laid down in northwest Oklahoma. The deepest of these is the Hutchinson salt, which is present in the upper part of the Wellington evaporites. This salt is 300 to 500 feet thick and contains interbeds of shale and anhydrite. The middle evaporite unit is the Cimarron evaporites, which consists of a Lower and Upper Cimarron salt separated by the Cimarron Anhydrite (middle blue band). Both the Lower and Upper Cimarron salts are present at considerable depth beneath the salt plain in the west near Freedom, but only the Lower Cimarron salt extends eastward to the area of Cherokee and Great Salt Plains (Area I). Both salt units consist of interbedded salt and shale, with the percentage of salt decreasing eastward. The youngest salt, the Flowerpot salt, is present only in the area west of Freedom, and it lies just below the gypsums of the Blaine Formation. The Flowerpot salt also consists of interbedded salt and shale, and it grades laterally into shale toward the east.

Ground water is circulating down to the Flowerpot salt in the west, is dissolving the salt, and is emerging as a brine at the salt plain near Freedom (Area II). The deeper Cimarron salts are too deep to be providing any of the brine at this site. Farther east, however, the Lower Cimarron salt is at shallow depth and it appears to be the major source of brine being emitted at the salt plain east of Cherokee. The only other salt underlying the area, the Hutchinson salt, is about 1,000 feet deep and is clearly not providing any of the brine at this site.

Slide 3

Nomenclature Chart Showing Permian Bedrock And Salt Units of Northwest Oklahoma

This slide shows the names of the principal rock units of Permian age that crop out and are at shallow depth in Areas I, II, and III. Also emphasized are the salt units that are present beneath each area, and the position at which salt is being dissolved to produce the brine emitted at each salt plain.

In Areas II-III, in the west, the Flowerpot salt is being dissolved and is seeping to the surface through fractures in the surrounding Flowerpot Shale.

Farther east, these same rock units are eroded and it is the Lower Cimarron salt that is being dissolved beneath Area I. Brine is migrating through aquifers in the overlying Harper and Salt Plains Formations and is reaching the surface at the salt plain.

(At this time, it is possible to point out or discuss any rock formation that will be of special importance later on in the talk.)

Slide 4

Generalized Geologic Map and Cross Section of Great Salt Plains (Area I)

The generalized geologic map shows the distribution of alluvium, terrace deposits, and bedrock in the vicinity of Area I. The salt flats, both Great Salt Plains and Sucker Flat, are developed on alluvium and low terraces near Salt Fork of Arkansas River. Brine comes up from the underlying bedrock and permeates the loose sand, silt, and clay at these sites. Water in the Great Salt Plains Reservoir and in Salt Fork of Arkansas River is highly charged with salt (chlorides) from this point on downstream: brine seeps into the river and the reservoir, and the salt periodically is flushed off the salt flats by rain and floods.

Bedrock units, including the Harper, Salt Plains, and Cedar Hills Formations (see cross section) are mantled by about 10 to 40 feet of alluvium and terraces in the area. Rock salt is present about 250 feet below the surface of the salt plain between the Harper Formation and the Ninnescah Shale.

Geologic Cross Section Showing Salt and other Bedrock Units at Great Salt Plains (Area I)

This cross section is drawn westward from a core drilled near the dam on Great Salt Plains Reservoir, and is based upon geologic study of 4 of the deeper cores drilled during the early stage of exploration. The data show that the Lower Cimarron salt decreases both in thickness and in amount of salt from west to east: it is 100 feet thick and 40% salt in the west, near the Alfalfa-Woods County line, and is only about 20 feet thick and 10% salt near its eastern limit beneath the salt plains. The Lower Cimarron salt sequence consists chiefly of shale, but it contains salt mainly as veins, nodules, and scattered crystals throughout the sequence.

Brine is migrating upward until it reaches the artesian zones (brown) in the Kingman Member of the Harper Formation and the lower part of the Salt Plains Formation. The brine then migrates updip into the base of the Quaternary overburden, and then it is drawn to the surface where the water evaporates and leaves a crust of salt on the surface.

