ORIGIN OF BEDDED SALT DEPOSITS:
A CRITIQUE OF EVAPORATIVE MODELS AND
DEFENSE OF A HYDROTHERMAL MODEL

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THESIS

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ABSTRACT

Current models for the deposition of large bodies of salts, based upon classical evaporative techniques, are inconsistent with field observations and experimental data. The desiccated, deep-basin model recently advanced to explain salt deposits in the Mediterranean Basin has some major shortcomings. The model illustrates how a common uniformitarian bias toward the evaporative process dictates the interpretation of many features and data.

A new model for the deposition of salts, termed the "hydrothermal model," is consistent with known field observations such as the tremendous lateral extent and thickness of deposits, their occurrence and distribution throughout the world, and their unique composition including the monomineralic nature, ionic concentrations, and relative abundance. Volcanic, tectonic, structural, stratigraphic, heavy metal, and hydrocarbon associations with salt deposits also support the hydrothermal model.

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Chapter One

INTRODUCTION

Salts represent some of the most common commodities today, including table salt, wallboard, and fertilizers. They are abundant in the rock record on continents worldwide. They are easy to recognize and describe, and yet their origin has been a subject of much discussion for hundreds of years. Theory upon theory has been offered. Whenever one theory is advanced to explain their deposition, another problem or unique feature comes to light which necessitates a modification of the theory.

The problem does not lie in explaining how to get the salts. That can easily come about by merely evaporating sea water (hence the term "evaporite" in describing this whole suite of minerals). The real problem arises in trying to explain some of the major features of salt deposits by a depositional model. It is one thing to talk about the formation of merely a few inches or feet of salts and an entirely different problem to explain the origin of deposits several thousand feet thick. Table 1 lists many salt deposits giving content and thicknesses of the deposits. As one

Table 1. Selected Salt Deposits of the United States.

Strata System	Area	Formation or Interval	Thickness of Section (ft)	Type
Silurian?	Michigan Basin	Bass Island, Salina	3,000	S,H
	West Virginia	Salina	800	S
Mississippian	Williston Basin	Otter, Charles	1,000	S
Pennsylvanian	Paradox Basin, Utah	Paradox	4,000	S,H,B
	Gypsum Basin, Colorado	Maroon	500+	S
Permian	Southeastern New Mexico	Rustler, Salado, Castile	4,500	S,H,B
	Texas Panhandle	Pease River, Clear Fork, Wichita	2,000	S
Jurassic?	Gulf Coast	Louann, Werner	1,500±	S,H
	Central Utah	Arapien	1,000	H
Cretaceous	South central Florida	Comanchean	6,000	S

Thicknesses are approximate and include interbedded sediments. Type of salts are calcium sulfates, including anhydrite and gypsum, S; halite, H; and bedded bittern salts of potassium and magnesium, B (Modified from Stewart, 1963, p. Y27).

can readily see, there are deposits of salts which stagger the imagination.

Furthermore, as also seen in Table 1, large deposits often include principally one mineral to the exclusion of the others. Concerning a large deposit of gypsum, Bateman (1942, p. 181) reports:

> Since the evaporation of 1,000 feet of sea water yields only 0.7 foot of gypsum, then the evaporation of 425,000 feet, or a depth of 80 miles, of sea water, would be required to yield 300 feet of anhydrite. As this is ridiculous, it follows that new supplies of sea water must have been added to the basin during evaporation, and the residual liquors became concentrated in subbasins.

The thickness of the deposit is only one problem. An additional concern is the whereabouts of the other types of salts that "should" be there if the deposit formed by the evaporation of seawater. This monomineralic deposition has stymied students of geology for years. In the experiments and observations of modern salt deposition, a definite order of precipitation giving several salts is noted. This is drastically different from the record of past deposits.

The problem of determining how these major salt deposits originated stems from an attempt to explain past geologic features by present day processes. This uniformitarianism forms the underlying principle and philosophy of most of today's geology. The philosophy is inherent in the genetic term "evaporite" used to describe the various salts. The logic of uniformitarianism tells us that since some salt is formed by the process of evaporation of water today, the giant deposits in the geologic past were probably also formed that way and hence should be called "evaporites."

