DISTRIBUTION OF SALT STRUCTURES IN THE GULF OF MEXICO: MAP AND DESCRIPTIVE TEXT

By Ray G. Martin

INTRODUCTION

Slender diapiric stocks, broad massifs, anticlinal masses, low-relief swells, and pillowy lobes of Middle to Upper Jurassic salt (Viniegra, 1971; Kirkland and Gerhard, 1971; Imlay, 1980) dominate the structural fabric of large parts of the continental margins and deep basin of the Gulf of Mexico (sht. 1, A). These structures, known collectively as "salt domes," are almost exclusively features of the terrigenous clastic margins of the northern and southwestern Gulf and the central Sigsbee Plain (sht. 2, A). Some salt structures may be present in the East Mexico Slope province of the western gulf, but they are difficult to distinguish from diapiric and nondiapiric shale anticlines, which are the dominant structures on this margin. Except for some piercement domes and nonpiercement uplifts in the northern Florida shelf region and in the eastern Golfo de Campeche, salt structures are not known in the extensive carbonate platform provinces off western Florida and the Yucatan Peninsula. The accompanying compilation from seismic-reflection data documents the distribution of Gulf of Mexico salt features and helps to define boundaries of structural provinces formed mainly, or in part, by tectonic movement of salt.

Deeply rooted salt domes pierce and deform Mesozoic and Cenozoic sedimentary units of the Continental Shelf and Slope of the northern Gulf of Mexico from the DeSoto Canyon westward to northern Mexico and from the inner Coastal Plain to the Continental Rise. Extremely large structures are concentrated on the Texas-Louisiana Slope west of the Mississippi Fan and on the Rio Grande Slope off northeastern Mexico. Large isolated stocks dot the Continental Shelf off Louisiana, and smaller stocks are clustered around the DeSoto Canyon on the northeastern shelf off the Florida panhandle. Large stocks and ridgelike masses are widely distributed across the upper Mississippi Fan between the Sigsbee and Florida Escarpments. The seaward limits of the northern gulf salt-dome province are well defined along the Perdido and Sigsbee Escarpments at the foot of the Continental Slope where salt structures abut and overlie Continental Rise strata. This boundary is less well defined in the Mississippi Fan province where salt structures are more widely distributed and are topographically obscured by thick deposits of late Quaternary age.

The Golfo de Campeche Slope in the southwestern Gulf of Mexico is a region of knolls and open basins underlain by masses of diapiric and nondiapiric material inferred to be salt. Though similar in topographic character and, to some extent, in internal structure to the Continental Slope of the northern gulf, the Golfo de Campeche Slope is characterized by broad, linear hillocks composed of thick sections of Continental Slope and Abyssal Plain strata that were uplifted, folded, and faulted by tectonic events apparently unrelated to salt mobility. Salt structures are present mainly in the western and uppermost parts of the slope and beneath the shelf; these structures suggest continuity between the Sigsbee Knolls structures and those in the Isthmian salt basin onshore in the Mexican States of Tabasco and Campeche.

The almost featureless expanse of the Sigsbee Plain in the central gulf is interrupted by a small group of knolls near lat 23.5° N. and long 92.5° W. The knolls are the surface expressions of a few of the large salt diapirs that pierce many thousands of meters of abyssal strata along a narrow belt parallel to the northwestern face of the Campeche Escarpment. Sizes and crestal depths vary considerably; for the most part, the structures are individual salt stocks that rise from the mother salt layer. Some evidence in the vicinity of the sea-floor knolls suggests that a few of these large structures may either coalesce at intermediate depths or be secondary growth features on several large ridgelike masses of salt. Seismic-reflection data between the Sigsbee Knolls area and the Campeche Escarpment also show the undulating surface and relatively underformed base of the mother salt layer and indicate updip pinch-out near the base of the Campeche Escarpment.

In addition to these major salt-dome provinces, individual saltlike structures are present within the Mexican Ridges fold province, in the Sigsbee Plain east of the Sigsbee Knolls, and at several localities along the foot of the Florida Escarpment.

Sheet 1, A shows the regional patterns, relative sizes, and interpreted shapes of salt structures in the Gulf of Mexico. The variety of structural forms, amplitudes, and depths of burial of salt domes in the Gulf of Mexico region are grouped into four broad categories: (1) near-surface and deeply buried salt structures that are either distinctly outlined in seismic data or well documented by drill-hole data and subsurface mapping (solid black); (2) salt anticlines onshore and anticlines believed to be cored at depth by salt offshore (conventional anticline symbol); (3) deeply buried, mainly nondiapiric, pillowlike mounds and swells that are rooted to the general stratigraphic level of Jurassic salt and that appear in seismic data to be acoustically and morphologically similar to salt masses (stippled pattern); and (4) tongues of Jurassic salt laterally extruded over Tertiary and Quaternary strata (cross-hatch pattern).

