THE FEASIBILITY OF LOCATING A TEXAS SALT TEST FACILITY

by

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EXECUTIVE SUMMARY

Differences in the geology of dome salt and bedded salt dictate that data and mining experience gained in one environment will not be fully applicable to the other. A test facility in a salt dome could be mined through a relatively thin section of clastics, a cap rock of evaporite minerals that may contain highly porous zones, and possibly 300 m (1,000 ft) of salt. The salt will probably be quite pure except for a few percent anhydrite, increasing in concentration toward the top of the salt stock (Balk, 1949; Muehlberger, 1959; and Dutton and Kreitler, 1980). Infrequent inclusions of the surrounding sediments may be found in dome salt that has been highly contorted and whose crystals show translational gliding as a result of salt dome emplacement (Muehlberger, 1959; Clabaugh, 1962; and Hofrichter, 1968).

Access to bedded salt will require mining through a sequence of dominantly terrigenous clastics and evaporites. The degree of consolidation, porosity, and permeability of these sediments will vary between horizons. The objective interval will be a required thickness of relatively pure salt. Crystallographic properties, water content, and clastic inclusions will be results of the original depositional environment rather than emplacement of a salt stock.

The feasibility of locating a Salt Test Facility in Texas has been studied and evaluated. Measured parameters are summarized in table 1. For primarily technical reasons the most feasible Texas sites are the Gyp Hill salt dome in Brooks County or bedded salt in Loving County.

Table 1. Significant characteristics of localities evaluated for a possible salt test facility.

	GRAND SALINE DOME, VAN ZANDT COUNTY	HOCKLEY DOME, HARRIS COUNTY	GYP HILL DOME, BROOKS COUNTY	PALANGANA DOME, DUVAL COUNTY	SECTIONS 5-8, BLOCK 20, LOVING COUNTY	SECTIONS 21-22, 27-28, BLOCK 9, REAGAN COUNTY
BIOLOGIC RESOURCES	Vegetation region: Post Oak Savannah. No unique resources known for dome area.	Vegetation region: Gulf Prairie. No unique resources known for dome area.	Vegetation region: Mesquite-Chaparral Savannah. No unique resources known for dome area.	Vegetation region: Mesquite-Chaparral Savannah. No unique resources known for dome area.	Vegetation region: Tarbush-Creosote Bush section of Chihuahuan Desert. No unique resources known for area of Sections 5-8.	
CLIMATE	Moist subhumid. Average annual rainfall 1,096 mm.	Moist subhumid. Average annual rainfall 1,224 mm. Possible heavy rains due to hurricanes.	Subhumid to semiarid. Average annual rainfall 594 mm. Possible heavy rains due to hurricanes.	Subhumid to semiarid. Average annual rainfall 594 mm. Possible heavy rains due to hurricanes.	Semiarid to arid. Average annual precipitation of 305 to 230 mm. Low humidity.	
EARTHQUAKE POTENTIAL	Risk zone 1 - minor damage possible	Risk zone 0 - no expected damage.	Risk zone 0 - no expected damage.	Risk zone 0 - no expected damage.	Risk zone 1 - minor damage possible.	Risk zone 1 - minor damage possible.
ENERGY RESOURCES (BASINAL)	No hydrocarbon production over or on the flanks of the dome.	Hydrocarbon production on southwest margin of the dome. Numerous dry wells over and around dome. Current (1980) exploration activity.	Hydrocarbons trapped against normal fault off southeast flank of the dome. No production over dome.	Gas production on southeast flank of the dome. Numerous dry holes over and around dome. No production over dome.	No hydrocarbon tests in Sections 5-8, Block 20. Dry holes in many adjacent sections. Nearest production is 4 km west.	
ENERGY RESOURCES (SURFICIAL)	No current uranium or lignite coal production in the county. Potential mineable lignite resource in Wilcox Group surrounding dome.	Neither lignite nor uranium resources are known in northwest Harris County.	Neither lignite nor uranium resources are known from the vicinity of Gyp Hill Dome in Brooks County.	Uranium deposit located in sedimentary strata over the dome. Uranium occurs in other parts of Duval County. Lignite resources not known from Duval County near dome.	Minor uranium exploration in region; no known deposits. No lignite resources known in Loving County.	
FLOOD POTENTIAL	Marsh and flood plain areas overlie parts of the dome. Surface facilities would be restricted to higher ground.	Floodplain over southeast quarter of dome. Creek flows over dome. Man-made lake bordering northern dome margin. Surface facilities would be restricted to higher ground.	A circular hill over the dome is not flood prone. Closed depressions in coastal prairie around Gyp Hill may be flooded by heavy rainfall.	Closed depressions occur within ring of hills over the dome. Hills stand above potential flood levels. Surface facilities would be restricted to higher ground.	Nonintegrated drainage. Closed depressions in windblown sand. Surface facilities would be restricted to a minor extent by avoiding areas of possible ponding.	
HISTORICAL RESOURCES	No known archeologic sites over dome. The Kleer Salt Mine in the dome has been listed for possible entry into the National Register of Historic Sites.	One minor archeologic site located over the dome.	No known archeologic sites over the dome. The gypsum quarry over the dome has been listed for possible entry into the National Register of Historic Sites.	One known archeologic site located over the dome. Two sites over and near the dome have been listed for possible entry into the National Register of Historic Sites.	No known archeologic sites in Sections 5-8. No actual or proposed National Register Historic Sites in Loving County.	
HYDROLOGY (BASINAL)	Heavy local use of ground water from Wilcox Group around dome. Brackish ground water discharges at surface into salt marsh.	Heavy local use of ground water in northwest Harris County. Hockley Dome penetrates the principal (Evangeline) aquifer.	Locally high water table in gypsum cap rock. Primary source of ground water in Brooks County is uplifted by the salt dome. Locally high TDS in ground water.	Primary source of ground water in Duval County is continuous over the dome. Locally high TDS in ground water.	Regional alluvial aquifer thin or absent. High TDS water available from minor aquifers with variable porosity in Sections 5-8.	
HYDROLOGY (SURFICIAL)	Area over dome moderately dissected; marsh occurs over dome. Larger creek within 0.5 km of dome.	Rock Hollow Creek dammed to form lake bordering dome. Larger creek 0.3 km from south flank of dome contributes to City of Houston water supply.	Intermittent streams and lakes and poorly integrated surface drainage. Internal drainage within windblown silts and sands.	Intermittent drainage along north margin and 1.1 km from south margin of dome. Bottom of central depression may be 4 m below outlet through ring of hills.	Surface drainage primarily internal within porous surficial sands. No intermittant streams in Sections 5-8.	
LAND OWNERSHIP	Private	Private	Private	Private	State	State
LAND RESOURCES	Land of low to moderate relief best suited as pastureland. No unique resources.	Mostly flat to gently rolling coastal prairie is suitable as rangeland and cropland (rice). Soils are moderately suitable for urbanization. No unique resources.	Unique occurrence of gypsum cap rock at land surface. Coastal prairie surrounding Gyp Hill is suitable as rangeland.	Calichified sandy prairie suitable as rangeland. No unique resources.	Windblown sand and calichified alluvium and bedrock suitable as rangeland. No unique resources.	

Table 1 (continued).

	GRAND SALINE DOME, VAN ZANDT COUNTY	HOCKLEY DOME, HARRIS COUNTY	GYP HILL DOME, BROOKS COUNTY	PALANGANA DOME, DUVAL COUNTY	SECTIONS 5-8, BLOCK 20, LOVING COUNTY	SECTIONS 21-22, 27-28, BLOCK 9, REAGAN COUNTY
MINERAL RESOURCES	Salt produced from underground mine by Morton Salt Company. Salt brines produced from the cap rock. No native sulfur or gypsum production.	Salt produced from underground mine by United Salt Corp. Gypsum was produced by underground mining until 1947. No sulfur production, but some sulfur potential.	Gypsum has been mined by open-pit methods. No sulfur encountered in one recent core of cap rock, but may be present elsewhere.	Salt produced by brine wells. Potash shows in wells drilled for brining operation. Uranium extraction attempted by in situ leaching over dome. Past production of sulfur from cap rock.	Caliche locally used as road base. Salt resource unlikely to be developed. No potash deposits comparable to those in New Mexico. Nearest potash show is 7 km from Sections 5-8.	
LAND USE	Surface facilities for salt mine. Town of Grand Saline over north edge of dome. Pastureland. Some cropland on nearby floodplains.	Surface facilities for salt mine. Rangeland and rice farming directly over dome. Oil and gas exploration.	Abandoned gypsum quarry over dome. Rangeland over and surrounding dome.	Brining wells and surface facilities over dome. Pipeline for transport of brine. Land over dome and adjacent areas is used for rangeland.	Intensively managed rangeland. Oil and gas exploration.	
OPEN OR CLOSED SYSTEMS	Open: active underground salt mine.	Open: active underground salt mine.	Closed	Closed	Closed	
OVERBURDEN CHARACTER	65 to 104 m of sand, sandy shale, and shale. 1 to 22 m (average: 8 m) cavernous gypsum and limestone cap rock.	30 to 60 m of clay, silt, and sand with minor amounts of gravel. 6 to 36 m of gypsum cap rock (absent near margins). 285 m (approximately) of anhydrite cap rock.	120 m of gypsum with basal transition zone to anhydrite. 150 m of anhydrite and gypsum-cemented anhydrite. Cavernous zone at base of cap rock.	150 to 180 m of sand, silty sand, and sandy clay. 30 m ± of gypsum cap rock, with some limestone. 90 m of anhydrite cap rock.	52 m of silt, sand, and gravel. 47 m of sandstone. 135 m of shale, siltstone, and sandstone. 112 m of dolomite, anhydrite, and terrigenous clastics. 294 m of salt and anhydrite.	
POPULATION CENTERS	Grand Saline (pop. 2,254) over part of dome. 6,064 in 10 centers within 16 km. 134,371 in 8 additional centers within 50 km.	1,799 in 3 centers within 16 km. 2,561,186 in 11 additional centers within 50 km. In growth path of City of Houston.	6,359 in 2 centers within 16 km. 32,059 in 3 additional centers within 50 km.	1,901 in 1 center within 16 km. 35,190 in 6 additional centers within 50 km.	No population centers within 16 km. 31,036 in 8 centers within 50 km.	
SALT COMPOSITION	Halite with 1 to 2% impurities. Thin bands contain up to 15% anhydrite.	Halite with 5.6% insoluble residue 2 m from cap rock contact and decreasing with increasing depth. No data on deeper salt.	Abundant anhydrite crystals in halite within 3 m of cap rock boundary. No data on deeper salt.	Varying from impure to very pure halite; anhydrite in blebs to 9 cm thick beds. Potash-bearing zones 3 to 6 m thick.	Relatively pure salt with some admixed mud and mud interbeds within the salt sequence. Minor amounts of potash minerals may be present. A possible dolomitic mudstone interbed.	Muddy salt and salt with mud and dolomitic mudstone(?) interbeds. Relatively poor salt quality with frequent interbeds suggests further study of this site is not warranted.
SALT DEPTH	Top salt at 73 to 112 m below surface, assuming 8 m average cap rock thickness.	Top salt at 308 to 338 m below surface.	Top salt at 252 to 276 m below surface.	Top salt at 260 to 300 m below surface.	An interval of relatively pure salt at a depth of 640 to 715 m below surface.	An interval of salt, salt mud mixtures, and mud interbeds at a depth of 419 to 500 m below surface.
SALT GEOMETRY	Dome with nearly flat, circular top approximately 2,000 m in diameter. Steep flanks dip 65° to 70°.	Salt dome is approximately 5,200 m by 4,000 m in diameter at 915 m m.s.l. Steep flanks dip 55° to 67°. Minor overhang on southwest flank.	Salt dome has been interpreted as circular (diameter 1,430 m) to elliptical (1,070 by 1,920 m) at 610 m m.s.l. depth.	Salt dome with diameter of 2,440 m at top. Flat top with steep flanks of 70° ±.	Bedded salt in a structural low trending approximately north-northeast. A component of dip to the south-southeast of less than 1° is present.	Bedded salt, relatively flat lying.
STRATIGRAPHY	Wilcox Group sand, sandy shale, and shale over the dome. Midway Shale and Cretaceous marl, chalk, shale, and sand surround upper part of dome. Woodbine Sandstone and Lower Cretaceous limestones occur at depth.	Willis Formation clay, silt, and sand occur over the dome. Sand and shale of the Frio and Vicksburg-Jackson Formations and older Tertiary formations occur at depth.	Gypsum cap rock is exposed at surface. The Goliad Formation, Lagarto Clay, and Oakville Sandstone are found at shallow depths around the dome. The Frio and Vicksburg-Jackson sands and shales occur at greater depths.	Goliad Formation and Oakville Sandstone overlie the dome. The Catahoula Tuff (tuffaceous clay), Frio Clay, and Jackson Group shales and sandstones occur around the dome, overlying Claiborne shales and sands.	Windblown sand and Cenozoic alluvium, Santa Rosa sandstone, Dewey Lake siltstone and sandstone, and Rustler Formation dolomite, anhydrite and terrigenous clastics overlie the salt-bearing Salado Formation.	Cretaceous limestone and sandstone. Dockum Group sandstone including Santa Rosa sandstone, Dewey Lake siltstone and sandstone, and Rustler Formation evaporites and clastics overlie the salt-bearing Salado Formation.
TRANSPORTATION ACCESS	Short distance to U. S. Hwy 80, Interstate 20, and main tracks of the Texas and Pacific Railroad.	5 mi north to U. S. Hwy 290. 12 mi south to Interstate 10. Railroad spur connects with Southern Pacific 5 mi to northeast. 12 mi north of Missouri, Kansas, Texas Railroad.	3 mi east of U. S. Hwy 281. 3 mi east of Texas and New Orleans Railroad.	8 mi northwest of Texas Hwy 359. 2.5 mi northwest of Texas-Mexican Railroad that has the former grade of a spur to the dome.	5 mi south of Texas Hwy 302. 11.5 mi northeast of Santa Fe Railroad.	2.5 mi north of U. S. Hwy 67.

INTRODUCTION

Rationale and Approach

Isolating nuclear wastes in geologic media requires detailed information on the physical properties of the host rock and its response to waste emplacement. Only on the basis of such information derived from in situ testing can a particular rock type be judged suitable for deep geological isolation of nuclear waste. Such data must be combined with exhaustive and thoroughly integrated studies of physical stratigraphy, structural geology, hydrogeology, geomorphology, resource potential, and rock physics when a rock type is evaluated in a particular geologic environment.

A Salt Test Facility is required for evaluating the physical characteristics of salt relevant to waste isolation prior to siting in order to substantiate laboratory tests. This study considers the feasibility of locating such a facility in Texas, based on geological, engineering, biological, economic, social, and political parameters. This study examines possible suitable locations for a Salt Test Facility largely on the basis of existing information, and is not a substitute for detailed investigations that would accompany selection of one or more localities for further consideration.

Texas contains salt domes in both interior and coastal provinces and contains stratiform salt less than 900 m (3,000 ft) deep. From these geologic environments six areas have been evaluated, including existing mined cavities in salt, salt domes, and salt strata. Public and private lands are included.

The areas evaluated (fig. 1) include: (1) Grand Saline and Hockley Domes, each of which contains an active salt mine; (2) Palangana and Gyp Hill Domes, representing domes around which minimal amounts of hydrocarbons have been discovered; and (3) bedded salt in Loving and Reagan Counties. The bedded salt localities are on state-owned lands, sections of which The University of Texas is the owner. Their stratigraphy is representative of that found beneath adjacent private lands.

Fundamental differences in salt geometry, salt depth, and salt composition between bedded salt and dome salt naturally divide these sites into two groups. Little can be done to avoid the major constraining factors of an individual salt dome because of limited lateral extent of the salt. Such a factor might be a large population center near a salt dome. Dome salt exhibits physical properties reflecting salt mobilization and emplacement as a dome. Similarly, the stratiform nature and possible

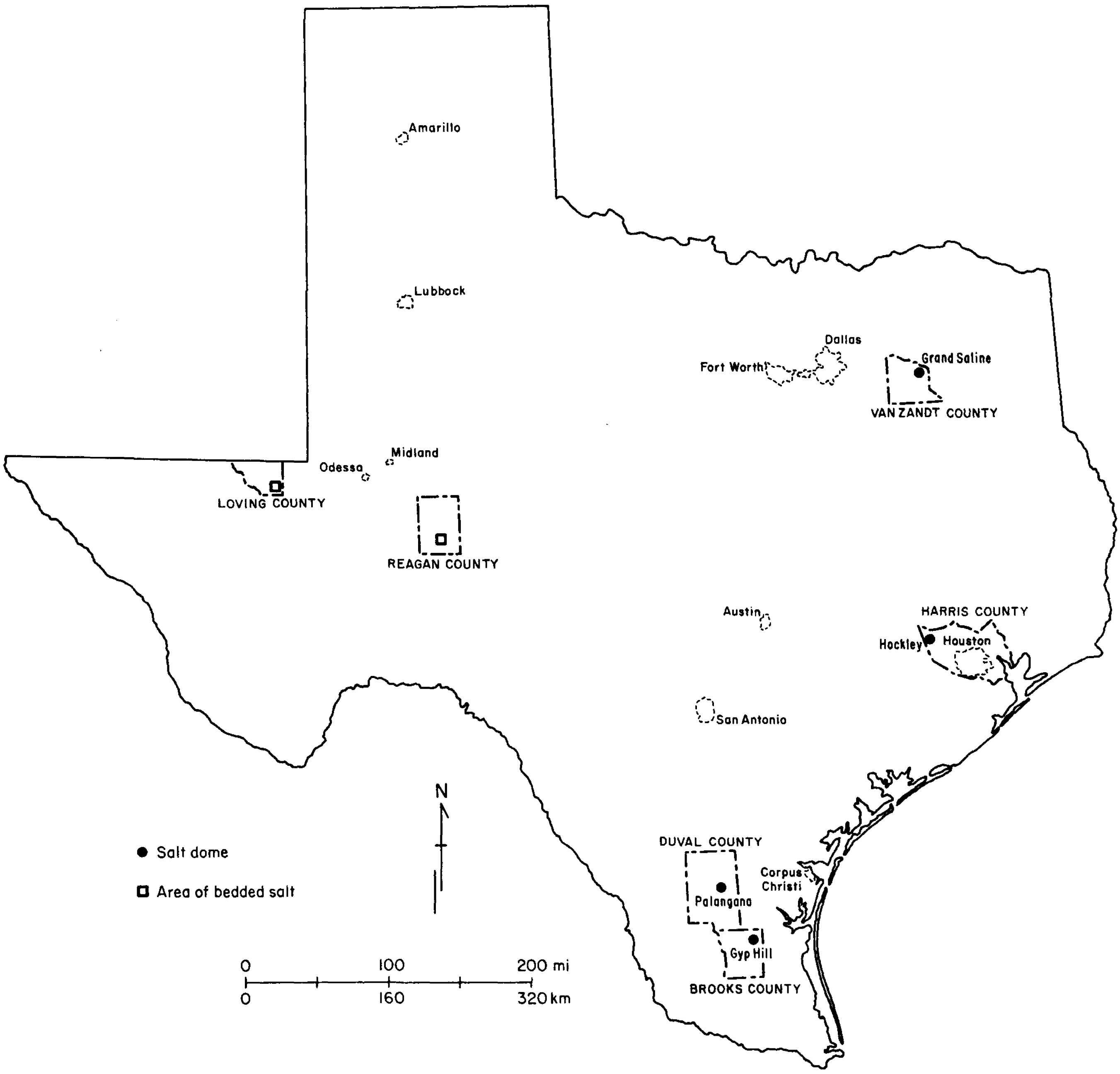


Figure 1. Index map of six sites evaluated as part of this feasibility study.

intercalations of other rock types characterize bedded salt. Bedded salt may potentially allow greater flexibility in site placement consistent with the lateral extent of good quality salt. Good quality implies lack of admixed mud or mud interbeds, or other rock types (dolomite, anhydrite, etc.). While the highest quality salt is desirable for the location of a salt test facility, the potential interactions between the most common impurities in a bedded salt sequence and nuclear waste should also be examined.

Data Matrix

The matrix (table 1) summarizes the significant information for a large number of variables related to the sites shown in figure 1. These data are supported by more detailed descriptions of each variable for each site, and by engineering analysis based on representative dome salt and bedded salt sites. Analysis of stratigraphy, salt composition, salt depth, and salt geometry for Block 9, Reagan County suggested a significantly lower salt quality than is desirable for a salt test facility. Additional characteristics of this site were, therefore, not investigated. Representative well logs on other state-owned lands in West Texas did not reveal bedded salt of appropriate quality at the desired depth (approximately 2,000 ft) in areas without present hydrocarbon production.

GRAND SALINE DOME

Grand Saline Dome is located in Van Zandt County in northeast Texas (fig. 2). Grand Saline is an open system in that salt is presently being produced at the Kleer Mine, an underground mine owned by Morton Salt Company.

Biologic Resources

Grand Saline salt dome lies within the Post Oak Savannah region of northeast Texas (Hoffman and others, 1976). Hardwoods present include post oak (Quercus stellata), hickory (Carya sp.), and blackjack oak (Quercus marilandica) (Arbingast and others, 1976; Haislet, 1963). The grassland savannah includes bluestem grasses; some of the savannah areas have been invaded by brush, including mesquite (Prosopsis juliflora), as a result of intensive grazing practices (Hoffman and others, 1976). Much of the original hardwood has been cleared for agriculture.

The immediate vicinity of Grand Saline Dome is covered with an oak-elm association and pastureland (Henry and Basciano, 1979). In addition, floodplain areas along Grand Saline Creek south and east of the dome support water-tolerant hardwoods, including cottonwood (Populus deltoides) and buckeye (Aesculus glabra) (Henry and Basciano, 1979; Bailey, 1978).

Fauna of the region include a mixture of species characteristic of prairie and forest areas. Squirrel, white-tailed deer, raccoon, and rabbit, some of which are limited to this region (Bailey, 1978), may be found here, as are various protected nongame species. Endangered species in Van Zandt County are listed in table 2.

Climate

The warm humid region of northeast Texas around Grand Saline Dome has heavy rainfall and high humidity, especially in the spring (Orton, 1964; White, 1973); the area is classified as moist subhumid (Thornthwaite, 1948). Data from Wills Point, 31 km (19 mi) west-northwest of Grand Saline Dome, show an annual average rainfall of 1,096 mm (43.16 in) for the 1940-1969 period. April is the wettest month, with an average precipitation of 149 mm (5.86 in), and August is the driest, with an average precipitation of 55 mm (2.16 in). The maximum monthly precipitation recorded at

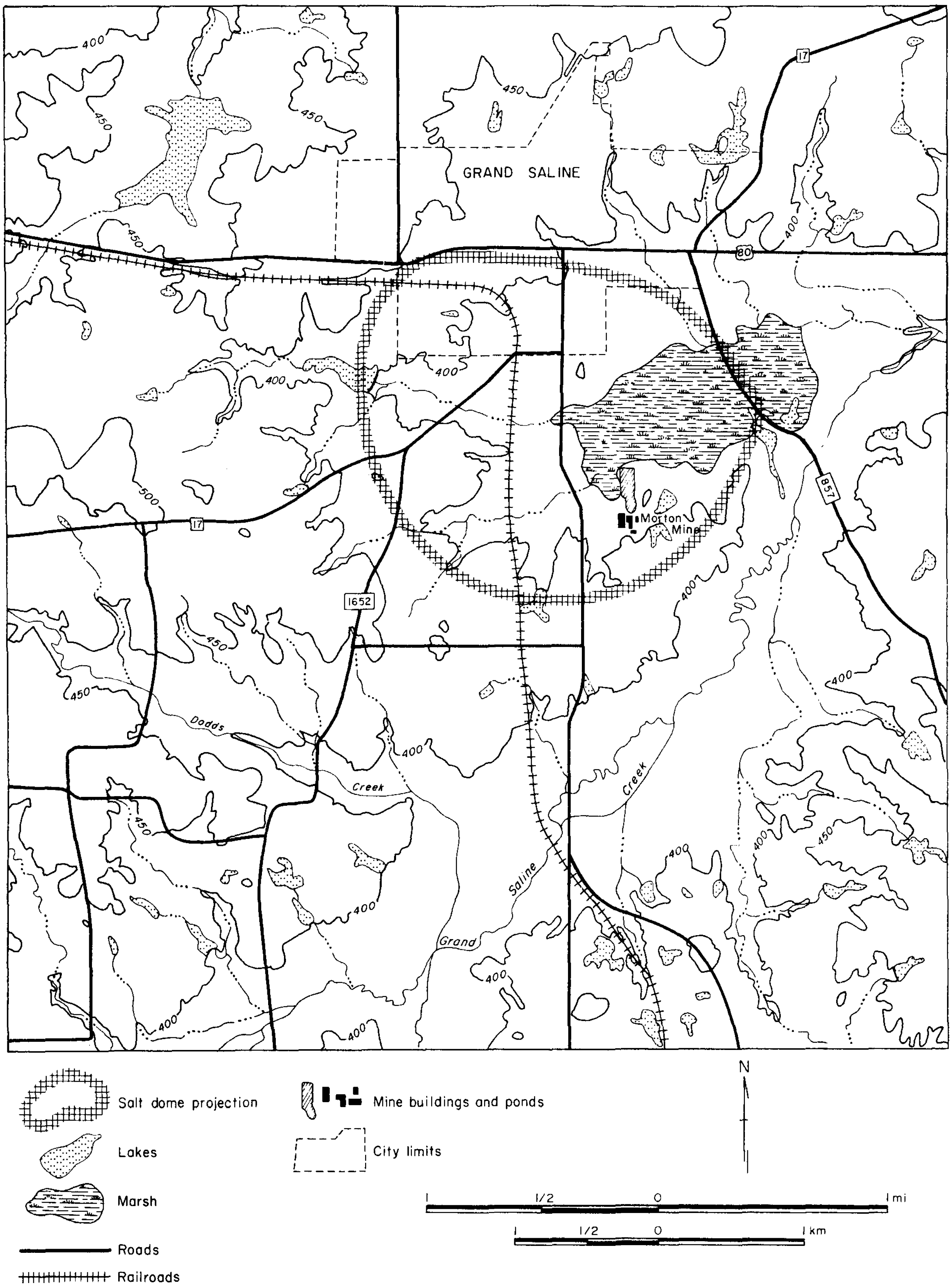


Figure 2. Generalized topography and cultural features over Grand Saline Dome (from U.S.G.S. 7.5-minute quadrangle, Grand Saline, Texas). Contour interval is 50 ft.

Table 2. Endangered species in Van Zandt County (F. E. Potter, personal communication, 1980).

CONFIRMED

American alligator, Alligator mississipiensis

PROBABLE

Southern bald eagle, Haliaeetus l. leucocephalus

Arctic peregrine falcon,* Falco peregrinus tundrius

Interior least tern,* Sterna albifrons athalassos

Paddlefish, Polyodon spathula

*mostly migratory

Wills Point was 556 mm (21.90 in) in April, 1966 (White, 1973). The average annual gross reservoir evaporation for the area is approximately 1,473 mm (58 in) (Kane, 1967).

Mean annual relative humidity is 80 to 85 percent at 6 a.m. and approximately 55 percent at 6 p.m. (Arbingast and others, 1976). The average monthly temperature at Wills Point varies from 45°F (7.2°C) in January to 85°F (29.4°C) in July and August. Whereas moderately hot temperatures prevail in summer, winters are relatively mild, and the first and last dates of killing frosts are November 21 and March 16, respectively.

Energy Resources (Basinal)

Hydrocarbon production from the Lower Cretaceous Rodessa and Paluxy Formations occurs north and northwest of the center of Grand Saline Dome (Railroad Commission of Texas, 1979; Caughey, 1977) (tables 3 and 4). Ten dry holes have been drilled over the top of the dome and along its immediate margins (Railroad Commission of Texas, undated). One well produces oil from the northeast flank of the dome; otherwise there is no production over Grand Saline Dome. The nearest production from a multiple-well field is approximately 3,650 m (12,000 ft) northwest of the center of Grand Saline Dome.

Table 3. Crude oil and casinghead gas production at Grand Saline Dome (from Railroad Commission of Texas, 1979).

Field*	Discovery Date	Depth, (ft)	1979 Production Casinghead Gas, MCF	1979 Production Crude Oil, BBLS	Cumulative Crude Oil, BBLS, Through 1/1/80
Grand Saline	12-3-63	5,781	300	3,854	84,463
Grand Saline (Rodessa)	2-17-61	8,290	none	none	11,837
Grand Saline (1st Rodessa)	7-16-76	8,204	236,718	128,519	336,881
Grand Saline (2nd Rodessa)	7-10-76	8,270	149,620	69,917	170,272

*Names in parenthesis refer to producing horizon.

Table 4. Gas well production and hydrocarbon liquids recovered on leases, 1979, at Grand Saline Dome (from Railroad Commission of Texas, 1979).

Field*	Producing Wells End of Year	Gross Gas Production, MCF	Hydrocarbon Liquids, BBLS
Grand Saline (2nd Rodessa)	1	135,252	10,162 (partial total)
Grand Saline (Smackover)	0	67,417	0

*Names in parenthesis refer to producing horizon.

Energy Resources (Surficial)

The only formation exposed in the vicinity of the dome is the Eocene Wilcox Group (Muehlberger and others, 1962). St. Clair and others (1976) showed the area around Grand Saline, and indeed a large part of Van Zandt County, as having potential mineable lignite in near-surface deposits within the Wilcox Group. As of 1976 no lignite mining was taking place in Van Zandt County and no mines were scheduled for production by 1980 (St. Clair and others, 1976). No uranium resources are known in the area of Grand Saline Dome.

Flood Potential

The surface projection of Grand Saline Dome (Balk, 1949) forms an area of approximately 518 ha (1,280 acres), of which some 174 ha (430 acres) are within the Special Flood Hazard Area (Zone A) mapped by the U.S. Department of Housing and Urban Development (1978). Although the flood frequency of this zone is undefined, it is the only category used for mapping flood-prone areas in the vicinity of the dome.

Most of the flood-prone area is within a brackish-water marsh overlying part of the eastern margin of the dome. The marsh is between the elevations of 113 m (370 ft) and 110 m (360 ft) and receives drainage from the central depression over the dome. Drainage from the marsh is to the east into Grand Saline Creek. The boundary of the Special Flood Hazard Zone approximates the 113-m (370-ft) contour along the margin of the marsh, but does extend into two narrow, 0.8 km- (0.5 mi-) long valleys to elevations of 117 m (385 ft) and 122 m (400 ft), respectively. The flood-prone designation seems to apply only to the thalwegs of these intermittent streams.

The physical facilities associated with salt mining at Grand Saline are between 116 m (380 ft) and 119 m (390 ft), or 3 to 6 m (10 to 20 ft) above the margin of the flood zone. State Highway 110, which provides access to the mine facilities, lies between 113 m (370 ft) and 116 m (380 ft) on the western margin of the marsh. One section of this highway has been built up to over the 113-m (370-ft) elevation. Flat areas up to 300 m (1,000 ft) long do occur above the 125-m (410-ft) elevation and overlying the top of the dome.

Historical Resources

No archeologic sites located within the surface projection of the Grand Saline Dome are listed with the Texas Archeological Research Laboratory (C. Spock, personal communication, 1980). Two sites, one of which is over the dome, have been surveyed for possible inclusion in the National Register of Historic Sites. A limited amount of data on these sites is available from the Texas Historical Commission (table 5).

Hydrology (Basinal)

The Carrizo Sand of the Claiborne Group and the Wilcox Group are the principal sources of fresh ground water in Van Zandt County in the vicinity of Grand Saline Dome (table 6) (White, 1973). Regional dip of these units is to the southeast in Van Zandt County (fig. 3); the Midway shale does not yield appreciable quantities of water and generally acts as a basal confining layer for the water stored in the overlying Wilcox Group. The Midway prevents any vertical movement of saline waters from below into the Wilcox. The Cretaceous strata below the Midway consist of clay, marl, and chalk with some limestone and sandstone, and are not considered water bearing. Water present in the permeable Woodbine Formation is saline (Bechtel National, 1978).

Table 5. Historic sites near Grand Saline Dome surveyed for possible entry in the National Register of Historic Sites.

Site	Description	Comments
Grand Saline Salt Works Site No. 48388	In the town of Grand Saline, presently functioning, owner undetermined.	Salt production at Grand Saline has operated since 1834.
Kleer Salt Mine Site No. 48853	Over Grand Saline Dome, first shaft started May 1, 1929, second shaft completed in 1969, presently functioning, privately owned.	Salt production by Morton Salt Co.

Table 6. Characteristics of water-bearing units in Van Zandt County (from White, 1973).

System	Series	Group	Geologic Unit	Approximate Maximum Thickness (m)	Character of Sediments	Water-Bearing Properties
Quaternary	Holocene and Pleistocene		Alluvium	15	Sand, silt, clay, and minor amounts of gravel	Not known to yield water to wells; the thicker deposits would probably yield small to moderate quantities of water
Tertiary	Eocene	Claiborne	Sparta Sand	15	Sand and clay	Cap hills in southeastern Van Zandt County; not known to yield water
			Weches Greensand	18	Glauconite, glauconitic clay and sand	Not known to yield water
			Queen City Sand	120	Sand, silt, and clay with stringers of lignite and bentonitic clay	Yields small quantities of fresh water to domestic and stock wells in southeastern Van Zandt County
			Reklaw Formation: Marquez Shale Member	12	Silty shale	Not known to yield water to wells in Van Zandt County
			Reklaw Formation: Newby Sand Member	9	Glauconitic sand	Yields small quantities of fresh water to large-diameter wells on the outcrop; wells tapping the Newby and Carrizo Sand in southeastern Van Zandt County yield moderate quantities
			Carrizo Sand	46	Sand and minor amount of silt and clay	Yields small to moderate quantities of fresh water to wells in southeastern Van Zandt County
		Wilcox		290	Lenticular beds of sand, with sandy clay, shale, sandstone, and lignite	Yields small to moderate quantities of water; large quantities have been pumped during aquifer tests in a few wells near Grand Saline
	Paleocene	Midway		-	Calcareous clay with stringers of limestone and glauconitic sand	Yields very small quantities of water

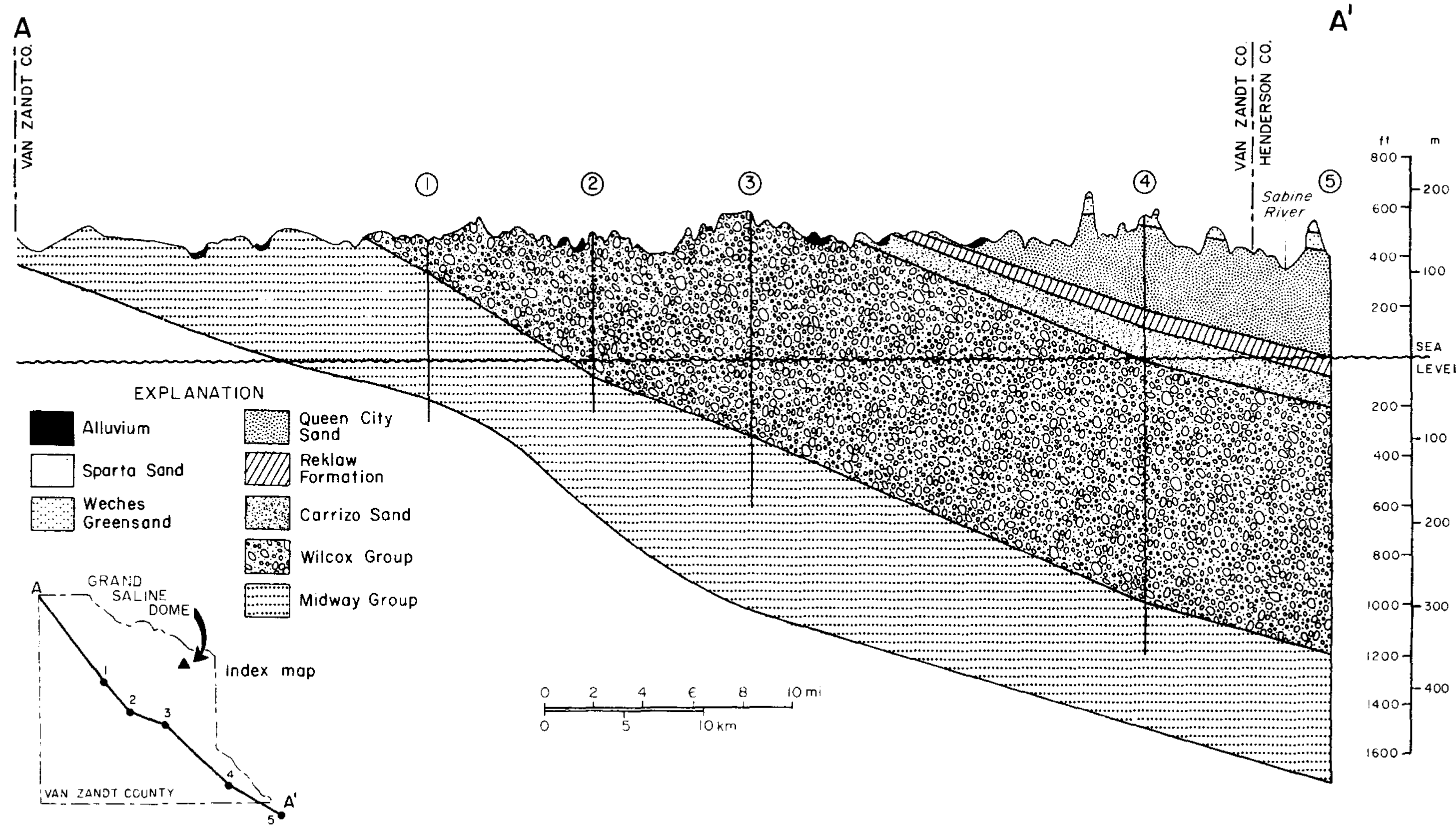


Figure 3. Cross section through shallow stratigraphic units of Van Zandt County, Texas (modified from White, 1973).

The Wilcox Group has a maximum thickness of 275 to 300 m (900 to 1,000 ft) west and southwest of Grand Saline Dome. Medium to very fine quartz sand constitutes about half the Wilcox; additional beds of shale, sandy shale, lignitic shale, and lignite compose the remainder of the unit. Individual lenticular beds of sand are usually thin, but some are as thick as 21 m (70 ft). Few of the sands can be correlated on a county-wide basis. Yields of 250 gpm generally cannot be sustained without lowering the water level below the well screen; however, wells near Grand Saline Dome have yielded 500 gpm during short-term aquifer tests (White, 1973). Grand Saline Dome lies within the outcrop belt of the Wilcox Group such that recharge may be occurring locally as well as updip from the dome.

The Carrizo Sand is a fresh-water source primarily in the southeast corner of Van Zandt County, although it is present at the surface approximately 6 km (4 mi) east of Grand Saline Dome. Yields are generally less than those of the Wilcox Group (White, 1973). It is not a water source around Grand Saline Dome.

Wilcox Group waters around Grand Saline Dome are good quality and contain 200 to 500 ppm total dissolved solids (TDS) and 9 to 150 ppm chloride (fig. 4). Transmissivities for 3 wells on the northwest flank of Grand Saline Dome average 19 m^3/day (670 ft^3/day). Generalized flow directions in the Wilcox aquifer are east and southeast, down structural dip, as illustrated for a line of section between the cities of Edgewood and Grand Saline (fig. 5). The brackish to saline marsh over the eastern margin of the dome indicates a local discharge of ground water that has been in contact with the core of the salt dome.

Figure 5 also shows that water levels have declined around Grand Saline Dome and the City of Grand Saline as a result of pumping for municipal and industrial use. The decline has been approximately 30 m (100 ft) since 1936 (White, 1973). Reported pumpage averaged 350 million gallons in the period 1965 to 1969.

Salinities of formation waters in units below the Midway Shale are given in table 7. These data have been extracted from formation salinity maps of the entire East Texas Basin and therefore represent generalized data for northeast Van Zandt County in the vicinity of Grand Saline Dome. More specific salinity data for the Woodbine Formation have been developed using the spontaneous potential curve of oil well geophysical surveys. Although this method is not considered to be highly accurate it does suggest (fig. 6) that some formation-water salinities in excess of 250,000 ppm occur northeast of Grand Saline Dome. Salinities in all units shown in table 7 increase toward the center of the East Texas Basin. Generalized data are available on the hydrologic characteristics of the saline aquifers of the East Texas Basin (table 8).

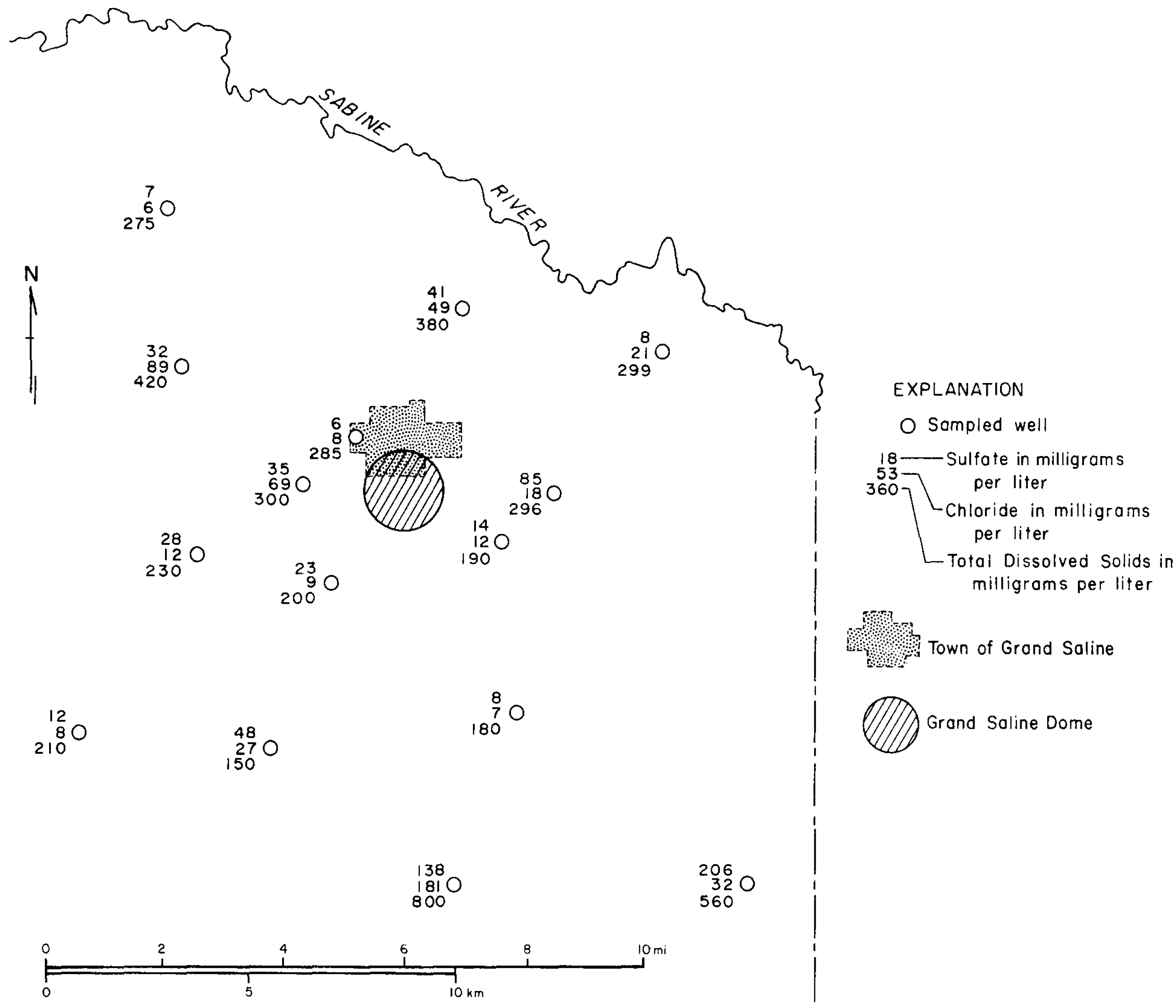


Figure 4. Chemical quality of ground water in the Wilcox Group in the vicinity of Grand Saline Dome, Van Zandt County, Texas (from White, 1973).

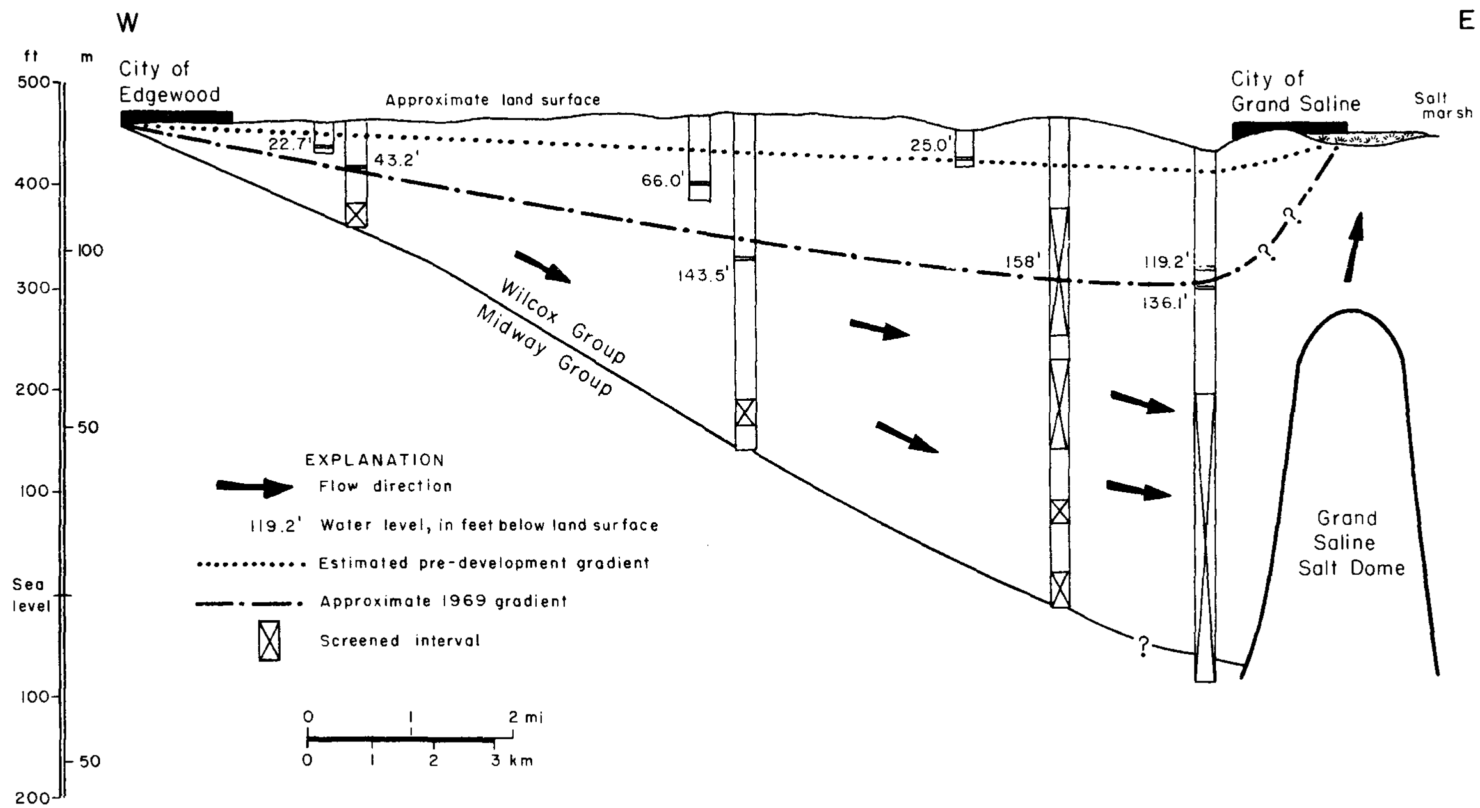


Figure 5. Ground-water levels and flow directions in the vicinity of Grand Saline Dome, Van Zandt County, Texas (modified from White, 1973).

Table 7. Generalized salinities of formation waters in units below the Midway Shale in northeast Van Zandt County (from Texas Water Development Board, 1972).