Slide 6

Generalized Geologic Cross Section Showing Brine Movement at Great Salt Plains (Area I)

This generalized cross section focuses on the flow of brine in the bedrock aquifer system and in the overburden at Great Salt Plains (Area I). Brine is formed at depth by dissolution of Permian salt beds, and then it flows under artesian pressure through the several artesian zones. Our studies have identified 2 principal artesian zones, which we refer to as the lower and upper artesian zones. These artesian zones are permeable sandstone and siltstone beds that make up part of an aquifer system, about 100 feet thick, through which most of the brine flows to the surface. The brine moves laterally through the artesian zones and locally it moves vertically upward through fractures in the adjacent shales.

Finally the brine emerges into the base of unconsolidated sand, silt, and clay that makes up the Quaternary overburden covering the bedrock. Once in the overburden, the brine continues moving upward due to hydrostatic pressure and capillary action. Evaporation of water from the brine at the surface causes a crust of salt to form over the salt plain.

Selenite crystals are growing in the overburden, just below the surface of the salt plains, in a few places where the gypsum and salt concentrations of the brine are favorable for precipitation of selenite gypsum. In addition to the high concentration of NaCl, the brine also locally contains high concentrations of calcium sulfate. When the water is evaporated in these areas, the calcium sulfate precipitates as selenite crystals in the loose sand in the same way as the salt crust forms on the surface.

Slide 7

Subcrop of Bedrock Artesian Zone
at Base of Overburden, Great Salt Plains (Area I)

Shown on this slide are the areas where the two artesian zones subcrop at the base of the overburden in the vicinity of Great Salt Plains (GSP) and Sucker Flat (SF). The artesian zones are beds of porous and permeable sandstone and siltstone that are carrying the major flow of brine under artesian pressure. The brine flows upward and eastward in these beds until it reaches the base of the overburden, and then it spreads out in the overburden.

Our geologic studies have centered on the salt plains and the areas just to the west and northwest. The few test holes drilled to the south and in the far north do not indicate that these zones are permeable or that they carry significant amounts of brine; therefore it appears as though the brine-emission problem is confined to Great Salt Plains and Sucker Flat, and to the areas close to these salt flats.

Slide 8

Chloride Concentration of Water at Top of Bedrock, Great Salt Plains (Area I)

This slide shows the area where high-salinity brine was encountered at the top of bedrock during the early geologic studies. A fairly large area has water with at least 250 ppm chloride, and the concentration increases markedly toward the Great Salt Plains and Sucker Flat. Locally the water is as much as 160,000 ppm chloride, and at this concentration the brine is fully saturated so that salt will precipitate as soon as the brine reaches the surface.

The area of high chloride concentration at Area I agrees closely with the subcrop of the lower and upper artesian zones (as seen on previous slide). Furthermore, it shows that the fractured shales that make up the remainder of the 100-foot-thick aquifer system are also carrying highly saline water and are emitting brine into the base of the overburden.

Slide 9

Geologic Map and Cross Section
Big and Little Salt Plains (Area II and Area III)

The generalized geologic map shows the distribution of the principal bedrock formations (Blaine gypsums and Flowerpot shales) and the overburden units in the vicinity of Areas II and III. The Blaine Formation is about 90 feet thick and consists of 3 main gypsum beds, each 10 to 25 feet thick, interbedded with thin beds of shale and dolomite. The Blaine and younger Permian units, such as the Dog Creek Shale and Whitehorse Group sandstones, comprise outcrops on top of the bluffs overlooking the salt plains on Cimarron River and Buffalo Creek. The rivers have cut down through the Blaine Formation in the area and now are incised in the underlying Flowerpot Shale, which is a thick unit of red-brown shale. The Flowerpot therefore is exposed in the high escarpments adjacent to the salt plains, and these shales would be the foundation and abutments for dams that might be constructed at most sites in the area.

Alluvium, consisting of loose gravel, sand, silt, and clay deposits 10 to 70 feet thick, partly fills the valleys of Cimarron River and Buffalo Creek. The terrace deposits, located mainly north of the river, consist cheifly of sand and gravel laid down by Cimarron River at a much earlier time, before it was deeply incised at its present location.

The top of the Flowerpot salt (see cross section) ranges from 30 to 200 feet below the surface of the salt plains, with dissolution being more advanced beneath the river. Brine formed by dissolution of this salt migrates upward and permeates the alluvium where it forms the two major salt plains. Fresh surface water flowing across these salt plains becomes highly charged with salt (chlorides), and periodic flushing of the salt flats by rain and floods further degrades the quality of water in Cimarron River.

