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SITE INVESTICATIONS FOR A BEDDED SALT PILOT PLANT IN THE PERMIAN BASIN[a]

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ABSTRACT

High-level radioactive waste contains long-lived nuclides that require complete confinement for long periods of geologic time. Rock salt has long been acclaimed as the preferred geologic medium for the ultimate disposal of these wastes as its unique self-healing properties make it impervious to the intraformational circulation of ground waters. Data have been compiled on the nature and extent of all major salt deposits in the conterminous United States; however, specific site studies have been confined to the Permian Basin and in particular to central Kansas and to a large tract of federally owned land in southeastern New Mexico. A series of core holes have been drilled to provide the critical data for selecting appropriate disposal levels and assessing the hydraulic characteristics of the overlying and underlying formations. Selective portions of the cores have been analyzed to determine the quantities and characteristics of various minerals in the evaporite section and in particular of any hydrated minerals and rocks that could dehydrate upon heating due to radioactive decay of the wastes. Measurements of the physical properties of these rocks have also been made to calculate their deformational behavior.

Because of the need for long-term waste confinement, several unique studies have been initiated. The long geologic history of relative quiescence coupled with data on historic earthquakes strongly suggests that the Permian Basin will continue to be tectonically stable for the next few hundreds of thousands of years or for the effective lifetime of the wastes. In addition, studies of subsurface salt dissolutioning show that the rates of basinward migration of the relatively shallow edges of the salt has, during Quaternary time, averaged only a few miles per

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million years. Also in central Kansas present rates of denudation have been found to average less than a foot per 1000 years while stream incisions in the same area during Quaternary time have not exceeded several hundred feet. Finally, investigations have revealed that the buried wastes would not be adversely affected with the advance of a new continental ice sheet.

INTRODUCTION

In 1955 a committee was established by the National Academy of Sciences - National Research Council at the request of the U. S. Atomic Energy Commission to consider the possibilities of disposal of high-level radioactive wastes in the United States. After some study, the NAS-NRC Committee reported that "the most promising method of disposal of high-level wastes at the present time seems to be in salt deposits. The great advantage here is that no water can pass through salt."[1] To determine the feasibility of utilizing salt deposits for waste disposal, the Committee recommended that investigations be conducted specifically to define the structural limitations of rock salt, to study the heat transfer and thermal effects problem and to examine the economics of such a disposal scheme. It has since been demonstrated through extensive laboratory studies and field tests that salt deposits are practicable repositories for high-level wastes. The remaining task is to construct a pilot plant repository in rock salt that will provide for the eventual permanent disposal of the anticipated large volumes of high-level wastes from the nuclear power economy. This facility will be located in an area which is tectonically stable and which contains geographically extensive thick and relatively flat-lying beds of rock salt. The Permian Salt Basin, lying within the stable interior of the United States and underlain by thick deposits of flat-lying salt, has been studied specifically for potentially acceptable repository sites. Some of the more important geohydrologic characteristics of the salt basin that affect the long-term containment of radioactive waste at specific study areas are discussed below.

CHARACTERISTICS OF RADIOACTIVE WASTES

Radioactive wastes are undesirable but inevitable products of the development and use of nuclear energy. In the past few decades significant quantities of radioactive wastes have been generated in building the nation's nuclear weapons arsenal. In addition, much smaller quantities of wastes have accumulated from a myriad of nuclear research activities and from various medical and industrial uses of radioactive materials. The most formidable wastes, however, are those anticipated from the rapidly expanding nuclear power economy. Figure 1 is a simplified diagram of the fuel cycle for light water, electrical-generating reactors. After mining, the uranium is converted to the hexafluoride for ^{235}U enrichment at gaseous diffusion plants. The material is then prepared in oxide form suitable for use in fuels and shipped to plants for fabrication into reactor fuel elements. Nuclear fission of the fuel in the reactor provides the thermal power for the generation of electricity, but the reaction also creates the fission products that comprise the bulk of the radioactive wastes generated in the fuel cycle. The lifespan of fuel elements in power reactors is about 3 years, after which time they are removed and transported to reprocessing facilities. Here the spent fuel elements are dissolved and the "unburned" uranium and newly generated plutonium are extracted, leaving a residue of intensely radioactive fission product wastes. At the present time only the ^{235}U isotope is recycled; however, within the next few years it is anticipated that the recoverable plutonium (as well as fissionable ^{233}U, which is not shown in Figure 1), will be utilized as fuel. In the fission product-actinide separation process, small but significant quantities of ^{239}Pu and other long-lived transuranium isotopes are unrecoverable and remain in the fission product waste residues. The impact of these contaminants on the disposal of the fission product wastes is indeed profound as the time required for decay to innocuous levels for fission products alone is a few hundred years, while that of the fission products-transuranic mixture is a few hundreds of thousands of years. Ultimate disposal schemes for these wastes such as burial in rock salt formations must therefore provide complete containment for long periods of geologic time.

Based on current projections of the nuclear power economy through the year 2000, estimates have been made of the expected quantities of the related radioactive wastes. In Table 1, which summarizes these power projections and waste estimates, it is observed that the installed nuclear electric generating capacity will increase from some 150,000 MW in 1980 to about 940,000 by the end of the century. Note too, the marked increases in the generation rates and accumulated volumes of wastes that occur during this same time span. The volumes of wastes generated annually will increase from 9.7×10^3 ft^3 in 1980 to 58×10^3 ft^3 by the year 2000. About 770×10^3 ft^3 of wastes will have accumulated by the year 2000 and will total about 1000 MW of thermal power and contain some 270,000 million curies of beta activity. Estimated quantities of some of the

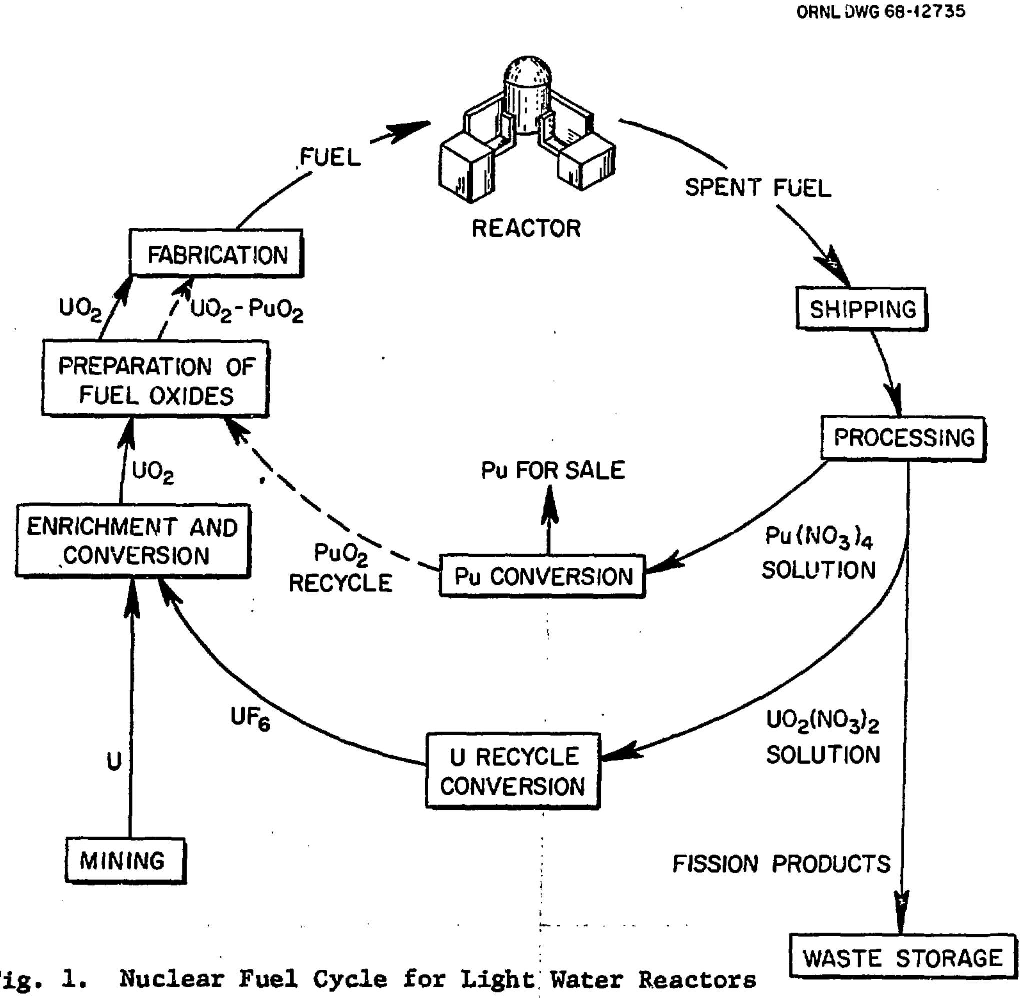

Fig. 1. Nuclear Fuel Cycle for Light Water Reactors

Table 1. High-Level Wastes Estimates from Projected Nuclear Power Economy*

	Calendar Year Ending		
	1980	1990	2000
Installed Nuclear Electric Capacity, MW (electric)	150,000	450,000	940,000
Field Reprocessed, metric tons/year	3,000	9,000	19,000
Solidified High-Level Waste[a]			
Annual Volume, 10^3 ft^3	9.7	33	58
Accumulated Volume, 10^3 ft^3	44	290	770
Total Accumulated Activity, MCi	19,000	110,000	270,000
Total Thermal Power, MW	80	410	1,040
Significant Isotopes Accumulated, MCi			
28.9-y ^{90}Sr	960	5,700	12,000
30-y ^{137}Cs	1,300	8,000	20,000
10.8-y ^{85}Kr	120	690	1,500
12.3-y ^{3}H	7.3	44	110
24,400-y ^{239}Pu[b]	0.022	0.3	1.7
Number of Shipments to Repositories[c]	23	240	590

[a]Assumes 1 ft^3 of solidified waste per 10,000 MWd (th).

