Thick Evaporites in the Basin and Range Province—Arizona

H. Wesley Peirce
Arizona Bureau of Mines
University of Arizona
Tucson

ABSTRACT

There are three known thick (over 1000 meters) evaporite sequences in the Basin and Range province of Arizona: (1) the Red Lake salt in the Red Lake paleo basin in Hualpai Valley, Mohave County, (2) the Luke Salt in the Luke paleo basin in western Salt River Valley, Maricopa County, and (3) the Picacho anhydrite in the Picacho paleo basin, Pinal County.

Limited drilling and geophysical data suggest that the two salt occurrences are analogous in mineralogy, texture, purity, dimensional proportions (length and width greater than height). All three deposits are analogous as regards regional stratigraphic and structural setting.

There are valid geologic constraints common to each of these deposits that narrow the bounds of applicable geologic history, yet leave room for imagination regarding genesis. State-wide stratigraphic and structural considerations nudge these deposits into a post mid-Miocene time frame.

The development of basins and ranges that are reflected in the present topography largely occurred in Late Tertiary time and was imposed upon a complex mid-Tertiary history of volcanism, sedimentation, and tectonism. Although the extent of development and preservation of possible mid-Tertiary evaporites is unknown, it seems likely that the thick evaporites are a response to a late Tertiary Basin and Range history marked by a complex system of partially interconnected, rapidly subsiding, basins.

The expression "Gila Low" is introduced to describe a 7770 square kilometer (3000 square mile) area in south central Arizona that presently drains a watershed of about 95,830 square kilometers (37,000 square miles). It is of paleogeographic significance in that the Luke salt and Picacho anhydrite are contained within the larger Gila Low system of interconnected basins.

INTRODUCTION

It is the purpose of this paper to discuss the general geologic setting that appears to pertain to the thick evaporites that have been discovered in the Basin and Range province of Arizona. Currently, there are three principal known deposits: (1) the Red Lake salt in the Red Lake basin of northwest Arizona, (2) the Luke salt in the Luke basin of south central Arizona, and (3) the Picacho anhydrite in the Picacho basin also in south central Arizona. The latter two deposits occupy basins that occur within a larger region here termed the "Gila Low" (Fig. 1).

There is little formal literature that discusses these specific features largely because of the paucity of developed data. Evaporite areas satellite to the Red Lake salt have been discussed (Longwell, 1928, 1935; Mannion, 1961) and there is a USGS professional paper on the Luke salt (Eaton and others, 1972). The Picacho anhydrite is a new discovery and has not been previously reported in the literature. Certain ideas have been expressed in informal outlets with limited circulation (Eaton and others, 1970, 1971; Koester, 1971; Peirce, 1972a; 1972b). The discussion has tended to revolve around ages and the origin of the two thick halites—whether they are intrusive from an elusive source or depositional and largely in place. The genesis of these evaporites has much to do with interpreting the range of possibilities of the occurrence of associated materials that might be of interest to various explorationists.

The thesis presented here is that a review of the general geologic setting suggests that these three thick evaporite deposits have much in common and that they originated in response to environments and conditions attendant to the late Tertiary Basin and Range orogeny.

