Lawrence Livermore National Laboratory
NUCLEAR SYSTEMS SAFETY PROGRAM
L-196

October 8, 1987

Mr. M. E. Blackford, MS-623ss
Project Officer
Technical Review Branch
Division of High-Level Management, NMSS
U.S. Nuclear Regulatory Commission
Washington, DC 20555

SUBJECT: Transmittal of Letter Report as Referenced
FIN A0297

Reference: "Numerical Modeling of Deformation in Salt Basins," BMI/ONWI Rept. No. 649, by Chang et al. (1987).

Dear Mr. Blackford:

The purpose of this letter is to transmit the subject letter report on our review of report titled "Numerical modeling of deformation in salt basins," BMI/ONWI Tech. Rept. No. 649. The review was accomplished by Dave W. Carpenter of our LLNL team.

You will note this analysis of the reference DOE study, we feel that the reference BMI/ONWI report is a major paper in the literature concerning seismo-tectonics of salt basins. If its findings are validated by the supplemental studies recommended in Carpenter's letter report, new tools for assessing the seismo-tectonic setting of the Deaf Smith County site will be available. We feel that, to the extent possible, NRC should consider to encourage DOE to continue with these studies and we closely monitor the effort.

If you have any questions, please let us know.

Sincerely yours,

Dae H. (Danny) Chung
Project Leader

DHC/ic
Enclosure as stated.

cc: T. Cardone, NRC/WMGT
J. Trapp, NRC/WMGT

REVIEW OF THE SUBJECT DOE DOCUMENT

by

NRC Nuclear Waste Management Project Team
Lawrence Livermore National Laboratory, Livermore, California

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SUBJECT: Numerical Modeling of Deformation in Salt Basins by C. Y. Chang, J. E. O'Rourke, F. C. Tsai and W. J. Silva, Woodward-Clyde Consultants, BMI/ONWI 649 (1987).

The subject report presents the results of a critical review of previous theory concerning deformation of bedded salt, modeling techniques of salt deformation, applicable constituitive laws for salt deformation and appropriate geotechnical properties of salt. The report then proceeds, using field and laboratory data obtained during study of the Paradox Basin, to test previous theories, computational techniques, constituitive laws and assumed geotechnical properties against recently developed field and laboratory data.

The subject study demonstrated that, acting alone, the theory of density inversion (e.g. the presence of higher density clastic and/or marine strata overlying lower density bedded salt) does not provide a sufficient driving force to produce observed salt deformation features within geologically reasonable time periods. The report demonstrated that apparent previous agreement between density inversion theory and salt deformation features was the result of a 4 order of magnitude error in previous assumptions of effective salt viscosity. When current, carefully researched, laboratory test data were applied, the need for a thorough restudy of the problem became evident.

The restudy included:

1. Development of a physical model of idealized salt basin stratigraphy.

2. Comprehensive identification of possible deformation mechanisms.

3. Acquisition of a numerical code that could handle the geologic material properties and the time and dimensional scales of the problem and that could simulate the boundary conditions and mechanics of the problem.

Because of the availability of good quality structural rock mechanical and stratigraphic data, the Paradox Basin was chosen as the data source and for model validation. A review of salt deformation research suggested three alternate deformation modes for study: (1) horizontal tectonic stress and strain across a basin, (2) pre-salt-deposition basement faulting effects and (3) post-salt-deposition basement faulting effects. A two-dimensional, viscoplastic, finite-element code, MANTLE, was selected to perform the analyses.

The principal conclusion of the study was that, in conjunction with density-inversion mechanics and a laboratory-derived effective viscosity, post-salt-deposition basement faulting, by inducing experimentally verified, reasonable vertical shear stresses in overlying salt, could produce salt perturbation growth rates and amplitudes that are consistent with the geologic evidence for the Paradox basin, whereas density inversion acting alone could not. The other salt deformation mechanisms, acting in conjunction with density inversion, did not significantly alter density-inversion effects acting alone. These results are a major breakthrough in revising previous theories on the causes and characteristics of deformation in salt basins.

