THE NORTHEAST RUSSIA SEISMICITY DATABASE AND EXPLOSION CONTAMINATION OF THE RUSSIAN EARTHQUAKE CATALOG

Kevin G. Mackey and Kazuya Fujita, Department of Geological Sciences, Michigan State University

Sponsored by U. S. Department of Defense
Defense Threat Reduction Agency
Contract No. DTRA-98-C-0168

ABSTRACT

Northeastern Russia (roughly east of 120ºE and north of 55ºN) is one of the most poorly understood regions on Earth from a seismological viewpoint. Even the plate tectonic setting of the region is still a matter of debate. The level of seismicity, epicentral locations, and crustal and upper mantle seismic velocities are poorly characterized. In order to improve our understanding of the baseline seismicity and velocity structure of the region for Comprehensive Nuclear-Test-Ban Treaty monitoring, seismicity data obtained through a cooperative research program between Michigan State University, the University of Alaska, and several institutes in northeastern Russia since 1990, are being analyzed.

The Northeast Russia seismicity database includes epicenter data for approximately 36,000 earthquakes and phase data for 10,000 of these events that occurred in northeastern Russia (Sakha Republic, Magadan District, Chukotka Autonomous District, Amur District; partial coverage of northern Kamchatka, Sakhalin, and Irkutsk Districts) primarily from 1961 to 1999. During this period, several regional networks operated in northeast Russia; however, phase data were not routinely exchanged among the network or with the United States. Sources used to compile the database include the annual *Zemletryaseniya v SSSR* (1961-1992), the International Seismological Center Bulletin (1964-1996), the U.S. Preliminary Determination of Epicenters (1993-1999), *Materialy po Seismichnost' Sibiri* (1970-1990), the Far East Seismic Bulletin (1972-1974, 1985-1988), the epicenter tape from the University of Alaska's Western Alaska regional network (1977-1982), the seismological bulletins of the Russian Yakutsk (1982-1998) and Magadan (1977-1999) regional seismic networks, and phase picks from seismograms.

Included in this database are industrial explosions that have been identified by the Russian regional networks as well as regional micro-earthquakes. The regional seismicity listings include a large number of mining and construction-related explosions, which are listed as earthquakes. In order to determine the level of explosion contamination of these regional catalogs and obtain a better idea of the level of natural seismicity in the region, we analyzed the entire database by examining the temporal variation of events. Since mining and industrial explosions tend to be concentrated during local day, and often to the winter season, extreme temporal biases are indicative of explosion contamination. Regions with such biases can be compared with maps showing placer excavation, roads and railroads, and locations of ore deposits. In this part of Russia, explosions occur in tin, coal, and placer gold mines, and in construction of roads and railroads. Most explosions have magnitudes of about 1.0-2.5 and occur during local day. Placer deposit explosions are concentrated from mid-winter to early spring when frozen placers are broken up for the summer processing season.

Areas with temporal biases indicative of mining or other explosions include the Yana River Delta and Chukotka (placers), southern Amur District (coal mining), the trace of the Baikal-Amur Railroad (construction), Lazo (quarry), south Yakutian gold fields, Omsukchan (tin), other Yakutian gold producing areas, areas of known prospecting (e.g., Lena River Delta), and the Kolyma gold belt. Many of these regions also have a large number of operator-identified explosions. The identification of these explosions indicates that natural seismicity may be of lower level, and not as diffuse, along the plate boundaries in northeast Russia as previously believed. Russian authors have also noted explosions near construction and survey sites for hydroelectric dams along the Kolyma and other rivers.

To obtain further ground truth on explosions, we hope to deploy several digital stations in the Magadan District and investigate waveform characteristics and other discriminants to better understand industrial explosions in the area and to obtain an improved baseline of natural seismicity in the region.

Key Words: explosion discrimination, northeast Russia, mining explosions, seismicity character

OBJECTIVES

Northeastern Russia is very poorly known in terms of its seismicity. Previous studies have focused on the seismotectonics of the region (e.g., Chapman and Solomon, 1976; Riegel et al., 1993), and we now have a better understanding of the plate tectonic setting of the region as a buffer zone between two large continental plates (Fujita et al., 1997). However, the crustal and upper mantle velocity structure, and their implications for earthquake locations from Russian regional network data, remain very poorly known. Mackey et al. (1998) used well located events to perform a first-order analysis of crustal and mantle velocities and determined that a 6.0 km/sec crust overlying an 8.0 km/sec mantle fit well for the region as a whole. They also identified variations in velocities and crustal thicknesses that coincided with pre-Quaternary extension in a broad region in the Verkhoyansk Mountains. In this paper, we report on the assembly of a data base of seismic data on northeastern Russia and the results of preliminary analyses for explosion contamination of the Russian seismicity catalog. Ultimately, we will relocate earthquakes and develop better models for the crustal and upper mantle seismic velocity structure. These will contribute a better understanding of the background seismicity of the region and improve event locations, both of which will support verification of the Comprehensive Nuclear-Test-Ban Treaty (CTBT).

RESEARCH ACCOMPLISHED

Introduction

The study area consists of the region east of 120ºE and north of the Chinese border. We focus on the Sakha Republic (Yakutia), the Magadan District, and the Chukchi Autonomous District, but also encompass the Amur District, northern Khabarovsk District, northern Koryak Autonomous Region, and Sakhalin.

The former Soviet Union operated several analog regional seismic networks in the study area for over 30 years, and significant amounts of data were collected. Of interest here are the former Soviet Magadan, Yakutsk, Amur, and Sakhalin networks, and the American Western Alaska network, as well as portions of the former Soviet Irkutsk and Kamchatka networks. The distribution of network boundaries is shown in Figure 1. As part of a cooperative research program between Michigan State University, the University of Alaska, and several research institutes in eastern Russia, phase and epicentral data from these networks were acquired and are being incorporated into an unified Northeast Russia Seismic Database (NRSD). Although this data base was compiled from Russian analog records, it would take the installation of several tens of permanent digital stations, and a minimum of two decades, to duplicate the database using modern acquisition methods, which is impractical given current economic conditions in Russia.