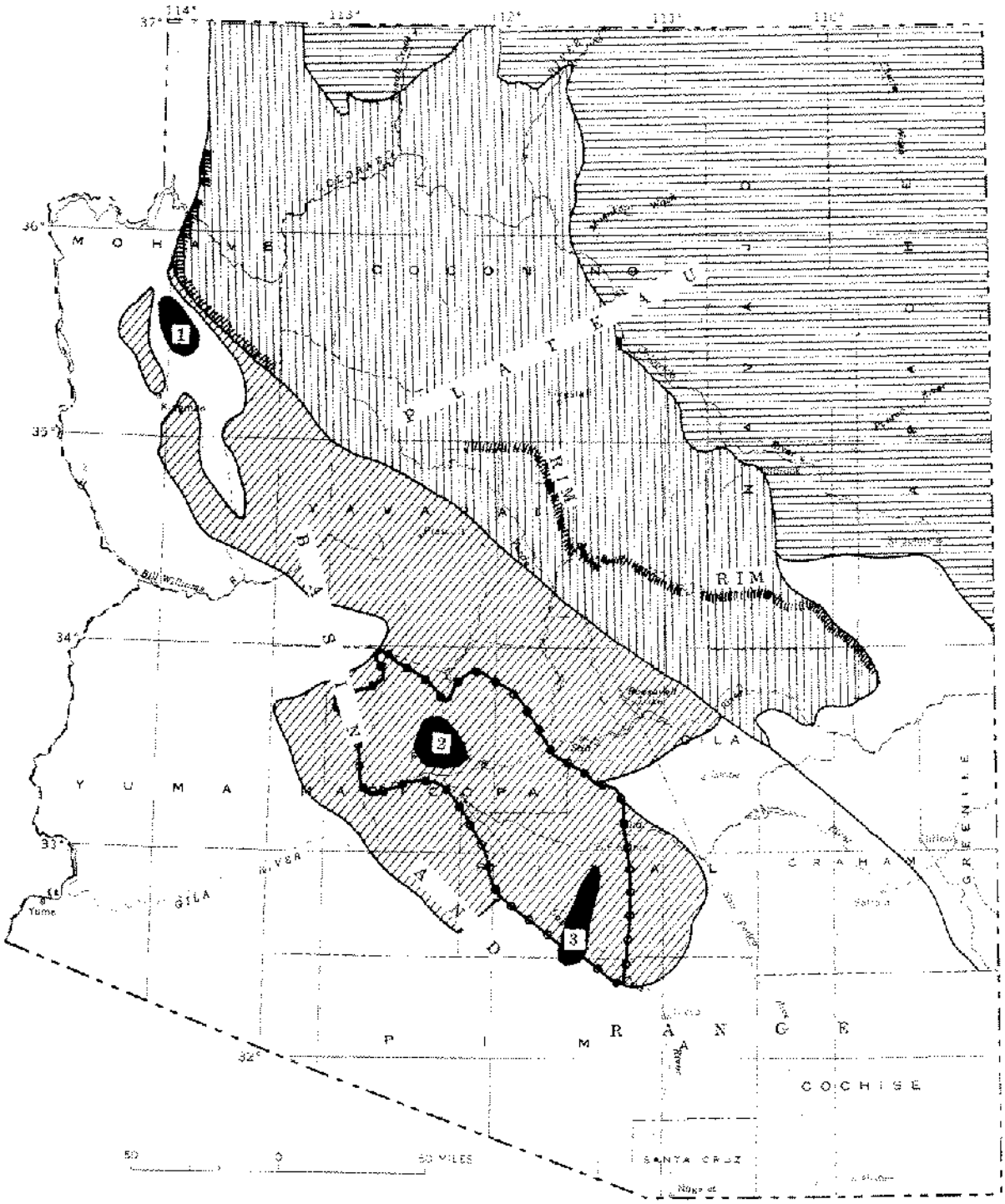

Figure 1. Stratigraphic setting of Arizona Basin and Range thick evaporite deposits.

HALITE DISCOVERY

Some halite is known to occur in at least six Arizona Basin and Range valleys. However, the first indications of possible thick halite occurrences within the alluviated valleys of Arizona's Basin and Range province resulted from the drilling of water wells utilized for cattle and agriculture. In 1958 the Kerr-McGee Corporation drilled two evaporite exploration holes near the Red Lake playa in Hualpai Valley, 45 Kilometers (28 miles) north of Kingman, Arizona, in Mohave County (Fig. 2). The Red Lake No. 1 evaporite test, located in the SE. ¼, SE.¼, SE.¼, Sec. 30, T.26 N., R. 16 W., cored 363 meters (1190 feet of coarsely crystalline halite. The Red Lake No. 2, drilled in the NE.¼, NE.¼, Sec. 28, T.26 N., R.16 W., cored 194 meters (635 feet) of similar halite. The salt top was about 457 meters (1500 feet) below the valley surface at an elevation of 396 meters (1300 feet) above sea level (Figs. 3, 4). Both holes bottomed in salt.

In July of 1970 El Paso Natural Gas Company drilled their Red Lake No. 1 in the SW.¼, SW.¼, Sec. 22, T.26 N., R.16 W. This test cut just over 1219 meters (4000 feet) of apparently similar halite but did not fully penetrate the halite section. Here the salt top is about 549 meters (1800 feet) below the surface at an elevation of near 305 meters (1000 feet.)

About 274 kilometers (170 miles) to the southeast, near Luke Air Force Base in the Luke basin (Fig. 1), Maricopa County, the Southwest Salt Company No. 1 evaporite test, located in the NW.¼, SW.¼, Sec. 2, T.2 N., R.1 W., cut about 1097 meters (3600 feet) of halite before terminating in salt. The top of the salt is at an elevation of 62.5 meters (205 feet) and is 268 meters (880 feet) below the surface. A few other holes have topped the salt and only a few feet of core has been taken.

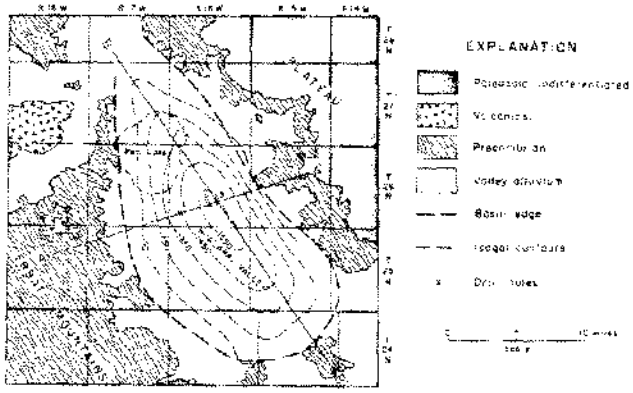

Figure 2. General geologic map with gravity contours, Red Lake-Hualpai Valley area, Mohave County.

In addition to the limited data derived from the drilling record cited above, some gravity work has been done by the USGS (Peterson, 1968) and El Paso Natural Gas Company in these two salt areas. Also, important data can be derived from the application of certain aspects of the regional geologic setting; aspects common to each of these deposits that narrow the bounds of applicable geologic history, yet leave room for imagination as to genesis.

The discovery of a thick sequence of anhydrite in the Picacho basin, and its geologic relationships, is thought to contribute fundamentally to concepts applicable to the thick halite occurrences.

