BACKGROUND, SUMMARY AND TECHNICAL REVIEW OF "CONCEPTUAL CONSIDERATIONS OF THE YUCCA MOUNTAIN GROUNDWATER SYSTEM WITH SPECIAL EMPHASIS ON THE ADEQUACY OF THIS SYSTEM TO ACCOMMODATE A HIGH LEVEL NUCLEAR WASTE REPOSITORY" BY J. L. SZYMANSKI, JULY 1989

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INTRODUCTION

A draft manuscript, "Conceptual Considerations of the Death Valley Groundwater System With Special Emphasis on the Adequacy of this System to Accommodate the High Level Nuclear Waste Repository" by Jerry L. Szymanski (Physical Scientist, US Department of Energy) was released by the Nevada Operations Office, DOE , in November 1987. That draft had been prematurely released and had not received a detailed technical peer review from within DOE. The report proposed a concept of a groundwater regime significantly different from the groundwater regime described in DOE's Site Characterization Plan (SCP) (DOE, 1988). The site ground-water regime conceptualized by Szymanski may be described as one in which the groundwater hydraulic parameters such as fracture permeability and porosity are subject to significant changes due to tectonic stresses. These changes in the hydraulic parameters are postulated to cause large changes in the local water table elevation. These changes are postulated by Szymanski to be capable of occurring within the time frame of a few thousand years. The groundwater regime described in the SCP is one in which the hydraulic properties of the rock stay constant over the period of performance assessment (10,000 years) and groundwater level changes are caused by climatic variations.

The DOE's Yucca Mountain Project (YMP) Office requested reviews of Szymanski's draft manuscript that involved over 40 scientists (Szymanski, 1989a). The reviewers were professional staff from the following participating organizations: U.S. Geological Survey (USGS), Science Applications International Corporation (SAIC), Sandia National Laboratory (SNL), and the Los Alamos National Laboratory (LANL).

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As a result of these reviews, Mr. Szymanski revised his first report and changed the title slightly. Although the revised report (Szymanski, 1989b) is somewhat thicker than the original report, with new figures comprising most of the additional pages, J. Szymanski's central thesis is still the same. The revised report was reviewed by staff of the Hydrologic Transport Section (HTS), with assistance from the Center For Nuclear Waste Regulatory Analyses (CNWRA).

This report has been arranged to provide a summary of the hypothesis proposed by J. Szymanski (1987) in his first report, summarize the evaluations made of the first report by a DOE review committee, present the NRC HTS review, and provide the staff's conclusions.

HYPOTHESIS AND RECOMMENDATIONS OF FIRST REPORT

Mr. Szymanski (1987) described a hypothesized cyclic behavior of the groundwater system that is a consequence of the ongoing extensional tectonic stresses. Fractures are used in the context of this study as any discontinuity which will relieve tensile stresses by opening. This cyclic behavior, as characterized by the review committee, may be paraphrased as follows:

* The cycle begins with the local horizontal tension relaxed due to the recent release of extensional tectonic stress. This local stress is termed the least principal stress and because of sign convention (compression is positive) is at its greatest magnitude. Fractures are at their residual apertures, producing minimum fracture permeability. Normal ('vertical') effective stresses increase with depth in a generally linear fashion.

* Tectonic extension of the system causes the normal effective stresses to be reduced on fractures that intersect the axis of the least principal stress, particularly on high angle (near-vertical) fractures. The shear stress along most fractures increases, whereas the resistance to failure decreases as the normal stress is reduced.

* Eventually, the shear stress approaches the shear strength, which depends upon material properties. Elastic shear dilation occurs until the maximum shear stress is reached, after which the shear deformation and consequent shear dilation are inelastic. Accumulated shear dilation increases significantly after the onset of inelastic deformation.

* These changes divide the geologic section into two regions. The dividing surface is where the shear stress has just reached its maximum and inelastic dilation is initiated. The depth to the

dividing surface increases with time due to the continued extension of the system.

* With continued extension, fractures in the upper region are increasingly dilated. This results in increased fracture porosity and permeability which tends to lower the water table.

