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Source Analysis of the Crandall Canyon, Utah, Mine Collapse

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Analysis of seismograms from a magnitude 3.9 seismic event on August 6, 2007 in central Utah reveals an anomalous radiation pattern that is contrary to that expected for a tectonic earthquake, and which is dominated by an implosive component. The results show the seismic event is best modeled as a shallow underground collapse. Interestingly, large transverse surface waves require a smaller additional non-collapse source component that represents either faulting in the rocks above the mine workings or deformation of the medium surrounding the mine.

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On August 6, 2007 a magnitude 3.9 seismic event was associated with the tragic collapse of a Utah coal mine, which ultimately killed six miners and three rescue workers. The event was recorded on the local network of the University of Utah Seismic Stations (UUSS) and the Advanced National Seismic System (ANSS) operated by the USGS. In addition, the NSF Earthscope USAarray stations had just been installed in Utah in the months prior (www.earthscope.org). These stations provided unprecedented coverage (Fig. 1a) of a seismic source of this type. Analysis of the recorded seismograms reveals a very shallow depth and an anomalous radiation pattern, both of which are contrary to what is expected for a tectonic earthquake.

First motion polarities from vertical-component records of the seismic event associated with the collapse reveals that all are initially down, or dilatational, indicative of an implosional source *(1)*. Consistent with this observation, the moment tensor inversion of complete, three-component, low-frequency (0.02 to 0.10 Hz) ground displacement records recovers a mechanism that is most consistent with the gravity driven vertical collapse of a horizontally oriented underground cavity at a shallow depth consistent with the mine workings (Fig. 1b). The total seismic moment of this mechanism is 1.91×10^{15} N-m (M_W4.2). However, a pure vertically closing horizontal crack theoretically has no Love wave excitation and in order to explain the large amplitude Love surface waves observed on the tangential component (Fig. 1c) the mechanism must contain a non-crack component that is 24% of the dominant vertical collapse component (1.71×10^{15} N-m).. The secondary source excitation of the moment tensor can be represented in multiple ways as the moment tensor decomposition is non-unique *(2)*. Plausible interpretations of the secondary source include additional vertical dip-slip faulting, horizontal shear, non-uniform crack closure, and elastic relaxation in response to the mine collapse *(3)*. The full moment tensor solution produces a pure dilatational P-wave first-motion mechanism consistent with the P-wave polarity observations.

The source-type diagram *(4)* in Fig. 1b illustrates the deviation from a pure earthquake double-couple (DC) source at the center in terms of a volumetric component (explosion or implosion) on the ordinate, and deviatoric component in terms of a volume compensated linear vector dipole (CLVD) on the abscissa. The moment tensor solution for the August 6, 2007 event plots in the region of a negative or closing crack. The diagram shows that despite the secondary source component the seismic waveforms are best fit by a model that is primarily comprised of a vertically closing horizontal crack, or underground collapse, and is similar to solutions obtained for other mine and Nevada Test Site (NTS) cavity collapses *(5, 6)*. In contrast, NTS nuclear explosions modeled with the same method plot squarely in the explosion region of the diagram. Both the explosions and collapses are significantly separated from the population of earthquakes, which locate in the center of the diagram. Deviation from pure DC mechanisms in the earthquake population can be due to several factors including complex faulting, noise, and the effect of approximate Earth structure models to compute the basis Green's functions for the inversion. Despite the scatter within the three source populations, there is clear separation between each, indicating that regional distance seismic moment tensor methods are capable of source-type discrimination.

Our findings show that the seismic waveforms associated with the mine collapse are to first order due to the collapse, however the seismic source process was more complex than observed in other collapse events *(5, 6*) with a large secondary source generating strong Love waves. The findings further show that the application of seismic moment tensor analysis to non-tectonic seismic events such as buried explosions or underground collapses as illustrated here, demonstrates the feasibility of continuous monitoring of regional distance seismic wavefields for source-type identification beneficial for nuclear explosion monitoring and given rapid access to the seismic waveform data, the possibility of mining related emergency response applications.

