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Studies of the Suitability of Salt Domes in East Texas Basin for Geologic Isolation of Nuclear Wastes

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STUDIES OF THE SUITABILITY OF SALT DOMES IN EAST TEXAS BASIN FOR GEOLOGIC ISOLATION OF NUCLEAR WASTES[1]

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ABSTRACT

The suitability of salt domes in the east Texas basin (Tyler basin), Texas, for long-term isolation of nuclear wastes is being evaluated. The major issues concern hydrogeologic and tectonic stability of the domes and potential natural resources in the basin. These issues are being approached by integration of dome-specific and regional hydrogeologic, geologic, geomorphic, and remote-sensing investigations. Hydrogeologic studies are evaluating basinal hydrogeology and ground-water flow around the domes in order to determine the degree to which salt domes may be dissolving, their rates of solution, and the orientation of saline plumes in the fresh-water aquifers. Subsurface geologic studies are being conducted: 1) to determine the size and shape of specific salt domes, the geology of the strata immediately surrounding the domes, and the regional geology of the east Texas basin; 2) to understand the geologic history of dome growth and basin infilling; and 3) to evaluate potential natural resources. Geomorphic and surficial geology studies are determining whether there has been any dome growth or tectonic movement in the basin during the Quaternary. Remote-sensing studies are being conducted to determine: 1) if dome uplift has altered regional lineation patterns in Quaternary sediments; and 2) whether drainage density indicates Quaternary structural movement.

On the basis of the screening criteria of Brunton *et al.* (1978), Oakwood and Keechi domes have been chosen as possible candidate domes. Twenty-three domes have been eliminated because of insufficient size, too great a depth to salt, major hydrocarbon production, or previous use (such as liquid propane storage or salt mining or brining). Detailed geologic, hydrogeologic, and geomorphic investigations are now being conducted around Oakwood and Keechi salt domes.

INTRODUCTION

The future of nuclear energy depends partly on the ability to safely dispose of high-level nuclear wastes for long periods of time. Several states (California, Oregon, and Maine) have placed moratoriums on future nuclear power plant construction until suitable technology for storage of high-level nuclear waste can be demonstrated. Since the mid-1950's salt deposits have been considered a geologically suitable medium for long-term isolation. The Committee on Radioactive Waste Management of the National Research Council/National Academy of Sciences recommended that deep salt formations were a logical geologic medium for long-term isolation. Salt was considered essentially impermeable. Because salt deforms plastically, fractures would not stay open. Even though salt is extremely soluble, known salt formations more than 200 m.y. old have not dissolved as evidenced by their presence in the subsurface today. A repository in salt therefore was expected to be dry, not subject to leaks, and stable for long-term storage (National Academy of Sciences, 1957).

The U.S. Department of Energy (and its preceding agencies) is responsible for a nationwide investigation of geologic formations to evaluate their suitability for repositories. Bedded salt, anticlinal salt, and dome salt are all being considered by various research organizations in the United States. Nonsalt units also being investigated are granite, volcanic ash, lava flows, shales, and arid basins.

In 1976 the U.S. Department of Energy, through the Office of the Governor (State of Texas), asked the Bureau of Economic Geology, The University of Texas at Austin, to investigate the geologic suitability of bedded salt in the Palo Duro and Dalhart basins of the Texas panhandle and salt domes in the east Texas basin (Tyler basin) for possible areas in which high-level nuclear waste might be stored. The east Texas basin studies are part of the studies of salt domes in interior basins of Texas, Louisiana, and Mississippi — the Gulf Coast Interior Salt Basin — which is one regional element of the national program. From the Gulf Coast Interior Basin, U.S. Department of Energy (DOE) hopes to choose one salt dome for a nuclear waste repository. This paper reviews only the salt dome program in east Texas and some preliminary conclusions on dome suitability as of this date.

Geologic Setting of the East Texas Basin

The east Texas basin is part of the Gulf Coast Interior Basin, which crosses east Texas, Louisiana, and Mississippi. This basin resulted from Triassic rifting in the Gulf of Mexico and the development of smaller grabens subparallel to the Gulf of Mexico graben.

