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THE PERMIAN BASIN AS A RADIOACTIVE WASTE REPOSITORY

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by

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for

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Introduction

The Permian Basin is not a structural basin. Instead, it is portions of many structural basins in which halite was deposited close together aerially during the Permian Period of time.

The Permian Basin contains at least five areas where salt beds within a formation cumulatively total greater than 200 feet, and are overlain by between 1,000 and 5,000 feet of strata (Figure 1). These are the Colorado-Kansas, Kansas, Oklahoma-Texas, Clovis and Carlsbad areas.

A few other areas within the Permian Basin may contain salt beds collectively greater than 200 feet thick, but published information about much of the remainder of the Permian Basin is scarce.

The Carlsbad area contains a great thickness of salt and covers a very large area (Figure 1). For the Clovis and Oklahoma-Texas areas there is little data available for the Texas portions. The Kansas area has the only halite mines with rooms comparable to those of the proposed waste repository facility. There is little data available for the Colorado-Kansas area, especially for the Colorado portion.

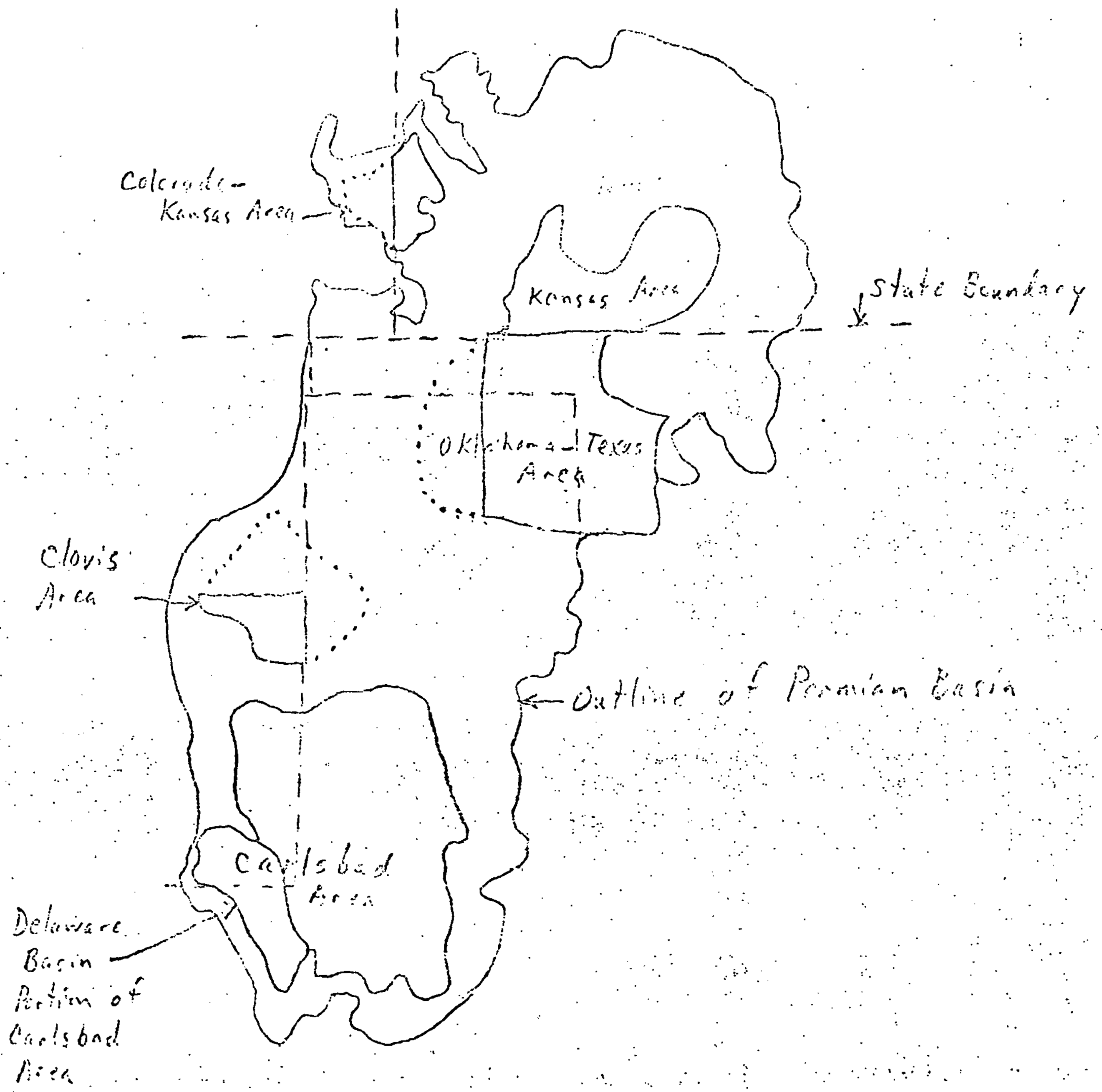

Figure 1 Areas with a 200 foot, or greater, Thickness of Halite between 1,000 and 5,000 feet below Ground

The Permian Basin major tectonic elements were formed before deposition of Permian salt beds, and only minor igneous activity and possible fault movement is along the peripheria. The greatest seismic activity is associated with the Nemaha Ridge along the northeast side of the Permian Basin, and there is no proven movement, only a suggestion of movement in the form of lineaments (Smith et al., in press), to have caused man recorded earthquakes. All of the Permian Basin is in zone 1 of Coffman and Cloud (1970) where only distant earthquakes may cause damage to structures; therefore, ground rupture is not anticipated in the Permian Basin during the time that the radioactive waste is dangerous.

Carlsbad Area

I. Physiographic Setting

According to Fenneman and Johnson (1930) the Carlsbad area is within the Interior Plains major division, Great Plains province, and mainly the HighPlains section but includes small areas of the Pecos Valley section and the Edwards Plateau section. The main characteristic of the land surface is broad intervalley remnants of smooth fluviatile plains, but the Pecos Valley in the southwestern portion of the Clovis area is a late mature to old plain and the Edwards Plateau in the southeastern corner of the area is a young plateau with mature margin of moderate to strong relief. Perennial streams are rare, and there are a few intermountain basins and playas. Glaciers will not likely extend this far south for the next quarter million years.

II. Tectonics and Seismicity

Since Precambrian time the area has gone up and down several times with epeirogenic movements as evidenced by marine and continental sediments interbedded and unconformities. Also the ground level of the area is 3,000+ feet above sea level. Locally there has been differential movement between two basins, the Midland Basin and Delaware Basin, and an intervening area called the Central Basin Platform (Figure 2) producing major northwest striking faults between basins and intervening area (Bayley and Muehlberger, 1968). From the cross section one can interpret that subsidence of the basins took place during most of Paleozoic time. More than 20,000 feet of sediments accumulated in the Deleware Basin. Much of the Permian sediments came from the Ouachitas to the south which were actively being overthrust at this time. Permian rocks are gently tilted and warped. Eardley (1951, p.229-230) has noticed minor linear tectonic features such as flexures in the Guadalupe Mountains west of the Delaware basin, and some linear features are faults. Most of the features he believes were formed during the Permian, but some moved again in the Cenozoic. It has been suggested that the Central Basin Platform is comparable to block-faulted mountain ranges, but vertical movement of the basins unrelated to major tensional forces seems more plausable due to lack of structural features of tensional origin in surrounding areas.