There are two major sections to the database developed here: A catalog of hypocenters for northeast Russia and western Alaska, and a database of arrival times by combining data from all sources and networks; phase data were not routinely exchanged between the Soviet networks. Other information include industrial explosions and seismic station locations. Approximately 36,000 individual earthquakes have been complied from throughout the region (Figure 1), primarily between 1968-1998. So far, phase data for over 10,000 events (over 100,000 arrival times) have been entered into the NRSD. Historic events and data recorded teleseismically are taken from standard sources such as International Seismological Summary (ISS), International Seismological Centre (ISC) Bulletin, and the United States Geological Survey (NEIC). A few arrivals have also been read from original seismograms.

Russian seismic networks generally report magnitudes (M) for events only of M > 4.0. However, all events have sizes assigned a K-class value, based on the $\log_{10}$ of work release in Ergs. K-class is determined from the maximum amplitudes of the P and S phases using a distance-corrected nomogram calibrated for individual regions (Solonenko, 1974; Pustovitenko and Kul'chitskii, 1974: Gunbina, pers. comm.). Unfortunately, this results in inconsistent size determinations between networks.

Database Sources

The NRSD has been compiled from a large number of sources which report epicentral and phase data. The primary sources, as well as some information on regional network histories, is presented below.

Zemletryaseniya v SSSR (1961-1991; Earthquakes of the USSR) and its successor publication

Zemletryaseniya Severnoi Evrazii (1992; Earthquakes of Northern Eurasia). This annual catalog lists event parameters for the larger earthquakes which occurred within each regional network. In general, only events of K-class 8.5 and larger are listed, although this varies from year to year and network to network. In addition, the cutoff was often raised for large aftershock sequences. These publications have previously been available in the US and incorporated into other U.S. digital databases (e.g., U.S. Geological Survey CD-ROM).

Materialy po Seismichnost' Sibiri (1970-1990; Data on the Seismicity of Siberia; hereafter *Materialy*). This is a bi-monthly publication with both epicenter lists and phase data for the continental seismic networks in Siberia (Irkutsk, Magadan, Yakutsk, Amur (1979-1990), and Altai). The epicenter list is generally complete, although isolated events found in the Far East Bulletin and in the network bulletins seem to be missing. This bulletin also contains phase data for events of K class 9.5 or greater occurring within a network. This study includes only a small portion of the Irkutsk network (south of 56 N between 120 and 122 E) and none of the data from the Altai network.

Seismologicheskii Byulleten' – Dal'nego Vostoka (Intermittent years obtained; Seismological Bulletin - Far East; hereafter *Far East Bulletin*). This quarterly bulletin is similar in format to *Materialy* and covers the Magadan, Amur, Sakhalin, Kamchatka, and Kurile networks. The epicenter list provided here is generally complete for Magadan and Amur. For the Kamchatka network, only events of K-class larger than 9.0 are listed. Coverage of phase data varies from network to network.

Magadan Network Bulletin (1977-1998). The Magadan Experimental Methodological Seismological Division (EMSD) network was formally established in December, 1979. Earthquakes were located using Pg and Sg time differences. Prior to 1982, locations were computed by hand. In 1982, computers were first used for locations, and the network switched to computer only determinations in the early 1990s. A velocity structure derived from the Magadan – Srednikan refraction profile (Davydova et al., 1968) was used (Pg 6.1 km/sec, Sg 3.5 km/sec). The epicenter lists and phase data for located events are identical to that found in the *Far East Bulletin*; however, the network bulletin contains additional material on explosions and unlocated events.

Yakutsk Network Material (1982-1998). The Yakutsk network was established in the mid-1960s. The Yakutsk network has operated a large number of permanent and temporary seismic stations in Yakutia and adjacent regions. All earthquake locations determined by the Yakutsk network are calculated by hand by drawing arcs on 1:5,000,000 scale maps. Epicentral distances are determined by Sg-Pg time differences for each station. Pg velocities of 6.0 or 6.1 km/sec and Sg velocities between 3.5 and 3.7 km/sec are used depending on location. Explosions with associated arrival times are also given, but are not always located. Data from the 1971 Artyk and 1989 South Yakutia aftershock studies are also included in the database.

Kamchatka Seismicity Catalog (1962-1966). Seismic stations were first opened on Kamchatka peninsula in 1948, with a rapid increase in the number of stations in the 1960s. Earthquake locations were computed by hand up until 1978, when location procedures were computerized (E. Gordeev, pers comm.). Only earthquakes in the region north of 56^{o} N (north of the subduction zone) are included in our database. The relevant epicenters were extracted from the catalog, which contains 55,000 earthquakes. Some phase data were taken from the *Far East Bulletin*.

Western Alaska Network. The Western Alaska Network was operated from 1977 to 1982 (closed for 1980), in the region of the Seward Peninsula, Alaska (Figure 1) (Biswas et al., 1983; Biswas et al., 1980). Focal parameters for 1,010 earthquakes were computer determined using first arrival P times and S-P differences. The epicenter catalog was taken from Biswas et al. (1983) and the complete computerized phase and arrival time listings were downloaded from archive tapes at the Geophysical Institute, University of Alaska, Fairbanks.

Northeast Russia Test Network. In the mid 1960's a number of experimental seismic stations were established throughout northeast Russia to determine background seismicity levels to aid in developing permanent seismic networks (Mishin, 1967). The distribution of seismicity located using the test network was instrumental in site selection for future seismic stations. Most of the temporary stations were deployed for between 6 months and 1 year. Hypocenters obtained from the test network given in Andreev (1967) are included in the database. Phase data for the events are not available.

Seismograms. Supplemental arrival times, mainly for teleseisms, were hand picked from seismograms in Yakutsk and Magadan. In addition, phase data for approximately 50 events from Chukotka were picked from develocorder records for Alaskan network stations. Additional data will be obtained.

