An Assessment Model for Salt Dome Stability—Tectonic and Hydrologic

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ABSTRACT

Salt domes are structural features which have developed through a dynamic response to an unstable geologic system. Coupled with this record of tectonic instability is one of hydrologic instability, a dissolution at the upper part of the salt stock. Evidence of dissolution is provided by the presence of caprock and truncation of the top of the salt stock. The question arises whether movement and/or dissolution has diminished or ceased for certain domes or families of domes? Are they now tectonically and hydrologically stable? This determination is particularly important in evaluating the suitability of salt domes for isolation of radioactive wastes. The long decay period of Plutonium, one of the toxic components, means that this material must be isolated from the biosphere for possibly 250,000 years. An assessment model for both tectonic stability and hydrologic stability of salt domes is presented. The assessment methodology utilizes evidence ranging in age from that of the salt deposits themselves to the present time. For a determination of tectonic stability, the long range view is provided by a study of relative rates of movement through long periods of geologic time. Particular emphasis is placed on possible movement in the Quaternary. Special efforts have been devised to detect evidence of current movement, using a system of instrumentation monitoring. Hydrologic stability over the long range is assessed on the basis of caprock thickness. Salinity determinations in ground water aquifers intersected by the domes provide a basis for evaluation of current hydrologic stability.

INTRODUCTION

There has been a long continued interest in the tectonic and hydrologic stability or conversely, instability of salt domes. The question however, has not been expressed in these terms except rather recently. Probably dating back to the time when they were first recognized as diapiric masses, geologists have speculated on their growth rates. Paradoxically, only a few quantitative estimates of rate of growth of salt domes have been published. These range from values of 0.3 mm per year attributed to Sanneman by Trusheim (1960) to a growth rate of less than 2 mm per year given by Borchert and Muir (1964). The paucity of estimates is a reflection of the great difficulties inherent in such an effort.

Similarly rates of dissolution of salt (a measure of hydrologic instability) have been a matter of interest in connection with theories of origin and development of caprock. Here, as well, quantitative estimates have not been readily available.

Clearly salt domes are both tectonically and hydrologically unstable in the context of geologic time. They exist as diapirs because of their dynamic response to an unstable geologic system. Thick caprock commonly mantles their truncated tops and attests to long periods of hydrologic instability.

SALT DOME ASSESSMENT FOR POTENTIAL RADIOACTIVE WASTE STORAGE

Although salt domes have been extensively exploited for valuable minerals and used as storage facilities for hydrocarbons, the rates of instability discussed above have been of little practical interest. The geologic time scales involved have relegated these matters to speculation by geoscientists concerned with problems of an academic nature. A new dimension has been added by proposals to utilize salt domes for the storage of high-level nuclear waste.

The slow rates of growth and dissolution may well be significant in view of the long period of time that high-level radioactive waste has to be isolated from the environment. The long decay period of Plutonium, a toxic component of the waste with a half-life of 24,360 years requires that it be isolated from the biosphere for 250,000 years. Feasibility studies are designed to apply geologic, hydrologic and engineering disciplines to an assessment of the tectonic and hydrologic stability of salt domes. The Gulf Coast salt domes of the U.S. specifically are under investigation. These studies range in perspective from an evaluation of evidence provided by older geologic formations to current monitoring by various geophysical techniques.

The advantages of natural salt deposits for providing isolation of radioactive wastes have been recognized for a number of years. Physical characteristics that make salt deposits attractive for this function include the impermeability, plasticity, and relatively high thermal conductivity of rock salt. Furthermore, salt masses are common in sedimentary basins in the USA and elsewhere. Such occurrences can be broadly divided into two types, bedded and domal. The bedded deposits are tabular and therefore horizontally extensive. The domal deposits are laterally restricted but vertically extensive.

Early studies of the potential use of salt deposits for the isolation of radioactive wastes were focused on bedded salt. In the last several years attention has also been directed to the possible utility of salt domes for this purpose with specific interest in the Gulf Coast region.

