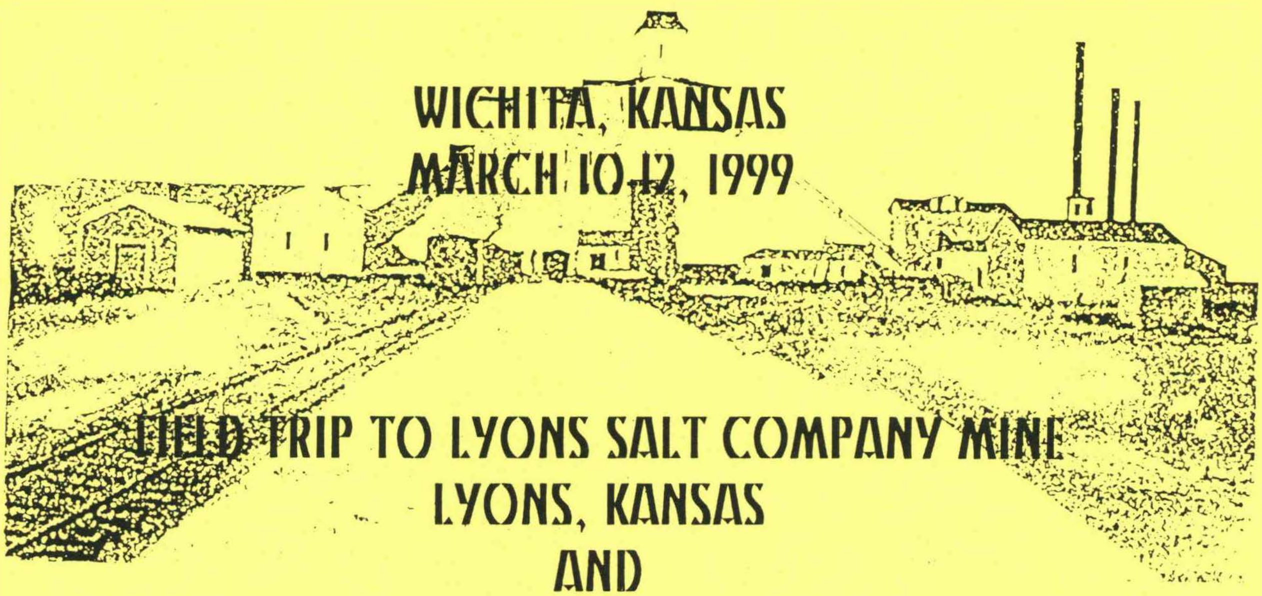
36TH SIPES ANNUAL MEETING



WICHITA, KANSAS
MARCH 10-12, 1999

FIELD TRIP TO LYONS SALT COMPANY MINE
LYONS, KANSAS
AND
KANSAS COSMOSPHERE
HUTCHINSON, KANSAS

SOCIETY OF INDEPENDENT PROFESSIONAL EARTH SCIENTISTS
SIPES

HOSTED BY THE KANSAS CHAPTER OF SIPES, WICHITA, KANSAS

FIELD TRIP GUIDE TO LYONS SALT MINE AND WICHITA - LYONS - HUTCHINSON AREA

PART I - ITINERARY

PART II - HISTORY OF THE LYONS SALT MINE

PART III - ORIGIN AND DISTRIBUTION OF THE HUTCHINSON SALT IN KANSAS

COMPILED BY:
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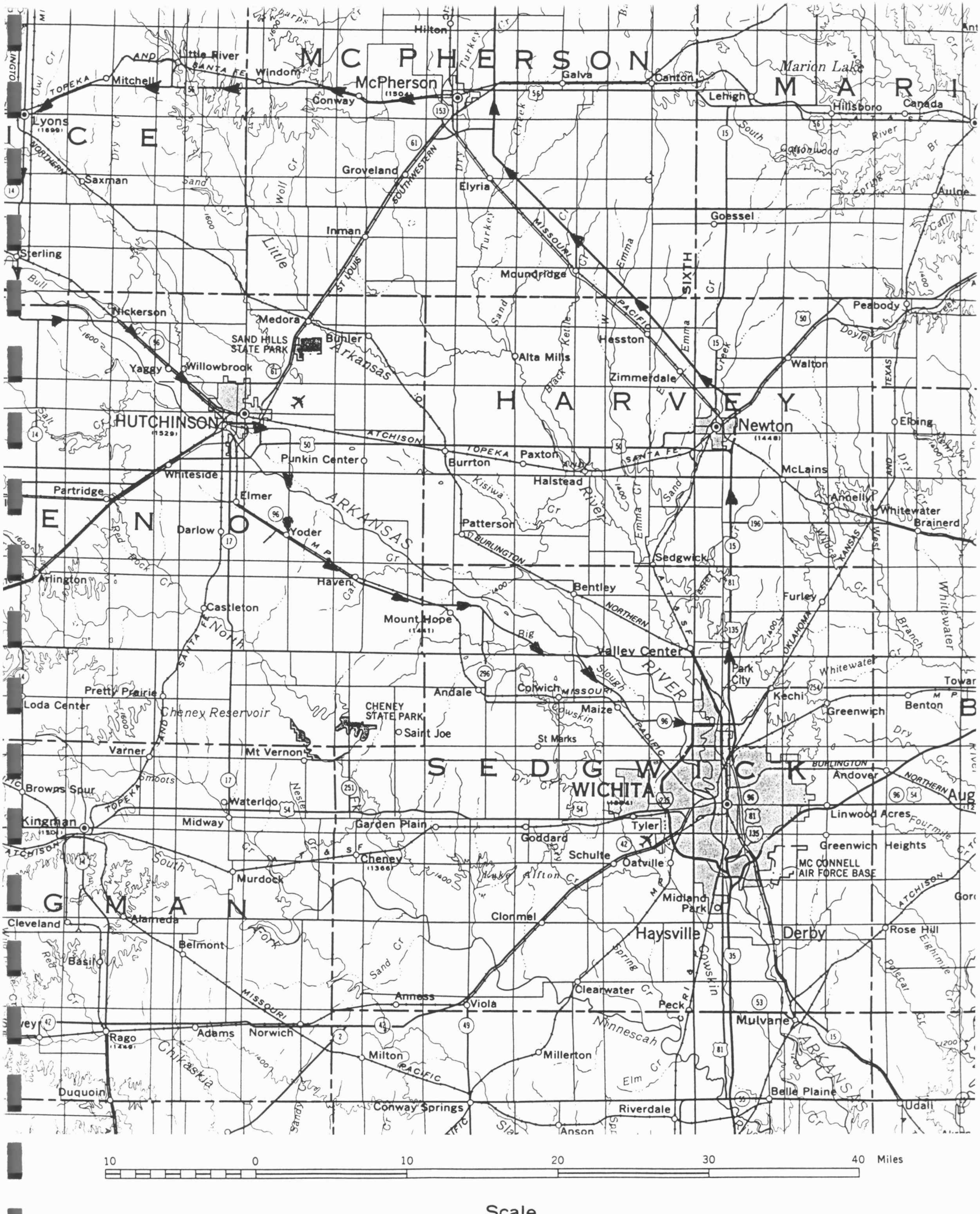
W. LYNN WATNEY, KANSAS GEOLOGICAL SURVEY

ITINERARY

BY
LAWRENCE H. SKELTON


MC PHERSON
HARVEY
SEDGWICK
Lyons
Mitchell
Little River
Windom
McPherson
Conway
Galva
Canton
Lehigh
Marion Lake
Hillsboro
Canada
Saxman
Groveland
Elyria
Goessel
Aulne
Inman
Sterling
Moundridge
Nickerson
Medora
Buhler
SAND HILLS STATE PARK
Yaggy
Willowbrook
Alta Mills
Hesston
Zimmerdale
Peabody
Walton
HUTCHINSON
Newton
Elbing
Punkin Center
Burrton
Paxton
Halstead
McLains
Whiteside
Partridge
Elmer
Darlow
Yoder
Patterson
Annelly
Whitewater
Brainerd
Arlington
Sedgwick
Haven
Bentley
Furley
Castleton
Mount Hope
Valley Center
Park City
Pretty Prairie
Loda Center
Cheney Reservoir
CHENEY STATE PARK
Saint Joe
Andale
Colwich
Maize
Kechi
Greenwich
Benton
St Marks
Varner
Mt Vernon
Browns Spur
Waterloo
WICHITA
Andover
Kingman
Midway
Garden Plain
Goddard
Tyler
Linwood Acres
Schulte
Oatville
Greenwich Heights
Cheney
Murdock
MC CONNELL AIR FORCE BASE
Midland Park
Cleveland
Alameda
Clonmel
Haysville
Derby
Rose Hill
Belmont
Basil
Anness
Viola
Clearwater
Peck
Mulvane
Rago
Adams
Norwich
Milton
Millerton
Duquoin
Conway Springs
Riverdale
Belle Plaine
Udall
Anson
ARKANSAS
ATCHISON TOPEKA AND SANTA FE
MISSOURI PACIFIC
SIXTH
10 0 10 20 30 40 Miles
Scale

ITINERARY

INTRODUCTION

Welcome to Kansas, the Sunflower State, and to its largest city, Wichita, the "Peerless Princess of the Plains" as it was called in local advertising a century ago. This field trip arranged by the host, the Wichita Chapter of SIPES, will traverse about 180 miles through south-central Kansas. The itinerary includes a visit to the underground mine of the Lyons Salt Company in Lyons. Kansas and visits to two museums, one being the nationally renown Kansas Cosmosphere in Hutchinson, Kansas.

The route travels through five counties which together encompass 4434 square miles. Of that area, slightly more than 4092 square miles (92.3%) is agricultural land. In 1997, total value of agricultural production was $541,600,000.00. Wheat alone was valued at $193,793,000.00 representing harvest of 62,366,700 bushels. The remaining $348,000,000 was made up of other grains and livestock, mostly cattle.
The area has produced oil and gas since the 1920's. Recent (fiscal year 1997) production for the five counties was 2,531,681 barrels of oil (6% of state production) and 3,982,825 MCF of gas (a little more than 0.5% of state production).

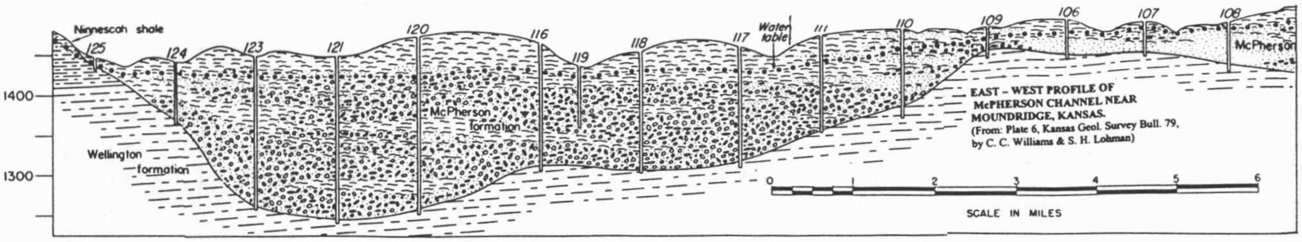
Although 30% of Kansas' natural gas production was produced in southwestern Kansas by major companies, Amoco and Mobil, it is noteworthy that the state's top ten oil producers were all independents. In fact, in 1998, Kansas had 2106 licensed operators: 75.03% of all active licensees in the United States. Many of these, however, are individuals who operate their own gas well for domestic use.

In the realm of industrial minerals, the five county area produces salt in Sedgwick, Rice and Reno Counties, clay in McPherson County, and sand and gravel in Sedgwick, Harvey and Reno Counties. Gross production and value of these commodities is not available. Helium in produced in nearby Ellsworth County. Kansas remains the leading helium producer in the United States. Crude helium production is valued at $27.6 million and refined grade A helium is valued at $104 million.

ITINERARY

inter. miles	accum. miles	
0.0	0.0	Leave the Wichita Hyatt Hotel to Kellogg (U.S. Highway 54) and travel east to intersection of Interstate Highway 135. Proceed to north on I-135.
5.3	5.3	Passing through the Wichita Oil Field, a 1957 discovery of the Derby Refining Company. It produces from the Ordovician age Viola limestone and Simpson sand. The discovery which was made while Derby was drilling a water disposal well has resulted in production of slightly over 3,000,000 barrels of petroleum during the past 42 years. Constructed on top of the oil field is the Coastal Corp. Wichita refinery. Closed down for the past five years, it had a daily refining capacity of 25,000 barrels of crude It was originally built in 1917 by the Western Refining Company. A.L. Derby, an entrepreneur involved with early development of the nearby El Dorado Field, bought the refinery in 1920 and expanded it. The Derby Company operated it until 1987 when Coastal purchased Derby. Coastal closed the refinery in 1993. This part of north Wichita has long been home to refineries. Five refineries were working in this general area by mid-1918.
5.2	10.5	Town of Park City on the right. The founders had big ideas and the town originally was named Cosmosa – cosmos with an "a".
2.3	12.8	The Wichita Greyhound Park on the right is presently the state's only operating dog track. It presents dog racing throughout the year. The Valley Center Oil Field is about 1.5 miles west of the highway. Discovered in 1928 by the Bu-Vi-Bar Oil Company, it produces oil from six zones and has produced 25,000,000 some barrels of oil since discovery. The field which was discovered from a core-drilling anomaly is developed on a closed structure on the Bluff City Anticline.

3.2	16.0	The highway crosses the middle of the Goodrich Oil Field which was a 1928 discovery of the Continental Oil Company. The field which produces from three zones at depths ranging from 2450 to 3350 feet is on a structural closure on the Valley Center trend and was discovered and outlined by core drilling. The discovery well initially produced at 1780 barrels per day. During its 70 years, the Goodrich has produced about 6,600,000 barrels of oil.
2.7	18.7	Sedgwick – Harvey County line.
9.5	28.2	To the left is Newton, the county seat of Harvey County and home of Bethel College founded in 1887, the oldest Mennonite college in America. Newton was an early railroad town and owes its name to the fact that its organizers were railroad financiers from Newton, Massachusetts. For a year or so, in 1871, the terminus of the new Santa Fe Railroad was at Newton and the end of the Chisholm Trail was there. During its tenure as a cattle shipping center, Newton held the record for the greatest number of violent deaths and had a reputation for being "bloody and lawless, the wickedest city in the West." The county was named in honor of the fifth (and then current) Kansas governor, James Madison Harvey, to curry political support for plans of the county organizers. Governor Harvey, who had been an officer in the Civil War, later served as U.S. senator.
3.5	31.7	Sand Creek
2.5	34.2	Crossing the Sixth Principal Meridian which divides the east range of Kansas from the west range which extends into Colorado. The meridian was allegedly laid out in the last century by U.S. Army Topographic Engineers whose orders were to ride three days west from Fort Leavenworth and on arising on the fourth day, to survey a north-south meridian.
0.5	34.7	East Emma Creek
2.8	37.5	Middle Emma Creek
0.5	38.0	Hesston, Kansas on the left. Home of Hesston College and the Hesston Corporation, a tractor and farm implement manufacturer presently owned by Italian interests.
3.0	41.0	Harvey - McPherson County line.
1.2	42.2	West Emma Creek
1.6	43.8	Moundridge exit. The highway is tangentially approaching the buried McPherson Channel. This feature is a "trough-like depression several miles wide, extending south from Salina [Kansas] to approximately 15 miles south of McPherson, connecting the Saline River of the Kansas River drainage with the Arkansas River drainage". The channel which seems to be early Pleistocene in age, is filled with Pleistocene deposits which form the well known Equus Beds, an aquifer which provides 40% of the public water supply of Wichita and virtually all the water supply for the smaller towns near it. The name "Equus" is from the fossil horses found in the re-worked Pliocene strata which with re-worked Cretaceous and Permian rock and Pleistocene alluvium constitutes the channel fill. The course of the channel is thought to have been caused during Pliocene time by solution and collapse of the (Permian) Hutchinson Salt along its eastern edge. This filled with stream and lake deposits. During Kansas time, glacial ice blocked the Kansas River and its tributary Smoky Hill River was diverted to the McPherson Channel which rapidly filled with alluvium. When the icecap retreated, the Kansas River recaptured the Smoky Hill and the McPherson Channel was abandoned.

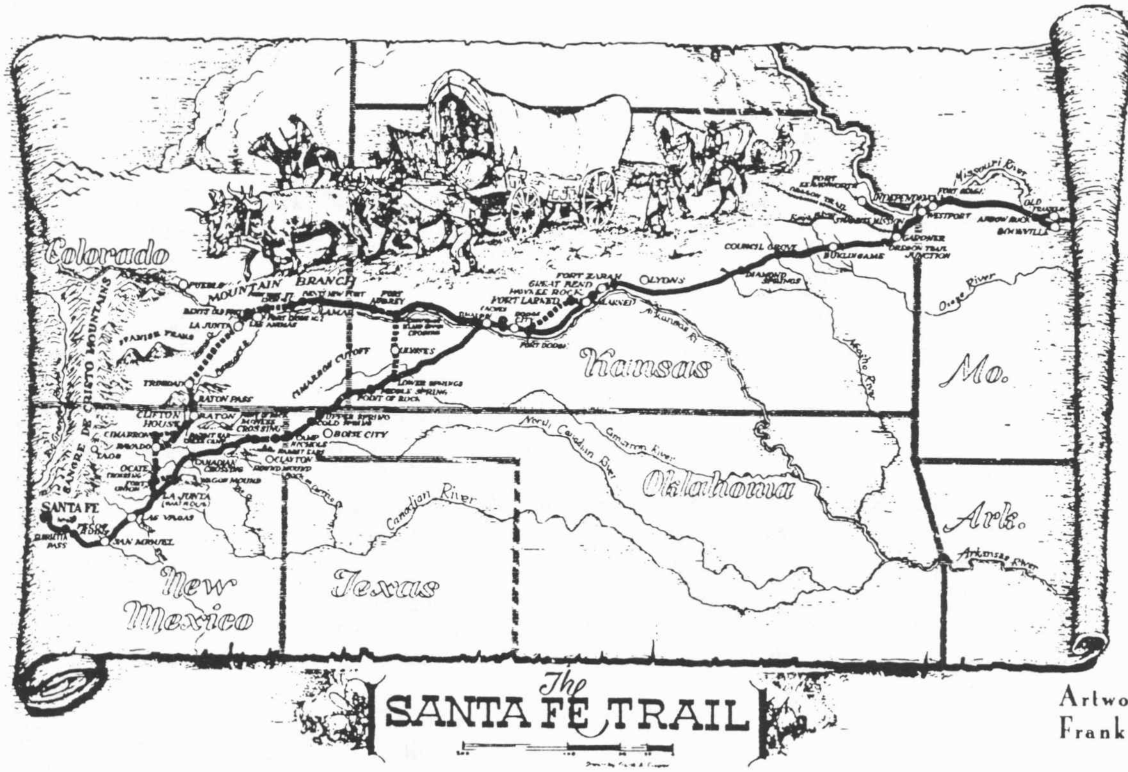


EAST - WEST PROFILE OF McPHERSON CHANNEL NEAR MOUNDRIDGE, KANSAS. (From: Plate 6, Kansas Geol. Survey Bull. 79, by C. C. Williams & S. H. Lohman)

1.5 45.3 Pass between the Winsinger Oil Field on the right and the Winsinger West on the left. The Winsinger which was discovered in 1968 has produced about 1.1 million barrels of oil from the Hunton Group (Silurian/Devonian) and Maquoketa Formation (Ordovician) The Winsinger West, a 1975 discovery, has produced about 121,000 barrels of Hunton Oil and 375,000 MCF of Mississippian Gas.

7.0 52.3 Running Turkey Creek. The round pond just north of the creek may represent evaporite dissolution.

1.4 53.7 Turkey Creek. There are 17 Turkey Creeks or variations of the name in Kansas. This particular Turkey Creek in McPherson County was important on the Santa Fe Trail, probably for filling water barrels. The trail crossed Turkey Creek in this vicinity.



