SEISMIC AND GEOPHYSICAL CHARACTERIZATION OF NORTHERN ASIA

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Sponsored by the National Nuclear Security Administration

Award Nos. DE-AC52-09NA29323[1], DE-AC52-06NA25396[2] and DE-AC52-07NA27344[3].
Proposal No. BAA09-19

ABSTRACT

We have begun a major research effort consisting of a combination of seismic field deployments, historical seismic data retrieval, and seismic data analysis to further improve the calibration of northern Asia for nuclear explosion monitoring purposes. This project builds off previous work, and is a cooperative effort between Michigan State University (MSU), Los Alamos National Laboratory (LANL), Lawrence Livermore National Laboratory (LLNL), and several seismic networks in Russia and Japan. The geographic scope of this project covers Russia from the Urals to the Bering Strait and from the Arctic Ocean to the North Korean border. We are expanding our unique data set on earthquakes and nuclear and industrial explosions. Combining historic datasets with data from approximately 50 existing Russian and MSU/Russian and Japanese/Russian digital seismic stations, new deployments, and geologic information, we will substantially increase ground truth data and our understanding of the seismicity, velocity structure, explosion discrimination, and wave propagation characteristics in northern Asia. Our work will further improve location and detection and discrimination capabilities, crustal and upper mantle structure, wave propagation, and natural seismic source characteristics of northern Asia.

Our initial work on this project covers several aspects.

- Updated our seismicity map and seismic database for eastern Russia through 2009. This update has added many thousands of events with associated bulletin information (phase arrival times, amplitude measurements, etc.). We are extending the map to cover the Altai-Sayan network.
- Targeted research on active faulting in the Nera Basin and the Moma Range by combining hypocenter locations, satellite and field analysis of fault scarps, and geomorphological analysis of geologic structures and river drainage.
- Continued our efforts to digitize and analyze historic seismograms from Soviet Peaceful Nuclear Explosions (PNEs) and analyze seismograms from more recent nuclear explosions in Asia.
- Made dispersion measurements for hundreds of paths and have used them to update group velocity maps of the region from 10 to 150 seconds period, which will be used to characterize the complex lithospheric structure of our study area.
- Re-examined mining explosion contamination present in eastern Russian seismic bulletins based on event time of day.
- We have improved the GT locations of the Yakutian PNEs, with most now classified as GT-1 or GT-0. Previously, actual errors for published locations were up to 40km.

OBJECTIVES

The objectives of this project are to characterize the seismicity and geophysical parameters of northern Asia.

RESEARCH ACCOMPLISHED

Expansion of the Eastern Russia Seismicity Map and Database

We continue the development of our seismicity map and database for eastern Russia. Specifically for this project, we have begun to expand project coverage further west to include the Altai-Sayan seismic network (Figure 1). Our seismicity map of eastern Russia has been previously presented on numerous occasions (see Mackey et al., 2007 and Mackey et al., in press). In addition to event locations, our database will also be expanded with phase data from the network.