Because of the influence of salt domes on the formation of structural and stratigraphic features that may act as traps for significant petroleum resources, this map provides a foundation for preliminary resource assessments and for the planning of exploration programs in the frontier petroleum provinces of the adjacent Gulf of Mexico Continental Slope.

METHOD OF COMPILATION

Salt-dome interpretations for this study are based on a network of seismic-reflection profiles (sht. 1, B) that consists of more than 70,000 km of single-channel recordings and 17,300 km of multichannel recordings. Locations of seismic sections used to illustrate this report are shown in sheet 2, B. Single-channel data range from small-volume airgun (490 cm^3) and intermediate-power sparker systems (40-80 kilojoules) to deep-penetration sparker units using power ranges from 120 to 160 kilojoules. Single-channel data were collected by the U.S. Geological Survey (USGS), U.S. Naval Oceanographic Office (USNAVOCEANO), U.S. National Oceanic and Atmospheric Administration (NOAA), Texas A&M University (TAMU), Lamont-Doherty Geological Observatory (LDGO), Woods Hole Oceanographic Institution (WHOI), and the University of Miami Rosenstiel School of Marine and Atmospheric Sciences (RSMAS). All multichannel seismic data used for this compilation were recorded by the Geophysics Laboratory, University of Texas Marine Science Institute (UTMSI); the data consist of 12-channel regional profiles and 24-channel grid studies on the Sigsbee Escarpment, Mississippi Fan, West Florida and Campeche

Escarpments, Campeche Knolls, and Mexican Ridges provinces. Outlines of salt structures on land and in offshore regions not covered by seismic data were compiled from Braunstein and others (1973) for the Texas and Louisiana Shelf region; from Hickey and others (1972) for the gulf Coastal Plain region; from Halbouty (1967) for the Veracruz and Tabasco States, Mexico; from numerous journal reports concerning recent petroleum discoveries in southern Mexico and adjacent offshore; and from miscellaneous maps of the Texas-Louisiana and Mississippi-Alabama shelf regions published by the U.S. Bureau of Land Management (BLM).

Interpretations of salt structures in seismic data were based on conventional criteria of recognition such as anticlinal or massive-irregular shape, the absence of coherent internal reflections, evidence of diapiric or nondiapiric syndepositional uplift, available core and drill-hole evidence, and interval velocities determined from seismic recordings. The distinction between salt and shale masses on seismic profiles is quite difficult, especially on single-channel recordings where velocity analyses cannot be performed on the reflected data. For this reason, many of the salt-dome outlines interpreted herein may include shale mantles, and some structures interpreted as salt diapirs may be shale piercements. Shale mantles and piercements are probably more likely to exist in the upper slope region of the northern Gulf of Mexico and in the Continental Slope of the western gulf where the salt-dome province merges with the shale-cored anticlines of the Mexican Ridges.

Interpretive salt-sediment interfaces that outline the flanks and crests of salt domes were marked on the seismic profiles, and apparent widths of individual structures along lines were transferred to corresponding shotpoint maps and ship's track charts. Widths of steeply flanked, well-defined domes generally were measured at 1.0 second of two-way travel time of seismic waves below the structural crest. The widths of less well defined, shallow structures and deeply buried domes were measured at the maximum apparent profile breadth, which for almost every structure, was less than 1.0 second below the structural crest of the salt mass. For some structures, only the widths of prominent secondary-growth structures that rise from very broad massifs were plotted rather than the entire structure. The deeply buried, low-relief, nondiapiric salt swells that are present mainly in the Sigsbee Plain and lower Mississippi Fan regions were measured from base-of-flank to base-of-flank.

Plots of salt-dome widths along ship's track lines were transferred to a bathymetric base map of the Gulf of Mexico region (Sorensen and others, 1975). Outlines of individual structures were then interpreted on the basis of plotted widths on adjacent closely spaced track lines, track-line intersections, sea-floor topography (which is directly related to salt diapirism in the Texas-Louisiana Slope and Rio Grande Slope provinces and in parts of the Campeche Knolls and Sigsbee Knolls provinces), and map plots of axes and thalwegs of intraslope basins and canyons. In areas of meager seismic and topographic control, salt-structure outlines were drawn as equidimensional or slightly elongated interpretations of the individual plots; many of these structures are shown as oval shapes to preserve or conform to the dominant structural grain of that particular part of the province.