Figure 2 Cross-section of Delaware and Midland Basins and Central Basin Platform

Eardley, p.229

III. Stratigraphy

Complete Column

The Carlsbad Area sediments were deposited in two basins and two different major stratigraphic sections developed, one in the Delaware Basin and the other in the Midland Basin. Figure 2 shows the interrelation between these basins with carbonate reefs, such as the Capitan Reef having developed in shallow water around the peripheria of the basins. The generalized stratigraphic column for the Gnome site (Figure 3) serves as a good example of Delaware Basin stratigraphy.

Deposition was thickest in the central part of the Delaware Basin, but some formations are thickest on the margins as exemplified by Pennsylvanian strata and some evaporite beds. Major lateral changes in sedimentary rock of the basin occur at the reefs. Shelf rocks close to the reefs consist of dolomite with subordinate amounts of limestone, shale, sandstone and a little anhydrite. Further away from the reefs onto the shelf area dolomite tends to give way to anhydrite. Deposits of the basin are typically shale, fine-grained sandstone, and dark-colored limestone.

Figure 3 Generalized Stratigraphic Column at Gnome Site
and Desctiption of Lateral Variations

Brokaw et al., 1972, p. 18

Salt Bearing Formations

There are two formations that contain many thick salt beds in the Delaware basin, Salado and Castile. The Midland basin contains only the Salado. The Rustler Formation overlies the Salado in both basins, but the Rustler contains only a few thin beds of salt. Areas with more than 1,000 feet of overlying strata and greater than 200 feet of combined thickness of salt beds in the whole stratigraphic section are shown on the map of Figure 1. Several isopachus maps of salt bearing formations are available (Brokaw, et al., 1972 and Jones et al., 1973). Salt bed variability in thickness across the basins is shown in Figure 4. From this cross section one can see that beds in general are thicker and more numerous toward the center of the basins. Thickest salt beds occur in the Salado Formation.

The Salado Formation contains thick beds of salt and thin intervals of anhydrite, shale, and polyhalite. Locally the middle part of the formation is rich in potash minerals. Salt of the Salado Formation is generally less pure than that in the Castile Formations. Exceptions are the very pure basal beds of the Salado Formation in the Delaware Basin. The thickest salt unit in the Carlsbad area of more than 1,700 feet is on the east and north side of the Delaware Basin within the Salado Formation. In the center portion of the Midland basin there is a salt unit in the Salado Formation more than 1,000 feet thick. Overlying the Salado

Figure 4 Cross-section of Salt Beds in Delaware and Midland Basins

Pierce and Rich, p. 34

Formation is the Rustler Formation which contains much anhydrite. And the underlying rock type is in most places, anhydrite. Anhydrite above and below the Salado Formation likely acts as barriers to water which might dissolve the salt. The Dewey Lake Red beds about 500 feet above the salt beds of the Salado Formation probably contain permeable water bearing zones. The Santa Rosa Sandstone about 1,000 feet above salt beds of the Salado Formation is definitely permeable and water bearing.

The Castile Formation

The Castile Formation is restricted to the Delaware basin. There are several beds of relatively pure rock salt up to 700 feet thick. A maximum aggregate thickness is about 1,000 feet. Salt beds are separated by anhydrite beds up to 500 feet thick. Salt comprises no more than 60 per cent of the formation thickness. Fine grained sandstone of the Bell Canyon Formation immediately underlies the Castile Formation in most areas. The sandstone is likely permeable and water bearing; yet, overlying and underlying salt beds there are beds of anhydrite which act as barriers to water which might dissolve salt.

Overlying permeable water bearing strata are the Santa Rosa Sandstone about 3,000 feet above thick salt beds in the Castile Formation, and the Dewey Lake Red beds possibly carries water about 2,500 feet above.

IV. Structure

Major structure is very gently dipping strata inward toward the central areas of two basins: the Midland Basin with a maximum of about 10,000 feet of strata and the Delaware Basin with a maximum of about 20,000 feet of strata. The basins are separated by an extremely gentle arch, the Central Basin Platform.

The Central Basin Platform has two main fault zones on either side of the elongate Platform which trends north-south. The faults are steep with the down side toward basins. Near the south end of the Platform there are several intersecting faults which strike northwest.

There are faults which almost encircle both the Midland and Delaware Basins (Cohee, 1962). Many faults are along the west side of the Delaware Basin (King, 1948 and Hayes, 1964), and Kelley (1971) has interpreted a prominent lineament as one of these fault traces; therefore, this fault may be of Holocene age. He has also mapped slight warps in strata of the backslope of the Sacramento Mountains, and these structures may extend into the salt beds (Bachman, et.al., 1973, p.23).

At least three alkali syenite dikes cut the Castile Formation south of Carlsbad. They are 1,000 to 4,000 feet long, strike about N60°E, and dip is about 80°N (Bachman and Johnson, 1973, p. 23 & 24). And on the south side of the Delaware Basin there is a large field of Tertiary volcanic rocks, the Davis Mountain Volcanic Area (Cohee, 1962).

In the Midland Basin a few miles southwest of Midland is the Odessa Disturbance covering about 10 acres. In an area of almost horizontal strata there are dips up to 30° near the Odessa crater. Many meteorites have been found in the immediate area establishing a meteoritic origin for the feature. There are many solution depressions in the surrounding plain (Lobeck, 1939, p.712 and 716). There are many lineaments, especially with a northwest strike, over most of the Carlsbad area. A few have been attributed to deflation between longitudinal sand dunes (Bachman, et. al., 1973, p.35). Olive (1957) has explained lineations in Eddy County, not far from Carlsbad, as due to solution-subsidence troughs along joint systems in gypsum.

Small Holocene domes have been described in southeastern New Mexico by Vine (1960, p. 1910-1911) as a result of weathering and prehaps combined rising of salt.

Of great concern is possible mobilization of the salt during the storage time of the radioactive waste, 250,000 years. During recent drilling in the Los Medanes area by Sandia Corporation a possible salt piercement type structure was encountered in the Castile Formation. A prominent bed of salt within the Castile Formation has been known for some time to have been deformed. Until recently this deformation has been interpreted as having occurred a short time after deposition and caused by tilting of the strata and subsequent gravity sliding of the salt bed which caused multiple folds to form at this one horizon and not to have affected beds above and below (Figure 5). The only other apparent cause for an internal bed of a formation to be deformend is by plastic flow due a unique load pressure to thickness of salt ratio plus possibly some irregularities of the salt bed prehaps caused by original processes of sedimentation. Prehaps a combination of interformational folding and plastic flowage has and is taking place, or maybe the folding and plastic piercement took place at the same time, long in the geologic past. "The folding has resulted in some bucking and downwarping of rocks in the Salado Formation, and it has uplifted the Salado and other rocks as young as the Chinle Formation ... it can be dated only very broadly as post-Late Triassic to pre-Pliocene." (Jones, et.al., 1973, p.32-33).