Slide 10

Geologic Cross Section Showing Bedrock and Brine at Big Salt Plain (Area II)

This cross section shows subsurface distribution of salt beds and other principal rock types beneath Cimarron River at Area II. The section begins (on the left) back to the south of the escarpment where the Blaine Formation is present and where the upper surface of the salt has been dissolved only a minor amount. The section continues northward to the Survey-Report axis (core 2) and then extends southeast along the river past the possible Freedom axis (core 101).

Total thickness of the Flowerpot salt is as much as 300 feet several miles away from the river (on the left), but the salt thins eastward due to dissolution at the top and due also to depositional thinning toward the eastern limit of the salt. The Flowerpot salt consists chiefly of red-brown shale interbedded with salt. Salt occurs largely as isolated or intergrown halite crystals embedded in certain beds of shale, with halite making up 10 to 90% of these salt beds. The percentage of salt throughout the Flowerpot salt unit is about 50% in the west (left), but it decreases eastward to 10-20% near Freedom.

Brine is forming in the shallow subsurface by dissolution at the upper surface of the Flowerpot salt. Fresh water enters the subsurface in the vicinity of the salt plains and percolates downward through sinkholes, fractures, cracks, and other openings in the rock until it reaches the top of the salt, and then it dissolves the salt until the water is saturated with NaCl. Solution cavities near the top of the salt (red areas), and collapse features just above the salt, are the main avenues for lateral movement of brine. These features are zones of high permeability or "lost circulation" (during drilling), and the water in these zones normally is under artesian pressure. Brine then moves upward under hydrostatic pressure through fractures in overlying shales and sandstones until it reaches the base of the alluvium, and then it is drawn to the surface where it forms the salt plain.

In general, the geologic problems related to dam construction decrease toward the east. The effect of dissolution at the top of the salt and disruption of overlying rock becomes less downstream from the Survey-Report axis, and appears to be absent in the Freedom area.

Slide 11

Geologic Cross Section Along Freedom Brine-Dam Axis Below Big Salt Plain (Area II)

Shown on this slide is a generalized cross section across Cimarron River downstream from Area II near the town of Freedom. The location is referred to as the Freedom site and it is a potential location for a brine dam.

Alluvium is 25 to 45 feet thick and it overlies a thick section of Flowerpot Shale above the salt. In the river valley the top of the salt is about 150 feet below the surface, and the test holes did not encounter a zone of high permeability or high artesian pressure at the top of the salt. Drilling water was lost, however, at the top of salt in core hole 107 (right).

The abutments on both sides of the river are escarpments of Flowerpot Shale, capped by gypsums of the Blaine Formation that are 120 feet above present stream level (thus the gypsum would be above the level of a brine pool). Outcropping strata are horizontal, or they may dip gently toward the river, and do not appear to be disrupted or fractured as the rocks do farther upstream.

Geologic Cross Section Along Buffalo Cr.
Fresh-Water Dam Above Big Salt Plain (Area II)

This cross section extends north-south along the Survey-Report axis of the fresh-water dam on Buffalo Creek. The Flowerpot salt is about 200 feet thick just back from Buffalo Creek, but quite a bit of the salt at the upper surface has been dissolved beneath the valley. The top of the salt is 100 to 120 feet below the surface. As a result of this salt removal beneath the valley, the overlying rocks have been let down and they now dip or drape towards Buffalo Creek from both sides of the creek; this drape is shown in the projection of the base of the Blaine Formation across the valley (there is a gentle downward "sag" in the middle of the cross section). The configuration of the top of salt and of the base of alluvium is based upon a seismic profile made by Geo Prospectors, Inc., in 1961.

Not enough data are now available at this site to determine if porous zones with artesian water are present at the top of salt beneath the valley. Undoubtedly brine is present in the fractured and jointed Flowerpot Shale, as well as in some of the alluvium. Some salt water was encountered at the top of salt in core hole 13 (left), and broken rock and core loss were encountered at the top of the salt in a hole (16-76) drilled 2.5 miles upstream from the site.