[b]Assumes 0.5% of plutonium in fuel is lost to waste.

[c]Each shipment consists of 57.6 ft^3 of waste in 36 6-in.-diam. cylinders. Half of the waste is aged 5 years and half is aged 10 years at the time of its shipment.

*Adapted from Culler, F. L., Blomeke, J. O. and Belter, W. G., Current Developments in Long-term Radioactive Waste Management, Proceedings of the Fourth International Conference, Geneva, 6-16 September 1971, Volume 11.

more significant isotopes are also given in the table. The 1.7 million curies of ^{239}Pu with a half-life of 24,400 years is especially noteworthy since its presence as a contaminant in the high-level fission product wastes increases the effective lifetime of the wastes to several hundreds of thousands of years and thereby affects greatly the conditions for disposal.

BEDDED SALT PILOT PLANT CONCEPT

Figure 2 is an illustrative drawing of a model waste repository in bedded salt. The wastes are to be transported in specially designed rail cars to the topside facilities at the Repository. Here, after inspection and monitoring, the individual containers of waste, which range up to 1 ft in diameter and 10 ft in length, are lowered down the charging shaft to the desired disposal level within the salt formation at a depth of about 2000 ft. A shielded carrier is then used to transport the containers through the underground workings to burial holes drilled in the mine floor. Initially it is planned to operate the facility as a pilot plant with the capability of complete retrievability of all waste containers. Eventually, after all safety related aspects of the scheme have been adequately demonstrated, a full-scale repository will be developed at the site of the Pilot Plant or possibly at some other location. The full-scale repository which covers an area of about 1000 acres is designed to accommodate all of the nation's high-level radioactive wastes for about 30 years.

OCCURRENCE AND DISTRIBUTION OF ROCK SALT DEPOSITS IN THE UNITED STATES

In selecting a site for the Bedded Salt Pilot Plant, investigations have been made of the nature and extent of all the major salt deposits in the conterminous U. S. Figure 3 is a map of the country showing the occurrences of rock salt. In the illustration it is seen that salt is indeed an abundant commodity with deposits underlying some 24 of the 50 states. In the geologic past, these areas were downwarped desicative basins where salt and other evaporites were laid down. In some places, such as the Gulf Coast Embayment, the salt rocks have been subsequently buried to extremely great depths while in other areas, such as the Permian Basin, the evaporite sequences have remained relatively near to the land surface. The depth of these deposits is an important factor in site

