Tectonic Behavior of Evaporites

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ABSTRACT

The great commercial importance of the salt domes of the Gulf Coast has focused attention of most American geologists on salt tectonics as it applies to these structures. These domes although illustrative of many general principles, represent only one type. Their formation and growth is in response to deep burial and essentially buoyant forces. Little, if any, effect of regional stress can be observed in the United States Gulf Coast, although such response is found in Mexico and elsewhere. Mineralogically, they are almost pure halite. Although banding of anhydrite rich layers has been mapped and the style of internal structure thus defined, no significant progress has been made in identifying and following banding throughout a mine. Neither has the more difficult task of correlating relict sedimentary layers from dome to dome been accomplished or even attempted. This is in contrast with the detailed stratigraphic work with the Zechstein saline deposits in Germany, made possible by the highly variable nature of the succession. The special concern with salt tectonics per se *in the Gulf Coast tends to detract from the importance of the structural behavior of the other evaporites. A framework is presented which classifies and places in perspective all aspects of the tectonic behavior of evaporites. One of the two major divisions deals with the response of evaporite sedimentation and accumulation to regional and local control. The other considers both the active and passive roles of evaporites as agents of tectonism.*

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TECTONIC CONTROL OF EVAPORITE DEPOSITION	EVAPORITES-AN AGENT OF TECTONISM
POLAR WANDERING	ACTIVE ROLE
CONTINENTAL DRIFT	DEFORMATION: FOLDING AND FAULTING RESULTING FROM BUOYANCY OF SALT
SUBSIDENCE CONCURRENT WITH DEPOSITION	PASSIVE ROLE
1. SUBSIDENCE RESULTING FROM DEPOSITION	DEFORMATION:
2. DEPOSITION LOCALIZED BY SUBSIDENCE	A. FOLDING AND FAULTING RESULTING FROM PLASTICITY OF EVAPORITES
	1. DUE TO PLASTIC NATURE OF THE MATERIAL ITSELF
	2. DUE TO FLUIDS GENERATED BY CONVERSION OF GYPSUM TO ANHYDRITE
	B. BRECCIATION AND FAULTING RESULTING FROM SOLUTION OF SALT

Figure 1. Classification scheme for evaporite tectonics.

INTRODUCTION

An effort to classify and place in perspective all aspects of the tectonic behavior of evaporites is presented in Figure 1. One of the two major divisions deals with the response of evaporite sedimentation and accumulation to regional and local control. The other considers both the active and passive roles of evaporites as agents of tectonism.

Tectonic processes and the nature and occurrence of evaporites are intimately related to each other. The very

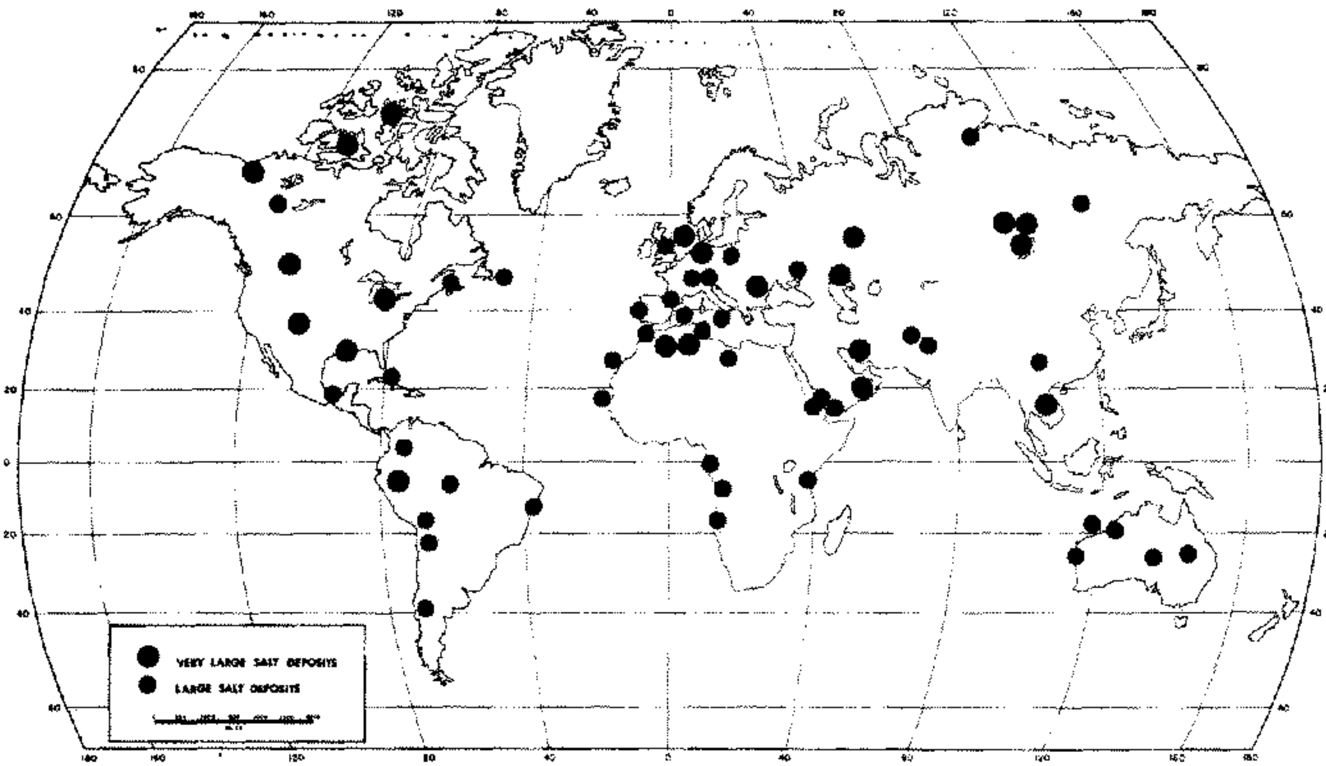


Figure 2. Worldwide distribution of major salt deposits. After Martinez (1971). Compiled from maps and data in Landes (1960), Lefond (1969), Lotze (1957) and Meyerhoff (1970).

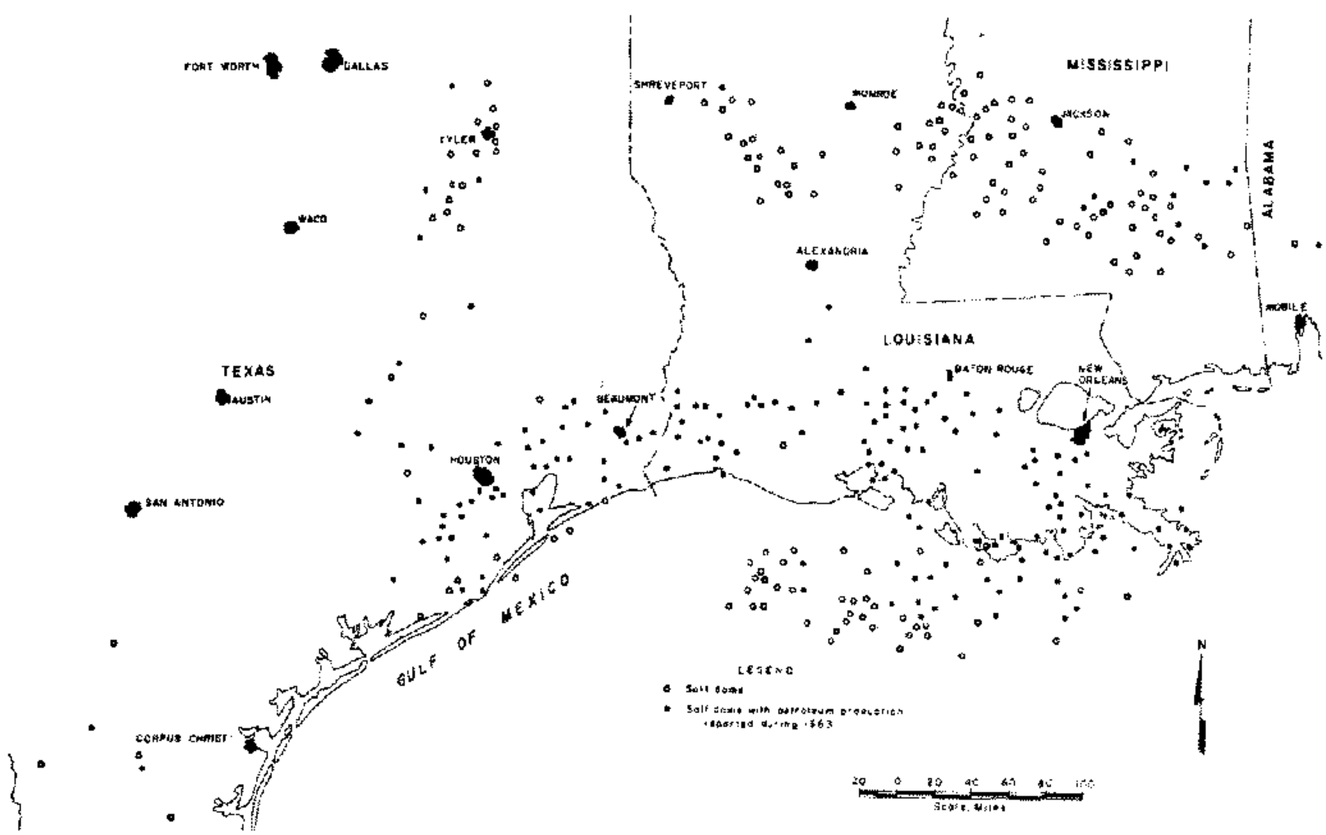


Figure 3. Salt domes in Gulf Coast States and tidelands. After Hawkins and Jirik, Bureau of Mines IC8313, 1966.

origin of thick deposits of evaporites is dependent on crustal subsidence concomitant with evaporation of seawater and precipitation of soluble salts. Without subsidence deposits of thicknesses commonly found could not accumulate. Thus a particular kind of local tectonism must exist to provide a requisite condition for significant evaporite accumulation.