Figure 5 Folds in Castile Formation

Jones et al., 1973, Figure 3

V. Hydrology

Surface Water

The Pecos River runs along the southwest side of the area. This is the only major perennial stream. It flows to the southeast. Most of the area drains east-southeastward across a plateau along subparallel temporary streams such as Sulpher Springs Creek. The area is very arid, and there are many temporary lakes and small playas. There are only a few small, permanent lakes, and some are man made. One perennial lake is Salt Lake, east of Loving.

Ground Water

The main aquifers are the Culebra Dolomite Member, the basal solution breccia zone of the Rustler Formation, and the Santa Rosa Sandstone. Locally the Gatuna Formation is an aquifer. The basal solution breccia zone is the unit that is most significant in solution of rock salt in the upper part of the Salado Formation. Formations above the Salado seem to be interconnected and constitute a single hydrologic system, and a map of the water table (Brokaw et al., 1972, p.44) is useful in predicting flow within the formations above the Salado Formation. The water table is 200 to 1,400 feet above rock salt in the Salado Formation. Near Carlsbad groundwater above the Salado Formation moves generally southward and southwestward into the Pecos River near Malaga Bend (Brokaw et al., 1972, p. 56).

Permeability of the Salado Formation is low. Locally there is great permeability due to fractures or solution cavities. Occassionally small pockets of water or gas are encountered in mining operations near Carlsbad. The dissolution front of the Salado Formation is estimated to have moved laterally at a rate of 3½ to 4 miles per million years (Bachman et al., 1972, p. 60).

Aquifers below the Salado Formation are the Capitan Limestone, Yates, and Tansill Formations, and water in them is under strong artesian pressure. The potentiometric surface is largely above the land surface. Some of this water may move upward and dissolve overlying salt beds. The distribution of chlorine in the water around Carlsbad suggests to Bachman et al. (1972, p.62) that upward movement of water does take place.

VI. Mineral Resources

The Carlsbad area contains potash mines, oil and gas fields, aquifers, and a site where a nuclear blast device was tested, and two areas of solution mining tests. Potash salts are recovered from the evaporite salt beds of the Salado Formation. Mineable deposits are restricted to a zone in the middle member of the formation. The underground workings are shown by Brokaw, et al. (1972) on their Figure 16. There are many exploratory holes in the area. Exploratory holes at the Los Medanos area have been plotted on a map by Jones, et al. (1973, Fig.12).

Oil and gas fields are shown on the map of Brokaw, et al. (1972, p.77). "The area will probably continue to be one of the most actively explored areas in the nation ..." (Brokaw, et al., 1972, p.78). Many holes drilled in the search for petroleum have passed through the evaporite beds and entered producing horizons which have been tabulated by Brokaw, et al. (1972, p.76).

The main aquifers from which water is obtained are the Culebra Dolomite Member, the basal solution breccia zone of the Rustler Formation, and the Santa Rosa Sandstone. Locally the Gatuna Formation is an aquifer. Location and other data on water wells in the Los Medanos Area have been tabulated by Jones, et al. (1973, p.45).

The Gnome site where a nuclear device was detonated is about 25 kilometers southeast of Carlsbad, and there is much data on the geology of the site, and a brief summary and availability of data are presented in a report by Brokaw, et al. (1972). The shot chamber was located in the upper third of the salt section of the Salado Formation.

The two solution mining tests were conducted 10 to 30 miles northeast of Carlsbad (Brokaw, et al., 1972, p.73). The projects have been abandoned for many years.

VII. Physical and Chemical Properties

Small pockets of gas or water under high pressure are occassionally encountered during potash mining operations near Carlsbad (Brokaw, et al., 1972, p.60).

Hydrated evaporite minerals are abundant in the Salado and Rustler Formations, but they do not form massive units in the Castile Formation.

VIII. Conclusions and General Evaluation of Rocks for Waste Repository

Rock salt beds are very thick in both the Salado and Castile Formations, but they are thickest in the Salado Formation. Castile Formation rock salt beds are more pure than those of the Salado Formation, except the basal Salado Formation beds in the Midland Basin are also very pure.

The presence of hydrous evaporite minerals in the Salado Formation will be a problem. The Castile Formation is probably free of this as a major problem.

There are many exploratory holes which penetrate part or all of the rock salt formations.

There are water source aquifers which must be protected from contamination.

In some areas the Salado Formation rock salt beds are subject to solution from water percolating upward from underlying aquifers through fractures.

The Salado Formation is above sea level and subject to erosion.

The rock salt beds in the middle member of the Castile Formation have been highly folded and it may be difficult to determine the age of the last deformation.

Clovis Area

I. Physiographic Setting

According to Fenneman and Johnson (1930) the Clovis area is within the Interior Plains major division, Great Plains province, and the High Plains section which is characterized by broad intervalley remnants of smooth fluviatile plains. Perennial streams are almost absent. Stream channels are small and drainage is gentle, and much is subterranean through numerous sinkholes according to the map of Raisz (1952). Glaciers will not likely be very effective in causing erosion this far south for the next quarter million years.

II. Tectonics and Seismicity

The Clovis area is in the Palo Duro Basin of Texas and Tucumcari Basin of New Mexico. These are bound by the Amarillo Uplift (a west-northwest extension of the Wichita Uplift) on the north, the Matador Uplift and Sierra Grande Arch to the west.

The Palo Duro Basin is a shallow foreland portion of the foreland basin of the Paleozoic Marathon Mountains orogeny to the south. The Palo Duro Basin was localized by bounding high areas during different times within the Paleozoic Era. One of these high areas, the Matador, is unusually narrow. It is bound on the south by faults and dikes. The Amarillo Uplift has faults on the south side adjacent to the Palo Duro Basin. Part of the Ancestral Rockies of Pennsylvanian age, the Pedernal Uplift, was intruded by ultrabasic rocks in the Mesozoic Era. The area was tilted, moderately folded and faulted between Late Cretaceous and early Tertiary time (Jones, 1974, p.17).

Several earthquake epicenters of small intensity have been located in and near the Clovis area (Northrop and Sanford, 1972, p.149 and Docekal, 1970, Figure 1), but the only concentration of epicenters which might be associated with known structures are those along the Amarillo Uplift.

III. Stratigraphy

Complete Column (Mainly from Jones, 1974)

Quaternary sediments are in local thin deposits, and they are composed mainly of alluvial sand with some gravel, and there are some wind transported sand deposits. Alluvium is concentrated along present stream channels.

The Pliocene to Miceno (Bachman, et al., 1973, p.25) Ogallala Formation is next below a disconformity and 15 to 415 feet thick. The Ogallala Formation is sandstone, siltstone, conglomerate, and caliche. This formation is a continental deposit washed mainly from the ancestral Rocky Mountains and the basin ranges of southern New Mexico to the west and probably covered all of the Permian Basin (Bachman, et al., 1973, p.24 and 25).

The Lower Cretaceous Tucumcari Shale is next under a major unconformity. It is 60 to 165 feet thick and composed of shale with minor amounts of sandstone. It occurs mainly as local outliers but is extensive in the subsurface of Curry and Roosevelt Counties.

Below a major unconformity underlying the Tucumcari Shale is the Upper Triassic Dockum Group containing the Chinle Formation and Santa Rosa Sandstone. The Dockum Group is 840 to 1,520 feet thick and composed of sandstone, shale and small amounts of conglomerate. The Triassic rocks are a sequence of terrigenous red beds.