* Hydraulic properties beneath the dividing zone are independent of stress and stay relatively constant. Therefore, hydraulic potential in the deeper zone remains higher than that represented by the water table which is declining.

* The above described process is interrupted by seismic events. This causes the least principal stress in the crust between the faults to increase and water-table rises due to the reduction of storage volume in the fractures. Upwelling of water along the fault zones may continue for hundreds of years due to thermal convection. The hydraulic potentials below the surface of limit equilibrium are now less than those above.

* This cycle repeats itself every few tens of thousands of years in response to thermal gradients.

This process was represented graphically in Plates 3.2.4-5 and 3.2.4-6 (1987 report) or Plates 3.3.4-5 and 3.3.4-6 (1989 report) and are copied here for reference [Figures 1 and 2].

The author proposed evidence for the postulated model consisting of potentiometric and thermal gradients, groundwater mounds, mechanical and hydraulic response to stress, and the geologic record. Much of the evidence is based on relatively sparse data which can be interpreted in alternative fashions. Dating of calcite and opaline-silica deposits was used to establish historical water table elevations.

The author also recommended that four investigations be completed before significant additional work was completed for site characterization purposes. These investigations are:

1) Analysis of water table monitoring data.

2) Complete investigation of the calcite-silica-sepiolite deposits occurring at Yucca Mountain.

3) Analysis of the chemistry of vadose-zone water at Yucca Mountain.

4) Investigation of known perched water mounds in the vadose zone of the Death Valley flow system.

DOE COMMITTEE REVIEW OF ORIGINAL REPORT

The following is a listing of the major concerns raised by the DOE internal review committee about the mathematical formulations of Mr. Szymanski's concepts:

1. The DOE review committee severely criticized Szymanski's discussion of coupled processes and conceptualization of hydrologic processes in Section 7, of the DOE Review Panel Report, (Dudley et al., 1989). Relevant review comments on these aspects follows:

   "The manuscript lists elements that would be included in a coupled model for Yucca Mountain. As stated by one of the reviewers: 'it does not represent such a model for Yucca Mountain any more than listing the contaminant transport equations from a hydrology textbook constitutes a radionuclide transport model.' In order to construct such a model one must not simply list the relevant equations and discuss possible constitutive relationships (as on page 3-24 of the manuscript) but one must do sufficient work to select the most relevant forms of the equations and constitutive relationships, with all the attendant assumptions and conditions, and assemble them with enough rigor for evaluation." (Dudley et al., 1989, p.58).

2. "Many of the mechanical concepts and constitutive relationships that are proposed are not integrated into the overall model, and they are not accompanied by physical coefficients that allow estimates of the effects of even the component processes" (Dudley et al., 1989, p.16).

3. "Coupling terms involving processes of specific interest to the author (thermomechanical and hydromechanical) are noticeably absent from the equations for flow (plates 2.2.1-4, Szymanski, 1987) and are introduced in an ad hoc fashion on Plate 3.4.4.1 (Szymanski, 1987). The problem of the 'critical surface' which the author specifies on the latter plate, appears to be a 'moving boundary' problem. Careful definition and solution, numerically or analytically, of this Stefan problem would strengthen the author's arguments. It is reasonable for reviewers to ask to see the mathematical analysis on which so much of the argument hinges" (Dudley et al., 1989, p.53).

4. "The relationship between stress, displacement, and strain energy in-situ is probably much more complex than represented in the manuscript (Szymanski, 1987), which led reviewers to question the technical adequacy of the author's treatment of strain energy" (Dudley, 1989, p.54).

5. "In summary, the manuscript asserts that lateral differences of hydraulic potential at depth, on the order of tens of meters

(corresponding to observations from the site), are expected from the characteristics of the proposed conceptual model. It does not mention that such differences are expected as a result of the geologic distribution of hydraulic properties within the flow system and that, as discussed in this review, there are good reasons to question the mechanisms proposed in the manuscript to account for these differences. However, it should be pointed out that the characterization of the major features of the flow system at Yucca Mountain is important unfinished business" (Dudley et al., 1989, p.60).