The distribution of the major salt deposits of the world, (Fig. 2) poses a problem because of the location of some deposits at high latitudes. Is it reasonable to suppose that evaporation at such latitudes could have been effective in producing significant evaporite accumulation? Perhaps Briden and Irving (1964) were correct in attributing this apparent paradox to continental drift. If so tectonism on a grand scale played a primary role in the geologic history of some salt deposits.

EVAPORITES AS A TECTONIC AGENT

Although tectonic control obviously plays an important part in evaporite deposition and accumulation, most interest has centered on evaporites as an agent of tectonism. The generally accepted and well demonstrated mode of origin of the United States Gulf Coast domes (Fig. 3) attributed to density contrast has perhaps distracted the attention of most U. S. geologists from different mechanisms of importance in other salt dome provinces. A casual glance at the difference in patterns expressed on maps of salt diapirs in the Gulf Coast (Figs. 4 and 5) and northeastern Mexico (Fig. 6) suggest obvious differences in origin. These different modes can be reduced to two basic types of evaporite tectonic behavior, either active or passive. The U.S. Gulf Coast type is an example of active tectonic behavior in which the salt rises plastically as a result of buoyant forces induced by density contrast. In this instance the salt itself provides the driving force which deforms the surrounding sediments. The salt structures in Mexico, in contrast, probably represent a passive behavior in which the entire evaporite sequence behaved as an incompetent and mobile element in response to regional compressive forces. Evidence of folding in response to regional stress is shown by the anticlinal nature of the folds and the alignment of the anticlines in belts. Buoyancy does not seem to be a requisite force for

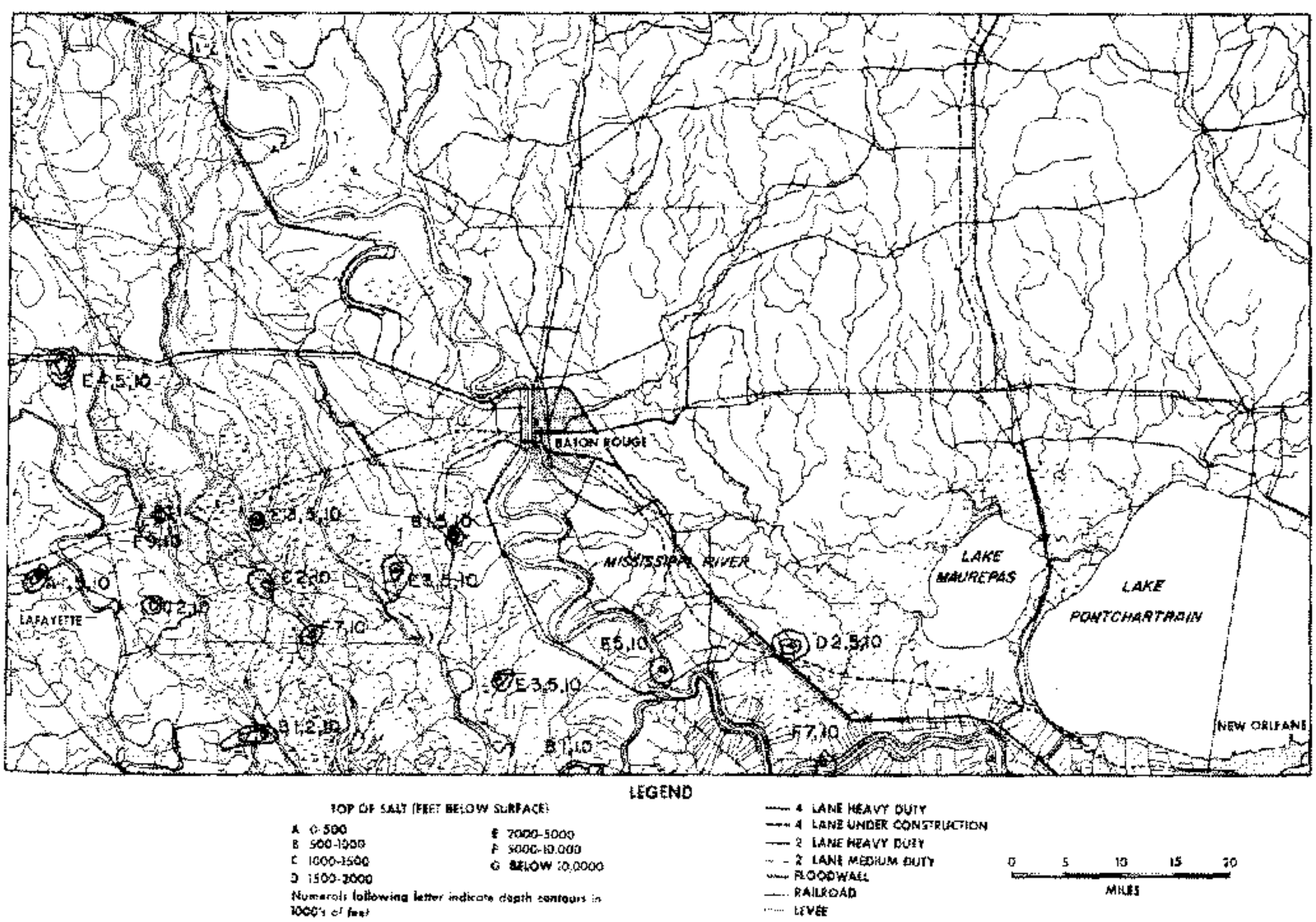


Figure 4. Relation of salt domes to cultural and topographic features in part of South Louisiana. Modified by Martinez (1971) from Wallace (1966).

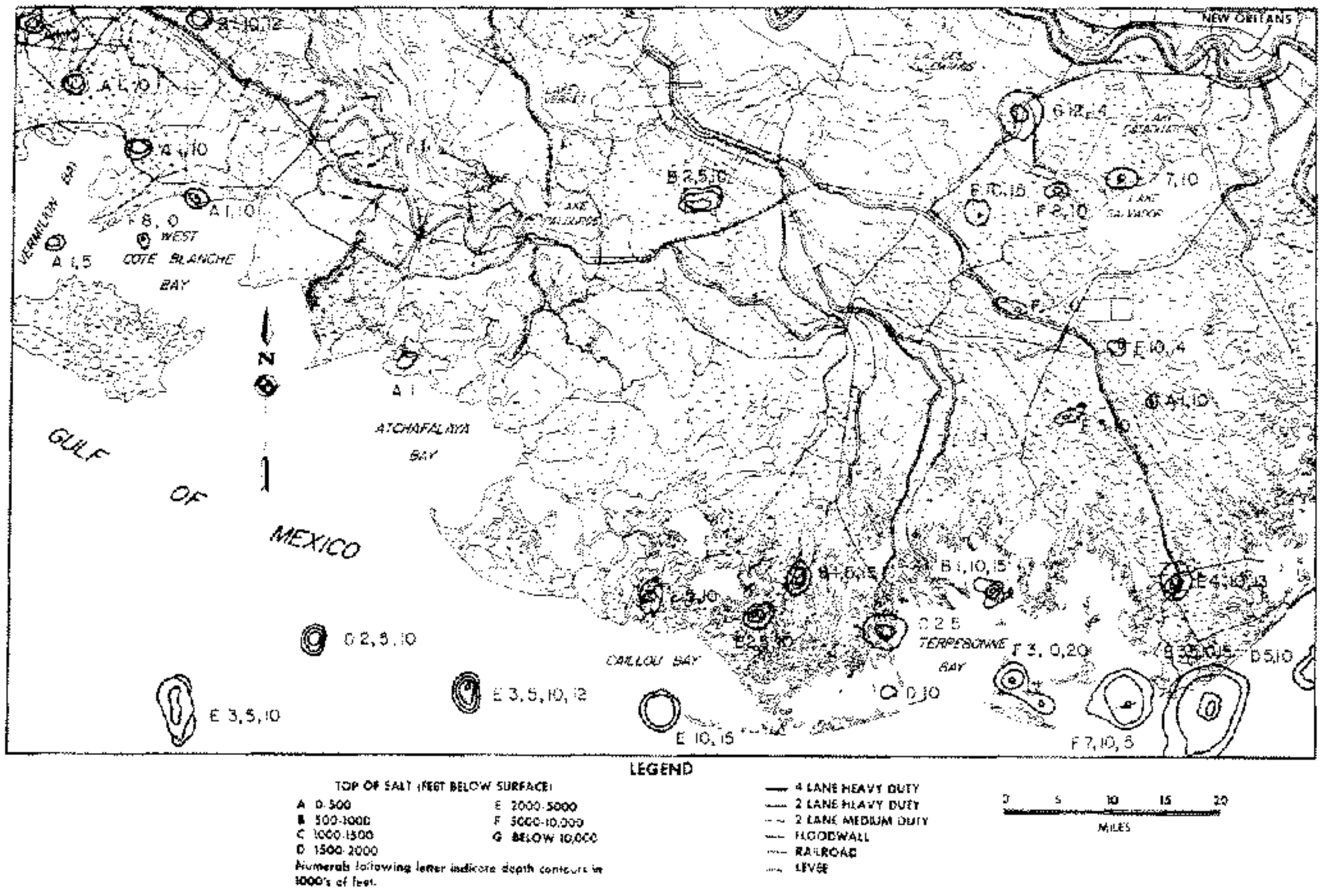


Figure 6. Relation of salt domes to cultural and topographic features in part of South Louisiana. Modified by Martinez (1971) from Wallace (1966).

the style of this folding (Weidie and Martinez, 1972). These conclusions are in general agreement with Wall, et al. (1961).

