KANSAS GEOLOGICAL SURVEY
OPEN-FILE REPORT ND-15

KANSAS SALT DEPOSITS

by

R.O. Kulstad

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Kansas salt deposits

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ABSTRACT

Three Permian salt deposits, each several hundred feet thick, underlie southwestern and south-central Kansas and extend into Oklahoma and Colorado. In order of their deposition these are: (1) The Hutchinson Salt Member of the Wellington Formation, (2) The salt beds genetically related to the Stone Corral Formation, and (3) The salt beds genetically related to the Blaine Formation. In vertical east-west cross section these salt deposits are arranged en echelon with the oldest (Hutchinson) extending farthest east. Each of the salt deposits cuts correlation lines established by well-defined key beds.

The physical-chemistry of brine derived by the evaporation of sea water severely limits the conditions under which salt deposits can accumulate. The stratigraphy of the Kansas salt deposits ~~is compared to the physical-chemistry of the brine. This comparison~~ indicates that during the time of deposition of the Hutchinson Salt: (1) Sea level was fluctuating about a mean at a relatively rapid rate and (2) The rate of accumulation of sediment was relatively slow but somewhat faster than the rate of subsidence of the basin. The two younger salt deposits ("Stone Corral" salt and "Blaine" salt) were deposited during subsequent periods when subsidence was faster than the rate of accumulation of sediment.

INTRODUCTION

Permian salt underlies most of southwestern and south-central Kansas and extends into Oklahoma and Colorado (Fig. 1). Three main deposits are present which transgress correlated key beds in the Kansas rock column. These are: (1) The Hutchinson Salt Member of the Wellington Formation, (2) the salt beds genetically related to the Stone Corral Formation, and (3) the salt beds genetically related to the Blaine Formation (Fig. 2; Plates 1,2,3). In vertical east-west cross section these salt deposits are arranged en echelon with the oldest deposit (Hutchinson) extending farthest eastward (Fig. 3). Several hundred feet of terrigenous clastic sedimentary rocks (mostly red beds) separate the deposits. The younger deposits lie more deeply buried than much of the Hutchinson because of the westward regional dip and beveling by erosion of the overlying strata.

Previous work

The first written reports concerning Kansas salt were newspaper articles in 1887 announcing the discovery of the Hutchinson Salt at several localities (Taft, 1946). One of the earliest scientific reports was by Haworth (1899), whose report included a stratigraphic cross section, and a map indicating areas that were thought to be underlain by the Hutchinson, and a description of the Kansas salt

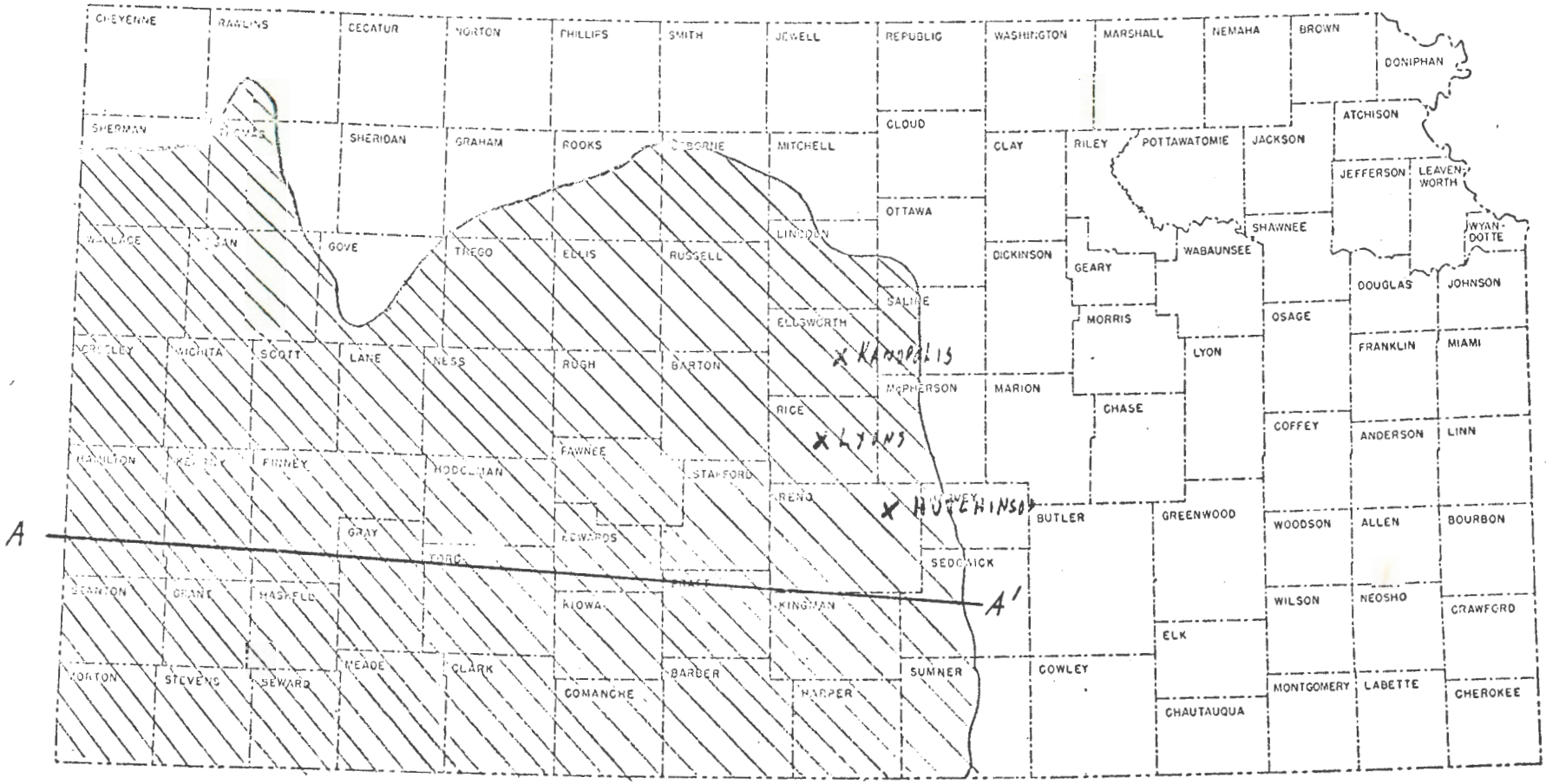
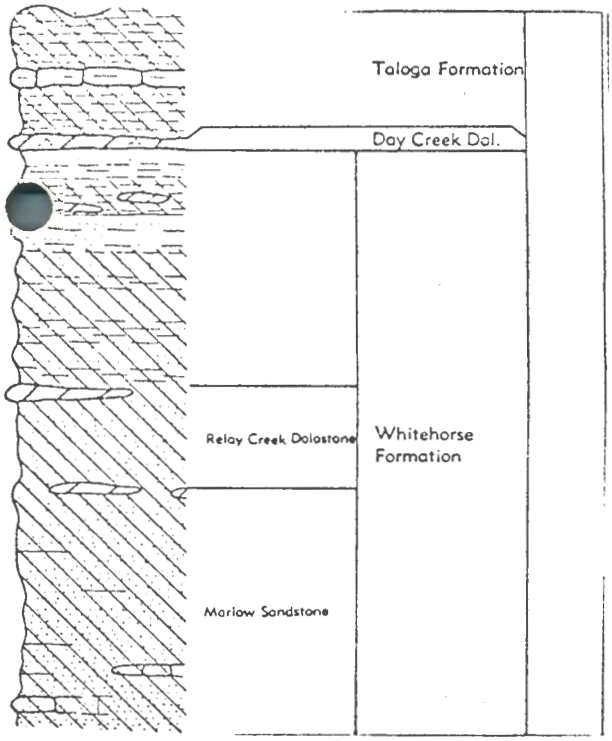


FIG. 1. GENERAL AREA UNDERLAIN BY SALT IN KANSAS

▨ SALT BEDS IN SUBSURFACE

X SALT MINES



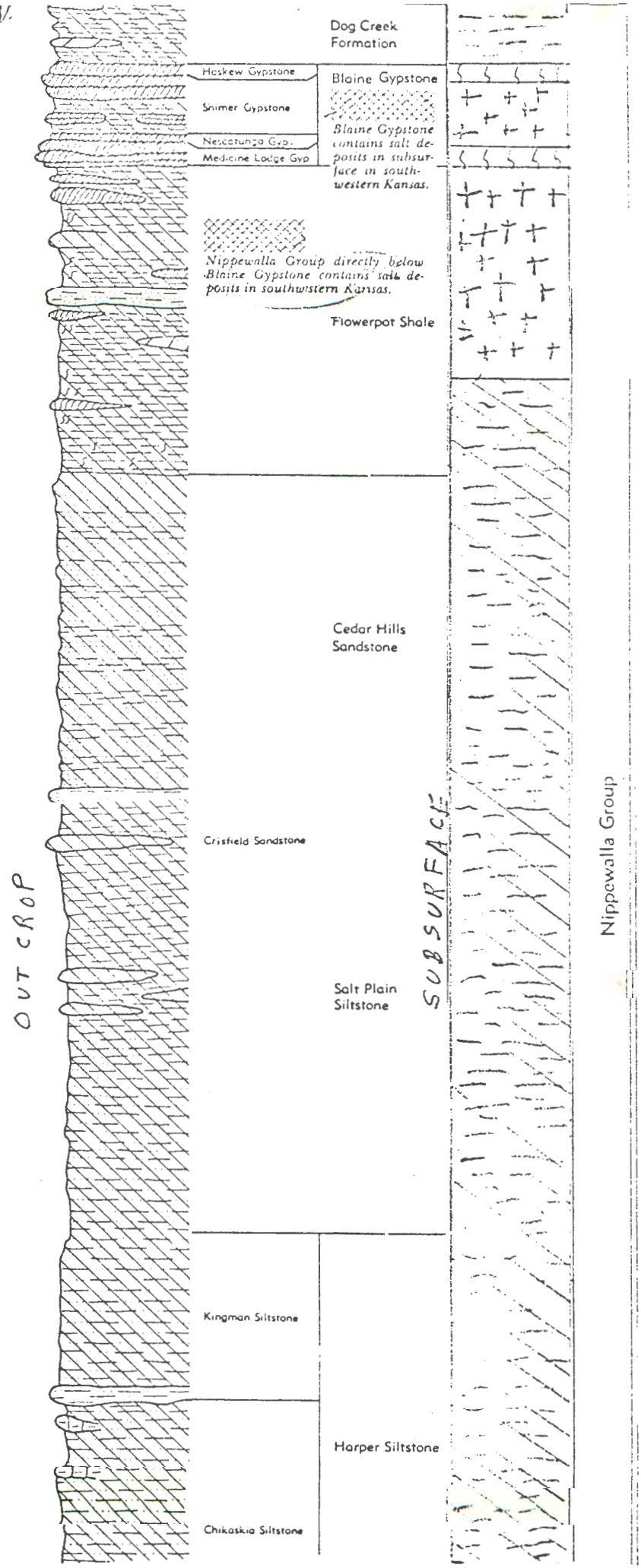
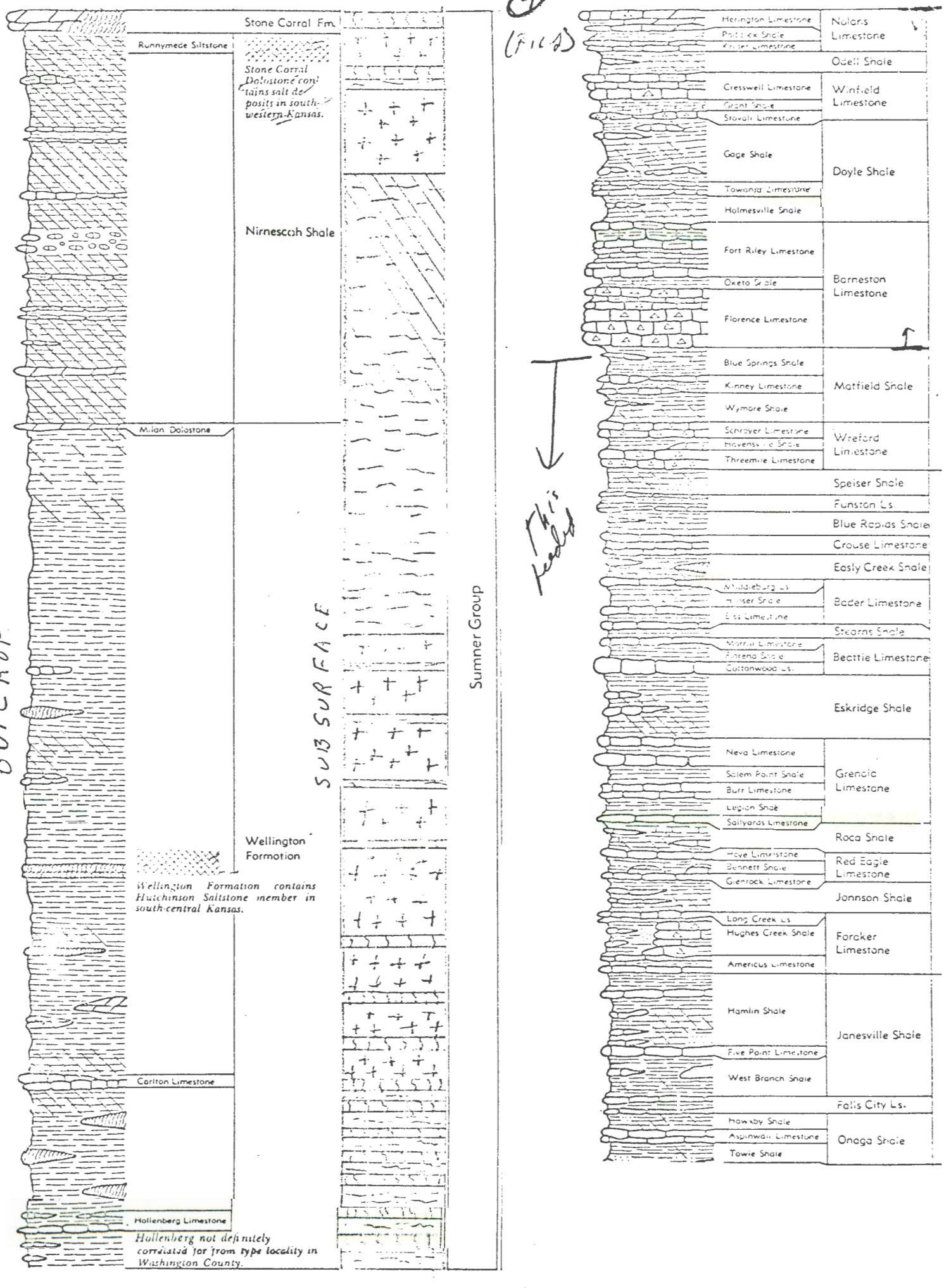


FIG. 2

GRAPHIC COLUMN OF PERMIAN ROCKS IN KANSAS (MODIFIED FROM JEWETT 1959)


Stone Corral Fm.
Runnymede Siltstone
Stone Corral Dolostone contains salt deposits in southwestern Kansas.
Nirnescah Shale
Milan Dolostone
Wellington Formation
Wellington Formation contains Hutchinson Saltstone member in south-central Kansas.
Carlton Limestone
Hollenberg Limestone
Hollenberg not definitely correlated for from type locality in Washington County.
OUTCROP
SUBSURFACE
Sumner Group
(4)
(FIGS)
This
Herington Limestone
Paddock Shale
Krider Limestone
Nolans Limestone
Odell Shale
Cresswell Limestone
Grant Shale
Stovall Limestone
Winfield Limestone
Gage Shale
Towanda Limestone
Holmesville Shale
Doyle Shale
Fort Riley Limestone
Oketo Shale
Florence Limestone
Barneston Limestone
Blue Springs Shale
Kinney Limestone
Wymore Shale
Matfield Shale
Schroyer Limestone
Havensville Shale
Threemile Limestone
Wreford Limestone
Speiser Shale
Funston Ls.
Blue Rapids Shale
Crouse Limestone
Easly Creek Shale
Middleburg Ls.
Hooser Shale
Ede Limestone
Bader Limestone
Stearns Shale
Morrill Limestone
Fairmont Shale
Cottonwood Ls.
Beattie Limestone
Eskridge Shale
Neva Limestone
Salem Point Shale
Burr Limestone
Legion Shale
Sallyards Limestone
Grenola Limestone
Roca Shale
Hove Limestone
Bonnett Shale
Glenrock Limestone
Red Eagle Limestone
Johnson Shale
Long Creek Ls.
Hughes Creek Shale
Americus Limestone
Forker Limestone
Hamlin Shale
Five Point Limestone
West Branch Shale
Janesville Shale
Falls City Ls.
Howsby Shale
Aspinwall Limestone
Towle Shale
Onaga Shale

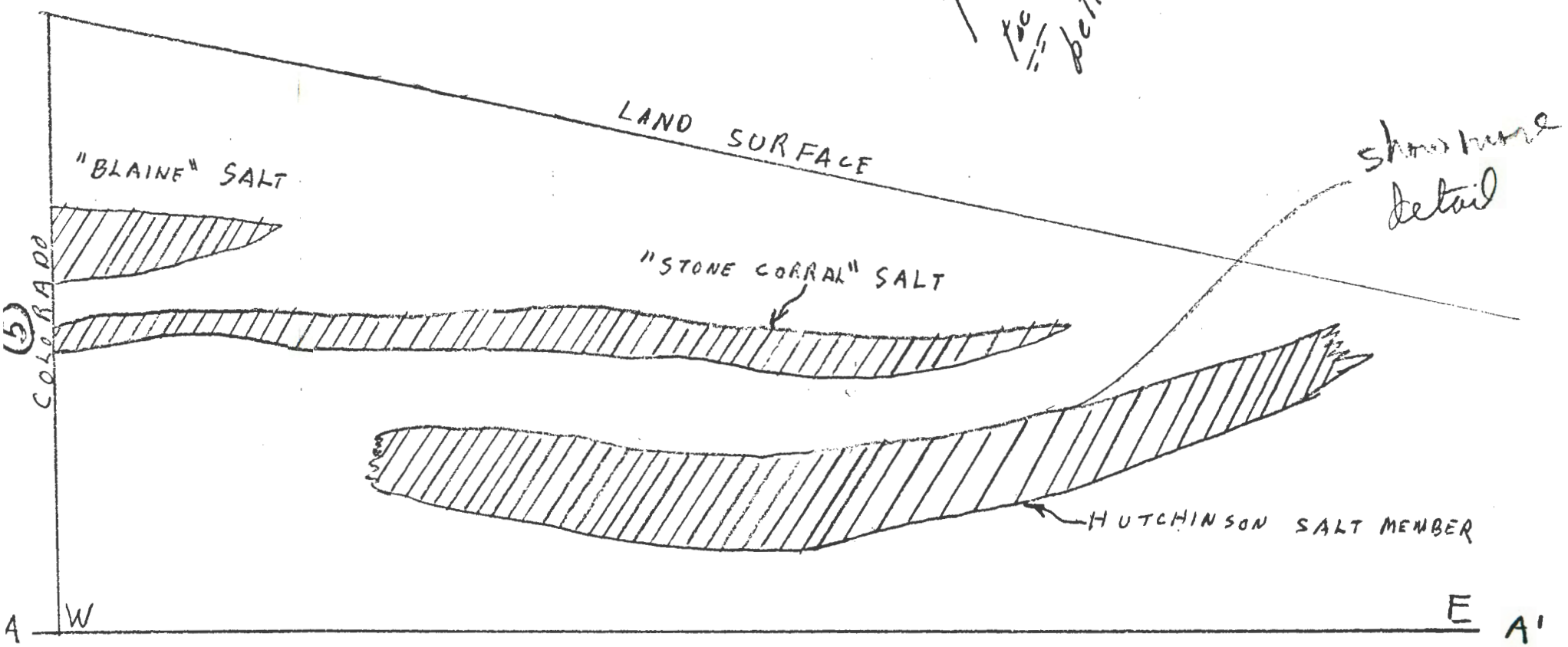


FIGURE 3. SCHEMATIC E-W CROSS SECTION OF KANSAS SALT DEPOSITS (SEE FIG. 1)

industry.

