Source Analysis of the Crandall Canyon, Utah, Mine Collapse

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On 6 August 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 Seismograph Stations and the Advanced National Seismic System (ANSS) operated by the U.S. Geological Survey. In addition, the National Science Foundation Earthscope USArray stations had recently been installed in the region (*1*). These stations provided good coverage (Fig. 1A) enabling seismic source analysis of the recorded signals, which revealed an unusually shallow depth and anomalous radiation pattern, both contrary to the expectation for a tectonic earthquake.

First-motion polarities from vertical-component records of the seismic event are down, or dilatational, indicative of an implosional source (*2*). Consistent with this observation, the moment tensor inversion of complete, three-component, low-frequency (0.02 to 0.10 Hz) ground displacement recovered a mechanism that also satisfies the observed first motions and is agreeable with the gravity-driven vertical collapse of a horizontally oriented underground cavity at a shallow depth (<1 km), consistent with the mine workings (Fig. 1B). The total seismic moment of this mechanism was 1.91×10^{15} N m ($M_W = 4.1$). However, a closing horizontal crack theoretically has no Love wave excitation, and in order to explain the large-amplitude Love waves observed on the tangential component (Fig. 1C) the mechanism must contain a secondary noncrack component that is 24% of the dominant vertical collapse moment (1.71×10^{15} N m). The secondary source excitation of the moment tensor can be represented in multiple ways because the moment tensor decomposition is nonunique (*3*). Plausible interpretations of the secondary source include vertical dip-slip faulting, horizontal shear, nonuniform crack closure, and elastic relaxation in response to the mine collapse.

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 a deviatoric component in terms of a volume compensated linear vector dipole (CLVD) on the abscissa. The moment tensor solution for the 6 August 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 composed of a closing horizontal crack, or underground collapse, and is similar to solutions obtained for other mine and Nevada Test Site (NTS) cavity collapses (*5*). In contrast, NTS nuclear explosions modeled with the same method (*6*) 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 a result of several factors, including complex faulting, noise, and the effect of approximate Earth structure models on the basis Green's functions used in 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 primarily reflect the collapse; however, the seismic source process was more complex than those observed in other collapse events (*5*) with a secondary source generating strong Love waves. This application of seismic moment tensor analysis demonstrates the feasibility of continuous monitoring of regional distance seismic wavefields for source-type identification, including nuclear explosion monitoring and given rapid access to the seismic waveform data, for emergency response applications.

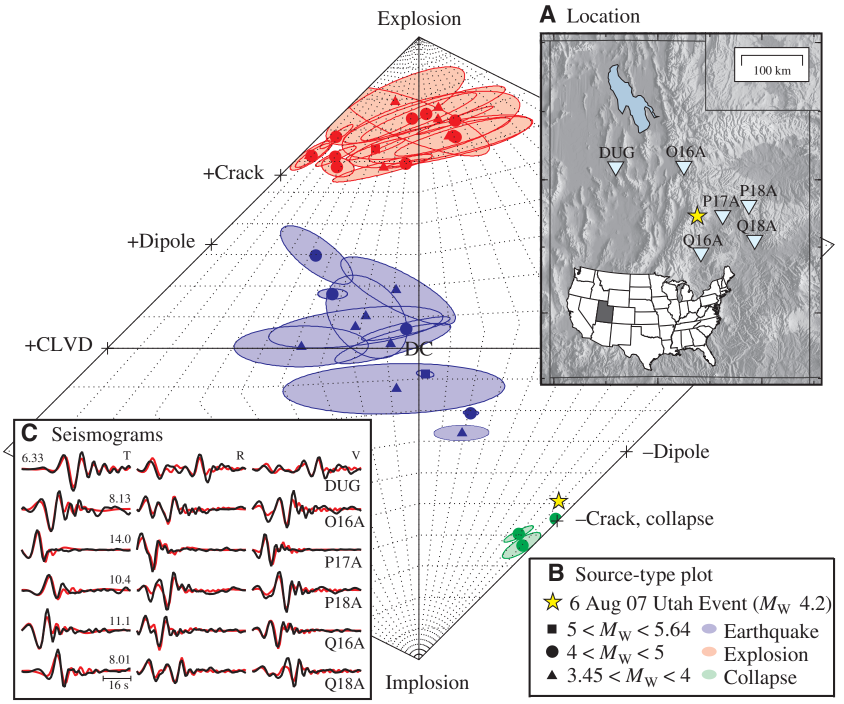

Fig. 1. (**A**) Locations of the 6 August 2007 event and six of the closest USArray and ANSS stations. (**B**) Source-type plot from the method of (*4*) shows separation of populations of earthquakes, explosions, and collapses. The yellow star shows the solution for the 6 August 2007 seismic event. (**C**) Observed seismograms (black) are compared to synthetics (red) for the non-dc 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.

References and Notes

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Supporting Online Material

www.sciencemag.org/cgi/content/full/321/5886/217/DC1
Figs. S1 and S2

5 March 2008; accepted 15 May 2008
10.1126/science.1157392

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