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MAJOR ARIZONA SALT DEPOSITS

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INTRODUCTION

Although not commonly known, rocksalt, ordinary sodium chloride, is very much a part of Arizona. It has accumulated in some places to thicknesses greater than the Grand Canyon is deep! From a geologic point of view, some of the state's rocksalt deposits are believed to be unique in North America, if not the world. As a rock, salt functions as an important component of Arizona's geologic foundation. From a human perspective, rocksalt can be either an asset or a liability; in Arizona, it is both.

This article summarizes what we have come to learn about salt deposits in Arizona. It should be pointed out that our focus is on *large* deposits and not the smaller, exposed occurrences that were exploited by aborigines.

BACKGROUND

The word *salt* is used here to mean a rock made from the natural aggregation of the sodium chloride mineral, halite. Most natural waters contain some sodium chloride in solution. Not only does this chemical come in small amounts from the weathering of common rock materials, but also from oceans via atmospheric circulation and rainfall (rainwater is *not* pure). Wherever waters gather and evaporate, mineral salts form. Large salt deposits require, over time, the evaporation of huge volumes of water. Thus, thick salt deposits, whether formed in interior lakes or ocean waters, require repeated cycles of inflow and evaporation. Once formed, special conditions are essential to preserve these readily soluble salt deposits from subsequent dissolution. Natural dissolution of subsurface salt can have deleterious physical and/or chemical effects.

DISCOVERY AND RECOGNITION

All of Arizona's large salt deposits were initially encountered during the course of exploration drilling for other substances. The first discovery seems to have been in 1920 during petroleum exploration drilling near Holbrook in the Colorado Plateau Province of northern Arizona. Since this initial discovery, many additional drill holes in the Holbrook region have penetrated salt. As a consequence, this particular occurrence is now reasonably well-outlined and understood (Figure 1, no. 1).

In the Basin and Range Province of southern Arizona, major discoveries took place from 1957 to 1968. In these cases the number of penetrations by drilling are few; therefore, deposit details are lacking. These latter discoveries are recent enough to have escaped the publicity needed to make their existence a matter of common knowledge. Most likely, additional deposits exist within this province.

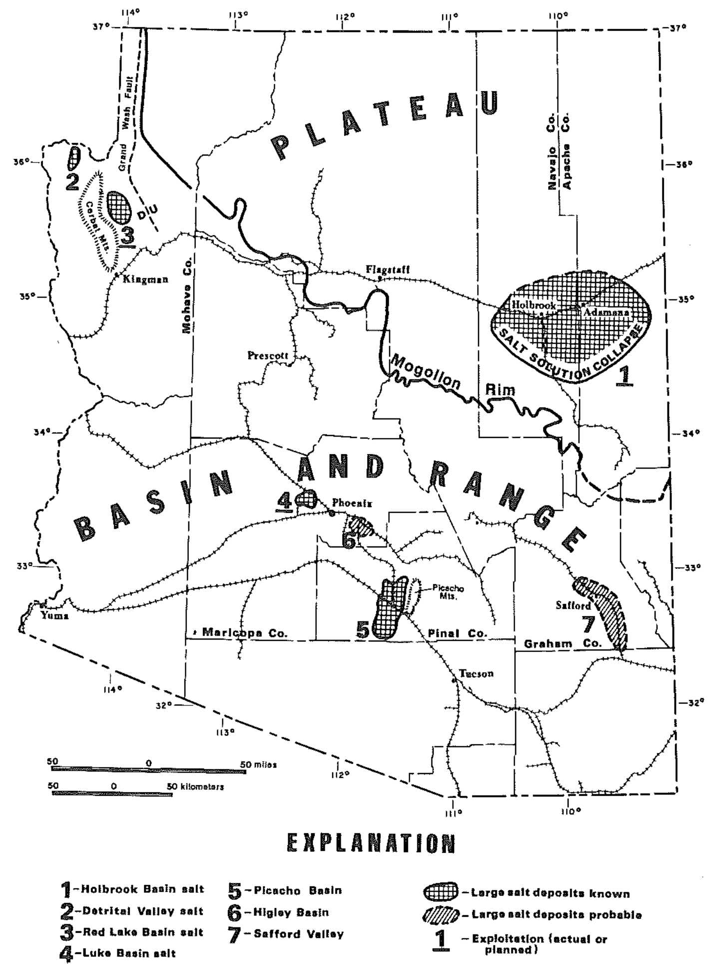

Figure 1. Index to Arizona Salt Deposits and Location of Railroads.

