# NUCLEAR-EXPLOSION PROFILES FOR SEISMIC CALIBRATION OF NORTHERN EURASIA

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Sponsored by Air Force Research Laboratory

Contract No. DTRA01-01-C-0081

**ABSTRACT**

In a four-year project sponsored by the Air Force Research Laboratory (AFRL) (75% of funding) and the National Science Foundation (NSF) (25%), the University of Wyoming and Center GEON (Moscow, Russia) are collaborating on restoration, digitizing, and delivery to Incorporated Research Institutes in Seismology (IRIS) and AFRL several long-range Deep Seismic Sounding (DSS) profiles. These datasets include nine major Soviet DSS projects using 22 Peaceful Nuclear Explosions (PNEs), and several hundred of chemical explosions. Data acquisition was performed by Center GEON (the Special Geophysical Expedition at the time) using ~400 specially designed three-component instruments recording on analogue magnetic tapes. These records are being digitized at GEON, verified, edited, and transformed into standard formats at the University of Wyoming, and delivered to seismological data repositories on compact disks (CDs).

PNE profiles recorded between the early 1970's and late 1980's represent sources of seismological and calibration information unparalleled anywhere in the world. Two to four reversed PNEs and several dozens of chemical explosions were recorded at 10-20-km spacing in each 2,000-3,800-km long profiles that formed a regular grid covering most of the former Union of Soviet Socialist Republic (USSR). Long listening times (up to ~600 sec after the first arrivals) allowed recording of the secondary phases (*S*, *Lg, Pg, Rg*) that are critical for nuclear test monitoring. The energies of the PNEs (7-22 kton, resulting in $m_b$ >5) were sufficient for reliable recordings beyond 3,000-4,000 km. Interpretations of the data from these projects inspired most of the recent high-resolution models of the uppermost mantle, and are still being actively discussed at present.

To date, digital seismic records from projects QUARTZ, CRATON, RIFT, KIMBERLITE, RUBY, and AGATE were delivered to IRIS and AFRL. Profiles BATHOLITH, BAZALT, and METEORITE are currently being processed and will be delivered next year. When this work is completed, most of recoverable data from the PNE projects will be preserved and made available to the nuclear test monitoring, as well as the broader seismological communities.

## OBJECTIVES

From the 1970's to the late 80's, Russian scientists acquired a network of dense, linear, long-range, three-component Deep Seismic Sounding (DSS) profiles using conventional and Peaceful Nuclear Explosions (PNEs) over a large territory of Northern Eurasia. These historic datasets, and in particular, their unique PNE components, provide unique opportunities to calibrate existing seismic nuclear discrimination techniques by studying regional wave propagation through complex lithospheric structures.

The objective of this research is to complete digitization, verify, edit and make broadly available through IRIS the key part of the collection of DSS PNE datasets currently stored at Center GEON. The data from nine major projects including 22 PNEs will be processed and transferred to IRIS over the four years of this research (Figure 1). As a result of this effort, we will deliver to the seismic monitoring, and also to the broad seismological community, a set of unparalleled recordings of a large number of nuclear explosions recorded across a variety of propagation paths to the distances of ~3000 km in Northern Eurasia.

## RESEARCH ACCOMPLISHED

DSS PNE data have been widely recognized as an unparalleled source of seismic information about the detailed structure of the upper mantle down to 400- to 800-km depth and even to the Earth's core that is practically impossible to obtain by other means. The core PNE data sets of the DSS program cover an intermediate distance range between 0 – 3200 km bridging the gap between conventional controlled source, earthquake, and nuclear–