"The manuscript explains piezometric observations from Yucca Mountain, including the flat water table and the steep water in bounding regions west and north of Yucca Mountain, in terms of in-situ stress heterogeneity. Altnough this is possible, observations of the water table are not sufficient to validate the mechanisms proposed. One reviewer compared Yucca Mountain to the Precambrian of the Front Range, Colorado, where the water table closely follows topography, because the decrease of conductivity with depth controls the transmissivity" (Dudley et al., 1989, p.60).

"The theoretical problems identified do not invalidate the idea that coupling between groundwater flow and tectonic deformation could be important. Most reviewers readily agree that the topic deserves further investigation. However, the problems illustrate that: (1) much of the complexity and formalism could be eliminated from the manuscript without materially affecting its impact, and (2) the author fails to develop a quantitative model using the information and concepts he presents" (Dudley et al, 1989., p.60).

In addition to the above comments, the review committee also recommended that the following tests be performed (Dudley et al., 1989, pp.29-30):

1) "The quality of geothermal data needs to be improved by completion of boreholes in a manner that provides good thermal coupling with the rock mass and that will preclude flow of air or water in the artificial pathway afforded by the hole itself." An additional temperature measurements should be obtained soon in borehole UE25p-#1.

2) Temperature measurements in conjunction with hydraulic head determinations by measurement of water levels in tubing above zones isolated by inflatable packers. This is to enable corrections for the relative density of water in the tubing.

3) Hydraulic testing should include ranges of both positive and negative hydraulic stresses to investigate further the coupling of mechanical and hydraulic stresses and to provide information on the distribution of in-situ stresses.

4) Plans for the study of post-closure hydrologic effects of tectonism and geothermal processes may require more emphasis on supporting investigations, such as in-situ stress, thermal, and geophysical studies, than would be indicated by the needs for their use to support pre-closure considerations alone.

5) "Completion of hydrologic holes to investigate hydraulic characteristics of faults of different styles and orientations should be considered in future planning. Long-term monitoring of fluid pressures, water-table positions, and rock-mass strain in such holes is also recommended."

6) "Geologic and hydrologic investigations of the large hydraulic gradients north and west of the site should include in-situ stress and thermal studies. Further, investigation of the hydraulic relationship of Yucca Mountain to Crater Flat is needed to evaluate the significance of the evidence of probable spring discharge in southern Crater Flat in Plio-Pleistocene time."

7) "Temperature measurements and heat flow calculations from borehole UE25a-#3 should be re-evaluated as to possible significance."

In addition to the tests, the review committee also suggested that calculations with simplified phenomenological models should be undertaken to establish the magnitudes of both potentiometric and water table response to physically possible ranges of stress change and to establish the limitations of thermal buoyancy in producing upwelling of water in fault zones.

Prior to the publication and formal submittal of the DOE review committee Report (Dudley et al., 1989), Mr. Szymanski received their extensive comments and criticisms of his first report (Szymanski, 1987) through numerous meetings and discussions with the committee members over a period of one and one half years. He noted in his letter of transmittal (Szymanski, 1989a) for his second report that he had received the major comments of the DOE Review Panel prior to July 29, 1988, and that he disagreed with the review panel members on all the major and substantive issues raised by them. He also mentioned that he had reached an agreement with the DOE Yucca Mountain Project Manager, Carl P. Gertz, on July 29, 1988, to have his second report (Szymanski, 1989b) reviewed by an external and independent peer review panel consisting of three scientists (unnamed) selected by the DOE and two other scientists, namely, Professor N.J. Price of the University College, London - United Kingdom; and Dr. C.B. Archambeau of the University of Colorado. The Hydrologic Transport Section staff does not know the present status of this proposed review nor have they received any report from this review.