In the center of the east Texas basin at about 15,000 ft, the Jurassic Louann-Werner salt/anhydrite (mother-salt) onlaps the Late Triassic-Early Jurassic (?) Eagle Mills Formation composed of continental red beds of rift-basin origin. One

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or two kilometers of salt were probably deposited originally as the basin was partly restricted. Upper Jurassic limestone shelf/shelf-edge deposits (Smackover/Haynesville Formations) accumulated and offlapped or prograded over the salt as the basin opened to normal marine salinities and moderate subsidence occurred. Late Jurassic clastic deposits (Cotton Valley/Terryville) of deltaic/barrier origin prograded gulfward over the limestone shelves. In Mississippi and eastern Louisiana, these Jurassic deltaic deposits probably initiated migration of Louann Salt into growing ridges and diapirs. In east Texas, where Jurassic clastic deposition was restricted, sufficient sedimentary burial to initiate salt movement probably did not begin until after deposition of Lower Cretaceous fluvial/deltaic clastics deposits (Travis Peak Formation, *etc.*) and were still moving during early Tertiary when Wilcox and Claiborne delta systems (Eocene) added thick clastic sections as they filled the northern margin of the Gulf of Mexico. Salt movement probably declined following delta building, and diapiric activity was greatly reduced if not stopped by Oligocene/Miocene time. Figures 1 and 2 show a schematic cross section and the location of the deep and shallow domes in the east Texas basin, respectively.

WASTE ISOLATION PROGRAM AT THE BUREAU OF ECONOMIC GEOLOGY

The program to investigate the suitability of salt domes in the east Texas basin addresses the stability of specific domes for potential repositories and evaluates the geologic and hydrogeologic stability of all the domes in a general fashion. Using the criteria discussed in the following section, two domes, Oakwood and Keechi salt domes, have been found acceptable for further study. Although the major emphasis is on these domes, studies are being continued for all domes as well as concurrent regional studies.

The suitability of a salt dome is dependent upon geological and environmental/engineering criteria. Geologic concerns address the short-term and long-term stability of the salt dome; that is, will man-made or natural phenomena cause a breach to the repository within the lifetime of the repository? Critical questions must be addressed: Are the domes dissolving and at what rate? Are the domes still growing in such a way that surface erosion could breach the dome within the life of the repository, or is the dome a nonmoving, insoluble formation in the subsurface? Do the domes or lands overlying or adjacent to the salt domes hold resources valuable to present or future societies? Are there now cavities within the domes resulting from the storage of varied products that we produce?

Other considerations address the economic and engineering constraints that must be placed on locating and constructing a repository. Are the domes located in the vicinity of significant populations? Dome size and dome depth are also important factors within these secondary considerations. If the dome is too small, then a repository may require mul-