Formation	Salinity (ppm)
Eagle Ford	50,000
Woodbine	80,000 - 100,000
Paluxy	80,000 - 100,000
Lower Glen Rose	150,000
Pettet-Travis Peak	250,000+

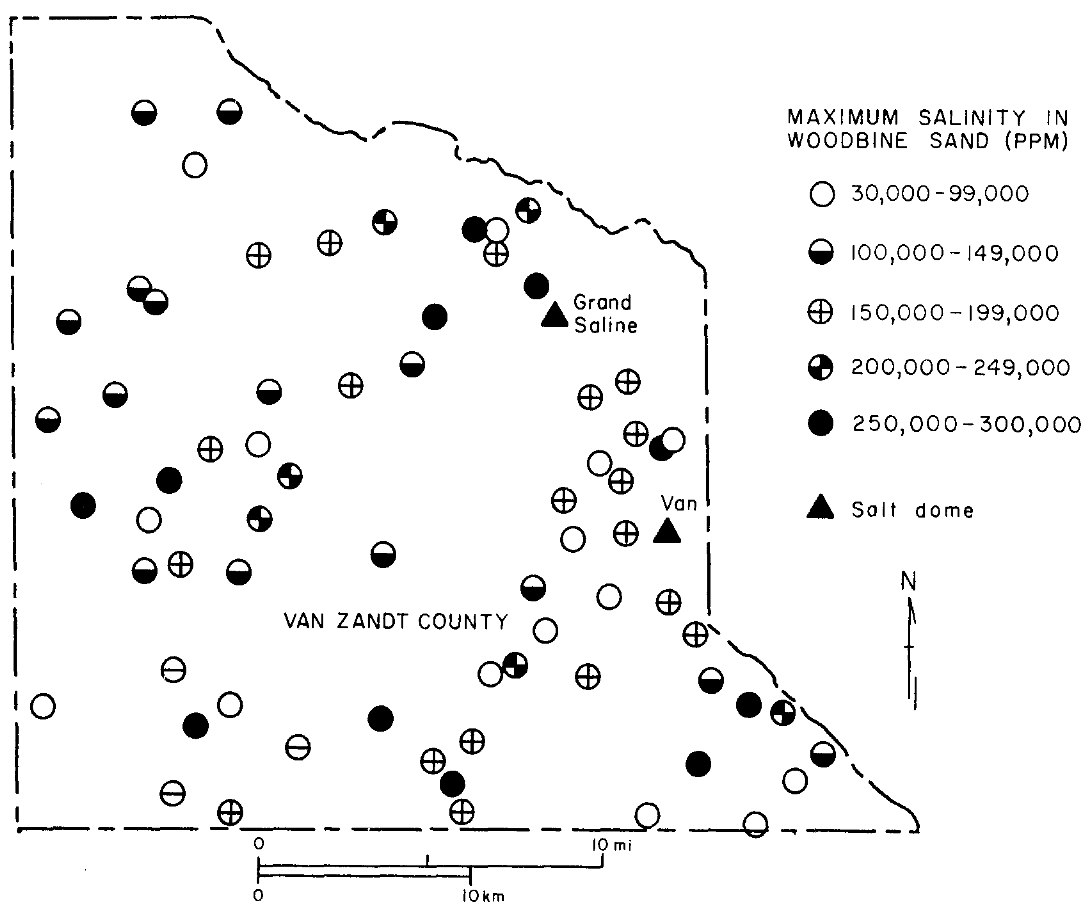


Figure 6. Salinity of Woodbine Formation water in Van Zandt County, Texas (from Fogg, 1980).

Table 8. Hydrologic characteristics of saline aquifers in the East Texas Basin (from Texas Water Development Board, 1972).

Formation	Porosity, average percent	Permeability, average*
Eagle Ford	24	80 - 600 millidarcys
Woodbine	up to 25	1 darcy, or more
Paluxy	6-30	1 millidarcy - 3 darcys
Lower Glen Rose	10	1 - 100 millidarcys
Pettet-Travis Peak	approx. 15	15 - 65 millidarcys

*varies according to shale content of local facies.

Collapse features on the surface as well as mining records indicate that the salt-caprock seal has been destroyed by solution. As a result, large cavities occur at the interface. It is not proven how or when the solution occurred; it was probably related to human intrusion into the dome area.

Hydrology (Surficial)

Grand Saline Dome lies within the Sabine River basin of northeast Texas. Grand Saline Creek, a tributary of the Sabine River, flows northeast within 0.5 km (0.3 mi) of the eastern margin of the dome (fig. 2). The central depression over the dome, part of which contains a brackish to saline marsh, drains into Grand Saline Creek. At its closest point the Sabine River is 5.8 km (3.6 mi) from the surface projection of Grand Saline Dome. The minimum altitude in Van Zandt County is at the confluence of Grand Saline Creek and the Sabine River at an elevation of 100 m (350 ft) MSL (White, 1973).

The rainfall distribution responsible for surface flows near Grand Saline Dome is described in the section on climate. Of rainfall received, approximately 229 mm (9 in) is mean annual runoff (Bechtel National, Inc., 1978). Runoff entering the upper reaches of the Sabine River, above the confluence with Grand Saline Creek, is controlled by the Iron Bridge Dam, 24.9 km (15.5 mi) northwest of Grand Saline Dome, and forms Lake Tawakoni. This lake has a total surface area of 14,850 ha (36,700 ac) and a total storage of 1,154 hm^3 (936,200 ac-ft) (Bechtel National, Inc., 1978).

Stream and lake water in Van Zandt County is chemically suitable for all purposes, with only a few local exceptions. The total dissolved solids (TDS) is normally less than 500 ppm. Analyses of 17 samples of untreated water from Lake Tawakoni and 5 other municipal lakes in the region showed TDS of 33 to 230 ppm, with an average of 126 ppm. Waters varied from soft to moderately hard. Sulfate and chloride concentrations were well below the recommended limits of 250 ppm (White, 1973).

Locally, however, water quality problems occur owing to either natural or man-induced introduction of salts into surface drainages. The brackish to saline marsh over Grand Saline Dome is fed by seeps and springs, and appears to be an area of ground-water discharge that carries NaCl dissolved from the core of the dome. Salt is then flushed into Grand Saline Creek and thence into the Sabine River. Additional salt may enter the surface flow system owing to overflow of disposal pits at the Morton Salt Company plant, and as a result of washing trucks and railroad tank cars. Sampling near the mouth of Grand Saline Creek during the period December 18, 1967, through September 30, 1968, showed that an average of 60 metric tons (65 tons) per day of dissolved NaCl passed the sampling station. The discharge-weighted average TDS was 406 ppm, with a range of 171 to 7,350 ppm. Normal TDS for surface water in the area is approximately 131 ppm (White, 1973).

The Wilcox Group, the principal aquifer around Grand Saline Dome, crops out diagonally across southwestern, central, and northeastern Van Zandt County. Grand Saline Dome is located east of the middle of this outcrop belt. Recharge is by precipitation on the outcrop belt, and an estimated 6 hm^3 (5,000 ac-ft) of recharge occurs annually, assuming a 1,810 km^2 (700 mi^2) contributing recharge area in Van Zandt and adjacent Rains Counties (White, 1973).

Land Resources

Except on the floodplain of Grand Saline Creek and along small tributaries of Grand Saline Creek, the land over Grand Saline dome has low to moderate relief, sandy loam and loamy sand soils and, where forested, an oak-elm vegetative association. The low-relief areas, such as south of the Morton Salt Company's mine facilities, have slopes of less than 3 percent. The mine site is located on an area of moderate relief with slopes of 3 to 8 percent. The lands of low and moderate relief are best used as pastureland (Henry and Basciano, 1979).

Morton Salt Company's mine facilities are situated on the Susquehanna fine sandy loam soil, the predominant soil type in Van Zandt County. Yellowish-gray fine sand extends 20 to 36 cm (8 to 14 in) deep and overlies a 1 to 2 m (3 to 6 ft) thick subsoil of dense, plastic clay. Erosion and gullying can be a problem if careful land use practices are not utilized (Goke and others, 1928). On nearly level upland surfaces and gently sloping drainage divides, mostly over the western half of the dome, the Bowie fine sandy loam is present. It is a loamy fine sand or fine sandy loam to a depth of 51 to 61 cm (20 to 24 in) and then grades into a fine sandy clay to a depth of 122 cm (48 in). Heavy plastic clay is present below 122 cm (48 in). Erosion problems are not common on this soil (Goke and others, 1928).

Other soils over the dome include the Ochlockonee very fine sandy loam along the tributaries of the Grand Saline marsh, and the Bibb silty clay loam in the marsh area itself (Goke and others, 1928).

Mineral Resources

Salt is extracted by underground mining by the Morton Salt Company at the Kleer Mine, located over the southeast quadrant of the dome. The Kleer Mine, which has been in operation since 1931 (Morton Salt Company, undated), is a major producing facility with a 210-m (700-ft) deep shaft. Salt brines are produced from the cap rock by wells approximately 60 m (200 ft) deep. Extensive mine workings are floored at 210 m (700 ft) and 180 m (590 ft) below ground surface. Internal salt structures have been mapped (Muehlberger, 1959) and a petrofabric analysis was conducted (Clabaugh, 1962).

Mixed sand and gravel resources are located along the floodplain of Grand Saline Creek immediately east and south of the dome (Gustavson, 1976). Neither native sulfur nor gypsum production was underway at Grand Saline as of 1976 (Hawkins and Evans, 1980), although the dome does have a thin cap rock (Balk, 1949; Muehlberger, 1959).

Land Use

Generalized land use, interpreted from 1:250,000-scale Landsat imagery, shows most of Van Zandt County to be non-irrigated cropland and pastureland with small areas of forest, mostly along rivers and streams. Rangeland predominates over cropland in the northwest corner of the county (Texas Department of Water Resources, 1977).

The town of Grand Saline adjoins the north margin of Grand Saline Dome and most surrounding areas are in pastureland. Crops are grown on the floodplain of Grand Saline Creek south and southeast of the dome (fig. 2). The surface facilities and holding ponds for the Morton Salt Company's mine are located over the southeast quadrant of the dome. Most of the area over the dome is pastureland. A railroad spur extends from the Texas and Pacific tracks in Grand Saline to the Morton Salt Company mine over the dome. A sewage disposal plant for the town of Grand Saline is located over the northeast edge of the dome and discharges into a tributary of Grand Saline Creek and possibly through part of the saline-to-brackish marsh overlying part of the dome.

Population

The center of Grand Saline Dome is located about 1.6 km (1 mi) south of Grand Saline in Van Zandt County. Van Zandt County is 2,189 km^2 (845 mi^2) in area. The population of the county has been increasing since 1950, as has the population of Tyler, the nearest Standard Metropolitan Statistical Area (SMSA) (Arbingast and others, 1976). In 1970, less than 25 percent of the total Van Zandt County population lived on rural farms. In 1977, the population of Van Zandt County was 27,400 (Dallas Morning News, 1980).

The population in surrounding counties ranges from 4,600 in Rains County to the north, to 111,500 in Smith County to the east-southeast. All surrounding counties showed stable to increased population in the period 1973 to 1977. Population centers near Grand Saline Dome are listed in table 9.

Salt Depth, Composition, and Geometry

Balk (1949) described Grand Saline Dome as a truncated cone with a nearly flat, circular top with a radius of 1.0 km (0.63 mi). The salt penetrates to within 65 to 104 m (212-342 ft) of the surface, and the outer margins of the salt dip steeply outward at an angle of 65^{o} to 70^{o}. In calculating the volume of the salt dome, Balk (1949) assumed a depth of 4,830 m (15,840 ft) to the Louann salt, which appears reasonable in view of more recent mapping of the top of the Smackover Formation at over 4,570 m (15,000 ft) near Grand Saline Dome (Texas Water Development Board, 1972). The volume Balk obtained was 57.9 km^3 (13.9 mi^3) of salt above the 4,830 m (15,840 ft) depth.

Because of the presence of the Morton Salt Company's Kleer Mine, much is known about the chemical composition, petrography, and large-scale structures of the Grand Saline salt dome. Mined salt is white to light gray and consists of halite with small amounts of admixed anhydrite. Anhydrite darkens the salt; however, only about 1 percent calcium sulfate may be present in some of the salt. Balk (1949) gave results of two chemical analyses, but did not state whether these are typical or better-than-average samples (table 10). The most common size of halite crystals found in the dome is 5 to 10 mm (0.25 to 0.50 in) in diameter. Muehlberger (1959), however, found an area of "giant salt crystals" with parallel cleavage planes over areas covering several square feet, with some crystals as much as 1.5 m (5 ft) long and 0.9 m (3 ft) wide. Also observed was a mass of coarse salt crystals 2.7 m (9 ft) wide, 6.7 m (22 ft) high, and 30 m (100 ft) long. Salt densities are given in table 11.

Layering in the salt mass is evident as darker bands due to thin beds of anhydrite-rich salt that remain from the original processes of deposition. These darker bands highlight the folding that has taken place as the dome was emplaced.

Table 9. Population centers near Grand Saline Dome, Van Zandt County, Texas (1976 data unless otherwise noted) (Dallas Morning News, 1980).

Within 16-km (10-mi) radius

Town	County	Population
Alba	Wood	676
Beacon	Van Zandt	no data
Emory	Rains	757
Fruitvale	Van Zandt	259
Golden	Wood	156
Grand Saline	Van Zandt	2,254
Jamestown	Smith	75
Oakland	Van Zandt	26
Silver Lake	Van Zandt	42
Van	Van Zandt	1,787
Wentworth	Van Zandt	32

Larger centers within 50-km (32-mi) radius

Town	County	Population
Athens	Henderson	9,201
Lindale	Smith	1,971
Mabank	Kaufman	1,802
Mineola	Wood	4,146
Quinlan	Hunt	1,009
Quitman	Wood	1,484
Tyler	Smith (Metro)	111,500 (1977)
Winnsboro	Wood-Franklin	3,258

Other Major Cities

City	Distance, km (mi)	Population (1977)
Dallas-Ft. Worth metro area	90 (56)	2,673,300 (estimate)

Table 10. Chemical analyses of salt mined from Grand Saline Dome (from Balk, 1949).

Constituent	A	B
Calcium carbonate	0.010	0.010
Calcium sulfate, anhydrous	0.690	0.571
Calcium sulfate, soluble	0.409	0.470
Sodium sulfate	0.008	0.023
Magnesium chloride	trace	-
Insoluble residue	trace	-
Sodium chloride (by difference)	98.883	98.926

The darkest bands contain up to 15 percent anhydrite, and are generally less than 13 cm (5 in) thick (Muehlberger, 1959).

The salt layering with dark bands of anhydrite produces an excellent series of markers for the complex folding mapped in the mine workings by both Balk (1949) and Muehlberger (1959). The size of the folds varies greatly, from wavelengths of a few centimeters to over 30 m (100 ft). All observed fold axes were parallel and nearly vertical due to the upwelling of the salt into the domal structure. The axial planes of most folds are straight but those of the larger folds may curve. Because of the vertical attitude of the folds, fold structures are best seen on the ceilings of the mine workings. Much smaller scale folding is superimposed on the limbs of larger folds.

In the newer mine workings, accessible to Muehlberger but not to Balk, a series of folds is exposed whose axial planes trend southwest and approach parallelism near the southern edge of the mine workings (fig. 7). Traces of axial planes of folds also show a radical change in strike from southwest to northwest along a line extending approximately east-west (fig. 7). Muehlberger (1959) suggested that this line may

Table 11. Densities of salt mined from the 700-ft level in Grand Saline Dome (from Peters and Dugan, 1945).

Material	Number of Samples	Density (g/cc) Range	Average
Clear salt	6	2.13 - 2.16	2.15
Dark salt*	2	2.22 - 2.25	2.24

*salt with included anhydrite

coincide with a former fracture in the overlying sediments that localized the upwelling of the salt. The salt then preferentially moved up along these fractures, tilting the overlying rocks, and therefore advanced in spines rather than as a single entity.

Specific examples of plastic flowage of salt are seen in the Kleer Mine, where warping and crushing of timbers has occurred in the old workings. In less than 20 years timbers 10 cm by 10 cm by 2.4 m (4 in by 4 in by 8 ft) long have been bent and deflected 8 cm (3 in) or more before failing (Muehlberger, 1959).

Petrofabric analyses of salt crystals from Grand Saline Dome suggest that salt movement occurs by translation gliding (Clabaugh, 1962). Salt glides at least as readily parallel to cubic glide planes as to dodecahedral glide planes. Measurements of oriented samples from the Kleer Mine show that the axial planes of the folds identify planes parallel to which crystal gliding has taken place. The physical characteristics of the salt mass will therefore vary in relation to position of major folds. Clabaugh (1962) concluded that the directions of blast fracturing during mining and the stability of mine walls and pillars may well be influenced by salt crystal orientation in areas where crystals show a strong preferred orientation.

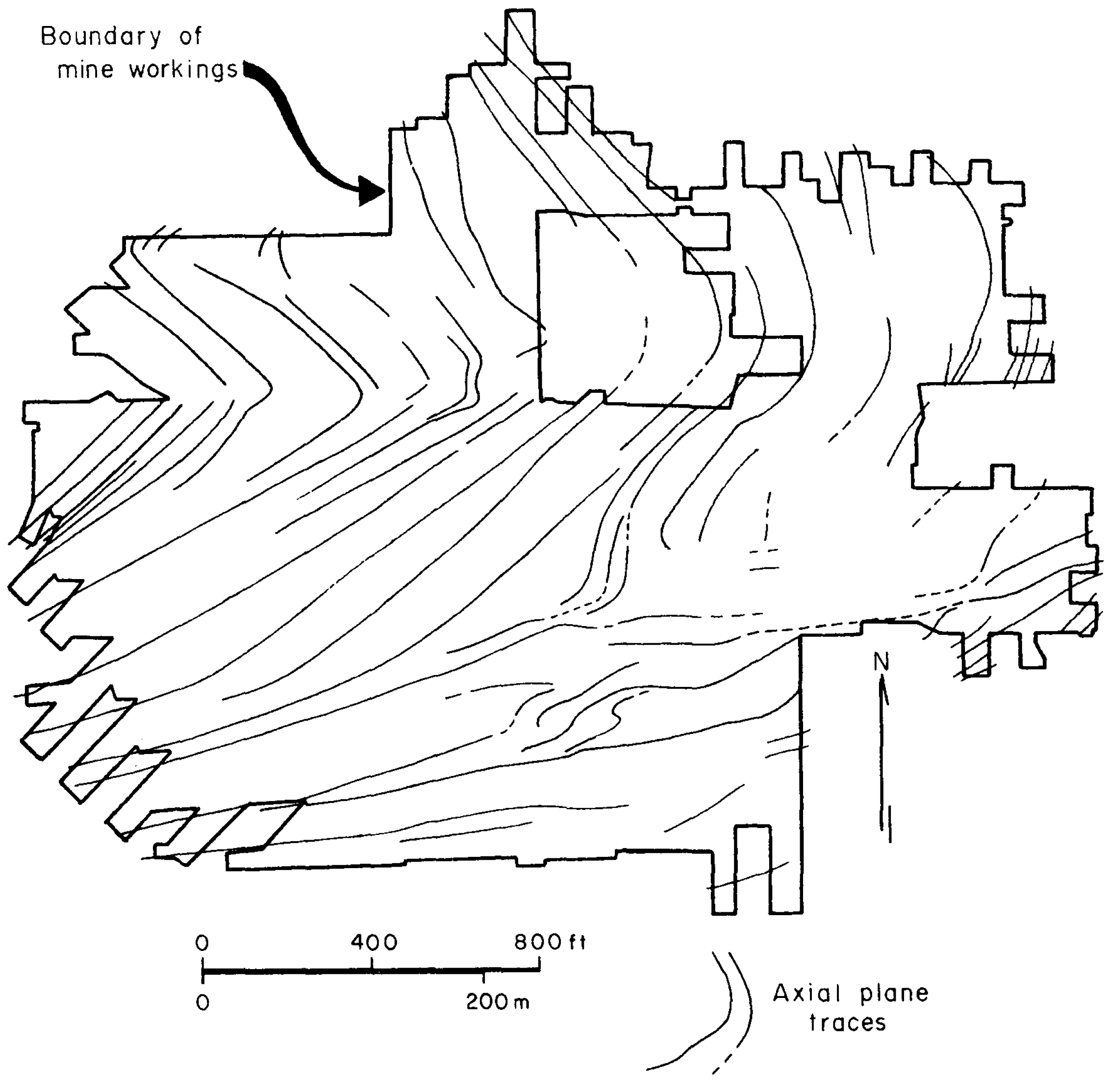


Figure 7. Plan view of salt structure based on mapping in the Morton Salt Company mine in Grand Saline Dome (from Muehlberger, 1959).

Regarding the electrical resistivity of salt, Scharon (1963) found some indications of moisture during tests within the Kleer Mine. These may, however, be more related to brine ponds constructed within the mine than to moisture generally distributed within the salt. Comparing results from Grand Saline Dome to those for bedded salt in a mine in Michigan, Scharon (1963) found that the bedded salt had lower apparent resistivity, which he suggested is an indicator of possible brine cavities. These results may reflect a greater content of minute fluid inclusions in the salt, rather than major cavities.

No subsurface structural effects of salt dissolution, such as well bores encountering collapsed zones or caverns, are reported in the literature on Grand Saline Dome. At the surface, dissolution of subsurface salt has created a central topographic depression over the dome. This depression is found between the Morton Salt Company mine and the town of Grand Saline; the eastern part of the depression is occupied by the brackish marsh that led to discovery of the dome. The presence of cap rock indicates past salt dissolution near the apex of the dome during emplacement and the accumulation of insoluble sediments.

Stratigraphy

The Grand Saline salt dome is located near the western margin of the East Texas embayment, also known as the Northeast Texas basin (Nichols and others, 1968), which is an embayment of the Gulf Coast basin. The deepest part of the Northeast Texas basin is bounded by the Mexia-Talco fault system on the west and north, the Sabine Uplift on the east, and the Elkhart-Mount Enterprise fault system on the south (fig. 8). The few wells that have penetrated Paleozoic strata in the Northeast Texas basin show that the Mesozoic and Tertiary rocks overlie faulted and folded Ordovician to Pennsylvanian strata and schist of unknown age. The Jurassic and Cretaceous strata (fig. 9), in general, dip and thicken toward the center of the basin (Nichols and others, 1968).

The present structural configuration of the sedimentary units has been significantly altered by flowage and diapirism of the Jurassic Louann salt. Eighteen salt domes penetrate to within 1,830 m (6,000 ft) of the surface; numerous other deeper salt structures also exist (A. Giles, personal communication, 1980).

At Grand Saline Dome salt penetrates to within 64.6 to 104.2 m (212 to 342 ft) of the surface, and the top of the dome is nearly flat. The dome is surrounded by Eocene (Wilcox) to Lower Cretaceous (Paluxy) formations at depths up to 2,000 m (6,600 ft)

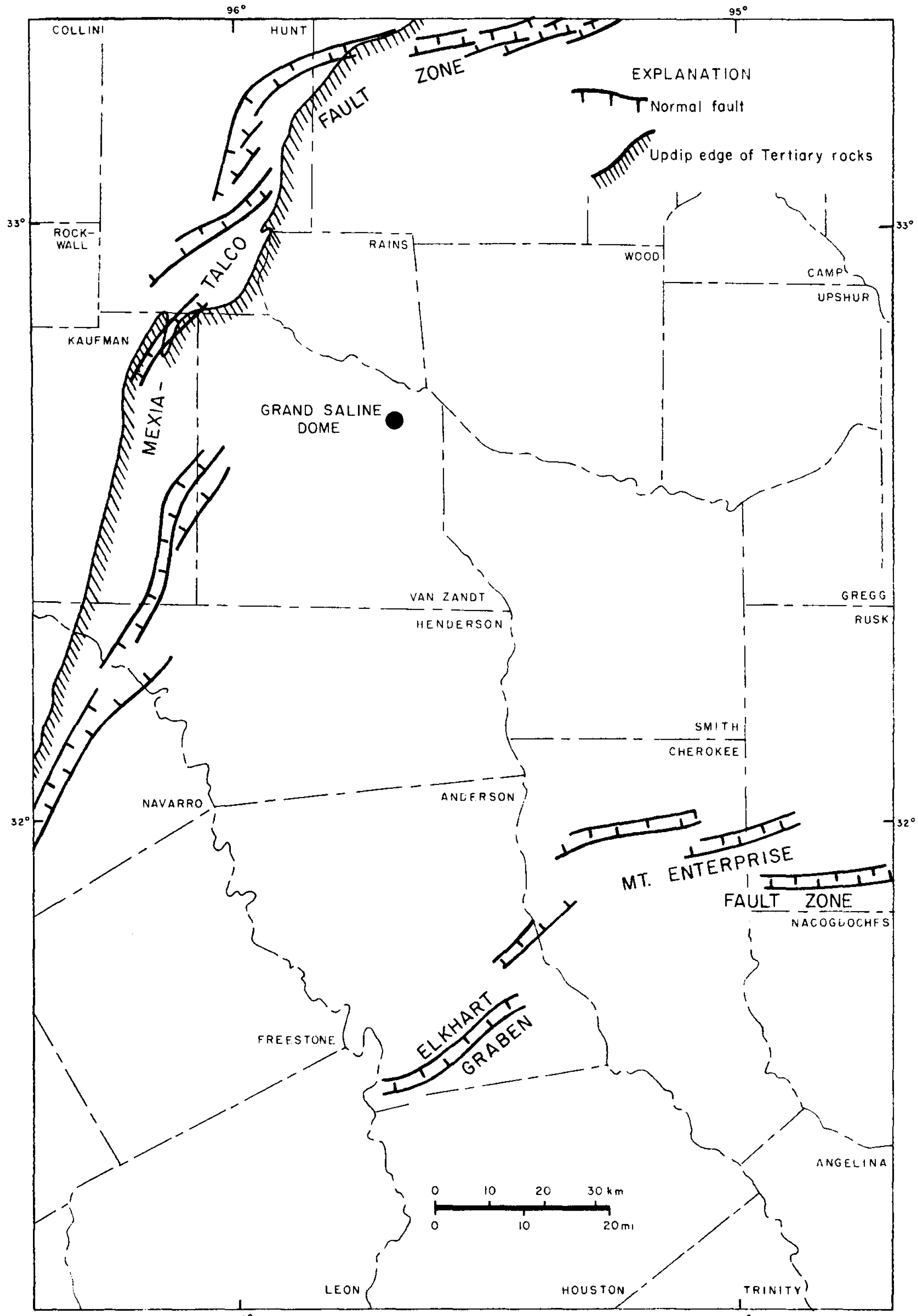


Figure 8. Grand Saline Dome in relation to faults bounding the East Texas Basin (after Agagu and others, 1980).

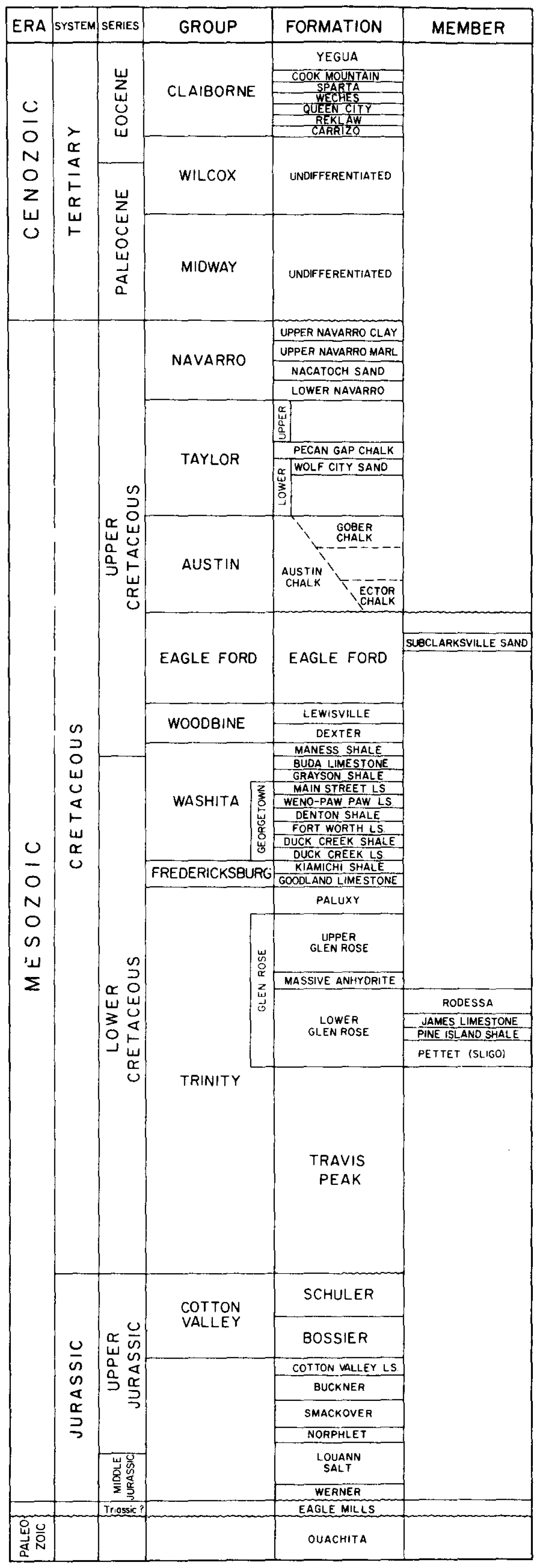


Figure 9. Stratigraphic sequence and nomenclature in the East Texas Basin (from Agagu and others, 1980).

(fig. 10). The diameter of the dome at depth is approximately 2,440 m (8,000 ft), and the outer margins of the salt dip steeply outward at an angle of 65°-70° (Balk, 1949). The Wilcox Group rocks outcropping around the dome dip radially away from the dome at angles as high as 20°. Over the dome to the top of the cap rock, the Wilcox consists of sand, sandy shale, and shale, which is limy and pyritic in places, with interbeds of lignite. These Wilcox strata vary from mostly poorly consolidated to very well consolidated. Powers and Hopkins (1922) provided detailed sample logs of some of the earliest wells drilled over and around Grand Saline Dome.

The cap rock of Grand Saline Dome varies from 1.2 m (4 ft) to 21.6 m (71 ft) and averages 7.6 m (25 ft) in thickness (Balk, 1949). The cap rock consists of gypsum, limestone, and interbeds of sand and shale, and contains cavities into which early wells lost all water and drilling mud (Powers and Hopkins, 1922).

The stratigraphic units in East Texas basin are given in figure 9, and can be related to the units around Grand Saline Dome through figure 10. Further descriptions can be found in Eaton (1956) and Nichols and others (1968).

Socioeconomic Setting

Grand Saline Dome is located in the city of Grand Saline, which has a population of nearly 2,500. The principal economic activity of the town is salt mining for the Morton Salt Company. Grand Saline is located in Van Zandt County, a county whose principal economy is based on oil, tourism, agribusiness, and light manufacturing. Many people commute to work in Dallas. The county is not poor; annual income approaches $140 million.

The Grand Saline salt dome is one of the few active mines in the Gulf Coast. The Morton Salt Company has two principal properties in the Gulf Coast: Grand Saline and Avery Island. Because of heater experiments in Avery Island, the Department of Energy knows the Morton executives who might favor use of the mine. However, because "radioactivity" could be associated with Morton products in a Salt Test Facility, it is doubtful that this property could be acquired. Morton would fear a decline in sales given an association of "radioactivity" with their product.

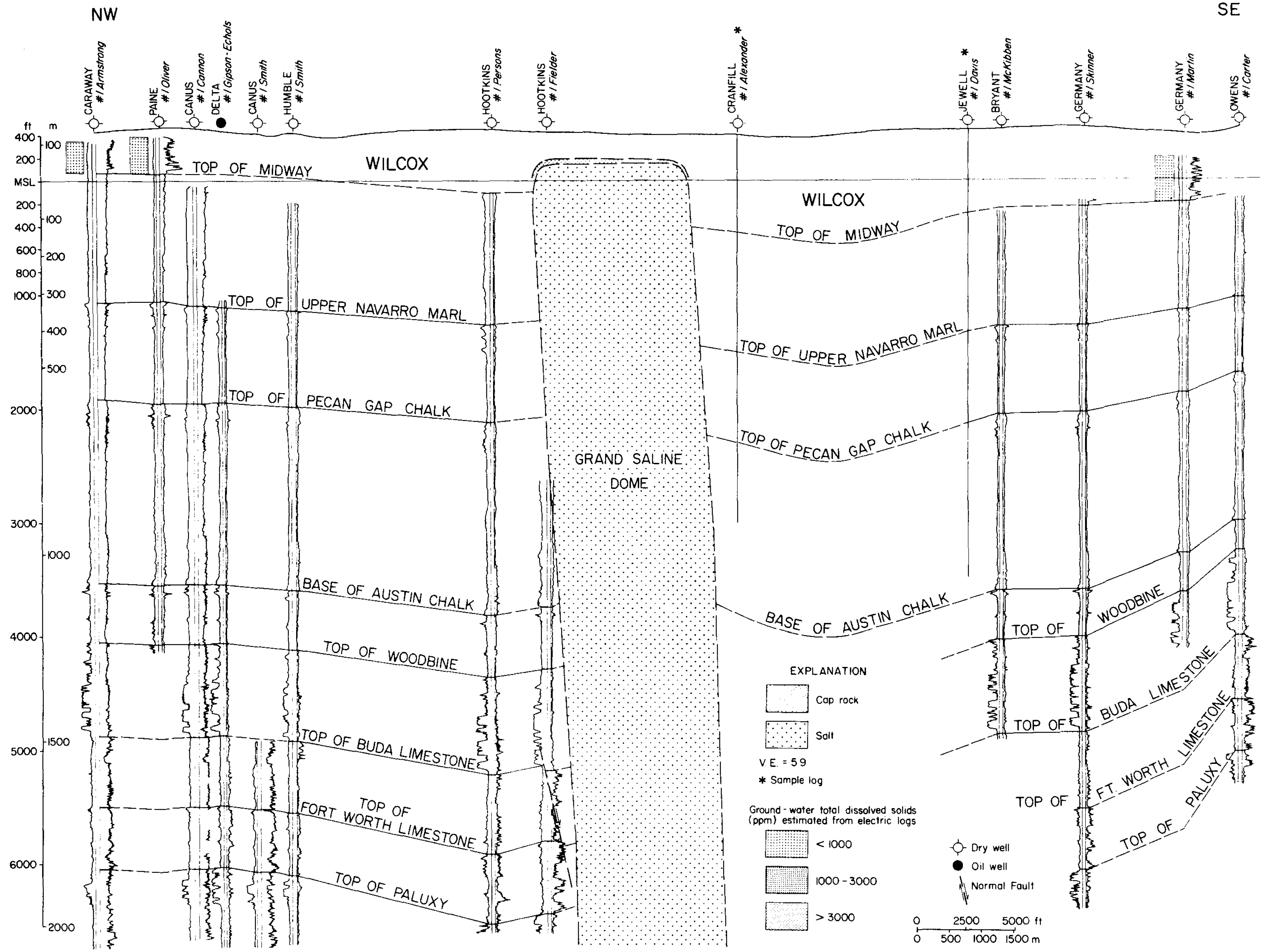


Figure 10. Dip-oriented structural cross section through Grand Saline Dome (from Giles, 1980).

HOCKLEY DOME

Hockley Dome is located in Harris County and is within the growth path of the northwest quadrant of the city of Houston (fig. 11). Hockley is an open system in that salt is presently being produced at an underground mine owned by United Salt Corporation. An underground gypsum mine has been operated at this dome in the past.

Biologic Resources

Hockley Dome lies within the Gulf Prairies region of southeast Texas (Hoffman and others, 1976). The principal grasses present are tall bunch grasses, including bluestem grasses. Grazing pressure has altered the mix of range grasses present so that species less valuable for forage and a variety of annual weeds are now present in many areas. Oak underbrush, mesquite (Prosopsis juliflora), and pricklypear cactus have invaded these grasslands (Hoffman and others, 1976).

The immediate vicinity of the Hockley Dome is covered by coastal prairie grassland. Fluvial woodlands along tributaries of Cypress Creek are found within 2 mi south and 3.5 mi west of the dome (St. Clair and others, 1975). Fluvial woodlands of the Gulf Prairies include pecan (Carya illinoensis), hickory (Carya sp.), and live oak (Quercus virginiana), as well as other water-tolerant hardwoods (Fisher and others, 1972).

Fauna in the area include small fur-bearers (squirrel, raccoon, opossum, and rabbit) that live in wooded areas along creeks. Birds, including quail, and snakes also prefer these areas (Fisher and others, 1972). Endangered species in Harris County are listed in table 12; various protected nongame species are also found.

Climate

Hockley Dome lies in the moist subhumid part of southeast Texas (Thornthwaite, 1948), and has a predominantly marine climate with high humidity. Rainfall is evenly distributed throughout the year. At Houston, southeast of Hockley Dome, the mean annual precipitation is 1,224 mm (48.19 in). May is normally the wettest month with an average precipitation of 130 mm (5.10 in), and March is normally the driest with average precipitation of 68 mm (2.68 in) (U.S. Dept. of Commerce, 1978). The average

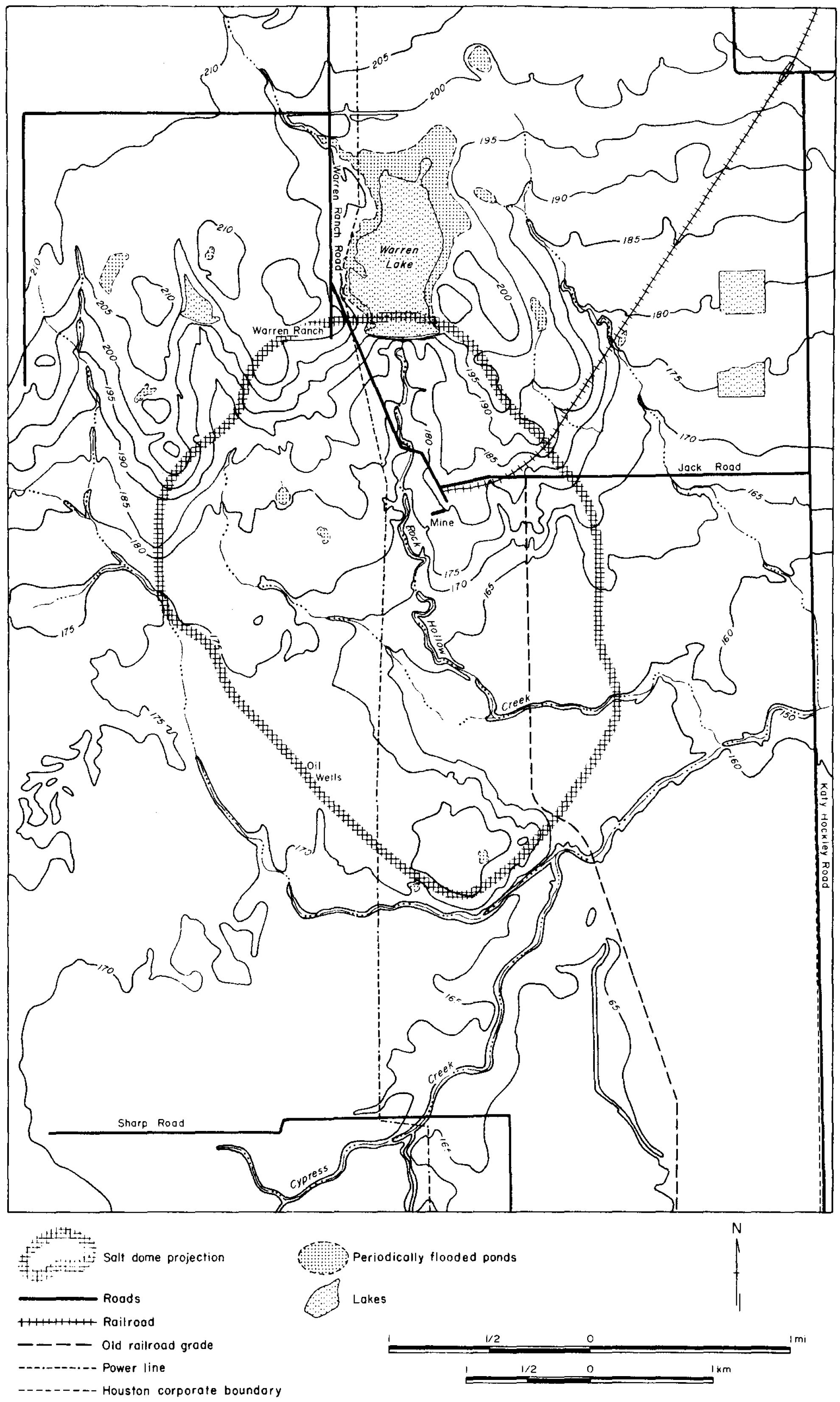


Figure 11. Topography and cultural features over Hockley Dome, Harris County, Texas (from U.S.G.S. 7.5-minute quadrangle, Warren Lake, Texas). Contour interval is 5 ft.

Table 12. Endangered species in Harris County (F. E. Potter, personal communication, 1980).

CONFIRMED

Southern bald eagle, Haliaeetus l. leucocephalus

Arctic peregrine falcon,* Falco peregrinus tundrius

Attwater's greater prairie chicken, Tympanuchus cupido attwateri

American alligator, Alligator mississipiensis

PROBABLE

Interior least tern,* Sterna albifrons athalassos

Red-cockaded woodpecker, Dendrocopus borealis

Houston toad, Bufo houstonensis

POSSIBLE

Brown pelican, Pelecanus occidentalis

*mostly migratory

annual gross lake surface evaporation for the area is approximately 1,498 mm (59 in) (Kane, 1967). Heavy rains occasionally occur in the area due to the passage of hurricanes and tropical storms.

Mean annual relative humidity is 85 to 90 percent at 6 a.m. and approximately 60 to 65 percent at 6 p.m. (Arbingast and others, 1976). The average monthly temperature in Houston varies from a minimum of 52.1°F (11.2°C) in January to 83.4°F (28.9°C) in August. Temperatures are moderated by winds from the Gulf of Mexico. The first and last dates of killing frost are December 11 and February 5, respectively (U.S. Department of Commerce, 1978). These data were collected at Hobby Airport, 69 km (43 mi) from Hockley Dome, and at Houston Intercontinental Airport, 51 km (32 mi) from Hockley Dome.

Energy Resources (Basinal)

Oil at Hockley Dome was discovered in 1923 with the drilling of the Texas Exploration Co. #13 Warren well to a depth of 555 m (1,820 ft). Commercial production was established in 1946 in deep caprock 1,936 m (6,352 ft) and later in Cockfield-Yegua sands. Subsequent testing located producing sands of Miocene age at 550 to 640 m (1,800 to 2,100 ft), of Oligocene age at 640 to 1,130 m (2,100 to 3,700 ft), and of Eocene age (Yegua Formation) at 1,740 to 1,950 m (5,700 to 6,400 ft). The depth to cap rock is as little as 30 m (99 ft) (Canada, 1953).

Currently three oil fields occur at Hockley Dome (Railroad Commission of Texas 1979), only one of which was productive in 1979 (table 13). Two gas fields are listed at depths of 1,890 m (6,200 ft) and 550 m (1,800 ft), but there was no production in 1979 and these may, in part, represent some of the many abandoned locations over the dome (table 14). Most of the current oil production is located along the southwest flank of the dome, approximately 2,290 m (7,500 ft) southwest of the salt mining facilities. Approximately 115 abandoned and active wells are located over and along the flanks of Hockley Dome (Railroad Commission of Texas, undated). Unrecorded well locations are likely to exist because drilling dates back to 1906, and includes exploration for sulfur (Canada, 1953). Current exploration activity is occurring over the dome, and new locations were recorded as recently as July 23, 1980.

Energy Resources (Surficial)

Neither strip-mineable lignite nor uranium is known from the Hockley Dome area in Harris County (St. Clair and others, 1976).

Flood Potential

Canada (1953) surface-outlined the top of Hockley Dome. This area is approximately 1,160 ha (2,860 acres), of which approximately 300 ha (740 acres) are within the Special Flood Hazard Area (Zone A) mapped by the U.S. Department of Housing and Urban Development (1976). Although the frequency of floods for this zone is undefined, it is greater than in Zone C, a zone of minimal flood hazard, over the remainder of the dome.

Table 13. Crude oil and casinghead gas production at Hockley Dome (from Railroad Commission of Texas, 1979).

Field*	Discovery Date	Depth (ft)	1979 Production Casinghead Gas, MCF	1979 Production Crude Oil, BBLS	Cumulative Crude Oil BBLS, through 1/1/80
Hockley	7-02-45	5,228	620	7,295	787,291
Hockley (FB-1, Y-1)	2-21-67	5,250	0	0	22,307
Hockley (FB-2, Y-2)	12-09-64	5,534	0	0	6,484

*Names in parenthesis refer to producing horizons.

Table 14. Gas well gas production and hydrocarbon liquids recovered on leases, 1979, at Hockley Dome (from Railroad Commission of Texas, 1979).

Field*	Producing Wells End of Year	Gross Gas Production, MCF	Hydrocarbon Liquids, BBLS
Hockley (Yegua 6200)	0	0	0
Hockley (1840)	0	0	0

*Names and/or numbers in parenthesis refer to producing horizon and/or depth (in feet).

Most of the flood-prone area of the dome is over the southeast quarter of its surface outline and along Rock Hollow Creek below the 50-m (165-ft) elevation. Rock Hollow Creek is a tributary of Cypress Creek, which flows as close as 150 m (500 ft) to the surface projection of the top of the salt (fig. 11). Immediately south of the dome, areas 300 m (1,000 ft) to 1,525 m (5,000 ft) on either side of Cypress Creek are in the Special Flood Hazard Area (Zone A). The surface slopes are extremely low (1.5 m/km; 5 ft/mi, or less) in the Cypress Creek drainage basin near the dome. Parts of the creek and its tributaries have been channelized (U.S.G.S. 7.5-minute quadrangle, Warren Lake, Texas).

Surface facilities for the existing salt mine are approximately 54 to 55 m (177 to 182 ft) in elevation. Rock Hollow Creek is located 215 m (700 ft) west of the mine facilities at an elevation of approximately 52 m (169 ft); the Creek has been dammed approximately 1,465 m (4,800 ft) north of the mine to form Warren Lake. The elevation of Rock Hollow Creek just below the dam is approximately 55 m (181 ft), and the maximum pool elevation is 29 m (196 ft) (U.S.G.S. 7.5-minute quadrangle, Warren Lake, Texas). Warren Lake provides some flood protection for Rock Hollow Creek near the mine site and for one of the two light-duty roads that provide access to the mining facilities. This road crosses Rock Hollow Creek northwest of the mine.

Historical Resources

One known archeologic site is located within the surface projection of Hockley Dome, and is listed with the Texas Archeological Research Laboratory (C. Spock, personal communication, 1980). The site is on the west bank of Rock Hollow Creek approximately 430 m (1,400 ft) northwest of the Hockley Salt Mine, and does not appear to be a major find (table 15). No existing or proposed National Register Historic Sites are over or immediately adjacent to Hockley Dome, according to files of the Texas Historical Commission.

Hydrology (Basinal)

Hockley Dome is within the Houston water district, a study area within which ground water has been extensively evaluated and utilized. The district includes all of Harris and Galveston Counties and parts of six adjacent counties.

Table 15. Archeologic site over Hockley Dome, Harris County, Texas (data from C. Spock, personal communication).

Site No.:	41 Hr 331 (Cy Cr 8)
Project:	Cypress Creek Survey Sq. No. 152
Type:	Isolated find of a unifacially worked brown chert flake
Cultural Affiliation:	Prehistoric
Site Description:	Slope wash (on) an eroded bare area on the west bank of Rock Hollow Creek; area used as garbage dump. No other prehistoric artifacts of any kind could be found in the area.
Recommendations for work:	None
Date:	16 November 1977

Within Harris County the Evangeline aquifer, consisting of the Pliocene Goliad Sand, is the major source of ground water. The Chicot aquifer, consisting of Pleistocene sands and clays, along with Holocene alluvium, is also a ground-water source but is not a major source in the vicinity of Hockley Dome (fig. 12; table 16) (Gabrysch, 1980).