Artwork by Frank A. Cooper

Artwork by Frank A. Cooper from: "Follow the Santa Fe Trail through Rice County, Kansas." Printed with permission of the Coronado - Quivera Museum, Lyons, Kansas.

2.5	56.2	Intersection with Kansas Highway 61. This intersection is in the middle of the Johnson Oil Field, a 1932 discovery by Shell Oil. Early wells produced about 500 BOPD of 37 degree oil. Accumulative production from Mississippian and Simpson state is 4.8 million barrels of oil and about 3.1 MMCF of gas. Note the National Cooperative Refinery Association's refinery which is visible to your left. One of the three operative refineries remaining in the state, it has daily crude capacity of 54,150 barrels.
2.1	57.3	Intersection with U.S. Highway 56. Turn west.
1.2	58.5	City limit of McPherson, the county seat, population 12,937. Both city and county are named in honor of General James Birdseye McPherson, the popular and able commander of the Army of Tennessee. He was with Sherman at Atlanta and was killed in action there in July, 1864, by Confederate troops under General John Bell Hood, McPherson's West Point classmate. Veterans returning to or moving to Kansas proudly named their new town for their commander.
2.0	60.5	Dry Turkey Creek. Intermittent at this point, it becomes a flowing stream about a mile-and-a-half south and flows nearly straight south for almost 14 miles. Its course probably was established by the solution front of the Hutchinson Salt.
1.9	61.4	McPherson County Courthouse. Built in 1894 and listed on the National Register of Historic Buildings. On the lawn is a statue (the only life size, bronze, equestrian statue in Kansas) of General McPherson mounted on a horse. Note that the statue faces to the south as do most northern Civil War monuments of people…Confederate monuments usually face northward.
1.1	62.5	Bull Creek Marshy areas which range several miles north and south of the highway are caused by subsurface salt solution. The 1893 edition of the USGS Hutchinson 15 minute topographic map indicates a marsh about 2560 acres in extent just to the north of here. Notice the escarpment ahead. It represents the edge of the salt.
1.8	64.3	About 8 miles south of here is Lake Inman, at about 160 acres surface area, it is the largest naturally formed lake in Kansas. It,too, is caused by solution of underlying salt.
3.1	67.4	Conway, Kansas. Conway is the site of underground gas storage caverns operated by Texaco, Mapco (Williams), Koch and NCRA. The caverns which generally are about 100 feet in diameter and 80 feet in height, were created by solution mining in the late 1950's and early 1960's, specifically for LPG storage. The Hutchinson Salt in this area is about 425 feet below the surface and is about 450 feet in thickness. At Conway, the highway leaves the Pleistocene McPherson Formation and for the next 3.5 miles is built atop of the Permian Ninnescah Shale. The Ninnescah Shale which overlies the Wellington Formation is a unit of the Permian (Leonardian) Sumner Group and is overlain by the Stone Corral Formation. The Ninnescah represents a transition from a siliciclastic, dolomitic carbonate and evaporite sequence to an evaporite – redbed sequence.
3.3	70.7	Williams Company gas fractionation plant. Koch Corporation isobutane separator immediately to the west.
0.8	71.5	The change in topography at this point corresponds with the Permian – Cretaceous unconformity in this area. The highway now is on the Kiowa Formation of Lower

Cretaceous age. Comprised of dark-colored shales and fine-grained sandstones in the area, the Kiowa is representative of a nearshore marine environment.

0.4	71.9	Lone Tree Creek. Several "lone tree" feature names may be found on Kansas maps, undoubtedly honoring the sparse vegetation encountered by early settlers. There once was a Lone Tree post office nearby.
0.8	72.7	Windom, Kansas on the right. Originally named Laura, then Hallville, in 1884, the name was changed to Windom to honor Senator William Windom of Minnesota who had chaired a Senate committee considering transportation routes to the Pacific.
0.8	73.5	Rice County line. Rice County is named in honor of Brigadier General Allen Rice, an Ohio River steamboat pilot who became attorney general of Iowa by age 28. He commanded an Iowa volunteer infantry regiment in the Civil War and died of wounds received at the Battle of Jenkins Ferry in 1864. Colonel Samuel J. Crawford of Kansas was at the same battle. He later was governor of Kansas and may have been responsible for Rice's name being attached to the new county.
0.2	73.7	Welch – Bornholdt Oil Field – The Welch – Bornholdt is a combination of several fields, all related to the Geneseo Uplift, a semi-detached easternmost lobe of the Central Kansas Uplift which is a major pre-DesMoinesian post-Mississippian positive structural feature. The Welch Field, which is the oldest, was discovered in 1924, allegedly on advice of a doodle-bugger, originally produced oil from the chert zone at the Mississippian – Pennsylvanian unconformity. The Bornholdt Field was a 1937discovery based on core drilling. Although principally a stratigraphic trap, it is located on a southeastward-plunging flexure in the pre-Pennsylvanian rocks. The Welch and Bornholdt fields were combined in 1953. It has about 560 operating wells and has produced 45,361,000 barrels of oil.
0.8	74.5	Harper Sandstone. The Harper Sandstone is the basal formation of the Lower Permian (Leonardian) Nippewalla Group. It is exposed for about a thousand feet here before again disappearing beneath the Kiowa Formation. The next 3.5 miles are over Quaternary loess and alluvium.
2.6	77.1	Little Arkansas River sometimes called the Little River.
		Kiowa Formation for the next half mile.
1.3	78.4	Turnoff to town of Little River.
		Quaternary loess.
4.5	82.9	Turnoff to town of Mitchell.
0.6	83.5	Jarvis Creek. Named for Don Antonio Jose Chavez , a wealthy member of a Santa Fe family who while traveling to Missouri with a wagon load of merchandise and $10,000 in cash and bullion in 1843, was killed by bandits at a site on this creek which was named Chavez Creek in his memory. The Spanish pronunciation eventually was Anglicized to Jarvis.
3.3	86.8	Lyons Gas Field. According to a 1939 Kansas Geological report, "The Lyons pool was discovered in 1888 and rediscovered in 1937" when Atlantic Refining Company's No. 1 Pulliam came in with 150,000 MCF per day from the Arbuckle. At the time, it was the second known Arbuckle gas producer in the state. Two years later, Derby Oil found Simpson oil and gas. As of late 1998, the Lyons has produced a total 102,000 barrels of oil and about 2,500,000 MCF of gas.

0.8	87.6	Owl Creek
0.6	88.2	City limit of Lyons, Kansas, birthplace and original home town of Bob Cowdery, past vice-president of SIPES and past president of AAPG. Here, we will visit the Lyons Salt Company's underground mine and the Coronado – Quivera Museum. Only a limited number of persons can be accommodated at one time in the mine, visitors will be shuttled between the mine and museum. As we travel through Lyons, note the limestone fenceposts in several front yards. This is the Fencepost Limestone unit of the Pfeifer Shale Member of the Cretaceous age Greenhorn Limestone. It is the uppermost unit of the Greenhorn and crops out for 215 miles from the Nebraska border in Washington County, Kansas, southwestward to near Dodge City in Ford County. Over that distance, it ranges in thickness from 0.55 feet to 1.1 feet and averages 0.79 feet for 15 measurements. The Fencepost's ease of working, consistent thickness, long outcrop and closeness to the surface in a band extending about 50 miles west of the outcrop made it a "natural" for use as a building stone and source of fence posts for settlers in the treeless plains of western Kansas. The nearest outcrop of the Fencepost Limestone is about 45 miles west of here.
3.0	91.2	Lyons Salt Company mine.

A Brief History of Kansas Salt

Several salt marshes were known to the settlers of Kansas by the earliest times. At the time of admission as a state, Kansas was allowed by Congress to set aside up to 12 salt springs each with six sections of land for exclusive use of the state. Subsequently, those reserves which all were located on salt marshes were given by the state to the endowment fund of the State Normal School. A Mr. Tuthill, a very early settler in southeastern Republic County was making salt by evaporation by the early 1860's and hauling it about 75 miles by wagon to Manhattan where he marketed it for ten cents per pound.
In 1867, on the basis of a near by salt spring, a brine well was drilled by the Continental Salt Company of New Bedford, Massachusetts, at Solomon City in Dickinson County. The well produced strong brine and a solar salt plant was built. The facility changed owners several times during the next 30 years. By 1899, it was owned by the Solomon Solar Salt Company and had capacity of nearly 1000 tons per year.

By the mid-1880's, settlers were swarming into central Kansas. Towns and factories were being started and money was available for speculation. Most of the new settlements were eagerly prospecting for coal, gas or any valuable commodity. Rock salt was frequently found but oddly ignored in so far as value. In 1887, a well at Ellsworth encountered salt at depth of 730 feet and penetrated 145 feet of salt. A mine shaft was begun but only reached 250 feet before depleting funds. Before it could recover, other towns more favorably located with respect to railroad transport were sinking shafts. A test well at Hutchinson in nearby Reno County found 400 feet of salt 500 feet below the surface although the operator, Ben Blanchard, had been hoping for gas and found traces of oil at total depth. New York salt companies quickly realized the value, came to Hutchinson, drilled two wells and erected a salt factory. By the end of 1890, 28 salt plants were operating in the state.

Early salt mining in Kansas was all by solution. However, by 1893, rock salt was being taken from underground mines: two at Kingman, two at Kanopolis and one at Lyons. All except one mine at Kingman had shafts extending a little over a thousand feet to the bottom of the salt and were mining at that level. Underground mining at Hutchinson began in 1923 when the newly constructed Carey Salt Mine was officially dedicated by then U.S. President Warren G. Harding.

From 1880 through 1997, approximately 105 million short tons of salt with value of about $1.5 billion have been produced in Kansas, placing the state among the top ten U.S. producing states since 1888. It has been estimated that about 13 trillion tons of reserves remain – roughly 1100 cubic miles – enough to build a salt wall 1000 feet high and two miles thick around the 1150 mile perimeter of Kansas…or to form a single halite crystal 10.33 miles on an edge.

A geological report on Kansas salt and an early history of salt mining at Lyons are included elsewhere in this guidebook.

0.8	92.0	South city limits of Lyons
0.5	92.5	Shumway Oil Field on the left. A 1965 discovery by Ben Hyde, the Shumway Field has produced 456,000 barrels of oil from the Mississippian Kinderhook.
0.7	93.2	D.A.R. marker. The Daughters of the American Revolution have placed several memorial markers along the Kansas portion of the Santa Fe Trail. This is one of eight in Rice County.
1.5	94.7	Cow Creek . This stream flows into the Arkansas River near Hutchinson. Its name is thought to have been translated from an Indian term referring to the bison cow.
0.7	95.4	Lyons Southwest Oil and Gas Field on both sides of the road. This field which was discovered in 1955 has produced 13900 barrels of oil from Pennsylvanian basal conglomerate and about 232,000 MCF of gas from the conglomerate, the Simpson and Arbuckle.
1.5	96.9	Union Gas Field on west side of highway and Union East Oil Field on east side. Discovered in 1950 and 1951 respectively, they produced gas and oil from Pennsylvanian basal conglomerate until their abandonment in the early 1980's.
0.4	97.3	Sand dune area. There are many small depressions on both sides of the road for the next six miles. Most of them likely are caused by blowouts of dune sand which presently are grown over by vegetation. Some are likely caused by solution of underlying Hutchinson Salt. Whether the solution is all naturally caused is moot since there have been oil and gas wells drilled in this area for the past 70 years or more. The dunes which are more prevalent a few miles to the west are the eastern fringe of the Great Bend Sand Prairie, a large sand sheet, about 1100 square miles in area, situated in the "great bend" of the Arkansas River. Current research indicates that the eolian dunes are Holocene in age.
1.7	99.0	Turnoff to Alden, Kansas.
1.6	100.6	Sterling, Kansas city limit. Sterling College on the right is a Presbyterian liberal arts institution founded in 1887. The town was founded by members of the Society of Friends (Quakers) and was named Peace. In 1876, it was changed to Sterling by two settlers from New York who re-named it for their father, Sterling Rosen.
2.0	102.6	Bull Creek. perhaps a friend of Cow Creek which was previously crossed.
3.8	106.4	Arkansas River. Pronounced with the accent on the "kan" only in Kansas, the Arkansas River which heads in Lake County, Colorado, is 1459 miles long to its confluence with the Mississippi River in Desha County, Arkansas. The Kansas portion is about 435 miles in length.

0.3	103.7	Sterling Oil and Gas Field to the left of the highway for the next three miles. Originally discovered in 1937, the Sterling has produced nearly 600,000 barrels of Mississippian oil and 467,000 MCF of Lower Permian gas.
0.8	107.5	Reno County line. Named for yet another Civil War general and West Point graduate, Jesse Lee Reno, who literally was "shot out of the saddle" during a surprise attack by Confederates at South Mountain, Maryland in September, 1862. Reno, Nevada also is named for him.
1.1	108.6	State highway 96 turns east here and skirts the south edge of the Sterling Field.
4.6	113.2	Gossage Gas pool to the right, one-half mile south. A 1973 discovery, it has produced about 430,000 MCF of gas from Mississippian strata.
0.3	113.5	Arkansas River. The remainder of the route to Wichita will parallel the river.
1.1	114.6	Nickerson, Kansas. Population: 1112. Named in honor of Thomas Nickerson of Boston, Massachusetts, president of the Santa Fe Railroad. In the 1640's, Nicholas Nickerson, founder of this family in America, tried to make a "land grab" which would have given him most of Cape Cod. He was thwarted by the colony's General Court. The federal land ceded to the Santa Fe Railroad 240-some years later *far* exceeded old Nicholas's dreams. Some dune sand may be noticable between Nickerson and Hutchinson. The dunes in this portion of Reno County are in the youthful stage but are not active. Sand thickness in the county ranges from a featheredge to as much as 120 feet.
9.8	124.4	Hutchinson city limit. Population about 40,000. Founded by C.C. Hutchinson, a Baptist preacher and agent to the Ottawa Indians, who followed the Santa Fe Railroad surveyors and picked this site (probably where the route crossed the Arkansas River) to lay out a town which he developed and named for himself. Salt was first discovered in Hutchinson in 1887 while drilling for oil and gas. The city became an important salt producing center and remains so with salt being recovered both from solution mining and shaft mining. Solution mining has caused some spectacular sinkholes in this area. An interesting spin off business is the use of abandoned salt mines for document archive storage. Hutchinson Community College offers the state's only small mine safety training program.
1.1	125.2	Cow Creek
1.7	126.9	STOP 2 . Kansas Cosmosphere and Discovery Center. This facility which last year became an official Affiliate of the Smithsonian Institute houses the nation's premier exhibit of space exploration artifacts. On departing, proceed eastward on 17th Street to the curve at Airport Road and turn south (right).
2.7	129.6	World's longest grain elevator to the right.
2.6	130.3	Salt Mine on right.
1.2	131.5	Intersection with U.S. Highway 50.
1.2	132.7	Cow Creek. The same Cow Creek crossed south of Lyons and on the west side of Hutchison. It enters the Arkansas River about 1.5 miles southeast of here.
2.4	135.1	Old Pretty Prairie railroad depot. Moved here in early 1980's from the community of Pretty Prairie which is about 16.5 miles SSE of Hutchinson.

0.6	135.7	Arkansas River.
1.9	137.6	Mennonite Church on left of road This area was settled by Mennonites, many of whom yet adhere to the old ways. Horse-drawn vehicles are a common sight.
0.9	138.5	Yoder, Kansas. Founded by Ely M. Yoder, its first postmaster who offered to give the railroad land for a station on condition that the town be named for him. A member of the Amish sect which split from the Mennonites in the 1600's, Yoder came to Kansas in a covered wagon from Belleville, Pennsylvania. At Yoder, turn and proceed to the southeast on state highway 96.
0.6	139.1	Yoder Oil Field on both sides of highway. Discovered in 1935, the Yoder Field was abandoned in 1964, revived in 1976 and abandoned a second time in 1982. During its active periods, it produced a total 77389 barels of oil from the Mississippian.
2.9	142.0	Devils Ditch , an intermittent stream that "flows" through six sections and, on the Haven Topographic Quadrangle map, dries up before it reaches the Arkansas River. It cuts across an open field at this point.
1.5	143.5	Panhandle Eastern Pipeline Company gas pumping station on right.
1.3	144.8	Community of Haven, population 1252, elevation 1480 feet.
1.7	146.5	Haven Oil Field on right. Discovered by Midstates Oil in 1951 and abandoned in 1960, this field produced 28847 barrels of oil from the Simpson and Viola Groups (Ordovician) and Hunton Group (Silurian/Devonian).
3.7	150.2	Sedgwick - Reno County line. Named for yet another Civil War general, Sedgwick County is named in memory of Major General John Sedgwick, a career soldier and West Point graduate who met his fate on May 9, 1864 at the Battle of the Wilderness in Virginia. He was forward, checking the battle lines and was told by the troops to get under cover as Confederate sharpshooters were about. He allegedly replied, "Nonsense! They couldn't hit an elephant at this dist….." His last word was cut off as a musket ball penetrated his forehead.
		Marshy area on left. Numerous marshes and lakes through the next several miles are caused by a combination of stream meandering on the Arkansas River floodplain and the solution of subsurface salt as it pinches out to the east.
1.7	151.9	Mount Hope, Kansas
9.8	161.7	Maize, population 1666. Founded when Kansas was yet counted among the corn-growing states rather than a wheat state, the name of Maize was selected by vote of nine of the community's 14 residents.
4.3	166.0	Sedgwick County Landfill. The landfill also serves as a source of methane which supplies the total energy requirements of the High Plains Corporation ethonol plant in Colwich, about 10 miles west. The recovered gas is dewatered, compressed and transferred through a pipeline (the nation's longest landfill gas pipeline) to Colwich. Methane is recovered from some of 150 wells, each three feet in diameter which extend to the original soil surface beneath the landfill. The operator is DTE Biomass, a division of Detroit Edison in Michigan.
1.1	167.6	Arkansas River

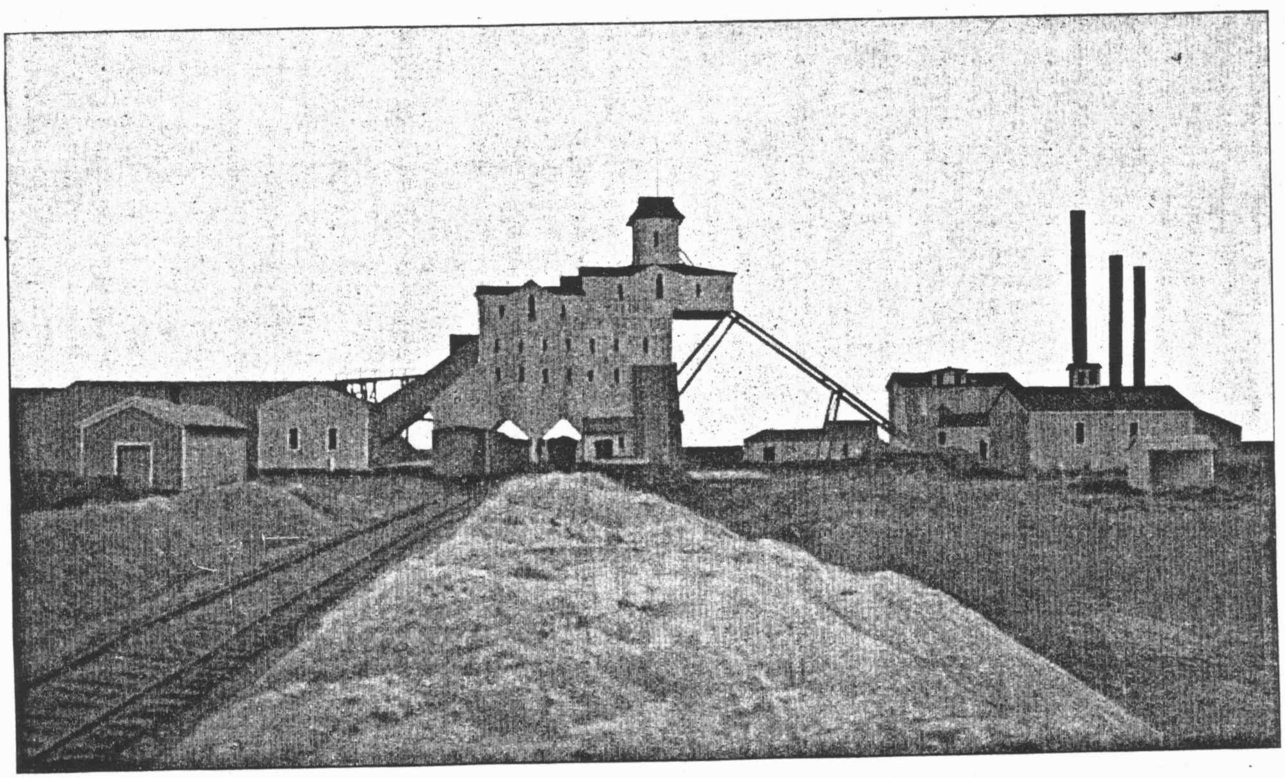
0.5	168.1	Sixth Principal Meridian. We are again back in "east range".
1.2	169.3	Little Arkansas River and Wichita – Valley Center Floodway. Locally referred to as :the Big Ditch" the floodway was constructed around the west side of Wichita during the late 1950's to divert floodwater from the Arkansas and Little Arkansas rivers. It drains back into the Arkansas River a few miles downstream from south Wichita. Before its construction, the central portion of Wichita was flooded every few years. The Big Ditch has proved its worth on several occasions; the most recent during last November when much of south-central Kansas received about ten inches of rain in 48 hours.
1.4	170.7	Exit State Highway 96 onto I-135 south.
7.5	178.2	Wichita Hyatt Hotel: end of trip. Your host, the Wichita Chapter of SIPES hopes that you enjoyed the trip and found it informative.

