Monitoring Stress Conditions in a Deep Borehole Repository

Fuel Cycle Technology

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SUMMARY

The integrity of a deep borehole repository for used nuclear fuel depends on a long-term stable geologic environment. Local seismicity or change in the stress field can cause a gradual or abrupt change in permeability or create new pathways for fluids and other materials. We present two complementary approaches for site evaluation and passive monitoring of the local microseismicity and state of stress for the purposes of establishing baseline behavior and monitoring any changes to stress conditions and seismicity. Changes may be naturally occurring or due to the construction or interactions of the repository with the surrounding rock. In these approaches we collect seismic and gravity time-series data on the surface. We monitor seismicity using our advanced microseismicity detection method known as inter-station seismic coherence and use seismic and gravity time series data to measure changes to elastic moduli and density within the repository. Changes in either the level or pattern of local microseismicity can reveal changes in stress conditions within the repository that may result in a confinement failure of the reservoir. Changes in microseismic behavior will be correlated and interpreted in conjunction with any detected changes in the stress field calculated from the elastic moduli and density models.

CONTENTS

MONITORING STRESS CONDITIONS IN A DEEP BOREHOLE REPOSITORY

1. INTRODUCTION

We propose a method that can be applied to characterize the state of stress within a deep borehole repository before, during, and after drilling and emplacement of waste without the need to deploy and maintain expensive down-hole sensors. An important component of long-term geologic stability is the isolation of fluids and materials in the repository from the surface and near surface environment. Permeability can be enhanced and pathways created from the repository to the near-surface environment if stress conditions lead to faulting and fracturing. Therefore we believe that geophysical characterization and monitoring should be an important component of the safety evaluation and monitoring of a deep borehole repository.

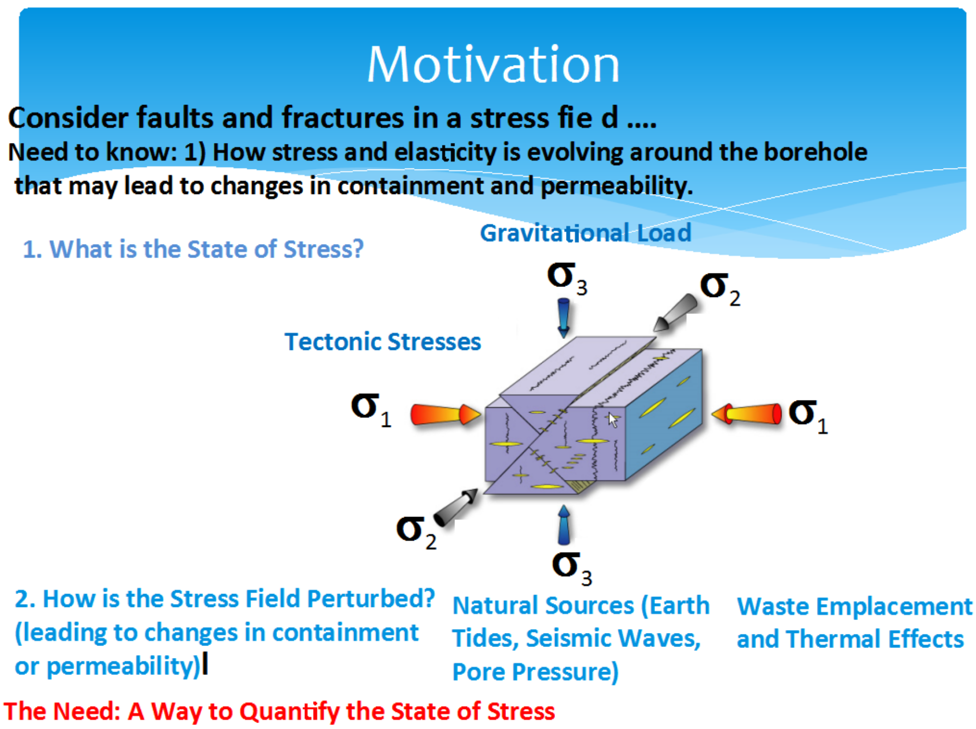

Fig 1. We need to know the state of stress and how stress evolves over time to understand the level of geologic stability in a waste repository.

Knowing how and when faults and fractures rupture is critical for any subsurface reservoir or repository. The equilibrium balance (or the lack thereof in the case of deformation) requires knowledge of the forces acting in the subsurface. These forces span a variety of scales from large-scale tectonic and gravitational effects to small-scale anthropogenic changes due to subsurface engineering. The state of stress is generally poorly known our ability to quantify the state of stress throughout the repository will provide a way to predict and monitor the important geomechanical responses in the subsurface. Quantifying the state of stress provides the means to understand and predict geomechanical phenomena. Our goals are to ensure reservoir integrity by monitoring microseismicity and stress conditions. Current qualitative approaches rely on empirical safety envelopes to monitor near-wellbore formation damage. A quantitative approach would allow site-specific determination of stress conditions to characterize geologic stability at repository scale (Fig. 1).