DISTRIBUTION OF SALT STRUCTURES

Salt structures are significant elements of the structural frameworks of the northern and southwestern continental margins and of the central deep basin of the Gulf of Mexico. The northern gulf region is a diapiric margin that resulted from the vertical intrusion and lateral flow of large volumes of salt and, locally, shale in response to rapid accumulation of prograding sediment loads mainly during Cenozoic time. Similar circumstances account for the variety and distribution of salt diapirs onshore in southern Mexico and parts of the adjacent Continental Shelf and upper slope regions. Along the western flank of the Golfo de Campeche Slope and in the Sigsbee Plain, diapir fields are the result of vertical salt intrusion in response to a more uniform distribution of sediment volume, which slowly accumulated in a deep ocean environment over thick salt deposits. The mobilization of relatively thin deposits of stratiform salt by crustal tectonic forces in the central and eastern parts of the Golfo de Campeche Slope and adjacent eastern shelf regions contrasts markedly with the overburden-induced salt mobility that is characteristic of diapir provinces elsewhere in the Gulf of Mexico region.

The regional patterns of salt-dome distribution (sht. 1, A) indicate the general extent of evaporite deposition in the gulf basin (sht. 1, C). Density of structural populations and sizes of individual features are proportional to original thicknesses of stratiform salt deposits. Evaporites that are too thin to behave diapirically under overburden load underlie parts of the northern gulf margin and the southeastern Sigsbee Plain region, and may be present beneath the eastern Mexico margin and elsewhere in the abyssal gulf basin. The age of these deposits has been generally established as Middle and Late Jurassic (Jux, 1961; Viniegra, 1971; Kirkland and Gerhard, 1971; Imlay, 1980). Although they are relative time-stratigraphic equivalents, the evaporite deposits of the northern, southern, and abyssal Gulf of Mexico regions (sht. 1, C) are referred to, respectively, as the Louann Salt (Hazzard, Spooner, and Blanpied, 1945), the Isthmian Salt or Salina Formation (Tschopp, 1931; Imlay, 1953), and the Challenger Salt (Ladd and others, 1976). Correlation between the salt that intrudes strata in the Continental Slope off Texas and Louisiana and the Louann Salt in the upper gulf Coastal Plain is not firmly established. Geophysical evidence showing that the top of salt is at depths of 9,000 to 13,000 m below Cretaceous shelf-edge deposits in southeastern Texas and the drill cores of Cretaceous carbonate sediment recovered from a large salt massif off southernmost Texas (Lehner, 1969) provide a rationale for stratigraphic continuity between the Louann Salt and the salt of the Texas-Louisiana Slope. Watkins and others (1978), however, suggested that evaporite deposits of the outer margin of the northern gulf accumulated in a basin separate from the Louann but continuous with the Challenger Salt of the central gulf. Salt domes in the Sigsbee Plain and lower Golfo de Campeche Slope are rooted to the Challenger Salt, and the apparent continuity of these structures with those of the upper Continental Slope and Isthmian basin of southern Mexico suggests that the Challenger and Salina (Isthmian) are probably physically continuous.

Northern Gulf of Mexico Margin

Salt domes pierce and uplift Mesozoic and Cenozoic strata of the northern gulf margin in the offshore regions between northwestern Florida and the northeastern Mexican Continental Slope, and from the inner gulf Coastal Plain to the Continental Rise and lower Mississippi Fan provinces of the central gulf basin (sht. 1, A). Salt structures are concentrated in interior Coastal Plain basins in southwestern and northeastern Texas, northern Louisiana, and central Mississippi; in the DeSoto Canyon region off northwestern Florida; in a narrow belt along the Florida Escarpment; and in a broad belt that includes the coastal regions of Louisiana and eastern Texas and the adjacent Continental Shelf and Slope provinces.

The distribution pattern of diapir fields in the northern gulf margin represents the overall extent of the Louann Salt basin of Middle and Late Jurassic time (sht. 1, C). "Domeless" areas in the margin are underlain either by salt accumulations too thin to be mobilized into diapirs or by time-equivalent nonevaporitic facies.

Diapir fields onshore and offshore represent areas of thickest Jurassic salt accumulation (McGookey, 1975; Martin, 1978). Variations in the sizes of individual salt structures within the fields result from relative differences in the thickness of the original salt available for diapiric injection and in the total thickness and rates of accumulation of the sedimentary overburden that induced and perpetuated salt mobility (Amery, 1978).

