SOURCE AND PROPAGATION CHARACTERISTICS OF EXPLOSIVE AND OTHER SEISMIC SOURCES

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ABSTRACT

Understanding of the source and propagation characteristics of seismic events of different types, including earthquakes, explosions, and mining-induced events is essential for successful discrimination of nuclear explosions. We are compiling a data set of mining related seismic events in east Eurasia. Natural earthquake data in the same region are also collected for a comparison study between mining related events and earthquakes. The ground-truth data set will provide a unique and valuable resource for monitoring research. We will use the data set to investigate the source and propagation characteristics of seismic sources of different types, including mine blasts, tremors, collapses, and earthquakes. We will use various seismological techniques, including spectral analysis and waveform modeling to conduct the investigation. The research will improve our understanding of the S-wave excitation and propagation characteristics of chemical explosions and other source types.

OBJECTIVES

The objective of this study is to build a ground-truth database of mining related seismic events, including mine blasts, mine tremors, and mine collapses, along with natural earthquakes in east Eurasia. We will use this unique data set to study the source and propagation characteristics of seismic events of different source types. The research will improve our understanding of the source and propagation characteristics of seismic events of explosives and other source types and our abilities to discriminate and monitor nuclear explosions with ground-based systems.

RESEARCH ACCOMPLISHED

Methodology

In the past 20 years significant advances have been made in small magnitude discrimination using regional body waves. In particular measurements that use high-frequency (> 4 Hz) regional phase (Pn, Pg, Sn, Lg) amplitude ratios can discriminate earthquakes from nuclear and contained chemical explosions in many different parts of the world (Taylor et al. 1988; Dysart and Pulli 1990; Baumgardt and Young 1990; Kim et al. 1993; Walter et al. 1995; Taylor 1996; Fisk et al. 1996; Hartse et al. 1997; Rodgers and Walter 2002, and many others). A factor undermining our confidence in using these discriminants in uncalibrated regions is the large variation in performance for the different regions where they have been tested. For example, some regional discriminant ratios such as low- to high-frequency spectral ratios in P and S phases work well at the Nevada Test Site but not at Eurasia test sites (e.g., Taylor and Denny 1991; Walter et al. 1995). The key unresolved issue is the lack of a firm physical basis for these discriminants.

The dense local to near regional distance data from east Eurasia, with both earthquake and mining sources, provide a unique data set to investigate some of these issues. In particular we will examine: 1) S-wave excitation and propagation in distance and azimuth from both earthquakes and mine seismicity (blasts, tremors, and collapses); 2) differences and similarities between fairly contained chemical explosions and those more distributed in space and time; and 3) issues of wave amplitude and frequency evolution during propagation from local to regional distances as interactions with basin, crustal and uppermost mantle structure take place.

The physical basis for the generation of S wave from nuclear explosions has remained a central issue in monitoring research for many years. Physically sound models of S-wave energy from explosions include tectonic release, rock cracking, spall, P to S conversion at the free surface and Rg to S scattering (e.g., Wallace 1991, Johnson and Sammis 2001, Day and McLaughlin 1991, Vogfjord 1997, Gupta et al. 1992). Recent observational evidence from the 1997 Kazakh depth of burial experiment points to Rg-to S scattering as a major source of S-waves (Myers et al. 1999) from explosions. However the relative importance of these mechanisms and their dominant frequency contributions is not clear. We will measure body wave amplitudes at the stations and utilize the independent information on the mine blast source characteristics to examine these possible mechanisms of explosion S-wave generation.

In many regions of the world, the only seismically recorded explosions are those from mine blasts. In such regions there have been studies discriminating the two (e.g., Baumgardt and Young 1990, Walter et al. 1997), but the application to nuclear explosion monitoring remains complex. While the equivalence between single contained chemical and nuclear explosions was demonstrated during the 1993 Non-Proliferation Experiment (Denny and Stull 1994), the relationship between the more complex mining explosions and nuclear blasts is more complicated. Because mine blasts come in a great variety of configurations in time, space, containment, and mass displacement, the relationship between discrimination performance for the three types of events— nuclear explosion, mining explosion, and earthquake— is not straightforward. For this study we will have some independent information about blasting practices for some of the mining shots. We will use this information to study the relationship between mine blasting practice and discrimination for east Eurasia. We will compare these results with ongoing efforts to study explosion phenomenology through experiments such as the 2003 Arizona Source Phenomenology Experiment (Bonner et al. 2003).

