Use of deformation based reservoir monitoring for early warning leak detection

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How well can surface deformation monitoring detect changes in the depth of a subsurface fluid?

- Surface deformation monitoring uses InSAR, GPS, Tiltmeters or a combination to monitor processes including fluid flow, fracturing, earthquakes and injection and production operations.
- Surface deformation increases quickly in magnitude and changes in spatial distribution as the source of the strain approaches the surface.
- This allows deformation to function as an effective early warning of impending or potential surface breach caused by cap rock or well casing failure.
- Sensitivity is a function of a number of parameters, including the original fluid depth, volume of fluid, geologic structure and uncertainty of surface-deformation measurements.
- The results of this study can be used to determine whether surface deformation monitoring is a valid approach to verify cap rock integrity and which types of measurements are required to obtain the necessary resolution. It also provides a basis for selecting the area to be covered by monitoring and the minimum density of monitoring stations to help ensure leaks cannot occur in an unmonitored zone between stations.

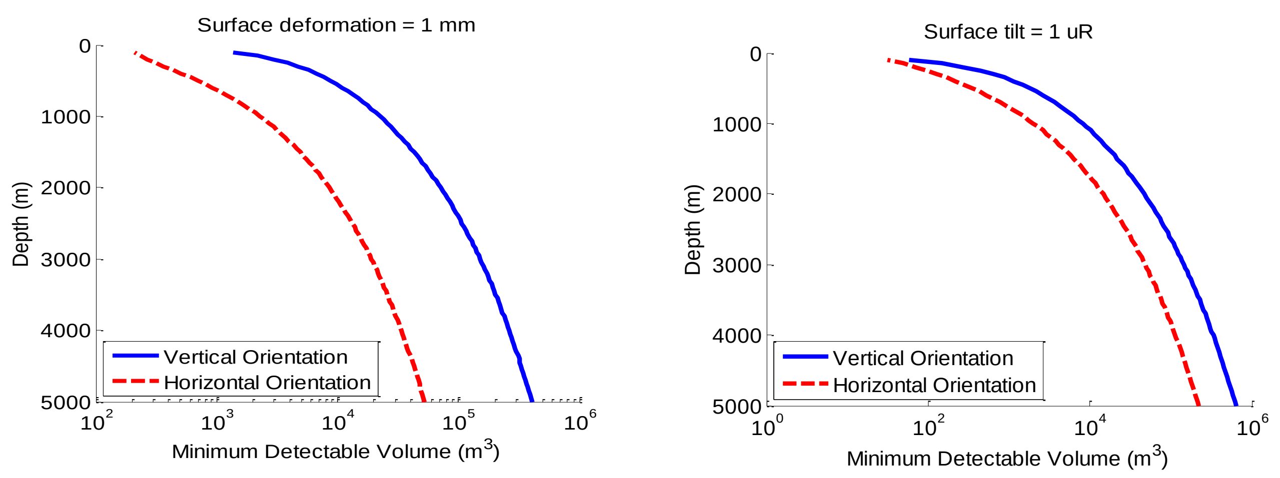
1. Introduction

Surface deformation monitoring began in the 1970s[1], but did not become a common method of monitoring hydraulic fracture treatments until purpose built tiltmeter instrumentation became available in the 1990s[2]. Use of the technology for longer term reservoir monitoring followed quickly with tiltmeter based data supplemented by high precision GPS data[3]. The development and commercialization of InSAR is now beginning to revolutionize long term monitoring.

This study uses dislocation sources to generate surface deformation, implying that fluid pressure exceeds the local fracturing pressure. The surface deformation produced by poro-elastic swelling is generally indistinguishable from that produced by the opening of a horizontal dislocation, but that does not imply that the results obtained here are inapplicable to non-fracturing situations.