The Houston district has been subdivided into areas based on pumpage. Hockley Dome is in the Katy area, consisting of northwestern Harris County, southeastern Waller County, and the northern part of Fort Bend County. All water used in the Katy area is ground water. More than 90 percent of all the 150.7 mgd pumped in 1974 was used for irrigation of rice. In 1974, 8.9 mgd were pumped for public supplies and 11.0 mgd were pumped for industrial uses.

The aquifers crop out in belts generally parallel to the shoreline of the Gulf of Mexico and dip toward the coast at 2.9-3.8 m/km (15-20 ft/mi). All formations thicken toward the coast and localized structures, such as salt domes, result in dip reversals or thickening and thinning of beds. Hockley Dome is located 43 km (27 mi)

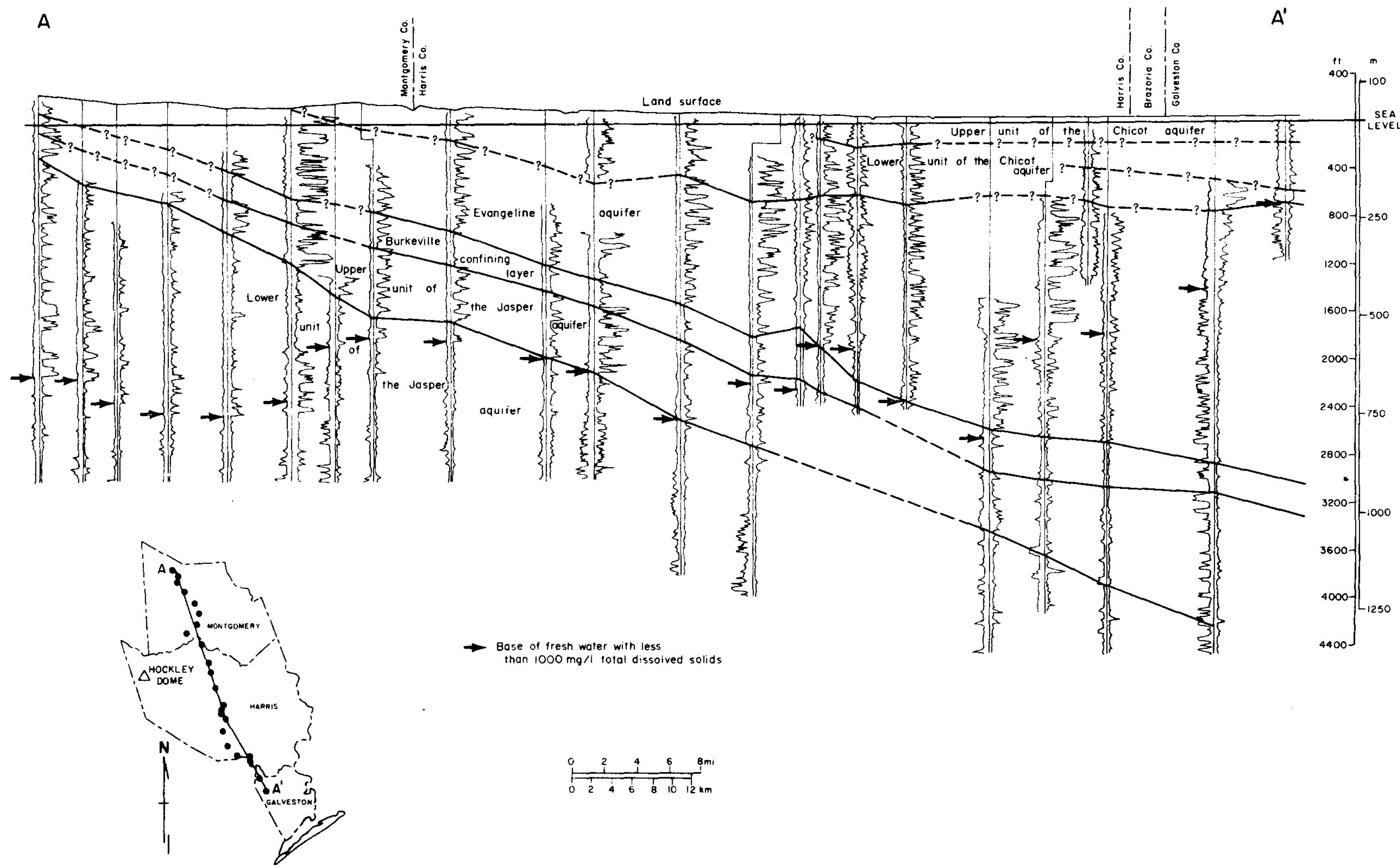


Figure 12. Cross section showing aquifers in the vicinity of Hockley Dome, Harris County, Texas (from Gabrysch, 1980).

Table 16. Stratigraphy of shallow water-beraing units in Harris County, Texas (modified from Gabrysch, 1980).

<table>
<tr><th>System</th><th>Series</th><th>Stratigraphic unit</th><th colspan="2">Aquifer</th></tr>
<tr><td rowspan="6">Quaternary</td><td>Holocene</td><td>Quaternary alluvium</td><td rowspan="6">Chicot aquifer</td><td rowspan="3">Upper unit</td></tr>
<tr><td rowspan="5">Pleistocene</td><td>Beaumont Clay</td></tr>
<tr><td rowspan="2">Montgomery Formation</td></tr>
<tr><td rowspan="3">Lower unit</td></tr>
<tr><td>Bentley Formation</td></tr>
<tr><td>Willis Sand</td></tr>
<tr><td rowspan="5">Tertiary</td><td>Pliocene</td><td>Goliad Sand</td><td colspan="2" rowspan="2">Evangeline aquifer</td></tr>
<tr><td rowspan="4">Miocene</td><td rowspan="4">Fleming Formation</td></tr>
<tr><td colspan="2">Burkeville confining layer</td></tr>
<tr><td rowspan="2">Jasper aquifer</td><td>Upper unit</td></tr>
<tr><td>Lower unit</td></tr>
</table>

south-southeast of the updip limit of the Chicot aquifer. The elevation of the base of the aquifer is approximately 3-12 m MSL (10-40 ft MSL) over the dome, or 43 to 52 m (140 to 170 ft) below ground surface. The base of the Evangeline aquifer has been dragged upward approximately 213 m (700 ft) around Hockley Dome, from an elevation of -366 m MSL (-1,200 ft MSL) southwest and northeast of the dome to -153 m MSL (-500 ft MSL) around the dome. The Evangeline aquifer (Goliad Sand) consists of a bentonitic clay interbedded with carbonate-cemented sand and gravel in the subsurface of the eastern Texas Coastal Plain, including Harris County (Wood and others, 1963).

Although water level declines have been significant in parts of the Houston district, this has not been so in the vicinity of Hockley Dome. For the period 1965 to 1975 the water level decline in the Chicot aquifer has been less than 6.1 m (20 ft) and in the Evangeline aquifer water level decline has been approximately 7.6 m (25 ft) near the dome (Gabrysch, 1980). Despite heavy pumping, water level declines in the Katy area have been lower than in other parts of the Houston district because of a relatively greater coefficient of storage and greater hydraulic conductivity of the sands in the two aquifers. There is a great amount of sand in the subsurface in the Katy area and a resulting better degree of lateral hydraulic continuity than anywhere else in the Houston district. Thus a significant fresh water resource exists and must be protected in the area of Hockley Dome.

Fresh water quality in the Houston district is good except far downdip from Hockley Dome where updip saltwater migration may be occurring as a result of heavy pumping. This is primarily in southern Harris and Galveston Counties. A well tapping both the Chicot and the Evangeline aquifers located approximately 8 km (5 mi) northeast of Hockley Dome had a total dissolved solids (TDS) content of 198 ppm and a chloride content of 27 ppm. A well 11 km (7 mi) south-southeast of the dome had 302 ppm TDS and 34 ppm chloride.

The saline water resources of the Gulf Coastal Plain have been mapped according to depth zones that cut across formation boundaries and time lines within the Tertiary-age stratigraphic units. These zones generally show increasing formation water salinity below the base of fresh to slightly saline water, which is in the Miocene Fleming Formation (fig. 12) in northwestern Harris County. Each depth zone is 610 m (2,000 ft) thick and is defined by arbitrary values; because there is practically no saline water above sea level, zone 1, 0 to +610 m MSL (0 to 2,000 ft MSL) was not mapped. Salinities for northwestern Harris County around Hockley Dome are listed in table 17 (Texas Water Development Board, 1972).

Table 17. Formation water salinities within 610-m (2,000-ft) thick zones of Tertiary Gulf Basin sands, northwestern Harris County (from Texas Water Development Board, 1972).

Zone	Depth, ft below MSL	Salinity, ppm
2	0 - 2,000	40,000+
3	2,000 - 4,000	40,000
4	4,000 - 6,000	60,000
5	6,000 - 8,000	70,000
6	8,000 - 10,000	No nearby data, probably 60,000+

Hydrology (Surficial)

Hockley Dome lies within the San Jacinto River basin of southeast Texas. Cypress Creek, a tributary of the San Jacinto River, flows east-northeast within 0.3 km (0.2 mi) of the south flank of the dome. A tributary of Cypress Creek, Rock Hollow Creek, flows south and southeast over the north-central, central and east-central parts of the surface projection of Hockley Dome. Rock Hollow Creek is dammed just over the north margin of the dome to form Warren Lake.

Cypress Creek joins Spring Creek before flowing into the West Fork of the San Jacinto River, which has been dammed to form one arm of Lake Houston. The spillway elevation of the San Jacinto Dam at Lake Houston is 13 m MSL (44 ft MSL). Lake Houston is part of the water supply system for the City of Houston.

The position of many of the creeks in the Houston area is controlled by faulting. That part of Cypress Creek south and southeast of Hockley Dome is possibly controlled by the Hockley fault (or fault zone). This fault (or fault zone) has produced a prominent surface scarp over the northern half of the surface projection of Hockley Dome (C. Kreitler, personal communication, 1980). Rock Hollow Creek and other unnamed tributaries of Cypress Creek are incised into this topographic break, which has a maximum local relief of 11 m (35 ft) over Hockley Dome.

The rainfall distribution responsible for surface flows near Hockley Dome is described in the section on climate. Approximately 280 mm (11 in) of precipitation runs off into streams in the Harris County area, which includes Hockley Dome, on an annual basis (Gabrysch, 1967). For the northwest part of the San Jacinto River basin the minimum annual runoff is 100 hm^3 (82,602 ac-ft) and the average annual runoff (1940-1956) has been 990 hm^3 (803,967 ac-ft) (Lockwood, Andrews and Newnam, 1960).

The chemical quality of water in Cypress Creek is good; flood flows are of excellent quality. During low flows some increase in chloride content suggests possible contamination by oilfield brine. Generally total dissolved solids are 100 to 150 ppm, the water is soft (30 to 60 ppm hardness as $CaCO_3$), and chloride content is typically 25 to 50 ppm (Hughes and Rawson, 1966). No surface water contamination due to salt mining apparently exists at Hockley Dome.

The Evangeline Aquifer (Goliad Sand) is the major aquifer in Harris County and the area around Hockley Dome. Although stratigraphically differentiated from the overlying Willis Sand (Pleistocene age) and Lissie Formation (Pleistocene age), the three units are hydraulically connected (Wood and others, 1963). Precipitation reaching the outcrop of all three units may therefore contribute to ground water in the Evangeline Aquifer, as well as in the Chicot Aquifer (Willis Sand and younger Pleistocene units). The outcrop of the Willis Formation occurs over and northwest of Hockley Dome (Barnes, 1968). The Goliad, or an equivalent unit, crops out in Montgomery County north of Harris County (Gabrysch, 1980). Baker (1979) did not differentiate the Goliad Sand from the underlying Fleming Formation (Miocene age) as part of the Evangeline Aquifer near the outcrop belt. Precipitation on the Fleming Formation outcrop belt may also recharge the Evangeline Aquifer.

Land Resources

The land over Hockley Dome is predominantly flat to gently rolling and moderately susceptible to erosion, with sandy and locally clayey sand substrates. It is easily excavated and has low to moderate corrosion potential and low shrink-swell potential. Bearing strength is high. Permeability is moderate and recharge to shallow aquifers is a consideration in land use. Small areas over the extreme northwest and southeast parts of the dome, on flat to sloping terrain, experience greater shrink-swell potential, low to moderate bearing strength, and higher corrosion potential on sandy clay substrates (St. Clair and others, 1975).

Soils over Hockley Dome include the Gessner loam and the Katy fine sandy loam. The mine is located on the latter unit, which is somewhat poorly drained and has severe limitations for building because of wetness. Corrosion potential is low for the first 1 m (3 ft) below the surface but increases beyond that depth. The overall suitability for urbanization for the Katy fine sandy loam is moderate, compared to some other soils in Harris County with very low to low suitability due to problems of shrink-swell potential and wetness (Wheeler, 1976).

Mineral Resources

Perkins and Lonsdale (1955) reported Hockley Dome as potentially productive of sulfur, but no production had occurred through 1953. Hawkins and Evans (1980) did not list any native sulfur production for Harris County, where Hockley Dome is located.

Gypsum was mined at Hockley Dome as late as 1947 by the Hockley Gypsum Company following various exploration and testing efforts begun in 1928 (Stenzel, 1943; Perkins and Lonsdale, 1955). Hawkins and Evans (1980) report no gypsum production for Harris County as of 1976. Mixed sand and gravel resources are found in the floodplain of Cypress Creek southeast of Hockley Dome (Gustavson, 1976).

Salt is presently produced from an underground mine at Hockley Dome by the United Salt Corporation (Lefond, 1969; Hawkins and Evans, 1980). A 490-m-deep (1,600-ft) vertical shaft is part of the mining operation (Canada, 1953).

Land Use

Generalized land use, interpreted from 1:250,000-scale Landsat imagery, shows much of rural northwest Harris County, including the area over Hockley Dome (Texas Department of Water Resources, 1977), to be irrigated cropland. Rice, which requires seasonal flooding, is the primary crop on these lands. Much of rural Harris County is rapidly urbanizing. Development is occurring along corridors following major highways, including U.S. 290, which is approximately 6 km (4 mi) north of the center of Hockley Dome. The point within the City of Houston nearest Hockley Dome lies 3.5 km (2.2 mi) to the southeast, and consists of a narrow corridor along a county road, the Katy-Hockley Cutoff.

Over the dome itself a dam has been built across Rock Hollow Creek to form Warren Lake, which extends north away from the surface projection of the dome (see section on hydrology, surficial). The Warren Ranch headquarters is located west of Warren Lake over the northern margin of the dome. Two light-duty roads and a spur of the Southern Pacific Railroad lead to the facilities of the United Salt Corporation's salt mine near the center of the dome. An electrical transmission line runs generally north-south over the center of the dome. Rangeland and rice cropland are located directly over the dome.

Population

Hockley Dome is located 6.4 km (4 mi) south of Hockley in Harris County. In 1977 Harris County had an estimated population of 2,138,300 (Dallas Morning News, 1980). The area of the county is 4,486 km^2 (1,723 mi^2). Harris County has been rapidly growing in population as a result of the growth of Houston, the major city in the county. Hockley Dome lies within the Houston Standard Metropolitan Statistical Area (SMSA). Less than 5 percent of the population of Harris County lives on rural farms (Arbingast and others, 1976).

The population in surrounding counties ranges from 14,000 in Chambers County to the east, to 195,400 in Galveston County to the south. All seven counties adjacent to Harris County increased in population between 1973 and 1977 (Arbingast and others, 1976). Population centers near Hockley Dome are listed in table 18.

Salt Depth, Composition, and Geometry

The salt core of Hockley Dome has penetrated to within 308 to 338 m (1,010 to 1,110 ft) of the surface and the top of the salt is fairly level (Stenzel, 1943). The dips on the sides of the salt are at least 55° to 67° (Deussen and Lane, 1925). The shape of the dome is slightly elliptical with the longer axis oriented north-northwest. As defined by drilling, the dimensions of the salt core are 5,180 m (17,000 ft) by 3,960 m (13,000 ft) at approximately the -915-m MSL (-3,000-ft MSL) depth contour (fig. 13). The southwest flank of the dome, where hydrocarbon production is concentrated, has a very irregular shape with two small areas of cap rock developed on the flank of the dome in addition to the main cap rock (fig. 14) (Canada, 1962). Deussen and Lane

Table 18. Population centers near Hockley Dome, Harris County, Texas (1976 data unless otherwise noted) (Dallas Morning News, 1980).

Town	County	Population
Within 16-km (10-mi) radius		
Cypress	Harris	260
Hockley	Harris	300
Waller	Harris-Waller	1,239
Larger centers within 50-km (32-mi) radius		
Town	County	Population
Houston Metro. Area	Harris	2,512,200 (1977 estimate)
Rosenberg	Fort Bend	15,580
Richmond	Fort Bend	8,993
Sugarland	Fort Bend	4,173
Fulshear	Fort Bend	200
Belleville	Austin	2,535
Sealy	Austin	3,183
Wallis	Austin	1,123
Brookshire	Waller	2,244
Katy	Harris-Ft. Bend	6,785
Missouri City	Harris-Ft. Bend	4,170

(1925) reported that the cap rock forms a thin wedge of material extending down the sides of the salt core for a limited distance, but presented little information to support their statement.

In figure 14 the shape of the salt at depth is inferred due to lack of well control. A well drilled for geophysical purposes, to determine the limits of the salt mass, was located near the center of the dome and reached 3,050 m (10,008 ft) still in salt (Canada, 1953).

The salt contains decreasing amounts of insoluble materials, presumably anhydrite, a short distance beneath the cap rock, as was verified by salt sampling when the shaft for the Hockley salt mine was constructed. Just below the cap rock contact (2.5 cm, or 1 in) the insoluble residue within the salt was 11.26 percent, decreasing to 5.55 percent 1.8 m (6 ft) below the contact (Teas, 1931).

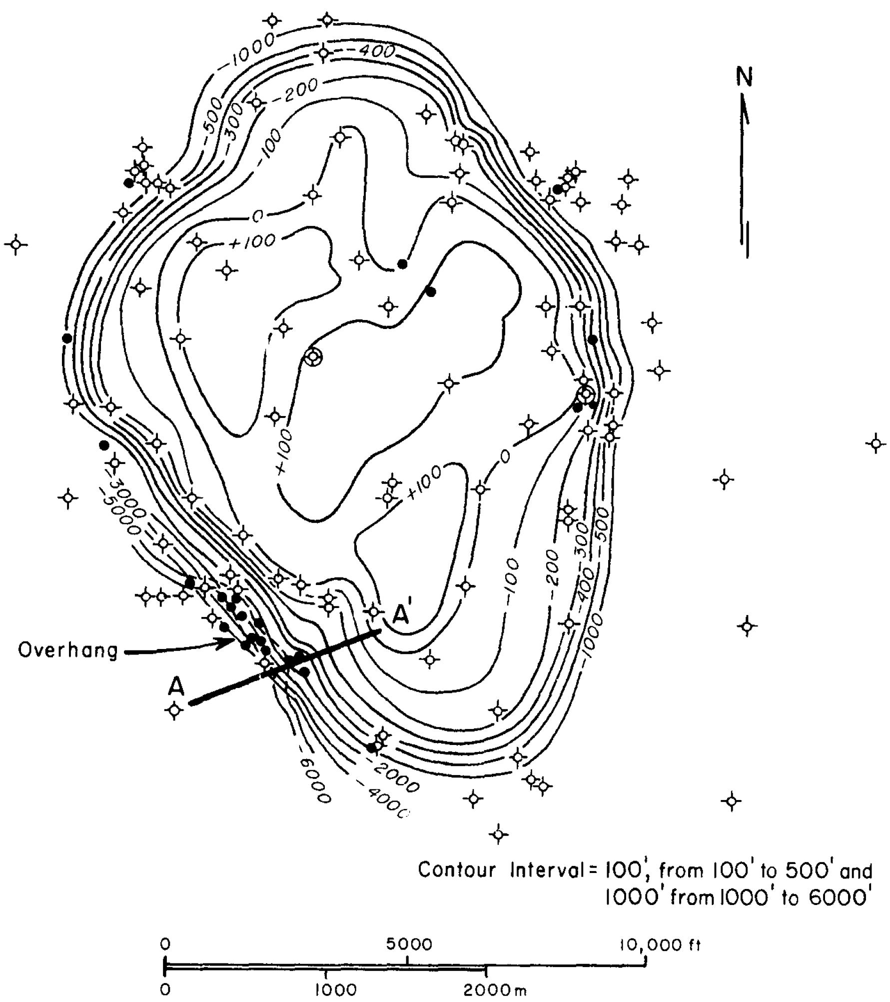


Figure 13. Structure contour map on the top of cap rock, Hockley Dome. Section A-A' is shown in figure 14. Contours dashed beneath a salt overhang (from Canada, 1953).

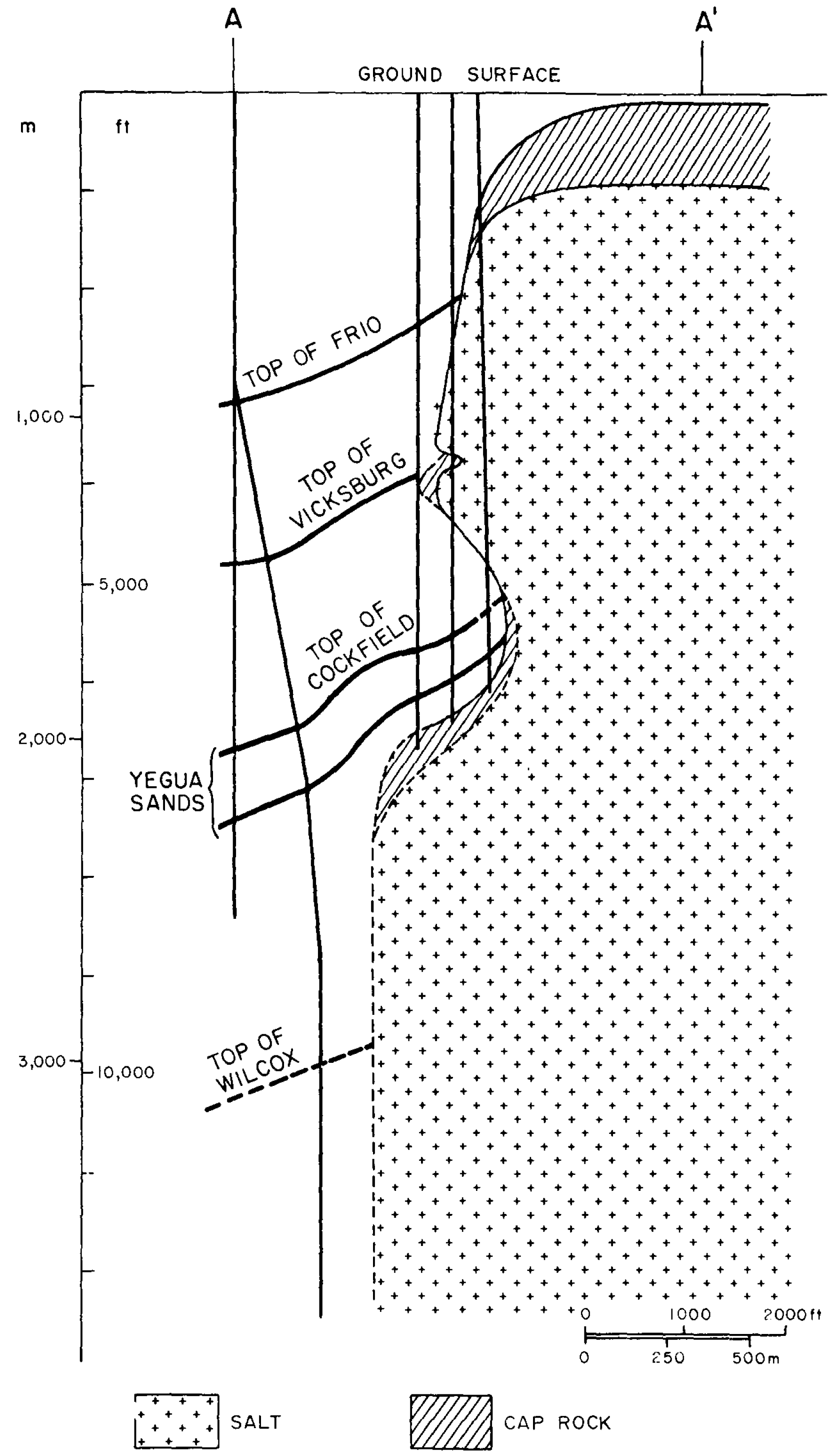


Figure 14. Cross section through the southwest flank of Hockley Dome. Hydrocarbons are produced from beneath the salt overhang. Note the development of cap rock on the flanks of the dome (modified from Canada, 1962).

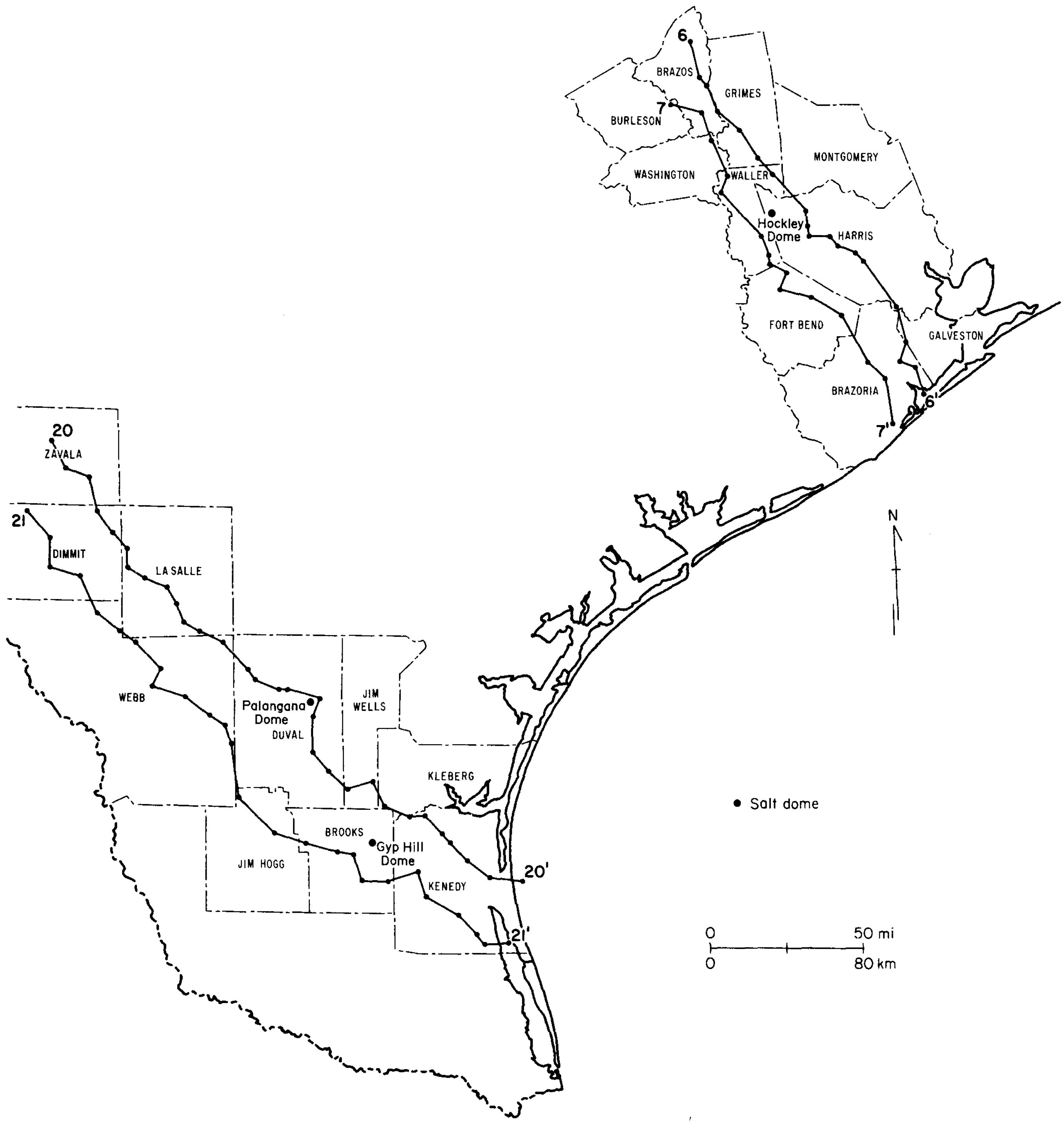


Figure 15. Location map of regional cross sections through Tertiary stratigraphic units of the Gulf Coast Basin (from Dodge and Posey, in press).

Data derived from studies within the salt mine at Hockley Dome have not been published. It is reasonable to expect folding, alignment of salt crystals, etc., that are similar to the internal features seen in the Grand Saline Dome.

No subsurface structural effects of salt dissolution regarding Hockley Dome have been reported. The presence of the cap rock suggests salt dissolution during emplacement of the dome and accumulation of insoluble anhydrite and other sediments.

Stratigraphy

Hockley Dome is situated within the seaward-dipping Tertiary strata of the northern Gulf Coast basin. A dip-oriented regional cross section located approximately 16 km (10 mi) west of Hockley Dome shows Eocene (Middle Wilcox) through Upper Oligocene-Pleistocene (undifferentiated) units (fig. 15; fig. 16 [in pocket]). These units (fig. 17) represent gulfward-thickening terrigenous clastic wedges, delivered by fluvial systems to the coastal depositional environment. There the sediments were deposited to form deltas or reworked into strike-parallel strandplains and coastal barriers (Dodge and Posey, in press). Salt domes subsequently formed by flowage and diapirism of the Jurassic Louann salt, induced by the weight of overlying sediments.

The surface geologic unit over Hockley Dome is the Pleistocene Willis Formation, consisting of clay, silt, and sand with minor siliceous gravel; this unit is of fluvial origin (Barnes, 1968). An isolated outcrop of very fine grained, grayish-white sandstone occurs along Rock Hollow Creek over the northern margin of Hockley Dome. This outcrop is dated as Miocene and possibly is the Catahoula Formation (Barnes, 1968). It is probably the same outcrop referred to by Deussen and Lane (1925), who considered it Miocene or Lower Pliocene; its stratigraphic and structural relationships are unclear, although the latter authors suggest it may be material dragged up by diapirism of the dome. The presence of this sandstone, exposed along Rock Hollow Creek, suggests that it may occur in other areas over the dome.

At Hockley Dome, salt has penetrated to within 308 to 338 m (1,010 to 1,110 ft) of the surface, and the top of the salt is fairly level (Stenzel, 1943). A cross section shows the general configuration of the dome, its surrounding syncline, and the adjacent stratigraphy (figs. 18 and 19). This section does not show the small reentrants in the sides of the salt and localized development of cap rock, as revealed by closely spaced development drilling on the southwest flank of the dome (Canada, 1962).

CENOZOIC — TEXAS GULF COAST

SYSTEM	SERIES	GROUP / FORMATION
Quaternary	Recent	Undifferentiated
	Pleistocene	Houston
Tertiary	Pliocene	Goliad
	Miocene	Fleming
	— ? —— ? —	Anahuac
	Oligocene	Frio
		Vicksburg
	Eocene	Jackson
		Claiborne
		Wilcox
		Midway

Figure 17. Stratigraphic sequence and nomenclature for the Tertiary and Quaternary Systems of the onshore Gulf Coast Basin (from Dodge and Posey, in press).

Stratigraphic units between the cap rock and the Willis Formation at the surface consist of unconsolidated sand and clay (Stenzel, 1943), probably Miocene and Oligocene (Deussen and Lane, 1925; Teas, 1931). A lignite stringer, a show of heavy oil, and concretionary layers bearing silicified wood were also noted in the sediments overlying the cap rock. The shallowest depths to the top of the cap rock are north and northeast of the center of the dome and at 30 to 60 m (100 to 200 ft) below the surface. In the shaft for the United Salt Corporation mine, cap rock was encountered at a depth of 23.2 m (76 ft) and extended to the top of the salt at a depth of 308.2 m (1,011 ft).

Stenzel (1943) describes the stratigraphy of the cap rock (from bottom to top) as consisting of anhydrite, gypsum, and limestone in varying thicknesses across the dome. In the salt mine shaft, the anhydrite layer is 285 m (935 ft) thick, is jointed, and includes some thin sandstone beds and sandstone fragments. Pyrite is present on the joint faces. The overlying gypsum layer varies from 5.5 m (18 ft) thick in the salt mine shaft to 36.3 m (119 ft) thick at the Hockley Gypsum Company mine shaft. In the latter shaft top of the gypsum was encountered at a depth of 33.5 m (110 ft).

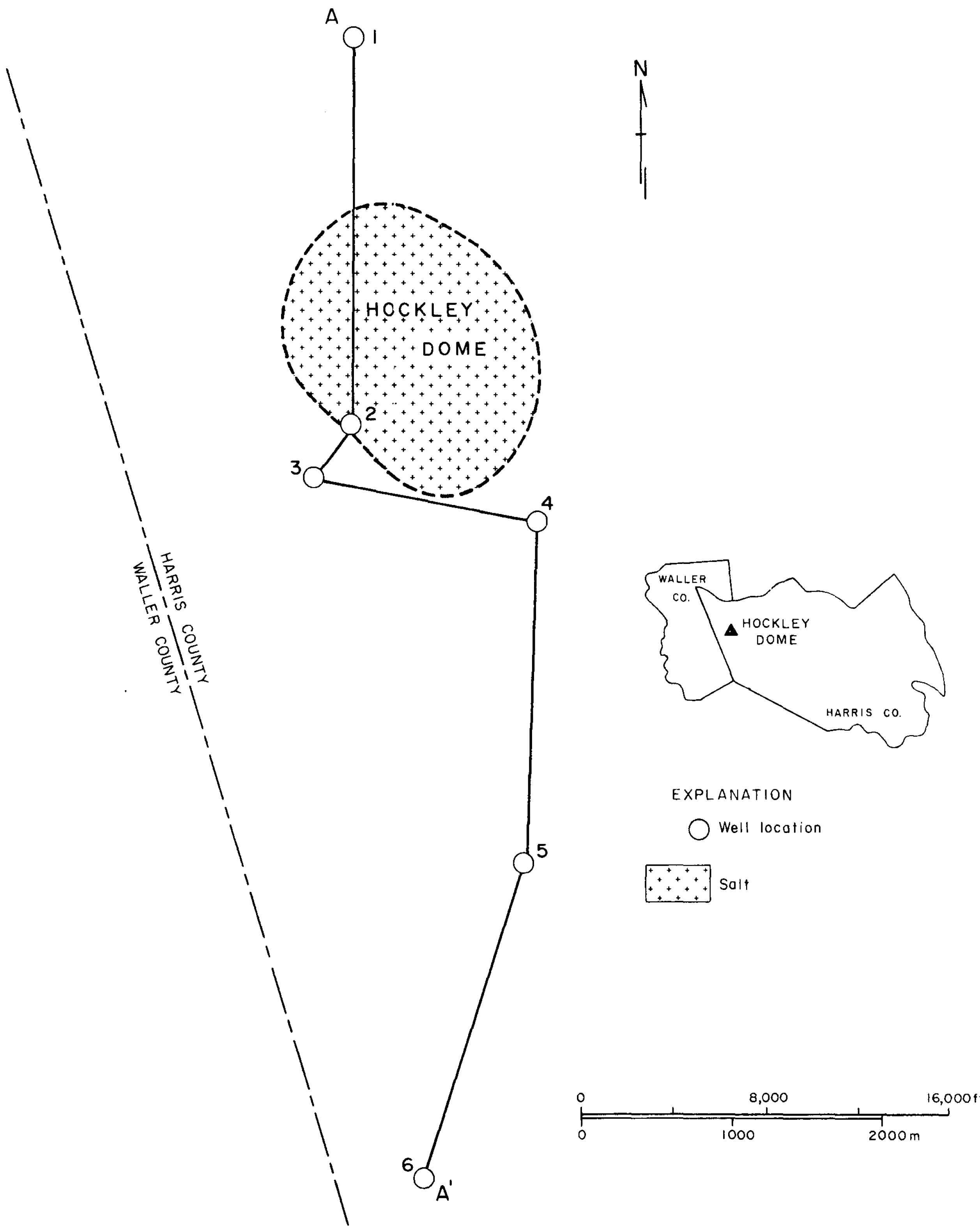


Figure 18. Location map of dip-oriented cross section through Hockley Dome.

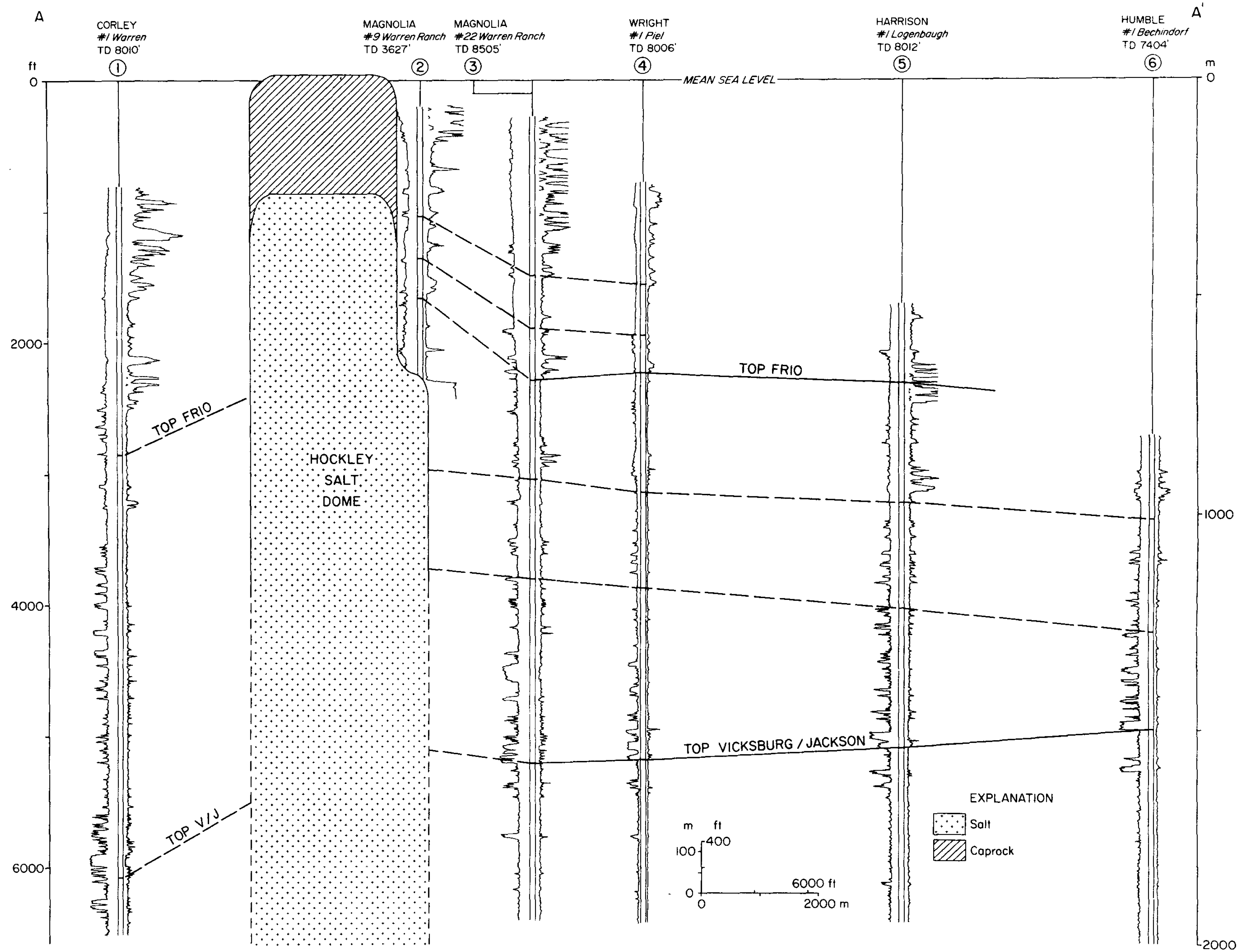


Figure 19. Dip-oriented cross section through Tertiary sand-shale sequences surrounding Hockley Dome.

According to Stenzel's (1943) writing, the gypsum layer is present only over the central area of the cap rock; where the cap rock lies more than 120 m (400 ft) below the surface, the gypsum is absent. This may be explained by incomplete hydration of anhydrite to form gypsum at greater depths. The uppermost layer of the cap rock is a brecciated limestone with vein calcite, calcite-filled vugs, and oil-filled vugs. This layer varied from 4.0 m (13 ft) thick in the gypsum mine shaft to 9.4 m (31 ft) thick in the salt mine shaft (Stenzel, 1943).

Socioeconomic Setting

Hockley Salt Dome is in the northwest corner of Harris County about 15 mi from Houston. There is an inactive salt mine in the dome, and also deep storage of propane. It is doubtful that United Salt Corporation, the owner of the property, would sell this property because the dome may be a valuable future resource.

Harris County is one of the wealthy counties in Texas; its income approaches $20 billion annually. In 1977, the county population was estimated as slightly more than 2,100,000; the city of Hockley has only 300. However, nearby Waller has a population of 1,300. Since 1977, the city of Houston has grown to more than two million. Not only is Harris County sustaining rapid growth, but the suburban areas including and surrounding Hockley are also rapidly developing. The area surrounding the dome has slightly higher relief, making the development of housing and supportive commercial construction especially attractive.

GYP HILL DOME

Gyp Hill Dome is located in Brooks County in South Texas (fig. 20). It is a closed system; however, the cap rock of the dome, which intersects the surface, has been quarried.

Biologic Resources

Gyp Hill lies within the Mesquite-Chaparral Savannah region, also known as the South Texas Plains (Arbingast, 1976; Hoffman and others, 1976). Distinct differences occur in the original plant communities on different types of rangeland, largely controlled by soil types. Low saline areas are inhabited only by grasses adapted to such environments, such as gulf cordgrass (Spartina spartinae). Much of the region is covered in brush, including mesquite (Prosopsis juliflora) and various types of cactus (Hoffman and others, 1976).

Gyp Hill is surrounded by brush-covered prairie and the Hill itself has a greater cover of woody vegetation (including mesquite) than the adjacent rangeland (Anderson and others, 1973; S. Dutton, personal communication, 1980). A shallow brackish-water lake, Laguna Salada, lies along the north margin of Gyp Hill. Similar water bodies in the adjacent county to the east support blue-green and red algae and some brackish water marsh species (Brown and others, 1977).

The coastal prairies support rodents, mammals, snakes, and birds. The Mexican ground squirrel, gray fox, white-tailed deer, wild turkey, and armadillo are present (Bailey, 1978). Endangered species found in Brooks County are listed in table 19; various protected nongame species are also found.

Climate

Gyp Hill Dome is within the subhumid to semiarid region of South Texas (Thornthwaite, 1948). Average annual rainfall was 594 m (23.37 in) (1931 to 1964) at Falfurrias, 10 km (6 mi) northwest of Gyp Hill. September is normally the wettest month with an average of approximately 114 mm (4.5 in) of precipitation, and March is the driest with approximately 23 mm (0.9 in) of precipitation (Myers and Dale, 1967). The average annual gross lake surface evaporation for the area is approximately

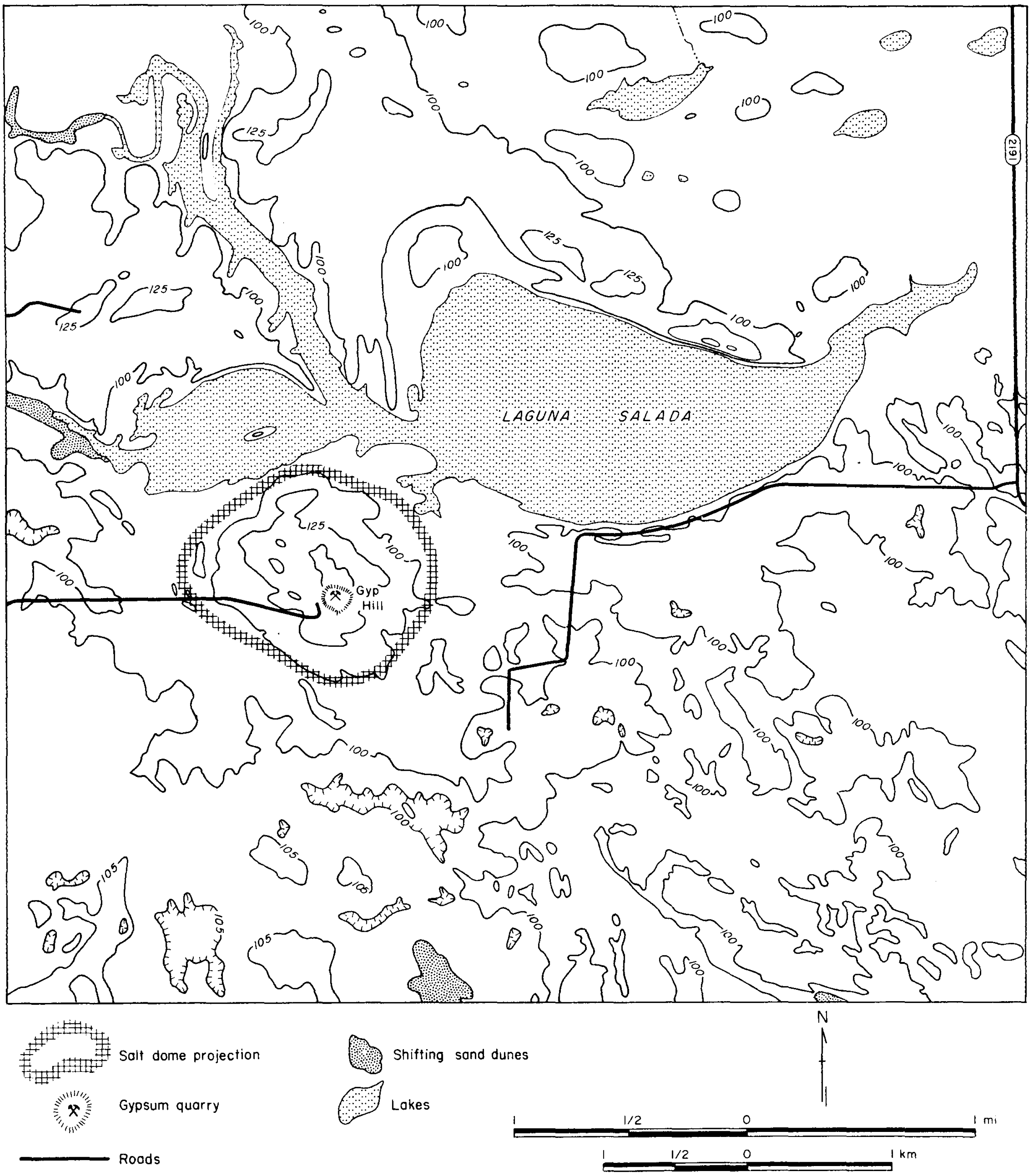


Figure 20. Generalized topography and cultural features over Gyp Hill Dome, Brooks County, Texas (from U.S.G.S. 7.5-minute quadrangle, Flowella, Texas). Contour interval is 25 ft with labeled supplementary contours.

Table 19. Endangered species in Brooks and Duval Counties (F. E. Potter, personal communication, 1980).

FAUNA	CONFIRMED
	American alligator, Alligator mississipiensis
	PROBABLE
	Jaguarundi, Felis yagouaroundi cacomitli
	Ocelot, Felis pardalis
	Southern bald eagle, Haliaeetus l. leucocephalus
	Arctic peregrine falcon,* Falco peregrinus tundrius
	Interior least tern,* Sterna albifrons athalassos
	POSSIBLE
	Brown pelican, Pelecanus occidentalis
FLORA	POSSIBLE
	Black lace cactus, Echinocereus reichenbachii

*mostly migratory

1,626 mm (64 in) (Kane, 1967). Heavy rains occasionally occur in the area due to the passage of hurricanes and tropical storms. Falfurrias received 833 mm (32.78 in) of rain in September, 1967, as a result of Hurricane Beulah (Shafer, 1974).

