# Origin of Salt Deposits[1]

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ABSTRACT

*Bedded salt deposits are the result of normal geological processes. They occur in sedimentary basins, the floors of which have sagged intermittently, making room for more sediments. Associated minerals and rocks are anhydrite, dolomite, shale, and (rarely) ultra-soluble salts. These sedimentary basins are world-wide in occurrence, and some contain evaporite deposits many hundreds of feet in thickness. Salt deposits occur in rocks of almost every geologic period.*

*The ocean is the primary source of all rock salt deposits. It has always been saline. Connate water ("fossil" sea water) deposited with ancient sediments in inland embayments of the ocean is as a general rule more saline than ocean water, except where it has been flushed out subsequently by meteroic (rain) water. This supersalinity is believed to be the result of concentration of the salts in the shallow embayment water by evaporation during the long fetch from the open ocean.*

*Evaporite precipitation takes place when, under a proper climatic and physiographic environment, a sagging basin develops in an embayment so that a shallow sill or reef separates the basin from the main body of water. An inflow across the sill of sea water, already enriched in sodium and chlorine ions by the trip from the open ocean, is brought about by the greater evaporation within the nearly enclosed basin. The seaward return of the deeper denser water is prevented by the sill.*

*This theory differs from the classic Bischoff-Ochsenius theory in that the modern concept of a sinking basin (to make room for hundreds of feet of evaporite deposits) is applied, a prior enrichment of the sea water is postulated, and a submerged sill or reef is substituted for a shoreline bar.*

## INTRODUCTION

This paper will be confined to a discussion of the origin of bedded salt deposits. With the exception of small local deposits along the continental margins formed by recent precipitation of salt from ocean water, all other salt deposits are either recycled from bedded salt or are due to flowage of bedded salt deposits under pressure. Only the larger aspects of bedded salt origin are considered in this paper.

[1] This is a somewhat revised and very much reduced version of "The Geology of Salt Deposits," Chapter 4, Sodium Chloride, American Chemical Society Monograph Series 145, 1960, pp. 28-69.

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Pertinent Facts. Any hypothesis of origin of bedded salt deposits has to conform to at least eight geological facts, most of which have been developed in relatively recent years due to the world-wide probing of the earth's crust by holes drilled in the search for oil. These facts, all them pertinent to rock salt origin, follow:

1. The major bedded salt deposits occur in sedimentary basins. These come in a wide variety of sizes and shapes, but they have one thing in common and that is that the floor of the basin sagged periodically, thereby making room for thousands of feet of sediment in the central part. At one time it was believed that the sagging was due to the weight of sediment, but we now have evidence that parts of the earth's crust will sag due to deep-seated forces regardless of whether or not any sediment has been or is deposited. Another feature in common with all sedimentary basins is that during the greater part of their existence as basins of deposition, they were flooded by marine rather than fresh waters. By far the most abundant rock in most basins is shale, with sandstones second, and carbonate rocks third in volume.
2. Sedimentary basins occur on all of the continental platforms of the world. Many of these basins are known to contain evaporite deposits and the list will no doubt grow as more basins are explored at depth. The major basins containing evaporites on the North American continent (Figure 1) are in the Maritime Provinces of Eastern Canada, the northeastern United States, the Gulf Coast salt basin, the Permian basin of the southwest, the Williston basin of North Dakota, Montana, and Saskatchewan, and the Mackenzie basin in the Northwest Territories.
3. Within the evaporite-containing basins, individual salt beds may reach thicknesses of hundreds of feet and the aggregate thickness of salt in the basin may reach thousands of feet.
4. In spite of the great thickness of many salt deposits, there is increasing evidence, such as the presence of ripple marks, that the water depth most of the time during the precipitation of the salt was relatively shallow.
5. Salt precipitation has taken place in sedimentary basins throughout geologic time. As can be seen on the accompanying chart, every geologic period after the Precambrian