References and Notes

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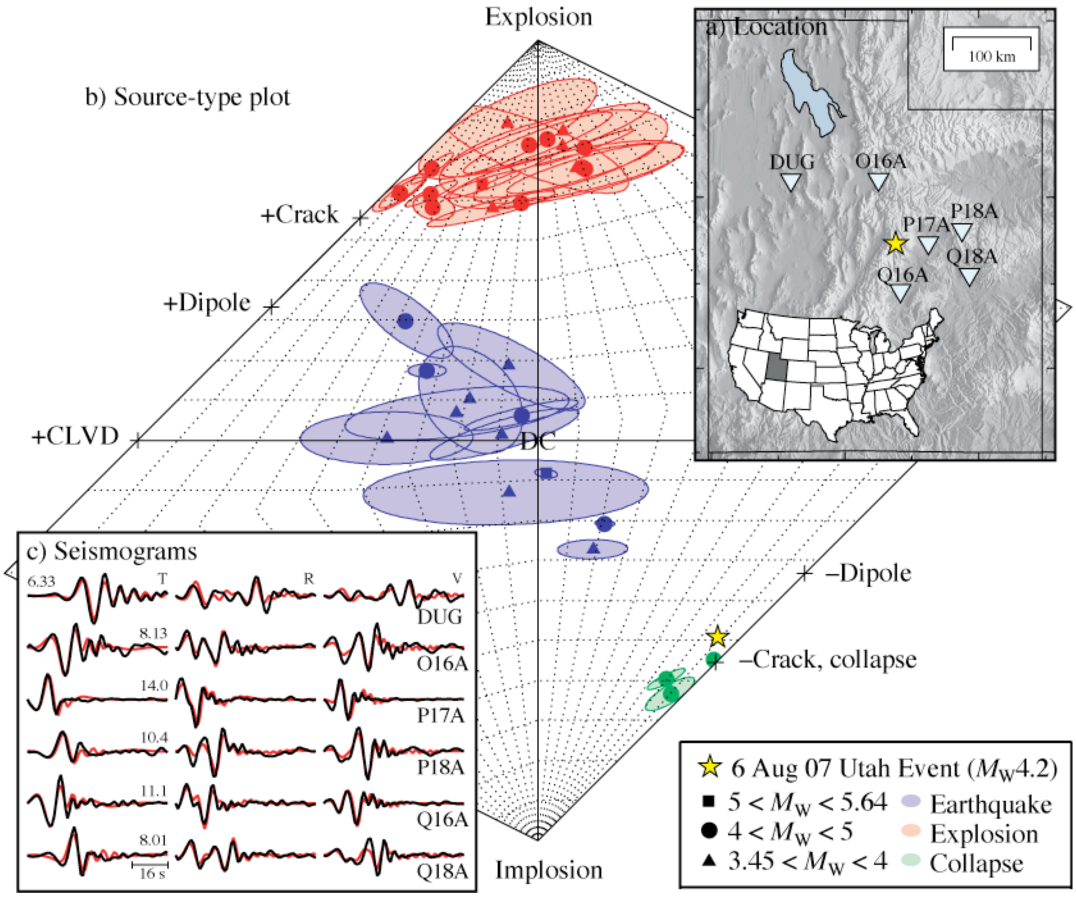

Fig 1. a) Locations of the August 6, 2007 event and 6 of the closest USArray and ANSS stations. b) Source type plot from the method of (*3*) shows clear separation of populations of earthquakes, explosions and collapses. The yellow star shows the solution for the August 6, 2007 seismic event. c) Observed seismograms (black) are compared to synthetics (red) for the non-double-couple solution, which is dominated by a horizontal closing crack (b). The maximum displacement (10^{-7} m) of each set of tangential (T), radial (R), and vertical (V) observations is given.