Mean annual relative humidity is 85 to 90 percent at 6 a.m. and approximately 60 to 65 percent at 6 p.m. (Arbingast and others, 1976). The average monthly temperature in Falfurrias is 56.7°F (13.7°C) in January, normally the coldest month, and 86.5°F (30.3°C) in July, normally the hottest month (Shafer, 1974). The first occurrence of frost each winter is approximately December 16 and the last frost is usually before February 14 (Arbingast and others, 1976).

Energy Resources (Basinal)

Oil at Gyp Hill Dome was discovered in 1945 with the drilling of the Texas Co. #3 Lassiter to a depth of 2,600 m (8,518 ft). Production was from the Frio Formation at depths of 345 to 2,040 m (4,050 to 6,700 ft).

Three oil fields are listed at Gyp Hill by the Railroad Commission of Texas (1979), only one of which was productive in 1979 (table 20). Fifteen gas fields, several of which are simply individual producing horizons stacked within the Frio Formation, are listed as parts of the Gyp Hill and Gyp Hill Southeast fields. Only the Gyp Hill field was active in 1979. The Gyp Hill Southeast field had one active well but no production in 1979 (table 21) (Railroad Commission of Texas, 1979).

Both the Gyp Hill and Gyp Hill Southeast fields are associated with down-to-the-coast normal faulting on the southeast flank of Gyp Hill Dome. The closest production to the salt dome lies approximately 915 m (3,000 ft) east of the center of the salt uplift and includes three oil wells. Four gas wells and 21 dry holes are also over and on the immediate flanks of the dome (Railroad Commission of Texas, undated). No shows of oil or gas were encountered in the cap rock of Gyp Hill Dome during recent drilling of a continuous core to the top of the salt stock (C. Kreitler, personal communication, 1980).

Energy Resources (Surficial)

Neither strip-mineable lignite nor uranium resources are known from the Gyp Hill Dome area in Brooks County (St. Clair and others, 1976).

Flood Potential

The surface expression of Gyp Hill Dome is marked by a circular hill with its base at 27 to 30 m MSL (90-100 ft MSL) and its highest point at over 47 m MSL (155 ft MSL) (fig. 20). The north-south diameter of the hill is approximately 1,372 m (4,500 ft) and the east-west diameter is approximately 1,676 m (5,500 ft) (U.S.G.S. 7.5-minute quadrangle, Flowella, Texas). No flood hazard exists above the 30-m MSL (100-ft MSL) elevation. However, a roughly circular depression around Gyp Hill which is as low as 26 m MSL (85 ft MSL) is a Special Flood Hazard Area (Zone A), as mapped by the U.S. Department of Housing and Urban Development (1980). The area of this circular depression is approximately 417 ha (1,030 acres).

Table 20. Crude oil and casinghead gas production at Gyp Hill Dome (from Railroad Commission of Texas, 1979).

Field*	Discovery Date	Depth, (ft)	1979 Production Casinghead Gas, MCF	1979 Production Crude Oil, BBLS	Cumulative Crude Oil, BBLS, Through 1/1/80
Gyp Hill	1946	4,070	2,801	3,233	63,598
Gyp Hill (Finley Sand)	11-25-55	7,425	0	0	203,307
Gyp Hill (Gardner Sand)	11-25-55	7,362	0	0	103,996

*Names in parenthesis refer to producing horizon.

Table 21. Gas well production and hydrocarbon liquids recovered on leases, 1979, Gyp Hill Dome (from Railroad Commission of Texas, 1979).

Field	Producing Wells End of Year	Gross Gas Production, MCF	Hydrocarbon Liquids, BBLS
Gyp Hill	3	268,598	1,664

Fourteen other fields, including those in Gyp Hill, SE, are recognized (stacked pay zones in the Frio and Vicksburg Formations), but did not produce in 1979.

The northern margin of Gyp Hill lies adjacent to the shoreline of Laguna Salada, a shallow brackish-water lake occupying a depression along Palo Blanco Creek (Anderson and others, 1973). Laguna Salada and the circular depression surrounding Gyp Hill is subject to flooding by hurricane aftermath rainfall that does not rapidly drain from the low-relief surface of the South Texas Coastal Plain. In 1967, Hurricane

Beulah resulted in 833 mm (32.78 in) of rain at Falfurrias, 11.3 km (7 mi) from Gyp Hill, in 4 to 5 days of aftermath storms (Shafer, 1974).

Light-duty and unimproved dirt roads leading to Gyp Hill must cross the outer, circular depression and may therefore be subject to local flooding reaching above the level of approximately 28 m MSL (92 ft MSL).

Historical Resources

No archeologic sites located within the surface projection of Gyp Hill Dome are listed with the Texas Archeological Research Laboratory (C. Spock, personal communication, 1980). One site, probably over Gyp Hill Dome, has been surveyed for possible inclusion in the National Register of Historic Sites. Limited data on this site are available from the Texas Historical Commission (table 22).

Hydrology (Basinal)

All of Brooks County wherein Gyp Hill Dome is located is underlain by formations containing fresh to slightly saline ground water. At Gyp Hill the approximate thickness of sand containing fresh to slightly saline water is 79 m (260 ft)

Table 22. Historic site near Gyp Hill Dome surveyed for possible entry in the National Register of Historic Sites.

Site	Description	Comments
Falfurrias Gypsum Mine Site No. 48868	Rural, owner undetermined, nonfunctioning, gypsum mine begun by Wilson & Wilson Co. Southern Pacific Railroad spur used to ship gypsum to Aransas Pass and San Antonio for use in cement.	This is presumably the abandoned gypsum quarry at Gyp Hill, which was worked from 1929 to 1942 (Perkins and Lonsdale, 1955).

on the southwest flank of the dome, increasing to between 128 and 152 m (420-500 ft) on the northeast, east, and southeast flanks of the salt dome (Myers and Dale, 1967). The altitude of the base of these units rises sharply to -93 m MSL (-305 ft MSL) around the dome, whereas the altitude is -244 to -275 m MSL (-800 to -900 ft MSL) in all directions beyond the effects of the domal structure. Fresh water is defined as having less than 1,000 ppm total dissolved solids (TDS) content, and slightly saline water is defined as having 1,000 to 3,000 ppm TDS.

The Goliad Sand is the primary source of ground water in Brooks County; small amounts of water are available from other units (table 23). The regional dip of the Goliad Sand is 4 m/km (20 ft/mi) to the east-southeast (Myers and Dale, 1967). The Goliad sands are interbedded with silt and clay, and tend to be relatively fine grained in the subsurface. The altitude of the base of the Goliad is -171.7 m to -194 m MSL (-563 to -636 ft MSL) surrounding Gyp Hill Dome (fig. 21). A regional dip section through central Brooks County, passing approximately 16 km (10 mi) south of Gyp Hill Dome shows the Goliad Formation, which is termed the Evangeline aquifer within the hydrogeologic framework of the Texas Coastal Plain (fig. 22) (Baker, 1979). Properly constructed wells may produce up to 500 gpm from the Goliad Sand (Myers and Dale, 1967).

The quality of ground water withdrawn from wells near Gyp Hill Dome is slightly above the drinking water standards of 500 ppm total dissolved solids (TDS), and varies from 595 to 731 ppm TDS. For these same wells the chlorinity varies from 118 to 135 ppm. The occurrence of salt in Laguna Salada, adjacent to the north flank of the dome, suggests that this is a discharge point for water that has been in contact with the salt core (C. Kreitler, personal communication, 1980).

Ground water recharge occurs over the outcrop of the Goliad Formation and through the Quaternary windblown sands that cover much of the county. Generally ground water moves east to southeast in Brooks County at an average rate of approximately 11 m/yr (35 ft/yr) (Myers and Dale, 1967).

Six pumping tests of the Goliad Formation are reported for Brooks County. Discharges of the wells varied from 195 to 350 gpm and averaged 252 gpm. The coefficients of transmissibility varied from 10,700 to 18,500 gpd/ft and averaged 13,300 gpd/ft. In two tests the coefficients of storage were determined to be 1.8×10^{-5} and 2×10^{-5} (Myers and Dale, 1967).

Approximately 95 percent of the water used in Brooks County is withdrawn from wells in the Goliad Sand. Pumpage of water for all purposes in 1964 amounted to 3.7 mgd. Falfurrias, 10 km (6 mi) northwest of Gyp Hill Dome, is the major city in the

Table 23. Stratigraphy of shallow water-bearing units in Brooks County (from Myers and Dale, 1967).

System	Series	Geologic formation	Approximate maximum thickness (m)	Character of rocks	Water-bearing properties
Quaternary	Recent	Windblown sand	18	Sand and small amounts of clay and caliche	Not known to yield water to wells
		Unconformity			
	Pleistocene	Beaumont Clay	Approx. 30	Clay, marl interbedded with clay, and layers of fine sand and gravel	Yields small quantities of less than 50 gpm of mostly highly mineralized water to domestic and livestock wells
		Lissie Formation	Approx. 90	Sand, lentils of clay and silt, and gravel near base	"
		Unconformity			
Tertiary	Pliocene	Goliad Sand	Approx. 300	Sand and sandstone interbedded with clay and silt; contains caliche in surface outcrop	Yields moderate quantities of 50 to 500 gpm of fresh to slightly saline water
		Unconformity			
	Miocene (?)	Lagarto Clay	210	Clay, silty clay, sandy clay, sand, and gravel	Capable of yielding small quantities of less than 50 gpm of fresh to slightly saline water
	Miocene	Oakville Sandstone	150	Fine sand, sandstone, and clay	Capable of yielding moderate quantitites of 50 to 500 gpm of fresh to slightly saline water

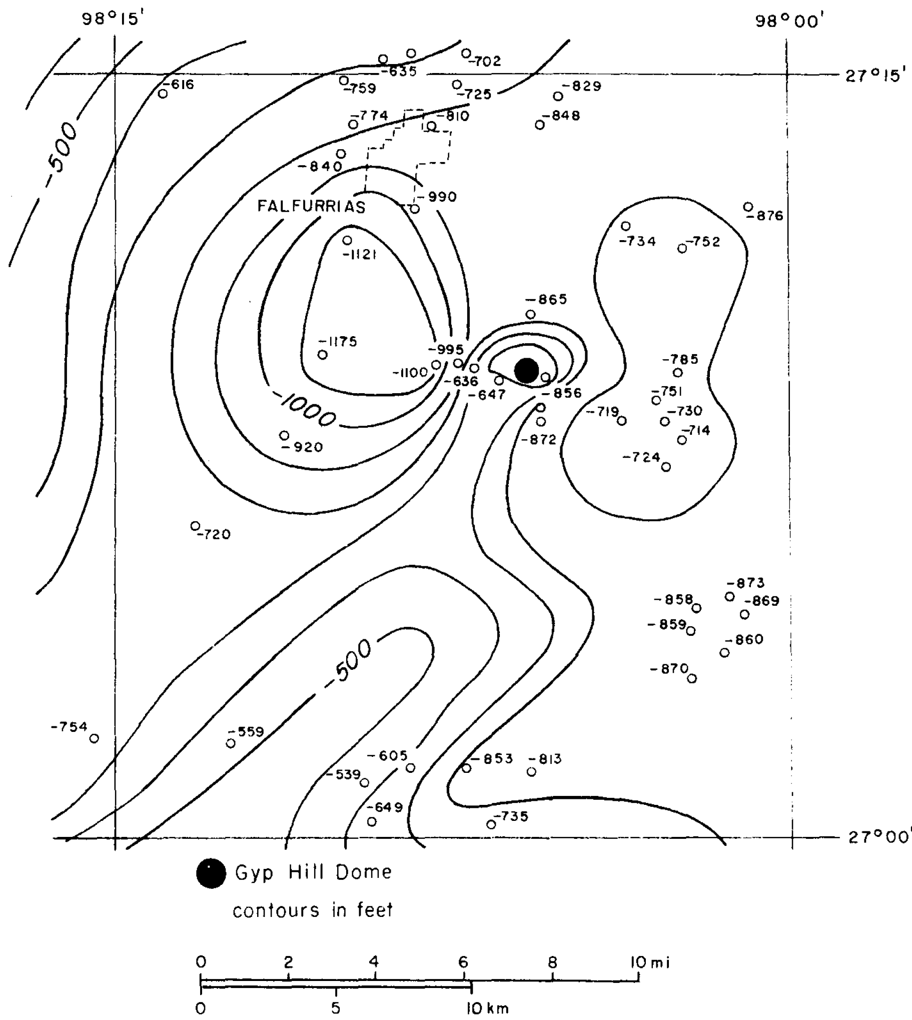


Figure 21. Structure contour map on the top of the Goliad Sand surrounding Gyp Hill Dome (modified from Myers and Dale, 1967).

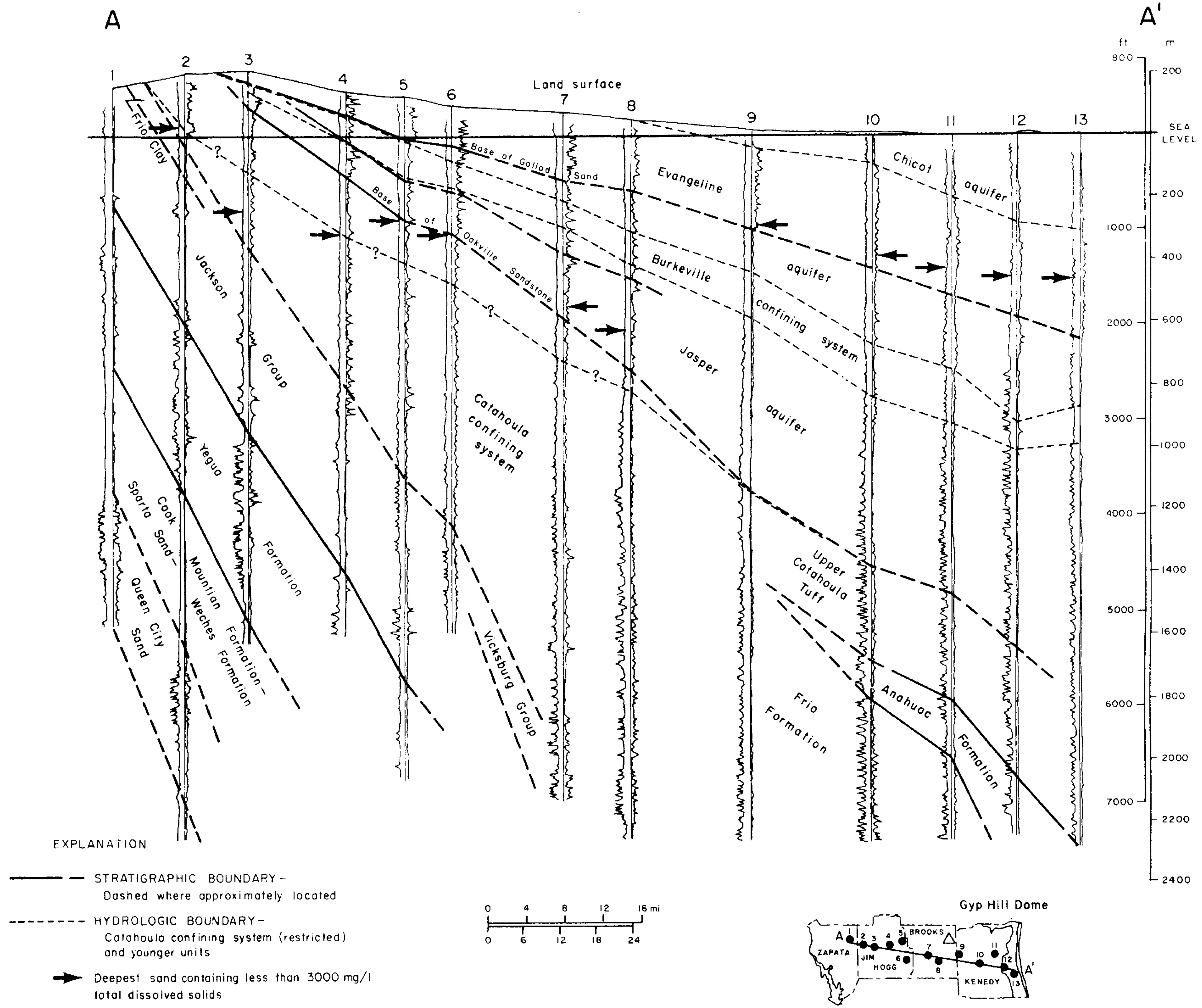


Figure 22. Cross section through the aquifers of Brooks County and the adjacent South Texas Coastal Plain (from Baker, 1979).

county with a public water supply system, with a total of 5 wells. Water level decline in the Goliad Sand immediately around Gyp Hill Dome has generally been 21 m (70 ft). Within 3 km (2 mi) of the center of the dome the water level decline has ranged from 15 to 23 m (50 to 75 ft), all in the period 1932-33 through 1964-65 (Myers and Dale, 1967). The relatively porous upper cap rock at Gyp Hill Dome contains a water table approximately 18 to 21 m (60 to 70 ft) below the surface of Gyp Hill and approximately 3 m (10 ft) below the floor of the abandoned gypsum quarry (C. Kreitler, personal communication, 1980).

Saline water resources of the Gulf Coastal Plain have been mapped according to depth zones that cut across formation boundaries and time lines within Tertiary stratigraphic units. Each of these zones is 610 m (2,000 ft) thick and is defined by arbitrary depth values. Because there is practically no saline water above sea level, zone 1, 0 to +610 m MSL (0 to 2,000 ft MSL) was not mapped. In zone 2 (0 to -2,000 ft) there are only approximately 30 m (100 ft) or less of saline water-bearing sands in northeast Brooks County and these sands have less than 5,000 ppm total dissolved solids. The remaining zones are listed in table 24 (Texas Water Development Board, 1972).

Hydrology (Surficial)

Gyp Hill Dome is located between the Nueces River and Rio Grande basins in an area of coastal plain just south of the Los Olmos Creek drainage basin. Los Olmos Creek is the southernmost of several small, intermittent creeks that drain eastward into Baffin Bay. South of Los Olmos Creek, drainage is internal within the coastal plain and its cover of sandy eolian deposits. Intermittent lakes are common in surface depressions and no through-going drainage reaches Laguna Madre.

One of these intermittent lakes, which frequently tends to be brackish, adjoins the north flank of Gyp Hill, the surface expression of Gyp Hill Dome (fig. 20). The lake, Laguna Salada, is fed by Palo Blanco Creek and Baluarte Creek, both intermittent streams entering from the west. The lake is drained by Palo Blanco Creek, which flows to the east and dies out on the sandy eolian surface approximately 27 km (17 mi) east of Gyp Hill. Runoff from Gyp Hill itself flows in several small gullies, either into Laguna Salada or into one of several small closed depressions around the margins of the hill. From these depressions the water is probably lost by evaporation and infiltration. The largest of these depressions is approximately 365 m (1,200 ft) long and 120 to 240 m (400 to 800 ft) wide.

Table 24. Formation water salinities within 610-m (2,000-ft) thick zones of Tertiary Gulf Basin sands, northeast Brooks County (from Texas Water Development Board, 1972).

Zone	Depth, ft below MSL	Salinity, ppm
3	2,000 - 4,000	10,000
4	4,000 - 6,000	25,000 - 35,000
5	6,000 - 8,000	45,000 - 60,000
6	8,000 - 10,000	60,000+

The climate in the region surrounding Gyp Hill is subhumid and is characterized by evaporation well in excess of precipitation (see section on Climate). Runoff is low; Lockwood, Andrews and Newnam (1960) showed zero runoff from a segment of the South Texas Coastal Plain including Gyp Hill. The areal extent of this segment of the coastal plain is 12,784 km^2 (4,936 mi^2), and all but the extreme northeast corner of Brooks County is included.

The only data on the chemical quality of surface water near Gyp Hill come from a sampling station on Los Olmos Creek, 13.7 km (8.5 mi) northwest of Gyp Hill Dome. Some of these data, showing slightly saline conditions, are summarized in the discussion on surficial hydrology for Palangana Dome.

Recharge to aquifers in Brooks County results from infiltration of precipitation on outcrops and on the sand overlying the bedrock units. Infiltration also takes place from ponds and streams. The windblown sand cover that overlies most of Brooks County, including the area around Gyp Hill Dome, greatly facilitates infiltration. The Goliad Sand, and possibly a thin sequence of younger sediments, immediately underlies the windblown sand cover (Myers and Dale, 1967).

Land Resources

The surface expression of Gyp Hill Dome is Gyp Hill, an outcrop of gypsum cap rock of moderate local relief (fig. 20). The gypsum has high solubility relative to most surficial materials (Kier and others, 1977). To the east and west of Gyp Hill, along Laguna Salada, are areas of active clay-sand dunes, consisting of mixed sand, silt, and clay. These substrates have low to moderate permeability and moisture retention capability. Shrink-swell potential is moderate to variable, corrosion potential is high; these lands make generally poor construction sites (White and Kier, 1979).

The area immediately south of Gyp Hill consists of a sheet of eolian sand and silt which is locally thin and discontinuous and overlies calichified sand and clay. These surface materials have moderate to high permeability and a low shrink-swell potential. Foundation strength is high and excavation is easy (Kier and others, 1977; White and Kier, 1979).

Soils of the eolian sheet are typically loose sand; clay and sandy loams occur over and immediately east and west of Gyp Hill. No detailed soil survey has been published for Brooks County.

Mineral Resources

At Gyp Hill Dome the gypsum cap rock crops out at the surface, and approximately 317,500 metric tons (350,000 tons) of gypsum were produced between 1929 and 1942. An estimated 11,800,000 metric tons (13,000,000 tons) of gypsum are available over an area of 81 ha (200 ac) (Maxwell, 1962). Commerical gypsum mining is presently being considered (S. Dutton, personal communication, 1980).

Some sulfur is present at Gyp Hill, but the deposit may not be commercial (Maxwell, 1962). No sulfur was encountered in a core recently drilled through the cap rock (C. Kreitler, personal communication, 1980).

No sand or gravel resources are mapped in the vicinity of Gyp Hill (Gustavson, 1976). In other parts of the coastal plain uranium deposits are leached from the Oakville and Goliad deposits.

Land Use

Generalized land use, interpreted from 1:250,000-scale Landsat imagery (Texas Department of Water Resources, 1977) supplemented by U.S. Geological Survey 7.5-minute quadrangle maps, show rangeland and brushland as the predominant land use/land cover types in northeast Brooks County.

Over and around Gyp Hill Dome rangeland predominates, with greater amounts of brushland and areas of scrubby trees east of the dome. Some rangeland has been improved by removal of woody vegetation. An abandoned gypsum quarry is located near the top of Gyp Hill. Access to Gyp Hill is by a light-duty road off U.S. Highway 281 4.3 km (2.7 mi) west of Gyp Hill. The Southern Pacific Railroad runs parallel to U.S. Highway 281. Unimproved dirt roads also lead to Gyp Hill Dome from the east.

Population

Gyp Hill Dome is located 12 km (7.5 mi) south-southeast of Falfurrias in Brooks County. In 1977 Brooks County had a population of 7,700 (Dallas Morning News, 1980). The area of the county is 2,341 km^2 (904 mi^2). Brooks County has been losing population since 1950 although Laredo, the nearest Standard Metropolitan Statistical Area (SMSA), has been gaining population in the same period. Less than 5 percent of the population of Brooks County lives on rural farms (Arbingast and others, 1976).

The population in surrounding counties ranges from 600 in Kenedy County to the east, to 232,300 in Hidalgo County to the south. Population in four adjacent counties increased and in three adjacent counties decreased during the period 1973 to 1977 (Arbingast and others, 1976). Population centers near Gyp Hill Dome are listed in table 25.

Salt Depth, Composition, and Geometry

At Gyp Hill Dome the depth to salt varies from 276 m (905 ft) (Dutton and Kreitler, 1980) to 252 m (831 ft) (Corpus Christi Geological Society, 1967). The volume of the salt dome has been estimated as 11.5 km^3 (2.76 mi^3) (Perkins and Lonsdale, 1955). The depth above which this volume applies is not stated; a generalized cross section (fig. 23) and data from Marshall (1967) suggest that the

Table 25. Population centers near Gyp Hill Dome, Brooks County, Texas (1976 data unless otherwise noted) (Dallas Morning News, 1980).

Within 16-km (10-mi) radius

Town	County	Population
Encino	Brooks	110
Falfurrias	Brooks	6,249

Larger centers within 50-km (32-mi) radius

Town	County	Population
Kingsville	Kleberg	29,088
Premont	Jim Wells	2,786
Sarita	Kenedy	185

Other major cities

City	Distance, km (mi)	Population (1977)
Corpus Christi	97 (60)	303,200 (estimate)
Laredo	145 (90)	85,000 (estimate)

source of the salt is greater than 3,050 m (10,000 ft) deep. The deepest well off the flanks of the dome penetrated the Vicksburg Formation at a depth of 3,925 m (12,880 ft).

Two interpretations of the shape of the salt core have been made. Corpus Christi Geological Society (1957) research showed the configuration at -610 m MSL (-2,000 ft MSL) as nearly circular with a diameter of 1,430 m (4,700 ft). Marshall (1967) showed an elliptical configuration for this same depth, elongate in a northwest-southeast direction with diameters of approximately 1,070 m (3,500 ft) and 1,920 m (6,300 ft). The well data on both maps appear to be the same; the difference could simply be a matter of interpretation, or perhaps additional seismic data were available to Marshall (1967).

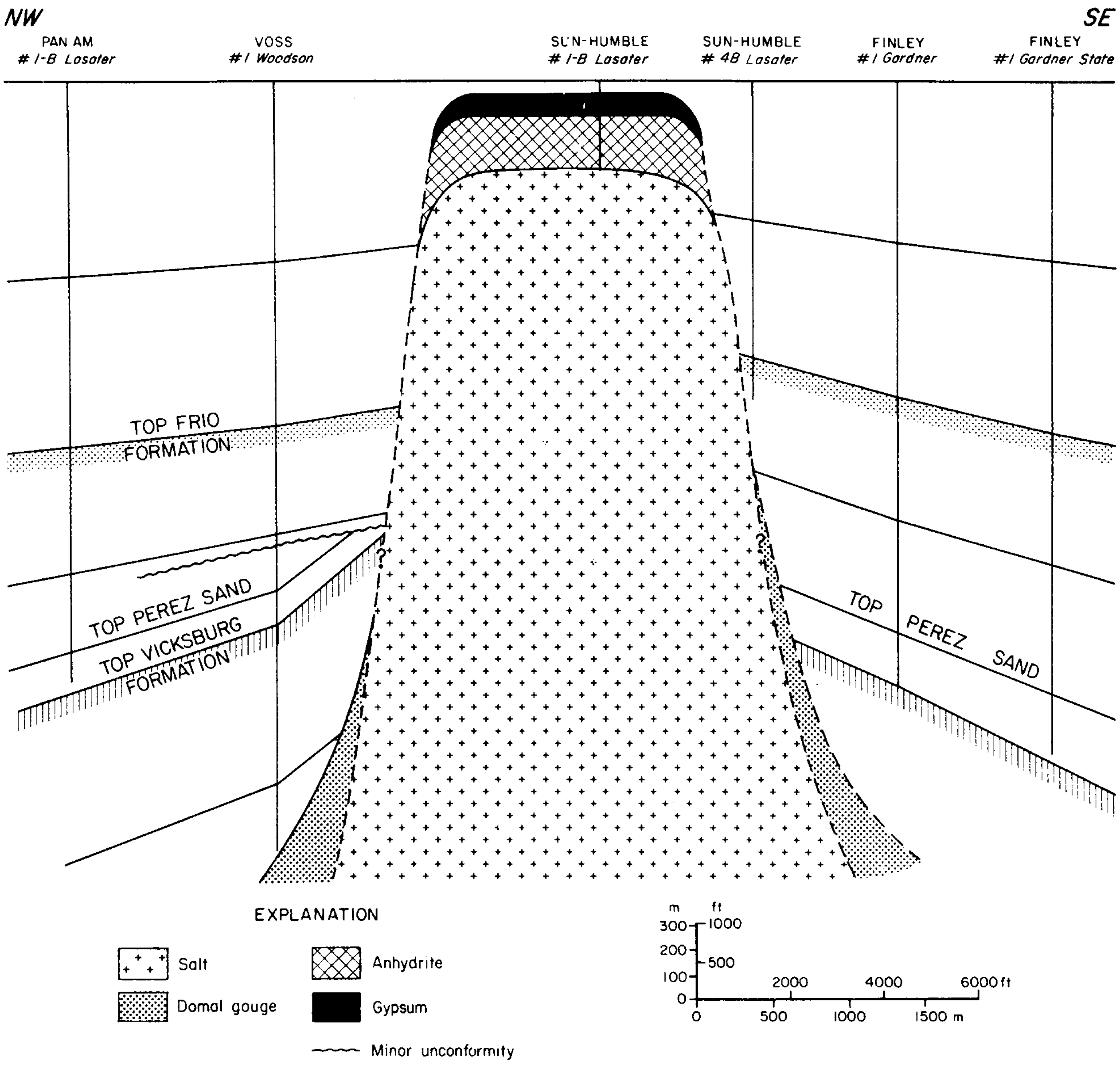


Figure 23. Generalized cross section through Gyp Hill Dome (modified from Marshall, 1967), and using data on the cap rock from Dutton and Kreitler, 1980).

Few data are available on the characteristics of the salt itself. Dutton and Kreitler (1980) recovered 3 m (10 ft) of salt from the bottom of a core hole drilled through the cap rock of Gyp Hill. The halite crystals in the core are mostly 0.3 to 0.5 cm (0.1 to 0.2 in) in diameter, with anhydrite both within and between the halite crystals. Anhydrite content ranged from 13 to 42 percent along the core. These values are relatively high, probably because the salt is from the upper 3 m (10 ft) of the salt stock and dissolution has concentrated the less soluble anhydrite. No specific data are available on the internal structure of the Gyp Hill salt. It is reasonable to assume that folding, similar to that described for Grand Saline Dome, has taken place.

This dome is unlike Grand Saline, Hockley, and Palangana Domes in that its surface expression is a positive topographic feature consisting of a hill of gypsum cap rock. No surface depression is associated with the dome, and no effects of subsurface salt dissolution are reported.

Stratigraphy

Surrounding Gyp Hill Dome are the seaward-dipping Tertiary strata of the northwest Gulf Coast basin. A dip-oriented regional cross section passing approximately 20 km (12 mi) south of Gyp Hill Dome shows Eocene (Vicksburg-Jackson) to Miocene (Fleming) units that have been drilled in Brooks County (figs. 15; fig. 24 [in pocket]). These gulfward-thickening terrigenous clastic wedges underwent depositional processes similar to those described for the units around Hockley Dome in Harris County. The Gyp Hill Dome itself has formed by flowage and diapirism of salt deposited within the Rio Grande Salt Basin (Ledbetter and others, 1975; Anderson and others, 1973).

Gyp Hill Dome is located toward the inner edge of the Modern-Holocene South Texas eolian system. The system contains active, partially stabilized and stabilized dunes, and sheets of sand and loess (Brown and others, 1977). Gyp Hill is generally surrounded by sand sheet deposits with no relict eolian grain and with a sparse grass cover (Barnes, 1976). The area immediately around Gyp Hill is covered with clay-sand dune deposits, consisting of light-gray calcareous clay, silt and sand. These deposits are derived from the periodically dry surface of intermittent shallow lake basins, including Laguna Salada along the north margin of the dome (Barnes, 1976).

The generalized stratigraphy over and around the dome is shown on a cross section by Marshall (1967) (fig. 23). Greater detail on the units over the dome and the stratigraphy and structure around the dome (fig. 25) are shown on figure 26. The gypsum cap rock over the dome reaches the surface and has been quarried. The thickness of the cap rock beneath the abandoned gypsum quarry near the center of the dome is approximately 276 m (905 ft) (Dutton and Kreitler, 1980). Salt has been encountered as shallow as 252 m (831 ft) (Corpus Christi Geological Society, 1957). The units around the salt core and the cap rock include (1) Fleming Group (Miocene), consisting of continental and brackish-water deposits of sands and shale; (2) alternating shales and generally discontinuous sands of brackish-water to shallow marine facies of the Frio Formation (Oligocene), and (3) the marine shales and thin to massive sands of the Vicksburg Formation (Oligocene) (fig. 23) (Marshall, 1967).

A continuous core of the cap rock of Gyp Hill Dome has been studied to determine cap rock origin and diagenesis (Dutton and Kreitler, 1980). Three major lithic zones were noted. At the base of the lower zone, no core was recovered from 273 to 276 m (896 to 905 ft), and part of this interval probably represents a cavity between the salt stock and the cap rock. This zone may, in part, contain some of the porous, friable anhydrite sandstone recovered at 273 m (895 ft). The remainder of this lower zone, from 273 to 120 m (895 to 400 ft) in depth, is composed primarily of gypsum-cemented anhydrite, with 0 to 75 percent gypsum cement. Porosity decreases within 6 m (20 ft) above the cap rock base due to the precipitation of gypsum cement. Almost no open vugs of fractures are found.

A transition zone between anhydrite and gypsum occurs at depths of 120 to 90 m (400 to 300 ft). The transition zone represents the beginning of the hydration of anhydrite to gypsum by meteoric ground water; within this zone the cap rock varies between 6 and 97 percent gypsum. Above 90 m (300 ft) the cap rock is mainly bladed, coarse-grained, and fine grained gypsum with minor anhydrite. Porosity and permeability measured in core plugs from the upper 90 m (300 ft) of the cap rock are generally low. However, many intervals within the gypsum cap rock contain much intercrystalline, fracture, and vuggy porosity (Dutton and Kreitler, 1980).

Three meters (10 ft) of salt were recovered from the top of the salt stock. The halite crystals are mostly 0.3 to 0.5 cm (0.1 to 0.2 in) in diameter. Anhydrite occurs both within and between halite crystals and ranges from 13 to 42 percent by volume. It is likely that dissolution near the top of the salt dome has concentrated the less soluble anhydrite near the top of the salt stock (Dutton and Kreitler, 1980).

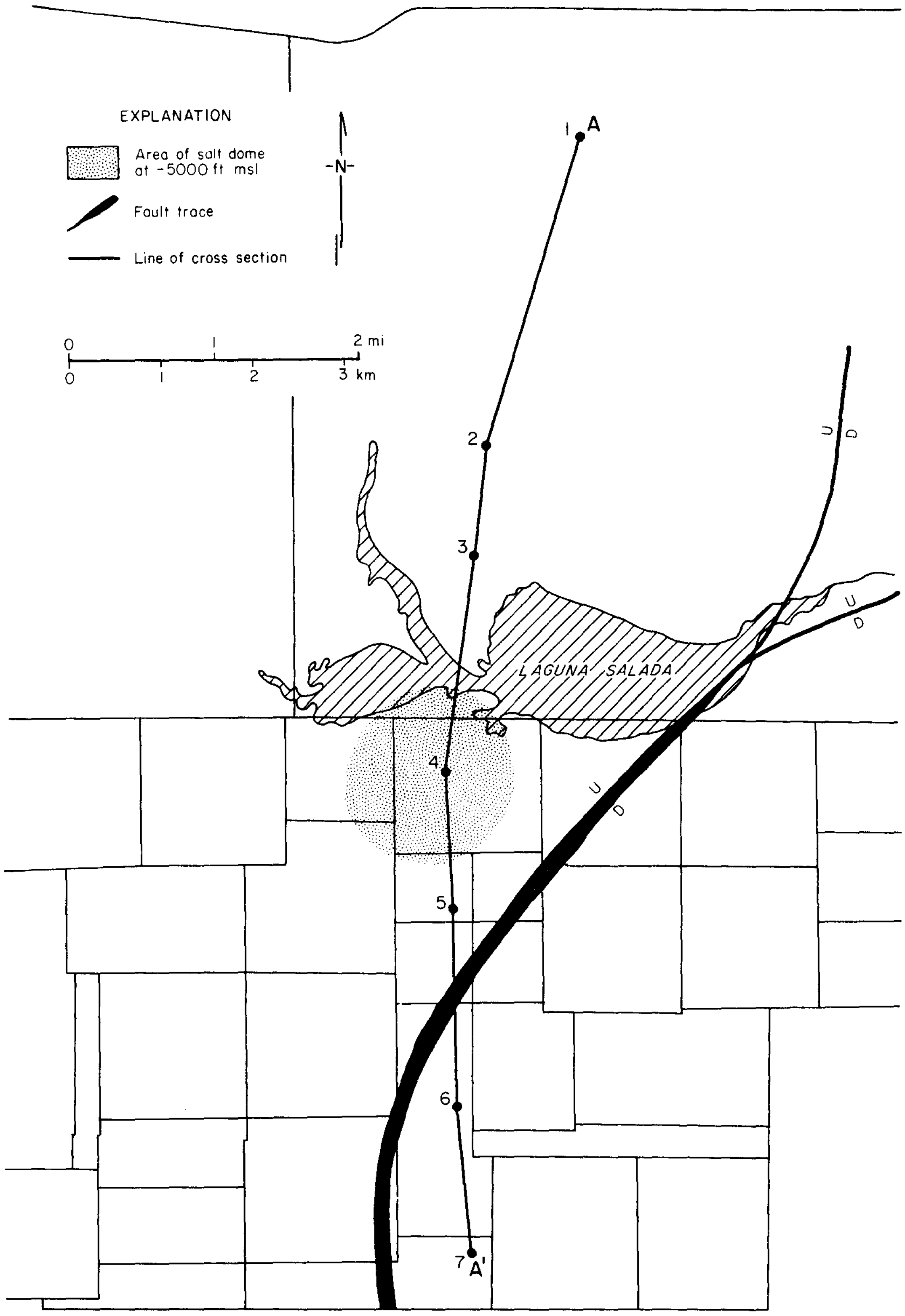


Figure 25. Location map of section A-A' through Gyp Hill Dome. Grid pattern shows land tract boundaries. The location of a subsurface fault trace at depths of -6,000 to -7,500 ft (upthrown side) has been adapted from Geomap, Inc.

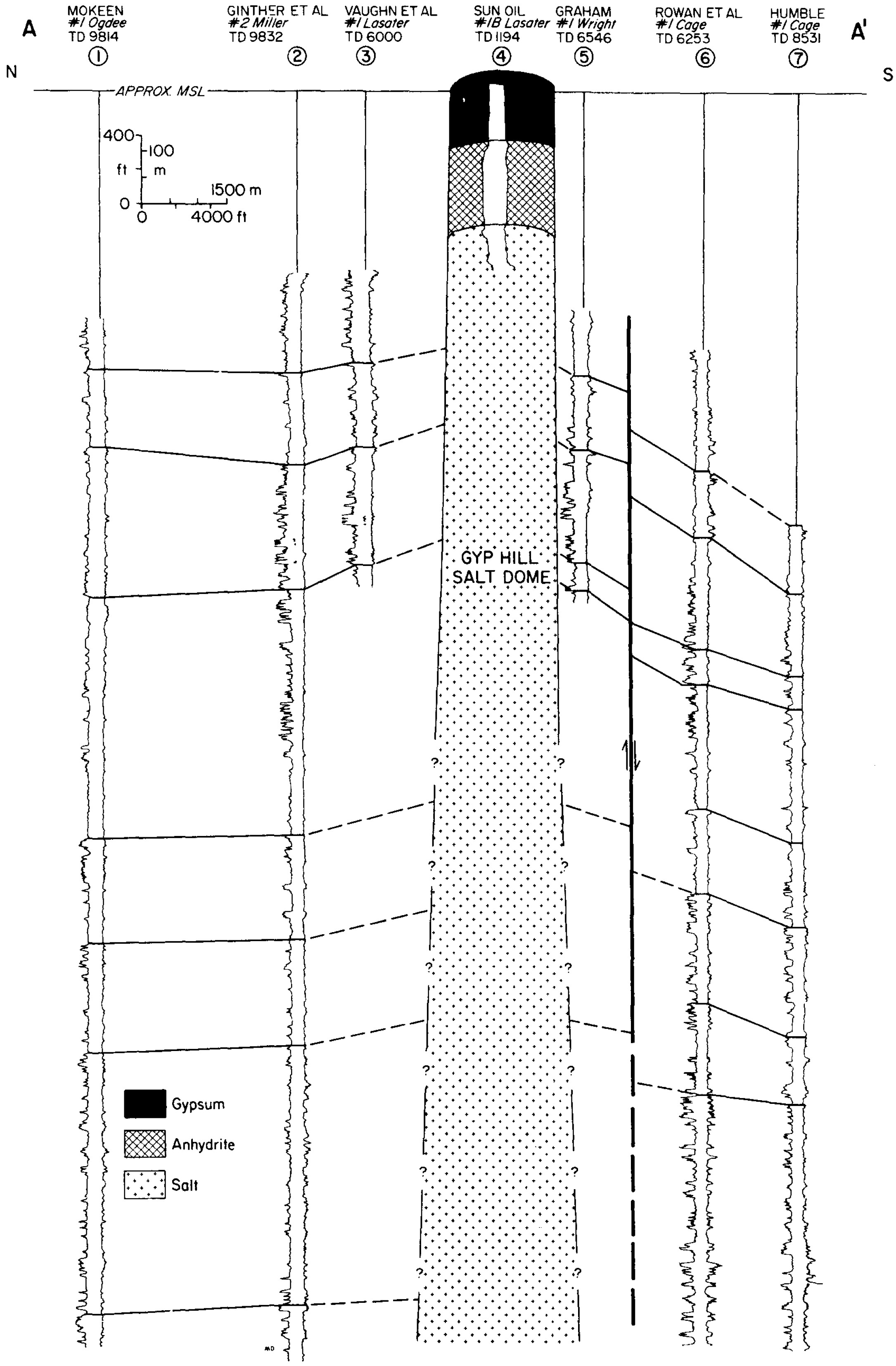


Figure 26. Cross section A-A' through Tertiary sand-shale sequences surrounding Gyp Hill Dome illustrating uplift of surrounding units. Units shown are primarily Miocene Fleming and Oligocene Frio Formations.

Lost circulation, cavities, and caving of the drill hole walls indicate poorly indurated and cavernous zones within Gyp Hill cap rock (table 26). Such conditions may occur at other salt domes and must be taken into account before and during mine shaft construction.

Socioeconomic Setting

Gyp Hill dome is in Brooks County, where the principal income is derived from oil and gas production and cattle raising. Gyp Hill dome is near the county seat of Falfurrias, which has a population of nearly 6,300, many of whom are Mexican-American. County income approaches $27,000,000 yearly.

U.S. Gypsum presently holds an option on the cap rock quarry to mine gypsum, but it will not consider gypsum mining until 1982. Mining could involve one of three options: (1) minimal development of portland cement rock; (2) major development of 150,000-200,000 tons per year for wallboard and portland cement; and (3) construction of a wallboard plant in Falfurrias and quarrying the cap rock. Under the first option, U.S. Gypsum would ship the rock by train to Corpus Christi and then by boat to other Gulf Coast cities.

Freeport Sulfur owns both the land over the dome and the cap rock. Freeport Sulfur bought the land and the caprock from the Lassiters, the Mahars, and the owners of the Falfurrias Creamery. Dick Runvic (U.S. Gypsum) believes that Lassiters and Mahars still own the oil and gas rights and the salt; Lassiters and Mahars also own ranches that once included the quarry.

Table 26. Notations in driller's log indicative of cavities and porous zones in the Gyp Hill Dome cap rock. Log is from Bureau of Economic Geology core hole drilled from surface to top of salt.

Depth, ft	Conditions
13	lost all circulation
47-58	broken gypsum with cavities
74-84	broken zone, hole caving
77-87	hole caving badly, despite use of heavy mud
71-89	hole caved in
202-205	hole caving, sand-sized sediment entering hole
74-91	zone caved in, 50 ft of caved sediment in bottom of hole (261 ft)
582	"bad spot" in hole, with sand-sized sediment entering
582-623	interval filled with sand-sized sediment (entering hole at 582 ft)
732	sand-sized sediment entering hole
890-895	no core recovery, sand-sized sediment in hole, rods not sticking

PALANGANA DOME

Palangana Dome is located in Duval County in South Texas approximately 68 km (42 mi) north-northwest of Gyp Hill (fig. 27). Palangana Dome is a closed system with little associated hydrocarbon production. Salt is being produced by a brining operation, however.

Biologic Resources

Palangana Dome lies within the Mesquite-Chaparral Savannah region, also known as the South Texas Plains (Arbingast, 1976; Hoffman and others, 1976). Distinct differences occur in the original plant communities on different types of rangeland, largely controlled by soil types. Low saline areas are inhabited only by grasses adapted to such environments, such as gulf cordgrass (Spartina spartinae). Much of the region is covered in brush, including mesquite (Prosopsis juliflora), and various types of cactus (Hoffman and others, 1976). Acacia spp. are also present.

Palangana Dome is located in an area of brushy mesquite and grass rangeland (White and Kier, 1979). Within 2.4 km (1.5 mi) of the northern margin of the dome lies Narcisena Creek with a narrow (less than 0.6 km (0.4 mi) wide) floodplain that supports dense scrub brush and grasses.

Coastal prairies support rodents, mammals, snakes, and birds. The Mexican ground squirrel, gray fox, white-tailed deer, wild turkey, and armadillo are present (Bailey, 1978). The occurrence of endangered species is similar to that listed for Brooks County (table 19).

Climate

Palangana Dome is within the subhumid to semiarid region of South Texas (Thornthwaite, 1948). The most complete climatological data for the area of Palangana Dome are also the data from Falfurrias, as described for Gyp Hill Dome. Palangana Dome is 35 mi north-northwest of Falfurrias, and has similar precipitation and temperature regimes (Shafer, 1974).

The annual relative humidity at 6 p.m. is slightly lower at Palangana than at Gyp Hill, averaging approximately 56 percent. The first occurrence of frost at Palangana

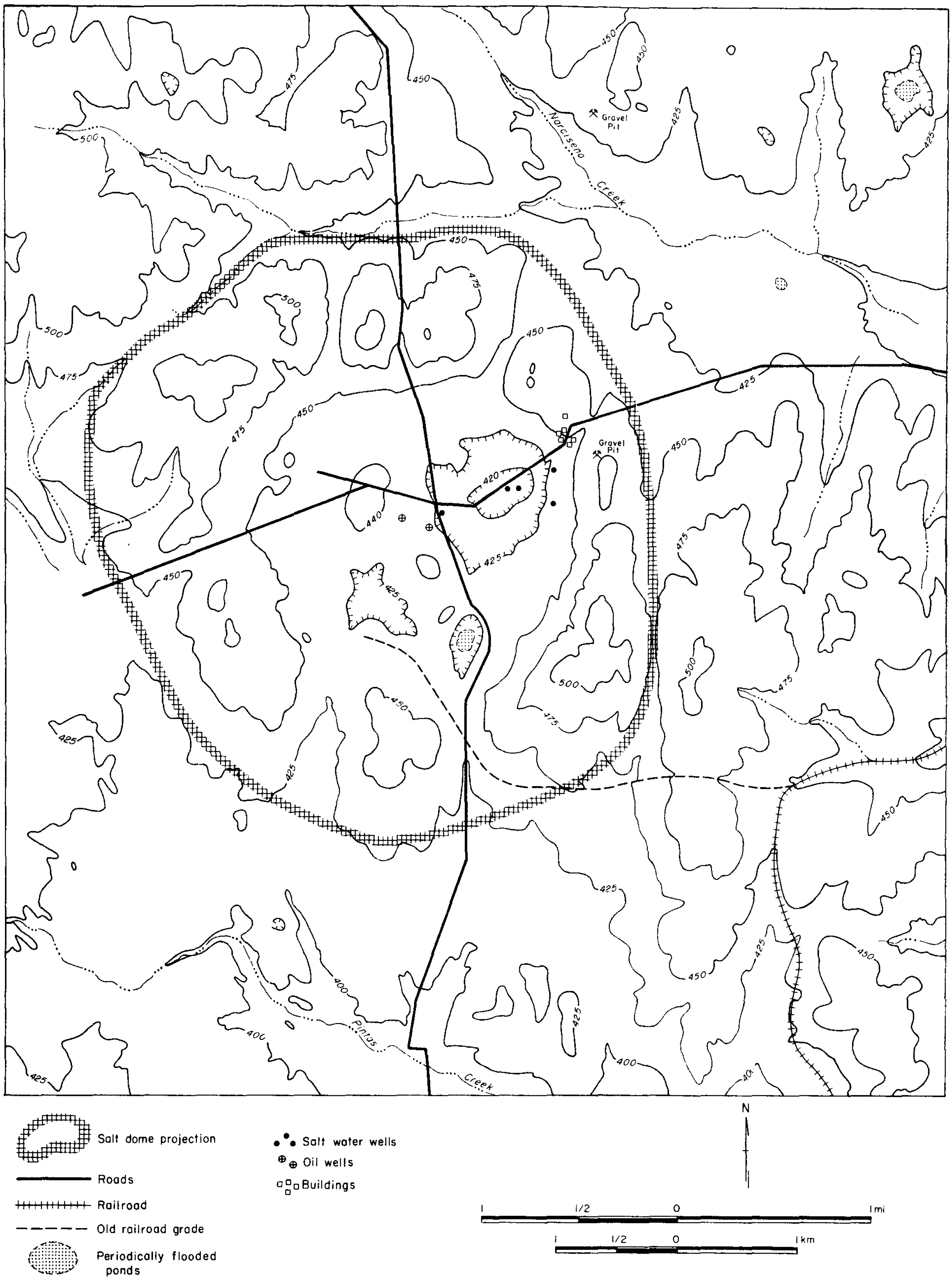


Figure 27. Topography and cultural features over Palangana Dome, Duval County, Texas (from U.S.G.S. 7.5-minute quadrangles, Benavides NW and Benavides NE, Texas).

is usually between December 1 and December 16 and the last occurrence of frost is usually after February 14 but before March 1 (Arbingast, 1976). The average annual gross lake surface evaporation for the area is approximately 1,727 mm (68 in) (Kane, 1967).