Other. Data were also acquired from other publications. Earthquake data for 1920-1999 were obtained from the ISS, the ISC Bulletin, NEIC (Preliminary Determination of Epicenters listings), the Alaska Earthquake Information Center (AEIC), Kondorskaya and Shebalin (1982), and Godzikovskaya (1995).

In compiling the database, numerous phases have been reidentified, and conflicts between the different sources have been resolved. Upon completion of the database assembly, all events will be computer relocated using travel-time curves determined separately for individual regions (generally 1 x 2 degree blocks).

Seismicity Map

The current seismicity map with plate boundaries after Fujita et al. (1997), network boundaries, and seismic stations is shown in Figure 1. Overall, seismicity levels in northeast Russia are much higher than is generally recognized in the literature. Moreover, the seismicity distribution is likely to be biased by station distributions. For example, there is a distinct lack of microseismicity in the northwestern Sea of Okhotsk. This may entirely be a result of the distribution of the regional seismic networks. Note on Figure 1 that this region is near the intersection of the Magadan, Yakutsk, Amur, Sakhalin, and Kurile networks. Although there is microseismicity trending into the region from each of the surrounding networks, the distances to individual stations are high, and combined with the lack of data exchange between neighboring networks, small events occurring in this region are most likely detected by only one or two stations in each network and thus below the detection or location threshold for any individual network. Since data were not exchanged between networks, the region appears aseismic.

Explosion Contamination

The seismicity catalog for Eastern Russia, and therefore Figure 1, is known to be contaminated by a large number of industrial explosions (e.g., Godzikovskaya, 1995; Odinets, 1996). In this part of Russia, explosions occur in tin, coal, and placer gold mines, as well as in prospecting and the construction of roads, railways, and dams. Many of the active mines are located in seismically active regions, which has resulted in misidentification of mine blasts as earthquakes. The contamination of the seismicity catalog with explosions results in an erroneous perception of the level and distribution of natural seismicity.

While analysis of waveform data for all reported earthquakes is desirable, it would require an unrealistic re-examination of several hundred thousand analog seismograms. However, a qualitative estimate of the level of explosion contamination can be obtained by examining the spatial, size, and temporal characteristics of earthquakes located by the regional networks. Thus, we investigated explosion contamination in the study area primarily through temporal analysis of origin times; both time of year and time of day were considered.

Early attempts at explosion filtering from the late 1960's through mid-1970's in the Magadan region simply removed all events within a particular radius of stations in some of the mining regions (V. N. Kovalev, pers. comm.); however, this also removes tectonic events and creates peculiar rings of seismicity (Riegel, 1994). Beginning in the late 1970's, station operators attempted to discriminate close events (up to 50 - 70 km) based on waveform characteristics and information from the mining companies. Unfortunately, not all mining companies provided information on their blasting activities (V. N. Kovalev, pers. comm.), and waveform characteristics tended to vary. Thus, all catalogs containing events of $M < 3.5$ (K-class 11) remain contaminated with explosions.

Previous work on identifying explosion contamination has been undertaken by Godzikovskaya (1995), who identified several regions of explosion contamination in the Amur and Kolyma Districts and Chukotka. Odinets (1996) also determined that a large fraction of earthquakes reported in the central Kolyma region are actually explosions. Industrial explosions locatable by the regional networks have magnitudes of about 1.5 - 3.0 and occur during the local day (Godzikovskaya, 1995; Odinets, 1996). Placer deposit explosions are also concentrated during the late winter and early spring, when frozen ground is broken up for the summer processing season.

The examination of this temporal bias in the seismicity can, in a broad sense, indicate potential regions of explosion contamination (Agnew, 1990). Unfortunately, unlike standard practice in the United States, blasting in Russia is not confined to a specific time of day, but may occur at any time during the workday. A small, but not statistically significant, number of explosions are also known to occur at night (Godzikovskaya, 1995) since Russian law requires that explosives loaded into boreholes can not be kept overnight, but must be detonated (V. N. Kovalev, pers. comm.). This results in some night blasting, and is supported by a small number of nighttime explosions listed in the network bulletins. In Figure 2, the study area is divided into cells in which the percentages of daytime earthquakes are calculated. Cells containing fewer than ten events were not considered to be statistically significant, and were not analyzed. The 12 hour local “day” has been shifted according to time zones. Dark gray areas represent regions where seismicity is roughly balanced between night and day, and light gray areas are those in which seismicity is concentrated during local night (>65%). There are many areas of nighttime-biased seismicity, most of which are in seismically less active regions and away from seismic stations. This is not unexpected since almost all seismic stations in the area are located in populated areas, and thus have lower cultural noise during the night.

Black areas on Figure 2 represent regions where more than 65% of the seismicity occurs during local “day”. Many of the regions with predominantly daytime events are found in discrete clusters or trends of seismicity, most of which can be associated with mining or construction related blasting. Several clusters of seismicity in the Amur region have more than 90% of the events occurring during local day. There are a few cells with predominantly daytime seismicity that we are unable to explain with explosions. These cells are probably a result of random statistics of small numbers as these cells generally are close to the 10 event cutoff. Below, we examine several regions shown in Figure 2 of daytime bias which can be positively related to explosion contamination.

Explosion Contamination by Region

One of the clearest regions of explosion contamination is the **Amur District** (Area 1, Figure 2). Here, the distributions of daytime and nighttime epicenters (Figures 3 and 4 respectively) show distinct differences. We present two examples of the temporal distribution of seismicity. The first (Figure 5) is Area A in the northern part of Figure 3. The seismicity here is believed to be tectonic, as the region is generally unpopulated and thus should not contain any contamination due to mining. This region can therefore be used as a baseline to which other analysis can be compared. The area analyzed contains 399 located earthquakes, with 189 having occurred during local daytime and 210 during local night. This corresponds to a day/night ratio of 0.9, which is essentially the same for the aftershock sequence of the 1989 South Yakutian earthquake.

