HQZ. 19870615. 1316

Cooley/Weston

② Dave Siefken

ONWI-28

HQZ.870615
.1316

Regional Summary and Recommended Study Areas for the Texas Panhandle Portion of the Permian Basin

Technical Report

December 1983

NUS Corporation

prepared for

Office of Nuclear Waste Isolation
Battelle Memorial Institute
505 King Avenue
Columbus, OH 43201-2693

Best Available Copy

ONWI
Office of Nuclear Waste Isolation

BATTELLE Project Management Division

BIBLIOGRAPHIC DATA

NUS Corporation, 1983. *Regional Summary and Recommended Study Areas for the Texas Panhandle Portion of the Permian Basin,* ONWI-28, Office of Nuclear Waste Isolation, Battelle Memorial Institute, Columbus, OH.

NOTICE

Printed in the United States of America
Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

NTIS price codes
Printed copy: A04
Microfiche copy: A01

ONWI-28
Distribution Category UC-70

Regional Summary and Recommended Study Areas for the Texas Panhandle Portion of the Permian Basin

Technical Report

December 1983

NUS Corporation

prepared for

Office of Nuclear Waste Isolation
Battelle Memorial Institute
505 King Avenue
Columbus, OH 43201-2693

The content of this report was effective as of January 1982. This report was prepared by NUS Corporation under Subcontract E512-01400 with Battelle Project Management Division, Office of Nuclear Waste Isolation ur 'er Contract Nos. DE-AC06-76RLO1830 and DE-AC02-83CH10140 with the U.S. Department of Energy.

ABSTRACT

This report summarizes the regional geologic and environmental characterizations that have been completed for the Permian region of study, and describes the procedure used to identify study areas for the next phase of investigation. The factors evaluated in the Permian region fall into three broad areas: health and safety, environmental and socioeconomic, and engineering and economic considerations. Health and safety considerations included salt depth and thickness, faults, seismic activity, groundwater, salt dissolution, energy and mineral resources, presence of boreholes, and interactive land uses. Salt depth and thickness was the key health and safety factor, and when mapped, proved to be a discriminator. The evaluation of environmental and socioeconomic conditions focused primarily on the presence of urban areas and on designated land uses such as parks, wildlife areas, and historic sites. Engineering and economic considerations centered primarily on salt depth, which was already evaluated in the health and safety area.

The Palo Duro and Dalhart basins are recommended for future studies on the basis of geology. In these two basins, salt depth and thickness appear promising, and there is less likelihood of past or future oil and gas exploratory holes. Environmental and socioeconomic factors did not preclude any of the basins from further study.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

The U.S. Department of Energy (DOE) has the responsibility to construct and operate facilities for the storage of spent fuel and high-level radioactive wastes from commercial nuclear power plants. The Department started the National Waste Terminal Storage (NWTS) program to develop the technology for, and to demonstrate the feasibility of, isolating nuclear waste in deep geologic formations. Part of this program is managed by the Office of Nuclear Waste Isolation (ONWI), Battelle Memorial Institute, Columbus, Ohio.

The plan for identifying potential terminal storage facility sites in geologic media involves geologic studies to ensure that requirements related to public health and safety and to engineering feasibility are met. It also involves, in parallel with the geologic studies, a sequence of studies to ensure that environmental values are considered in each decisionmaking step, as required by the National Environmental Policy Act (NEPA).

The selection process for the identification of qualified site(s) for a waste repository will be iterative (U.S. Department of Energy, 1979a). Rock formations that potentially could support a waste repository will be evaluated in terms of their geologic, environmental, and engineering properties. Areas containing rock units that appear favorable will be studied in greater detail to identify the most promising locations. Further studies will be performed at these locations to provide enough of the necessary geologic, environmental, and engineering data to qualify candidate sites. Sites proposed for waste repositories will be the subjects of Federal and state reviews and public hearings before a construction authorization is issued by the U.S. Nuclear Regulatory Commission (NRC).

Regional geologic and environmental characterization studies of the Permian basin have been completed. This report was based upon results contained in reports by Johnson, 1976; Bachman and Johnson, 1973; and NUS Corporation, 1979. More detailed geologic investigations of the Palo Duro and Dalhart basins were begun by the Texas Bureau of Economic Geology in 1977; the Bureau continues to develop a broad data base far more detailed than the regional studies. This report evaluates only the preliminary regional data for the Texas and Oklahoma portions of the Permian basin, referred to here as the Permian region of study (Figures 1-1 and 1-2). Other portions of the Permian basin were evaluated during an earlier U.S. Atomic Energy Commission and U.S. Energy Research and Development Administration regional geologic reconnaissance of salt deposits considered potentially suitable for repository sites; they have not been considered in the same level of detail in this study (see Section 3).

This report summarizes the regional geologic and environmental characterizations that have been completed for t Permian region of study and describes the procedure used to identify study areas for the next phase of the investigation.

The results of this preliminary evaluation, which identify areas for further study, should not be interpreted to mean that a repository will be sited in one of these areas.

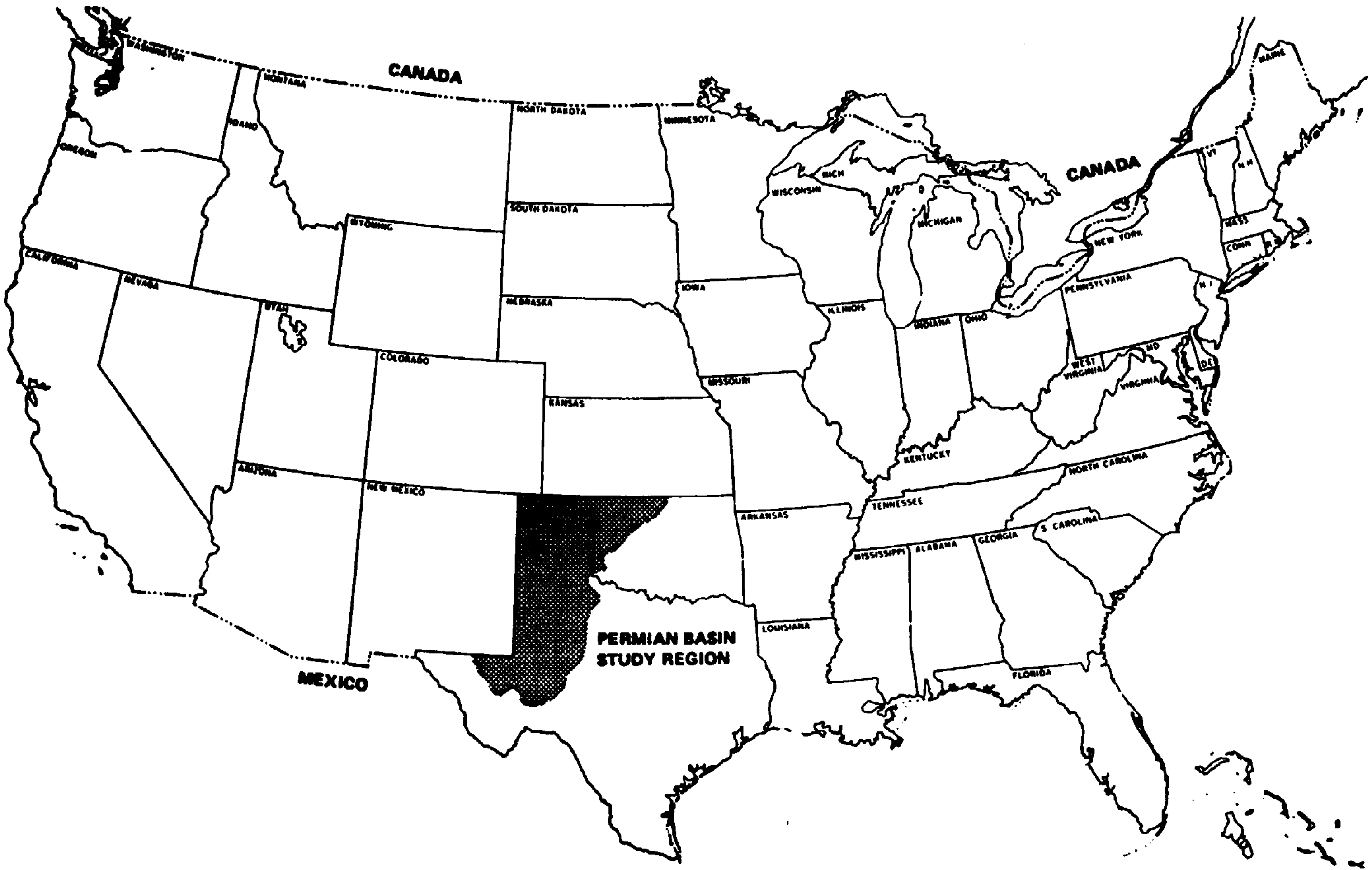


Figure 1–1
Permian Region of Study

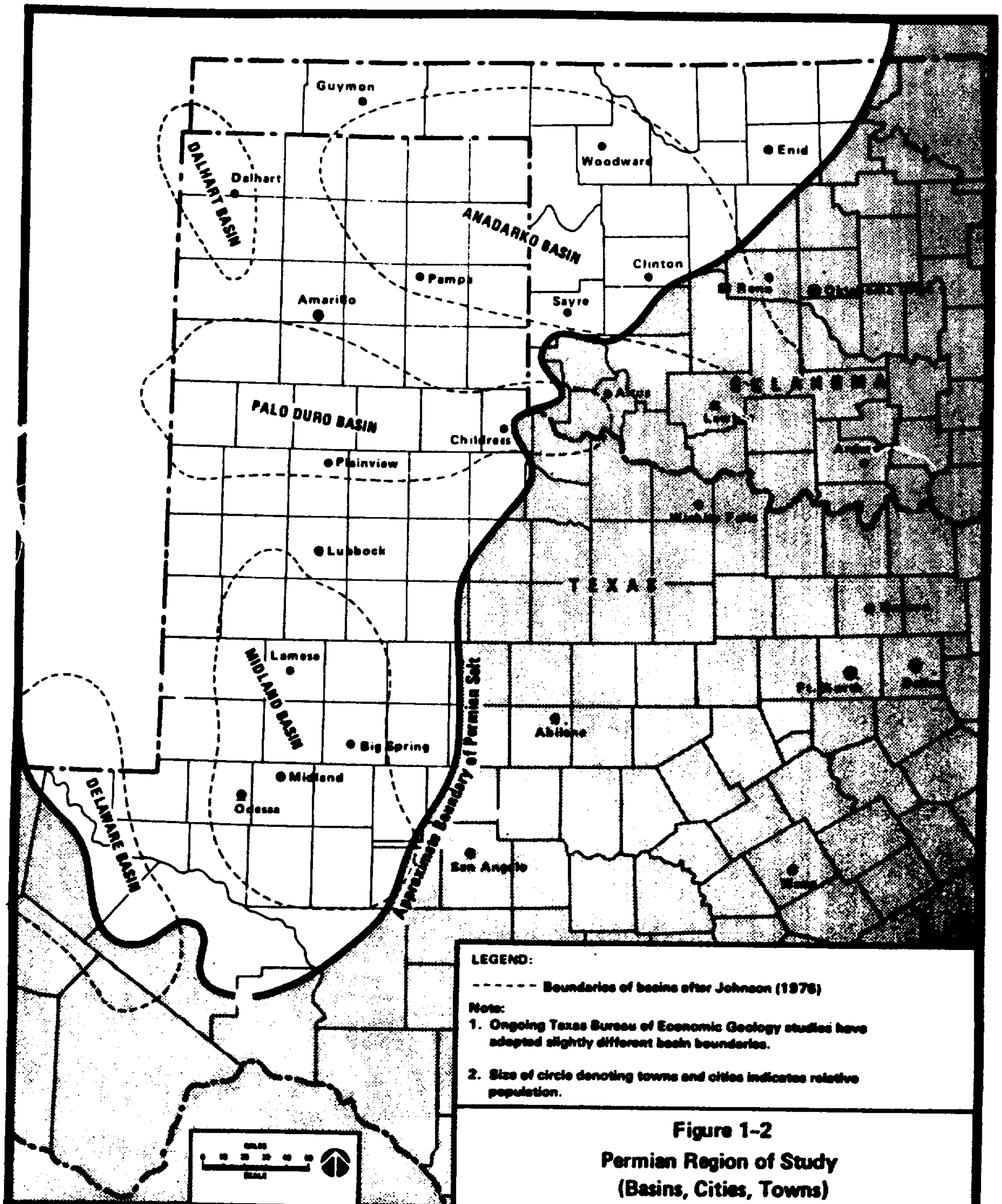


Figure 1-2
Permian Region of Study
(Basins, Cities, Towns)

Source: NUS Corporation (1979)

To ensure that the site-characterization activities are conducted reasonably and adequately, a continuous program of consultation will be maintained with the officials and agencies of each state; their concurrence will be sought. Thus, the information collected and the recommendations reached will reflect the needs and inputs of the states as well as those of the NWTS program.

2 SUMMARY AND CONCLUSIONS

Regional geologic and environmental data have been collected for the Texas and Oklahoma portions of the Permian basin; the information is summarized and evaluated in Sections 4 and 5 of this report. These broad data have been evaluated to narrow the search area by identifying basins or subareas that are preferable for further study. Factors related to health and safety, environmental and socioeconomic, and engineering and economic criteria were considered; those most relevant to a regional evaluation in the Permian basin were mapped or qualitatively compared. Features of particular interest are summarized below.

2.1 HEALTH AND SAFETY CONSIDERATIONS

The health and safety features of the Permian region of study can be described as follows:

- Thickness and Depth of Salt-Bearing Units. The Palo Duro basin contains five salt-bearing units more than 200 feet thick and located from 1000 to 3000 feet below the surface. (Due to differences in salt unit nomenclature, the Texas Bureau of Economic Geology (BEG) recognizes seven salt-bearing units in the Palo Duro basin.) The other basins contain one to three salt-bearing units that meet these specifications. Some areas between basins also contain salt-bearing units of similar nature.

- Faults. Permian age (280-220 million years) and younger rocks are not actively faulted or otherwise deformed in the Permian region of study.

- Seismic Activity. The entire Permian region of study lies within seismic risk zone 1, which indicates a region of relatively low seismic potential. The Palo Duro and Delaware basins have had no recorded earthquakes with a Modified Mercalli (MM) Intensity of V or greater; the Dalhart and Midland basins both have had one such event, and the Anadarko basin has had seven earthquakes with an intensity of MM V or greater in the basin and three more near the eastern boundary.

- Aquifer. The Ogallala aquifer, which underlies a large part of the Permian region of study, is the most important source of water in the Permian region. Its intense development for irrigation has led to an agricultural- and range-cattle-based economy.

- Salt Dissolution. Data indicate that some salt deposits in the Permian region are being dissolved most commonly at depths of 500 to 800 feet below the surface. (Ongoing Texas Bureau of Economic Geology Studies indicate depths of 600 to 1400 feet.) The rate of dissolution and the relationships between dissolution zones and brine emission sites are not yet clearly understood and will be studied in more detail.

- Oil and Gas. The western Texas part of the Permian region of study is one of the major oil-producing areas of the United States. Oil and natural gas occur only in small fields in the Dalhart and Palo Duro basins. Extensive deep drilling continues in a major portion of the Anadarko basin, which is anticipated to remain one of the great petroleum provinces of the continental United States.

- Other Mineral Resources. There are vast, largely unused salt resources in the Permian region. Potash deposits exist in the Delaware and Midland basins; there is no evidence of significant potash deposits in the Palo Duro, Dalhart, and Anadarko basins. Small deposits of uranium are scattered across the Texas Panhandle and western Oklahoma.

- Boreholes. Compared to the rest of the region, few boreholes have been drilled through the salt units in the Dalhart and Palo Duro basins (e.g., in the Palo Duro, one oil or gas test hole per 30 to 40 square miles is estimated), and no underground mines exist in these two basins. In contrast, many boreholes have been drilled through the salt units in search of oil and gas in the Anadarko, Midland, and Delaware basins.

- Conflicting Land Uses. Substantial portions of the Midland basin are included in restricted, alert, or military operations areas (MOA). Part of the Delaware basin is also within such an area. In contrast, the Palo Duro and Anadarko basins contain only small portions of these areas, and the Dalhart contains none.

2.2 ENVIRONMENTAL AND SOCIOECONOMIC CONSIDERATIONS

The preliminary environmental and socioeconomic evaluation of the five basins within the Permian study region considered the following factors:

- National and state parks, national monuments, national wildlife refuges, and historic and archaeological sites protected by environmental legislation

- Urban areas

- Other unique natural or recreational areas

In general, this broad regional screening has not revealed any readily discernible environmental or socioeconomic reasons for not proceeding with further studies in any of the basins. From an environmental and socioeconomic viewpoint:

- The Dalhart asin includes one National Register site and no standard metropolitan statistical areas (SMSA); part of the basin lies within a national grassland.

- The Delaware basin has one National Register site, no SMSAs, and no recreational or natural areas larger than 1000 acres.

- The Palo Duro basin contains five National Register sites, two state parks, one national wildlife refuge, and one SMSA county.

- The Midland basin contains five National Register sites, parts of three SMSAs, and no natural or recreational areas.

- The Anadarko basin contains 22 National Register sites, a national wildlife refuge, and one corner of Canadian County in the Oklahoma City SMSA.

2.3 ENGINEERING AND ECONOMIC CONSIDERATIONS

For mining and construction feasibility salt-bearing units that do not lie more than 3000 feet beneath the surface are preferred. The parameters of maximum and minimum depth for the salt units are included in Section 2.1.

2.4 CONCLUSIONS

Geological considerations about the potential of salt basins in the Permian Region for yielding sites suitable for waste repositories led investigators (Johnson, 1976) to recommend that the Palo Duro and Dalhart basins be given preference for further search efforts. The dominant factors favoring the Palo Duro and Dalhart basin are the promise of salt units with depths and thicknesses of particular interest, less prevalence of known oil and gas fields and less evidence of past exploratory investigations (boreholes). An evaluation of regional environmental features (NUS, 1979) reveals no environmental or socioeconomic uniqueness that should preclude further study of these basins.

3 EVALUATION PROCESS TO IDENTIFY AREAS FOR FURTHER STUDY

3.1 BACKGROUND

Extensive studies on the suitability of rock-salt deposits as a geologic medium for the disposal of radioactive wastes have been performed in the United States for more than 20 years. The choice of salt has received continued support from a number of scientific groups, including the National Academy of Sciences-National Research Council (1957, 1970), and research and development programs are still in progress. Engineering evaluations have indicated that a repository in salt can be designed, built, and operated to provide the required degree of waste isolation (Bradshaw and McClain, 1971).

The National Waste Terminal Storage (NWTS) program is exploring the suitability of several regions in the United States that are underlain by rock salt at a reasonable depth and thickness:

- The Salina basin bedded salt in Michigan, northeastern Ohio, western Pennsylvania, and western New York

- The Gulf Interior Region--a portion of the Gulf Coast Plain and the adjacent offshore area in Texas, Louisiana, and Mississippi that is underlain by more than 500 salt domes

- The Paradox basin bedded salt in eastern Utah and western Colorado

- The Permian basin bedded salt in western Oklahoma, western Texas, and eastern New Mexico

The plan for the identification and qualification of potential repository sites in salt formations involves two separate and complementary programs. Of these, the more important is the assessment of the geologic formations under consideration, because the stability and compatibility of the formation with long-term waste storage are fundamental to the integrity of the repository and to the health and safety of the public. The second study program involves the development of nongeologic data and analyses required to support the site-selection process and environmental impact assessments to comply with the National Environmental Policy Act.

This summary report focuses on the Texas and Oklahoma portions of the Permian basin. Other portions of the basin have been screened as part of an earlier Atomic Energy Commission-Energy Research and Development Administration (AEC-ERDA) repository site-evaluation program. For example, after the Lyons, Kansas, site was abandoned in 1972, a search was made of many bedded-salt formations and salt domes in various sections of the country. The Permian basin in western Kansas and Texas, eastern Colorado, and New Mexico was included in the site evaluation for the Waste Isolation Pilot Plant (WIPP) (U.S. Department of Energy, 1979b). Eastern New Mexico (the Delaware basin) was selected for the WIPP facility for defense wastes because of favorable salt characteristics. The Delaware basin was not considered for another repository for the storage of commercial spent fuel and high-level radioactive wastes in an effort to achieve environmental diversity in candidate locations. The Midland basin was eliminated from consideration because of extensive oil and gas activities.

3.2 EVALUATION APPROACH

This summary report is based on Johnson's (1976) regional study approach, but organizes and presents his geologic information with supplemental geologic information from Bachman and Johnson (1973). The geologic information is combined with environmental information, as described below.

Section 4 presents a general review of regional geologic analyses and environmental data. The objective of this analysis is to identify basins (areas) that are preferable for further study as potential sites for a repository for high-level radioactive waste from commercial nuclear power plants. This evaluation of the Permian region of study consisted of (1) the preparation of factor maps, and (2) the development of tabulated comparative information. The evaluation was conducted in accordance with desirable objectives that are being defined in the form of criteria and associated screening factors being developed by the Battelle Office of Nuclear Waste Isolation (ONWI). These criteria and factors are used to reduce the size of the area under consideration, thereby focusing the search on areas more likely to contain suitable sites.

Factors related to health and safety, environmental and socioeconomic, and engineering and economic criteria were considered, and those most relevant to a regional evaluation and to the Permian region were used.

The health and safety, and engineering and economic factors consist of: the thickness and depth of the salt-bearing units, the proximity to aquifers, mineral resources (oil and gas, and potash), and conflicting land use. The factor maps showing the thickness and depth of salt-bearing units are themselves composites of thickness and depth contour maps of the salt-bearing units described in Section 4.

The environmental and socioeconomic factors include excluded areas (historic sites, national and state parks, national monuments, and national wildlife refuges) and recreation and natural areas. At this level of evaluation, only exclusionary land uses were considered. These include certain natural areas, historic sites, and parks that are protected by legislation. These factors are considered important in regional analysis only if they cover large areas (more than 1000 acres) or occur in large numbers within a basin.

The factor maps are supplemented by tabulated comparative information on the five basins within the Permian region of study. The information in the tables contains mapped and unmapped factors and consists of modified data reported by Johnson (1976), Bachman and Johnson (1973), and NUS Corporation (1979). Unmapped factors include such considerations as faults, seismic activity, salt dissolution, stratigraphic settings, boreholes, and underground mines.

Section 5 describes the results of the preliminary evaluation process to identify basins (areas) of the Permian region of study that are suitable for further study.

4 REGIONAL CHARACTERIZATION SUMMARY

This section summarizes the geologic and environmental information collected in Bachman and Johnson (1973), Johnson (1976), and NUS Corporation (1979), and uses these data as a basis for the regional evaluation described in Section 5. Much of the geologic information used in the following section is based on Johnson's (1976) report, while information on salt deposits in western Texas south of the Panhandle (Midland and Delaware basins) is based on Bachman and Johnson (1973).

4.1 GEOLOGY

4.1.1 Geologic Characterizations

Johnson (1976) evaluated the Palo Duro, Dalhart, and Anadarko basins in terms of several geologic parameters: salt thickness and depth, tectonic and seismic history, lithology, proximity of aquifers, mineral resources, and extent of drilling and mining. Before Johnson's investigations, no comprehensive study had been made of the salts in this region. A major part of his assessment involved a study of electrical logs and some sample logs for about 300 wells drilled in the region. The results of this evaluation are part of the basis for the salt thickness and depth factor maps and descriptions in this report. These results are a reconnaissance of the Permian geology but they do provide insights into the general character, thickness, distribution, depth, and structure of the salt deposits.

A more general and less comprehensive report (with respect to the extent of salt units) written by Bachman and Johnson (1973) was used as the primary source of information on salt in the Midland and Delaware basins. It was also used for information related to salt stability over the whole region of study. The Bachman and Johnson report provides a compilation of data available through 1973 on the stability of bedded salt in the Permian salt basin.

The references used in this summary do not provide a comparable coverage over the region of study. In general, the characterizations and evaluations of the Texas Panhandle and western Oklahoma are more detailed than those to the south, in western Texas.

This geologic characterization summarizes only information that was available immediately following the regional studies of Johnson (1976), and which lead to focusing on the Palo Duro and Dalhart basins. Additional geologic studies by the Texas Bureau of Economic Geology (BEG) focusing specifically on the two basins began in early 1977 and will continue. The data from these studies will expand the data base and might change details of geologic information presented herein. However, the more current BEG studies to date have not contradicted the conclusions and recommendations made by Johnson (1976) or this report.