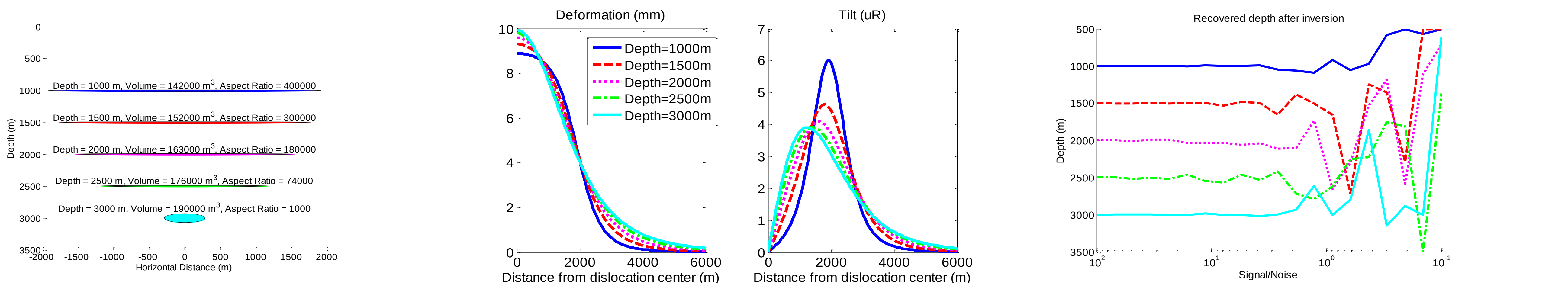
2. Sensitivity

- Away from the free surface, the deformation is approximately proportional to depth$^{-1.9}$, while the tilt is proportional to depth$^{-2.9}$. As sources get deeper, it eventually becomes easier to detect the deformation than the surface tilt.
- The magnitude of surface deformation is proportional to the dislocation volume.
- Large modulus contrasts can modify the surface deformation.



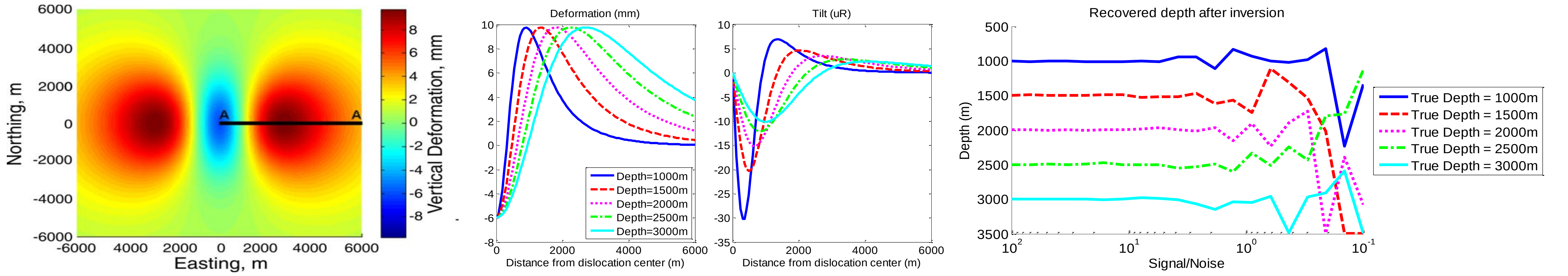
3. Detection of Depth – Horizontal Dislocations

Resolution of dislocation depth is a function of how well the surface gradient can be distinguished. With individual deformation readings at the millimeter level or tiltmeter readings at the microradian level, one can distinguish between the 1000 m and 1500 m cases presented in the figure. An array of measurements is needed to distinguish between the remaining curves in the presence of measurement noise. The results show that depth in this situation can be determined down to a signal-to-noise ratio of roughly 2, with an error of less than 10% in the depth.



