Storage Opportunities in Arizona Bedded Evaporites

by

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ABSTRACT

Arizona is endowed with incredibly diverse natural beauty, and has also been blessed with at least seven discrete deposits of bedded salt. These deposits are dispersed around the state and cover some 2,500 square miles; they currently contain 14 LPG storage caverns, with preliminary plans for more in the future. The areal extent and thickness of the deposits creates the opportunity for greatly expanded storage of LPG, natural gas, and compressed air energy storage (CAES). The location of salt deposits near Tucson and Phoenix may make CAES an attractive prospect in the future. The diversity of both locations and evaporite characteristics allows for much tailoring of individual operations to meet specific requirements.

The Oil and Gas Program Administrator, Arizona Geological Survey, is responsible for permitting storage wells for the Arizona Oil and Gas Commission. Rules covering Class II injection wells in Arizona (*Arizona Administrative Code* Title 12, Chapter 7) were amended January 2, 1996. Most are similar to rules in other states. The permit applicant must demonstrate the feasibility of a storage system at a particular site in a public hearing, and design solution-mined storage systems on site-specific geologic and engineering parameters. The rules provide the Commission discretion, however to grant exceptions to certain specific requirements if the applicant can show the exception is reasonable, justified, and consistent with the overall intent of the rules governing physical and environmental safety, conservation of the resource, and prevention of waste. R12-7-175 specifies classes of wells permitted by the Commission; R12-7-176 covers specific permitting requirements; R12-7-178 covers start up, abandonment, and transfer of injection wells; R12-7-179 covers testing, monitoring, and reporting requirements; R12-7-180 specifies supplemental requirements for storage wells; R12-7-181 covers design and construction requirements; and R12-7-182 specifies operation, inspection, and abandonment requirements.

Introduction

Arizona is the sixth largest state in the United States, comprising nearly 114,000 square miles, most of which is arid. A small percentage of the state is underlain by evaporite deposits at moderately shallow depth, three percent of which is bedded salt, a fact unknown to many, and only to geologists and engineers in about the past forty or fifty years. The auspicious position of Arizona between major energy producers and consumers creates an ideal environment for energy storage in caverns in the salt. Fourteen LPG caverns already exist—11 at

Adamana in the northeast corner of the state, and three at Glendale in west Phoenix. The dispersed occurrences of evaporite deposits in Arizona creates additional opportunities for energy storage, both in expanded LPG storage, and for natural gas and compressed air. While market requirements currently may not favor such development, the rapid expansion of population in the state makes future prospects attractive.

Regulatory concepts and rules are not significantly different from those in other states; however, the arid environment may offer certain advantages that few other states can. For example, the exceptionally high evaporation/precipitation ratio offers opportunities for brine concentration and use that may not be feasible elsewhere. Ground water is also usually deeper, creating specialized environmental conditions.

Evaporite Occurrence

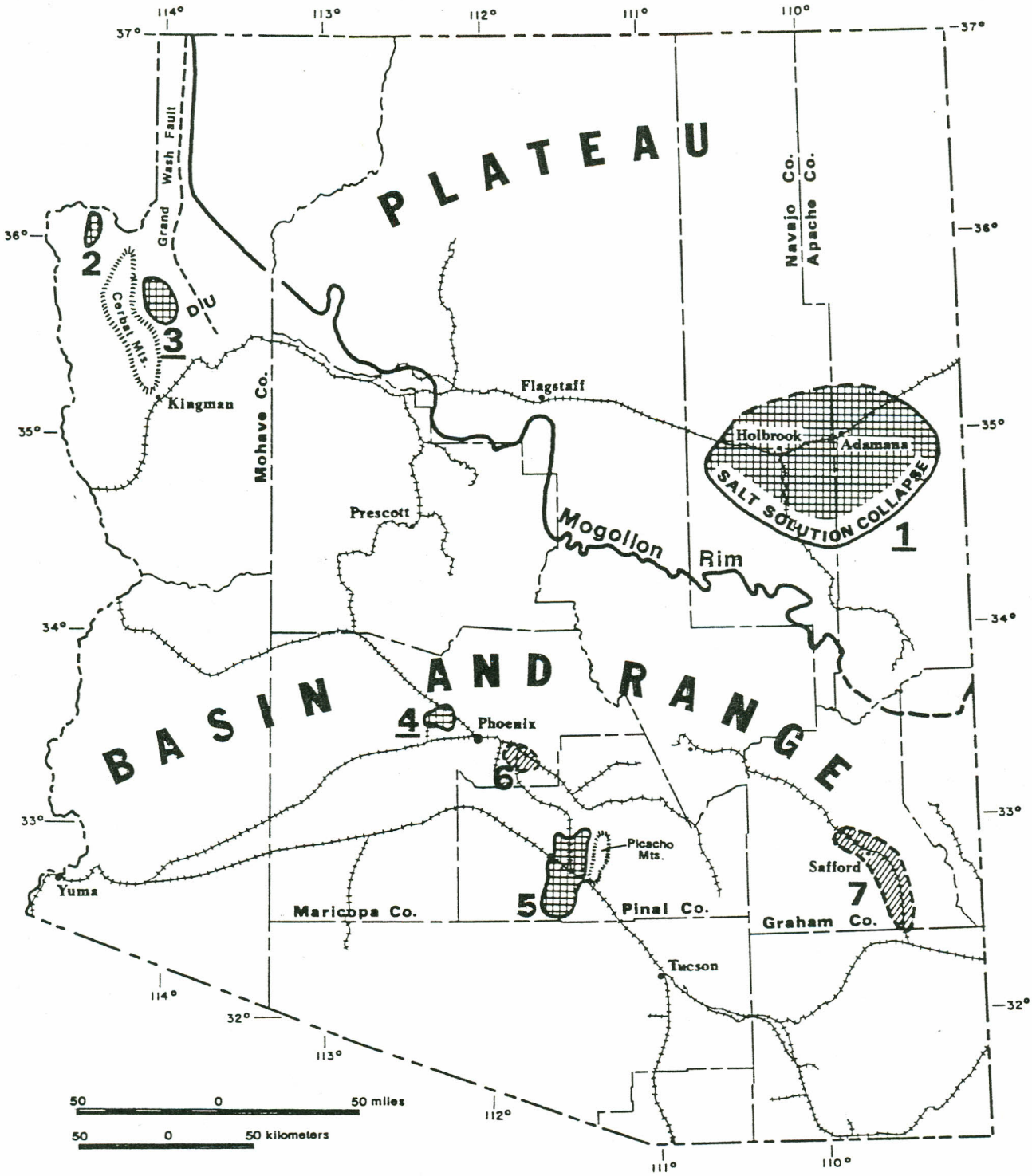
Subsurface evaporite occurrences have been identified in at least seven separate locations in Arizona (Fig. 1). Many of these occurrences have been previously studied as a result of the search for sites for storage of radioactive waste (Pierce and Rich, 1962; Johnson and Gonzalez, 1978). Three of these (Red Lake, Luke, and Picacho) are more than 3,300 feet (1,000 m) thick, creating a cavern storage environment potentially suitable for specialized applications, including natural gas and compressed air storage. Varying amounts of halite are found in all of the deposits, although the Picacho Basin in Southern Arizona is largely anhydrite with some shale interbeds.