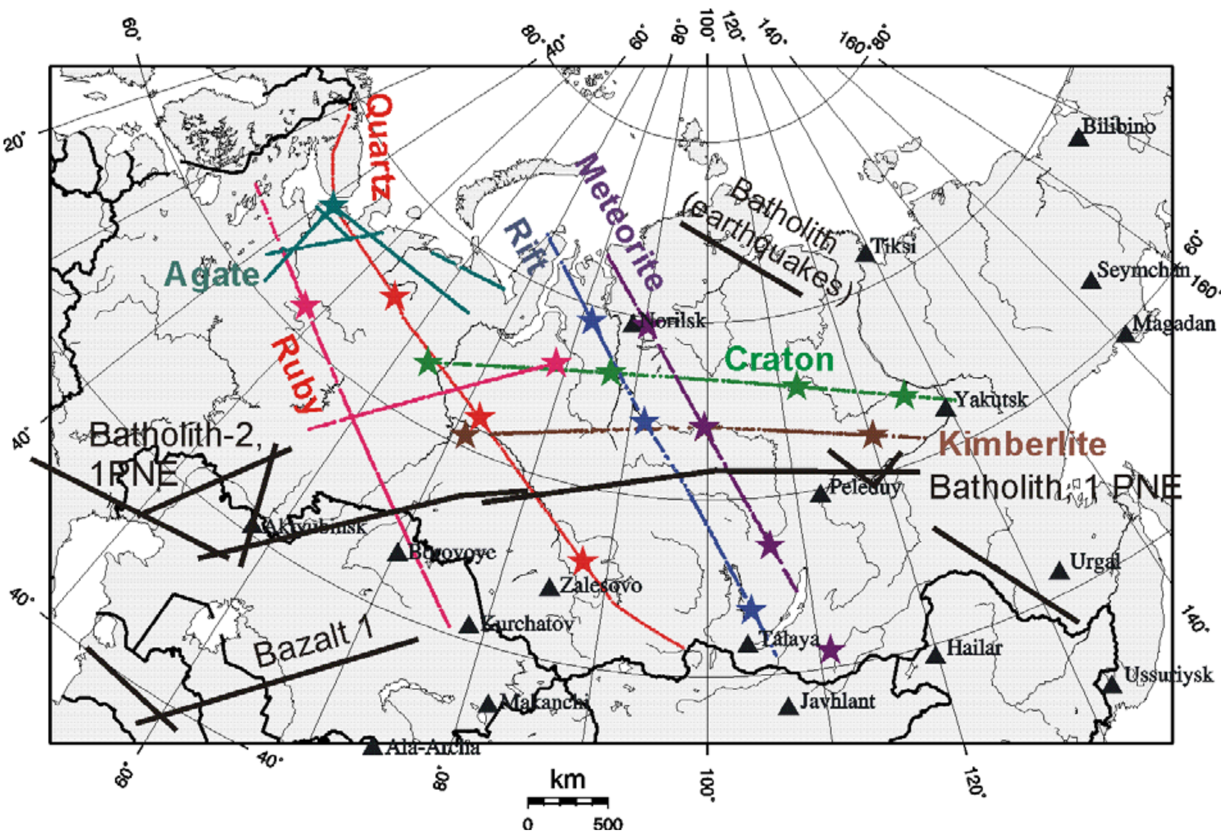


**Figure 1 Nine DSS PNE projects of this project. Colored lines show the profiles that were delivered to IRIS and AFRL. Large stars are the PNEs, small triangles are recording sites. Black lines indicate the approximate locations of the profiles that will be delivered in 2004-2005. Note the extent of systematic, continuous profiling, with PNEs detonated at the nodes of a 2-D recording grid. Note that the profiles cover a vast aseismic area that would be difficult to calibrate by other means. IMS stations are also shown (black triangles).**

explosion-monitoring seismology (Figure 1). The dense, linear systems of PNEs and chemical explosions allow determination of unusually detailed models of the crust and uppermost mantle over 4000-km long geotraverses. These datasets provide virtually the only dense three-component recordings of regional phases in aseismic regions of Northern Eurasia.

Analogue data are stored on magnetic tapes and digitized at Center GEON, Moscow (Figures 2 and 3), and pre-processed and edited at the University of Wyoming. PNE yields were 7 – 23 kton, providing reliable seismic recording throughout the full recording ranges (Figure 1). Continuous and often reversed PNE recordings allow observations of seismic phases diving to depths of ~800 km (e.g., Egorkin et al, 1987; Ryaboy, 1989; Kozlovsky, 1990; Morozova et al., 1999). On a typical PNE profile, 3 – 4 nuclear explosions were recorded at up to 400 three-component seismograph stations with a nominal spacing of 10 to 15 km. About 50 – 80 chemical explosions (typically, each 3000 – 5000 kg) per profile were also recorded to enable interpretation of crustal and uppermost mantle structures. The locations, depths, yields, and times of the PNEs, and characterizations of the source conditions were recently reported by Sultanov et al. (1999).