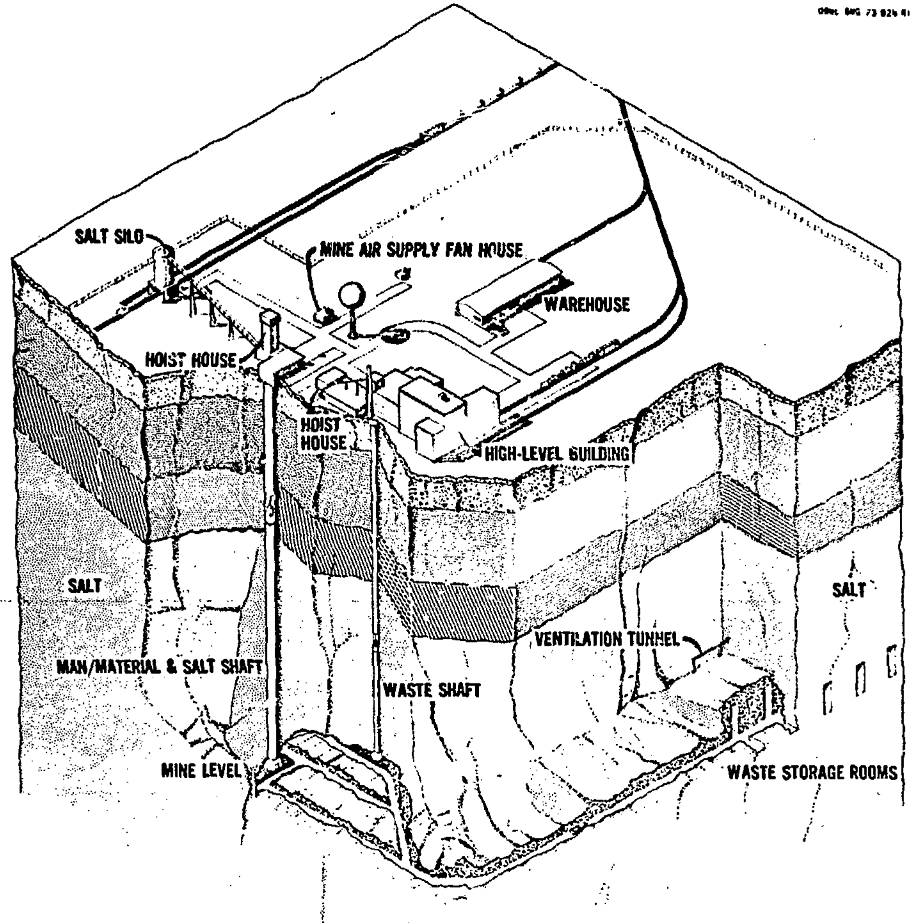

Fig. 2. Bedded Salt Pilot Plant

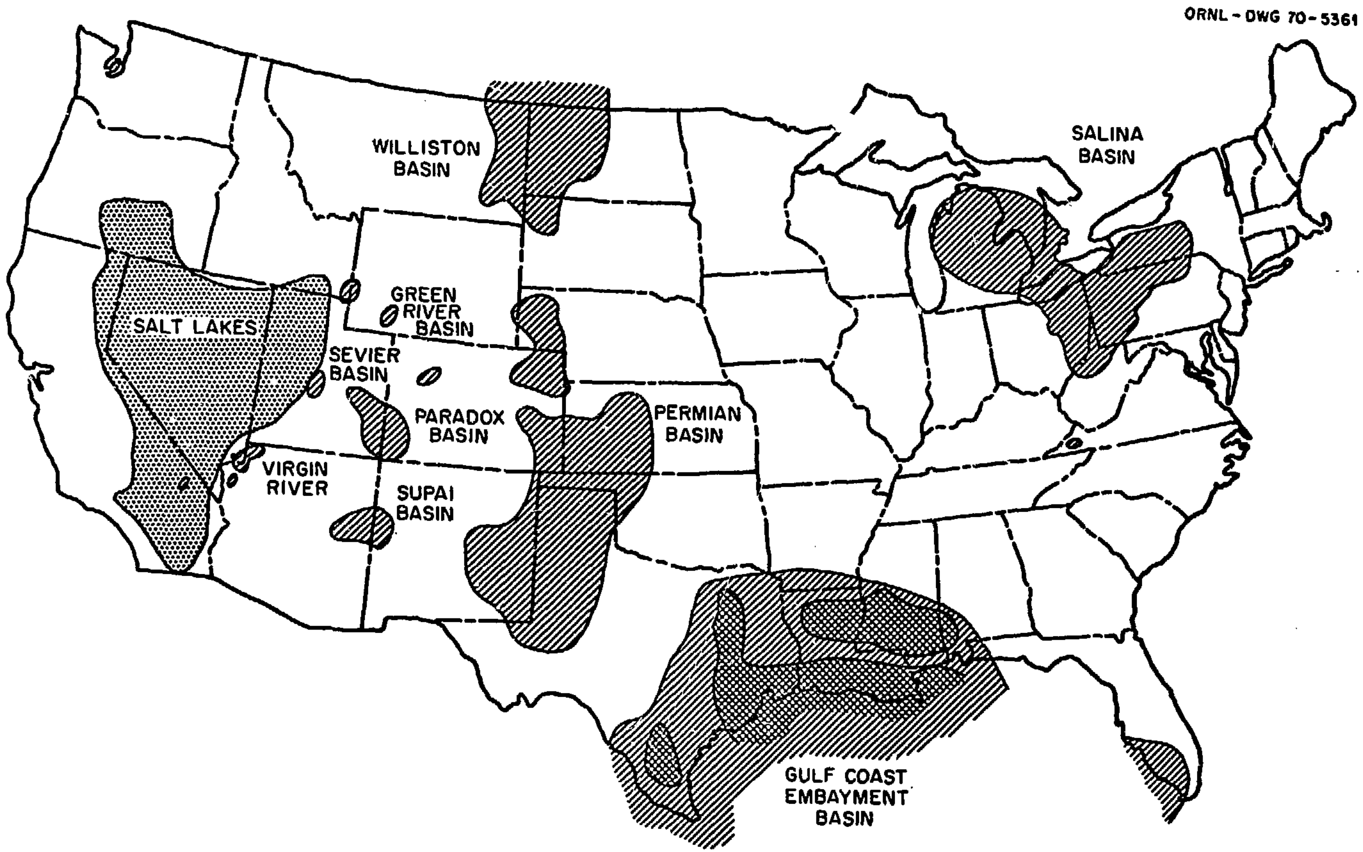

Fig. 3. Map of the Conterminous United States Showing Areas Underlain by Rock Salt--Double Cross-Hatched Portions of the Gulf Coast Embayment Represent Salt Dome Areas

selection since it is impractical to make and maintain excavations for a waste repository in salt beds at depths greater than about 3500 ft. For this reason the bedded deposits in the Gulf Coast Embayment, which are all greater than 4000 ft deep, were excluded from further consideration as were all the salt beds in the Williston Basin and large portions of the deposits in the Appalachian and Michigan Basins (Salina Salt Basin) of the northeastern states. The salt deposits in southern Florida were also rejected for repository use since they lie at depths of from 11,000 to 12,000 ft. In the western states, rock salt is known to exist at moderate depths in at least parts of the Paradox, Sevier, Supai, Green River and Virgin River Basins. Also, salt beds exist at favorable depths and thicknesses at the southern and northern tips of the Michigan Basin and in a portion of the Appalachian Basin in western New York state. Finally, some of the more than 300 salt domes in the Gulf Coast Embayment area lie at depths suitable for repository use. Undoubtedly, favorable conditions for the Bedded Salt Pilot Plant exist at many of these localities where the rock salt lies at moderate depths. However, due primarily to the extensiveness of the thick and shallow salt beds in the Permian Basin and to the tectonic stability of the region encompassing the Basin, specific site investigations have been confined to the Permian Basin and in particular to central Kansas, where a demonstration of disposal in salt was conducted recently in an abandoned mine, and to a large tract of federally owned land in southeastern New Mexico.

SITE SELECTION INVESTIGATIONS IN THE PERMIAN SALT BASIN

Extent and Thickness of Salt

Salt deposits occur throughout the Permian Basin which stretches from central Kansas through the Oklahoma Panhandle and into western Texas and eastern New Mexico, covering an area about 120,000 square miles. In general salt deposits within the basin become progressively younger, thicker and deeper toward the southwest; however, in most areas the salt body is found at depths of less than 2000 ft. As seen in Fig. 4, which shows the aggregate thicknesses of the principal salt bearing formations in the Permian Basin, it is seen that extremely thick beds of salt occur in the Salado formation in southeastern New Mexico in the study area. This slightly eastward dipping formation along with the overlying Rustler formation and the underlying Castile formation, which locally contain appreciable quantities of salt, comprise the Ochoan

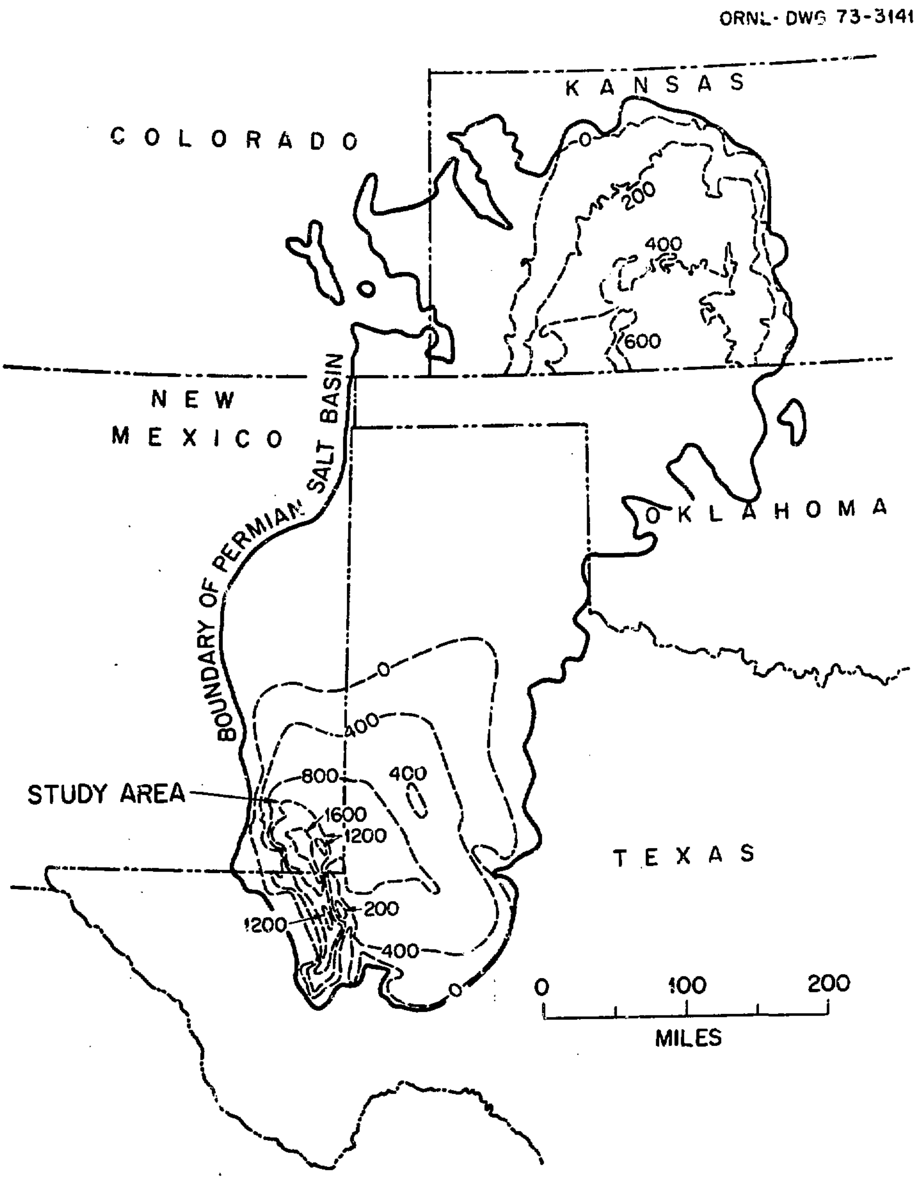

Fig. 4. Outline of the Permian Salt Basin Showing the Aggregate Thicknesses of the Salt in the Salado and Wellington Formations (After Hayes, P. T., 1958, "Salt in the Ochoa Series, New Mexico and Texas," U. S. Geol. Survey Trace Elements Iv., Report 709. 28 p., and Kulstad, R. O., 1959, "Thickness and Salt Percentage of the Hutchinson Salt," in Hambleton, W. H., Ed., Symposium on Geophysics in Kansas: Kansas State Geol. Bull. 137, p. 241-247.)

series of evaporites of Late Permian age. The Salado formation is characterized by thick salt beds with thin intervals of anhydrite, shale and polyhalite. Locally, near Carlsbad, New Mexico, the formation is also rich in potash minerals. In Kansas, the thickest and most widespread salt deposit is the Hutchinson salt member of the Wellington formation, a part of the Sumner Group of westward dipping Upper Permian rocks. Salt deposits have also been found in the younger Nippewalla Group of Permian rocks toward the southwest, but their distribution and thickness is not precisely known. The Hutchinson salt, as seen in Fig. 4, underlies central and south central Kansas and extends southward into Oklahoma. The eastern edge of the salt body lies approximately 400 ft below the land surface, but near its western edge in Kansas, it is found at a depth of more than 1500 ft. Thicknesses of the unit in the state range up to 700 ft. In general, the Hutchinson consists of a complex misture of salt, anhydrite and shale, with salt being the predominant fraction throughout most of its extent in Kansas. Figure 4 shows the salt to be the thickest in the south central part of the state. At Lyons, where a demonstration disposal in salt was completed recently in an abandoned mine and which was subsequently evaluated for its potential as a waste repository, the salt is about 300 ft in thickness but is a higher purity than in the thicker section to the southwest.