Much of the existing work on body wave discriminants has been at regional distances. The performance of discriminants such as high frequency P to S ratio at local distances is much less well characterized. In particular, it is known that body waves undergo very large amplitude variations over their first few hundred kilometers of propagation as they interact with local basin structure, crustal layering, Moho reflections, and uppermost mantle refractions. In preliminary study of earthquake and mine blast discrimination using high frequency P/S ratios in

Israel, Walter et al. (1997) noted that some stations at local distances showed good separation between event types and others did not. They attributed some of this effect to local propagation issues. With the coincidence of earthquake and mine blast source types and dense distance and azimuthal coverage, we will use the east Eurasia data to examine these issues. Specifically, we will measure instrument corrected local and regional amplitudes at a range of frequencies to study discriminantion performance as a function of distance, azimuth and relationship to crustal structure.

Data Collection and Processing

We initiated the project by investigating seismicities, including natural earthquakes and mining events in the studied region. East Eurasia is a region with vast mine resources as well as frequent earthquakes. Mining-induced seismic events occur frequently in many areas all over the region. There are over 3,500 seismic events reported by the regional seismic networks from 2001 to 2003 in the region (Figure 1). Valuable seismic data on mine related seismic events as well as earthquakes have been collected and archived for the region in data repositories such as IRIS, IDC, etc.

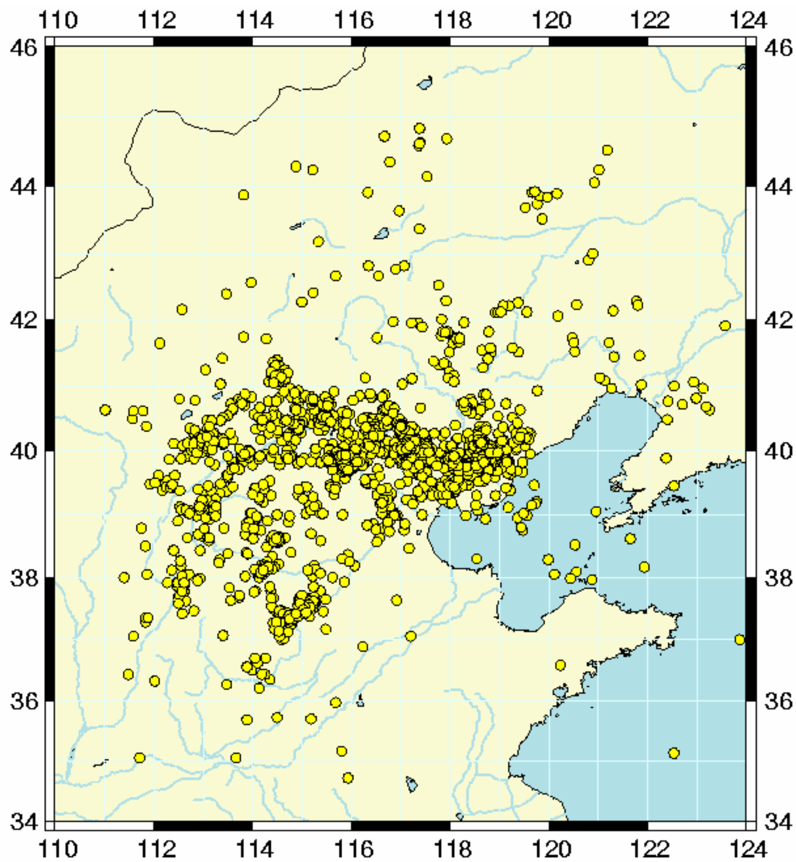

Figure 1. Over 3,500 seismic events recorded in east Eurasia from 2001 to 2003.

At data processing centers of the regional seismic networks in east Eurasia, data analysts routinely single out suspicious explosions based on characteristics of waveform, such as arrival onset, surface wave development, etc. Among the over 3,500 seismic events recorded from 2001 to 2003, more than 1,800 events are classified as possible mine blasts. The seismic stations in the regional seismic networks are equipped with very-broad-band seismographs with a bandwidth from 120 s to 20 Hz, broadband seismographs from 20s to 20Hz, and short-period seismographs in boreholes from 1 to 20Hz (Figure 2). The instruments have GPS timing, a 24-bit recording module, and a dynamic range greater than 130dB.