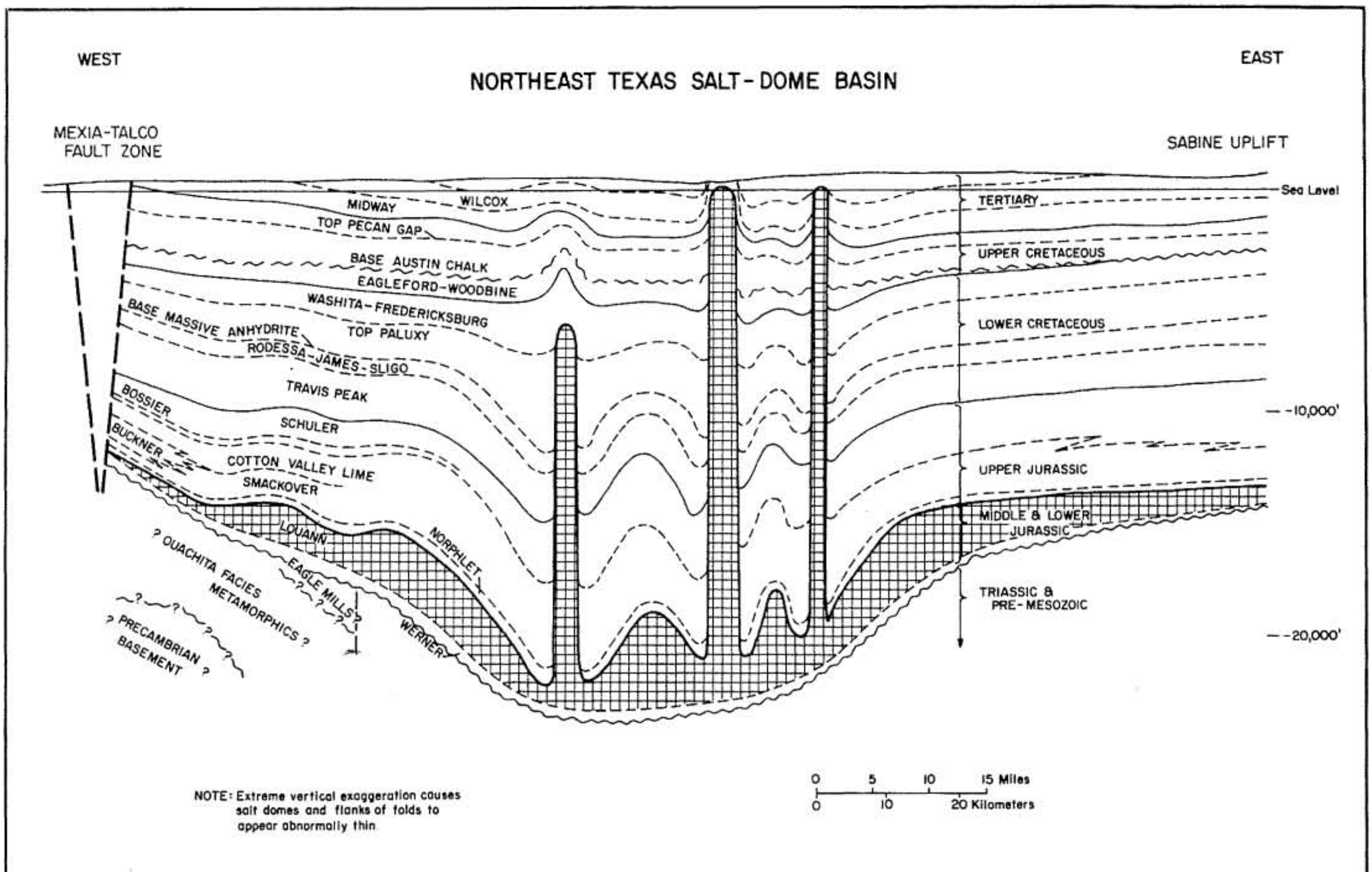

Figure 1. Schematic cross section of east Texas basin (modified from Netherland, Sewell and Associates, 1976).

tiple working levels, which are more expensive than a single mine level. Similarly, if the dome is too deep below the land surface, the cost of mine and shaft construction will be too expensive, and engineering problems of the retrieval of waste canisters from hot, plastically-deforming salt are uncertain.

Furthermore, studies of salt dome suitability must address generic regional aspects as well as site-specific problems. Apparent dome suitability may result from an inability to record a particular phenomenon or a lack of locally available data. Regional generic studies of a single phenomenon offer insights as to whether that particular phenomenon is a problem even though it cannot be measured on a specific candidate dome. A hypothetical example is the possible growth of salt domes during the Quaternary. Warping of Pleistocene river gravels over a candidate dome would indicate relatively recent uplift. However, if there are no gravels over this dome, uplift or lack of it cannot be identified. The resolution of the problem is to investigate gravels over other domes in the basin to determine whether there is domal uplift. If geologically recent uplift occurred over other salt domes in the basin, then relatively recent uplift may also have occurred or may now be occurring at the dome under investigation.

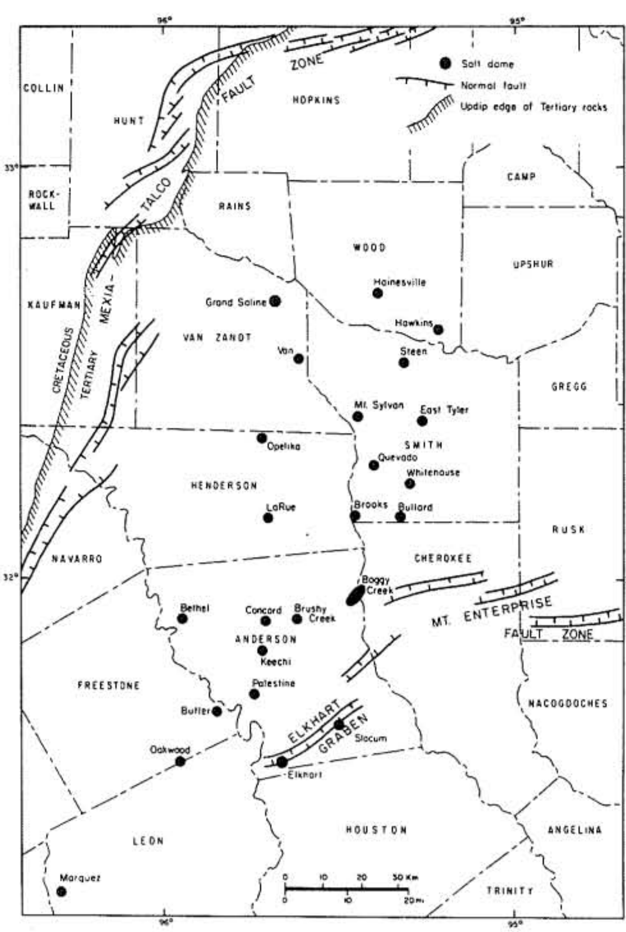

Figure 2. Location of salt domes in east Texas.