Tectonics and Seismicity

The Permian Salt Basin is located within the stable mid-continent area of North America which is characterized by low topographic relief and flat-lying beds of sedimentary rocks (see Fig. 5). Even though the Permian Salt Basin and the stable interior of the country have not yet been subjected to distrophic movements since Precambrian time, some areas have been structurally positive (rising) in the geologic past, while others have been structurally negative (subsiding). These ancient structural features, while largely masked by surface rocks today, are extremely important in the subsurface as they were instrumental in controlling the deposition of the salt rocks. Principal events in the geologic history of the region include, during the early Palezoic, the submergence and deposition of marine sediments on an irregular and long-eroded surface of Precambrian igneous and metamorphic rocks. During Mississippian and Pennsylvanian time, the region was alternately submerged and elevated before experiencing a period of aridity during the late Permian as evidenced by the extensive evaporite deposits of that age. Another major period of emergence and erosion occurred over most of the region

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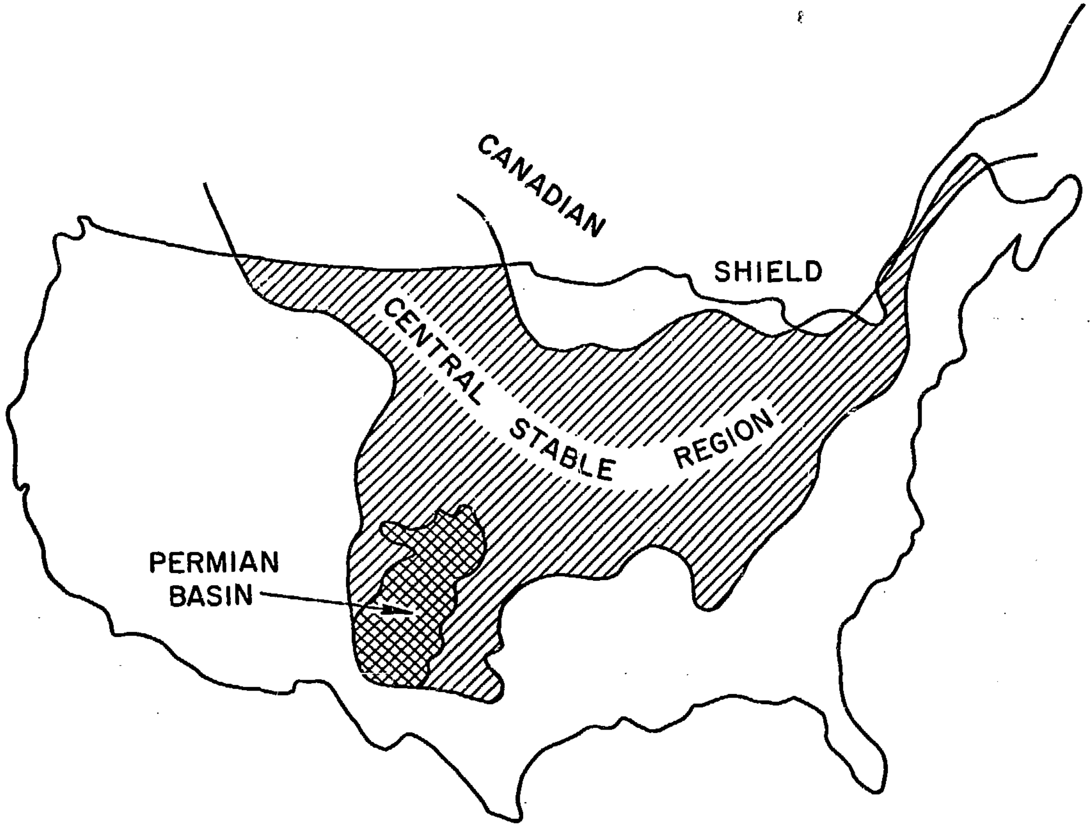

Fig. 5. Location of Permian Basin in Central Stable Region

during the Mesozoic era before the deposition of marine and continental sediments of mostly Cretaceous age. Erosion was prominent during the early Tertiary, but later eastward and southeastward flowing streams left thick accumulations of gravel, sand, and silt over the area. Some slight tilting and warping along with wind and water erosion have since formed the present plains landscape of the region.

In addition to the long geologic history of tectonic stability of the Permian Basin, as revealed by the generally flat-lying nature of the rocks and by the dearth of deep-seated faults and igneous intrusions, the seismicity of the region also suggests quiescence and stable tectonics. Figure 6 is a map of a part of the southwestern United States showing the epicentral locations of all major earthquakes recorded in that region. From this map it is observed that relatively few earthquakes have occurred within the Permian Basin during historic times. More specifically none have been recorded in the New Mexico portion of the Permian Basin, and only two have occurred within the Basin in central Kansas. The few earthquakes that have occurred within the Permian Salt Basin range up to a modified Mercalli Intensity Site rating of Vl (damage small) and are believed to represent minor adjustments in the underlying granitic crustal rocks. Outside the salt basin it is noted in Fig. 6 that the frequencies and intensities of earthquakes are markedly higher in tectonically active areas such as the Rio Grande Valley in central New Mexico and the Rocky Mountain front region of central Colorado.

Figure 7 is the most recent seismic risk map of the United States published by ESSA and the U. S. Coast and Geodetic Survey. As seen the entire Permian Salt Basin lies within zone 1 (expected minor damage), while most of the area to the west and a smaller area immediately to the east are designated zone 2 (expected moderate damage). The areas of expected major damage (zone 3) in the United States are associated with major active fault zones and/or areas that have experienced great earthquakes in historic times. It is significant that none of these zones of expected major damage lie close to the Permian Salt Basin.

Dissolutioning of Rock Salt

All rocks that lie relatively near to the land surface undergo some leaching by circulating ground waters. However, rock salt is unique in that generally only the uppermost surface is vulnerable to the leaching action of water as its self-healing properties preclude the development of open fractures, fissures,

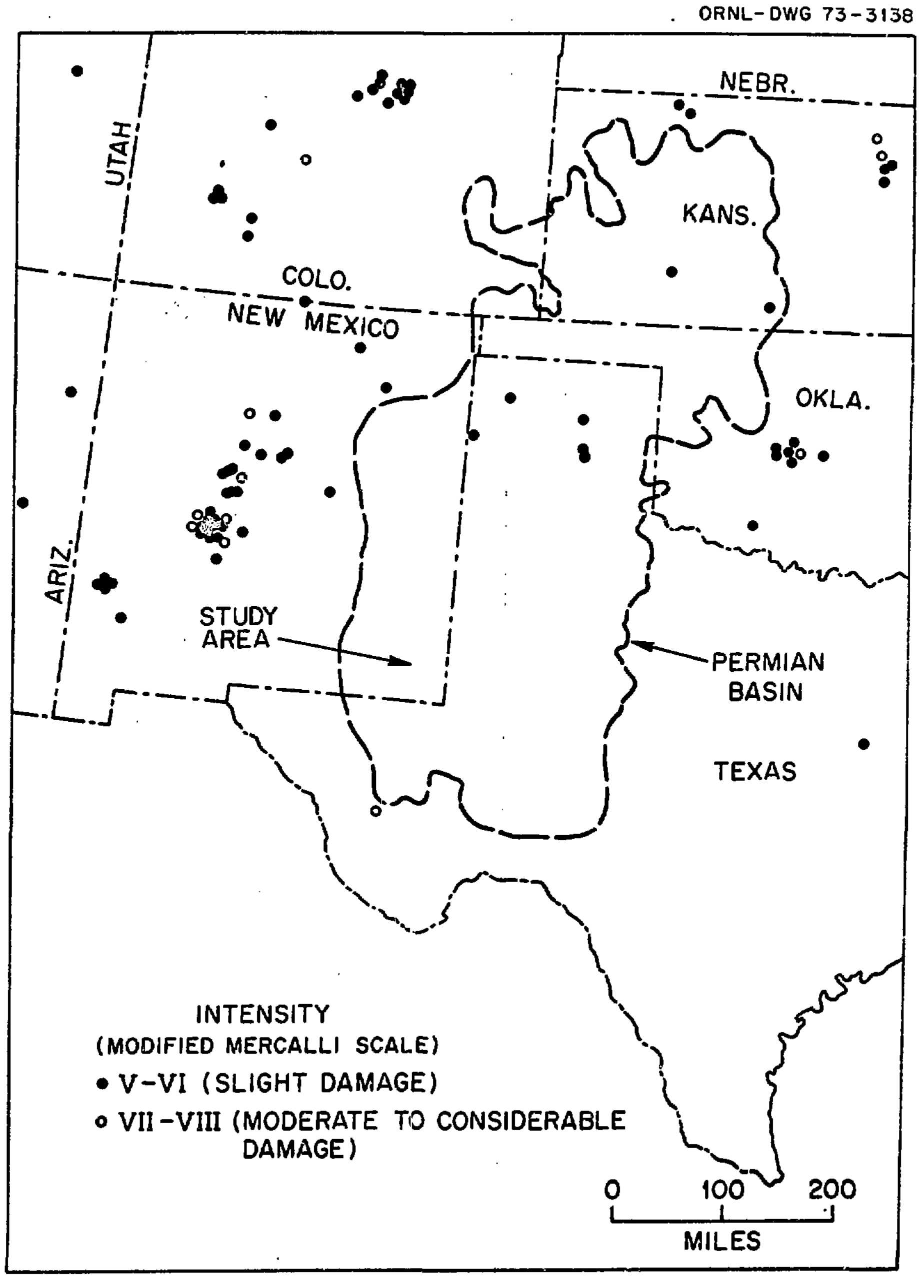

Fig. 6. Major Recorded Earthquakes in a Part of the Southwestern United States (Adapted from The National Atlas of the United States of America - U. S. Dept. of the Interior Geol. Survey, Wash., D.C., 1973.)