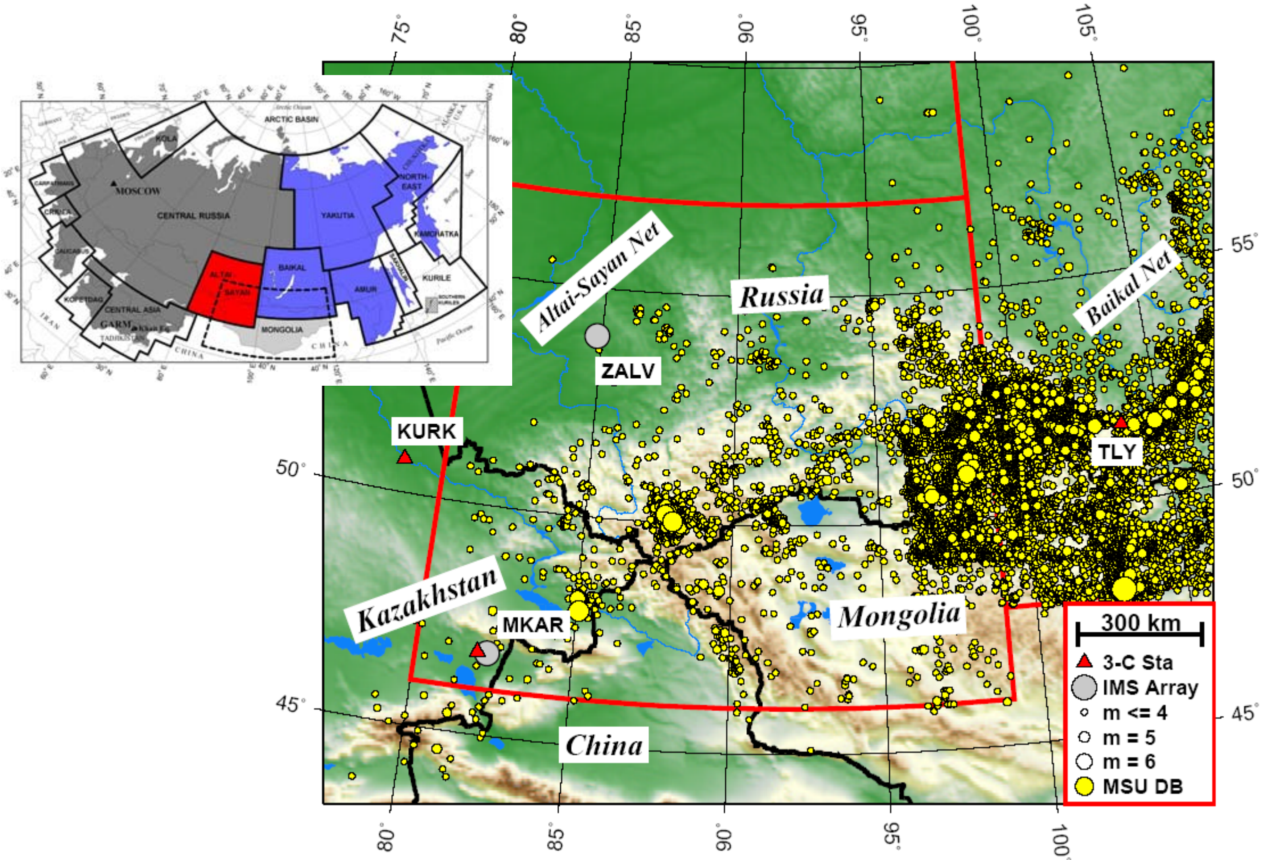

Figure 1. Seismicity of the Altai-Sayan seismic network, covering intermittent years between 1990 and 2010. High event densities east of 96°E are due to overlapping network coverage from the Baikal network. Total, there are about 37,000 events plotted on this map. Inset shows the location of the Altai-Sayan seismic network (red) relative to the existing MSU seismic database (blue).

Surface Wave Studies

For improving the quality of our surface wave studies, we have improved our path coverage of regions north of 60°N in eastern Russia. Figure 2 shows a path map of surface wave dispersion measurements in our study region. Blue paths are the background dispersion paths, while the magenta paths indicate new dispersion measurements made in the past year. Most new data shown here were obtained from IRIS. Additional waveforms recorded at several other broadband stations (not shown) have been acquired, but are not yet integrated into the study.

Figure 3 is a plot of 80 second Rayleigh wave tomography. Rayleigh waves in this period are sensitive to upper mantle structure, particularly the upper mantle shear-wave velocity and lithospheric thickness. Interestingly, we see a couple of key features. First, is the fast velocity signature of the Central Siberian Platform (shown in blue), which has faster mantle velocities and a thicker lithospheric lid. We see slow Rayleigh wave velocities along both the back-arc regions of the Pacific subduction zones and the Lake Baikal Rift. While it appears that the boundaries between these somewhat correspond to the boundaries of the microplates, it is our intention to use significantly more data from the region to define these boundaries in finer detail.

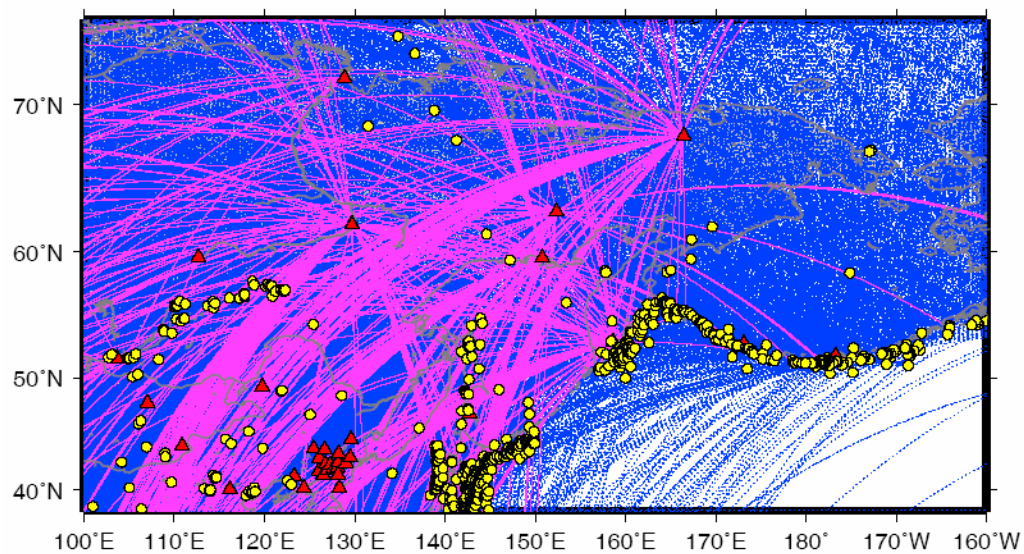

Figure 2. Path coverage in eastern Russia for 80.0 second Rayleigh wave surface wave studies. Pink shows newly acquired paths, while blue indicate earlier measurements. Events and stations used are shown as yellow circles and red triangles, respectively.

