NUCLEAR-EXPLOSION PROFILES FOR SEISMIC CALIBRATION OF NORTHERN EURASIA

Igor B. Morozov[1,2], Elena A. Morozova[2], Scott B. Smithson[2], and Igor N. Kadurin[3]

University of Saskatchewan[1], University of Wyoming[2], and Center GEON[3]

Sponsored by Air Force Research Laboratory

Contract No. DTRA01-01-C-0081

ABSTRACT

In a four-year project, the University of Wyoming, in cooperation with the Center for Geophysical and Geoecological Studies (GEON) in Moscow, Russia, is preprocessing and organizing digital data from several unique long-range Deep Seismic Sounding (DSS) profiles using Peaceful Nuclear Explosions (PNEs).The data are being digitized from the original field tapes by GEON, quality-checked, edited, reformatted, and transferred to the Incorporated Research Institutions for Seismology (IRIS). As a result of this effort, seismic data from nine major DSS projects using 22 PNEs and several hundred chemical explosions are becoming broadly available for seismological and nuclear test monitoring research. To date, complete sets of records from the projects BAZALT, BATHOLITH, CRATON, KIMBERLITE, RIFT, RYBY, and QUARTZ have been delivered to IRIS. Project METEORITE is planned for delivery later this year.

DSS PNE profiles were recorded by GEON (the Special Geophysical Expedition at the time) from the early 1970s through late 1980s using 200-400 three-component analog instruments deployed in a grid of lines traversing most of the territory of the Former USSR. Each profile recorded 2-4 PNEs and several dozen chemical explosions at the same receiver locations. Long listening times of up to ~600 sec after the first arrival allowed recording of the secondary phases (S, Lg, Pg, Rg) critical for nuclear test monitoring. The energies of the PNEs ($m_b \approx 5$) were sufficient for reliable recordings beyond 3000 km, including consistent reflections from the mantle transition zone and several reflections from the core-mantle boundary. Chemical explosions of 5-12 tons yielded reflections from ~100-km depths and were recorded to 300-600-km distance.

DSS PNE data represents an unparalleled source of seismic information about the detailed structure of the upper mantle down to 400-800 km depth. Longer-offset recordings from some PNEs (QUARTZ-4, BATHOLITH-1, CRATON-1) show reflections from the core-mantle boundary. The PNE data sets cover an intermediate distance range (between 0-3200 km) and bridge the gap between controlled-source, earthquake-, and nuclear-explosion monitoring seismology. Dense, linear systems of DSS PNE observations lead to unusually detailed models of the crust and uppermost mantle over 4000-km long geotraverses. For regional seismic calibration, these datasets provide virtually the only dense three-component recordings of regional phases in aseismic regions of Northern Eurasia.

OBJECTIVES

From the mid-1970s and to the time of the break up of the Soviet Union, Russian scientists carried out an unparalleled program for Deep Seismic Sounding (DSS) of the territory of this vast country. In the course of this program they acquired a network of dense, linear, long-range, three-component profiles using large conventional and Peaceful Nuclear Explosions (PNEs). Fortunately for seismic nuclear test monitoring that emerged at about the time the DSS PNE program ended, these profiles systematically covered much of the aseismic parts of Northern Eurasia that would be difficult to calibrate by other means. These historic data provide unique opportunities to study seismic nuclear discrimination techniques and regional wave propagation through complex lithospheric structures.

The objective of this four-year project, which is currently near its end, was to complete digitization, verify, edit and make the key part of the unique collection of DSS PNE datasets broadly available to the monitoring and research communities.

RESEARCH ACCOMPLISHED

The data were being digitized at Center GEON, Moscow, and pre-processed and edited at the University of Wyoming. After nearly four years of this effort, the data processed and archived at IRIS currently include 18 PNEs and 522 chemical explosions recorded in eleven major seismic projects (Figure 1). The project is near completion, and only the METEORITE dataset (including 4 PNEs) remains to be delivered in November 2005. As a result of this effort, the broad seismological and seismic monitoring communities are obtaining a set of digital recordings of a large number of nuclear explosions recorded across a variety of propagation paths to the distances of ~3000 km.