Coastal Plain and Continental Shelf

Deeply rooted salt diapirs, commonly shaped like slender columns having enlarged and, in a few places, mushroomlike tops; diapiric and nondiapiric salt anticlines; and deep-seated nonidapiric salt pillows are characteristic of the interior Coastal Plain salt basins, coastal areas of Texas and Louisiana; and the Continental Shelf from Florida to Texas. The diameters of salt diapirs range from less than 1 km to as much as 30 km; salt anticlines, including those in the Mississippi salt basin and the Destin structure off northwestern Florida, range from 15 km to 70 km in length. Diapiric structures in the Coastal Plain and inner Continental Shelf regions generally are less than 8 km across. Large salt stocks are commonly situated along intricate networks of growth faults in the middle shelf and Mississippi Delta regions off Louisiana and in the outer shelf off Texas (sht. 2, C).

Upper Continental Slope

Large salt stocks surrounded by thick sheaths of deformed shale and ridgelike masses of diapiric salt are typical of the diapiric structural style to the shelf-edge and upper Continental Slope regions (water depths from 90 to 1,000 m) from the Mississippi Delta vicinity westward to the Rio Grande Slope off South Texas (sht. 2, D). Structural sizes of salt stocks range from 5 to 30 km across, and some salt anticlines extend for more than 50 km. Salt structures are spearated by broad sedimentary basins that are filled to near capacity and are only moderately expressed in the sea-floor topography. Upper slope basins commonly contain 2,000 to 3,500 m of sediment and some, especially those in the Mississippi Fan and western slope regions, contain bedded deposits exceeding 5,000 m in thickness. Sea-floor expressions of salt domes in the forms of mounds and banks that were produced by arching and faulting of strata over diapiric centers are common throughout the area. Some of the more prominent banks along the shelf-edge consist of carbonate caps built by faunal growth active since late Pleistocene time. That these reefs thrived in the photic zone, and that some continue to thrive on East and West Flower Garden Banks (sht. 2, A), during subsidence, high sedimentation rates, and a wide range of sea-level fluctuations indicates a recent and continuing history of vertical salt uplift.

As many as 24 individual salt structures penetrate and uplift Cretaceous units and Tertiary strata as young as late Miocene in the upper slope region of the West Forida Platform around DeSoto Canyon. Other piercement domes and nondiapiric salt swells are known to exist in the area between the DeSoto Canyon diapiric field and the large salt uplifts of the Destin Dome area to the northeast. The positions and sizes of these structures, however, cannot be included here owing to the proprietary nature of the seismic data that show them. The apparent detachment of these structures from the main diapiric province to the west may be due more to a lack of data control in this region than to depositional or paleostructural factors.

Mississippi Fan

The middle slope region of the Mississippi Fan province is underlain by a system of northeast-trending salt anticlines (shts. 1, A and 2, E) first recognized by Shih and Watkins (1974). Salt ridges range from 1 to 15 km in breadth and from 30 to 140 km in length. Narrow troughs between the ridgelike structures commonly contain stratified sedimentary sections 2,000 m or more thick. Thick deposits of upper Quaternary strata over the entire region obscure all but the most subtle topographic expression of the underlying salt-ridge structure. The morphological contrast between the subparallel ridge system of the Mississippi Fan province and the random pattern of salt structure in the Texas-Louisiana Slope region to the west may be the result of a more uniform distribution of prograding sediment loads in the relatively younger deltaic-slope province (Watkins and others, 1978).

The seaward edge of the northern gulf diapiric province is less well defined in the Mississippi Fan region than elsewhere along the margin. Small, isolated diapiric plugs and nondiapiric, pillowlike swells (sht. 2, F) pierce and uplift Cretaceous and lower Tertiary strata in a poorly defined belt that is subparallel to the Florida Escarpment and that extends from the salt-ridge system of the upper fan southeastward to near lat 25° N. Similar deeply buried structures are present beneath the lower fan province in the east-central gulf north of the Campeche Escarpment. These structures are presumed to be salt cored on the basis of morphological characteristics and the general stratigraphic level at which they are rooted.

Texas-Louisiana Slope

Between the Mississippi Fan province and the Alaminos Canyon, the middle slope region off Louisiana and eastern Texas is characterized by the presence of very broad, steeply flanked diapiric stocks and ridges distributed in a totally random pattern (sht. 1, A). In cross section, these structures appear as flat-topped, thinly covered salt massifs separated by deep topographic depressions and canyons filled with thick, bedded deposits (sht. 2, G). Sediment distribution patterns on the slope are controlled principally by the growth of salt structures, which have often blocked active submarine canyon systems or coalesced to form topographic depressions in noncanyon areas (Martin and Bouma, 1978; Trabant and Presley, 1978; Bouma and Garrison, 1979; Martin and Bouma, in press). Sedimentary loading on thick subsurface salt deposits in such local basins thus may be a prime factor in the evolution of the random structural pattern of salt diapirs in the Texas-Louisiana Slope (Watkins and others, 1978; Martin and Bouma, in press).