Thickness maps of the Hutchinson salt were published by Bass (1926), Moore and Landes (1927), Ockerman (1932), Taft (1946), and Kulstad (1959). Maps outlining areas underlain by salt in Kansas include those ~~published~~ by Jewett and others (1942); Lee, Leatherock and Botinelly (1948); and Lee (1956), as well as Mineral Resources Maps published by the State Geological Survey of Kansas in 1942 and 1951.

Stratigraphic cross sections of Kansas salt are included in publications by Phalen (1919); Darton (1921); Kellet (1932); Norton (1939); Edson (1945,1947); Taft (1946); Maher (1946); Lee Leatherock, and Botinelly (1948); Lee (1949, 1953, 1956); and Kulstad, Fairchild, and McGregor (1956). Reports that contain stratigraphic information concerning Kansas salt in text ~~but not illustrated.~~ include those by Cragin (1896), Ver Wiebe (1937); Moore, Frye, and Jewett (1944); Moore and others (1951); and Swineford (1956).

Reports on mining methods and refining of Kansas salt were written by Bailey (1902), Taft (1946), Nexon (1950), Inman (1951), and Bowdish (1951). Exceptional mineralogic features of the Hutchinson Salt were described by Kleihege (1948); Runnels, Reid, and Schleicher (1952); and Swineford and Runnels (1953). Dellwig (1958) and Snyder (1960) reported on plastic flow of rocks in Kansas salt

add Malone — Widness — see reference list in Compton 1962 Illinois

mines. Reiser and Tasch (1960) investigated bacteria from the Hutchinson Salt, and Tasch (1960) described fossil plant fragments from the member.

Acknowledgements

Gratitude is expressed for the help and encouragement from Dr. John Imbrie, Mr. Henry Ley, and Dr. Floyd Preston during the development of the theoretical aspects of this report. Research was in part under the direction of Dr. Louis Dellwig, and Dr. Ralph H. King, Dr. E. J. Zeller and Dr. R. C. Moore reviewed portions of the report. Prof. Kenneth Rose of the Mining and Metallurgical Engineering Department of the University of Kansas granted use of equipment for preparation of rock samples for laboratory examination. Paul C. Franks investigated several specimens with x-ray diffraction.

Mr. D. M. Hunt of the Independent Salt Company, Kanopolis; Mr. Otto Rueschoff of the American Salt Company, Lyons; and Mr. Leo Reid of the Carey Salt Company, Hutchinson, kindly granted access to the salt mines. Help received underground from the miners, too numerous to be named individually, is also acknowledged.

Methods of study and sources of information

Study of Kansas salt was limited to subsurface data because of the complete lack of outcrops. The two sources of information are the logs of the thousands of holes that have been drilled through the salt deposits in search for oil and

gas in deeper rocks and the exposures in the three salt mines in the Hutchinson salt in central Kansas (Fig. 1).

Records of oil and gas exploration

The stratigraphy of the Kansas salt beds and their associated strata was derived chiefly from the correlation of key beds as revealed by wire-line logs (electrical and radioactivity logs) of holes that pass through the salt deposits (Pl. 4 to Pl. 11). Methods of detecting salt strata from these logs are discussed by Kulstad (1959). These logs combined with sample examination provide the most refined data available concerning Kansas salt stratigraphy. Sample logs and drillers logs were used for areas where wire-line logs were not available.

Salt mines

The three salt mines in the Hutchinson Salt Member offer the only opportunity for direct observation of any part of the Kansas salt deposits. Samples for petrographic study were collected from various parts of each of the mines.

STRATIGRAPHY

Introduction

Three main salt deposits occur in Kansas: (1) Hutchinson Salt Member of the Wellington Formation (lower Sumner Group), (2) the salt beds genetically related to the Stone Corral Formation (upper Sumner Group), and (3) the salt beds genetically related to the Blaine Formation (upper Nippewalla Group) (Fig. 2). Stratigraphic

classification of Kansas rocks is based chiefly on outcrop exposures. Inasmuch as Kansas salt deposits do not crop out, their stratigraphic classification is dependent upon tracing outcropping beds into the subsurface to a position where they are interbedded with the salt deposits. Subsurface investigation indicates that there is a genetic relationship between all of the salt in any one deposit; nevertheless, ~~based on the tracing of key beds~~, each of the three salt ~~deposits~~ bodies transgresses ~~correlation lines~~ non-salt key beds, some of which ~~are~~ mark formational boundaries. In this report each salt deposit is considered as a complete entity. For example, the salt genetically related to the Stone Corral Formation is referred to as "Stone Corral" salt, although in some areas part or all of that salt deposit seems to be a part of the underlying Ninnescah Shale.

Stratigraphy of the Hutchinson Salt

The Hutchinson Salt Member is by far the most complex of the three salt bodies. As used in this report, the member includes all salt beds in the Wellington Formation and the nonhalite strata interbedded within the salt. Based on this definition ~~it~~ the Hutchinson Salt Member is a complex heterochronous succession (based on superposition of beds) of intercalated salt, anhydrite, and shale as much as 700 feet thick in Kansas (Pl. 1). Salt of the Hutchinson Member is interbedded with associated key beds that laterally lie either above or below the salt. These associated strata

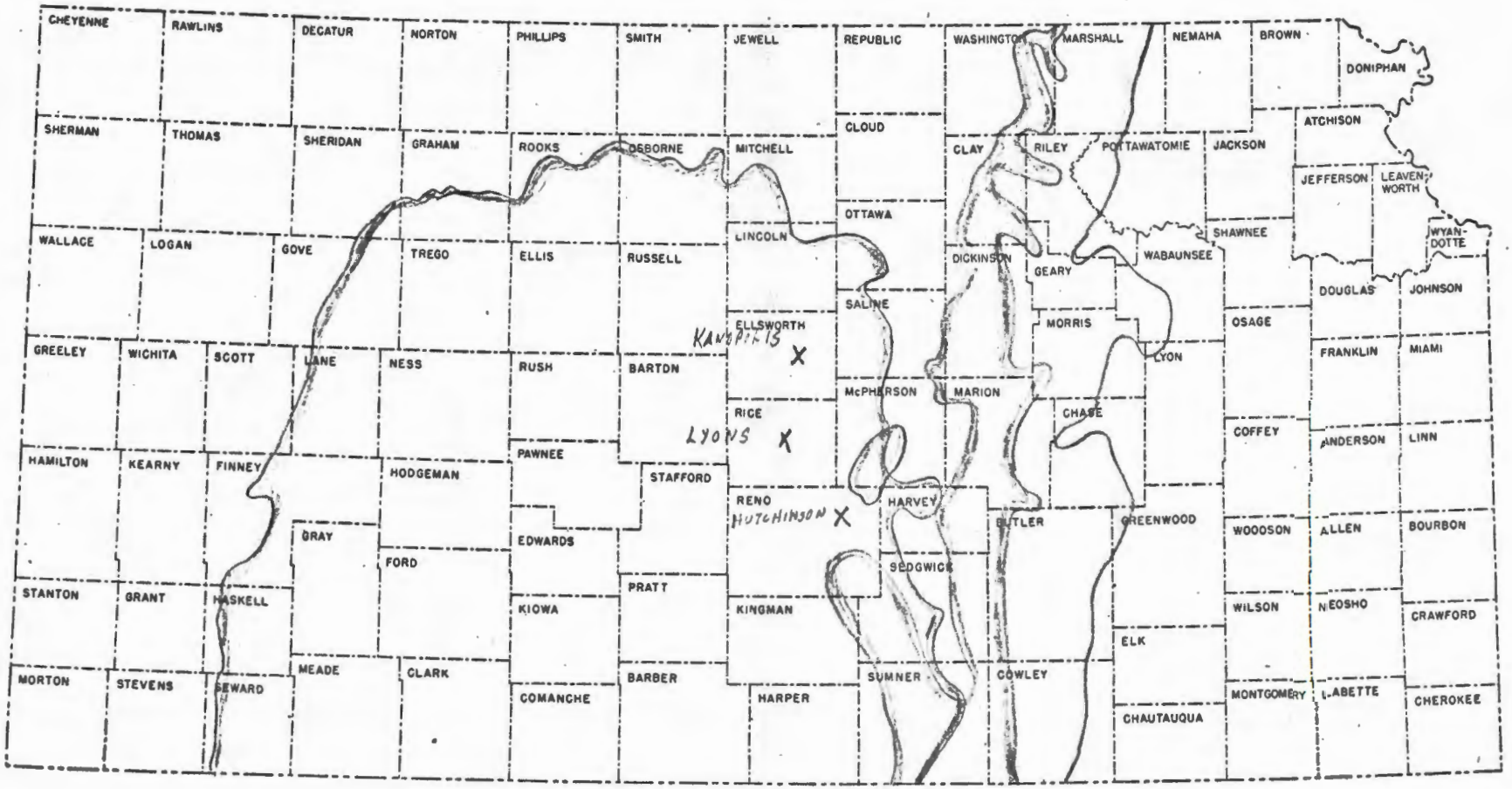
must be considered in an investigation of the Hutchinson because their relationship with salt beds as well as the succession in which they were deposited reveal the conditions that brought about the deposition of the salt ~~deposit~~. Rocks included in the Hutchinson investigation range from the base of the Barneston Limestone (Chase Group) to a position near the contact between the Wellington Formation and the Ninnescah Shale (Chase Group)(Fig. 2). The area of outcrop of the Chase and Sumner Groups and area underlain by Hutchinson Salt is shown in Figure 4. Regional dip of the rocks is to the west about 20-30 feet per mile.

In this report this succession of beds is divided into four ~~lithostratigraphic~~ units. In ascending order these are: (1) carbonate-shale unit, (2) sulfate-shale unit, (3) Hutchinson Salt Member, and (4) thick shale unit (Pl. 4 to 8). Because the boundaries between these ~~lithostratigraphic~~ units are not ~~correlation lines~~, established by well-defined key beds, their stratigraphic classification is indefinite. Their approximate stratigraphic position is ~~presented~~ indicated in the discussion that follows.

Good statement

Rocks chiefly in the Chase Group

Carbonate-shale unit -- The carbonate-shale unit is chiefly an alternating succession of shale and limestone or dolomite with a few beds of anhydrite. The base of this unit is arbitrarily placed at the base of the Barneston Limestone, although this general pattern of alternating beds extends much lower stratigraphically



AREA UNDERLAIN BY HUTCHINSON SALT

GENERAL OUTCROP AREA OF SUMNER GROUP

GENERAL OUTCROP AREA OF CHASE GROUP

X LOCATION OF SALT MINE

FIGURE 4. INDEX MAP OF HUTCHINSON SALT MEMBER

(Fig. 2). The top of the carbonate-shale unit is placed at the stratigraphic position that divides the unit from an overlying succession of shale and anhydrite beds. On the outcrop this position commonly divides the Chase Group from the overlying Sumner Group. Carbonate beds in the unit are as much as 50 feet thick. Shale beds are as much as 20 or 30 feet thick. Representative total thickness is 300 feet (Pl. 4 to 7).

Rocks chiefly in the Sumner Group

Sulfate-shale unit -- The sulfate-shale unit, which overlies the carbonate-shale unit, is an alternation of shale and anhydrite or gypsum beds. In some areas a few beds of dolomite or limestone are closely associated with the sulfate beds. In general, the sulfate-shale unit forms the lower part of the Wellington Formation. The shales in this unit are 10 to 20 feet thick and the sulfate beds are 20 to 30 feet thick. Representative thickness of the unit is 250 feet (Pl. 4 to 7).

Hutchinson Salt Member -- The Hutchinson Salt Member, as used in this report, includes all of the salt beds in the Wellington Formation and those nonhalite beds interbedded with them. The unit overlies the sulfate-shale unit. Throughout most of its area it is chiefly salt but contains many intercalated shale and anhydrite beds. It is not a single layer of salt nor is it a succession of layers ~~of which~~ in which

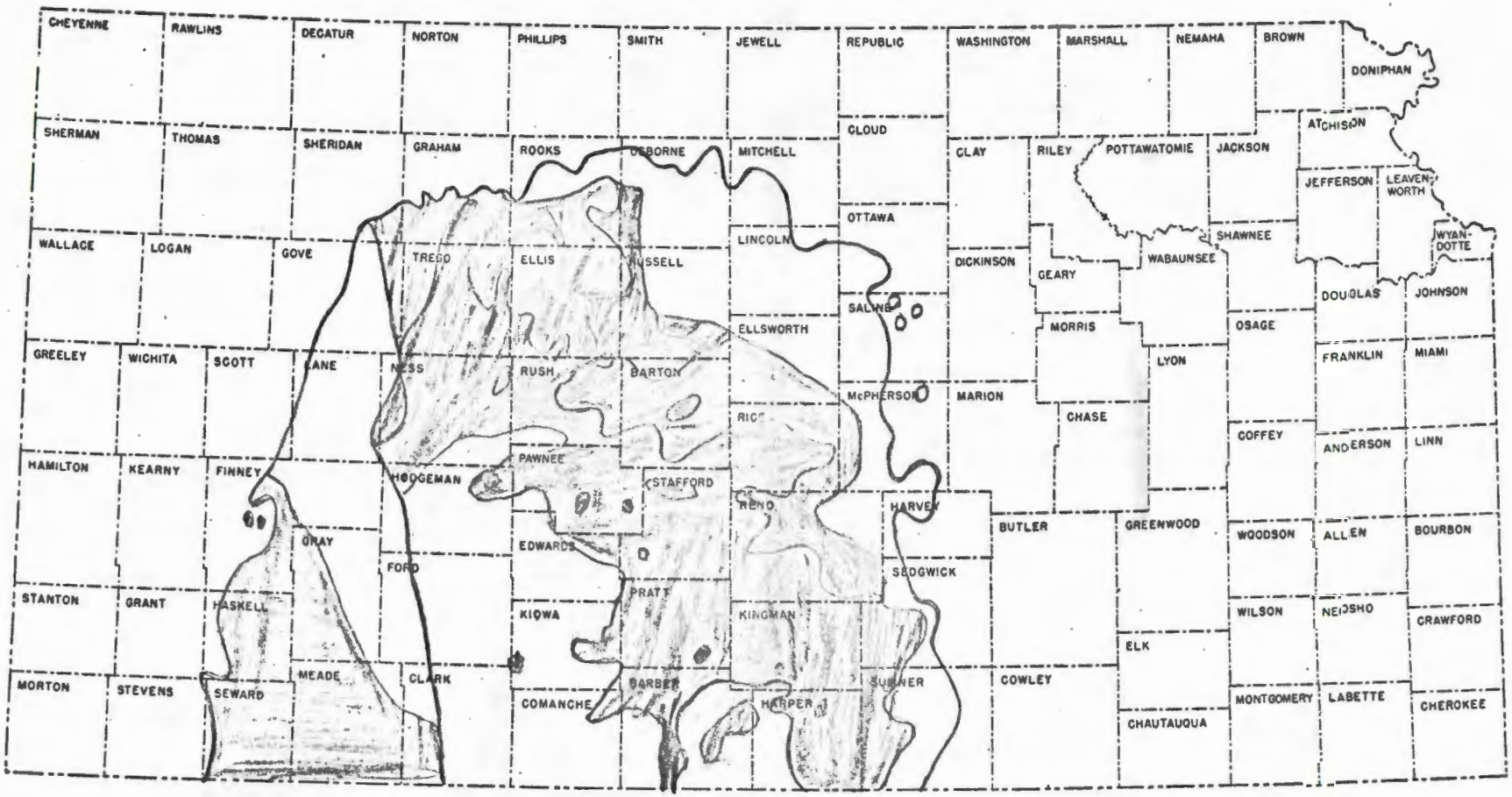
each layer has relatively wide areal distribution. The area underlain by any single salt bed within the unit is relatively small compared with the area underlain by the unit as a whole.

Areal distribution and thickness -- The distribution and thickness of the Hutchinson Salt Member in Kansas are shown on Plate 1. The thickness is more than 700 feet in some parts of the State. Depth of the Hutchinson below the land surface is approximately 400 feet along its eastern edge and approximately 2,000 feet near its western edge. The eastern edge of the salt body has been dissolved by ground water. According to Charles K. Bayne, State Geological Survey of Kansas (personal communication 1960) sinks or depressions at the surface mark in part the eastern boundary of the member. The rest of the Hutchinson does not appear to have been altered by ground water since its deposition.

Check the material I got from Evan Fair - reprint from Ohio conference in my file -

The Hutchinson is predominantly salt throughout most of its area in Kansas (Fig. 5). In the southwest part of that area, however, the member is mainly anhydrite (Pl. 8), and thickness and percentage of salt in the member at that place is extremely variable.