Energy Resources (Basinal)

A hydrocarbon discovery was made at Palangana Dome in 1938 with the drilling of the National Oil Co. #1 Schallert into Miocene-age sands at depths of 520 to 565 m (1,700 to 1,850 ft) (Patrick, 1953). This discovery probably refers to the first fully commercial production, because at least 14 wells had been drilled in and prior to 1923. The depth to cap rock is not precisely given in the literature, but is probably 120 to 150 m (400 to 500 ft) below the surface (Weeks and Eargle, 1960).

Oil production at Palangana has not been significant (table 27), and there was no production in 1979. More than one-third of the cumulative production to date was extracted before 1952. Recent activity has focused on gas production (table 28) on the southeast flank of the dome with several wells completed in 1974, 1976, and 1978 (Railroad Commission of Texas, undated). Absolute open flows of gas have generally been low (400 to 4,000 mcf), however, and some wells have been plugged within a year of their original completion.

More than 50 dry holes and plugged wells are located over and around Palangana dome. These are in addition to at least 28 test wells for sulfur (Barton, 1925) and a 21-well drilling program for potash (Hofrichter, 1962). Three of the latter were deviated holes bottoming out at least 610 m (2,000 ft) horizontally from where the well first entered salt. Most of the wells drilled for potash evaluation were 1,070 to 1,100 m (3,500 to 3,600 m) deep. During sulfur and potash exploration, great difficulty resulted from noxious hydrogen sulfide gas which in fact may interfere in the potential construction of a Salt Test Facility.

Energy Resources (Surficial)

Strip-mineable lignite resources are not known from the Palangana Dome area of Duval County. Uranium resources occur in Duval County and are being mined through in situ leaching (St. Clair and others, 1976; W. Galloway, personal communication, 1980). All in situ leaching in southwestern Duval County is being done from the Catahoula Formation.

Table 27. Crude oil and casinghead gas production at Palangana Dome (from Railroad Commission of Texas, 1979).

Field	Discovery date	Depth, (ft)	1979 Production Casinghead Gas, MCF	1979 Production Crude Oil, BBLS	Cumulative Crude Oil, BBLS, Through 1/1/80
Palangana Dome	8-11-47	3,030	0	0	23,088

Table 28. Gas well gas production and hydrocarbon liquids recovered on leases, 1979, at Palangana Dome (from Railroad Commission of Texas, 1979).

Field*	Producing wells end of year	Gross gas production, MCF	Hydrocarbon liquids, BBLS
Palangana (Frio, Middle 1700)	1	5,997	0
Palangana Dome	2	48,964	0
Palangana Dome (1970)	0	0	0

*Name and/or number in parenthesis refers to producing horizon and/or depth (in feet).

A known uranium deposit occurs in the Goliad Sand overlying Palangana Dome (Weeks and Eargle, 1960). The deposit is reported as "chiefly very finely divided sooty pitchblende" in a clay-ball conglomerate interbedded with fine to medium sand. Recent attempts at in situ leaching of this deposit have been abandoned, possibly due to technical problems in extracting the resource or to current market conditions (W. Galloway, personal communication, 1980).

Flood Potential

The surface expression of Palangana Dome consists of a ring of hills approximately 3,350 to 3,660 m (11,000 to 12,000 ft) in diameter enclosing a central depression (fig. 27) (U.S.G.S. 7.5-minute quadrangle, Benavides NW, Texas). The bases of the hills vary from 130 to 142 m MSL (425 to 465 ft MSL) in elevation, and the crests vary from over 140 m MSL (460 ft MSL) to over 155 m MSL (505 ft MSL). The lowest point of the central depression is estimated to be 127 m MSL (416 ft MSL) and it is this depression, where below the 130-m (425-ft) elevation, that is designated as a Special Flood Hazard Zone (Zone A) (U.S. Department of Housing and Urban Development, 1977). Two smaller depressions extending below 130 m MSL (425 ft MSL) and located south and southwest of the central depression are also mapped as Zone A; it appears that the 130 m (425 ft) elevation was used as a cutoff for the flood hazard designation. These three areas of flood hazard total only 100 ha (250 ac).

The floodplain of Narciseno Creek lies within 490 m (1,600 ft) of the northeast margin of the surface projection of the salt dome. Narciseno Creek is an intermittent stream. Approximately 275 m (500 ft) of the primary access road to the industrial facilities over the dome is barely within the Narciseno Creek floodplain. This road is a light-duty road with an improved surface (U.S.G.S. 7.5-minute quadrangle, Benavides NE, Texas).

As at Gyp Hill, hurricane or tropical storm aftermath rainfall poses a threat of flooding to the Palangana Dome area. The large central depression and the two minor depressions have no outlets below approximately 130 m MSL (426 ft MSL).

Historical Resources

One known archeologic site is located within the surface projection of Palangana dome, as listed with the Texas Archeological Research Laboratory (C. Spock, personal communication, 1980). The site is on the east margin of the central depression overlying the dome. The site is a shallow zone approximately 90 m (300 ft) in length at an elevation of 131 m MSL (430 ft MSL) and is located approximately 240 m (800 ft) southeast of the No. 10 brine well (table 29).

Two sites over and near the Palangana Dome have been surveyed as possible sites to be included in the National Register of Historic Sites. A limited amount of data on these sites is available from the Texas Historical Commission (table 30).

Hydrology (Basinal)

The Pleistocene-age Goliad Sand is the primary source of ground water in Duval County, wherein Palangana Dome is located, and is the source of 4.0 mgd of the county's water supply. Lesser amounts are obtained from the Catahoula Tuff (0.6 mgd) and the Oakville Sandstone (0.7 mgd; table 31) (Shafer, 1974). In the hydrogeologic framework of the Texas Coastal Plain, the Goliad Sand is known as the Evangeline Aquifer and the Oakville Sandstone as the Jasper Aquifer. A dip-oriented cross section through central Duval County shows the regional relationships among these units (fig. 28).

The Catahoula Tuff crops out in the northwest part of Duval County and dips southeastward at 15 m/km (80 ft/mi). The downdip limit of fresh to slightly saline water is approximately 6 km (4 mi) west of Palangana Dome; the Catahoula is absent over the dome itself. The Oakville Sandstone crops out in the north-central part of Duval County and dips southeastward at 11 to 15 m/km (60 to 80 ft/mi). The Oakville has been dragged upward around Palangana dome, but it is absent over the dome itself. Because water from the Goliad Sand is of better quality and occurs at shallower depths than the Oakville Sandstone, the Oakville has not been heavily developed. Yields from the Oakville can be good, however, as one industrial well near Palangana Dome produced 460 gpm from a depth of 337 to 382 m (1,106 to 1,252 ft) with 1,550 ppm total dissolved solids (TDS) content (slightly saline) (Shafer, 1974).

The Goliad Sand is the bedrock beneath more than half the land surface of Duval County and is continuous over Palangana Dome. The base of the Goliad is uplifted by the salt dome 24 m (80 ft) above its regional dip slope to the southeast. The Goliad yields small to large quantities of fresh to slightly saline water and provides the public supply for the town of Benavides, 10 km (6 mi) south of the center of Palangana Dome. The regional southeastward flow of water in the Goliad has been interrupted by heavy pumping from the Goliad around Palangana Dome, resulting in local northward movement. This water is used for industrial purposes (Shafer, 1974) and may be related to the brining operation over the dome.

Table 29. Archeologic site over Palangana Dome, Duval County, Texas (data from C. Spock, personal communication, 1980).

Site No.:	TAC 004763 (41 DV 4)
Type:	Occupational or workshop area bearing numerous Scallorn-type arrow points, small lozenge-shaped dart points, and other knife and point types.
Cultural Affiliation:	Not given in site data.
Site Description:	See text. Also, site has been disturbed by building of low berms for erosion control. The soil used and the area of soil removal was the richest in artifacts. No "heavy concentration" of flakes and artifacts was found, nor do any signs of hearth pits, charcoal or burned limestone exist.
Recommendations for Work:	Not given in site data.
Date:	Surface collections were made in 1966-67.

Table 30. Historic sites near Palangana Dome surveyed for possible entry in the National Register of Historic Sites.

Site	Description	Comments
San Diego and Gulf Railway Site No. 48919	Rural, condition not known, owner not identified. Chartered in 1929 to connect a sulfur deposit at Palangana Dome with the Texas-Mexican Railroad. Later abandoned.	Exact location not given, but presumed to be the "Old Railroad Grade" over Palangana Dome noted on the Benavides NW 7.5-minute quadrangle map.
Benavides Salt Mines Site No. 58207	In Benavides (10 km S of Palangana Dome), non-functioning, privately owned. Five brine wells used in solution mining of salt from Palangana Dome.	Available information does not clarify what part of the salt production process may have taken place in Benavides. May only have been company offices (?).

Table 31. Stratigraphy of shallow water-bearing units in Duval County (from Shafer, 1974).

System	Series	Geologic Formation	Approximate Thickness (m)	Lithology	Water-Bearing Properties
Quaternary	Holocene	Alluvium		Very fine to fine sand, silt, and calcarerous clay	Not known to yield water to wells in the county
	Holocene and Pleistocene (?)	South Texas eolian plain deposits	0-3	Fine to very fine, tan to white sand	Not known to yield water to wells in the county
	Pleistocene	Lissie Formation	0-30	Variegated red to brown calcareous clayey sand, some gravel near base	Not known to yield water to wells in the county
Tertiary	Pliocene	Goliad Sand	0-180	Fine to coarse, mostly gray, calcareous sand interbedded with sandstone, gravel, and varicolored calcareous clay; an abundance of caliche over most of the outcrop	Principal aquifer in the county; yields small to large quantities of fresh to slightly saline water to public-supply, industrial, irrigation, rural-domestic, and stock wells
	Miocene	Fleming Formation	0-300	Yellow to green calcareous or marly clay and some local seams of silty sand and lentils of coarse sand and gravel	Not known to yield water to wells in the county
		Oakville Sandstone	0-180	Medium to fine sand, sandstone, silt, bentonitic clay, and small amount of ash	Yields small to moderate quantities of fresh to slightly saline water to industrial, rural-domestic, and stock wells
		Catahoula Tuff	0-430	Pink tuffaceous clay and tuff; local lenses of sandy clay and thin to thick beds of sand and conglomerate	Yields small to moderate quantities of fresh to moderately saline water to industrial, rural-domestic, and stock wells
	Oligocene (?)	Frio Clay	120-180	Gypsiferous clay and thin beds of sand and silt	Not known to yield water to wells in the county
	Eocene	Jackson Group	300-500	Brown to buff, sandy shale, fossiliferous sandstone, and beds of volcanic ash; does not crop out in the county	Reported to yield small quantities of moderately saline water to a few wells in the northwest part of the county

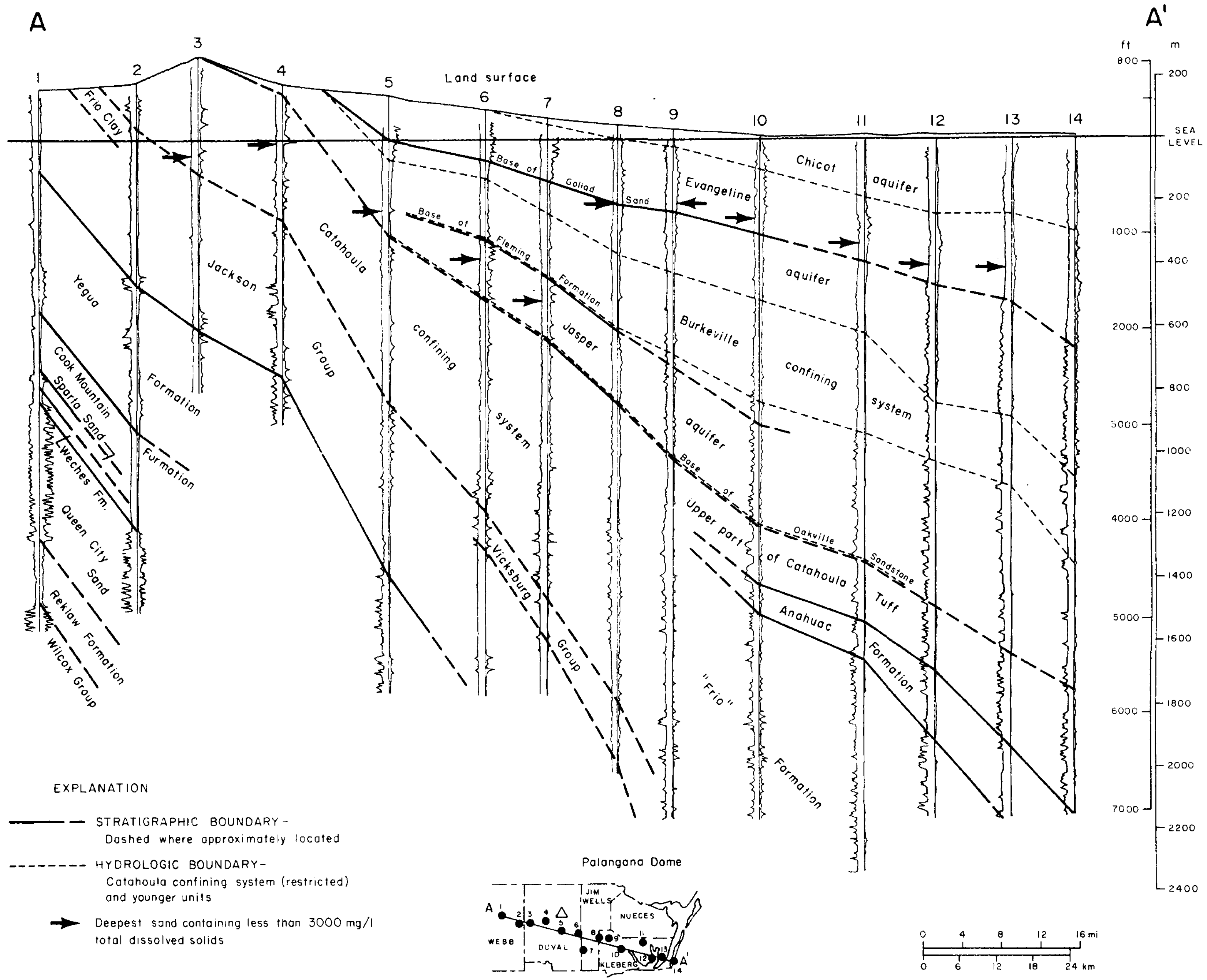


Figure 28. A cross section through the aquifers of Duval County and the surrounding South Texas Coastal Plain (from Baker, 1979).

Water quality for wells generally within 3 km (2 mi) of Palangana Dome and that tap the Goliad Sand have chloride contents of 250 to 470 ppm and a TDS content of 768 to 1,300 ppm. A well within 10 km (6 mi) of the center of the dome has 1,250 ppm chloride and 2,900 ppm TDS. A well tapping the Oakville Sandstone 5 km (3 mi) southeast of the center of the dome yields water with 325 ppm chloride and 1,550 ppm TDS. All these waters would be classified as within the upper range of fresh water to slightly saline water on the basis of TDS content (Shafer, 1974).

Aquifer tests of the Goliad Sand in two water supply wells for Benavides, south of Palangana Dome, show transmissivities of 960 and 990 ft^2/day. The average transmissivity of the Goliad Sand in Duval County is 700 ft^2/day. The coefficient of storage was determined for one of these wells as 6.2×10^{-4} (Shafer, 1974).

Moderate to large declines in water level within the Goliad have occurred in the east-central parts of Duval County, which would include the area around Palangana Dome. These declines are due to irrigation, public supply, and industrial well pumpage (Shafer, 1974).

The saline water resources of the Gulf Coastal Plain have been mapped according to depth zones that cut across formation boundaries and time lines within the Tertiary-age stratigraphic units. These zones generally show increasing formation water salinity with depth below the base of fresh to slightly saline water, which is within the Catahoula Tuff in western Duval County and within the Oakville Sandstone in eastern Duval County. Each depth zone is 610 m (2,000 ft) thick and is defined by arbitrary values; because there is practically no saline water above sea level, zone 1, 0 to +610 m MSL (0 to 2,000 ft MSL) was not mapped. Salinities for east-central Duval County around Palangana Dome have been listed in table 32 (Texas Water Development Board, 1972).

Hydrology (Surficial)

Palangana Dome is located between the Nueces River and Rio Grande basins in an area draining eastward into Baffin Bay through a number of small, intermittent creeks. Baffin Bay is often hypersaline because of high evaporation, its limited connection to the Gulf of Mexico through Laguna Madre, and low surface runoff, except after the intense rainfall of tropical storms.

Narciseno Creek, located north of the dome, and Piedras Pintas Creek, located south of the dome, are tributaries of Santa Gertrudis Creek, which empties into Baffin Bay. One branch of Narciseno Creek flows over the north margin of the surface

Table 32. Formation water salinities within 610-m (2,000-ft) thick zones of Tertiary Gulf Basin sands, east-central Duval County (from Texas Water Development Board, 1972).

Zone	Depth, ft below MSL	Salinity, ppm
2	0 - 2,000	10,000
3	2,000 - 4,000	<10,000
4	4,000 - 6,000	10,000 - 20,000
5	6,000 - 8,000	40,000
6	8,000 - 10,000	40,000+

projection of the dome, just outside the ring of hills that marks the position of the dome (fig. 27). Drainage from the central depression over Palangana Dome flows south into Piedras Pintas Creek, but only when water levels exceed the elevation of a low divide in the ring of hills over the dome. The elevation of this divide is estimated to be between 130 m and 131 m MSL (426 and 430 ft MSL). The elevation of the low point of the central depression is between 127 and 128 m MSL (416 and 420 ft MSL). No surface streams empty into the central depression, and therefore the flood hazard in the depression is related solely to intense rainfall immediately over the dome.

The climate is characterized by evaporation well in excess of precipitation (see section on climate), and therefore runoff is low. For a subbasin area that includes Palangana Dome and most of Duval County the minimum annual runoff is 4.9 hm^3 (4,000 ac-ft) and the average annual runoff (1940-1956) has been 113 hm^3 (91,588 ac-ft) (Lockwood, Andrews and Newnam, 1960). This subbasin area is bounded on the north by the Nueces River basin and on the south by the Los Olmos Creek basin, another coastal plain stream that drains into Baffin Bay.

Data on chemical quality of surface waters are sparse in the subbasin containing Palangana Dome, no doubt because this is a region of low rainfall and intermittent streamflow. The only sampling station in the region is located 53 km (33 mi) southwest of Palangana Dome on Los Olmos Creek in Brooks County. At Los Olmos Creek the average discharge has been (1967-1975) 0.203 m^3/sec (7.18 ft^3/sec), or 6.41 hm^3/yr (5,200 ac-ft/yr). Total dissolved solids averaged 2,894 ppm for 10 low-flow samples taken during the 1975 water year. Chloride averaged 708 ppm and sulfate averaged 1,013 ppm during this same period (U.S. Geological Survey, 1976).

Outcrop of the Goliad Sand, the principal aquifer in the area of Palangana Dome, makes up more than half the land surface in Duval County. Locally this unit may be mantled with eolian deposits up to 3 m (10 ft) thick or by alluvial deposits of variable thickness. Recharge occurs by seepage of precipitation into the aquifer, although locally recharge may be retarded by near-surface caliche deposits (Shafer, 1974).

No surface water storage reservoirs for municipal use exist in Duval County. Local stock tanks not replenished from wells probably contain water only during and immediately following rainfall periods.

Land Resources

The land over and surrounding Palangana Dome in Duval County consists of moderately hard to hard calichified sand with local gravel, and caliche karst features. Surficial materials have low to moderate permeability and low moisture retention capability. Excavation is moderately difficult to difficult, but foundation strength is high and corrosion potential for metal in contact with the soil is low to moderate (White and Kier, 1979).

Soils are thin clay loams within the land resource unit surrounding Palangana Dome (Kier and others, 1977). A detailed soil survey of Duval County has not been published.

Mineral Resources

Perkins and Lonsdale (1955) reported the total production of 215,552 metric tons (237,607 tons) of sulfur from the cap rock of Palangana Dome by the Duval Texas Sulfur and Potash Company. By 1962, however, the deposit had been depleted (Maxwell, 1962).

Recovery of gypsum has not been reported at this location.

Salt has been extracted by means of artificial brines obtained from wells drilled into the salt (Perkins and Lonsdale, 1955). Production is by the Pittsburgh Plate Glass Co., Chemical Division, Corpus Christi, Texas (Lefond, 1969). The location of some wells in the salt-water well field is shown over the dome on the Benavides NW, Texas, U.S.G.S. 7.5-minute quadrangle map.

Although potash was discovered in one of the wells drilled for brine production, the potash-bearing beds were found to be discontinuous (Hofrichter, 1968), and as of 1976 no potash production had been established (Hawkins and Evans, 1980).

Mixed sand and gravel resources may be associated with the floodplains of Piedras Pintas and Narciseno Creeks to the south and north, respectively, of Palangana Dome. This resource may locally contain excessive fine sediments (Gustavson, 1976).

Land Use

Generalized land use, interpreted from 1:250,000-scale Landsat imagery, supplemented by U.S. Geological Survey 7.5-minute quadrangle maps, shows rangeland and brushland to be the major types of land use/land cover in central Duval County (Texas Department of Water Resources, 1977).

Around Palangana Dome most of the land is in scrub brush and is used as rangeland. Some tracts have been cleared, fenced, and wells with wind-driven pumps installed for use as improved rangeland. The central depression over the dome has largely been cleared of brush, and is the area of brine production from wells. Surface facilities associated with brine well operation are located over the northeast flank of the dome within the ring of hills marking its surface expression.

A gravel road extends approximately 8 km (5 mi) from State Highway 359 to the brining facilities. The Texas-Mexican Railroad extends to within approximately 4 km (2.4 mi) of the center of the dome, and an abandoned railroad grade extends from this line to near the center of the surface projection of the dome (fig. 27).

Population

Palangana Dome is located 9 km (5.5 mi) north of Benavides in Duval County. The estimated population of Duval County in 1977 was 12,100 (Dallas Morning News, 1980). The area of the county is 4,698 km^2 (1,814 mi^2). Population in Duval County has been stable to decreasing since 1950. Laredo, the nearest Standard Metropolitan Statistical Area (SMSA), has been increasing in population since 1950. Persons living on rural farms made up less than 10 percent of the county population in 1970 (Arbingast and others, 1976).

In the surrounding counties the population ranges from 800 in McMullen County to the north, to 34,200 in Jim Wells County to the east. Four adjacent counties increased in population and two decreased or remained stable between 1973 and 1977 (Arbingast and others, 1976). Population centers near Palangana Dome are listed in table 33.

Salt Depth, Composition, and Geometry

Approximately 120 to 180 m (400 to 600 ft) of sediments overlie the approximately 107-m (350-ft) thick cap rock of the dome (Hofrichter, 1962). The top of the salt core varies from 260 to 300 m (850 to 1,000 ft) below the surface (Weeks and Eargle, 1960).

The salt core of Palangana Dome is approximately circular in outline with a diameter of 2,440 m (8,000 ft). The dome has a flat top and very steep flanks. The slope on the east flank is more than 70^{o}; on other flanks slope is slightly more or less (Barton, 1925). The volume of salt in Palangana Dome is estimated to be 15.0 km^3 (3.61 mi^3) (Perkins and Lonsdale, 1955).

Following detection of a potassium salt-bearing bed during brine well drilling, drilling was started to delineate the possible potassium resource. Much information on the salt was gained through core analysis (Hofrichter, 1962). The salt was divided into four generalized stratigraphic units (table 34) and a geologic map and cross sections prepared (figs. 29 and 30). Palangana salt core consists of white to gray halite with anhydrite unevenly distributed throughout the mass. Where potash is present, it is composed of sylvine, a mixture of halite and sylvite crystals, which is light gray to gray tinged with pink or red. No conclusive relative age assignment can be made among the four salt groups (table 34). Sandstone inclusions present in the salt are probably derived from adjacent strata during dome emplacement (Hofrichter, 1962).

The dips of layers within the salt are steep, averaging 70^{o}, as revealed by study of oriented core. Strike of the salt at the margins of the dome is parallel to the edge of the salt body. Numerous isoclinal folds were cored, and multiple repetitions of anhydritic and potassium-bearing beds occurred within 1 m (3 ft) to 30 m (100 ft) lengths of core. The fold axes appear to plunge at steep angles, as they do in other domes such as Grand Saline (Hofrichter, 1962).

Table 33. Population centers near Palangana Dome, Duval County, Texas (1976 data unless otherwise noted) (Dallas Morning News, 1980).

Within 16-km (10-mi) radius		
Town	County	Population
Benavides	Duval	1,901

Larger centers within 50-km (32-mi) radius		
Town	County	Population
Alice	Jim Wells	20,468
Hebbronville	Jim Hogg	4,050
San Diego	Duval-Jim Wells	4,771
Freer	Duval	2,901
Premont	Jim Wells	2,786
Bruni	Webb	214

	Other major cities	
City	Distance, km (mi)	Population (1977)
Corpus Christi	100 (62)	303,200 (estimate)
Laredo	109 (68)	85,000 (estimate)

No subsurface structural effects of salt dissolution are reported for Palangana Dome. As at other domes, the presence of cap rock is evidence for salt dissolution and accumulation of insoluble sediments over the salt as the dome was emplaced. The topographic depression over the central part of the dome is evidence of possible near-surface salt dissolution and collapse of part of the overlying cap rock.

Table 34. Stratigraphic groups within the Palangana Dome salt stock (from Hofrichter, 1968).

Group	Characteristics
Anhydritic	Relatively impure halite; flakes and pebbles of anhydrite up to 5 cm (2 in) diameter; a few beds of dense anhydrite up to 1 m (3 ft) thick; some potassium-bearing beds.
Benavides	Medium-grained, gray to light gray halite with anhydrite flakes and blebs up to several centimeters; layers of anhydrite to 8 cm (3 in) thick; alternating beds of pure halite and anhydritic halite in some areas.
Palangana	Very pure, coarsely crystalline halite with few thin, indistinct bands of gray fine- to medium-grained halite containing abundant anhydrite flakes; impurities generally rare; maximum halite crystal size exceeds 8 cm (3 in); contains 6 potassium-bearing beds, 3 of which are 3 to 6 m (10 to 20 ft) thick; the most important potassium-bearing group.
San Diego	Medium- to coarse-grained pure halite, generally similar to the Palangana Group, but without potassium-bearing seams; includes sandstone intercalations (up to 3.7 m (12 ft) thickness) and sandstone pebbles.

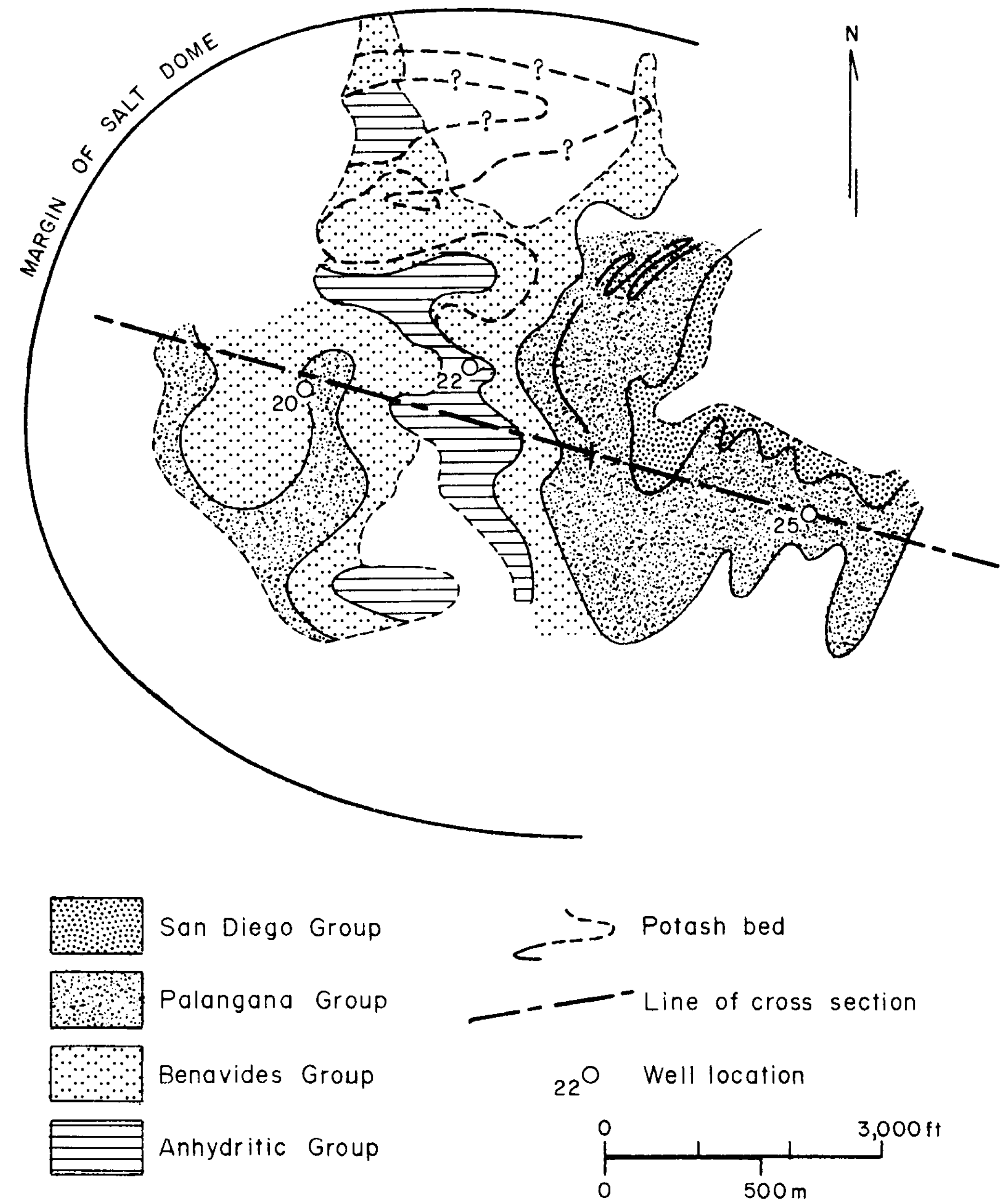


Figure 29. Generalized map of salt units across the top of Palangana Dome (from Hofrichter, 1968).

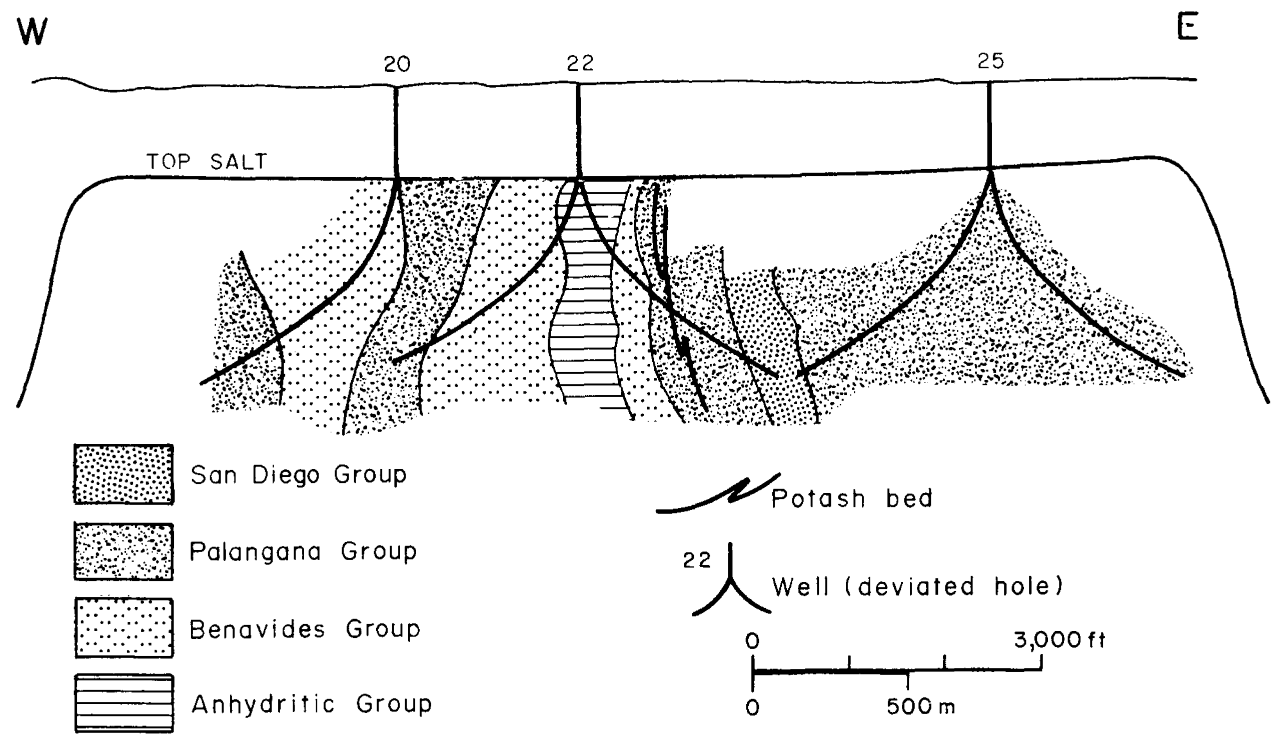


Figure 30. Cross section of the uppermost part of Palangana Dome along a line of section shown in figure 29 (from Hofrichter, 1962).

Stratigraphy

Palangana Dome is situated within the seaward-dipping Tertiary strata of the northwest Gulf Coast basin. A dip-oriented regional cross section passing approximately 8 km (5 mi) south of Palangana Dome shows Eocene (Lower Claiborne) through Miocene (Fleming) units (fig. 17) drilled (fig. 15; fig. 31 [in pocket]) in Duval County. These gulfward-thickening terrigenous clastic wedges underwent generalized depositional processes similar to those described for the units around Hockley Dome. The dome itself has formed by flowage and diapirism of salt deposited within the Rio Grande Salt Basin (Ledbetter and others, 1975; Anderson and others, 1973). A dip-oriented cross section through Palangana Dome shows the upturned strata around the salt core (figs. 32 and 33).

The surface geologic unit over Palangana Dome is the Pliocene Goliad Sand, consisting dominantly of clay, sand and sandstone, marl, and caliche (Barnes, 1976). Approximately 120 to 180 m (400 to 600 ft) of sediments overlie the approximately 107-m (350-ft) thick cap rock of the dome (Hofrichter, 1968). The top of the salt plug varies from 260 to 300 m (850 to 1,000 ft) below the surface (Weeks and Eargle, 1960).

Coring the uranium deposit over the dome reveals the lithology of the Goliad Formation (Weeks and Eargle, 1960). The uranium-bearing horizon, approximately 100 m (325 ft) below the surface, is a calcareous clay-ball conglomerate interbedded with friable fine- to medium-grained sand. The sediments above the conglomerate show little variability and are mainly slightly calcareous, fine-grained silty sandstone or sandy clay. Some fine-grained disseminated pyrite is found in the ore zone and immediately below it. The sand under the ore zone was interpreted as the Miocene Oakville Sandstone, which generally is a massive sand with some gravel, clay balls, and ashy clay (Weeks and Eargle, 1960). The Oakville overlies the cap rock.

A generalized section through the cap rock of Palangana Dome consists of 90 m (300 ft) of anhydrite overlain by 30 m (100 ft) of gypsum with some mudstone at the top of this unit overlain by 0.9 to 7.6 m (3 to 25 ft) of limestone, calcite, and shale. The cap rock thins from 110 m (362 ft) (Sinclair Oil and Gas Co., Schallert Nos. 1 and 2) and 129 m (425 ft) (National Oil Company, No. 1) over the north-central part of the dome to as little as 46 m (150 ft) on the southwest flank (Humble Oil and Refining Company, No. 3) (Barton, 1925). Barton (1925) reported one sample of the upper cap rock as consisting of oil-soaked, medium-grained granular limestone, cut by many

Figure 32. Location map of section A-A' through Palangana Dome. Grid pattern shows land tract boundaries.

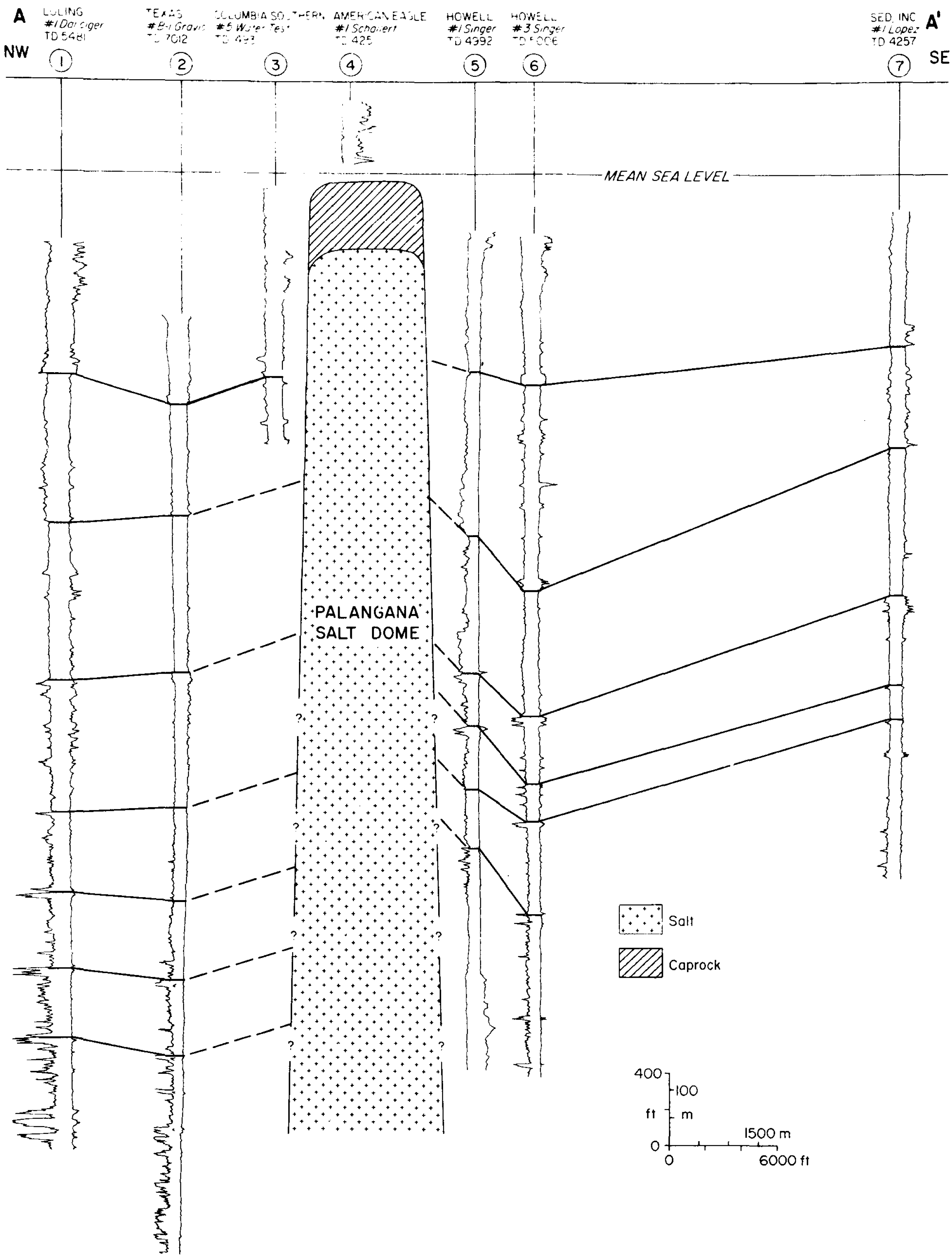


Figure 33. Cross section through Tertiary sand-shale sequences surrounding Palangana Dome and illustrating uplift of surrounding units. Units shown are primarily Vicksburg-Jackson, Frio, and Fleming Formations.

fissures partly filled by calcite or dolomite. Some sulfur is present. Barton (1925) did not describe the gypsum of the cap rock in detail but noted that it "showed more evidence of shearing" than other samples he had seen.

Two samples of anhydrite from the cap rock of Palangana Dome are described as fine-grained, dense, hard, and well-crystallized, and more coarsely crystalline with a saccharoidal texture, respectively. The color is deep-blue to white (Barton, 1925). Sulfur occurs in the anhydrite of the cap rock and was commercially extracted in the past.

Socioeconomic Setting

Palangana Salt Dome is located in Duval County, where the principal businesses are ranching, petroleum, and tourism. Annual income is presently about $49 million. The population is approximately 12,000, many of whom are Mexican-Americans. Concepcion, the community nearest Palangana, has a total population of only 25.

BLOCK 20, LOVING COUNTY

Block 20, in southeast Loving County, is a tract of state-owned land underlain by bedded salt of the Salado Formation. It is in a semiarid to arid part of West Texas (fig. 34).

Biologic Resources

Block 20 is within the northern part of the Tarbush-Creosote Bush section of the Chihuahuan Desert ecoregion (Bailey, 1978). The vegetation is characteristic of a desert shrub savannah with short, arid-land grasses and shrubs in open stands. On the desert flats, black gramma, burrograss, and fluffgrass are common. The land surface is a relatively smooth plain which becomes more irregular in western Loving County (Arbingast and others, 1976; Hoffman and others, 1976). Sections 5-8 of Block 20 are presumed to be covered with sparse grass and scattered brush, based on interpretation of aerial photographs and lack of brushland/woodland overprint on the Soda Lake NE and Soda Lake NW 7.5-minute U.S. Geological Survey quadrangles covering the area.

Fauna of the region include deer and quail. The black-tailed jackrabbit, desert cottontail, kangaroo rat, and wood rat are found in the Chihuahuan Desert ecoregion. Rodents are prey for coyote, golden eagle, owls, and hawks (Bailey, 1978). Endangered species in Loving County are listed in table 35; various protected nongame species are also found.

Climate

Southeastern Loving County in the semiarid region of West Texas receives less than 305 mm (12 in) of mean annual precipitation (Arbingast and others, 1976). The town of Pecos, in Reeves County, approximately 39 km (24 mi) south-southwest of Sections 5-8, Block 20, received a mean annual precipitation of 230 mm (9.06 in) for the period 1935-1967. During that period an annual precipitation maximum of 534 mm (21.04 in) and an annual precipitation minimum of 60 mm (2.36 in) occurred in 1941 and 1956, respectively (White, 1971). Most of the rainfall is received in late spring and summer (Orton, 1964). The average annual gross lake-surface evaporation is approximately 2,083 mm (82 in) (Kane, 1967). The highest recorded precipitation for one month in the period 1935-1967 was 188 mm (7.41 in) in August 1966.

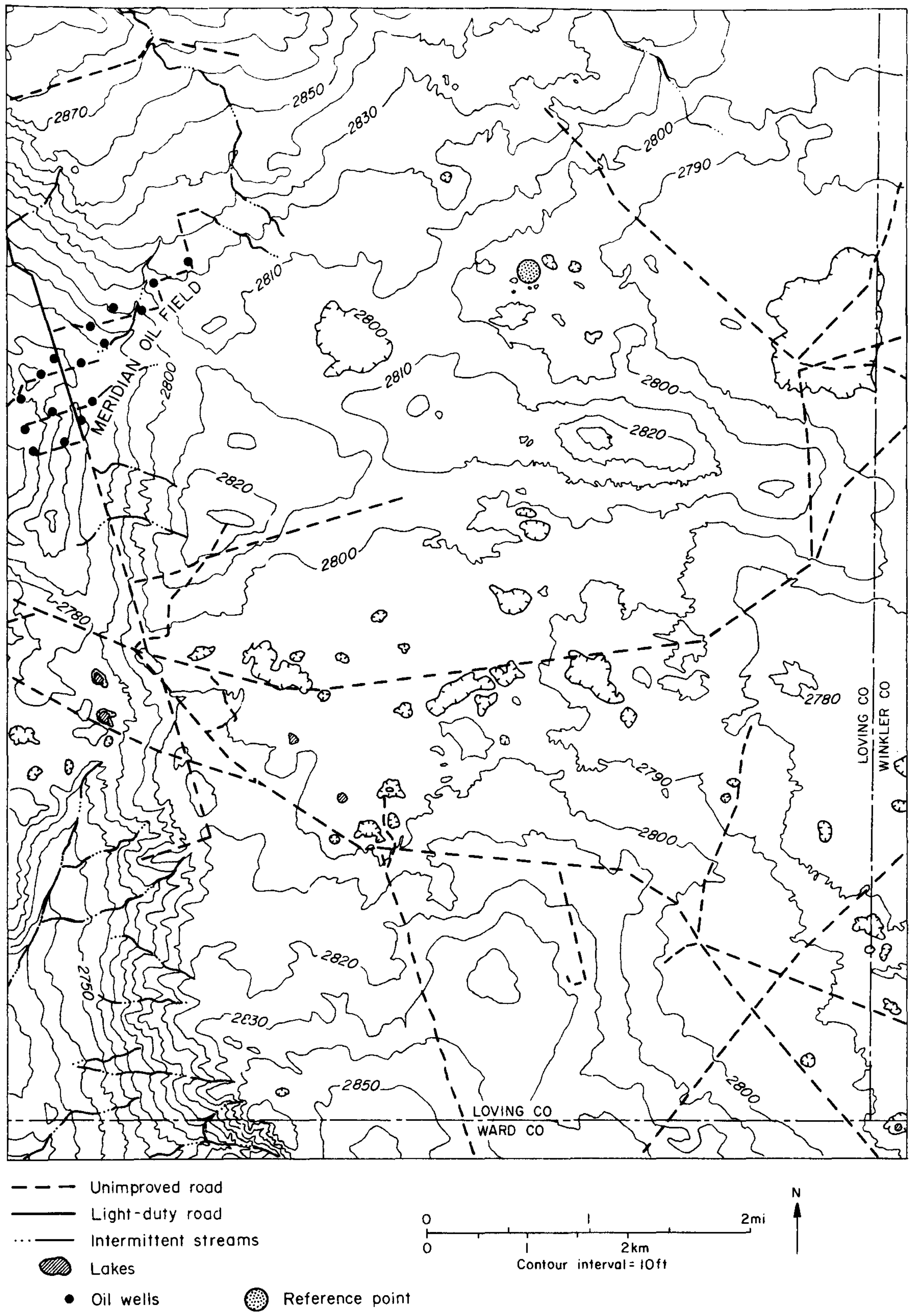


Figure 34. Topography and cultural features of southeastern Loving County, Texas. The reference point is at the center of Sections 5-8, Block 20 (from U.S.G.S. 7.5-minute quadrangles, Soda Lake NW and Soda Lake NE, Texas).

Table 35. Endangered species in Loving County (F. E. Potter, personal communication, 1980).