AN ASSESSMENT MODEL

The Institute for Environmental Studies at Louisiana State University has been conducting an investigation for over three years with the broad objective of evaluating the potential utility of salt domes in the Gulf Coast for the isolation of radioactive wastes based on a scientific assessment (Martinez, 1977). Because of the many differences in the geologic characteristics and cultural settings of the more than 500 domes in this region it is necessary to introduce a process of selection into the methodology of the investigation. This approach leads naturally to the choice of certain regions and domes as study areas on which to focus attention. This "winnowing out" approach is absolutely necessary to reduce financial requirements to a manageable level and to ensure that time tables imposed by overall management strategy are adhered to.

The essential rationale of the plan of study is best summarized by two flow diagrams which differentiate, insofar as possible, two separate phases of the investigation. Phase one outlined in Figure 1 incorporated geologic, hydrologic, and engineering studies which, by using planning and published information, focused on the question of the hydrologic and tectonic stability of Gulf Coast salt domes. The first approximation conclusions from this phase led to the selection of several study areas (domes).

Phase two (Fig. 2) incorporates more detailed and specific work for certain selected salt domes. These field studies are expected to produce new information that will be fed into refined geologic, geohydrologic and engineering

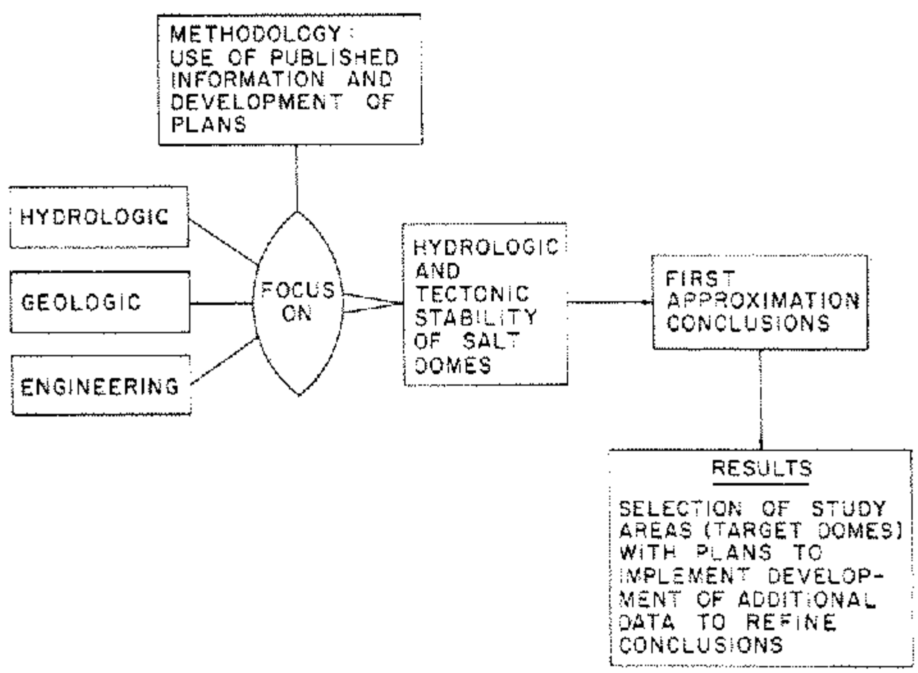

Figure 1. Phase One of Salt Dome Study.

analyses, which in turn, will lead to firmer conclusions regarding the suitability of salt domes for radioactive waste isolation. The distinction between phases one and two, as outlined here, is to some extent artificial. Actually basic studies of tectonic and hydrologic stability and research planning will continue throughout the complete term of the investigation.