Recent studies indicate that brine is being emitted into Buffalo Creek just upstream from this axis, and thus it may be desireable to shift the axis upstream about 1 mile in order to exclude this brine from the fresh-water impoundment. The abutments at the Survey-Report axis, or at a site 1 mile upstream, would be the Flowerpot Shale, and the base of the overlying Blaine gypsums is about 60 feet above stream level in the area.

Geologic Cross Section Along Comanche Fresh-Water Dam Above Little Salt Plain (Area III)

Shown here is a cross section along the Comanche fresh-water dam. This site is the Survey-Report axis, and it is located upstream of any known significant brine emission on Cimarron River. The Flowerpot salt is believed to be about 250 feet thick in the area. The top of the salt is 120 to 150 feet below the surface in the Cimarron River valley, and the upper surface of the salt has been modified by dissolution that was more pronounced beneath the river. The configuration of the top of salt was established in a seismic profile made by Geo Prospectors in 1961.

As at Area II, the Flowerpot salt consists chiefly of red-brown shale interbedded with salt. The salt occurs in certain beds as crystals of halite intermixed with shale, and salt makes up 50 to 80% of the unit in cores.

Dissolution of the upper surface of the salt has occurred in the past, and it may be going on at present. Several of the core holes drilled on or near the axis encountered some brine, high-permeability zones, and/or broken rock above the somewhat irregular upper surface of the salt. The high-permeability zone here does not appear to be as cavernous as it is farther downstream at Area II.

The abutments for a dam at this site would require excavation of sandy terrace deposits, and some special consideration of the Blaine gypsums if the pool were to be more than about 20 feet deep. About 20 feet of Flowerpot Shale would be present in both abutments after removal of sand.

Major Facies During Deposition of Middle Permian Evaporites in Southwest United States

During much of Permian time, western Oklahoma and surrounding areas were covered by a shallow inland sea that extended northward behind limestone reefs that bordered the Delaware and Midland basins of West Texas and southeast New Mexico. Normal marine water entered this inland sea from the ocean farther southwest, and as it crossed the shallow sea it was partly evaporated until a series of evaporite minerals (chiefly gypsum and rock salt) were precipitated as layers of sedimentary rock on the sea floor. This was the way the thick deposits of salt that now underlie the various salt plains of Oklahoma, north Texas, and Kansas were formed.

While salt was being deposited in the central parts of the inland sea, fresh water drained from surrounding land areas and flowed into the sea. The fresh water mixed with the highly saline sea water and prevented further precipitation of salts near the coastal areas, and it also brought in sand, silt, and clays which were deposited as muds and other fine-grained clastic sediments. The redbed shales, siltstones, and sandstones therefore grade laterally into salt beds toward the sea, and some of them extended out into the sea as thick layers that are interbedded with the evaporites.

Slide 15

Map and Cross Section Showing Distribution of Permian Salt and Salt Plains

The salt beds deposited in the inland sea during Permian time now underlie a vast area that extends from north-central Texas into central Kansas. In the schematic cross section (below) you can see the salt consists of several thick deposits that are overlain now by a moderately thick sequence of younger rocks. Fresh meteoric and stream water appears to be entering the ground back to the west of the leading (eastern) edge of the salt, and this water is dissolving the salt beds at relatively shallow depths back to the west or beneath the salt springs. The brine formed by dissolution of salt appears to be migrating eastward under hydrostatic pressure until it reaches the land surface where it forms a series of salt plains and salt springs.

As shown on the map, these natural salt plains are located on the eastern side of the area underlain by salt, and the brines reaching the surface are degrading Red River and the Arkansas River. Individual salt plains are releasing water with concentrations of 20,000 to 300,000 ppm NaCl, and they each contribute 100 to 3,000 tons of NaCl per day. A total of 5,000 to 10,000 tons of salt enters each of the two major rivers and its tributaries each day.

Complete Cycle of Evaporite Deposition
Flowerpot, Blaine, and Dog Creek Formations

Shown on this slide is the vertical sequence of rocks that were deposited during a normal cycle of evaporite deposition. They were laid down successively on the sea floor as the water was evaporated and became more saline.