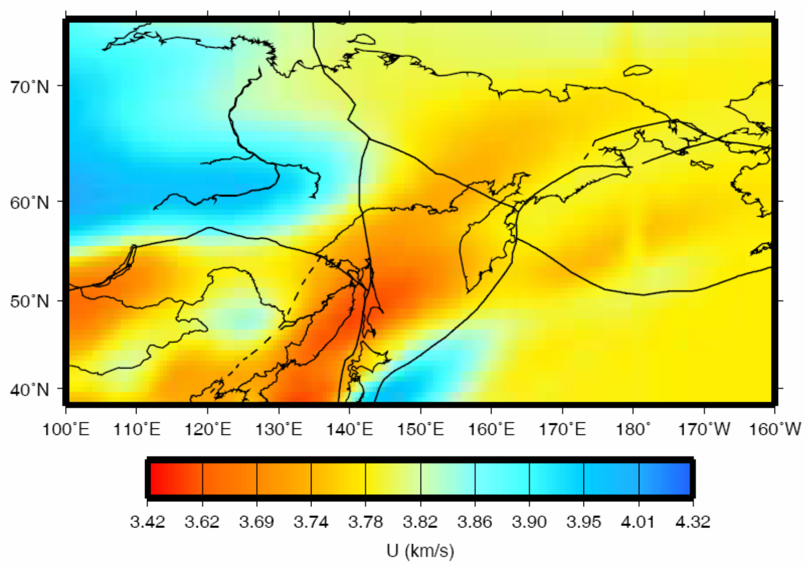

Figure 3. 80.0 second Rayleigh wave tomography of eastern Russia. Main features of note are high velocities associated with the Siberian Platform and lower velocities associated with the Baikal Rift zone and back-arc regions of the pacific subduction zones.

Seismograms of the 2009 DPRK Nuclear Explosion

On 25 May, 2009, North Korea detonated its second nuclear test. This test was recorded moderately well across continental eastern Russia by stations of the Russian regional seismic networks. Figure 4 shows a record section of seismograms primarily from the Magadan and Yakutsk regions. Paths transiting the back-arc regions of the pacific subduction zones to stations in Kamchatka did not record the explosion as clearly (Figure 5). Within Kamchatka, stations either along the central axis of the peninsula or close to the western coast recorded the explosion better than stations along the eastern coast. This suggests that the subduction zone processes interferes with good transmission of the seismic signal from North Korea.

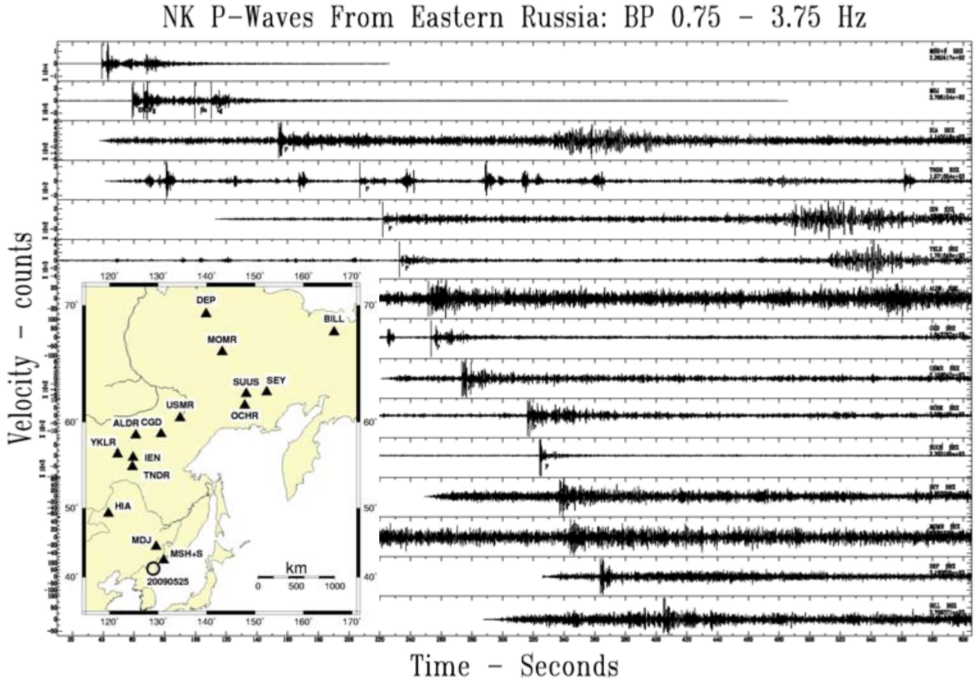

Figure 4. Vertical component seismograms from continental eastern Russia of the 2009 DPRK nuclear test. Traces are bandpass filtered from 0.75-3.75 Hz. Index map on inset.