REGIONAL GEOLOGIC SETTING

Arizona is divided into two major geologic provinces: (1) the Plateau province to the northeast, and (2) the Basin and Range province to the southwest. The SW edge of the Plateau is, in places, a well defined escarpment (Mogollon

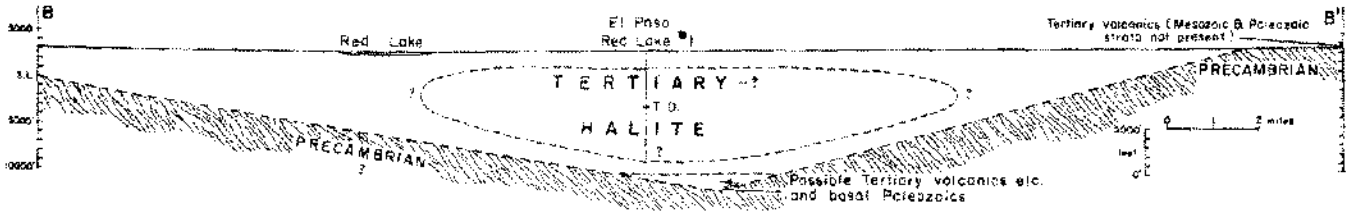

Figure 3. Longitudinal generalized geologic section B-B' along Hualpai Valley.

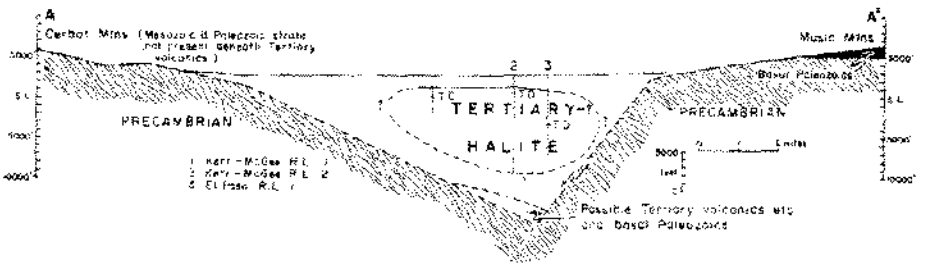

Figure 4. Generalized geologic cross-section A-A' across Hualpai Valley.

Rim) that, in the central part of the State, is a recessional fault scarp (Tonto Rim) (Fig. 1). In passing it might be of interest to note that a complete study of possible salt sources for these large masses, especially Luke, requires treatment of the structural and erosional history of this southwest edge of the Plateau.

The Plateau largely is a sedimentary rock province. The strata were tilted slightly to the northeast in pre-upper Cretaceous time so that the southwest edge is structurally high and more deeply eroded such that Mesozoic strata are now confined largely to the northeast. Paleozoic strata crop out in an irregular belt between the Mesozoics and the southwest edge of the Plateau. Still further southwest Precambrian rocks are exposed in a wide belt that parallels the present Plateau edge (Fig. 1). From available evidence it is clear that Paleozoic and Mesozoic strata, if deposited, were stripped from this region by two episodes of erosion: (1) pre-Upper Cretaceous as indicated by remnants of Upper Cretaceous strata resting on older strata southward (Jurassic to Permian), and (2) pre-Middle Tertiary because the Precambrian rocks are characteristically overlain by rock units largely no older than middle Tertiary. Middle Tertiary gravels that cap Paleozoic as well as remnants of Cretaceous strata at the Plateau edge, contain clasts of Precambrian rock types. These data, combined with oft cited evidence of northeast drainage direction (Peirce, 1967, plate 13), suffice to demonstrate the total stripping of Paleozoic-Mesozoic strata over a widespread area adjacent to and southwest of the present Plateau edge.

The significance of these observations is that the three thick evaporite masses are in valleys or basins that not only occur in this stripped region but which formed after the stripping history. These deposits, therefore, are considered to be no older and likely younger than Middle Tertiary (Oligocene-pre-Mid Miocene) in age. If, as suspected, they are a part of the geologic history associated with the Basin and Range orogeny, they are late Tertiary phenomena (Mid Miocene-Pliocene).

Surface exposures of sedimentary rocks indigenous to Arizona in late Tertiary basins have long been known to include low energy continental types such as fine-grained clastics, diatomites, limestones, marls, and gypsum which often grade rapidly into basin margin coarse clastics including fanglomerates. The implications of lacustrine conditions are widespread. Given this setting halite occurrences should be expected. However, the large volume thick deposits were not anticipated.

EVAPORITE DEPOSITS

General statement

Literature pertaining to the Red Lake and Luke salt deposits is scant. The Red Lake area, however, is not far from previously known salt occurrences in the Lake Mead region of northwest Arizona and southeast Nevada.

Northwest Arizona

Halite crops out in the Virgin Valley of Nevada and has been drilled in Detrital Valley in Arizona (Fig. 5). Near the mouth of Detrital Wash along Lake Mead about 58 Kilometers (36 miles) northwest of Red Lake, there is an area of gypsum outcrop designated "Big Gypsum Ledges" on topographic maps. The elevation of Lake Mead is near 366 meters (1200 feet) and the ledges occur between 390–439 meters (1280–1440 feet). Sixteen kilometers or so to the southwest drilling in Detrital Valley sections 12, 13, 14, T.30 N., R.21 W., encountered a calcium sulfate-clastic section about 213 meters (700 feet) thick that overlies plutonic igneous rock. Evaporite tops in the three holes lie between the elevation range 396–488 meters (1300–1600 feet) which suggests that these are likely continuous with the exposed gypsum. Still further south, eleven exploration holes were drilled in T.29 N., R.21 W. (Fig. 5). Eight of these cut halite up to 218 meters (715 feet) thick. One cut sulfate, clastics, halite, sulfate-clastics, and bottomed in conglomerate. Evaporite top elevations range between 360 and 457 meters (1180 and 1500 feet) with salt tops being between 338–414 meters (1109–1357 feet). It seems likely that all of these occurrences are laterally