Holbrook Basin

The Holbrook Basin is located along the southern margin of the Colorado Plateau on the Mogollon Slope. Several subsurface structural features form the margins of the depression: the Zuni-Defiance Uplift on the north and east, the Sedona Arch on the west, the Kaibab Arch on the north, and the Mogollon Shelf on the south. These features controlled sedimentation during Pennsylvanian and Permian times.

The Holbrook Basin covers some 2,300 square miles and has about 4,000 feet of Paleozoic strata (Fig. 2). The Corduroy unit of the Supai Group of Peirce (1989, p. 353) contains the evaporite section. However, not all workers agree on the terminology and correlation of Permian strata in this region (Peirce and Gerrard, 1966; Blakey, 1980, 1990; and Peirce, 1989). Halite with some anhydrite, dolomite, and shale covers the central part of the basin, and noncommercial potash (sylvite) is present in the center of the basin (Peirce and Scurlock, 1972). The interbedded anhydrite, carbonate, and sandstone sequence of the Fort Apache and Corduroy units of the Supai along the eastern margin of the basin (Wengerd and Methany, 1958) are correlative and laterally continuous with the Yeso Formation in New Mexico. Mytton (1973) claims this is the thickest Permian section in Arizona.

The thickness of the Supai is approximately 1,950 feet (600 m). The evaporite section in the Corduroy unit is



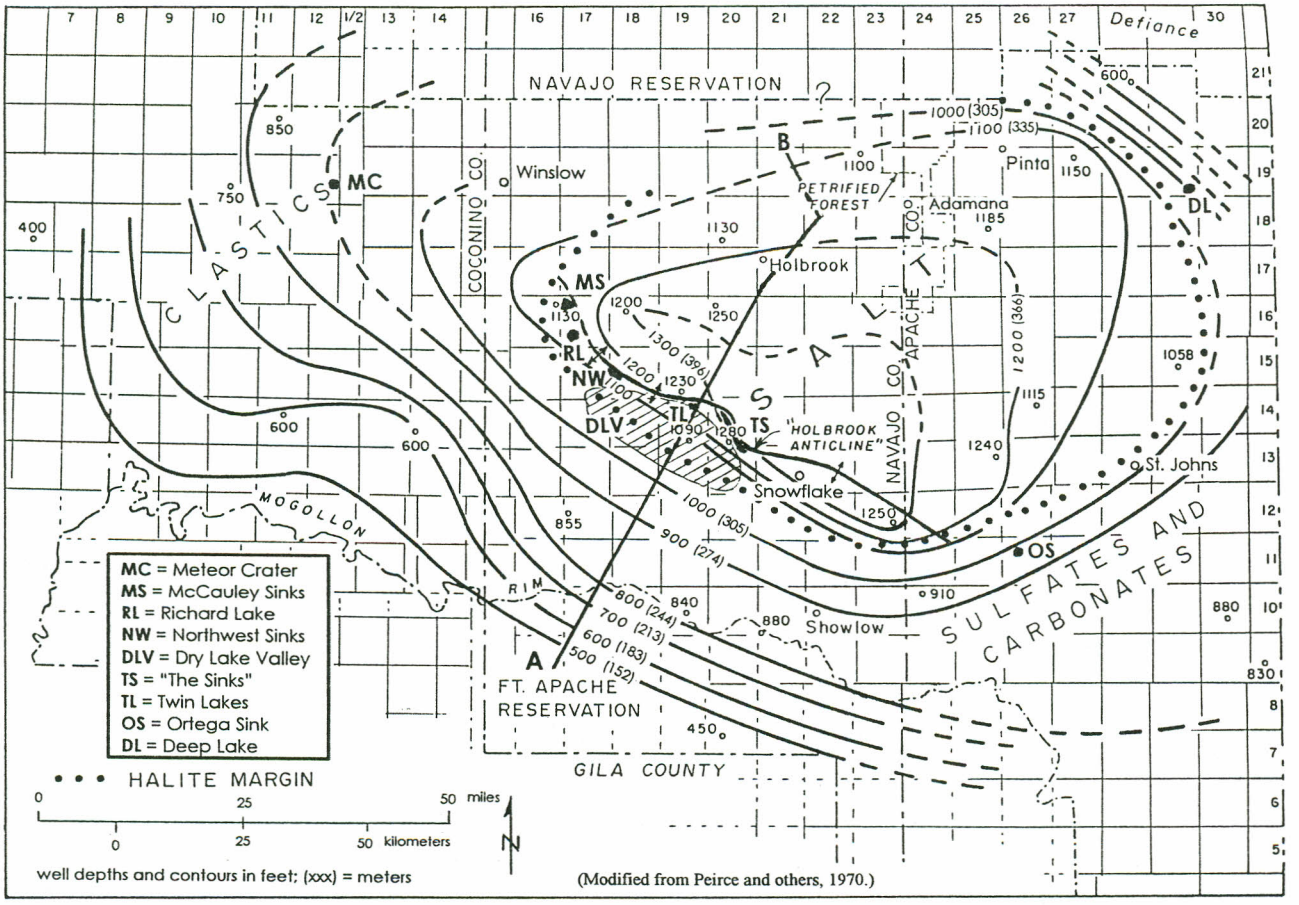
EXPLANATION

1 - Holbrook Basin salt
2 - Detrital Valley salt
3 - Red Lake Basin salt
4 - Luke Basin salt
5 - Picacho Basin
6 - Higley Basin
7 - Safford Valley

- Large salt deposits known
- Large salt deposits probable
- 1 - Exploitation (actual or planned)

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

From Peirce (1981).