To attempt to categorize salt structures this rigidly represents an oversimplification. A more realistic view can be attained by considering these two modes of deformation as end members of a continuous range of a spectrum of possibilities (Fig. 7). The Gulf Coast type clearly serves as an anchor for one end. There are sufficient sedimentary thicknesses overlying the salt to account for rise of salt. Furthermore there is no evidence of regional compressive forces. In fact, down-to-the-basin faults suggest regional tension. The outline in plan view of the individual domes is more nearly circular than elliptical. Besides there is no evident alignment of long axes of those that are slightly elliptical.

It is more difficult to present as convincing an argument for an origin of salt dome structure, in which the element of buoyant rise of the salt is completely lacking. Even in the example offered of the salt anticlines in Mexico, one cannot positively rule out some degree of influence due to gravitational rise of the salt. Instances in which the mode of origin of salt structures are probably dependent on *both gravitational and tectonic influences* can readily be found. Rios (1968) concluded that the Oligocene semidiapiric folds in the Ebro depression of Spain were partly a result of tectonic pressures. He based this judgment on an insufficient weight of sediments overlying the evaporites to produce deformation as well as the coincidence of fold orientation with tectonic trends of mountains surrounding the Ebro depression. He did draw a contrast with fourteen domes of Keuper salt in the Contabric trough which he considered to be good examples of structures produced by purely gravitational tectonics.

Benavides (1968) considers that compressive lateral orogenic deformation initiated as well as provided the main force responsible for salt extrusions in eastern Peru. Isostatic forces are thought to have been a secondary factor on the basis of a thick sedimentary overburden above the mother salt and the simple oval shapes of some of the structures.

Liechti (1968) has reviewed the diapiric and semidiapiric structures of the Aquitanian Basin of Southern France (Fig. 8). According to him the structures range from sheet diapirism along major fault planes to circular salt domes similar to those of the U.S. Gulf Coast. He

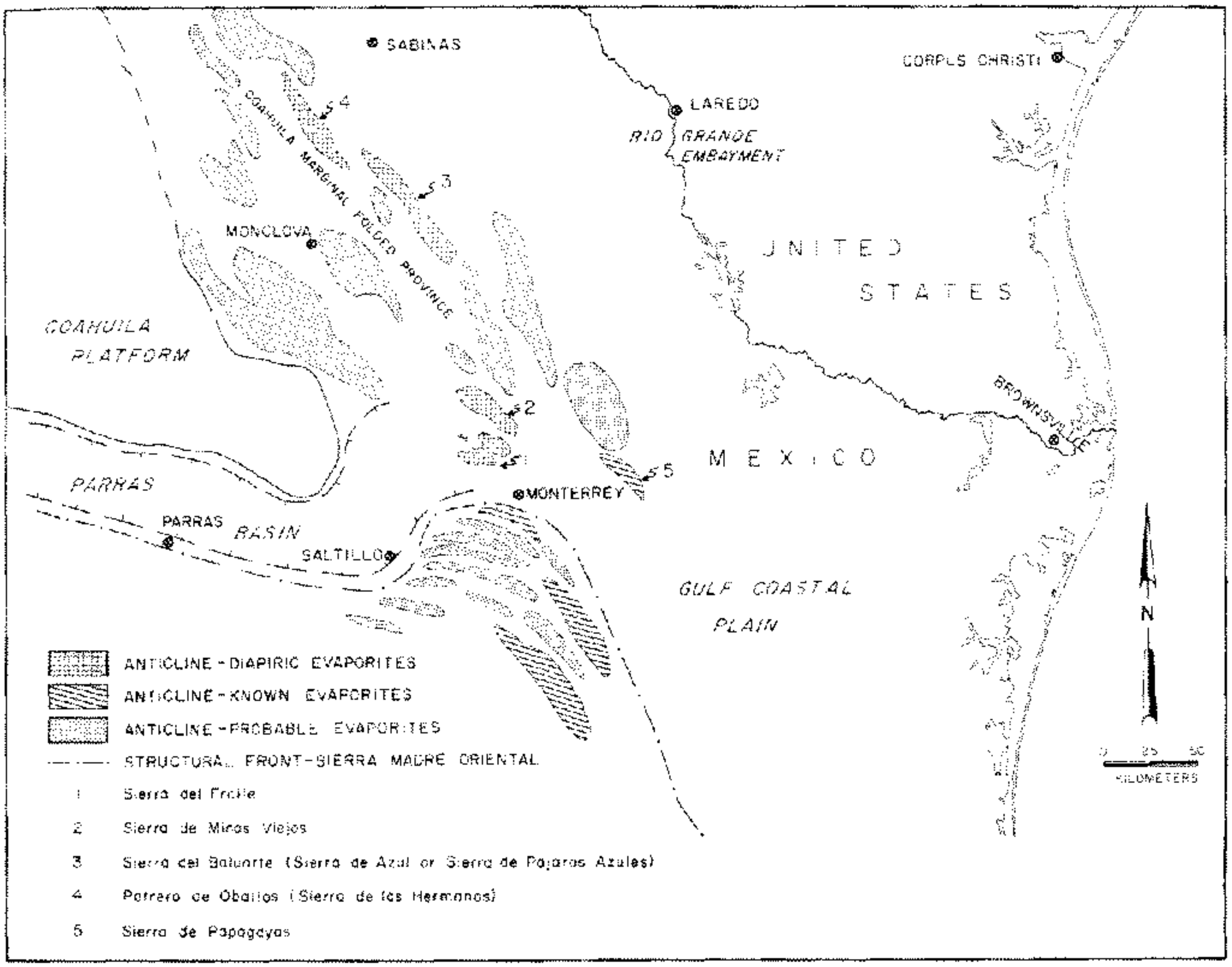


Figure 6. Map of northeastern Mexico showing distribution of Minas Viejas evaporites probably of Jurassic age. From Weidie and Martinez, 1970 and 1972.

concludes that buoyancy played an early part in diapirism with orogenic deformation superimposed later with the combined effect serving to obliterate the early diapirism. Unfortunately, Liechti apparently equates diapirism with gravitational tectonics. There is no basis for this inasmuch as orogenic forces can result in diapiric intrusion of competent strata by incompetent core material. In any event, he lists Audignon as an anticline with a diapiric Triassic core (presumably representing active tectonism at that time). The subsurface evidence that he presents seems to confirm this but the pattern of folding shown on the map in Figure 8 strongly indicates a response to compressive forces as well. This is much more likely for Plagne, an anticline with a non-diapiric core; and Benesse-Clermont, which contains an exposed Triassic core. Even one of the diapiric domes, Bastennes-Gaujacq, is clearly related to orgenic structural features and thus genetically involved with compressive orogenic forces. Liechti recognizes this by pointing out that features such as this are fundamentally different from salt domes developed by purely gravitational forces.

The salt-cored anticlines of Nova Scotia (Shea, 1970 and Bidgood, 1970) and other Maritime provinces of Canada also probably represent structures largely developed by regional orogeny. Van de Poll (1972) stated that the cause of this salt tectonism is not quite clear but he repeated a suggestion by Howie (op. cit. Webb, 1963) "that the salt-cored structures in western Nova Scotia are the result of decollement slippage concomitant with uplift of the Cobequid Mountains or alternatively, to a combination of salt tectonics and northeasterly thrusting." Van de Poll also called attention to a close relationship between salt intrusion and fault zones in some instances in New Brunswick. The coincidence of local Carboniferous unconformities and piercement anticlines was thought by Van de Poll to be evidence of continuous salt tectonism in

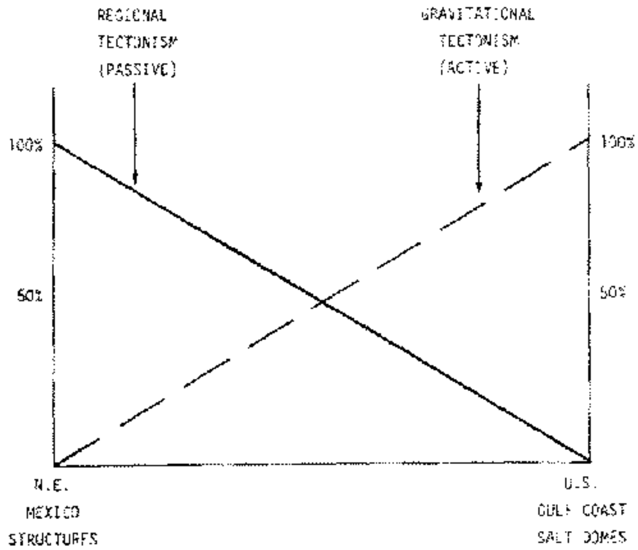


Figure 7. Varying degrees of influence of regional stress and gravitational tectonism on development of salt structures.

post-Windsorian. Presumably this might be evidence of some gravitational involvement in the development of some of the salt structures.