NRC HYDROLOGIC TRANSPORT SECTION REVIEW OF REVISED REPORT

The Hydrologic Transport Section (HTS) compared the Szymanski (1989b) report with his earlier report to determine if the DOE Panel comments were addressed and to identify significant changes that were made. The HTS also directed CNWRA to perform a focused review of the revised report in regard to model formulation of geohydrologic and coupled processes.

Staff Evaluation and Report Comparison

The following is a section by section comparison of the body of Szymanski's (1989b) revised report with his earlier report with significant differences noted:

Section 2 - "Mathematical and Conceptual Models of Groundwater Systems- Statement of the Problem"

* A paragraph was added recognizing that for most ground water systems the governing equations of flow must be stated in a form that allows the inclusion of heterogeneity and anisotropy.

* A discussion was added concerning problems with conventional methods of determining hydraulic conductivity.

* A discussion was added regarding non uniqueness of solutions using conventional methods.

* A more detailed discussion was added regarding the requirements of a conceptual model.

Section 3 - "Conceptual Framework for the Yucca Mountain Groundwater System"

* This section was rearranged and rewritten with subsection 3.2 added.

* A simple calculation for Rayleigh Number was demonstrated to backup the author's contention regarding convective heat transfer through the earth's crust at the site.

* The discussion of tectonic stresses in rocks was expanded and more figures were added.

* The discussions of thermal-hydraulic coupling were modified and expanded.

Section 4 - "Characteristics of the Death Valley Groundwater System in Light of the Existing Data"

* Hydraulic fracturing results were discussed in regard to implications regarding insitu pore pressures and breakdown pressures.

* Yucca Mountain Geothermal measurements were described in greater detail.

* Discussions regarding Geochemical data were expanded.

* The Ardvark and Handley events were added to the descriptions of hydrologic effects of nuclear detonations.

* Discussions of 4 distinct groundwater level anomalies near the site were added as possible evidence of non-meteoric origin.

Unfortunately, the author did not directly address the review committee's comments nor identify changes or additions intended to address the comments. It is the judgement of this review that the above listed changes and additions will not satisfy the majority of the major comments expressed by the review committee.

In regard to Section 5 - "Summary, Conclusions, and Recommendations", the author's conclusions have remained basically the same as those expressed in the 1987 report. The author has, however added four new recommendations, which are:

1) A comprehensive investigation of the Yucca Mountain in situ stress field should be undertaken.

2) A deep exploratory borehole should be drilled to determine the vertical distribution of hydraulic potentials in the area.

3) A thorough study of the Yucca Mountain "mosaic breccias" should be undertaken.

4) An investigation of the Whamonie gypsum paleo-spring mound should be performed.

Basically, all the recommendations for additional studies by J. Szymanski and the review committee except for "a deep exploratory borehole..." (No. 2 above) are encompassed by or could be accommodated in the planned DOE (1988) investigations. For the investigation of the regional hydrologic system, four studies with 11 activities are planned. For the investigation of the saturated zone hydrologic system, three studies with 15 activities are planned. For the investigation of the water chemistry within the potential emplacement horizon and along potential flow paths there are two studies with five activities, and for an investigation of the stability of minerals and glasses there are three studies. (Note there are 5 other geochemistry investigations, with numerous studies and activities, to primarily evaluate retardation issues.) The investigation of the geologic framework of the Yucca Mountain site, which is based on integrated drilling and geophysical activities, has three studies with 12 activities. The investigation of the nature and rates of change in climatic conditions to predict future climates has six studies with a total of 16 activities. The investigation of potential effects of future climatic conditions on hydrologic characteristics has two studies with 8 activities, of which the first study is the characterization of the Quaternary regional hydrology. In the thermal and mechanical rock properties program, it is noted that there is an investigation of the spatial distribution of ambient stress and thermal conditions.

The HTS staff review (NRC, 1989) of the DOE Site Characterization Plan expressed some concern about the utilization of complete descriptions based on presently available information to plan field tests, completely identifying assumptions for initial modeling strategies, completeness of program with respect to consideration of all potentially important geochemical conditions and processes, adequacy of some geochemical methodologies, and the applicability of laboratory findings to the natural site. In general, the DOE site characterization program is very extensive, and it either encompasses or can be adjusted to incorporate significant recommended studies or analyses of the DOE review committee and Mr. Szymanski.