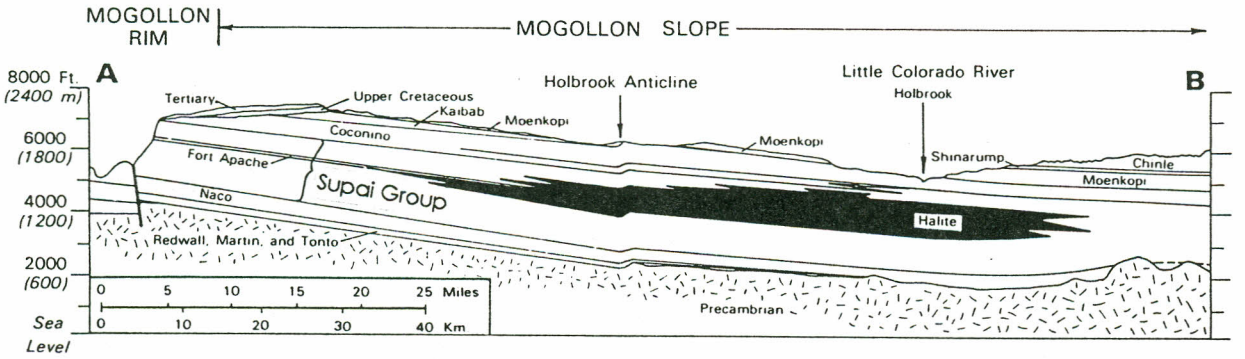


Figure 2 Holbrook salt basin, often referred to as the Supai salt basin, showing thickness (map) of the Corduroy evaporite member. Adamana LPG storage facility is in T18N, R24E, well north of the principal karst features (bold letters). North-to-south cross section **AB** shows relationship of major structure, including the Mogollon Rim and Slope, and the Holbrook Anticline and associated dissolution front. From Neal and others, 1996 (modified).

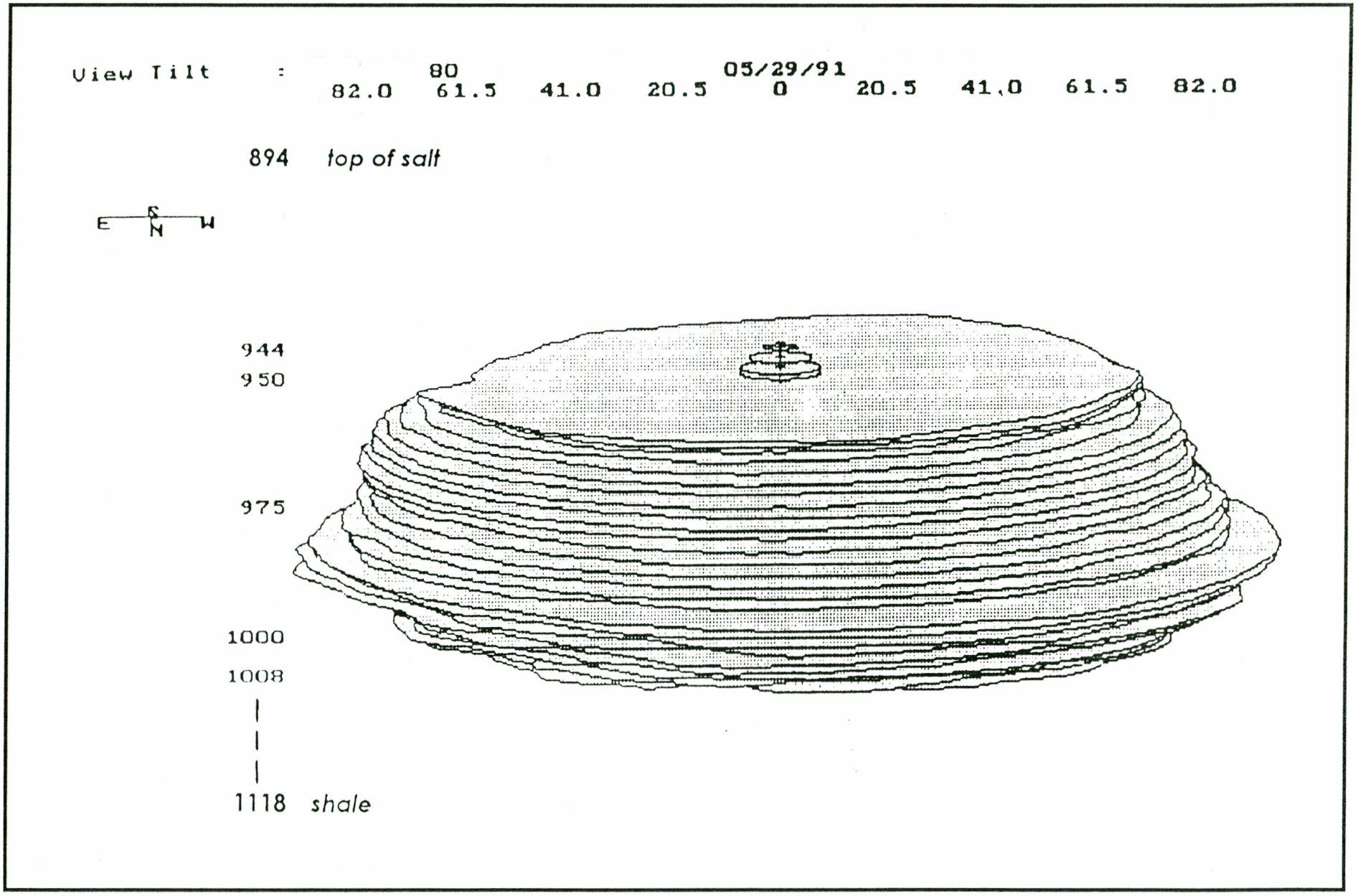


Figure 3 Caverns in the Supai Salt Basin at Adamana, Arizona, require short, squat configurations for LPG caverns. Sonar survey of Ferrellgas Cavern 3 reveals cavern height of 64 feet in salt section of 224 feet.

more than 1,000 feet (300 m) thick (Fig. 2). The Supai Group is underlain successively by the Pennsylvanian Naco Group, Mississippian Redwall Limestone, and the Devonian Martin Dolomite; all units rest nonconformably on Precambrian crystalline basement.