POSSIBLE
Black-footed ferret, Mustela nigripes
Arctic peregrine falcon,* Falco peregrinus tundrius
Interior least tern,* Sterna albifrons athalassos
PROBABLE
Southern bald eagle, Haliaeetus l. leucocephalus
*mostly migratory

The mean annual temperature for southeastern Loving County is approximately 18.3°C (65°F) (Arbingast and others, 1976). At Pecos, for the period 1935 through 1960, the average monthly temperature ranged from 6.9°C (44.4°F) in January to 28.9°C (84.1°F) in July. The recorded extremes were -21°C (-5°F) and 47°C (116°F).

The mean annual relative humidity in Loving County is approximately 68 percent at 6 a.m. and approximately 33 percent at 6 p.m. (Arbingast and others, 1976). The approximate dates for the last and first killing frosts are April 1 and November 10, respectively.

Energy Resources (Basinal)

Basinal energy resources of Loving County include oil and gas produced from the Delaware Sand at the top of the Guadalupian Bell Canyon Formation (tables 36 and 37) (Railroad Commission of Texas, 1979). Additional hydrocarbon production is found lower in the Bell Canyon and Cherry Canyon Formations. Loving County is surrounded by major areas of production in Winkler and Ward Counties. The Hendrick Field, over the Central Basin Platform in Winkler County, has produced over 255,000,000 barrels of crude oil from the Upper Guadalupian Yates Formation. The center of Sections 5-8 in Block 20 is approximately 22.5 km (14 mi) from the western edge of the Hendrick Field.

Table 36. Crude oil and casinghead gas production within 8 km (5 mi) of Sections 5-8, Block 20, Loving County (from Railroad Commission of Texas, 1979).

Field	Discovery Date	Depth (ft)	1979 Production Casinghead Gas, MCF	1979 Production Crude Oil, BBLS	Cumulative Crude Oil, BBLS, Through 1/1/80
Meridian (Blk. 19-Sec. 2, 3, 9)	1961	4,993	1,501	3,585	731,655
Two Freds (W. & NW R.R. Co., Blk. 1-Sec. 38-45)	1957	4,895	286,862	297,117	9,669,348
Two Freds, E (Blk. 19-Sec. 7, 16)	1967	4,929	0	0	401
Block 20 (Blk. 20-Sec. 11)	1953	5,096	0	0	34,180

Table 37. Gas well gas production and hydrocarbon liquids recovered on leases, 1979, within 8 km (5 mi) of Sections 5-8, Block 20, Loving County (from Railroad Commission of Texas, 1979).

Field	Producing Wells End of Year	Gross Gas Production, MCF	Hydrocarbon Liquids, BBLS
Meridian, South (Blk. 19-Sec. 26, 27; Blk. 20-Sec. 31, 41, 42, 44, 45, etc.)	1	57,641	1,046

No oil or gas tests have been drilled in Sections 5-8 of Block 20 (fig. 34). The nearest fields (Meridian, Two Freds, and Two Freds, East) produce from the Delaware Sand (table 36). The Meridian South field produces gas from the Lower Permian Wolfcamp (table 37) (Railroad Commission of Texas, 1979).

Energy Resources (Surficial)

Coal or lignite resources are not found in Loving County (St. Clair and others, 1976). There has been some uranium exploration in Triassic sands and clays in Loving, Ward, Winkler, and Crane Counties. The economic potential of these occurrences, however, is considered minimal (Groat and others, 1971).

Flood Potential

Surface drainage in the immediate vicinity of Sections 5-8, Block 20 consists of an intermittent stream segment, northeast of Section 5, that drains into a broad 3-km-(1.9-mi-) wide flat, east of Sections 5 and 8. This flat may be a local deflation surface because it shows less eolian grain than surrounding areas (U.S.G.S. 7.5-minute quadrangle, Soda Lake NE, Texas). Intermittent drainage occurs northwest of the center of Sections 5-8, Block 20 (fig. 34).

The center of Sections 5-8 falls in an area of prominent eolian grain, suggesting sandy substrates. Rapid infiltration of precipitation into a sandy surface leads to the observed poor development of surface drainage. Closed depressions developed in the windblown sand surface probably contain water after heavy rains and before its loss to infiltration and evaporation. An area approximately 1,220 m (4,000 ft) long by 366 m (1,200 ft) wide along the southern edge of Sections 7-8 is 3 m (10 ft) to 6 m (20 ft) above the surrounding surface and all local closed depressions. A light-duty access road from the east to the vicinity of Sections 5-8, Block 20, does not cross any intermittent drainage on the Soda Lake, NE, U.S.G.S. 7.5-minute quadrangle.

Historical Resources

No National Register Historic Sites or proposed sites are located in Loving County, Texas, and no known archeological sites are within Block 20 (C. Spock, personal communication, 1980). This part of Loving County has not been systematically surveyed, however.

Hydrology (Basinal)

The Triassic Santa Rosa Sandstone and the Permian Rustler Formation are minor aquifers in southeast Loving County. The Permian Dewey Lake Formation may also yield usable water (fig. 35). Water quality from the Santa Rosa is generally fair to poor, with total dissolved solids (TDS) content of 1,000 to 3,000 ppm. Sulfate and chloride commonly exceed 250 ppm and fluoride commonly exceeds 1.5 ppm. Locally water quality has been further reduced by contamination due to disposal of oilfield brines in unlined pits (Groat and others, 1971). Water available from the Rustler Formation is generally unsuitable for human consumption and, where developed, is used for irrigation and stock watering. TDS exceeds 2,000 ppm in most places and is commonly as much as 6,000 ppm (moderately saline). The water is high in sulfate, although low in chloride. In Ward County, south of Loving County, the main producing intervals in the Rustler are porous zones in dolomite and limestone. Porosity ranges from minimal to very high in cavernous zones and is very irregular in extent. Wells yield mostly less than 300 gallons per minute (gpm), but up to 650 gpm have been recorded (White, 1971). Such water-yielding zones could affect shaft construction if similar porosity exists at any site selected in Loving County.

Block 20 in southeast Loving County does not yield water from Cenozoic alluvium, the primary unit in the Allurosa aquifer, which is tapped in western Loving County and adjacent Winkler County. The alluvial fill is thin or absent in this area, because structural collapse due to salt dissolution has been minor.

The high concentrations of dissolved solids in ground water in Loving County are typical of water within the Delaware Basin. TDS is typically 3,000 ppm or more throughout much of the basin. The only major quantities of potable water are found in aquifers west of and along the Pecos River. While surficial eolian sands have high infiltration capacity, many of these sand areas are underlain by caliche, which restricts recharge of ground water. Much of the infiltration returns to the atmosphere by evapotranspiration (Powers and others, 1978). In Ward County the Quaternary windblown silts and sands do yield small quantities of fresh water to pits and shallow wells (White, 1971). It is possible that lenses of fresh water in eolian sands may be perched above calichified impermeable horizons.

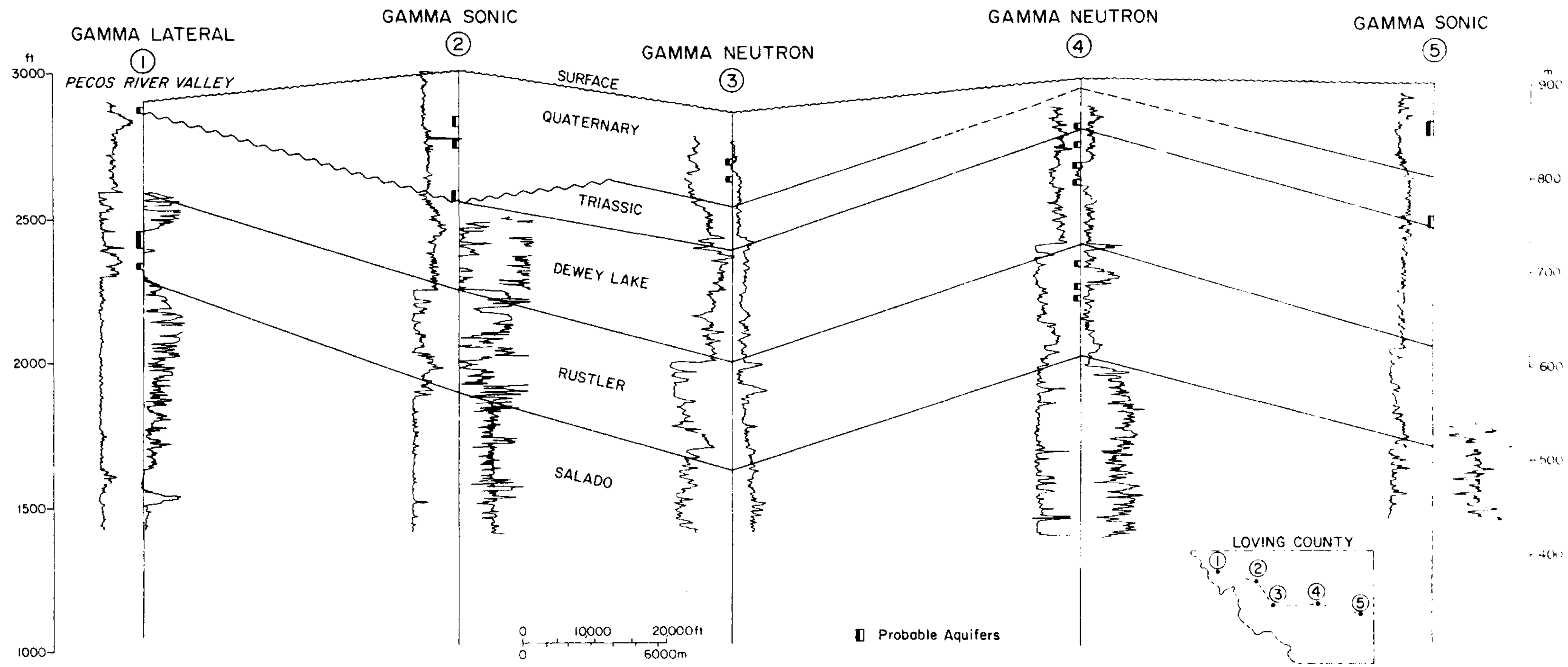


Figure 35. Aquifers and shallow stratigraphy of Loving County (modified from Hills, 1961).

The Guadalupian Capitan Limestone, representing the reef facies along the margin of the Central Basin Platform (fig. 36), yields large quantities of moderately to very saline water to wells in Ward County (White, 1971). In Winkler County the Capitan is found at depths greater than 610 m (2,000 ft), and is not extensively developed due to depth and poor water quality (Garza and Wesselman, 1959). Other parts of the Upper Guadalupian Series (primarily the Delaware Mountain Group, fig. 37) range in thickness from 1,070 to 1,160 m (3,500 to 3,800 ft) in southeast Loving County and contain water with approximately 200,000 ppm total dissolved solids. The porosity and permeability of the Delaware Mountain Group are highly variable depending on the facies. Salinity data for deeper strata are summarized in table 38.

Hydrology (Surficial)

Block 20 of Loving County is located within the Pecos River basin, a subbasin of the Rio Grande basin. Drainage over the eolian deposits of Sections 5-8, Block 8, is nonintegrated and primarily internal within the porous surficial sands. Short segments of unnamed intermittent streams are present west of Sections 5-8 and one is present northeast of Sections 5-8. Small closed depressions approximately 75 m (250 ft) in diameter may contain intermittent ponds (fig. 34).

Because of low rainfall, internal drainage of the surficial deposits, and high rates of evaporation, surface water flow is sporadic; hence, there are no streamflow or surface water quality measurements for eastern and central Loving County. Data are available for stations along the Pecos River, which forms the western boundary of Loving County, but these measurements are not representative of the intermittent surface flows in Block 20. A subbasin of the Pecos River basin that includes most of Loving, Winkler, Ward, and Crane Counties has zero average annual runoff (Lockwood, Andrews and Newnam, 1960).

Whether substantial recharge of the underlying Santa Rosa Sandstone and Rustler Formation is occurring through the surficial deposits of southeastern Loving County is unknown. Where caliche underlies the surficial deposits the infiltration of water would only be moderate to low (Kier and others, 1976).

Land Resources

Southeast Loving County, including Block 20, lies in an area of windblown sand, with a strong relict eolian grain, and calichified bedrock/alluvial material. The center of Sections 5-8 contains eolian sediments that are characterized by low slope stability, moderate foundation strength, easy excavation potential, and high infiltration capacity

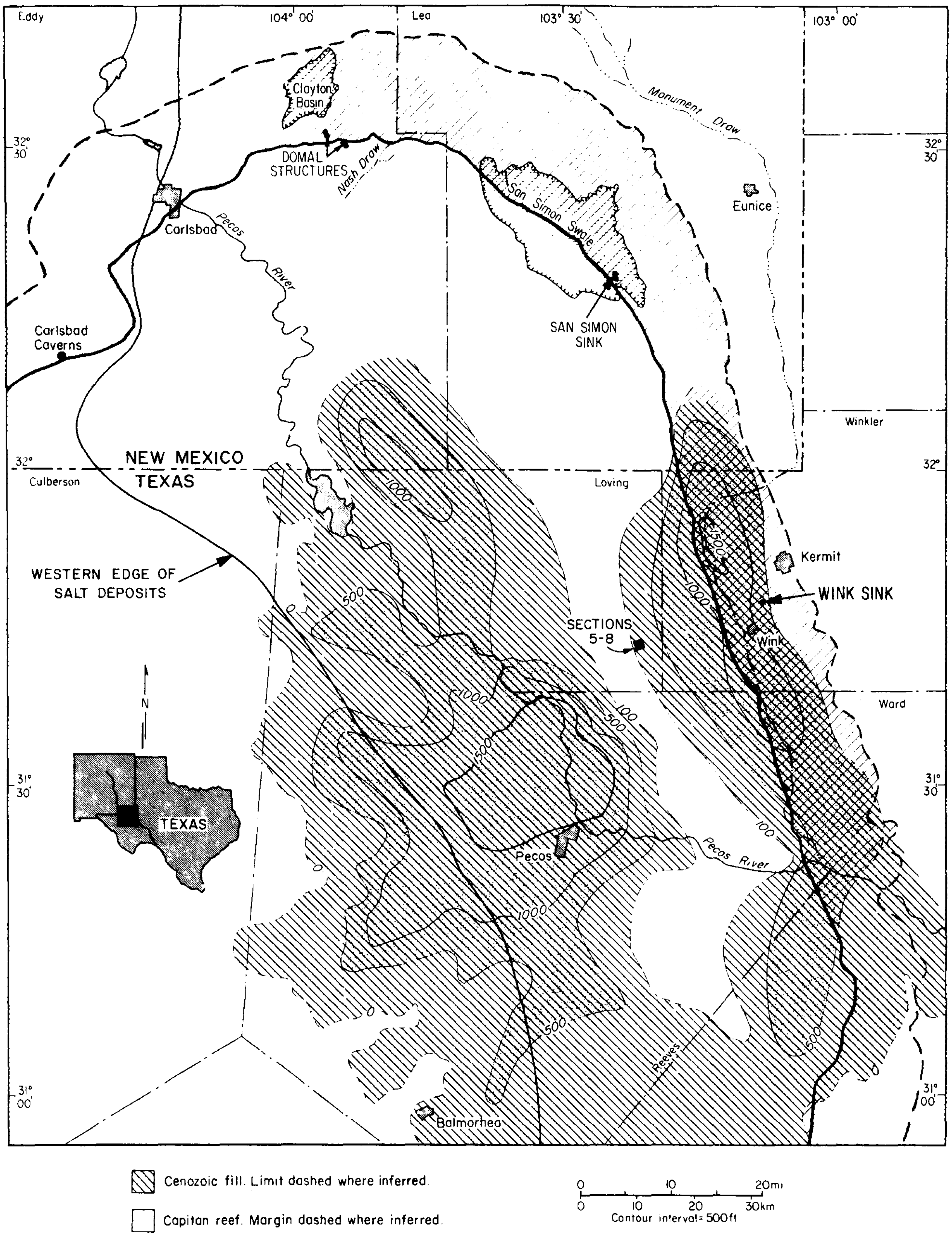


Figure 36. The northeastern Delaware Basin, bounded by the Capitan Reef trend, includes areas of Cenozoic clastic fill. The fill overlies salt dissolution zones at depth (from Baumgardner and others, in press; original data primarily from Maley and Huffington, 1953).

SYSTEM	SERIES	FORMATION
PERMIAN	OCHOA	DEWEY LAKE RUSTLER SALADO CASTILE
	GUADALUPE	DELAWARE MT. GROUP -BELL CANYON -CHERRY CANYON -BRUSHY CANYON
	LEONARD	BONE SPRING
	WOLFCAMP	WOLFCAMP
PENNSYLVANIAN	VIRGIL	CISCO (ABSENT OR THIN)
	MISSOURI	CANYON (ABSENT OR THIN)
	DES MOINES	STRAWN
	ATOKA	ATOKA — BEND
	MORROW	MORROW — BEND
MISSISSIPPIAN	CHESTER MEREMEC OSAGE KINDERHOOK	CHESTER MEREMEC- OSAGE "BARNETT"
		KINDERHOOK
DEVONIAN		WOODFORD DEVONIAN
SILURIAN		MID. SILURIAN FUSSELMAN
ORDOVICIAN	UPPER	SYLVAN MONTOYA
	MIDDLE	SIMPSON
	LOWER	ELLENBURGER
CAMBRIAN	UPPER	CAMBRIAN

Figure 37. Stratigraphic sequence and nomenclature of the Delaware Basin (from Waldschmidt, 1966).

Table 38. Generalized salinities of formation waters below the Ochoan Series in southeast Loving County (from Texas Water Development Board, 1972).

Rock System or Series	Formation	Salinity (ppm)
Upper Guadalupe		200,000
Leonard		150,000
Wolfcamp*	---	--------
Pennsylvanian**	---	150,000+
Mississippian**	---	50,000 - 150,000
Siluro-Devonian**	---	25,000 - 50,000
Upper Ordovician	Montoya	40,000 - 150,000 (?)
Middle Ordovician	Simpson	50,000 - 200,000+ (?)
Lower Ordovician	Ellenburger	150,000 - 200,000

*thin or absent

**undifferentiated

(Kier and others, 1977). The area is subject to wind erosion and dune migration. Small-scale irregular topography and closed depressions characterize the land surface. Rangeland is the most suitable land use.

Areas surrounding Sections 5-8 that may be traversed in accessing these sections include calichified bedrock and alluvial sediments. These areas have high slope stability, high foundation strength, moderate to difficult excavation potential, and moderate to low infiltration capacity. Calichification is a continuing natural process on these lands, and soils are thin and stony. The caliche may be locally used as a road base material (Kier and others, 1977). A recent soil survey of Loving County has not been published.

Mineral Resources

Mineral resources in the vicinity of Block 20 in southeast Loving County include caliche and possibly potash, primarily north of Block 20. None of the principal mineral producers in Texas were operating in Loving County as of December 31, 1976 (Hawkins and Evans, 1980). Gravel pits noted on topographic maps of Loving County probably indicate intermittent production of caliche for local use as aggregate and road base. No sand and gravel resources occur in eastern Loving County (Gustavson, 1976).

No potash production has been established in Texas, due largely to mining of the deposits in New Mexico, which are thicker, richer, and mineralogically more suitable than those in Texas (Groat and others, 1971; Garner and others, 1979). One reported show of potash on University lands in Loving County has been noted in Block 19, Section 4, at a depth of 1,084 m (3,558 ft). This location is approximately 7 km (4.5 mi) west of Sections 5-8, Block 20. Potash in Winkler County has been reported in Section 11, Block 20, approximately 5.5 km (3.4 mi) east of Sections 5-8, Block 20 (Groat and others, 1971).

Although salt is present in the subsurface in Block 20, its isolation relative to abundant deposits closer to existing markets makes development unlikely. There has been some uranium exploration in the Triassic sands and clays in the region of Loving, Ward, and Winkler Counties, but the economic potential is minimal (Groat and others, 1971).

The carbonate rocks in the northern part of Block 20 are mostly surficial deposits, including calichified alluvium. These deposits have limited industrial suitability because the carbonate content is below 85 percent.

Land Use

The land in Block 20, Loving County, is used as rangeland (Texas Department of Water Resources, 1977). This block and other lands in the vicinity have been intensively explored for oil and gas. Surface improvements are minimal, consisting of unimproved roads and trails, stock tanks, and fencing. No wells have been drilled for hydrocarbon exploration in Sections 5-8 of Block 20.

The center of Sections 5-8 is approximately 6 km (4 mi) south of Ranch Road 1211, which runs from Mentone in Loving County to Kermit in Winkler County. This location is approximately 4 km (2.5 mi) east of a private gravel road leading from Ranch Road 1211 to the Meridian oil field.

Population

Sections 5-8 of Block 20, Loving County, are located approximately 25.7 km (16 mi) east of the town of Mentone. In 1977, Loving County had a population of 100, 60 of whom lived in Mentone. Loving County has an area of 1,678 km^2 (648 mi^2). The trend in population change since 1950 indicates a steady to declining population level. Odessa and Midland, Texas, which are nearby Standard Metropolitan Statistical Areas (SMSA's), have been increasing during that same time period. The 1977 population for adjacent counties in Texas was 9,600 for Winkler County and 15,800 for Reeves County. Loving County also borders on Eddy County, New Mexico, wherein Carlsbad is located (Arbingast and others, 1976; Dallas Morning News, 1980). Population centers near Block 20 are listed in table 39.

Salt Depth, Composition, and Geometry

Salt within the Salado and Castile Formations is present in southeast Loving County near the eastern margin of the Delaware Basin (fig. 36). An area within University Land, Block 20, Sections 5-8 (fig. 38), has been studied in detail. No wells have been drilled within this block of four sections; however, salt depth can be estimated from cross sections to the south and north. In the Pennzoil-United Inc., University #19-1 well, an interval of relatively clean salt is present 640 to 715 m (2,105 to 2,350 ft) deep (fig. 39). Approximately 7 km (4.5 mi) to the north-northeast, in the Hill and Meeker, Bowdle #1 well, the same salt sequence is present at a depth of 640 to 716 m (2,095 to 2,348 ft) (fig. 40). A difference in ground elevation of 23 m (76 ft) between these wells indicates that these strata have a component of dip of 0.2^{o} between these wells.

This salt sequence is readily correlated between wells, because it is bounded by easily recognizable anhydrite beds. In addition, a thin bed, possibly consisting of dolomitic mudstone, retains a distinctive log character throughout the area.

Salt present at depths near 600 m (2,000 ft) in Block 20, Loving County is part of the Salado Formation. The Salado Formation is within the Upper Permian Ochoan Series (fig. 37), and has a maximum thickness of approximately 670 m (2,200 ft). The Salado Formation is composed of salt with subordinate amounts of anhydrite, and includes some potash minerals, such as sylvite (KCl) and the more common polyhalite ($K_2 Ca_2 Mg (SO_4)_4 \cdot 2H_2O$) (T. S. Jones, 1953). Thin stringers of sand and mud may also be present. Dolomite or magnesite stringers or diffused grains are present in most of the anhydrite beds, especially at the north end of the Delaware Basin (Adams, 1944). Potash salts are mined in the northern Delaware Basin of southeast New Mexico.

Salt beds in the south-central part of the Delaware Basin are much cleaner than those near the north rim (Adams, 1944). Halite constitutes 85 to 90 percent of the Salado where its composition is well known (Powers and others, 1978).

Table 39. Population centers near Sections 5-8, Block 20, Loving County, Texas.

Within 16-km (10-mi) radius		
	None	
	Within 50-km (32-mi) radius	
Town	County	Population
Mentone	Loving	50
Wink	Winkler	1,055
Kermit	Winkler	7,700
Pyote	Ward	159
Wickett	Ward	605
Barstow	Ward	671
Monahans	Ward	8,151
Pecos	Reeves	12,645
	Other major cities	
City	Distance, km (mi)	Population (1977)
Midland	130 (80)	72,500
Odessa	96 (60)	103,300

Few data are available on the detailed composition of salts of the Salado Formation along the eastern margin of the Delaware Basin. Many of the detailed studies of the Salado Formation have been done as part of studies of potash deposits near the northern basin margin, and as part of analysis of the Waste Isolation Pilot Plan (WIPP) Site, which is located approximately 100 km (60 mi) north-northwest of Block 20, in Eddy County, New Mexico. Many beds within the Salado Formation are laterally persistent over wide areas (Adams, 1944; C. L. Jones and others, 1973, and Powers and others, 1978), therefore these studies and compilations can be used to establish a general framework for the Salado Formation in Block 20.

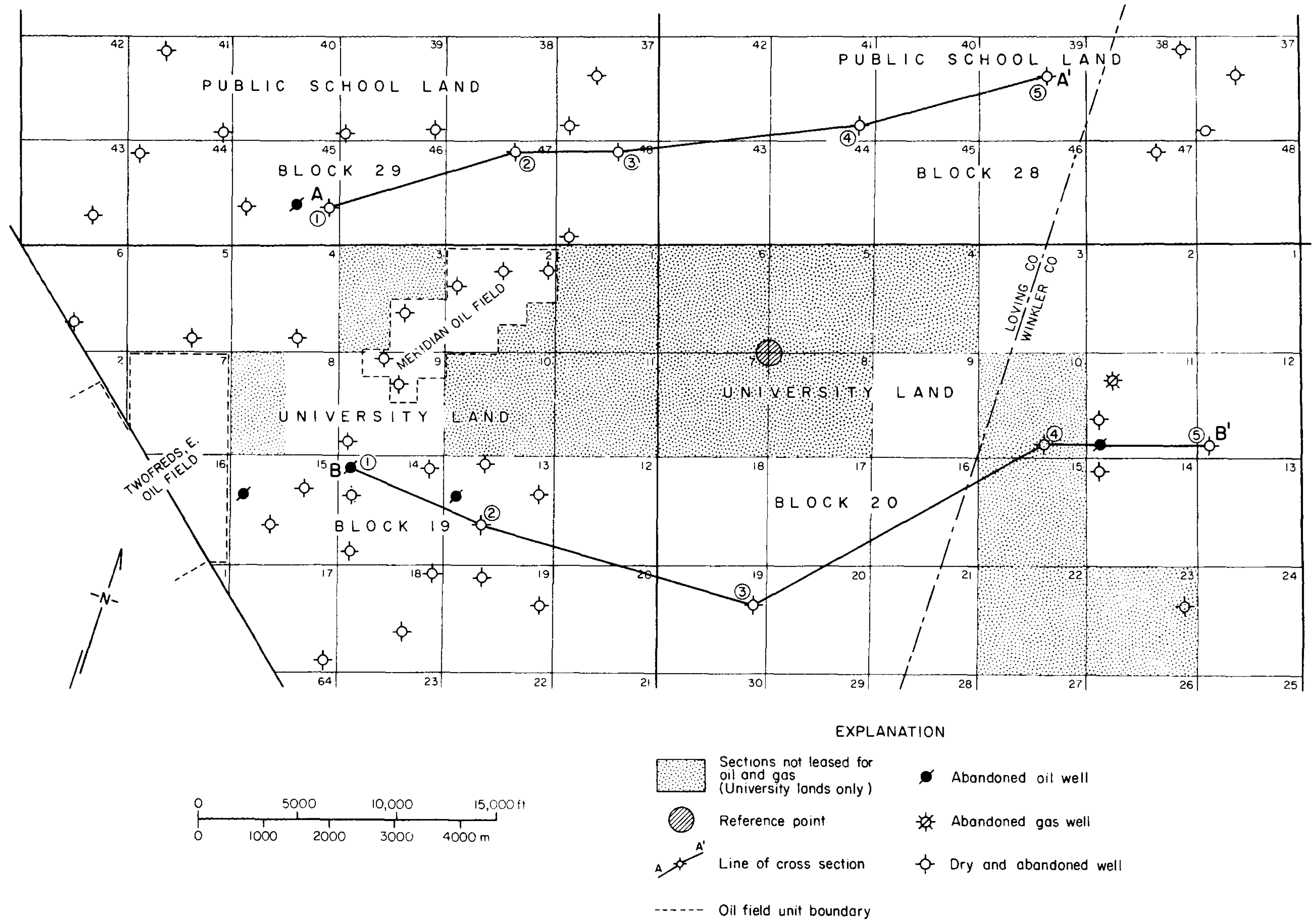


Figure 38. Land tracts in part of Block 20 and adjacent blocks, southeastern Loving County. Reference point marks center of Sections 5-8. All wells outside existing fields are shown.

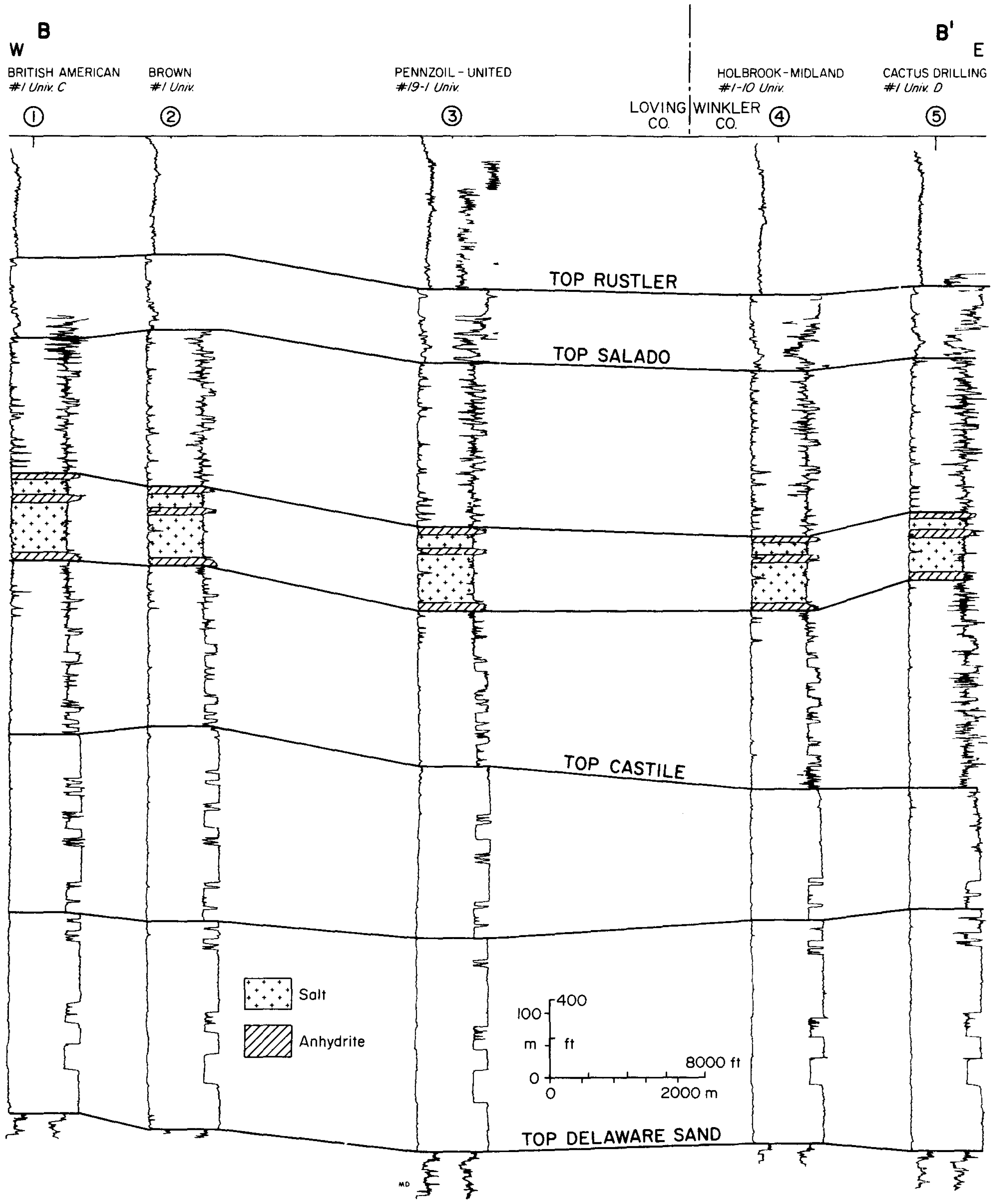
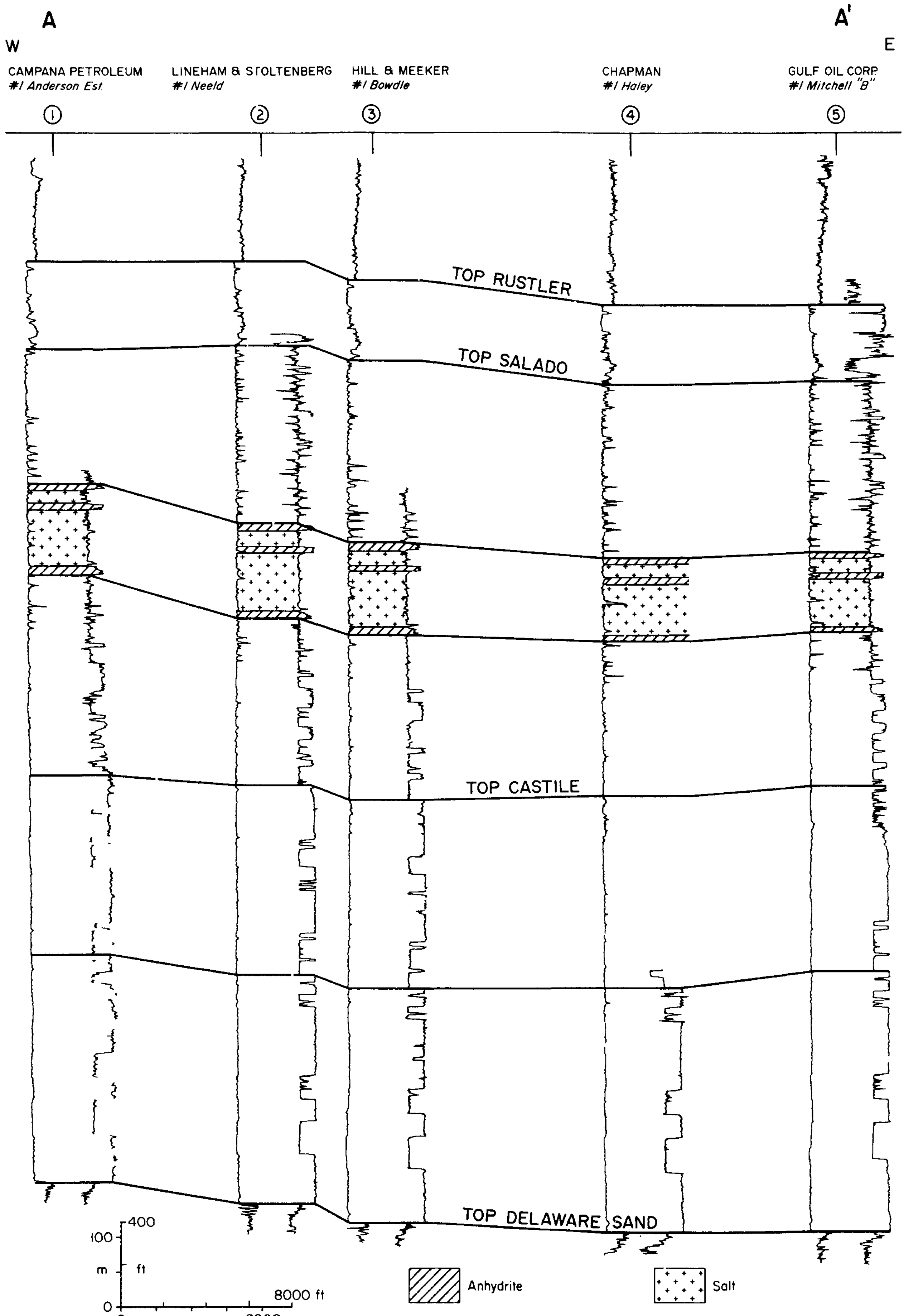


Figure 39. Section B-B', Blocks 19 and 20, Loving County. Location shown in figure 38. All logs are gamma-ray sonic.


A
A'
W
E
CAMPANA PETROLEUM
#1 Anderson Est.
LINEHAM & STOLTENBERG
#1 Neeld
HILL & MEEKER
#1 Bowdle
CHAPMAN
#1 Haley
GULF OIL CORP
#1 Mitchell "B"
TOP RUSTLER
TOP SALADO
TOP CASTILE
TOP DELAWARE SAND
100
m
0
400
ft
8000 ft
0
2000 m
Anhydrite
Salt

The Salado Formation is divided into three members:

. . .an unnamed lower member, a middle member known locally [in southeastern New Mexico] as the McNutt potash zone, and an unnamed upper member. The three members are about equally rich in rock salt, anhydrite, polyhalite and fine-grained clastic rocks, and they are generally similar in all but one major respect. The lower and upper members are generally lacking or poor in sylvite, carnallite and other potassium- and magnesium-bearing minerals, while the McNutt potash zone is generally rich in these minerals. . . (Powers and others, 1978).

In southeast New Mexico the lower member of the Salado Formation is composed almost entirely of halite with thinner seams of anhydrite and polyhalite (C. L. Jones and others, 1973). In the Los Medaños area, east of Carlsbad in Eddy and Lea Counties, New Mexico, the lower Salado is generally free of carnallite and other hydrous potassium and magnesium evaporite minerals (C. L. Jones and others, 1973). Seams and partings of claystone underlie the anhydrite and polyhalite beds, and thin mudstones cap muddy halite where it occurs. Similar stratigraphy is found in Block 20, based on log interpretation of the Pennzoil-United University #19-1 well (fig. 39).

The middle member of the Salado Formation is known as the McNutt potash zone. It contains at least six distinct ore zones that have been mined for sylvite and langbeinite (Cheeseman, 1978). Apart from the potassic rocks, the McNutt is similar to other members of the Salado and consists of halite alternating with beds of anhydrite and polyhalite (Powers and others, 1978).

The upper Salado Formation generally consists of halite, minor anhydrite, and polyhalite, but, unlike the other members, includes two persistent beds of fine-grained halitic sandstone in the potash-producing areas (C. L. Jones and others, 1973). Traces of potash minerals occur in the upper Salado in parts of Eddy and Lea Counties, New Mexico. A thin sandstone, rarely more than 3 m (10 ft) thick, is widespread over the northeastern Delaware Basin and marks the base of the upper Salado Formation (Adams, 1944).

A study of large-scale geophysical well logs for wells 2, 3, and 4 of figure 39 illustrates some of the local variations in lithology of part of the middle and the upper part of the lower Salado Formation (fig. 41). Shown are three prominent anhydrite beds and a halite sequence. The objective interval for a possible salt test facility is located between the lower and middle anhydrites. With only a gamma-ray-sonic log, a tentative interpretation of lithologies can be made, suggesting that relatively pure salt

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Figure 40 (left). Section A-A', Blocks 28 and 29, Loving County. Location shown in figure 38. All logs are gamma-ray sonic.

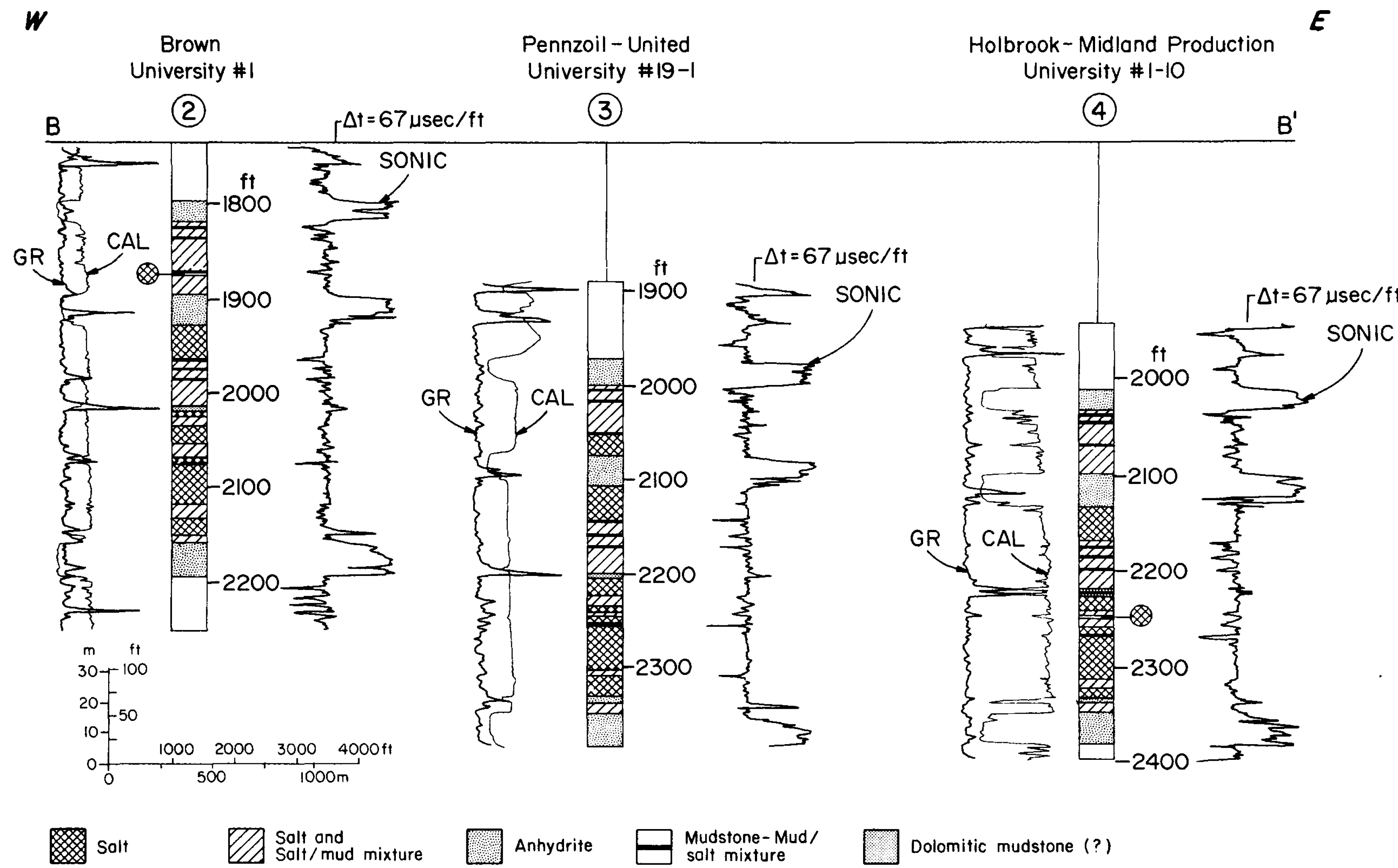


Figure 41. Lithologic interpretation for wells 2-4 of an anhydrite and salt sequence highlighted on cross section B-B' (fig. 39). The objective interval is the sequence from 2,105 to 2,350 ft on strike with well no. 3. GR denotes the gamma-ray trace and CAL denotes the caliper trace.

extends from 687 to 711 m (2,253 to 2,332 ft) in the Pennzoil-United University #19-1 well, an objective interval of 24 m (79 ft). Thin beds of mud, some muddy salt, and a dolomitic mudstone (?) are present above this depth interval. This well is approximately on strike with Sections 5-8 of Block 20. The relatively pure salt occurs in the same stratigraphic position in adjacent wells (Nos. 1 and 5) in cross section B-B' and also along the line of cross section A-A' (fig. 40). These relationships indicate that the relatively pure salt is laterally persistent through Block 20 into Block 28 (fig. 38) and through Sections 5-8 of Block 20.

Geophysical well logs from Loving County were compared to the core log and geophysical well logs of the DOE-Gruy Federal, #1 Rex White well in Randall County, Texas (Gustavson and others, 1980) to help interpret the salt stratigraphy of Block 20. The salt in the objective interval appears to be relatively pure and some of the smallest variations of the gamma-ray curve may be due to minor amounts of polyhalite present within the salt section. The gamma-ray logging tool is highly sensitive to emissions from potassic salts such as polyhalite. The content of mud within the salt cannot be precisely evaluated for the objective interval in Block 20, Loving County by this comparison. A suite of several logs would be required for an improved evaluation and actual core required for a final determination.

These conclusions are supported by analysis of cable-tool samples from the Durham, Inc., No. 19-1 well drilled in November 1980. This well is located in Section 14, Block 19 (fig. 38). A sample log of part of the Salado Formation shows a sequence of salt and 3 anhydrite beds (table 40) correlating with the sequence highlighted in section B-B' (fig. 39). Study of the interval between the lowermost and middle anhydrites which is equivalent to the objective interval in Sections 5-8, Block 20, shows only a trace of clastic impurities within the salt (table 41). Red-brown to brown mudstone was found within or adhering to very few halite grains. The orange to pale yellow stain on 1 to 2 percent of the halite grains resembles an iron stain. Iron-stained salt was found in salt cored in the DOE-Gruy Federal, #1 Rex White well in Randall County, Texas (M. W. Presley, personal communication, 1980).

Part of the stratigraphic sequence listed in table 40 for the Durham, Inc., University No. 19-1 well was subsampled for chemical and x-ray diffraction analysis. Representative splits of the cable-tool samples were analyzed for the intervals listed in table 42. Results confirmed the mineralogy determined visually, and indicated the presence of minor to trace amounts of the potash-bearing minerals polyhalite and sylvite or langbeinite. Immediately above the lowest anhydrite informally termed "1st anhydrite" (sample k) is a salt sequence stratigraphically equivalent to the objective

Table 40. Generalized sample log of part of the Salado Formation from the Durham, Inc. No. 19-1 well in Block 19, Loving County, Texas.

Depth, ft	Lithology
1,715-1,809	salt
1,809-1,840	3rd anhydrite
1,840-1,928	salt
1,928-1,975	2nd anhydrite
1,975-2,225	salt*
2,225-2,293	1st anhydrite
2,293-2,395	salt

* equivalent to objective interval in Sections 5-8, Block 20, Loving County

Table 41. Sample log of part of the Salado Formation, from the Durham, Inc. No. 19-1 well. Percentages are visual estimates.

Depth, ft	Lithology	
1,956-1,975	100%	anhydrite, light gray
	trace	mudstone, light gray
1,975-1,995	98%	halite, clear to white
	2%	halite, light yellow to yellow-orange
1,995-2,015	99%	halite, clear to white
	1%	halite, light yellow to orange
2,015-2,035	98%	halite, clear to white
	2%	halite, light yellow-orange to orange
	trace	mudstone, white to light gray
2,035-2,062	98%	halite, clear to white
	2%	halite, light yellow-orange to orange
2,062-2,081	99%	halite, clear to white
	1%	halite, yellow-orange to light yellowish-pink
	trace	mudstone, white to bluish white
2,081-2,102	98%	halite, clear to white
	2%	halite, yellow-orange to light yellow
	trace	halite, with brown to red-brown mud adhering to halite
2,102-2,135	98%	halite, clear to white
	2%	halite, yellow-orange to light yellow
	trace	halite, with brown to red-brown mud adhering to or included in grain

Table 41. (continued)

Depth, ft	Lithology	
2,135-2,160	99%	halite, clear to white
	1%	halite, yellow-orange to light yellow
	trace	halite, with brown mud adhering to grains
2,160-2,180	98%	halite, clear to white
	2%	halite, yellow-orange to light yellow
	trace	halite, with brown to red-brown mud adhering to or included in grains
2,180-2,200	98%	halite, clear to white
	2%	halite, yellow-orange to orange and light yellow
	trace	halite, with brown to red-brown and gray mud adhering to or included in grains
2,200-2,225	98%	halite, clear to white
	2%	halite, yellow orange to light yellow
	trace	halite, with brown to red-brown mud adhering to or included in grains
2,225-2,240	100%	anhydrite, light gray to white

Table 42. Chemical element analysis by inductively coupled plasma-atomic emission spectroscopy of selected intervals in the Salado Formation drilled in the Durham, Inc. University No. 19-1 well. Results rounded to nearest 1/100 of 1 percent.