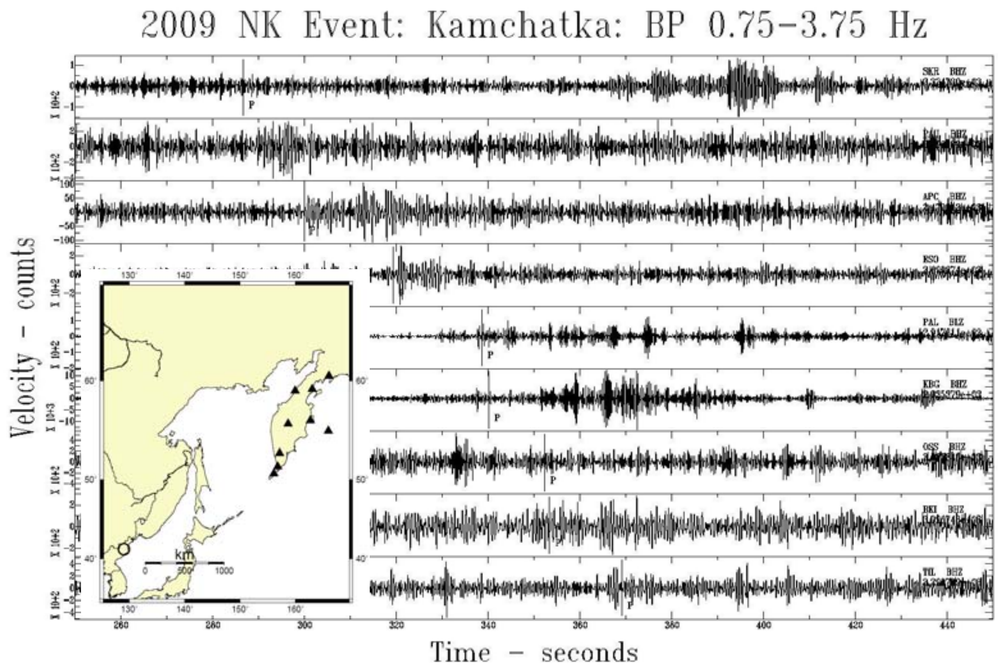

Figure 5. Vertical component seismograms from Kamchatka, Russia of the 2009 DPRK nuclear test. Traces are bandpass filtered from 0.75-3.75 Hz. Index map on inset. Stations either along the central axis of the peninsula (third and fourth traces from the top) or close to the western coast (fifth trace from top) recorded the explosion better than stations along the eastern coast.

Improved Ground-Truth for Yakutian PNEs

The monitoring community has generally accepted the source coordinates for PNEs presented in Sultanov et al. (1999) as representing ground truth, although in reality there remains considerable variability in location quality. Working from recent Russian literature, we present revised coordinates here for PNEs detonated in Yakutia (see Figure 5 inset), with revised coordinates generally at either a GT-0 or GT-1. The Yakutian PNEs can be divided into two categories; those detonated for Deep Seismic Sounding (DSS) geophysical surveys, and those detonated for industrial applications such as oil recovery or dam construction. Locations cited by Sultanov et al. (1999) for PNEs associated with industrial applications are derived from seismically determined parameters and are poor, with errors up to 40km. We summarize each of these below. Deep seismic sounding associated events appear accurate to the GT-1 level or better, and are not discussed in detail other than minor corrections as listed in Table 1. Regarding Yakutian PNEs, Fujita (1995) presented an overview and provided preliminary estimates on their locations based on Russian publications from the mid-1990s. Mackey et al. (2009) discussed, and summarized here, Crystal, Craton-3, and Horizon-3 in detail using a combination of satellite images and newly released Russian papers. Mackey et al., (2005) discussed Neva-1 and the Neva-2 series on the basis of Soviet military topographic maps.

On October 2, 1974, a small (1.7 kt) explosion, “Crystal,” was detonated near the Udachnyi diamond mine to create a foundation for a tailings storage pond dam. The epicenter cited by Sultanov et al. (1999) is taken from the International Seismological Center (ISC) Bulletin with coordinates of 66.1°N and 112.65°E. Fujita (1995) cited the location of the detonation as on the “left bank of the Ulakhan-Bysyttaakh stream, 2.5 km north of the town.” Examination of this site using Google Earth imagery reveals a circular dome (Figure 6). According to Gedeonov et al. (1997), in 1992 the crater was covered with an artificial mound about 300 m in diameter and 7-20 m in height, consistent with the Google Earth image. This site falls approximately 40 km north-northwest from the location given by Sultanov et al. (1999). The center of the dome is located at 66.4573±0.0001°N, 112.3989±0.0001°E. Although this is one of the smallest and most poorly recorded PNEs in this region, it now must be considered the best located.