4.1.2 Physiography, Topography, and Geomorphology

The Permian region of study lies in the southern portions of the Central Lowland and the Great Plains physiographic provinces (Figure 4-1). The Osage Plains section of the Central Lowland province comprises the eastern portion of the Permian region of study and consists of unglaciated plains. These

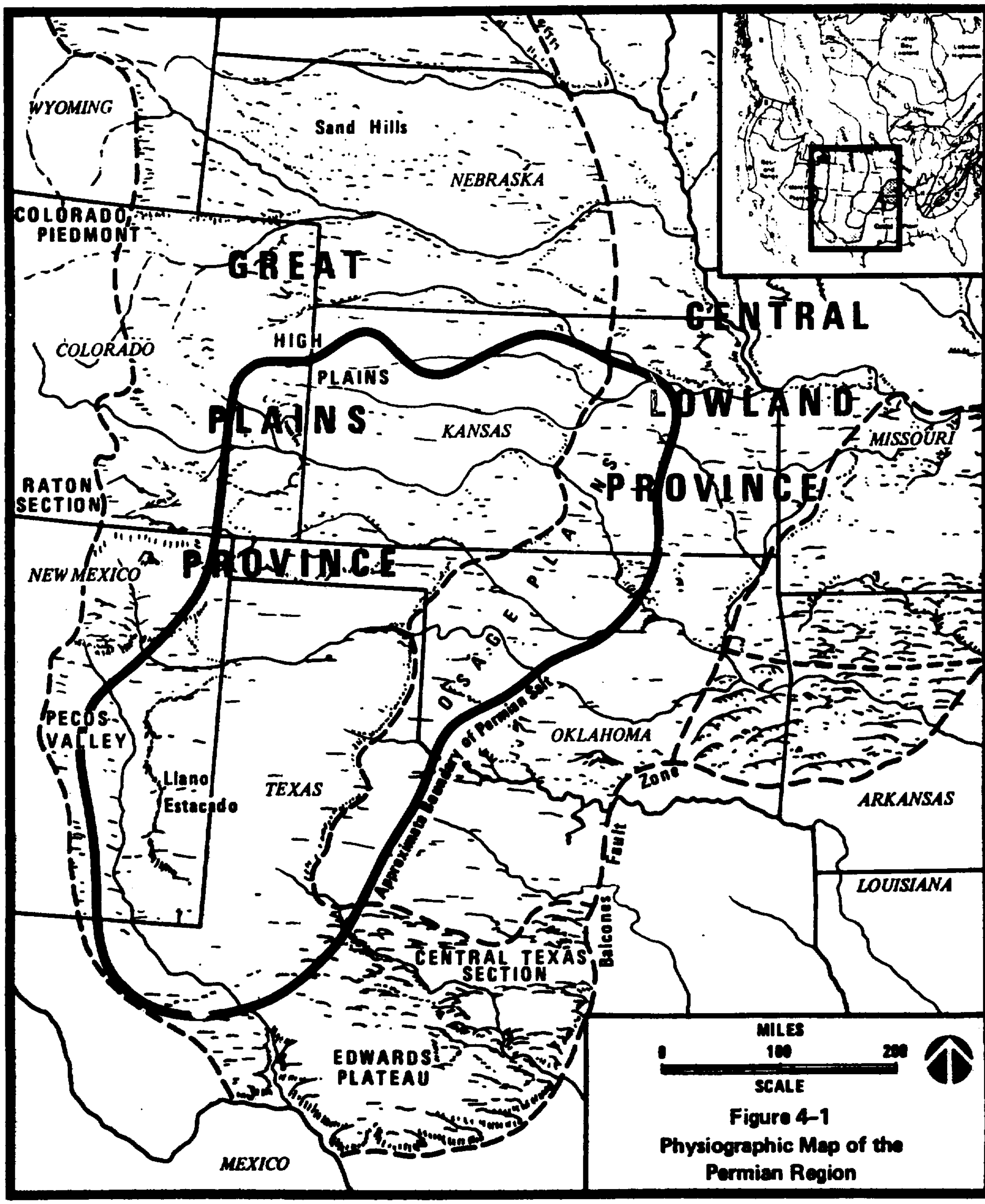


Figure 4-1
Physiographic Map of the Permian Region

Source: NUS Corporation (1979)

plains have low east-facing cliffs in Oklahoma and form uplands in which rivers are entrenched in ravines a few hundred feet deep in Texas. Elevations in the Osage Plains section are generally about 2000 feet above sea level.

The western and central part of the Permian region of study is within the Great Plains physiographic province. This province is a broad highland belt sloping gradually eastward from the Rocky Mountains and Basin and Range province and meeting the Central Lowlands along a low east-facing escarpment. In the region of study the Great Plains consists of the High Plains section, which extends south from the Oklahoma-Texas Panhandle to the Edwards Plateau section, and a very small part of the central Texas section. Elevations in the Permian region of study generally range from 2000 feet above sea level in the east to about 5000 feet in the west.

The High Plains are remnants of a former great alluvial plain, which stretched from the mountains on the west to the Central Lowlands on the east. Large portions of this plain are very flat and have undergone very little stream dissection. Other parts are more dissected and the original flat surface is still preserved only along stream divides. This terrain was sculptured by stream erosion features. The most significant topographic features are playa lakes.

The Edwards Plateau section is characterized by flat-lying areas and bold escarpments. The section is highly cut by dissection in the eastern part and consists of a plain to the west. Surface features are the results of erosion and dissolution.

4.1.3 Stratigraphy

Rocks older than Permian age are not exposed at the surface in the Permian region of study (see Appendix A for geologic time scale). The Precambrian "basement" rocks of the region are largely metamorphosed clastic rocks intruded by silicic igneous rocks, though in western Oklahoma (central Anadarko basin), Lower Cambrian rhyolite is the "basement" rock (Bachman and Johnson, 1973). Locally occurring volcanic rocks have been identified.

Subsurface Paleozoic rocks include thin glauconitic sandstone and dolomite of Late Cambrian or Early Ordovician age. The Paleozoic rocks are overlain by shale, limestone, and dolomite beds with some thin beds of sandstone of Ordovician, Devonian, and Mississippian age. In the Permian region of study these rocks probably do not exceed 3000 feet in aggregate thickness (Bachman and Johnson, 1973).

Pennsylvanian age rocks in the region of study include conglomerate, sandstone, shale, and limestone, which are present in all areas except in some parts of western Texas. In these areas, they have been eroded from mountainous uplifts of Late Pennsylvanian and Early Permian age. In general, the thickness of Pennsylvanian rocks ranges from about 1000 feet in shelf areas to more than 20,000 feet in the Anadarko basin in western Oklahoma (Bachman and Johnson, 1973).

While rocks of Permian age underlie the entire Permian study region, good surface outcrops occur only in limited areas in southeastern New Mexico and along a belt in the western parts of Texas, Oklahoma, and Kansas. According to Bachman and Johnson (1973), these rocks include dark-reddish-brown conglomeratic sandstone and sandstone interbedded with shales at the base. Fine-grained sandstone, shale, gypsum, halite and associated salts, and some limestone and dolomite characterize the later Permian sequence.

Permian rocks vary in thickness, ranging from an eroded edge in the midcontinent region to more than 15,000 feet in southeastern New Mexico and southwestern Texas (Bachman and Johnson, 1973). The approximate boundary of Permian salt, shown in Figure 1-2, establishes the limits of this report's region of study. While salt is not exposed at the surface in the study region, the insoluble portions of salt-bearing rocks do crop out in many places as breccias. Breccias are the residuum of the formation after the salt beds have been dissolved away by surface and near-surface solution. Figure 5-1 shows areas with salt units 200 feet and greater in thickness and between 1000 and 3000 feet below the surface.

In the Delaware basin of western Texas, major salt units occur in the Castile, Salado, and Rustler Formations. The Castile Formation is confined to the Delaware basin; the salt units in the Salado and Rustler Formations extend from the Delaware basin over the Central Basin platform and into the Midland basin and surrounding areas.

In the Texas Panhandle and western Oklahoma, the Permian is a thick sequence of reddish-brown shales and sandstones (red-beds) containing six principal salt-bearing units. Due to differences in salt unit groupings and nomenclature, other authors have recognized different numbers of salt-bearing units. The Texas Bureau of Economic Geology, for example, has identified seven units. According to Johnson (1976) the Permian strata are thickest (nearly 7000 feet) in the Anadarko and Palo Duro basins; these rocks are as much as 5000 feet thick in the Dalhart basin and about 3000 feet thick over the Amarillo uplift area. The six principal salt-bearing units identified by Johnson (1976) are, in ascending order, Hutchinson salt, Lower Clear Fork (Lower Cimarron) salt, Upper Clear Fork (Upper Cimarron) salt, San Andres (Blaine) Formation salt, Seven Rivers Formation (Artesia Group) salt, and Salado-Tansill salt. Figure 4-2 summarizes the correlations of key beds, salt units, and red-bed units in the three major basins. In addition, it shows the nomenclature generally applied in each province. The geologic references used in preparing this summary report (Johnson, 1976; Bachman and Johnson, 1973) do not provide complete information on the extent of five of the six salt units south of the Texas Panhandle (broken line in Figure 5-1).

The Salado-Tansill salt is the only unit with a complete mapped extent south of the Texas Panhandle. It is also the salt unit with the greatest extent in this area.

Hutchinson Salt. The Hutchinson salt of the Wellington Formation is the oldest Permian salt-bearing unit in the region. It is about 200 to 500 feet thick and occurs only along the north flank of the Anadarko basin. The Hutchinson salt can be found throughout the northeastern portion of the Texas Panhandle as well as in most of northwestern Oklahoma. The unit reaches its maximum thickness of 565 feet in western Woodward County (Johnson, 1976).

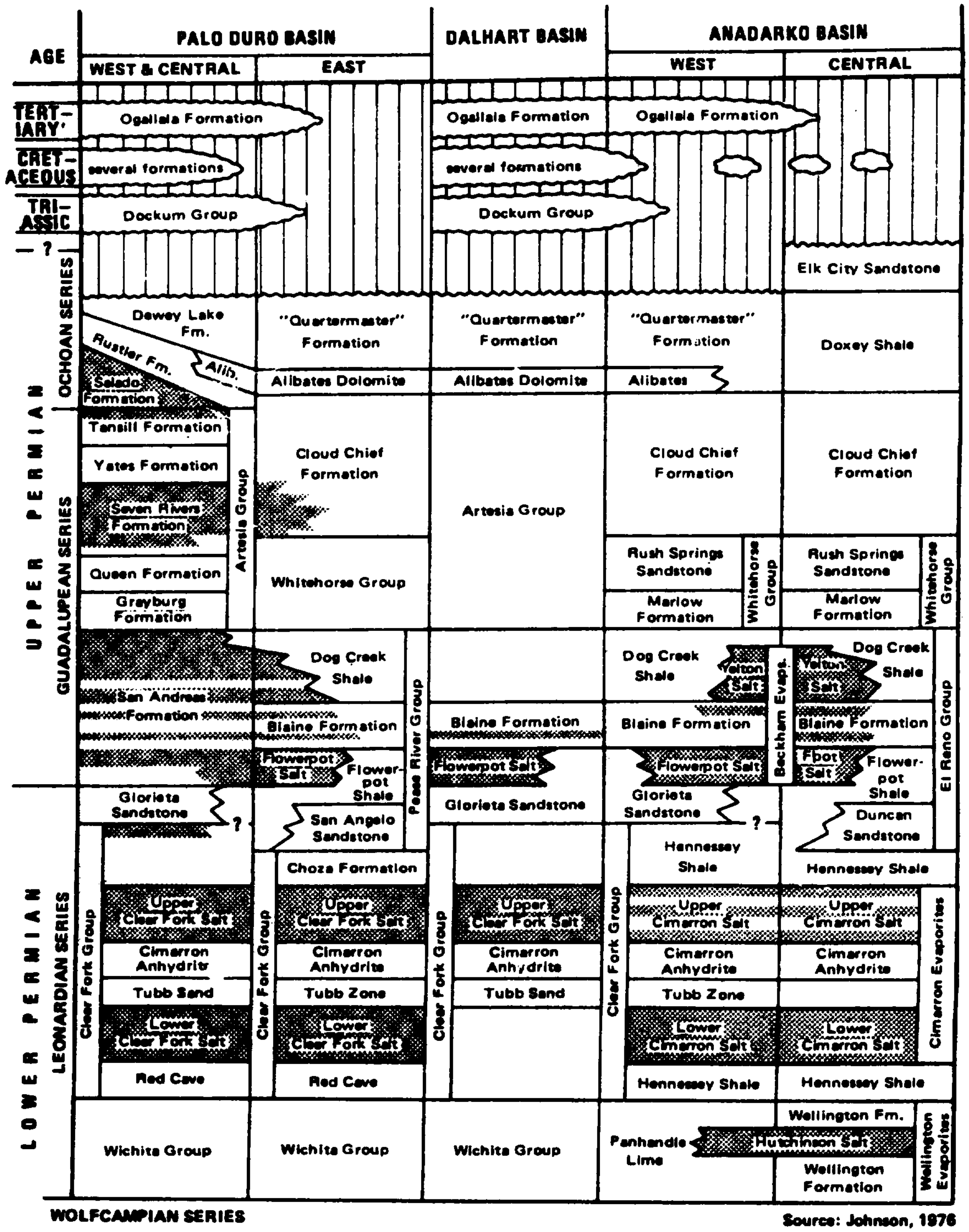


Figure 4-2
Stratigraphic Nomenclature of Permian and Younger Strata in the Texas Panhandle and Western Oklahoma

According to Johnson (1976), the Hutchinson salt-bearing unit is underlain by a sequence of interbedded anhydrite and shale 200 to 300 feet thick, with salt beds within the sequence typically 5 to 20 feet thick. Overlying the salt is 500 to 800 feet of shale (with some thin anhydrite beds) that extend upward to the base of the overlying Lower Cimarron salt-bearing unit. These thin anhydrite beds, which are about 100 feet above the salt, make up the upper anhydrite unit of the Wellington Formation.

The Hutchinson member is a sequence of interbedded salt, anhydrite, and shale, with salt occuring in layers typically 5 to 25 feet thick, separated by shale or anhydrite layers typically 1 to 10 feet thick. Normally 40 to 55 percent of the rock in the sequence is salt; about 30 percent of the sequence is typically anhydrite, and about 25 percent is shale (Johnson, 1976).

The top of the Hutchinson salt-bearing unit is located 1000 to 3000 feet below the surface in an area covering about 12,000 square miles. The depth to the top of the salt ranges from about 800 feet in Grant County in the northeast to about 4,000 feet near the axis of the Anadarko basin in Washita County (Johnson, 1976).

While the purity of the salt in Oklahoma and Texas has not been reported, Johnson (1976) indicates that in central Kansas the Hutchinson is typically 95 to 97 percent NaCl and 2 to 4 percent $CaSO_4$.

Lower Clear Fork (Lower Cimarron) Salt. The name "Lower Clear Fork salt" is applied to the salt-bearing strata below the Cimarron Anhydrite and above the Wichita Group in the Palo Duro basin. In the Anadarko basin, north of the Amarillo uplift, the equivalent strata are called the Lower Cimarron salt.

According to Johnson (1976), in the Anadarko basin, shale that is typically 300 to 500 feet thick underlies the Lower Cimarron salt. At the base of the shale are the thin anhydrite beds of the uppermost Wellington evaporites. Above the Lower Cimarron salt-bearing unit is 25 to 100 feet of shale, which is then overlain by the Cimarron Anhydrite.

In the Palo Duro basin, the Lower Clear Fork salt-bearing unit is described by Johnson (1976) as commonly underlain by 300 to 500 feet of shale and anhydrite that are part of the Lower Clear Fork evaporites and the Red Cave. Directly beneath the Red Cave are the anhydrite, shale, and dolomite beds of the Wichita Group. Lying above the Lower Clear Fork salt, separating it from the Cimarron Anhydrite, is 100 to 200 feet of shale and sandstone of the Tubb sand (Johnson, 1976)

The Lower Clear Fork (Lower Cimarron) salt unit occupies a 125-mile-wide area extending northeast to southwest across the Texas and Oklahoma Panhandles. It is present under most of the Anadarko basin, spans the Wichita Mountains uplift, and is present in all but the southern part of the Palo Duro basin. According to Johnson (1976), in most of the area, the salt unit ranges in thickness from 200 to 500 feet, reaching its greatest thickness of 550 feet in the Palo Duro basin in Randall County, Texas. Other particularly thick occurrences have been identified in southwest Carson County, Texas (415 feet), and in several areas of the Anadarko basin (420 feet).

Johnson (1976) indicates that the Lower Clear Fork salt unit lies between 1000 and 3000 feet below the surface, over an area of about 20,000 square miles in the Texas and Oklahoma Panhandles. The depth to the top of the salt in the study region ranges from several hundred to 5800 feet. This depth generally increases in the Anadarko and Palo Duro basins. Only in the northeastern corner of the two Panhandles is the salt shallower than 1000 feet, and only in the southwestern Texas Panhandle is it deeper than 3000 feet below the surface.

The Lower Clear Fork (Lower Cimarron) salt unit is made up of a sequence of interbedded salt, shale, and anhydrite. The various beds of rock salt, which are typically 5 to 25 feet thick, are interbedded with shale in the Anadarko basin and with anhydrite and shale in the Palo Duro basin. These interbeds are commonly between 1 and 20 feet in thickness (Johnson, 1976).

Salt comprises between 30 and 70 percent of the total thickness of this salt unit in most of the study region (Johnson, 1976). The only mineralogic or petrographic description of the salt strata found in the literature was derived from cores from Beaver County, Oklahoma. The unit is described as 78 percent halite with relatively few interbeds of reddish-brown or greenish-gray shale. Clay between the crystals makes this salt appear gray, though much of it is actually coarsely crystalline and colorless (Johnson, 1976).

Upper Clear Fork (Upper Cimarron) Salt. Lying directly above the Cimarron Anhydrite throughout the area is the Upper Clear Fork, which is the next youngest salt-bearing unit in the region. In the Palo Duro and Dalhart basins it is called the Upper Clear Fork salt, and in the Anadarko basin it is called the Upper Cimarron salt.

Below the Upper Clear Fork lies the Cimarron Anhydrite, which is typically 10 to 25 feet thick in the northern half of the region and 50 to 100 feet thick in the south. This anhydrite commonly consists of a series of beds 5 to 15 feet thick that are interbedded with shale and dolomite (Johnson, 1976). Between 200 and 500 feet of shale and some salty shale overlie the Upper Clear Fork salt and extend up to the base of an overlying sandstone or the next salt-bearing unit.

The thickness of the Upper Clear Fork salt-bearing unit commonly ranges from 100 to 600 feet in the Texas and Oklahoma Panhandles. In most parts of the Palo Duro basin it is more than 300 feet thick, and reaches a maximum thickness of 600 to 6[illegible]0 feet in Parmer County, Texas, and adjacent areas. In most of the Anadarko basin the stratigraphic position of this principal salt unit is occupied only by salty shale with some salt. While these salty strata are 50 to 600 feet thick, they do not contain enough salt to be considered a major salt unit. The Dalhart basin contains about 300 to 550 feet of a stratigraphically similar salty shale with some salt (Johnson, 1976).

The depth to the top of the Upper Clear Fork salt-bearing unit is between 1000 and 3000 feet over a large area that extends from the southeastern part of the Texas Panhandle across the north-central and northwestern parts. This area includes both the Dalhart basin and the eastern and northern parts of the Palo Duro basin and encompasses about 5000 square miles where the salt is at least 200 feet thick. In the central and western Palo Duro basin, the top of the salt is deepest, occurring 3000 to 5100 feet below the surface (Johnson, 1976).

Johnson (1976) reports that, in the only known cores of this unit, the Upper Cimarron salt is mostly shale and contains some salt. The cores, which are from eastern Beaver County, Oklahoma, indicate that about one-third of the 184-foot-thick section consists of salt beds 1 to 3 feet thick, and the remainder consists of shale and salty shale. Interbedded and intermingled halite and reddish-brown shale comprise the cores, which appear dull-reddish-brown due to clay in the halite.

Elsewhere in the region, electric logs show that the Upper Clear Fork salt consists of salt beds 5 to 20 feet thick, interbedded with shale, anhydrite, and dolomite beds of the same thickness. In the north part of the study area, nonsalt strata consist primarily of shale, and in the south the nonsalt strata consist primarily of shale, anhydrite, and dolomite. Layers of salt generally comprise 30 to 50 percent of the unit in most parts of the study region (Johnson, 1976).

San Andres (Blaine) Formation Salt. According to Johnson (1976), San Andres and Blaine Formation salt deposits are distributed widely in the Texas and Oklahoma Panhandles. In the central and western Palo Duro basin, they are referred to as the San Andres Formation. However, in the Anadarko, Dalhart, and eastern Palo Duro basins they are subdivided into (in ascending order) the Flowerpot salt, the Blaine Formation, and the Yelton salt, and in the Anadarko basin they have been called Beckham evaporites. In all areas underlying salts of the San Andres and equivalent formations are either shale or the Glorieta Sandstone. The Glorieta, which occurs in the western half of the Texas and Oklahoma Panhandles, is a salt-water-bearing sandstone 50 to 200 feet thick. In the southwest the Glorieta is underlain by about 100 feet of salt beds that are herein considered part of the San Andres salt-bearing unit. The Duncan and San Angelo Sandstones, which occur only in the eastern part of the study area, are separated from the base of the salt by at least 50 to 100 feet of shale.

From 50 to 200 feet of shale overlie the salt unit separating the salt from the sand and shale of the Whitehorse or Artesia Group.

The San Andres salt and the salts associated with the Blaine Formation are the thickest salt-bearing unit in the study area. In the central and western parts of the Palo Duro basin, salt-bearing strata are 800 to 1590 feet thick; along the axis of the Anadarko basin the strata are 400 to 720 feet thick. The salt-bearing unit is typically 200 to 400 feet elsewhere (Johnson, 1976). In some areas the San Andres salt-bearing unit occurs in separate beds 5 to 20 feet thick; and in others, it is in massive units from 50 to 2000 feet thick with only a few thin layers of shale. The onsalt strata are composed of shale and some anhydrite in the north, and anhydrite, dolomite, and shale in the south.

In most parts of the Anadarko basin the depth to the top of the salt is less than 1000 feet, but along the axis of the Anadarko basin it ranges between 1000 to 1390 feet (Johnson, 1976). In most parts of the Palo Duro basin, the top of the salt is 1000 to 3000 feet below the surface, which increases to a maximum of 3240 feet in the far southwest. In most areas of the Dalhart basin the depth to the top of the salt is 1200 to 1765 feet. The salt-bearing unit is more than 200 feet thick and occurs from 1000 to 3000 feet below the surface in 11,000 square miles of the Palo Duro basin, in 1,500 square miles of the Anadarko basin, and in 1000 square miles of the Dalhart basin.

In the Palo Duro basin the entire San Andres Formation is typically 20 to 40 percent salt, whereas the individual massive salt units are as much as 90 percent salt. Salt commonly comprises 40 to 70 percent of the total thickness of the mapped unit in the Anadarko and Dalhart basins, and 90 percent of some of the individual massive salt units (Johnson, 1976).

Seven Rivers Salt. The Seven Rivers Formation contains salt only in the southern part of the Texas Panhandle, occupying the central and western parts of the Palo Duro basin. The unit ranges in thickness from about 100 feet in the north to more than 500 feet in the south, and reaches 530 to 540 feet along the axis of the basin. The salt is somewhat thinner over the Matador arch (Johnson, 1976).

The Seven Rivers Formation is in the middle of the Artesia Group, and the Seven Rivers salt-bearing unit embraces the entire Seven Rivers Formation in the southwestern portions of the Texas and Oklahoma Panhandles. In the north and east the salt is confined to the middle or upper part of the formation.

Johnson (1976) reports that the Seven Rivers salt-bearing unit is underlain by 300 to 400 feet of shales, interbedded with sandstones and anhydrites, that comprise the Queen and Grayburg Formations (Whitehorse Group). The salt is overlain by shales locally interbedded with anhydrite and sandstone. Where overlain by the Salado-Tansill salt unit, the shales are about 100 feet thick and, where the Salado-Tansill salt is not present, the shales are several hundred feet thick (up to the base of the Alibates Bed).

The Seven Rivers salt that is at least 200 feet thick and lies at least 1000 feet deep occupies an area of about 7500 square miles. In almost all parts of the Palo Duro basin the depth to the top of the Seven Rivers salt-bearing unit is 1000 to 2000 feet, reaching a maximum depth of 2275 feet in Bailey County, Texas.