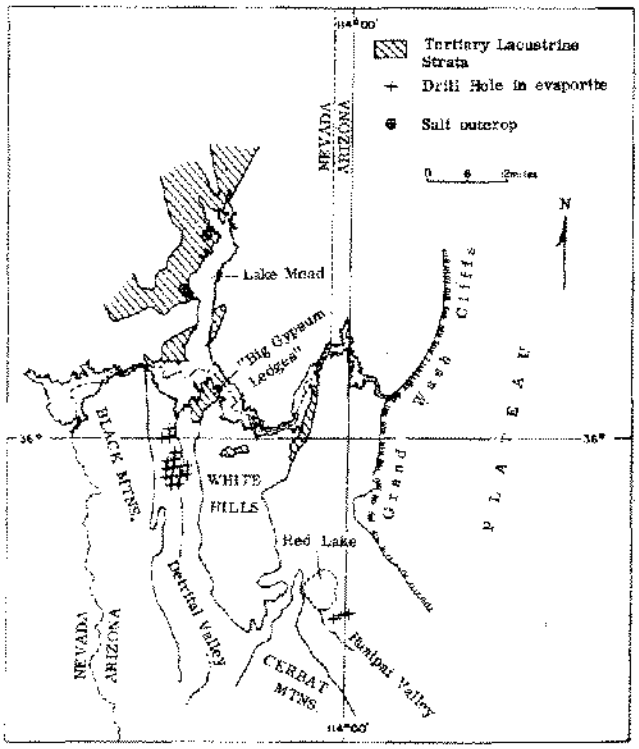

Figure 5. Evaporite localities in northwest Arizona-southeast Nevada-Lake Mead area.

related and that facies changes occur. Mannion (1961, p. 169) states that:

> "Within the trough of the Virgin and Detrital Valleys the distance between the northernmost and southernmost known salt is 40 miles, and thicknesses of many hundreds of feet have been drilled. It is not at all certain, however, that these represent a continuous deposit of salt; rather there are probably several bodies which were deposited separately in lakes which were intermittently connected."

According to Longwell (1936, p. 1419), salt occurs in the lower part of the Muddy Creek Formation of Pliocene(?) age. This formation consists of non-marine lake, playa, and fluviatile strata, with volcanics and landslide debris. According to Longwell and others (1965, p. 48):

> "Gypsum is abundant in the Muddy Creek Formation; some beds are thick and extensive. Prior to the creation of Lake Mead, large beds and plugs of rock salt, included in the Muddy Creek Formation, were exposed in several parts of Virgin Valley. Clearly the formation represents deposition in interior basins, before the Colorado River was in its present location as a through-flowing stream."

Thus, downcutting associated with the Colorado-Virgin river drainage system exposes evaporites in Nevada and along portions of the south edge of Lake Mead in Arizona. However, evaporites in northwest Arizona largely remain buried because of the absence of sufficient erosion to expose them.

Pierce and Rich (1962, p. 65) comment that:

> ". . . the salt has domed and pierced the Muddy Creek strata in some places and may be older than that formation."

Similarly, Eaton and others (1972, p. 26) suggest that:

> "The halite associated with the Muddy Creek Formation may have originated in older rocks and achieved its position within the formation by diapirism and doming. If so, then it, too, could be of middle Tertiary or older age."

Comments such as these are casual in that they do not explore the implications so as to assist in judging the credibility of the possibility suggested, namely that the deposits may contain halite significantly older than the Muddy Creek Formation. The weight of evidence contained in the regional structural, stratigraphic, and climatic histories, join to reinforce the idea of salt deposition in interior basins at the time of Basin and Range breakup in late Tertiary time. It follows, then, that salt flowage phenomena might well represent Muddy Creek salt adjustments within Muddy Creek strata.

Red Lake. Hualpai Valley, which contains the buried Red Lake salt mass or deposit, beneath its floor, is geologically unique. Its northeast margin is the edge of the Colorado Plateau while its southwest margin is the northeast flank of the first range in the Basin and Range province—the Cerbat Mountains (Fig. 2). Hualpai Valley, as a receptacle for sediment accumulation in the past (the Red Lake basin), has all of the earmarks of an elongate closed basin. Surface bedrock pattern suggests this and geophysical data (Randolph, 1971) appear to confirm it (Fig. 2). Although on spatial grounds alone it is tempting to consider the salt as related to the Cenozoic evaporites that crop out in the Lake Mead region and beneath the surface of Detrital Valley, there are independent observations that suggest that the salt is to be explained, as regards accumulation and positioning, not only as Cenozoic but as a Late Tertiary phenomena.

Koester (1971, p. 9) suggests that Hualpai Valley is a graben between two "upthrust" masses, the Cerbat Mountains and the Colorado Plateau, and that the "structural relations of the salt with Tertiary or pre-Tertiary beds are unknown." Furthermore, he considers the Red Lake mass to be a salt dome and that "Radiometric dating and palynological studies of the cores establish the age of the upper part of the salt series at Red Lake as Triassic-Jurassic."