The lack of perspective or scale (note that there are no time or length scales in Figures 1 and 2) make it difficult to evaluate the significance of Mr. Szymanski's hypothesized process with respect to repository performance. What depth is needed for "a deep exploratory borehole"? The repository is situated in the top 1 km layer of hydro-thermal-stress system that extends to 15 or 40 km deep (Cathles, 1990) depending on how far one wants to carry the problem. To what depths should borehole investigations be made and what should be the boundaries of the system for the evaluation of performance. To date, the HTS has not had a concern about exploring depths beyond those already existing or planned in the saturated zone.

<u>Other Related Reports and Project Reviewed by Staff</u>

The HTS staff has reviewed two other studies relating to the issue raised by the Szymanski. One is a NRC requested report from the Bureau of Mines and the second is a USGS report. The staff is following a National Research Council project resulting from discussions of the Szymanski reports. A summary of each report and the National Research Council project follows.

Under Interagency Agreement NRC-0285-004, the Bureau of Mines, US Dept. of Interior, (Raney, 1988) was requested by the Division of Waste Management ".... to examine well and mine data for western US mines to determine any effect of regional earthquakes on ground water or underground mines. Hydrologic effects should include documented well fluctuations, flooding in mines or tunnels, or spring modifications. Mine data should be examined for any documentation of damage to openings or underground workings as a result of earthquakes. In addition, if there are any mining areas where persistent induced seismicity has been observed or numerous rock bursts have been reported, these locations should be included in the mine damage survey." The geographic region considered lies between the Rocky Mountains and the Cascade-Sierra Nevadas and extends from Mexico to Canada.

The closest analog to the repository site was considered to be the Dixie Valley, Nevada earthquake of 1954. Dixie Valley is located northwest of the test site. Some water levels increased and some declined in the months following the earthquake. The greatest increase was about 11 feet above the pre-earthquake levels which was reached about 6 months after the earthquake. This was thought due to increased groundwater flow into Dixie and Fairview Valleys from the adjoining East Gate and Cow Kick Valleys. There was no evidence of groundwater temperature change after the earthquake.

No events were cited in the report which clearly showed a groundwater rise of the type postulated by Szymanski.

The HTS staff also reviewed an open-file report by the USGS regarding measurements of temperature, thermal conductivity, and heat flow near Yucca Mountain (Sass et al., 1988). This report was referenced both by Szymanski (1989 Report) and by the DOE Review Committee. While the report confirms some of the heat flow anomalies cited by Szymanski it also states that the present data base is insufficient for unambiguous interpretations of the existing heat flow near Yucca Mountain and the hydrologic implications.

The National Research Council, Board on Radioactive Waste Management, has approved (in response to a DOE proposal) the formation of a panel of experts to make a generic evaluation of the issue - "Coupled Hydrologic/Tectonic/Hydrothermal Systems for Applicability to the Proposed Geologic Repository at Yucca Mountain." More specifically, the panel is to evaluate the interactive processes involving the hydrologic, tectonic, and hydrothermal systems that may be present and/or that may evolve in the Yucca Mountain region. They are to prepare a final report that will provide an evaluation of the plausible outcomes of the coupled tectonic, hydrologic, and hydrothermal effects in Yucca Mountain region, the probabilities of the extreme consequences proposed, and the uncertainties associated with the various aspects of the hypothesis. The panel has 17 experts covering a broad range of disciplines relevant to the topic. The initial meeting of the panel was April 12, 1990 and the evaluations and a final report are to be completed in about 24 months. See Attachment A for a listing of the panel members.

CNWRA Focused Review

In accordance with direction from the Hydrologic Transport Section, the Center for Nuclear Waste Regulatory Analysis (CNWRA) reviewed the Szymanski Report focusing on the mathematical formulation of concepts and quantitative deductions from physical principals as contained in the text.