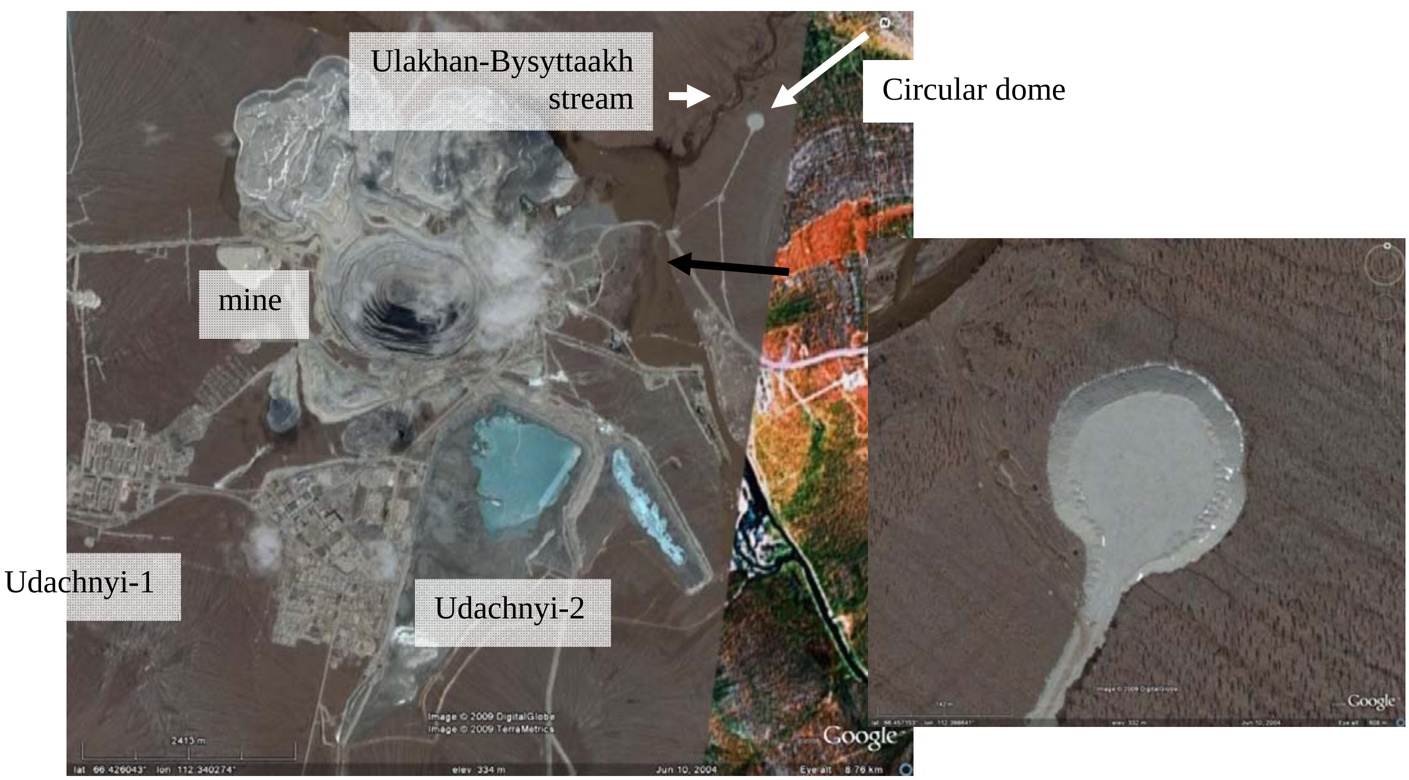

Figure 6. Google Earth image of the Udachnyi Mining complex and encapsulated crater from the Crystal PNE (circular dome). The inset shows a close-up of the site.

The Neva series of PNEs as well as Oka, Sheksna, and Vyatkta were detonated primarily to enhance oil recovery in the Central Botuobuya Oil and Gas field (Figure 7). The locations of these detonations were given in Burtsev (1993) in terms of distance from Tas-Yuryakh settlement. It has been unclear whether the distances were as “the crow flies” or distance along a connecting road. Mackey et al. (2005) used the direct line distance to suggest that the Neva-2 sequence was detonated along the Telgespit River, southeast of its confluence with the Uspun (Figure N2a). Mikulenko et al. (2006) present a map (Figure N2b) showing the details of the locations of the nuclear detonations in the Butuobaya area. Using this map and distances from Burtsev (1993), we examined the detonation sites in detail on satellite imagery. The Neva-2 series events are located almost exactly as predicted by Mackey et al. (2005, Figure 8).

Mikulenko et al. (2006) place the Neva-2 series sites on the east bank of the Telgespit River where satellite imagery reveals a series of disturbed areas that corresponds to almost the exact location predicted by Mackey et al. (2005) (Figure N4). This confirms that the distances presented in the various Russian publications represent straight-line distances, and we have used this to locate the other PNEs, both in the Central Botuobuya region as well as Craton-4 and Kimberlite-4, below, which are given distances from specific settlements.