The Upper and Lower Permian Artesia Group is next below a major unconformity.It is composed of the Tansill and Yates Formations, Seven Rivers Formation, and Green and Grayburg Formations. The Tansill and Yates Formations are up to 210 feet thick and composed of sandstone, siltstone, and minor amounts of dolostone, anhydrite, and rock salt. The Seven Rivers formation is 155 to 500 feet thick and composed of rock salt, shale, and anhydrite. The Green and Yates Formations are 210 to 370 feet thick and composed of sandstone, shale, and minor amounts of rock salt, anhydrite, and dolostone. The Artesia Group is a complex deposit of red beds and evaporite.

The Lower Permian San Andres Formation is next below an unconformity. It is 660 to 1,250 feet thick and composed of rock salt, anhydrite, shale, and dolostone. The formation thickens northward and eastward and is composed of lower and upper members. In recent years this formation has been a strongly favored exploratory target for petroleum.

Conformably below is the Lower Permian Glorieta Sandstone 95 to 160 feet thick composed of sandstone and minor dolostone and anhydrite. Halite may be in the sandstone as a cement in Curry and Roosevelt Counties. The sandstone is generally permeable and yields brackish water to wells in the western part of DeBaca County and salt water to wells in the eastern part of the county (Mourant and Shomaker, 1970, p. 14, 77 , and 79).

Next below are the Abo and Yeso Fromations consisting of a red bed sequence of shale and sandstone and lesser amounts of anhydrite and dolostone. Rock salt is also present but data on the two formations is meger.

The stratigraphy below the Permian is not described by Jones (1974) but further information is likely available in the published work of Foster, et al. (1972). Many holes have entered Precambrian basement rocks which are felsic igneous rocks, mainly rhyolite flows and pyroclastic rocks; micrographic granite; and supra crustal continental clastic sedimentary rocks (Bayley and Muehlberger, 1968).

Salt Bearing Formations (Mainly from Jones, 1974)

Introduction

Salt beds are in a varied sequence of evaporites, red beds, and carbonate rocks known as the San Andres Formation and the Artesia Group. "The San Andres is mostly salt and anhydrite interbedded with dolomite and shale, and is 660-1,250 feet (200-380m) thick. By contrast, the Artesia Group is chiefly shale and sandstone interbedded with rock salt and anhydrite and ranges in thickness from 365 feet (105m) to 1,100 feet (335m)." (Jones, 1974, p.1). The salt beds are not known to contain hydrous minerals. Salt beds are thicker in the San Andres and contain fewer interbedded sedimentary rocks.

San Andres Formation

Figure 6 shows the aerial distribution and thickness of salt in the San Andres Formation. The further distribution outside the area of the mapped area was estimated for Figure 1. Thickness of overlying rocks exceeds 1,500 feet over most of the area. It is

Figure 6 Thickness Map of Salt-bearing Interval in Upper Member of San Andres Formation

Jones, 1974, Figure 3, p. 11

1,000 feet in the northwest corner and about 3,000 feet in the vicinity of Portales in the southeast corner.

The San Andres Formation consists of an upper member and a lower member. The upper member is 400 to 1,000 feet thick and contains seven major beds of rock salt from 12 to 150 feet thick. The upper member is largely rock salt and anhydrite interbedded with shale and dolostone. The lower member is 200 to 300 feet thick and is predominantly dolostone and anhydrite interbedded with shale.

Artesia Group

The Artesia Group unconformably overlies the San Andres Formation and consists of five formations in descending order Tansill, Yates, Seven Rivers, Queen, and Grayburg. Rock salt and anhydrite are interbedded with the red beds of the Group but are most plentiful in the middle part which includes the Seven Rivers Formation, much of the combined Queen and Grayburg Formations, and a small part combined Yates and Tansill Formations. Salt content of the stratigraphic section and thickness, 1,650 to 2,000 feet, of overlying rocks are greatest in the vicinity of Clovis and Portales (Figure 7). Salt beds are thickest, up to 60 feet, in the Seven Rivers Formation.

Figure 7 Thickness Map of Salt-bearing Interval in the Artesia Group

Jones, 1974, p. 15

IV. Structure

Beds of the Clovis are extremely flat lying. Different stratigraphic horizons slope gently in different directions. The basement nonconformity dips toward the center of the Tucumcari Basin to the west and toward the PaloDuro Basin Center to the east. The top most, formerly continuous stratum, the base (major unconformity) of the Ogallala Formation of Pliocene and locally Miocene age, has a gentle homoclinal eastward dip over a very large area. The top of the San Andres Formation (unconformity) of Early Permian age has a gentle southeastward dip (Jones, 1974, p.11).

There are a few faults in and near the Clovis area. There are steep faults that strike north-northeast and are known to cut at least Permian through Triassic formations but are not believed to have affected the Ogallala Formation of Pliocene to Miocene age (Figure 8). Their last movement is considered by Jones (1974, p. 17) to be Late Cretaceous or Early Tertiary, but he indicates their precise age is unknown. The Bonita Fault (Figure 9) is Cretaceous or younger. It strikes northeast and strata are down on the northwest side. An east-west striking fault is along the Matador Arch on the south side of the area. There are numerous northwest and a few northeast trending lineaments over most of the area. Their origin and age are unknown.

There are two east-west trending dikes southwest of the area about 10 to 20 miles. One is about 30 feet wide and 25 miles long, and the other 70 to 100 feet wide and 30 miles long, and it is an olivine gabbro.

Figure 8 Cross-section Showing Faulting Has Not Off-set Ogallala Formation

Figure 9 Structure Map of the Permian Basin

Bachman et al., 1973, p. 30

V. Hydrology

Surface Water

Most surface water drains eastward along a subparallel set of channels. The main one is Running Water Creek. A small portion of the area drains westward and enters the Pecos River which flows southward. There are many closed basins of drainage into playas and sinkholes. Large amounts of sodium chloride are carried by the streams which drain the area.(Bachman, et al., 1973, p.49).

Ground Water

The Ogallala Formation is a major water reservoir in the irrigated parts of the Clovis-Portales area (Jones, 1974, p.17). Water is being used so fast it is being depleated, and by the year 2020 the quantity may be critically low (Bachman et al., 1973, p.43). The sandstone beds of the Artesia Group are water bearing (Jones, 1974, p.16), and sandstone and shale make up about half of the Group. The Glorieta Sandstone which underlies the salt-bearing San Andres Formation contains permeable sandstone which yields brackish water in the western part of DeBaca County and salt water in the eastern part (Mourant and Shomaker, 1970,p.14, 77, and 79). Throughout the area aquifers are probably fewer to the south because sandstone is less in this direction.

Dissolution of salt beds from outcrop has been taking place very slowly. The present dissolution front has been retreating for 230 million years. It is estimated that dissolution in the vicinity of Carlsbad, New Mexico has taken place at a rate of 6 to 8 miles per million years (Bachman et al., 1973, p.2). This is based upon the rate estimated for the last 4 million years; therefore, the climate for the next quarter million years is not likely to be radically different from that over the last 4 million and dissolution should not create a problem for waste several miles from the dissolution front.