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 depths (e.g., Ryaboy, 1989; Kozlovsky, 1990; Morozova et al., 1999). PNE yields of ~7 – 23 kton provided reliable seismic recording throughout the full recording ranges (Figure 2). Several PNE record sections (BATHOLITH, CRATON-1, and QUARTZ-4) show reflections from the Earth's core. On a typical PNE profile, 3 – 4 nuclear explosions were recorded at up to 400 of three-component seismograph stations with nominal spacing of 10 to 15 km. About 50 – 80 chemical explosions (typically, each 3000 – 5000 kg, with some shots up to 15000 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 media were reported by Sultanov et al. (1999).

PNE data sets of the DSS program cover an intermediate distance range between 0 and 3200 km bridging the gap between the conventional controlled source, earthquake, and nuclear–explosion-monitoring seismology. Dense, linear systems of PNE and chemical explosions profiles cross a variety of contrasting tectonic structures in Northern Eurasia and result in unusually detailed models of the crust and uppermost mantle over 4000-km long geotraverses (Yegorkin, 1992; Pavlenkova, 1996). 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). These datasets also provide virtually the only dense three-component recordings of regional phases in aseismic regions of Northern Eurasia. Some of our recent results related to nuclear test monitoring were presented in Morozov (1998b), Morozov and Smithson (2000, 2002), and Morozov et al. (2005). One of the most spectacular PNE records from PBE QUARTZ-4 that received most attention in the past decade and which led to a number of far-reaching conclusions (some of them highly controversial) about the detailed structure of the upper mantle is shown in Figure 2.

Our current project schedule is shown in the table below. To date, we are on schedule for deliveries to IRIS and AFRL, although the chemical-profile data from project METEORITE were seriously delayed by GEON due to a series of unforeseen circumstances. Regardless of the delay with chemical-explosion data from METEORITE, we anticipate that its PNEs will be delivered to IRIS and AFRL as planned.

Table 1. Updated planned and actual data delivery schedule as of September, 2005.

#	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	-	-	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(chemical)
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 (3 profiles)	10/2003	12/2003	11/2004	12/2004
8	BATHOLITH-2** (4 profiles)	03/2004	12/2003	11/2004	12/2004
9	BAZALT-1** (3 profiles)	06/2004	01/2004	06/2005	07/2005
10	BAZALT-2 **(2 profiles)	10/2004	09/2004	06/2005	07/2005
11	METEORITE	03/2005*		11/2005	

*Only chemical explosion data sets need to be delivered to UWYO. Delivery delayed.
**Only chemical explosions used in these projects.

CONCLUSIONS AND RECOMMENDATIONS

The newly available PNE and chemical-explosion datasets from eleven major Russian seismic projects should boost research on seismic calibration of the region and on transportable seismic discriminants in Northern Asia. Greater availability of the unique PNE recordings would foster current research on several NNSA, AFRL, and DOE-sponsored nuclear test monitoring 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 targeted by US Array.

REFERENCES

Cipar, J., K. F. Priestley, A. V. Egorkin, and N. I. Pavlenkova (1993), The Yamal Peninsula-Lake Baikal deep seismic sounding profile, *Geophys. Res. Lett*. 20: (15), 1631-1634.

Egorkin, A. V. and A. V. Mikhaltsev (1990), The Results of Seismic Investigations along Geotraverses, in *Super-Deep Continental Drilling and Deep Geophysical Sounding*, K. Fuchs, Y. A. Kozlovsky, A. I. Krivtsov and M. D. Zoback (Eds.), Springer, Berlin, 111-119.

Kozlovsky, Y. A. (1990), The USSR Integrated Program of Continental Crust Investigations and Studies of the Earth's Deep Structure under the Globus Project, in *Super-Deep Continental Drilling and Deep Geophysical Sounding*, Fuchs K., Kozlovsky Y. A., Krivtsov A. I. and Zoback M. D. (Eds.), Springer, Berlin, 90-103.

Lorenz, F., F. Wenzel, and J. Mechie (1997), Lateral heterogeneity implications from 2-D nuclear-seismic travel-time inversion, in: Fuchs, K. (Ed.) Upper mantle heterogeneities from active and passive seismology, pp. 237-248, *Kluwer Academic Publ*., Dordrecht.

Mechie, J., A. V. Egorkin, K. Fuchs, T. Ryberg, L. Solodilov, and F. Wenzel (1993), P-wave velocity structure beneath northern Eurasia from long-range recordings along the profile Quartz, *Phys. Earth Planet Inter*. 79: 269-286.