COLORADO PLATEAU DEPOSITS

The largest salt deposits of the Colorado Plateau Province occur near Holbrook. Salt, in beds or layers within the Supai Formation, occurs in the subsurface of southern Navajo and Apache Counties beneath a region approximating 2,300 square miles in size (Figures 1 and 2). The area of thickened Supai Formation, within which

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salt and other evaporites are associated, is frequently called the Holbrook Basin. The principal salt deposits, associated with other sedimentary rocks, occur as discontinuous units or zones within the stratigraphic interval between the Fort Apache Limestone Member of the Supai Formation below and the Coconino Sandstone above (Figure 2). Over the region, this stratigraphic interval ranges in thickness between 450 and 1,300 feet. The salt occurs within the thicker, or basinal, parts. Depths to the top of the evaporite interval, marked by an anhydrite-gypsum (calcium sulfate) zone, range from 600 to 2,500 feet, the deepest portions being in the northeastern part of the basin. Indications are that the principal concentration of salt occurs in a zone 400 feet thick within the upper half of the evaporite interval, along a northeast-trending belt that is about 55 miles in length (Peirce, 1969).

More than 150 drill holes have encountered either part or all of the Supai salt section (Peirce and Scurlock, 1972). Many of these were drilled in 1964–65 during an intensive effort to outline commercial deposits of associated potash in the form of sylvite (potassium chloride). The potash drilling outlined an area of about 300 square miles that is underlain by a potash zone that occurs at depths ranging from 700 to 2,000 feet and within the upper 150 feet of the evaporite section. Although only low-grade deposits were identified, changing economics and supply patterns could one day render these deposits of interest to the state and nation [sylvite is the principal source of potassium, an essential element in plant growth, and is extensively used in agricultural fertilizers]. A significant portion of the mineral rights are held by the State of Arizona.

A subsurface storage facility has been developed along the Santa Fe Railroad at Adamana (Figure 1). Liquid petroleum gas (LPG) products, propane and butane, produced at oil refineries, are held in eleven cavities that were created by dissolving salt. These cavities are developed between 900 and 1,200 feet beneath the surface, and, because of relative thinness of the salt beds, they are elongated horizontally. The company operates as a storage facility for other energy companies. Whereas propane is burned directly for heat, butane is added to winter gasoline supplies to assist in cold weather starting. Because of the seasonal usage, butane must be stored during the hotter season. Propane is stored, in part, for distribution to rural markets in northern Arizona. These products come from a combination of California, New Mexico and Texas refineries, by truck and rail. Of the eleven cavities, three are presently used for propane, and eight are used for butane. Future expansion of this facility is anticipated.

An interesting environmental impact of the Supai salt interval is sink hole development that results from salt solution and surface collapse. Sink holes on the Mogollon Slope have long been known. Depression contours are widespread on topographic maps of both southern Navajo and Apache Counties. Darton (1925) called attention to sinks in this region, and rather casually related them to a classic explanation—the solution of a shallowly buried limestone. Subsequently, the few geologists aware of these phenomena have agreed that the sinks are caused by the solution of salt in the subsurface. There is a feature west of Snowflake known as Dry Lake Valley, a basin of internal drainage. This valley covers an area of at least 120 square miles and almost certainly represents collapse above a major zone of salt dissolution (Bahr, 1962; Peirce and Wilt, 1970). The uppermost part of the salt-bearing Supai section appears to underlie the valley at a depth approximating 600–700 feet. It is suspected that the regionally extensive development of variably sized depressions with internal drainage is directly related to the solution of salt in the areas where salt probably occurs within 1,000 feet of the surface.