Vertical stratigraphic relationships -- The Hutchinson Salt Member is a relatively large heterochronous stratigraphic unit that, within any one area, contains several lithologic subdivisions. In this respect it resembles a



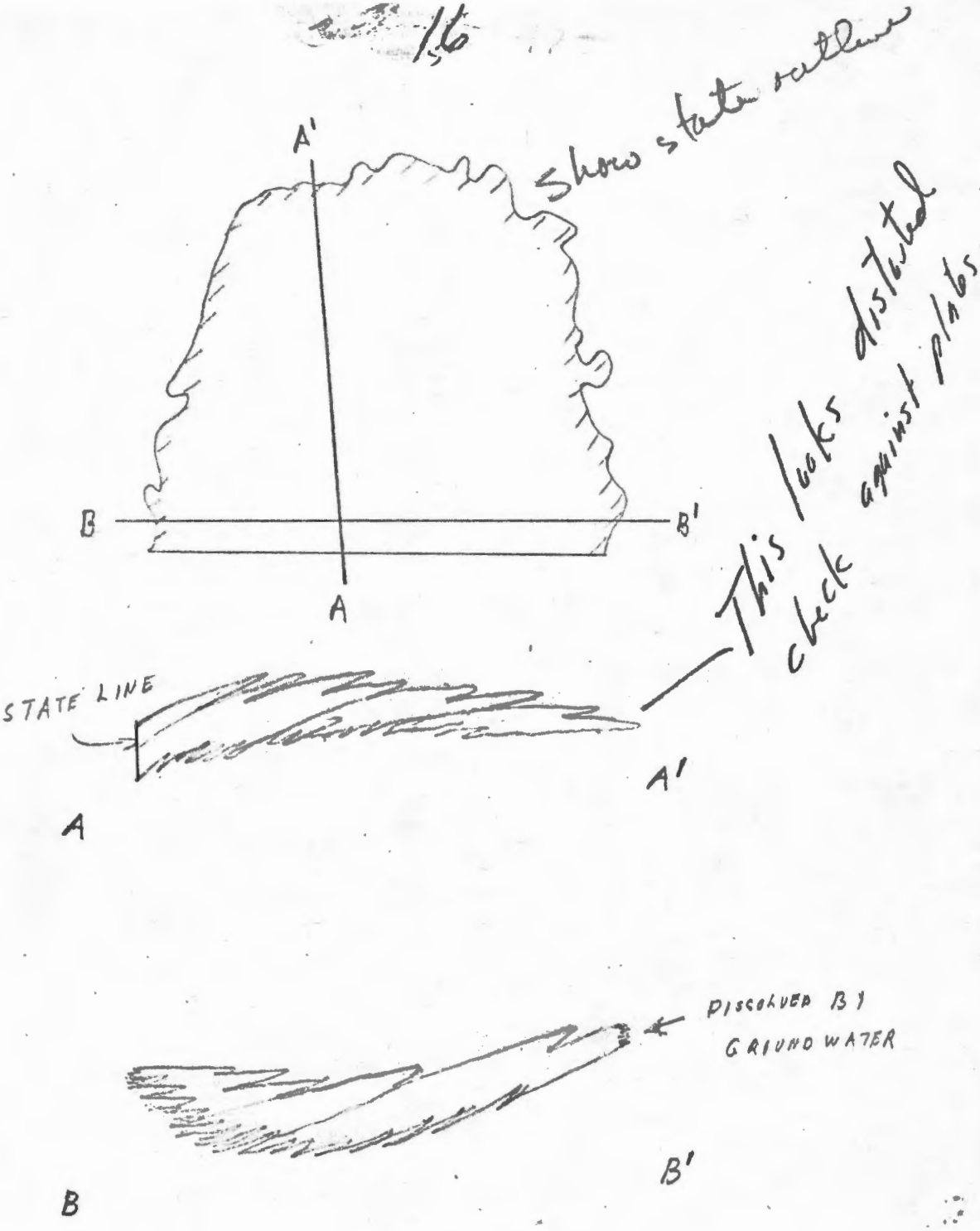
80-100%, 60-80%, 40-60%, EXTREME PERCENTAGE VARIATION, INADEQUATE DATA

FIG. 5 PERCENTAGE OF SALT IN TOTAL HUTCHINSON MEMBER OF WELLINGTON FORMATION

magnafacies (Caster, 1934; Moore, 1949; and Teichert, 1958). Evidence of this stratigraphic relationship is found in the logs of the thousands of holes that have been drilled through the Hutchinson. Detailed stratigraphic relationships of small parts of the Hutchinson can be depicted in cross sections constructed from these graphic logs (Pl. 4 to 8). These illustrations depict the "typical" local stratigraphy of the Hutchinson and its associated strata. Long-distance stratigraphy of the Hutchinson must be depicted schematically if the illustration is to be of a size that can be published (Fig. 6). Many key beds can be correlated only for short distances; hence, the horizontal scales used in plates 4 to 8 are necessary to illustrate these correlations. An east-west cross section through the Hutchinson drafted at the scale of plate 4 would be several hundred feet long.

Based on the correlation of key beds, individual salt strata within the Hutchinson are imbricated with respect to each other and have an oblique relationship with the upper and lower boundaries of the salt body as a whole. Superposition of beds indicates that the salt body is in general progressively younger to the south and west (Fig. 6). However, locally the direction of this age progression may be reversed. Intercalated anhydrite beds in the lower part of the Hutchinson at one location (log C, Pl. 6) are correlated with anhydrite beds in the upper

16



Show state outline

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FIG. 16 OVER SIMPLIFIED SCHEMATIC CROSS SECTIONS ILLUSTRATING IMBRICATION OF HUTCHINSON SALT MEMBER OF THE WELLINGTON FORMATION

part of the underlying sulfate-shale unit in other locations (logs B and D, Pl. 6). Shale beds in the upper part of the Hutchinson in some places (log A, Pl. 6) can be traced into the thick shale unit in other places (logs B, C, and D, Pl. 6).

Stratigraphy revealed in mine exposures -- All three mines (Fig. 4) are operating at or near the bottom of the lithostratigraphic unit, but information is lacking that would indicate whether or not ~~they are extracting~~ The salt extracted from stratigraphically equivalent beds. In detail the Hutchinson Salt exhibits conspicuous dark and light layers (Pl. 12). ~~In a few places in each of the mines~~, Locally, the layering has been destroyed ~~apparently~~ by post-depositional recrystallization of halite. In these small areas, 4-8' maximum diameter, large crystals (6 inches or more) of halite, ~~which~~ are almost invariably underlain by a pocket of dark constituents, ~~occur in these places~~. Stringers or wedges of shale can be seen in the upper walls where the roof has caved or where it has been raised to provide additional height needed for machinery (Pl. 12). No shale is exposed at the levels where the salt is mined. The floors of the mines are within a few inches of a nonhalite bed.

This suggests large areal extent. Not so. Areas are few and far between and never over 8-10 feet in diameter

~~Seemingly~~ Two types of red halite are occasionally found in ~~isolated parts of~~ the Hutchinson Member. ~~One type is found~~ In veins associated with shale beds ~~and is found~~ in all three mines. These veins consist chiefly of ~~iron~~-stained halite ppt. by bacteria (Kleihege, 1948).

See Cleveland-Dellwig in part



Plate 12. Conspicuous dark and light layering of salt in the Hutchinson mine. Note the wedges of shale that penetrate the upper layers. Approximately 15 feet exposed vertically.

Suggest entering a shale wedge.

W Inc Co

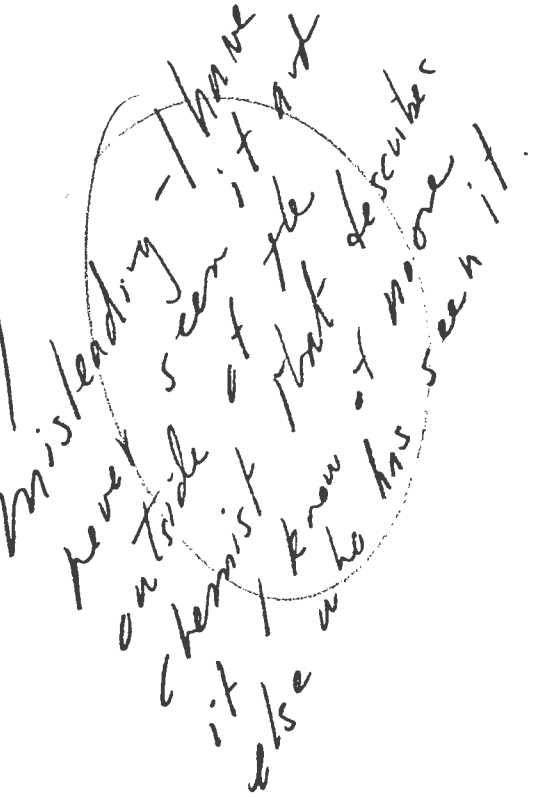
Bdr

of Cary Salt Co.

Pg. 18

A second type occurs as blotches or blebs within the salt beds ~~themselves and has been found in abundance only~~ in the Hutchinson mine ~~of the Carey Salt Company.~~ The blebs are probably ~~about the size of a thumb nail and are indicative of the mineral~~ polyhalite.

In general, the stratigraphic section is the same throughout any single mine. A general description of the stratigraphic section of each of the three mines is presented below.



Partial section of the Hutchinson Salt in Hutchinson mine (from top downward)

	Thickness feet
(1) Shale, dark blue gray, ~~seemingly~~ anhydritic; horizontal stringers of brown salt, vertical fracture fillings of red halite. Locally this bed penetrates downward into salt as much as 3 feet; commonly exposed thickness is less than	.0.5
(2) Salt, brown, similar to interbedded stringers above	.0.2
(3) Salt, clear to cloudy, contains dark layers, especially prominent 0.3 feet and 0.7 feet below top, dark inclusions are also dispersed, layers as much as 0.3 feet apart	1.6
(4) Salt, prominent bed free of dark inclusions	0.5
(5) Salt, two white beds separated by a dark layer	0.2
(6) Salt, dark ~~impurities~~ clay layered and dispersed, halite crystals cloudy	0.8
(7) Salt, layered but not prominently, dark layers less than 0.1 feet apart. Position is at or near top of mining level	0.5
(8) Shale, relatively prominent bed, less than	0.1
(9) Salt, halite crystals cloudy and clear, dark ~~impurities~~ clay layered and dispersed	2.2
(10) Salt, prominent layer, dark ~~impurities~~ clay layers layered and dispersed, as much as 0.1 feet between dark layers	0.9
(11) Salt, prominent bed free of dark impurities, two dark layers at base, halite crystals clear and cloudy	0.3
(12) Salt, like (11) except dark ~~impurities~~ clay layers are more dispersed	0.4
(13) Salt, dark ~~inclusions~~ clay layers dispersed but localized enough to give layered appearance	0.3
(14) Salt, layered, halite crystals cloudy for most part; as much as 0.1 feet between layers	0.4
(15) Salt, halite crystals cloudy, dark ~~inclusions~~ clay layers found only in blebs; base is a prominent dark layer	0.9
(16) Salt, massive, some suggestion of layering of impurities prominent but discontinuous dark layer 2.6 feet above base	5.3

Partial Section of the Hutchinson Salt in Lyons mine (from top downward)

	Thickness feet
(1) Salt, halite crystals for the most part clear, dark constituents segregated into layers 0.05 to 0.3 feet apart	3.0
(2) Salt, halite crystals cloudy, several minor or subdued layers of dark constituents, most of which are concentrated near the bottom of the unit	1.0
(3) Salt, halite crystals generally clear, dark constituents segregated into subdued layers, thickness between layers as much as 0.3 feet; base of unit is top of prominent dark layer	3.2
(4) Salt, halite crystals more cloudy than in (3), layers of dark constituents more prominent than above, thickness between layers somewhat less than above	4.6

Partial Section of the Hutchinson Salt in Kanopolis mine (from top downward)

	Thickness feet
(1) Salt, halite crystals clear, very sparse dark constituents, no apparent regular layering	1.6
(2) Shale, dark, penetrating underlying salt as much as 1 foot prevalent thickness	0.2
(3) Salt, halite crystals clear with cloudy cores, dark constituents segregated into layers as much as 0.2 feet apart	3.1
(4) Salt, prominent white layer similar to (1)	0.4
(5) Salt, similar to (3), thickness between layers as much as 0.3 foot	3.9
(6) Salt, prominent white layer	0.4
(7) Salt, halite crystals clear and cloudy, dark constituents segregated into prominent layers as much as 0.3 foot apart	0.5

Petrography -- Several specimens of rock salt were collected from each of the three mines for study. Polished surfaces of these specimens were studied with a binocular microscope, and thin sections were investigated with a petrographic microscope. The nonhalite, water-insoluble residue of a few specimens were analyzed by x-ray diffraction by Paul O. Franke, State Geological Survey of Kansas.

The chief constituent (90 percent or more) of the salt specimens is halite, and except for minor amounts that have recrystallized, the halite is generally segregated into layers commonly one crystal thick (Pl. 13). The crystals range up to 3 centimeters in length and are elongate normal to the layering, but within single layers interlocking crystals give the rock a mosaic texture. Many crystals have cloudy chevron-shaped structures in their centers with clear overgrowths (Pl. 13). Cloudy halite appears light in the mine face, and transparent halite appears dark.

Nearly all the minor constituents are localized in clusters between the crystals of halite. The individual clusters, which are commonly less than 1 millimeter in diameter, are grouped in irregular layers. Anhydrite, hydrocarbon, clay minerals, and pyrite are the main constituents of the clusters. Polyhalite was found in veinlets in a part of the Hutchinson mine.

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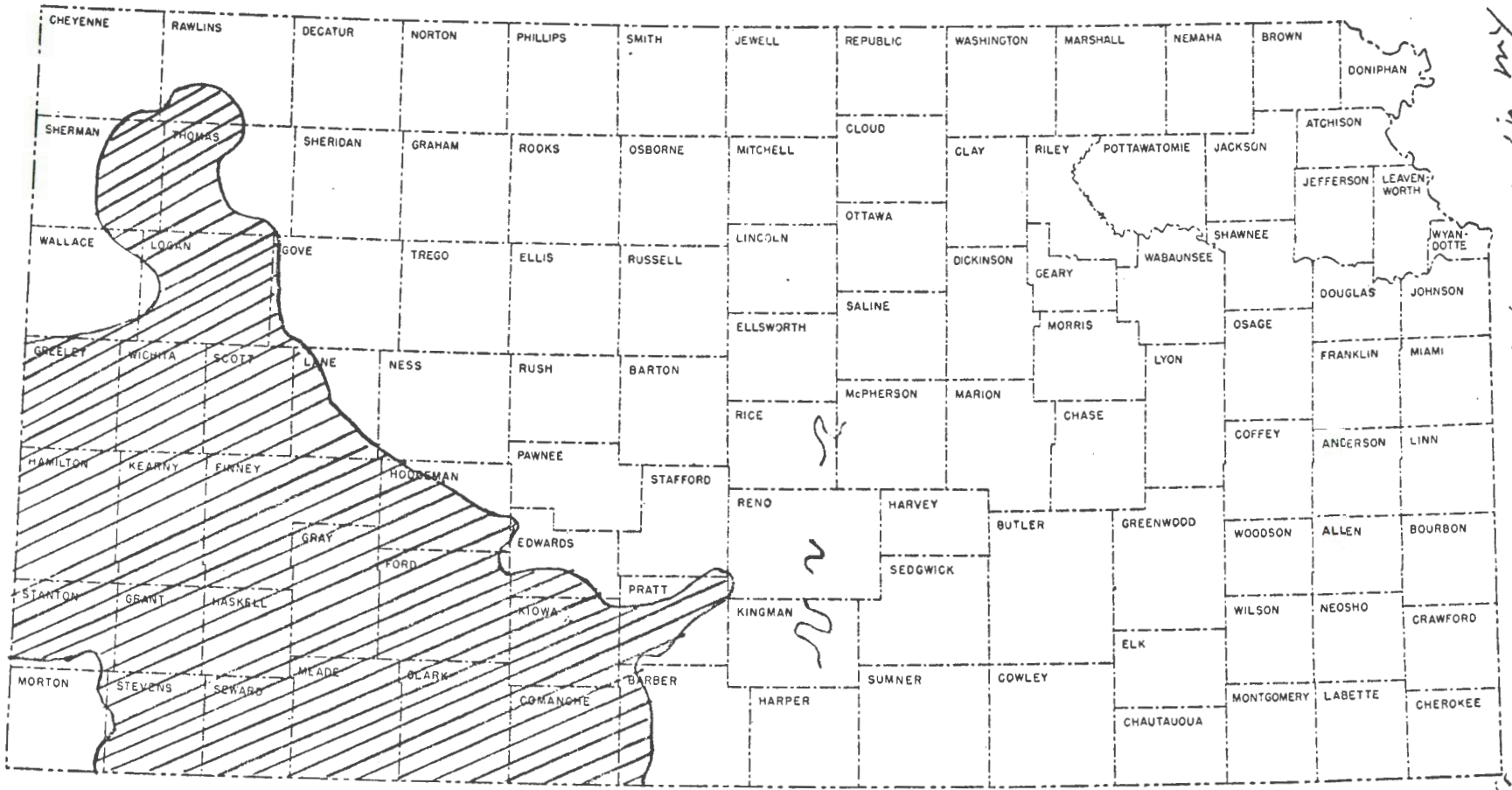
Plate 13 Polished surface of typical salt specimen.
Note the chevron structures.
(Approximately 3/4 natural size.)

Thick shale unit -- Several hundred feet of undivided terrigenous sediment overlie the Hutchinson Salt. The lower part of this succession, which is gray shale is the upper part of the Wellington Formation (Norton, 1939; Swineford, 1956). The upper part, which is red, is the overlying Ninnescah Shale. The Wellington-Ninnescah contact usually cannot be picked on wire-line logs; hence, parts of both formations are included in this unit in plates 4 to 7.

Stratigraphy of "Stone Corral" salt

These salt strata underlie most of the southwestern quadrant of Kansas (Pl. 2, Fig. 7). The stratigraphy of this salt deposit is much less complex than that of the Hutchinson Salt; consequently it can be illustrated over relatively long distances (Pl. 9 to 11). Thickness indicated on plate 2 includes the Stone Corral Formation and all genetically related beds. Shaded areas are underlain by "Stone Corral" salt. Because the Stone Corral Formation extends beyond the edge of its genetically related salt beds the line marking the edge of the salt does not represent the zero contour of the formation.

On the outcrop the Stone Corral Formation consists of a relatively thin (6 feet) bed of dolomite (Fig. 2), but in the subsurface the formation is best known for its one or more anhydrite beds whose composite thickness is as much as 50 feet. Salt genetically related to the Stone Corral Formation consists of two



Not good

AREA UNDERLAIN BY "STONE CORRAL" SALT

OUT CROP OF THE STONE CORRAL FORMATION

FIG. 7 INDEX MAP OF "STONE CORRAL" SALT

Check this against Campbell - M.S. thesis, Malone, M.S. " Widress AAPG

KU Wichita

main beds. A lower salt bed lies below ~~what is considered by most Kansas sub-~~ ~~surface stratigraphers as~~ the base of the Stone Corral Formation. In some areas this salt is in contact with the basal anhydrite beds of the Stone Corral and ~~was never observed to be~~ not separated from the Stone Corral by no more than 100 feet of intervening sediment. ~~Technically~~ this salt bed is a part of the Ninnescah Shale, but ~~in this report it~~ is included here as a part of the total "Stone Corral" salt. An upper salt bed lies between anhydrite strata usually included in the Stone Corral and is ~~but~~ It is regarded here as the upper is no more a part of the total "Stone Corral" salt deposit ~~than is the lower salt bed~~ (Pl. 9, 10, and 11). Relationship between "Stone Corral" salt and Hutchinson Salt Member is shown in plate 7.

~~Although there is some overlap between~~ the upper and lower "Stone Corral" salt beds for the most part they do not overlap ~~are mutually exclusive~~. The lower bed is limited to the southeastern part of the area underlain by the "Stone Corral" salt in Kansas (Pl. 9 and 10). The upper salt bed extends farther north and west (Pl. 11). Greatest total thickness (Stone Corral Formation plus related salt) is more than 250 feet and is found along the Kansas-Oklahoma state line within the area where only the lower bed is present. It should be noted that this thickness includes significant amounts of shale and anhydrite.