Mechie, J., A. V. Egorkin, L. Solodilov, K. Fuchs, F. Lorenz, and F. Wenzel (1997), Major features of the mantle velocity structure beneath northern Eurasia from long-range seismic recordings of peaceful nuclear explosions, in: Fuchs, K. (Ed.) Upper mantle heterogeneities from active and passive seismology, pp. 33-50, *Kluwer Academic Publ*., Dordrecht.

Morozov, I. B. (2001), Comment on “High-frequency wave propagation in the uppermost mantle” by T. Ryberg and F. Wenzel, *J. Geophys. Res*. 106: 30,715-30,718.

Morozov, I. B., and S. B. Smithson (2000), Coda of long-range arrivals from nuclear explosions, *Bull. Seism. Soc. Am.* 90: 929-939.

Morozov, I. B., and Smithson, S. B. (2002), Imaging crustal structure along refraction profiles using multicomponent recordings of first-arrival coda, *Bull. Seismol. Soc. Am.* 98: (8), 3080-3086.

Morozov, I. B., E. A. Morozova, and S. B. Smithson, (1998a), On the nature of the teleseismic Pn phase observed in the recordings from the ultra-long range profile "Quartz", Russia, *Bull. Seismol. Soc. Am*. 88: (1), 62-73.

Morozov, I. B., E. A. Morozova, S. B. Smithson, and L. N. Solodilov. (1998b), 2-D image of seismic attenuation beneath the Deep Seismic Sounding profile "Quartz", Russia, *Pure and Applied Geoph.* 153: 311-348.

Morozov, I. B., E. A. Morozova, S. B. Smithson, P. G. Richards, V. I. Khalturin, and L. N. Solodilov (2005), 3-D first-arrival regional calibration model of northern Eurasia, *Bull. Seismol. Soc. Am*., 95: (3), 951-964, doi:10.1785/0120030173.

Morozova, E. A., I. B. Morozov, S. B. Smithson, and L. N Solodilov (1999), Heterogeneity of the uppermost mantle beneath the ultra-long range profile "Quartz," Russian Eurasia, *J. Geophys. Res.,* 104 (B9), 20,329-20,348.

Pavlenkova, N. I., (1996), General features of the uppermost mantle stratification from long-range seismic profiles, *Tectonophysics* 264: 261-278.

Priestley, K. F., J. Cipar, A. Egorkin, and N. I. Pavlenkova (1994), Upper-mantle velocity structure beneath the Siberian Platform, *Geophysical Journal International* 118: (2), 369-378.

Ryaboy, V. (1989), Upper mantle structure studies by explosion seismology in the USSR, Delphic Associates, 138 pp.

Ryberg, T., F. Wenzel, J. Mechie, A. Egorkin, K. Fuchs, and L. Solodilov (1996), Two-dimensional velocity structure beneath Northern Eurasia derived from the super long-range seismic profile Quartz, *Bull. Seismol. Soc. Am*. 86: 857-867.

Ryberg, T., K. Fuchs, A. V. Egorkin, and L. Solodilov (1995), Observations of high-frequency teleseismic *Pn* on the long-range Quartz profile across northern Eurasia, *J. Geophys. Res.* 100: 18151-18163.

Schueller, W., I. B. Morozov, and S. B. Smithson (1997), Crustal and uppermost mantle velocity structure of northern Eurasia along the profile Quartz, *Bull. Seismol. Soc. Am.* 87: 414-426.

Sultanov, D. D., J. R. Murphy, and Kh. D. Rubinstein (1999), A seismic source summary for Soviet Peaceful Nuclear Explosions, *Bull. Seism. Soc. Am.*: 89: 640-647.

Yegorkin, A. V. (1992), Crustal structure along seismic geotraverses, International Geology Review, 34 (4), 345-362.