METHODOLOGY

Figure 3 summarizes the methodology used in a determination of tectonic and hydrologic stability. As indicated in the figure, the methodology of the investigation of either type of stability differs depending on the chronological age of the evidence. One approach to the question of tectonic stability is to determine relative rates of movement through long periods of geologic time. If, for example, it could be demonstrated that there has been decreasing movement with time through the Mesozoic and Tertiary, this would suggest the possibility of present quiescence of the dome. This approach has been pursued by Kupfer in (Kupfer, 1976; Kupfer et al., 1976; and Kupfer *in* Martinez et al., 1975, 1976), Huckaba (Netherland, Sewell & Associates, Inc., 1976), and Kumer (Martinez et al., 1977). Both Huckaba and Kumar computed "uplift-vs-time" values from comparative thickness measurements of time equivalent units over domes and in the basin. Kumar has discussed the various assumptions and consequent uncertainties inherent in this method of computation of growth rates of salt domes.

The absence of significant movement in Quaternary time based on studies of Pleistocene and Recent sediments would constitute evidence of domal stability in late geologic time (Kolb *in* Martinez et al., 1976, 1977). Finally a system of instrumentation monitoring is designed to detect evidence of any current movement of the dome.

Figure 4 from Thoms in Martinez et al., (1977) is a schematic representation of some of the field instruments

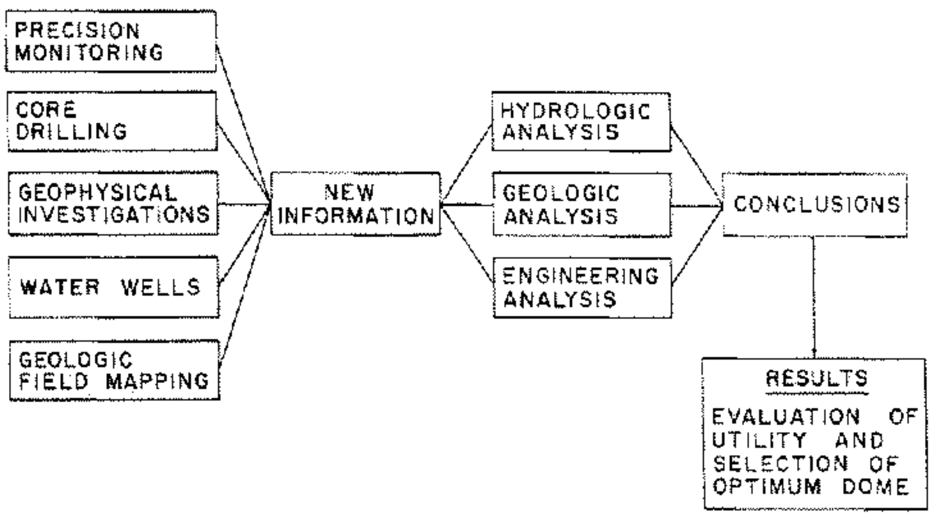

Figure 2. Phase Two of Salt Dome Study.

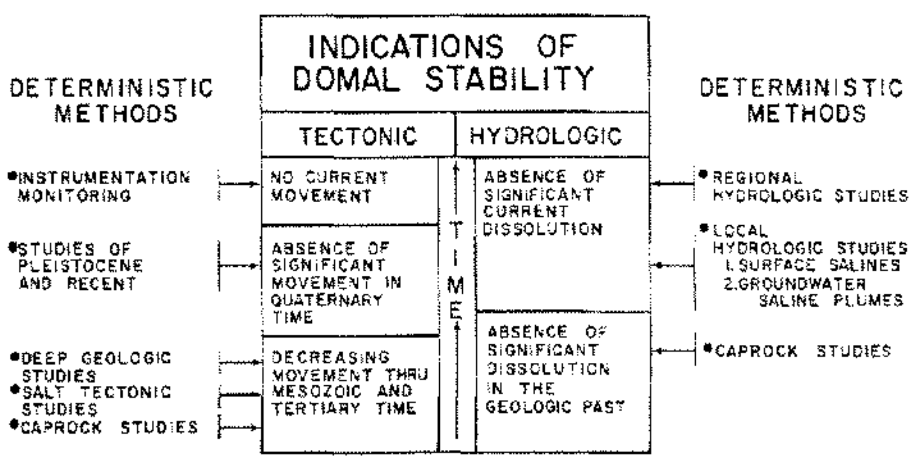

Figure 3. Methodology of Salt Dome Study.