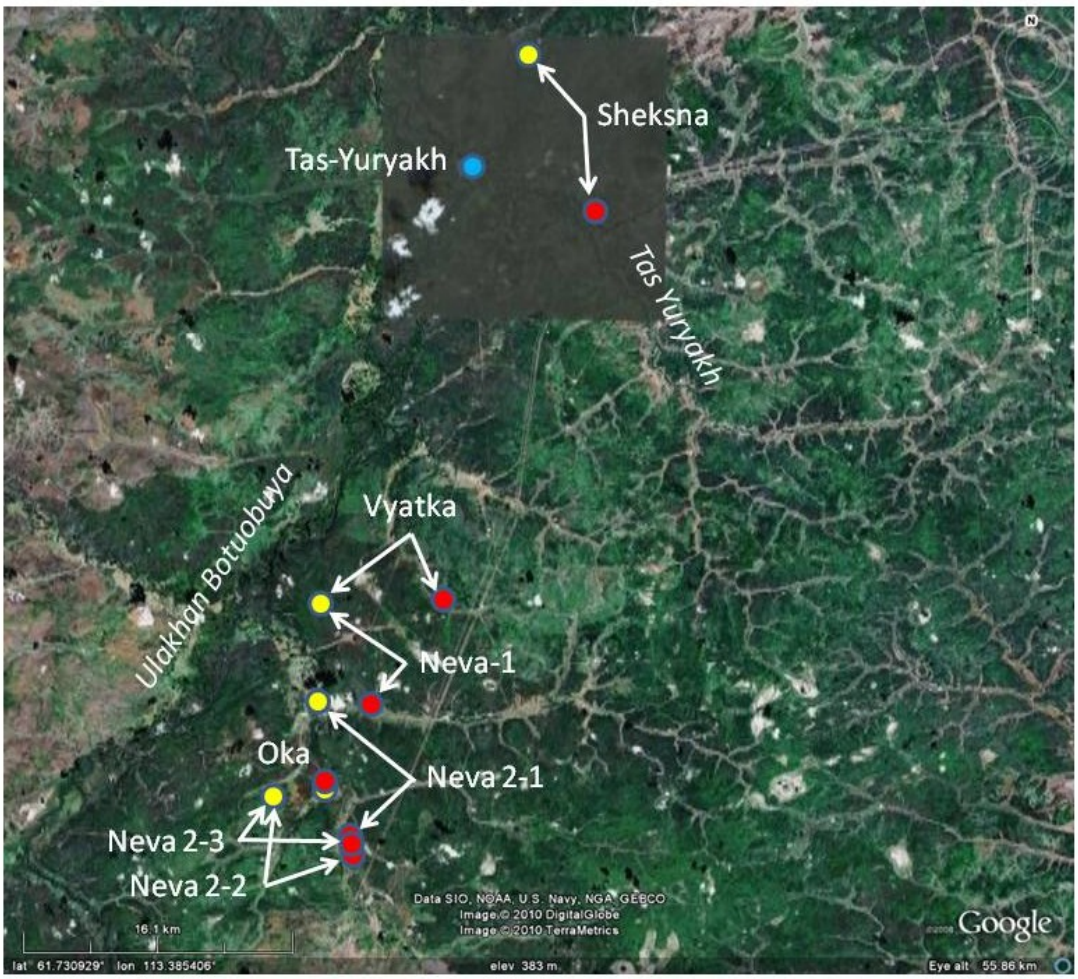

Figure 7. Satellite image of the Central Botuobuya Oil and Gas field. Locations of the Neva series of PNEs as given by Sultanov et al. (1999; yellow) ISC (orange), and in this report (red) also shown. Tas-Yuryakh shown as blue dot. The locations by Sultanov et al. (1999) are essentially the same as ISC for the Neva 2 series.

Neva 2-1 is the northernmost of the cluster, Neva 2-2 is the southernmost, and Neva 2-3 is in between. Table 1 presents our estimates of the location of the Neva 2 series and determinations from other sources. These are a significant improvement over Sultanov et al. (1999) and the ISC. Neva 2-3 was detonated with the intent of creating an underground oil storage facility.

Oka was detonated on November 5, 1976, 38 km from Tas-Yuryakh (Burtsev, 1993). Mikulenko et al. (2006) place the site on the west bank of the Telgespit, just below its confluence with the Uspun River (Figure 8b). Examination of satellite imagery shows a disturbed area with many roads leading to it as well as a larger area of apparently disturbed ground along the Uspun (Figure 10a). Based on the figure from Mikulenko et al. (2006, Figure 8b), which places the borehole below the confluence of the two rivers, we select the northern site; however, from a distance viewpoint, both are essentially 38 km from Tas-Yuryakh. The two sites are less than 300 m apart, and the coordinates reported by Sultanov et al. (1999) are in between.

Neva-1 was detonated on October 10, 1982, 31.5 km from Tas-Yuryakh. Mikulenko et al. (2006) place it along the Kudulakh River, 2.75 km above its confluence with the Telgesit (Figure 8b). There is a cleared area with apparent road access from the south (Figure 10b). This site is closer to 32.5 km from Tas-Yuryakh. An alternate possibility, a cleared formerly swampy area, located about 2 km to the north, would not fit the Mikulenko et al. (2006) map. In the absence of additional information, we suggest this is the possible site. Sultanov places Neva-1 close to the ISC coordinates (Figure 7). This is the most poorly located of the Botuobuya PNEs.