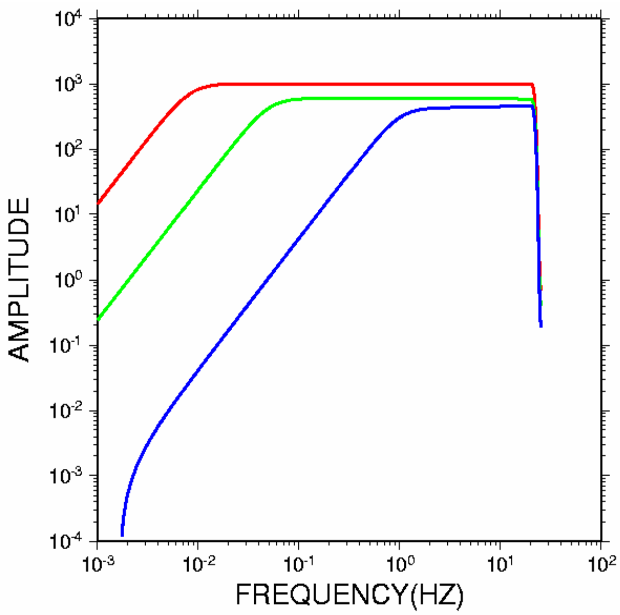

Figure 2. Instrument responses of the very-broad-band (red), broad-band (green) and short-period (blue) seismographs in the regional seismic networks in east Eurasia.

The waveform data are archived in SEED format. Figure 3 shows the vertical components of a possible mine blast that occurred on June 15, 2002. Figure 4 represents the vertical components for a magnitude 4.7 earthquake on May 18, 2002 in the nearby region. Initial observation reveals distinctive characteristics of the two different types of seismic events. We are in the process classifying and validating the raw data, making phase identification and measurement, and will perform discrimination studies in the next phase.

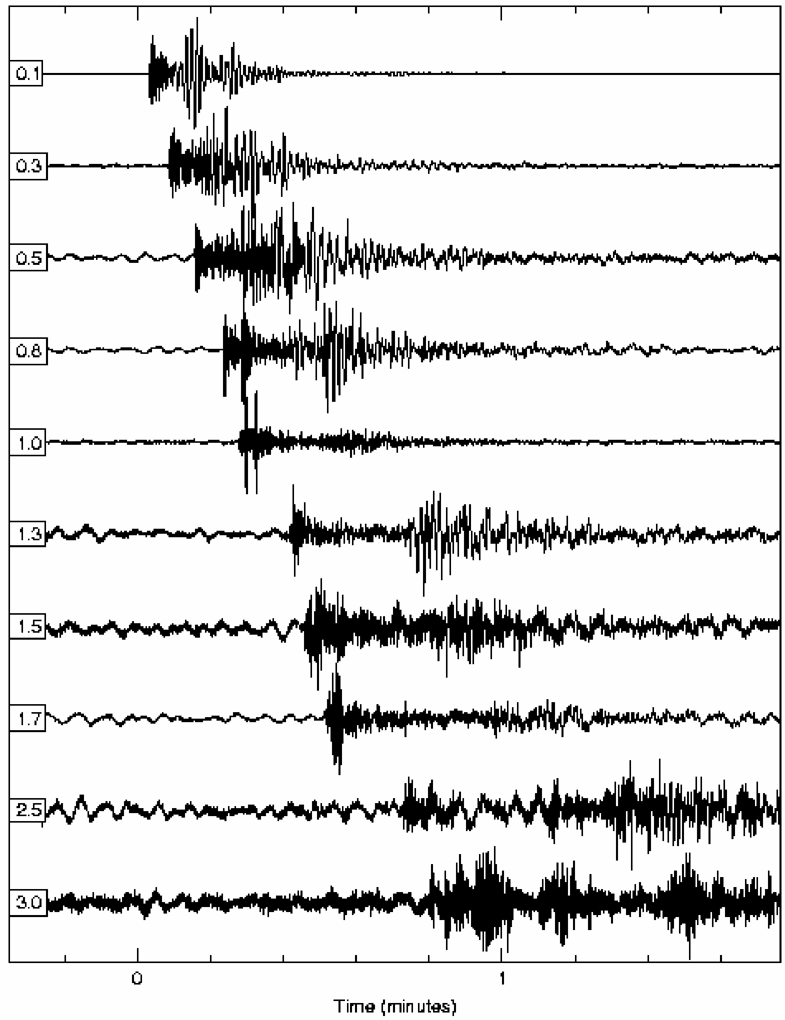

Figure 3. Vertical components of a possible mining blast recorded by regional seismic networks in east Eurasia on June 15, 2002. The numbers at the beginning of each trace indicate epicentral distance in kilometers.