The salt structures of northern Germany were long thought to have been formed by compressional forces. However, a paper by Trusheim in 1960 seems to have established their origin to represent essentially a gravity phenomenon. Trusheim refers to structures of this kind as halo-kinetic in contrast to halo-tectonic structures caused by compressive tectonic forces. He also made the point that every conceivable transition between the two types is to be found in the world. Trusheim's arguments are quite convincing except for the regional pattern of elongate salt anticlines which he admits is an unsolved problem. He notes that many structural trends run approximately parallel with the contours on the Zechstein base and ascribes this to some sort of large scale rhythmical phenomenon of salt migration. He furthermore likens this to trends in other basins one of which is the Ebro basin in Spain. However, we have already seen that Rios (op. cit.) has

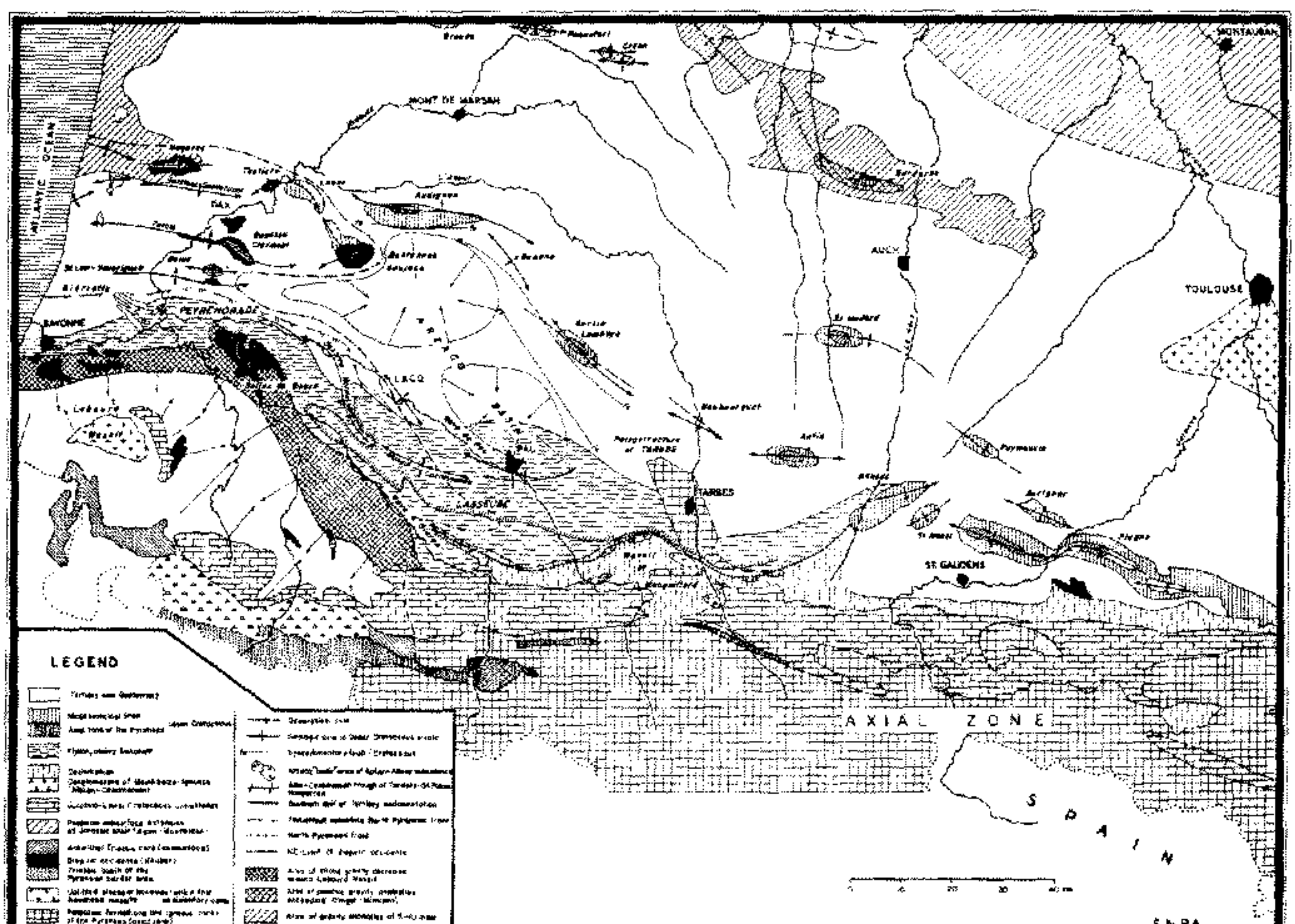


Figure 8. Structural sketch map of western Aquitania and the northern Pyrenees. From Liechti (1968). After T. Henry, J. Dupouy-Camet, and others.

used this same fact as evidence of tectonic influence on the formation of salt structures there.

The pattern of salt anticlines in the Paradox basin suggests tectonic control. However this origin is not generally accepted. Mattox (1968) in a review of structural features of the Paradox basin summarized some of the hypotheses advanced to explain the development of the salt anticlines of that region. These include: regional compression, differential pressures resulting from the development of canyons, differential loading through uneven distribution of post-Pennsylvanian continental deposits and faulting within the basement complex. He considered that the forces involved in the development of these structures are as yet matters of conjecture.

A current version of the origin and growth of the salt anticlines of the Paradox basin is provided by Cater (1972). He cites evidence by Elston and Landis (1960) that the salt cores started forming before deep burial (less than 2,000 feet) of the salt. Because of this thin overburden at the time of initial salt movements and evidence of pre-Paradox faulting he believes that early salt deformation resulted from tectonic activity. However, he considers that further upward movement of the salt was due to gravitational loading which was enhanced by rapid sedimentation in synclinal areas developed by flow of the salt into the main structure. Following deposition of the Mesa Verde formation, anticlines were formed along the old salt structures in response to deep-seated deformation. Finally collapse of anticlinal crests occurred after arching of the Mesa Verde sediments and later epirogenic uplift.

The important point to be gained from this analysis is that there is no unifying theory for the origin of all salt structures. A note of caution is thus raised in the early economic evaluations of inadequately tested salt structures in mobile settings.

It is not the intent of this author to review exhaustively the involvement of the enclosing sediments with salt tectonics. In the interest of a balanced presentation, however, a general statement on the stress field produced by a rising dome and a brief summary on solution tectonics involved with domal growth are presented.

The nature of deformation, both folding and faulting, caused by salt dome growth is exceedingly well known. The oil industry is responsible for a detailed understanding of this subject. Nonetheless it may be well to examine at least superficially the nature of the stress field which has produced this deformation. Figures 9 and 10 present a novel approach to the examination of the pattern of the stress. These figures are photographs of models of salt intrusions examined with circularly polarized light. The dome itself is represented by solid plastic material while the surrounding sediments are modeled with a transparent gel. The usual methods of stress analysis by photoelasticity can be used to interpret the stress field in the sediments. The contrast between domes of different shape is self-evident. It is suggested that this technique might be used to advantage in predicting structural conditions in the near and far vicinity of salt domes.

Figure 9. Stress field produced in a two dimensional gel model by uplift of a solid block of plastic representing a perfectly symmetrical dome. Model is viewed with circularly polarized light.

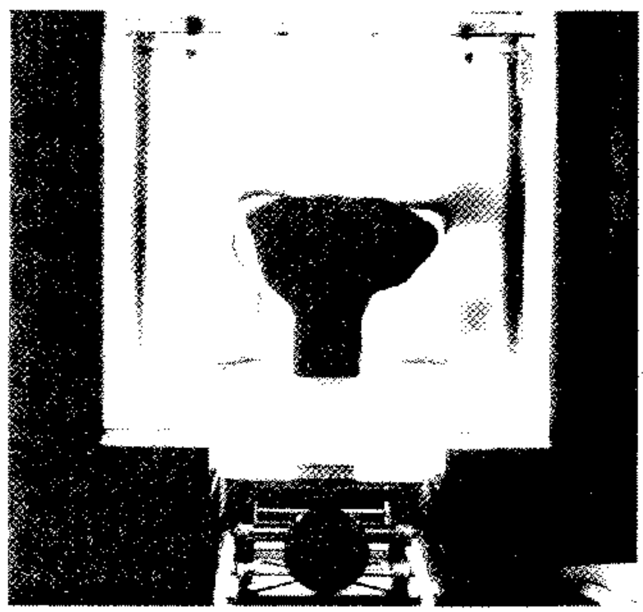


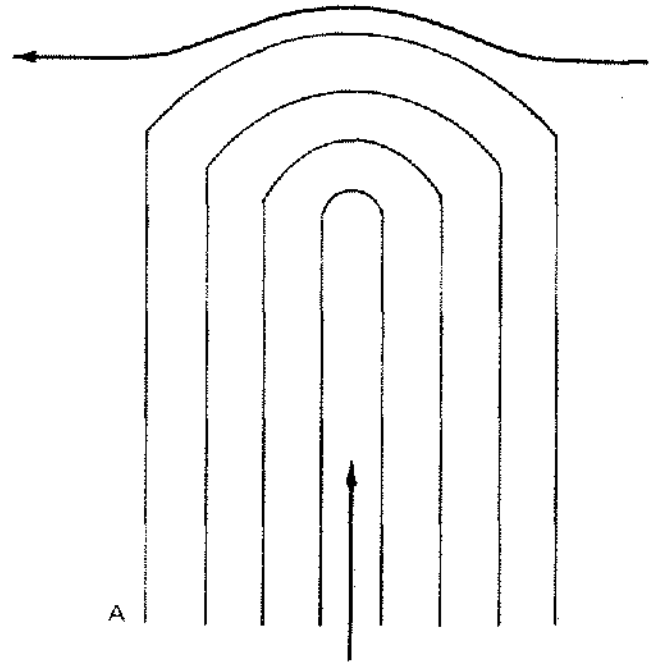
Figure 10. Stress field produced in a two dimensional gel model by uplift of a solid block of plastic duplicating a cross section of the Bethel dome in Texas, shown by Halbouty (1967). Model is viewed with circularly polarized light.