A. B.

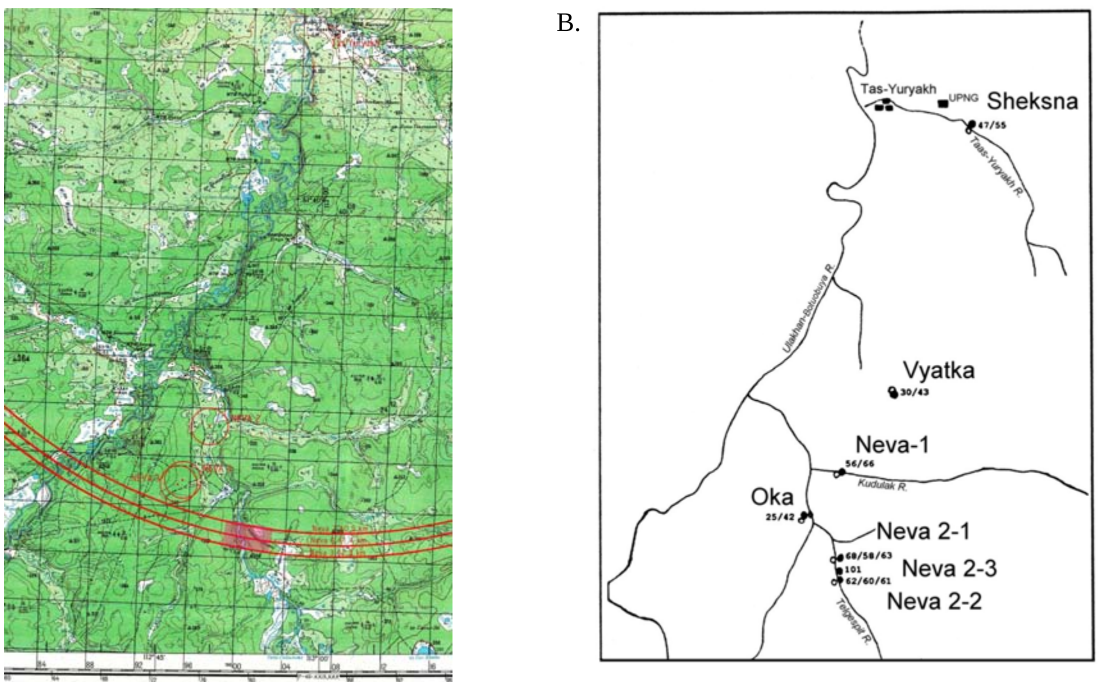

Figure 8. a) Location of Neva-2 series (pink area) as predicted by Mackey et al. (2005) based on direct-line distance (red arcs) from Tas-Yuryakh as reported by Burtsev (1993) and Tsyganov (1993). b) Location of PNEs in the Central Botuobuya Oil and Gas field as published in Mikulenko et al. (2006). Black dots represent PNE locations.

Vyatka was detonated on October 7, 1978, 26 km from Tas Yuryakh. There is a disturbed area visible in satellite imagery (Figure 11a) exactly 26 km from Tas Yuryakh along the Uspun stream at the relative location indicated on the Mikulenko et al. (2006) map (Figure 8b). Our proposed location is about 6 1/2 km east of the location given in Sultanov et al. (1999), which is located at the same coordinates as they propose for Neva-1.

Sheksna was detonated on October 7, 1979, 7.2 km from Tas-Yuryakh. Examination of the locality identified by Mikulenko et al. (2006; Figure 8b), a small area of disturbed ground is found (Figure 11b) approximately 7.2-7.6 km from Tas-Yuryakh (depending on starting point). Another area of disturbed ground, farther southeast along the present highway, is even further from Tas-Yuryakh. This location is significantly south-southeast of the ISC, PDE, and Sultanov et al. (1999) locations (Figure 7), which are to the north of Tas-Yuryakh and far away from the Tas-Yuryakh River; the Mikulenko et al. (2006) map is unambiguous about the location of Sheksna close to the river.

Figure 9. Detail of the Telgespit River valley 40 km from Tas-Yuryakh showing disturbed areas proposed to be the detonation sites (red dots) of the Neva 2 series of PNEs in 1987.

a). **b).**

Figure 10. a) Proposed location of Oka (arrow) and location from Sultanov et al. (1999; yellow dot). b) Region along Kudulakh River above its confluence with the Telgespit showing possible location (arrow) for Neva-1. The Sultanov et al. (1999) location is off the map.

a) b)