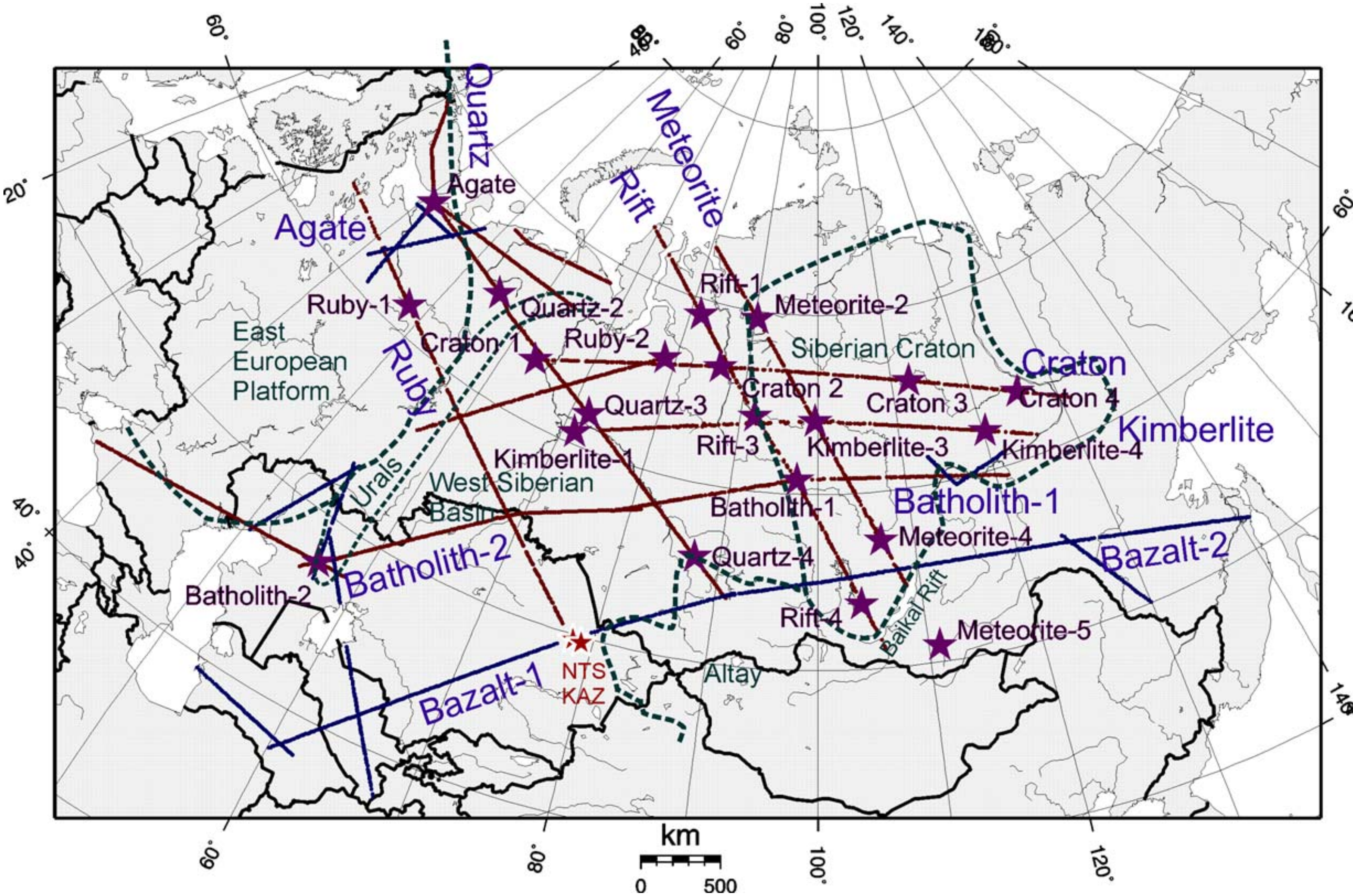

Figure 1 Eleven DSS PNE projects of this project (blue labels). With the exception for project METEORITE, all data were already delivered to IRIS and AFRL. The coordinates and other parameters of the PNEs used in these profiles were reported by Sultanov et al. (1999). Major tectonic units are indicated in green. Note the extent of systematic, continuous profiling, with PNEs (labeled stars) detonated at the nodes of a 2-D recording grid. Small brown circles are PNE recording stations, and blue circles are chemical-explosion recording stations. Project RUBY also recorded two Semipalatinsk nuclear test site explosions (red).