The second (Figure 6) is an example of a cluster of “day” only seismicity that correlates with the Raychikhinsk coal mining region (Figure 3). Here, and in some other regions, the seismicity also varies by season. Figure 6 shows activity only during winter months and during local “day”. However, in the nearby Khingansk mining region (Figure 3), events occur throughout the year but only during the day. There is also industrial activity in the region around Komsomolsk' na Amur. Origin times and times of year for explosions vary from place to place, for example, events in the Raychikhinsk, Khingansk, and Komsomolsk' na Amur center around 05 hours UTC, which corresponds to 1 PM local time. However, the explosion maximum occurs around 05 hours UTC (12 noon local time) in the mines about 5 km to the north of Chegdomyn and there is a bias towards summer months.

The seismicity near Svobodniy is consistent with an anthropogenic origin. However, the existence of mining in this region is unclear from the available maps. Events here show a slight bias toward summer months. Events occur about 40 km northeast of Shimanovsk along the west bank of the Zeya river. Events located in this region occur exclusively during daylight hours, but with a slight bias towards mid winter. Near Oktyabrskiy, extensive placer mining has occurred in the vicinity of the town, primarily to the north and southeast, and along the Gar' River valley to the south. Origin times indicate that almost all blasting occurs during the winter daytime.

Some regions have a mix of natural and anthropogenic seismicity. Prior to 1981, a small number of earthquakes occurred in the Taldan region with no bias in origin times, indicating natural seismicity. In addition, a magnitude 5.0 event occurred during the night of January 31, 1985. Beginning in 1981, however, the number of events rose drastically, and a strong daytime bias was introduced into the origin times. Explosion contamination due to dam construction in the Zeya basin region to the east (near 54°N, 127°E) is discussed at length by Godzikovskaya (1995). The region around Ekimchan is also consistent with a mix of tectonic events and explosions. There are a total of 283 events in this region, with 92 occurring during the nighttime. If we assume that the number of daytime tectonic events is 0.9 of the nighttime level (83 events), then the total number of tectonic events in this region is about 175. Therefore, the number of explosions is 106, representing a 37% contamination of the database.

In the north-central portion of Figure 3, there is a northwest-southeast trend of predominantly daytime and summer seismicity extending several hundred kilometers which correlates with the route of the Baikal-Amur railroad (BAM) and is assumed to be explosions associated with its construction in the 1980's. Note also that most events are located to the west of the track in the central portion, and to the north of the track in the northern portion, indicating systematic errors in the epicentral locations. The region also has some tectonic earthquakes, as there are a reasonable number of nighttime events. A cluster of events south of the railway south of Tynda is likely to be mining associated as the events are biased more towards early winter.

Overall, as the explosion contamination appears to be confined to daylight hours, nighttime seismicity should better reflect the level and distribution of tectonic earthquakes (Figure 4). Compared to the daytime map (Figure 3), a different, more northerly trend appears in the plotted nighttime earthquake epicenters, which probably delineates an active tectonic feature that was previously obscured with clusters and trends of explosions. We also note that the teleseismically located events fall almost entirely within the regions where seismicity occurs in the night. Clusters and trends of primarily daytime events have very few events of magnitude 4 or larger.

Polyarnyi and **Leningradsky** (Area 2, Figure 2) are placer gold deposits located along the coast of the Chukchi Sea, while Plamennyi, slightly inland, is a mercury deposit which was mined from 1967 to 1972 (Pilyasov, 1993). From 1966 to 1982, most of the events located in this area were single station locations obtained by the three-component station at Iul'tin (ILT). A clear bias towards winter and daytime is evident for the events in the mining region. Several events are also located near Plamennyi after closure of the mine and may be due to known continued prospecting or mislocations from Leningradsky and Polyarnyi. Comparison of origin times of ILT-located events with more recent, known, explosions from the same area yields a nearly identical temporal distribution, with blasting primarily in the daylight hours of late winter and spring. The complete lack of teleseismically recorded events around Polyarnyi-Leningradsky-Plamennyi, as compared to an area a few hundred kilometers to the southeast, is also consistent with explosions. Some previous authors (e.g., Lander, 1996) have used the explosions reported here both in tectonic models, and assessment of seismic risk, resulting in erroneous conclusions. Earthquakes located by ILT in eastern Chukotka do not show any temporal bias, and probably represent tectonic events.

A cross of predominantly daytime seismicity lies in the **Kolyma gold mining belt** (Area 3, Figure 2). Tectonically, this region is extremely complex in that it is located just south of the Ulakhan Fault system along which motion between the Okhotsk block and the North American plate is occurring (Riegel et al., 1993). Therefore easy statistical separation of anthropogenic and tectonic sources is difficult. Mining in this region is primarily placer gold, but also includes coal and other minerals. Temporal analysis of a cluster of events northwest of Susuman yields a clear bias towards local day and winter/spring. This is consistent with the distribution of known explosions from the Magadan seismic bulletin for this region. The eastern half of the cluster is composed entirely of explosions, while the western half probably contains some tectonic events. There is also a reduced numbers of nighttime events within a 100 kilometer radius of Susuman, which is also indicative of mining.

The Kolyma hydroelectric dam is located about 200 kilometers southeast of Susuman. Blasting during construction of this dam resulted in contamination of the earthquake catalog (Godzikovskaya, 1995) and there is a an elevated level of daytime seismicity for approximately 100 km upriver from the dam. A second cluster of primarily daytime events exists approximately 120 km to the east in the vicinity of the Ust' Srednikan dam project. Godzikovskaya (1995) also notes explosion contamination there.

A puzzling cluster of seismicity is located south of Susuman near the town of Kulu. This cluster is biased towards winter months, but only slightly towards daylight hours. The events occurred in the 1970's and 1980, with a few events each year. In 1980, when the seismic station at Kulu opened, the earthquakes essentially stopped. This would be consistent with explosions, with the local operator removing explosions from the catalog.

Placer gold deposits around **Ust' Nera** (Area 4, Figure 2) are on the northwest extension of the Kolyma gold belt. Seismicity in the vicinity of Ust' Nera is biased towards daytime, with 10 “day” and 2 “night” events, although statistics of small numbers may be a factor. The region immediately to the southeast and east of Ust' Nera, however, is very active tectonically, and events of up to magnitude 7 have occurred.