Salt constitutes about 50 percent of the unit throughout the area. The beds in the Seven Rivers Formation being are 5 to 20 feet thick. Typically, these salt beds are interbedded with shale and some anhydrite and sandstone. Cores of the Seven Rivers salt are not available for study, so Johnson (1976) derived this information from electrical logs and sample logs.

Salado-Tansill Salt. The youngest salt-bearing unit in the region is the Salado-Tansill salt. It occupies the southern part of the Texas Panhandle, and also extends somewhat into the Midland and Delaware basins and the areas surrounding them. The salt unit includes all the Salado Formation and the upper part of the Tansill Formation. In the Palo Duro basin the SaladoTansill salt is limited to the south-central part, where the unit is commonly 100 to 300 feet thick, reaching a maximum thickness of 340 feet in southern Hale County. It is somewhat thinner over parts of the Matador arch.

Johnson (1976) reports that in the Texas and Oklahoma Panhandles the Salado-Tansill salt is separated from a deeper Seven Rivers salt by an interval of 100 feet of shale, anhydrite, and sandstone. Above the Salado lies 10 to 50 feet of shale, separating the Salado-Tansill salt from the top of the Rustler Formation.

In almost all places where it is present, the top of the Salado-Tansill salt-bearing unit is 1000 to 2000 feet below the surface. In southern Bailey County, Texas, the top of the salt reaches its maximum depth of 2070 feet. The salt that is at least 200 feet thick and between 1000 and 2000 feet deep extends over about a 1500-square mile area. In most areas, salt constitutes 40 to 70 percent of the unit; individual beds are about 5 to 30 feet thick. The individual salt beds are interbedded with shale and some anhydrite. Nonsalt beds are typically 3 to 20 feet thick. Cores of the Salado and Tansill Formations were not available for study; therefore Johnson (1976) based this information on interpretations of electrical logs and sample logs.

South of the Texas and Oklahoma Panhandles are three prominent salt-bearing units. In the Midland basin the Rustler and Salado Formation together total between 200 to more than 800 feet in thickness. In the Delaware basin the thickness of the Rustler and Salado Formations ranges from about 200 to more than over 1600 feet; the thickness of the Lower Castile Formation ranges from about 200 to more than 600 feet.

All of the previously described Permian strata are overlain by Triassic Cretaceous, Tertiary, and some Quaternary sediments. According to Johnson (1976), the Triassic beds range from 100 to 1500 feet in parts of western Oklahoma and the Texas Panhandle. They consist primarily of sandstone, shale, and conglomerate. Cretaceous strata are typically less than 100 feet thick and contain sandstone, shale, and limestone. Tertiary sediments are typically unconsolidated and range from 100 to 400 feet in most areas. These beds are largely sand, silt, clay, gravel, and caliche (Johnson, 1976). The Ogallala Formation (Pliocene and locally Miocene in age), which is the most significant aquifer in the region, is an important Tertiary unit. The Ogallala consists of sand and gravel capped by an extensive caliche caprock, and underlies most of the High Plains.

4.1.4 Structure and Tectonics

The Permian study region is included in the larger Permian salt basin. This basin includes several variously oriented, smaller basins and uplifts (Figure 4-3). These tectonic features were developed mainly during the Pennsylvanian Period, before the deposition of the Permian salts about 280 million years ago. The tectonic activity had largely subsided by the end of Pennsylvanian time; since Permian time, there has been only minor tectonic movement. Minor vertical movements might result from post-tectonic adjustments within the crust of the Earth itself, or they might result from differential rates of compaction where a thicker column of Permian and pre-Permian sedimentary rocks in the basins permit a greater amount of settlement. Thus the Permian and younger strata are virtually free of tectonic deformation and in most areas have a dip of less than 0.5 degrees, although the pre-Permian rocks are locally faulted and complexly folded (Johnson, 1976).

The Central Basin platform separates the Delaware basin from the Midland basin in southwestern Texas and extends in a northerly direction as much as 200 miles. The basin abuts the south flank of the east-west-trending Matador arch. On the Central Basin platform, rocks of Early Permian and older age are broken by many large north and northwest-trending faults. However, all predate the salt deposition in the adjacent basins. With the exception of some instability during Late Devonian time and considerable instability in

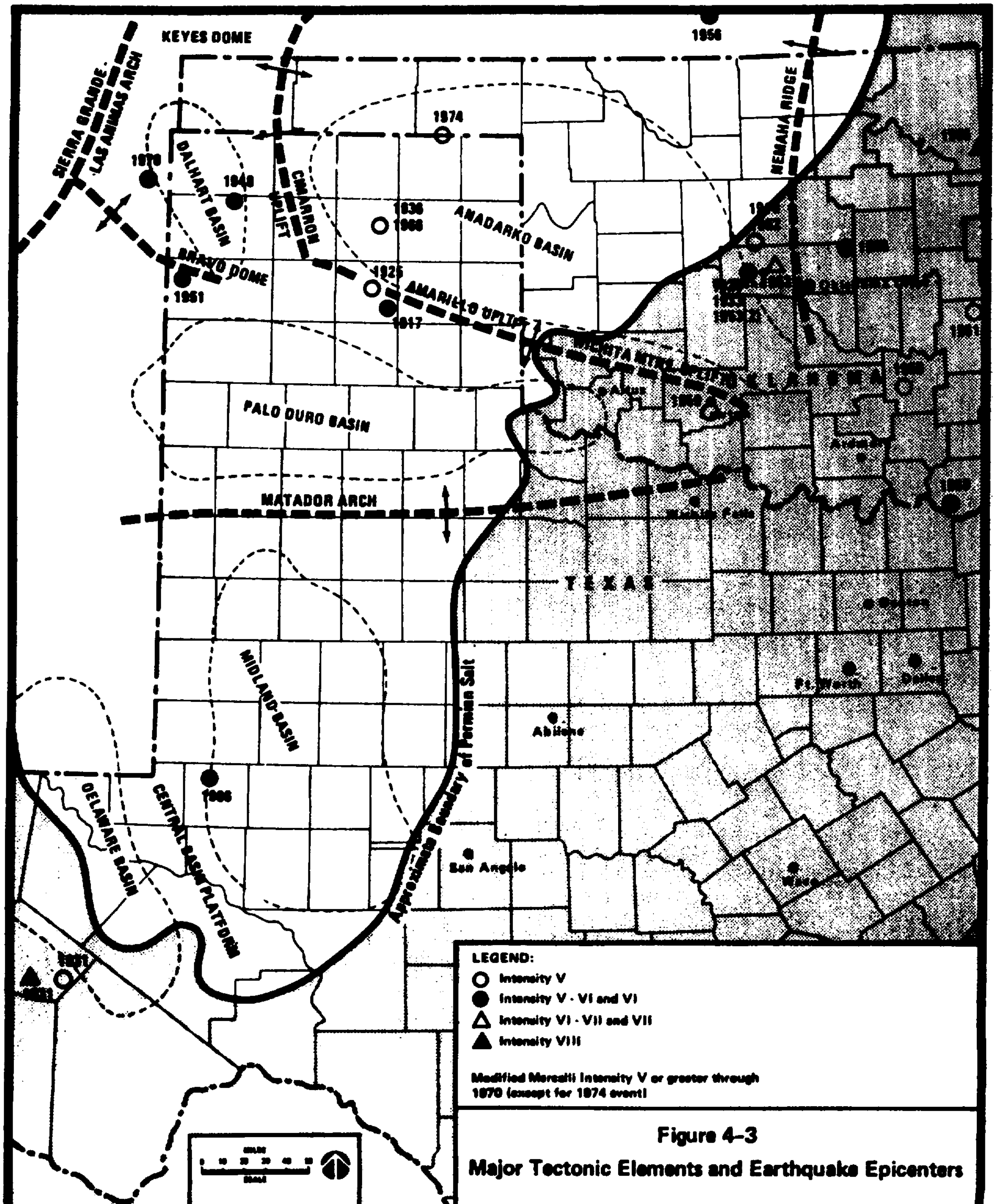


Figure 4-3
Major Tectonic Elements and Earthquake Epicenters

Source: Johnson (1976)

Late Pennsylvanian and Early Permian time, the platform was an area of stability throughout the Paleozoic Era (Bachman and Johnson, 1973).

The Wichita Mountains uplift east of the Permian region of study was thrust upward and slightly northward during the Early and Middle Pennsylvanian orogeny. This uplifted crustal block is 20 to 40 miles wide and extends west-northwestward across southwestern Oklahoma. The uplift is continuous with the Amarillo uplift in the Texas Panhandle. Complex fault zones bound the Wichita on the north and the south and separate the uplift from the Anadarko basin to the north and the eastern part of the Palo Duro basin to the south (Johnson, 1976).

The Amarillo uplift, as described by Johnson (1976), is a westward extension of the Wichita Mountains uplift. Typically it is 15 to 30 miles wide and extends west-northwest across the central part of the Texas Panhandle. The Amarillo uplift was thrust upward during the Pennsylvanian Period but was worn down and covered by Early Permian sediments. The Amarillo uplift is bounded by the north Wichita fault zone, which separates it from the west part of the Anadarko basin; other faults are present on and along the south side of the uplift.

The Matador arch is a sharp uplift just south of the Palo Duro basin trending from east to west. It separates the Palo Duro basin from the Midland basin and its associated platform and shelf areas. The arch is typically 10 to 15 miles wide and about 300 miles long (Johnson, 1976). The Matador arch was uplifted during Pennsylvanian time.

The Cimarron uplift is a relatively low positive feature about 10 to 15 miles wide separating the Anadarko and Dalhart basins. It extends 70 miles in a north-south direction and connects the Keys dome and the Amarillo uplift.

The Keys dome is a broad subcircular uplift at the north end of the Cimarron uplift. It appears to be about 20 to 30 miles in diameter and dips gently away from the center. On the east side of the Keys dome, Permian rocks apparently are merely flexed with somewhat steeper dips over a zone of deep-seated faults (Johnson, 1976).

The Bravo dome is an uplift that straddles the Texas-New Mexico state line, partly separating the Dalhart basin on the northeast from the Palo Duro basin on the south. It is about 20 miles south of the Wichita-Amarillo trend, though Johnson (1976) reports that it was uplifted during the same Pennsylvanian tectonic episodes as the Wichita Mountains and the Amarillo uplifts.

The Nemaha ridge is a long north-south uplift extending northward from central Oklahoma into Kansas and Nebraska. It developed as a number of small crustal blocks that were raised sharply along the axis of the uplift during the Pennsylvanian Period.

The Anadarko basin is a large asymmetrical basin extending in a west-northwesterly direction, located just north of the Wichita Mountains and Amarillo uplifts. While the Wichita Mountains and Amarillo uplifts were being raised just to the south during the Pennsylvanian Period, the sinking of the crust beneath the Anadarko basin was most pronounced. The Anadarko contains about 40,000 feet of sedimentary rock along its axis in Oklahoma, and is about 300 miles long.

Permian strata dip gently toward the axis of the Anadarko basin. The dip is typically 10 to 20 feet per mile southward on the north flank of the basin, and 50 to 200 feet per mile northward on the south flank. Principal zones of faults cutting Permian rocks have been identified only on the south flank of the basin near the frontal fault zone (Johnson, 1976). This frontal fault zone separates the Anadarko basin from the Wichita Mountains and Amarillo uplifts.

The Palo Duro basin is a large asymmetrical basin about 175 miles long and 60 miles wide. It is located between the Wichita-Amarillo uplift and the Bravo dome on the north, and the Matador arch on the south. (Present Texas BEG nomenclature defines the Hardeman basin as the easternmost part of the Palo Duro basin shown on Figure 1-2.) The basin's axis trends east-west about 5 miles north of the Matador arch. It began developing while the adjacent uplifts were being raised in Pennsylvanian time. The main episode of downwarping and sedimentation occurred during Permian time, though the Palo Duro basin became a distinct tectonic feature in Pennsylvanian time. Permian rocks in the basin typically dip gently southward and to the southwest at about 20 to 40 feet per mile. The Permian units are thinner northward toward the Amarillo uplift, and are thicker toward the southern part of the basin.

The Delaware basin is a deep asymmetrical trough west of the Central Basin platform. Extending in an arc for more than 200 miles in a north-south direction, it has more than 20,000 feet of relief. However, in spite of its extreme depth, faulting is apparent only near its boundary with the Central Basin platform; this faulting occurred before salt deposition. The Delaware basin might have begun to subside during early Pennsylvanian time, though subsidence reached its maximum and the basin assumed its present shape during Permian time (Bachman and Johnson, 1973).

The Midland basin, a shallow symmetrical basin east of the Central Basin platform, also extends for more than 200 miles in a north-to-northwest direction, but has only 4,000 to 5,000 feet of relief. While extensive major faulting has occurred in the southern part of the basin and on its west flank near the Central Basin platform. Bachman and Johnson (1973) report that the faulting occurred before the salt was deposited.

4.1.5 Seismicity

The entire Permian region lies within seismic risk zone 1, which indicates that ground rupture is not anticipated. The recorded seismic activity is low compared with most other parts of the United States. Only seven earthquakes with a Modified Mercalli (MM) Intensity V or greater have occurred within the region of study (Figure 4-3). The part that has undergone the strongest activity is on the flanks of the Amarillo uplift and along its west northwesterly continuation across the Bravo dome and the Dalhart basin (Johnson, 1976). Areas that are free of recorded earthquakes with intensities of MM V or greater are the central and most of the western Anadarko basin, all parts of the Palo Duro basin except in the far north adjacent to the Amarillo uplift and the Bravo dome (Johnson, 1976), and the Delaware basin and most of the Midland basin (Bachman and Johnson, 1973). Several earthquakes greater than MM VI have occurred outside the region of study in Oklahoma, Kansas, Texas, New Mexico, and Colorado. Some have occurred near and along the trend of the Wichita uplift and the Nemaha ridge, east and northeast of the region of study, respectively.

4.1.6 Energy and Mineral Resources

Energy and mineral resources found in the Permian study region include oil and gas, helium, carbon dioxide, salt, gypsum and anhydrite, potash, uranium, dolomite, caliche, volcanic ash, bentonite, stone, lime, clay, and sand and gravel (Johnson, 1976).

Oil and Gas. The western Texas part of the Permian study region is one of the major oil-producing areas of the United States. Oil and gas reservoirs range from Ordovician to Permian in age in the Delaware and Midland basins and surrounding areas. Major natural-gas fields and some oil fields are also present in western Oklahoma and the Panhandle of Texas (Figure 5-3).

Johnson (1976) reports that natural gas and some oil are being produced in the Panhandle field over the Amarillo uplift, and in the Hugoton field overlying the Cimarron arch, the Keys dome, and the western part of the Anadarko basin. Production in these fields is from below the lowest salt layers from the Lower Permian and Pennsylvanian strata.

Petroleum exploration activity currently is focused on deep drilling (depths of 17,000 to 21,000 feet) for Silurian and Devonian gas reservoirs near the axis of the Anadarko basin in Texas and Oklahoma. Deeper drilling in the north and northwest shelf of the Anadarko basin also is of current interest. The Anadarko basin will probably remain one of the great petroleum provinces of the continental United States, and thus will probably attract continued exploration for years to come (Johnson, 1976).

Oil and natural gas production is limited and occurs only in small fields in the Dalhart and Palo Duro basins. Because of the low ratio of successful wells drilled in these two basins, exploration for oil and gas has been inhibited. According to Johnson (1976), there is, in much of the Palo Duro basin, an estimated average of one oil or gas test per 30 to 40 square miles. Oil is produced from Pennsylvanian rocks at a few sites in the Dalhart basin and from several fields along the crest of the Matador arch on the south side of the Palo Duro basin. The large and important oil-producing province of the Midland basin and its adjacent shelf areas is farther south of the Matador uplift.

In and near the study region other gaseous minerals associated with oil and natural gas are being produced. Helium is produced at three localities in eastern Cimarron County, Oklahoma, and in Hansford and Moore Counties, Texas. Carbon dioxide is produced from Permian rocks at the Bueyeros field in Harding County, New Mexico, about 30 miles west of the study region (Johnson, 1976).

Salt. As indicated in the discussion of stratigraphy, salt occurs throughout the Permian region of study. The salt resources in western Oklahoma and the Texas Panhandle are vast--estimated at nearly 22 trillion tons of salt in the Anadarko basin and possibly another 35 trillion tons in the Palo Duro and Dalhart basins (Johnson, 1976). (The total United States production of salt in 1972 was 50 million tons; the total world production was 150 million tons).

Only limited use is being made currently of the salt resources in the region. In southwestern and northwestern Oklahoma, two companies produce a total of about 10,000 tons of salt annually by solar evaporation from brine springs at natural salt plains. In Beckham County, Oklahoma, brine is produced by pumping fresh water into the Upper Cimarron salt at a depth of 1518 feet; a two-well brine field has been producing brine and evaporative salt intermittently there since 1934. The Phillips Petroleum Company operates a brine well in Hutchinson County, which is the only reported production of brine in the Texas Panhandle (U.S. Bureau of Mines, 1972).

Salt can also be used for the storage of liquefied petroleum gas (LPG) in underground manmade cavities. Oklahoma has four LPG storage facilities in salt. The Shell Oil Company operates the Elk City storage facility (Beckham County) in the Blaine Formation at a depth of 1360 to 1411 feet; Texaco, Inc., operates a storage cavern below a depth of 833 feet in the Camrick district (Beaver County) in the Flowerpot salt. The Warren Petroleum Corporation has four caverns below 1579 feet at the Mocane plant (Beaver County) in the Lower Cimarron salt; and the Continental Oil Company has a facility near Medford (Grant County) in the Hutchinson salt at a depth of 900 feet. In addition, 13 LPG-storage facilities are operated in Texas in the Panhandle field over the Amarillo uplift in the following counties: Moore (5 storage facilities), Hutchinson (2 facilities), Potter (1 facility), Carson (2 facilities), and Gray (3 facilities).

Gypsum and Anhydrite. The Permian system rocks of the Texas Panhandle and western Oklahoma contain large gypsum and anhydrite resources. Johnson (1976) indicates that reserves of surface and near-surface gypsum (with maximum overburdens of 30 feet) are estimated to be 48 billion tons in Oklahoma alone. Additional near-surface reserves in the southeastern Texas panhandle are probably about 5 to 10 billion tons. In the eastern part of the region, eight companies produce about 1 million tons of gypsum annually from surface mines.

According to Johnson (1976): "Gypsum and anhydrite are too deep in most areas (especially in the Texas and Oklahoma Panhandles) to compete with the near-surface reserves, and it is not likely that the deep gypsum or anhydrite beds associated with or below the salt deposits will be regarded as commercial minerals in the foreseeable future."

Potash. While potash deposits exist in the Delaware and Midland basins (see Figure 5-4) in western Texas, Johnson (1976) indicates that there is no evidence that significant amounts of potash have been deposited in the Texas Panhandle and the western Oklahoma region. Potash is being mined underground by seven companies in southeastern New Mexico in Eddy and Lea Counties. This potash is interbedded with Salado Formation salts.

Others. Other minerals being mined in western Oklahoma include dolomite, caliche, volcanic ash, bentonite, and sand and gravel; those produced in the Texas Panhandle include stone, lime, cement, clays, and sand and gravel (U.S. Bureau of Mines, 1972). All of these operations are relatively small surface mines. Johnson (1976) reports no known metal occurrences within the Permian region of study. However small deposits of uranium are scattered across the Texas Panhandle in Oldham, Briscoe, and Garza Counties, and in western Oklahoma in Roger Mills, Custer, Washita, and Beckham Counties.

4.2 ENVIRONMENTAL MEDIA SYSTEMS

4.2.1 Hydrosphere

The groundwater and surface water resources of the region are major assets. Because of its accessibility, good quality, and low cost of utilization, groundwater has played a significant role in satisfying the demands for fresh water in the Permian Region. In 1975, the total water withdrawals for the subregions were 29,760 million gallons per day (mgd), of which 20,445 mgd, or 69 percent, came from groundwater. Agriculture, with a withdrawal of 24,998 mgd, or 84 percent of the total, is the major use of regional water resources.

- Surface Water -- Many of the rivers in the Permian region originate on the High Plains and the eastern slopes of the Rocky Mountains and flow eastward to southeastward across nearly flat plains. The region has a semiarid to subhimid climate characterized by low rainfall and runoff, high evaporation, and frequent strong winds. The mean annual precipitation varies from less than 16 inches in the western part to about 30 inches in the eastern part of the Permian study region. The mean annual runoff varies from less than 0.2 inch to about 4 inches from west to east. The rivers typically slope eastward at 5 to 15 feet per mile.

- Groundwater -- Groundwater in the Permian region lies within two prominant boundaries: the High Plains and the Unglaciated Central regions. Figure 5-2 shows the general extent of the Ogallala aquifer, which is the primary freshwater aquifer within the study region. Deeper water resources tend to be more mineralized and the fresh groundwater is generally shallow and typically confined to local drainage basins. The direction and flow characteristics of groundwater in the deeper zone can be independent of local terrain and controlled by regional hydrogeologic conditions. Ongoing hydrogeologic studies by the Texas Bureau of Economic Geology are augmenting the information currently available on the Ogallala aquifer.

<u>High Plains</u>. The High Plains groundwater region approximately coincides with the High Plains section of the Great Plains physiographic province. It is a very sizable remnant of a gigantic alluvial apron that formerly extended from the foot of the Rockies and the mountains in southern New Mexico to an unknown terminus probably some hundreds of miles east of its present edge. The alluvium is uniform enough to be classified as a single stratigraphic unit, the Ogallala Formation.

The Ogallala Formation contains as much as 600 feet of lenticular beds of gravel, sand, clay, silt, and caliche. Sand typically makes up 60 to 70 percent of the total thickness. Locally, the lower part of the formation can contain sandstone, siltstone, or limestone. The zone of groundwater saturation ranges from a few feet to more than 250 feet thick and the depth to water ranges from less than 50 to more than 300 feet. The yields of wells range up to 1500 gpm, depending largely on the saturated thickness. The water is generally of good quality but can be hard locally.

The Ogallala aquifer is the most important source of water in the Permian region and is one of the most intensively developed aquifers in the United

States. It is estimated to contain about 2 billion acre-feet of water in storage (Weeks, 1978). It is the sole source of water in a large part of the High Plains. In the Texas-Gulf region, the Ogallala aquifer supplies water to an estimated 50,000 irrigation wells (Baker and Wall, 1976).

The development of large quantities of groundwater that is suitable to irrigate the semiarid land and to serve its population has led to a substantial agricultural and cattle-range economy in the study region. Virtually all the withdrawal in the heavily pumped areas comes from storage (i.e., the water is being mined at a rate that exceeds recharge). This has caused a decline of the water table in the Ogallala aquifer. The decline began shortly after irrigation reached a substantial state of development in the 1930s and has continued at a rapid rate ever since. For example, the rate of depletion of the reservoir from the mid-1930s to 1973 averaged about 2.5 feet per year at a site near Plainview, Texas (Baker and Wall, 1976). Since 1941, the rates of depletion have increased sharply and the yields of wells have decreased.

Unglaciated Central Region. The Unglaciated Central region includes plains and plateaus underlain by horizontal or gently dipping consolidated sedimentary rocks. Alluvial deposits of substantial width and thickness and of moderate to high permeability are found only along the major streams. The aquifers of the region are limestone and sandstone of low to moderate productivity. The region includes some of the least productive aquifers in the United States. A few others, though not truly very permeable or productive, are well known because of their high potentiometric surfaces and initial availability of water by artesian free flow. Although there are marked exceptions, generally the Unglaciated Central region is characterized by consolidated-rock aquifers whose productivity is limited by low yields and by the presence of saline water at shallow depths (McGuinness, 1963).

Subsurface Salt Dissolution. Ongoing studies conducted by the Texas Bureau of Economic Geology (BEG) are advancing the knowledge of salt dissolution beyond what is reported here.

Dissolution of salt beds is now occurring at shallow depths, mainly in the eastern part of the study region, east of the High Plains (Figure 4-4). Johnson (1976) states that "a tentative observation can be made that salt in the Permian region : being dissolved most commonly at depths of 500 to 800 feet below the surface, although at many places the dissolution occurs as deep as 1000 feet and at other places salt is still present as little as 30 feet below the surface" (BEG studies now indicate depths of 600 to 1400 feet). There is an apparent coincidence of the areas of brine emissions on the eastern side of the study region with the areas where the salt beds are abruptly truncated by solution (Johnson, 1976).

Salt dissolution has affected or is presently affecting five of the six major salt-bearing units in the Texas Panhandle and western Oklahoma. According to Johnson (1976), the present limits of the Hutchinson salt have not been modified by dissolution and indicate the original depositional limits of the salt beds.