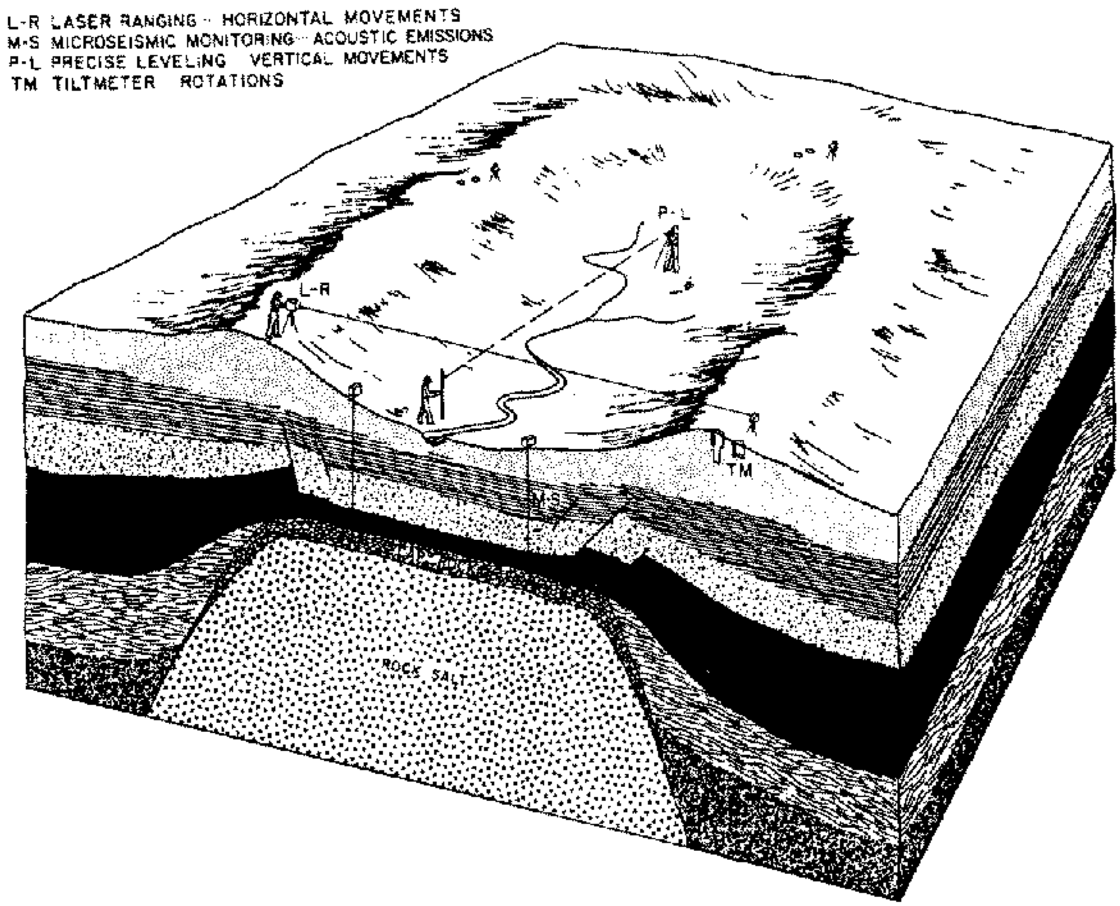

Figure 4. Schematic representation of field instrumentation for monitoring dome movements.

that are designed to monitor movements of the dome and surrounding rocks and sediments if such movements occur. Rotational movement will be detected and measured by tilt-meters with a sensitivity of 1×10^{-8} radians. Horizontal stretching will be detected and measured by laser ranging. Vertical movements will be measured by precise leveling. Microseismic monitoring is designed to detect any acoustic signals emitted from active fracturing. The systematic plan for data analysis is shown in Figure 5 from Thoms *in* Martinez et al. (1977). The absence of movement now would suggest present domal stability which might represent either a temporary cessation of movement or complete termination of growth.