Stratigraphy of "Blaine" salt

These several separate deposits, in Kansas, (Pl. 3, Fig. 8). Like the "Stone Corral" salt, the stratigraphy of this salt deposit is much less complex than that of the Hutchinson Salt (Pl. 11). The most widespread "Blaine" salt deposit underlies more than two-thirds of the Kansas and Colorado and extends eastward more than 60 miles into Kansas. The other smaller deposits are located to the southeast. Thicknesses indicated on Plate 3 include the Blaine Formation and all of its genetically related salt beds. Shaded areas are underlain by "Blaine" salt. Because the Blaine Formation extends beyond the edge of its genetically related salt beds, the line marking the edge of the salt does not represent the zero contour.

On the outcrop the Blaine Formation consists of one or more gypsum beds (Fig. 2). The formation can be traced to one or more anhydrite beds in the subsurface. Stratigraphic relationships between the Blaine and its genetically related salt are analogous to those between the Stone Corral and its salt. The "Blaine" salt is divided into an upper and lower bed. The lower bed lies directly below anhydrite beds generally accepted as basal Blaine Formation (Pl. 11). This lower salt is part of the underlying Flowerpot Shale (Fig.2). The upper salt bed lies between anhydrite beds in the Blaine Formation

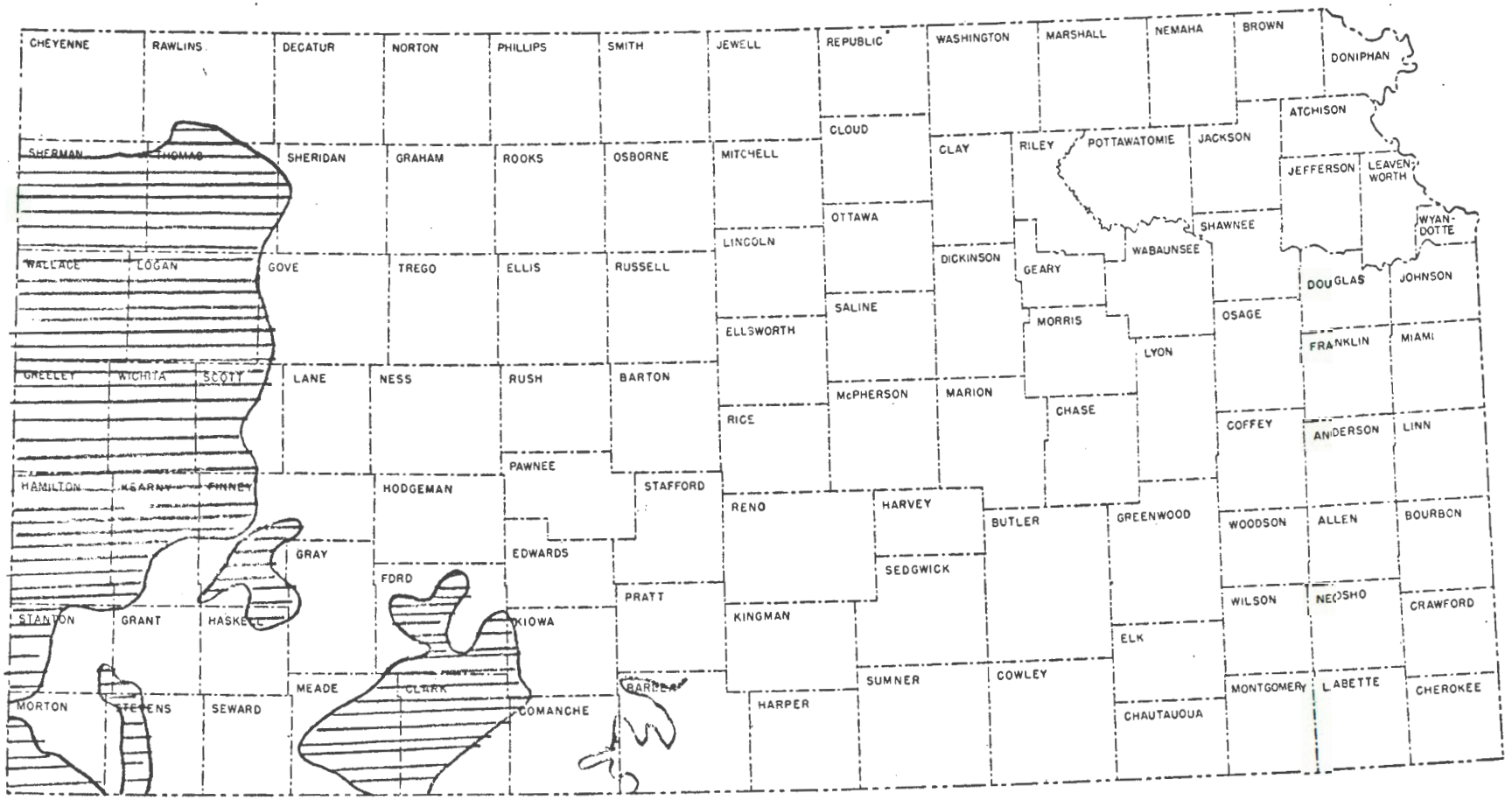


FIG. 8 INDEX MAP OF "BLAINE" SALT

AREA UNDERLAIN BY "BLAINE" SALT

OUTCROP OF BLAINE FORMATION

-86-

(Pl. 11). Each bed is an integral part of the total "Blaine" salt deposit.

There is relatively greater overlap between upper and lower salt beds of "Blaine" salt than between upper and lower beds of "Stone Corral" salt. Greatest observed thickness (more than 600 feet) was found along the Kansas-Colorado state line.

DEPOSITION OF EVAPORITES

Introduction

If it is agreed that large salt deposits such as those in Kansas were formed as a result of the evaporation of sea water and not by some other process (for example magmatic intrusion) the events necessary to cause sodium chloride to be precipitated from sea water as a result of its evaporation must be accounted for in any postulated process set forth to explain the origin of Kansas salt. Inasmuch as there are no places in the world today where evaporite deposition is proceeding at the scale it was during the deposition of ancient salt beds (Richter-Bernburg, 1953) many of these events can be determined only through deductive reasoning without benefit of field evidence. The same type of reasoning is used by geologists who conclude that when the North American Continent was glaciated during Pleistocene time climatic conditions produced a net gain in snow accumulation in the Northern Hemisphere.

The present investigation, like most others of ancient evaporites, assumes that the composition of ancient sea water was the same as that of modern sea water. Rubey (1951, p. 1114) after an exhaustive study of the problem states "...the composition of sea water and the atmosphere varied surprisingly little since early geologic time." Modern sea water is a relatively dilute solution with respect to almost all of its dissolved salts. It is therefore concluded that the precipitation of the dissolved salts from ancient sea water was chiefly the result of evaporation and not from some other process (for example cooling the brine).

Seemingly the only data showing the results of evaporating sea water to dryness comes from an experiment performed by Usiglio in 1849. The data from this experiment are presented in Grabau (1920) and Clarke (1924). In the course of his experiment Usiglio periodically separated the salts that were precipitated from the brine used in the experiment. As Phillips (1947) noted, this prevented the formation of certain types of salts that may form under natural conditions of evaporite deposition. The data, nevertheless, illustrate several phenomena that should occur under almost any circumstances in which evaporites are precipitated from brine derived from sea water and are accurate enough for the purpose for which they are used in this report.

Reaction of sea water to evaporation

When a specified volume of sea water is evaporated to dryness, three changes take place during the process: (1) volume reduction, (2) density increase, and (3) precipitation of salts. The degree of evaporation of sea water can be expressed as the percent of water loss or 100 times the weight of water evaporated divided by the weight of water present before evaporation. For example, a liter of sea water contains approximately 987 grams of water and approximately 38 grams of dissolved salts. If 493.5 grams of water were evaporated from this original liters, the water loss or degree of evaporation would be 50 percent. In Usiglio's data partial evaporation is presented by recording the volume of brine remaining from an original liter of sea water (Clarke, 1924). In this report these data are converted to degree of evaporation expressed in percent for better graphical presentation.

Volume reduction

The relationship between volume of remaining brine and degree of evaporation, based on data from Clarke (1924), is shown in Table 1. These data, presented graphically in figure 9, indicate that the volume of remaining brine is almost inversely proportional to the degree of evaporation.

Table 1

Relationship between volume of remaining brine and degree of evaporation of a liter of sea water. (Data from Clarke, 1924, by calculation).

Degree of evaporation in percent	Volume of remaining brine in ~~thousandths of a liter~~ cc
0.0	1000
47.2	533
69.2	316
76.5	245
82.0	190
86.7	144
88.2	131
90.1	112
91.7	95
94.5	64
96.7	39
97.5	30
98.1	23
98.8	16
100.0	00

Vol remaining = 30 cc

Vol	Wt
1000 cc	1025 g
loss 970 cc	970 g

% wt. H_2O loss = $\frac{970}{\quad}$ = 96.6 %

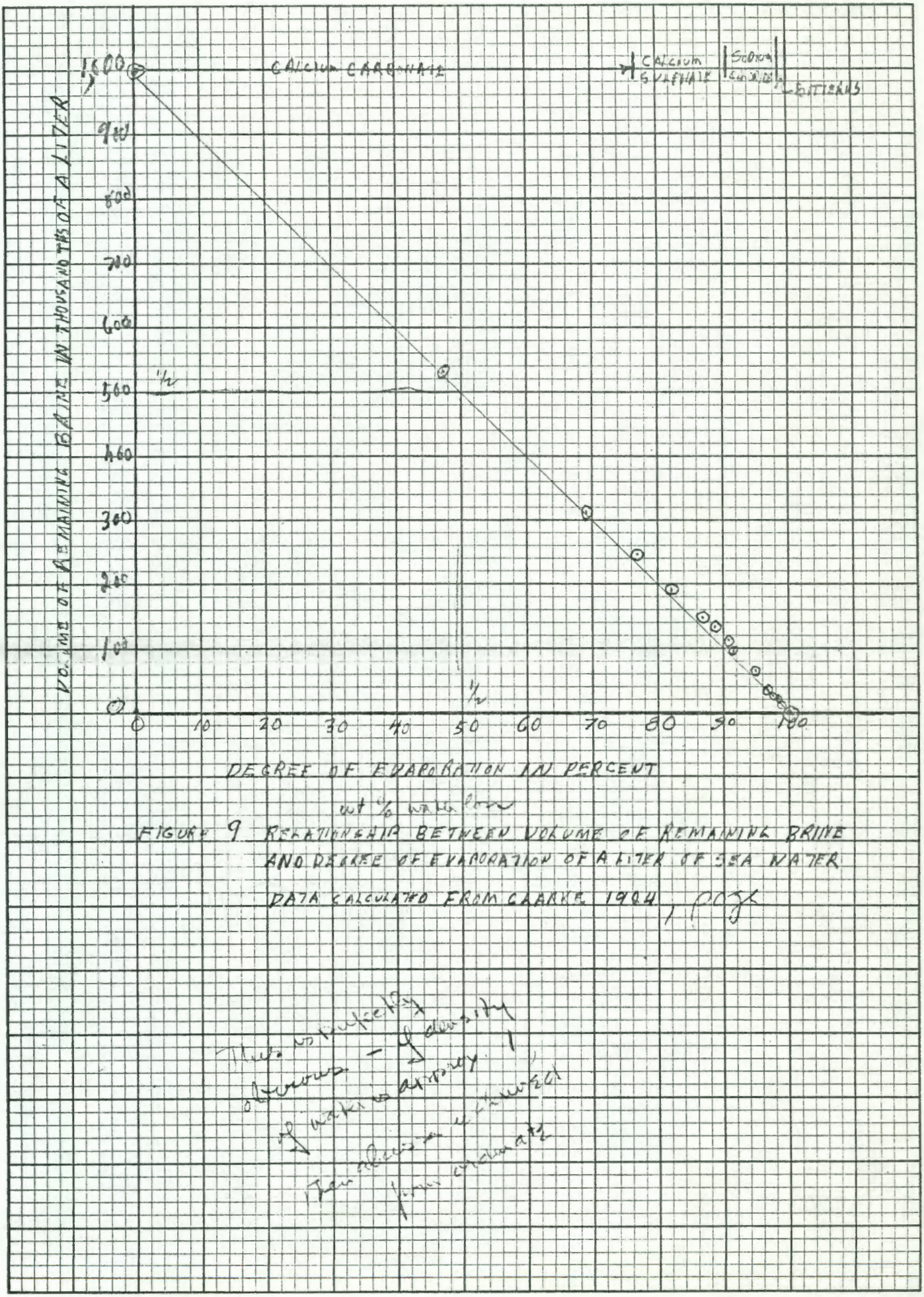


FIGURE 9 RELATIONSHIP BETWEEN VOLUME OF REMAINING BRINE AND DEGREE OF EVAPORATION OF A LITER OF SEA WATER

DATA CALCULATED FROM CLARKE, 1924, p. 67

5 X 5 TO THE ½ INCH
KEUFFEL & ESSER CO.
358-6
MADE IN U.S.A.

Density increase

The relationship between density of brine and degree of evaporation is shown in Table 2 based on data from Clarke (1924). These data, presented graphically in figure 10, indicate that the density increases almost exponentially with degree of evaporation. There is an important anomaly at the point of saturation of the brine with respect to sodium chloride (approximately 91 percent degree of evaporation), resulting from the precipitation of this dominant salt in sea water. If sodium chloride were the only salt in sea water, further evaporation could not further increase the density of the brine after it became saturated with respect to that salt.

Precipitation of salts

The relationship between volume and type of salts precipitated and degree of evaporation is presented in Table 3 based on data from Clarke (1924). These data are presented graphically in figure 11. It is convenient to classify the precipitates from sea water in groups according to the order of precipitation of predominant salts. This order is as follows: (1) calcium carbonate group (0-76 percent degree of evaporation), minor precipitate iron oxide; (2) calcium sulfate group (76-91 percent degree of evaporation), minor precipitate of calcium carbonate; (3) sodium chloride group (91-99 percent degree of evaporation), minor precipitates calcium sulfate, magnesium sulfate, magnesium chloride, sodium

Table 2

Relationship between density of brine and degree of evaporation of a liter of sea water. (Data calculated from Clarke, 1904?).

Degree of evaporation in percent (wt % water loss)	Density of brine in grams per milliliter
0.0	1.0258
47.2	1.0500
69.2	1.0836
76.5	1.1037
82.0	1.1264
86.7	1.1604
88.2	1.1732
90.1	1.2015
91.7	1.2138
94.5	1.2212
96.7	1.2363
97.5	1.2570
98.1	1.2778
98.8	1.3069
100.0	------

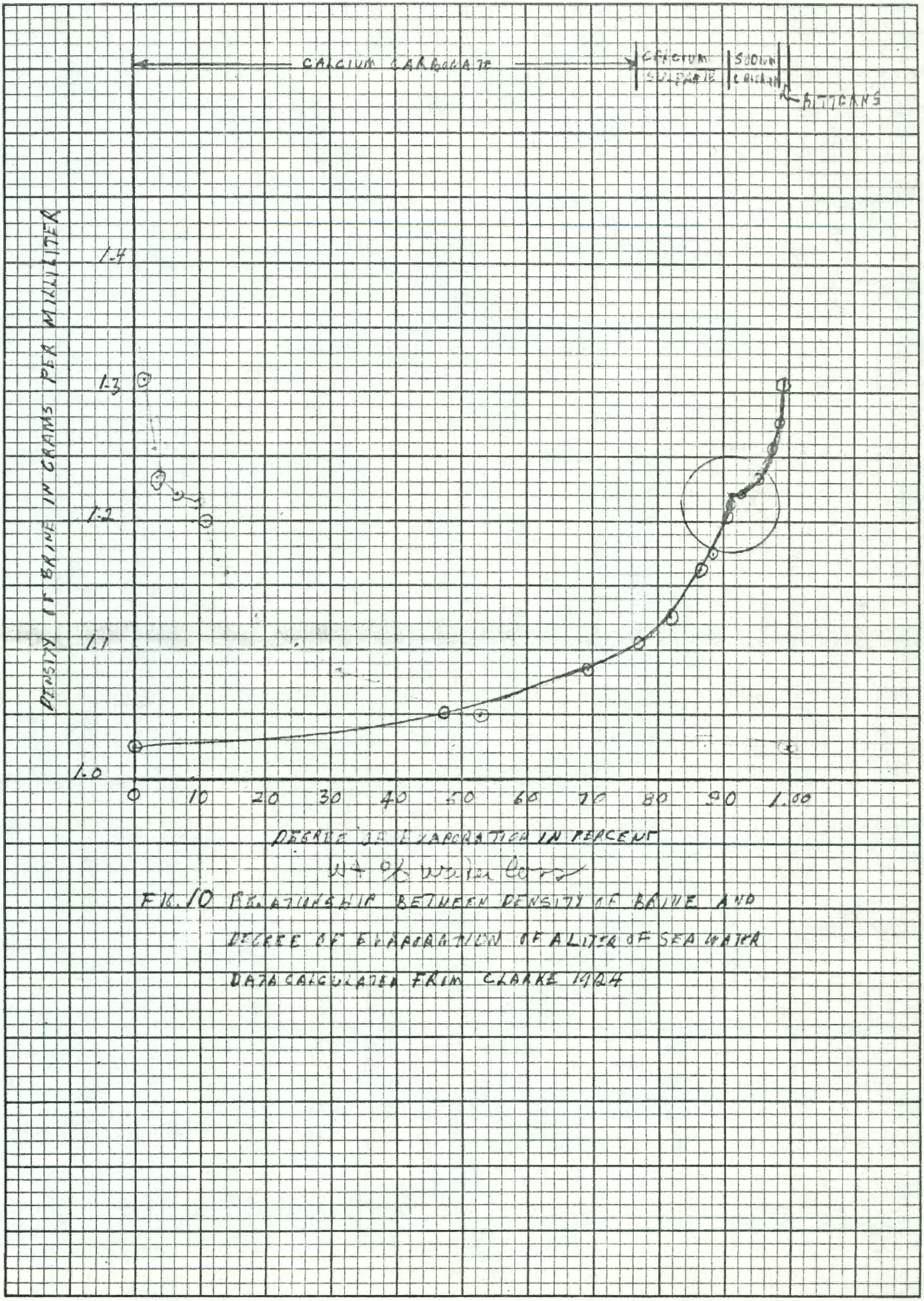


FIG. 10 RELATIONSHIP BETWEEN DENSITY OF BRINE AND DEGREE OF EVAPORATION OF A LITER OF SEA WATER

DATA CALCULATED FROM CLARKE 1924

K&E 5 X 5 TO THE ½ INCH 358-6 MADE IN U.S.A. KEUFFEL & ESSER CO.

