# SEISMIC REGIONALIZATION IN NORTHEAST RUSSIA

Kevin G. Mackey,[1] Kazuya Fujita,[1] Lee K. Steck,[2] and Hans E. Hartse[2]

Michigan State University,[1] Los Alamos National Laboratory[2]

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## ABSTRACT

In an effort to characterize seismicity in support of nuclear explosion monitoring for the continental regions of northeast Russia, we have been analyzing information obtained from regional seismic network operators. Our goal is to merge catalog, bulletin, waveform, and other ground truth data from several regional networks into a comprehensive data set that we will use for various seismic research projects. To date we have compiled a bulletin from published and unpublished event data of about 200,000 events and over 150,000 arrival times. We have also determined that the Russian regional network catalogs are contaminated with mining-explosion events. Hence, one of our primary efforts is to identify mining events when possible and move them into a separate bulletin from the natural earthquakes.

We have extended our preliminary analysis of explosion contamination of Russian seismicity catalogs using temporal analysis into the Irkutsk and Chita districts and the Buryat Republic. Based on analysis of epicenters and origin times reported in *Material po Seismichnost' Sibiri* for 1970 – 1993, it is likely that considerable explosion contamination occurs in the gold (Bodaibo, northern Irkutsk Region, and in the Chita region), mica (Vitim, northern Irkutsk Region), and other mining areas (Bushulei, Nerchinsk, and Petrovsk in the Buryat and Chita areas). Explosion contamination is also observed in northernmost Mongolia in the mining and industrial district near Darkhan. Explosions associated with the construction of the Baikal-Amur Mainline Railroad are likely, as was observed in the Amur district; however, the amount of natural seismicity dominates the activity and makes it impossible to resolve the railroad separately.

In conjunction with the Magadan Seismic Network operators, we have deployed a small network of digital stations to aid in our calibration efforts. We have been obtaining digital waveforms from this deployment for several years. As part of our current project, we will be deploying additional stations in other regions of Siberia. In the later stages of this three-year project, we will derive regional velocity models, calibrate regional magnitude scales [such as mb(Lg) and mb(coda)], test regional event discriminants, and rank ground truth events for calibration of far-regional and teleseismic stations.

## OBJECTIVE

The objective of our research is to improve event location and identification capability in northeast Russia in support of nuclear-explosion and treaty monitoring. We plan to reach our objectives through (1) collection, analysis, and merging of regional catalogs and bulletins, (2) deployment of additional digital seismic stations in northeast Russia, (3) relocating events and estimating appropriate correction surfaces for improved locations, and (4) analysis of waveform characteristics to identify effective regional event discriminants.

## RESEARCH ACCOMPLISHED

This is a newly-funded project that has been underway for only a few months. However, to date we have obtained bulletins and catalogs, begun merging and analysis of the bulletins, and deployed new stations in northeast Russia.

We have expanded our previous seismicity catalog (Mackey and Fujita, 2001a) for northeast Russia (Figure 1; approximately 200,000 events) to include the Irkutsk district, the Buryat Autonomous Republic, and the Chita district. These areas are under the auspices of the Irkutsk regional seismic network. Catalog data were obtained from *Materialy po Seismichnost' Sibiri* (1970-1993; Data on the Seismicity of Siberia; hereafter *Materialy*), a bi-monthly publication with both epicenter lists and phase data for the continental seismic networks in Siberia (Irkutsk, Magadan, Yakutsk, Amur (1979-1993) and Altai). We have supplemented this listing with catalog data from the Irkutsk regional network (1993-1996). For the Irkutsk network, the catalog is generally complete for K-class greater than about 8 (approximately magnitude 2 ¾; Figure 2). Data for the Kamchatka peninsula were obtained from the Kamchatka seismic network.