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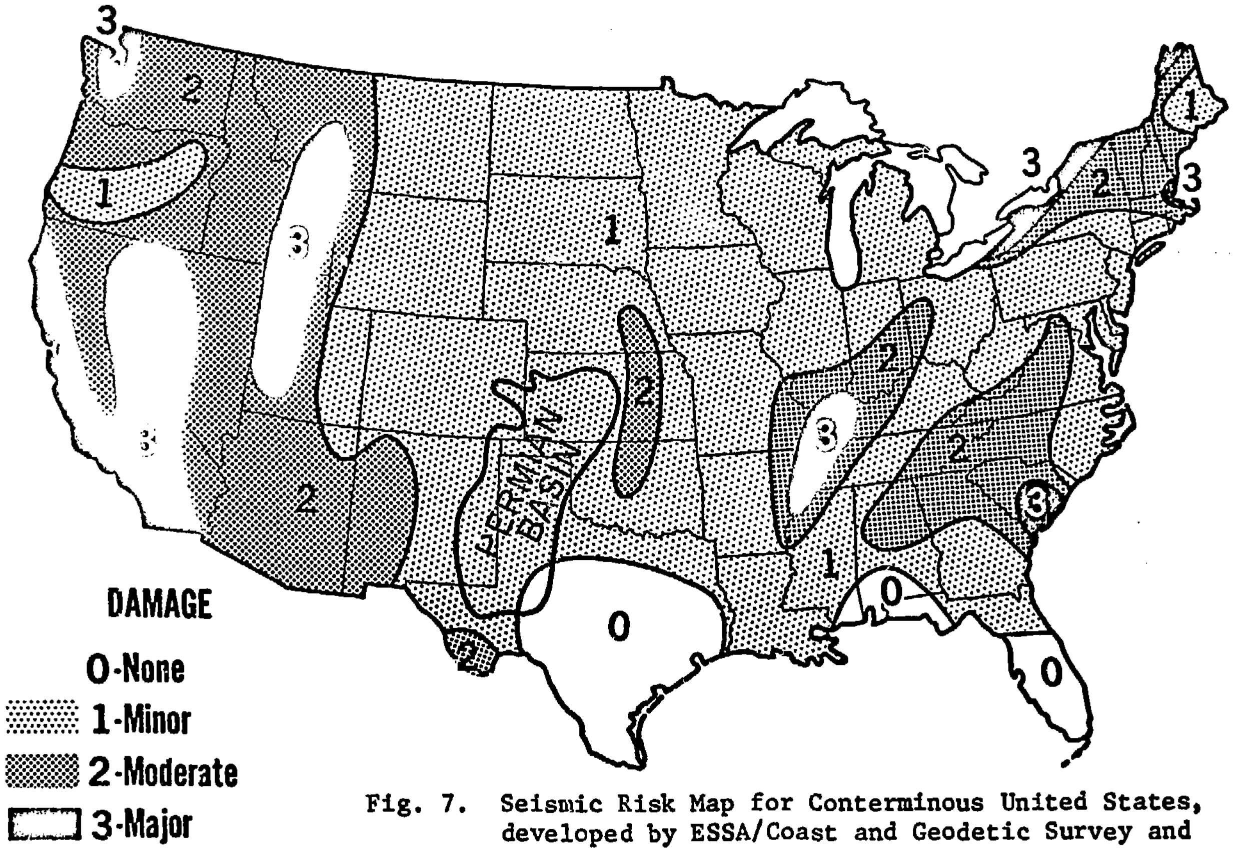

Fig. 7. Seismic Risk Map for Conterminous United States, developed by ESSA/Coast and Geodetic Survey and issued in January 1969. Subject to revision as continuing research warrants, it is an updated edition of the map first published in 1948 and revised in 1951. The map divides the U. S. into four zones: Zone 0, areas with no reasonable expectancy of earthquake damage; Zone 1, expected minor damage; Zone 2, expected moderate damage; and Zone 3, where major destructive earthquakes may occur.

and faults, etc., that provide the avenues for deeper and intraformational circulation in all other rock types. In the Permian Salt Basin dissolutioning of rock salt at shallow depths by circulating ground water is a common phenomenon. In central Kansas at least a part of the eastern edge of the salt basin has been dissolved in the subsurface by ground water as has the western edge of the salt in southeastern New Mexico. Active solutioning of shallow salt beds in other parts of the basin is also occurring as evidenced by the high salinities of rivers such as the Arkansas, Red, Canadian, Brazos, and Pecos that drain the region. Figure 8 is a generalized cross section of a portion of central Kansas that shows the prominent stratigraphic and structural features of the Hutchinson salt member. It is observed that the gently westward dipping salt body does not extend to the land surface but is dissolved along its eastern edge to a depth of several hundred feet. The abrupt end of the deposit coupled with an overlying series of subsidence ponds and salt water springs strongly suggest that the original limits of the salt extended somewhat further eastward. Channel-fillings of Pleistocene and older sediments near the edge of the salt show a distinct westward progression of younger sediments that are presumed to have been laid down as the underlying salt was removed in that direction. Precise dating of these sediments indicate that during the last few million years the edge of the salt body has retreated westward at the rate of a few miles per million years. Therefore, only the first few miles of the salt body along its eastern edge would be vulnerable to dissolutioning by this phenomenon for the lifetime of the wastes or for the next few hundreds of thousands of years.

In southeastern New Mexico the western boundary of the Permian Salt Basin is believed to have migrated eastward at the rate of a few miles per million years during the recent geologic past. From Fig. 9, which depicts the present state of the salt and overlying beds in the region near Carlsbad and the study area, it is apparent that the uppermost beds of salt once extended further west but were subsequently eroded with the development of the Pecos River Valley east of the Guadalupe Mountains. Indeed, Bachman[2] has suggested that at the close of Ogallala time (4 million years ago) the Salado salt may have extended as far westward as the base of the Guadalupe Mountains or another 25-35 miles. With this premise he concluded that the rate of retreat averaged some 6-8 miles per million years during this span of time. Furthermore, Bachman[2] has found that the quantities of salt presently being removed from water sheds within the Permian Salt Basin range up to about 0.5 ft/1000 years. With these rates of vertical and horizontal removal of salt, it is seen that the study area, which is some 20-30 miles from the western edge of salt and is more than 1000 ft deep into the salt beds, would not be affected by dissolutioning for the next few hundreds of thousands of years or for the duration of the wastes.

