



LAWRENCE  
LIVERMORE  
NATIONAL  
LABORATORY

# Source and Propagation Characteristics of Explosive and Other Seismic Sources

X. Ni, W. Chan, R. Wagner, W. R. Walter, E. M.  
Matzel

July 18, 2005

27th Annual Seismic Research Review  
Palm Springs, CA, United States  
September 20, 2005 through September 22, 2005

## **Disclaimer**

---

This document was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor the University of California nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or the University of California, and shall not be used for advertising or product endorsement purposes.

# **SOURCE AND PROPAGATION CHARACTERISTICS OF EXPLOSIVE AND OTHER SEISMIC SOURCES**

Xiaoxi Ni, Winston Chan and Robert Wagner

Multimax, Inc.

William Walter and Eric Matzel

Lawrence Livermore National Laboratory

Sponsored by National Nuclear Security Administration  
Office of Nonproliferation Research and Engineering  
Office of Defense Nuclear Nonproliferation

Contract No. DE-AC52-04NA25538

## **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 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 utilize 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, 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 objectives of this study are 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 utilize 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 (e.g. 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 NTS 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, provides 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 an 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 discrimination 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 (Fig.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.

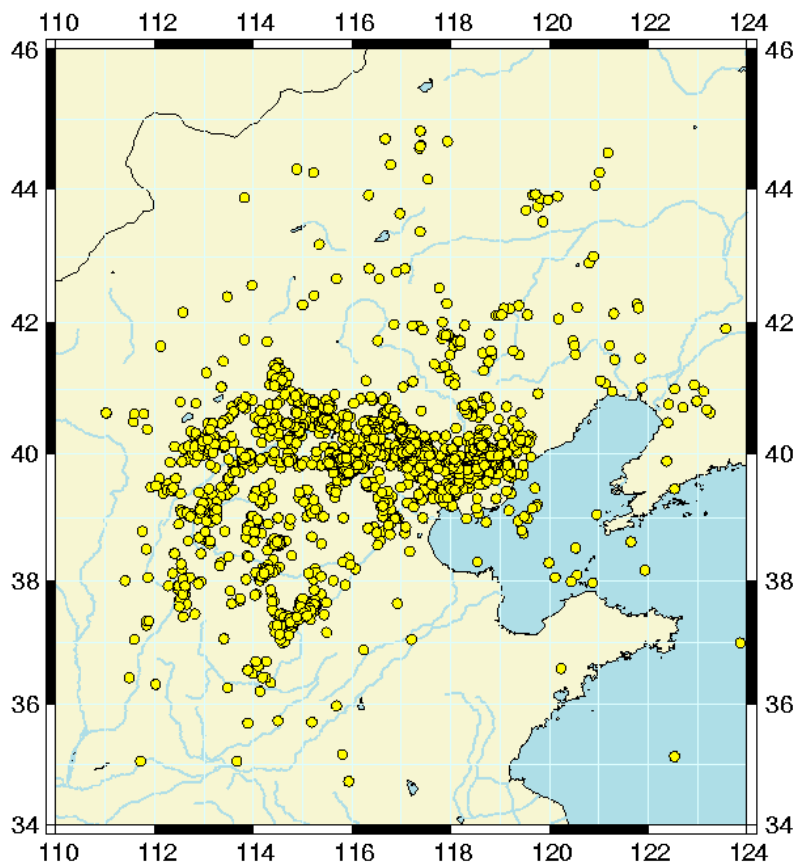


Fig.1 Over 3,500 seismic events recorded in east Eurasia from 2001 to 2003.

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 120s to 20Hz, broad-band seismographs from 20s to 20Hz, and short-period seismographs in boreholes from 1-20Hz (Fig.2). The instruments have GPS timing, a 24-bit recording module and a dynamic range greater than 130dB.