SALT THROUGH THE GEOLOGIC AGES

| Era | Period | Examples of Salt Deposits |
|---|---|---|
| Cenozoic | Quaternary | Playas, salt lakes |
| | Tertiary | Middle East |
| Mesozoic | Cretaceous | Florida |
| | Jurassic | Mexico |
| | Triassic | France |
| Paleozoic | Permian | Germany, U.S. Permian Basin |
| | Carboniterous | Maritime Provinces |
| | Devonian | Williston Basin (U.S. and Canada) |
| | Silurian | Northeastern United States |
| | Ordovician | Asiatic Russia |
| | Cambrian | Persian Gulf, India (?) |
| Proterozoic | Precambrian | India (?) |
| Archeozoic | | Australia (?) |


Figure 1. Major salt basins of North America.

contains known bedded salt deposits. Some salt deposits in Asia are either early Paleozoic or Precambrian in age. As we shall see presently, there is no known geologic fact which would preclude salt precipitation and accumulation in Precambrian time.

6. The time needed for the deposition of a bed of salt can be measured in days, months, and years rather than in geological time (Paul Weaver, address at the University of Michigan, 1949). In other words, while over two thousand feet of salt was being deposited in the Michigan basin during Salina time, only a few feet of non-evaporite sediment was being deposited elsewhere.

7. In most sedimentary basins, the water contained within the sediments below a few hundreds of feet is not only saline, but is from three to seven times more saline than ocean water. On the North American continent this supersalinity exists in the deeper ground waters throughout the eastern two-thirds of the continent; the higher elevations of much of the terrain in the western third has permitted the flushing of the originally deposited water by downward percolating rain water, or by artesian circulation.

8. Bedded salt deposits are very effectively protected from leaching by water passing by, except when they lie close to the surface where erosion has breached the protective material. Due to conditions at time of deposition, only fine sediment, such as shale, is normally in contact with evaporites. This rock is relatively impermeable to the passage of water. Many salt beds are underlain by, or are interbedded with, anhydrite, which is even more impermeable than shale. But in addition to the overlying or underlying shale or anhydrite beds that may protect salt from solution by percolating waters, salt bodies themselves may provide their own protection by developing sheaths of anhydrite due to selective solution of salt which concentrates the anhydrite, originally within the salt mass, in the peripheral zone. The best example of this are the salt domes (actually salt intrusives) in the Gulf Coast region of the United States. Here the salt mass, containing scattered through it from 5 to 10 per cent anhydrite, comes into contact with undersaturated ground waters as it pokes its way upward. These waters dissolve salt until saturated, largely by-passing the much less soluble anhydrite so that it accumulates in the border area, producing a cap across the top and a sheath on the flanks.

   Perhaps the best evidence of the insulation of salt bodies from percolating water is the fact that with the exception of an occasional pocket of concentrated brine, which is soon drained, salt mines are desert-dry, providing, of course, that higher acquifers are adequately sealed where passed through by shafts and boreholes.

   Under these circumstances it is most unlikely that the ubiquitous supersaline brines in the deeper aquifers derived their salinity by contact with salt masses, even though this is the usual explanation for supersalinity. Furthermore there are large areas (the Illinois basin for example) where there is no salt, but none the less the deeper waters are supersaline.

Hypotheses. Although the salt deposits upon the continents actually occupy many cubic miles of space, the relative volume compared with the salt dissolved in the ocean is insignificant. The amount of salt in the ocean has been estimated at 4 1/2 million cubic miles.

The first hypothesis, which is now supported by many geologists, is that the primary source of all rock salt is ocean water from which this salt precipitated in the geologic past. This subject is pursued further in the companion paper: "Effects of Solution of Bed Rock Salt in the Earth's Crust" (this volume).

The first hypothesis leads naturally to the second hypothesis which is that the oceans have always been just as saline as they are today (Rubey, 1951). The average dissolved solid content of sea water is 3 1/2 per cent by weight. An original fresh water ocean which has become saline through geologic time by run-off from the continents has existed only in the minds of men. There is absolutely no evidence, chemical, geologic, or biologic, to support this idea. The connate ("fossil" sea water) waters within the Cambrian sandstones may be just as saline as those deposited in Cretaceous or in Tertiary sands. The solids carried in solution into the oceans by the rivers today are just what one would expect from the leaching of emergent terranes containing all types of rock, including salt, plus the natural drainage of connate waters. Papers have been written determining the age of the ocean's salinity by dividing the total chlorine content by the annual increment from rivers. The writers apparently have been completely unaware of the fact that most of the chlorine ions in the rivers have come from ancient oceanic salt deposits and are merely returning home.