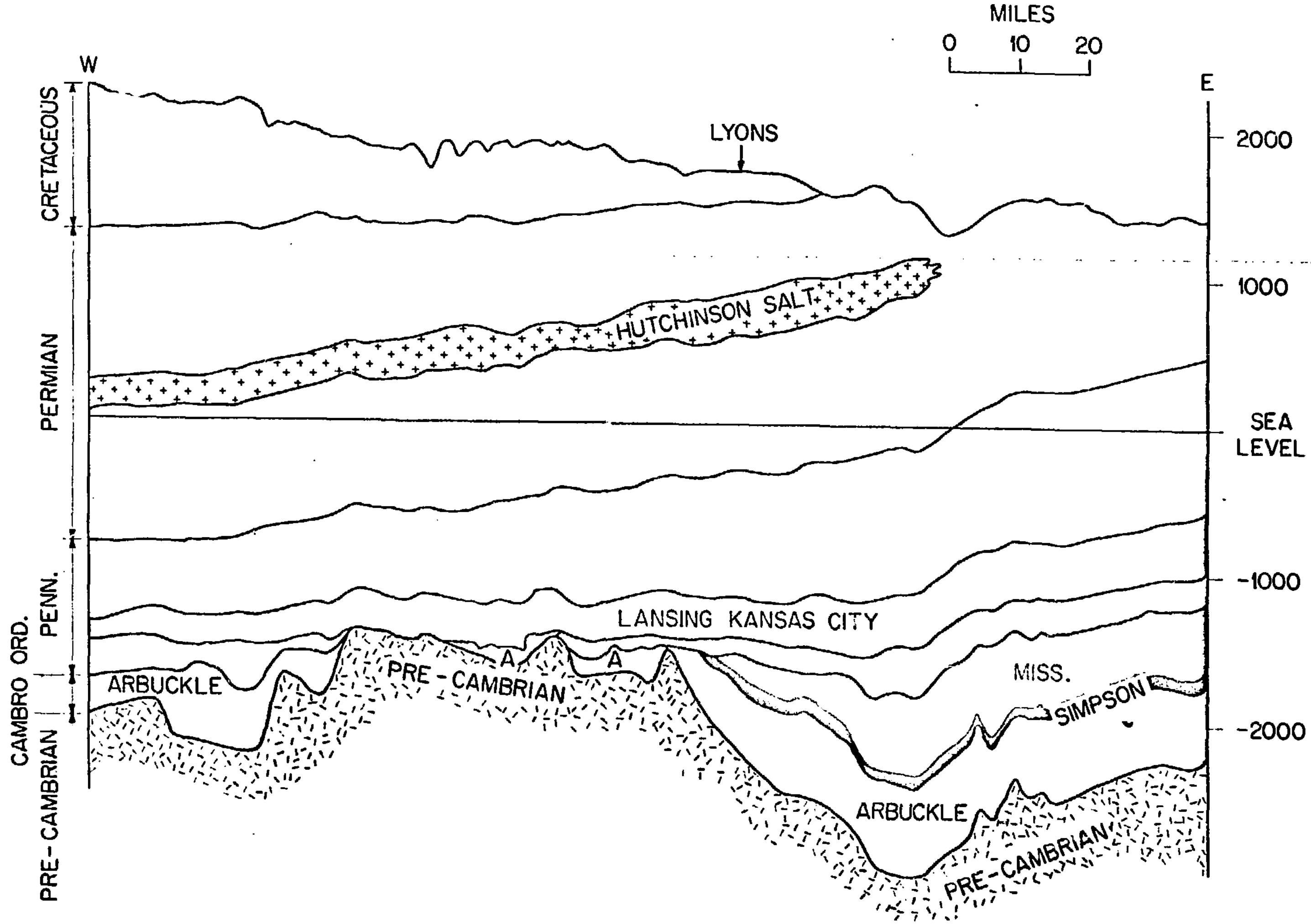

Fig. 8. Geologic Cross Section of a Portion of Central Kansas

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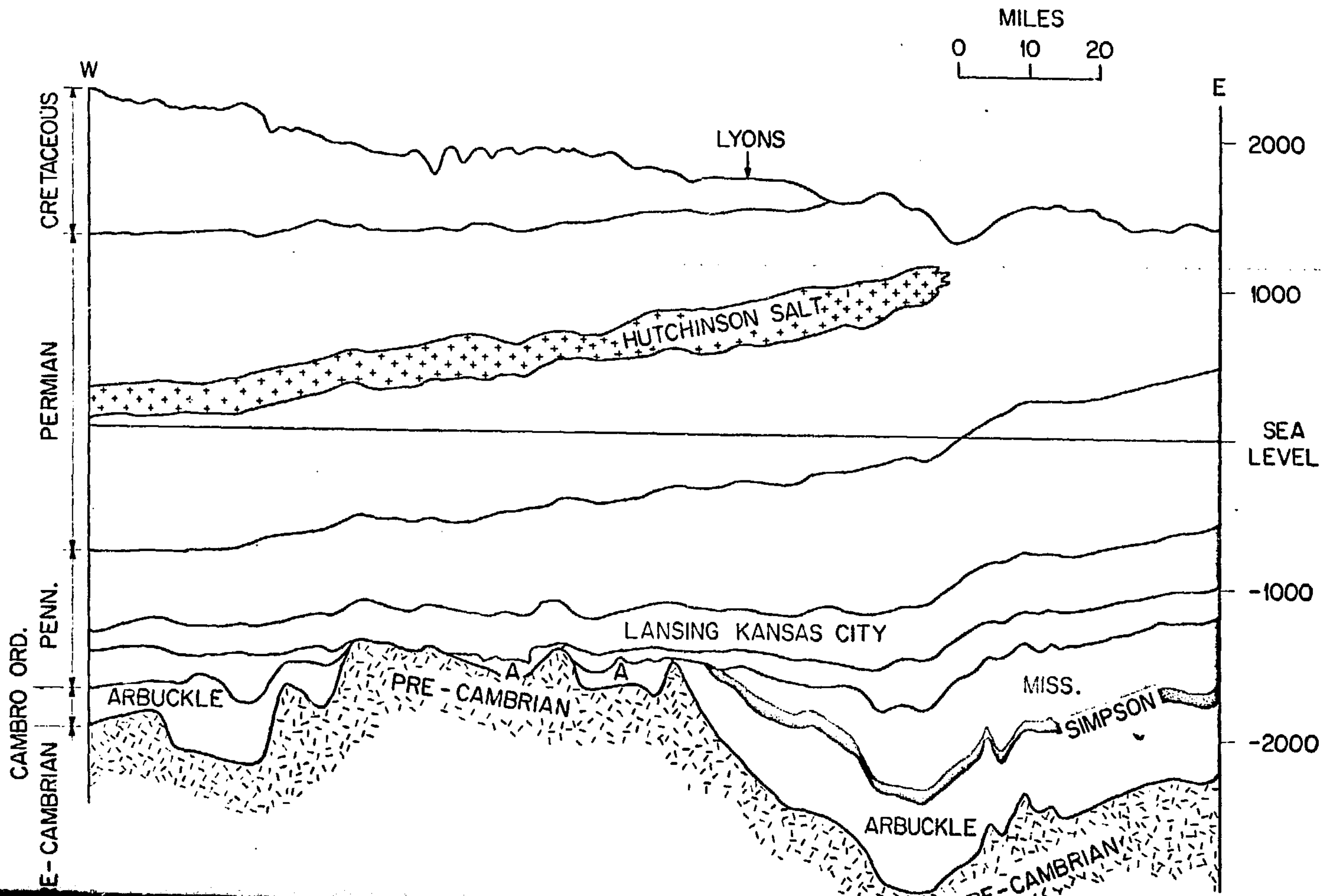

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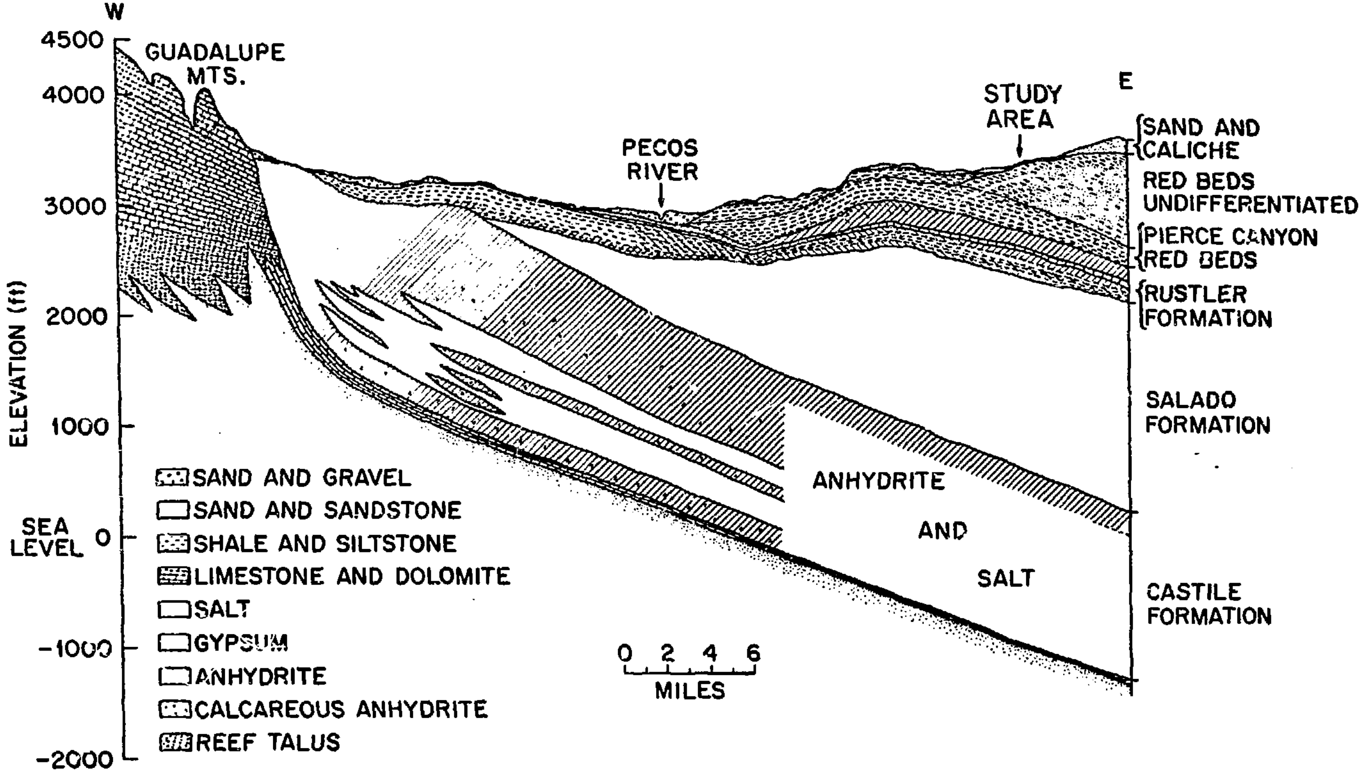