Lazo (Area 5, Figure 2) is a gold placer deposit between the Adycha and Nel'gese Rivers at 66.51N, 137.01E. Seismicity here is almost entirely confined to the daytime in the early part of the year, thus they are likely to almost exclusively be explosions. A similar looking cluster of seismicity about 100 km south of Lazo has been suggested to be of mining origin (V. Imaev, pers. comm.), although the temporal variation is more consistent with tectonic activity.

The **Deputatsky** (Area 6, Figure 2) tin mining region is completely biased to winter events, with 13 events reported during winter day and 2 events during winter night. There are no events reported in the summer months, a good indicator of an anthropogenic origin. However, caution must be taken as the number of events is small. A cluster to the north appears to be tectonic in origin.

The region around **Kular** (Area 7, Figure 2) and to the north is an extensive placer gold mining region. Coal has also been mined southeast of Kular along the banks of the Yana River. The coal mining operations closed in the past few years, but in the mid-1990's gold mining operations began south of Severnyi, about 25 km southeast of Kular. Reported seismicity in the Kular region forms an elongated north-south trend, an excellent correlation with explosion locations. Temporal analysis of reported seismicity in the Kular region shows a strong bias to winter and daytime, also consistent with explosions from mining (Figure 2-34).

Reported seismicity in the **Stolb** (Area 8, Fig. 2) region is probably contaminated by daytime explosions. From 1988 to present, the geological survey in Moscow has been conducting explosions in this region along the Lena River looking for placer deposits of diamonds. Although there are only 12 earthquakes that fall within this region, 9 occur during daylight hours, and 8 occur between 1989 and 1994.

Yugorenok (Area 9, Fig. 2) is a mining region along the Yudoma and Allakh-Yun rivers. Of the 25 earthquakes located in the vicinity, 20 occur during winter daytime hours. In addition, there are no large events associated with this cluster of seismicity. Two other small seismicity clusters to the north are both associated with teleseismic events, and do not show any strong temporal biases in their origin times, which suggests tectonic origins.

South Yakutia (Area 10, Fig. 2) is similar to the Kolyma gold belt in that there are tectonic events occurring in the vicinity of mining regions. Several cells in this area show strong daytime biases, each of which is associated with mining. Three regions are of note in the south Yakutia region. Aldan is a mining region with extensive deposits of gold and phlogopite mica (Shabad, 1969). The region is associated with a diffuse cluster of predominantly daytime reported seismicity. Explosions from the Aldan mining region are also located and listed in the Yakutsk bulletin.

Approximately 200 km south of the Aldan is an extensive coal mining region near Chul’man. The Chul’man mining region produces many explosions, some of which are located by the Yakutsk network and identified and listed in the bulletin. The seismic station at Chul’man seems able to identify and filter the explosions, as a plot of the temporal distribution of reported earthquakes shows no bias.

To the northeast of Chul’man is a dense cluster of seismicity near the settlement of Spokoynii. The events show a strong bias towards daytime and winter events, which is consistent with placer mining and Soviet military 1:200,000 scale topographic maps (dated 1986) which show extensive mine workings in the region. The published literature, however, has no mention of any mining activity in this region, nor does the Yakutsk network bulletin identify any explosions in the region. Overall, the nature of activity at this location remains unclear.

Finally, there is one cell in northern Alaska with seismicity predominantly in the summer and fall. This coincides with the location of the **Red Dog Mine** (Area 11, Figure 2) in the western Brooks range. Exploratory work prior to the opening of the mine occurred while the Western Alaska Network was in operation, which probably recorded and located a number of blasts (D. Thurston, pers. comm.).

CONCLUSIONS AND FUTURE WORK

Compilation of the NRSD and based on simplistic temporal analysis thereof, it is evident that the seismicity catalog of northeast Siberia is heavily contaminated with industrial explosions. Identification of these explosions and their removal from the seismicity catalog is essential in studying and understanding the tectonics and associated natural seismicity of the region. Overall, it appears that the majority of contamination in the seismicity catalog results from daytime mine blasts. Using phase data from the NRSD, we plan to derive local travel-time curves, relocate events using them, and further refine crustal and upper mantle seismic velocities in northeast Russia. In addition, several seismic stations were deployed in the Magadan district in the summer of 1999 to obtain digital waveforms and further improve our understanding of local explosions and wave propagation in the area.

REFERENCES

Andreev, T. A., Kravets, I. F., and Mishin, S. V.,1967, On the seismic activity of the Northeast: *Trudy SVKNII*, v. 30, Magadan, p. 159-166 (in Russian).

Agnew, D. C., 1990, The use of time-of-day seismicity maps for earthquake/explosion discrimination by local networks, with an application to the seismicity of San Diego county, *Bulletin of the Seismological Society of America,* v. 80, p. 747-750.

Biswas, N.N., Gedney, L., and Agnew, J., 1980, Seismicity of western Alaska: *Bulletin of the Seismological Society of America*, V. 70, p. 873-883.

Biswas, N. N., Pujol, J., Tytgat, G., and Dean, K., 1983, *Synthesis of Seismicity Studies for Western Alaska*, Final report, contract NA81-RAC00112: Fairbanks, Alaska, University of Alaska Geophysical Institute, 74 p.

Chapman, M. E., and Solomon, S. C., 1976, North America – Eurasian plate boundary in northeast Asia: *Journal of Geophysical Research*, v. 81, p. 921-930.

Davydova, N. I., Shvarts, Ya. B., and Yaroshevskaya, G. A., 1968, Wave patterns in deep seismic sounding along Magadan-Kolyma profile, *in* Deep Seismic Soundings of the Earth's Crust in the USSR: *International Geology Review* - Book Section, v. 10, p. 93-102.

Fujita, K., Stone, D. B., Layer, P. W., Parfenov, L. M., and Koz'min, B. M., 1997, Cooperative program helps decipher tectonics of northeast Russia: *Transactions of the American Geophysical Union (Eos*), v. 78, p. 245, 252-253.