It seems likely that this process is continuing, although at an unknown rate. Bahr (1962, p. 18) makes this statement: "That solution is a continuing factor in the structural development of the area (Dry Lake) is evidenced by the appearance of several deep sinks on air photos flown in 1953, which are absent on photos flown only 17 years earlier."

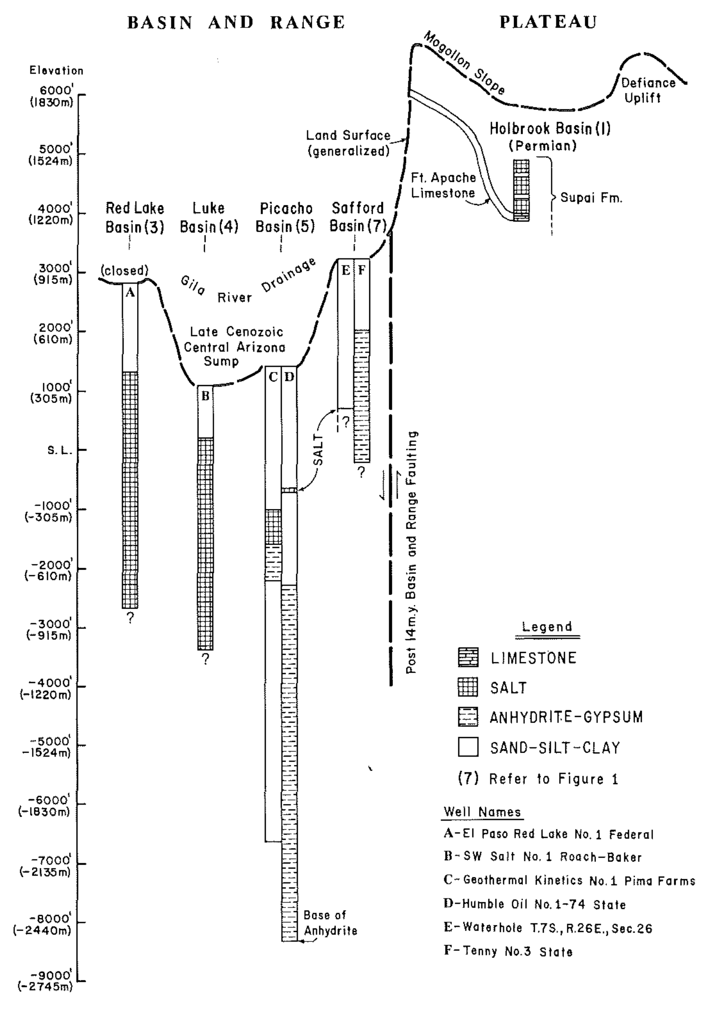

Figure 2. Geologic Setting of Arizona Salt Deposits in the Basin and Range and Colorado Plateau Provinces.

The southern edge of the Supai evaporites defines a belt that is at least 50 miles in length. The solution-collapse process has significant land use implications for the region and appears to warrant more attention than it has thus far been given.

A preliminary report (Mytton, 1973) evaluates the Supai salt as a possible target for the development of either a noxious waste or a radioactive waste disposal site. The evidence of salt solution was a significant factor in urging caution in future waste storage considerations. Another report (Johnson and Gonzales, 1978) includes the Supai salt in a nationwide survey of salt deposits potentially suitable for radioactive waste storage. They, too, urge a very close look at the salt dissolution question prior to any serious consideration of using this salt as a radioactive waste storage site.

BASIN AND RANGE DEPOSITS

Perhaps the most intriguing salt deposits are those that have been encountered in relatively recent times in the Basin and Range country. Although their existence is known, little detail about each is available. Because our scientific knowledge about these deposits remains so general, there is room for debate and legitimate differences in opinion concerning their age and manner of origin. All of the deposits occur beneath valley or basin floors, and were first encountered by drilling.