The location of the Santa Fe railroad through the northern part of the basin provides a logistical advantage for storing LPG; caverns have been operated at Adamana since 1971. Ferrellgas now has 11 caverns and provisional plans for more as needed. The salt thickness at this location is less than 250 feet, so that individual caverns are tailored to this geometry in horizontally-extended shapes, and cavern heights are on the order of 100 feet. (Fig. 3). The largest cavern volume is about 200,000 barrels, and the total facility capacity is about two million barrels. Because of the constraining salt geometry and shallow depth, this type of storage is typical of what is possible in the Holbrook Basin in the future. Greater salt thicknesses are likely farther south in the basin, but at some distance from the existing transportation infrastructure.

The southern margin of the Holbrook Basin is an area of active karst formation, occurring along a linear zone for more than 35 miles (Neal and others, 1996). This zone is generally coincident with the axis of the Holbrook Anticline, which has been explored in numerous oil well tests, all without success. The areas of active sinkholes and subsidence are well removed from the existing storage caverns. A suspected solution-collapse structure has been tentatively identified in the Petrified Forest National Park, some 5 miles southeast of the storage facility, but no other dissolution features exist in the area (Colpitts and Neal, 1996).

Detrital Valley

The Basin and Range country of northwestern Arizona has known deposits of bedded salt in at least two locations, Detrital Valley and Red Lake in Hualapai Valley (Figs. 1, 4, and 5). Numerous boreholes have been drilled over an area of several square miles just south of Lake Mead and some 25 miles east of Las Vegas, outlining a relatively pure salt mass with a maximum thickness of about 700 feet that extends from about 300 to more than 800 feet beneath the surface (Pierce and Rich, 1962). The salt and associated gypsum-anhydrite-clastics probably are part of the Miocene Muddy Creek Formation that crops out in the Lake Mead area and elsewhere in Arizona.

The Detrital Valley salt is structurally continuous with the Virgin River salt deposit not far to the north in Nevada, and underlying Lake Mead, but the salt may not be continuous. Although it has not been established that they are parts of the same mother salt, the similarity of their geologic setting and structural continuity is suggestive of their equivalence. Mannion (1961) suggested they could have been separate bodies deposited in lakes which were intermittently connected.

The presence of this salt has been known for some time, but the shallow depth and limited extent of the deposit apparently has not been attractive for cavern storage or other development, although many have looked at its possibilities because of its proximity to Las Vegas. Much of this salt in these two valleys underlies the Lake Mead

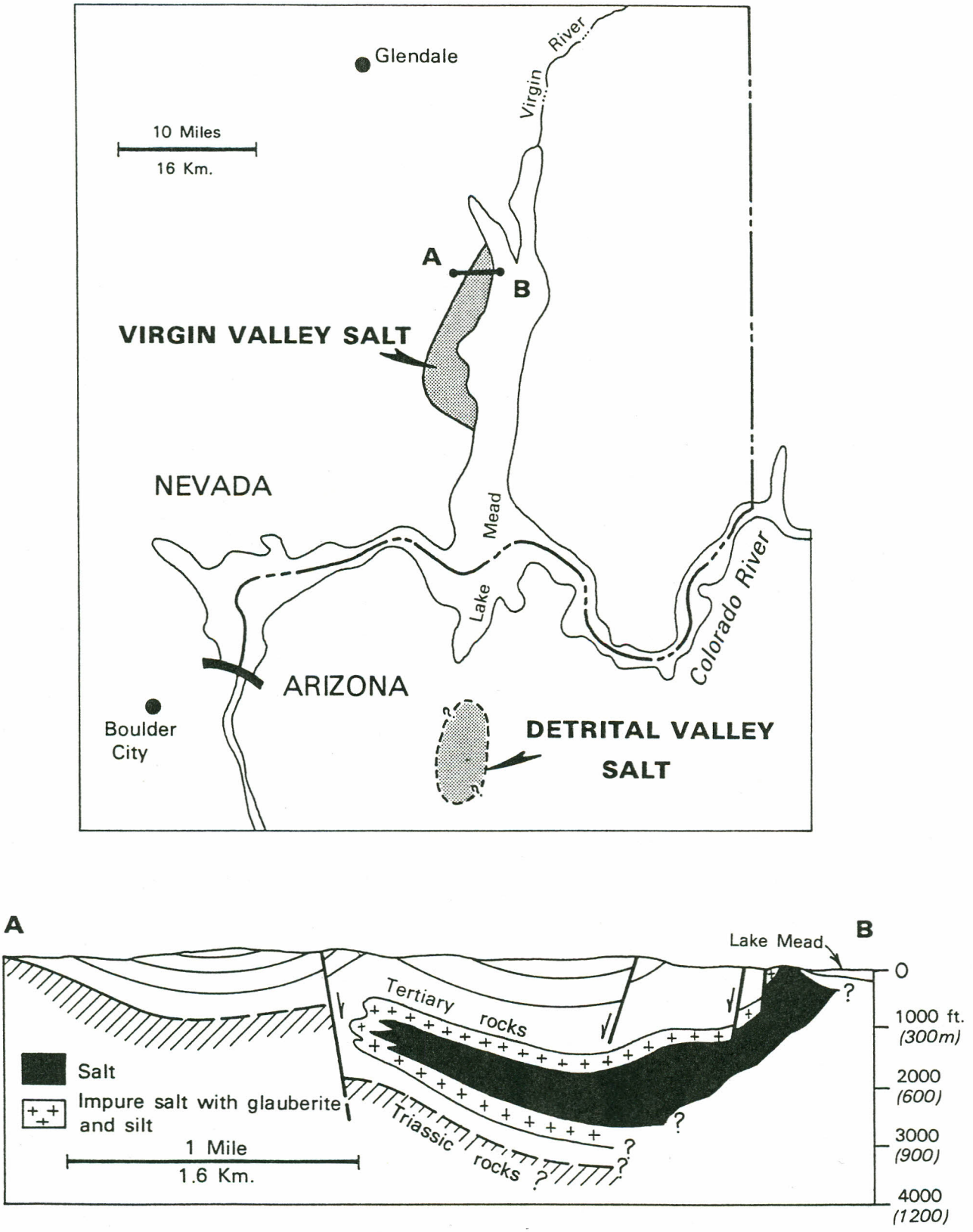


Figure 4 Generalized map and cross section showing Virgin Valley-Detrital Valley salts in southeastern Nevada and northwestern Arizona (modified from Mannion, 1961). From Johnson and Gonzales (1978).