State of stress at locations within a repository or basin cannot be measured directly. At the wellbore, stress orientation and magnitude could be inferred from analysis of hydraulic fracturing and borehole breakouts. However, in the region away from the wellbore, stress cannot be evaluated at scales relevant to a deep borehole repository. We lay out a path to derive state of stress at relevant scales using combinations of indirect observations (e.g., gravity and seismic data) coupled with tomographic analysis (Fig 2.). The approach is an outgrowth of recent developments in the joint-inversion of different geophysical datasets to derive material properties that are required to calculate stress. This effort is aimed at applying the algorithm needed for deriving state-of-stress from the seismic velocity and density.

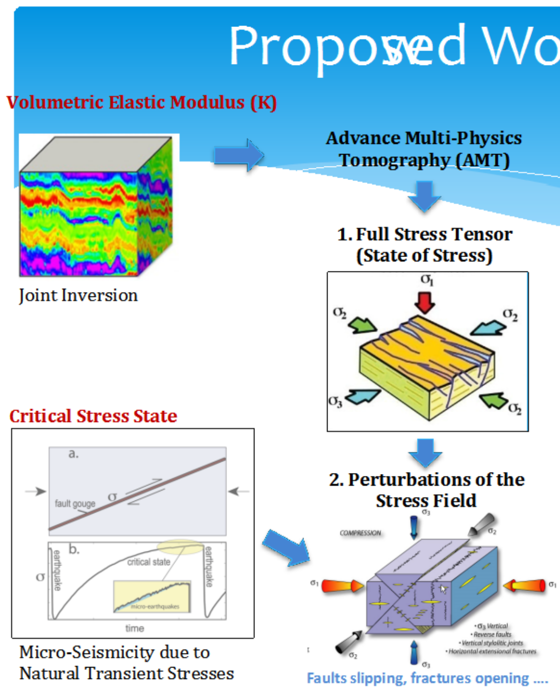

Fig. 2. We use a joint inversion of gravity and seismic data to obtain an image of density and elastic moduli. With these models we can calculate stress due to body forces and combine with background tectonic stress to obtain the complete stress field. We also monitor seismicity to detect evidence of critically stressed faults in a repository.

In addition to imaging material properties, we will use microseismicity as a probe of stress conditions. Our experimental work characterizing dry fault systems(1,2) shows that triggering takes place only in rock that is in a *critically stressed state(3)*. This key observation suggests that dynamically triggered seismicity can be used as a stress probe, a notion supported by both our numerical simulations(4) and recent seismic observational work (1,5).

Detecting small triggered earthquakes offers the only direct in situ critical stress probe that exists, aside from borehole tests that are expensive, frequently unfeasible, and most importantly, point tests. Dynamic loads (seismic waves & tides) probe the entire reservoir, making the technique extremely powerful.

2. Stress Tensor

We will use our advanced multi-physics tomography algorithm to obtain the full stress tensor at the repository-scale (Fig 3.). We will use a novel approach applying tomography to integrate two in situ data sets (gravity and seismic) to obtain elastic wave velocities (C) and density (ρ) from which the elastic modulus ($K=C^2\rho$) can be calculated. This approach builds on our earlier joint inversion work to map elastic properties (6) and more recent smaller-scale applications of this method to volcanoes (7). The strain field is modeled by combining gravitational (the above procedure) and tectonic (from plate-to-regional scale modeling) components. The full stress tensor can thereby by be computed using the strain and modulus fields. The raw data errors can be propagated forward to induce a distribution on strain and stress in order to address uncertainty in the stress estimation.

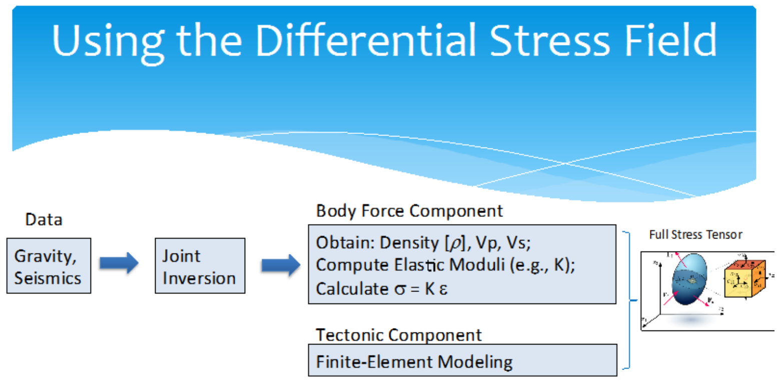

Fig. 3. We determine density and elastic moduli by inverting seismic and gravity data. From these models we can calculate stress due to body forces.