Godzikovskaya, A. A., 1995, *Local Explosions and Earthquakes*: Rossiskoe Aksionernoe Obshchestvo Energy and Electrification "EES Rossii", Moscow, p. 55-66 (In Russian).

Imaev, V. S., Imaeva, L. P., Koz'min, B. M., and Fujita, K, 1994, Active faults and modern geodynamics of the Yakutia seismic belts: *Geotektonika*, p. 59-71 (in Russian).

Kondorskaya, N. V., and Shebalin, N. V., eds., 1982, *New Catalog of Strong Earthquakes in the USSR from Ancient Times Through 1977*: World Data Center A for Solid Earth Geophysics, Report SE-31, xi+608 pp.

Lander, A. V., Bukchin, B. G., Droznin, D. V., and Kiryushin, A. V., 1996, The tectonic environment and source parameters of the Khailino, Koryakia earthquake of March 8, 1991: Does a Beringia plate exist?: *Computational Seismology and Geodynamics*, v. 3, p. 80-96.

Mackey, K. G., Fujita, K., and Ruff, L. J., 1998, The crustal thickness of northeast Russia: *Tectonophysics*, v. 284, p. 283-297.

Materialy po Seismichnost' Sibiri, 1970-1990: Academy of Sciences of the USSR, Siberian Branch, Irkutsk (bi-monthly, in Russian).

Mishin, S. V., 1967, *Experimental Instrumental Seismological Investigations in the Northeast USSR*: Laboratory of Regional Geodynamics, NEISRI, Magadan, 165 pp. (In Russian).

Odinets, M. G., 1996, The problem of polluting the earthquake catalog with industrial blasts in northeastern Russia, *in* Lin'kova, T. I., and Bobrobnikov, V. A., eds., *Geophysical Models of Geologic Processes in Northeast Russia*: NEISRI, Magadan, p. 90-99 (in Russian).

Pilyasov, A. N., 1993, Regularities in the mining-industrial mastery of northeast Russia: *Kolyma*, 1993(8), p. 5-12 (in Russian).

Pustovitenko, B.G., and Kul'chitskii, V.E., 1974, About energy estimates of earthquakes in the Crimea-Black Sea region *in* Kondorskaya, N. V., Nersesov, I. L., Gorbunova, I. V., Rautian, T. G., and Korchagina, T. G., eds*., Magnitude and Energy Classification of Earthquakes v. 2*: IPE AS USSR, Moscow, p. 113-124 (In Russian).

Riegel, S. A., Fujita, K., Koz'min, B. M., Imaev, V. S., and Cook, D. B., 1993, Extrusion tectonics of the

Okhotsk plate, northeast Asia: *Geophysical Research Letters*, v. 20, p. 607-610.
Riegel, S. A., 1994, *Seismotectonics of Northeast Russia and the Okhotsk plate*: M.S. Thesis, Michigan State University, East Lansing, ix + 70 pp.
Seismologicheskii Byulleten' – Dal'nego Vostoka, 1972-1988: Academy of Science of the USSR, Far Eastern Branch, Yuzhno Sakhalinsk (in Russian).
Shabad, T., 1969, *Basic Industrial Resources of the USSR*: Columbia University Press, New York, 393 pp.
Solonenko, 1974, Energy classification of earthquakes of Prebaikalia,. *in* Kondorskaya, N. V., Nersesov, I. L., Gorbunova, I. V., Rautian, T. G., and Korchagina, T. G., eds., *Magnitude and Energy Classification of Earthquakes, v. 2*: IPE AS USSR, Moscow, p. 174-179 (In Russian).
Zemletryaseniya v SSSR, for *1961-1989*: Nauka, Moscow (annual, in Russian).
Zemletryaseniya v SSSR, for *1990-1991*: Russian Academy of Sciences, Moscow (annual, in Russian).
Zemletryaseniya Severnoi Evrazii, *1992*: Geoinformmark, Moscow (in Russian).