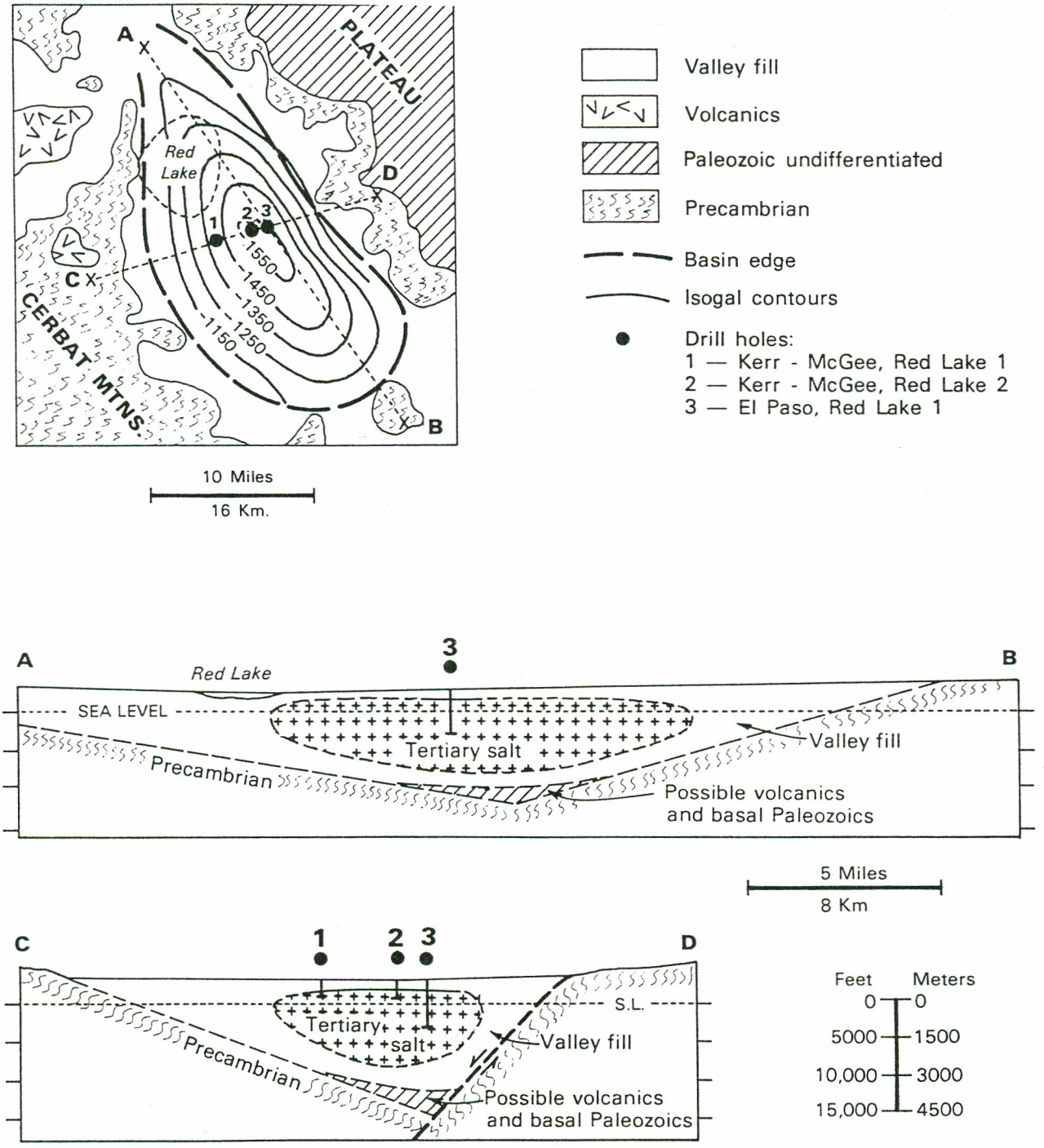


Figure 5 Generalized geologic map and cross sections showing salt in Red Lake basin of northwestern Arizona (modified from Peirce, 1972). From Johnson and Gonzales (1978).

National Recreation Area and its commercial availability is questionable.

Hualapai Valley

The Red Lake Salt Mass occurs in Hualapai Valley north of Kingman, with bedded halite occupying some 60 to as much as 100 cubic miles (Peirce, 1972). In contrast with Detrital Valley, this salt is at least 4,000 and as much as 10,000 feet thick. The extent of this deposit is known from three exploratory boreholes, and from gravity observations (Fig. 5). It occurs from approximately 1,500 to 1,800 feet beneath a surface elevation of 2,800 feet. Although the surface relief is some 300 feet, this does not appear to reflect diapiric rise of this tabular body. Some previous authors (McCaslin, 1972) have considered this salt a dome, citing caprock-like material on top of the salt, and the proximity to apparent diapiric salt at the Overton Beach area at Lake Mead. The salt appears to be an isolated deposit of Tertiary (Pliocene) age although many questions remain in regard to its source and emplacement history.

Natural gas storage projects have been proposed several different times at Red Lake, but none have materialized and none are pending. In 1996, undersubscription and excess interstate pipeline capacity of the California gas market (OGJ, 1995) has evidently delayed the need for immediate cavern storage, at least for several years. The depth and thickness of salt are ideally suited for large and deep caverns, which could also be used for compressed air. However the ready availability of Hoover Dam hydropower effectively negates this possibility for the near-term, but may be considered at a later date.

Cavern construction for natural gas storage at Red Lake would require special logistical considerations, as the desert valley is far removed from ready sources of raw water for leaching, and the hydrologic environment for either deep well injection or surface evaporation has many uncertainties. Insufficient data presently exists for brine disposal wells, and the possibility of surface evaporation and overland salt transport to distant markets requires further study. The Red Lake playa, a possible location for brine evaporation ponds, contains giant desiccation fissures which could serve as conduits for brine to migrate into fresh water aquifers if breaching of the evaporation ponds occurred.