Table 3

Various salts

Relationship between ~~type~~ and volume of salts that are precipitated and degree of evaporation of a liter of sea water. (Calculated from Clarke, 1924).

Degree of evaporation in percent	VOLUME AND TYPE OF PRECIPITATED SALTS IN CUBIC CENTIMETERS								
	Fe_2O_3	$CaCO_3$	$CaSO_4 \cdot 2H_2O$	NaCl	$MgSO_4$	$MgCl_2$	NaBr	KCl	Cumulative Total
0.0									
47.2	0.0006	0.0237							0.0243
69.2		Trace							0.0243+
76.5		Trace							0.0243+
82.0		0.0195	0.1892						0.2330
86.7			0.1899						0.4229
88.2			0.0622						0.4851
90.1			0.0541						0.5392
91.7			0.0172	1.5078	0.0015	0.0034			2.0691
94.5			0.0499	4.4614	0.0049	0.0157			6.6010
96.7			0.0236	3.6505	0.0098	0.0187	0.0227		10.3263
97.5			0.0049	1.2131	0.0065	0.0064	0.0112		11.5684
98.1				1.0504	0.0095	0.0103	0.0162		12.6548
98.8				0.6500	0.2023	0.0118	0.0193		13.5382
100.0				1.1967	0.6972	1.3609	0.1030	0.2691	17.1651

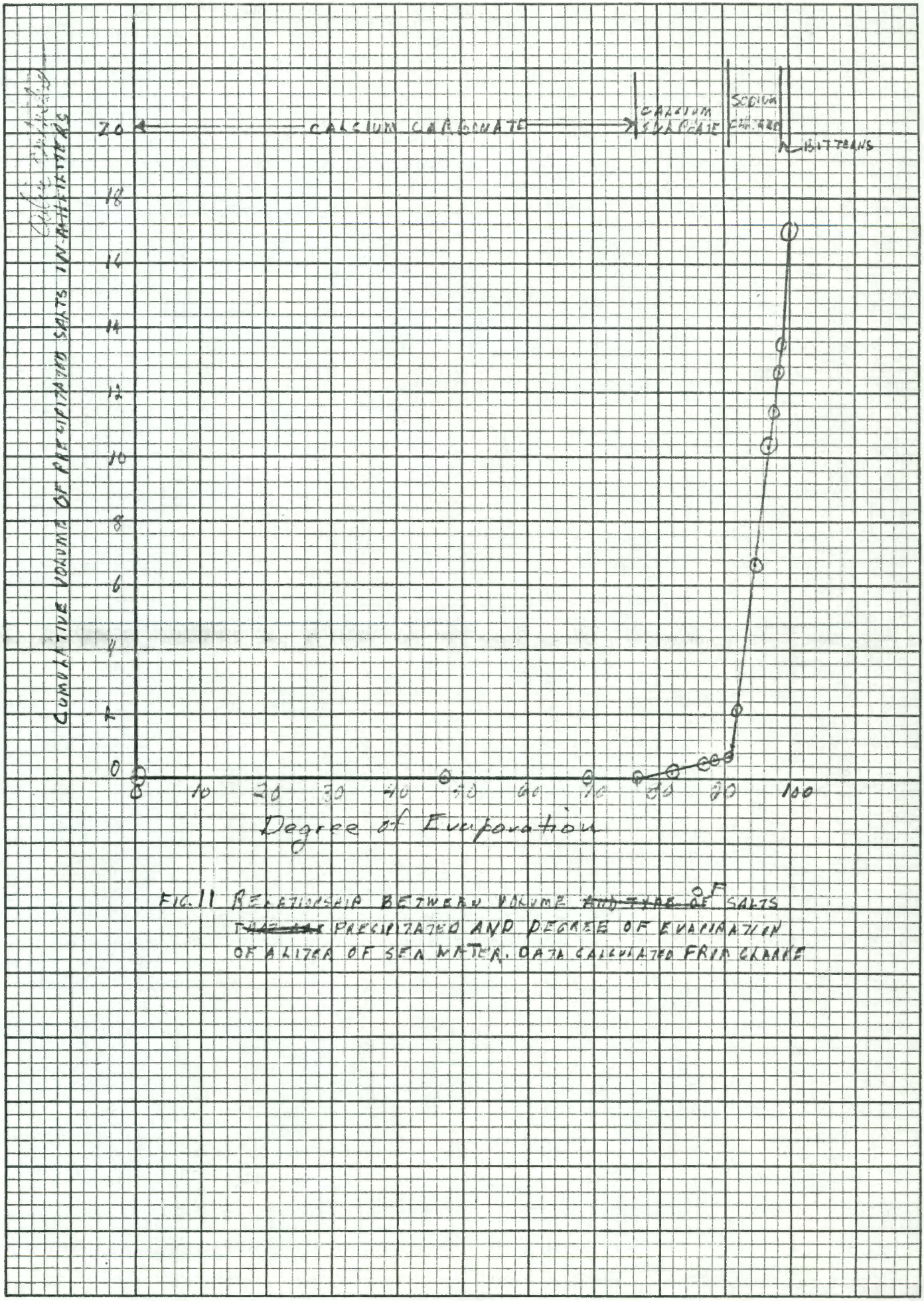
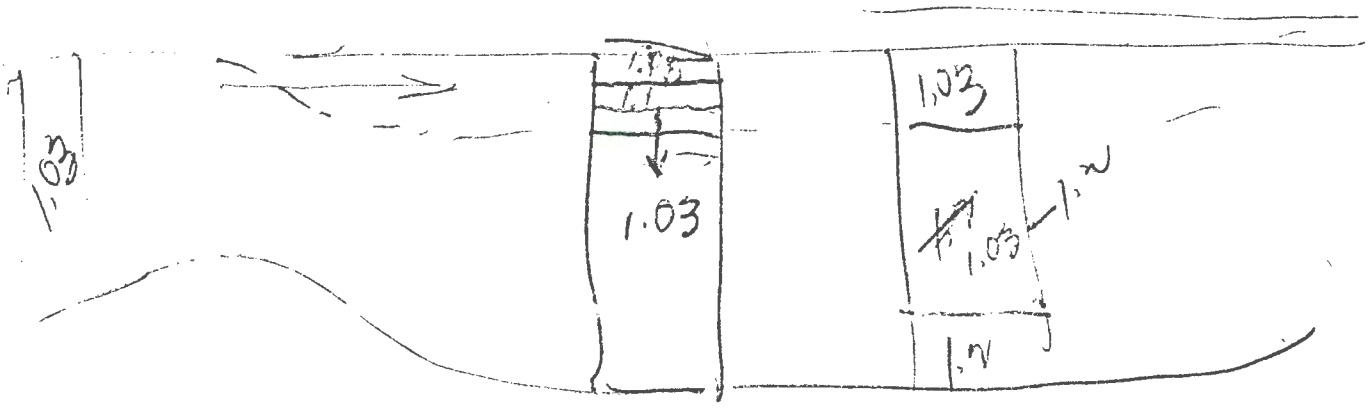


FIG. 11 RELATIONSHIP BETWEEN VOLUME ~~AND TYPE OF~~ OF SALTS ~~THAT ARE~~ PRECIPITATED AND DEGREE OF EVAPORATION OF A LITER OF SEA WATER. DATA CALCULATED FROM CHAREE

K&E 5 X 5 TO THE ½ INCH .358-6 KEUFFEL & ESSER CO. MADE IN U.S.A.


1,03
1.03
1,03
1,03
1,2
1,2

$.9V + (.9)^2V + (.9)^3V + \cdots\cdots$

$V \sum_{1}^{\infty} .9^k$

$.1V + .1(.9)V + .1(.9)^2V + .1(.9)^3V + \cdots\cdots = V$

$.1 + .1(.9) + .1(.9)^2 + .1(.9)^3 + \cdots\cdots = 1$

$\sum_{0}^{\infty} .1(.9)^k = 1$

$.1 + .1 * \sum_{k=1}^{\infty} .9^k = 1$

$1 + \sum_{k=1}^{\infty} .9^k = 10$

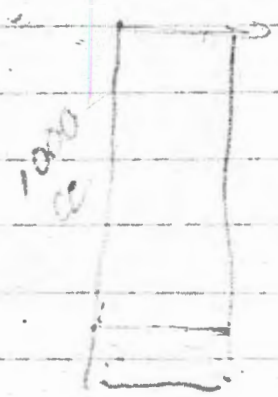
$\sum_{k=1}^{\infty} .9^k = 9$

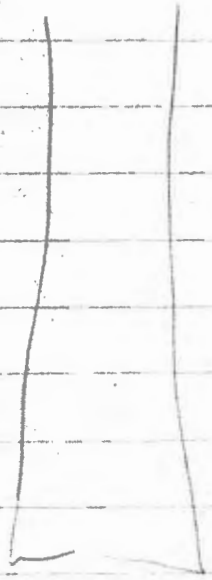
$V \sum_{1}^{\infty} .9^k = 9V$

$P_1 = 1.0258$

$P_2 = 1.2138$

10,000 cc





$.9 + (.9)^2 + (.9)^3 + \cdots$

$\sum_{1}^{\infty} .9^k = 9$

$.1 + .1(.9) + .1(.9)^2 + .1(.9)^3 + \cdots = 1$

$.1 + .1(.9) + .1(.9)^2 + .1(.9)^3 + \cdots = 1$

$\sum_{0}^{\infty} .1(.9)^k = 1$

$.1 + \sum_{1}^{\infty} .1(.9)^k = 1$

$\sum_{1}^{\infty} .1(.9)^k = .9$

$\sum_{k=1}^{\infty} .9^k = 9$

$dV = m$

bromide; and (4) bitterns (99 to 100 percent degree of evaporation) a mixture of potassium, magnesium, and sodium salts none of which is predominant. Indicated degrees of evaporation are approximate.

If the rate of evaporation remained constant the process of saturation of the brine with respect to a new group of precipitates would automatically increase the rate of precipitation. For example, if the brine were saturated with respect to the calcium sulfate group, approximately 250 milliliters of water would have to be evaporated to cause the precipitation of 1 cubic centimeter of salts. When the brine is saturated with respect to the sodium chloride group, only about 8 milliliters of water would have to be evaporated to precipitate the same volume of salts.

Mechanics of evaporite deposition

The interpretation of the depositional history of large salt deposits encounters two major problems. (1) The volume of sodium chloride group salts that can be precipitated from a specified volume of sea water is very small (about 12.5 milliliters per liter). This fact is well known and has been taken into account in nearly all of the postulated processes of evaporite deposition. (2) The composition of the brine from which thick accumulations of bittern-free sodium chloride was precipitated must have remained relatively constant (between

p. 40 insert

(Clarke, 1916 p. 220-221)

In 1877 Ochsenius (~~Grabau, 1920~~) proposed the bar theory in which he postulated a deep bay, or body of sea water, connected with the sea by a narrow and shallow channel, but otherwise cut off from oceanic circulation by a bar. No large streams enter the bay ~~and~~ resulting in small outflow, but sea water ~~can~~ enters freely to offset the losses due to evaporation. Evaporation takes place only at the surface, and the upper layers, thus becoming denser, must sink, so ~~becoming~~ producing a saline concentration at the bottom. In this manner, being continually supplied with new material from without, ~~the salinity of the bay~~ the salinity of the bay, which is will gradually increase until saturation is reached and the deposition of salt begins. So long as salt water can enter the bay this process ~~will~~ continues, and the depths of the basin will, in time, become a solid mass of salts, covered with a sheet of bittern.

91 and 99 percent degree of evaporation) during the period of deposition. Maintenance of constant brine composition has not been considered in all postulated processes of salt deposition.

Three theories concerning the deposition of evaporites, ~~are~~ the bar theory, the modified bar theory, and the reflux theory. ~~These~~ are explained below.

Bar theory

In 1877 Ochsenius (Grabau, 1920) ~~set forth~~ the bar theory wherein he postulated that water ~~vaporized in an~~ evaporat~~ion basin~~ is replaced by the lateral flow ~~of sea water through an inlet~~ from the open ocean (Fig. 12). If this process were to continue long enough the brine in the basin would become saturated, salts would be precipitated, and relatively thick evaporites could be deposited in a comparatively shallow basin. Almost all other theories of evaporite deposition are variations of the bar theory.

If sea salts were to be precipitated strictly according to the bar theory the composition of the brine in the evaporation basin would change continually until it eventually became saturated with respect to all dissolved salts, ~~(Zen, 1969).~~ Usiglio's data indicate that if the depth of brine in this type of evaporation basin were 1,000 feet, less than 50 feet of bittern-free sodium could accumulate.

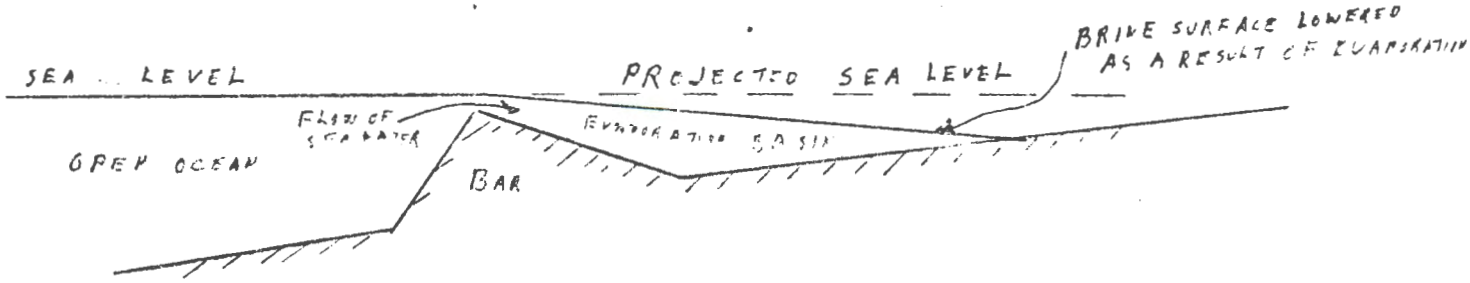


FIGURE 12 SCHEMATIC CROSS SECTION ILLUSTRATING THE PRINCIPLES OF THE BAR THEORY OF EVAPORITE DEPOSITION (NOTE, LOWERING OF THE BRINE SURFACE IS EXAGGERATED FOR ILLUSTRATIVE PURPOSES)

This relationship can be understood if it is imagined that the basin is made of several 1,000 foot columns of brine each of which is one square foot in cross section. One of these columns is analogous to a liter column of brine that is 1,000 centimeters high and is one square centimeter in cross section from which water is evaporated but maintained at constant volume by addition of sea water. For each liter of water that is evaporated and replaced by a liter of sea water the degree of evaporation of the brine in the column is increased by one half. For example, after the first liter of water is evaporated and replaced by the first liter of sea water the degree of evaporation of the brine is 50 percent. Repeating the process would produced brine whose degree of evaporation was 75 percent. Evaporating the third liter of water and replacing it with sea water would increase the degree of evaporation of the brine to $87\frac{1}{2}$ percent. Sodium chloride would not be precipitated until the brine reached approximately 91 percent degree of evaporation, and bittern free sodium chloride would cease to be precipitated when the degree of evaporation reached approximately 99 percent degree of evaporation. After the brine became saturated with respect to sodium chloride approximately 12.5 milliters of sodium chloride would be precipitated each time a liter of water was evaporated and would be deposited as 12.5 centimeters of sediment on the bottom of the column, whose cross

the math for the next 2 pages is not correct. I am sure that it can be reduced and also that should be included

I think that this discussion should better be in terms of Density.

am not sure if it is

sectional area is one square centimeter. However, after the brine became saturated with respect to sodium chloride at approximately 91 percent degree of evaporation less than four liters of water could be evaporated and replaced by sea water before the brine reached the saturation point of the bittern salts at approximately 99 percent degree of evaporation. Hence, less than 50 centimeters of sodium chloride could accumulate at the base of a 1,000 centimeter column of brine before it became saturated with respect to bittern salts, and less than 50 feet of bittern free sodium chloride could accumulate in a 1,000 feet of brine if the process of sodium chloride deposition proceeded strictly according to the bar theory. Intermittent isolation of the evaporation basin from the open ocean does not increase the capacity for bittern free sodium chloride deposition providing streams bring in no salts.

The Kansas salt deposits are seemingly free of significant accumulations of bittern salts. Some modifications of the bar theory seem necessary to explain their desposition without postulating an unrealistic depth of brine during their time of deposition.

↑ a bad word - Richter-Bernburg and others say that there need not be sinking during deposition - 1000's salt = basin at least 1000' deep.

The composition of the brine in an evaporation basin could remain essentially the same throughout the deposition of thick accumulations of evaporites if some of the residual brine in the basin were ~~displaced~~ replenished by sea water from the adjacent ocean during the process of evaporite deposition. Two theories, based on the bar theory,

have been set forth that suggest processes by which ~~displacement~~ replacement of residual brine in the basin could take place. One is the modified bar theory, and the other is the reflux theory.

Modified bar theory

This theory postulates that the evaporite depositional area is separated into several connecting basins (Branson, 1915; Grabau, 1920). The basin nearest the open ocean receives normal sea water and discharges partially evaporated brine into an adjacent basin. The second basin discharges brine, which is evaporated to an even greater degree, into a third basin. This process, it is suggested, continues until brine is moved into the basin farthest from the open ocean (Fig. 13). Relatively great thicknesses of bittern-free sodium chloride could be precipitated in one of these basins if it received brine saturated with respect to sodium chloride and discharged brine that was rich in bitterns but not saturated with respect to those salts. In this process the discharge brine would eventually become saturated with respect to bittern salts, and their precipitation in one of the succeeding basins would be inevitable. Thus a sizeable accumulation of evaporites rich in bitterns would be a necessary adjunct to a bittern-free deposit of sodium chloride. The seeming absence of a bittern-rich deposit in close association with Kansas salt deposits indicates that their deposition cannot be

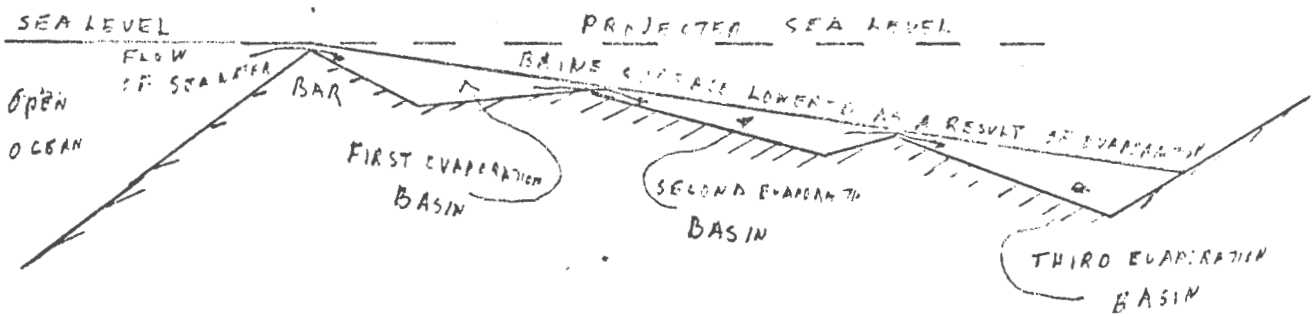


FIGURE 13 SCHEMATIC CROSS SECTION ILLUSTRATING THE PRINCIPLES OF THE MODIFIED BAR THEORY (NOTE LOWERING OF BRINE SURFACE IS EXAGGERATED FOR ILLUSTRATIVE PURPOSES)

explained by the modified bar theory.