The Lower Clear Fork salt boundaries also represent the original depositional limits of the salt layers in all areas except the extreme northeast, where the

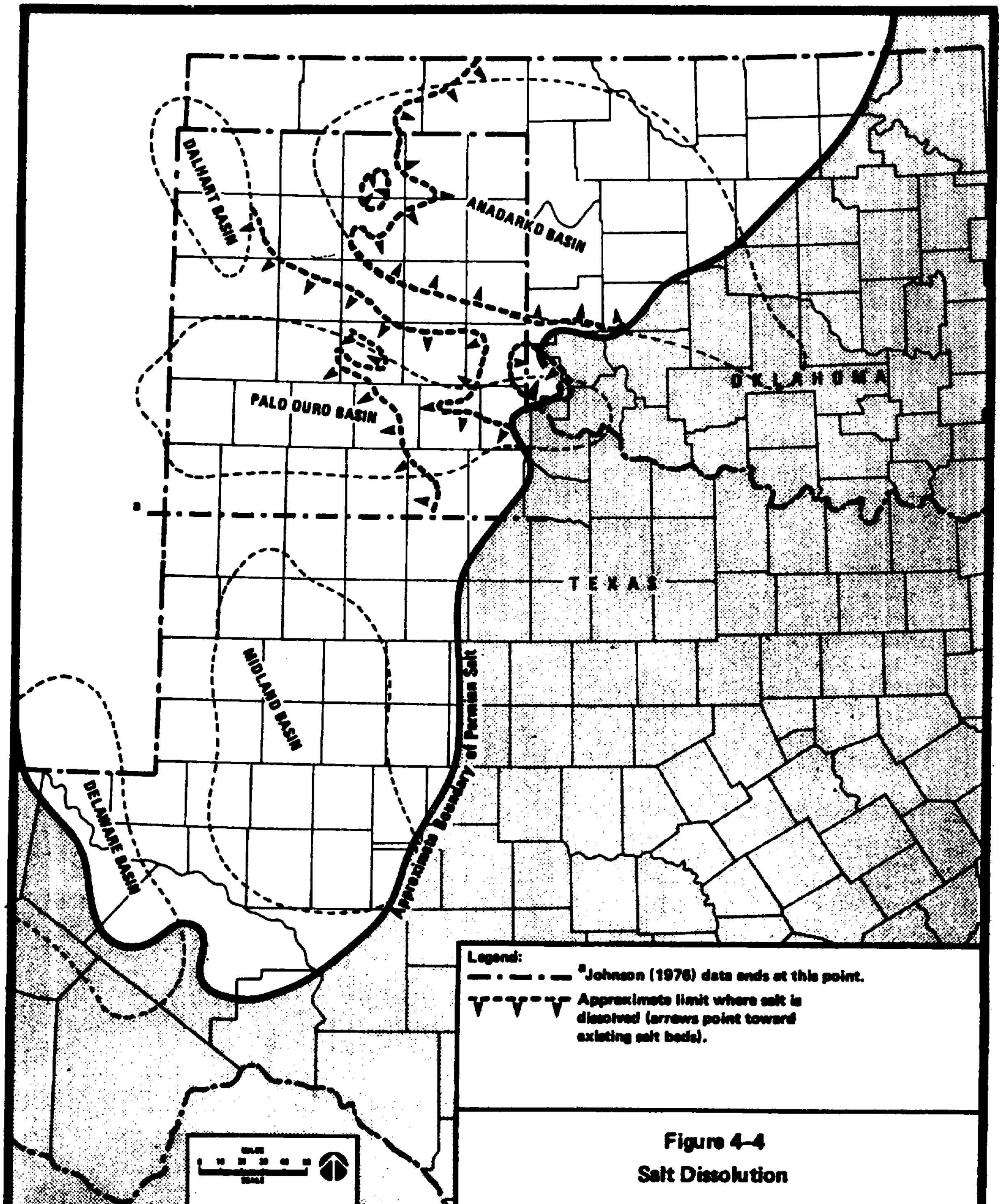


Figure 4-4
Salt Dissolution

Source: Johnson (1976)

salt is within several hundred feet of the surface and apparently is being dissolved, producing the natural brines that surface at Great Salt Plains in Alfalfa County, Oklahoma.

The Upper Clear Fork salt unit boundaries appear to be depositional in most areas. However in Blaine County, Oklahoma, at the far eastern part of the salt, dissolution apparently is occurring. In other areas to the north and northwest salt apparently has dissolved in the past (Johnson, 1976).

The San Andres salt once was present over the basins as well as the Wichita Mountains and the Amarillo and Cimarron uplifts. It is not clear whether San Andres salt was ever deposited on the Bravo dome. However, the salt has been dissolved from the mountains and major uplifts and now is limited to the basin areas. Salts probably are being dissolved on the east side of the salt area. In the Oklahoma counties of Harmon, Woods, Woodward, and Harper, and the Texas counties of Hall, Childress, and Cottle, natural brine formed by salt dissolution is appearing at the surface (Johnson, 1976).

The northern limit of the Seven Rivers salt-bearing unit, where the salt grades laterally into shale and sandstone, appears to be a depositional limit. However, the abrupt thinning and disappearance of the salt in the eastern Palo Duro basin is due to shallow-depth salt dissolution (Johnson, 1976). Seven Rivers salt appears to be at full thickness at depths of 540 to 980 feet, and at some greater depths. However, just to the east of the full-thickness area, the salt is missing where it should be 300 to 640 feet below the surface. The dissolution of this salt apparently is forming the natural brines being emitted in Armstrong, Briscoe, and Hall Counties, Texas (Johnson, 1976).

The Salado-Tansill salt-bearing unit's eastern margin is abrupt due to dissolution at shallow depths, in areas where salt is present less than 435 to 780 feet below the surface. This dissolution might be forming the natural brines that reach the surface in Briscoe County, Texas (Johnson, 1976).

4.2.2 Atmosphere

The Permian region is in the Southern Plains and Lowlands climatic zone. In general, climatic changes are gradual across the zone because there are no significant climatic barriers. Differences in climatic conditions within this zone are controlled primarily by latitude, general air mass and other storm movements, elevation, and distance from sources of moisture (Baldwin, 1973).

The climate of the Permian region is predominantly continental, with cold winters and warm to hot summers. The region has a dry climate because of the blocking and orographic effect of the mountains to the west. The region is frequently affected by cold polar arctic air masses during the winter (Baldwin, 1973). Wind and precipitation patterns indicate a relatively high erosion potential for the region (Jutze and Axetall, 1976).

Fundamental changes in the climate of the region have occurred over the last million years (the Pleistocene Epoch). During this time, there have been four ice ages, the most recent of which ended about 10,000 years ago (Sellers, 1965). Although glaciers did not extend to the Permian region, the climate was probably cooler, wetter, and stormier than at present (Brooks, 1970; Schwarzbach, 1963). Flooding was probably more frequent. The current epoch

(Holocene) is considered to be interglacial (Sellers, 1965). However, there are indications that a long-term global cooling trend is presently underway (Kukla and Matthews, 1972; Lamb, 1966).

In the Permian region the expected 24-hour maximum rainfall with a 100-year recurrence interval ranges from 5 inches in the northwestern portion to 8 inches in the eastern portion (U.S. Department of Commerce, National Oceanic and Atmospheric Administration, 1961). These values are rather typical for the contiguous United States. The region is associated with relatively frequent occurrences of tornadoes (Pautz, 1969). It is characterized by 100-year maximum winds of greater than 90 miles per hour, which is relatively high in comparison with typical values in the United States (ANSI, 1972). Restrictive dispersion conditions are relatively infrequent in the region compared with those in the contiguous United States. The occurrence of restrictive dispersion episodes increases from east to west across the region (Holzworth, 1972).

Data indicate that the national ambient air quality secondary standards for particulates are being exceeded throughout the western half of the region and in some eastern areas. Furthermore, the particulate concentrations in the area between Amarillo and Midland, Texas, exceed the national primary ambient air quality standards for particulates. These ambient air loadings are due primarily to existing dust conditions in the area.

4.2.3 Background Radiation

Background radiation is ubiquitous, resulting from cosmic, terrestrial, and fallout sources. The limited data available on background radiation for the Permian region reveal no anomalous areas.

4.3 DEMOGRAPHIC, SOCIOECONOMIC, AND LAND USE SYSTEMS

4.3.1 Demography

The Permian study region is relatively sparsely populated. Only two urban areas in the region support a population of more than 100,000 inhabitants: Lubbock, Texas (approximately 150,000), and Amarillo, Texas (less than 130,000). Odessa and Midland, Texas, have populations of just over 80,000 and 60,000, respectively (U.S. Department of Commerce, Bureau of the Census, 1971b).

Six standard metropolitan statistical areas (SMSAs) are located either wholly or partially within the Permian basin. These include.

- Amarillo SMSA, Texas
- Lubbock SMSA, Texas
- Midland SMSA, Texas
- Odessa SMSA, Texas
- San Angelo SMSA, Texas
- Oklahoma City SMSA, Oklahoma

Four SMSAs are located within 75 miles of the region boundaries:

- Colorado Springs SMSA, Colorado
- Pueblo SMSA, Oklahoma
- Lawton SMSA, Oklahoma
- Abilene SMSA, Texas

4.3.2 Socioeconomics

The total regional income, based on an aggregation of Bureau of Economic Analysis economic areas that best approximate the geographical limits of the study region, amounted to about 5.6 billion dollars in 1970. By the year 2000, earnings are forecast to reach more than 14 billion dollars (U.S. Water Resources Council, 1974). This projection is slightly more than half the earnings for the entire Permian Region (NUS Corporation, 1979) and nearly 1 percent of U.S. earnings.

Manufacturing accounted for approximately 13 percent of total earnings for the study region in 1970. This share is expected to increase slightly, to 15 percent, by 2000. Agriculture provided more than 14 percent of the regional earnings in 1970 but, by 2000, its share is projected to decrease to 5 percent. Mining and other extractive industries accounted for approximately 5 percent of the total earnings in the region. Trade, government, and service activities together provide the majority of total regional earnings--more than 50 percent in 1970. These sectors will expand in the future and, by 2000, are expected to account for more than 76 percent of the total earnings in the region (U.S. Water Resources Council, 1974).

4.3.3 Land Use Systems

Agricultural Land. The most extensive land use in the Permian region is agriculture, including range land and pastureland, cropland, and cropland with pasture (NUS, 1979). The principal farm products are livestock, wheat (mainly hard winter), sorghum, and cotton. Despite the importance of field crops, the livestock industry--from breeding and pasturing to dairying--yields more earnings than all field crops combined. The Texas High Plains area is one of the largest feed-cattle production areas in the country (NUS, 1979).

Based on the average crop and livestock production for the total land area, the leading agricultural counties in the Texas and Oklahoma portion of the region are in the central Oklahoma Panhandle and the adjacent north-central and western sections of the Texas Panhandle (U.S. Department of Commerce, Bureau of the Census, 1974).

Recreation, Natural Areas, and Historic Sites. Many recreation and natural areas are within and adjacent to the Permian region. Carlsbad Caverns National Park in New Mexico covers about 47,000 acres and lies just outside the region's boundaries. Guadalupe Mountains National Park is adjacent to the region along the Texas-New Mexico border (National Park Service, 1975). Lake Meredith National Recreation Area, which covers nearly 47,000 acres, is located northeast of Amarillo (Texas State Department of Parks and Wildlife, 1977).

There are two state parks in the region, both in Texas. Palo Duro Canyon State Park, the largest in Texas, covers about 15,000 acres in Armstrong and Randall Counties, and Caprock Canyon State Park, in Briscoe County, covers about 13,654 acres (Texas Department of Parks and Wildlife, 1977).

The Permian region includes nearly 500,000 acres of national forests and grasslands, including Comanche, Cimarron, Black Kettle, and Rita Blanca National Grasslands. These grasslands are multiple-use lands that are leased for grazing.

There are a variety of other recreation and natural areas within the study region, including three National Wildlife Refuges that cover some 45,000 acres (U.S. Department of the Interior, Fish and Wildlife Service, 1976) and the Bureau of Reclamation recreation area at Foss Reservoir (U.S. Department of the Interior, Bureau of Reclamation, 1976).

Numerous sites and areas throughout the Permian region have been recognized as having unique or important historic or archaeological value. Sites listed in the National Register of Historic Places have been identified as being most significant. There are 67 National Register sites in the Texas and Oklahoma portions of the region--31 in Texas and 36 in Oklahoma (U.S. Department of the Interior, Heritage, Conservation, and Recreation Service, 1979).

Transportation. Several Interstate, U.S., and state highways cross the Permian region. Interstates 40, 20, and 10 run east to west, while Interstate 27 crosses portions of the region between Amarillo and Lubbock. The major north-south U.S. highways include 385, 87, 83, and 183, which traverse the entire region from north to south, and U.S. highways 180, 60, and 70, which traverse the entire region in an east-west direction (Figure 4-5).

The railroad system in the Permian region consists of several large, medium, and small hubs within and outside the region. Most of the trackage in the region radiates from and into these hubs. The major rail hubs within or near proximity to the Permian region are Wichita, Kansas; Denver, Colorado; Oklahoma City, Oklahoma; and Amarillo, Lubbock, and Fort Worth/Dallas, Texas. Figure 4-6 shows the railroad network within the study area.

Potentially Conflicting Land Uses. On a regional basis, there are a number of restricted, alert, and military operations areas. Restricted areas denote the existence of unusual hazards (particularly to aircraft), including artillery firing, aerial gunnery, or guided missiles. Alert areas indicate a high volume of pilot training or unusual aerial activity. Military operations areas are possibly hazardous locations in which military training and maneuvers might take place.

Within the Permian region are an estimated 23,850,000 acres, or about 37,300 square miles, of restricted, alert, or military operations areas that individually equal or exceed 10,000 acres. These areas account for approximately 21.83 percent of the air space overlying the land area in the Permian region (U.S. Department of Commerce, National Oceanic and Atmospheric Administration, 1977a, b, c, d).

4.4 ECOSYSTEMS

4.4.1 Terrestrial Ecology

The Permian Region includes a diversity of soil, topographic, and land use patterns. The predominant vegetation communities in the region are grasslands and shrub steppes (Bailey, 1976; Kuchler, 1975). Forested lands, representing approximately 3 percent of the area, are scattered along the major river drainages. While not of major commercial value, such forests provide important wildlife habitat. The Federal list of endangered and threatened plant species includes 19 plants whose ranges can fall within the TexasOklahoma portion of the Permian region of study. Oklahoma lists a single species;

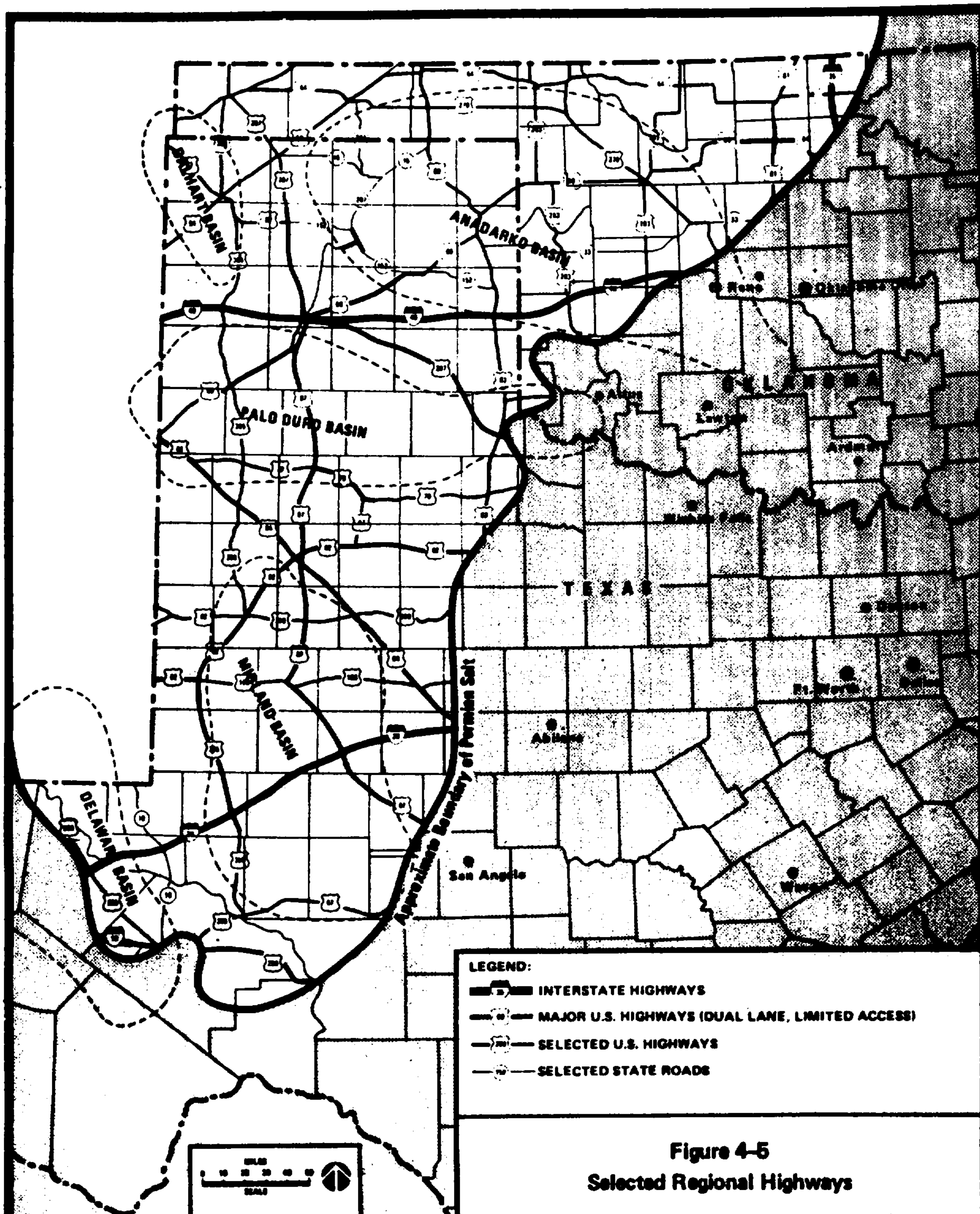


Figure 4-5
Selected Regional Highways

Source: Adapted from Rand McNally Road Atlas (1978)

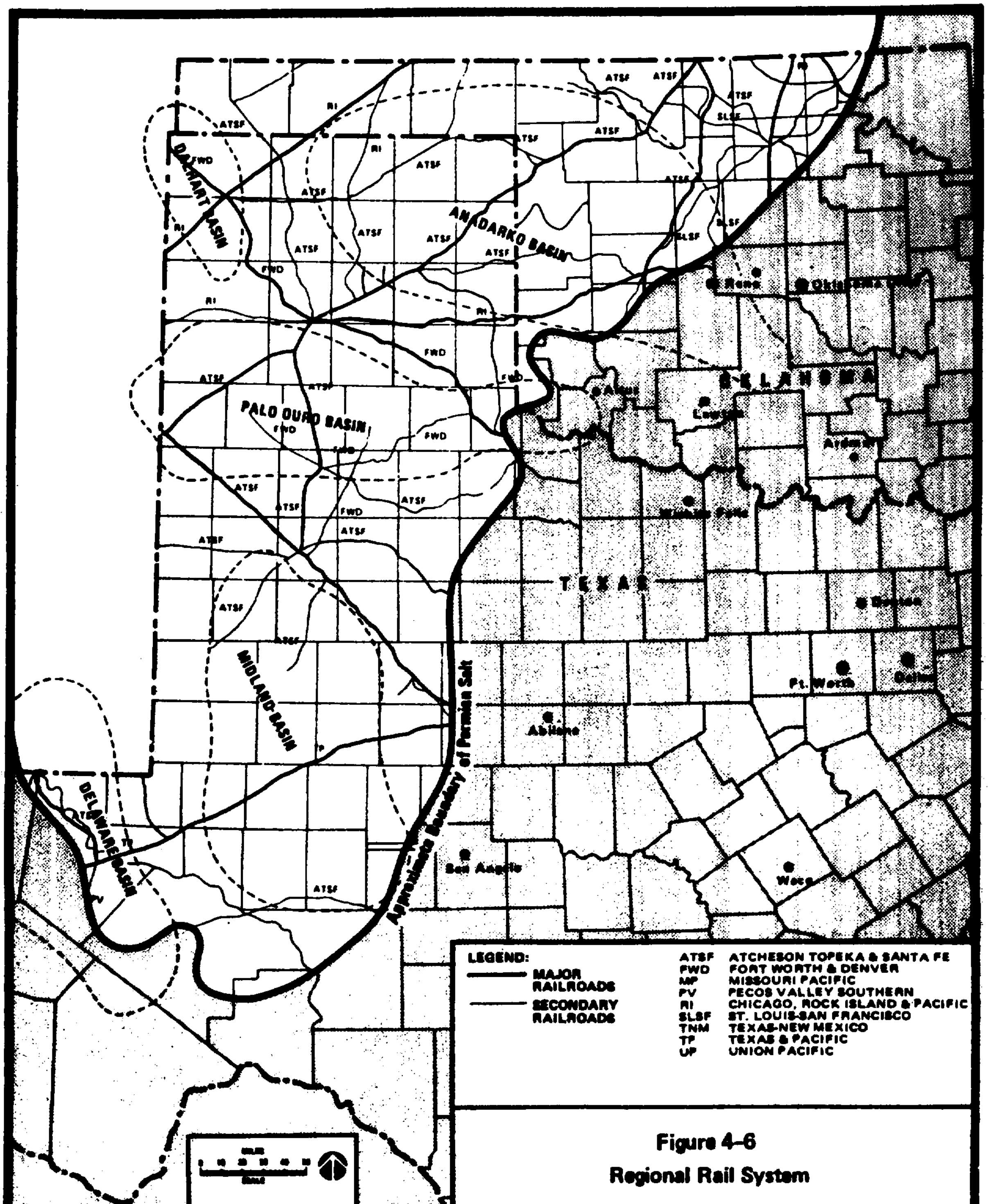


Figure 4-6
Regional Rail System

Source: Adapted from U.S. Geological Survey (1975)

Texas recognizes 18 (U.S. Department of Interior, Fish and Wildlife Service, 1976; Committee of Rare and Endangered Species of Oklahoma, 1975; University of Texas, 1974).

Wetlands are uncommon but important ecosystems in the Permian Region. Two wetland types are distinguished; riparian wetlands (river floodplains and marshes) and playa lakes. Goodwin and Niering (1975) identify three important regional wetlands: (1) Great Salt Plains (Salt Plains National Wildlife Refuge, Alfalfa County, Oklahoma; 32,000 acres); (2) Los Lingos Canyon, a 50,000-acre tract that includes at least three springs and a freshwater marsh habitat in Briscoe County, Texas; and (3) XIT Springs (Buffalo Springs, Dallam County, Texas), a privately-owned series of freshwater springs. Many freshwater wetlands are present along drainageways and reservoirs and in ephemeral playa lakes. Permanent playa lakes which are primarily saline are also present (Rowell, 1971).

The study region contains five National Wildlife Refuges (NWRs) covering more than 81,000 acres (U.S. Department of the Interior, Fish and Wildlife Service, 1977a; Riley and Riley, 1979). These include the Optima NWR (Texas County; 4333 acres), the Salt Plains NWR (Alfalfa County; 32,000 acres), and the Washita NWR (Custer County; 8100 acres) in Oklahoma; the Buffalo Lake NWR (Randall County; 7700 acres) and Muleshoe NWR (Bailey County; 5800 acres) in Texas; and the Bitter Lake NWR (Chaves County; 23,350 acres) in New Mexico. The Nature Conservancy has designated at least three natural areas in the Oklahoma portion of the Permian region of study: the sand dunes near Waynoka, Woods County; a portion of the Permian sea beds north of Alva, Woods County; and part of the Glass Mountains west of Orienta, Major County. In addition, the Society of American Foresters has designated two natural areas in Kansas, and the Carlsbad Caverns National Park is near the western edge of the Permian region.

Regional wildlife includes 107 species of amphibians and reptiles (Conant, 1975), 350 species of birds (Johnston, 1960), and 85 species of mammals (Burt and Grossenheider, 1976). With the exception of common amphibians such as Woodhouse's toad, bullfrog, and Great Plains toad, reptiles are the most important and abundant herpetofauna in the region. Typical reptiles include the bullsnake, plains rat snake, prairie rattlesnake, western box turtle, prairie lizard, and Texas horned lizard. No species of amphibian or reptile in the Permian Region is on the Federal list of endangered species (U.S. Department of the Interior, Fish and Wildlife Service, 1977b).