DSS profiles cross a variety of contrasting tectonic structures in Northern Eurasia and their analysis has resulted in detailed images of the crust and uppermost mantle (Yegorkin, 1992). Some of the recent interpretations were performed by Egorkin and Mikhaltsev (1990), Mechie et al. (1993, 1997), Cipar et al. (1993), Priestley et al., (1994), Ryberg et. al. (1995, 1996), Schueller et al., (1997), Lorenz et al. (1997), Morozov et al. (1998a), and Morozova et al. (1999). The interpretations of the profile QUARTZ (**Figure** ) by the University of Wyoming utilized the full spectrum of seismic data, including refractions and reflections from all 51 explosions of the dataset, lithospheric multiples, crustal-guided phases, seismic attenuation (Morozov et al., 1998b), coda amplitude decay (Morozov and

**Figure 2. Analogue magnetic tapes from DSS project in GEON's basement in Moscow.**

**Figure 3. Digitization system for magnetic tapes from portable seismograph "Taiga."**

Smithson, 2000), receiver functions (Morozov et al, in press), and empirical travel-time regionalization (Morozov et al., in review). Using travel-time, amplitude, and attenuation data, this study resulted in unusually well constrained images of crustal and mantle heterogeneity (Schueller et al., 1997; Morozov et al. 1998a, 1998b; Morozova et al., 1999).

Without doubt, PNE datasets still remain a source of the most detailed seismic information about the upper mantle (down to ~700 km) that is not likely to be surpassed even by the USArray and its satellite projects in Canada and Europe. As an example, PNE data from profiles QUARTZ and RUBY (Figure 4) served as a basis for a new class of stochastic models of the uppermost mantle (e.g., Ryberg et al., 1995; Enderle et al., 1997), which, however, also resulted in a significant controversy (Morozov et al., 1998a; Morozov, 2001) which is being actively debated at present. The datasets contain spectacular and unusually continuous, 3-component recordings of regional phases (Figure 4), and still hold great potential for nuclear test monitoring research (for more detail, see our reports to previous SRR symposia).

According to the project schedule to date, we have delivered to IRIS digitized seismic data from six profiles: QUARTZ, CRATON, RIFT, KIMBERLITE, RUBY, and AGATE (Figure 1). GEON has also digitized and transferred to the University of Wyoming records from projects BATHOLITH-1, 2, and BAZALT-1 (Table 1). The schedule for further planned data deliveries is given in Table 1.

**Table 1. Revised planned and actual data delivery schedule as of September 2003.**

| # | Data set | Raw data delivery from GEON to UWyo (months) | | Edited and reduced data delivered to IRIS DMS (months) | |
|---|---|---|---|---|---|
| | | *planned* | *actual* | *planned* | *actual* |
| 1 | QUARTZ | - | 1995 | 12/2001 | 12/2002 |
| 2 | CRATON | 02/2002 | 10/2002 | 08/2002 | 11/2002 |
| 3 | KIMBERLITE | 05/2002 | 11/2002 | 11/2002 | 11/2002,10/2003(chem) |
| 4 | RIFT | 08/2002 | 11/2002 | 05/2003 | 10/2003 |
| 5 | RUBY | 02/2003 | 02/2003 | 10/2003 | 02/2004 |
| 6 | AGATE (5 profiles) | 08/2003 | 07/2003 | 05/2004 | 06/2004 |
| 7 | BATHOLITH-1 | 10/2003 | 12/2003 | 11/2004 | |
| 8 | BATHOLITH-2 | 03/2004 | 12/2003 | 11/2004 | |
| 9 | BAZALT-1 | 06/2004 | 01/2004 | 06/2005 | |
| 10 | BAZALT-2 | 10/2004 | | 06/2005 | |
| 11 | METEORITE | 03/2005* | | 11/2005 | |