Reflux theory

The reflux theory (King, 1947) postulates ~~that during the deposition of ancient evaporites there was~~ exchange of brine between the evaporation basin and the open ocean ~~in the same manner that~~ brine circulates between present-day evaporation basins and the open ocean (Scruton, 1953; Sverdrup, Johnson, and Fleming, 1942). The Mediterranean Sea is an example of a modern evaporation basin because more water is removed through evaporation than is added by the sum of rainfall and runoff water from the surrounding land. Water from the Atlantic Ocean flows eastward through the Straits of Gibraltar ~~to compensate for~~ the volume deficit in the Mediterranean. This is influx. At the same time, water from the Mediterranean flows westward through the same channel under the influxing water from the Atlantic. This is reflux. The greater bottom pressure in the Mediterranean than at equal depths in the Atlantic, which results from the higher density of the sea water in the Mediterranean, activates the westward-flowing reflux current. The process of reflux was known as early as the time of Ochsenius (Grabau, 1920), but it remained for R. H. King (1947) to suggest that the imbalance between the volume of the different types of evaporites preserved in the geologic record and the chemical composition of sea water was a result of reflux.

Relatively thick bittern-free salt beds such as those in the Hutchinson can be explained by the reflux theory. The circulation resulting from influx and reflux (Fig. 14) continually renews the brine in an evaporation basin, and great thicknesses of salts can accumulate without changing the chemical composition of the brine in the depositional area. Furthermore, this theory takes into account conditions of circulation that result from the evaporation of sea water. In view of the limitations of the modified bar theory, the reflux theory seems the only one acceptable to explain the deposition of the Hutchinson Salt, and the discussion that follows is based on this conclusion.

Circulation of brine in an evaporation basin

The exchange of brine between an evaporation basin and the open ocean is activated by the circulation of brine within the basin. Although currents can be activated by many agents only those activated by the volume loss and density increase that result from the evaporation of sea water are considered. This discussion is based chiefly on deductive reasoning. A careful consideration of the alternatives leaves little doubt of the validity of these deductions.

Throughout most parts of an evaporation basin influxing brine is migrating toward the inlet from the open ocean, and refluxing brine is migrating in the opposite direction toward the inlet. This exchange of brine can be termed the

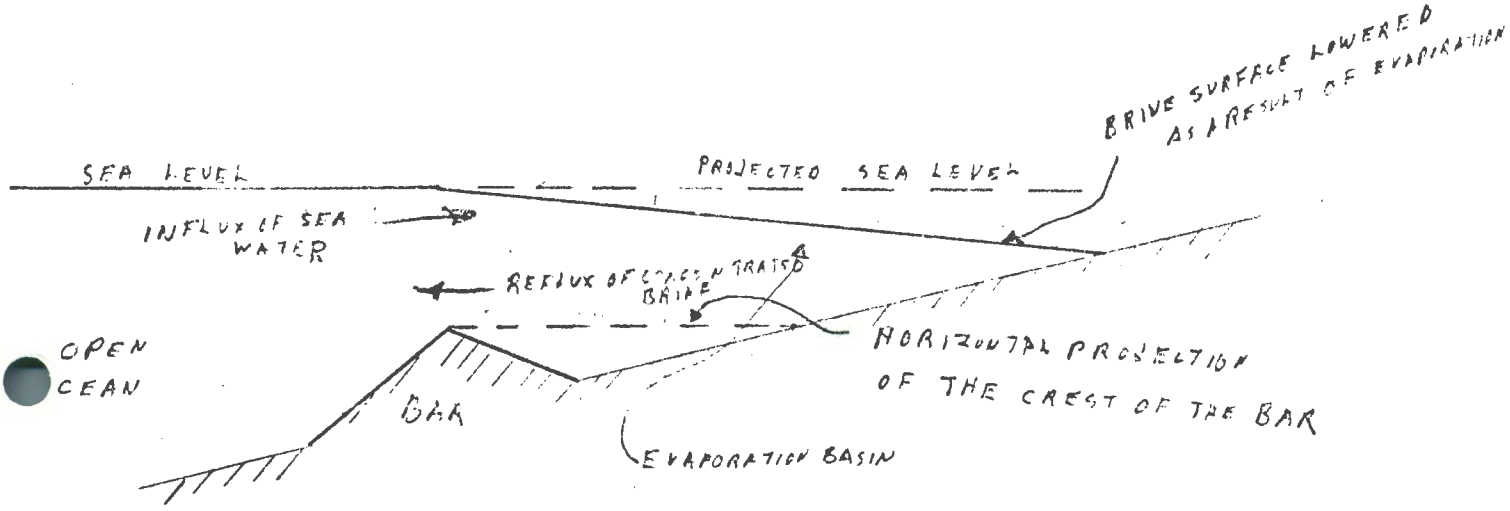


FIGURE 14 SCHEMATIC CROSS SECTION ILLUSTRATING THE PRINCIPLES OF THE REFLUX THEORY (THE LOWERING OF BRINE SURFACE IS EXAGGERATED FOR ILLUSTRATIVE PURPOSES)

sea water circulation system. Evaporites ~~can be~~ are precipitated within this circulation system provided the degree of evaporation of the circulating brine is increased to the point of saturation with respect to its dissolved salts. Influx is activated by the hydrostatic head caused by the volume loss in the evaporation basin. Volume loss is caused both by evaporation and reflux. Reflux is activated by the increase in density of brine that results from its partial evaporation. ~~Reflux~~ and must overcome the dynamic barrier or hydrostatic head causing influx (Scruton, 1953). Within any specific part of the sea water circulation system an increment of influxing brine reverses its direction and joins the refluxing brine (Fig. 15). This reversing current is activated because local evaporation increases the density of influxing brine while it passes through that part of the system. The brine that is expelled from the evaporation basin into the open ocean is a summation of all these local reversing currents within the evaporation basin. Attention is directed to the fact that reflux is locally activated.

The same type of circulation system is present where fresh runoff water enters an evaporation basin (Scruton, 1953). Runoff water, which may carry considerable terrigenous detritus, flows over the brine surface away from its place of addition at the strand line. At depth brine flows in the opposite direction

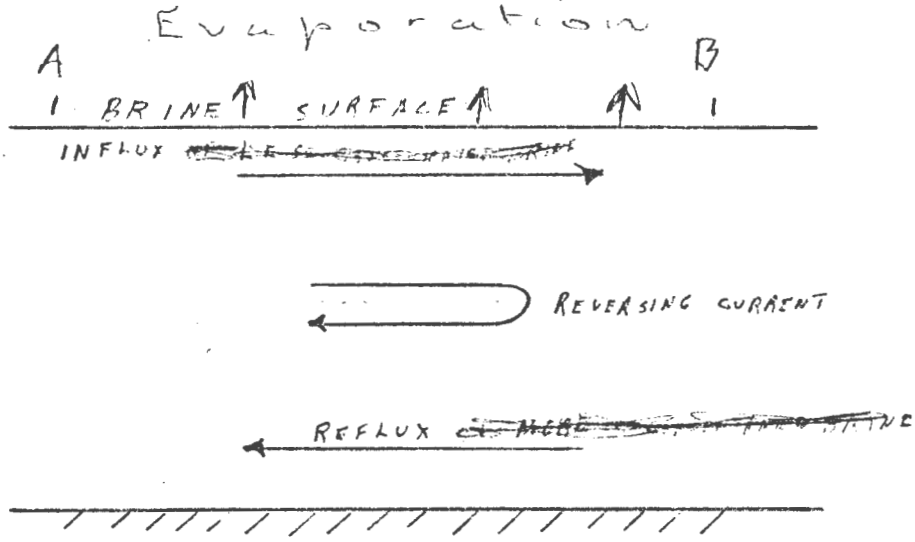


FIG. 15 SCHEMATIC DIAGRAM OF BRINE CIRCULATION WITHIN MOST AREAS OF AN EVAPORATION BASIN. REVERSING CURRENT IS ACTIVATED BECAUSE INFLUXING BRINE HAS GREATER DENSITY AT B THAN IT DOES AT A.

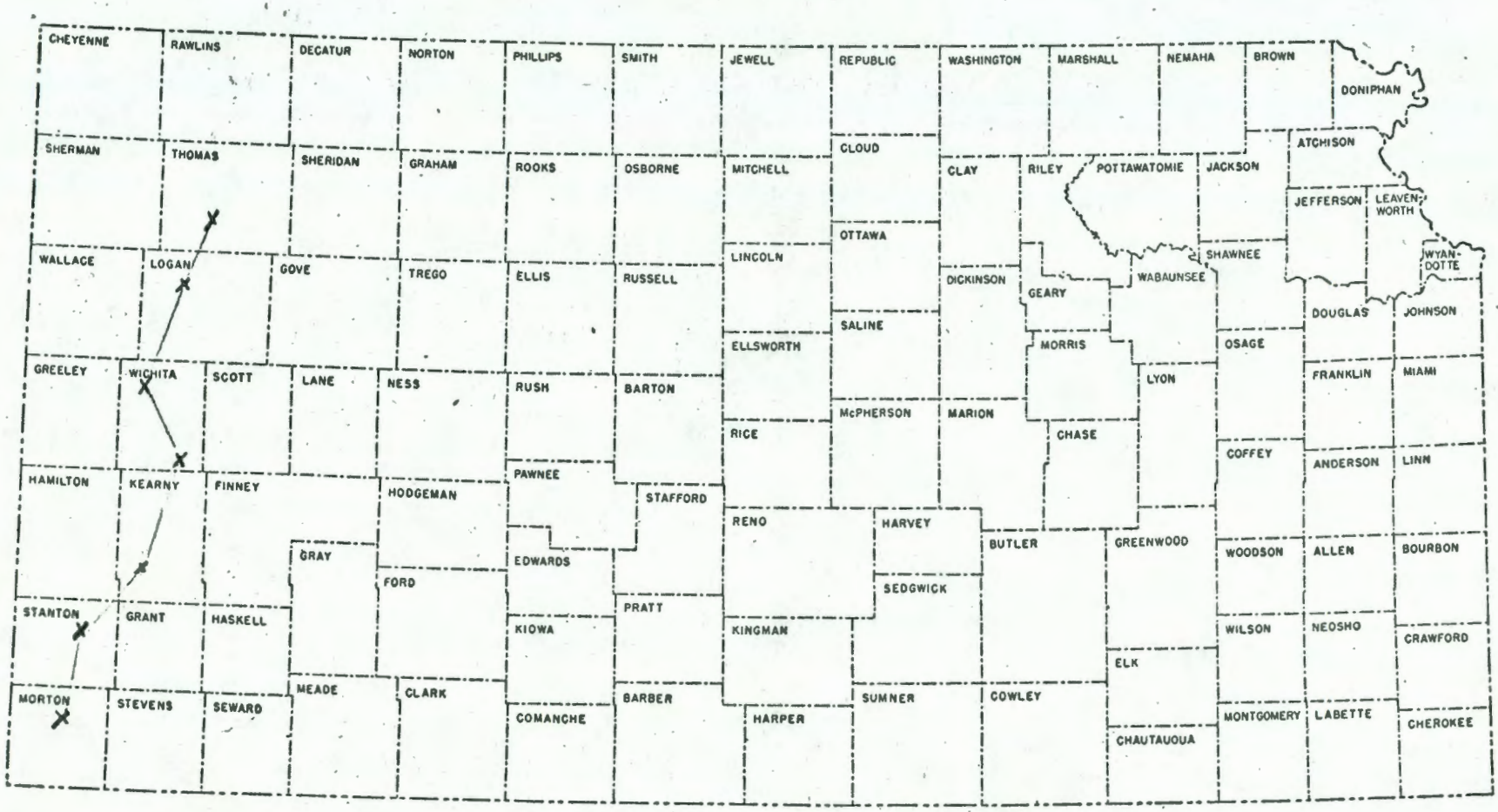
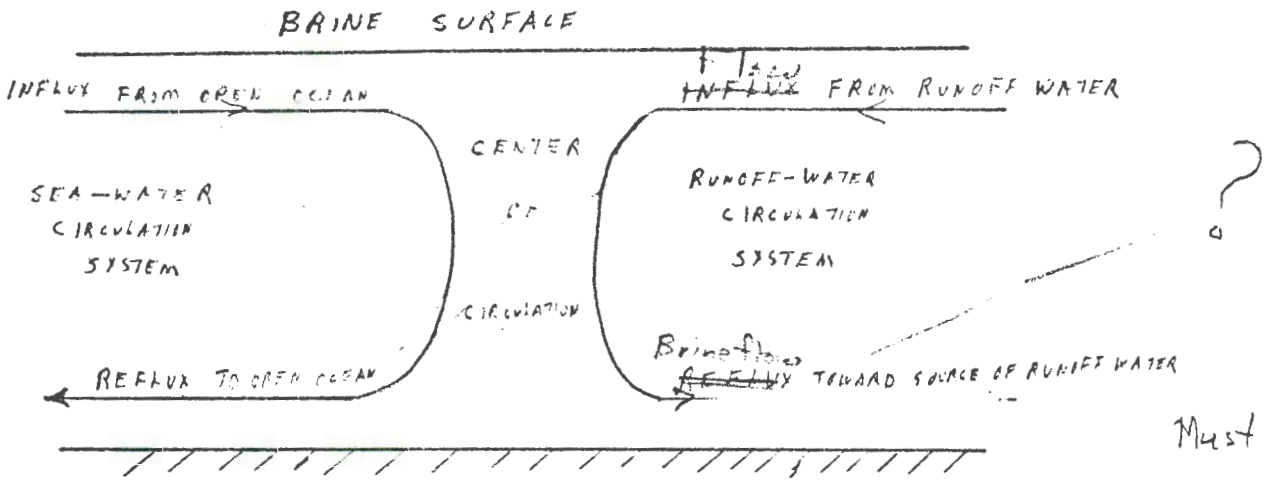


PLATE 4 NORTH-SOUTH CRISS SECTION OF BLAINE FORMATION AND ITS GENETICALLY RELATED SALT BEDS AND STONE CORRAL FORMATION AND ITS GENETICALLY RELATED SALT BEDS

into estuaries and up the mouths of rivers. No evaporites can be deposited in the runoff water circulation system ~~assuming~~ because the runoff water ~~contains no~~ is low in dissolved salts.

Logic dictates that in every evaporation basin there is at least one ~~place~~ area and perhaps several ~~places~~ where most (all) of the influxing brine is either evaporated or reverses its direction of flow to form reflux. These ~~places~~ areas can be termed centers of circulation, and providing there is only one inlet from the open ocean all centers of circulation are located at the junction between the sea water and the runoff water circulation systems (Figs. 16 and 17). The most highly concentrated brine in an evaporation basin is found at the surface of one of these centers of circulation because this brine has been subjected to the most evaporation and the least dilution. The more dense brine that has been observed at depth in some parts of evaporation basins must have first been concentrated through evaporation when it was surface brine. This deep brine cannot be more highly concentrated than it was at the time it was surface brine and has probably undergone some dilution since it left the surface. Precipitation of any dissolved salt therefore begins at a center of circulation (location of the most highly concentrated brine), and if the depositional area is enlarged, its growth eminates from that center of circulation but always within the sea water circulation system. Precipitation could also be initiated independently from other centers of circulation

Bobs report - J. 29.



Must be very small amt. More goes toward inlet

FIG. 16 SCHEMATIC DIAGRAM OF CURRENTS AT A CENTER OF CIRCULATION

NOTE INFLUXING BRINE FROM BOTH SOURCES WOULD BE HIGHLY CONCENTRATED UNDER CONDITIONS IN WHICH EVAPORITES WERE DEPOSITING; HOWEVER, ONLY THE SEA-WATER CIRCULATION SYSTEM WOULD CONTAIN SATURATED BRINE. RUNOFF-WATER CIRCULATION SYSTEM WOULD CONTAIN TERRIGENOUS DETRITUS

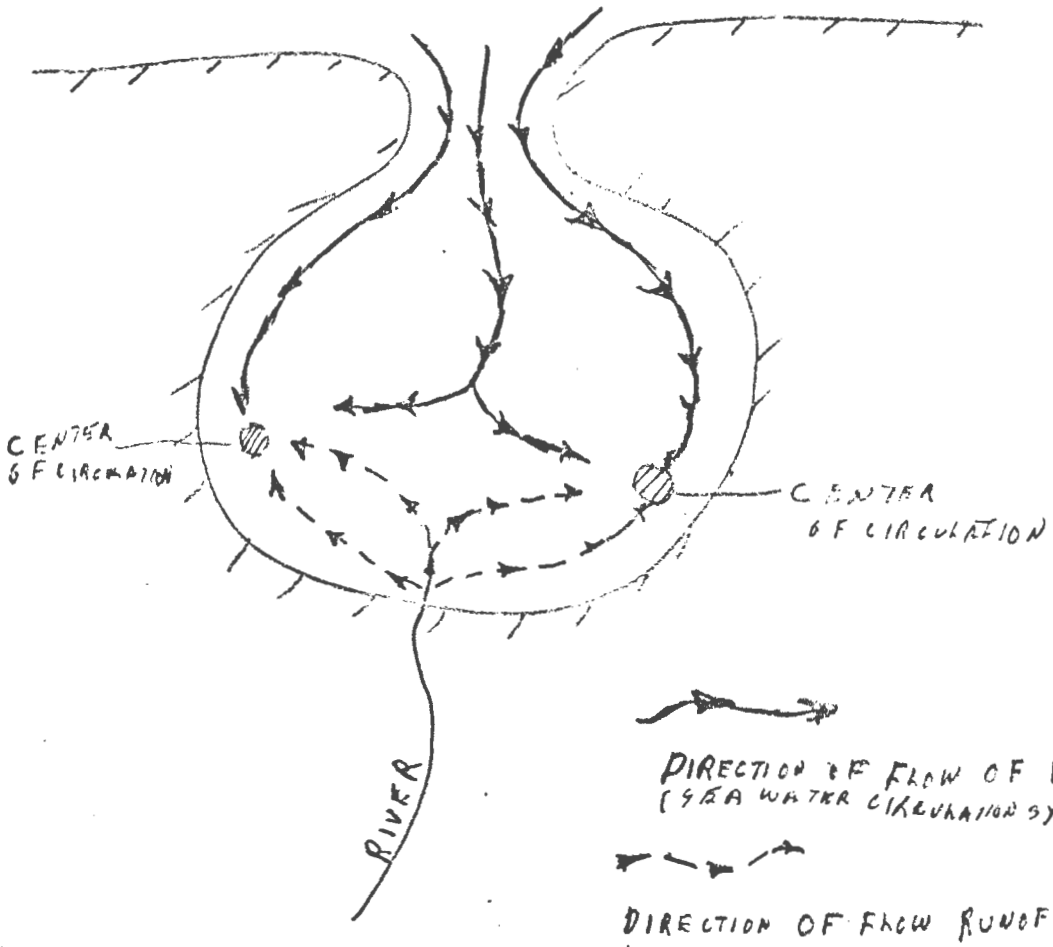


FIG. 17 POSSIBLE RELATIONSHIPS BETWEEN SEA-WATER AND RUNOFF-WATER CIRCULATION SYSTEMS IN AN EVAPORATION BASIN

providing they are present.

