25  Moment Tensor Inversion of Seismic Events and Tremor-Tilt Observations Associated with the Sinkhole at Napoleonville Salt Dome, Louisiana

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Introduction

The formation of a large sinkhole at the Napoleonville salt dome (NSD), Assumption Parish, Louisiana (Figure 2.25.1) in August, 2012 was accompanied by a rich sequence of complex seismic events. Preliminary investigations suggest that the possible collapse of the sidewall of a plugged and abandoned brine cavern, Oxy Geismar 3, might be a potential cause of the sinkhole. It has been hypothesized that the collapse fractured to the surface, creating a disturbed rock zone, which provides a pathway for formation fluids, natural gas and crude oil from deeper strata that are now accumulating in the sinkhole and the surrounding aquifer.

Application of GRiD MT to 24 hours of data during August 1–2, 2012 (just before the appearance of the sinkhole) with a 71% VR detection threshold reveals 71 events with magnitudes M<sub>W</sub> 0.8 to 1.9. Their locations are well constrained to the western edge of the salt dome, close to the sinkhole, at an approximate depth of ~420 m, which is much shallower than the roof of the cavern at 1.0 km (Figure 2.25.2). The M<sub>W</sub> distribution of ~1100 events detected during an extended period of time doesn't follow the Gutenberg Richter relationship and shows distinct absence of larger magnitude events indicating a structural limit on size of the source.

Moment Tensor Inversion

We investigate source mechanisms of these seismic events, represented by a general point source centroid seismic moment tensor (MT). We use data recorded by a temporary network of broadband seismometers deployed by the U.S. Geological Survey (USGS). Because of uncertainties in hypocenters estimated from travel-times and large number of seismic events, we employ a grid-search approach, GRiD MT (Kawakatsu, 1998), which continuously scans the seismic wavefield and performs MT inversions of low frequency displacement waveforms (causal 0.1-0.2 Hz 4-pole Butterworth filter) assuming a discrete 3D grid of point sources. For a given time window of data, the source location and MT solution which give the best Variance Reduction (VR) is inferred to be the true seismic source. Green’s functions are computed using frequency-wavenumber integration software FKRPROG using two separate 1D velocity models for the salt dome and the surrounding sediment sequence.

Figure 2.25.1: Google Earth Image (dated March 12, 2013) shows the study region at the western edge of NSD, with 1000 ft and 10,000 ft contours indicated by white lines, locations of the five USGS broadband stations (white triangles), approximate location of the Oxy Geismar 3 cavern (white square), and an average point location of the sinkhole (white balloon).

Figure 2.25.2: Source depth and M<sub>W</sub> distribution. Red and blue lines are Gutenberg Richter relationships for various ‘a’ and ‘b’ values.

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Figure 2.25.3: NSS of event TE1 on the Hudson source-type plot, major theoretical source-types (black crosses), tensile cracks in various media and full MT solution of event TE1 (white star). White circle is the source-type corresponding to the maximum VR recovered by NSS (VR<sub>max</sub>). The inset shows distribution of 71 events of the seismic sequence (white ‘+’ signs) in source-type space.

The MT solutions are comprised of large (66-92%) isotropic volume-increase components, and can be interpreted as a N-NE striking steeply dipping tensile crack in a high Poisson ratio (0.43) medium coupled with a normal-style double couple. For one representative event, TE1, the volume-increase component...
is found to be statistically significant using an F-test and stable with respect to: (1) velocity models and stations used, (2) first motion polarities, and (3) uncertainties in GRID MT location and MT elements. In the network sensitivity solution (NSS) of Figure 2.25.3, MT solutions that produce best fits (>80% VR) are tightly clustered in a region between theoretical explosions and tensile cracks, quite far away from theoretical deviatoric mechanisms and expected closing crack mechanisms, which produce fits only up to 50-75% VR. For further details on MT analysis of this sequence and a complete list of references, readers are referred to Nayak and Dreger (2014).

We believe that the events in this study are caused by high-pressure flow of natural gas or water-gas mixture through voids in the disturbed rock zone or pre-existing zones of weaknesses like fractures or faults at the edge of the salt dome by volumetric expansion or tensile failure mechanisms similar to those observed in geothermal and volcanic environments. This hypothesis is supported by the intense influx of natural gas (primarily methane) into the aquifer over an area of 5 km² around the sinkhole from the disturbed rock zone below. As of September 2013, ~16x10³ Mcf natural gas has been vented or flared out as a remediation measure.

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References