Sample	Depth, ft	Na	K	Mg	Ca	Al	Fe
AA[1]	1735 - 1750	29.92	2.76	1.14	7.02	.02	.03
A[1]	1790 - 1809	32.09	3.00	1.08	4.84	.01	.02
B[1]	1825 - 1840	.06	.02	1.84	29.50	.02	.02
C[1]	1840 - 1850	19.19	1.70	1.02	13.00	.01	.04
D	1870 - 1885	46.78	.03	.16	1.86	.02	.02
E	1928 - 1942	3.14	.77	.78	25.72	.03	.02
F	2035 - 2062	47.62	.02	.04	.03	.01	.01
G[1 2]	2135 - 2160	48.55	.03	.02	.08	<.01	.01
H[1 2]	2160 - 2180	48.25	.03	.02	.06	<.01	.01
I[1 2]	2180 - 2200	47.82	.02	.02	.09	<.01	.01
J[1 2]	2200 - 2225	48.96	.02	.02	.09	<.01	.01
K[1]	2225 - 2240	1.07	.07	.05	30.18	.04	.02
L	2293 - 2315	39.95	.04	.02	3.72	.06	.04

[1]Mineralogy interpreted from these results and X-ray diffraction analysis, table 43.
[2]Stratigraphically equivalent to objective salt interval in Sections 5-8, Block 20, Loving County.

salt interval in Sections 5-8 of Block 20. This sequence is represented by samples G through J at depths of 650 to 678 m (2,135 to 2,225 ft) in the Durham, Inc. well (table 42). Chemical analysis indicates that these salts are the purest of any analyzed with only 0.02 to 0.03 percent each of K and Mg. Aluminum was present at a level of less than 0.01 percent, suggesting that this interval is relatively free of aluminosilicates such as clays. X-ray diffraction of selected samples from among those chemically analyzed shows that samples G through J consist of halite of high purity with no minor constituents and only a trace of sylvite or langbeinite (table 43). Differentiation of the latter minerals will require additional x-ray diffraction analysis; the primary peak for sylvite occurs at d = 3.15Å and for langbeinite at d = 3.14Å.

The Durham, Inc. University No. 19-1 well is located between wells nos. 1 and 2, cross section B-B', on figure 38. The similarity in log character for the objective salt interval along section B-B' suggests that Sections 5-8, Block 20 likely contains salt of a purity similar to that encountered in the Durham, Inc. well. Further studies could determine the lateral extent beyond blocks 19 and 20 of the interval of relatively high purity salt.

Data on fluid inclusions within the Salado Formation come primarily from the region around the WIPP site. Samples from cores AEC No. 7 and No. 8 of the Salado Formation at the WIPP site had a water loss of 0.0 to 3.5 weight percent (Kopp and Combs, 1975). Testing of the ERDA No. 9 core yielded 0.1 to 1.7 weight percent of fluid (Powers and others, 1978). The latter values may be low, however, as a result of the analytical methods used (R. Bassett, personal communication, 1980). Significant local variability in fluid content can be expected, based on analysis of very closely spaced samples, and the in situ fluid content of the Salado salt is very likely to be greater than the above values (Powers and others, 1978; Roedder and Belkin, 1979).

The Delaware Basin trends generally northwest for approximately 240 km (150 mi), and has a maximum depth estimated at over 7,600 m (25,000 ft). The rocks in the Delaware Basin (fig. 37) differ from the Central Basin Platform in that the Pennsylvanian carbonates grade into shale, limy shale, and sand where they enter the basin. The primarily dolomitic Permian section of the platform is equivalent basinward to a 2,400-m (8,000-ft) thick section of mostly terrigenous clastics. This includes the Wolfcamp, Leonard, and Guadalupe Series. The Delaware Sand forms the upper part of the Bell Canyon Formation (fig. 37) and has been an exploration target in Block 20. Along the platform margin, the Capitan Reef is formed by the Guadalupian Goat Seep Limestone and Capitan Limestone (Waldschmidt, 1966; T. S. Jones, 1953).

The youngest Permian series, the Ochoan Series, includes the Castile Formation, which is dominantly anhydrite and some salt, and occurs only in the Delaware Basin,

Table 43. Mineralogy based on X-ray diffraction analysis of selected intervals of the Salado Formation drilled in the Durham, Inc. University No. 19-1 well. Results expressed as major, minor, and trace components.

Sample	Depth, ft	Major	Minor	Trace
AA	1735 - 1750	halite	polyhalite	anhydrite and sylvite or lagbeinite
A	1790 - 1809	halite	polyhalite	anhydrite and sylvite or langbeinite
B	1825 - 1840	anhydrite	---	halite
C	1840 - 1950	halite	anhydrite	polyhalite and sylvite or langbeinite
G[1]	2135 - 2160	halite	---	sylvite or langbeinite
H[1]	2160 - 2180	halite	---	sylvite or langbeinite
I[1]	2180 - 2200	halite	---	sylvite or langbeinite
J[1]	2200 - 2225	halite	---	sylvite or langbeinite
K	2225 - 2240	anhydrite	---	halite

[1]Stratigraphically equivalent to objective salt interval in Sections 5-8, Block 20, Loving County.

where it attains a thickness of 640 m (2,100 ft). Anhydrite within the Castile is typically "banded anhydrite," composed of alternating laminae of anhydrite and brown, bituminous calcite (T. S. Jones, 1953). Four major anhydrite units are recognized (Dean and Anderson, 1978).

Geophysical well logs show that the Salado Formation salt at depths of 640 to 715 m (2,105 to 2,350 ft) is continuous through University Lands Blocks 19 and 20 and into Public School Lands Blocks 28 and 29. Cross sections (figs. 39 and 40) show that the area surrounding the reference point in Block 20 is structurally low relative to points to the east and west. A component of dip to the south-southeast of less than 1^{o} exists between the two cross sections.

East and west of Block 20 salt dissolution has occurred creating troughs which are filled with Cenozoic clastic sediments (fig. 36). The axis of the nearest trough is approximately 16 km (10 mi) east of the reference point in Block 20, and overlies the reef margin of the Central Basin Platform in Winkler County (fig. 36). The accumulation of Cenozoic fill is a result of salt dissolution in the Castile and Salado

Formations (Maley and Huffington, 1953). The development of breccia beds and breccia pipes has resulted from the dissolution of Ochoan evaporites in the Delaware Basin (Anderson and others, 1978). One control on the dissolution process along the eastern margin of the Delaware Basin may be removal of salt by undersaturated ground water moving through the reef rocks (Hiss, 1975, cited in Anderson and others, 1978).

Detailed stratigraphic analysis will be required to evaluate possible salt dissolution in the vicinity of Block 20. Probably no more than 40 m (130 ft) of Quaternary deposits are present in the Pennzoil-United Inc., University #19-1 well (fig. 39), compared to a maximum of more than 490 m (1,600 ft) in northwestern Winkler County (fig. 36). Quaternary deposits are present at the surface throughout Loving County, therefore their deposition is not restricted to salt dissolution troughs.

Stratigraphy

Block 20 in Loving County is located along the eastern margin of the Delaware Basin and just west of the buried reef which marks the edge of the Central Basin Platform (fig. 36). The Central Basin Platform contains a folded and faulted core of dark marine shales, limestones, and dolomites with few sandstones and chert-bearing strata. This sequence is Cambrian through Pennsylvanian and is covered by a thick series of Permian rocks containing abundant dolomite (Waldschmidt, 1966).

Analyses of 19 selected core segments of Salado salt from the ERDA No. 9 well show dense zones of very minute (mostly less than 5 μm) fluid inclusions and randomly arrayed inclusions up to 2 mm. Inclusion water present in the salt slabs occurred principally (over 90 percent) as larger inclusions greater than 1 mm in size (Roedder and Belkin, 1979). Rates of migration of fluid inclusions have been measured as 1.2 to 5.4 cm/yr (0.47 to 2.13 in/yr) for cubic inclusions 1 mm on an edge (Roedder and Belkin, in press).

The Salado Formation occurs within the Delaware, Midland, and Palo Duro subbasins of the larger Permian salt basin of the southwestern United States (Johnson and Gonzales, 1978). The Salado reaches its maximum thickness in the Delaware Basin, and in the subsurface it crosses the Capitan Reef and is present over the Central Basin Platform, which separates the Delaware and Midland Basins (Adams, 1944).

The Salado Formation contains primarily salt, some anhydrite, and potash minerals which are mined extensively in New Mexico. The Salado contains three informal members; potash occurs primarily in the middle member, the McNutt potash zone. Further detail on the Salado Formation is included in the sections on salt depth, composition, and geometry. The Rustler Formation (dolomite, anhydrite, and a zone of basal clastics), and the Dewey Lake Formation (fine sandstone and siltstone) complete the Permian sequence of the Delaware Basin.

The uppermost stratigraphic units in the Delaware Basin include the Triassic Dockum Group (Tecovas Formation) and Santa Rosa Formation, both of which consist of terrigenous clastics. The Santa Rosa locally contains fresh to slightly saline water. Surficial Quaternary deposits of alluvial fill are found over salt dissolution troughs and Quaternary eolian and alluvial deposits mantle much of the present land surface. A lithologic log of the Pennzoil-United University, Inc., #19-1 well in Section 19, Block 20 provides details on rock types and bed thicknesses overlying the objective salt stratigraphy in Block 20 (table 44).

Local variations in stratigraphy include breccia beds and breccia pipes that form due to dissolution of salt and evaporites in shallow parts of the stratigraphic column. Shallow swales and basins may be formed at the surface, and the formation of collapse sinks has been recorded. The most recent of these is the Wink Sink (location shown in fig. 36), which has been attributed to salt dissolution in the Salado Formation at depths less than 460 m (1,500 ft) (Baumgardner and others, 1980).

Socioeconomic Setting

Loving County borders New Mexico not far from the WIPP site. The county is distant from any larger communities. Ranching is the principal business in this sparsely populated county of about 100 persons.

Most land in Loving County is owned and/or managed by the State, either as University Lands or Public School Lands. The Board of Regents controls University Lands, whereas Public School Lands are supervised by the Land Commissioner. In some instances the surface is leased for grazing; the subsurface is held by the State for potential energy and mineral resources.

Table 44. Stratigraphic interpretation of a gamma ray-sonic log from the Pennzoil-United Inc., University #19-1 well, Section 19, Block 20, Loving County, Texas (elevation: 2,791 ft MSL).

Depth, ft	Tops, ft	Lithology
0 - 170	---	Quaternary windblown silt and sand; Quaternary and Tertiary silt, sand and gravel, partially calichified.
170 - 325	Triassic: 170 (approximate)	Dockum Group including Santa Rosa Sandstone: medium- to coarse-grained micaceous well-cemented sandstone interbedded with shale and siltstone (White, 1971).
325 - 770	Dewey Lake: 325 (approximate)	Dewey Lake Redbeds: red shale, siltstone and very fine grained sandstone, some gypsum cement in lower part (White, 1971).
770 - 1,140	Rustler: 770	Rustler Formation: dolomite and anhydrite (770 to 910 ft); interbedded dolomite, anhydrite and shale or siltstone (910 to 1,010 ft); primarily shale or siltstone (1,010 to 1,140 ft).
1,140 - 3,170	Salado: 1,140	Salado Formation: salt with anhydrite interbeds (3 to 12 ft thick) and mud interbeds (<2 to 5 ft thick) (1,140 to 1,470 ft); anhydrite (1,470 to 1,500 ft); salt with anhydrite interbeds (up to 10 ft thick), mud interbeds (2 to 6 ft thick), and a possible zone of muddy dolomite and anhydrite (18 ft thick) (1,500 to 1,972 ft); for lithology from 1,972 to 2,350 ft see detail of objective section, well 3, cross section B-B'.

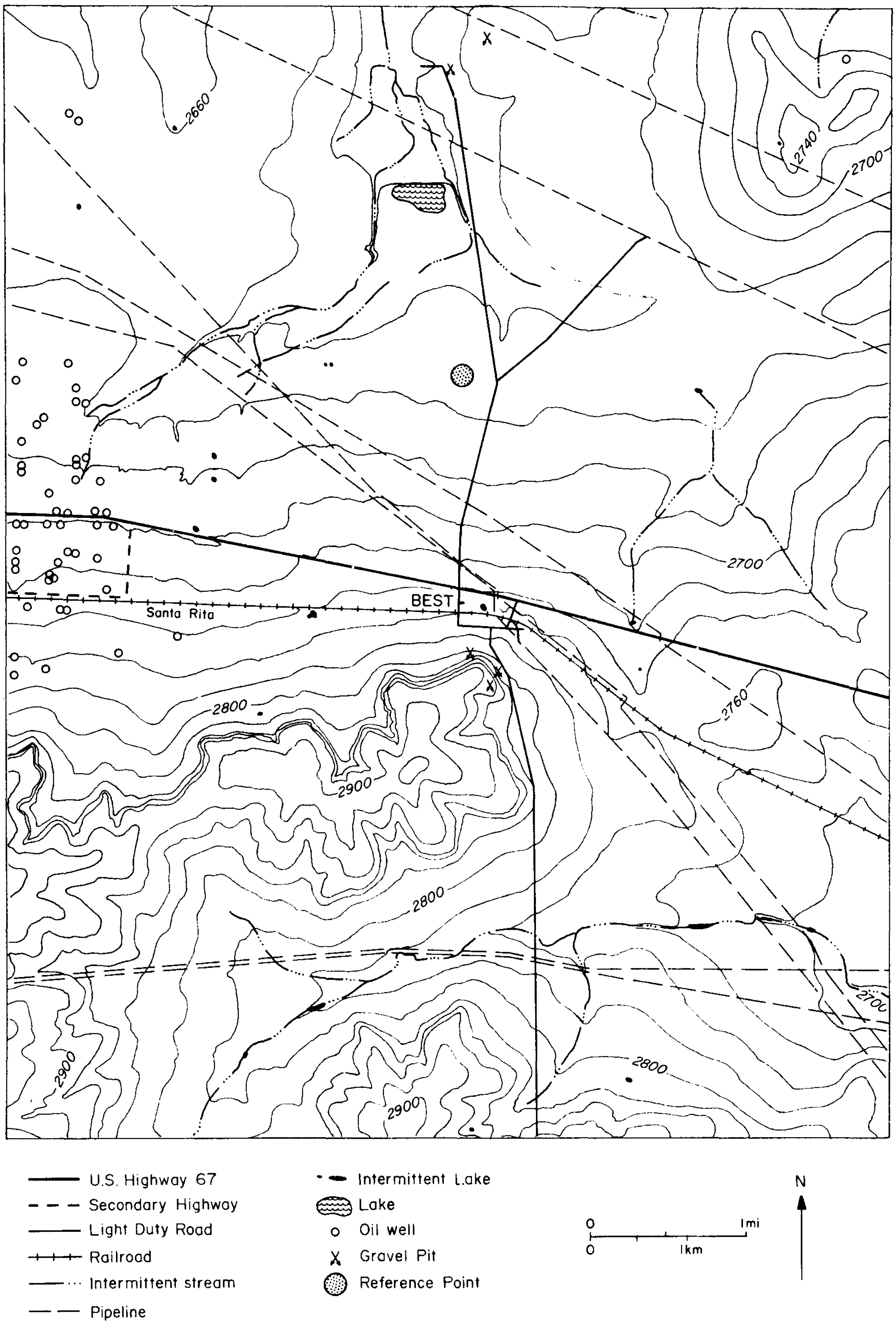


Figure 42. Topography and cultural features of part of Reagan County, Texas. The reference point is at the center of Sections 21-22 and 27-28, Block 9 (from U.S.G.S. 7.5-minute quadrangles, Texon, Best, Gardener Draw, and Garrison Draw, Texas). Contour interval is 20 ft.

BLOCK 9, REAGAN COUNTY

University Land, Block 9, in Reagan County, Texas is a tract of state-owned land underlain by bedded salt of the Salado Formation. It is in a semiarid part of West Texas (fig. 42). Salt quality in this area appears to be significantly lower than in Loving County; therefore, only stratigraphy and salt characteristics were studied.

Salt Depth, Composition, and Geometry

An additional locality on state lands, not presently hydrocarbon productive, was sought within the Permian Basin of West Texas. Block 9 in Reagan County (fig. 43) overlies the southern margin of the Midland Basin and includes Salado Formation (Ochoan) salt. Old sample logs from wells drilled with cable-tool equipment indicated a salt section in the Salado at depths less than 600 m (2,000 ft). These wells were drilled as part of exploration for potash within the Ochoan evaporites.

Examination of geophysical well logs from wells in Block 9 (fig. 44) shows, however, that the quality of the salt in the Salado Formation is significantly lower than that in Block 20 of Loving County. The highly irregular sonic log trace and greater gamma ray response of the Salado in Block 9 indicate interbedded mud within the salt sequence between the top of the Salado Formation (419 m; 1,374 ft) and the top of the Cowden anhydrite member (500 m; 1,640 ft) (fig. 45). The Cowden is a prominent and laterally persistent anhydrite within the lower Salado Formation.

The interval between the top of the Salado Formation and the Cowden member was examined in detail. Geophysical well logs were compared to the core-calibrated logs of the D.O.E.-Gruy Federal #1 Rex White well in Randall County. The sonic-gamma ray log patterns of two wells in Block 9 (fig. 44) are similar to log patterns in the Glorieta Formation and cycle 2 of the Upper Clear Fork Formation (Gustavson and others, 1980). The latter units are characterized by mostly chaotic mudstone/salt with interbedded siltstone and massive salt; these units generally contain 75 percent or less salt, and rarely contain as much as 90 percent salt. The similarity in log patterns suggests that the Salado salt in Block 9, Sections 21-22, is relatively impure.

Further analysis of the Block 9 location does not appear justified because of relatively low salt quality. Additional analysis of locations within the Midland Basin would require avoidance of existing hydrocarbon production in a basin that is heavily prospected, in conjunction with a search for better salt quality.

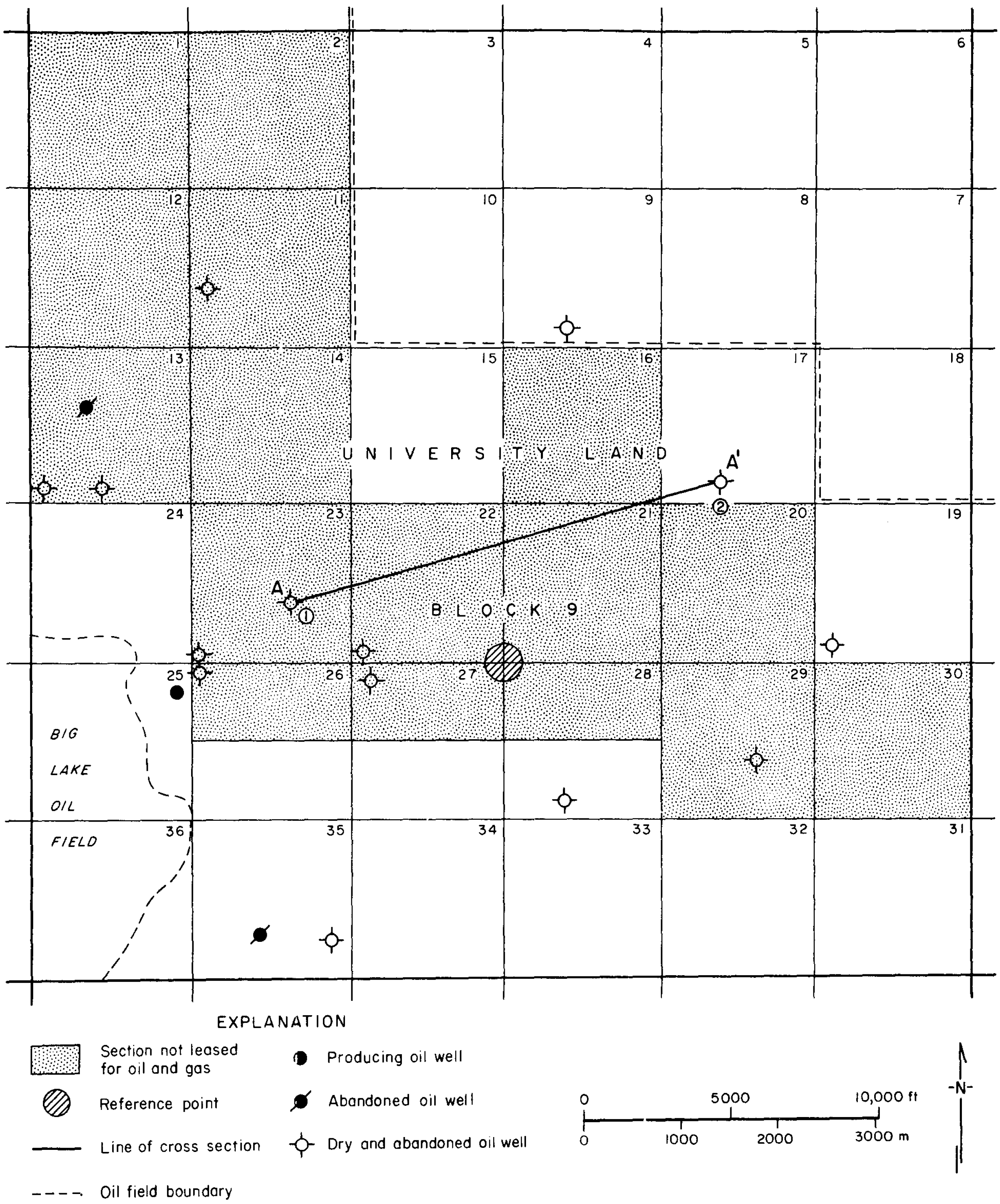


Figure 43. Land tracts in Block 9, Reagan County. Reference point marks center of Sections 21-22 and 27-28. All wells outside existing fields are shown.

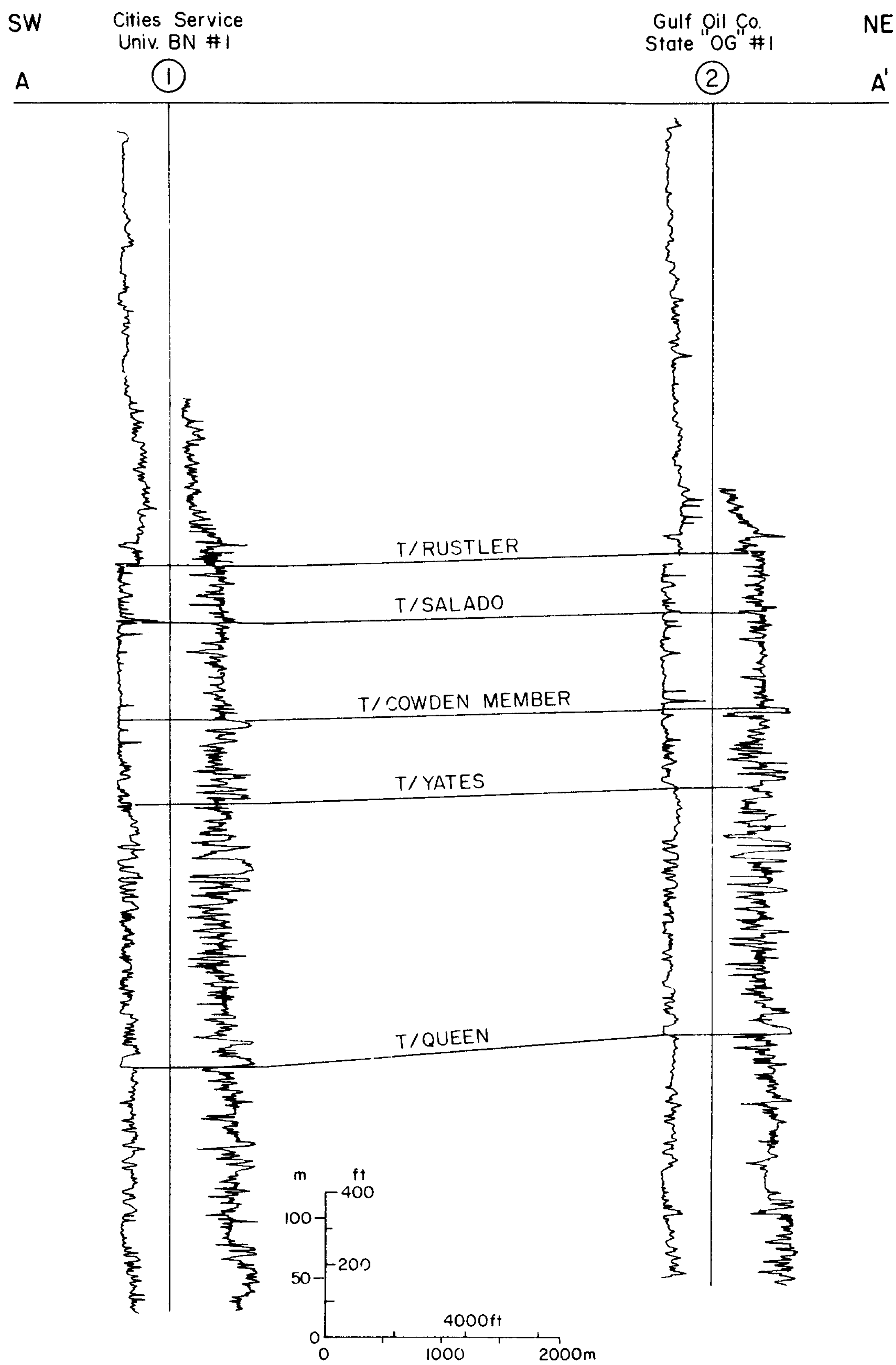


Figure 44. Cross section A-A', Block 9, Reagan County. Location shown in figure 43. Both logs are gamma-ray sonic.

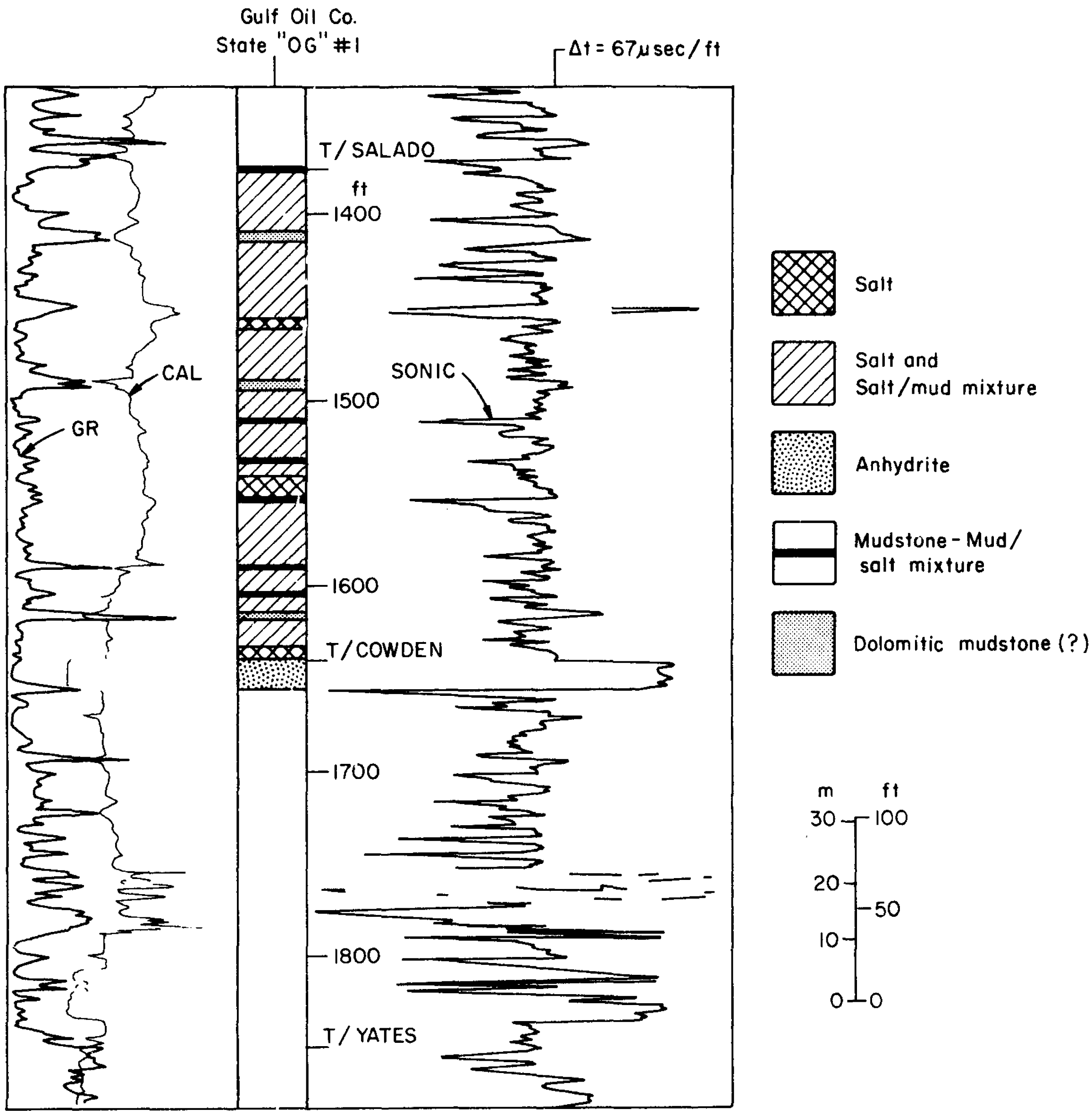


Figure 45. Lithologic interpretation for well no. 2, cross section A-A' (fig. 44) of the Salado Formation above the Cowden Member. GR denotes gamma ray trace and CAL denotes caliper trace.

EARTHQUAKE POTENTIAL, STATE OF TEXAS (ALL LOCALITIES)

The seismic risk map for the continental United States shows a large section of Texas in Zone 0, or that of no expected damage (fig. 46) (Coffman and Cloud, 1970). Zone 0 includes the Texas Coastal Plain and the locations of Gyp Hill, Palangana, and Hockley Domes. Two earthquakes of Intensity V did occur approximately 80 km (50 mi) west-southwest of Hockley Dome in 1914 (von Hake, 1977).

Parts of North and West Texas lie in seismic risk Zone 1. This is a zone of minor damage where earthquakes may cause damage to structures with fundamental periods greater than 1.0 second. In risk zone 1 the expected Modified Mercalli Intensities are V and VI (Coffman and Cloud, 1970). An Intensity V earthquake occurred southeast of Grand Saline Dome in 1957 (fig. 47). This earthquake consisted of four shocks over a 6-hour period and affected an area of 26,000 km^2 (10,000 mi^2) in northeastern Texas and nearby Arkansas and Louisiana (von Hake, 1977).

West Texas and the Trans-Pecos region have experienced earthquakes of Intensities VI through VIII (fig. 47). The 1966 earthquake near Kermit, Texas, had a magnitude of 3.4 and an intensity of VI (von Hake, 1977). The Texas Technological College Observatory at Lubbock, Texas, has recorded at least 11 additional earthquakes in the same general area (Shurbet, 1969). As Shurbet (1969) pointed out, it is possible that increased seismicity in the area is related to extensive injection of water as part of secondary recovery of hydrocarbons. Further work over the Central Basin Platform of the Delaware Basin by Rogers and Malkiel (1979) seems to support this suggestion, in that the best-located earthquakes occur at the depths of sedimentary rocks within zones of hydrocarbon production.

Keller (1980) reported that, based on an array of 12 seismograph stations in Winkler County, centers of earthquake activity have coincided with areas of hydrocarbon production near Jal, New Mexico, and War-Wink Field in northwest Ward and southwest Winkler Counties. These events have not been uniformly distributed with time during nearly 4 years of monitoring. Further correlation of earthquake events with records of increased reservoir pressures due to fluid injection will aid in determining more precise causes for earthquakes in the Permian Basin (Rogers and Malkiel, 1979).

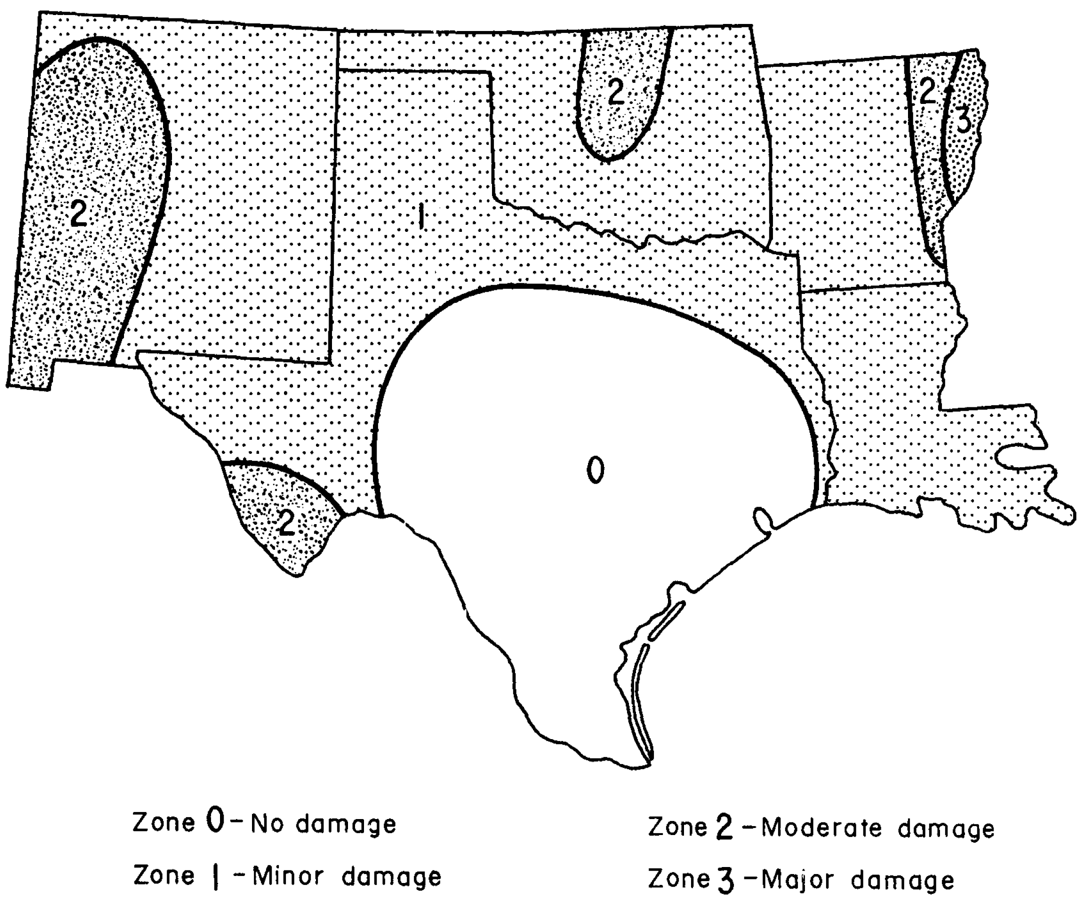


Figure 46. Seismic risk zone map for Texas and adjacent states (from Coffman and Cloud, 1970).

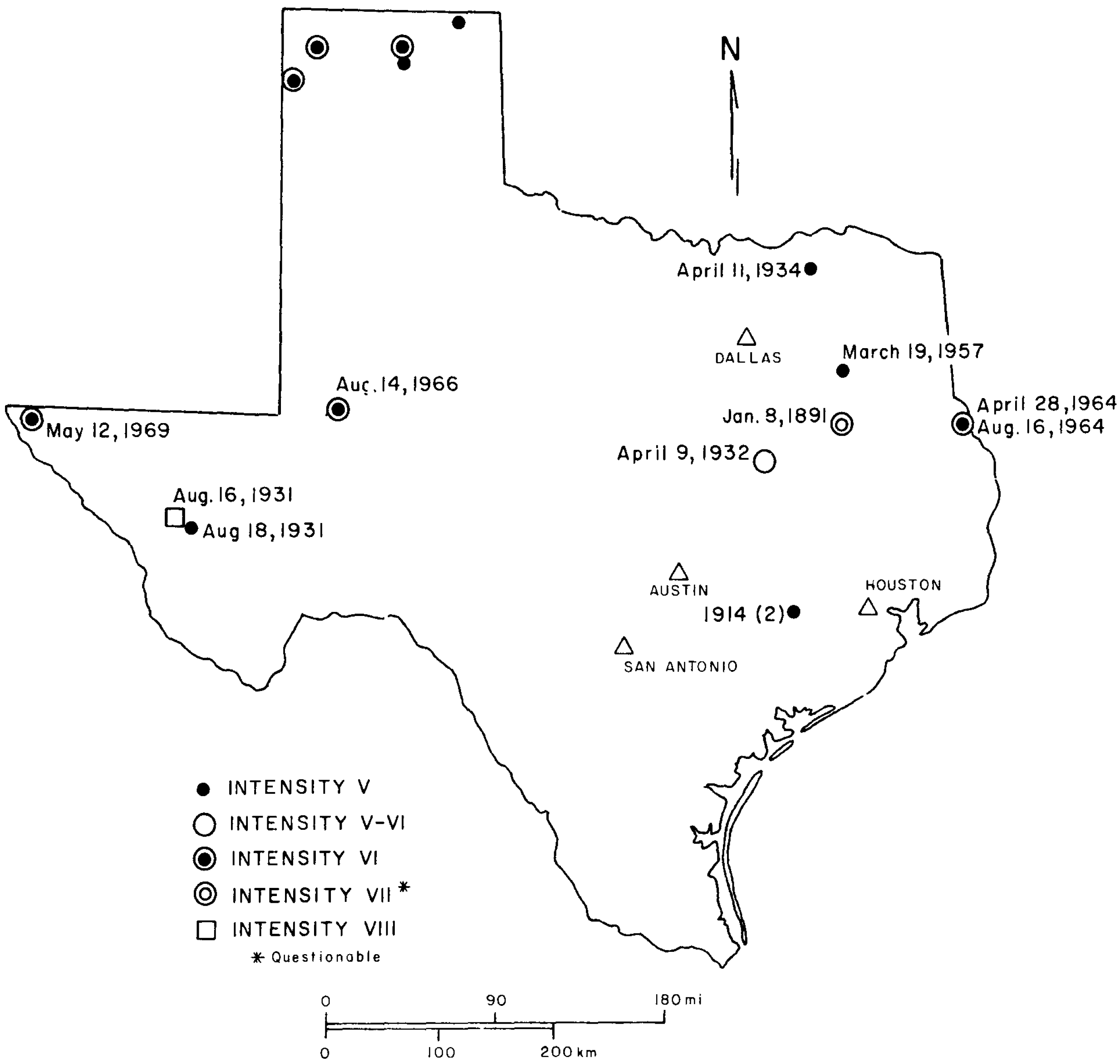


Figure 47. Earthquakes in Texas of Modified Mercalli Intensity V or greater (from von Hake, 1977).

ALTERNATIVE LOCALITIES

An alternative locality to those investigated in this feasibility study might involve salt deposits already under evaluation for potential nuclear waste isolation. Permian bedded salts are present in the Palo Duro and Dalhart Basins of the Texas Panhandle (fig. 48) in a series of facies-related genetic units consisting of salt, anhydrite and/or gypsum, minor amounts of limestone, and red beds (Presley, 1980a). These rocks represent cyclic deposition in shelf, supratidal, and terrestrial environments and have been investigated in detail (Dutton and others, 1979; Gustavson and others, 1980) (fig. 49).

The salt deposits present are extensive and comprise four major genetic units: Lower Clear Fork-Tubb, Upper Clear Fork-Glorieta, San Andres, and Post-San Andres (figs. 50-51) (Presley, 1980b). Within these units salt depth and thickness studies have delineated areas where more than 15 m (50 ft) of net salt occurs at depths between 305 and 915 m (1,000 and 3,000 ft) (Presley, 1980a). These studies show that in most areas of the Texas Panhandle there are major deposits of salt present, bounded by lateral pinch out of salt beds and salt dissolution zones. Salt deposits of the above depth and thickness occur progressively further south toward the southern boundary of the Palo Duro Basin in each progressively younger salt-bearing unit.

The quality of salt in the Palo Duro Basin has thus far been verified by two continuous cores to depths of 1,220 m (4,000 ft). Massive salt with minimal impurities was found, for example, over a 60 m (200 ft) interval of the Lower San Andres in the D.O.E.-Gruy Federal, #1 Rex White well in Randall County. This interval is included between the depths of approximately 535 to 595 m (1,750-1,950 ft).

In the East Texas basin (fig. 52), Kreitler and others (1980) have examined all shallow salt domes as potential sites for the deep geological isolation of nuclear waste. Compared to locating a salt test facility, however, the filter had stricter requirements to locate only large shallow domes of which Oakwood (fig. 53) and Keechi (fig. 54) salt domes appear most suitable. As the geotechnical requirements for a salt test facility can require a smaller dome, other possible East Texas domes would include Bethel, Bullard, Hainesville, and Whitehouse.

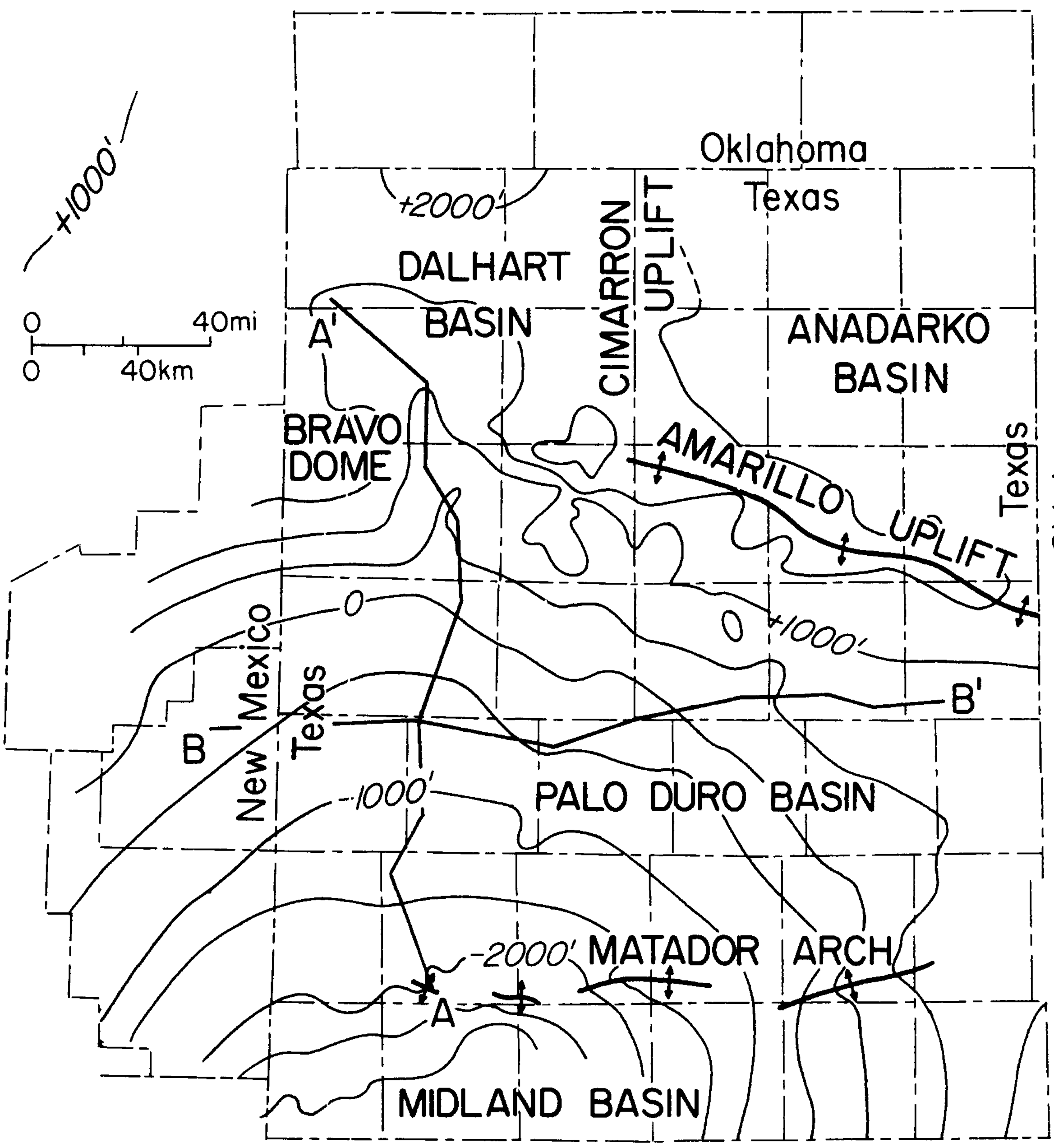


Figure 48. Regional structural setting and location of cross sections in the Palo Duro and Dalhart Basins.

System	Series	Palo Duro Basin		Dalhart Basin	
PERMIAN	Ochoa	Post - San Andres Interval	Dewey Lake Formation	Post-Blaine Red Beds	Dewey Lake Formation
			Alibates Formation		Alibates Formation
	Guadalupe		Salado Formation		Undifferentiated
			Yates Formation		
			Seven Rivers Formation		
			Queen/Grayburg Formation		
		San Andres Formation		Blaine Formation	
	Leonard	Clear Fork Group	Glorieta Formation	Glorieta Sandstone	
			upper Clear Fork Formation	Clear Fork Formation	
			Tubb Formation	Undifferentiated Tubb - Wichita Red Beds	
			lower Clear Fork Formation		
			Red Cave Formation		
		Wichita Group			
	Wolf-camp				

Figure 49. Stratigraphic chart of Permian rocks in the Palo Duro and Dalhart Basins of the Texas Panhandle.

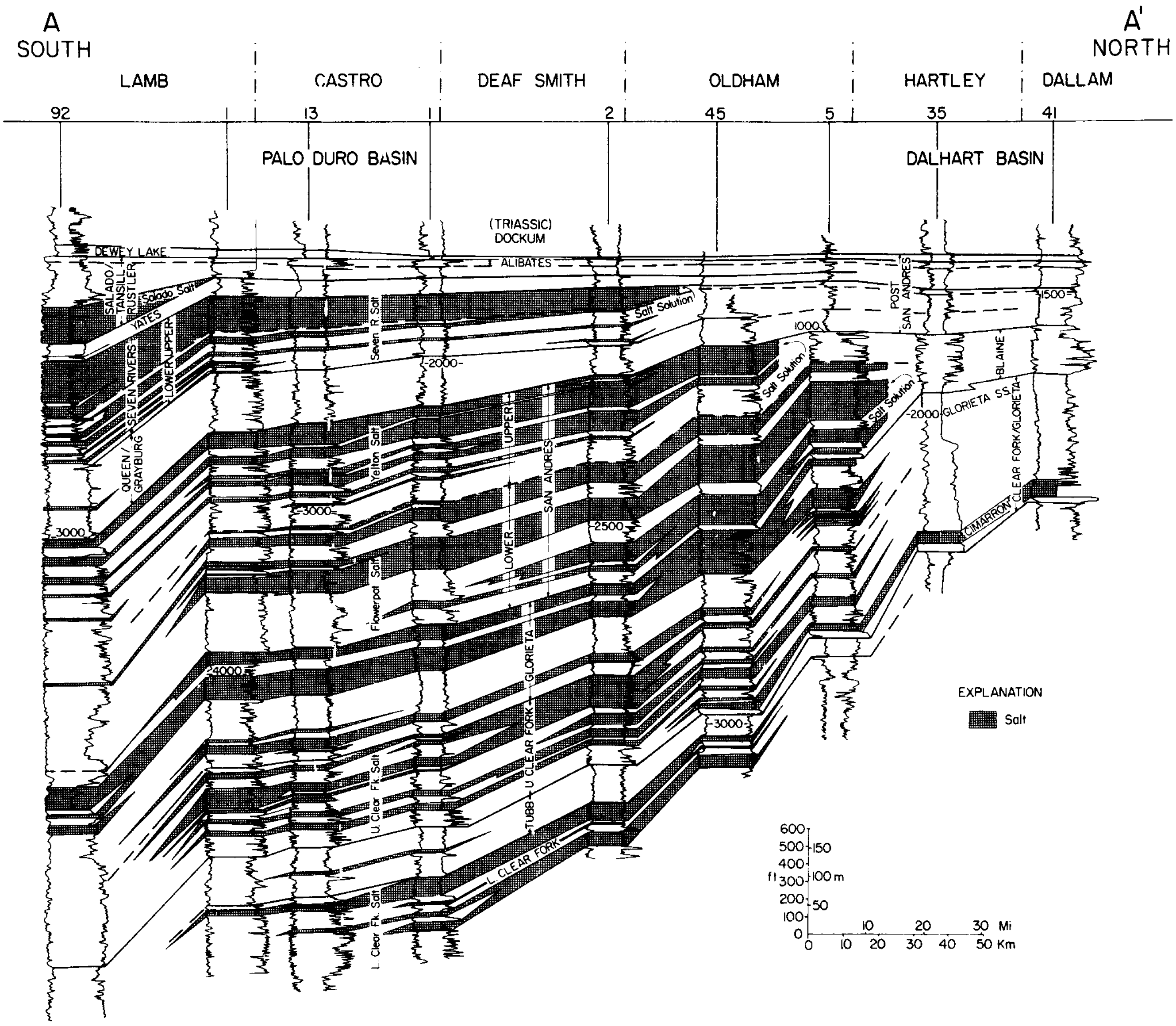


Figure 50. North-south correlations of generalized salt units in Middle and Upper Permian strata of the Texas Panhandle.