The slope of the density curve (Fig. 10), which indicates the increase in density of brine per unit increase in its degree of evaporation, is significant in the discussion of brine circulation because it is the change in density of influxing brine within a given area that activates the local reversing currents. When the degree of evaporation is increased from 9 to 10 percent the increase in density is slight compared to the increase between 89 and 90 percent. This means that if all other factors were equal the reversing currents would be stronger in those parts of a circulation system where influxing brine is 90 percent evaporated than where it is 10 percent evaporated. The general exponential shape of the density curve indicates that ~~in the main~~ reversing currents are stronger where the brine is more highly concentrated.

The anomaly in the density curve (Fig. 10) at the point of saturation of the brine with respect to sodium chloride (approximately 91 percent degree of evaporation) is of great importance in view of the preceding discussion. Brine of this type should tend to maintain its own existence because its evaporation causes its density to increase only a slight amount. When sodium chloride-saturated brine is formed at a center of circulation, the reversing currents should be only weakly activated, and its rate of expulsion from that center of

circulation would be relatively slow. This would allow the brine saturated with respect to sodium chloride to maintain contact with the evaporating atmosphere for a longer time than if the reversing currents were strong. Longer desiccation would further increase the degree of evaporation of the brine and so tend to keep it saturated.

The upturn in the density curve (Fig. 10) before the brine becomes saturated with respect to bittern salts indicates that before these potassium and magnesium salts could be precipitated the reversing currents would again become strong in the center of circulation containing the most highly concentrated brine. This factor would inhibit the precipitation of the bitterns and could account for their scarcity in Kansas salt.

Location of evaporite deposition

The area of evaporite deposition should be relatively near shore. The site of saturated brine is determined by the centers of circulation along the junction of the two circulation systems (Fig. 17). If saturated brine is to be formed the runoff water circulation system must be small compared to the sea water circulation system. The junction between the two systems would be relatively near shore under these conditions.

DEPOSITIONAL HISTORY OF KANSAS SALT

Introduction

The Kansas salt deposits offer an excellent opportunity to study the manner in which evaporites accumulated in a depositional basin. They have undergone only slight deformation since their deposition (P. B. King, 1951), and relatively accurate stratigraphic information is readily available from many logs of holes that have penetrated the deposits. Direct observation of the Hutchinson Salt is also available in the Kansas salt mines.

Deposition of the Hutchinson Salt

The Hutchinson Salt Member contains the oldest known deposit of sodium chloride in Kansas. The member has several features exclusive of lithology that distinguish it from strata deposited prior to its deposition. These features can be attributed to the special conditions necessary for sodium chloride deposition.

Petrogenesis

The petrography of the Hutchinson Salt, as well as the regular layering of the mine exposures, indicates a lack of vigorous currents during its deposition (p. 17). This lack of agitation can be attributed to the subdued circulation present in those parts of the evaporation basin containing brine saturated with respect to sodium chloride.

Halite -- Primary crystals of halite appear to have undergone two stages of crystallization. The first stage is indicated by the cloudy chevron structures in the centers of the crystals and the second by the clear overgrowths (p.21). Dellwig (1955) observed similar structures in halite crystals of the Salina Salt of Michigan. Because evaporation takes place at the brine surface he postulated that halite first crystallized at the surface and floated before settling to the basin floor. He further theorized that the chevron shaped structures were formed while the crystals floated and the clear overgrowths formed after the crystals settled. The halite crystals in the Hutchinson may have had a similar history. Their interlocking pattern suggests that the final growth of individual crystals was controlled by the presence of neighbor crystals indicating that final crystallization was subsequent to deposition.

The crystallization of halite on the basin floor required either some precipitating agent other than evaporation or some mechanism to transfer the effect of evaporation to the bottom of the basin. Dellwig (1955, p. 92) postulated that temperature change caused the crystallization of the clear overgrowths pointing out: "Although the solubility of salt (sodium chloride) varies but a small amount with temperature, a relatively large amount of salt can be taken into solution with temperature change if there is a large enough quantity of water". If

fluctuation of brine temperature caused the crystallization of the clear overgrowths, larger crystals grew at the expense of smaller ones. When the brine was warmed solid sodium chloride was dissolved. The larger crystals were reduced in size, but the smaller crystals were completely destroyed. Later, when the brine was cooled, the undissolved remnants of the larger crystals served as centers of crystallization for the recrystallizing halite. The net result was the crystallization of the clear overgrowths on the larger crystals.

Factors other than temperature change could have produced the same results. Daniels and Alberty (1955) note that extremely small crystals are slightly more soluble than larger crystals, and if a mixture of different sized crystals is allowed to stand in a saturated solution the larger ones will grow at the expense of the smaller ones. Dellwig (1955) also states that pressure on halite crystals resulting from the growth of adjacent crystals could cause dissolving at the points of contact and recrystallization on noncontact surfaces. Elongation of the crystals normal to the stratification can be attributed to restriction of lateral growth by neighboring crystals.

Nonhalite constituents -- The clusters of anhydrite, hydrocarbon, and clay minerals (the chief nonhalite constituents) were possibly deposited as flocs.

According to Dr. Fred Kurata, [Chemical Engineering Department, University of Kansas] (personal communication, 1959) the dissolved calcium sulfate could have served as a flocculating agent for all of these sediments. Their layering can be attributed to the intermittent settling of the halite and more regular deposition of the flocs. Subsequent to their deposition they were altered by diagenesis.

Interpretation of stratigraphy

The local succession of beds of the Hutchinson and its associated strata (Pl. 4 to 8) indicates both an alternation of depositional environment as well as a systematic change in the alternations. Initially there was an alternation between terrigenous and nonterrigenous sedimentation (carbonate-shale and sulfate-shale units) (Pl. 4 to 7). Next the alternation was between calcium sulfate and sodium chloride deposition (lower part of the Hutchinson Salt) (Pl. 4 to 7). Still later the alternation was between sodium chloride and terrigenous sedimentation (upper part of the Hutchinson Salt) (Pl. 4 to 7). Finally the alternation of environments ceased and sedimentation was almost continuously terrigenous (thick shale unit). (Pl. 4 to 7).

Almost all of these environmental changes can be explained if it is postulated that prior and during the time of Hutchinson deposition the rate of

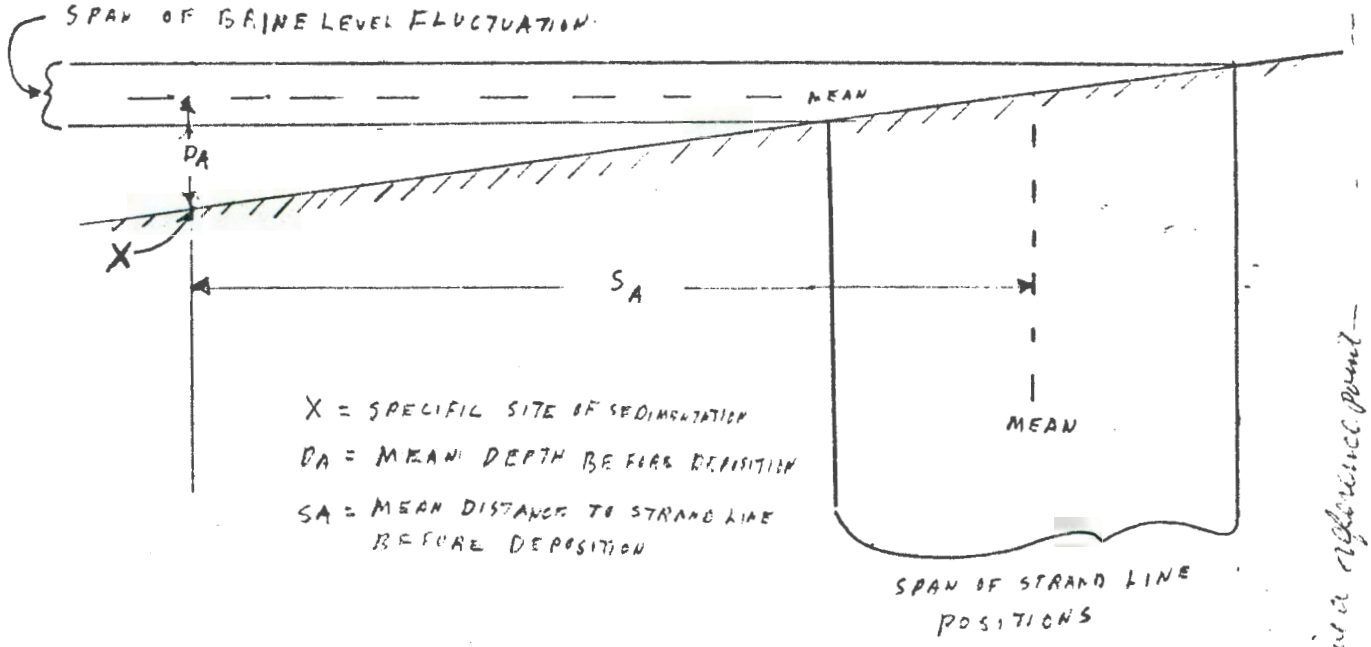
evaporation remained relatively constant while sea level rose and fell at a relatively fast rate between fixed limits and sediment accumulated at a relatively slow rate, but somewhat faster than the rate of subsidence of the basin. Under these circumstances (1) the position of the strand line would oscillate about a mean, (2) the depth of brine would oscillate about a mean, (3) the mean position of the strand line would shift gradually in a basinward direction, and (4) the mean depth of brine would gradually decrease (Fig. 18). Factors (1) and (2) can account for the alternation of environments. Factors (3) and (4) can account for the systematic change in type of alternation.

The postulations set forth in the previous paragraph are based chiefly on the fact that early in the accumulation of the Hutchinson Salt the change to sodium chloride deposition was in phase with the change to terrigenous sedimentation. Early-deposited salt beds are correlated with shale beds and not anhydrite beds. This suggests that change in brine depth and strand-line position controlled the change in depositional environment because the same action (lowering of sea level) under these circumstances could have caused the deposition of both shale and salt beds. Lowering of sea level would have shifted the strand-line position in a basinward direction thereby enhancing terrigenous sediment. Lowering of sea level could have also caused saturation of the brine with respect to sodium chloride by

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A

BEFORE DEPOSITION



Point of reference Point

B

AFTER DEPOSITION

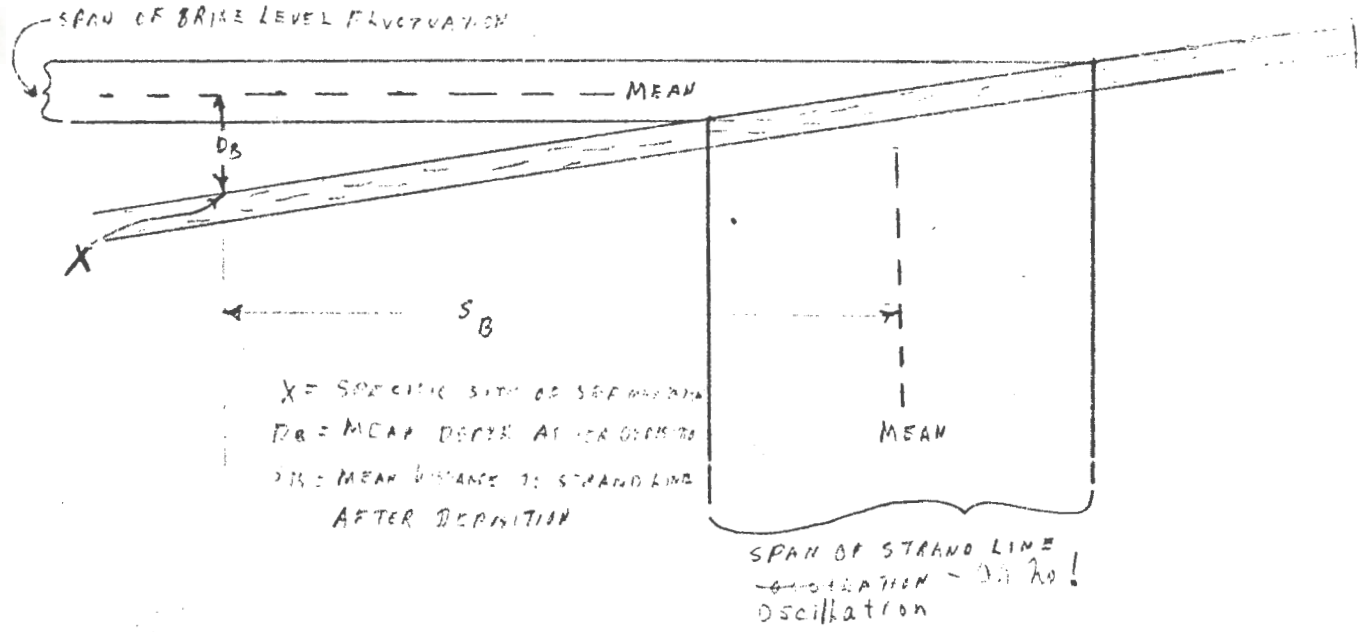
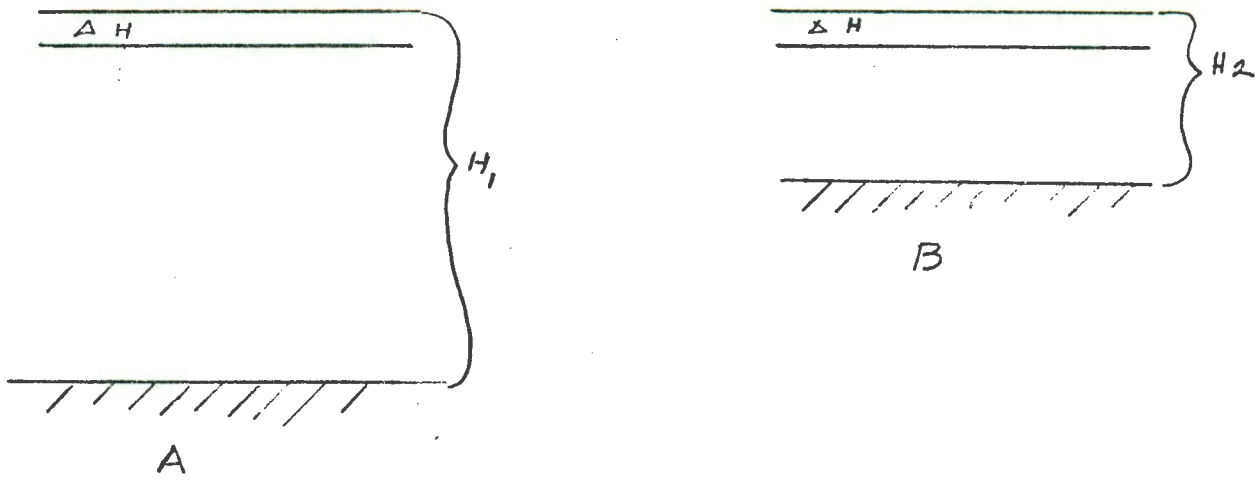


FIGURE 18 INFLUENCE OF BRINE LEVEL FLUCTUATION AND DEPOSITION OF SEDIMENT ON DEPTH OF BRINE AND DISTANCE TO STRAND LINE AT A SPECIFIC SITE OF SEDIMENTATION X.

reducing brine depth (Fig. 19). Other explanations of the correlation of salt beds with shale beds seem unrealistic.

Deposition of the carbonate-shale and sulfate-shale units -- The alternating succession of sediment types in these units can be attributed chiefly to the reciprocation of the strand-line position from which the detritus carrying run-off water circulation system was eminating. A basinward shift of the strand line caused terrigenous detritus to be deposited where nonterrigenous sediment had previously been deposited. A landward shift of the strand line reversed the process. The change from the carbonate-shale unit to the sulfate-shale unit can be attributed to the decrease in mean brine depth that resulted when sediment accumulated faster than the basin subsided. This could have saturated the brine with respect to calcium sulfate (Fig. 19).

Deposition of the lower Hutchinson Salt -- The alternation of anhydrite and salt beds in the lower Hutchinson Salt Member (Pl. 6) can be attributed to the alternate increase and decrease in brine depth that resulted from a rise and fall in sea level (Fig. 19). Sodium chloride was deposited during low stands of brine level and calcium sulfate was deposited during high stands of brine level. Deposition of sodium chloride could have been instigated by the continued decrease in mean brine depth that resulted from the postulated accumulation of



$H_1 + H_2$ DEPTH OF BRINE BEFORE EVAPORATION

ΔH CHANGE IN DEPTH RESULTING FROM EVAPORATION

EQUAL EVAPORATION (ΔH) WILL CONCENTRATE SHALLOW BRINE (B) MORE THAN DEEP BRINE (A) BECAUSE ΔH IS A GREATER FRACTION OF H_2 THAN OF H_1.

FIGURE 19 INFLUENCE OF BRINE DEPTH ON EFFECTIVENESS OF EVAPORATION

sediment at a rate more rapid than the basin was subsiding. The area of exclusive deposition of sodium chloride at or near log (Pl. 6) could have been a center of circulation during periods of low brine level, where more highly concentrated brine was localized. The more extensive salt deposition in the overlying beds can be attributed to the further reduction of mean brine depth during the later cycles of sea level fluctuation. Because brine saturated with respect to sodium chloride tends to maintain its own existence (p. 51) areas overlain by brine of this type were protected from invasion by the runoff water circulation system laden with terrigenous detritus.

Deposition of the upper Hutchinson -- The alternation of salt and shale beds in the upper part of the Hutchinson can be attributed to the reciprocation of the strand-line position. Sodium chloride was deposited during high stands of brine level and shale was deposited during low stands. (During the initial stages of Hutchinson deposition sodium chloride was deposited exclusively during low stands of brine level). This reverse in association between sodium chloride precipitation and position of sea level can be attributed to the continued decrease in mean brine depth and basinward shift of the mean position of the strand line. Mean brine depth was reduced enough so that even during high stands of sea level actual depth was shallow enough to cause the brine to be saturated with respect to

sodium chloride (Fig. 19). The mean position of the strand line was shifted far enough in a basin ward direction so that during low stands of brine level the detritus ladened runoff water circulation system was able to invade sodium chloride-saturated brine in areas where this previously was not the case (P. 58).

Deposition of the thick shale unit -- The undivided terrigenous sediment in the thick shale unit indicates the almost continuous presence of the runoff water circulation system during its deposition. This can be attributed to the continued basinward movement of the mean position of the strand line until specific areas were continuously remote from the sea water circulation system during the fluctuation of sea level.