Additional information on ground water can be obtained from published data. Ground water in the area has been studied by Theis (1932), Mourant and Shomakor (1970), and Cronin (1969).

VI. Mineral Resources

Some carbonate rocks of the San Andres Formation are oil and gas producing horizons (Jones, 1974, p.10); however, developed oil and gas fields are not extensive in the Clovis area (Bachman et al., 1973, p.16).

The major groundwater source for the area is the Ogallala Formation. Water, especially for irrigation, comes from this formation.

VII. Physical and Chemical Properties

The salt bearing units, the San Andres and the Artesia, contain more detrital materials than those of the Carlsbad area; but they are free of polyhalite and other hydrous salt minerals as have been reported in the Ochan deposits of the Carlsbad area (Brokaw et al., 1972, Appendix A).

Water has apparently moved along faults and dissolved some of the salt beds (Figures 6 and 7).

VIII. Conclusions and General Evaluation of Rocks for Waste Repository

Salt beds are probably thick enough and deep enough, and hydrous minerals are not known to be present in association with the salt. Underground movement of water is going to be extremely difficult to understand, mainly because dips of beds are so near horizontal and yet warped in many different directions. Permeable sandstone beds are numerous and near thickest salt beds.

Oklahoma-Texas Area

I. Physiographic Setting

According to Fenneman and Johnson (1930) the east half approximately is Interior Plains major division, Central Lowland province, and Osage Plains section which is characterized as old scarped plains beveling faintly inclined strata with main streams intrenched. The western part of the Oklahoma-Texaz area is in the same major division as the eastern part but is within the Great Plains province and High Plains section characterized by broad intervalley remnants of smooth fluviatile plains, and also a small area is within the Great Plains province and Plains Border section characterized by submaturely to maturely dissected plateau.

Streams are chiefly subparallel and flow eastward away from the Southern Rocky Mountains. The main stream is the Canadian River which is deeply incised and will likely be a major cause of several hundred feet of strata to be eroded from much of the Oklahoma-Texas area over the next few thousand years. Due to great thickness of salt that is very soluble and high elevation of the area above sea level, erosion may remove many hundreds of feet of strata in the next quarter million years. The edge of a few glaciers may reach this far south over the next 250,000 years, but erosional effects will not be great.

II. Tectonics and Seismicity

The Oklahoma-Texas area is within the Anadarko Basin with the Wichita Uplift along the south side. To the east of the basin where salt beds thin to extinction is the Nemaha Ridge.

The north flank of the Anadarko basin is a long dip slope of Paleozoic rocks on top of the Precambrian basement. The basin descends to a depth of 25,000 feet. On the south side, the basin is fault bound, and dip of beds is very steep. The basin developed throughout Paleozoic time with occassional epeirogenic uplifts which produced unconformities. In early Cambrian time there was wide spread volcanic activity producing mainly acidic rocks (Bayley and Muehlberger, 1969).

Since the area was uplifted by epeirogenic forces toward the end of Paleozoic time, no tectonic forces are known to have affected the area. The Oklahoma-Texas area is within the mid-continent central stable region and seismic activity is low. Docekal (1970, Figure 1) has plotted a MMI VII to VIII and several smaller intensity epicenters near and along trend of the Wichita Uplift suggesting activity of faults which extend into basement rocks between the Anadarko Basin and Wichita Uplift. Yet, there is no substantiated historical offset on these faults.

The Nemaha Ridge has four MMI VII to VIII and several smaller intensity epicenters near and along trend of the Nemaha Ridge. This suggests activity of faulting associated with the Nemaha Ridge. There is no substantiated historical movement on faults associated with either the Wichita Uplift or Nemaha Ridge. Yet, according to Smith et al. (in press) there are prominent lineaments on ERTS images which parallel, if not not coincide with, fault traces associated with the Nemaha Ridge.

III. Stratigraphy (Mainly from Leford, 1968, and Pierce and Rich, 1962)

The Oklahoma-Texas Area is underlain by the Clear Fork Group which contains halite units interbedded with red shale, anhydrite, and some dolomite. The Group consists of three formations of Lower Permian age belonging to the Leonard Series. The three formations from top to bottom are the Beckham Formation, Cimarron Formation, and the Wellington Formation. The details of the formations are depicted in a drawing by Louise Jordan (Leford, 1968, p.33).

The Beckham Formation is divided into an upper member the Yelton Salt Member, a middle member the Blaine Anhydrite Member, and a lower member the Flowerpot Salt Member.

The Yelton Salt Member is about 300 feet thick. At the type locality the Yelton Salt is 20 to 25 percent shale.

Conformably below the Yelton Salt Member is the Blain Anhydrite Member. It is about 200 feet thick and composed of anhydrite with interbeds of halite and some shale.

The Flowerpot Salt Member is about 300 feet to 625 feet thick. In northern Gray and west-central Wheeler County, Texas, the Flowerpot Salt Member lies about 1,200 feet below the surface of the ground.

The Cimarron Formation is composed of four members: an upper shale member, the Upper Cimarron Salt Member, the Cimarron Anhydrite Member, and the Lower Cimarron Salt Member.

The upper shale member is about 300 feet thick and contains discontinuous interbeds of halite and some gypsum and siltstone. This unit would probably be impermeable to downward movement of water toward a radioactive waste repository in the two Members below.

The Upper Cimarron Salt Member is about 200 feet thick and is coarse halite that is reddish brown due to small amounts of clay, and there are interbeds of reddish brown shale and some anhydrite.

The Cimarron Anhydrite Member is about 100 feet thick and contains thin interbeds of shale and dolomite.

The Lower Cimarron Salt Member is about 200 feet thick with a maximum thickness of about 450 feet in north-central Wheeler County, Texas. The Member is composed of coarse clear halite. There are a few intercalations of moderate reddish-brown or greenish-gray shale. The halite is generally pure and some sections as much as 30 feet thick contain 95 percent halite. Such a unit is likely the best in the section as a site for a radioactive waste repository.

The Wellington Formation is composed of three members: an upper shale member, the Hutchinson Salt Member, and a lower anhydrite member. The upper shale member is about 450 feet thick and would probably serve as a barrier to water circulation into an overlying waste repository.

The Hutchinson Salt Member is about 400 feet thick and is composed of halite and interbedded shale and anhydrite. Halite beds are not as thick as in the overlying two members and there is probably not a halite unit as thick as 200 feet in the Oklahoma-Texas Area except in the north portion where The Oklahoma-Texas Area overlaps the Kansas Area.

The lower anhydrite member is about 150 feet thick. This unit would also probably serve as a barrier to upward movement of water.

IV. Structure

Beds dip toward the lowest part of the Anadarko Basin in the southeast corner of the Oklahoma-Texas area. Beds dip gently except along the south side they dip steeply northward off the Wichita Uplift or they are faulted with the down side on the north toward the Anadarko Basin. This is one of the deepest basins. It has more than 20,000 feet of structural relief. There are no faults except those along the south side, and no folds; yet there is much oil production and many structures have probably been found during petroleum exploration.

The area has not been examined thoroughly for lineaments, but a few have been found near the Kansas border by Smith et al. (in press) ~~(1974)~~. North northeast striking lineaments are the most numerous.