HISTORY OF THE LYONS, KANSAS SALT MINE

FROM:
GEOLOGY OF KANSAS SALTS BY ERASMUS HAWORTH
AND
TECHNOLOGY OF SALT BY M.Z. KIRK
IN: ANNUAL BULLETIN OF MINERAL RESOURCES OF KANSAS FOR 1898, BY ERASMUS HAWORTH, LAWRENCE, KANSAS, 1899

The enterprising citizens of Lyons organized the Natural Gas, Oil and Mineral Company, and began sinking a prospect well in November, 1887. On December 2 of the same year, rock salt was struck at a depth of 793 feet, which was 275 feet in thickness. This town was able to distribute its product by means of the Atchison, Topeka & Santa Fe, the Missouri Pacific, and the St. Louis & San Francisco. So ardent was the support of the citizens that at one time it looked as if Lyons would be the greatest salt city of the state, but water was more easily procured in the Arkansas valley, and thus the salt wells were mostly located there.

In 1890 some of the principal bankers and business men of Lyons, and a few from St. Louis, organized the Lyons Rock Salt Company for the purpose of sinking a shaft and opening the rock salt mine. Work was commenced August, 1890, and the salt was reached the following January. A little later the Midland Salt Company put down a shaft to the salt bed, but the mine was never developed, and the shaft filled with water to-day is entirely destroyed. The construction and the capacity of the mine at Lyons will be discussed in another chapter. An excellent illustration of this splendid plant is given in Plate XI.



The Lyons Rock Salt Plant.

Lyons Rock Salt Mine.

In August, 1890, Mr. Jesse Ainsworth, the superintendent of the Lyons Rock Salt Company, began the construction of a shaft at Lyons for the production of rock salt. When completed, the shaft was large enough to give two hoisting departments 6x7 feet each, and one ventilating shaft 3x7 feet, inside dimensions.

Shaft of the Lyons Rock Salt Company.

Lyons. (See Plate IX.) Reported by Supt. Jesse Ainsworth, a record without doubt the most perfect in the whole salt region, as it was a large shaft, and the superintendent was very careful to keep an accurate record.

No.	Material.	Thickness.	Depth.
1	Soil and sandy loam	30	30
2	Sandy loam	15	45
3	Sandstone	10	55
4	Variegated clays	12	67
5	Blue clay	13	80
6	Black shale	30	110
7	Grey sandstone	10	120
8	Red sandstone	78	198
9	Red sandy shale	56	254
10	Red clay	18	272
11	Soft limestone	3	275
12	Gypsum and limestone	9	284
13	Blue shale	4	288
14	Red shale and blue shale mixed with gypsum	292	580
15	Dark grey shale	60	640
16	Reddish grey shale	30	670
17	Dark grey shale	123	793
18	Light grey salt rock	2	795
19	Dark grey salt and rock	½	795½
20	Light grey salt rock	1½	797
21	Light grey salt rock	1	798
22	Dark grey salt rock	4	802
23	Light grey salt rock	3½	805½
24	Reddish grey salt rock	½	806
25	Grey shale	8	814
26	Dark grey salt rocks	8½	823
27	Dark grey salt rock	2	825
28	Grey shale and salt, mixed	3	828
29	Grey shale	4	832
30	Light grey salt rocks	9	841
31	Rock salt and shale	1½	842
32	Light grey salt rock	8½	851
33	Grey shale	1½	852
34	Light grey salt rock	8½	861
35	Shale	1	862
36	Light grey salt rock	6½	868
37	Shale and salt rock, mixed	2½	871
38	Dark salt and shale	8½	879
39	Crystal salt	4	883
40	Shale and salt	7	890
41	Dark salt and shale	2½	893
42	Dark salt and shale	16	909
43	Dark red shale	6	915
44	Dark salt and rock	10	925
45	Dark salt with crystals	17	942
46	Rock and salt and shale	19	961
47	Dark salt and shale	21	982
48	Crystal salt	2	984
49	Shale	1	985
50	Light grey salt	9½	994½
51	Shale	½	995
52	Light grey salt and a little shale	10	1,005

The drilling in sinking the shaft was principally done by hand, as machine drills could not be used to any advantage.

The method of mining consists essentially of undercutting or channeling from five to six feet back from the face, then blasting the salt down from above. The channeling and drilling machines are operated by compressed air carried into the mine through pipes leading from the engine-room, where the air-compressor is located, as rock salt is tough and difficult to cut. In the earlier days of operating the channeling was done in the shale immediately underlying the salt beds, but this caused considerable dirt to be mixed with the salt, thereby interfering with its sale, and more recently the channeling has been done in the salt itself near the bottom, thereby preventing the admixture of the shale, as the only floor of the mine is now one of pure salt.

The drilling machine is backed to a post which is held in position by end pressure on the floor and roof, produced by set-screws. When the post is once in place a large number of drill holes are made in the salt. Sometimes fifty or more are made at one setting of the post. They are drilled to a distance of from four to six feet in the wall and are charged with dynamite powder and exploded by electricity. In this way more than a hundred tons of salt are broken down at once. The large pieces are then broken up with hammer and pick so that they can be loaded into cars, which in turn are pushed by hand over the tracks to the bottom of the shaft and hoisted in a manner similar to the way coal is hoisted from a large coal-mine. The underground cars at Lyons hold about two tons each.

The salt is hoisted to the upper part of the hoisting house, thrown from the cars into the breakers, which are similar to those used in the anthracite coal-mining districts, and broken into moderately small pieces. From the breakers the salt passes through a series of screens which separate it into nine different sizes or grades. As the salt contains a considerable amount of earthy matter which is difficult to separate, experience has shown that it is best to resort to hand separation for getting rid of such impurities. At Lyons this hand-work is done by a large force of boys and girls, who throw out all the discolored fragments after the salt has passed through the breakers and screens.

Lump Rock Salt.—The largest size of salt marketed is called "lump" rock salt, and is marketed just as it comes from the mine. The lumps weigh from 25 to 200 pounds each, and are used extensively by farmers and ranchmen in Kansas and surrounding states for salting stock. The large lumps can be placed in the pasture, feed lots, and barns, so the stock can always have ready access to them.

"C" Fine Salt.—"C" fine salt is the same as above, only it has been reduced to a powder by a crushing process. This is put up in 200-pound burlap sacks and 280-pound barrels for those who prefer the fine salt to the lump. This brand is also sold in large quantities to the ranchmen of Kansas and the Indian territory.

Capping Salt.—Capping salt is the largest size of the crushed material. It is made up of beautiful, clear cubic pieces about three-fourths to seven-eighths of an inch across. To separate out the impurities a large force of boys and girls is employed, who separate the discolored pieces from the pure salt. This carefully collected material is used quite extensively by the various packing companies to place in the bottom and on the top of barrels of pork for export.

No. 3 or Refrigerator Salt.—No. 3 or refrigerator salt is in blocks from a fourth to half an inch across. It is especially well adapted for use in a refrigerator car and other refrigerators, as the pieces are large and dissolve so slowly that there is but little waste. About five or six hundred pounds are usually placed in a car at a time with ice. It is used quite extensively, not only in Kansas but also in neighboring states.

No. 2 or Hide Salt.—This brand averages about one-half the size of No. 3. But few pieces measure more than a quarter of an inch in diameter. It is used extensively for salting hides and is much better than the finer grades, because it is not all absorbed or dissolved at once. In case a part of the brine escapes there is plenty of solid salt to produce more.

No. 1.—No. 1 is much finer than the above, the grains being about the size of grains of wheat. This size is well adapted for various purposes. Butchers use it for salting hides, chemical manufactures for making soda ash and caustic soda, packers for making brine, soap makers for making soap, and ice-cream makers prefer it to all other sizes for freezing purposes.

No. 6.—No. 6 ranges from very fine salt dust to pieces as large as grains of wheat. This size is used extensively to remove snow and ice from the rails and frogs of railroad and street-car tracks. Some even prefer this size for salting stock and for curing hides.

No. 7.—No. 7 is much finer than No. 6, the grains being only about one-twentieth of an inch in diameter. Besides being used for curing sheep pelts and for salting stock, it is used extensively in pickle factories.

No. 4.—No. 4 is about the same as coarse evaporated salt. It is used by stockmen, soap makers, and glass manufacturers. There is a good market for this grade among the smelters of Colorado and other mining states, where it is used in the chlorination furnaces.

PACKERS' FINE SALT.

Packers' fine salt is perhaps the finest, purest and cleanest produced at the mines. It is about as fine as common evaporated salt and is used for general domestic purposes and for packing beef and pork.

These various grades of salt are held in bins occupying the left part of the main building, shown in Plate XI, from which a car can be loaded with any of the above kinds of salt in a very few minutes. The building to the extreme left is the storeroom for the barreled and the sacked salt; the small building immediately in front is the office. The track in the distance and above the storeroom leads from the top of the shaft in the upper part of the building to the dump pile, where the refuse is thrown. Immediately beneath the main building are railroad tracks connecting with the Missouri Pacific, Atchison, Topeka & Santa Fe and St. Louis & San Francisco railroad systems.

The building to the extreme right is the boiler-house, in which are five 250-horse-power boilers.

The next building to the left is the engine-house, in which are two large four-horse-power hoisting engines, supplied with two immense drums, around which is wound the strong steel cable for lifting the cars of salt from the bottom of the shaft. In this building is also the large air-compressor, which compresses the air to a pressure of 100 pounds per square inch. It is then conducted through pipes to the mining machinery described above. North of the engine-house is a higher building, in which are two large 600-horse-power porcupine boilers.

With the above excellent equipment, this mine has a capacity of 1000 tons per day. But they have no occasion at present to run to full capacity. With the present demand, it could easily supply all of the rock salt consumed by the states west of the Mississippi river.

An average of about seventy-five hands are employed during the year. From twenty to twenty-five of these are girls and small boys, employed to sort out the impurities from the salt, at $2 a week. The remainder can be classed as skilled labor, receiving from $1.75 to $3 per day.

ORIGIN AND DISTRIBUTION OF THE HUTCHINSON SALT (LOWER LEONARDIAN) IN KANSAS

BY

W. LYNN WATNEY, JAMES A. BERG, AND SHIRLEY PAUL

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Origin and distribution of the Hutchinson Salt (lower Leonardian) in Kansas

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Abstract

The Hutchinson Salt deposit is an important economic resource. It is a source of chlorides found in ground water and a major cause of numerous natural and manmade sink holes. Stratigraphic changes resulting from the presence or absence of salt adversely affect seismic and gravity surveys.

The Hutchinson Salt is a member of the lower Leonardian (Permian) Wellington Formation which is part of the Sumner Group. The Hutchinson Salt Member covers some 37,000 mi^2 in the subsurface of Kansas, occupying a volume of approximately 1100 mi^3.

An extensive subsurface study was conducted using cores, wireline logs, and sample descriptions to re-evaluate the lateral and vertical distribution of halite and associated strata in the Sumner Group, an interval between the Stone Corral Formation and the Chase Group. Correlations were established between basic lithologic types and wireline-log responses. From some 4000 wireline logs, maps of interval thickness, iso-halite, and structural elevation were produced using computer methods.

The Hutchinson Salt Member was deposited in a shallow depression that was intermittently open to the south. Halite is thickest and most continuous in the northeastern part of that basin. Halite deposits progressively offlap and grade into sulfate southwestward into Oklahoma, the site of the waning Anadarko Basin. The abruptly thinning eastern limit of the Hutchinson Salt in Kansas is a result of solution of salt near the present land surface.

Thin, but basinwide anhydrite-shale couplets punctuate the halite succession, some of which serve as excellent wireline log markers. The interval between the marker beds is composed of multiple successions of shale, rare dolomite, anhydrite, and bedded and unbedded halite.

Bromide geochemistry and petrography of the halite indicate that it is a primary precipitate from a fluctuating, shallow-marine brine body.

Introduction

This study examines the stratigraphic and spatial distribution of the Hutchinson Salt in Kansas using a limited number of cores and an extensive wireline-log data base. Limited petrographic data and bromine analyses of the halite complement this regional subsurface geologic study.

Halite is an important economic resource in Kansas. It is mined underground and is also extracted through the wellbore using downhole solution processes. Inactive portions of mines are used for storing documents.

Abrupt variations in the thickness and composition of salt can adversely affect structural interpretations of gravity and seismic surveys. However, the cause of that variation may be indicative of depositional topography created by structural deformation either contemporaneous with deposition of the salt or during a later event such as local dissolution of the halite. Much of the eastern edge of the Hutchinson Salt in Kansas is an active dissolution front developed in response to near-surface weathering and contact with meteoric water (Gogel, 1981; Lane and Miller, 1965; Walters, 1980).

The purpose of this study was to explain the distribution of the salt and to interpret the origin of the deposit. The use of wireline logs facilitated detailed regional stratigraphic interpretation and provided a new view of this deposit from that previously published (Bass, 1926; Kulstad, 1959).

Methods

The initial investigation began with the description of cores that penetrated the Hutchinson Salt interval (Table 1). Mine descriptions were used from those published in the literature (Dellwig, 1968) and from visits to the Lyons and Hutchinson mines by the senior author. The initial objective was to correlate the major lithologies found in the cores (halite, anhydrite, shale, and carbonate

TABLE 1—Core and mine descriptions utilized in this study.

Cores			
Name	**Location**	**County**	**Hutchinson Salt Interval**
AEC1 #1 test hole	NE NE NW Sec 26-19S-8W	Rice	815 ft-1084 ft
LPG Hydrocarbon Trans. Co., well no. 85	NW NW Sec 32-17S-9W	Ellsworth	942 ft-1159 ft
Hutchinson Naval Air Station core hole	Sec 30-24S-5W	Reno	433 ft-711 ft
Mines			
Name	**Location**	**County**	**City**
American Salt Co.	NW Sec 10-20S-8W	Rice	Lyons
Carey Salt Co.	NW Sec 17-23S-5W	Reno	Hutchinson
(Dellwig, 1968)	SW Sec 30-15S-7W	Ellsworth	Kanapolis

rock) to responses on the wireline logs. Wireline logs were then used to extrapolate stratigraphic details of the halite and adjacent strata across the study area and to calculate net salt at each well location.

Whole-rock samples of halite were initially sampled for bromine analysis using X-ray fluorescence in order to facilitate interpreting the origin of the halite. Individual crystals of halite were later analyzed for bromine using a more sensitive spectrophotometric measurement to further refine the bromine profiles. In this method phenol red indicator was brominated by oxidized bromine, producing a colormetric response for measuring bromine concentration (Taras et al., 1971). Approximately 0.5 gram of halite was extracted from the core. The sample was ground and washed in alcohol to remove brine from the fluid inclusions. From 0.15 to 0.16 gram of halite was dissolved in 100 mL of water. Standards were made for bromine using the same chloride concentrations and were regularly analyzed with the samples according to methods described by Whittemore et al. (1979) to remove the effects of chloride interference. The precision of +12 ppm at two sigma was estimated for most samples, but precision declined to +30 ppm at one sigma for those samples which contained minor amounts of a white insoluble material. Argillaceous and anhydritic halite were intentionally not sampled. Details are more fully described in Berg (1981).

Stratigraphy

The lower Leonardian Wellington Formation is the lowest unit of the Sumner Group, which also consists of, in ascending order, the Ninnescah Shale, Runneymeade Sandstone, and the Stone Corral Formation (Figure 1).

The Wellington Formation is subdivided into three members: a lower anhydrite member, the Hutchinson Salt, and an unnamed upper shale (Norton, 1939) (Figure 1). The Wellington Formation is the transition

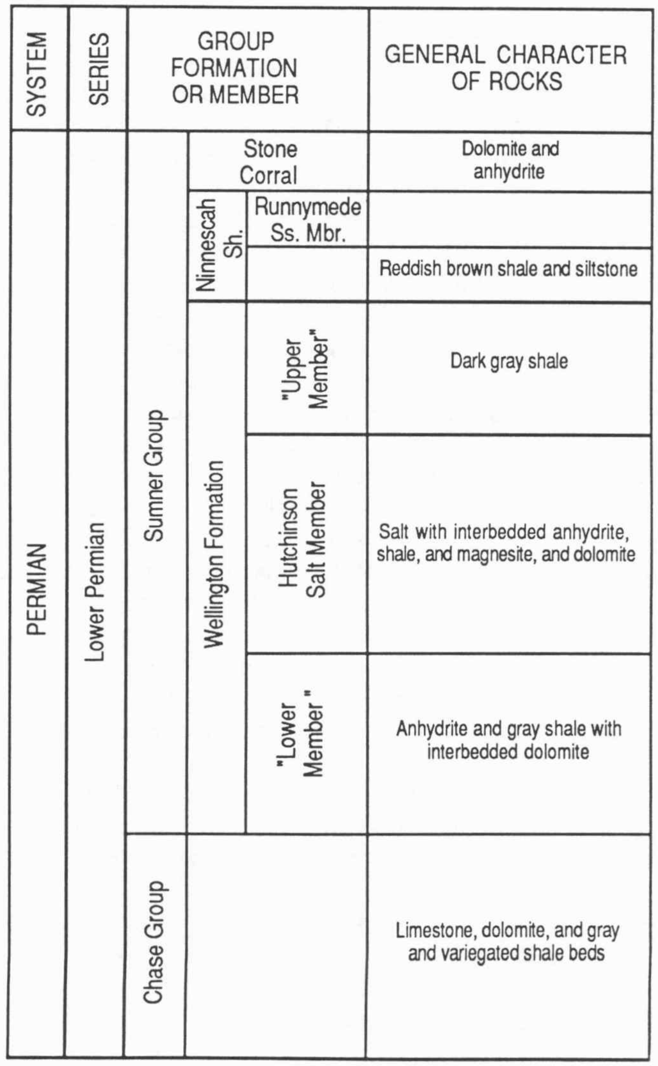


FIGURE 1—Stratigraphic chart of Sumner Group, Lower Permian in Kansas.

between alternating marine limestone, dolomite, shale, and siltstone of the underlying Wolfcampian (Lower Permian) Chase Group and the overlying red-bed evaporites of the Ninnescah Shale and Stone Corral Formation. The Ninnescah Shale is in a disconformable relationship with the Wellington Formation in northwestern Kansas (Rascoe, 1968, this volume).