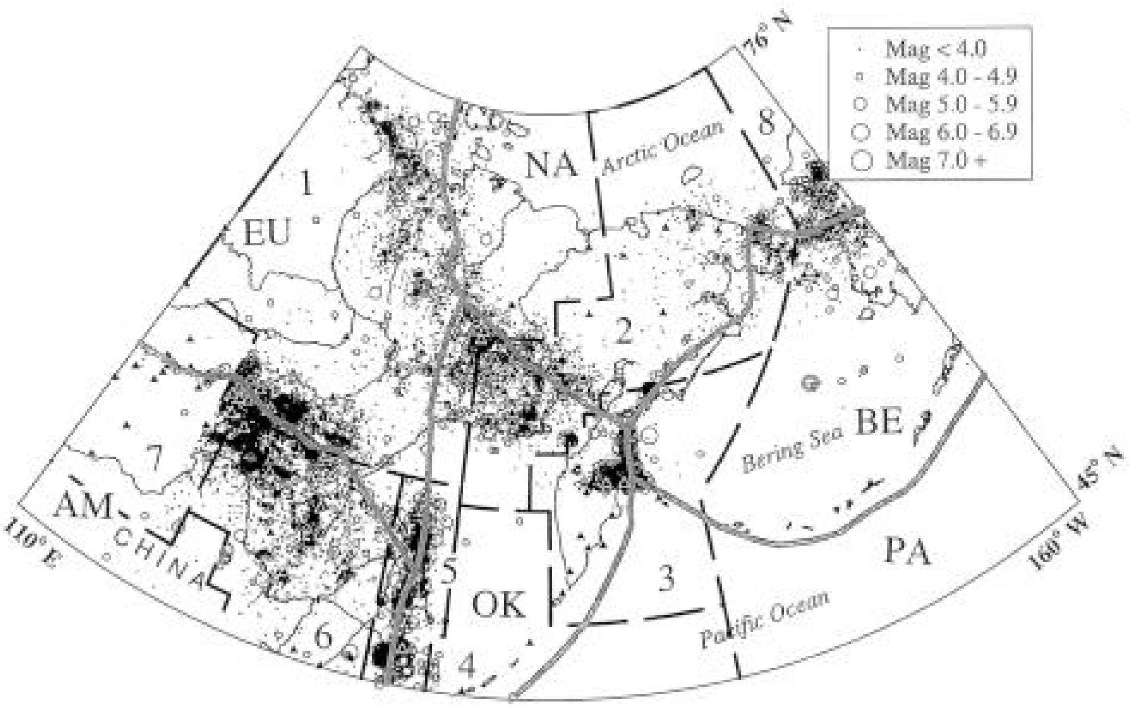

Figure 1. Seismicity map of northeast Russia showing network boundaries (long-dashed lines), plate and block boundaries (stippled lines), and all earthquake epicenters (dots, sized by magnitude). Triangles show locations of regional seismic stations. Abbreviations for plates or blocks are: PA – Pacific; NA – North America; EU – Eurasia; AM – Amur (North China) block; OK – Okhotsk block; and BE – Bering Block). Networks identified by number 1 – Yakutsk; 2 – Magadan; 3 – Kamchatka ; 4 – Kurile; 5 – Sakhalin; 6 – Amur; 7 – Irkutsk; and 8 – Western Alaska.

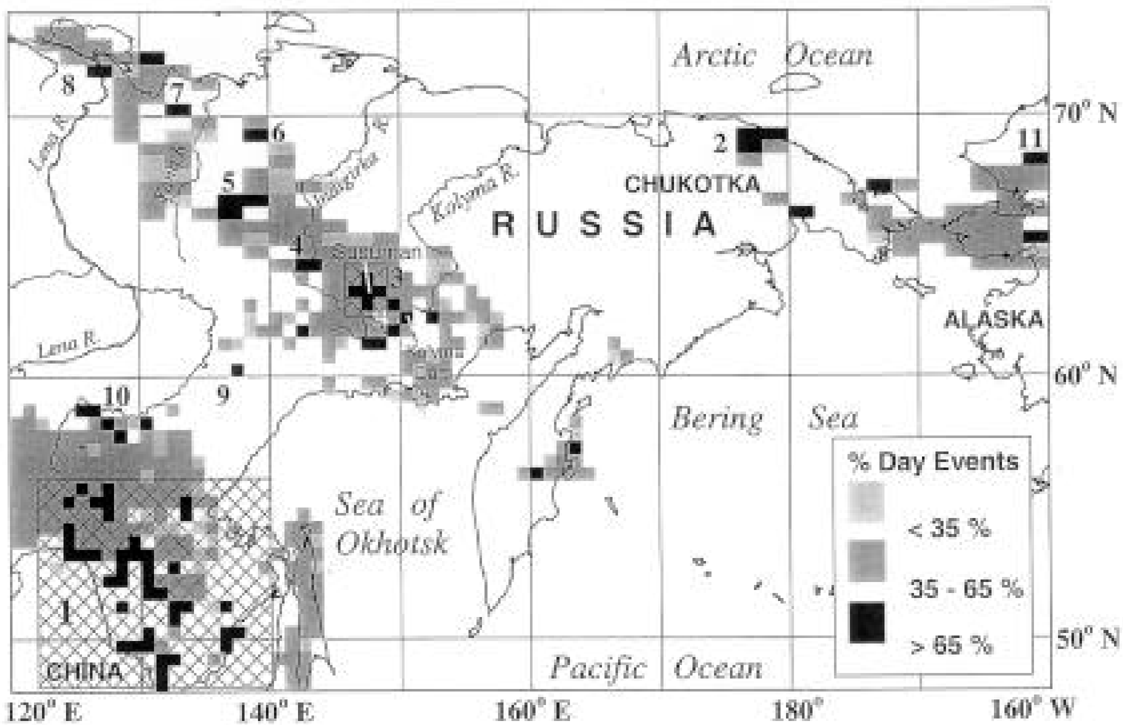

Figure 2. Grid map of northeast Russia showing areas where seismic events are concentrated during local day (black), local night (light gray), or balanced (dark gray). White indicates insufficient data. Numbers denote areas discussed in text; cross hatching denote larger areas.