The third elementary hypothesis is that at many times in the geologic past the seas overrunning the submerged parts of the continents were shallow and supersaline with a dissolved mineral content greater than that of the open ocean. The greater salinity was due to the warming by the sun's rays of the shallow waters of the invading sea to considerably higher temperatures than those prevailing in the open ocean. This brought about greater evaporation so that there was a constant movement of water from the ocean across the submerged shelf to replace the water lost by evaporation. Other things being equal, the longer the fetch from the open ocean, the more saline the water on the shelf became, and the higher the salinity of the connate water trapped in the sediment deposited on the sea floor. Further concentration was possible by additional evaporation of the connate water itself at low tide, and from sea water that had seeped inland, as along the Persian Gulf shore today.

The Natural History of a Thick Bedded Salt Deposit. The stage must first be prepared by eroding a continent or a considerable part of a continent down to a base level which does not rise far above sea level. Geologists refer to this extensive low-lying erosion surface as a peneplain (almost a plain).

The next step is the submergence of at least a part of the peneplain beneath the ocean by either continental tilting or subsidence. The sea advances across the depressed surface (Figure 2) as it has done many times during geologic history. The submergence will result in a veneer of new sediment; the thickness of the deposits depends upon the supply of sediment available and the length of time the area remains inundated. However, if any part of this surface sags, due to crustal downwarping, a sedimentary basin may come into being which will permit the accumulation of a thick series of sediments through intermittent renewals of the downwarping. A part at least of the rim of the depressed area is under water and can be described as a sill separating the basin from the rest of the submerged peneplain and the open ocean. The sill may be a series of reefs (Alling and Briggs, 1961).

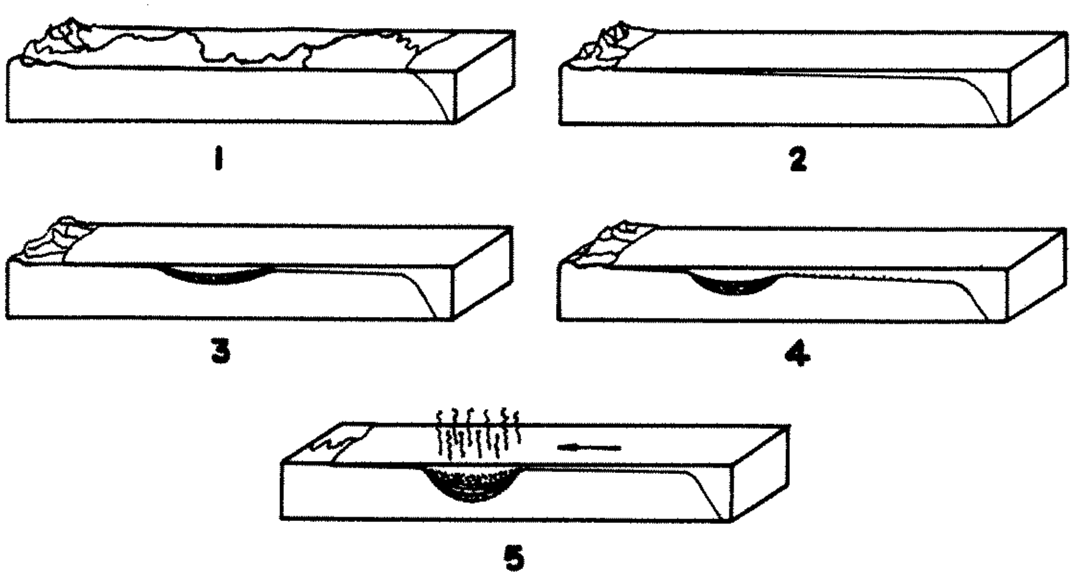


Figure 2. Panel showing evolution of salt deposit.
1. Peneplained continental margin.
2. Submergence.
3. Development of a sag. Limestone and fine clastic deposition.
4. Continued sagging and continued non-evaporite deposition.
5. Continued sagging, shallowing of sill depth, evaporite deposition.