The Wellington Formation covers the western two-thirds of Kansas, whereas the Hutchinson Salt is limited to only a portion of central Kansas, extending southward into Oklahoma (Figure 2). In Kansas the halite covers an area of 37,000 mi^2 and occupies a volume of 1100 mi^3.

The unnamed lower anhydrite member of the Wellington Formation averages 200 ft in thickness and consists of alternating light- and dark-gray, contorted and brecciated, laminated shale and argillaceous siltstone; dark-brown, massive, micritic dolomite; and beds of very finely crystalline anhydrite. Inch-sized nodules of anhydrite also are common in dolomite and shale beds. The contact between the lower anhydrite member and the Hutchinson Salt is gradational because discontinuous beds of halite are recognized in the upper part of this interval based on interpretation of wireline logs at various locations in Kansas.

Thin and uncommon beds of shaley dolomite and magnesite, and anhydrite occur in the eastern portion of the Hutchinson Salt, but become much thicker and more abundant to the southwest.

The unnamed upper shale member of the Wellington Formation averages 250 ft in thickness near the outcrop but varies significantly in thickness in the subsurface. A gradational relationship exists with the underlying Hutchinson Salt, and lenses of anhydrite and halite occur in the lower portion of that regularly laminated, gray shale. The shale is very similar to the beds of shale found within the halite. The shale that is laterally equivalent to the salt is also gray (reduced), unlike the red beds associated with the younger salts which succeed the Hutchinson Salt.

The stratigraphic succession in the Hutchinson Salt consists of halite, shale, minor anhydrite, and dolomite/magnesite. The halite contains laminations of clay and less abundant anhydrite ranging in thickness from 0.1 to 0.4 inches at a spacing of 0.2-1.6 inches. (Jones, 1965; Dellwig, 1963). Shale consists of clay shale, silty shale, and siltstone. Shales are rather soft and waxy and have a conchoidal fracture. There is little or no fissility. Horizontal laminations of light and dark layers are common. Shales range from light to dark gray and nearly all the shales contain magnesite. Narrow (<0.2 inches wide) nearly vertical veinlets of coarse, fibrous, red-colored halite are common in the shales. Veins and lenses of anhydrite are also common (Jones, 1965). Clay minerals include illite, montmorillonite, and chlorite. Detrital minerals include quartz primarily, but orthoclase, plagioclase, muscovite, and heavy accessory minerals also are present (Jones, 1965).

Polyhalite is found between halite crystals in association with small, irregular masses of anhydrite. Polyhalite is a complex, water-soluble, potassium sulfate, which occurs as microcrystalline spherulites or matted aggregates of tiny crystals reaching 0.2 inches in width (Jones, 1968). It is found in cores from the medial portion of the Hutchinson Salt in intervals of abundant clear halite.

Fossils in the halite include scattered blue-green algal remains. Magnesite layers at the base of the salt commonly contain the pelecypod *Permonphorus* sp. and the foraminifera *Serpulopsis* sp. Those two fossils indicate periods of temporary relative freshening of the water between periods of evaporite accumulation. The magnesite appears to be an early diagenetic replacement of calcite.

Ripple cross-laminations are rare, and microfaults and slumps are common in the Hutchinson Salt.

Halite fabrics and their origin

The Hutchinson Salt contains two common types of halite. The **cloudy** type is predominately finely crystalline, translucent, and contains "chevron" planes. It is found with dark-gray, silty shale partings in beds less than 3 ft thick. The **clear** type is massive, coarsely crystalline, and clear, and interrupted by inch- to foot-thick beds of soft, non-fissile, light- to dark-gray, silty shale (Figure 3). Beds of clear halite range up to 12 ft in thickness. Both types of halite crystals are generally anhedral ranging from 0.1 to 0.5 inches in diameter. Locally, clear halite crystals can be on the order of 1-5 inches in diameter.

Most of the contacts between interstratified clear and cloudy chevron halite are gradational (Figure 4). Gradational contacts are most common in the lower portions of halite beds within the Hutchinson Salt and these contacts are in contrast to the abrupt, arcuate, and sutured contacts of chevron crystals in examples from the Prairie Evaporite Formation (Wardlaw and Schwerdtner, 1966) and sections of the Silurian Salina Salt of the Michigan Basin (Nurmi and Friedman, 1977).

Cloudy halite

Fabrics—The cloudy or translucent halite is generally grayish white to white. Its color is related to the abundance of minute (<.004 inches) fluid inclusions, which disperse light. The inclusions are oriented along "chevron" planes which apparently were growth surfaces. The inclusions contain brine and some contain gas bubbles and mineral matter. Jones (1965) described the occurrence of another cloudy halite from the Hutchinson Salt. Its cloudy appearance is due to rows of fluid inclusions filled with brine and tiny bubbles of gas enclosed in clear halite. The cloudy halite described by Jones (1965) is euhedral to anhedral, with borders that may be straight, sinuous, jagged, scalloped, embayed, and gradational.

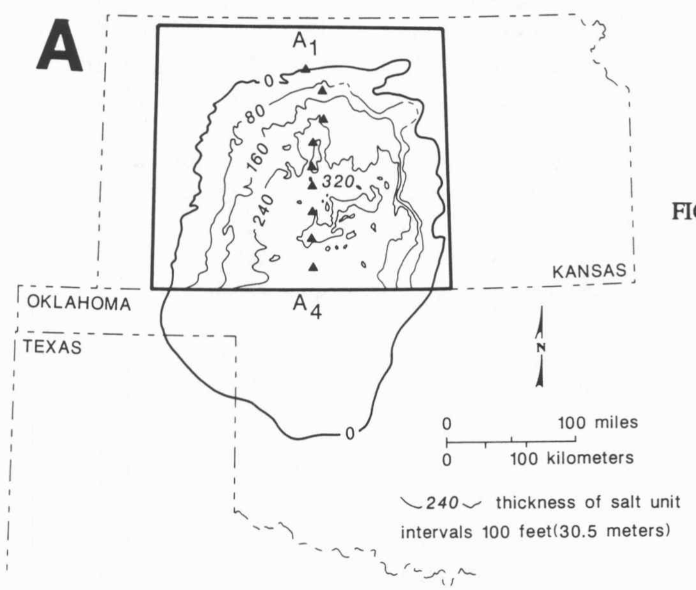
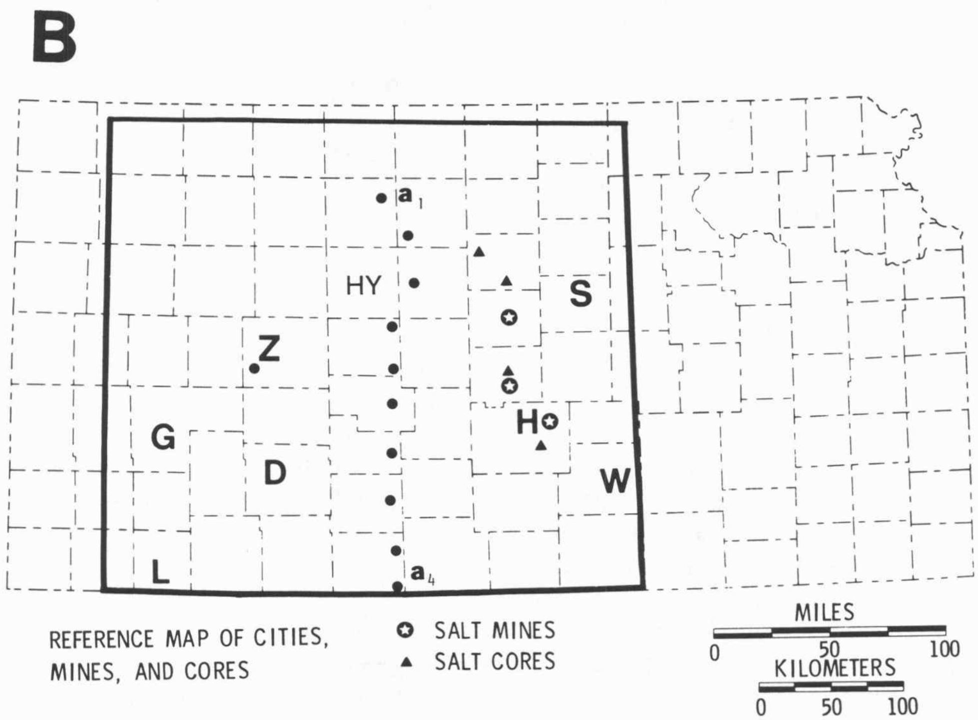


FIGURE 2—A) Distribution of Hutchinson Salt in Kansas, Oklahoma, and Texas. Kansas: net salt isopach with 80-ft-contour interval and outline of study area shown. Oklahoma and Texas: limit of Hutchinson Salt (Johnson, 1976). B) Index map identifying study area shown on succeeding maps. Letters refer to cities: W: Wichita; H: Hutchinson; HY: Hays; S: Salina; D: Dodge City; G: Garden City; L: Liberal; and Z: Zuelhke well site shown in Figure 10. Letters appear on succeeding maps. Line of cross section A1-A4 (Figure 13) shown.



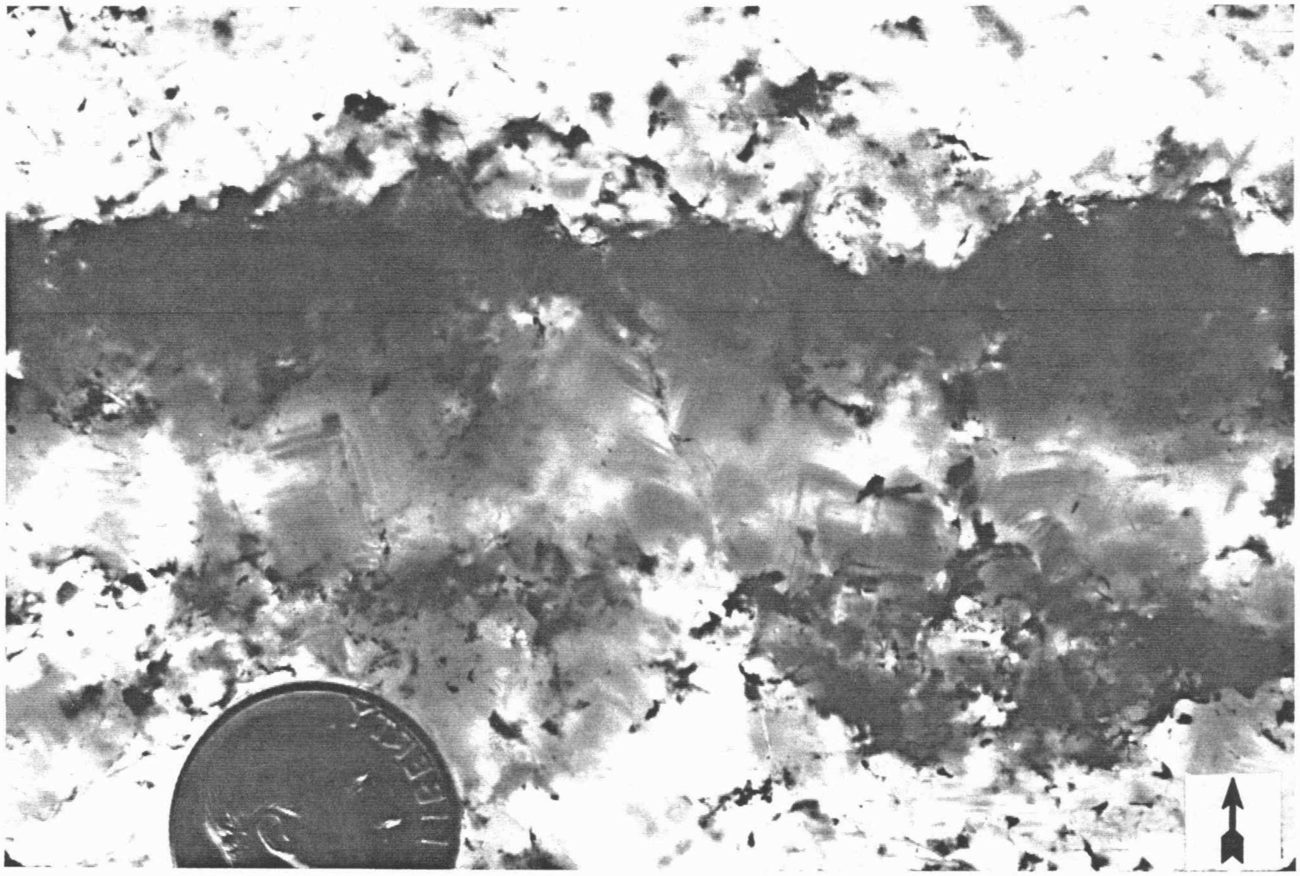


FIGURE 3—Cloudy (chevron) halite band between dark-clay/anhydrite-rich zones. Coarse, crystalline halite is found at top and bottom of polished slab. Arrow indicates stratigraphic "up." Coin has diameter of 0.69 inches. Sample from depth of 1102.6 ft in Hydrocarbon Transportation Company, Well No. 85, Ellsworth County, Kansas (see Figure 8).

The tops of chevron crystals in the Hutchinson Salt are commonly covered by shale and anhydrite. Commonly, in the upper portions of halite beds, the top and sides of chevron crystals have been truncated or rounded. Following truncation, the crystals were coated by clay and anhydrite or clear halite and then overlain by additional chevron halite, indicating episodic precipitation and dissolution (Figure 5).

Origin—The cloudy, inclusion-rich anhedral to euhedral halite is considered a primary precipitate (Figure 3). Fluid inclusions were trapped along crystal faces as the halite precipitated. The chevron orientation of fluid inclusions indicates preferential growth of crystals, probably as a result of halite cubes being positioned with their edges projecting upward at the sediment-brine interface (Shearman, 1978).

The crystals described by Jones (1965) are thought to be hoppers, which formed on the surface of the brine and are indicative of a shallower brine (Shearman, 1978).

Clear halite

Fabrics—The clear or limpid halite generally forms anhedral and interlocking aggregates. It is more abundant and widely distributed than the cloudy halite and contains fewer but larger fluid inclusions, which fill large cubic or rectangular cavities (greater than .04 inches diameter). Some of the larger crystals have inclusions that commonly contain gas bubbles.

Mineral matter, including patches of shale, commonly surround the larger clear crystals, suggesting that the particles were expelled when recrystallization took place (Figure 6). A red to orange color of some halite is attributed to hematite associated with extremely slender filaments of blue-green algae (Tilden, 1930; Dellwig, 1968).

Origin—Dreyer et al. (1949) found that filling temperatures of large, clear, rectangular fluid inclusions similar to those described in the Hutchinson Salt ranged from 70 to 100°C and concluded that these particular

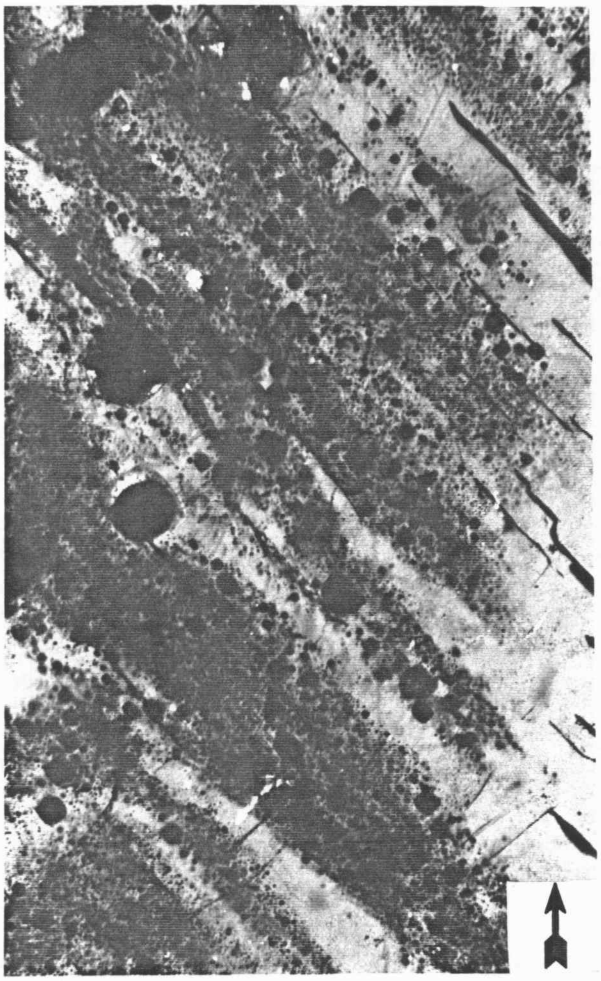


FIGURE 4—Gradational clear-cloudy (chevron) halite contact. Dark speckled areas are fluid-inclusion rich zones that give the chevron its cloudy appearance. Arrow indicates stratigraphic "up." Sample 4-1-5, 1108.2 ft. 26X, partially crossed polars.

crystals developed during burial diagenesis, probably due to recrystallization of earlier crystals.

The studies of Wardlaw and Schwerdtner (1966) and Nurmi and Friedman (1977) cited above concluded that the clear halite grew along solution pipes which formed in a supratidal environment penecontemporaneous with sedimentation, analogous to the brine pans along the modern Baja California coast described by Shearman (1970).

Gradational boundaries between cloudy halite and clear halite in the Huchinson Salt resemble those obtained by the experiments of Authurton (1973) and suggest that they may be cogenetic phases. However, the origin of clear halite gradational with cloudy halite has been debated. Wardlaw and Schwerdtner (1966) suggested that it was a replacement or recrystallization fabric, whereas Dellwig (1955) believed it to be primary.

Polyhalite

Polyhalite is a minor phase intimately dispersed in the halite. Holser (1966) suggested that polyhalite is pseudomorphous after gypsum and anhydrite, a relationship also common in both modern and ancient evaporites. We conclude that the polyhalite resulted from the percolation of potassium-rich diagenetic waters through the salt, probably shortly after accumulation of the salt when it was still permeable. Precipitation of a thin anhydrite layer occasionally followed deposition of the polyhalite-bearing units, apparently when the brine body was reestablished.

Solution pipes

Halite found directly beneath shales is composed of mostly clear crystals. The upper parts of many of these halite beds contain shale clasts and, locally, channel-form features that are commonly shale-lined and resemble solution pipes (Figure 7). Some are filled with clear halite and others contain cloudy inclusion-rich halite.

Vertically oriented pipes filled with cloudy, finely crystalline halite are similar to those described by Fuller and Porter (1969) from the Middle Devonian Elk Point Formation in Alberta, which they attributed to collapse features and contemporaneous recrystallization of exposed

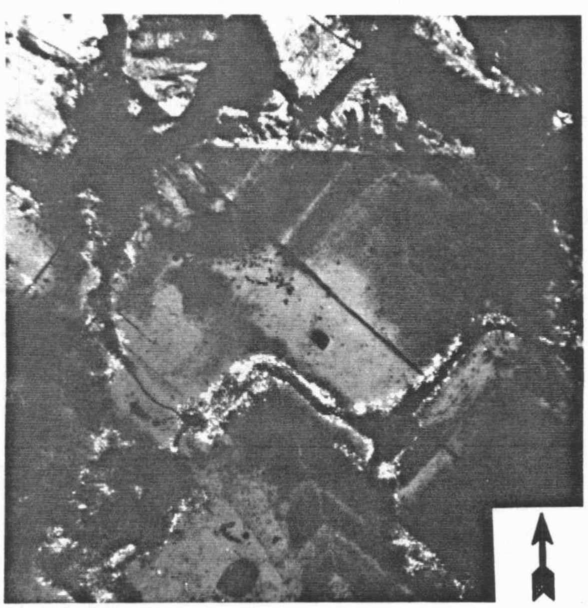


FIGURE 5 (left)—Two generations of cloudy (chevron) halite. The original morphology of the first generation of chevrons is preserved and overlain by a thin layer of anhydrite. The second generation is truncated at a clay-anhydrite lamina. Arrow indicates stratigraphic "up." Sample 3-18-1, 1102.0 ft. 5X, partially crossed polars.