While the salt environment appears excellent for cavern development, the problems cited here suggest that the demand for storage must increase substantially before projects can materialize. Additional study of the several avenues of technical uncertainty will be required.

Luke Salt Basin

The Luke Salt Basin west of Glendale is a paleo basin (without surface expression) near its namesake, Luke Air Force Base (Figs. 1, 6). It was discovered only ~30 years ago when 3,600 feet of salt were penetrated (Eaton and others, 1972). There may be twice that thickness of salt, or more, but no borehole has penetrated the entire thickness (Rauzi, 1991). The salt body shows at least 600 feet of relief on top and a volume of at least 15 cubic miles of halite; gravity values suggest some diapiric rise; thus some local investigators refer to this as "Arizona's salt dome," perhaps envious of

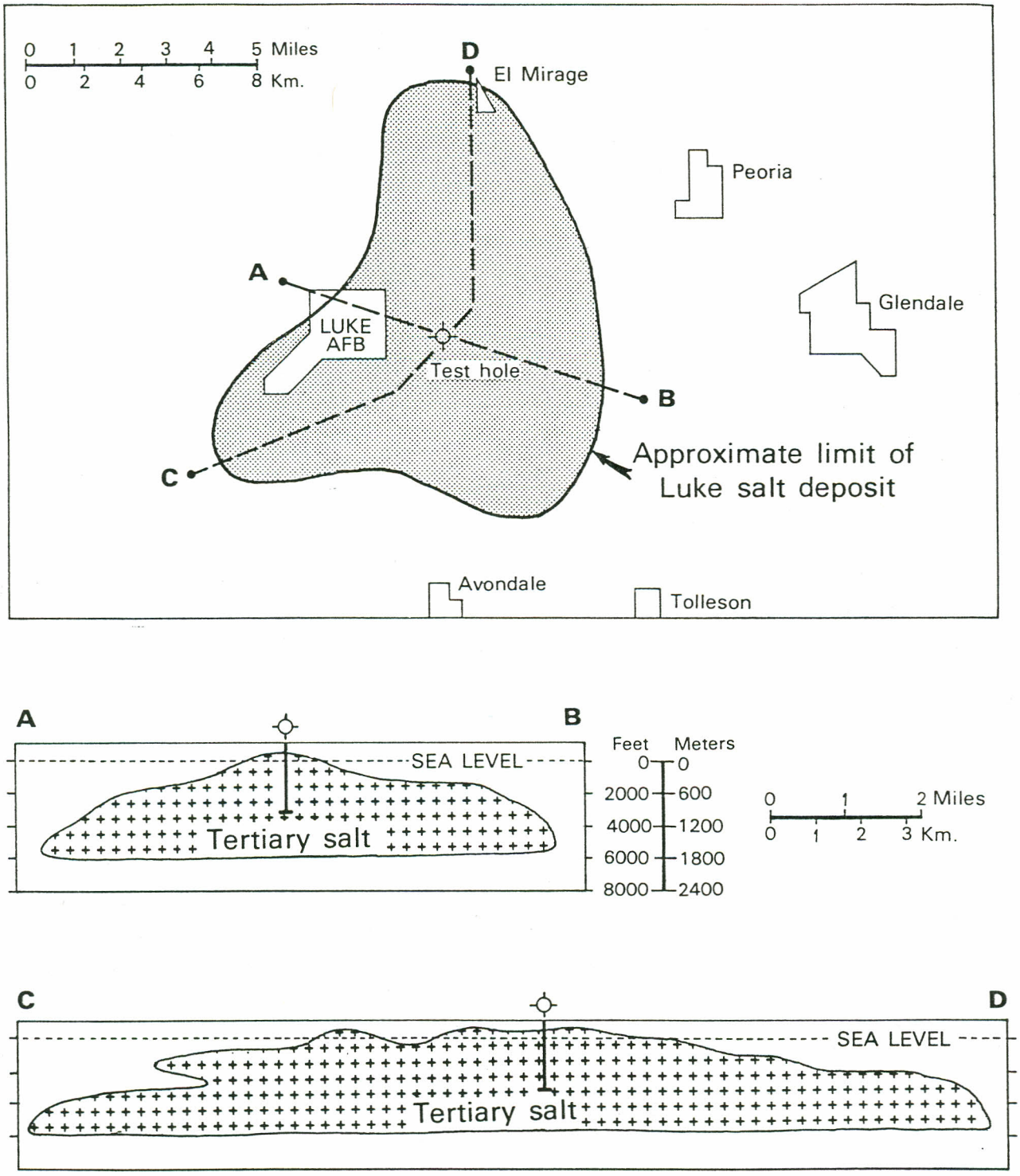


Figure 6 Map and cross section showing generalized geophysical interpretation of Luke basin salt deposit west of Phoenix, Arizona (modified from Eaton and others, 1972). From Johnson and Gonzales (1978).