The CNWRA reviewed Sections - 1.0 Introduction; 2.0 Mathematical and Conceptual Models of Groundwater Systems Statement of the Problem; 3.0 Conceptual Framework for the Yucca Mountain Groundwater Systems; and 5.0 Summary, Conclusions and Recommendations. They then provided specific comments on sections 1.0, 2.0 and 3.0.

A summary of CNWRA comments follows:

* "The overall impression from the report is that of an eclectic, fragmented mass containing many schematic ideas, intentions, and hypothetical scenarios, seldom leading to a fully developed analysis of the coupled processes of interest. We have found the report to be lacking in clarity and concision,"..."the technical quality of the plates to be below average, and the internal organization of the report too fragmented and somewhat awkward. There is an exaggerated profusion of plates, many of which appear to be mutually redundant, such as six plates devoted to groundwater flow equations in [Sect. 2]. Others describe repetitive raw data: about 60 plates of Mohr circle diagrams for the in-situ stresses of [Sects. 4.2.5.2, 4.2.5.3, 4.2.5.4], and about 70 plates for the in-situ injection test curves of [Sect. 4.2.5.4]."

* The review "found a number of technical inconsistencies, incorrect equations, and conceptual inaccuracies, in addition to a frequent lack of rigor in the use of scientific terms and mathematical symbols. These compounded factors result in vagueness, and tend to dilute the author's arguments and conclusions. The general effect is that the partial results and conclusions summarized at the end of each sub-section of the report are difficult to verify or back-up by independent calculations."

* "A particularly troublesome aspect of the report is the discrepancy between the claims of formulating and using 'mathematical' and 'conceptual' models (see title of report and titles of Sections 2.0, 2.2, 2.3, 3.0, 3.3, 3.3.4, 3.4, 3.4.4, and 3.5) and the actual assemblage of empirical models being used. Apart from directly traceable errors and inaccuracies, we have also found in many instances that the models actually used to rationalize hypothetical scenarios were so simplified that they failed to take into account basic physical principles (mass balance, balance of stresses, forces, and momentum, dynamic/inertial effects, dimensionality) and did not represent truly coupled processes with reasonable feed back effects."

* Specific comments in the Center's review include the incorrect formulation of the groundwater flow equation in three dimensions and numerous comments on Szymanski's use of Mohr

circles and of the Griffith-Coulomb theory of failure for analyzing the progress of deformation and failure in fractured media.

* The Center's review concludes that Szymanski fails to provide a "uniform theoretical background" for licensing concerns contrary to his intentions.

The Center's review is attached to this report as Attachment B and a reading of it is recommended for an appreciation of the conclusions drawn above.

<u>CONCLUSIONS</u>

The HTS staff concludes that Szymanski's 1989 report has not adequately addressed the DOE Review Committee comments on his 1987 report. In general, the DOE site characterization program is very extensive, and it either encompasses or can be adjusted to incorporate significant recommended site studies or analyses of the DOE review committee and Mr. Szymanski. Reviews of other relevant reports provide no indications of historical earthquake events that show a groundwater rise of the type postulated by Mr. Szymanski. Further, while there are indications of heat flow anomalies as cited by Mr. Szymanski, the present data base is insufficient for unambiguous interpretations of the existing heat flow near Yucca Mountain and the hydrologic implications. In addition, the staff does not consider the mathematical formulations as presented to be a sufficient foundation for modeling of groundwater levels as a result of tectonic stresses or geothermal heat transfer or both coupled together.

HTS staff will follow the site characterization program and be prepared to advise management as to the adequacy of information and data collected to satisfy the DOE Review Committee recommendations and legitimate concerns raised by Szymanski. The staff will also follow the ongoing evaluation by the National Research Council.