Detrital and Hualapai Valleys

In extreme northwestern Arizona there are two salt occurrences just south of Lake Mead in Mohave County (Figure 1). One is the

Detrital Valley deposit (Figure 1, no. 2) and the other is the Red Lake deposit beneath Hualapai Valley (Figure 1, no. 3).

A dozen or more exploration holes have been drilled in Detrital Valley over an area of several square miles south of Lake Mead (Peirce, 1969; 1974). Bedded salt occurs from 300 to 800 feet beneath the surface and attains a maximum thickness of about 715 feet above nonsalt rocks. It is believed that the salt and associated gypsum-anhydrite-clastics belong to the Miocene Muddy Creek Formation. This formation crops out around Lake Mead and, in Arizona, includes outcropping evaporite in the form of gypsum. Outcrop elevations of gypsum are consistent with evaporite tops in Detrital Valley drill holes.

Whereas the Detrital Valley salt is less than 1,000 feet thick, the Red Lake deposit is at least 4,000 feet thick and could be as thick as 10,000 feet [for comparison, the Grand Canyon is generally less than 6,000 feet deep]. Only three exploration holes provide direct data about this salt. Both geologic and geophysical information combine to assist in formulating a generalized concept of what this salt body represents. Considering that the volume of salt likely exceeds 100 cubic miles, there is interest in seeking an explanation for it. This author's views have been expressed elsewhere (Peirce, 1972; 1976) and will only be summarized here.

Hualapai Valley contains Red Lake Playa, one of two remaining, sizable basins of internal drainage in Arizona (Willcox Playa is the other). Geophysical data demonstrate rather clearly that the Red Lake basin is closed on all sides with a buried bedrock sill at its northern end. The deposit may be on the order of 12 miles long (parallel to the length of the valley), five miles wide and two miles thick. The elevations of the evaporite and/or salt tops are similar to those in Detrital Valley and in outcrop on the south side of Lake Mead. The indicated conformance of the deposit and associated strata to the overall basin shape, and suspected affinity with the nonmarine Muddy Creek Formation, strongly suggest a genesis related to the origin of the basin itself. The buried sill of bedrock at the north end combines with all else to suggest that the Red Lake Basin has all of the earmarks necessary to have been a classic basin of salt accumulation.

One boundary of this basin is the margin of the Colorado Plateau Province—the other is the Cerbat Mountain range block (Figure 1). This disruption of geologic continuity is a manifestation of the Basin and Range disturbance (faulting) that took place subsequent to about 13 million years ago (Stanley and Eberly, 1978; Scarborough and Peirce, 1978) in late Miocene time. Salt deposition was accommodated by an actively subsiding basin. The model suggests that the salt is thick, nonmarine and late Cenozoic in age, and represents an Arizona salt deposit type that is unique in the United States, and perhaps even the continent. Other large North American salt deposits are older and most are marine in origin (Johnson and Gonzales, 1978).

The Red Lake deposit is buried by at least 1,500 feet of other sedimentary materials. There is no suggestion that either salt movement or salt solution have affected the ground surface.

Major transportation arteries pass by the southern end of Hualapai Valley. These include a railroad, a major interstate highway and a gas line. There are no such deposits recognized in either California or Nevada. Because of these factors, Southwest Gas Co. is planning to construct a natural gas storage facility in this salt (Peirce, 1981). Cheap storage in man-made solution cavities will enable the company to respond more effectively to winter-time peaking demands in Las Vegas and vicinity. The deposit is large and could eventually be utilized by other interests. Both federal and state lands are involved.