SOLUTION TECTONICS

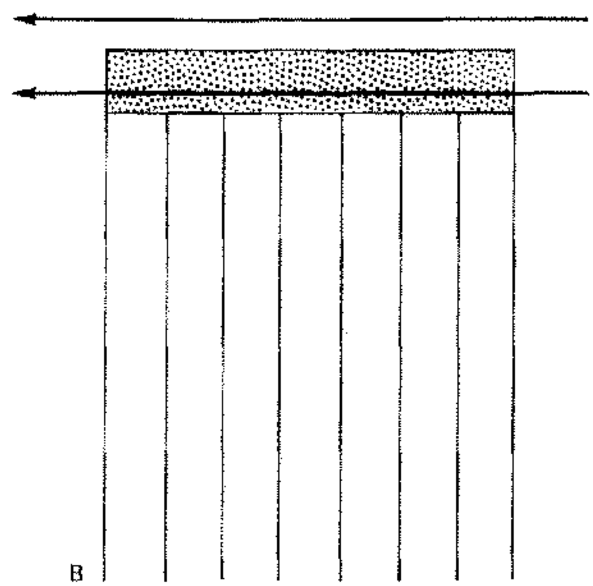
The subject of solution tectonics has been neglected in saline studies and should be included in any paper on salt tectonics. This discussion will focus on the involvement of solution tectonics with salt dome growth, an important aspect of the general topic. The currently accepted theory for the derivation of salt dome cap rock from anhydrite, which is a residue from solution of salt, has provided an insight into the magnitude of dissolution of a growing salt dome.

Figure 11 (A-F) presents diagramatically the postulated sequence of events involved in cap rock formation as outlined in a review article by Murray (1966). If this explanation is valid the scale of solution of salt is extraordinary. In order to develop a thousand foot thick cap rock from a rising salt mass containing five percent anhydrite, 20,000 feet or nearly four miles of salt would have had to be dissolved from the top of the dome. Actually, according to Kupfer (1963) the average anhydrite content is less than three percent and some domes have cap rock thicker than 1,500 feet. Although this theory is generally accepted, the quantities of salt removal have led to a reexamination of this question by Walker (1972). He has proposed an alternative explanation which is being presented at this symposium. However for the purpose of this analysis the "residual accumulation" theory will be followed. An analogy can be drawn between the pattern of salt dome growth and salt solution and the flow of a glacier of ice which experiences continuous melting at its extremity. Whether a glacier advances or retreats as ice flows from snow field to terminus depends on both the rate of flow and rate of melting. If rate of flow exceeds rate of melting, the glacier advances. If rate of melting exceeds rate of flow the glacier retreats. If the two rates are in equilibrium, the foot of the glacier remains stable. In a similar manner, if the rate of growth of a salt dome exceeds the rate of solution, the upper surface will continue to rise. If the rate of solution exceeds the rate of growth, subsidence over the dome will result. A steady state is brought about by an equivalence of these two processes. Of course, it is of no consequence whether or not cap rock is formed. The important point is that when cap rock is formed it provides a measure of the amount of solution that has occurred. The presence of a thick cap rock means that much salt has been lost by solution. This presents three possibilities: (1) the dome has grown faster than solution has occurred at its upper surface, (2) the upper surface has been dissolved away faster than the salt is replaced by upward growth which must have resulted in subsidence of the overlying sediments, (3) the upper surface of the salt remained at the same level as salt removed by solution was replaced by upward growth of the dome.

A better understanding of salt dome tectonics might result from a critical analysis of variations in cap rock thickness on salt domes. For example, there is scant evidence in the literature of subsidence over United States salt domes *due to solution of the salt.* Solution collapse

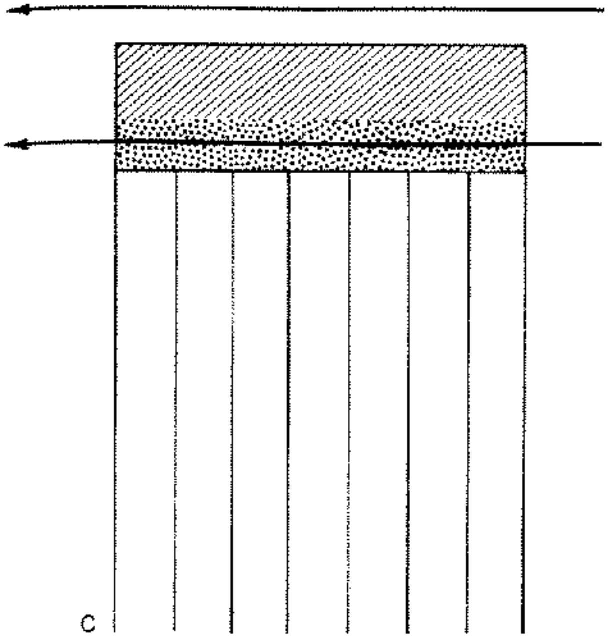


Salt plug penetrates zone of water circulation.



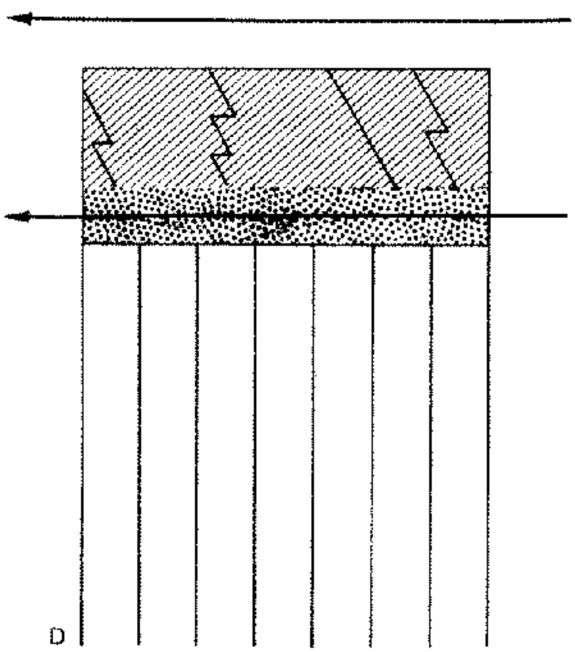
Truncation of top of salt, decapitation of folds, formation of solution table, and accumulation of residual anhydrite sand.

Figure 11. (A-F) Postulated sequence of events involved in cap rock formation. Based on Murray's written summary (1966).



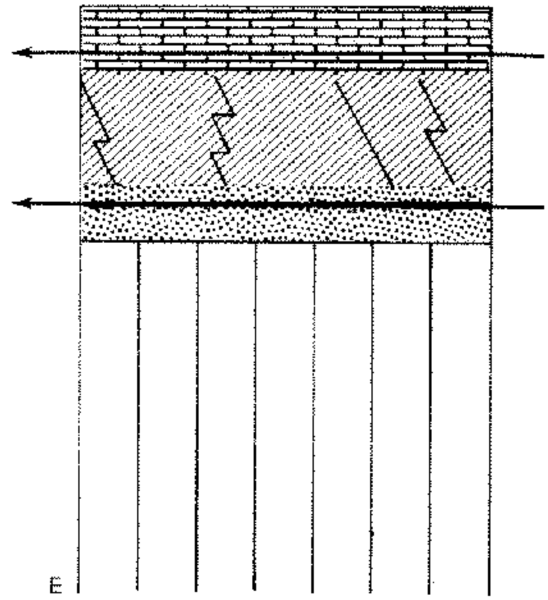
C

Compaction of cap rock, precipitation of anhydrite from solution, and intergrowth of anhydrite grains.



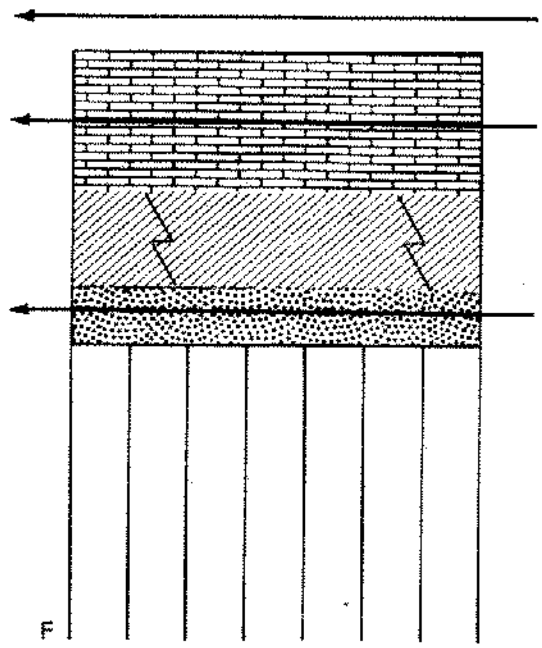
D

Continued solution of salt. Growth of salt plug compensates for salt removed by solution. Consolidation and subsequent shearing of anhydrite by upthrust and collapse.