Geologic Criteria for Evaluation of Salt Dome Suitability

Criteria for specific dome evaluation follow, based on work by Brunton and McClain (1977) and Brunton *et al.* (1978), as well as conversations with personnel from the Office of Nuclear Waste Isolation, Battelle Memorial Institute, the present scientific monitor for DOE. These criteria identify areas of critical research but in most cases do not provide absolute constraints to salt dome selection.

Dome size. – A candidate salt dome should have a cross-sectional area of at least 1,700 acres at a depth of 2,000 ft below the top of the dome. Any salt domes having significantly less acreage than this are considered unacceptable.

Depth to salt. – The depth to salt must be less than 3,000 ft; deeper domes are unacceptable.

Structural stability. – A candidate salt dome must be structurally stable. For a repository storing commercial high-level and transuranic (intermediate-level) nuclear wastes of varied half lives, 250,000 years is assumed as an appropriate life for the repository. Salt movement in the past 250,000 years makes the structural stability of a salt dome suspect.

Hydrogeologic criteria. – Candidate salt domes must be hydrogeologically stable in the same time frame as for a structural stability, 250,000 years. Two main concerns are that the salt dome could dissolve sufficiently to cause a breach and that a leak of radionuclides from a dome may be transported to the biosphere.

Natural resources. – There should be no natural resources, valuable in the economics of today or tomorrow, that encourage the breaching of a repository in a salt dome in search of oil and gas, coal, uranium, clays, or other potentially valuable mineral resources. Similarly, previous usage of the dome for either mineral extraction, for example, oil and gas, salt mining or mineral storage (for example, liquid propane gas storage) may exclude a dome.

Earlier Decisions

Using the criteria previously discussed in this paper, Kreitler *et al.* (1978) found that only Keechi, Oakwood, and Palestine domes met the minimal requirements. Most salt domes in the east Texas basin were found unacceptable because they were too small, too deep, or had prior usage. Kreitler *et al.* (1978) tentatively concluded that uncertainties about three remaining salt domes, Keechi, Palestine, and Oakwood, needed to be resolved. The size of the Keechi salt dome was borderline; the Oakwood salt dome pierced the Wilcox aquifer and also had oil production on an overhang; and Palestine salt dome had a brining operation in the dome during the early 1900's.

Since the work by Kreitler *et al.* in 1978, the Palestine salt dome has been eliminated from further consideration as a potential repository because of the extensive deleterious effects from brining. Over 15 collapse sinks, resulting from the abandoned brine production, were discovered over the shallowest part of the dome. On the other hand, the Keechi salt dome has been found (by gravity modeling) to be large enough (1,810 acres) for a repository. The impact of the Oakwood oil field and the dissolution by ground water of the Oakwood salt dome is not yet known, but is currently being investigated.

THE PROGRAM TODAY

This initial cut to two salt domes is based on relatively easily definable parameters: depth, size, and prior usage. The major emphasis in the program must and does go well beyond these easily definable criteria and addresses the geologic and hydrologic stabilities of the domes. The safe, long-term disposal of nuclear wastes is dependent on these two parameters. The program to investigate the stability of salt domes in the east Texas basin is divided into three subprograms: 1) subsurface geology; 2) surficial geology, remote sensing, and geomorphology; and 3) hydrogeology. We hope that the integration of the results of these three subprograms will determine: 1) the general suitability of salt domes in east Texas basin for a waste repository; and 2) identify candidate salt domes for further, more detailed studies. The following three sections describe the subprograms, the goals, the approaches, preliminary conclusions, and a discussion of new or interesting problems created by these investigations.

Subsurface Program

The purpose of the subsurface program is to: 1) identify pre-Pleistocene growth histories for domes in the east Texas basin; 2) understand the relationship of basin infilling and salt dome growth; 3) map detailed subsurface geology around the salt domes; and 4) determine size and shape of salt domes, depth to caprock, and depth to salt.