V. Hydrology

Surface Water

Major streams form a subparallel pattern and flow generally eastward. The longest streams are the Canadian River, the North Canadian River, and the North Fork of the Red River which runs along the southern edge of the area.

Ground Water

Little information is available on ground water. Much of the movement of the ground water is controlled by the deep Anadarko Basin structure. Extensive salt springs in and around the area indicate active solution of Permian halite beds (Bachman et al., 1973, p.49). Chlorite concentration ranges from 20,000 to 200,000 ppm. Nine major springs are estimated to dissolve 6,300 tons per day (Lefond, 1968, p.38).

VI. Mineral Resources

At the southeastern edge of the area salt is solutioned near Sayre in Beckham County. The Upper Cimarron Salt Member is brined from a depth of 1518 feet (Lefond, 1968, p.39). Salt production in Oklahoma is only about 10,000 tons per year.

Oil and gas are produced throughout much of the area and is concentrated in the southern part where the Anadarko gives way to the Wichita Uplift (Bachman et al., 1973, p.16). Producing horizons occur throughout much of the Paleozoic section all the way down to granite wash on top of the Precambrian rocks.

VII. Physical and Chemical Properties

In a Beaver County well of the Warren Petroleum Company (Mocane Plant) the Lower Cimarron Salt Member contains a section 30 feet thick which is at least 95 percent salt (Lefond, 1968, p. 38). Some analyses by the Oklahoma Geological Survey of Cimarron salt are shown in the following table:

Depth, ft.	Thickness, ft.	NaCl %	Principal Impurities
1490.5-1510	19.5	91.57	Shale, anhydrite
1529 - 1540	11	86.7	Anhydrite
1617 - 1640	23	94.08	Shale, anhydrite
1642.5-1666	23.5	93.15	Anhydrite, shale
1669 - 1694	25	90.89	Shale, anhydrite
1713 - 1738	25	93.79	Anhydrite, shale

VIII. Conclusions and General Evaluation of Rocks for a Waste Repository

The Cimarron Formation contains halite beds sufficiently thick, pure, and deep for this area to be considered for a waste depository. The Lower Cimarron Salt Member is the purest and likely contains a unit sufficiently thick. Immediately above the Upper Cimarron Salt Member there is shale which will likely be impermeable to circulating fluids and prevent solution of the underlying halite. And immediately below the Lower Cimarron Salt Member there is shale in the Wellington Formation which will likely be impermeable to circulating fluids and prevent solution of the overlying halite.

In the northern part of the area there are halite zones greater than 200 feet thick in both the Cimarron and Wellington Formations. There are probably potential waste repository sites in both stratigraphic horizons.

There is very little published information about the halite bearing formations. Yet, there is much well data likely available from the state geological surveys and the oil companies.

There is a great deal of oil and gas production in the area which will present problems of locating all the wells near a possible waste repository, and removal of the fluids may cause unwanted circulation of fluids near the waste repository.

The many soluble halite beds above the Cimarron Salt Member coupled with the fact that many of the halite beds are above sea level may present a possible rapid erosion rate over the next quarter million years.

Kansas Area

I. Physiographic Setting

According to Fenneman and Johnson (1930) the Kansas area is within the Interior Plains major division, Great Plains province, and the Plains Border section which is characterized by a submaturely to maturely dissected plateau. Drainage is subparallel and mainly southeastward. The Arkansas River is the major stream, and it is along the north side of the area. The Cimarron River runs through the southern portion of the area, and the North Canadian River is along the southern tip of the area. Thousands of years from now the Arkansas River may cut across the area and produce some relatively rapid erosion of a few hundred feet of the relatively flat strata. A few glaciers may cover the area in the next quarter million years, but erosion will not likely be great this far south.

II. Tectonics and Seismicity

The Kansas area is within the Hugoton Embayment bound on the east by the Nemaha Ridge and on the north by the Central Kansas Arch and on the west by the Las Animas Arch. The Hugoton Embayment is a broad, shallow northward extension of the Anadarko Basin. No more than a few thousand feet of sediments were deposited in the Hugoton Embayment.

The Hugoton Embayment began subsidence in the Cambrian Period and continued throughout most of Paleozoic time. There were several epeirogenic uplifts with resulting unconformities. Much of the arching of the Las Animas Arch developed in Pennsylvanian time probably due to subsidence of the basins on either side (Eardley, 1951, p.219). The Nemaha Ridge associated faults have been active from Precambrian into the Permian Period and prehaps to the present if associated seismic activity is an indication of movement on the faults. The Central Kansas Arch and underlying Ellis Arch as it is called in pre-Mississippian rocks have been positive during Paleozoic time and possibly in Cretaceous time (King, 1951, p.60); so, a symmetrical broad arch has developed with local folds with axes parallel to the main arch axis trending northwest. Also faults parallel fold axes and lineaments visable on ERTS images (Smith, ~~1974~~ et al. in press). The presence of the lineaments suggests possible tectonic activity into very recent time, but the seismic record of epicenters is not yet developed sufficiently to make very positive statements (Doseckal, 1970 Figure 1). There are a couple of MMI VII to VIII intensity epicenters which might be associated with the arch, but the activity could be due to movement associated with the Nemaha Ridge since the epicenters are near the intersection of these two major tectonic features. There are several smaller intensity earthquake epicenters which might very well be due to activity along the Central Kansas Arch. Most all this seismic activity does not have to be of tectonic origin. It may only be due such smaller forces as erosion and isostatic adjustment.

The Kansas area is very seismically stable. It is in the mid-continent, and only a few earthquakes of less than MMI VII have been recorded. There doesn't seem to be any linear trends of epicenters through the area. Nearest earthquakes of MMI VII or larger have occurred far to the northeast along the north-south trending Nemaha Ridge, and also far to the southeast along the west-northwest trending Wichita Uplift.

III. Stratigraphy

Generalized Section (Modified from Lefond, 1968, p.26)

System and Series		Group	Formation
Quaternary			Alluvium and bolson deposits
Miocene and Pliocene			Ogallala
Cretaceous			Cretaceous Formations including Dakota Formation
Triassic		Dockum (?) Group	
Permian	Upper	Quartermaster Group	Taloga Formation
Permian	Lower	Nippewalla Group	Dry Creek Dolomite
			Whitehorse Sandstone
			Dog Creek Shale
			Blaine Formation (contains halite)
			Flower Pot Shale (contains halite)
			Cedar Hill Sandstone
			Salt Plain Formation (contains halit
			Harper Sandstone
		Sumner Group	Stone Corral Formation (contains halite
			Ninnescah Shale
			Wellington Formation (contains halit
		Chase Group	
		Council Grove Group	
		Admire Group	
Pennsyl-vanian		Wabousee Group	

Salt Formations

The salt bearing formation which has a cummulative thickness of greater than 200 feet and occurs at greater than 1,000 feet below the surface of the ground is the Wellington Formation as determined from Bachman et al. (1973, p.16). The purest unit in the Wellington Formation is the Hutchinson Salt Member. The Hutchinson Salt Member has very complex internal stratigraphy. Usually, anhydrite is missing in the upper part of the Member, but both anhydrite and shale are interbedded with the lower part of the Hutchinson (Lefond, 1968, p. 26).