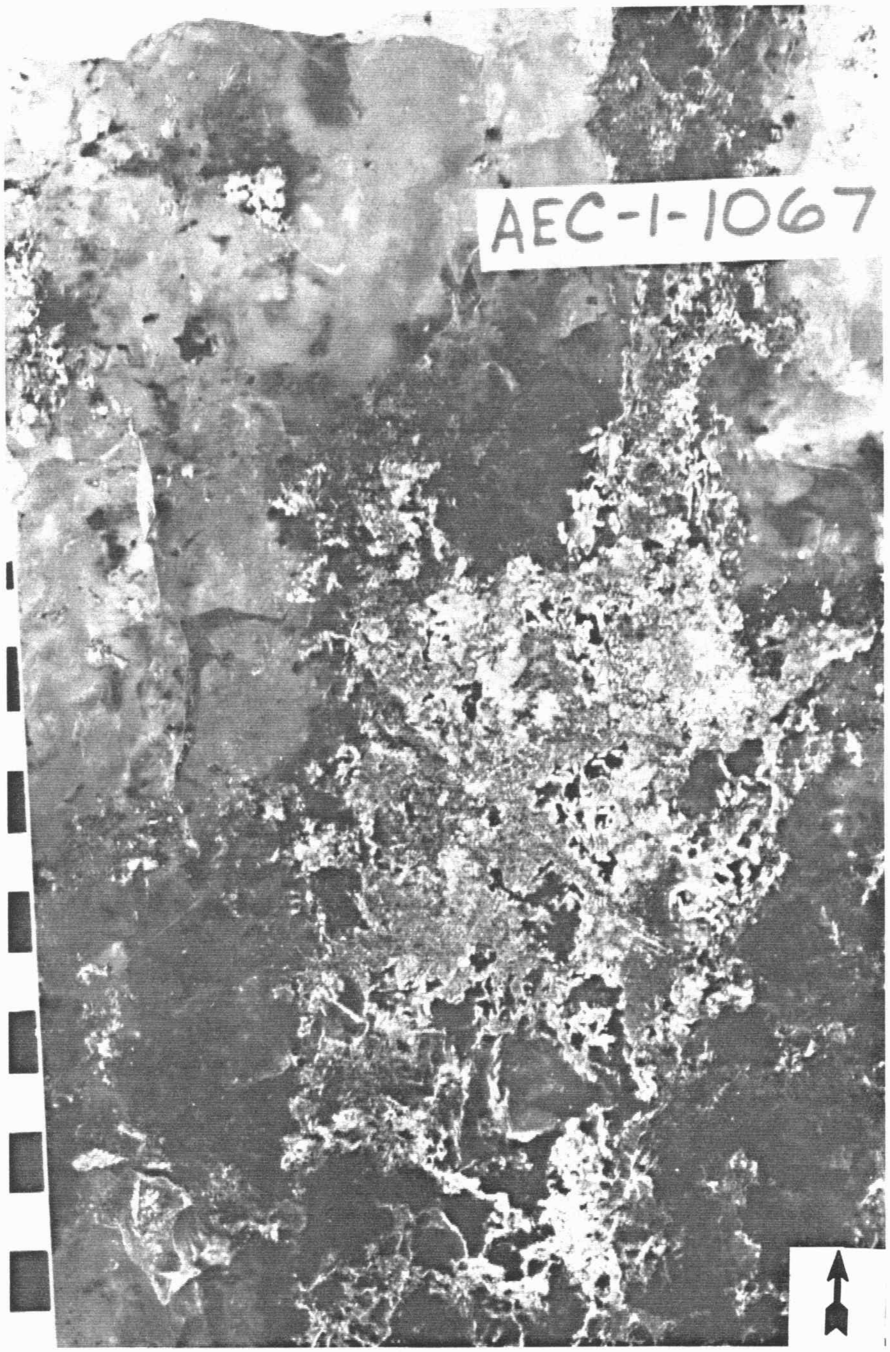


FIGURE 6—Clear halite with multi-sized, irregular patches of anhydrite (light gray) and shale (black). Intervening areas are halite. Divisions on scale are each 1 inch. Core slab from a depth of 1,067 ft in the A.E.C. #1 Test Hole, Lyons County, Kansas.

salt. Dissolution fabrics are also common in modern salt-pan evaporites, but in those the halite filling is clear (Lowenstein and Hardie, 1985).

The halite filling the pipes in the Hutchinson Salt however is not clear but, more commonly, is cloudy and impure. Accordingly, we suggest that it resulted from slumping of unconsolidated halite crystals which was caused by only a slight decrease in the saturation of the brine. There is little or no slumping or collapse of adjacent laminations, suggesting that the process was slow. Nor is there a significant change in composition between halite-filled pipes above and below undisturbed shale laminae,

FIGURE 7—CLOUDY (CHEVRON) HALITE BED WITH SMALL PORTIONS OF INTIMATELY ASSOCIATED CLEAR HALITE. THE THIN DARK VERTICAL LINES ARE "WALLS" OF CLAY AND ANHYDRITE WHICH OUTLINE THE CHEVRONS. ARROW INDICATES STRATIGRAPHIC "UP." SAMPLES 940 1-3, 951.5 FT. COIN IS 0.68 INCH IN DIAMETER.

which suggests that halite precipitation was intermittent with episodes of minor dissolution. Gradational contacts between clear and chevron halite also suggest that recrystallization occurred during episodes of lowered salinity. Halite precipitation was renewed when brine saturation was reestablished (Richter-Bernburg, 1953).

Shales

Silty shales are interbedded with halite and contain ripple cross-laminations and polygonal fractures filled with anhydrite (Dellwig, 1963). The fractures are 7 inches wide and 2 inches deep. Both features suggest that shallow water, and possibly subaerially exposed conditions, existed periodically during halite accumulation. The precipitation of polyhalite may have occurred during times of shale desiccation and minor halite dissolution.

Summary

The petrographic observations of the Hutchinson Salt are consistent from core to core and in the mine workings. Those observations and the association of salt with non-oxidized shales suggest the presence of an extensive brine body from which much of the halite was episodically precipitated under moderate water depths.

A record of hyper-salinities of the brine body is sparse. Minor replacement of anhydrite to polyhalite suggests a flux of an early diagenetic brine during times of greatly reduced volume compared to the original brine from which the halite was precipitated. The medial position of the polyhalite in the most-halite-rich portion of the stratigraphic sequence suggests that this strata-bound mineral precipitated after the brine level dropped significantly and the supernatant fluid became isolated enough from marine influx to permit the salinity to reach that required for polyhalite precipitation (45 X seawater; Eugster, 1980). However, during periods of lowered brine levels, episodic dilution of brine by influx of less saline waters from around the basin margins may have also occurred.

Bromine geochemistry

BROMINE AS A PALEOSALINITY INDICATOR (THEORY)—Bromine has been used as a paleosalinity indicator in evaporite sequences for the last 30 years, but its interpretation is complicated by differences between theoretical and observed results. Bromine replaces chlorine in halite. The concentration of Br is described by a partition coefficient, which is defined as the ratio of the weight % of bromine in halite versus that in a co-existing brine.

The partition coefficient decreases from 0.14 ±0.01 when halite saturation is reached at brine concentrations of 11X seawater, down to 0.07 when the sylvite (KCl) saturation is reached at 65X seawater (Holser, 1966; Herrmann et al., 1973). Bromine concentrations in brines with concentration limits between 11-65X vary from 500 ppm to about 2300 ppm (Valyershko, 1956) and, accordingly, halite should contain 70 to 161 ppm bromine in the halite precipitated at the initial and ending brine concentrations for halite (Table 2).

Thus, as brine is progressively concentrated through evaporation and halite precipitation, the Br concentration found in the halite crystal lattice should increase through time. The bromine concentration would continue to increase during times when there is no inflow of brine to replenish that lost to evaporation.

Replenishment of the brine lost to evaporation by inflow of normal seawater to maintain a constant volume would also lead to an increase in bromine in the halite, but at increasingly smaller increments for the same amount of salinity increase (Holser, 1966). This later situation, with limited inflow of seawater, is an essential ingredient in the barred-basin model for halite accumulation originally proposed by King (1947) and refined by Scruton (1953). Under conditions of constant brine volume during which halite is deposited, the dense brines exit the basin and a reflux system is established.

BROMINE CONCENTRATIONS IN THE HUTCHINSON SALT—Bromine analyses for the Hutchinson Salt prior to this work were done with whole rock samples. We analyzed bromine concentrations in detail along profiles of individual halite beds and individual crystals. This approach has never been done before. Three salt beds from the No. 85 core of the Hydrocarbon Transportation Company in Ellsworth County were selected for this analysis—Bed 1: 1098.5-1109 ft, Bed 2: 943.7-973.5 ft, and Bed 3: 965-966.3 ft. The salt beds are bounded by significant shale or anhydritic shale intervals. Only chevron-bearing zones of halite were selected for chemical analysis. Both chevron and clear halite were extracted and analyzed separately.

The bromine profile of bed 1 is displayed in Figure 8. The details of the analyses are included in Table 3. The overall trend is a gradual increase in bromine up from the base of the halite bed followed by almost constant values and then a small increase at the top. The halite bed contains two anhydritic halite units, indicating minor interruptions in the trend of what appear to be rather constant conditions. The core reveals that an 8-inch interval at 1101 ft has clearly undergone solution of halite and related slumping, suggesting introduction of undersaturated brine (Figure 9). Chevrons of halite immediately above that zone, but below the shale at the top of this halite bed, have significantly lower bromine concentrations, a reversal in the trend established below. That decline in bromine suggests lowered salinities.

The bromine concentration of most clear and chevron halite is the same in the lower part of the halite bed, whereas the bromine concentration in the clear halite in the upper part of the bed is distinctly lower than in the chevron halite. That relationship corroborates the petrographic evidence that these two types of halite in the lower parts of the halite beds are cogenetic precipitates whose differences resulted from slight fluctuations in saturation levels of the brine.

In contrast, the bromine content in clear halite near the top of the bed suggests that it may have resulted from secondary dissolution and precipitation events. Different bromine concentrations in the clear halite suggest the presence of both more saline (e.g., 1107.3 ft) and less saline conditions for this late-stage brine than those exisitng when the chevron-banded halite was initially deposited. Polyhalite is not present in this particular salt bed.

TABLE 2—VARIATION IN BROMINE IN HALITE LATTICE

$$.14 = \frac{X_{11}}{0.05}; \text{ where } X_{11} = 0.007 \text{ wt. \% (70 ppm) Br at 11X conc. of seawater}$$

and

$$.07 = \frac{X_{65}}{.23}; \text{ where } X_{65} = 0.0161 \text{ wt. \% (161 ppm) Br at 65X conc. of .23 seawater}$$

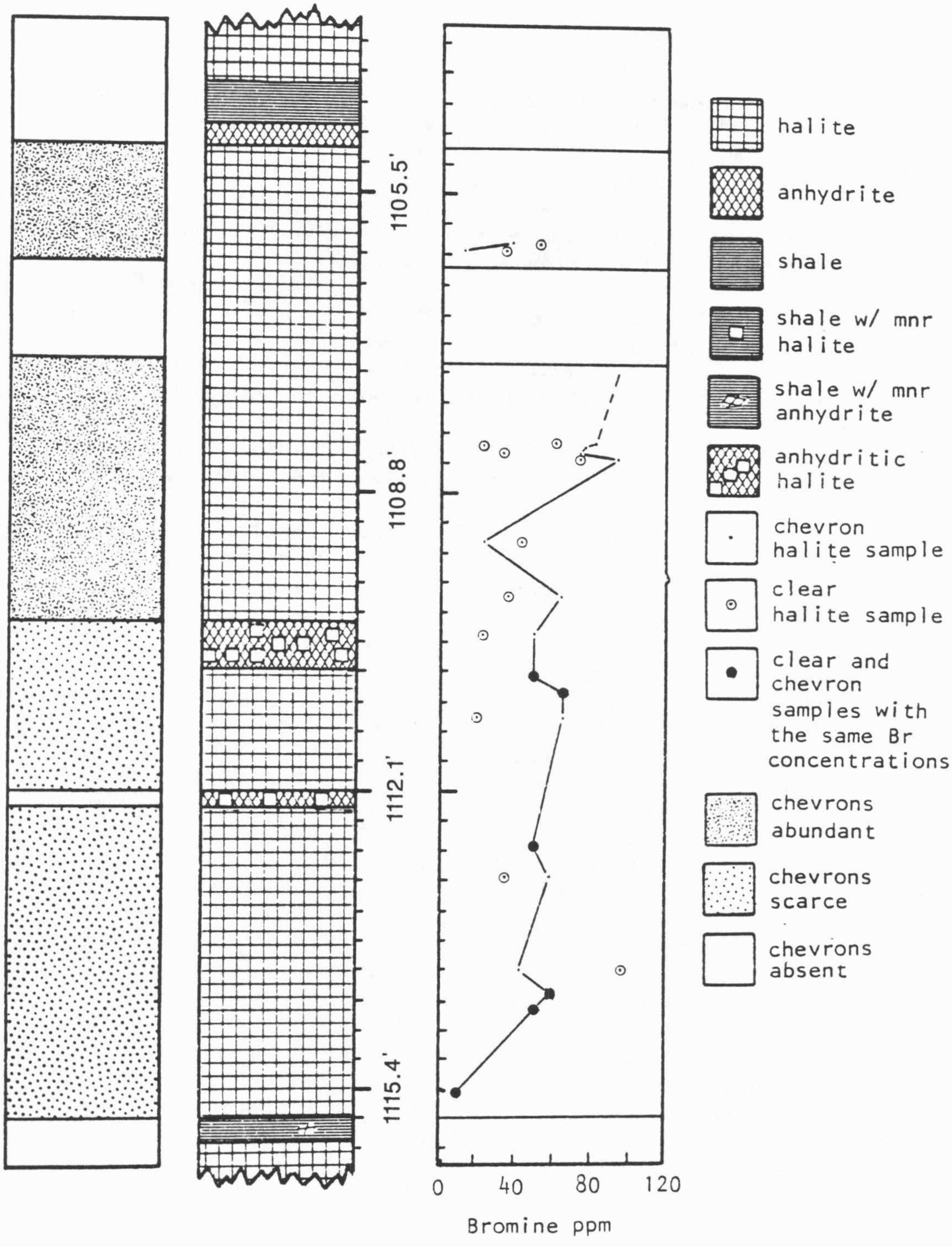


FIGURE 8—Bromine profile through Bed 1 of the Hutchinson Salt in Well No. 85. Samples are of individual crystals of chevron and clear halite. Values from chevron crystals are connected by line. Halite bed bounded by layers of shale and anhydrite. Depths in feet.

In clear halite the bromine concentration averages 43 ppm, whereas it averages 51 ppm in the cloudy chevron crystals. Neither concentration is as high as theoretically predicted, even during initial halite precipitation from concentrated sea water (75 ppm according to Holser, 1966). However, bromine values do rise to nearly that level in chevron crystals through much of the interval, indicating a brine of increasing salinity which nearly reached a constant concentration in the lower range of halite precipitation. The presence of anhydritic halite interrupting the sequence suggests episodically lowered salinity, but those interruptions appear to have been insufficient in magnitude to disturb the overall trend of evaporite precipitation.

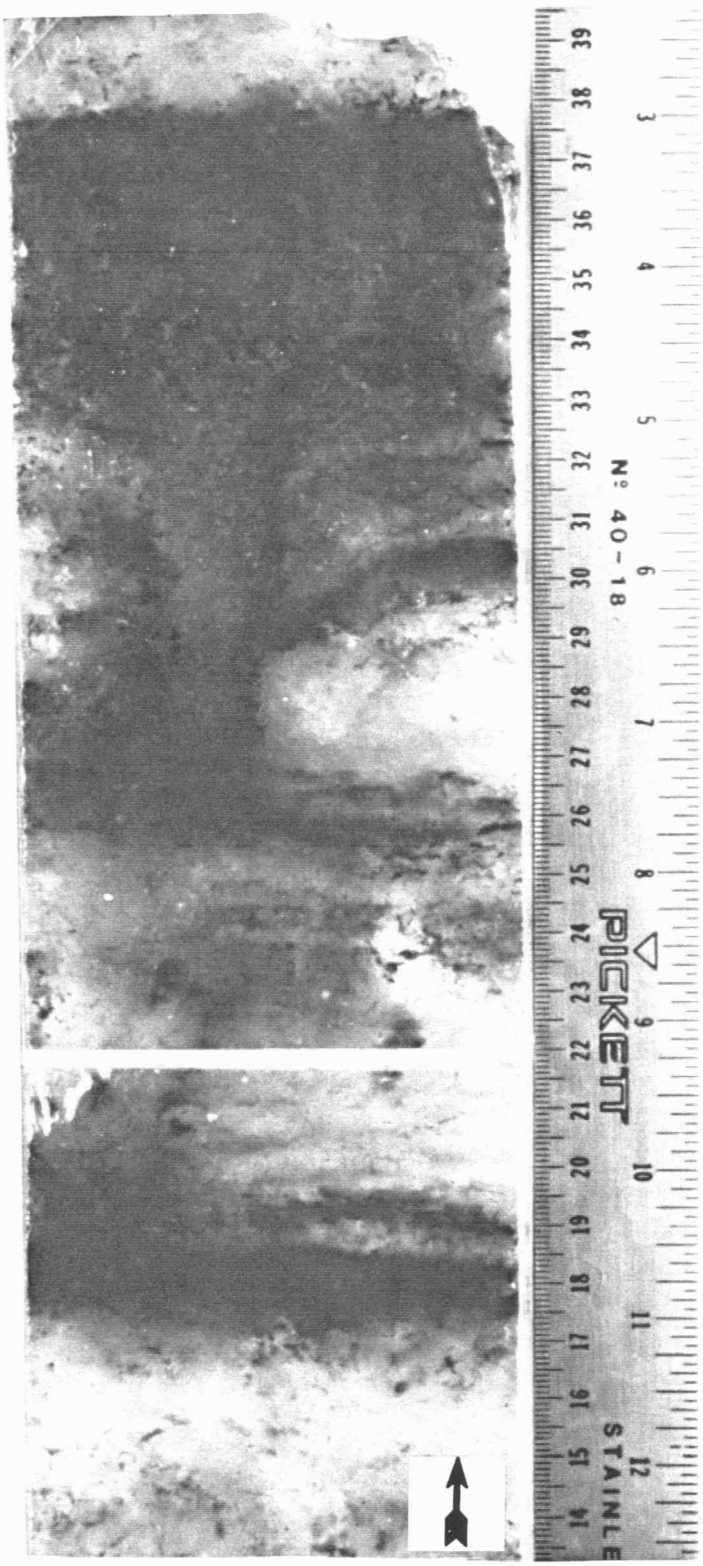


FIGURE 9—Photographs of two polished halite samples from depth of 1099.3 ft. in Company Well No. 85 in the Hutchinson Salt (see Figure 8). Inch-sized pipe structure filled with argillaceous- and anhydrite-rich halite. Note wall of pipe is partially lined by clay. Arrow indicates stratigraphic "up." Scale is in centimeters and inches.

Proposed model for halite accumulation

The relatively low values (below 75 ppm) of bromine in primary chevron halite of the Hutchinson Salt have not been adequately explained. Freshwater influx and seawater reflux in a salt basin is a possible mechanism to produce those bromine values. Local freshwater influx around the edges of the basin probably led to lowered salinities along the basin perimeter and, eventually, those lower salinity waters mixed with brines near the basin center. Freshwater influx became more significant near the end of deposition of each bed of halite as evidenced by the presence of dissolution features and significant shales. If significant amounts of halite were dissolved along the edges of the basin due to freshwater influx, the bromine to chloride ratio in the resultant brine would be lowered. If that brine became sufficiently concentrated for halite precipitation and did not mix with other brines, the bromine concentrations would be drastically less, perhaps as low as 3 ppm (Holser, 1970).