4. Detection of Depth – Vertical Dislocations

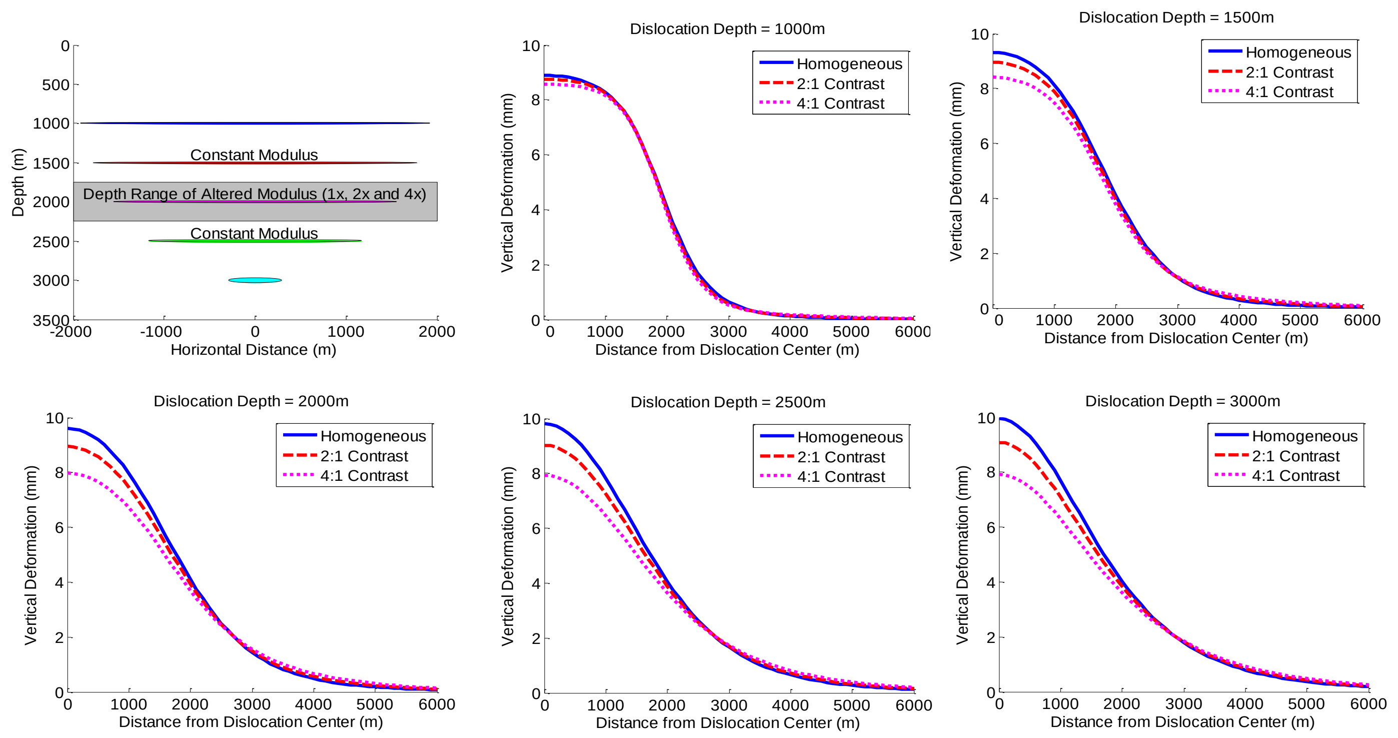
For vertically oriented dislocations, there is a more straightforward indicator of depth. The distance from the trough above the center of the dislocation to the peak perpendicular to the azimuth is a linear function of the depth.



5. Impact of Layers

In an attempt to partially quantify the degree to which the best-fit depth and dislocation volume are affected, this study looks at the best-fit solution using the previous examples, except in a layered formation. The model used was developed by Wang, Lorenzo-Martin, and Roth[4,5] and employs Hankel transforms to develop a set of Green's functions that integrate the wave-number spectra functions.

The figure shows the set of five dislocations used in this study, with the center dislocation in a zone of increased modulus. To look at the effects of this intervening layer, the predicted surface deformations from all five dislocations are plotted using modulus contrast ratios of 1, 2, and 4 between the bounding and center layers. Given that the best-fit depth is a strong function of the surface gradient, the changes in theoretical gradient introduced by the layers once the dislocation is close to or within the boundary are clearly important to obtain the best results. In each case, using horizontal dislocations, the intervening high modulus layer lowers the surface deformation gradient.



6. Conclusions

- The determination of whether subsurface fluid can be detected using surface deformation can be quantified by the strain volume, depth, and the sensitivity of the measurement.
- Detection of depth and dimensions is reasonably accurate, at least in single-dislocation systems, where an adequate number of measurements exist and the s/n ratio is greater than about 2.
- Accurate detection of fluid depth depends on having sufficient instrumentation to define the gradient of the surface deformation and a model that accounts for large changes in formation properties.
- Applying a homogeneous model could result in a best-fit solution depth that differs significantly (20% in the cases tested) from that obtained with a correct layered model.

References

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