The Hutchinson Salt Member is up to 400 feet thick and is fairly pure with the principal impurity being anhydrite. At Hutchinson, Kansas, the Member consists of alternating clear and white coarse halite layers several inches thick with thin laminae of silty shale, gypsum, and anhydrite. The Wellington Formation is divided by the Hutchinson Salt Member into 3 members (Lee, 1956, p. 116). An unnamed shale member is above the Hutchinson. The shale is about 100 feet thick and composed of gray and red shale. The lower member is about 150 feet thick and consists of anhydrite interbedded with gray shale. The upper and lower members are probably impermeable and will likely keep circulating fluids from dissolving the halite of the Hutchinson Salt Member.

At the Kansas-Oklahoma border at least three formations, and maybe four, overlap with at least 600 feet total halite thickness. The Cimarron Salt Members are mapped in Oklahoma extending this far north, and, at about the same stratigraphic position, the Stone Corral Formation halite beds are mapped in Kansas (Lefond, 1968, p.29), and they are indicated to extend south across the state line. Perhaps the Cimarron Salt Members and halite in the Stone Corral Formation are equivalent. Also the Blaine Formation has been mapped in Kansas in the same general area along the state line as the Stone Corral (Lefond, 1968, p. 28).

IV. Structure

The Kansas area is underlain by the Prairie Plains homoclinal surface structure with westward very gently dipping strata; however, subsurface strata do not share the westward dip. For example, the Precambrian surface dips very gently to the south.

The Meade Fault in Meade County (Figure 9) is Pliocene or younger. Bayley and Muehlberger (1968) depict a fault near the Meade Fault but with different strike which cuts basement rocks. There are two faults between Hutchinson and McPherson (Bachman, et al., 1973, p.30). Several other faults a few miles west of Wichita have been mapped as cutting basement rocks (Bayley and Muehlberger, 1968).

There are several lineaments striking northwest near the Meade Fault (Bachman et al., 1973, p.10). Many short lineaments and a few circular features are in the area, and to the east along the Central Kansas Uplift there are northwest striking lineaments which transect north-south lineaments along the Nemaha Uplift (Smith et al. (in press) ~~, 1974~~).

V. Hydrology

Surface Water

Major streams run subparallel east-southeastward. The Cimarron River is the largest stream to run across the area. The Salt Fork of the Arkansas River, Bluff Creek, Rattlesnake Creek, and Medicine Creek originate within the area. The largest stream, the Arkansas River, runs along the north side of the area and the Canadian River along the south side. There is a small man-made lake on Bluff Creek.

Ground Water

Some very large sinks produced by dissolution of soluble rocks are in the western part of the area (Bachman et al., 1973, p.30). Some of those sinks are so large they are visible on ERTS imagery (Smith et al. (in press) ~~1974~~). One large sink is man-made, i.e. having developed over a cavity made by the Meade Salt Well in Meade County, Kansas (Bachman et al., 1973, p.26).

Studies, including hydraulic testing, were made of three areas several miles north of the Kansas Area in Lincoln County, Kansas and several miles northwest in Wichita County, Kansas (Bayne amd Brinkley, 1972). Aquifers reported from these three areas are Quaternary alluvium, Ogallala Formation, and the Cretaceous Dakota Formation. In Lincoln County hydraulic tests on Permian rocks above and below the Hutchinson Salt Member are quite impermeable. However, in Wichita County only 45 feet above the Blaine-Cedar Hills salt there is sandstone with some permeability. Below the salt to the top of the Stone Corral Formation there is little permeability (Bayne and Brinkley, 1972, p. 19).

VI. Mineral Resources

Twenty-five to fifty miles north and east of the Kansas area there are eight salt mines, three of which are active (Geotechnical Corp., 1958, p.24 & 25). Within the Kansas Area salt was produced from a brine well in Meade County.

There are a great number of oil fields in the eastern half of the area, and only a few oil and gas fields in the western half. Producing horizons are both above and below the Permian salt beds.

VII. Physical and Chemical Properties

Halite has apparently thickened in possible anticlinal structures suggesting plastic movement of the salt (Pierce and Rich, 1962, p.38). When taking samples of water for chemical analyses, it is easy to contaminate the sample where beds of soluble salt are concerned. Holes drilled specifically for collecting samples may be necessary, or at least special care will likely be necessary (Bayne and Brinkley, 1972).

VIII. Conclusions and General Evaluation of Rocks for Waste Repository

At least two formations containing salt beds which overlap at the Kansas-Oklahoma border have not less than 400 total feet of halite, and there is probably at least 1,000 feet of overlying strata. Some of the overlying strata is halite as in the Blaine Formation, and this may result in some unusually rapid erosion in terms of a quarter of a million years. Because of the shallow dip of beds, movement of ground water will be extremely difficult to understand presently. After erosion over thousands of years movement of ground water will be almost impossible to predict.

Colorado-Kansas Area

I. Physiographic Setting

According to Fenneman and Johnson (1930) the Colorado-Kansas area is within the Interior Plains major division, Great Plains province, and almost entirely within the High Plains section but may include a small portion of the Colorado Piedmont on the west edge of the area. The High Plains section is characterized by broad intervalley remnants of smooth fluviatile plains. The Colorado Piedmont is a late mature to old elevated plain. Drainage is subparallel, and the major streams flow eastward away from the Southern Rocky Mountains. The edge of a few glaciers may reach this in the next quarter million years, but glacial erosion will not likely be great enough to affect a radioactive waste site thousands of feet below ground.

II. Tectonics and Seismicity

The Colorado-Kansas area is a forelandward extension of the Aughton Basin from the Paleozoic orogenic zone of the Marathon Mountains and Ouachita Mountains to the south. The Colorado-Kansas area is transected by the northeast trending Las Animas Arch along which Precambrian rocks may have been exposed above sea level in early and middle Pennsylvanian time. During Cretaceous and early Tertiary time this area was the foreland downwarp for the Denver Basin to the west which developed during the Laramide Orogeny as the Front Range was folded, thrust faulted, and intruded by magma which developed a great peripheral dike system.

There are no epicenters within the Colorado-Kansas area. The nearest large intensity (MMI VII to VIII) earthquakes have occurred near Denver along the Front Range faults which strike principally north and therefore do not trend toward the Colorado-Kansas area. Recently some earthquakes in the vicinity of Denver have been demonstrated to be associated with Front Range faulting by associating fluid injection into wells at the arsenal with frequency of earthquakes. Dosekal (1970, Figure 1) shows a weak concentration of much smaller intensity epicenters with an eastward trend from the Front Range generally toward the Colorado-Kansas area. However, these epicenters are probably associated with the Apishara Uplift which extends along the southwest side of the Colorado-Kansas area.

III. Stratigraphy

The Permian salt deposits are not well known in the Colorado-Kansas area. The Blaine Formation contains halite beds up to 500 feet thick. The map of Figure 10 shows the maximum thickness of the Blaine Formation to be a little over 600 feet thick. Therefore, the Formation must be almost all halite where the formation is thickest. Where the Formation is 400 feet thick it probably contains at least 200 feet of halite. The 400 foot contour was used to outline the Colorado-Kansas Area. The extent of the Colorado-Kansas Area in Colorado is estimated from the outline of the Permian Basin as published by Bachman et al. (1973, Fig.1).