These goals are being accomplished by regional mapping of Cretaceous and Tertiary basinal stratigraphic elements and depositional systems as well as detailed mapping of localized domal areas. Electric logs and seismic cross sections are being utilized. Size and depth of the Keechi and Oakwood salt domes are being approximated with gravity, supplemented by electric log correlations, and eventually by seismic explorations. The growth history of a dome and whether a dome has completed the growth cycle is important in determining its geologic stability. The growth history of a salt dome probably follows a generalized pattern: 1) bedded salt; 2) pillow stage; 3) diapir and rim syncline; 4) extrusion and rim syncline collapse (in some cases); 5) post-extrusion, low rate of diapiric movement; and 6) end of salt migration (Trusheim, 1960; Kupfer, 1975) (fig. 3). Geologic histories of the east Texas salt domes indicate different times of dome growth and either different styles of dome growth or different stages of growth history. At Hainesville Cretaceous and Tertiary beds dip toward the dome. Loocke (1978) concluded that the dome has grown through the extrusion phase and that the rim syncline (primary peripheral sinks of Trusheim, 1960) has collapsed. The last period of movement was probably Wilcox time. At Palestine and Keechi, Wilcox beds are uplifted around the dome — latest movement of the dome has occurred post-Wilcox time, and the extrusion phase and subsequent collapse of the rim syncline has not occurred or has not be completed (Guevara and Giles, 1979). In most areas around Oakwood dome geologic units dip slightly toward the dome. No obvious uplift of Eocene units, (for example, Palestine or Keechi domes) is evident (see Guevara and Giles, 1979, this volume, for a more detailed discussion of dome growth in the east Texas basin). Hainesville and Oakwood are probably more geologically stable than Palestine or Keechi salt domes because Hainesville and Oakwood, as defined by Trusheim (1960), have completed their growth cycle whereas Palestine and Keechi have not. Another critical parameter in determining future dome growth is whether the salt has been pinched from the mother Louann salt bed. If the amount of salt that can flow into the dome is limited, then the continued growth of the dome is also limited, regardless of where the dome is in its growth cycle. Seismic reflection surveys will determine if additional salt from the mother salt can flow to the dome for future growth.

Surficial Geology, Geomorphology, and Remote-Sensing Program

The purpose of the surficial geology and geomorphology program is to: 1) determine if there has been dome growth during the Quaternary; 2) determine detailed surface geology over the domes; 3) evaluate the structural framework of the basin to determine if there has been any structural activity during the Quaternary; and 4) map surface Tertiary formations and determine how they relate to dome and basin history.

These goals are being accomplished by: 1) detailed mapping and leveling of Quaternary stream terraces over the domes; 2) comparing drainage network analysis of dome and non-dome areas; 3) mapping lineations from aerial photography over the domes and within the east Texas basin region to determine if anomalous lineation patterns occur over the domes; 4)

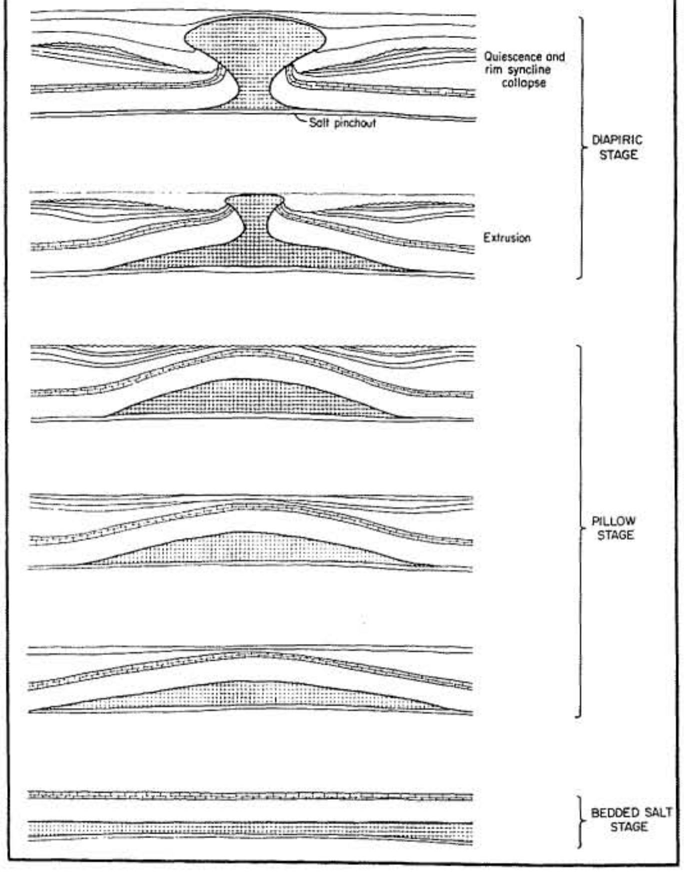

Figure 3. Schematic history of salt dome growth. Salt diapirism follows a pattern of bedded salt, diapirism and rim synclines, extrusion and rim syncline collapse, slow growth that is post-extrusion, and finally, quiescence (modified from Trusheim, 1960).

detailed geologic mapping of strata overlying the domes; 5) detailed geologic investigations of the fault zones that encircle the east Texas basin; and 6) geologic mapping of the Queen City Formation, the youngest Tertiary formation with extensive outcrop exposure, as a potential key to dome growth and regional structural changes in the east Texas basin.