Hualpai Valley likely is not a simple graben. Remnants of probable Middle Tertiary volcanics unconformably overlie Precambrian gneisses in the Cerbat range adjacent to Hualpai Valley. Northeast dips of about 20 degrees on the volcanics suggest that the Cerbats were rotated towards the northeast. Projection of this dip to meet the assumed fault that is the structural edge of the Plateau suggests a basin depth of the magnitude of about 4573 meters (15,000 feet) (Fig. 4). Longwell (1936) postulated a stratigraphic throw of 4878 meters (16,000 feet) for the Grand Wash fault which bounds the Plateau further north.

Having been regionally stripped prior to basin formation, the Mesozoic section and most of the Paleozoic section are not expected to be preserved within the basin. The "Triassic-Jurassic" dates of Koester were acquired by El Paso Natural Gas Company. The radiometric date is on insolubles in halite (written communication, Spitler, 1972) which dates source rock ages and not halite, and the pollen date likely represents transported material. The material containing the pollen, which is above the salt, occurs within a sequence of Cenozoic-like strata.

Geophysical studies by the USGS (Gillespie, J. B., and Bentley, C. B., 1971) and by El Paso Natural Gas Company (Randolph, 1971) suggest a closed basin with a bedrock sill or shelf at the north end (Fig. 3). The deposit may be on the order of 19 kilometers (12 miles) long paralleling the length of Hualpai Valley, 8 kilometers (5 miles) wide perpendicular to the sides of the valley, and as much as 3.2 kilometers (2 miles) thick (oral communication, Davis, 1972), 1220 meters (4000 feet) of which has been drilled. If these data represent good approximations, the salt mass in gross aspect is tabular in shape. The long and intermediate axes occupy a horizontal plane oriented along and across the valley, respectively. The shortest dimension is the vertical axis or thickness factor.

Core descriptions emphasize that the salt is commonly

coarsely crystalline (over 1½ inches on a side), with 5 percent or more black to brown impurities ("shale," silt, clay), lacks thick interbeds, and contains a paucity of other recognized evaporite minerals although some glauberite has been identified in Detrital Valley samples.

Evaporite top elevations in the three holes drilled into the Red Lake deposit range from about 364 to 457 meters (1194 to 1500 feet) on anhydrite and 312 to 421 meters (1024 to 1382 feet) on halite. It is interesting to note that these elevation ranges closely match those on the Detrital Valley subsurface evaporites over 56 kilometers (35 miles) to the northwest in an apparently distinct and separate basin (Fig. 5). Too, the evaporite tops in both basins are within the elevation range of the outcropping gypsum ledges exposed along the south edge of Lake Mead. These relationships are not believed to be fortuitous. All of these occurrences would seem to be related and should properly be included within the same stratigraphy. The Muddy Creek Formation still seems to be the applicable nomenclature with which to embrace these evaporites—thick or thin. Longwell (1963, p. E10) comments:

> "Although the several areas of outcrop south of the lake may represent separate basins, possibly all these coalesced as the sections built upward and spread laterally. As the formation east of the Black Mountains includes evaporites, chiefly halite and gypsum, hundreds of feet thick, and at a maximum the total section measures thousands of feet. . . ."

Does a thickness of halite known to be at least 1220 meters (4000 feet), and possibly twice this, demand thickening by flowage? There is no deformation of the surface of Hualpai Valley. Its absence cannot be explained by erosion because the valley is still one of interior drainage. Regionally, there is general accordance of elevation on evaporite tops. The salt itself, though generally described as recrystallized, does not appear to be of much help in establishing flowage magnitudes, if any. On the other hand, there seems to be good circumstantial evidence to suggest that the Red Lake salt was deposited in a continental setting in late Tertiary time largely where it now is.

Gila Low

The expression "Gila Low" is tentatively introduced here as a geologically distinct and important region of south central Arizona that merits recognition (Fig. 1). The region is irregularly elliptical in shape, the long axis being over 160 kilometers (100 miles) in length aligned in a northwest direction parallel to the central mountain region and the southwest edge of the present plateau. Maximum width is about 56 kilometers (35 miles). That the region is today low is emphasized by the fact that drainage from over 95,830 square kilometers (37,000 square miles) of watershed, the Gila System in southeast Arizona and western New Mexico, passes through the low via the Gila, Santa Cruz, Salt, and Verde rivers. These and others join in or near the low to become the Gila River. That the region was low in the past is emphasized by the deep, evaporite filled basins that are coming to light. It is characterized by a complex of paleo closed basins of varying depths and contents, buried saddles (spill points), and buried pediments (habitat of copper deposits). As a physiographic Basin and Range subprovince it has a small areal percentage of short, low elevation granitic ranges surrounded by a large areal percentage of alluviated valleys. These factors combine to make the low a current center of Arizona agriculture much of which lies between Phoenix and Tucson. Groundwater supplies in this region are essential to Arizona therefore their management should include (1) recognition of underlying saliferous materials, and (2) the implications of encroaching urbanization in relation to the quality of future water supplies.

Within the Gila Low are two of the State's known major evaporite basins: (1) the Luke salt basin, and (2) the Picacho anhydrite basin.

Luke Basin. The Luke Basin is a paleo feature that underlies the western Salt River Valley. The Luke salt deposit has been discussed by Eaton and others (1972). For details and a discussion of the numerous geologic parameters, the interested reader is referred to this paper.