Fig. 9. Generalized Geologic Cross Section of a Portion of the Rocks in Southeast New Mexico (Adapted from Cooper, James B., 1960, Geologic Section from Carlsbad Caverns National Park through the Project Gnome site, Eddy and Lea Counties, New Mexico, TEI-767

Mineral Resources

Significant quantities of potash ore and extensive deposits of oil and gas occur in selected localities of southeast New Mexico. To preclude conflicts of interest in the economic development of the region, the rocks underlying the study area of the Pilot Plant should preferably have a low potential for oil or gas development and should not contain extensive high-grade potash ores. Potash mines in the southeast New Mexico region produce more than 80% of all the potassium minerals mined in the U. S. However, most of the higher grade commercial ore within the area is nearing depletion. As seen in Fig. 10, which depicts the locations and extent of the underground workings within the region, most of the mining has centered along a northward trending belt some 10-12 miles east of Carlsbad, although two mines have been opened 6-8 miles further to the east. The study area is more than 5 miles from the nearest workings and is far removed from the important mineralized bodies of ore. Indeed, the site is located outside the potash mining district as designated by the Secretary of the Interior, May 1965.

Figure 11 is a generalized oil and gas map of a portion of southeast New Mexico. In this map it is seen that major oil and gas fields have not been discovered in the vicinity of the study area, although some localized accumulations of oil and gas are known to occur in nearby rocks. Exploration for gas has intensified recently in the deeper rocks of southeastern New Mexico and will undoubtedly lead to a renewed interest in the deeper rocks in the vicinity of the study area.

Hydraulic Testing in Open Boreholes

Since circulating ground water is perhaps the only mechanism for dispersing and transporting radioactive wastes placed in rock salt, it is essential to determine the hydrological characteristics of the rocks that lie in close proximity to the salt. In the Permian Salt Basin fresh water is generally confined to the first few hundred feet of surface rocks while saline waters commonly occur in the rocks below the salt beds. The hydraulic characteristics of water-bearing rock formations can best be identified through testing in open boreholes. In Kansas, hydraulic tests have been made in boreholes near the Lyons site as well as the more northern part of the basin. These tests showed that the rocks immediately above and below the salt beds were extremely tight and incapable of transporting significant quantities of ground water; however, at greater vertical distances from the salt some prolific water-bearing

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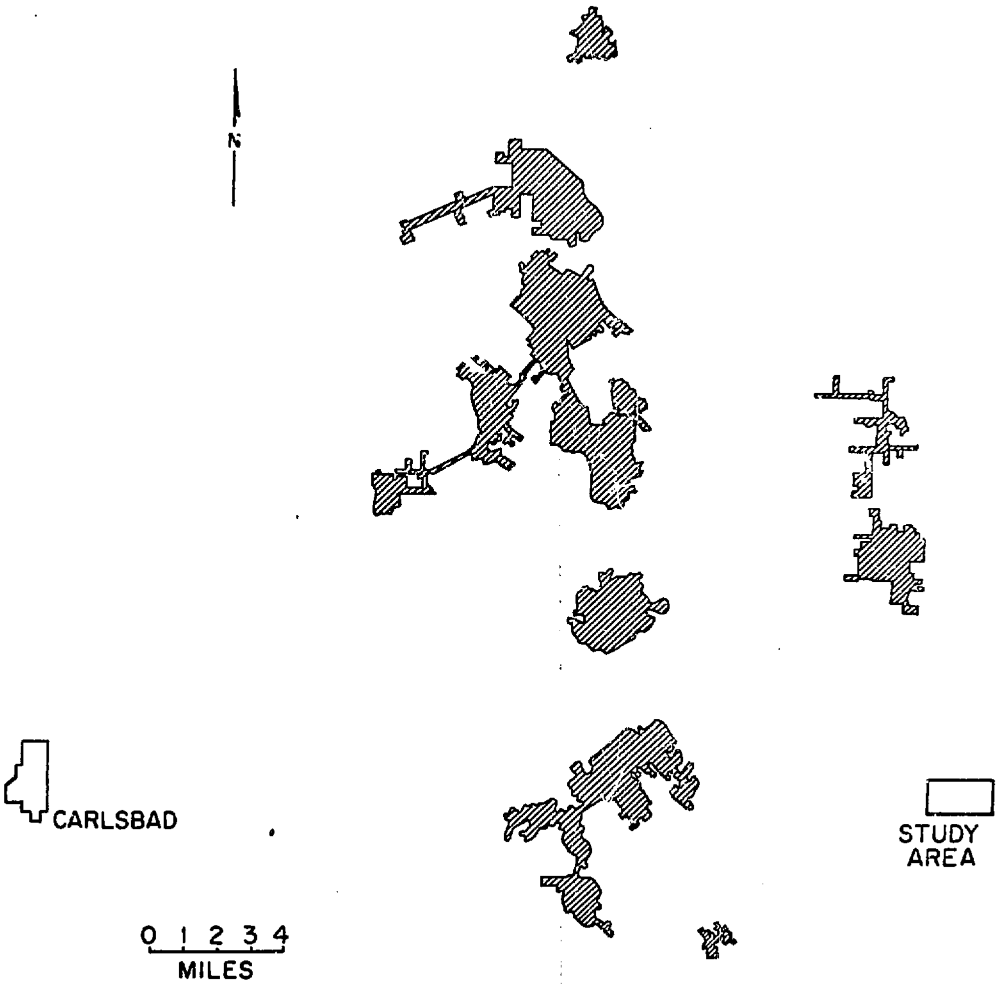

Fig. 10. Map of Potash Workings, Southeastern New Mexico

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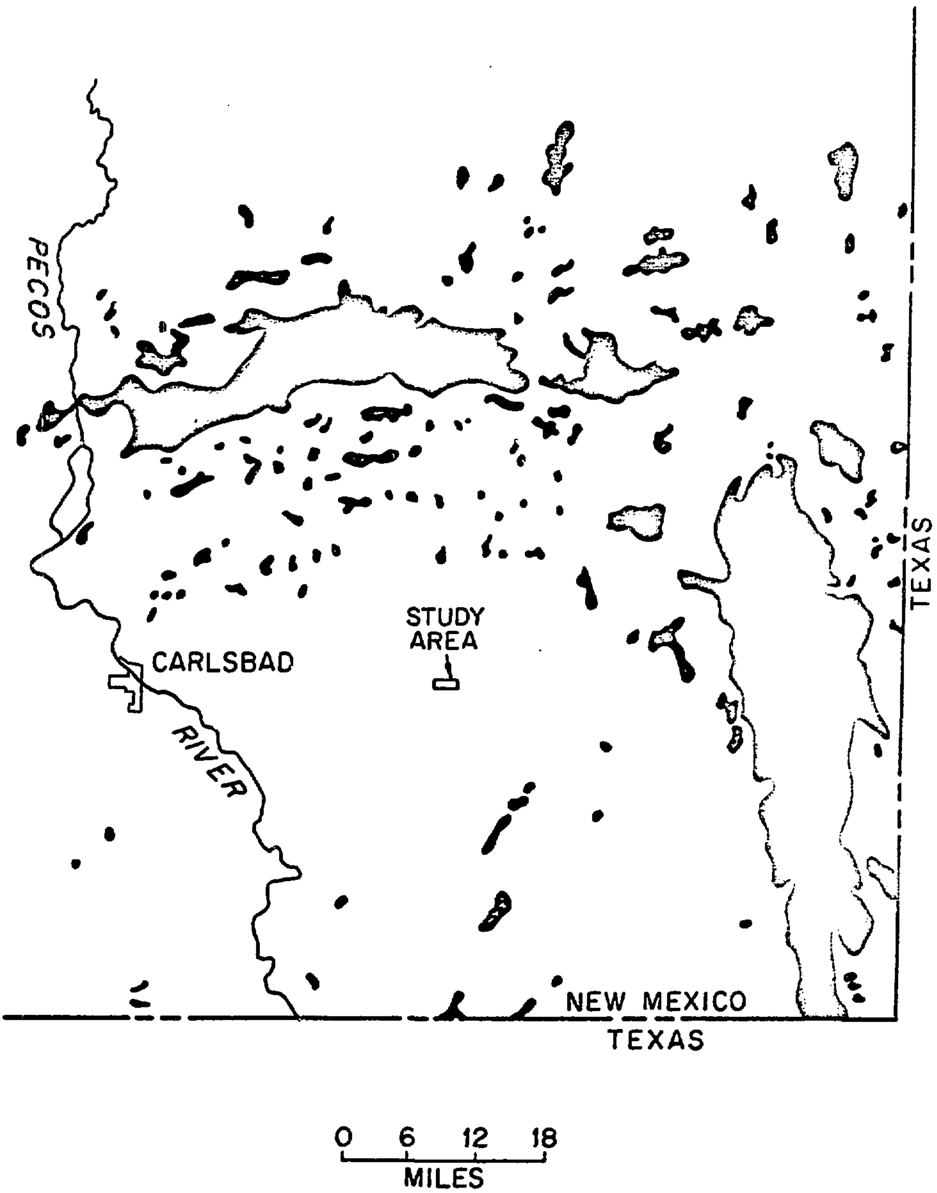

Fig. 11. Map of Oil and Gas Field in Southeastern New Mexico

zones were found. Thus, the Hutchinson salt is intact and not undergoing dissolutioning at the test sites.