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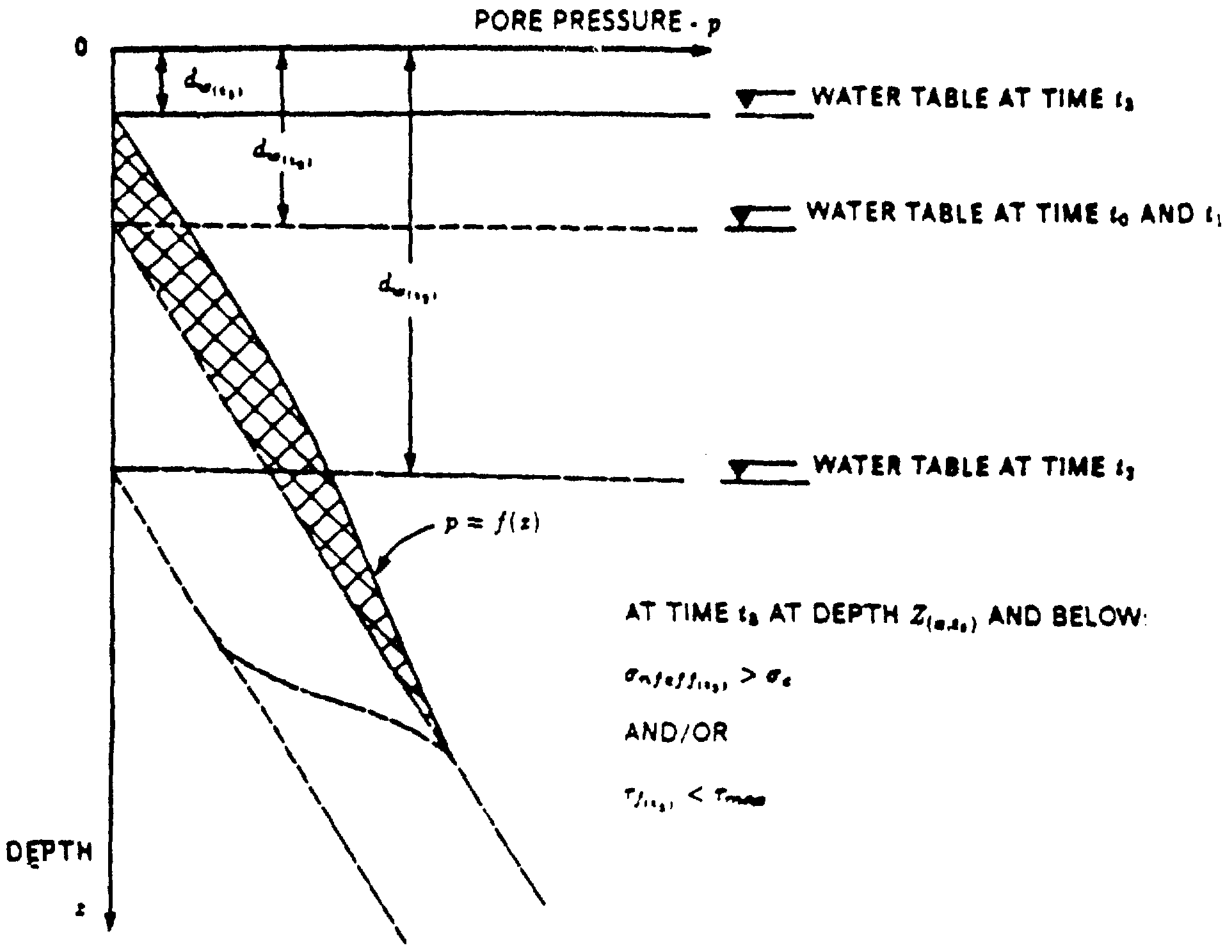
t_3 - END OF THE TECTONIC CYCLE