The presence of significant dome growth during the Pleistocene disqualifies a dome for consideration as a repository. For example, several domes in the Texas coastal zone have uplifted Pleistocene sediments as high as 76 ft (Damon Mound) above the coastal plain, and salt domes in that region have been rejected because of obvious geologically recent movement. Studies to date have not documented any evidence of recent salt movement such as warped terraces across east Texas domes. Drainage network analyses over salt domes, using the link method of drainage analysis (Smart, 1970; Abrahams and Campbell, 1976) indicate general tectonic stability across domes.

The structural history of the east Texas basin is important from two considerations: 1) Have any of the faults in Mexia-Talco, Ginger, or Elkhart Graben/Mt. Enterprise fault systems been active in the Quaternary; and 2) Is there any regional uplift or downwarp of the east Texas basin that is presently occurring, and what are the implications of this movement?

Collins and Hobday (1979) have identified a fault associated with Elkhart Graben that is displacing Quaternary Trinity river terrace gravels (possibly 30,000 years old). Small earthquakes have been previously documented farther east along this trend in the Mt. Enterprise fault system. The Quaternary fault further suggests that there is seismicity in the east Texas basin and that the Rusk earthquake (1891) may actually have been an earthquake rather than a large wind storm as some investigators have suggested. The critical concern with this fault is its proximity (approximately 10 mi) to Oakwood dome, a possible candidate dome for a repository. Subsurface studies indicate that this fault does not trend toward the dome. If the fault does not intersect the dome, the proximity of the fault to the dome may not be a problem. Future seismic reflection surveys across the fault in the subsurface will help resolve this problem. Pratt *et al.* (1978) have shown that there is a significant reduction of earthquake damage to subsurface structures such as mines, tunnels, shafts, and wells when compared to surface structures. On the basis of the observations of Pratt *et al.* (1978) earthquake damage to a repository in a salt dome would probably be minimal. The impact of this fault system on stability of Oakwood dome is not known.

Future rates of erosion and denudation in the east Texas basin are dependent on whether the Tyler basin is still uplifting (relative to present sea level). Preliminary surficial studies indicate that the east Texas basin area has been uplifted since the Eocene. Structure maps of the top of the Wilcox Group (Kreitler, 1979, fig. 47) shows a slight uplift in the center of the basin. Mapping of the Queen City Formation shows a shoaling of waters in the center of the basin in Claiborne time (middle Eocene). This shoaling may result from regional uplift in this area. Holdahl and Morrison (1973) showed a recent elevation rise of 3 to 5 mm/year in east Texas, based on National Geodetic Survey data points. The importance of this uplift to the potential for increased erosion and a subsequent erosional breach of a repository is not known, but is being investigated further. The occurrence of uplift, however, argues against the possibility of renewing sedimentation in the basin and subsequent reactivation of the salt domes.

Hydrogeology Program

The two primary purposes of the hydrogeology program are to: 1) determine if salt dissolution will breach a salt dome and permit a repository leak during the life of the repository; and 2) examine regional flow paths to determine where radionuclides would migrate if there were a leak. These goals are being accomplished by understanding the detailed hydrogeology around domes and by delineating the regional hydrogeology in the fresh-water aquifers and the regional hydrogeology in the deeper saline aquifers.

Dome hydrogeology. – There are six ongoing studies of dome hydrogeology:

1) Salinity mapping in the Wilcox aquifer is being conducted to determine the extent of saline plumes around salt domes. Salinity plumes associated with several domes occur in the lower portions of the Wilcox aquifer. This phenomenon may result from density gradients, uneven dissolution of the dome, leakage of saline water from deeper saline aquifers or an influx of fresh recharge water directly over the dome.
2) Subsurface geologic mapping provides detailed permeability distribution of the aquifers around the domes. The lithologic composition of the Wilcox aquifer, which is in contact with many of the aquifers around the domes of the east Texas domes, is extremely heterogeneous. This heterogeneity of sediment distribution is expected to affect ground-water flow patterns. For example, a heterogeneous permeability distribution will cause irregular flow velocities, which in turn cause dispersion of solutes moving with the ground water.
3) Water chemistry data and head measurements from pre-existing water wells are being collected on or near Oakwood and Keechi domes. Water analyses to date show no abnormal chloride distribution in the shallow section of the Wilcox aquifer around Oakwood salt dome.
4) Water wells around Oakwood dome are monitoring the distribution of head, water chemistry, and ages of ground waters and will be used to conduct pumping tests for estimating aquifer parameters. Four well clusters, each composed of six to eight wells, are located at different depths in the Wilcox aquifer, around Oakwood salt dome. Monitoring wells are located hydrogeologically updip on the flanks of the dome and hydrogeologically downdip to delineate the concentrations and extent of any saline plume that might be associated with the dome. The monitoring wells will help delineate the hydrogeologic complexity that is expected around Oakwood.
5) A three-dimensional ground-water flow model of Oakwood salt dome vicinity is being constructed. The information collected from the aquifer heterogeneities, existing water chemistry and head data, and data from the monitoring wells will be incorporated into the model to help predict how ground water flows around

the dome and whether significant dissolution is occurring.

6) Salt dome caprock studies are being conducted to investigate the role of caprock in dome dissolution. Salt dome caprock represents the end product of salt dome dissolution. Caprock may also function as an impervious seal preventing continued dissolution. The Gyp Hill salt dome, Brooks County, Texas, has been recently cored to provide information about the origin of caprock, the mechanism of hydration of anhydrite to gypsum, and the dissolution of caprock and development of permeability.

Regional hydrogeology. – Regional hydrogeology includes two major subprograms: 1) hydrogeology of the fresh-water aquifers, Wilcox, Carrizo, Queen City; and 2) hydrogeology of the saline aquifers, Woodbine and Nacatoch.

Fresh-Water Aquifers. Many of the domes in the east Texas basin are in contact with the Wilcox aquifer. If a repository in an east Texas salt dome were breached by dissolution, it probably would result from dissolution by Wilcox ground waters. Direction, rate, and distance of transport of radionuclides will be determined by understanding the geology and hydrogeology of the Wilcox aquifer. The following studies address the most critical potential problems associated with regional ground-water flow in the Wilcox aquifer.

Potentiometric surface mapping of the Wilcox and Carrizo aquifers indicates that ground-water flow in the southern half of the east Texas basin is to the south, whereas ground-water flow in the northern half is to the northeast. The potentiometric surface in the overlying Queen City aquifer is higher than that in the Wilcox aquifer, indicating leakage from one unit to the other. This leakage is important as a control on radionuclide transport. Leakage will dilute the concentration of radionuclides, alter flow velocities of the ground water, and possibly alter the chemistry of the ground water, which will affect radionuclide retardation.

The Wilcox aquifer in the east Texas basin is a fluvial-deltaic sandstone in which major sand bodies are dip oriented. Interfluvial mud units lie between the channels (Kaiser *et al*, 1978). How this sand-body geometry controls rates and direction of flow of ground water and potential radionuclide transport is not known, but is being investigated.

The water chemistry of the Wilcox ground water shows an evolution from a neutral pH, silica-rich, oxidizing calcium-bicarbonate water to a high pH, low-silica, reducing, sodium-bicarbonate water. These hydrogeochemical variations are important for potential radionuclide transport studies because the retardation and immobilization of radionuclides in an aquifer are dependent on pH and Eh.

The geochemical changes observed in the ground water of the Wilcox aquifer result from its interaction with the aquifer mineralogy and the ground-water circulation patterns. Mineralogy of the Wilcox aquifer is being studied to determine the mineralogic controls on the water chemistry and to determine the ability of the rock matrix to absorb potential radionuclides.

Ground waters in the Wilcox aquifer are being age dated by carbon-14 technique to help evaluate: 1) the ages of waters around salt domes; 2) whether the saline water around the domes in the lower Wilcox aquifer originates from deeper saline aquifers; 3) regional rates of ground-water flow; 4) whether water in the upper Wilcox aquifer is significantly younger than that in the deeper Wilcox aquifer because of leakage from the overlying Queen City aquifer; and 5) whether the major sand channels have younger ground water than the adjacent interfluvial muddy strata. These objectives address how rapidly ground water is moving past a salt dome and how fast a potential radionuclide release would be transported in the Wilcox aquifer.