The upper 1098 meters (3600 feet) of the salt sequence has been drilled and, based upon an admittedly subjective interpretation, these authors suggest that the total thickness could approach twice this amount whereas the bottom of the paleo basin is projected to 3049–4573 meters (10,000–15,000 feet). Surface elevations being near 305 meters (1000 feet), the salt mass and basin extend considerably below sea level. Eaton and others (1972, p. 22) conclude:

> "The origin of the Luke halite is problematic. Neither its age nor its specific mode of accumulation is known and—the interpretation of ultimate origin is closely tied to the problem of age."

Also:

> "Inferences based on regional geologic observations provide some loose guidelines as to age, but they hardly serve as sharply limiting constraints."

Elsewhere, these workers say:

> "Possibly, Mesozoic and older sedimentary rocks containing evaporites once blanketed the region and were stripped erosionally from the uplifted ranges, but they lie buried in place beneath the floor of the western Salt River Valley."

In that the Luke area is analogous to that surrounding Hualpai Valley in northwest Arizona, the regional geologic setting would seem to be more constraining than is recognized by these authors. The zone of the Gila Low is characterized by a stratigraphic setting in which middle Tertiary volcanics or coarse textured sedimentary rocks rest unconformably on Precambrian crystallines (Fig. 1). Paleozoic and Mesozoic strata likely were not present in central Arizona at the onset of late Tertiary basin formation. On this basis it seems questionable that rocks of this

vintage could constitute a possible "mother" salt for the diapirism these authors prefer while commenting:

> "Now, however, in the light of additional data, we believe that the salt body can be justifiably interpreted as an in situ evaporite facies of the valley-fill section."—"In the evaporite prism interpretation, only the uppermost part of the body would have been involved in actual doming. . . ."

It seems clear that the salt is confined, at least in its upper part, by Late Tertiary fine-grained clastics. Like the Red Lake deposit, specific contact relationships have not clearly been established. However, just as at Red Lake, there do not seem to be compelling reasons why thick Late Tertiary salt should not be surrounded, regardless of contact types, by Late Tertiary fine-grained clastics. Figure 6 shows the gravity anomaly that reflects Luke Basin. Also shown is the USGS interpretation of the position of the base of the Luke salt.

Only 4.0 meters (13 feet) of core has been taken from this deposit. Except for an overlying anhydrite (called a "cap rock" by some), halite is the overwhelming evaporite mineral. Intercrystalline clastics are observed but have not been specifically identified. A generalized lithologic log resulting from interpretation of gamma ray-neutron logs by R. J. Hite of the USGS is included by Mytton (1973, p. 35) as follows:

Feet	*Lithology*
60	Anhydrite
500	Halite w/sh interbeds 2–8' th.
600	Halite w/argillaceous material
500	Halite & halite w/arg.-alternating
1360	Halite w/sh interbeds less than 1–6' th.
210	Halite
100	Halite & halite w/arg.-alternating
380	Halite w/sparse sh interbeds less than
3710	1–6' th.