E

Solutions pass through the cap rock and alter anhydrite to gypsum and both gypsum and anhydrite to calcite and sulphur forming a transition zone.



F

Transition zone moves downward, H_2S escapes or is oxidized to sulphur, calcite is deposited. Other minerals develop in upper part of calcite zone. Influx of hydrocarbons causes reduction of the sulphates to sulphur with redeposition in another part of cap rock, or escape.

Figure 11. (Continued)

features are often produced over salt domes in Germany according to Borchert and Muir (1964). They report that such depressions frequently become the site of a lake and some are occupied by Tertiary coal swamps. Thus thick, circular, or elliptical bodies of lignite are found above some of these domes. A relatively small amount of subsidence over the Jefferson Island dome in Louisiana is reflected by the presence of a lake (Fig. 12). A much more impressive, presumably solution generated, subsidence feature over the Chestnut dome (Fig. 13) has been pinpointed by Dinnean (1958). In view of the common occurrence of cap rock on Gulf Coast salt domes (Fig. 14), it is surprising that more collapse features caused by solution have not been identified. There are three possible explanations. Either most salt dome growth exceeds salt removed by solution or in spite of intense study of salt

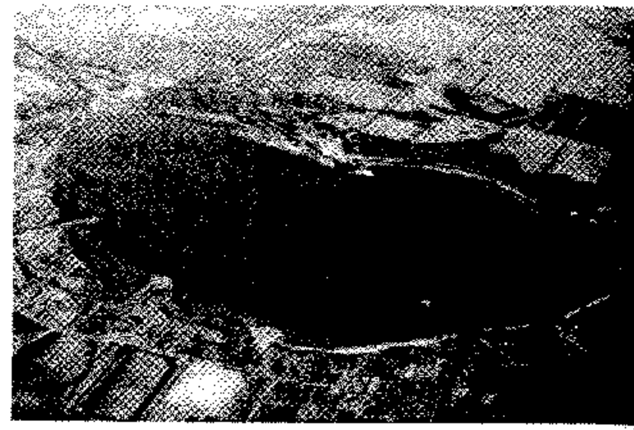


Figure 12. Lake over Jefferson Island salt dome reflecting natural dissolution of salt.

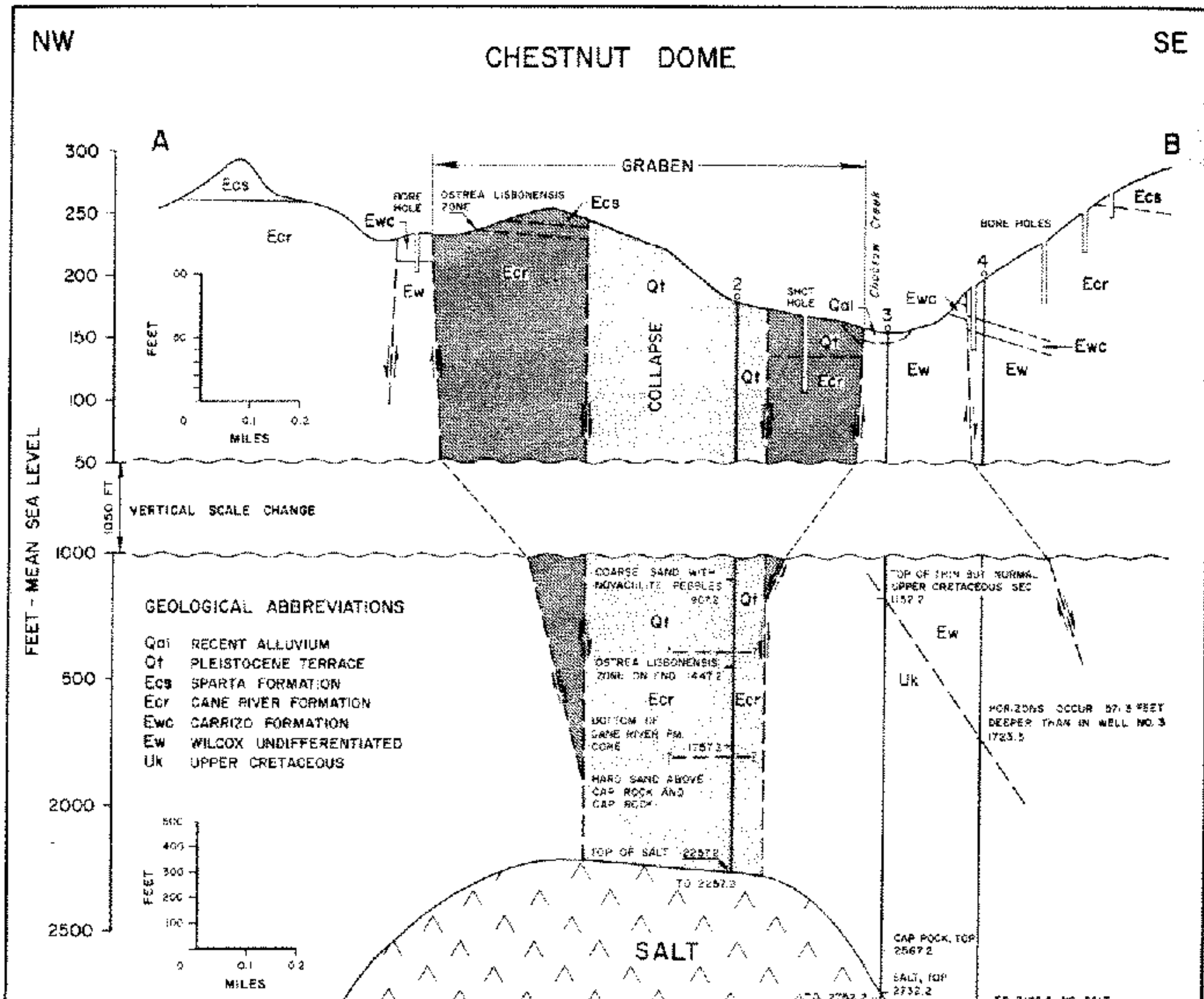


Figure 13. Subsidence over the Chestnut dome probably resulting from solution of salt. After Dinnean (1958).

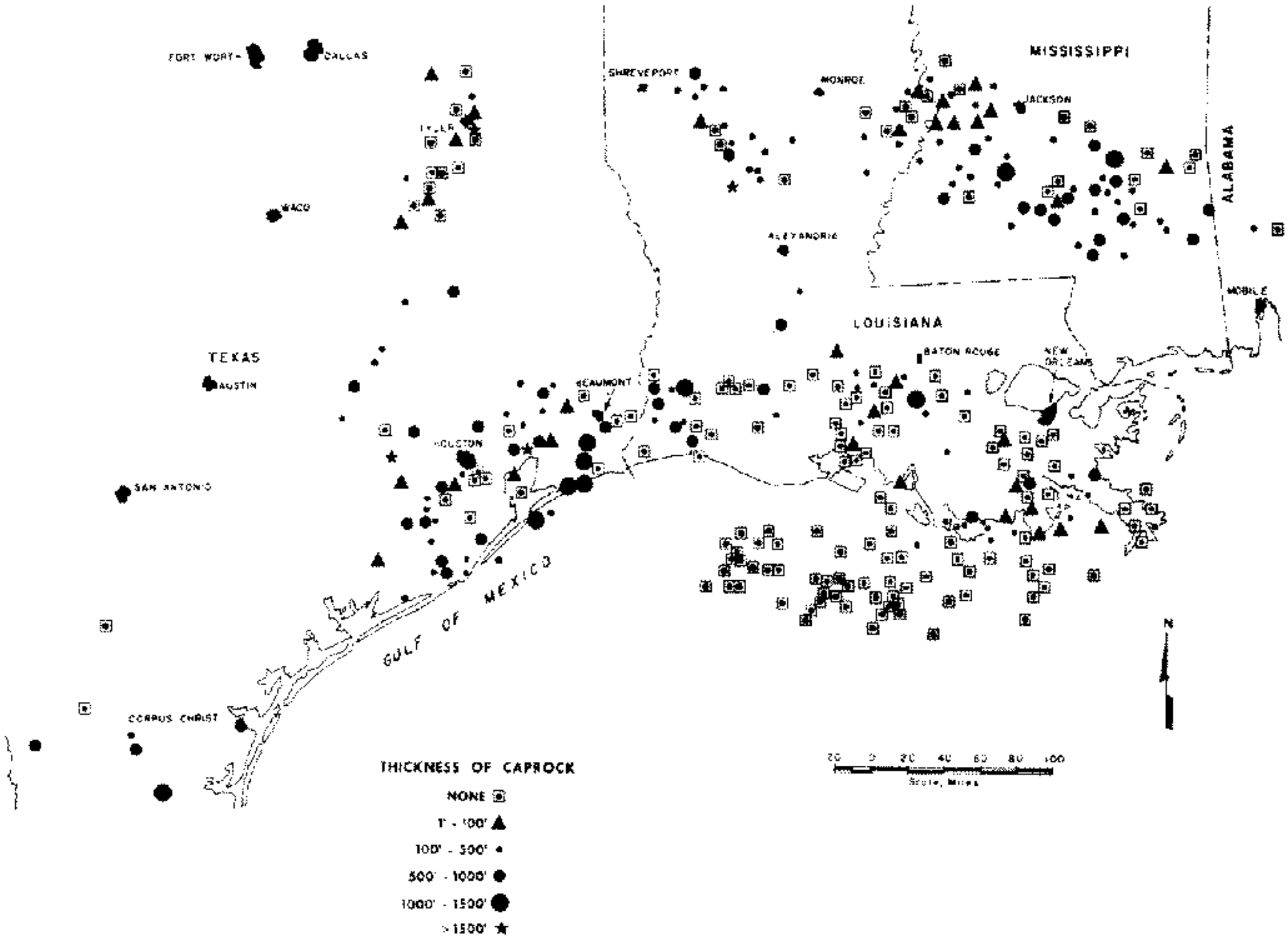


Figure 14. Thickness of cap rock over Gulf Coast salt domes. Base map and data from Hawkins and Jirik (1966).

dome geology this kind of feature has been overlooked, or the residual accumulation theory of cap rock formation is not valid.

