CHARACTERIZATION OF MINING-INDUCED SEISMICITY IN THE WITWATERSRAND BASIN, SOUTH AFRICA

T. H. Jordan and E. Richardson
Department of Earth, Atmospheric and Planetary Sciences, MIT, Cambridge, MA 02139

C. Wright, S. Webb, E. Kgaswane, T. Kwadiba, and R. McRae-Samuel
Bernard Price Institute, University of Witwatersrand, Johannesburg, South Africa

DTRA Contract Number 98-C-0158

ABSTRACT

The objective of this research is to characterize the seismicity of South Africa, with emphasis on understanding the distribution and properties of mining-induced events in the Witwatersrand Basin. The study has focused on the two-year period from April, 1997 to May, 1999, when MIT and the Carnegie Institution of Washington, supported by the U.S. National Science Foundation and in cooperation with the University of Witwatersrand and a number of other research organizations in southern Africa, operated a temporary, 54-station array of broadband, three-component seismometers. This "Kaapvaal" array was distributed on a NE-SW axis from Cape Town, South Africa, to Masvingo, Zimbabwe, for the primary purpose of imaging the deep structure of the South African continent, but it also produced excellent recordings of regional seismicity.

Seismicity and Waveform Catalogs. The following cataloging tasks have been completed or are nearing completion:

1. *Standard Catalog.* In cooperation with the South Africa Council of Geosciences, a catalog of southern African seismicity has been constructed for the two-year period using data from the South African Seismological Network (SANSN) and the Council's standard procedures for associating arrivals and locating events.

2. *Local Mine Catalogs.* Locations, origin times, and magnitudes have been collected for all events with $M_L \geq 2$ from in-mine seismic networks maintained by the following mine operators:

East Rand:	East Rand Proprietary Mine
Central Rand:	West Rand Consolidated, Randfontein Estates, Durban-Roodepoort Deep
West Rand:	Kloof, Libanon, Venterspost
Far West Rand:	Deelkraal, Elandsrand, Western Deep Levels (Tautona, Savuka, Mponeng), Blyvooruitzicht, Doornfontein, Driefontein Consolidated (West & East).
Free State:	Joel, Masimong (Saaiplaas), Bambanani (President Steyn), Matjhabeng (Western Holdings), Harmony, Unisel, St. Helena
Klerksdorp:	Vaal Reefs, Stillfontein, Hartebeestfontein, Buffelsfontein, African Rainbow Minerals

3. *Calibration Catalog.* Events common to the standard and local mine catalogs have been identified and being used to calibrate the performance of SANSN and the Kaapvaal array.

We are currently constructing a catalog of waveforms recorded on the Kaapvaal broadband array, and we plan to use these waveforms in conjunction with the precise locations from the in-mine networks to improve the location and source-modeling procedures in South Africa.

Properties of Mining-Induced Seismicity. We have completed our first detailed study of mining-induced seismicity in the Far West Rand mining district of South Africa. The study was done in cooperation with AngloGold, Ltd., at five of its mines: Deelkraal, Elandsrand, and the three mines of Western Deep Levels (Tautona, Savuka, Mponeng). These mines, which are the deepest in the world, extract ore at 2-4 km and are very seismically active; each is equipped with state-of-the-art, on-reef seismic networks comprising 13-

28 three-component stations that record hundreds of events per day. Based on these data, we have identified two distinct classes of events, designated Type A and Type B. Type A events are tightly development end; they have spectra comparatively enriched in high frequencies, their focal mechanisms often involve isotropic components, and they show an upper magnitude cutoff at $M \sim 0.5$. We interpret these events to be "fracture-dominated" ruptures of competent rock at low normal stress, induced by dynamic stresses during blasting and quasi-static stress perturbations from the excavation and closure of individual stopes.

In contrast, Type B events are temporally and spatially distributed throughout the active mining region. We interpret them to be "friction-dominated" ruptures occurring on existing faults or other weak geologic structures at near-lithostatic normal stresses. They have double-couple focal mechanisms and scaling properties that agree with extrapolations from tectonic earthquakes. For example, the energy/moment ratios for Type B events yield apparent stresses in the range .01-1 MPa with a distinct increase in apparent stress with moment, consistent with the observations of small earthquakes in tectonic environments. Although the data show considerable scatter, the increase in apparent stress scales approximately as $M^{2/3}$. A second important observation is a lower magnitude cutoff in the Type B events at M ~ 0. We interpret this cutoff in terms of a critical patch size for nucleation of shear failure, which yields a critical slip distance $D_c = 10^{-4}$ m. This result is consistent with an upper frequency cutoff, f_{max}, near 200 Hz, which is observed on accelerograms recorded in the near field of large events. The implications of these results for nuclear monitoring in deep-mining environments will be discussed.