Concurrent loss of dense, more saline brines from the basin and inflow of seawater that was undergoing evaporative concentration through a process of reflux would also have affected the net brine composition. The result would be intermediate bromine concentrations in the halite, such as that observed here.

The primary balance in brine concentration during Hutchinson Salt deposition was probably maintained through the operation of a reflux system in which the salt basin was connected to a seaway. The Hutchinson Salt has bromine profiles quite similar to the Salina Formation (Michigan), Ochoan Series (Texas–New Mexico), and the Prairie Evaporite Formation (Saskatchewan). Each of those units has irregular vertical bromine concentrations, generally ranging from 30 to 80 ppm and, less commonly, up to 150 ppm (Holser, 1966). The distribution of bromine in the Hutchinson Salt is attributed to the cumulative effects of repeated seawater incursions (reflux) and, perhaps, dissolution and reprecipitation of bromine-deficient halite. That led to the fluctuating levels of bromine.

In contrast, the bromine profiles of the 2100-ft-thick Strassfurt Series of the German Zechstein and the 165-ft and 90-ft-thick salt beds, No.'s 4 and 5, in the Paradox member of the Hermosa Formation (Raup and Hite, 1978) resemble those associated with the constant inflow model created in a barred basin.

Additional cores and bromine analyses from along basin perimeters and toward the source of seawater would be required to thoroughly test the extent of freshwater influx and seawater reflux during deposition of the Hutchinson Salt.

TABLE 3—Bromine concentrations of halite samples from bed 1.

Sample no.	Elevation above base of salt (ft)	Depth to top of bed (ft)	Br concentrations (ppm) Cloudy halite	Clear halite
1	3.51	1152.23	—	28
2	47.04	1108.67	9	9
3	47.95	1107.75	51	52
4	48.38	1107.28	42	96
5	49.43	1106.31	58	34
6	49.76	1105.95	48	50
7	51.17	1104.54	65	20
8	51.46	1104.24	65	67
9	51.66	1104.08	49	53
10	52.09	1103.62	50	23
11	52.51	1103.20	64	36
12	53.10	1102.60	23	43
13	54.02	1101.69	95	74*
14	54.09	1101.65	74	33*
15	54.15	1101.56	77	23
16	56.35	1099.39	12	34
17	56.38	1099.36	37	52

*Sample contained minor amounts of water-insoluble material which reduced precision to approximately ±30 ppm at one sigma.

Spatial distribution of lithofacies using wireline logs

Wireline logs were found very useful in discriminating halite from shale, carbonate, and anhydrite. Our wireline-log data base is considerable (3753 wireline logs) and has grown significantly since previous regional examinations of the Hutchinson Salt were made. Gamma ray and neutron log combinations were primarily used in this study. Furthermore, modern log types now allow a better discrimination between lithologies, which was not always possible with older wireline logs. The identification of lithologies using the response of wireline logs was made only after correlating log response to core and sample descriptions.

Technique—Salt is usually dissolved (washed-out) in the vicinity of the borehole due to undersaturated drilling mud, and commonly the hole diameter is significantly increased adjacent to beds of halite. A cross plot of neutron vs. gamma ray values, and depth traces of the gamma ray-neutron log are shown in Figure 10. The uncompensated neutron tool is very sensitive to washout of the borehole in which it is suspended. Washed-out salt results in very low counts of neutron flux from hydrogen and of gamma ray emissions. Thus, very high porosity values are indicated on the neutron log. In boreholes with no wash-out, halite has the lowest hydrogen content of common rocks (low porosity or high counts), followed by carbonate rocks and anhydrite.

Low gamma radiation of the halite readily distinguishes it from shale, which typically has high values. The gamma-ray response increases slightly in hole-washout zones, where radiation is contributed from dispersed clay in the drilling mud. The net result is that adjacent to the dissolved halite, the gamma ray curve is still low relative to shale, but somewhat higher than carbonate or anhydrite.

The mapped area covers 42,000 mi². Five wells per township (36 mi²) were sought, resulting in one well per 7 mi². The data recorded for each log were determined after a grid of 10 north-south and east-west cross sections was constructed across the salt deposit. Those cross sections were then used as reference sections to compare with and correlate to during the compilation stage. Data acquired directly from the wireline logs include elevations of major stratigraphic units such as the Stone Corral, Wellington marker, top and base of Hutchinson Salt, and top of Chase Group, and the elevation of six significant, regionally correlatable anhydrite and shale marker beds within the halite. The net halite thickness was determined from the wireline logs. A total of 20 entries were recorded per well; additional entries were added to each well by combining existing entries to make structural contour, isopach, and ratio maps.

Data processing, calculations, and contouring were done on a Honeywell mainframe and Data General mini-computer using SURFACE II contouring programs.

Lithofacies Distribution—The index map on Figure 2B includes an outline of the mapped area to be

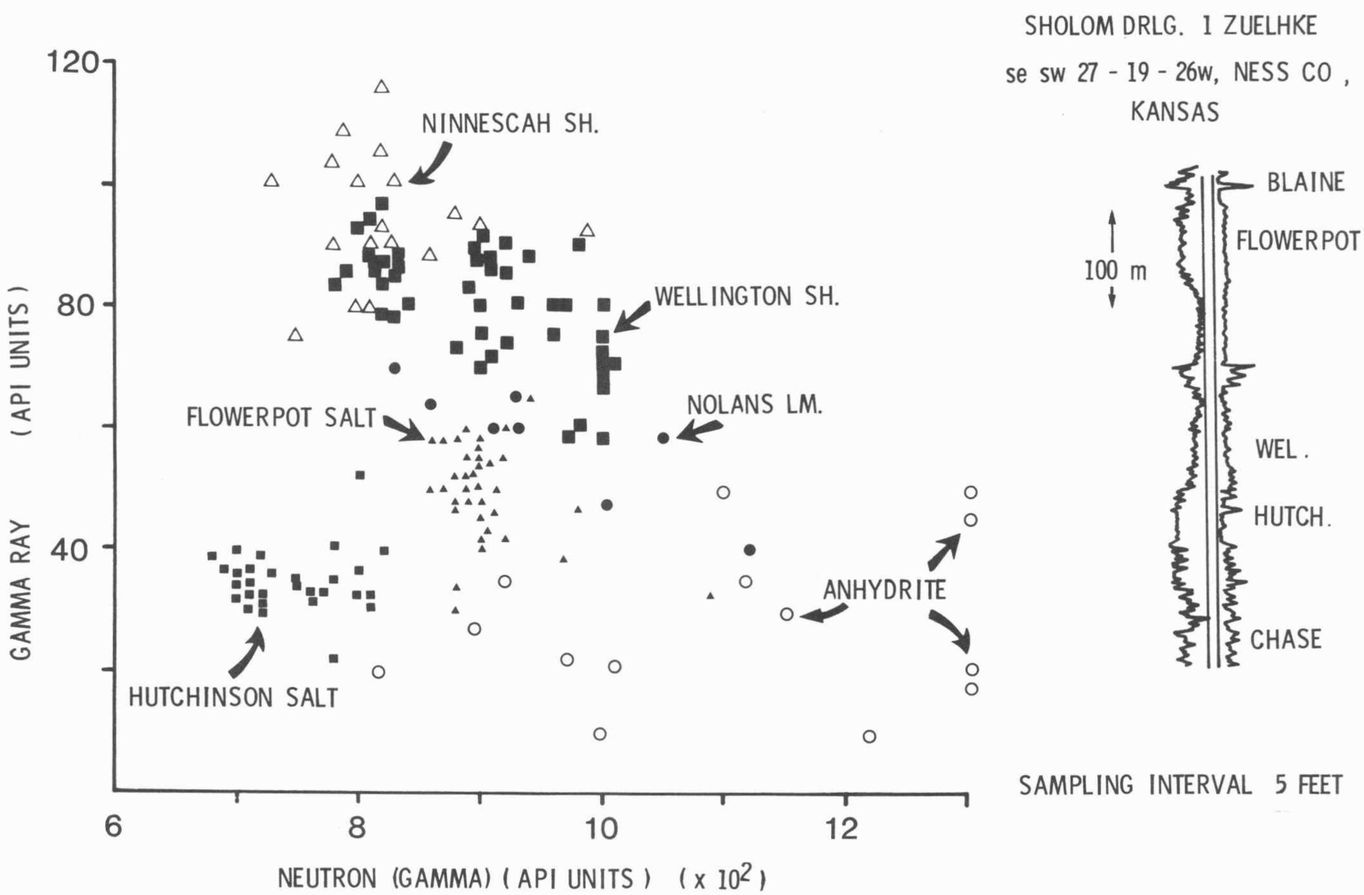


FIGURE 10—Scatter plot of gamma ray and neutron response for various lithologies from the Sholom Drilling #1 Zuelhke well, Ness County, Kansas (identified in Figure 2B). The halite (Hutchinson Salt) is distinct from the other lithologies.

shown in the succeeding contour maps. Figure 11 identifies the location of the wireline logs used in this phase of the study. An interval isopach of the Hutchinson Salt in Figure 12 is illustrated with variable shading between contours. That map demonstrates a gentle and generally uniform dip to the depositional basin. Thicknesses increase from less than 50 ft on the north to over 500 ft on the south-central map area.

That 10-fold increase in interval thickness is mainly the result of the increase in the thickness and number of halite beds toward the south. Succeeding maps and cross sections help illustrate how the basin was filled.

The north-south stratigraphic cross section A1-A4 (Figure 13) was constructed from gamma ray-neutron logs and extends southward from the northern depositional limit of the salt to the center of the basin. The datum of the cross section is a wireline-log marker in the Wellington Formation occurring approximately 100 ft above the top of the Hutchinson Salt. The marker is at or very close to the base of the red-brown siltstone in the Ninnescah Shale.

The correlation line at the top of the section is the Stone Corral Formation and the lowermost line is the top of the Chase Group. The salt thickens to the south as does the overlying shale section.

Note the continuity of the anhydrite-shale markers (correlation markers 1-5) recognized as spikes on the neutron and/or gamma ray log within the salt section. The markers emphasize the southward, overall offlapping nature of younger salt layers toward the thicker portion of the basin in the south. The CM_3 marker divides the salt into an upper and lower section used in mapping. The markers within the salt show limited convergence on approach to the basin margins.

The lithofacies cross section on Figure 14 is based on an interpretation of wireline logs. It extends across the salt basin from southwest to northeast along a traverse greater than 250 mi. The halite is more massive in the northeast, particularly in the lower interval beneath the CM_3 marker (represented by the next highest heavy line above the datum line within the halite section in Figure 14). Individual halite beds become thinner and interfinger with shale and anhydrite and onlap anhydrite along the southwestern limits of the salt, whereas halite interfingers only with shale in the northeast. The anhydrite becomes thicker to the southwest. There are four bundles of multiple halite beds; each younger set offlaps southward from the older set.

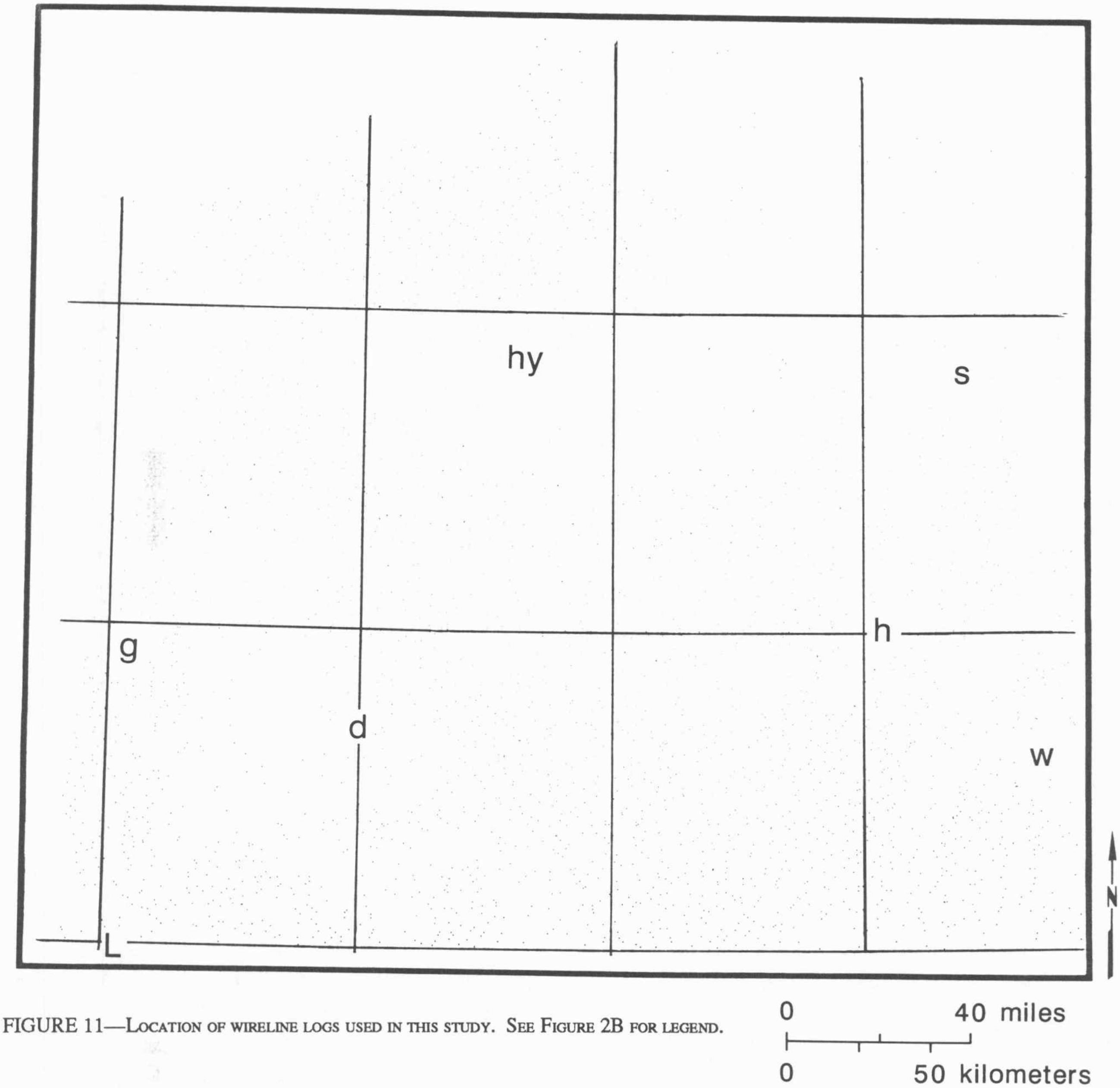


FIGURE 11—LOCATION OF WIRELINE LOGS USED IN THIS STUDY. SEE FIGURE 2B FOR LEGEND.

The total-net-salt isopach map of the Hutchinson Salt interval is shown on Figure 15. The net halite ranges from 0 to nearly 400 ft in thickness, averaging 250 ft. The salt is thickest along a NE-SW trend from Kiowa County to Rice County. This apparent depocenter is a composite of many episodes of halite accumulation, not all of which conform with that pattern.

An isopach map of the lower net salt in Figure 16 includes only the salt below the CM_3 marker. It presents a considerably simpler pattern than the total-net-salt isopach map (Figure 15). A thick lobe or depocenter of salt occurs along a distinct NW-SE trend. Note that this is perpendicular to the direction of thickening of the Hutchinson Salt interval (Figure 12) and is north of the thick on the total-net-salt isopach (Figure 15). Maximum thickness of the lower salt is just over 200 ft immediately west of the town of Hutchinson. It is in the lower part of this interval that salt is mechanically mined.

An isopach of the upper net salt (Figure 17), above the CM_3 marker, shows a NE-SW- trending depocenter perpendicular to that of the lower salt (Figure 16), but parallel to the thickness trends of the total-net-salt map (Figure 15) and halite-bearing-interval map (Figure 12). The maximum thickness of the upper salt is over 200 ft and its southwest depocenter is southwest of Hutchinson.

The ratio of total-net-salt to thickness of the total salt-bearing interval (halite percentage) shows a markedly asymmetric pattern (Figure 18). The percentage of halite significantly increases toward the northeast sector of the Hutchinson Salt, mimicking in particular the pattern in the lower net salt isopach map. Moreover, the pattern on the halite-percentage map (Figure 18) is considerably different from that of the interval isopach of the Hutchinson Salt (Figure 12). Halite percentage is greater than 90 percent in areas immediately west of Hutchinson, whereas it is less than 60 percent near the maximum thickness of the salt south of Dodge City.

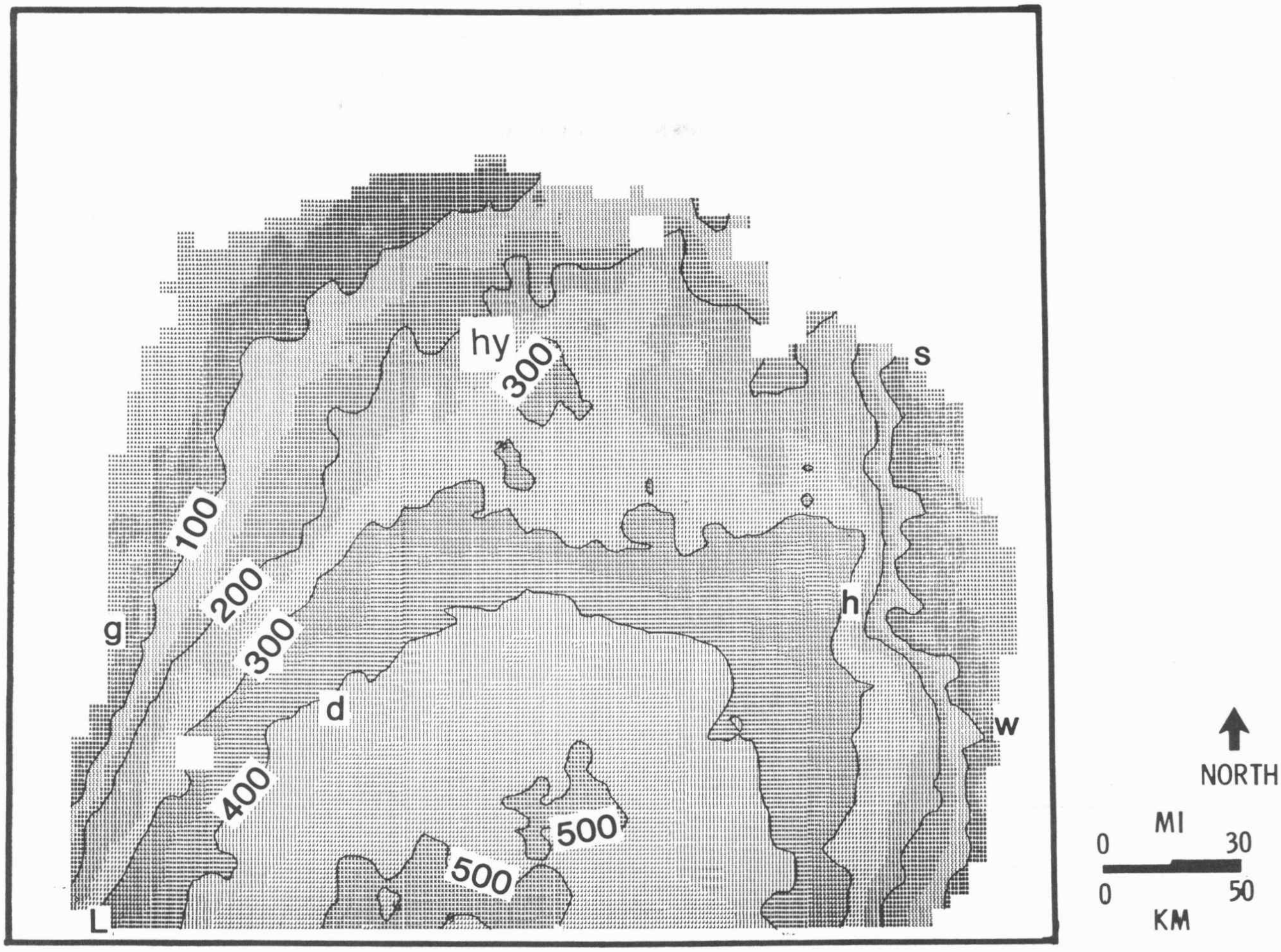


FIGURE 12—Variable-density contour map of thickness of halite-bearing interval in Hutchinson Salt. See Figure 2B for legend.