Excluding migratory species, the approximate number of regularly occurring or breeding birdlife is less than 200 species (Oberholser, 1974; Robbins, et al., 1966). Grassland species such as the dickcissel, horned lark, western meadowlark, long-billed curlew, burrowing owl, and mountain plover would be typical of the region. Thirty-five species of game birds occur in the Texas and Oklahoma portions of the Permian region (Bellrose, 1976; Johnsgard, 1973, 1975). The most widely hunted nonmigratory species include the bobwhite and scaled quail, with ring-necked pheasant, lesser prairie chicken, and turkey of lesser importance (Johnsgard, 1973; Wallmo, 1973; U.S. Department of the Interior, Bureau of Sport Fisheries and Wildlife, 1971a). Of the migratory species, mallards, pintails, and mourning doves represent the major portion of harvested birds (Buller, 1964; Johnsgard, 1973). Endangered or threatened birds include the brown pelican, southern bald eagle, arctic and American peregrine falcons, whooping crane, eskimo curlew, Mexican duck, red-cockaded woodpecker, and ivory-billed woodpecker (U.S. Department of the Interior, Fish and Wildlife Service, 1977b).

Of the 85 species of mammals in the Permian Region, 27 species are considered game species, furbearers, or both. Mule deer, white-tailed deer, and pronghorn are important big game mammals, whereas eastern and desert cottontails, black-tailed jackrabbit, and fox squirrel are the most widely hunted small game (U.S. Department of the Interior, Bureau of Sport Fisheries and Wildlife, 1971b). The most important furbearers of the region includes coyote, raccoon, muskrat, and opossum (U.S. Department of the Interior, Bureau of Sport Fisheries and Wildlife, 1971b). The black-footed ferret is the only mammal on the Federal list of endangered species, while the desert shrew, prairie vole, Palo Duro mouse, river otter, and mountain lion are listed as threatened (U.S. Department of the Interior, Fish and Wildlife Service, 1977a).

For scientific names of the above species refer to Appendix B.

4.4.2 Aquatic Ecology

A large portion of the Permian region is semiarid, with intermittent streams and playa lakes comprising the major naturally occurring aquatic habitats. Additionally, manmade structures (reservoirs, metal stock tanks, and stock ponds) have been created in parts of the Permian region. The naturally occurring aquatic habitats are generally high in mineral content from salt springs, brine seeps, or gypsum, and from such human activities as petroleum and natural gas production or irrigation return flows. Because of the water quality and ephemeral status of many of these natural surface waters, the type of flora and fauna that can exist is limited. Perhaps the most important recreational opportunities can be found at the manmade impoundments, where a warm-water fishery might be established if habitat conditions are adequate.

Rivers of the north-central Permian region, including the Arkansas, Cimarron, Canadian, and Red Rivers, have poor water quality as a result of natural and man-induced pollution. These streams (with the possible exception of the Arkansas River) originate in semiarid regions and frequently exhibit no flow or subsurface flow conditions. Consequently, suitable habitats for aquatic organisms are mainly outside or near the eastern periphery of the region. However, an impoundment (Lake Meredith) on the Canadian River provides an abundant fishery.

A few locally endangered or threatened species can occur in the north-central Permian region, but are expected primarily in the headwater areas of Colorado and New Mexico or near the eastern boundary of the Permian region, where the streams become larger and flow continuously.

Much of the central Permian region, although within the watersheds of the Brazos and Colorado rivers, consists mainly of playa lakes and dry creeks. Playa lakes, which are numerous in the Llano Estacado, have been investigated by Sublette and Sublette (1967), who reported temporary pond forms, including fairy, tadpole, and clam shrimps (anostracons, notostracans, and conchostracans). The aquatic insects that invade the playa lakes are generally strong fliers and include: certain odonatans; Dytiscidae (predaceous diving beetles), Hydrophilidae (water scavenger beetles) of the coleopterans;

Corixidae (water boatmen) and Notonectidae (back swimmers) of the hemipterans; and a number of Chironomidae (nonbiting midges) of the dipterans. No fish were recorded in these seasonally wet, shallow, and often salty lakes.

A few tributaries (e.g., the Concho River of the Colorado River system, which is essentially spring-fed) maintain flows and water quality that support recreational fish populations. Such streams are generally near the eastern boundary of the Permian region. In the south and southwest portions of the Permian region, the Pecos River, although polluted from natural brines and irrigation return flows, supports a diverse fish fauna in tributaries to the mainstream river. Many of the fish species and subspecies of this region (particularly the several species of desert pupfish *Cyprinodon* and musquitofish *Gambusia*) have been isolated by natural barriers and are restricted to specific habitats (often a single tributary or spring). Because of their highly restricted distributions and dependence on unique habitats for survival as a species or subspecies, many of these fishes are considered to be endangered by Federal authorities.

5 REGIONAL EVALUATION AND RECOMMENDATION OF STUDY AREAS

The factor maps and summary comparison tables in this section highlight the comparison of basins and provide a basis for the recommendations of the next-phase study areas (basins) that are presented at the end of the report.

5.1 HEALTH AND SAFETY EVALUATION

Figures 5-1 through 5-5 show the results of a regional evaluation by separate mapped health and safety and engineering-related factors. Factors of thickness and depth of salt-bearing units and their specifications (200 feet and greater in thickness and between 1000 and 3000 feet below the surface) were applied to geologic information in Johnson (1976) and Bachman and Johnson (1973). Salt deposits with such attributes extend continuously from the Delaware basin in the south to the Anadarko basin in the north and include parts of each basin and the surrounding areas (Figure 5-1). Thickness was the dominant factor in the narrowing-down process; depth accounted for a relatively small additional area. At the time of Johnson's (1976) work, a 200-foot minimum thickness of the salt-bearing unit was recommended.

Major aquifers occur over a large part of the region of study (Figure 5-2), but are absent in parts of the Delaware basin, in the northeastern part of the Midland basin, in the central and eastern part of the Palo Duro basin, in the southern part of the Dalhart basin, between the Dalhart and Palo Duro basins, in part of the south-central Anadarko basin, and in some other areas between basins. Some salt dissolution has occurred in deposits within approximately 500 to 1000 feet of the surface in the Palo Duro, Dalhart, and Midland basins.

Oil and gas fields occur abundantly in the Delaware, Midland, and Anadarko basins. The Dalhart and Palo Duro basins have few or no fields (Figure 5-3). Economically exploitable potash deposits are not known at present in the Palo Duro or Dalhart basins (Figure 5-4).

Transportation is briefly discussed in Section 5.3. As noted in Section 4.3.3, major highways and railroads focus on a number of central hubs such as Amarillo and Lubbock. One result of this configuration might be that waste shipments will have to be routed through areas of high population density. This possibility does not involve any particular basin; therefore, transportation was not used in comparing the basins. To assess this factor fully, transportation routes into the region (not just within it) must be examined. This kind of evaluation will be performed as part of the follow-on studies.

Major streams occur in all the basins, but with less density in the Midland and Delaware basins.

The Midland basin area includes a large number of restricted, alert, and military operations areas (Figure 5-5). The only section that is reasonably free of these potential conflicts lies in a band across the southern third of the basin. A significant portion of the south-central part of the Delaware basin is included in a military operations area. The Dalhart, Anadarko, and Palo Duro basins include very small restricted, alert, or military operations areas.

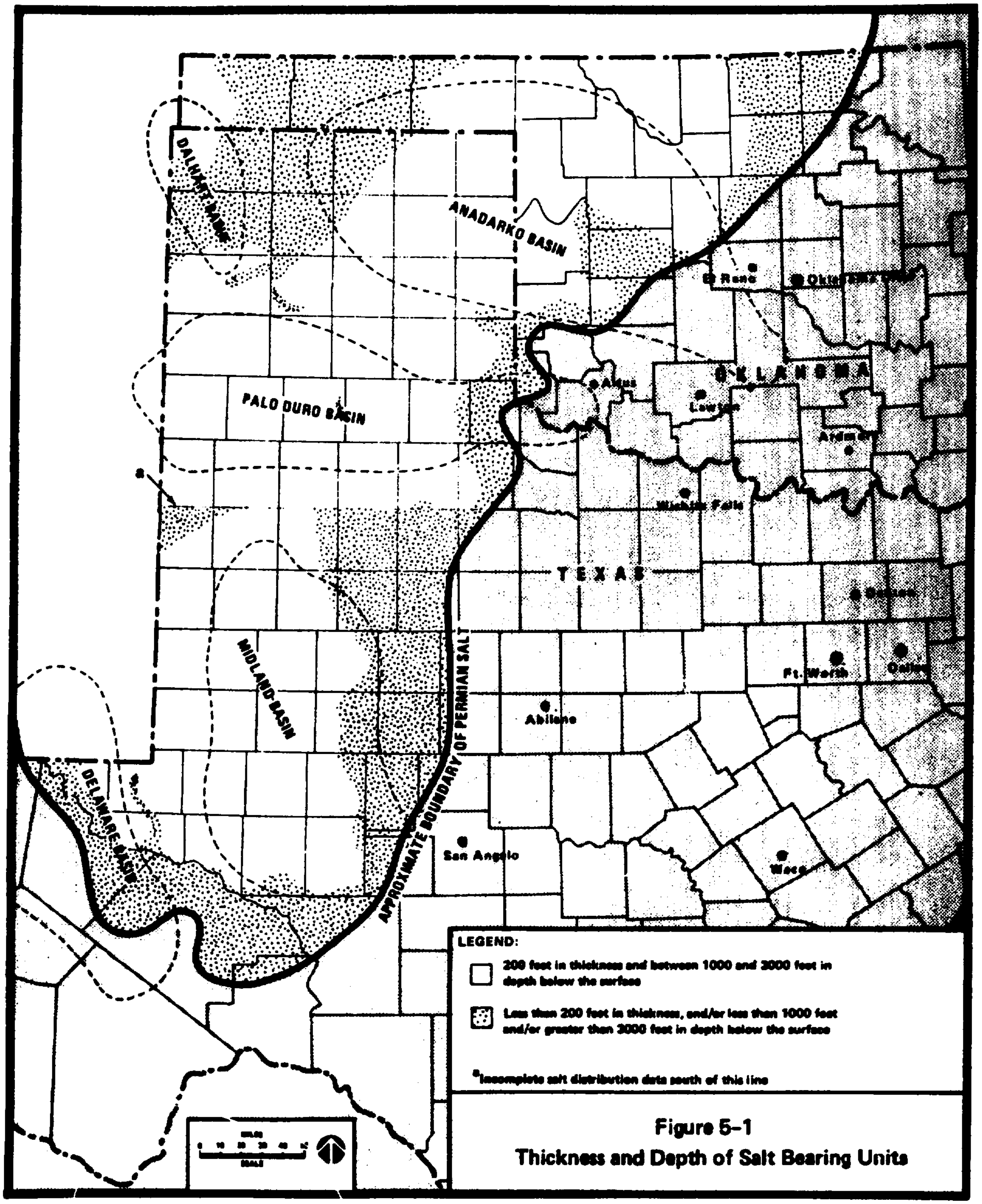


Figure 5–1
Thickness and Depth of Salt Bearing Units

Source: Modified from Johnson, 1976 and Bachman and Johnson, 1973

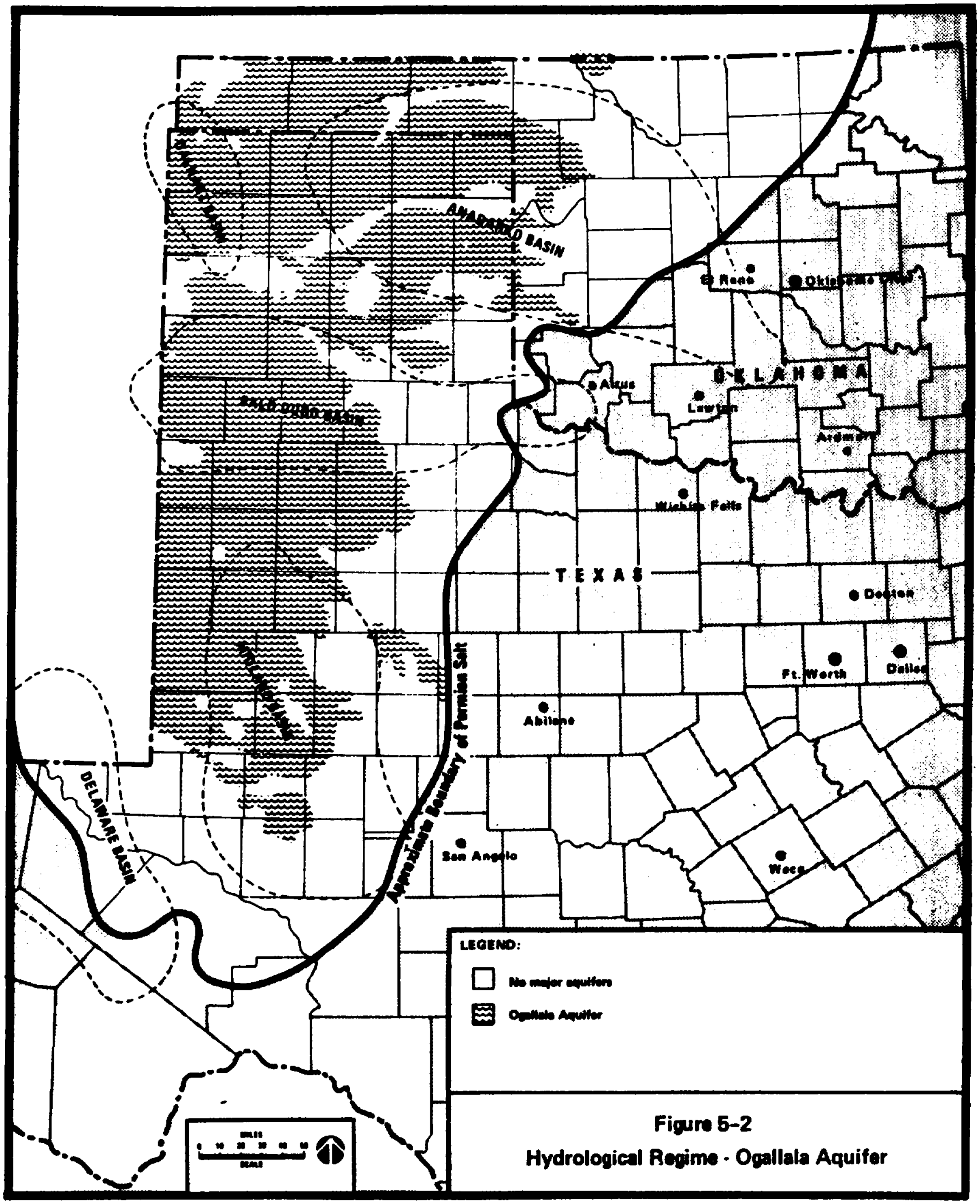


Figure 5-2
Hydrological Regime - Ogallala Aquifer

Source: Bachman and Johnson (1973)

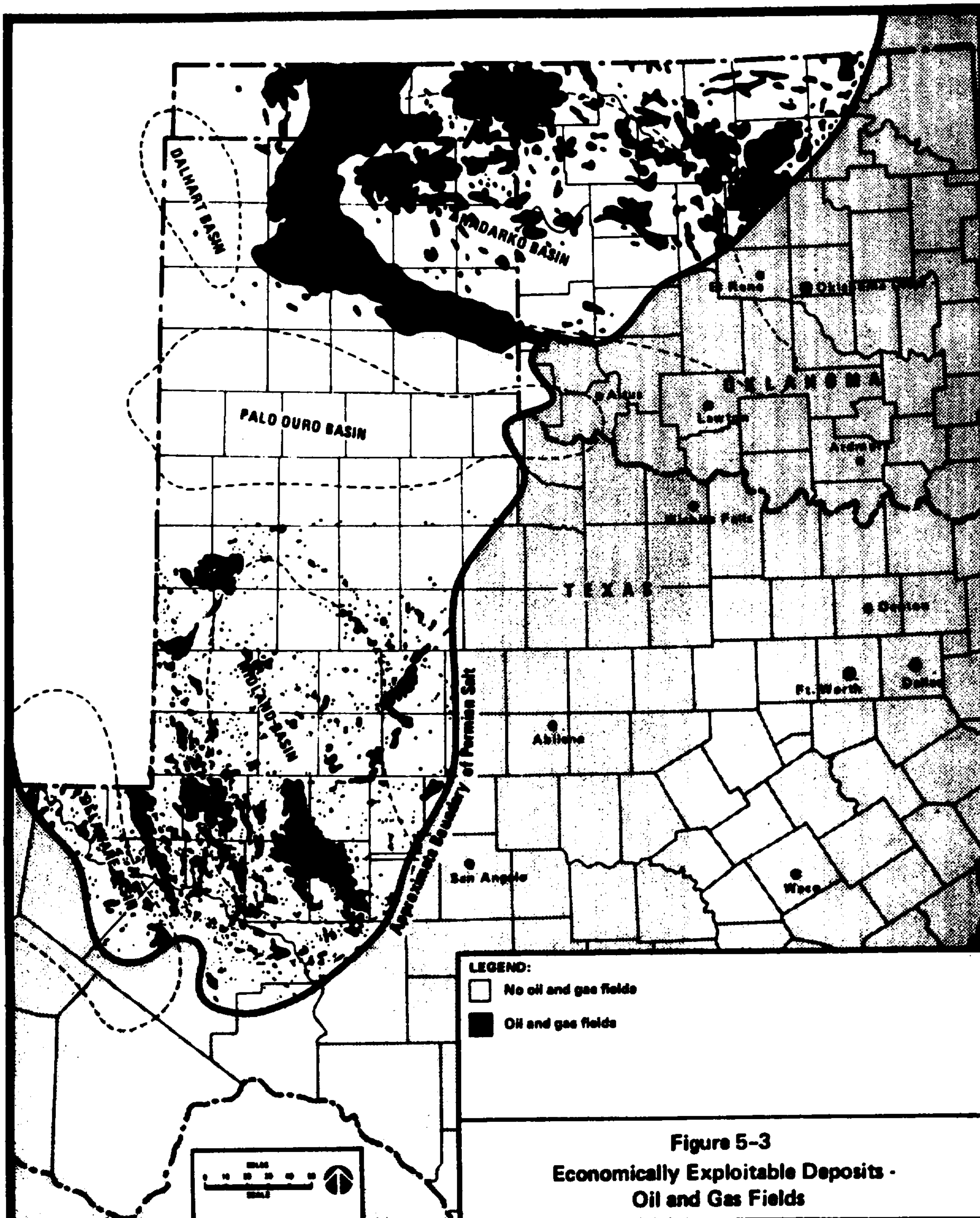


Figure 5-3
Economically Exploitable Deposits - Oil and Gas Fields

Source: Modified from Johnson (1976) and Texas Bureau of Economic Geology (1976)

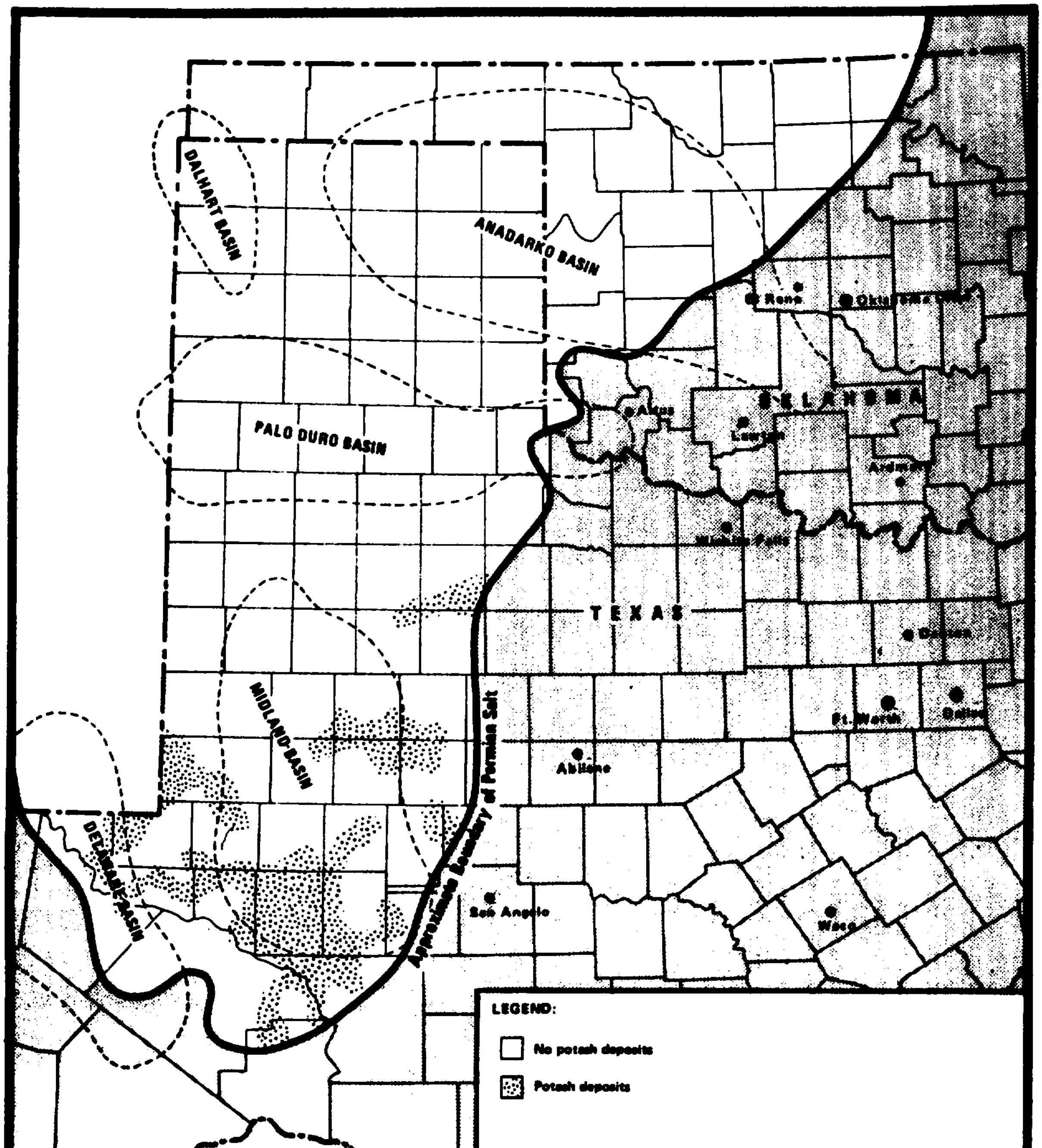


Figure 5-4
Economically Exploitable Deposits - Potash Deposits

Source: Modified from U.S. Dept. of Interior (1955)

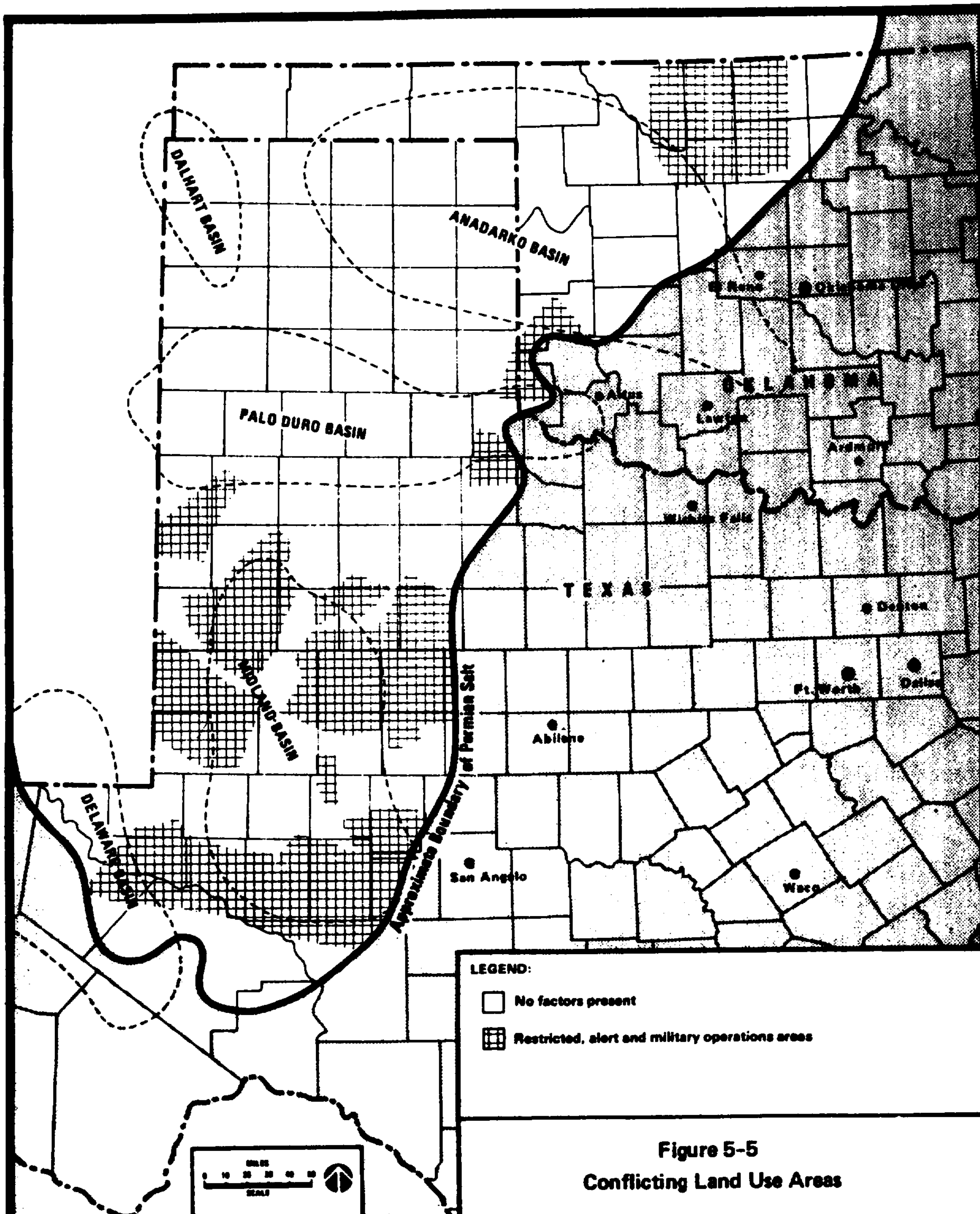


Figure 5-5
Conflicting Land Use Areas

Source: Adapted from National Oceanic and Atmospheric Administration (1977)

Table 5-1 compares the results of evaluating the Permian study region from health and safety and engineering considerations (factors), which are mapped in Figures 5-1 through 5-5.