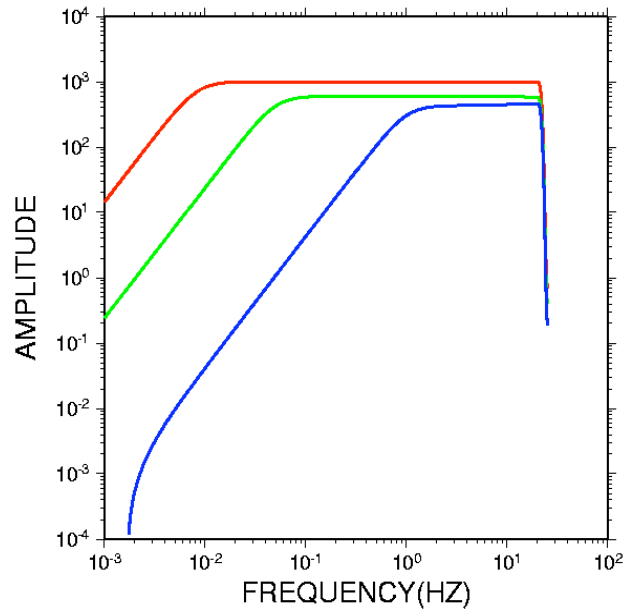


Fig.2 Instrument responses of the very-broad-band (red), broad-band (green) and short-period (blue) seismographs in the regional seismic networks in east Eurasia.

The waveform data are archived in SEED format. Fig.3 shows the vertical components of a possible mine blast occurred on 6/15/2002. Fig.4 represents the vertical components for a magnitude 4.7 earthquake on 5/18/2002 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 next phase.

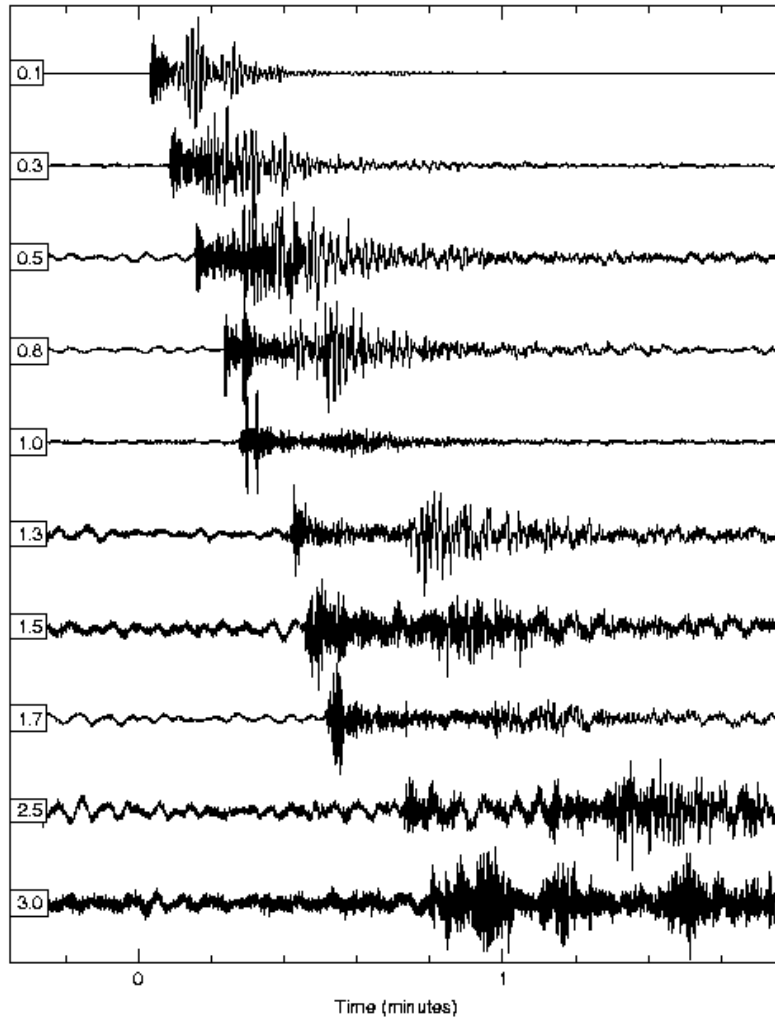


Fig.3 Vertical components of a possible mining blast recorded by regional seismic networks in east Eurasia on 6/15/2002. The numbers at the beginning of each trace indicate epicentral distance in kilometers.