Interpretation—The southward gradation of some of the halite into anhydrite in concert with a continued southward thickening of the evaporitic interval suggest that marine brines originated from the south. The increased amount of shale in the upper Hutchinson Salt interval in the southwest suggests that progradation of shale along the basin margins restricted the size of the brine body.

The depocenter of the upper part of the Hutchinson Salt (Figure 17) shifted to the southwest with respect to that of the lower salt. The long axis of the depocenter is oriented parallel to the trend of thickening on the interval isopach map (Figure 12).

The depocenter of the Hutchinson Salt was initially the northeastern sector of the basin but, later, maximum halite precipitation migrated southwestward. The lithofacies cross section on Figure 14 reveals a progradational sequence where initial halite precipitation began in the most saline portion of the brine body in the northeastern sector while more anhydritic sediments accumulated to the southwest. Halite accumulation then shifted basinward (southwest), overstepping an area previously dominated by anhydrite. The later NE-SW elongation of the salt depocenter (Figure 17) resulted from restriction in the size of the basin due to shale infilling along its margins.

The northern pinchout of the salt is a facies change into shale along the margin of the embayment. Thus, the basin filled with aggrading salt within the central part of the embayment and prograding shale along the basin margin.

The thicker, persistent beds of shale may indicate episodes of regional lowering of brine levels and fluctuating salinity, as suggested by the presence of desiccation polygons filled with anhydrite in the shale and low bromine concentrations in salts adjacent to them. Anhydrite commonly succeeded the thicker shale beds and frequently precipitated as lenses or filled the large polygonal fractures in the shale. Thick (greater than 2 ft), laterally extensive anhydrites suggest lower salinities and basinwide deepening of the brine body.

The eastern edge of the salt in central Kansas nearest the present land surface is a solution front occurring at shallow depths (<300 ft). Along the solution front

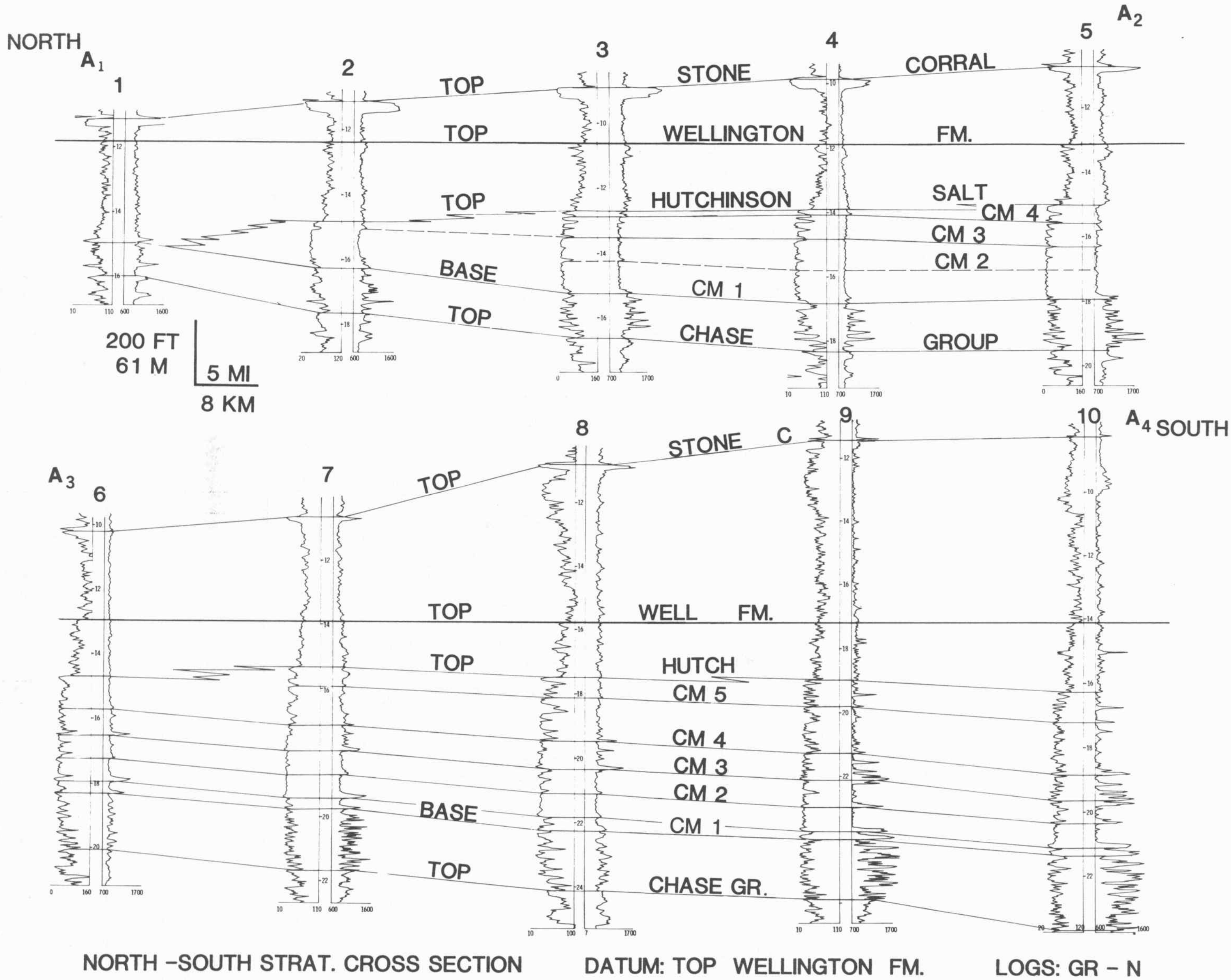


FIGURE 13—A1-A4 north-south, wireline-log, stratigraphic cross section of interval from Stone Corral (top) to Chase Group. Datum is top Wellington Formation "marker." See Figure 2B for cross section location. CM_3 marker divides Hutchinson Salt into upper and lower units. Note distinction of halite, anhydrite (beneath Hutchinson Salt), carbonate (Chase Group), and shale (above the salt). Gamma ray logs on left; neutron logs on right (API Units).

there is an abrupt decrease in salt thickness from the top downward. Shallow wells drilled along the solution front commonly experience lost circulation. Numerous evidence of subsidence on the surface and brine seeps are associated with that solution edge (Gogel, 1981; Lane and Miller, 1965; and Walters, 1980). The active solution front of the halite extends north to south for 84 mi from the city of Salina to just southwest of Wichita and is identified as closely spaced contours along the eastern edge of the total-net-salt isopach map (Figure 15). South of the front the contour spacing increases indicating little or no solution.

Compare the pattern of contours on the net salt isopach (Figure 15) that define the position of the salt-dissolution front along the eastern edge of the map with the position of the depositional pinchout of the salt in the southeast and around the north and west sides of the map. The southeastern and northern flanks are similar to each other and show a rather rapid transition of halite to shale, whereas the western edge, particularly the southwestern area, is characterized by a more gradual transition of halite (with anhydrite) to shale units. The lithofacies cross section on Figure 14 indicates an interfingering of halite and anhydrite throughout the stratigraphic section.

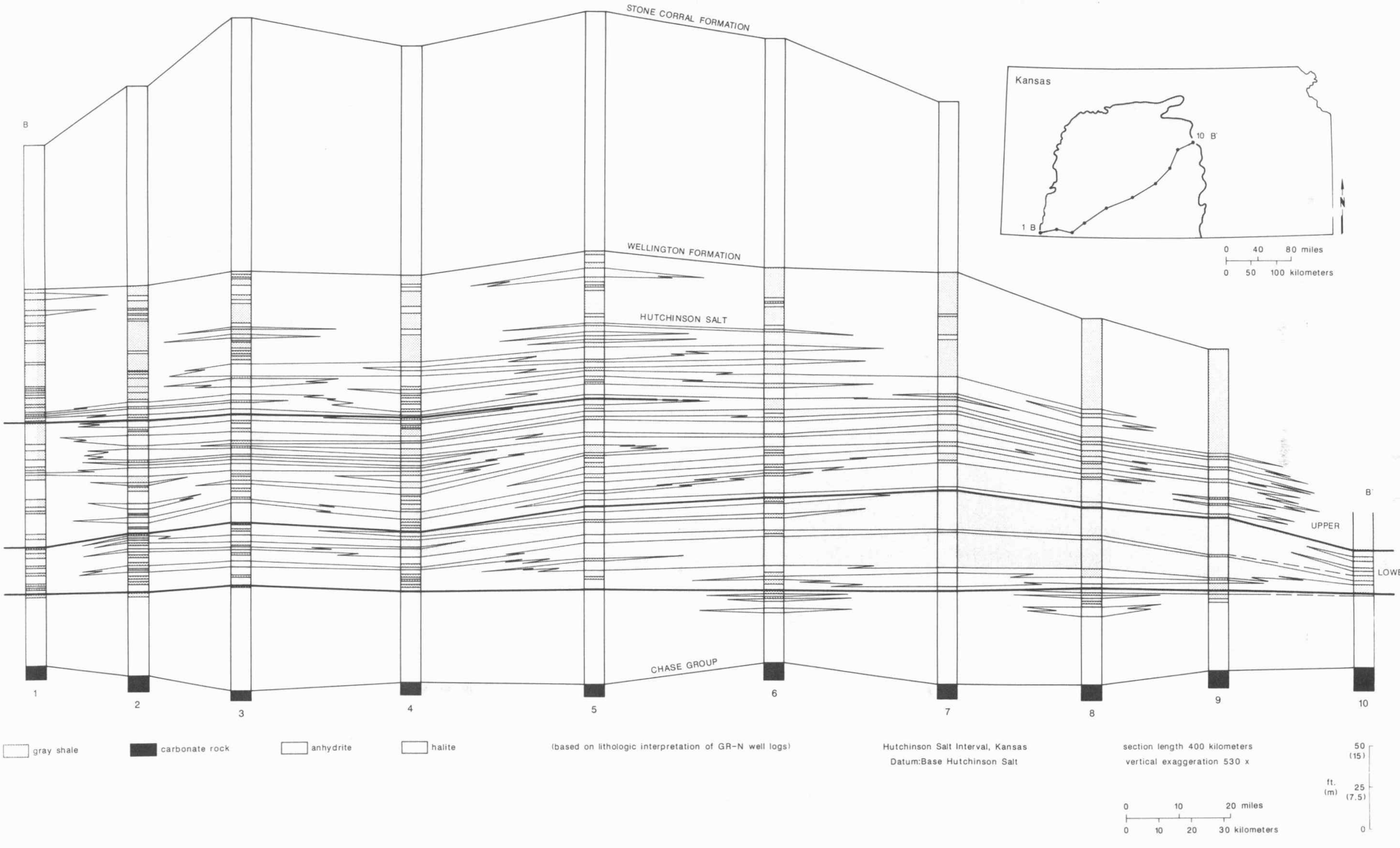


FIGURE 14—Southwest to northeast stratigraphic cross section B-B' based on lithologic interpretation of Hutchinson Salt interval using gamma ray and neutron wireline log combinations. Datum is base of Hutchinson Salt. Thicker beds of halite, anhydrite, and shale are identified.

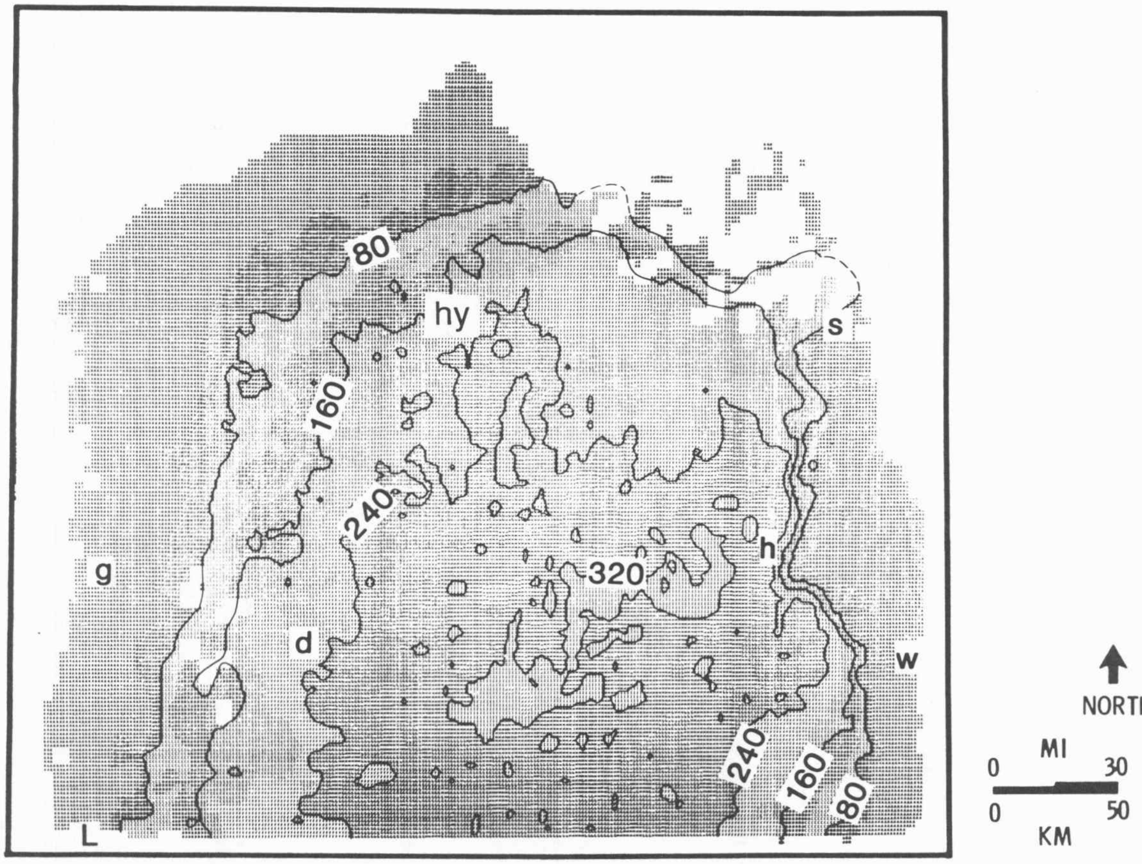


FIGURE 15—Net halite thickness of Hutchinson Salt. See Figure 2B for legend.

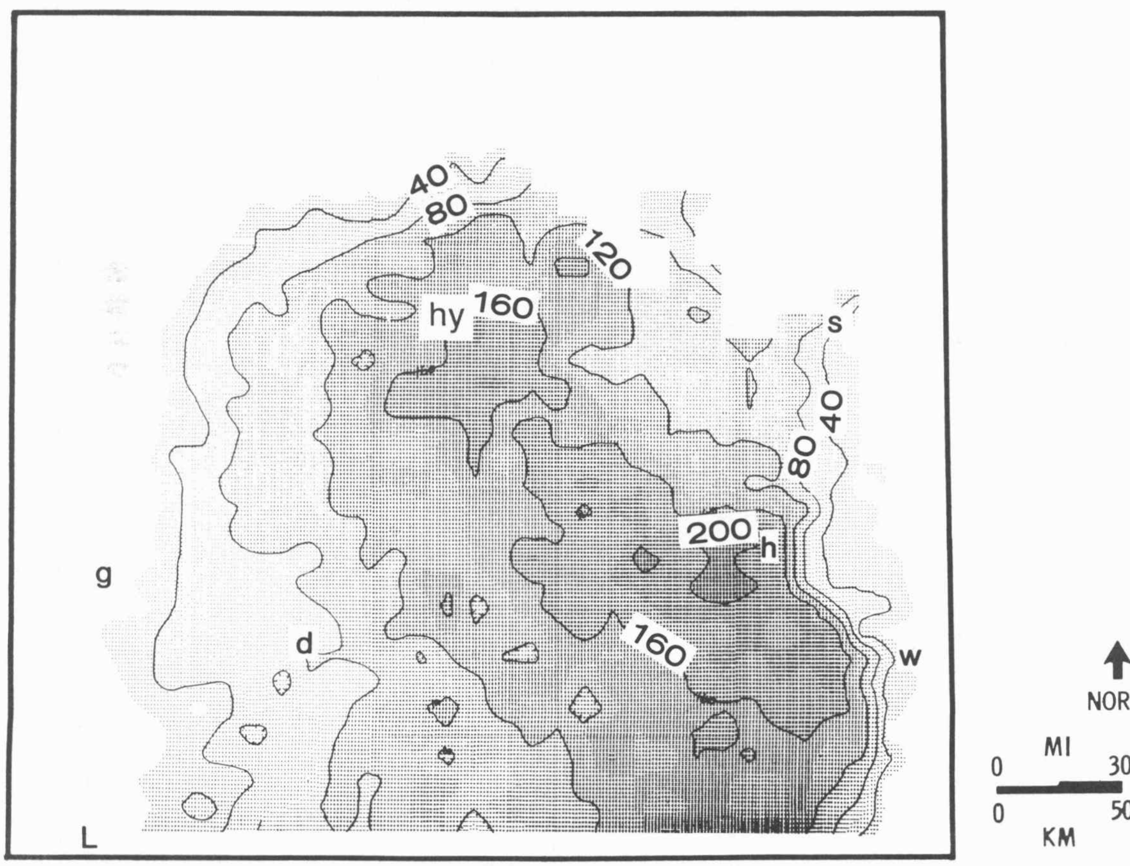


FIGURE 16—Net halite thickness of lower part of Hutchinson Salt (below CM_3 shale/anhydrite marker). See Figure 2B for legend.

The broadly spaced north-south-trending contours along the western edge and the closely spaced east-west-trending contours along the northern edges of the salt converge sharply in northwestern Lane County, Kansas, near the arrow shown in Figure 18. From that pivotal position note how the generally north-south-oriented contours directly south of this point fan out and become more widely spaced northwest-southeast-trending contours east of this position. The general pattern of thickening of the Permian strata is to the south.

Origin of Hutchinson Salt

Discussion

The halite-percentage map, net salt map, and cross sections indicate that halite precipitation was dominant in the northeastern portion of an embayment extending from Oklahoma into north-central Kansas. The lithofacies cross section indicates that the pre-Cm_3 strata are thicker in northeastern Kansas than to the south, suggesting a topographic depression in the northeast in which the Hutchinson Salt was deposited. The greater abundance and thickness of anhydrite in the southwest suggest that salinities did not often reach levels that led to halite accumulation in that part of the basin, particularly in the early history of the Hutchinson Salt. This southwestern area was closer to the region of influxing seawater from the Anadarko Basin.

Halite was extensively deposited early in the history of the Hutchinson Salt, but became more limited in areal extent as the basin decreased in size due to halite precipitation and shale progradation or shifting patterns of subsidence. Active subsidence apparently continued to the south, maintaining an open connection to the source of seawater and leading to the accumulation of a thick succession of strata.

The bromine study suggests that a brine of nearly constant salinity and constant volume was established repetitively during the accumulation of this deposit. That requires a seawater source for incoming brines, evaporative concentration of the brines, and a means for exit of the concentrated brines.

The barred-basin model proposed by Scruton (1953) appears to be an acceptable depositional model for the Hutchinson Salt. A circulation pattern in a brine body results from inflowing seawater and outflow of dense brines. Evaporative concentration of the incoming seawater leads to increasing salinity and, eventually, precipitation of evaporites. Reflux of seawater and brine would then hold salinity steady. Within the Hutchinson Salt, sulfate deposits increase seaward (southwest) and are replaced by halite to the north, which suggests some form of pre-concentration of the brine before it reached Kansas.