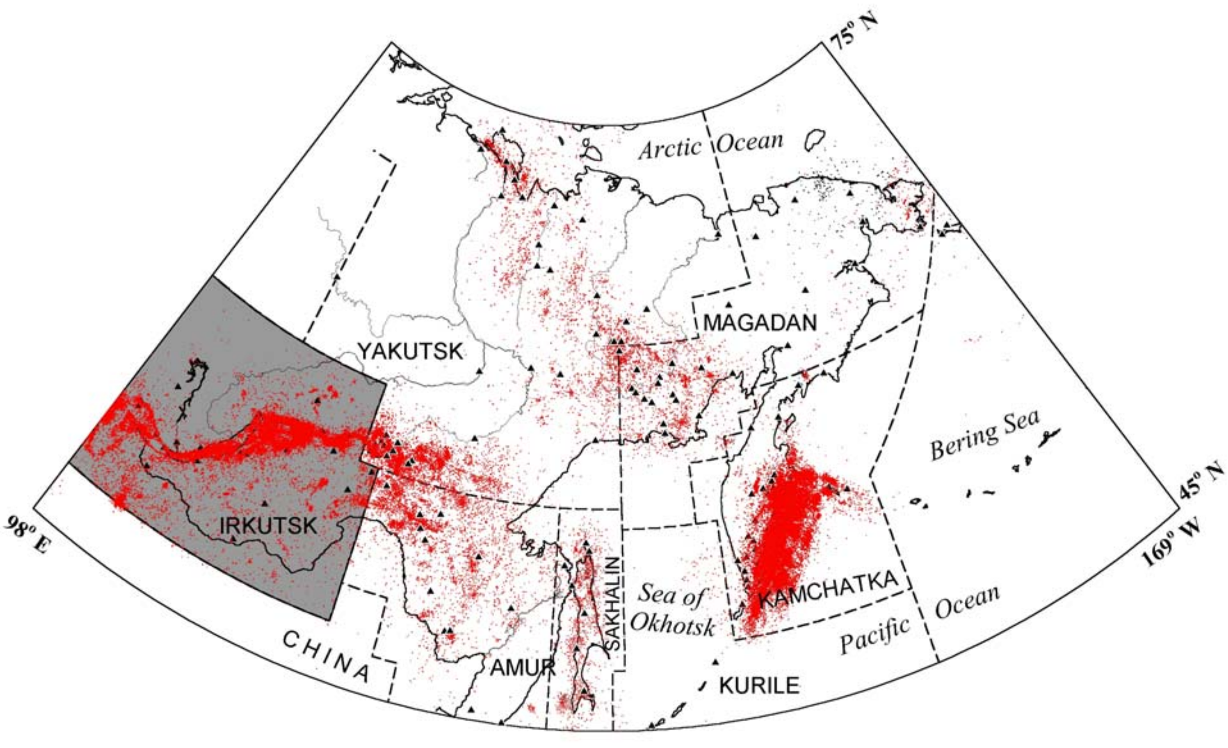


**Figure 1.** Seismicity catalog of northeast Russia depicting approximately 200,000 events. Events of the Irkutsk network (shaded gray) were recently incorporated into the catalog. Seismic network boundaries are depicted by dashed lines and historically operated seismic stations by triangles.

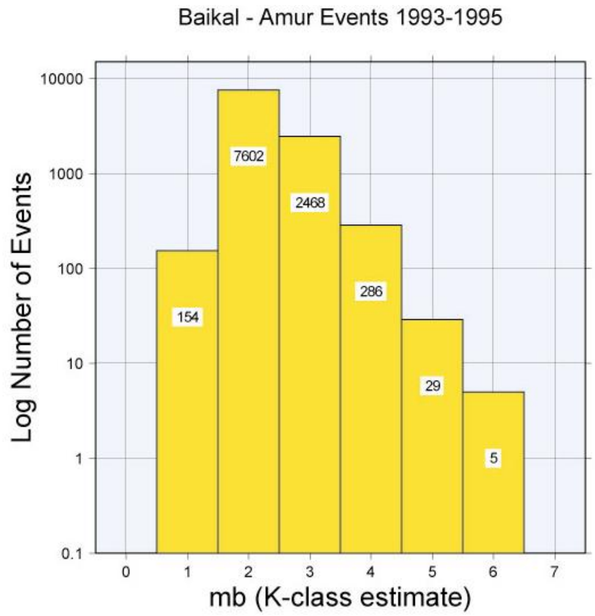


**Figure 2**. Histogram for the earthquakes in the Irkutsk network (1993-1995) showing magnitude (derived from K-class) versus number of events. This indicates that the catalog is complete for events larger than magnitude 2.5 or 3.0, which corresponds to a K-class of about 8.

## Explosion Contamination

The seismicity catalog for the Irkusk, Buryat, and Chita regions is presumed to be contaminated by a large number of industrial explosions (e.g., Godzikovskaya, 1995) in a manner similar to other areas discussed in our previous study (Mackey and Fujita, 1999). As in the rest of eastern Russia, explosions occur in mica, iron, tin, coal, and placer gold mines, as well as in prospecting and the construction of roads, railways, and dams. In the study area, many of the active mines are located outside highly seismically active regions, which makes identification of regions contaminated by mining explosions relatively easy. However, much of the blasting associated with the construction of the Baikal-Amur railroad (BAM) occurs in regions of high tectonic activity that mask all but the highest levels of explosion contamination. Contamination of the seismicity catalog with explosions here, as elsewhere, results in an erroneous perception of the level and distribution of natural seismicity.

As in our previous study (Mackey and Fujita, 1999), a qualitative estimate of the level of explosion contamination and levels of natural seismicity can be obtained by examining the spatial and temporal characteristics of earthquakes located by the regional networks (e.g., Agnew, 1990). The study area was 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. Light blue (light gray) areas in Figure 3 represent regions where seismicity is roughly balanced between night and day, and dark blue (dark gray) areas are those in which seismicity is concentrated during local night (>65%). There are several areas of night time-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.