For the study area in southeast New Mexico hydraulic tests will be conducted in a series of boreholes as illustrated in Fig. 12. As seen the boreholes will penetrate all of the rocks overlying the salt and will extend some 2000 ft into the salt or to a depth of about 1000 ft below the disposal level. Since rock salt is known to be impermeable, all water zones penetrated by the holes will lie above the salt rocks. To test specific water-bearing zones, inflatable packers will be set in the holes above and below the water zones. The isolated intervals will then be subjected to slug and/or swabbing tests. For the higher yielding aquifer (Santa Rosa Sandstone) pumping tests will be made. These tests will be used to determine such things as formation transmissivities, yields and hydraulic conductivities. Pumping tests will then be made over the combined water bearing-zones to ascertain the adequacy of the individual tests and to give assurance that all water-bearing zones have been identified.

Erosion and Denudation

In extreme cases the natural geologic processes of erosion and denudation have the potential, over long periods of geologic time, for stripping away significant quantities of overburden and subjecting wastes that are buried at shallow depths to circulating ground and surface waters. Based on general knowledge of the Great Plains' landscape and on the sediment loads of streams that drain the province, it appears that the rates of denudation and stream incision within the Permian Salt Basin range up to only a few hundreds of feet per million years. This general conclusion is substantiated in part by the recent work on erosion and denudation in the Lyons, Kansas, area.[3] Based on the precept that glacial and interglacial episodes similar to those of the Pleistocene will continue throughout the next one million years, Stewart concludes that the probability that stream erosion will leach the salt formation in the Lyons area is judged to be so small that it is inconsequential. By extrapolating and adjusting present day rates of denudation in central Kansas to accommodate glacial as well as interglacial conditions, Stewart also finds that, for all practical purposes, the probability of denudation exceeding 25 ft during the next one million years in the Lyons area is zero. Should continental glaciers advance into central Kansas, Stewart judges that the flow patterns of the major streams will not change appreciably nor will the rise and fall of sea level accompanying

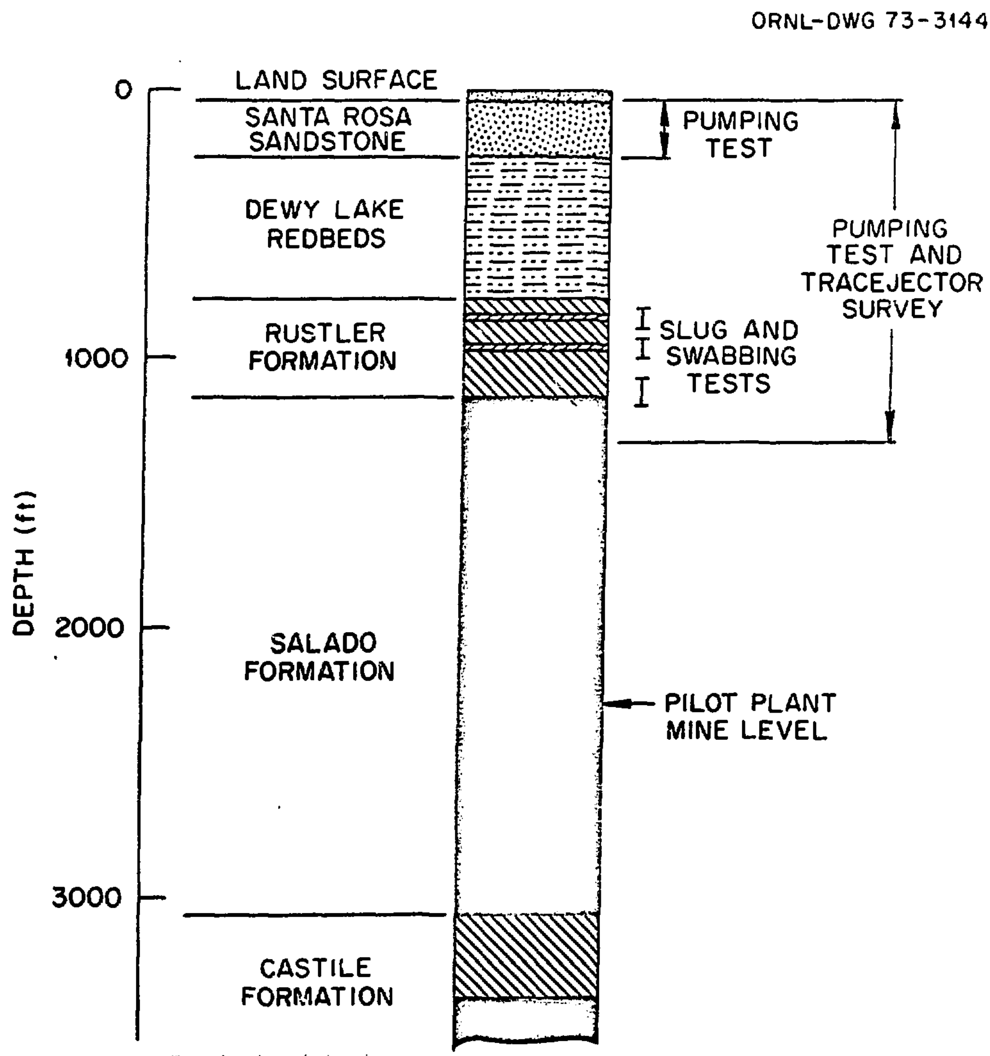

Fig. 12. Hydraulic Tests in Boreholes, Southeastern New Mexico

glaciations and interglaciations affect stream entrenchment and valley alluviation in the midcontinent. The effects of new ice sheets on the underlying rocks in central Kansas have also been evaluated and it is concluded that deep scouring is unlikely and only minor fracturing and flexuring would be expected in the near surface rocks due to glacial loading and unloading.[4]

Rock Properties

In order to establish the stratigraphic levels for waste disposal and to provide sample specimens for mineralogical determinations and rock-property testing a series of core holes are drilled at the study areas. In central Kansas mineralogical studies of cores indicate that hydrated minerals and water-bearing rocks occur throughout the evaporite section with a general decrease in water content with depth.[5] Upon heating sample specimens to 100°C it was found that gypsum is the major mineral constituent for rocks that lose more than 10% water. Similarly for rocks that lose from 2 to 10% water upon heating, shales are dominant or the rocks have high clay contents. The relatively pure halite rocks were found to lose less than 2% water upon heating. Thus, to avoid extensive dewatering, the heat-generating waste containers should be placed only within the relatively pure halite beds of the evaporite sequences. The cores also provide samples for establishing the thermal and mechanical properties including conductivity, specific heat, density, eleastic moduli, Poisson's ratio, etc., for the several rock types at the study areas for use in thermal analysis calculations and the rock deformation analyses.

CONCLUSIONS

Rock salt, because of its plastic flow characteristics, is impervious to the passage of ground water and thus is the preferred geologic medium for the ultimate disposal of high-level radioactive wastes. Rock salt is also widely distributed, being known to underlie portions of 24 of the 50 states. For selected areas within the Permian Salt Basin, which extends beneath a portion of several southwestern states, thick deposits of essentially flat-lying beds of rock salt are known to lie at depths that would be suitable for disposal of wastes. In addition the entire basin is located in the stable interior of the continent where major earthquakes occur infrequently. Dissolution of rock salt in the subsurface is a common phenomenon throughout the Basin; however, it proceeds at such slow rates that the containment of buried wastes would not be jeopardized. Erosion and denudation rates within the basin are also judged to be extremely small and would not be expected to uncover the salt for the effective duration of the wastes. Thus because of its long history of tectonic stability and the characteristics of the salt, the Permian Basin is judged to contain suitable areas for the long-term containment of radioactive wastes.

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