The presence of thick caprock on a salt dome is convincing proof of dissolution in the past geologic time. Conversely, the absence of caprock may be interpreted as suggesting little or no dissolution in the geologic past. The absence of current dissolution and hence hydrologic stability, would be suggested by the lack of saline plumes in ground water aquifers adjacent to salt domes and by the absence of salt water springs over the dome, Martinez et al., (1975), Martinez *in* Martinez et al., (1975), Smith et al., (1976), Thoms et al., (1976) and Smith *in* Martinez et al., (1975, 1976, and 1977) and Smith (1977). The data used in making such assessments of hydrologic stability may be obtained from conventional hydrologic interpretations of electric logs and from water quality data from drilled wells. Numerical modelling may be employed to use this information for purposes of prediction. Another line of evidence of active dissolution may be provided by the nature of the salt-caprock interface. An unconsolidated anhydrite sand in the presence of brine would suggest hydrologic instability. A firm caprock-salt contact would indicate stability, Martinez *in* Martinez et al., (1975).

The study of hydrologic stability described above addresses the question of the extent of dissolution of salt from the outer surface of the dome. A somewhat different, but probably more important problem, revolves around the well known matter of water leaks into some salt mines. An investigation of the extent of this possible threat to a potential storage site encompasses an evaluation of past, present, and potential entrapment and movement of fluids through any part of the salt stock. This study deals therefore, with internal characteristics of the entire stock. It is most important to assess current theories of leaks in mines and to develop and test new ideas. The rationale is to develop sufficiently viable and supportable explanations to provide base line data from which an analysis of cores from study domes can be used to predict internal characteristics of part of the stock or the entire stock as they affect movement of water. A plan to study this problem of salt mine hydrology is given in Figure 6 from Martinez and Thoms *in* Martinez et al., (1977).

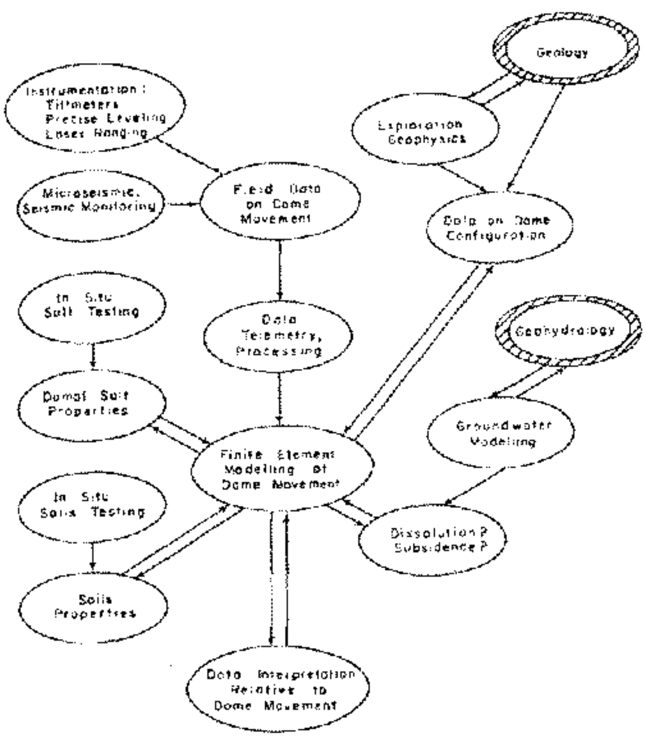

Figure 5. Interaction of efforts relative to monitoring current rates of dome movements.

CONCLUSIONS

The assessment model outlined in the preceding paragraphs may seem to suggest distinct lines of demarcation between principal goals of this salt dome evaluation, 1) a determination of tectonic stability and 2) a determination of hydrologic stability. Even the subsets of monitoring of current movement, Quaternary studies and regional geology and tectonics in one category and plume studies and caprock studies in the other category may appear to be essentially isolated topics. It is quite clear that despite the value of defining specific goals and approaches there is a need to recognize the mutual relationships between the various subsets of this investigation.