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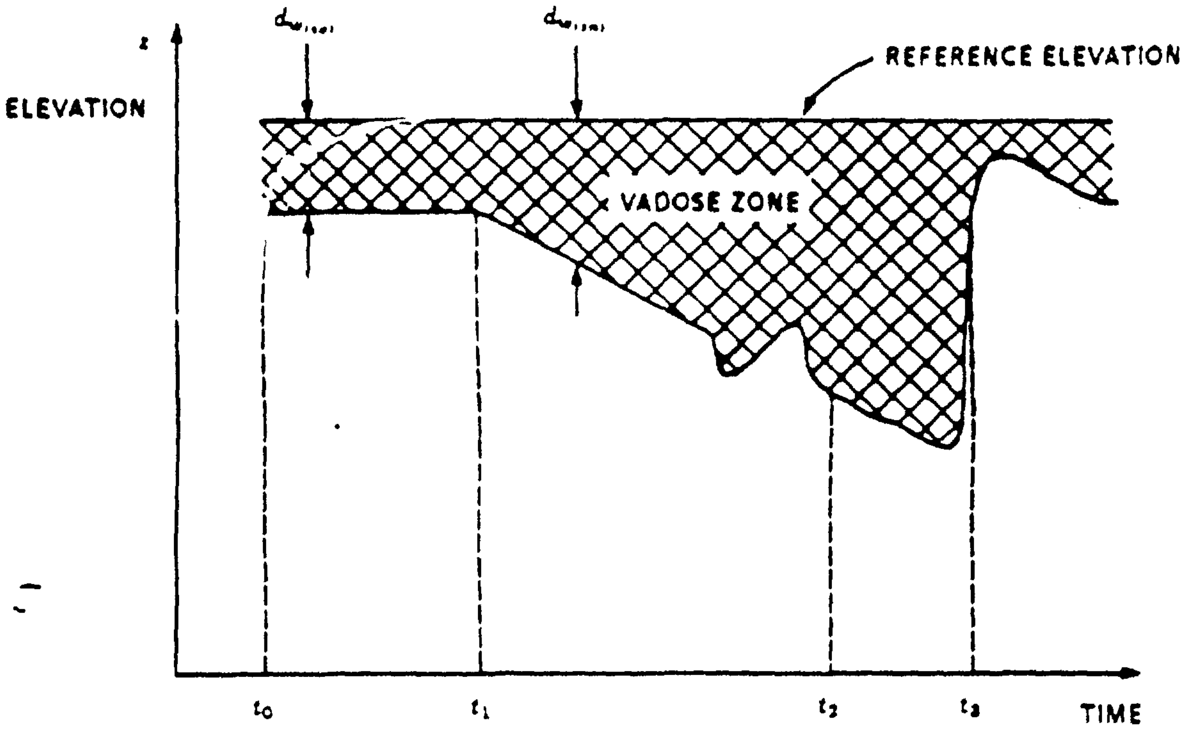
$a_{eam(t_3)} = a_{res}$
$S^{UZ}_{(t_3)} = S^{UZ}_{(t_0)} < S^{UZ}_{(t_2)}$
$S^{SZ}_{(t_3)} = S^{SZ}_{(t_0)} < S^{SZ}_{(t_2)}$
$K^{UZ}_{f(t_3)} = K^{UZ}_{f(t_0)} < K^{UZ}_{f(t_2)}$
$K^{SZ}_{f(t_3)} = K^{SZ}_{f(t_0)} - < K^{SZ}_{f(t_2)}$
POROUS OR EQUIVALENT FLOW

Deforming fractured medium-idealized history of changes in hydraulic potential.

Figure 1-Plate 3.3.4.-5 from Szymanski, 1989



Note. The drawing is diagramatic - no relationship between initial thickness of the vadose zone and magnitude of tectonic lowering of the water table is implied

Idealized history of the position of the water table for a single point $P_{(x,y)}$.

Figure 2-Plate 3.3.4.-6 reproduced from Szymanski, 1989

ATTACHMENT A

PANEL ON COUPLED HYDROLOGIC/TECTONIC/HYDROTHERMAL SYSTEMS AT YUCCA MOUNTAIN

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April 1990

ATTACHMENT B

FOCUSED REVIEW OF:

"Conceptual Considerations of the Yucca Mountain Groundwater System with Special Emphasis on the Adequacy of this System to Accommodate a High-Level Nuclear Waste Repository"
by Jerry S. Szymanski, US DOE
Las Vegas, Nevada, July 26, 1989

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