Salt River Valley

In 1970 the Southwest Salt Company drilled 3,600 feet of salt in Maricopa County west of Glendale and just east of Luke Air Force Base (Figure 1, no. 4). This area has come to be referred to as the Luke Salt, and the envisioned basin in which the salt accumulated, as the Luke Basin. Only a few holes penetrate into salt; however, not one penetrates the entire thickness of the deposit. As with the Red Lake occurrence, there is little direct data about the overall salt deposit. Again, geophysical information, especially gravity studies (Peterson, 1968) suggest that the salt, with minor clastic interbeds, could be as thick as 10,000 feet. The top of the deposit is 880 feet beneath the ground surface where Southwest Salt first drilled (Figure 2, Well B). Although details are lacking, it is estimated that this deposit could contain on the order of 30 cubic miles of halite. It is smaller than Red Lake in areal extent, but otherwise appears analogous in many ways.

Ideas about the origin and history of this salt deposit vary. Eaton and others (1972) suggest that the Luke Salt could represent a diapiric intrusion (i.e., an oozing, vertical flow of a plastic substance, such as salt), and could thus be a salt dome similar to occurrences along the U.S. Gulf Coast. However, they also concede that it could be an "*in situ* evaporite facies of the valley-fill section," in which the uppermost part has been somewhat plastically deformed or domed. Peirce (1974) suggests that there is evidence for at least 600 feet of upward salt movement. However, he subscribes to the idea that the salt was originally deposited in a local structural basin in late Cenozoic time (Peirce, 1976).

The Luke Salt is being utilized in two basic ways: 1) production of solar salt in evaporation ponds, and 2) the storage of propane and butane in man-made solution cavities. The storage facility presently consists of three cavities, each shaped like an inverted carrot, and each capable of holding 30 million gallons of LPG. The length of each cavity is 1,000 feet, oriented vertically; the maximum width is about 70 feet. The facility is served by a nearby railroad spur where facilities allow loading and unloading through a system of pipes. Brine is used to maintain appropriate pressures and to protect cavity walls [hydrocarbon products do not react with salt].

Earth cracks occurring near the surface evaporating facility pre-exist its establishment. The region is farmed and the cracks are believed to be related to groundwater withdrawal and subsequent surface subsidence. The salt deposit represents a subsurface discontinuity around which dewatered sediments tend to differentally compact and crack. Here the salt acts just like bedrock does in the subsiding Picacho region (Laney and others, 1978; Peirce, 1979).

Rights to produce and utilize this salt are obtained by the acquisition of a sodium lease from the federal government.

Picacho Basin

In 1973 Humble Oil and Refining Co. drilled a deep test hole near Picacho (Figure 1, no. 5; Figure 2, Well D). The geologic highlights of this test were presented by Peirce (1974). Of particular interest is the presence of a vertical interval of 6,000 feet that consists largely of anhydrite ($CaSO_4$), another type of evaporite. Some salt (less than 100 feet) was drilled at a depth of about 2,100–2,200 feet. A volcanic rock unit that is isotopically dated at 15 million years lies 700 feet beneath the evaporite sequence (Shafiqullah and others, 1976). Thus, this basin-filling sequence is considered to be late Cenozoic in age—a product related to the Basin and Range disturbance, a faulting event that framed many of southern Arizona's ranges and valleys. The basinal feature is referred to as the Picacho Basin. Although there are few definitive drill holes, geophysical data suggest basin shape and dimensions. It is about 30 miles in length, nine miles in width, and trends just east of north, parallel to the west side of the Picacho Mountains (Figure 1).

About five or six miles northwest of the Humble hole, Geothermal Kinetics, Inc., in 1974, drilled an 8,000 foot test in the Picacho Basin (Figure 2, Well C). Drilling records suggest that, although the overall evaporite section is much thinner, the section of salt is thicker. Whereas the overall evaporite section is on the order of 1,500 feet thick, the upper 600–700 feet is believed to be salt. Considering the indicated size of the Picacho Basin, these brief clues suggest that the potential for the occurrence of an abundance of salt is high.

Many transportation arteries cross the southern end of the Picacho Basin. Should low-cost subsurface storage in salt become of interest between Phoenix and Tucson, the Picacho Basin is a likely region to explore.