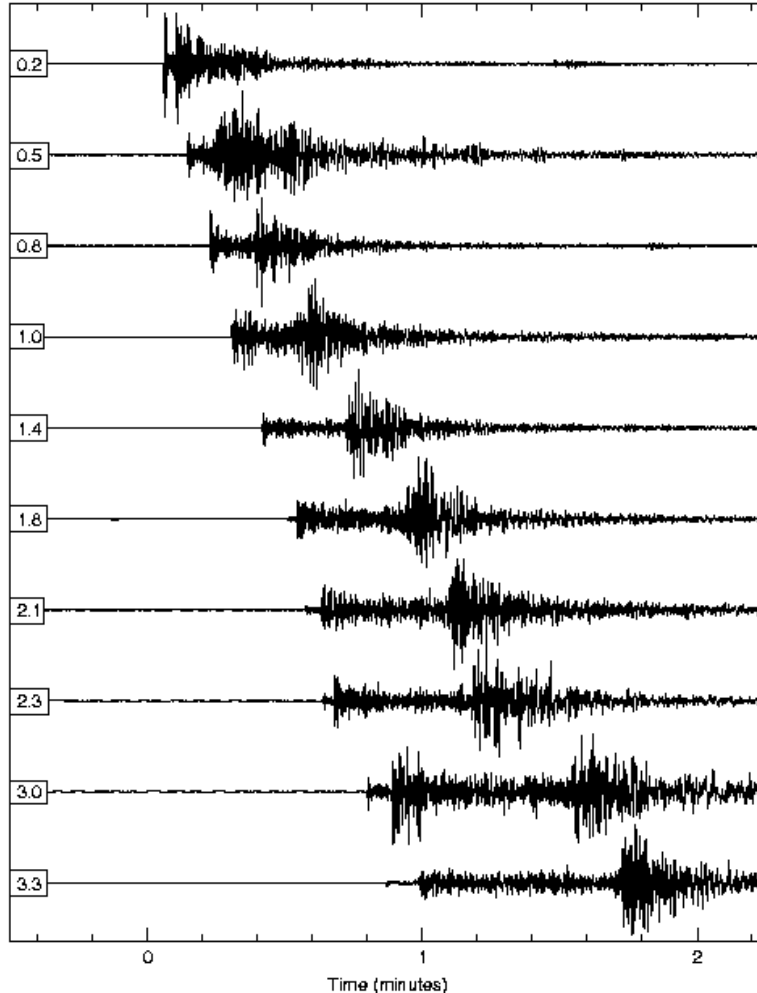


Fig.4 As a comparison with the possible mining blast in Fig. 3, this panel shows the vertical components of a magnitude 4.7 earthquake recorded by the same networks on 5/18/2002. The numbers at the beginning of each trace indicate epicentral distance in kilometers.

### **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 magnitude greater than 4.0 from the USGS PDE (United States Geological Survey Preliminary Determination of Epicenters) 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 blasts 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 volume). In future work we will expand our dataset and analysis over the region to look at discrimination behavior with distance and source type.