Transgression of environments -- Correlation of key beds indicates that the deposition of the Hutchinson Salt was not a simultaneous occurrence. The area overlain by sodium chloride-saturated brine at any one time was probably very small compared to the entire depositional area of the Hutchinson. Fluctuation of sea level would have caused this depositional area to shuttle back and forth as well as to expand and contract. Basinward advance of the mean position of the strand line and reduction of the mean brine depth would have caused the mean position of the shuttling area of sodium chloride deposition to migrate from the distal parts of the basin toward the inlet through which influxing sea water entered the

evaporation basin. Superposition of beds (Fig. 6) indicates that the distal parts of the basin were to the north and east and that influxing brine came from the southwest.

Deposition of sodium chloride would have enhanced its own further precipitation for two reasons. (1) Brine saturated with respect to sodium chloride tends to maintain its own existence (p. 51). (2) Sodium chloride was probably a fast accumulating sediment (p. 36) and diminished the brine depth in the area of deposition at a relatively rapid rate. Migration of the sodium chloride depositional area toward the source of influxing sea water continued as long as the enhancement of sodium chloride precipitation as a result of its own deposition overcame the increased dilution that resulted from its migration toward the source of inflowing sea water. Lateral migration of the sodium chloride depositional area would have ceased when this was no longer the case. Deposition toward the southwest of the Hutchinson Salt in Kansas, where the stratigraphic section is chiefly anhydrite (Pl. 8),probably was terminated by dilution from influxing brine. Southwestern termination could have occured in or near the inlet through which brine was exchanged between the evaporation basin and the open ocean. This investigation was terminated at the state line so it is not known how far these interfingering salt and anhydrite beds extend into Oklahoma. Although the brine need not have

passed over a bar (Richter-Bernburg, 1953) there is presently an anticline in the rocks that underly this southwestern extremity, which could reflect the existence of a bar during Hutchinson time.

Deposition of the "Stone Corral" and "Blaine" salt

Events that brought about the deposition of these two younger salt deposits seem almost identical; consequently, they will be discussed together. Both of these salt deposits indicate a return of sodium chloride depositional conditions to southwestern Kansas and adjacent areas subsequent to its termination at the end of Hutchinson deposition.

Stratigraphy of the Hutchinson Salt and its associated strata indicates a gradual decrease in mean depth of basin and a gradual basinward shift of mean position of the strand line during the time of deposition of those rocks. This was attributed (p. 56) to a somewhat faster accumulation of sediment than rate of subsidence of the basin. This action could not have continued indefinitely and still have maintained the depositional basin. During the time of deposition of the Kansas Permian there must, therefore, have been times when subsidence was faster than the accumulation of sediment. This reverse action would have increased the mean depth of brine and shifted the mean position of the strand line in a landward direction resulting in a return of sodium chloride depositional

conditions to southwest Kansas by inundating the area with saturated brine. Each of the younger salt deposits could indicate a period of increased rate of subsidence. The intercalated calcium sulfate beds in these younger deposits can be attributed to the continued influence of sea level fluctuation during these periods of accelerated subsidence. Both Fay (1961) and Ham (1960) postulate fluctuation of sea level during the deposition of the Blaine Formation in Oklahoma.

CONCLUSIONS

1. The reflux theory is the only logical explanation for the deposition of large sodium chloride bodies in which there is an absence of closely associated bittern salts. The most highly concentrated brine in a refluxing basin is at the surface of a center of circulation. Brine saturated with respect to sodium chloride tends to maintain its own existence in an evaporation basin because its evaporation induces only weak reflux.

2. Mine exposures and petrographic samples of the Hutchinson Salt indicate an absence of vigorous circulation in its depositional area. This reflects the slow reflux that would be present in an area overlain by brine saturated with respect to sodium chloride.

3. Local stratigraphy of the Hutchinson Salt and closely associated strata can be accounted for if it is postulated that (a) strand line oscillated about a mean position (b) brine depth oscillated about a mean in phase with the oscillation of the strand line, (c) mean position of the strand line was shifted gradually in a basinward direction, and (d) mean brine depth was gradually decreased. Such conditions would have been present if (1) sea level fluctuated between fixed limits at a relatively fast rate and (2) sediment accumulated at a relatively slow rate but faster than the subsidence of the depositional basin.

4. Long-distance stratigraphic correlation indicates that the area of sodium chloride deposition at any one time was relatively small compared to the total depositional area. Deposition began in the north and east and proceeded toward the south and west. Based on conclusion 3 this indicates that the distal parts of the basin were to the north and east, and the influxing brine came from the southwest.

5. The younger salt bodies (those related to the Stone Corral and Blaine Formation) were deposited during periods when the rate of subsidence exceeded the rate of accumulation of sediment.

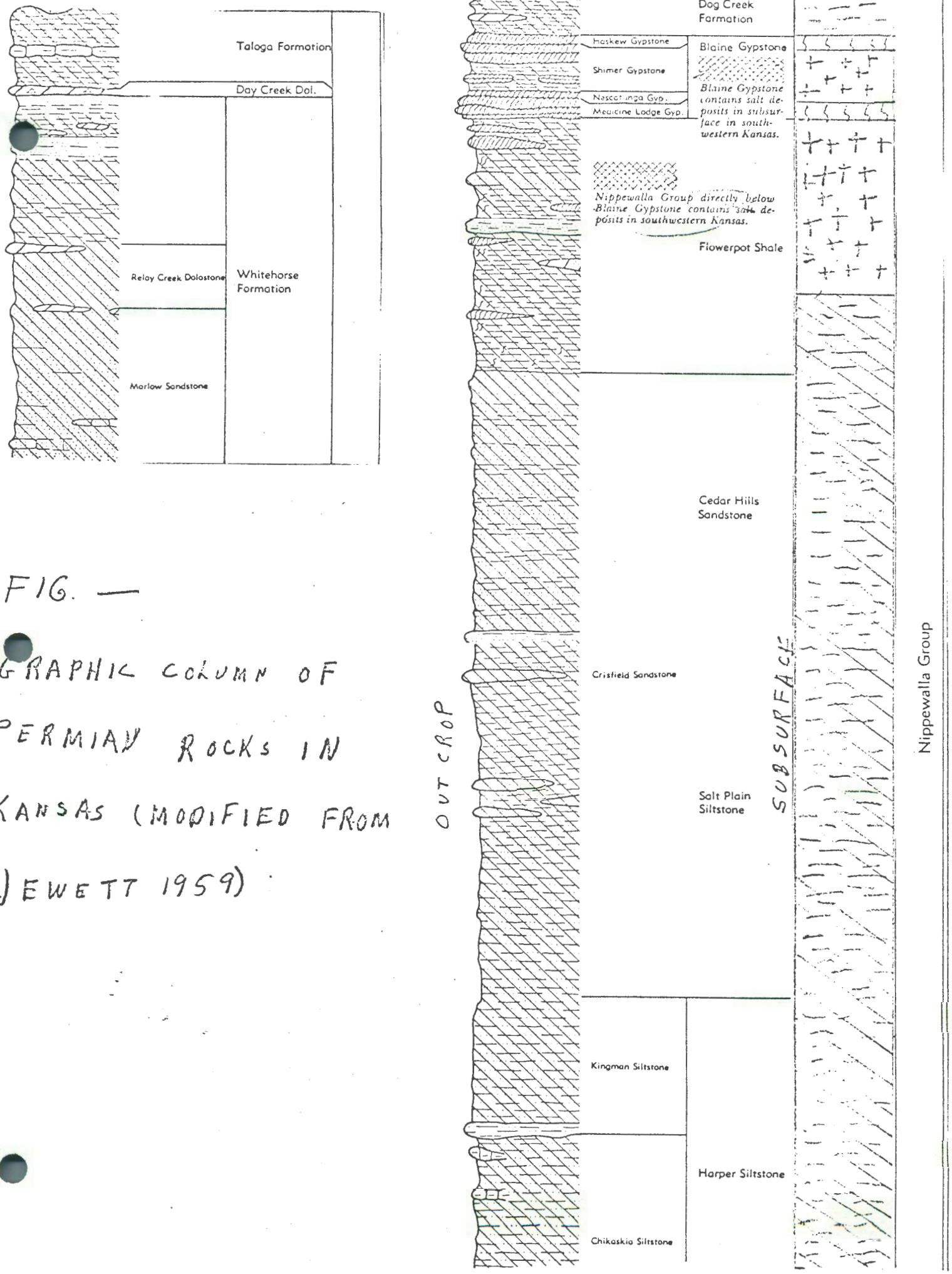
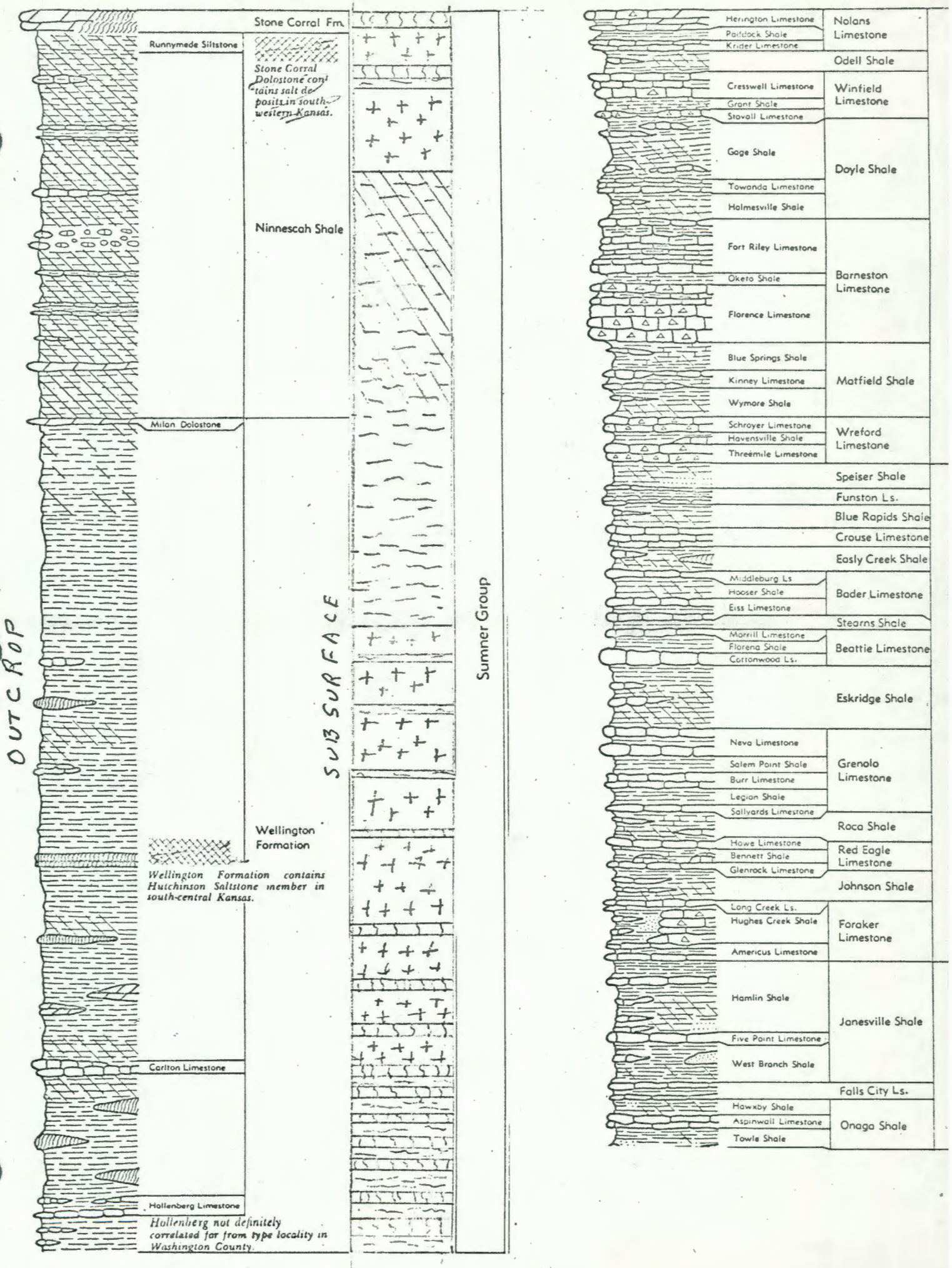


FIG. —

GRAPHIC COLUMN OF PERMIAN ROCKS IN KANSAS (MODIFIED FROM JEWETT 1959)


OUTCROP
SUBSURFACE
Stone Corral Fm.
Runnymede Siltstone
Stone Corral Dolostone contains salt deposits in southwestern Kansas.
Ninnescah Shale
Milan Dolostone
Wellington Formation
Wellington Formation contains Hutchinson Saltstone member in south-central Kansas.
Carlton Limestone
Hollenberg Limestone
Hollenberg not definitely correlated far from type locality in Washington County.
Sumner Group
Herington Limestone
Paldock Shale
Krider Limestone
Nolans Limestone
Odell Shale
Cresswell Limestone
Grant Shale
Stovall Limestone
Winfield Limestone
Gage Shale
Towanda Limestone
Holmesville Shale
Doyle Shale
Fort Riley Limestone
Oketo Shale
Florence Limestone
Barneston Limestone
Blue Springs Shale
Kinney Limestone
Wymore Shale
Matfield Shale
Schroyer Limestone
Havensville Shale
Threemile Limestone
Wreford Limestone
Speiser Shale
Funston Ls.
Blue Rapids Shale
Crouse Limestone
Easly Creek Shale
Middleburg Ls.
Hooser Shale
Eiss Limestone
Bader Limestone
Stearns Shale
Morrill Limestone
Florena Shale
Cottonwood Ls.
Beattie Limestone
Eskridge Shale
Neva Limestone
Salem Point Shale
Burr Limestone
Legion Shale
Sallyards Limestone
Grenola Limestone
Roca Shale
Howe Limestone
Bennett Shale
Glenrock Limestone
Red Eagle Limestone
Johnson Shale
Long Creek Ls.
Hughes Creek Shale
Americus Limestone
Foraker Limestone
Hamlin Shale
Five Point Limestone
West Branch Shale
Janesville Shale
Falls City Ls.
Hawxby Shale
Aspinwall Limestone
Towle Shale
Onaga Shale

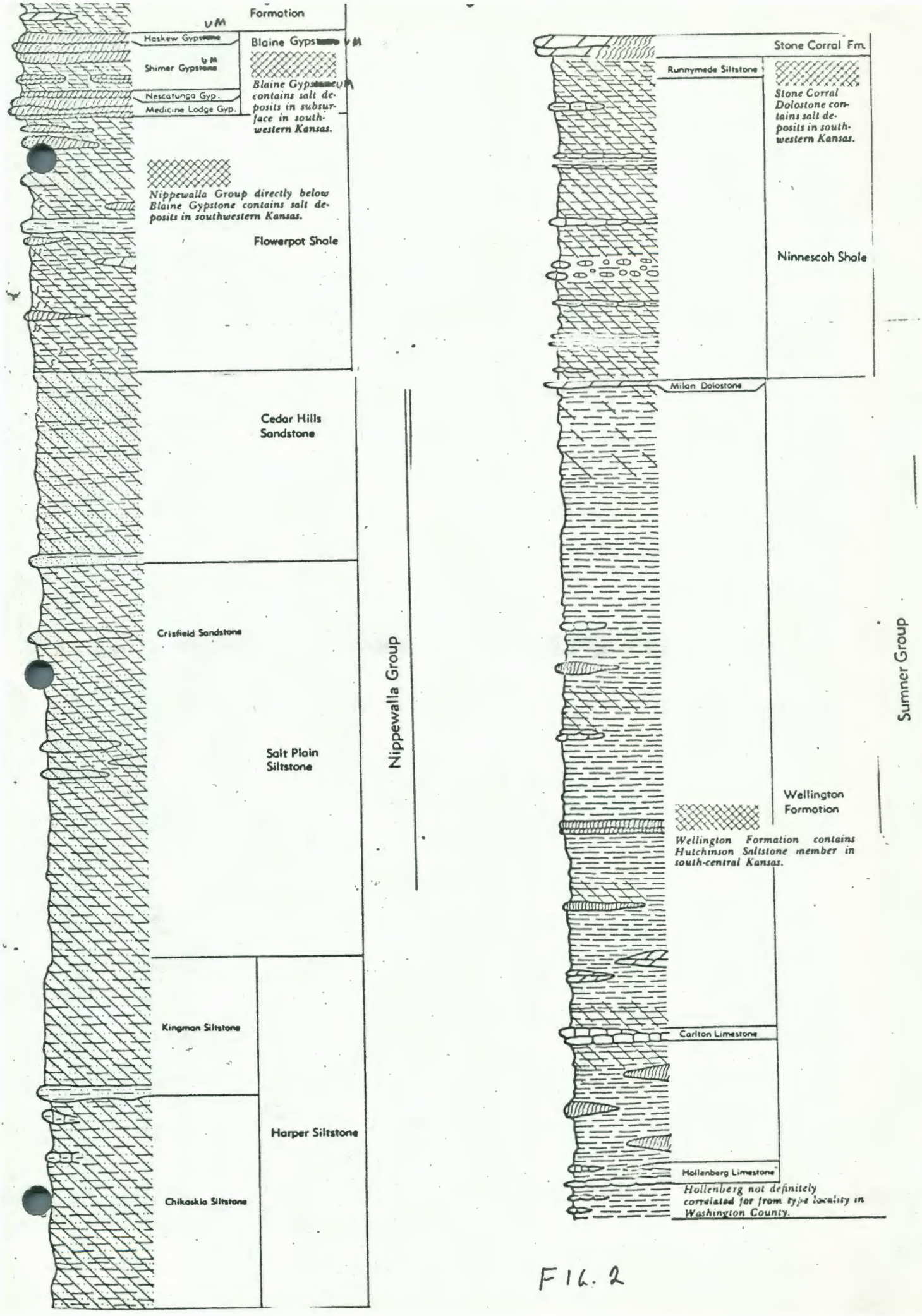

Formation
Haskew Gypstone
Blaine Gypstone
Shimer Gypstone
Nescatunga Gyp.
Medicine Lodge Gyp.
Blaine Gypstone contains salt deposits in subsurface in southwestern Kansas.
Nippewalla Group directly below Blaine Gypstone contains salt deposits in southwestern Kansas.
Flowerpot Shale
Cedar Hills Sandstone
Crisfield Sandstone
Salt Plain Siltstone
Nippewalla Group
Kingman Siltstone
Harper Siltstone
Chikaskia Siltstone
Stone Corral Fm.
Runnymede Siltstone
Stone Corral Dolostone contains salt deposits in southwestern Kansas.
Ninnescah Shale
Milan Dolostone
Sumner Group
Wellington Formation
Wellington Formation contains Hutchinson Saltstone member in south-central Kansas.
Carlton Limestone
Hollenberg Limestone
Hollenberg not definitely correlated far from type locality in Washington County.

FIG. 2

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