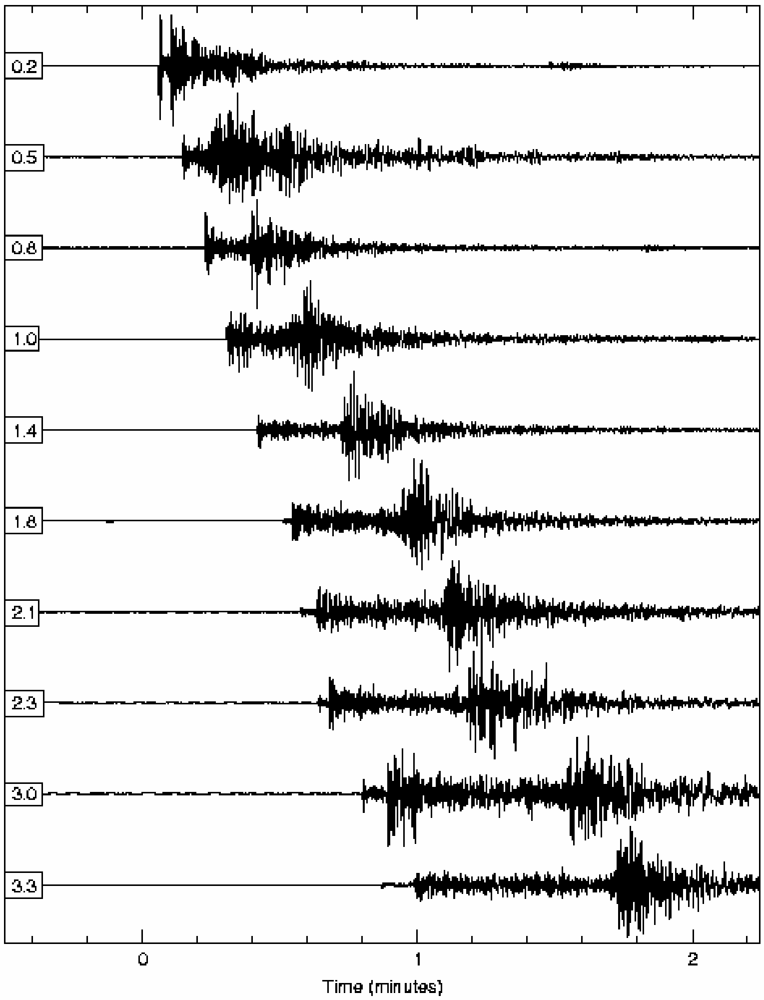

Figure 4. As a comparison with the possible mining blast in Figure 3, this panel shows the vertical components of a magnitude 4.7 earthquake recorded by the same networks on May 18, 2002. The numbers at the beginning of each trace indicate epicentral distance in kilometers.

Preliminary Results

In a preliminary look at the behavior of the regional body wave amplitudes in this region we have collected waveform data through IRIS from the CDSN station BJT. We focus on data within a few hundred kilometers of the station to look at local to regional effects. We selected about 23 earthquakes with magnitudes greater than 4.0 from the United States Geological Survey Preliminary Determination of Epicenters (USGS PDE) catalog and about 19 presumed mine blasts with magnitudes between 3 and 4. For each event we windowed the Pg and Lg phases using group velocity windows of about 6.0 to 5.0 km/s for Pg and 3.6 to 3.0 km/s for Lg. Windows were slightly adjusted by hand in order to best capture each phase. We then formed log averaged raw spectral amplitudes in the 2–4 and 6–8 Hz bands and examined some possible discriminant measures as a function of distance. Many studies have identified high-frequency P/S ratios as possible discriminants. In the top of Figure 5, we see that at 2–4 Hz the populations are quite intermixed but at 6–8 Hz we see some reasonable separation, although some of the mine blast signals are weak and fall below our signal to noise threshold of 2. At the bottom of the plot we look at low- to high-frequency spectral ratios and see some trend in the earthquake with distance. Looking at events at the same distance range, we see some separation in populations, but we have not yet corrected for source size effects, which may enhance the separation. Mine blasts can be different from single fired explosions, such as being relatively richer in S-waves leading to different discrimination behavior than nuclear explosions (see for example Walter et al. and Bonner et al. this Proceedings). In future work we will expand our dataset and analysis over the region to look at discrimination behavior with distance and source type.