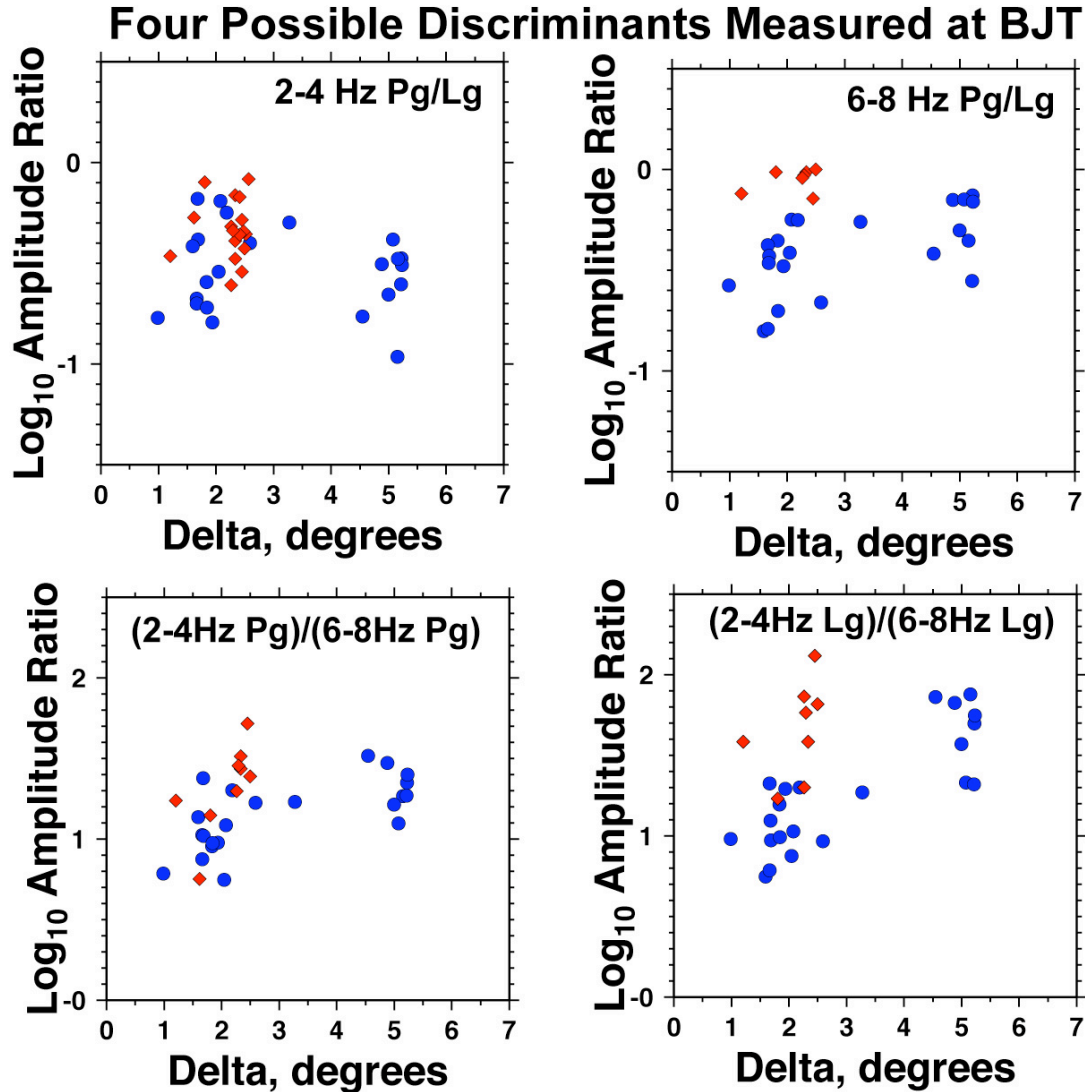


Fig.5 This plot shows four possible local to regional body wave amplitude ratio measures that have previously shown some ability to discriminate earthquakes from explosions (e.g. Walter et al. 1995). Earthquakes are shown as blue circles and presumed mine blasts as red diamonds. The two measures on the 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 at 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 study of source and propagation characteristics of explosives and other seismic sources. 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 in the next phases of the project.

### ACKNOWLEDGEMENT

Some of this work was performed under the auspices of the U.S. Department of Energy by the University of California, Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48.