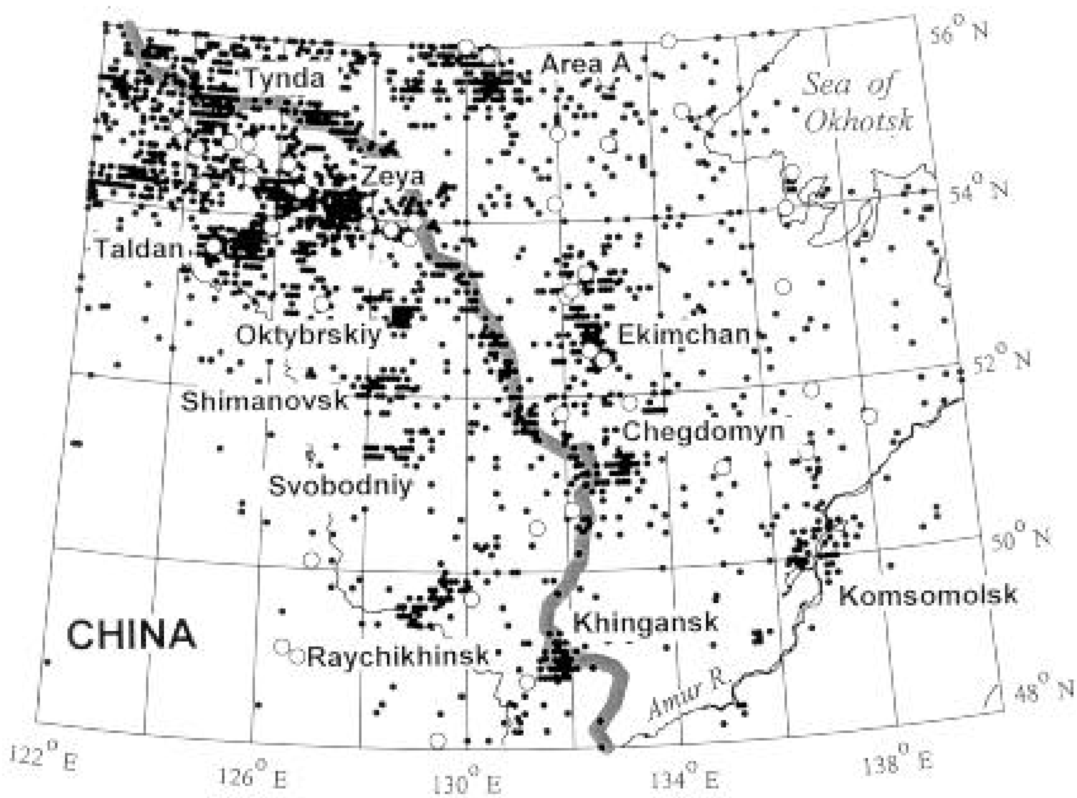

Figure 3. Daytime seismicity of the Amur district and locations discussed in text. Grey line shows Baikal-Amur railroad. Open circles are teleseisms.

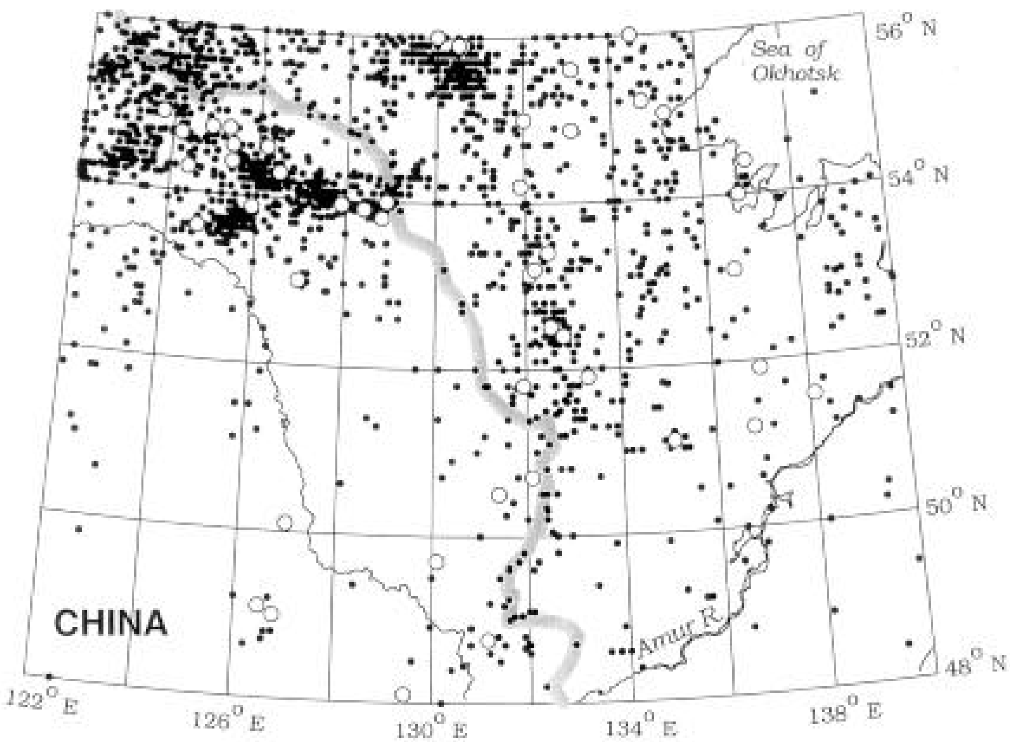

Figure 4. Nighttime seismicity of the Amur district. Key is identical with Figure 3.

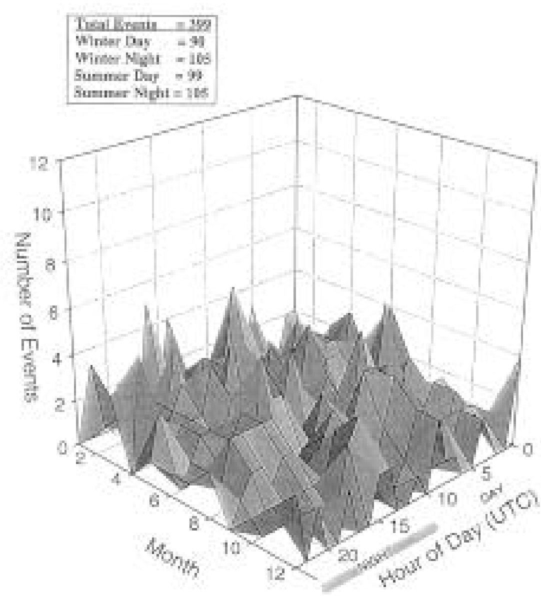

Figure 5. Temporal distribution of earthquakes in "Area A" of Figure 3.

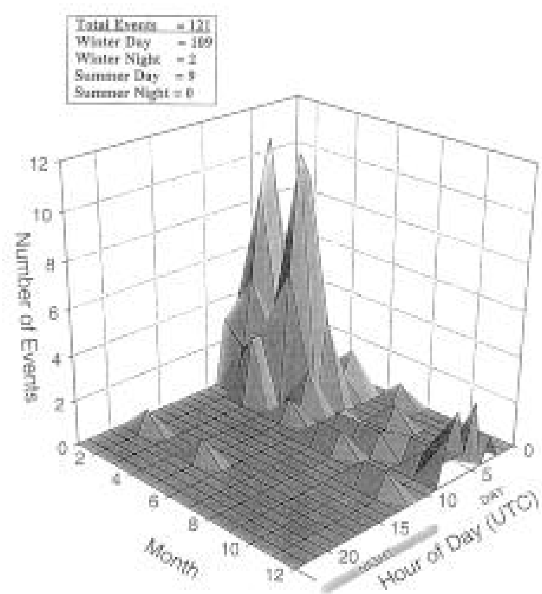

Figure 6. Temporal distribution of earthquakes in the Raychikhinsk coal mining district (Figure 3).