This evaluation shows that:

1. Salt deposits with satisfactory specifications (200 feet or greater in thickness and between 1000 and 3000 feet below the surface) exist in all basins of the study region.

2. Further study of the Palo Duro and Dalhart basins is preferable to studies if the Midland, Delaware, or Anadarko basins, primarily because the Palo Duro and Dalhart basins have not been subject to the extensive oil and gas production of the other basins. As a result, fewer boreholes have been drilled through the salt units. The smaller probability of oil and gas exploration in these basins represents a positive attribute from the health and safety standpoint and with regard to the resource conflict issue. Earthquakes in and near the Anadarko basin make it less desirable for a nuclear waste repository. As noted earlier, the Delaware basin in eastern New Mexico has been selected as the site for the Waste Isolation Pilot Plant for the storage of radioactive defense wastes, and was not considered in this study for the disposal of high-level wastes from commercial nuclear power plants. No factors preclude the Palo Duro or Dalhart basins from further investigations.

5.2 ENVIRONMENTAL AND SOCIOECONOMIC EVALUATION

Table 5-2 summarizes environmental and socioeconomic characteristics of the five basins which are mapped on Figures 5-6 through 5-8.

National and state parks, national monuments, national wildlife refuges, and National Register historic sites were inventoried to determine areas that might be precluded from repository siting due to legislative constraints (see Figure 5-6). One of these factors would not eliminate an entire region from consideration; however, concentrations of these sites would make finding a suitable repository site more difficult.

The Anadarko basin has many natural and historic sites within and directly adjacent to its boundary. The Palo Duro and Midland basins have scattered historic sites and natural areas, but their density is not great. The Dalhart basin contains one National Register historic site and the Delaware basin has none.

At the regional scale, standard metropolitan statistical areas were used to indicate concentrations of urban population density that could represent a conflict in land use. The SMSAs defined by the Bureau of the Census contain land that is nonurban. Nonetheless, the SMSA counties contain a major portion of the region's total urban population.

As shown on Figure 5-7, four of the SMSAs within the study region are located in either the Palo Duro or the Midland basin. The Midland basin includes parts of the L··bbock, Midland-Odessa, and San Angelo SMSAs. The Palo Duro

TABLE 5-1. QUALITATIVE COMPARISON OF HEALTH/SAFETY AND ENGINEERING/ECONOMIC FACTORS IN THE PERMIAN SUBBASINS*

CRITERION	FACTOR	DALHART BASIN	PALO DURO BASIN	ANADARKO BASIN	MIDLAND BASIN	DELAWARE BASIN
Site Geometry	Salt Thickness	The Flowerpot and Blaine Formation make up the only salt-bearing unit that is 200 to 410 feet thick. This unit is typically 50- to 65-percent salt.	Five salt-bearing units are each more than 200 feet thick; Lower Clear Fork salt (200-500 feet thick); Upper Clear Fork salt (200 to 650); San Andres salt (200 to 1,590); Seven Rivers salt (200 to 540); and Salado-Tansill salt (200 to 340). These units are typically 20- to 60-percent salt.	Three salt-bearing units are more than 200 feet thick; Hutchinson salt (200 to 565 feet thick); Lower Cimarron salt (200 to 420); Flowerpot salt, Blaine Formation, and Yelton salt (200 to 710). These units typically are 40- to 70-percent salt.	Two salt-bearing units are the Rustler and Salado Formations (200 to 800+ feet thick).	Three salt-bearing units are the Rustler, Salado (200 to 1,600+ feet thick), and the Castile (200 to 600+ feet thick) Formations.
	Salt depth	The above salt unit is 1,200 to 1,765 feet below the surface in an area of about 1,000 square miles.	The above five units are 1,000 to 3,000 feet below the surface over an area of about 12,000 square miles.	The above three units are 1,000 to 3,000 feet below the surface over an area of about 17,000 square miles.	The above salt units are 1,000 to 3,000 feet below the surface over wide areas.	The above salt units are 1,000 to 3,000 feet below the surface over wide areas.
Tectonic Environment	Faults	Permian and younger rocks are not fractured or otherwise deformed	Permian and younger rocks are not significantly fractured or otherwise deformed.	Permian and younger rocks are not fractured or otherwise deformed.	Permian and younger rocks are not tectonically faulted.	Permian and younger rocks are not tectonically faulted.
	Seismic Acitivity	The basin is in seismic risk zone 1. A single earthquake of MM VI has been recorded in the basin.	The basin in entirely within seismic risk zone 1. No earthquake of MM V or greater have been recorded in the basin.	The basin is entirely within seismic risk zone 1. Three earthquakes of MM V have occurred in the western part of the basin, and seven events of MM V to MM VII have occurred in and near the eastern part of the basin.	The basin is entirely within seismic risk zone 1. One earthquake of MM VI has occurred in the Central Basin Platform.	The basin is entirely within seismic risk zone 1. One earthquake of MM VI has occurred nearby to the east in the Central Basin Platform.
Subsurface Hydrology	Aquifers	Freshwater aquifers in various areas include the Ogallala Formation, the Santa Rosa Sandstone, the Dakota and Cheyenne Sandstones, and Quaternary terrace and alluvial deposits. The salt-water-bearing Gloreita Sandstone underlies the salt.	Freshwater aquifers at or near surface in various areas include the Ogallala Formation, Edwards-Trinity strata, the Blaine Formation and Quaternary terrace and alluvial deposits. Salt-water-bearing sandstones (Tubb, Glorieta, and parts of the Artesia Group) are above or below several of the salt units in parts of the basin.	Freshwater aquifers at and near the surface in various areas include the Ogallala Formation, the Elk City Sandstone, the Rush Springs Sandstone, and Quaternary terrace and alluvial deposits. The salt-water-bearing Glorita Sandstone underlies the Flowerpot salt in the western Anadarko basin.	Freshwater aquifers at and near the surface in various areas include the Ogallala Formation and the Edwards-Trinity (Plateau) aquifer.	Freshwater aquifers at and near the surface in various areas include alluvial sand and gravel and the Edwards-Trinity (Plateau) aquifer.
	Salt Dissolution	There is no evidence of dissolution of salt at depths of 1,260 to 1,765 feet in most of the area.	There is no evidence of dissolution of salt beds at depths greater than about 1,000 feet.	There is no evidence of dissolution of salt beds at depths greater than about 1,000 feet.	**	**

* Modified from Johnson (1976) and Bachman and Johnson (1973).
** Information limited or not available in the referances used for preparing this summary report.

TABLE 5-1. (Continued)

CRITERION	FACTOR	DALHART BASIN	PALO DURO BASIN	ANADARKO BASIN	MIDLAND BASIN	DELAWARE BASIN
Subsurface-Hydrology (Continued)	Salt Dissolution	Salt is dissolved in an area where it is 950 to 1,200 feet below the surface.	Salt is partially or completely dissolved by circulating ground-water at most places where the salt is less than 500 to 800 feet below the surface, and locally the resultant brine is emitted at the surface.	Salt is partially or completely dissolved by circulating groundwater at most places where the salt is less than 500 to 800 feet below the surface, and locally the resultant brine is emitted at the surface.	**	**
Geologic Characteristics	Stratigrapny	Interbedded sandstone, shale, and gypsum/anhydrite layers overlie the salt unit.	Some of the salt units are overlain and underlain by impermeable shales.	The salt units are generally overlain by impermeable shales.	**	**
Human Intrusion	Oil and Gas	Oil is produced at only a few small fields, and the basin is not considered a significant petroleum province.	Oil is produced at only a few small fields, and the basin is not considered a significant petroleum province.	The Andarko basin and adjacent uplifts make up one of the major petroleum-producing provinces in the nation, and continued exploration is anticipated in all parts of the basin.	Extensive oil and gas production and exploration.	Extensive oil and gas production and exploration.
	Other Energy and Mineral Resources	Excluding petroleum and salt, there are no known significant mineral deposits within or below salt units.	Excluding salt, there are no known significant mineral deposits within or below the salt units.	Excluding petroleum and salt, there are no known significant mineral deposits within or below the salt units.	Potash deposits are associated with salt units.	Potash deposits are associated with salt units.
	Boreholes and Underground Mines	Many boreholes have been drilled through the salt units in most areas. No underground mines exist in the region.	Many boreholes have been drilled through the salt units. No underground mines exist in the region.	No underground mines exist in the region. Many boreholes have been drilled through the salt units in search of oil and gas. Brine wells and LPG-storage facilities have been developed in the salt units at six widely scattered localities.	Many boreholes have been drilled through the salt units in search of oil and gas.	Many boreholes have been drille. through the salt units in search of oil and gas.
Surface Characteristics	Conflicting Land Use	No alert, restricted, or military operations areas are located within the basin.	A small part of the basin included in alert, restricted, or military operations areas.	Two small sections of the basin are within alert, restricted, or military operations areas.	A large portion of the basin is within alert, restricted, or military operations areas.	A part of the basin is within alert, restricted, or military operations areas.

* Modified from Johnson (1976) and Bachman and Johnson (1973).
** Information limited or not available in the references used for preparing this summary report.

TABLE 5-2. QUALITATIVE COMPARISON OF ENVIRONMENTAL/SOCIOECONOMIC FACTORS IN THE PERMIAN SUBBASINS

	DALHART	PALO DURO	ANADARKO	MIDLAND	DELAWARE
EXCLUDED NATURAL AREAS, HISTORIC SITES AND PARKS	MOST FAVORABLE One National Register site in entire area.	FAVORABLE Few National Register sites. Some state parks and a wildlife refuge is in the area.	LESS FAVORABLE The Oklahoma portion has numerous National Register sites within the area and many adjacent.	FAVORABLE Few National Register sites or other natural or historic sites within the area.	MOST FAVORABLE One National Register site on edge of area.
URBAN POPULATION	MOST FAVORABLE No SMSA counties. All counties average less than 5 persons/mi^2.	FAVORABLE Area includes one county of Amarillo SMSA. Population density ranges from about 70-99.9 persons/mi^2 to less than 5 - 15.	FAVORABLE 1 small corner of Oklahoma City SMSA. Population density within most of the area is from 5 - 25 persons/mi^2.	LESS FAVORABLE Area includes counties of Midland-Odessa, one county of Lubbock SMSA and a portion of San Angelo SMSA. Population density ranges from less than 5 to 250 persons/mi^2. Most of the area is between 5 and 15.	MOST FAVORABLE No SMSA areas. Population ranges from less than 5 to 25 persons/mi^2. Much of the area is less than 5 persons/mile.
VALUABLE AGRICULTURAL LANDS	MOST FAVORABLE No part of the area has a level of agricturel-product value that is more than twice the state average.	LESS FAVORABLE About half of the area has a level of agricultural-product value per acre that is more than twice the state average.	FAVORABLE A small portion of the area has an agricultural-product value per acre that is more twice the state average.	FAVORABLE A part of the area has an agricultural-product value per acre that is more than twice the state average.	MOST FAVORABLE No Part of the land has a level of agricultural-product value per acre that is more than twice the state average.
RECREATION AND NATURAL AREAS	LESS FAVORABLE A large area is part of a National Grassland.	MOST FAVORABLE One natural wetland.	FAVORABLE Few scattered natural areas and recreation sites.	MOST FAVORABLE None within the area.	MOST FAVORABLE None within the area

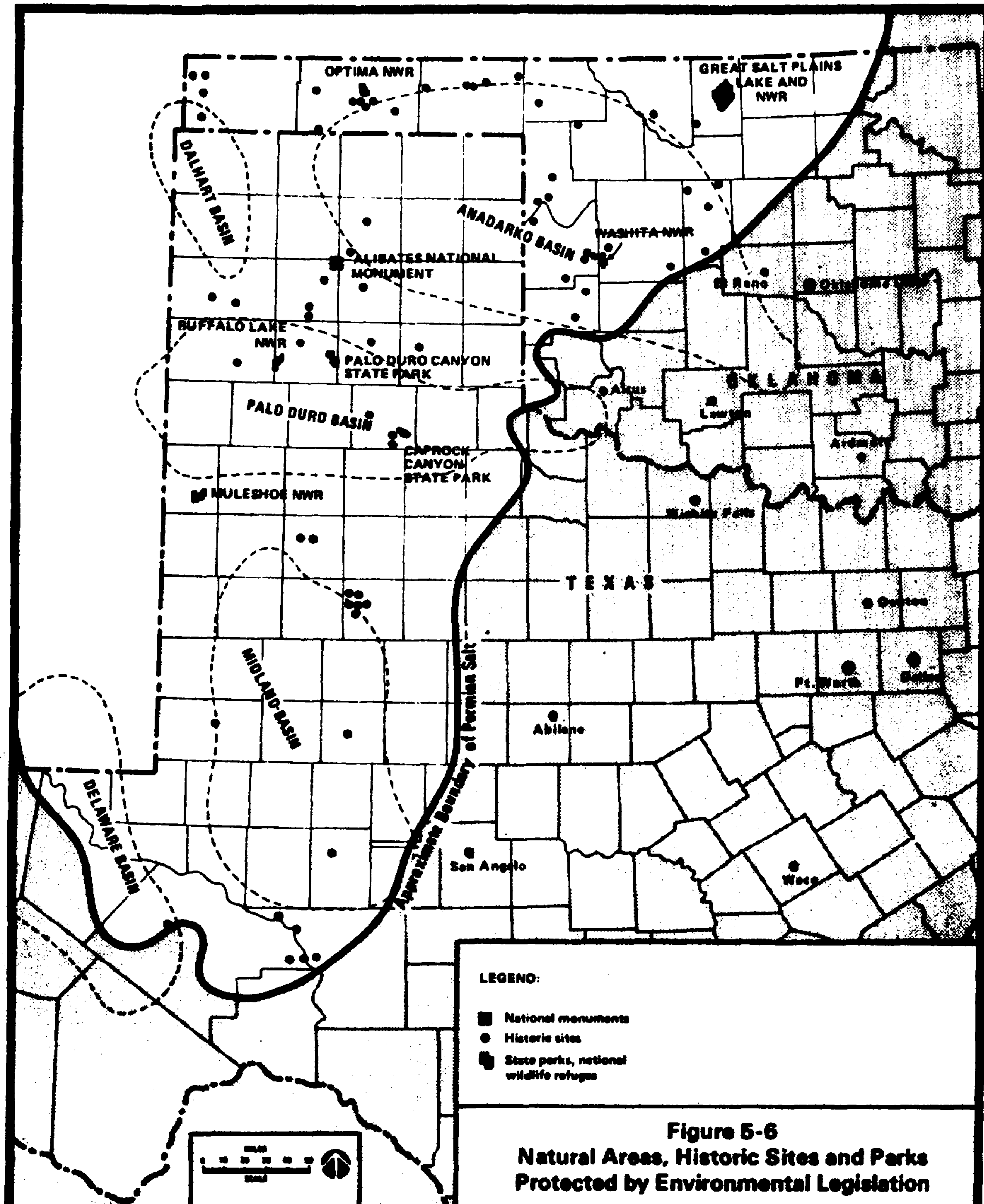


Figure 5-6
Natural Areas, Historic Sites and Parks Protected by Environmental Legislation

Source: U.S. Heritage Conservation and Recreation Service (1979)
U.S. Fish and Wildlife Service (1977)

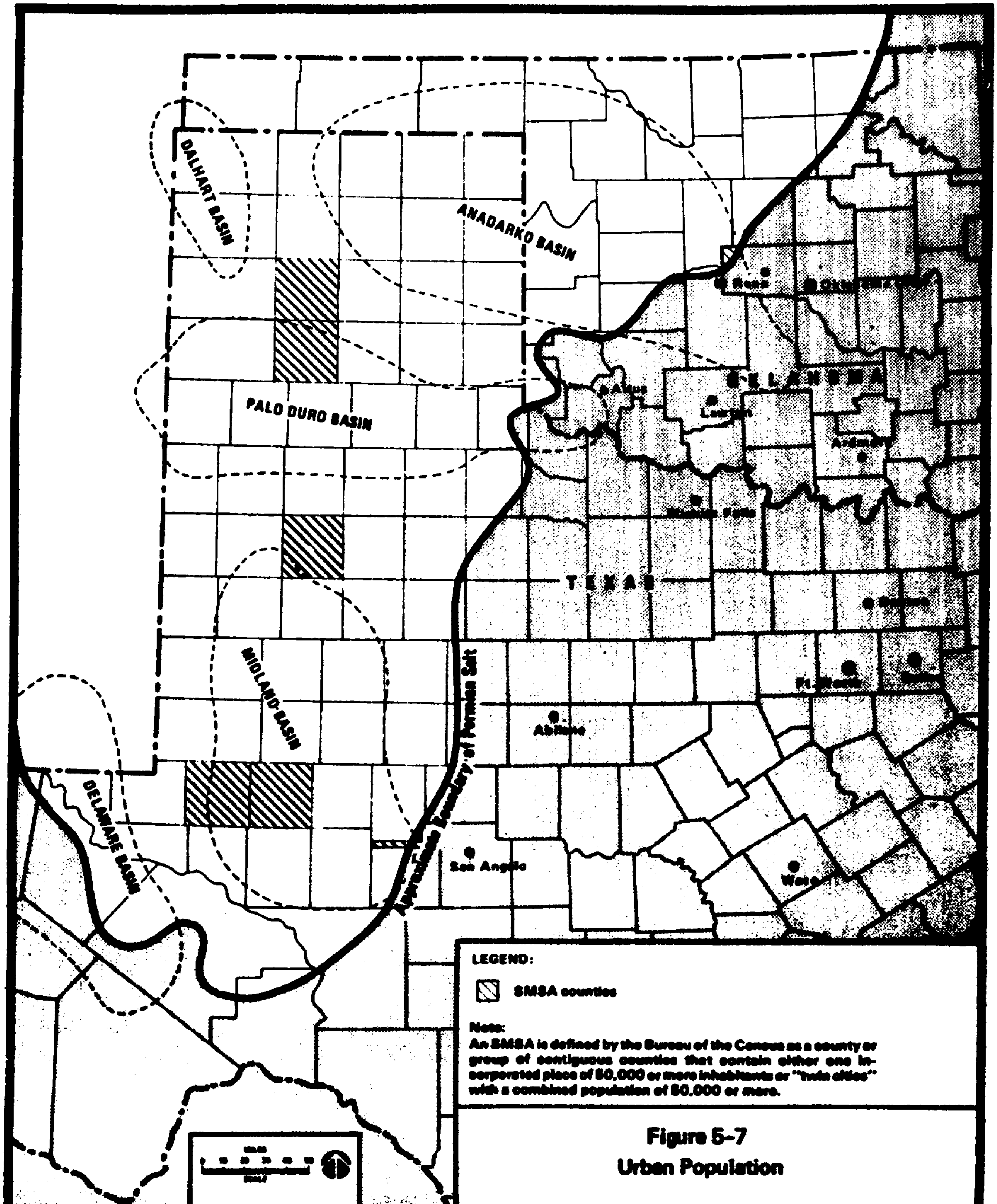


Figure 5-7
Urban Population

Source: U.S. Bureau of the Census (1971)

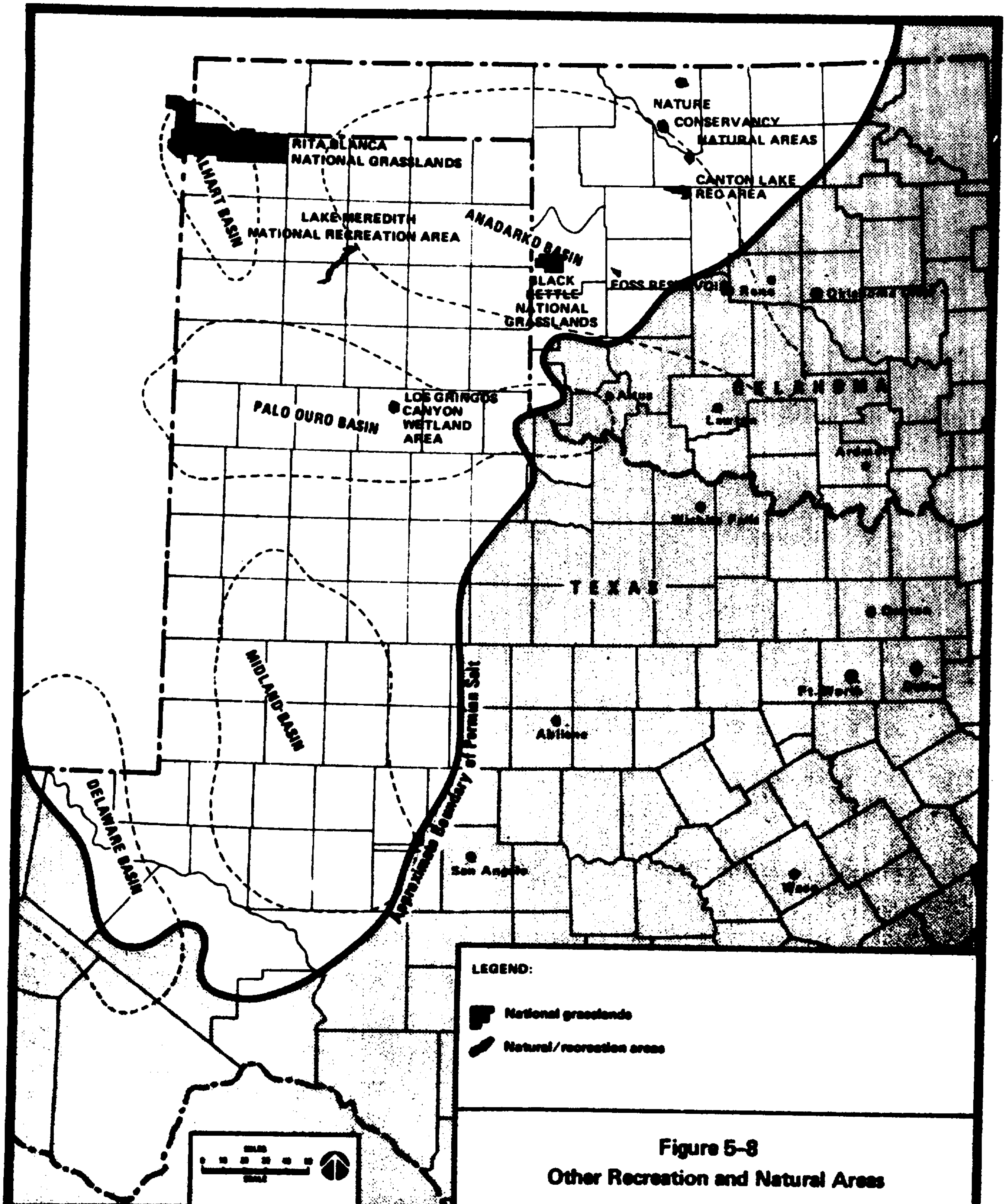


Figure 5-8
Other Recreation and Natural Areas

Source: Adapted from National Park Service (1976)
U.S. Bureau of Reclamation (1976)
Godwin and Niering (1975)

basin includes only a section of the Amarillo SMSA. The Anadarko basin contains a small portion of the Oklahoma City SMSA. The Dalhart and Delaware basins include no SMSAs.