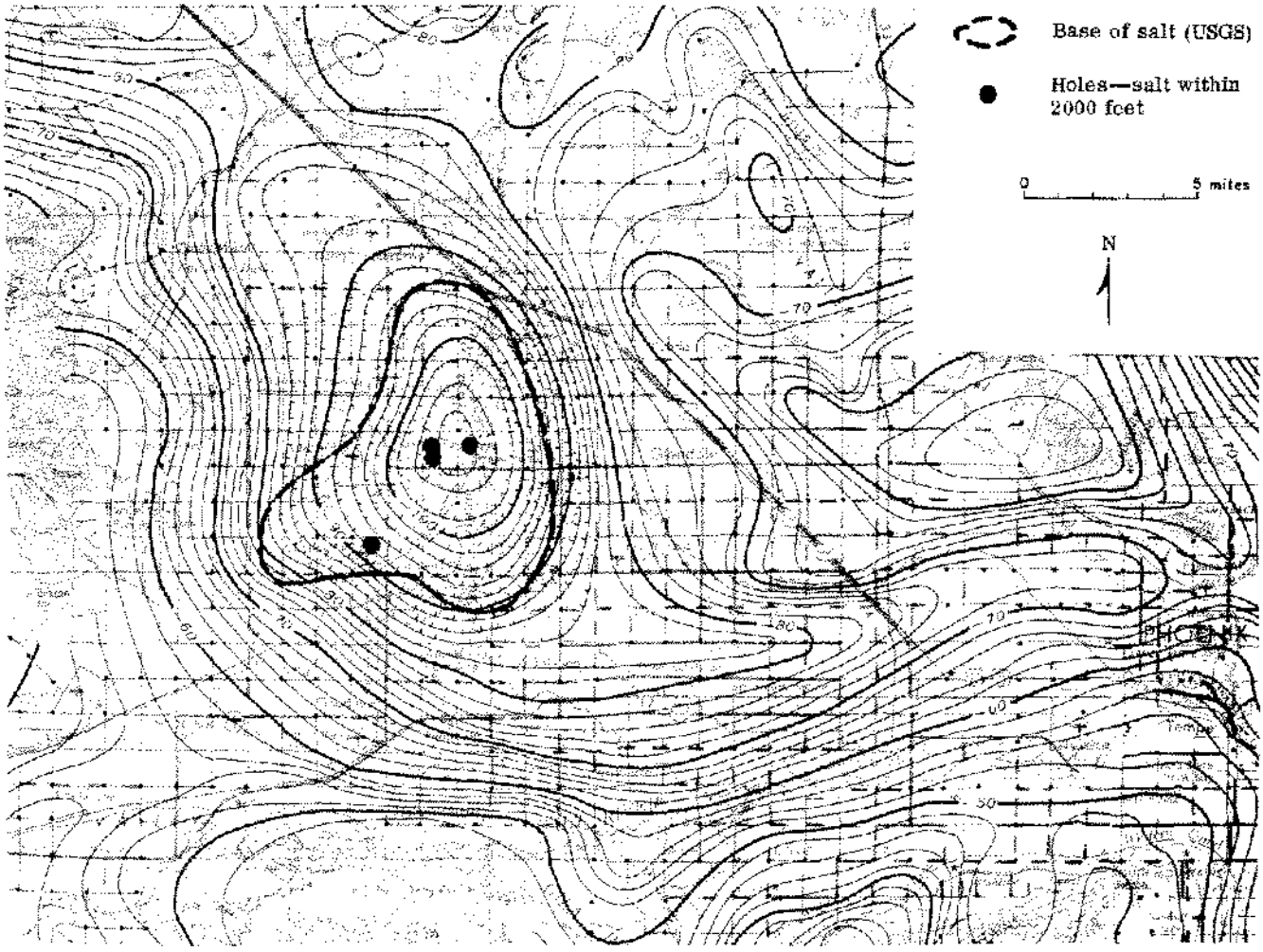

Figure 6. Bouguer gravity map of the Luke Basin (Peterson, 1968) showing the base of salt (Eaton, and others, 1972).

The implication of Hite's analysis is that the sequence is stratified with halite being the predominating lithology. Technically, should the resulting halite deposit be called a "mass" or "body" as if it was a single, homogeneous unit without potentially recognizable time planes?

The gravity map of Luke basin suggests that there are three principal directions to the structural grain, NS-EW-NW. The EW trend terminates in a saddle at Phoenix that might represent a spill point relative to other basins north and southeast of Phoenix that are within the Gila Low. The NW trend suggests that the east margin of the basin might be a fault zone. A buried pediment appears to extend eastward to the Phoenix Mountains. Samples from water wells thought to penetrate bedrock in the southern part of this zone reflect Middle Tertiary conglomerate and biotite bearing volcanics overlain by fine-grained clastics believed to be equivalent, in part, to salt.

On the basis of low bromine content and other data, Eaton and others (1972, p. 23) conclude that the Luke halite is probably of nonmarine origin". . . . and was probably deposited in a saline lake."

Like the Red Lake deposit, there seems to be circumstantial evidence to suggest that the Luke salt was deposited in a continental setting in late Tertiary time largely where it is now. Salt adjustment is indicated by both surface and subsurface evidence but this is not believed to significantly alter the basic premise presented here.

Picacho Basin. The Picacho Basin (Fig. 1) recently has become of geological interest because of the thick sequence of anhydrite that it contains. It is about 48 kilometers (30 miles) long and 14 kilometers (9 miles) wide and trends a few degrees east of north parallel to the Picacho Mountains that form its east boundary. The basin is also in the Gila Low and is crossed by the northwest flowing Santa Cruz drainage. There is a strong suspicion that the evaporite history of this paleo basin is closely related to that in the Luke basin 113 kilometers (70 miles) to the northwest.

The following information generously was released by Exxon (oral communication, Stanley, 1973) regarding their 3103 meter (10,177 foot) test in Sec. 2, T.8 S., R.8 E., Pinal County, that spudded at an elevation of 482 meters (1580 feet):

Interval (feet)	*Lithology*
0–660	Sd. & Gravel
660–2335	Clay
1615	1st sign gyp. x'tals
2140–2220	Some halite
2335–8320	Anhydrite-thin sh stringers
8320–9060	Conglomerate
9060–9670	"Basalt"
9670–9880	Conglomerate
9880–10,177	Gneiss

Mr. Stanley indicated that the "basalt" had been dated but that the information was not for release. However, he did say that it was no older than Middle Tertiary. Pollen found in gypsum at 591 meters (1940 feet) in a nearby hole was declared Plio-Pleistocene by King (written communication, 1972). Of additional interest is Eastwood's work (1970, p. 62–63) on the volcanic units in the Sanmaniego Hills at the southern end of the Picacho basin, less than 32 kilometers (20 miles) south of the Exxon test. Five potassium-argon ages are cited ranging from about 15 to 22 m.y. on andesites and basalt. On the basis of two determinations Cerro Prieta basalt, which in places is overlain and underlain by conglomerates, is dated as 17 to 22 m.y. This age range is late middle Tertiary and if the "basalt" in the test hole is of this vintage, then the anyhdrite sequence is likely late Tertiary in age.

Relief on the Precambrian gneissic basement surface utilizing the high point on gneiss in the adjacent Picacho Mountains and the low point in the Exxon test, is near 3963 meters (13,000 feet). However, the test might not have probed the deepest part of the basin and there is no reference surface above the outcropping gneiss. According to Mr. Stanley there is no evidence of marine activity in the basin nor is the anhydrite noticeably disturbed. The above data support the idea that has been stressed to the effect that Paleozoic and Mesozoic strata were removed in the Gila Low, and elsewhere, prior to the late Tertiary Basin and Range orogeny that produced partially closed basins in which thick evaporites, largely halite and anhydrite, accumulated.