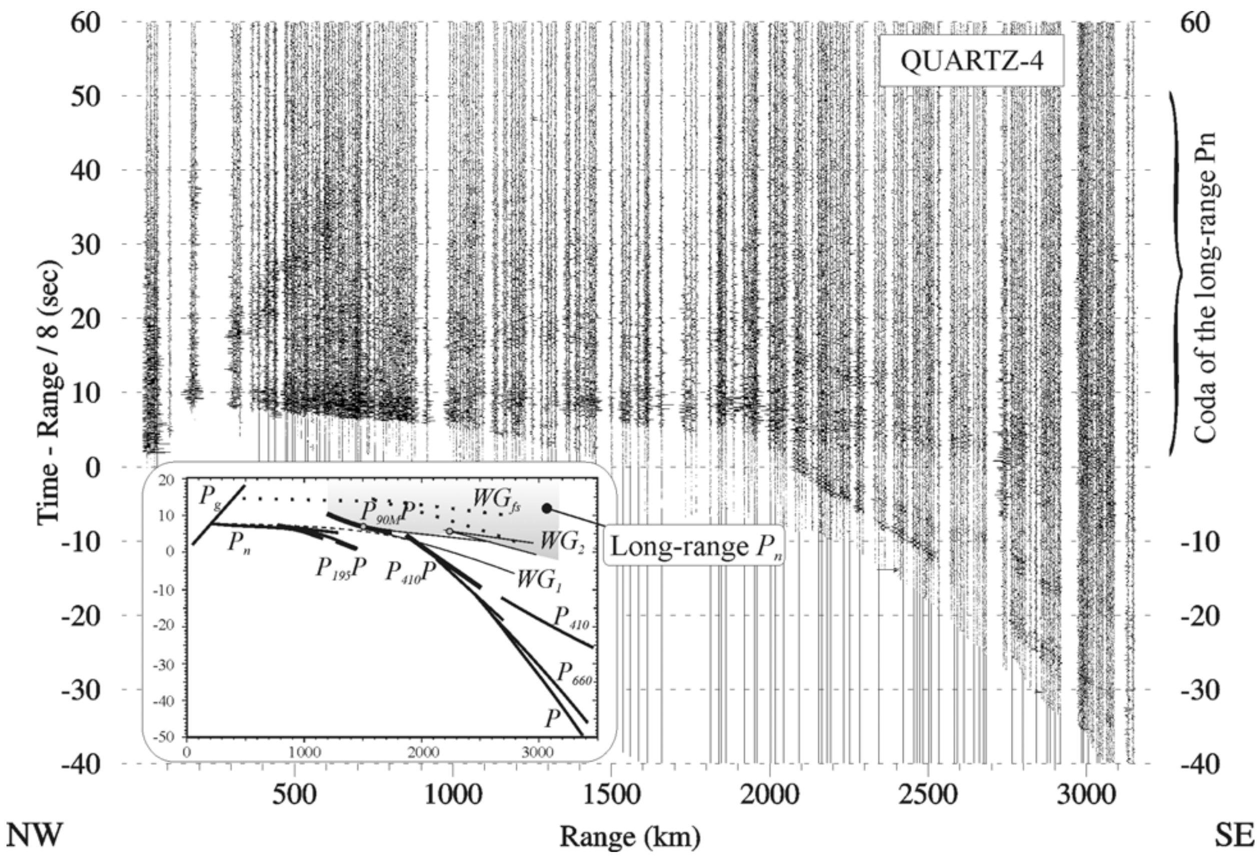


**Figure 4. Vertical component record from PNE QUARTZ-4 (at the southeastern end of profile QUARTZ; Figure 1). Inset shows a sketch of seismic phases identified in the wavefield. Note the free-surface and Moho *P*-wave multiples (PP, or whispering-gallery modes) labeled $WG_{fs}$ and WG, respectively. These phases were interpreted as caused by strong scattering within the uppermost mantle (Ryberg et al., 1995); however, in another interpretation, they may be due to a strong velocity gradient and mantle layering beneath the East European platform and the southern part of the West Siberian Basin (Morozov, 2001). Both of these inferences might have significant implications for nuclear test monitoring along the critical NW-SE paths across the East European Platform.**

## CONCLUSIONS AND RECOMMENDATIONS

Preliminary examination of the newly obtained Russian PNE records from the Siberian DSS PNE profiles demonstrates that the data provide valuable information for the analysis of the propagation of $L_g$ and other regional phases for their use in nuclear test monitoring and calibration studies. When made broadly accessible for nuclear test monitoring research, the datasets will boost research on seismic calibration of the region and on transportable seismic discriminants in Northern Eurasia. Availability of the unique PNE recordings should foster current research on several DoD-sponsored projects and facilitate extension of such research in the future. In addition, from a broader scientific perspective, the digitized DSS recordings and models of the upper mantle could also provide ideal reference and calibration data sets for the detailed structure of the upper mantle, and particularly for USArray.

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