It would appear to be important to seek the answer to the question posed by these observations. The data for the map of Figure 14 is taken principally from Hawkins and Jirik (1966) and is spotted on their map of salt dome occurrence. Inasmuch as these data are highly generalized they must be used with caution in this kind of analysis. Bearing this in mind, there is another point brought out from the distribution shown by the map. Domes with great thickness of cap rock are found to occur close to domes with little or no cap rock. If certain groups are examined in cross section such as the group of domes near Tyler, Texas shown in Figure 15 and the three domes in Figure 16, it is interesting to note that domes which have reached nearly identical levels show great differences in cap rock development. This may indicate differences in rate of growth. Cap rock may serve as a "speedometer" to indicate relative rate of salt dome growth. Analyses of this kind performed in detail may prove useful in a reexamination of the dynamic geology of certain groups of salt domes.

INTERNAL STRUCTURE OF SALT DOMES

Studies of internal structure of the salt itself in Gulf Coast domes by Balk (1949 and 1953), Muehlberger (1959), Kupfer (1962), and Hoy, et al. (1962) have provided an excellent understanding of the anatomy of these salt structures and the basis for the principles of their growth. Detailed mapping by these workers has established the style of folding of the salt. Richter-Bernburg (1972) pointed out that the interior of the Zechstein salt structures of Germany is not well known. However, according to him several of these structures explored by drilling and mined for potash have been studied. The variability of the Zechstein evaporite sequence has made it possible to map the internal structure in these instances more completely than has been possible for the Gulf Coast

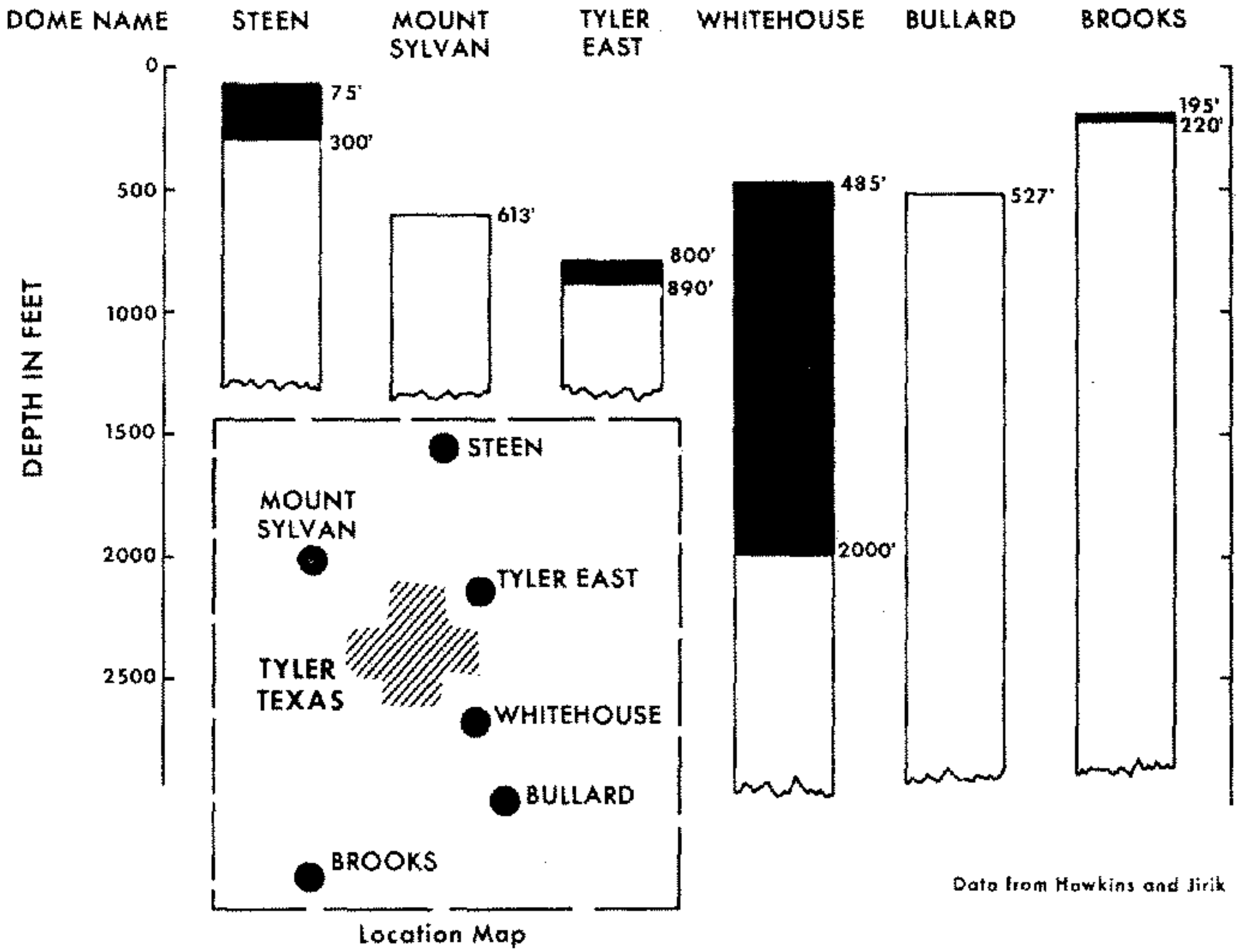


Figure 15. Cap rock development on salt domes near Tyler, Texas. Data from Hawkins and Jirik (1966).

domes, since correlations could be extended from one mine opening and one drill hole to another. Such mapping has been useful in following the minable potash beds. Rhythmic banding in evaporite rocks has been used for regional correlation by Richter-Bernburg (1960) in the Zechstein basin. New and controversial ideas for the influence of high temperatures in salt dome growth have been advanced by Gussow (1968). A recent excellent review of salt tectonics by Gera (1972) discusses the mechanics of salt deformation in detail particularly with respect to the value of salt domes as a reservoir for radioactive waste disposal. It is quite apparent from the writings of all of these workers and from a casual appraisal of domal salt itself that this material is indeed a metamorphic rock. It seems reasonable to consider it a gneiss both on the basis of its texture and genesis. Many other typical structures of metamorphic rocks such as boudinage are found in some deformed salt beds.

OTHER EVAPORITES

Equal attention has not been given to the metamorphic nature of other evaporites. Wall, et. al. (1961) called attention to the schistose nature both on a macroscopic and a microscopic scale of gypsum in a salt anticline, in northeast Mexico, Portero Chico, (Figure 17). Weidie and Martinez (1972) made a detailed structural analysis of this deformed gypsum and proposed a history of its development. They concluded as Wall, et. al. had that the gypsum was intrusive and they were able to estimate the maximum depth at which schistosity was developed.

CONCLUSIONS

The purpose of this paper has been to show that evaporite tectonics although a broad and complicated subject can be fitted into a simple classification. The value of attempting to reduce complexity to a few unifying con-