The following example illustrates the problem. Suppose we see a man who is digging a hole with a shovel. Can we assume the next time we see a hole somewhere else, that the same man with the same shovel also dug this hole? Of course we cannot. There are other individuals who can dig a hole and other operations which would result in a "thing" called a hole. In the same way, other methods besides evaporation can produce the so-called "evaporite" minerals.

Because the bias concerning the origin of salt is inherent in the term "evaporite," its use in this paper will be in quotations to emphasize this bias. Other times these deposits will merely be called salts.

In this study, various classical models for the origin of salts will be discussed along with their strengths and failures. The underlying bias referred to above, along with the secondary assumptions, will be demonstrated in discussions of one of the newest theories of salt deposition, the desiccated deep-basin model, as well as in discussion of problems assoociated with the theoretical and experimental geochemistry of salt deposition.

A new model for the deposition of salts, the "hydrothermal model," will be presented as an alternative to the classical evaporative models. This model will be shown to be consistent with known field data and to alleviate many of the "problems" other models cannot solve. It is hoped that this model will cause geologic thinking to progress in a new, fresh, direction since the old direction involving evaporative flats and basins has become stagnant.

Chapter Two

EVAPORATIVE MODELS FOR DEPOSITION OF SALT

Many depositional models have been proposed in attempts to explain the origin of salt. Most postulate one of two main depositional environments: either the mud flats (sabkhas) along coastal tidal zones and inland lakes, or deeper water basins. Both rely on concentration of salts through evaporation. Proponents of one are often bitterly opposed to the other. The main theories will be discussed here, along with their strengths and weaknesses.

Basinal Deposits

The concept of basinal evaporite deposits has been used, overused, and often greatly misused in explanations of various salt deposits. The beginning of the modern barred basin models was first put forth by Bischof in his 1854 publication of *Elements of Chemical and Physical Geology*. He suggested the deposits may have formed in a basin behind a bar over which the sea poured during high tide seasons. The model was later revitalized in the last quarter of the nineteenth century by Ochsenius, whose famous barred basin model has since dominated the thinking of most geologists. His theory has led to numerous publications adopting the same or a slightly modified plan for evaporite deposition. In his 1888 model, he describes a barred basin:

> When a nearly horizontally running bar cuts off a bay from the sea, so that only as much sea-water runs in over it as is compensated by evaporation from the surface of the lagoon, and the so partially separated portion receives no large additions of fresh --, i.e. rain or running water a deposition of salt takes place in the way to be described. (Ochsenius, 1888, p. 181)

He then goes on to describe the order of deposition of salts as the seawater becomes more and more concentrated.

In essence the traditional view of a barred basin is a body of water cut off in whole or in part from the open marine environment by a reef, shelf or sand bar. The water trapped in the basin is concentrated by evaporation until the salinity is sufficient to precipitate "evaporite" minerals. Periodic or perhaps constant recharging of the basin with water from the outside environment, provides more material for precipitation resulting in many feet of deposition.

Shortly after workers tried to match the theory to the actual data, they realized a major problem existed. Ochsenius' theory in their estimation could not explain the deposits having a great thickness of a single mineral to the exclusion of other minerals that "should" have also been deposited. Gypsum deposits hundreds of meters thick would demand the evaporation of an unreasonably tall column of water, implying an extremely deep basin. What happened to the precipitation of the other salts then?

In 1915, Branson published a modification of the Ochsenius bar theory to try to account for the monomineralic deposition common to many of the large salt deposits. About the same time, it was noticed that the ratio of sodium chloride to calcium sulfate in normal seawater is about 30:1; yet in the Castile Formation of Texas and New Mexico, it is about 0.25:1. This puzzled workers for years. Therefore, King (1947) put forth his reflux model. He suggested that while the thick deposits of one "evaporite" mineral were accumulating, the more soluble salts escaped as a dense countercurrent of thick brine beneath the inflowing seawater. This idea (or a very similar one) is currently held to by many barred basin advocates.

Schmalz (1969), discontent with the idea of salt forming in shallow basins, argued that basins had to be very deep in order to account for the saline giants such as the Zechstein (in Germany and the Netherlands) and the Castile. For him, it was very unreasonable to assume that the basin could be subsiding at exactly the precise rate to allow continuation of salt deposition. He summarized evidence suggesting that salt accumulated in a deep basin with deep water.