Low bromine levels from the salt body in the northeastern portion of the basin support the idea that salinities were only in the low range of those necessary for halite to precipitate, or that some of the halite is reprecipitated. Usually, low bromine values in halite suggest that it was precipitated from brines derived from dissolution of pre-existing halite in the basin. A simple calculation in Table 4 suggests that 40% of the halite may have come from pre-existing halite which was dissolved in the basin. The cores that were analyzed are all located near each other in the northeastern section of the salt deposit. That sampling is not adequate to evaluate the extent of dissolution in the basin, which may have been significant along its fringes (see Figure 19).

The Hutchinson Salt is composed of many separate halite beds each 0.5-10 ft thick and bounded by beds of non-halite lithologies. The pattern is repetitive. Shale is overlain by carbonate or sulfate which, in turn, is overlain by halite; halite is the most abundant lithology in the sequence in the basin proper. The origin of the sequences can be explained in terms of sea-level fluctuations, as follows. Halite was precipitated during intermediate and falling levels of the brine. As sea level fell, regional circulation of the brine was disturbed and local runoff of meteoric water became increasingly important in dissolution of pre-existing halite and influx of terrigenous detritus. A subsequent sea-level rise transported brines of lowered salinity into the basin. Evaporative concentration led to the production of more dense brines and eventual re-establishment of refluxing currents. Then, widespread sulfate accumulation ensued, followed by halite precipitation and accumulation. Accumulation of thin carbonate sediments could have preceded precipitation of sulfates if salinity was low enough.

Approximately 15 of these transgressive-regressive episodes of halite precipitation in the Hutchinson Salt occur in the cored wells. The average duration of the episodes is 270,000 years based on an approximate 4-m.y. interval for the accumulation of the Sumner Group.

The evaporite succession and the petrographic data support an interpretation of a moderately deep subaqueous origin for a majority of the halite. The clastics are fine grained and are not oxidized. Much of the halite is intimately banded with mm- to cm-thick layers of dark-gray shale. Those shale laminae are not generally associated with truncated bottom-precipitated chevron crystals. Truncation of chevron halite and variable bromine values are more common in the upper parts of individual halite beds, suggesting fluctuating brine conditions and shallowing brine depths.

In the Palo Duro and Dalhart Basins, the early Leonardian strata equivalent to the Wellington Formation belongs to the Wichita Group. Those rocks are cyclical, dolomitized shelf carbonates that are succeeded by shallow brine-pan halite deposited across a wide, low-relief shelf (McKee, Oriel, et al., 1967). It was necessary for marine waters to flow from the Midland Basin and across that

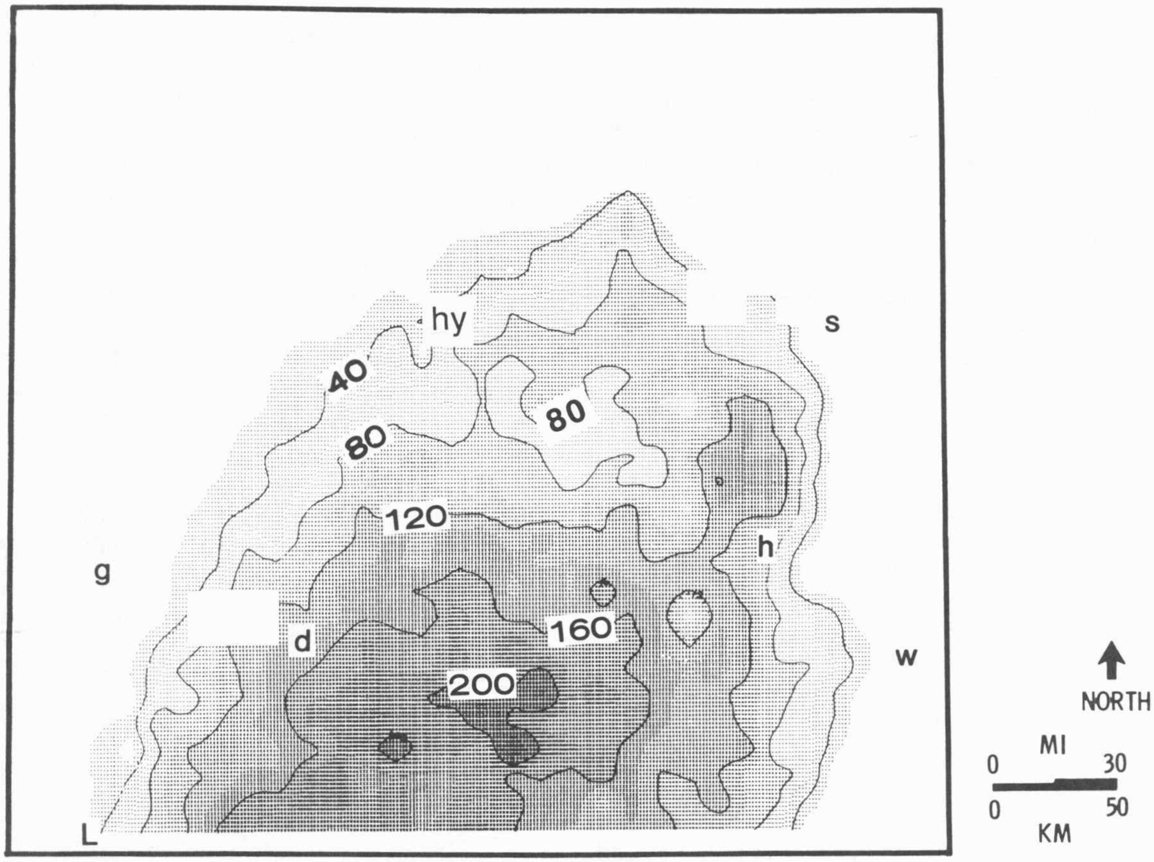


FIGURE 17—Net halite thickness of upper part of Hutchinson Salt (above CM_3 shale/anhydrite marker). See Figure 2B for legend.

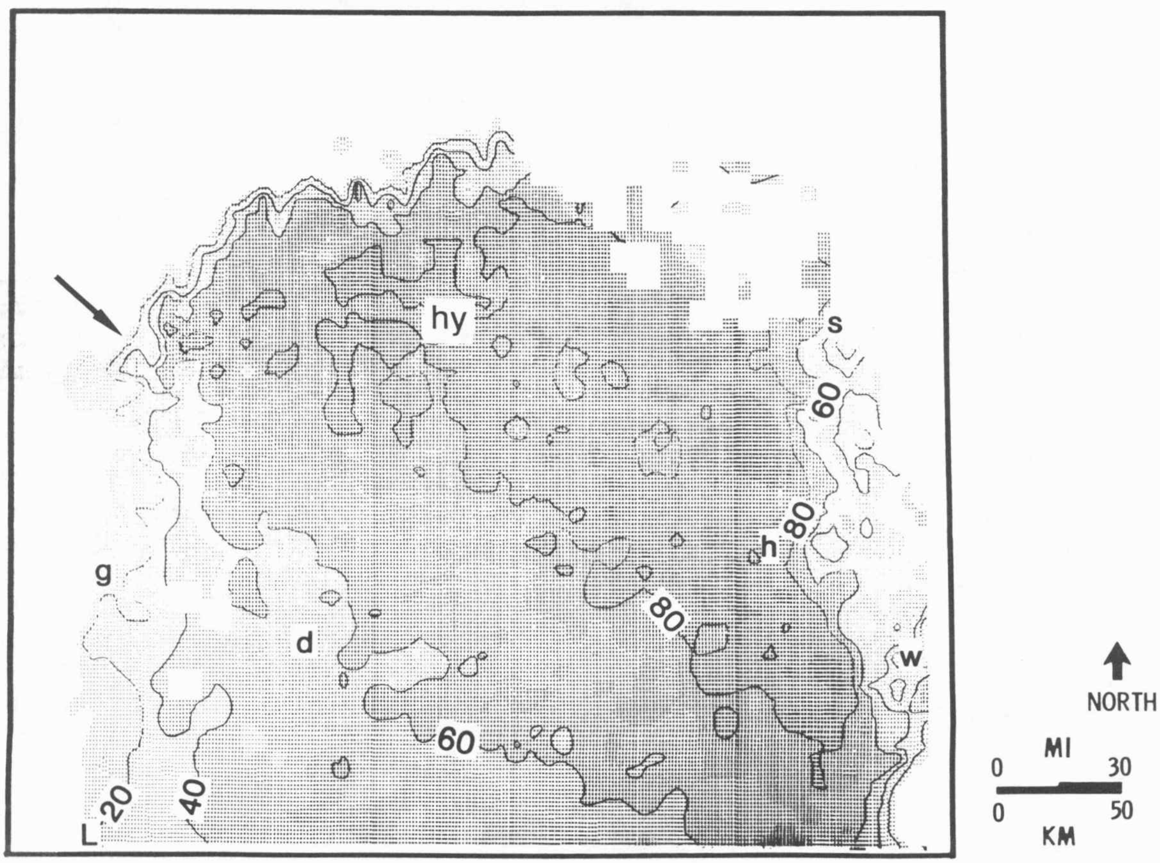


FIGURE 18—Ratio of total net halite to thickness of halite-bearing interval of the Hutchinson Salt (i.e. halite percentage). Arrow points to change in contour spacing referred to in text. See Figure 2B for legend.

TABLE 4—Estimation of brine derived from dissolution of pre-existing halite.

Example: 40 ppm bromine (Br) in halite

$$\text{partition coefficient of Br} = .14 = \frac{40 \text{ ppm Br in halite}}{X_{40}}$$

$$X_{40} = \begin{array}{c}\text{Br conc. of a brine}\\ \text{that precipitates halite}\\ \text{with a 40-ppm Br conc.}\end{array} = \frac{40}{.14} = 286 \text{ ppm}$$

Halite precipitates when brine reaches concentration of 11X seawater. Brine at that concentration derived entirely from normal seawater would have ~500 ppm bromine

A brine with 286 ppm bromine is equivalent to normal seawater concentrated to 6.29X original salinity.

The fraction of the brine derived from dissolution of preexisting halite that would precipitate halite with a Br concentration of 40 ppm is:

$$1 - \frac{6.29}{11} = 0.43$$

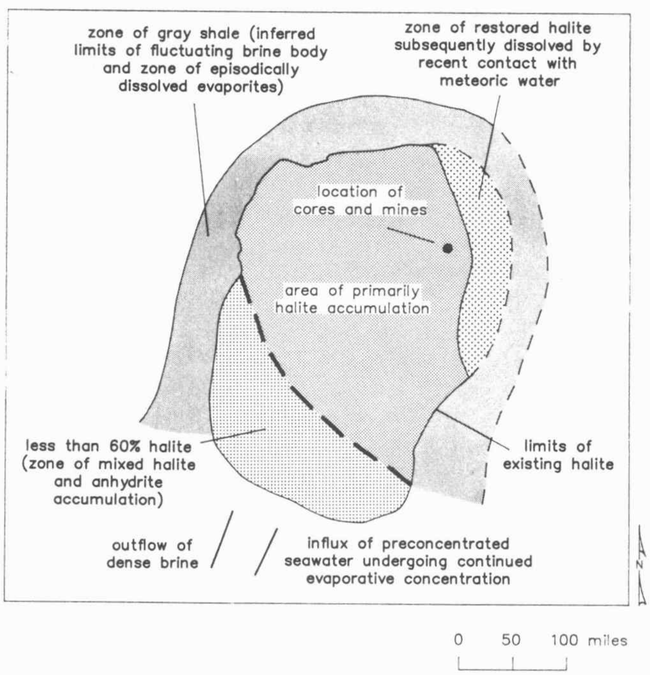


FIGURE 19—Process-response model of Hutchinson Salt accumulation and preservation.

shelf to reach the study area. Concentration of the brine probably occurred as it flowed northward.

Interpretations of Wolfcampian strata that preceded the Wichita Group in the Palo Duro and Dalhart Basins indicate that those areas were deep basins which permitted normal seawater to reach the study area (McKee, Oriel, et al., 1967). The closing of that seaway was probably more important to the development of the extensive Hutchinson Salt than an increasingly drier climate.

The actual water depth in the study area during accumulation of the Hutchinson Salt was not necessarily any greater or lesser than during deposition of the carbonates of the Chase Group, which preceded the accumulation of these evaporites. Rather the waters on this shelf had become much more saline.

Conclusions

Petrology, vertical bromine profiles, and regional correlation and mapping from wireline logs suggest that an extensive brine body was responsible for the accumulation of the Hutchinson Salt in Kansas and Oklahoma. The brine body exhibited a salinity gradient increasing from southwest to northeast which fluctuated through time. Small cycles are recognized which indicate repetitive changes in brine composition and level of the brine body, whereas thick basinwide anhydrites and shales record significant episodic perturbations in water chemistry and volume.

A simple depositional sequence is proposed for the Hutchinson Salt:

1) The basin was inundated from a marine source to the southwest and the brine became more concentrated through evaporation, which led to carbonate accumulation, then anhydrite precipitation.
2) Further concentration of brines led to primary halite accumulation, initially in the distal, more-restricted portions of the basin in the northeast.
3) Outflow of dense brines and influx of new seawater led to precipitation of a thick succession of halite strata in the northeast, as suggested by bromine geochemistry.

4) Periodically the brine level fell, perhaps as influx of seawater was terminated or diminished, which led to further concentration of the brine and reduction in the level of the brine body. At least the edges of the basin were episodically subaerially exposed, as suggested by the presence of desiccation polygons in the thick shales. Locally elevated salinities resulted in polyhalite replacement of some of the anhydrite. Local collapse features consisting of lithified shale clasts in recrystallized salt beds link the dissolution event to a time shortly after the accumulation of thicker shales. The thicker shale beds indicate episodes of siliciclastic influx, which apparently became more significant during the fall of the brine level when circulation in the brine body may have been diminished. The decreased volume of the brine body may have also resulted in greater concentration of suspended clay particles and increased rates of accumulation. In contrast, thin shale laminations indicate only temporary, episodic turbidity of the water and an insignificant change in water level or chemistry, at least near the bottom of the brine body. Petrography of samples from cores in the northeastern sector of the halite body indicates that the thin clays are associated with limited or no halite dissolution in the bedded sequences of halite containing clay laminations. Perhaps an influx of freshwater from surrounding land areas floated over the denser brine, providing a source for the detrital clay, but only momentarily interrupting precipitation of halite. Brines derived from local dissolution of halite by freshwater along the basin margins would lower the bromine concentrations in the brine body and lead to unusually low concentrations of bromine in halite.
5) Following a period of significant brine-level lowering and, commonly, deposition of shale, renewed inundation of the basin by less saline brines resulted in extensive accumulation of anhydrite.
6) The evaporative-reflux cycle was repeated at least 15 times to create the Hutchinson Salt.

Average water depth did not necessarily differ greatly from the time when carbonates and shales of the Chase Group were deposited. The cyclical nature of the halite beds, i.e. the transgressive- regressive events which are defined by the bromine profiles, are as yet poorly understood. Those alternations may be analogous to the alternating carbonate-shale successions of the Wolfcampian deposits in the area, albeit under much more hypersaline conditions.

Acknowledgments

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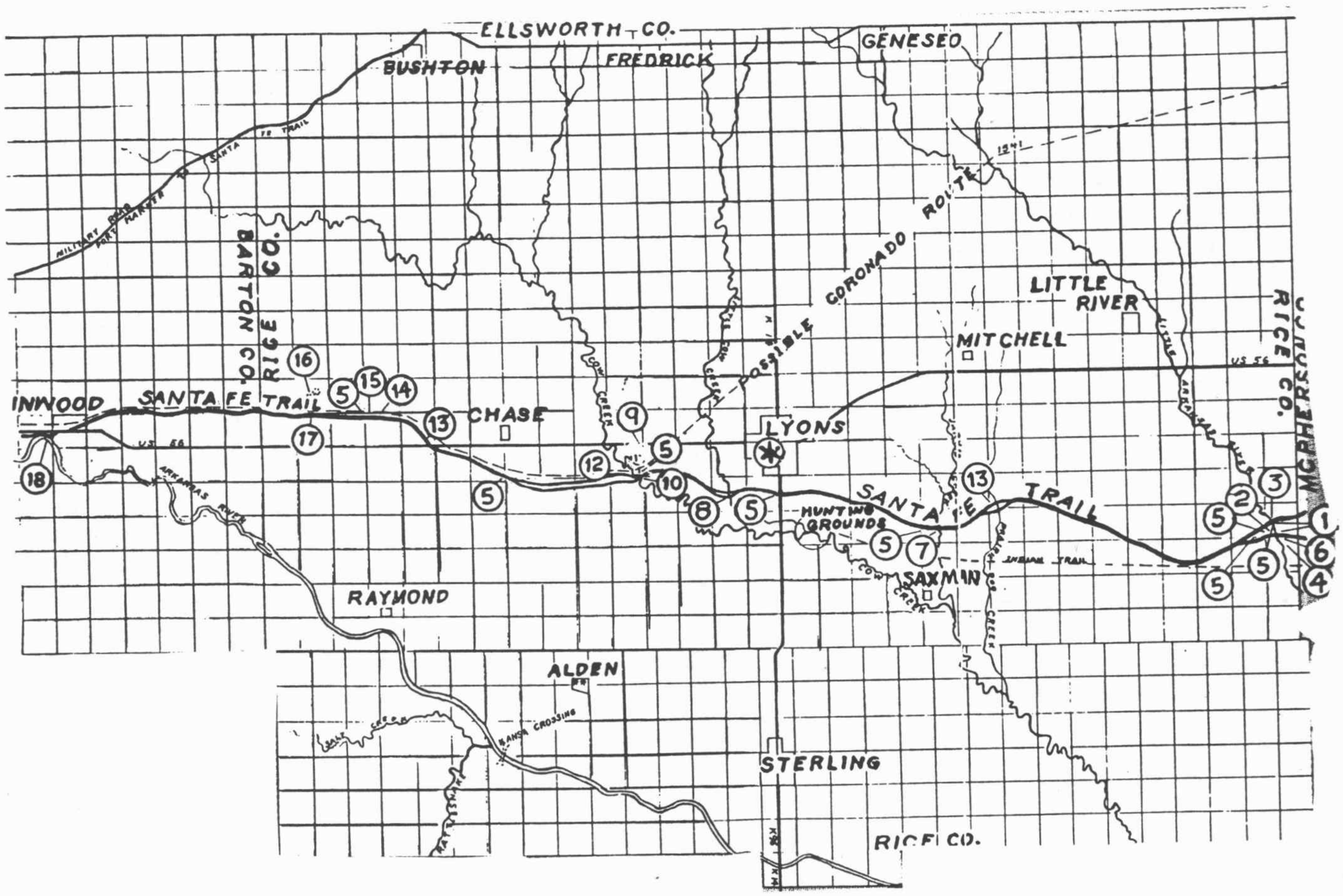
MAP OF HISTORIC PLACES IN RICE COUNTY, KANSAS



1. Little Arkansas Crossing
2. Stone Corral Site
3. Marker Cottonwood
4. Cottonwood Grove Cemetery
5. Dar Marker
6. Rifle Pits
7. Jarvis Creek Crossing – Site of Chavez Murder
8. Little Cow Creek Crossing
9. Historical Sign – Father Padilla Cross
10. Cow Creek Crossing
11. Buffalo Bill Mathewson's Well
12. WagonTrain Siege Area
13. Trail Ruts
14. Plum Buttes Massacre Site
15. Ralph's Ruts
16. Plum Buttes
17. Gunsight Notch
18. Big Bend of Arkansas River
19. Atchison, Topeka,Santa Fe Railroad Depot

ERRATA

Please note the following corrections on the pages described:

At accumulative mileage 56.2, following the word "Simpson" in the third line, the printed word "state" should read "strata".

At accumulative mileage 166.0, the word "ethonol" in the second line should read "ethanol".

At accumulative mileage 169.3, following the semicolon at the end of the first line should be a space and a quotation mark to read : "the Big Ditch".

At the bottom of the introduction or cover page preceding the "History of the Lyons , Kansas Salt Mine, change the word "minerial" in *Annual Bulletin of Minerial Resources of Kansas for 1898* to read Mineral.