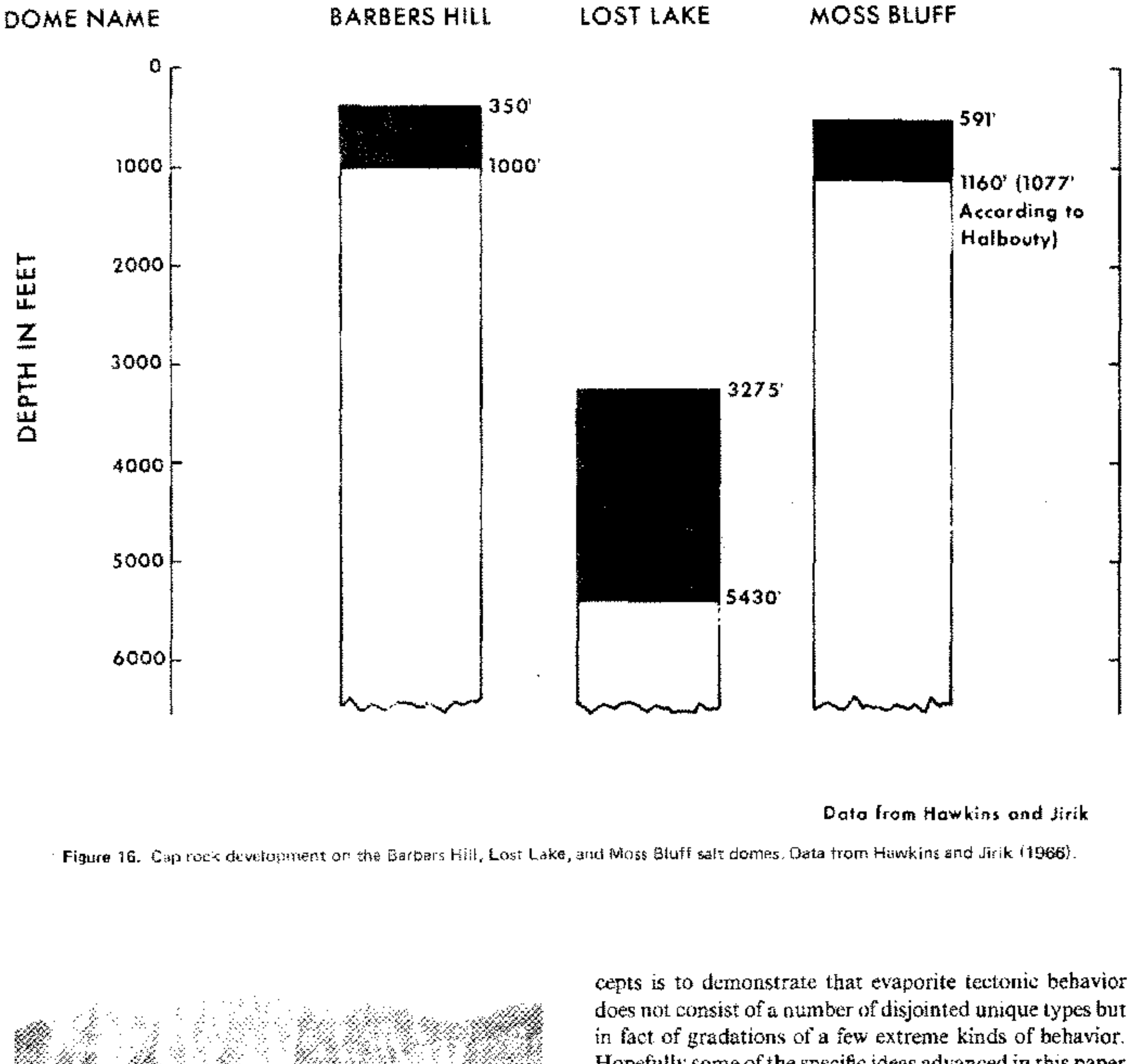


Figure 16. Cap rock development on the Barbers Hill, Lost Lake, and Moss Bluff salt domes. Data from Hawkins and Jirik (1966).

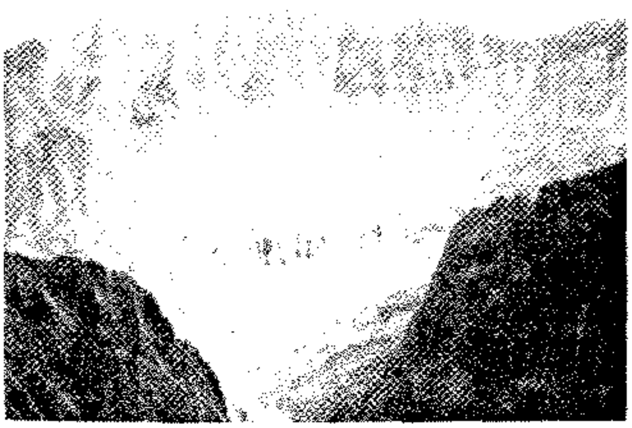


Figure 17. Aerial view of gypsum outcrop viewed through gap on flank of Potrero Chico, a salt-cored anticline near Monterey, Mexico.

cepts is to demonstrate that evaporite tectonic behavior does not consist of a number of disjointed unique types but in fact of gradations of a few extreme kinds of behavior. Hopefully some of the specific ideas advanced in this paper will generate interest in more detailed study and evaluation.

REFERENCES

Balk, Robert, 1949, Structure of Grand Saline salt dome, Van Zandt County, Texas: *Am. Assoc. Petroleum Geologists Bull.*, 33, no. 11:1791–1829.

Balk, Robert, 1953, Salt structure of Jefferson Island salt dome, Iberia and Vermillion Parishes, Louisiana: *Am. Assoc. Petroleum Geologists Bull.*, 37, no. 11:2455–2474.

Benavides, Victor, 1968, Saline deposits of South America: *Geol. Soc. America Spec. Paper* 88:249–290.

Bidgood, D. E. T., 1970, The distribution and diapiric nature of some Nova Scotia evaporites—a geophysical evaluation, in *Third symposium on salt: Northern Ohio Geol. Soc.*, p. 298–305.

Borchert, Hermann, and Muir, Richard O., 1964, *Salt deposits:* D. Van Nostrand Co., Ltd., 338 p.

Briden, J. C., and Irving, E., 1964, Palaeolatitude spectra of sedimentary palaeoclimatic indicators, in *Problems in palaeoclimatology:* New York, A. E. M. Nairn, ed., Interscience, p. 199–224.

Cater, Fred W., 1970, Geology of the salt anticline region in southwestern Colorado: *U.S. Geol. Survey Prof. Paper* 637, 80 p.

Cater, Fred W., 1972, Salt anticlines within the Paradox basin: *Denver, Geol. Atlas Rocky Mnt. Region, U.S.A.*, p. 137–138.

Dinnean, Robert F., 1958, Geology of the Chestnut salt dome area, Natchitoches Parish, Louisiana: *La. Dept. Conservation, Geol. Survey, Geol. Summ.*, no. 1:9 p.

Elsont, D. P., and Landis, E. R., 1960, Pre-Cutter unconformities and early growth of the Paradox Valley and Gypsum Valley salt anticlines, Colorado, in Short papers geol. sciences: *U.S. Geol. Survey Prof. Paper* 400-B, B261–B265.

Gera, Ferruccio, 1972, Review of salt tectonics in relation to the disposal of radioactive wastes in salt formations: *Geol. Soc. America*, 83, no. 12:3551–3574.

Gussow, William Carruthers, 1968, Salt diapirism: importance of temperature, and energy source of displacement, in Mem. 8, Diapirism and Diapirs: Am. Assoc. Petroleum Geologists, p. 16–52.

Halbouty, Michael T. 1967, Salt domes: Gulf Region, United States and Mexico, Houston: Gulf Publishing Company, p. 99.

Hawkins, M. E. and Jirik, C. V., 1966, Salt domes in Texas, Louisiana, Mississippi, Alabama, and offshore tidelands: survey: information circular 8313 U.S. Bur. of Mines, 78 p.

Howie, R. P., and Cumming, L. M., 1963, Basement features of the Canadian Appalachians: Canada Geol. Survey Bull. 89.

Kupfer, D. H., 1962, Structure of Morton Salt Company mine, Weeks Island salt dome, Louisiana: Am. Assoc. Petroleum Geologists Bull., v. 46, no. 8, p. 1460–1467.

Kupfer, D. H., 1963, Structure of salt in Gulf Coast domes, in First symposium on salt: Northern Ohio Geol. Soc., p. 104–123.

Liechti, P., 1968, Salt features of France: Geol. Soc. America Spec. Paper 88, p. 83–106.

Martinez, Joseph D., 1971, Environmental significance of salt: Am. Assoc. Petroleum Geologists Bull, v. 55, no. 6, p. 810–825.

Mattox, Richard B., 1968, Salt anticline field area, Paradox basin, Colorado and Utah: Geol. Soc. America Spec. Paper 88, p. 5–16.

Muehlberger, W. R., 1959, Internal structure of the Grand Saline salt dome, Van Zandt County, Texas: Texas Univ. Bur. Econ. Geology, Rept. Inv. no. 38, 18 p.

Murray, Grover E., 1966, Salt structures of Gulf of Mexico Basin—a review: Am. Assoc. Petroleum Geologists Bull., v. 50, no. 3, p. 439–478.

Richter-Bernburg, G., 1960, Zeitmessung Geologischer Vorgange nach warvenkorrelationen im Zechstein: Geologische Rundschau, v. 49, no. 1 p. 132–148.

Richter-Bernburg, G., 1972, Saline deposits in Germany: a review and general introduction to the excursions, in Proc Hanover symposium: Geology of saline deposits, 1968, Unesco, p. 275–287.

Rios, J. M., 1968, Saline deposits of Spain: Geol. Soc. America Spec. Paper 88, p. 58–74.

Shea, F. S., 1970, Salt basins in Nova Scotia, in Third symposium on salt: Northern Ohio Geol. Soc., p. 306–316.

Trusheim, F., 1960, Mechanism of salt migration in northern Germany: Am. Assoc. Petroleum Geologists Bull., v. 44, no. 9, p. 1519–1540.

Van de Poll, H. W., 1972, Stratigraphy and economic geology of Carboniferous basins in the Maritime provinces: *Guidebook XXIV Internat. Geol. Congress Field Excursion* A60, 96 p.

Walker, Charles W., 1972, *The nature and origin of cap rock overlying Gulf Coast salt domes:* La. State Univ., unpub. Ph.D. thesis.

Wall, J. R., Murray, G. E., and Diaz, G. T., 1961, Geologic occurrence of intrusive gypsum and its effect on structural forms in Coahuila marginal folded province of northeastern Mexico: *Am. Assoc. Petroleum Geologists Bull.*, 45, no. 9:1504–1522.

Wallace, W. E., 1966, Fault and salt map of south Louisiana: *Gulf Coast Assoc. Geol. Socs. Trans.*, 16, 373 p.

Weidie, A. E., and Martinez, Joseph D., 1970, Evidence for evaporite diapirism in northeastern Mexico: *Am. Assoc. Petroleum Geologists Bull.*, 54, no. 4:655–657.

Weidie, A. E., and Martinez, J. D., 1972, Evaporite diapirism and related problems of Sierra del Fraile, Mexico, in *Proc. Hanover symposium: Geology of saline deposits, 1968, Unesco*, p. 161–172.