Figure 5-8 shows natural and recreational areas within the study region that are not protected by environmental legislation, but that from a land use standpoint, might be in conflict with repository siting objectives. Few such areas are extensive enough to appear in a regional evaluation, but the two national grasslands indicated total more than 110,000 acres. A large portion of the Dalhart basin is included in Rita Blanca National Grassland. The Anadarko basin includes a few scattered sites.

In summary, the Delaware and Dalhart basins appear to offer relatively fewer possibilities for environmental and socioeconomic conflicts than the others. However, the regional evaluation did not reveal any environmental or socioeconomic considerations that should preclude further study in any of the basins.

5.3 ENGINEERING AND ECONOMIC FACTORS

As described in Section 5.1, all basins in the study region appear to have salt that is thick enough and deep enough to satisfy preliminary engineering specifications. Rail and highway transportation networks service all basins. Based on regional considerations, transportation distances do not eliminate any basins from further consideration. However, as the search area narrows, some portions of the basins are better served by existing transportation systems than others.

5.4 SUMMARY EVALUATION

The evaluation of regional geologic and nongeologic factors has been summarized in Sections 5.1, 5.2, and 5.3. While both geological and environmental factors have been considered, the geological aspects are dominant. All the basins appear to have salt beds of thicknesses and depths of engineering interest. However, the Palo Duro and Dalhart deposits have shown far less potential for oil and gas production and consequently have been penetrated less extensively by exploratory or production drillings. A site in the Delaware basin has already been selected as a candidate repository location; and hence, searches elsewhere for other potential locations seems particularly desirable to achieve an environmental diversity in candidate locations.

Regional environmental data suggest that the Delaware and Dalhart basins offer relatively fewer possibilities for environmental and socioeconomic conflicts than the others. However, the evaluation based on regional scale information did not reveal any environmental and socioeconomic considerations that should preclude further study in any of the basins.

On balance, the Palo Duro and Dalhart basins are more preferable for further study than the Midland, Delaware, and Anadarko basins.

6 REFERENCES

ANSI, 1972. "Building Code Requirements for Minimum Design Loads in Buildings and Other Structures." American National Standards Institute, New York, ANSI A58.1-1972 (revision of A58.1-1955).

Bachman, G.O. and R.B. Johnson, 1973. Stability of Salt in the Permian Salt Basin of Kansas, Oklahoma, Texas, and New Mexico. U.S. Geological Survey Open File Report (4339-4), p.1-45.

Bailey, R.D., 1976, Ecoregions of the United States. U.S. Department of Agriculture, Forest Service, Ogden, Utah.

Baker, E.T., Jr. and J.R. Wall, 1976. Summary Appraisals of the Nation's Groundwater Resoures--Texas-Gulf Region. U.S. Department of the Interior, Geological Survey, Professional Paper 813-F.

Baldwin, J.L., 1973. Climates of the United States. National Oceanic and Atmospheric Administration, Washington, D.C.

Bellrose, F.L., 1976. Ducks, Geese and Swans of North America. Stackpole, Harrisburg, Pa.

Bradshaw, R.L. and W.C. McClain, Editors, 1971. Project Salt Vault, A Demonstration of the Disposal of High-Activity Solidified Wastes in Underground Salt Mines. Oak Ridge National Laboratory, ORNL-4555, Chapter 2.

Brooks, C.E.P., 1970. Climate Through the Ages. 2nd revised edition, Dover Publications, Inc., New York.

Buller, R.J., 1964. "Central Flyway," pp. 209-232 in Waterfowl Tomorrow. J. P. Linduska, ed. U.S. Department of the Interior, Fish and Wildlife Service, Washington, D.C.

Burt, W.H., and R.P. Grossenheider, 1976. A Field Guide to the Mammals. Houghton Mifflin, Boston, Mass.

Committee for Rare and Endangered Plants of Oklahoma, 1975. Rare and Endangered Vertebrates and Plants of Oklahoma. U.S. Department of Agriculture, Soil Conservation Service, Washington, D.C.

Conant, R., 1975. A Field Guide to the Reptiles and Amphibians of Eastern and Central North America. Houghton Mifflin, Boston, Mass.

Goodwin, R.H. and W.A. Niering, 1975. Inland Wetlands of the United States. Connecticut College, New London, Connecticut.

Holzworth, G.C., 1972. Mixing Heights, Wind Speeds, and Potential for Urban Air Pollution Throughout the Contiguous United States. U.S. Environmental Protection Agency, Washington, D.C.

Johnsgard, P.A., 1973. North American Game Birds of Upland and Shoreline. University of Nebraska, Lincoln, Nebraska.

Johnsgard, P.A., 1975. Grouse and Quails of North America. University of Nebraska, Lincoln, Nebraska.

Johnson, K.S., 1976. Evaluation of Permian Salt Deposits in the Texas Panhandle and Western Oklahoma for Underground Wastes. Prepared for Union Carbide Corporation, Nuclear Division, Office of Waste Isolation, Y/OWI/SUB-4494/1.

Johnston, R.F., 1960. Directory of the Birdlife of Kansas. Museum of Natural History, Lawrence, Kansas.

Jutze, G.A., and K. Axetall, 1976. "Factors Influencing Emissions from Fugitive Dust Sources," in Symposium on Fugitive Emissions Measurement and Control Held in Hartford, Connecticut, on May 17-19, 1976 (compiled by E.M. Helming). Prepared by the Research Corporation of New England for the U.S. Environmental Protection Agency, PB-261 955.

Kuchler, A.W., 1975. Potential Natural Vegetation of the Conterminous United States. American Geographical Society, New York.

Kukla, G.J., and Matthews, R.K., 1972. Science, 178(4057), 190-191.

Lamb, H.H., 1966. The Changing Climate. Methuen & Co., Ltd., London, England.

McGuinness, C.L., 1963. The Role of Groundwater in the National Water Situation. Department of the Interior, Geological Survey, Water Supply Paper 1800.

National Academy of Sciences--National Research Council, 1957. The Disposal of Radioactive Waste on Land. Division of Earth Sciences, Committee on Radioactive Waste Disposal, Washington, D.C., Pub. 519.

National Academy of Sciences--National Research Council, 1970. Disposal of Solid Radioactive Wastes in Bedded Salt. Report by the Committee on Radioactive Waste Management, Washington, D.C.

NUS Corporation, 1979. Environmental Characterization of Bedded Salt Formations and Overlying Areas of the Permian Basin. Prepared for the Office of Nuclear Waste Isolation, Battelle Memorial Institute, Columbus, Ohio, ONWI-27.

Oberholser, H.C., 1974. Bird Life of Texas. University of Texas Press, Austin, Texas.

Pautz, M.E., ed., 1969. Severe Local Storm Occurrences, 1955-1967. ESSA Technical Memorandum, Environmental Science Services Administration, Washington, D.C., WBTM FCST 12.

Rand McNally and Company, 1978. Road Atlas.

Riley, L. and W. Riley, 1979. Guide to the National Wildlife Refuges. Anchor Press/Doubleday, Garden City, New York.

Robbins, C.S., B. Bruun, and H. S. Zim., 1966. Birds of North America. Golden Press, New York.

Rowell, C.M., Jr., 1971. "Vascular plants of the playa lakes of the Texas Panhandle and South Plains," Southwestern Naturalist, 15(4), pp. 407-417.

Schwarzbach, M., 1963. Climates of the Past, An Introduction to Paleoclimatology. Translated and edited by R.O. Muir, D. Van Nostrand Company, Ltd., Princeton, N.J.

Sellers, W.D., 1965. Physical Climatology. University of Chicago Press, Chicago, Ill.

Sublette, J.E. and M.S. Sublette, 1967. "The Limnology of Playa Lakes on the Llano Estacado," New Mexico and Texas Southwestern Naturalist, 12 Vol. (4): 369-406.

Texas Bureau of Economic Geology, 1976. Energy Resources of Texas. 1:1,000,000, Austin, Texas.

Texas State Department of Parks and Wildlife, 1977. Facilities Directory.

U.S. Bureau of Mines, 1972. Minerals Yearbook. Vol. 11, "Area Reports, Domestic", Washington, D.C.

U.S. Department of Agriculture, Forest Service, 1976. National Forests and Forest Service Field Offices. U.S. Government Printing Office, Washington, D.C. Stock No. 0-221-034.

U.S. Department of the Army, Corps of Engineers, 1974. Recreation Statistics, 1974. U.S. Government Printing Office, Washington, D.C., Stock No. 008-002-00098.

U.S. Department of Commerce, Bureau of the Census, 1971a. U.S. Census of Population: 1970, Number of Inhabitants, Final Report. PC(1)-A38, Oklahoma, U.S. Government Printing Office, Washington, D.C.

U.S. Department of Commerce, Bureau of the Census, 1971b. U.S. Census of Population: 1970, Number of Inhabitants, Final Report. PC(1)-A45, Texas, U.S. Government Printing Office, Washington, D.C.

U.S. Department of Commerce, Bureau of the Census. 1977. U.S. Census of Agriculture, 1974. Volume 1, State and County Data, Part 43, Texas and Part 36, Oklahoma.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration, 1961. Rainfall Frequency Atlas for the United States for Durations from 30 Minutes to 24 Hours and Return Periods from 1 to 100 Years. National Oceanic and Atmospheric Administration, Washington, D.C., Technical Paper No. 40 (reprinted in 1963).

U.S. Department of Commerce, National Oceanic and Atmospheric Administration, 1977a. Albuquerque Sectional Aeronautical Chart, 19th edition.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration, 1977b. Dallas Fort Worth Sectional Aeronautical Chart, 18th edition.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration, 1977c. San Antonio Sectional Aeronautical Chart, 19th edition.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration, 1977d. El Paso Sectional Aeronautical Chart, 19th edition.

U.S. Department of Energy, 1979a. Draft Environmental Impact Statement for the Management of Commercially Generated Radioactive Waste, Vol. 1, Washington, D.C., DOE/EIS-0046-D.

U.S. Department of Energy, 1979b. Draft Environmental Impact Statement for the Waste Isolation Pilot Plant. Washington, D.C., DOE/EIS-0026-D.

U.S. Department of the Interior, Bureau of Sport Fisheries and Wildlife, 1971a. Big Game Inventory for 1970. Washington, D.C., Wildlife Leaflet 497.

U.S. Department of the Interior, Bureau of Sport Fisheries and Wildlife, 1971b. Fur Catch in the United States, 1970. Washington, D.C., Wildlife Leaflet 499.

U.S. Department of the Interior, Bureau of Reclamation, 1976. Western United States Showing Location of Bureau of Reclamation Projects (map). U.S. Government Printing Office, Washington, D.C., Stock No. 837-308.

U.S. Department of the Interior, Fish and Wildlife Service, 1976. "List of Endangered and Threatened Wildlife and Plants," Federal Register, 41 (117): 24524-24572, June 16, 1976, U.S. Government Printing Office.

U.S. Department of the Interior, Fish and Wildlife Service, 1977a. Directory of National Wildlife Refuges--1977. U.S. Government Printing Office, Washington, D.C., Stock No. 916-533.

U.S. Department of the Interior, Fish and Wildlife Service, 1977b. "Endangered and Threatened Wildlife and Plants," Federal Register, 42 (135), 36420-36421, Washington, D.C.

U.S. Department of the Interior, Geological Survey, 1955. United States Potash 1:5,000,000. Washington, D.C.

U.S. Department of the Interior, Geological Survey, 1965. United States of America, National Parks and Monuments, National Forests, Indian Reservations, Wildlife Refuges, Public Lands and Historical Boundaries (map). U.S. Government Printing Office, Washington, D.C.

U.S. Department of the Interior, Geological Survey, 1970. The National Atlas of the United States of America. U.S. Government Printing Office, Washington, D.C.

U.S. Department of the Interior, Geological Survey, 1975. State Transportation Maps, Colorado, Kansas, New Mexico, Texas, Oklahoma. Prepared for the Federal Railroad Administration, U.S. Government Printing Office, Washington, D.C. (five separate maps).

U.S. Department of the Interior, Heritage Conservation and Recreation Service, 1979. "National Register of Historic Places." Published in the Federal Register, February 6, 1979, U.S. Government Printing Office.

U.S. Department of the Interior, National Park Service, 1975. Index of the National Park System. U.S. Government Printing Office, Washington, D.C., Stock No. 024-000-00612-5.

U.S. Water Resources Council, 1974. 1972 OBERS Projections, Series E, Population. U.S. Government Printing Office, Washington, D.C.

University of Texas, Bureau of Business Research, 1976. Atlas of Texas.

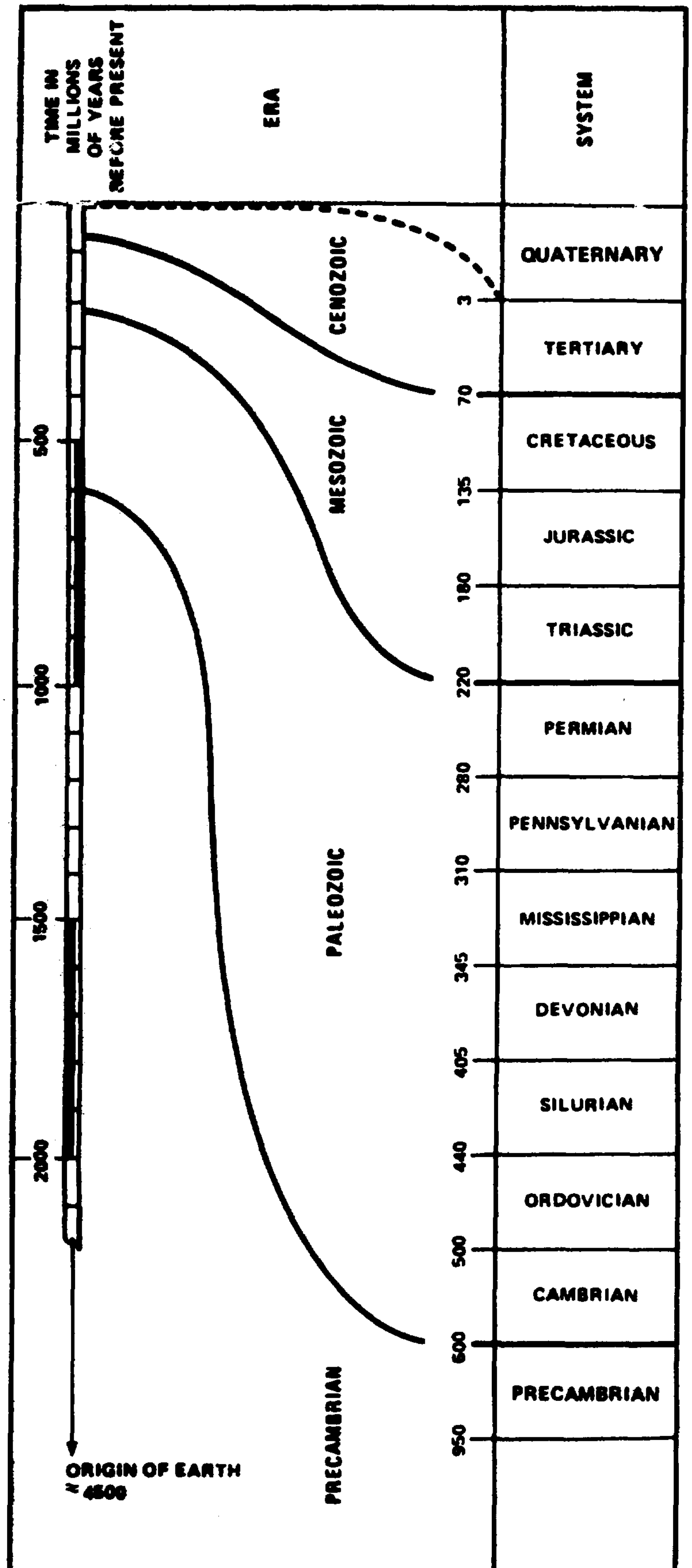
University of Texas, Rare Plant Study Center, 1974. Rare and Endangered Plants Native to Texas. Austin, Texas.

Wallmo, O.C., 1973. "Important Game Animals and Related Recreation in Arid Shrublands of the United States," pp. 98-107 in Arid Shrublands, Proceedings of the Third Workshop of the United States/Australia Rangelands Panel. Tucson, Arizona, 1975.

Weeks, J.W., 1978. Plan of Study for the High Plans Regional Aquifer--System Analysis in Parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming. U.S. Department of the Interior, Geological Survey, Water Resource Investigations 78-70.

APPENDIX A

Appendix A
Geologic Time Scale



APPENDIX [illegible]

APPENDIX B

COMMON WILDLIFE SPECIES IN THE PERMIAN REGION OF STUDY

Common Name	Scientific Name
Reptiles and Amphibians	
Woodhouse toad	*Bufo woodhousei woodhousei*
Bullfrog	*Rana catesbeiana*
Great Plains toad	*Bufo cognatus*
Bullsnake	*Pituophis melanoleucus sayi*
Plains rat snake	*Elaphe guatta emoryi*
Prairie rattlesnake	*Crotolus viridis viridis*
Western box turtle	*Terrapene ornata*
Prairie lizard	*Sceloporus undulatus consobrinus*
Texas horned lizard	*Phrynosoma cornutum*
Birds	
Dickcissel	*Spiza americana*
Horned lark	*Eremophila alpestris*
Western meadowlark	*Sturmella neglecta*
Long-billed curlew	*Numenius americanus*
Burrowing owl	*Athene cunicularia*
Mountain plover	*Charadrius montanus*
Bobwhite	*Colinus virginianus*
Scaled quail	*Callipepla squamata*
Ring-necked pheasant	*Phasianus colchicus*
Lesser prairie chicken	*Tympanuchus pallidicinctus*
Turkey	*Meleagris gallopavo*
Mallards	*Anas platyrhynchos*

APPENDIX B (Cont)

COMMON WILDLIFE SPECIES IN THE PERMIAN REGION OF STUDY

Common Name	Scientific Name
Birds	
Pintails	Anas acuta
Mourning doves	Zenaida macroura
Brown pelican	Pelecanus occidentalis
Southern bald eagle	Haliaeetus leucocephalus
Artic & American peregrine falcons	Falco Peregrinus
Whooping crane	Grus americana
Eskimo curlew	Numenius borealis
Mexican duck	Anas diazi
Red-cockaded woodpecker	Picoides borealis
Ivory-billed woodpecker	Campephilus principalis
Mammals	
Mule deer	Odocoileus hemionus
White-tailed deer	Odocoileus virginianus
Pronghorn	Antilocapra americana
Eastern cottontails	Sylvilagus floridanus
Desert cottontails	Sylvilagus audubonii
Black-tailed jackrabbit	Lepus californicus
Fox squirrel	Sciurus niger
Coyote	Camislatrans
Raccoon	Procyon lotor
Muskrat	Ondatra zibethicus

APPENDIX B (Cont)

COMMON WILDLIFE SPECIES IN THE PERMIAN REGION OF STUDY

Common Name	Scientific Name
Mammals	
Opossum	Didelphis marsupialis
Black-footed ferret	Mustela nigripes
Desert shrew	Notiosorex crawfordi
Prairie vole	Microtus ochrogaster
Palo Duro mouse	Peromyscus comanche
River otter	Lutra canadensis
Mountain lion	Felis concolor

DISTRIBUTION LIST

ACRES AMERICAN INC
R. STRUBLE
AEROSPACE CORP
BARRETT R. FRITZ
ALABAMA STATE GEOLOGICAL SURVEY
THORNTON L. NEATHERY
AMARILLO PUBLIC LIBRARY
APPLIED MECHANICS INC
JOHN R. WILLIAMS
ARGONNE NATIONAL LABORATORY
DAVID F. FENSTER
WYMAN HARRISON
J. HOWARD KITTEL
ARKANSAS GEOLOGICAL COMMISSION
WILLIAM V. BUSH
NORMAN F. WILLIAMS
ARTHUR D. LITTLE INC
CHARLES R. HADLOCK
ATKINS RESEARCH & DEVELOPMENT - UNITED KINGDOM
T. W. BROYD
ATOMIC ENERGY CONSULTANTS
DONALD G. ANDERSON
ATOMIC ENERGY OF CANADA LTD
T. CHAN
BATTELLE COLUMBUS DIVISION
JOHN T. MCGINNIS
JEFFREY L. MEANS
BECHTEL GROUP INC
TOM S. BAER
N. A. NORMAN
BENDIX FIELD ENGINEERING CORP
CHARLES A. JONES
MICHAEL H. MOBLEY
JOHN C. PACER
BRIGHAM YOUNG UNIVERSITY
HAROLD B. LEE LIBRARY
BROOKHAVEN NATIONAL LABORATORY
M. S. DAVIS
P. W. LEVY
PETER SOO
HELEN TODOSOW (2)
BUNDESANSTALT FUR GEOWISSENSCHAFTEN UND ROHSTOFFE - W. GERMANY
MICHAEL LANGER
BUREAU DE RECHERCHES GEOLOGIQUES ET MINIERES - FRANCE
PIERRE F. PEAUDECERF
BURNS AND ROE INDUSTRIAL SERVICES CORP
JOHN PIRRO
CALIFORNIA DEPT OF CONSERVATION
PERRY AMIMITO
CHALMERS UNIVERSITY OF TECHNOLOGY - SWEDEN
BERT ALLARD
CITIZENS ASSOCIATION FOR SOUND ENERGY
JUANITA ELLIS
COLORADO GEOLOGICAL SURVEY
JOHN W. ROLD
COLORADO OUTWARD BOUND SCHOOL
PETER ANTHONY ONEIL
COLORADO SCHOOL OF MINES
DONALD LANGMUIR
COLUMBIA UNIVERSITY
M. ASHRAF MAHTAB
CONTINENTAL GROUP INC
GEORGE F. ROLLEND
D.R.E.
KARL J. ANANIA
DAMES & MOORE
RON KEAR
JEFFREY KEATON
CHARLES R. LEWIS

DAPPOLONIA CONSULTING ENGINEERS INC
LISA K. DONOHUE
ABBY FORREST
CARL E. SCHUBERT
DEAF SMITH COUNTY LIBRARY
DUGOUT RANCH
ROBERT & HEIDI REDD
E.I. DU PONT DE NEMOURS & CO
D. H. TURNO
E.L.H. PUBLICATIONS - THE RADIOACTIVE EXCHANGE
HELMINSKI & WILKEN
E.R. JOHNSON ASSOCIATES INC
E. R. JOHNSON
G. L. JOHNSON
EAL CORP
LEON LEVENTHAL
EARTH SCIENCE AND ENGINEERING INC
LOU BLANCK
EARTH SCIENCES CONSULTANTS INC
HARRY L. CROUSE
EAST TENNESSEE STATE UNIVERSITY
ALBERT F. IGLAR
EBASCO SERVICES INC
ZUBAIR SALEEM
ECOLOGY & ENVIRONMENT INC
MICHAEL BENNER
EDISON ELECTRIC INSTITUTE
R. E. L. STANFORD
EDS NUCLEAR INC
C. SUNDARARAJAN
EG & G IDAHO INC
M. D. MCCORMACK
ELSAM - DENMARK
A. V. JOSHI
ENERGY RESEARCH GROUP INC
MARC GOLDSMITH
ENGINEERS INTERNATIONAL INC
FRANCIS S. KENDORSKI
ENVIROLOGIC SYSTEMS INC
JIM V. ROUSE
ENVIRONMENT CANADA
CLAUDE BARRAUD
ENVIRONMENTAL POLICY INSTITUTE
DAVID M. BERICK
FRED MILLAR
ENVIROSPHERE COMPANY
ROGER G. ANDERSON
K. E. LIND-HOWE
EXXON NUCLEAR IDAHO COMPANY INC
ROGER N. HENRY
FENIX & SCISSON INC
JOSE A. MACHADO
CHARLENE U. SPARKMAN
FERRIS STATE COLLEGE
MICHAEL E. ELLS
FLORIDA INSTITUTE OF TECHNOLOGY
JOSEPH A. ANGELO, JR.
FLORIDA POWER & LIGHT COMPANY
JAMES R. TOMONTO
FLORIDA STATE UNIVERSITY
JOSEPH F. DONOGHUE
FORD, BACON & DAVIS INC
DARRELL H. CARD
BURTON J. THAMER
FOSTER-MILLER ASSOCIATES INC
NORBERT PAAS
FOX CONSULTANTS INC
MIKE E. BRAZIE
FRIENDS OF THE EARTH
RENEE PARSONS