The Picacho country is a major agricultural region that utilizes large volumes of groundwater. It is germane to speculate on the extent to which the near-surface fresh water zone is limited downward by saline materials, a question that can be asked about much of southern Arizona's groundwater-dependent region.

Other Occurrences and Potential

Geophysical studies and some drilling data indicate that deep basins underlie many of the valleys of southern Arizona (Oppenheimer and Sumner, 1980). This is to say that the valleys are underlain by thick-to-thicker sequences of relatively low-density sedimentary rocks that overlie more dense rocks. As has been shown, these sedimentary materials, in places, include evaporite materials such as salt. Many of the basin-filling sequences remain largely untested, and, therefore, there is potential for additional salt and related rocks.

In 1973 a 9,000 foot geothermal test was drilled in Maricopa County, about eight miles east of Chandler. The sedimentary section at the site is about 7,000 feet thick and includes evaporite strata over an interval of 1,500 feet. Anhydrite is the principal evaporite, but some salt could be present and have remained undetected because of solution of drill cuttings prior to sample recovery. Geophysical studies suggest that the sedimentary section significantly thickens west of the drillsite, indicating a center of deposition in that direction. Significant salt could be present nearer the depocenter four to five miles east of Chandler. The top of the anticipated evaporites could be nearly 2,300 feet beneath the surface. This inferred depositional center is called the Higley Basin (Figure 1, no. 6).

The San Simon Valley of Graham County is one of southeastern Arizona's very long valleys and the Gila River occupies a portion of it. Unfortunately, despite its size, there is no deep drilling within the valley. Geophysical data suggest that it has zones within it that contain basin-fill sediments that are several thousands of feet thick, perhaps as much as 10,000 feet.

In 1971 a relatively shallow hole was drilled to a depth of 3,500 feet, about 20 miles south of Safford. Incomplete records suggest that the hole penetrated gypsum and/or anhydrite in the interval 1,200–3,500 feet (a thickness of 2,300 feet). The hole terminated in the evaporite. Therefore, there is no present way of knowing the true extent and nature of the complete evaporite sequence. About four miles west of Safford a hole, drilled in search of water, returned core samples that contain discrete halite (salt) in mudstone from a depth of about 2,300 feet (Figure 2, Well E). These clues suggest that the depths of San Simon Valley could contain significant quantities of salt and related substances.

GENERAL CONCLUSIONS

Though not widely recognized, Arizona's geologic framework contains large, subsurface deposits of rocksalt. Some of these deposits appear to be unique in North America, and, no doubt, others remain to be discovered. The fact of their existence is potentially both a regional asset and a local liability. They can be constructively utilized as a source of salt products, as well as a medium for cheap, convenient storage of certain nonreactive materials. However, their solubility in fresh water can lead to potentially destructive effects, as evidenced in the Mogollon Slope collapse belt.

It is significant to note that, in several areas, rocksalt underlies the freshwater aquifer systems of Arizona valleys or basins. The extent to which rocksalt constitutes a limiting factor in the development of future potable groundwater reserves remains to be evaluated.

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Wes Peirce has been with the Bureau of Geology twenty-five years. During that time, he has witnessed the emergence of an environmental-ecological awareness and an increased public demand for knowledge about the earth. He has also seen the increase and expansion of federal-support programs, resulting in grant monies for supplementary staff and for on-going geologic projects.

Peirce's general areas of interest and familiarity involve the geologic history of Arizona, the impact of Arizona geology on land use, and the ecological significance of things geologic. Because of the public demand for geologically related services, in conjunction with a small operating staff, Wes advocates the necessity of a multi-disciplinary, versatile, generalist approach to things geologic.

Wes received his Ph.D. in geology from the University of Arizona in 1962, his M.S. in 1952 from Indiana University, and, a B.S. from the University of Montana (1949).

The following are some of the diverse publications prepared by Wes Peirce.

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