Saline Aquifers. The potential for salt dissolution of salt domes is not limited to the shallow fresh-water aquifers. The deeper permeable formations with saline water have a potential for dome dissolution. The deeper saline aquifers may also be leaking into the shallower formations. The saline aquifers under consideration are the Woodbine and the Nacatoch units. The aquifer lithology and geometry, head distribution, and salinity distribution are being mapped for each aquifer.

CONCLUSIONS

The selection of a candidate salt dome for a nuclear waste repository depends on the geologic and hydrogeologic stabilities of the domes and the potential for natural resources that might be associated with specific domes. The selection must be based on the integration of many program elements, both site-specific and regional. The Bureau of Economic Geology has an integrated program addressing these problems. Major elements or functions are studies of: 1) subsurface; 2) surficial geology, geomorphology, and remote sensing; and 3) hydrogeology. Important conclusions (May 10, 1979) in each of these areas are: 1) salt domes in the east Texas basin are in different stages of dome growth when compared with the dome growth cycle of Trusheim (1960); 2) a surface fault in the Elkhart graben has probably been active during the Quaternary; and 3) the flow of ground water around a salt dome and the process causing dome dissolution are very complex.

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REFERENCES CITED

Abrahams, A.D., and R.N. Campbell, 1976, Source and tributary-source link lengths in natural channel networks: Geol. Soc. America Bull., v. 87, p. 1016-1020.

Brunton, G.D., and W.C. McClain, 1977, Geologic criteria for radioactive waste repositories: Oak Ridge National Laboratories, Y/OWI/TM-47, 12p.

Brunton, G.D., R.B. Laughon, and W.C. McClain, 1978, Screening specifications for Gulf Coast salt domes: Oak Ridge National Laboratory, Y/OWI/TM-48, 14 p.

Collins, E.W., and D.K. Hobday, 1979, Quaternary faulting in east Texas and its implications (abs.): Geol. Soc. America Abs. with Program, v. 11, no. 2, p. 145.

Guevara, E.H., and A.B. Giles, 1979, Upper Cretaceous - lower Eocene strata, Hainesville, Keechi, and Oakwood salt domes, east Texas: Gulf Coast Assoc. Geol. Socs. Trans., v. 29, p. 112-120.

Holdahl, S., and N.L. Morrison, 1973, Regional investigations of vertical crustal movement in the U.S. using precise relevelings and mareograph data: Tectonophysics, v. 23, p. 373-390.

Kaiser, W.R., J.E. Johnston, and W.N. Bach, 1978, Sand-body geometry and the occurrence of lignite in the Eocene of Texas: Texas Univ. Bur. Econ. Geology Geol. Circ. 78-4, 19 p.

Kreitler, C.W., 1979, Ground-water hydrology of depositional systems, *in* W.E. Galloway, C.W. Kreitler, and J.H. McGowen, Depositional and ground-water flow systems in the exploration of uranium — a research colloquium: Texas Univ. Bur. Econ. Geology, p. 118-176.

Kreitler, C.W., E.G. Wermund, E.H. Guevara, A.B. Giles, and G. Fogg, 1978, Preliminary evaluation of salt domes in east Texas for the National Waste Terminal Storage Program: U.S. Dept. of Energy, Interim Contract Report, 16 p., 1 table, 9 figs.

Kupfer, D.H., 1975, Mesozoic and Tertiary studies, *in* J.D. Martinez, D.H. Kupfer, R.L. Thoms, C.G. Smith, and C.R. Kalb, An investigation of the utility of Gulf coast salt domes for the storage or disposal of radioactive wastes: Louisiana State Univ., Inst. for Environmental Studies, ORNL-Sub-4112-10, p. 15-80.

Loocke, J.E., 1978, Growth history of the Hainesville salt dome, Wood County, Texas: Master's thesis, Univ. Texas, Austin, 95 p.

National Academy of Sciences - National Research Council, 1957, The disposal of radioactive wastes on land — Report of the Committee on Waste Disposal, Division of Earth Sciences, Publication 519.

Netherland, Sewell and Associates, Inc., 1976, Geologic study of the salt domes of northeast Texas salt dome basin to investigate their suitability for possible storage of radioactive waste material as of May, 1976: Contract Report for the Office of Waste Isolation, Union Carbide Corp., 57 p.

Pratt, H.R., W.A. Hustrulid, and D.E. Stephenson, 1978, Earthquake damage to underground facilities: Savanah River Laboratory, DP-1513, 83 p.

Smart, J.S., 1970, use of topologic information in processing data for channel networks: Water Resources Research, v. 6, p. 932-936.

Trusheim, F., 1960, Mechanism of salt migration in northern Germany: AAPG Bull., v. 44, no. 9, p. 1519-1540.