Salt structures on the lower Texas-Louisiana Slope between the Mississippi Fan and Alaminos Canyon consist mainly of gentle, pillowlike swells that rise only a few hundred meters above an almost continuous mass of relatively shallow salt (sht. 2, H and I). Structural crests are covered by thin sections of moderately deformed bedded sediments and slump deposits. In contrast to the thick sections of downbuilt sediments (Humphris, 1978) that occupy deep interdomal basins and canyons elsewhere in the Texas-Louisiana Slope and that occupy structural troughs between salt ridges in the Mississippi Fan province, the sedimentary cover of the lower slope region is relatively thin (500 to 2,000 m) and is perched on the shallow salt surface. The almost continuous body of shallow salt that underlies the lower slope region is divided into broad, lobelike masses by submarine-canyon systems that open onto the Continental Rise and extend for several tens of kilometers into the slope province as pronounced topographic features. These canyons, and broad basins and troughs that separate lower slope salt masses from the large diapiric stocks and ridges on the middle slope, contain substantial thicknesses of well-stratified deposits.

Sigsbee Escarpment

Thinly covered, tonguelike masses of salt (sht. 2, J) overlie Continental Rise strata that range in age from Miocene to early Pleistocene along the Sigsbee Escarpment at the foot of the Texas-Louisiana Slope. Salt tongues of this nature were initially recognized by deJong (1968) and Amery (1969) near long 92° W., in the area of the southernmost bulge in the escarpment, and were described in later reports by Watkins and others (1975, 1978) and by Humphris (1978). Seismic-reflection profiles available for this study show that such salt tongues are not local features but are present in a zone 10 to 15 km wide (cross-hatched pattern, sht. 1, A) along the escarpment from near long 91° W. westward to long 94° W. In profile, the salt tongues generally are shaped like inverted wedges pointed basinward. Salt thicknesses range from 1.0-1.5 km upslope to only a few tens of meters along nearly exposed basinward edges. Basal surfaces of individual salt tongues are in angular contact with the Tertiary and Quaternary strata that continue basinward into the adjacent Sigsbee Wedge (Wilhelm and Ewing, 1972) sequence. The salt tongues result from lateral flowage, probably contemporary with the deposition of upper Tertiary and Quaternary strata so that the leading edges of individual flows were never buried more deeply than they are at present. Collectively, the flows represent the leading edge of a large salt body that extruded seaward in response to the rapid accumulation of regional sediment loads during late Teritary and Quaternary time. That little evidence exists of salt intrusion or uplift in the deeper strata beneath the salt tongues further suggests lateral salt flowage beyond the basinward limits of Jurassic salt deposition (Martin, 1980).

Northwestern Continental Slope Province

The structural styles of salt diapirs and uplifts of the Continental Slope regions off South Texas and northeastern Mexico contrast markedly with those of the Texas-Louisiana Slope region (sht. 1, K and L). In the "elbow" area of the Continental Slope off South Texas, where the trend of the slope swings from east-west to north-south, the structural style of salt deformation is considerably subdued. Most of the middle and lower slope regions are underlain by a shallow salt layer whose surface has been deformed into gentle anticlinal and irregularly shaped forms that mainly uplift and fault the overlying strata but commonly do not intrude them. Steeply flanked, well-defined diapiric anticlines and stocks are common features in the upper slope and near Alaminos Canyon but are the exception elsewhere. To the south in the Rio Grande Slope province (sht. 2, M), isolated diapiric stocks and narrow anticlines are the predominant salt forms of the upper slope region to about 1,000-m water depths. Structures are covered and separated by thick sections of sedimentary deposits, and few are topographically expressed. The ridge and knoll topography of the middle and lower slope region is formed by very large, northeast-trending salt anticlines separated by deep basins and troughs that contain thick sections of clastic sediment. Southward from Alaminos Canyon, large anticlinal massifs underlie the Perdido Escarpment at the foot of the Rio Grande Slope. Isolated stocks, salt ridges, and deeply buried anticlinal swells intrude and fold well-stratified deposits in the adjacent Continental Rise province. Folded strata of Pleistocene age and sea-floor topographic expression of many structures in this area indicate that salt has moved recently.

Salt anticlines and anticlinal structures cored by diapiric shale (Buffler and others, 1979) extend southward from this region of the Rio Grande Slope into the East Mexico Slope where shale deformation is recognized as the principal structural mechanism affecting the Cenozoic clastic sequence. A distinction between salt-cored and shale-cored anticlines and domal structures south of lat 25° N. is most difficult with those data available for this study and was not attempted. Salt structures probably do exist in the East Mexico Slope province, but their recognition must await further study.