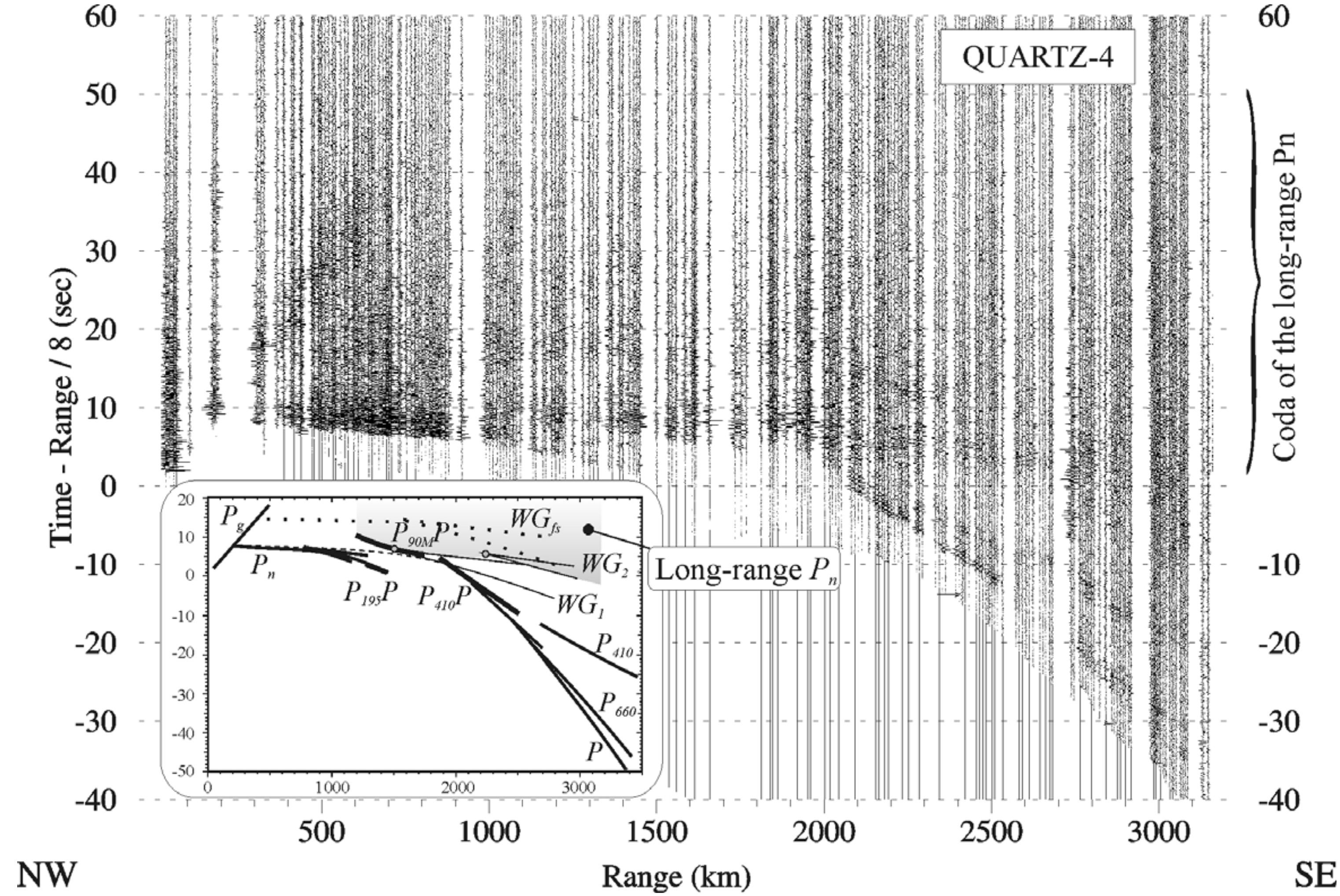

Figure 2. Vertical-component record from PNE QUARTZ-4 (Figure 1). Inset shows a sketch of seismic phases identified in the wavefield. Note the free-surface and Moho *P*-wave multiples (*PP*, or whispering-gallery modes) labeled WG_{fs} and *WG*, respectively. These phases were interpreted as caused by strong scattering within the uppermost mantle (Ryberg et al., 1995); however, in our interpretation, they are more likely to be the *PP* caused by a strong velocity gradient and mantle layering beneath the East European platform and the southern part of the West Siberian Basin (Morozov, 2001). Also, note the ~5-s gap in the first arrival caused by interpreted mantle low-velocity zone characteristic of the East European Platform and SW Western Siberia (Morozova et al., 1999). Both of these observations have significant implications for nuclear test monitoring along NW-SE paths across the East European Platform.