Quaternary studies designed to evaluate tectonic stability, must include considerations of salt dissolution and evidence provided by caprock in assessing the significance of topographic lows over interior domes as contrasted with topographic highs over coastal domes. Any disruptions of beds of Quaternary age must be evaluated not only in terms of possible uplift in the Pleistocene or Holocene but also in terms of possible collapse due to dissolution which might be recorded in the character and thickness of caprock over the dome in question. Also, tectonic studies designed to determine rates of movement from the stratigraphic record must include a consideration of amount and rates of dissolution based on caprock thickness.

The data developed from drilling wells for hydrologic studies has contributed important evidence pertinent to studies of tectonic stability. Conversely, structural and stratigraphic relations determined by regional and local geologic studies provide an important basis for constructing models of dissolution and hydrologic transport.

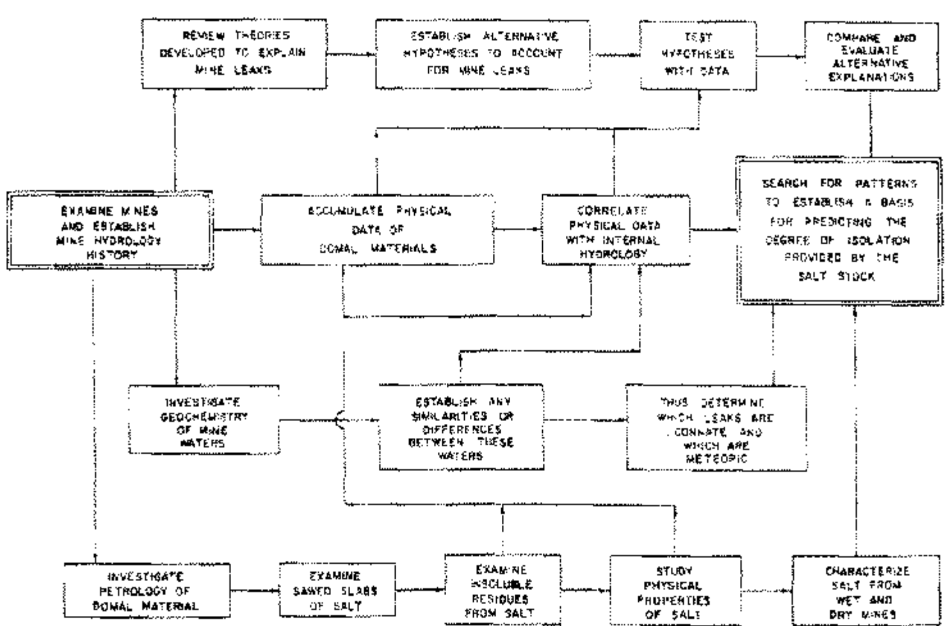

Figure 6. Plan for mine hydrology investigation.

Finally, the monitoring of current tectonic movement is heavily dependent on analysis by numerical modelling which is in turn dependent on a thorough knowledge of geologic parameters largely determined through these other studies.

It is important in implementing this proposed assessment model for salt dome stability that these kinds of interrelationships be kept in mind. To successfully conduct a major salt investigation of the scope and depth outlined herein it is imperative that the various threads of the investigation be woven into a unified program.

DISCUSSION

J. Hamstra:

Comment. Your extensive reconnaissance programme on tectonic and hydrologic stability of a salt dome will only reveal the situation of today. Probable future changes in the geological and climatological conditions may reactivate the upward movement of the salt or lead to more unfavorable hydrologic conditions around the salt dome.

For this reason we based the assessment model for our long-term safety analysis on a containment shield of undisturbed rock salt around the waste repository, which thickness should be sufficient to provide for a 250,000 years isolation even if the salt dome would become tectonically and hydrologically unstable.

ACKNOWLEDGEMENTS

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