The water depth of the top of the sill has a very important control on the sedimentation within the basin. If the sill top is at considerable depth, it will not impede the circulation of water into and out of the basin. However, if the depth is shallow, there cannot be complete mixing of the two waters on opposite sides of the sill. Therefore, if the climatic conditions are such as to encourage extensive evaporation where the waters are shallow and hence warmer than in the open ocean, the greater evaporation of the water on the basin side of the sill will result in a constant movement of water from the ocean across the submerged peneplain and into the basin. The denser sea water resulting from that evaporation sinks below the incoming fresher water, and it cannot flow out over the sill. It becomes trapped in the basin and the stage is set for an evaporite precipitation cycle. In most evaporite-containing basins, the sill depth was great enough during most of the natural history of the basin so that normal clastic and carbonate rock deposition took place, except when a lowering of the water level made the sill depth shallow. Even during a precipitation cycle there were interruptions brought about by minor fluctuations of sill depth, which either stopped entirely the inflow of new sea water through emergence of the sill or which permitted the temporary outward escape of the denser water due to deepening of the sill depth. Furthermore, precipitation was subject to interruption by rainfall on the watershed on the landward side of the basin which would bring in both fresh water and clastic sediment. There would also be mineral matter in solution brought in from the watershed; chemically unusual terranes would contribute unusual additives to the evaporating waters of the basin.

A frequent question is what actual water depths are involved, both above the sill and out in the evaporating basin itself. The answer has to be based more upon opinion than upon as yet known facts. It is my belief that during an evaporite producing cycle, the sill depths are rarely more than five feet (and perhaps then only at high tide), and the maximum basin floor depths are usually less than ten feet. However, during some stages of basin development it may be "starved," i.e., sagging may exceed infilling so that greater water depths are present temporarily.

It is the thesis here that where the basin sagging took place at a considerable distance inland from the continental margin, the long fetch of the ocean water across the shallow submerged continental shelf brought about, through evaporation while en route, a pre-concentration of the salt water which made possible the deposition of great thicknesses of sodium chloride on the basin floor in an extremely short span of geologic time. Furthermore, the supersaline water moving across the submerged shelf in many instances reached the saturation point for $CaSO_4$, so gypsum or anhydrite was deposited out beyond the periphery of the salt basin itself. This could explain (1) the greater horizontal extent of anhydrite compared with salt, and (2) the absence of anhydrite beneath many thick salt beds, as in the Michigan Basin for example. Calcite precipitation due to saturation in the inflowing water could also take place (Zen, 1961).

The evaporite precipitation phase within a basin was brought to a close when either the basin ceased its periodic downwarping and became filled to the brim or when diastrophism (movements of the earth's crust) destroyed the sill. The evaporite deposits, in order to be preserved to the present, had to be covered by younger non-evaporite sediment. During the submergence necessary to the deposition of most protective covers some of the salt at the top of the evaporite section without a doubt was re-dissolved. Therefore, the salt thickness which we see today is less than the original thickness deposited in most cases. This re-solution also caused the removal of any mother liquor salts that may have been present at the top of the section due to complete dessication. Incidentally, where these highly soluble salts are present today, such as the potash salts of north Germany, southeastern New Mexico, and northern Saskatchewan, it is unlikely that they were ever of such great thicknesses that they could withstand resubmergence beneath the sea. Probably the only way that the mother liquor salts could preserved was by being covered by very fine windblown sediment, which was sufficiently impervious so that very little water penetrated this protective cover when the next submergence did take place.

Conclusion. This theory differs from the classic Bischoff-Ochsenius theory in that the modern concept of a sinking basin (to make room for hundreds of feet of evaporite deposits) is applied, a prior enrichment of the sea water is postulated, and a submerged sill is substituted for a shoreline bar.

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See also Geol. Surv. Bull. No. 1025, p. 158.