The general conclusions for large-scale deformation features in salt basins are as follows:

1. In areas with no post-depositional basement faulting beneath overlying salt beds (or other conditions conducive to an internal shear stress development in the salt), perturbation of

the salt formation is believed to be unlikely. The appropriate relationship governing the perturbation growth rate is a nonlinear salt flow law based on laboratory creep test data. The nonlinear flow law is sensitive to an effective stress term raised to a power. Translated to terms of effective viscosity, the salt remains relatively stiff (highly viscous) and insensitive to flow for at least a moderate range of any assumed initial perturbations (at least to 50 m). The most significant difference between the use of linear or nonlinear property analysis is that the growth rate of a perturbation in a nonlinear model is approximately a million-fold smaller at the start of growth (e.g., perturbation less than one meter) due to the dependence of viscosity on a power term of effective stress. Nonetheless, if the linear model's constant viscosity is based on some average effective stress, the nonlinear model growth rate will overtake it when that effective stress level is reached, sometime during growth. Previously published works rely on Newtonian fluid models using an assumed viscosity 4 orders of magnitude less than can be supported by laboratory data. This can result in total growth times for a thousand-fold increase in perturbations in salt that are about 2 orders of magnitude less than would be required with the laboratory-derived viscosity, thus leading to the apparent but unfounded agreement between density-inversion theory and actual salt dome growth.

2. In areas with post-depositional basement faulting beneath overlying salt beds, early growth rates of the salt formation perturbations are controlled principally by accompanying shear stress distribution in the salt. As the total growth of the perturbation increases, the influence of shear stress on perturbation growth rate diminishes and the influence of a density-inversion mechanism on growth rate increases. When internal shear stress is assumed to be acting along with density inversion in the salt, the difference between the calculated

early growth rate using a linear model or a nonlinear model greatly decreases compared to the case of density inversion acting alone. For an assumed shear stress of 0 to 4 MPa and a perturbation of approximately 300 m, the nonlinear model has an early growth rate equal to approximately one half that of a linear model. The difference in growth rates continues to decrease with total perturbation growth thereafter.

The general conclusions for interbed and internal deformation within perturbed salt formations are as follows:

1. In those areas of salt basins away from major perturbation features (such as anticlines) and consequently removed from basement faulting/vertical shear effects, the deformation characteristics of interbeds and internal salt fabric are expected to be generally symmetric to the major deformation characteristics of the host salt formation. Brittle layers such as anhydrite may, however, be fractured and show some dislocations and irregularities along the interface zone.

2. In regions near major deformation features (such as anticlines) and consequently in areas presumed to be near basement faulting/vertical shear zones, interbeds and internal salt fabric may be deformed strongly asymmetric to the major deformation surface of the host salt formation. Brittle layers such as anhydrite are expected to be broken in the deformation process, and these layers may be rotated and displaced after rupture by salt flow. The salt flow is a function of effective stress distribution induced by shear from the basement faulting. Flow intensity increases when moving stratigraphically downward and toward the shear plane or zone of shear.

The findings of this study provide important new insights into the roles of the physical rock properties and effective geologic mechanisms that combine to produce observable gross features of in-situ salt deformation. High quality laboratory test data and flow theory for salt have been shown to be capable of simulating growth rates and deformation amplitudes corresponding to geologic evidence when shear mechanisms are considered. Corroborating evidence for the vertical shear forces assumed in the numerical modeling was found in field data for basement faulting beneath deformation features within the Paradox Basin and at the WIPP site, and possibly in the Richton Dome area. Supporting data is provided by laboratory analysis of subgrain size in naturally deformed salt samples.

The report makes several recommendations:

1. Additional supporting evidence of basement faulting underlying moderate and major deformation features (e.g., buried and piercement anticlines) may be acquired by closer examination of the geophysical exploration data available in the potentially acceptable repository regions or other salt basins, and such a study should be done.

2. More laboratory testing of the subgrain-size relationship to effective stress levels should be carried out, particularly on samples from strongly perturbed salt regions, to further strengthen this supporting evidence.

3. More detailed numerical modeling of the deformation of interbeds and internal fabric of the salt should be done. To support the detailed modeling analyses, analytical studies should include additional sensitivity and uncertainty analyses and field studies should include geologic mapping of in-situ deformation characteristics in existing mined excavations in salt, such as the Cayuga salt mine in New York and the WIPP excavations in southeastern New Mexico, where relevant depths and geologic structures are available. Further analysis of the Grand Saline in Texas is also recommended.

The subject report appears to be a major paper in the literature concerning the seismo-tectonics of salt basins. It also points out that theory and modeling must be continually revisited as improved field and laboratory data become available. As the authors state, additional field, laboratory and modeling studies are required to further test and validate their findings. If these studies confirm the results obtained to date, new geologic tools will be available to assess the seismo-tectonics of the Deaf Smith County bedded salt site, to evaluate ages of basement fault structures, and to evaluate the geologic stability of the repository site itself.

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