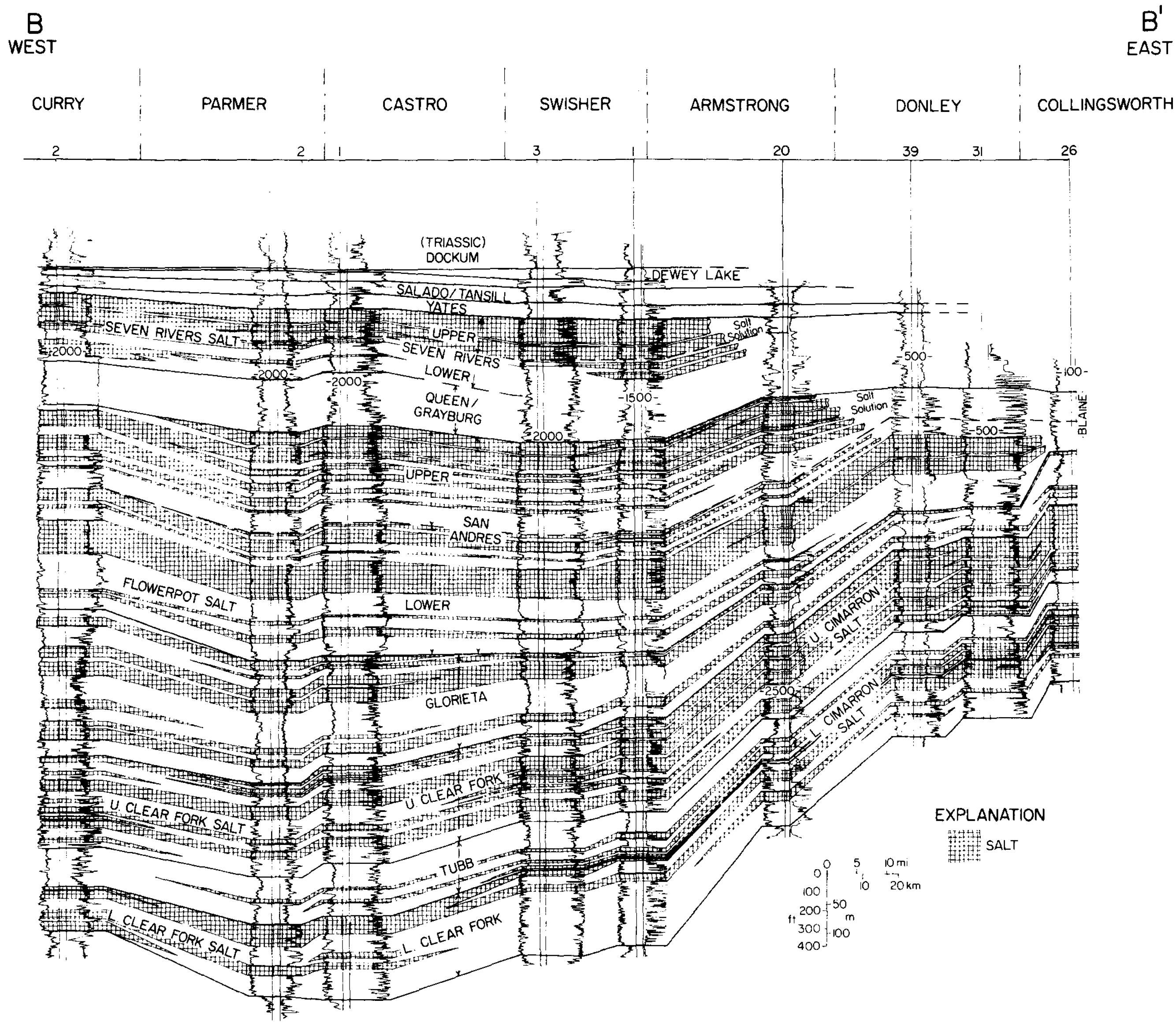


Figure 51. East-west correlations of generalized salt units in Middle and Upper Permian strata of the Texas Panhandle.

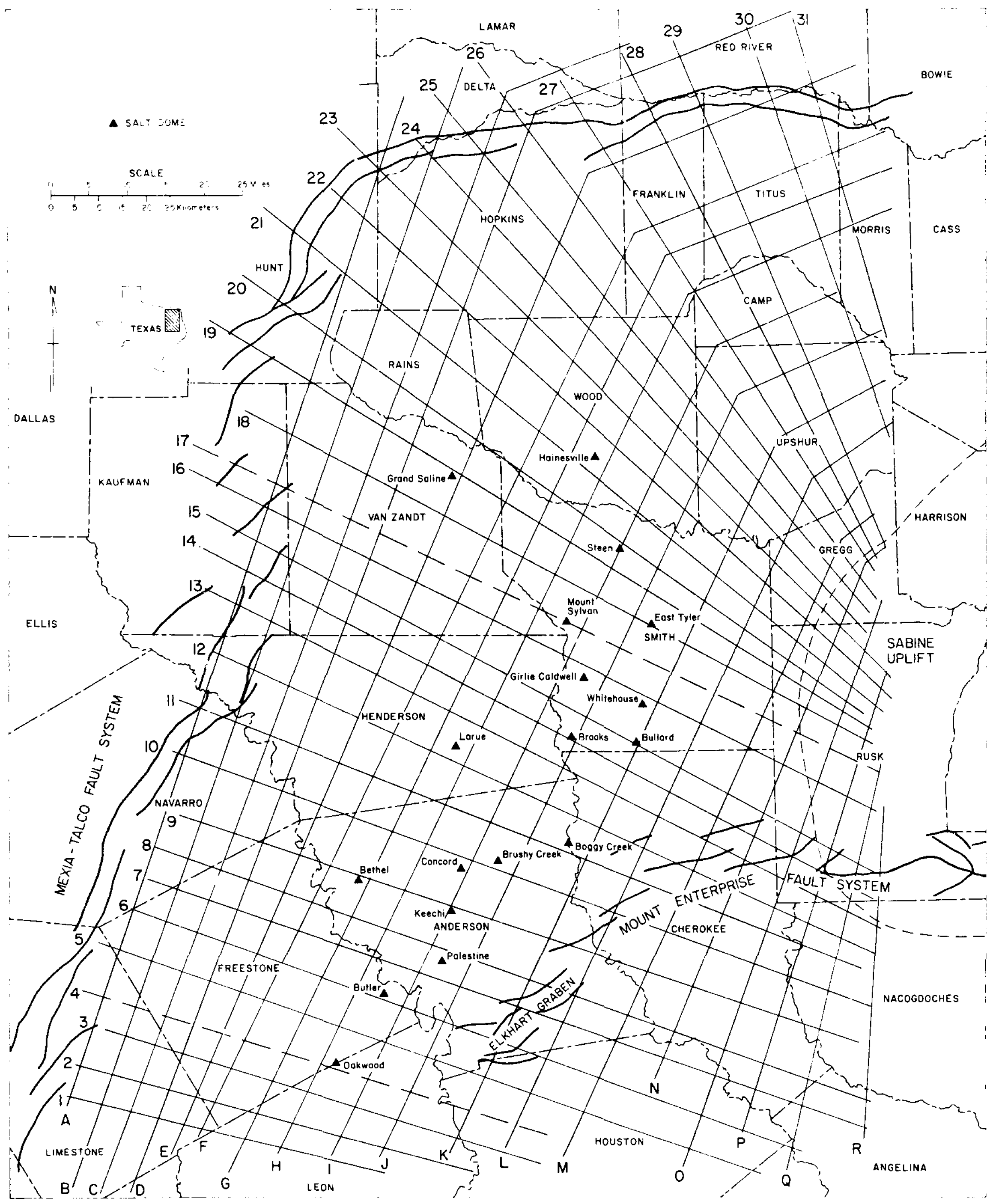


Figure 52. Location map of salt dome province, East Texas Basin (from Kreitler and others, 1980).

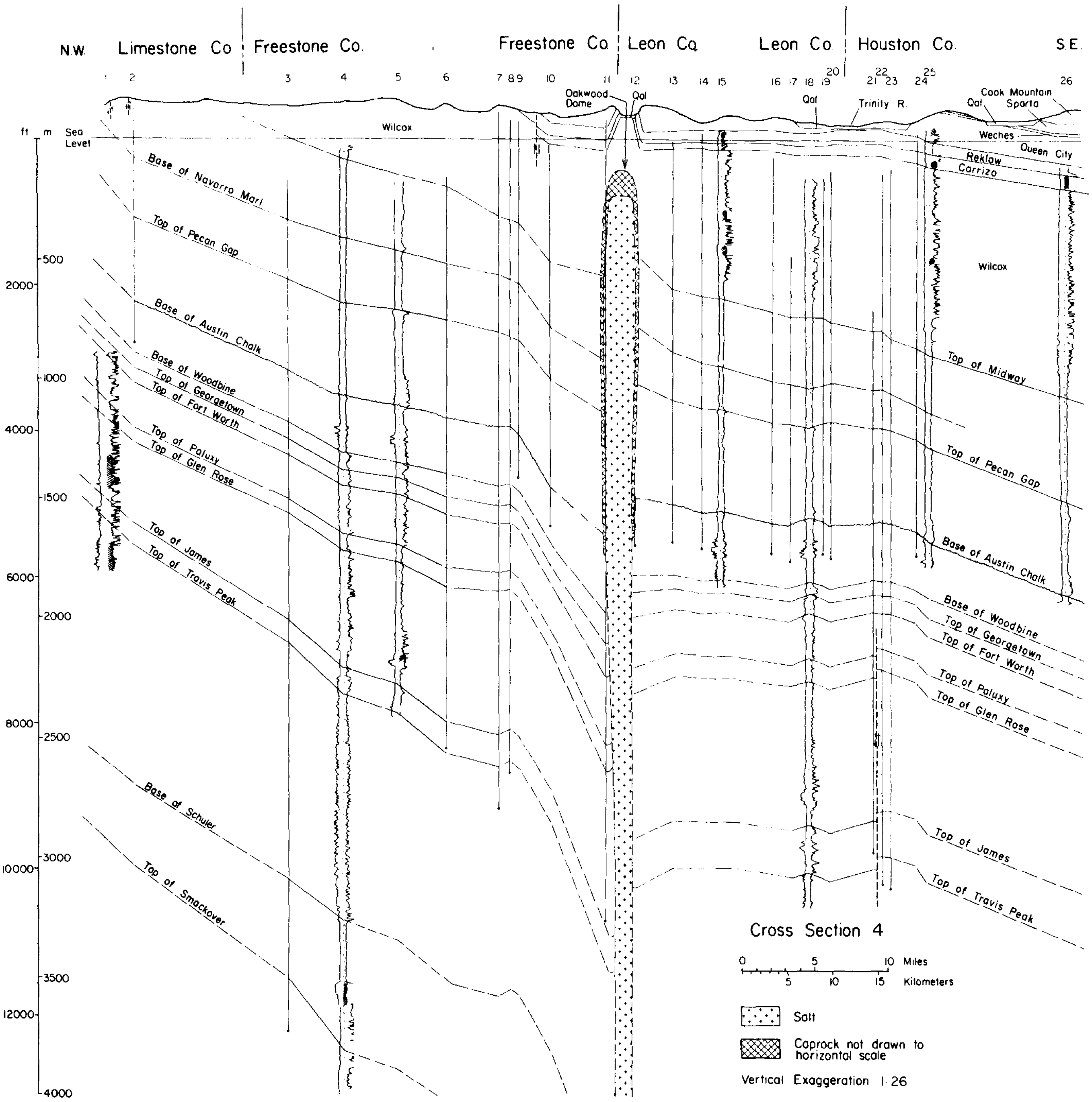


Figure 53. Dip structure cross section through Oakwood salt dome (from Kreitler and others, 1980).

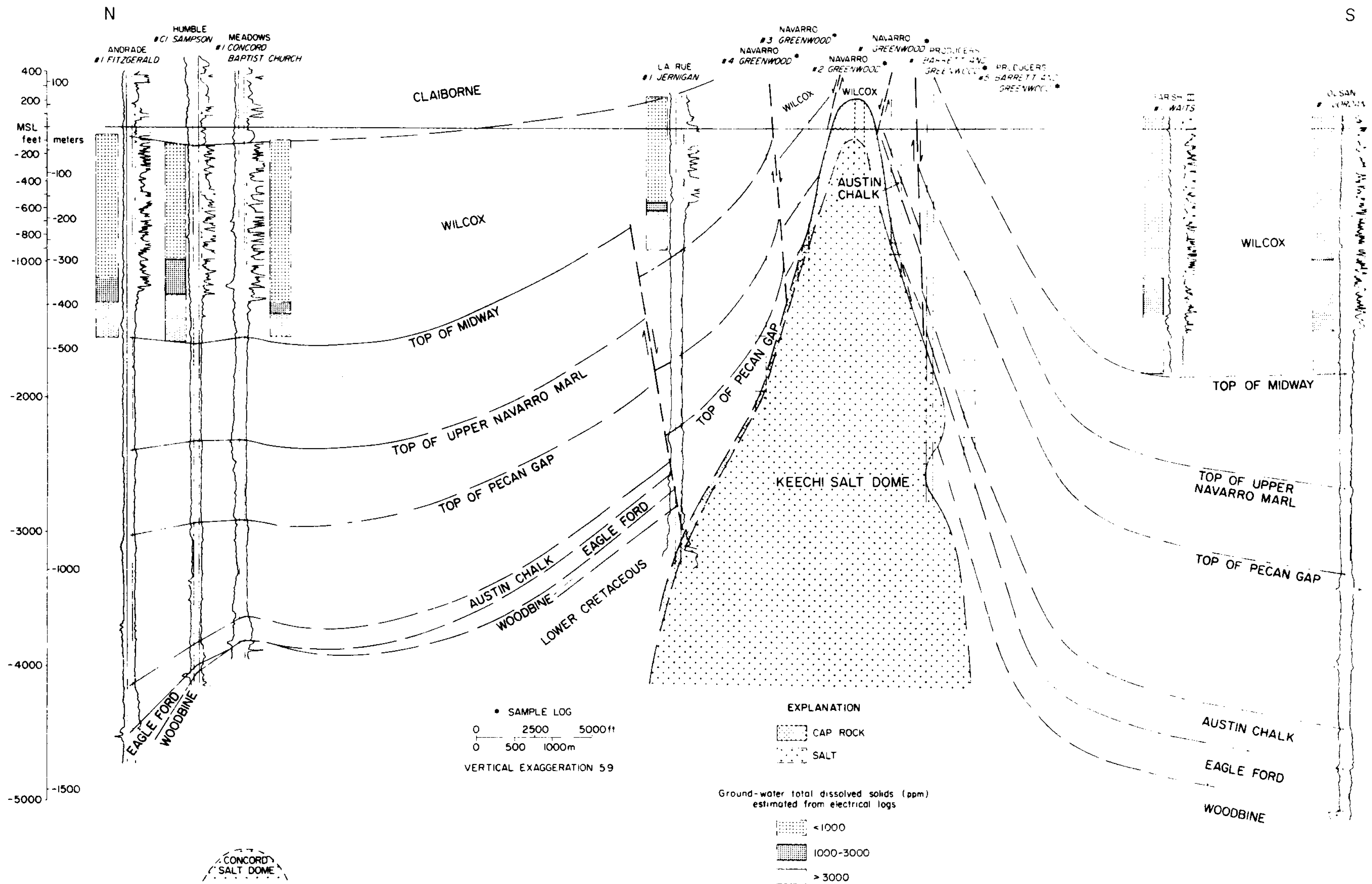


Figure 54. North-south structure section through Keechi salt dome (from Kreitler and others, 1980).

ENGINEERING

Preconceptual Design and Cost Estimates

Preconceptual design information for a Salt Test Facility (STF) presented here includes preliminary cost estimates for constructing, operating, and decommissioning the facility (table 45). This information is input for detailed conceptual designs for either or both of the locations being recommended. Preliminary costing was done to aid in planning and obtaining funding for the test facility, not as a basis for selecting either of the sites using cost considerations.

Rationale

The magnitude of the designs shown is in keeping with the decision that the STF be a semi-works facility. The principal features incorporated herein are selected, with or without adaptation, from the comparable items in the conceptual designs of the National Waste Terminal Storage Repositories (NWTSR's) for dome salt (No. 1; Stearns-Roger, 1979) and bedded salt (No. 2; Kaiser, 1978). In addition to the NWTSR conceptual design reports, the preparation of this report involved copious use of the summaries and descriptions contained in a subsequent document, ONWI-39 (Battelle, 1979). The STF, as conceived here, is an order of magnitude smaller than the NWTSR's, but it is larger than any of the test facilities to date. The STF is planned to be large enough to permit full-scale operational testing, as opposed to pilot plant observations.

Procedural Plan

The general plan for staging the various procedures in the overall program is shown in table 46. It is envisioned that the facility would be built as expeditiously as possible. Fast-track construction procedures might be considered in the interest of saving time; i.e., the construction may be ongoing before the final plans are completed. Moving ahead on all items, even those which may not be used immediately (such as the waste shaft and rail spur), could be desirable enough to warrant the difficulties certain to be encountered.

Table 45. Preliminary cost estimate for a salt test facility.

		$1,000's
Item 1:	Land Acquisition	
	Domed site (800 ac x $2,000/ac)	1,600
	Bedded site (Owned by UT)	0
Item 2:	Site Surface Preparation	
	Fencing (2,400 ft @ $12.50/ft)	30
	Guard house (400 sq ft @ $75/sq ft)	30
	Roads, aprons, and parking lots (including salt storage) 2,100 sq yd roads, 12,400 sq yd other — 15,000 @ $40/sq yd	600
	Grading (holding pond, foundations, etc.) 15,000 cu yd @ $5/cu yd	75
	Landscaping (native)	15
		750
Item 3:	Offsite Support	
	Domed site	
	Road (3 mi @ $350,000/mi)	1,050
	Rail Spur (3 mi @ $400,000/mi)	1,200
	Electricity (3 mi @ $15,000/mi) and transformer station @ $200,000	245
	Water line (5 mi @ $10/ft = $265)	265
	Phone (4 mi @ $5,000/mi)	20
	Gas supply	20
		2,800
	Bedded Site	
	Road (5 mi @ $300,000/mi)	1,500
	Rail spur (16 mi @ $350,000/mi)	5,600
	Electricity (6 mi @ $15,000/mi) and transformer station @ $200,000	290
	Water supply development	200
	Phone (15 mi @ $5,000/mi)	75
	Gas supply	35
		7,700

Preliminary cost estimate (cont.)

		$1,000's
Item 4:	Transfer and Shops Building (6,000 sq ft @ $80/sq ft)	$ 480
	Shop equipment	320
	Total	$ 800
Item 5:	Ops Control, Test Labs, and Visiting Research Scientist Quaters Building (6,000 sq ft @ $150/sq ft)	$ 900
	Lab instrumentation	300
	Total	$ 1,200
Item 6:	Waste Receiving and Handling Building (6,000 sq ft @ $100/sq ft)	$ 600
	Equipment (casks, transporter)	2,000
	Total	$ 2,600
Item 7:	Exhaust Filter Facility (max. cap. 2,500 cfm)	
	HEPA filter	
	Fabric filter	
	Standby scrubber and adsorber	
	Fan and duct	
	Housing	
	Total	$ 3,000
Item 8:	Air Conditioning Chiller and Compressor	$ 2,500
Item 9:	Man and Materials Shaft (22'0 diameter)	
	Shaft	$12,500
	Head frame	1,800
	Station	1,300
	Equipment	1,500
	2,000' Dome Total	$17,100
	2,300' Bed Total	$19,000

Preliminary cost estimate (cont.)

				$1,000's
Item 10:	Waste Shaft (16'ϕ)			
	Shaft			$10,800
	Head frame			1,800
	Station			1,300
	Equipment			1,000
	2,000'	Dome	Total	$14,900
	2,300'	Bed	Total	$16,500
Item 11:	Initial Mine Development (37,500 cu yd @ $80/cu yd)			$ 3,000
Item 12:	Movable Surface Equipment			
	Crane			$ 400
	End loader			175
	Truck (low-boy)			125
			Total	$ 700
Item 13:	Equipment in Mine			
	Continuous miner (electric)			$ 440
	Rock bolting machine			100
	Shuttle cars for salt hauling (4)			200
	Waste transporter			400
	Air compressor			20
	End loader			100
	Crane			200
	Drilling machinery			200
	Material and man conveyance			60
	Other			380
			Total	$ 2,100

			$1,000's
Item 14:	Onsite Utilities		
	Electricity		
	Communications		
	Water		
	Sewerage		
	Gas		
		Total	$ 2,000
Item 15:	Testing and Observation for Retrievability Period		
	Monitoring effects		
	Running retrievability tests		
	Support for experiments with non-waste involvement ($2,000,000/yr x 5 yr)		
		Total	$10,000
Item 16:	Mine Shutdown		$ 2,000

Actual scheduling of operations should follow accepted PERT/CPM techniques. Cognizance should be taken of the highly variable levels of effort that will be required at various times during the construction, operation, and decommissioning of the facility. The conceptual designs prepared from this report must be made with full awareness of the actual locale. For example, the soil and moisture conditions are such that the local highway department expertise should be used in the road designs and the landscaping should be native to the region, not the grass and box elder conventions of wetter climates.

The STF must be a paragon of cleanliness and safety if it is to carry out its objectives satisfactorily, especially since good public image is requisite to the success of the operation. Even the construction site of the facility must be kept relatively clean—no part of the total operation should result in a junkyard appearance. Strong emphasis must be placed on safety for the entire project, because of both the hazardous nature of construction and mining and the desirability of a good public image. Cleanliness and safety must not be mere compliance with the regulations; they need to be positive efforts, purposefully made toward achieving the goals.

Table 46. Salt Test Facility: General plan for staging functions.

Pre-Planning
Site Selection
Funding
Land Acquisition
Site-Specific Planning
Construction
Phase I: Transportation Utilities Security Fencing Site Preparation Temporary Housing
Phase II: Headworks Sinking Shafts Mining Drifts Onsite Buildings
Phase III: Installing Lab Equipment Permanent Housing
Operation
Waste Placement
Testing Waste Effects
Develop Mining & Placement Procedures
Backfilling Storage Rooms
Other Tests
Decommissioning
Removing Wastes
Decontaminating Facilities
Conversion/Demolition of Facilities

Surface Facilities

Surface facilities will consist of the 16-acre operations area that is under the tightest security, the buffer area around the operations area that brings the total site area to 800 acres, the onsite appurtenances for carrying on the testing, and the offsite connections to transportation, utilities, and communications.

Offsite

Offsite facilities consist of a roadway (24 ft surface) to connect with the nearest state and/or federal highway, a railroad spur to connect with the nearest railroad, an electric system to bring in 3000 kVA, a system to furnish water to the site, phone lines, and a gas supply (may be onsite LPG).

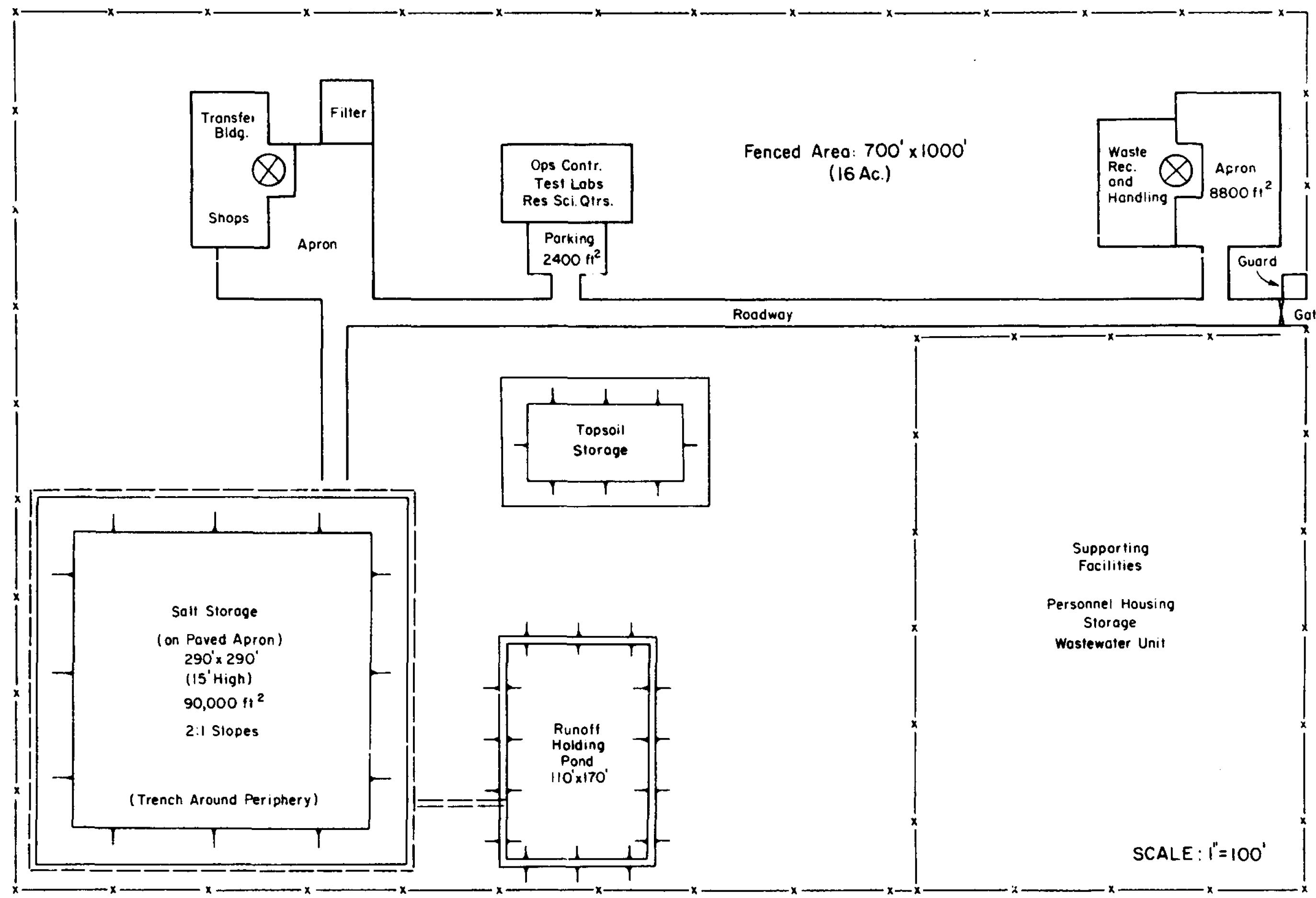
Onsite

Onsite facilities are at two locations--the surface and underground in the mine and connecting shafts.

Surface

An operations control building will house not only the administrative activities but also the testing laboratories and quarters for visiting research scientists (fig. 55). The testing facilities will be capable of assaying the mechanical properties of mined specimens, measuring and identifying radionuclides in samples of air, water, and materials, and monitoring by remote means the temperatures at selected places underground, the stresses shown by strain gauges underground, and any possible radioactivity in the exhaust gases from the mine.

The transfer building will house the buffer storage of materials to be sent down to or brought up from the underground area. All materials except the waste and salt should pass through this building. The building will house the showers and clothes change areas for the underground personnel. The shops will have the capabilities required for doing the light and moderate machine work needed by such a test facility.



SURFACE LAYOUT

Figure 55. General surface plan for a double shaft facility.

The waste receiving and handling building will house any wastes being moved to or from underground along with the casks needed for handling such wastes. This building will serve as a temporary storage area for the wastes that should be packaged as desired for storage when received. The building will be equipped for decontamination of any unexpected leaks of radioactive materials.

The guard house will shelter guard(s) needed to maintain security. The size of the operations area should permit adequate security to be maintained by one person. As a result of the nature of the facility, additional electronic security measures may be needed. The guard house can be eliminated and the operation controlled by remote means from the operations control center, if desired.

A salt storage area is to be provided for storing the mined salt. The storage should be on a paved apron with drainage into a holding pond. The holding pond should be water tight, probably with a membrane. Water in the pond should be kept to a minimum and the salt from the evaporated brine solution can be returned to the storage when necessary.

The topsoil storage will act as a repository of the soil removed during site preparation. Storage will need to be stabilized, preferably with native grasses and/or other plants. The stored soil is to be used for restoration of the site after decommissioning.

The supporting facilities should be contained under fencing separate from the secure area. These facilities are envisioned to contain housing for the technical and operating personnel if none is available in nearby towns. The housing will probably be temporary. Such housing will be especially desirable at the bedded salt site in West Texas during the heavy construction phase when the number of employees may run into the hundreds. This area will contain a warehousing space (open or under a shed). The wastewater treatment facility should be located within the supporting facilities area, whether a septic tank or a packaged treatment facility. Because of the low numbers of people anticipated, except during the construction phase, the package unit hardly seems justifiable.

The filter building will house the bag filters for use during the mining phase and as pre-filters or roughing filters when wastes are emplaced. The exhaust air from the test area will be routinely filtered. There will also be standby equipment to scrub the exhaust gases of soluble components and to adsorb organic components on impregnated activated carbon should any significant releases of radioactive materials cause the exhaust gases to become radioactive. In keeping with current philosophies of containment, it may be deemed desirable to include holding tanks (inflatable plastic balloons or similar) for containing the radioactive gases during a possible release.

Air conditioning may be by individual buildings or may be from a central chilling station located near the operations control center. No air conditioning should be needed in the mined area. If such is deemed desirable, the downflow ventilation induced by the exhaust ventilation system will carry the conditioned air down the shafts.

Shafts

There should be two shafts to the underground mined area, one for workers and materials and the other for transfer of wastes. If the salt test facility is to test actual operational conditions, both shafts are necessary even though they are quite expensive.

Men and Materials Shaft

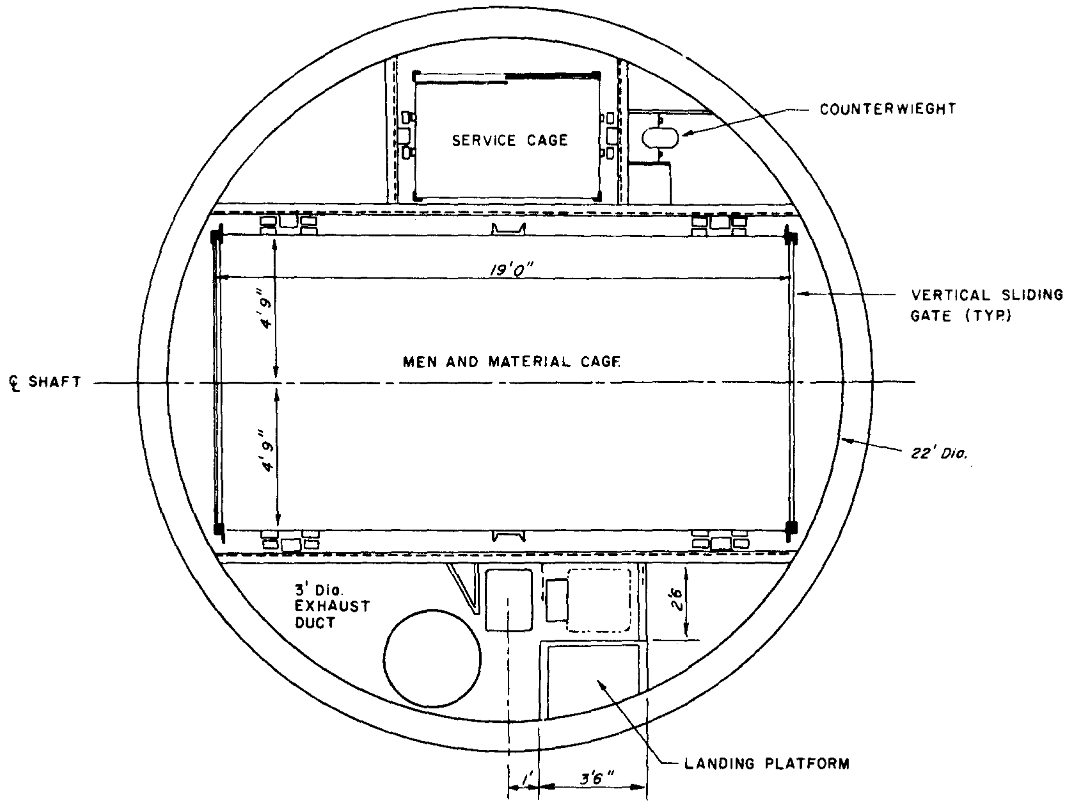
The men and materials shaft is identical to that in the NWTSR-2 except that a 3-ft diameter exhaust air duct is included as shown (fig. 56). The shaft is 22 ft inside diameter and concrete-lined. Real efforts should be made in construction to keep the inleakage of water to a minimum through the judicious use of expansive cement, molten sulfur, polymer concrete, and membranes. The amount of inleakage should be quite small. The elevator cage is large enough to accommodate major pieces of equipment, including the shuttle cars used to transport the mined salt and the refill salt.

Waste Shaft

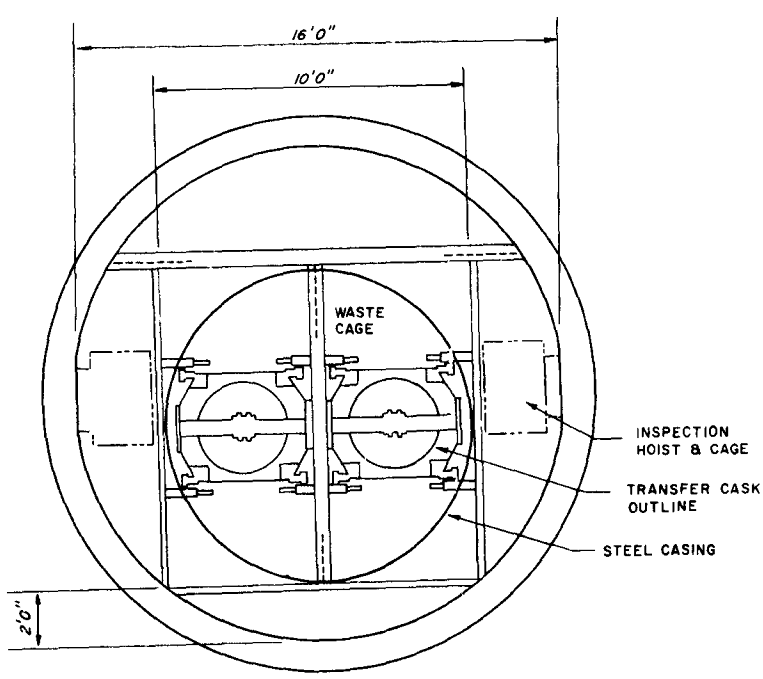
The waste shaft is identical with that shown in NWTSR-2 (fig. 56). It has a 22-ft inside diameter to accommodate the passage of 2 casks for counterweighting purposes. Preventing inleakage of water through the concrete lining is important.

Mined Facility

The mined facility will be 2,000 ft below ground in the domed salt or about 2,300 ft below ground in the bedded salt (fig. 57). The size of the facility will permit several simultaneous tests to be run.



MEN & MATERIAL SHAFT



WASTE HANDLING SHAFT

Figure 56. Components of the two principal shafts.

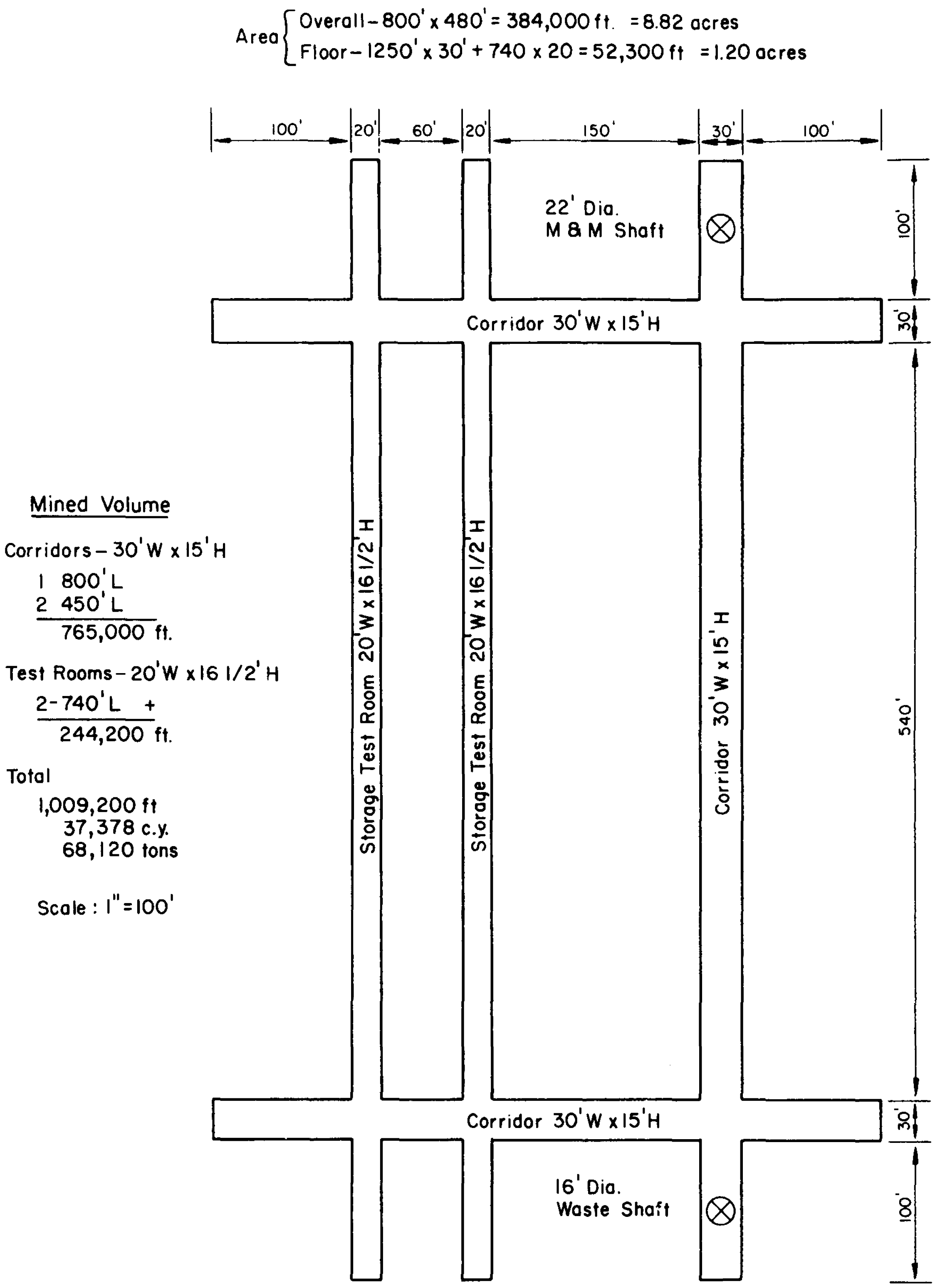


Figure 57. Underground plan for a salt test facility.

Geometry

The test facility's geometry has been selected to maximize the facility's usefulness. The design provides space for both the radioactive waste storage testing and the rock mechanics and mining testing. Two storage rooms of 540 ft length should provide ample space for testing various waste (heat) loadings. The stub rooms provide for other types of testing in areas isolated from the storage rooms by the intervening corridors.

Excavation

Mining operations are large enough to obtain valuable experience in the problems to be encountered in a repository; however, they are small enough to permit all of the mined salt to be removed through the workers and materials shaft without resorting to a special shaft for the purpose. Mining is to be done by a boring machine as laid out in the NWTSR reports. The amounts of salt removed are too small to justify conveyor handling procedures. Such procedures may be deemed appropriate for the experience to be gained.

Ventilation

Ventilation of the mined cavity can be carried out with a simple system of exhaust ducts with termini at the various corridor and room ends. The ducts should be provided with cutoffs so that the total air flow during the mining operation can come from the working face. The 3-ft diameter duct shown running up the workers and materials shaft to conduct the exhaust to the surface for filtering may be larger than needed for ventilation of the mined cavity. Air flow should be kept to a relative minimum because of the treatments that may be required for the exhaust gases.

Closure of Room Sections

Part of the testing procedure will be to backfill sections of the rooms and/or corridors with mined salt. The salt should be crushed, brought into the mined cavity, and tamped into position to obtain the maximum density of the backfill.

Decommissioning

When the facility ceases to be useful, the underground facility will be decommissioned, salvageable equipment removed, and the cavity filled with salt. Decommissioning processes will be facilitated by accurate mapping procedures during waste emplacement and careful mining procedures to adhere as closely as possible to the planned configuration.

Equipment

The test facility will require equipment with heavy duty capabilities. Hoist towers will be needed to move the mining equipment, the wastes casks, and other heavy objects into and out of the mined area.

Equipment needed above ground includes a crane, an end loader, and a low-boy truck to handle waste casks. Underground equipment will include mining equipment and waste-handling equipment. Shuttle cars for handling the salt will move from the mined area to the surface and down a ramp to the salt storage pile.

Cost Estimates

Costs estimates shown are strictly preliminary (see tables 47, 48, and 49). They are intended to be guidelines, not precise numbers. In numerous areas the numbers may change markedly; for example, the allowance for instrumentation in the control center is quite modest. Extensive, automated sampling and monitoring equipment could result in much higher costs for instrumentation. The land acquisition figure is only grossly estimated.

Costs for offsite facilities vary markedly between the two sites as a result of the distances involved. The Block 20 (Loving County) site is nearly 16 mi from railroads, one east-northeast of the site (1 mi east of Wink) and one south-southeast of the site (between Pyote and Barstow). The Gyp Hill site is only 3 mi east of a railroad going south out of Falfurrias. Costs of the electrical service to the Block 20 site were estimated with help from a local utility company.

Table 47. Salt Test Facility:
Preliminary cost estimate for domed salt (1,000's of dollars).

Item No.	Description	Capital	Operating	Decommissioning
1	Land Acquisition	1,600		
2	Site Surface Preparation	750		200
3	Offsite Support	2,800		500
4	Transfer & Shops Bldg.	800		100
5	Ops. Control & Labs Bldg.	1,200		
6	Waste Rec. & Handling Bldg.	2,600		1,000
7	Exhaust Filter Facility	3,000		200
8	Air Conditioning Facility	2,500		
9	Man & Materials Shaft	17,100		1,000
10	Waste Shaft	14,900		1,000
11	Initial Mine Development	3,000		
12	Movable Surface Equipment	700		
13	Equipment in Mine	2,100		
14	Utilities Onsite	2,000		200
15	Testing & Observation Period		10,000	
16	Mine Shutdown			2,000
	Subtotal	55,050	10,000	6,200
	Contingency (25%)	13,760		
	Engineering (10%)	5,505		620
	Total	74,315	10,000	6,820

Table 48. Salt Test Facility:
Preliminary cost estimate for bedded salt (1,000's of dollars).

Item No.	Description		Capital	Operating	Decommissioning
1	Land Acquisition		0		
2	Site Surface Preparation		750		200
3	Offsite Support		7,700		500
4	Transfer & Shops Bldg.		800		100
5	Ops. Control & Labs Bldg.		1,200		
6	Waste Rec. & Handling Bldg.		2,600		1,000
7	Exhaust Filter Facility		3,000		200
8	Air Conditioning Facility		2,500		
9	Man & Materials Shaft		19,000		1,000
10	Waste Shaft		16,500		1,000
11	Initial Mine Development		3,000		
12	Movable Surface Equipment		700		
13	Equipment in Mine		2,100		
14	Utilities Onsite		2,000		200
15	Testing & Observation Period			10,000	
16	Mine Shutdown				2,000
	Subtotal		61,850	10,000	6,200
	Contingency	(25%)	15,460		
	Engineering	(10%)	6,185		620
	Total		83,495	10,000	6,820

Table 49. Salt Test Facility:
Bases of preliminary cost estimates for bedded salt and dome salt localities.

Item No.	Item Inclusions
1	Acquisition of land and mineral rights.
2	Fencing, site grading, onsite roads, salt storage apron, holding ponds, topsoil storage, and landscaping.
3	Offsite support items: road, rail spur, electricity, water, phone, gas.
4	Transfer tower for man and materials shaft, loading dock for receiving, ramp for salt-carrying buggies, clothes-change and shower facilities, temporary warehousing, shops for mechanical operations, utility connections (space only).
5	Administrative offices, laboratory instruments, test equipment, visiting research scientist quarters, housing (temp. & perm.).
6	All radioactive materials functions which are onsite.
7	Bag filters for mine dust during development, HEPA (absolute) filters during testing, radiation monitors, standby liquid scrubbers and impregnated carbon adsorbers.
8	Compressor, chilling tower, and housing.
9	Concrete-lined shaft (22'), station, and head frame.
10	Waste shaft (16'), station, and head frame.
11	Excavation of corridors and storage rooms, storing salt.
12	Crane (heavy duty), front-end loader, truck.
13	Continuous mining machine, waste transporter, crane, drilling machine, shuttle cars for mined salt, rock bolting machine, material and man conveyance.
14	Electricity, communications, water, sewerage, and gas.
15	Operating costs during 5-year retrievability period.
16	Retrieving wastes, decontaminating, and closing mine.

Air Quality

The proposed Salt Test Facility will have negligible impact on the air quality in any of the areas considered. The planned facility is non-polluting as a result of planned filtration and electrically driven equipment.

The National Ambient Air Quality Secondary Standards for the criteria pollutants may be summarized as follows with concentrations in $\mu g/m^3$ and values not to be exceeded more than once a year (long-term geometric means and short-term individual samples): particulates--60 for annual and 150 for 24 hours; sulfur dioxide--80 for annual, 365 for 24 hours, and 1,300 for 3 hours; carbon monoxide--10,000 for 8 hours and 40,000 for 1 hour; nitrogen dioxide--100 for annual; and ozone--60 (considered 3 years at a time).

The five areas of consideration are Loving County (Kermit-Wink-Mentone area), Brooks County (5 mi SE of Falfurrias), Van Zandt County (S of Grand Saline), Duval County (12 mi WSW of San Diego), and Harris County (16 mi N of Katy). The areas are for bedded salt, Gyp Hill Dome, Grand Saline Dome, Palangana Dome, and Hockley Dome, respectively.

All of the areas considered are assumed to be attainment areas, except for the ozone standard in Harris County, which is non-attainment (L. Butts, personal communication, 1980). Since no data have been collected from the given sites, the areas are unclassifiable; however, it is presumed that non-attainment would have occasioned sampling at the sites.

The STF will filter the air return from the mine to remove entrained particles. All below-ground equipment will be electrically driven, as will the hoists and other indoor equipment aboveground. As a result the only polluting equipment will be the endloader, crane, and truck; these items will result in minuscule amounts of air pollution being put into the ambient air.

CONCLUSIONS

Following the screening of Grand Saline, Hockley, Palangana, and Gyp Hill salt domes in East and South Texas and two areas of bedded salt in the Delaware Basin of West Texas, two sites are posed for technical reasons as being the best for locating a Salt Test Facility (STF). They are an area of bedded salt in Loving County, Texas, and the Gyp Hill salt dome in Brooks County, Texas.

The Loving County area will require negotiations with The University of Texas at Austin, for sites in which university lands overlie the salt, or with the General Land Office of Texas, for sites in which good quality bedded salt underlies State school lands. The Loving County area will be more expensive, requiring longer transport of power, extra efforts to secure a potable water supply, and additional road or railroad construction. Principal reasons favoring bedded salt for a STF are that more inhomogeneities occur in bedded salt than in domal salt and more may be learned testing a wider range of natural variables as they react to emplacement of radioactive waste.

Acquisition of the Gyp Hill salt dome as a STF presents a different set of problems, because the property is privately owned. Mining through the caprock presents some difficult hydrological problems in upper permeable zones.

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