GARTNER LEE ASSOCIATES LTD - CANADA
ROBERT E. J. LEECH
GENERAL ATOMIC COMPANY
MICHAEL STAMATELATOS
GENERAL COURT OF MASSACHUSETTS
TIMOTHY J. BURKE
GEORGIA INSTITUTE OF TECHNOLOGY
ALFRED SCHNEIDER
CHARLES E. WEAVER
GEOTECHNICAL ENGINEERS INC
RONALD C. HIRSCHFELD
GEOTHERMAL ENERGY INSTITUTE
DONALD F. X. FINN
GEOTRANS
JAMES MERCER
GESELLSCHAFT F. STRAHLEN U. UMWELTFORSCHUNG M.B.H. - W. GERMANY
WOLFGANG BODE
H. MOSER
GILBERT/COMMONWEALTH
JERRY L. ELLIS
GOLDER ASSOCIATES
MELISSA MATSON
J. W. VOSS
GRAND COUNTY PUBLIC LIBRARY
GTC GEOLOGIC TESTING CONSULTANTS LT CANADA
JOHN F. PICKENS
GULF STATES UTILITIES COMPANY
JOHN E. BARRY
HANFORD ENGINEERING DEVELOPMENT LABORATORY
W. E. ROAKE
HARVARD UNIVERSITY
CHARLES W. BURNHAM
DADE W. MOELLER
RAYMOND SIEVER
HIGH PLAINS UNDERGROUND WATER DISTRICT
TROY SUBLETT
HIGH PLAINS WATER DISTRICT
DON MCREYNOLDS
DON D. SMITH
ILLINOIS DEPT OF NUCLEAR SAFETY
MILTON ZUKOR
IMPERIAL COLLEGE OF SCIENCE AND TECHNOLOGY - ENGLAND
B. K. ATKINSON
INSTITUT FUR TIEFLAGERUNG - W. GERMAN
KLAUS KUHN
INSTITUTE OF GEOLOGICAL SCIENCES - ENGLAND
STEPHEN THOMAS HORSEMAN
INTER/FACE ASSOCIATES INC
RON GINGERICH
INTERA ENVIRONMENTAL CONSULTANTS IN
F. J. PEARSON, JR.
LARRY RICKERTSEN
ROBERT WILEMS
INTERNATIONAL ENERGY ASSOCIATES LTD
BLYTHE K. LYONS
INTERNATIONAL ENERGY SYSTEMS CORP
JOHN A. BOWLES
INTERNATIONAL ENGINEERING COMPANY INC
MAX ZASLAWSKY
INTERNATIONAL RESEARCH AND EVALUATION
R. DANFORD

INTERNATIONAL SALT COMPANY
LEWIS P. BUSH
JACKSON STATE UNIVERSITY
ESTUS SMITH
JAY L. SMITH COMPANY INC
JAY L. SMITH
JOHNS HOPKINS UNIVERSITY
JARED L. COHON
JOINT STUDY COMMITTEE ON ENERGY
T. W. EDWARDS, JR.
KAISER ENGINEERS INC
H. L. JULIEN
KANSAS DEPT OF HEALTH AND ENVIRONMENT
GERALD W. ALLEN
KARNBRANSLESAKERHET - SWEDEN
LARS B. NILSSON
KELLER WREATH ASSOCIATES
FRANK WREATH
KIHN ASSOCIATES
HARRY KIHN
KLM ENGINEERING INC
B. GEORGE KNIAZEWYCZ
KOREA INSTITUTE OF ENERGY AND RESOURCES (KIER)
CHOO SEUNG HWAN
CHONG SU KIM
KQIL
KYOTO UNIVERSITY - JAPAN
YORITERU INOUE
LAWRENCE BERKELEY LABORATORY
EUGENE BINNALL
M. S. KING
LAWRENCE LIVERMORE NATIONAL LABORATORY
DAE H. CHUNG
EDNA M. DIDWELL
W. G. SUTCLIFFE
TECHNICAL INFORMATION DEPARTMENT L-53
LOCKHEED ENGINEERING & MANAGEMENT COMPANY
STEVE NACHT
LOS ALAMOS NATIONAL LABORATORY
P. L. BUSSOLINI
WAYNE R. HANSEN
LOS ALÁMOS TECHNICAL ASSOCIATES INC
R. J. KINGSBURY
LOUISIANA GEOLOGICAL SURVEY
CHARLES G. GROAT
LOUISIANA TECHNICAL UNIVERSITY
R. H. THOMPSON
LUBBOCK COUNTY SOIL AND WATER CONSERVATION DISTRICT
DON LANGSTON
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
MARSHA LEVINE
MCDERMOTT INTERNATIONAL
KAREN L. FURLOW
MEMBERS OF THE GENERAL PUBLIC
L. ROBERT ANDERSON
THOMAS G. BRADFORD
ROGER H. BROOKS
LAWRENCE CHASE, PH.D.
TOM & SUSAN CLAWSON
STEVE CONEWAY
JIM CONKWRIGHT
JOANN TEMPLE DENNETT
KENNETH & ALICE M. DROGIN
ROBERT DUDEK
JEAN EARDLEY
THALMAS P. EHR
BRUCE GABOW
BOB GAMMELIN
CARL A. GIESE
SHIRLEY M. GIFFORD
MICHAEL J. GILBERT
DOUGLAS H. GREENLEE
KENNETH GUSCOTT
A. M. HALE
ROBERT HIGGINS
KENNETH S. JOHNSON
THOMAS H. LANGEVIN
W. D. MCDOUGALD
MAX MCDOWELL
A. ALAN MOGHISSI
BARBARA MORRA
THEA NORDLING
CAROLINE PETTI
SHAILER S. PHILBRICK
TOM & MARY REES
OWEN SEVERANCE
PATRICIA SNYDER
P. E. STRALEY-GREGA
MARGUERITE SWEENEY
MARTIN & ELAINE WALTER
A. E. WASSERBACH
RICHARD J. WILLIS
LINDA WITTKOPF
MICHAEL BAKER, JR. INC
C. J. TOUHILL
MICHIGAN DEPT OF NATURAL RESOURCES
R. THOMAS SEGALL
MICHIGAN DEPT OF PUBLIC HEALTH
GEORGE W. BRUCHMANN
LEE E. JAGER
MINNESOTA GEOLOGICAL SURVEY
MATT S. WALTON
MINNESOTA STATE ENERGY AGENCY
MISSISSIPPI ATTORNEY GENERALS OFFICE
MACK CAMERON
MISSISSIPPI BUREAU OF GEOLOGY
MICHAEL B. E. BOGRAD
MISSISSIPPI CITIZENS AGAINST NUCLEAR DISPOSAL
STANLEY DEAN FLINT
MISSISSIPPI DEPT OF ENERGY AND TRANSPORTATION
RONALD J. FORSYTHE
MISSISSIPPI DEPT OF NATURAL RESOURCES
CURTIS W. STOVER
MISSISSIPPI MINERAL RESOURCES INSTITUTE
MISSISSIPPI STATE BOARD OF HEALTH
EDDIE S. FUENTE
GUY R. WILSON
MISSISSIPPI STATE HOUSE OF REPRESENTATIVES
HILLMAN TEROME FRAZIER
MITRE CORP
LESTER A. ETTLINGER
MONTANA BUREAU OF MINES AND GEOLOGY
EDWARD C. BINGLER
NATIONAL ACADEMY OF SCIENCES
JOHN T. HOLLOWAY
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MICHAEL R. HELFERT
NATIONAL HYDROLOGY RESEARCH INSTITUTE - CANADA
DENNIS J. BOTTOMLEY
K. U. WEYER
NATIONAL PARK SERVICE
DONALD F. GILLESPIE
NATIONAL PARKS & CONSERVATION ASSOCIATION
TERRI MARTIN
NATIONAL SCIENCE FOUNDATION
ROYAL E. ROSTENBACH
NAVAL WEAPONS STATION EARLE
GENNARO MELLIS
NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
FRANK E. KOTTLOWSKI
NEW MEXICO ENVIRONMENTAL EVALUATION GROUP
ROBERT H. NEILL
NEW YORK GEOLOGICAL SURVEY
ROBERT H. FAKUNDINY
NEW YORK STATE ASSEMBLY
MAURICE D. HINCHEY
NEW YORK STATE PUBLIC SERVICE COMMISSION
FRED HAAG
NEW YORK STATE SENATE RESEARCH SERVICE
DAVID WHITEHEAD
NORTH CAROLINA STATE SENATE
J. R. ALSBROOK
NORTH CAROLINA STATE UNIVERSITY
M. KIMBERLEY
NORTH ILLINOIS UNIVERSITY
B. VON ZELLEN
NORTHEAST UTILITIES SERVICE COMPANY
PATRICIA ANN OCONNELL
NTR GOVERNMENT SERVICES
THOMAS V. REYNOLDS
NUCLEAR ENERGY AGENCY/OECD - FRANCE
ANTHONY MULLER
NUS CORP
W. G. BELTER
OAK RIDGE NATIONAL LABORATORY
CATHY S. FORE
DAVID C. KOCHER
ELLEN D. SMITH
OKLAHOMA STATE DEPT OF HEALTH
R. L. CRAIG
ONTARIO HYDRO - CANADA
K. A. CORNELL
ONTARIO MINISTRY OF THE ENVIRONMENT - CANADA
JAAK VIIRLAND
ORANGE COUNTY COMMUNITY COLLEGE
LAWRENCE E. OBRIEN
OREGON STATE UNIVERSITY
JOHN C. RINGLE
OTHA INC
JOSEPH A. LIEBERMAN
P.O.W.E.R
TIM REVELL
P.O.W.E.R.
RALPH DILLER
PACIFIC GAS AND ELECTRIC COMPANY
ADRIAN C. SMITH, JR.
PACIFIC NORTHWEST LABORATORY
DON J. BRADLEY
CHARLES T. KINCAID
ROBERT MCCALLUM
PARSONS BRINCKERHOFF QUADE & DOUGLAS INC
ROBERT PRIETO
MARK E. STEINER

PARSONS-REDPATH
GLEN A. STAFFORD
PB-KBB INC
JUDITH G. HACKNEY
PENNSYLVANIA STATE UNIVERSITY
MARY BARNES
DELLA M. ROY
WILLIAM B. WHITE
PERRY COUNTY CITIZENS AGAINST NUCLEAR WASTE DISPOSAL
WARREN STRICKLAND
PETTIS WALLEY
PHYSIKALISCH-TECHNISCHE BUNDESANSTALT - W. GERMANY
HORST SCHNEIDER
POINT BEACH NUCLEAR PLANT
JAMES J. ZACH
PRESQUE ISLE COURTHOUSE
PSE & G
JOHN J. MOLNER
PUBLIC SERVICE INDIANA
ROBERT S. WEGENG
PURDUE UNIVERSITY
PAUL S. LYKOUDIS
RALPH M. PARSONS COMPANY
JERROLD A. HAGEL
RED ROCK 4-WHEELERS
GEORGE SCHULTZ
RIO ALGOM CORP
DUANE MATLOCK
ROCKWELL HANFORD OPERATIONS
ROCKWELL INTERNATIONAL ENERGY SYSTEMS GROUP
HARRY PEARLMAN
ROGERS & ASSOCIATES ENGINEERING CORP
ARTHUR SUTHERLAND
ROGERS, GOLDEN & HALPERN
JACK A. HALPERN
ROY F. WESTON INC
WILLIAM IVES
MICHAEL V. MELLINGER
ROBERT SCHULER
HARRY W. SMEDES
LAWRENCE A. WHITE
RPC INC
JAMES VANCE
S.E. LOGAN & ASSOCIATES INC
STANLEY E. LOGAN
SALT LAKE CITY TRIBUNE
JIM WOOLF
SAN JUAN RECORD
DEBORAH A. MARCUS
SANDIA NATIONAL LABORATORIES
G. C. ALLEN
SHARLA BERTRAM
NANCY C. FINLEY
R. W. LYNCH
WIPP CENTRAL FILES
SCIENCE APPLICATIONS INC
JEFFREY ARBITAL
J. ROBERT LARIVIERE
DAVID H. LESTER
JOHN E. MOSIER
HOWARD PRATT
MICHAEL E. SPAETH
KRISHAN K. WAHI
ROBERT A. YODER
SENATE RESEARCH SERVICE
DAVID WHITEHEAD
SENECA COUNTY DEPT OF PLANNING & DEVELOPMENT

SERIOUS TEXANS AGAINST NUCLEAR DISPOSAL (S.T.A.N.D)
DELBERT DEVIN
SHANNON & WILSON INC
HARVEY W. PARKER
SIERRA CLUB
MARVIN RESNIKOFF
BROOKS YEAGER
SIERRA CLUB - COLORADO OPEN SPACE COUNCIL
ROY YOUNG
SLICKROCK COUNTRY COUNCIL
BRUCE HUCKO
SNAKE RIVER ALLIANCE
TIM MCNEIL
SOGO TECHNOLOGY INC
TIO C. CHEN
SOUTH DAKOTA SCHOOL OF MINES AND TECHNOLOGY
CANER ZANBAK
SOUTHERN STATES ENERGY BOARD
J. F. CLARK
NANCY KAISER
SOUTHWEST RESEARCH AND INFORMATION CENTER
DON HANCOCK
SPRINGVILLE CITY LIBRARY
ST & E TECHNICAL SERVICES INC
STANLEY M. KLAINER
STANFORD UNIVERSITY
IRWIN REMSON
STATE UNIVERSITY OF NEW YORK AT BINGHAMTON
FRANCIS T. WU
STATE WORKING GROUP
JOHN GERVERS
STONE & WEBSTER ENGINEERING CORP
JOHN H. PECK
ARLENE C. PORT
EVERETT M. WASHER
SWEDISH GEOLOGICAL
LEIF CARLSSON
SYRACUSE UNIVERSITY
WALTER MEYER
T.M. GATES INC
TODD M. GATES
TECHNICAL INFORMATION PROJECT
DONALD PAY
TERRA TEK INC
KHOSROW BAKHTAR
TEXAS A & M UNIVERSITY
EARL HOSKINS
STEVE MURDOCK
JAMES E. RUSSELL
TEXAS BUREAU OF ECONOMIC GEOLOGY
WILLIAM L. FISHER
TEXAS DEPT OF AGRICULTURE
ROBERT J. KING
TEXAS DEPT OF HEALTH
DAVID K. LACKER
TEXAS DEPT OF WATER RESOURCES
C. R. BASKIN
ALFRED DAREZZO
TEXAS ENERGY COORDINATORS OFFICE
ARNULFO ORTIZ
TEXAS GOVERNORS OFFICE OF GENERAL COUNSEL
R. DANIEL SMITH
TEXAS HOUSE OF REPRESENTATIVES
ELLEN SALYERS

TEXAS STATE HOUSE OF REPRESENTATIVES
PETE LANEY
THE BENHAM GROUP
KEN SENOUR
THE EARTH TECHNOLOGY CORP
MATT WERNER
KENNETH L. WILSON
THE JACKSON CLARION-LEDGER
MARK SCHLEIFSTEIN
TRU WASTE SYSTEMS OFFICE
K. V. GILBERT
TUN ISMAIL ATOMIC RESEARCH CENTRE (PUSPATI)
SAMSURDIN BIN AHAMAD
U.S. BUREAU OF LAND MANAGEMENT
MARY PLUMB
U.S. BUREAU OF RECLAMATION
REGE LEACH
U.S. DEPT OF ENERGY
CHED BRADLEY
R. COOPERSTEIN
LAWRENCE H. HARMON
CARL NEWTON
U.S. DEPT OF ENERGY - ALBUQUERQUE OPERATIONS OFFICE
JOSEPH M. MCGOUGH
DORNER T. SCHUELER
U.S. DEPT OF ENERGY - CHICAGO OPERATIONS OFFICE
VICKI ALSPAUGH
PAUL KEARNS
C. MORRISON
PUBLIC READING ROOM
R. SELBY
U.S. DEPT OF ENERGY - DALLAS SUPPORT OFFICE
CURTIS E. CARLSON, JR.
U.S. DEPT OF ENERGY - GEOLOGIC REPOSITORY DIVISION
J. W. BENNETT
C. R. COOLEY (2)
JIM FIORE
RALPH STEIN
U.S. DEPT OF ENERGY - HEADQUARTERS
PUBLIC READING ROOM
U.S. DEPT OF ENERGY - IDAHO OPERATIONS OFFICE
PUBLIC READING ROOM
U.S. DEPT OF ENERGY - NEVADA OPERATIONS OFFICE
PUBLIC READING ROOM
U.S. DEPT OF ENERGY - NUCLEAR WASTE POLICY ACT OFFICE
JANIE SHAHEEN
U.S. DEPT OF ENERGY - NWTS PROGRAM OFFICE
J. O. NEFF
U.S. DEPT OF ENERGY - OAK RIDGE OPERATIONS OFFICE
PUBLIC READING ROOM
U.S. DEPT OF ENERGY - OFFICE OF ENERGY RESEARCH
FRANK J. WOBBER
U.S. DEPT OF ENERGY - OFFICE OF PROJECT AND FACILITIES MANAGEMENT
D. L. HARTMAN
U.S. DEPT OF ENERGY - SAN FRANCISCO OPERATIONS OFFICE
ENERGY RESOURCES CENTER
PUBLIC READING ROOM

PARSONS-REDPATH
GLEN A. STAFFORD
PB-KBB INC
JUDITH G. HACKNEY
PENNSYLVANIA STATE UNIVERSITY
MARY BARNES
DELLA M. ROY
WILLIAM B. WHITE
PERRY COUNTY CITIZENS AGAINST NUCLEAR WASTE DISPOSAL
WARREN STRICKLAND
PETTIS WALLEY
PHYSIKALISCH-TECHNISCHE BUNDESANSTALT - W. GERMANY
HORST SCHNEIDER
POINT BEACH NUCLEAR PLANT
JAMES J. ZACH
PRESQUE ISLE COURTHOUSE
PSE & G
JOHN J. MOLNER
PUBLIC SERVICE INDIANA
ROBERT S. WEGENG
PURDUE UNIVERSITY
PAUL S. LYKOUDIS
RALPH M. PARSONS COMPANY
JERROLD A. HAGEL
RED ROCK 4-WHEELERS
GEORGE SCHULTZ
RIO ALGOM CORP
DUANE MATLOCK
ROCKWELL HANFORD OPERATIONS
ROCKWELL INTERNATIONAL ENERGY SYSTEMS GROUP
HARRY PEARLMAN
ROGERS & ASSOCIATES ENGINEERING CORP
ARTHUR SUTHERLAND
ROGERS, GOLDEN & HALPERN
JACK A. HALPERN
ROY F. WESTON INC
WILLIAM IVES
MICHAEL V. MELLINGER
ROBERT SCHULER
HARRY W. SMEDES
LAWRENCE A. WHITE
RPC INC
JAMES VANCE
S.E. LOGAN & ASSOCIATES INC
STANLEY E. LOGAN
SALT LAKE CITY TRIBUNE
JIM WOOLF
SAN JUAN RECORD
DEBORAH A. MARCUS
SANDIA NATIONAL LABORATORIES
G. C. ALLEN
SHARLA BERTRAM
NANCY C. FINLEY
R. W. LYNCH
WIPP CENTRAL FILES
SCIENCE APPLICATIONS INC
JEFFREY ARBITAL
J. ROBERT LARIVIERE
DAVID H. LESTER
JOHN E. MOSIER
HOWARD PRATT
MICHAEL E. SPAETH
KRISHAN K. WAHI
ROBERT A. YODER
SENATE RESEARCH SERVICE
DAVID WHITEHEAD
SENECA COUNTY DEPT OF PLANNING & DEVELOPMENT
SERIOUS TEXANS AGAINST NUCLEAR DISPOSAL (S.T.A.N.D)
DELBERT DEVIN
SHANNON & WILSON INC
HARVEY W. PARKER
SIERRA CLUB
MARVIN RESNIKOFF
BROOKS YEAGER
SIERRA CLUB - COLORADO OPEN SPACE COUNCIL
ROY YOUNG
SLICKROCK COUNTRY COUNCIL
BRUCE HUCKO
SNAKE RIVER ALLIANCE
TIM MCNEIL
SOGO TECHNOLOGY INC
TIO C. CHEN
SOUTH DAKOTA SCHOOL OF MINES AND TECHNOLOGY
CANER ZANBAK
SOUTHERN STATES ENERGY BOARD
J. F. CLARK
NANCY KAISER
SOUTHWEST RESEARCH AND INFORMATION CENTER
DON HANCOCK
SPRINGVILLE CITY LIBRARY
ST & E TECHNICAL SERVICES INC
STANLEY M. KLAINER
STANFORD UNIVERSITY
IRWIN REMSON
STATE UNIVERSITY OF NEW YORK AT BINGHAMTON
FRANCIS T. WU
STATE WORKING GROUP
JOHN GERVERS
STONE & WEBSTER ENGINEERING CORP
JOHN H. PECK
ARLENE C. PORT
EVERETT M. WASHER
SWEDISH GEOLOGICAL
LEIF CARLSSON
SYRACUSE UNIVERSITY
WALTER MEYER
T.M. GATES INC
TODD M. GATES
TECHNICAL INFORMATION PROJECT
DONALD PAY
TERRA TEK INC
KHOSROW BAKHTAR
TEXAS A & M UNIVERSITY
EARL HOSKINS
STEVE MURDOCK
JAMES E. RUSSELL
TEXAS BUREAU OF ECONOMIC GEOLOGY
WILLIAM L. FISHER
TEXAS DEPT OF AGRICULTURE
ROBERT J. KING
TEXAS DEPT OF HEALTH
DAVID K. LACKER
TEXAS DEPT OF WATER RESOURCES
C. R. BASKIN
ALFRED DAREZZO
TEXAS ENERGY COORDINATORS OFFICE
ARNULFO ORTIZ
TEXAS GOVERNORS OFFICE OF GENERAL COUNSEL
R. DANIEL SMITH
TEXAS HOUSE OF REPRESENTATIVES
ELLEN SALYERS
TEXAS STATE HOUSE OF REPRESENTATIVES
PETE LANEY
THE BENHAM GROUP
KEN SENOUR
THE EARTH TECHNOLOGY CORP
MATT WERNER
KENNETH L. WILSON
THE JACKSON CLARION-LEDGER
MARK SCHLEIFSTEIN
TRU WASTE SYSTEMS OFFICE
K. V. GILBERT
TUN ISMAIL ATOMIC RESEARCH CENTRE (PUSPATI)
SAMSURDIN BIN AHAMAD
U.S. BUREAU OF LAND MANAGEMENT
MARY PLUMB
U.S. BUREAU OF RECLAMATION
REGE LEACH
U.S. DEPT OF ENERGY
CHED BRADLEY
R. COOPERSTEIN
LAWRENCE H. HARMON
CARL NEWTON
U.S. DEPT OF ENERGY - ALBUQUERQUE OPERATIONS OFFICE
JOSEPH M. MCGOUGH
DORNER T. SCHUELER
U.S. DEPT OF ENERGY - CHICAGO OPERATIONS OFFICE
VICKI ALSPAUGH
PAUL KEARNS
C. MORRISON
PUBLIC READING ROOM
R. SELBY
U.S. DEPT OF ENERGY - DALLAS SUPPORT OFFICE
CURTIS E. CARLSON, JR.
U.S. DEPT OF ENERGY - GEOLOGIC REPOSITORY DIVISION
J. W. BENNETT
C. R. COOLEY (2)
JIM FIORE
RALPH STEIN
U.S. DEPT OF ENERGY - HEADQUARTERS
PUBLIC READING ROOM
U.S. DEPT OF ENERGY - IDAHO OPERATIONS OFFICE
PUBLIC READING ROOM
U.S. DEPT OF ENERGY - NEVADA OPERATIONS OFFICE
PUBLIC READING ROOM
U.S. DEPT OF ENERGY - NUCLEAR WASTE POLICY ACT OFFICE
JANIE SHAHEEN
U.S. DEPT OF ENERGY - NWTS PROGRAM OFFICE
J. O. NEFF
U.S. DEPT OF ENERGY - OAK RIDGE OPERATIONS OFFICE
PUBLIC READING ROOM
U.S. DEPT OF ENERGY - OFFICE OF ENERGY RESEARCH
FRANK J. WOBBER
U.S. DEPT OF ENERGY - OFFICE OF PROJECT AND FACILITIES MANAGEMENT
D. L. HARTMAN
U.S. DEPT OF ENERGY - SAN FRANCISCO OPERATIONS OFFICE
ENERGY RESOURCES CENTER
PUBLIC READING ROOM