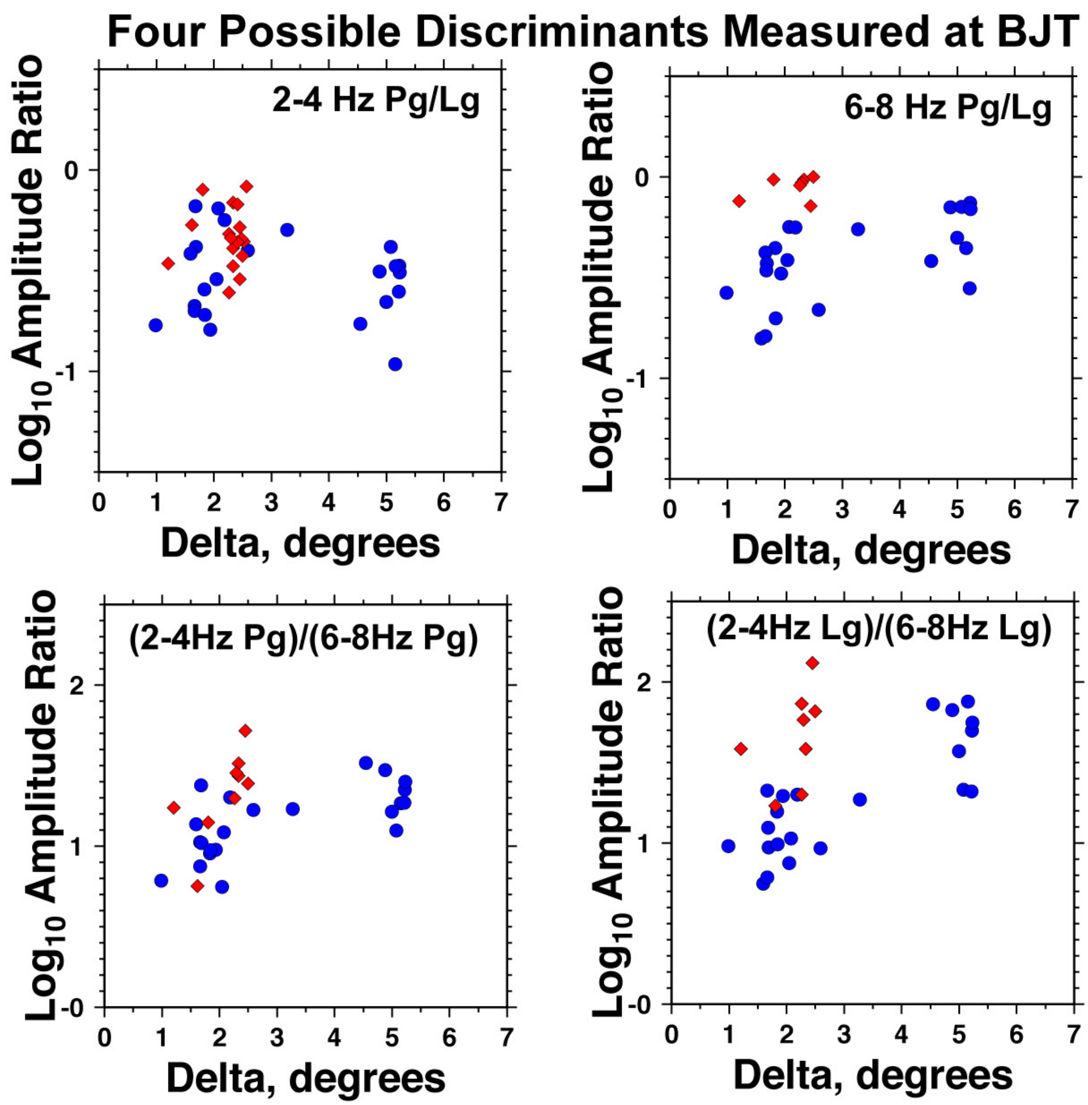

Figure 5. This plot shows four possible local-to-regional body wave amplitude ratio measures that have previously shown some ability to discriminate earthquakes from explosions (e.g., Walter et al. 1995). Earthquakes are shown as blue circles and presumed mine blasts as red diamonds. The two measures on the right hand side show some separation between the means of the populations, the log amplitude ratios are plotted versus distance, and no attenuation or source corrections have been applied.

CONCLUSIONS AND RECOMMENDATIONS

The current project is in the early stages. We have collected ground-truth data for seismic events of different sources including mine blasts, tremors, collapses, and natural earthquakes in east Eurasia. Digital waveform data from regional seismic networks in the region have been collected and archived. This data set will serve as a unique resource for the study of source and propagation characteristics of explosives and other seismic sources. In the next phase of the project, we shall conduct spectral analysis, discrimination studies and waveform modeling on the waveform data and investigate the S-wave excitation and propagation characteristics of different seismic sources.

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