At the beginning of a cycle, dolomite or limestone was deposited as a normal-marine sediment. Dolomite beds of the region range from 0.1 to 10 feet thick, but they average about 3 feet.

As the water became more concentrated through evaporation, gypsum or anhydrite were precipitated onto the sea floor. This happened when sea water was evaporated to about one-third of its original volume. The thickness of these gypsum beds averages 15 feet, although it ranges from 3 to 30 feet.

With further evaporation of the water to one-tenth its original volume, salt began to precipitate onto the sea floor. Individual salt beds generally range from 5 to 40 feet and average about 15 feet.

Freshening of the water, either by an influx of fresh water from the shore or of a large amount normal marine water from the open sea, ended evaporite deposition and led to deposition of red- and gray-colored shales washed into the sea by streams and rivers.

With a marked decrease in the amount of clay being brought into an area, dolomite or limestone were again deposited and thus began a new cycle.

Nearly 20 major evaporite cycles have been identified in north-central Texas and southwest Oklahoma, and 5 major cycles have been identified in northwest Oklahoma. These cycles may be complete or they may only be partial: none are complete on the outcrop, because at no place in the Permian basin are beds of rock salt found at the land surface. Even in the subsurface, all parts of the cycle may not be present at all locations:

1. the water may have been <u>diluted</u> before the next evaporite unit was deposited.

2. the water may have been <u>depleted</u> of certain chemicals needed for the next evaporite unit before it reached a particular location.

3. a soluble evaporite unit (mainly salt or gypsum) may have been deposited originally, but was later <u>dissolved</u> by percolating ground water.

Distribution of Salt Beds in Subsurface
(Childress, Hall, Cottle, and Motley Counties, Texas)

This slide shows stratigraphic and geographic distribution of bedded rock salt that is feeding the salt plains on Red River and Please River in north-central Texas. Thick salt deposits occur in the Flowerpot, Blaine, and Dog Creek Formations, all of which were deposited during Permian time on the east side of a broad, shallow, inland sea.

The oldest and deepest of the salts (Flowerpot) underlies most of the area and extends farther east and northeast than any shallower salt. The present eastern and northeastern limit of the Flowerpot salt is a dissolution limit: that is, it once extended farther east but has been dissolved and thus has produced the brine which is being emitted at the various salt plains along the eastern edge.

The next youngest salts, those in the Blaine Formation, have also been dissolved in the east and now are restricted only to Motley County and southwest Hall County.

The youngest salts, those of the Dog Creek Formation, are limited still further to the western 2/3 of Motley County and only a small part of Hall County. This limit also results from dissolution of a salt that once extended farther to the east.

In all cases, the nearby salt plains are obtaining their brine by dissolution of subsurface salt beds that are back to the west or southwest and downdip from the salt plain.

Slide 18

Structural Cross Section Showing Salt in Flowerpot, Blaine, and Dog Creek Fms. (Childress, Hall, Cottle, and Motley Counties, Texas)

This cross section is drawn from southwest to northeast and it shows the general subsurface distribution and dissolution of salt beds in the Flowerpot, Blaine, and Dog Creek Formations. The cross section, made from 6 oil and gas test holes, covers a part of north-central Texas, near Areas V, XII, XIV, and XV, on Prairie Dog Town Fork Red River.

Salt beds of these 3 formations were once more widely distributed in this area than they are today. The depth to the top of various salt beds to the southwest (left) is about 500 to 800 feet, and the salt has been dissolved by ground water in those updip areas farther northeast (to the right) where salt would now be less than about 500 feet below the surface. Accompanying this dissolution of salt is widespread disruption and collapse of overlying rock layers, and this enhances the later access of more fresh water to the underground salt beds. Salt dissolution is most pronounced beneath and along Red River, where the land surface has been lowered close to the salts and where the amount of circulating fresh ground water has been greatest. Evidence that salt once had a greater distribution is seen in the outlying mass of Flowerpot salt that has not been dissolved because it is preserved at considerable depth in the syncline northeast (right) of the Plaska dome: salt once present between this mass and the main body of salt has been dissolved.

Although hydrogeologic tests have not been made along this cross section, it appears that fresh ground water percolates down to the salt, dissolves it, and the resultant brine is forced laterally and upward through cavernous and disrupted rock to the surface in Red River and its tributaries.