3. Microseismicity as a Stress Probe

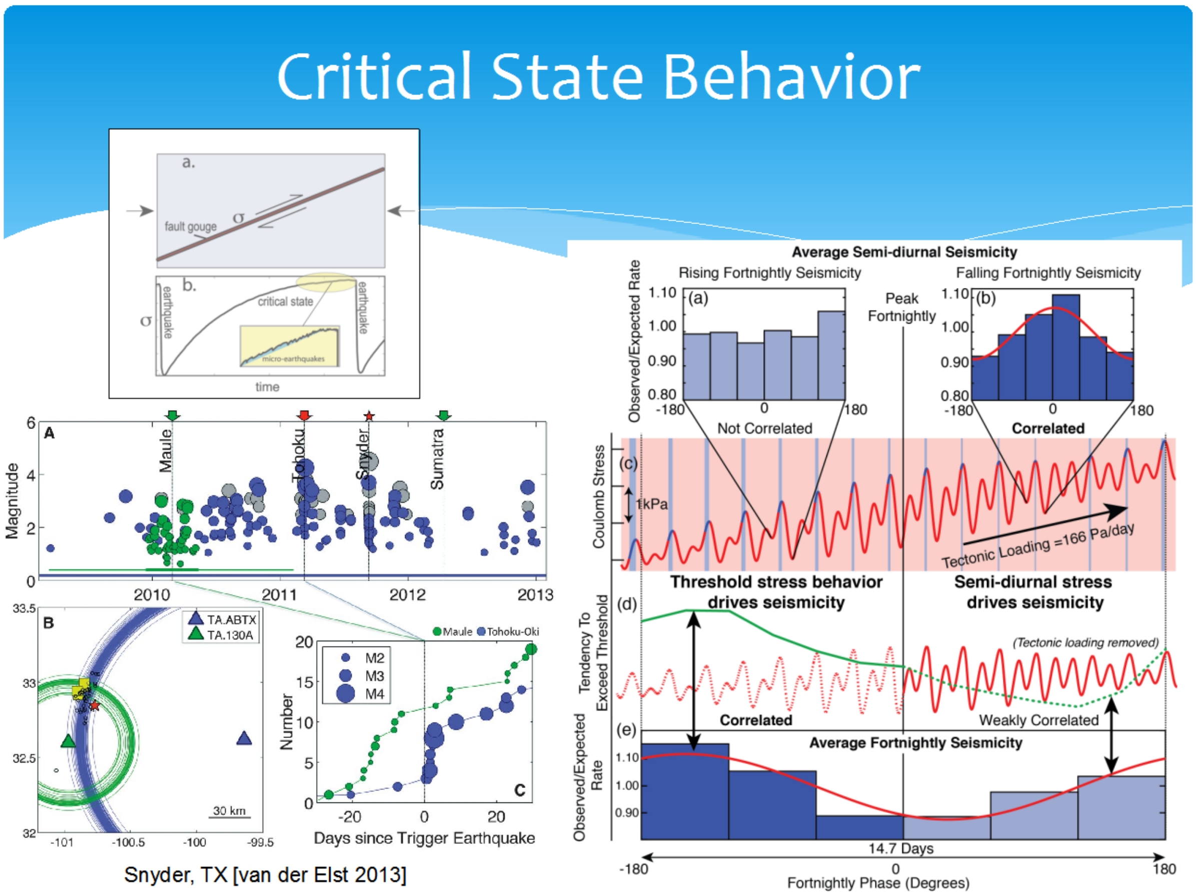

Fig 4. By observing a system's response to transient stresses like seismic waves from distant earthquakes (left) and solid Earth tides (right) we can monitor critically stressed faults in the repository.

Reservoir selection and monitoring relies substantially on understanding quantifying critical state behavior. LANL is at the forefront of characterizing and identifying critical state behavior (faults near failure) both in the laboratory and in the Earth. We use laboratory experiments to study how shear systems behave throughout the stress cycle (3,8,9,10), then apply what we learn to Earth observations (11,12). Experiments suggest that faults are only triggered by dynamic stresses when critically stressed (3,8,9,10). We have used dynamically triggered earthquakes to reveal frictional and poroelastic behavior of faults and quantify critical state behavior in the Earth (11,12,13,14). In support of these efforts we have developed and applied a microseismicity detector known as interstation-seismic coherence to greatly increase the number of detected events (13). We are developing machine-learning algorithms to reveal new signals and new physics of shear failure, which may lead to forecasting and predictive capabilities. In the context of reservoir management our tools can be applied both during the site selection process and as part of a comprehensive monitoring program.

4. References

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