Southwestern Gulf of Mexico Margin

The continental margin of the southwestern Gulf of Mexico includes the Coastal Plain regions of the States of Veracruz, Tabasco, Chiapas, and Campeche; the adjacent Continental Shelf; and the Golfo de Campeche Slope. Salt structures are present in the Coastal Plain regions of eastern Veracruz and western and central Tabasco onshore, in the adjacent Continental Shelf between long 91° 30' and 95° W., and over the entire Continental Slope province between the Campeche Escarpment and the Veracruz Tongue.

Coastal Plain

The slender diapiric stocks and anticlinal massifs of the Mexican Gulf Coastal Plain are small relative to their offshore counterparts as are the structures of the northern gulf margin. In contrast to the northern gulf however, the thickness of the sediment load above salt is relatively thin (5,000 to 8,000 m). Vague linear trends in the distribution pattern of salt structures probably reflect localization of salt growth along gulf coast-type growth faults. Except for brief mention by Halbouty (1967), Murray (1961), and Viniegra (1971), little additional information concerning the morphology, diapiric history, and distribution pattern of these structures is available.

Campeche Shelf

Very large salt stocks, anticlinal massifs, and pillowlike swells intrude and uplift the thick (5,000 m) section of Mesozoic and Cenozoic strata that forms the Continental Shelf. Structural sizes range from about 2 to 20 km in breadth and from about 10 to 30 km in length. Structural crests of inshore domes generally are 3,000 to 4,000 m below the sea floor, in contrast to those in the outer shelf region, which reach to within 1,000 m of the surface. Inner and middle shelf structures appear to be deeply rooted and to be separated by broad areas of thick strata. Some outer shelf diapirs and massifs merge with one another below depths of 3,000 m to 4,000 m, but most structures are separated by basins containing sediment thicknesses in excess of 5,000 m. The structural distribution pattern shown on sheet 1, A is incomplete because of the very limited amount of seismic data available.

Structural patterns in the eastern part of the shelf province, outlined by heavy dashes (sht. 1, A) are taken from a variety of trade-journal articles that report on recent offshore petroleum discoveries in the Bay of Campeche. The actual locations, sizes, and shapes of these salt-cored, faulted anticlines are uncertain inasmuch as geodetic control has been omitted from the maps and illustrations that accompany these articles. Salt structures in this area of the Campeche Shelf are principally pillowlike swells that are confined within fault blocks and arch overlying Jurassic and Cretaceous strata but do not penetrate them. Mobilization of the apparently thin Jurassic salt layer is more apt to have resulted from the Laramide tectonic events that intensely faulted the region at the close of Cretaceous time than from sedimentary loading (Meyerhoff, 1979).

Golfo de Campeche Slope

The Continental Slope province of the Golfo de Campeche is a region of pronounced topographic knolls and open basins that are underlain by thick sections of folded and faulted strata and masses of diapiric and nondiapiric material thought to be salt. Although similar to the Continental Slope region of the northern gulf in topographic character and, to some extent, internal structure, the Golfo de Campeche Slope includes a considerable number of broad linear hillocks composed of thick sections of Continental Slope and Abyssal Plain strata that were uplifted, folded, and faulted by tectonic forces rather than by salt diapirism (Watkins and others, 1978).

Very large salt stocks and ridges intrude and uplift the thick sedimentary cover of the northern and western flanks of the slope province (sht. 2, N). These deeply rooted structures range from 2 to 10 km in breadth and from 5 to 80 km in length. Thick (3,000 to 4,000 m) sections of uplifted, tilted, and moderately folded strata, identical in seismic-stratigraphic character to undeformed strata in the adjacent Sigsbee Plain and Veracruz Tongue regions, occupy basins and troughs between the diapiric structures. Isoclinal and moderately asymmetrical folds of well-stratified sediments parallel the southwestern flank of the diapiric province and are probably cored at depth by salt.

The structural framework of the upper slope region is dominated by large, closely spaced, diapiric stocks and ridgelike massifs (sht. 2, 0); some structures appear to be the result of secondary diapiric growth caused by sedimentary loading on broader, more deeply buried, masses of salt or saltlike material. Diapiric stocks and anticlinal cores are covered by 1,000 to 3,000 m of folded and faulted strata; maximum observed thicknesses of sediments in interdomal basins and troughs are estimated to exceed 5,000 m. Although some deeply rooted salt plugs and secondary-growth structures are alined along major down-to-basin and down-to-land growth faults, much of the linearity in the structural pattern of this part of the slope may be an interpretive artifact caused by widely spaced seismic data.