Evaporites occur elsewhere in the Gila Low. A recent geothermal test in Sec. 1, T.2 S., R.6 E., between the Picacho and Luke basins, bottomed below 2744 meters (9000 feet) in volcanics. The following information was released by Mr. Austin (oral communication, 1973). The surface elevation is 408 meters (1338 feet). An evaporite interval is indicated between the depths of 698–1155 meters (2290–3790) consisting of anhydrite, probably some halite, and reddish clastics. Anhydrite constitutes most of the interval between 698–796 meters (2290–2610).

Elevations on the two anhydrite tops, in the Exxon test and the geothermal test, are 236 meters (775 feet) below sea level and 290 meters (952 feet) below sea level, respectively. The elevation of the anhydrite over the Luke salt is, on the other hand, 87 meters (285 feet) above sea level which is 377 meters (1237 feet) higher than that in the geothermal test. If, as it seems likely, there was an integrated system of drainage, lakes, and evaporites in the Gila Low, it is probable that the Luke basin was near the lower end of the system receiving chloride enriched waters. The higher elevation of the evaporite top at Luke can be explained in several ways: (1) evaporite accumulation lasted longer such that the upper part is equivalent to clays that overlie the evaporite in the vicinity of the geothermal well; (2) the salt has bulged upward; or (3) both of these.

On the basis of data in hand, though not developed here, it seems likely that both factors are involved. There is reason to think that the salt top at Luke might well be at least 183 meters (600 feet) higher than when it was originally deposited.

CONCLUSIONS

The geologic history of thick halite and anhydrite deposits being discovered in Arizona valleys (basins) is of much interest. Although the final story of their genesis is not yet available, the general geologic setting does tend to severely restrain the range of geologic history applicable to their origins. Furthermore, explanations of "thickness" should be examined in the perspective of Late Tertiary Basin and Range history and possibilities. It seems most likely that these three thick evaporite deposits are of Late Tertiary age and that they represent deposition in a complex system of continental interior basins. The Luke salt most likely has or is undergoing adjustment but this is viewed as an effect and not a principal cause of thickness. There is much of interest still to be learned about thick evaporites in the Basin and Range province of Arizona.

REFERENCES

Eaton, G. P., Peterson, D. L., and Schumann, H. H., 1970, Luke Dome—a holokinetic salt mass near Phoenix, Arizona (abs.): *Geol. Soc. America Abs. with Programs*, 2, no. 5:332.

_____, 1971, Geophysical, geochemical, and geohydrological reconnaissance of the Luke salt structure, central Arizona (abs.). *Arizona Acad. Sci. 15th Ann. Mtg.*, Tempe, p. 46.

_____, 1972, Geophysical, geohydrological, and geochemical reconnaissance of the Luke salt body, central Arizona. *U. S. Geol. Survey Prof. Paper* 753, 28 pp.

Eastwood, R. L., 1970, *A geochemical-petrological study of mid-Tertiary volcanism in parts of Pima and Pinal Counties, Arizona.* Univ. Ariz., Ph.D. Thesis, 212 pp.

Gillespie, J. B., and Bentley, C. B., 1971, Geohydrology of Hualapai and Sacramento Valleys, Mohave County, Arizona. *U.S. Geol. Survey Water Supply Paper*, 1899–H.

Koester, E. A., 1971, Salt domes in Arizona: *Ariz. Oil and Gas Conservation Commission, Geol. Report No.* 1, 20 pp.

Longwell, C. R., 1928, Geology of the Muddy Mountains, Nevada, with a section through the Virgin Range to the Grand Wash Cliffs, Arizona. *U.S. Geol. Survey Bull.* 798, 152 pp.

_____, 1936, Geology of the Boulder Reservoir floor. *Geol. Soc. American Bull.*, 47, no. 9:1393–1476.

_____, 1963, Reconnaissance geology between Lake Mead and Davis Dam, Arizona-Nevada. *U.S. Geol. Survey Prof. Paper* 374–E, 51 pp.

_____ and others, 1965, Geology and mineral deposits of Clark County, Nevada: *Nevada Bur. Mines Bull.* 62, Univ. of Nevada, Reno, 218 pp.

Mannion, L. E., 1961, Virgin Valley salt deposits, Clark County, Nevada. *in Symposium on salt, Northern Ohio Geol. Soc.*, Cleveland, 166–175.

Mytton, J. W., 1973, Two salt structures in Arizona: the Supai salt basin and the Luke salt body. *U.S. Geol. Survey Open-file report 4339–3*, 40 pp.

Peirce, H. W., 1967, Geologic Guidebook 2—Highways of Arizona, Arizona Highways 77 and 177. *Ariz. Bur. Mines Bull.* 176, Univ. of Ariz., Tucson, 73 pp.

_____, 1972a, Red Lake salt mass: Ariz. *Bur Mines Fieldnotes*, 2, no. 1:4–5.

_____, 1972b, Thick Arizona salt masses-autochthonous? (abs.) *Ariz. Acad. Sci. 16th Ann. Mtg.*, Prescott, p. 46.

Peterson, D. L., 1968, Bouguer gravity map of parts of Maricopa, Pima, Pinal, and Yuma Counties, Arizona. *U.S. Geol. Survey Geophysical Invest. Map* GP–615.

Pierce, W. G., and Rich, E. I., 1962, Summary of rock salt deposits in the United States as possible storage sites for radioactive waste materials. *U.S. Geol. Survey Bull.* 1148, 91 pp.

Randolph, P. L., 1971, Natural Gas Storage. Paper presented at the *ANS/AIF Ann. Conf.*, Miami Beach, Oct. 1971.