## **REFERENCES**

- Baumgardt, D. R., and G. B. Young (1990), Regional seismic wave form discriminants and case-based event identification using regional arrays, *Bull. Seism. Soc. Am.*, **80**, 1874-1892.
- Bonner, J., I. Orrey, and A. Rosca (2002). Modeling Short-period Surface Waves from Small Explosions at the Shagan Test Site, *Proceedings of the 24<sup>th</sup> Seismic Research Review—Nuclear Explosion Monitoring: Innovation and Iteration*, 488-497.
- Bonner, J., B. Stump, W. Walter, D. Pearson, C. Hayward, A. Velasco, D. Baker, C. Edwards, J. Lewkowicz, S. Harder, T. Wallace, S. Russell, M. Leidig, and S. Myers (2003). Planning source phenomenology experiments in Arizona, in Proceedings of the 25th Seismic Research Review – Nuclear Explosion Monitoring: Building the Knowledge Base, *National Nuclear Security Administration Report ,LA-UR-03-6029*, 363-372.
- Bowers, D. and W. R. Walter, Discriminating between large mine collapses and explosions using teleseismic P-waves, *Pure Appl. Geophys.*, 159, 803-830, 2002.
- Chan, W. and X. Ni (1999). Collection and Analysis of Seismic and Ground-truth Information in Northeastern China, *Proceedings of the 21st Seismic Research Symposium: Technologies for Monitoring The Comprehensive Nuclear -Test-Ban Treaty*, 27-39.
- Chan, W. and X. Ni (2000). Tomographic Inversion of 3-D Crustal Structure and Relocation of Earthquakes in Northeast China, *EOS, TRANSACTIONS, AMERICAN GEOPHYSICAL UNION*, **81**, No. 19, Suppl., p. 323, May. 9.
- Chan, W., W. Jiao, R. Wagner, and I. Gupta (2001). Regional Seismic Database for Southwest China, *Proceedings of the 23rd Seismic Research Symposium: Worldwide Monitoring of Nuclear Explosions*, 21-29.
- Day, S. and K. McLaughlin, (1991). Seismic source representations for spall, *Bull. Seism. Soc. Am.*, **81**, 191-201.
- Denny, M.D., and S.P. Stull, (1994). Proceedings of the Symposium on The Non-Proliferation Experiment (NPE): Results and Implications for Test Ban Treaties, Rockville Maryland; Lawrence Livermore National Laboratory.
- Dysart, P. S. and J. J. Pulli (1990), Regional seismic event classification at the NORESS array: seismological measurements and the use of trained neural networks, *Bull. Seism. Soc. Am.*, **80**, 1910-1933.
- Fisk, M. D., H. L. Gray, and G. D. McCartor (1996). Regional event discrimination without transporting thresholds, *Bull. Seism. Soc. Am.*, **86**, 1545-1558.
- Guo, B., Q. Liu, J. Chen and S. Li (2002). Test of Epicenter Determination of Microearthquakes Recorded by the Digital Seismic Network in Capital Circle, *Seismology and Geology*, Vol.24, No.3, 453-460.
- Gupta, I. N., W. W. Chan and R. A. Wagner (1992). A comparison of regional phases from underground nuclear explosions at East Kazakh and Nevada test sites, *Bull. Seism. Soc. Am.*, **82**, 352-382.
- Hartse, H., S. R. Taylor, W. S. Phillips, and G. E. Randall (1997). A preliminary study of regional seismic discrimination in Central Asia with an emphasis on Western China, *Bull. Seism. Soc. Am.*, **87**, 551-568.
- Hedlin, M. A.H. (1998). Identification of Mining Blasts at all Regional Distances Using Low-Frequency Seismic Signals, *Proceedings of 20<sup>th</sup> Annual Seismic Research Symposium on Monitoring A Comprehensive Test Ban Treaty (CTBT)*, 570-579.
- Johnson, L.R., and C.G. Sammis, (2001). Effects of rock damage on seismic waves generated by explosions, *Pageoph*, **158**, 1869-1908.
- Kim, W.-Y., D. W. Simpson, and P. G. Richards (1993), Discrimination of earthquakes and explosions in eastern United States using regional high-frequency data, *Geophys. Res. Lett.*, **20**, 1507-1510.