The eastern flank of the slope, along Campeche Canyon, seems to be characterized by a zone 30 to 60 km wide of narrow, closely spaced anticlines (sht. 2, P) and broad, tilted blocks of relatively undeformed strata. Anticlinal structures are composed of faulted, well-stratified sediments, from 500 to 2,000 m thick, that are tightly folded over material resembling salt, shale, or acoustically unresolvable, steeply dipping strata. Acoustically similar material that possibly lubricated large-scale tectonic movements, lies beneath large blocks of tilted and overthrust strata. Intraslope basins between topographic expressions of structural crests commonly contain less than a few hundred meters of post-tectonic deposits. In the adjacent Campeche Canyon area, saltlike pillows and broad diapiric masses arch and intrude the deeper stratigraphic section.

The interior region of the slope is characterized by a broad area (15,000 km_2) of folded, faulted, and generally uplifted strata that range from 1,000 to 4,000 m in thickness (sht. 2, Q). Some structures are cored by diapiric material, presumably salt, that reaches to within 1,000 m of the sea floor. Most structures in this region, however, are composed of thick, stratified deposits folded and uplifted over cores and pillows of saltlike material. Reverse faults that displace salt and overlying strata in this part of the slope were recognized by Watkins and others (1978), who suggested that salt emplacement into anticlinal cores was the result of mobilization by late Tertiary, compressional tectonic events. Intraslope basins and troughs in this part of the province, as in the eastern region of the Golfo de Campeche Slope, contain very little evidence of post-tectonic depositional fill.

Abyssal Gulf of Mexico

The abyssal regions of the Gulf of Mexico include (from west to east) the Sigsbee Plain, the lower Mississippi Fan, and the Florida Plain provinces. Salt-cored structures are known mainly in the Sigsbee Plain. The buried and surficially expressed pluglike features in the Florida plain resemble salt diapirs, but associated positive magnetic anomalies suggest that they are probably of igneous origin (Pyle and others, 1969; Garrison and Martin, 1973).

Sigsbee Plain

The Sigsbee Plain is the deepest part of the Gulf of Mexico and has a maximum depth of about 3,700 m. The sea floor is essentially flat and is the surface of a well-stratified section of horizontally layered turbidites and interbedded pelagic oozes that range from Pliocene to Holocene in age (Burk and others, 1969). The Sigsbee Knolls (Ewing and others, 1958; Nowlin and others, 1965; Ewing and Antoine, 1966) are the only features that interrupt the smooth topography of the plain. The knolls are the surface expressions of a few of the large salt diapirs (sht. 2, R) that pierce and uplift many thousands of meters of abyssal strata along a relatively narrow zone that parallels the northwestern face of the Campeche Escarpment. The main concentration of salt diapirs in the plain is the sea-floor knolls near lat 23 5° N. and long 92.5° W. A very narrow belt of widely spaced diapirs connects the Sigsbee salt structures to those in the Golfo de Campeche Slope. Isolated salt domes are present for as much as 200 km northeast of the main center of diapirism.

Structural sizes of salt diapirs in the Sigsbee Plain range from 2 to 20 km in width; maximum diameter of the average dome is about 10 km. All structures are deeply rooted to a mother salt layer at the general level of 7,600 m subsea, or about 3,900 m below the floor of the plain. Large structures in the vicinity of the sea-floor knolls, such as Challenger Knoll (sht. 2, S), appear in seismic-reflection data to merge with adjacent diapirs at depths of less than 2,000 m subbottom. Ridgelike patterns on sheet 1, A represent these closely spaced, coalesced diapirs, which conceivably could be features of secondary growth on large salt ridges that were formed in response to regional tilting and differential sediment loading on the stratiform Challenger Salt.

Mingled with major salt diapirs, and occurring elsewhere in the Sigsbee Plain diapiric belt, are many pillowlike structures that arch overlying strata of considerable thickness (sht. 2, I). The structures are deeply buried and many are small in areal extent; two very large swells several tens of kilometers across are present just east of the Sigsbee Knolls area. Although subjective acoustic characteristics normally indicative of salt are indistinct in many of the seismic data across these features, they are considered to be salt cored because their level of occurrence corresponds with the seismic horizon that approximates the top of the Challenger Salt.