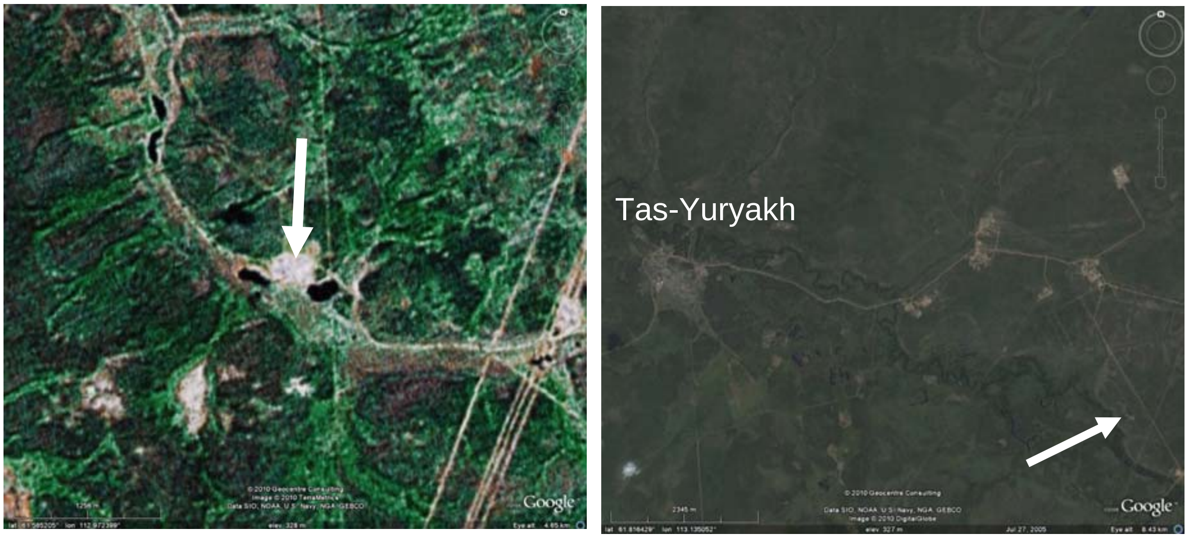

Figure 11. a) Satellite image of the proposed location of Vyatka (arrow). b) Tas-Yuryakh and vicinity showing the proposed site of Sheksha (arrow).

Craton-3 was detonated on August 24, 1978, and also produced radioactive contamination. Sultanov et al. (1999) lists coordinates of 65.925°N, 112.338°E, and a depth of 577 m. Gedeonov et al. (1997) gives a detailed map which yields coordinates of 65.9249± 0.0005°N, 112.3330± 0.0005°E, within 400 m of the Sultanov et al. (1999) coordinates. The description in Burtsev (1993) of the event being on the left-bank of the Chukuka stream, and hence the Fujita (1995) epicenter, is erroneous.

Horizon-4 was detonated on August 12, 1975. A crater-like feature visible in satellite imagery on the north bank of the Erikit, the location described in Burtsev (1993), is suggested to be the site of Horizon-4 (Table 1). The resolution is insufficient to be certain of the site and there is another crater-like feature in close proximity, thus there may be uncertainty on the order of a km.

Kimberlite-4 was detonated on August 12, 1979. Mikulenko et al. (2006) and papers in Burtsev (1993) place the site as being on the shores of Lake Daban, 27-28 km from Tuobuya. A disturbed area visible in satellite imagery at the south end of the lake (Table 1); the coordinates from Sultanov et al. (1999) are in a forested area.

Craton-4 was detonated on August 9, 1978. The detonation site is given in papers in Burtsev (1993) and Mikulenko et al. (2006) as being 12 km from Lake Nidzhili and 19 km from Aryktakh. In addition, a map of radiation sampling in Burtsev (1993) can be scaled to fit a lake near these coordinates. A disturbed area corresponding to the map location is suggested to be the detonation site (Table 1). There are some other disturbed areas within 300 m, thus a small amount of uncertainty remains.

For the PNEs of the Central Botuobuya region, Sultanov et al. (1999) have located Oka very well, but differ significantly (5 to 10 km) for the others. The conformity of satellite imagery, the map presented in Mikulenko et al. (2006), and the distance from Tas-Yuryakh (always within 1 km in a direct-line) gives us confidence about our proposed coordinates for these PNEs. For other PNEs in Yakutia, the Sultanov et al. (1999) coordinates are very close (< 1 km) to our final coordinates for proposed sites (Table 1), except for Crystal. Table 1 also includes our estimates of their GT classification. We suggest that the revised coordinates supersede those found in Sultanov et al. (1999) in future GT studies.

Table 1. Revised GT locations of Yakutia PNEs.

PNE	Proposed Coordinates		Sultanov Coordinates		Difference (km)	Proposed GT
	Latitude (ºN)	Longitude (ºE)	Latitude (ºN)	Longitude (ºE)		
Crystal	66.4573	112.3989	66.10	112.65	41.4	GT0
Neva 2-1	61.4316	112.8867	61.50	112.85	7.8	GT0
Neva 2-2	61.4185	112.8904	61.45	112.80	6.1	GT0
Neva 2-3	61.4288	112.8878	61.45	112.80	5.2	GT0
Oka	61.4606	112.8592	61.458	112.860	0.3	GT1
Neva-1	61.5006	112.9110	61.55	112.85	6.4	GT5
Vyatka	61.5562	112.9915	61.55	112.85	7.5	GT0
Sheksna	61.7683	113.1625	61.85	113.10	9.7	GT0
Craton-3	65.9249	112.3330	65.925	112.338	0.2	GT0
Horizon-4	70.7635	126.9520	70.763	126.953	0.0	GT1
Kimberlite-4	61.8000	122.4159	61.803	122.430	0.8	GT0
Craton-4	63.6800	125.5289	63.678	125.522	0.4	GT0

CONCLUSIONS AND RECOMMENDATIONS

This project will improve our knowledge on many geophysical aspects of northern Asia. As summarized here, this is inclusive of seismic characterization, surface wave tomography, analysis of nuclear explosion seismograms, and improving the GT classification of events.

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