There have been so many variations of bars and basinal deposits, that later workers found it extremely helpful to provide a classification (Krumbein and Sloss, 1963; Schreiber, 1978; Sloss, 1969). Several types of basins have been suggested based either upon their environmental relationships with stratigraphic sequences, or upon the tectonic setting. These can be grouped into three main types: basins of the craton proper, basins of the stable continental margin, and basins of the rifted continental margin.

The last major type of basin suggested is that associated with rifted continental margins due either to diverging or converging lithospheric plates. These are extremely deep oceanic basins. An example given of a basin due to convergence is the Mediterranean Sea (Hsü, 1972) and that of divergence is in the Red Sea and along the margins of the south Atlantic Ocean (Kinsman, 1974). Deposits in these types of basins have rather recently been suggested because of the efforts of the oceanic researchers from Wood's Hole and Scripps Institution of Oceanography as well as geophysical exploration companies. This is the new hot spot for active research.

Although each of the major models appear to be quite different in approach, they all depend upon the concentration of seawater by evaporation and deposition as the waters reach sufficient salinities. Problems with all of these basinal models are perhaps best illustrated by the paper written by Woolnough (1937). Although Woolnough is a supporter of the barred basin hypothesis, his approach is not one of most traditional geologists. He recognizes the inadequacy of the "Doctrine of Uniformitarianism" in the explanation of geologic formations which include major salt deposits, major coal measures, major fresh water series of sediments, and source rocks of oil deposits. In general, he does not want to give up the doctrine, but to modify it:

> The writer would therefore ask to be permitted to advance three postulates: (1) the geological processes active in the world at the present day represent only a fraction of the processes which have acted, throughout geological history, in modifying the earth's crust; (2) existing phenomena are capable of extension, both qualitatively and quantitatively, to account for results which defy explanation by the strict application of the Doctrine of Uniformity; (3) processes may be envisaged which have no counterpart at present, provided that the assumptions so made are not contrary to the fundamental laws of nature, and that there can be found objective instances explicable by such assumptions only and by no recognized and accepted phenomena. (Woolnough, 1937, p. 1105)

In regard to the origin of salt, he states:

> The writer was engaged for a number of years in an intensive investigation of salt deposits, in the course of which he studied the literature carefully, and visited arid regions where, if anywhere, such deposits should have been observed in course of formation. In no instance were conditions encountered which could conceivably have produced any of the major primary salt deposits of the geological past. Some circumstances or set of circumstances, entirely lacking under present day conditions, must have been operative when such major salt deposits were generated. (p. 1104, emphases his)

Woolnough's main thesis in the paper is that ideal conditions for barred basins existed in the past to a lot greater extent than they do today. The conditions as he sees them would be just right for the deposition of the salt as well as oil formations, black shales, and foraminifera:

> The main thesis of this paper is an amplification of the "Bar Theory" of Ochsenius. It is suggested that, when all implications of this theory are considered, the possibility is indicated of existence in the geologic past of "barred basins" of dimensions and characters entirely unrepresented at the present day. (p. 1101)

Woolnough lists what he considers to be modern enclosed basins of very large proportions. He includes the Mediterranean Sea, Black Sea, Red Sea, Persian Gulf, Baltic Sea, Caribbean Sea, Gulf of Mexico, Hudson Bay, Gulf of St. Lawrence, Sea of Japan, and other enclosed basins of the East Indies. These vary in their degree in which they are cut off from the main open ocean. He sees all of these except for the Black Sea as having what he calls a balanced faunal assemblage. His idea is that unless the basin becomes even more isolated and conditions are severely altered, the development of basinal deposits will not happen.

Woolnough's willingness to consider the unusual in geologic processes is rare but perceptive. He undoubtedly would be open to many of the ideas put forth in this paper.

Sabkhas

During the last 15 years the concept of the sabhka has been used extensively as a blanket explanation of many of the ancient evaporites. This suggestion has been made as a result of detailed study of recent deposits of salts accumulating along such areas as the Trucial Coast on the south side of the Persian Gulf and the Laguna Madre mudflats of southwest Texas (Masson, 1955).

The sabkha environment is the supratidal desert environment of either coastal margins or large inland lake margins. The term, sabkha, is Arabic and refers to flat salt-crusted deserts. It was first used in the present sense to describe the coastal desert supratidal plain along the Trucial Coast. Kinsman (1969) defines it as a fairly level, salt-encrusted surface that only occasionally is inundated. He