The areal distribution and thickness of stratiform Challenger Salt are mappable from most high-energy, deep-penetration seismic data recorded in the region between the Sigsbee Knolls and Campeche Escarpment; both the surface and the base of the salt unit are clearly evident on such data (sht. 2, U). The undulating salt surface indicates flowage into broad swellforms of low relief. Deformation of post-salt deposits is limited to minor warping and faulting. The base of salt is a generally smooth, northwesterly dipping surface conformal with the presalt strata that underlie it. The internal acoustical characteristics of the salt unit consist of incoherent reflections and diffractions. The Challenger Salt pinches out just seaward of the base of the Campeche Escarpment and thickens to as much as 2,500 m at the edge of the diapir field. Seismic data reveal no unit of comparable acoutical characteristics north and west of the Sigsbee Knolls, thus suggesting that the seaward edge of the Challenger Salt basin is subcoincident with the northern and western periphery of the Sigsbee diapir field.

Lower Mississippi Fan

Deeply buried pillowlike structures that can be interpreted as being cored with salt are present under a wide area of the lower Mississippi Fan northeast of the Sigsbee diapir field. Structural effects from the growth of these low-relief features are confined to only a few hundred meters of overlying strata. The swells occur generally at the stratigraphic level of the Challenger unit, as do similar features in the Sigsbee Plain. Evidence that these structures are salt features is inconclusive; conceivably, they could be basement highs over which sediments have compacted differentially. No known salt structures in this region, except those near the Florida Escarpment, are similar to diapirs in the Sigsbee Plain. The low relief and small size of these features, together with the absence of any distinct diapirs suggest that if these swells are salt cored, they are the result of loading on a relatively thin salt layer.

SUMMARY AND CONCLUSIONS

Salt structures are significant elements of the structural framework of the northern and southwestern Gulf of Mexico margins and of the central Sigsbee Plain region of the deep gulf basin. The structural growth of these features has been controlled by sedimentary and tectonic processes that vary in effect both locally and regionally. The northern gulf region is a diapiric margin that resulted from the vertical intrusion and lateral flowage of large volumes of Middle and Upper Jurassic salt in response to the rapid accumulation of prograding sediment loads, mainly during Cenozoic time. Initial dip of stratiform salt deposits, variations in crustal subsidence rates, migration of sediment supply sources, and unequal patterns of depositional loading combined in varying degrees to produce the wide variety and random distribution patterns of salt structures in this margin. Similar circumstances account for the variety and distribution of salt diapirs in the Isthmus of Tehuantepec and the adjacent shelf and slope regions of southern Mexico. Diapir fields along the western flank of the Golfo de Campeche Slope and in the Sigsbee Plain are the result of vertical salt intrusion in response to a more uniform distribution of sediment volume, slowly accumulated in a deep-ocean environment over thick deposits of Jurassic salt. Salt in these regions probably has been moving continuously since the Late Jurassic and especially during the late Tertiary and Quaternary when large volumes of sediment were delivered to the gulf margins and deep basins. Elsewhere in the Golfo de Campeche Slope and adjacent shelf, relatively thin deposits of stratiform salt were mobilized and emplaced into cores of anticlines and beneath large irregular uplifts by crustal tectonic forces that affected the southwestern Gulf of Mexico region during Late Cretaceous and late Tertiary time. The thicknesses of deformed strata in the Golfo de Campeche Slope, their seismic-stratigraphic character, and drill-hole data indicate that this region of the Mexican margin is composed mainly of lower Continental Slope, Rise, and Abyssal Plain deposits that were uplifted and intensely folded and faulted by tectonic forces active during the late Tertiary.

GLOSSARY

Salt domes, ridges, and massifs: These features are mainly diapiric but may include nondiapiric emplacements in anticlinal cores; locally, they may include sheaths of deformed shale, and some structures may be shale diapirs. The salt is considered to be Callovian and Oxfordian (Middle and Late Jurassic) in age. It has been mobilized mainly by sediment loading in northern Gulf of Mexico continental margin, in Sigsbee Plain, and western Bay of Campeche Slope; it has been tectonically mobilized in eastern Bay of Campeche and southern Mexico.

Pillows: Low-relief, deep-seated, mainly nondiapiric features; inferred to be salt from seismic-reflection characteristics, seismic-stratigraphic level of occurrence, and association with salt diapirs; may locally include differential-compaction features over basement highs.

Salt tongues: Thin wedges of structurally shallow salt that overlie Tertiary and Quaternary strata along Sigsbee Escarpment.

Salt uplifts: Deep-seated emplacements in cores of faulted anticlines; tectonically mobilized during Laramide orogeny; size, shape, and location approximate.

Salt anticlines: Nondiapiric, deep-seated, elongate salt pillows in Mississippi salt basin. Salt anticlines denote axes of broad anticlines and distinct folds believed to be cored by salt in offshore regions.

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