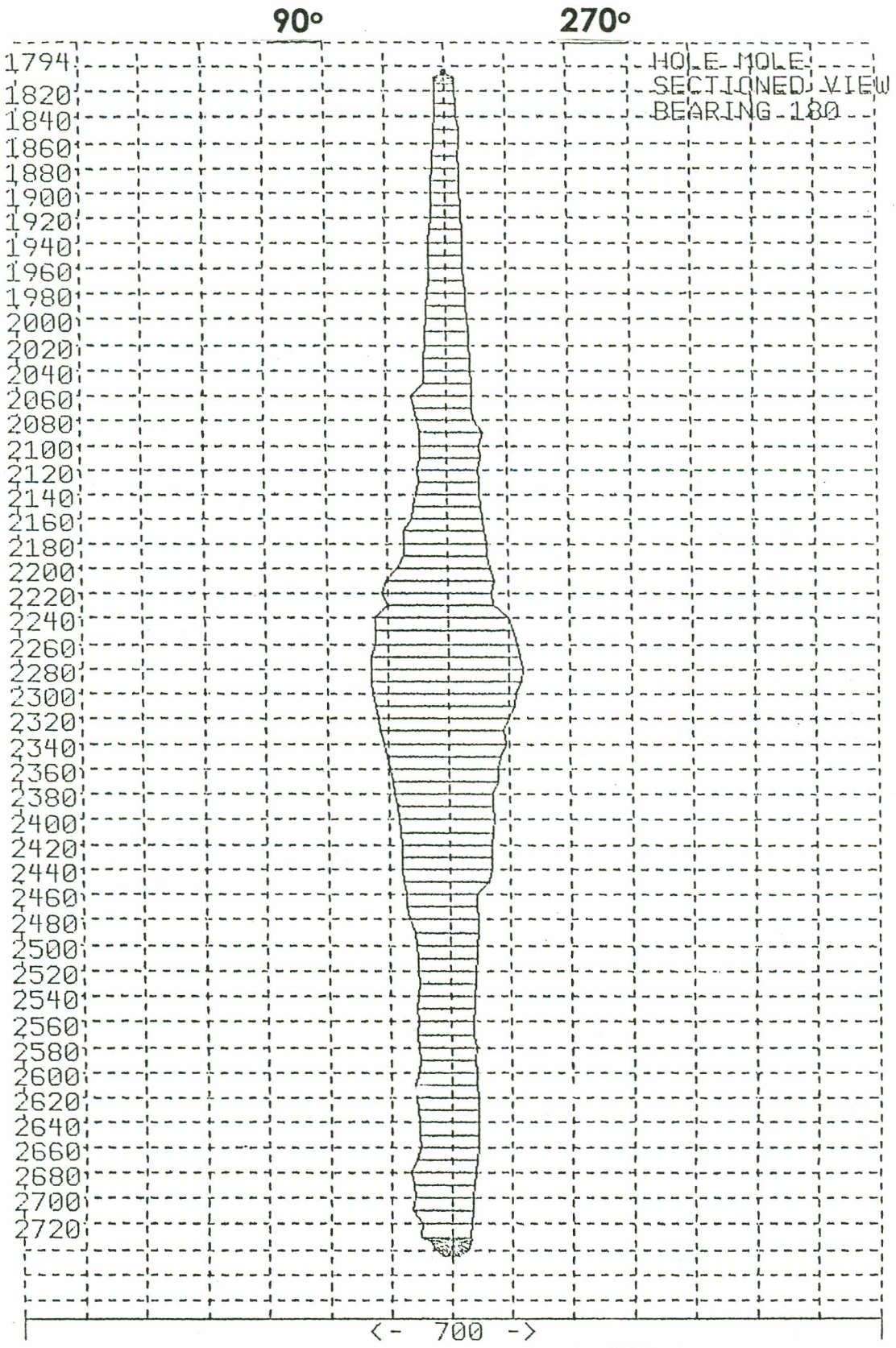


Figure 7 East-West sonar section of Amerigas Cavern 1, looking south, Luke salt basin. Horizontal division = 50 ft, depths in feet below surface; cavern volume was ~950,000 barrels on May 26, 1987.

Gulf Coast geology! However, Rauzi points out that bromine levels of 2 ppm represent nonmarine salt, in contrast with much higher values for marine origin. The evidence favors a playa or lacustrine origin in a desert basin of at least Miocene geologic age, but does not exclude some diapiric rise (Eaton and others, 1972).

The thick salt mass afforded by the Luke occurrence allows for deeper and quite different cavern storage than at Adamana. Three caverns currently are operated for LPG storage by Amerigas, with a total volume of about 3.6 million barrels. Caverns are taller and deeper and have substantially greater volume than at Adamana. Cavern #1 is shown at Fig. 7, extending from approximately 1,800 to 2,750 feet. Brine obtained from leaching these caverns is evaporated and marketed by Morton Salt International. The availability of brine from the Morton facility increases the working capacity of the Amerigas caverns.

The strategic location of the Luke salt body within the greater Phoenix metropolitan area, a rapidly growing one, suggests there may be a need for either or both natural gas and compressed air storage in the future, in addition to more LPG. The expansion of the metropolitan area could preclude some kinds of development, in addition to the location under Luke Air Force Base. The Palo Verde nuclear power plant is also nearby and could compete with energy development.

Picacho Basin

The Picacho Basin (Fig. 1) evaporites were discovered in 1973 in an Humble well that transected some 6,000 vertical feet of anhydrite, with lesser interbeds of halite intersected from 2,100-2,200 feet. More halite is likely in the basin, as a 1974 well located 6 miles northwest and drilled by another operator encountered 600-700 feet of salt, even though the evaporite section only totaled 1,500 feet. Peirce (1981) believed the Picacho basin extended some 30 miles and had a width of about 9 miles with a potential for substantial evaporites sequences. Additional exploration is required to exploit this potential. Its strategic location midway between Phoenix and Tucson suggests storage potential for LPG may exist in the future.

Peirce (1974) thought the Picacho basin might be closely related in origin to that of the Luke basin. He noted that both occurrences are within a topographic and geologic feature called the "Gila Low." Much information about this basin is proprietary, but is known to exist in oil company files.

Higley Basin

The Higley Basin is located about five miles east of Chandler, in the Greater Phoenix area. A 1973 geothermal test well near the edge of the basin encountered evaporites over an interval of 1,500 feet, including anhydrite and possibly some salt. Peirce (1981) believed more salt was likely near the depositional center, at a depth of approximately 2,300 feet below the surface.

Safford Valley

A 1971 drill hole about 20 miles south of Safford, in southeastern Arizona, encountered 2,300 feet of gypsum and anhydrite evaporites below 1,200 feet and terminated in the evaporites at 3,500 feet. Thus the full extent and thickness is unknown.

Another hydrologic exploratory borehole four miles west of Safford returned halite in some core samples taken at 2,300 feet, suggesting that this deposit in San Simon Valley could be a resource for extensive evaporites, similar to Picacho Basin. Gravity anomalies suggest at least three centers of evaporite deposition in Safford Valley.

Evaporites in Arizona

The above discussion of principal known evaporite occurrences, many of which have been discovered only recently, suggests that more are likely to be present—and in all areas of the state. The challenge for further exploration is clear and will surely follow societal needs.

Permitting Solution-mined Storage Wells in Arizona

Storage wells in Arizona are regulated by the Arizona Oil and Gas Conservation Commission (AOGCC), which is attached administratively to the Arizona Geological Survey (AZGS) in Tucson. Rules regulating storage wells are listed in the Arizona Administrative Code (A.A.C.) Title 12, Chapter 7. These rules cover permitting, design, construction, and operation of wells used to store liquid or gaseous hydrocarbons and non-hydrocarbon liquids and gases. Questions about the AOGCC, its rules, or applications to drill storage wells in Arizona should be directed to the Oil and Gas Program Administrator at the AZGS.