In Thomas County, Kansas, about 25 miles north of the Colorado-Kansas Area, the halite beds are 2,250 feet below the surface of the ground. In the south part of the Colorado-Kansas Area, in Hamilton County, the halite beds are 1,100 feet below the surface of the ground. It is, therefore, assumed that the Colorado-Kansas Area is all greater than 1,000 feet below the surface of the ground.

Figure 10 Thickness Map of Salt Beds in the Blaine Formation

Lefond, p. 28 (Add stippled pattern in area surrounded by 400' contour.)

IV. Structure

The Colorado-Kansas area has an extremely shallow dip of the Precambrian surface southeastward toward the deeper portion of the Hugoton Basin and in Colorado includes most of the crest of the Las Animas Arch (Bayley and Muehlberger, 1968). There are no known faults in the area. The Las Animas Arch is a very broad flexure with a northeast trending axis. This is the only reported fold, but in searching for oil or gas others have probably been found. A few lineaments trend northwest just south of the Arkansas River (Bachman et al., 1973, p.30). Smith ~~(1974)~~ et al. (in press) using ERTS imagery found several lineaments in the area, especially east-west trending ones and a large circular feature at the prominent bend in the Arkansas River. All the lineaments are of unknown origin.

V. Hydrology

Surface Water

Drainage is eastward along subparallel streams. The major streams are the Arkansas River, White Woman Creek, and North Fork Ladder Creek. In the west corner of the area Big Sandy Creek flows to the south and there are several large lakes.

Ground Water

There is very little published information available on ground water in the Colorado-Kansas Area. Sharon Springs occurs in the north corner of the area.

VI. Mineral Resources

A small gas field is in the southern part of the area in Hamilton County, Kansas. One possible reason for the little amount of exploration for oil and gas in the area is the shallowness of the Hugoton structural basin.

VII. Physical and Chemical Properties

No specific information was found, but interbedded with the halite will likely be much shale since the area is near the border of the Permian Basin. This should result in a high ion exchange capacity for these strata.

VIII. Conclusions and General Evaluation of Rocks for a Waste Repository

Very little information is available on these salt deposits. Lack of mineral exploration in the area would be of benefit since there are fewer exploration wells. Also there are not many minerals which will be lost to future generations if a repository is developed at this locality.

References

Bachman, G.O., R.B. Johnson and F.A. Swenson (1973) Stability of Salt in the Permian Salt Basin of Kansas, Oklahoma, Texas, and New Mexico: U.S.G.S. Open file report no. 4339-4, 62pp.

Bayley, R.W. and W.R. Muehlberger (1968) Basement Rock Map of the United States, U.S. Geol. Survey.

Bayne, C.K. and D. Brinkley (1972) Geology, Hydrology, Thickness and Quality of Salt at Three Alternate Sites for Disposal of Radioactive Waste in Kansas: report prepared for U.S. Atomic Energy Comm., Union Carbide Corp. under AEC/UC Subcontract no. 3484.

Brokaw, A.L. and others (1972) Geology and Hydrology of the Carlsbad Potash Area, Eddy and Lea Counties, New Mexico: U.S.G.S. Open file report no. 4339-1, 86pp.

Coffman, J.L. and W.K. Cloud (1970) United States Earthquakes, 1968: Environmental Sci. Ser. Admin., Coast and Geodetic Survey, 111 pp.

Cohee, Geo. V. (1962) Tectonic Map of the United States, U.S. Geol. Survey and Amer. Assn. Pet. Geologists.

Cronin, J.G. (1969) Ground water in the Ogallala Formation in the Southern High Plains of Texas and New Mexico: U.S.G.S. Hydrol. Inv. Atlas HA-330, 4 sheets.

Docekal, Jerry (1970) Earthquakes of the Stable Interior with Emphasis on the Mid-continent: PhD dissertation, Univ. Neb., unpub.

Eardley, A.J. (1951) Structural Geology of North America: Harper & Bros., New York, 624 pp.

Fenneman, N.M. and D.W. Johnson (1930) Physiographic Map of the United States: U.S. Geological Survey, Reston, Va.

Foster, R.W. and others (1972) Subsurface geology of east-central New Mexico: New Mexico Geol. Soc., Spec. Pub. No. 4, 22 pp.

Geotechnical Corp. (1958) Possibilities for the Storage of Radioactive Waste in Salt Cavities in the Northeastern United States: report under contract no. W 7405-Eng-26 for U.S. Atomic Energy Comm., subcontract no. 1195 for Union Carbide Nuclear Corp.

Hayes, P.T. (1964) Geology of the Guadalupe Mountains, New Mexico: U.S.G.S. Prof. Paper 446, 69 pp.

Jones, C.L. and others (1973) Salt Deposits of Los Medanos Area, Eddy and Lea Counties, New Mexico: U.S.G.S. open file report no. 4339-7, 67 pp.

Jones C.L. (1974) Salt Deposits of the Clovis-Portales Area, East-central New Mexico: U.S.G.S. open file report no. 74-60, 22pp.

Kelley, V.C. (1971) Geology of the Pecos County, southeastern New Mexico: New Mwxico Bur. Mines and Min. Resources Mem.24, 75 pp.

King, Philil B. (1951) The Tectonics of Middle North America: Princeton Univ. Press, Princeton, N.J., 203 pp.

Lee, Wallace (1956) Stratigraphy and Structural development of the Salina basin area: Kansas State Geol. Sur. Bull. 121, 167 pp.

Lefond (1968) Handbook

Lobeck, A.K. (1939) Geomorphology: McGraw-Hill Book Co., Inc. New York, 731 pp.

Mourant, W.A. and J.W. Shomaker (1970) Reconnaissance of Water Resources of DeBaca County, New Mexico: New Mexico Bur. Mines and Min. Resources Groundwater Rept. 10, 87pp.

Northrop, S.A. and A.R. Sanford (1972) Earthquakes of northeastern New Mexico and the Texas Panhandle, in Kelley, V.C. and F.D. Trauger, eds., Guide book of east-central New Mexico: New Mexico Geol. Soc. 23rd Field Conf., Sept. 1972, p. 148-160.

Olive, W.W. (1957) Solution-subsidence Troughs, Castile Formation of Gypsum Plain, Texas and New Mexico: Geol. Soc. Am. Bull., v. 68, p. 351-358.

Pierce, W.G. and E.I. Rich (1962) Summary of Rock Salt Deposits in the United States as Possible Storage Sites for Radioactive Waste Materials: U.S. Geol. Survey Bull. 1148, 91pp.

Raisz, Erwin (1952) Map of the Landforms of the United States, E. Raisz, 107 Washington Ave., Cambridge, Mass.

Smith, J.W. and others (in press) Structural and Photographic Lineaments, Gravity, Magnetics, and Seismicity of Central USA: proceedings First International Conf. on the New Basement Tectonics, Utah Geol. Assn.

Theis, C. V. (1932) Report on the ground water in Curry and Roosevelt Counties, New Mexico: in 10th Bienn. Rept., New Mexico State Engineer, 1930-32, p. 100-160.

Vine, J.D. (1960) Recent domal structures in southeastern New Mexico: Am. Assn. Petroleum Geol. Bull., V. 44, no. 12, p. 1903-1911.