- Liu X., P. Sheng, L. Zhang and Y. Li (2003). Using Method of Energy Linearity in Wavelet Transform to Distinguish Explosion or Collapse from Nature Earthquake, *Northwestern Seismological Journal*, Vol.25, No.3, 204-209.
- Myers, S. C., W. R. Walter, K. Mayeda and L. Glenn (1999). Observations in support of Rg scattering as a source for explosion S waves: regional and local recordings of the Kazakhstan depth of burial experiment, *Bull. Seism. Soc. Am.* 89, 544-549.
- Pechmann, J. C., W. R. Walter, S. J. Nava, and W. J. Arabasz, The February 3, 1995 M<sub>L</sub> 5.1 seismic event in the trona mining district of southwestern Wyoming, *Seism. Res. Lett.*, 66, 25-34, 1995.
- Rodgers, A. J. and W. R. Walter (2002). Seismic Discrimination of the May 11, 1998 Indian Nuclear Test with Short-Period Regional Data From Station NIL (Nilore, Pakistan), *Pure. App. Geophys.* 159, 679-700.
- Stump, B., C. Hayward and R. Zhou (2002). A Comparative Study of Natural and Man-induced Seismicity in the Yanqing-Huailai Basin and the Haicheng Area, *Proceedings of the 24<sup>th</sup> Seismic Research Review—Nuclear Explosion Monitoring: Innovation and Iteration*, 192-199.
- Taylor, S. R., N. W. Sherman and M. D. Denny (1988). Spectral discrimination between NTS explosions and western United States earthquakes at regional distances, *Bull. Seism. Soc. Am.*, 78, 1563-1579.
- Taylor, S. R. and M. D. Denny (1991). An analysis of spectral differences between Nevada Site and Shagan River nuclear explosions, *J. Geophys. Res.* 96, 6237-6245.
- Taylor, S. (1996). Analysis of high-frequency Pg/Lg ratios from NTS explosions and Western U.S. earthquakes, *Bull. Seism. Soc. Am.*, 86, 1042-1053.
- Vogfjord, K. (1997). Effects of explosion depth and earth structure on the excitation of Lg waves: S\* revisited, *Bull. Seism. Soc. Am.*, 87, 1100-.
- Wallace, T. C. (1991). Body wave observations of tectonic release, in *Explosion Source Phenomenology* edited by Taylor, S. R., H. J. Patton, and P. G. Richards, American Geophysical Union Geophysical Monograph 65, 161-170.
- Walter, W. R., K. M. Mayeda and H. J. Patton, (1995). Phase and spectral ratio discrimination between NTS earthquakes and explosions, part I: empirical observations, *Bull. Seism. Soc. Am.* 85, 1050-1067.
- Walter, W. R., D. B. Harris, and S. C. Myers, Seismic discrimination between earthquakes and explosions in the Middle East and North Africa, in *Proceedings of the 19th Seismic Research Symposium on Monitoring a Comprehensive Test Ban Treaty*, *Defense Special Weapons Agency Report*, 459-468, 1997.
- Xia, A. and X. Liu (2002). Recognition of Artificial Explosion and Earthquake Using the Records at the Urumqi Digital Telemetry Seismic Station, *Inland Earthquake*, Vol.16, No.4, 337-345.
- Yamamoto, J., L. Quintanar, C.J. Rebolgar and Z. Jimenez (2002). Source Characteristics and Propagation Effects of the Puebla, Mexico, Earthquake of 15 June 1999, *Bull. Seism. Soc. Am.*, Vol.92, No.6, 2126-2138.
- Yang, X. (1998). Mineseis - A Matlab GUI Program to Calculate Synthetic Seismograms from a Linear, Multi-shot Blast Source Model, *Proceedings of 20<sup>th</sup> Annual Seismic Research Symposium on Monitoring A Comprehensive Test Ban Treaty (CTBT)*, 755-764.
- Zhang, S.Q., J. P. Wu, and L. B. Xia, (1997). On non-natural earthquake sources, in *Advances of China Seismological Research*, (Editor: Y.T. Chen) Beijing, China.
- Zhuang, C. (1999). Technical Structures of the Capital Region Digital Telemetric Seismic Network, *Seismological and Geomagnetic Observation and Research*, Vol.20, No.5, 23-27.