Liquefied petroleum gas (LPG) is stored at two locations in Arizona and a third has been considered for storage of natural gas. The two LPG storage facilities have 14 active caverns—11 are at Adamana in Permian salt and have a capacity of 2 million barrels, and three are at Glendale in Tertiary salt and have a capacity of 3.6 million barrels. Natural gas storage has been considered at Red Lake north of Kingman, but no application is pending.

The Permitting Process

Permitting storage wells in Arizona requires an injection permit from the AOGCC after notice and hearing. A permit is required before drilling a new storage well or converting an existing well to a storage well. Permit requirements and the permitting process are summarized below. However, an operator considering Arizona for the development of solution-mined storage wells should obtain a copy of the rules before preparing an application to drill a storage well. The rules provide a complete listing of permit requirements.

Informal initiation encouraged. The first step is to advise the Oil and Gas Program Administrator of the possibility of drilling a solution-mined storage well. This initial contact and informal discussion about the project, its location, and the known geologic and engineering parameters generally reveals that helpful information about particular sites is available at the AZGS, including geology, ground water, and drilling conditions. The AZGS maintains well files, rock cuttings, and an excellent geological library. Necessary forms for permitting are

provided once the decision to proceed has been reached.

The Application

Submission of an application, a written request for a hearing, and a $50 fee initiates the permit process. The $50 fee is applied toward the cost of the hearing, including publication of the notice and court reporter. The applicant pays for the hearing costs. The notice is published at least 15 days before the hearing date, but the hearing is normally not held for at least 30 days after receipt of the application. This allows the Administrator time to review the application for compliance with rules, prepare background material and recommendation, and schedule a date for the hearing that is mutually convenient for the applicant and the AOGCC.

The application must be prepared in accordance with A.A.C. R12-7-176, R12-7-180, and R12-7-181. These rules form the basis for the Administrator's review and recommendation as well as the AOGCC's decision to approve, request modification, or deny the permit. Minimum contents of a complete application include a well location plat, geologic and engineering studies, injection plan, and proof of notification of neighboring operators and surface owners. These should be prepared as succinctly as possible and all maps, diagrams, and exhibits should be clearly labeled as to scale and purpose, and identify all wells, boundaries, zones, contacts, and other relevant data.

Testimony at the hearing should follow the written application as closely as possible. Be prepared to explain and elaborate on all maps, diagrams, and exhibits. An attorney for the applicant is not required at the hearing, and generally is not necessary.

Exceptions. An injection permit is issued for the operating life of a well and is reviewed at least once every five years for continued compliance with AOGCC rules. As a result, the AOGCC requires the submission of an application to transfer ownership or to plug and abandon a storage cavern. The AOGCC may grant exceptions to certain specific requirements if the applicant can show that the exception is reasonable, justified, and consistent with the overall intent of the rules regarding physical and environmental safety, conservation of the resource, and prevention of waste. Requests for exceptions should be in writing, submitted with the application, and based on geologic and engineering parameters of the particular site.

The well location plat should include the location of each proposed injection well and the location and status of all wells within one-half mile of the proposed well. The plat should include the lease boundary lines, the names of surface and subsurface lessees and owners within one-half mile of the injection well, and the name of each offset operator.

The geologic study should show the depth and thickness of the salt in relation to the depth, size, shape, number, and spacing of the storage cavities. A contour map and a geologic cross section showing these relationships, and the base of any fresh water strata should be included in the written application and presented in the public hearing. A description of the properties and structural integrity of the host rock and overlying sediments should be included.

The engineering study should demonstrate the feasibility of a storage system at the particular site, describe details of the proposed well construction, and assess the stability of each proposed cavity design. Diagrams of the wellhead and casing should be included, along with an explanation of the proposed method of integrity testing of the casing and cavern prior to starting injection. Provisions should be made for continuous review of the design and solution mining throughout the construction phase, to account for new subsurface information. Modifications to the original development and operational plans must conform with currently accepted engineering practices in the solution mining industry.

The injection plan should include a diagram of the injection facilities, estimated injection pressures and rates, the location and depth of each water-source well that will be used, and a comprehensive plan for disposition of brine and salt produced during the course of creating a solution-mined cavity. A flare or other safety system is required at or near each brine pit or other location where escape of gases is likely to occur.

Approval of Applications

Availability of fresh water for solutioning and the method of brine disposal are important factors in the generally arid climate of Arizona. Some unique methods of brine disposal and use have been proposed in the past, including evaporation and sale of salt, and the farming of brine shrimp. These methods are preferred over subsurface disposal in areas where limited groundwater increases the potential for contamination from the injection of large volumes of brine.

The injection permit is approved if the applicant successfully demonstrates that project development can be constructed in a reasonable, prudent, and systematic manner, and ensure physical and environmental safety and the prevention of waste. The hearing normally takes no more than an hour when the evidence is well prepared in the written application, succinctly presented at the hearing, and there are no objections from the neighboring operators or surface owners. In such cases, the AOGCC may reach its decision at the hearing, and issue its authorizing order within 30 days. Drilling permits for injection wells are valid for 180 days from the date of issue.

Operation of Storage Wells

Active storage wells and facilities are regulated by A.A.C. R12-7-178, R12-7-179, and R12-7-182. These rules cover the testing, monitoring, and closure of injection wells. These rules ensure that once constructed, storage-well systems are operated safely and in an environmentally sound manner. The rules require such things as monitoring operating pressures, keeping accurate records, filing of monthly storage reports, and occasional verification of cavity volumes and mechanical integrity tests. Inspections are made of every storage well twice each year to ensure that wellheads, valves, safety systems, and flares are maintained in good working condition.

The State of Arizona recognizes the value of its bedded salt for development of solution-mined storage caverns. It welcomes and encourages this development and the Arizona Geological Survey stands ready to

provide additional information and assist in this pursuit.

Acknowledgment

The advancement of knowledge of Arizona salt deposits has benefited in a major way from the career-long efforts of the late Dr. H. Wesley Peirce of the Arizona Geological Survey. We owe much to Wes, who helped us greatly, and dedicate this paper to his memory.

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