Pink (medium gray) areas on Figure 3 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 Patom Highlands region have more than 90% of the events occurring during local day. Below, we examine several regions, shown in Figure 3, of daytime bias that can be positively related to explosion contamination.

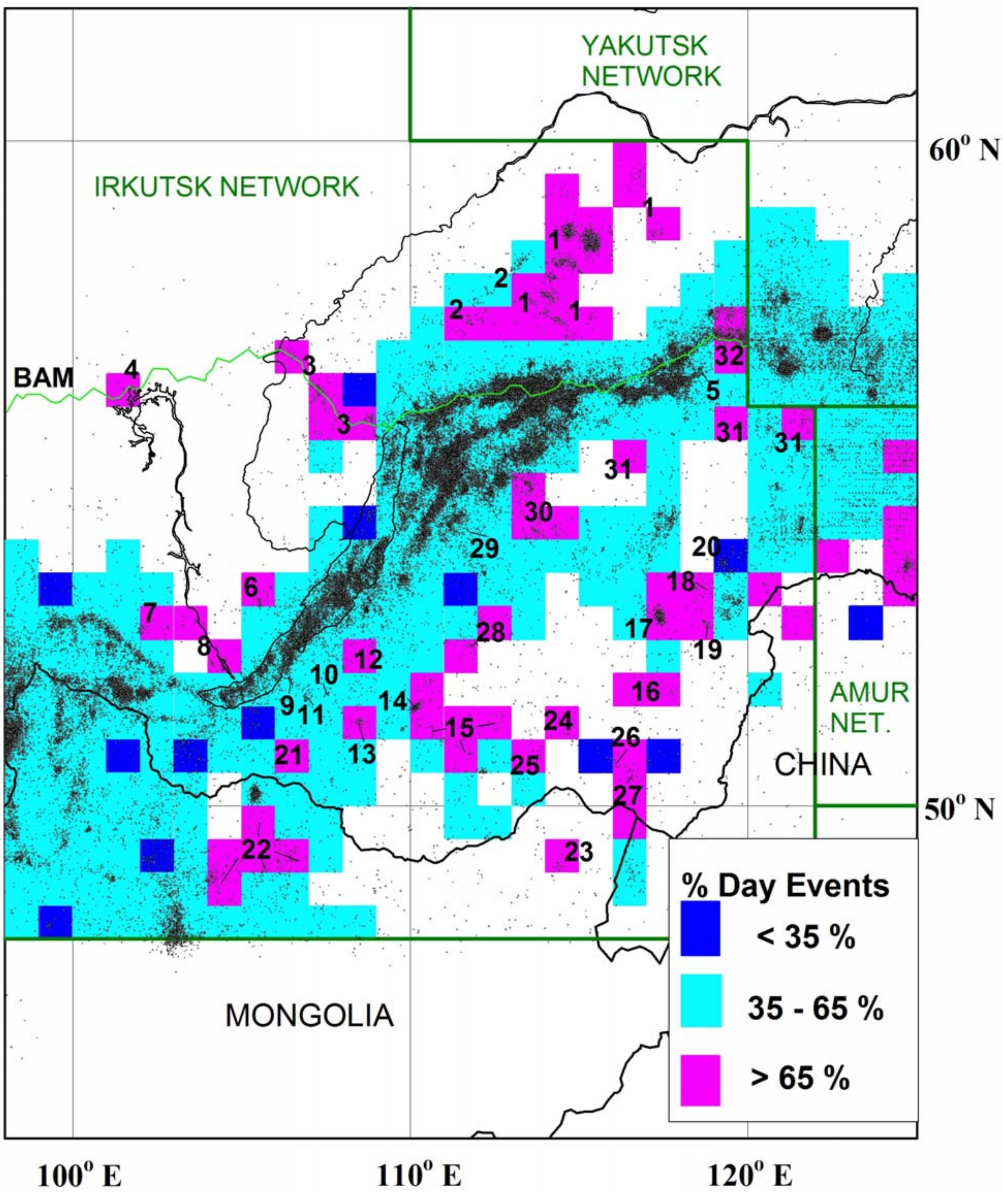


**Figure 3**. Seismicity of the Irkutsk network showing percentages of daytime events by cell. Explosion contamination of the seismicity catalog is suspected where cells are pink (> 65% of the events occur during local daytime). Numbers are keyed to text. The green line depicts the Baikal Amur Mainline railroad (BAM).

Recently, there have been attempts to filter explosions and many areas of explosion activity have been identified for the late 1990s (Masal'sky, pers. com.); however, analysis of temporal distributions remains the best way to study contamination of the historical seismicity catalog. 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. Because few explosions exceed magnitude 3.5, teleseismically recorded events in the historical catalog are not likely to be contaminated. 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 night time explosions listed in the network bulletins.

**Explosion Contamination by Region**

Possible anthropogenic origins of explosion contamination identified in the compiled seismicity catalog were researched using various publications on tourism and economic geography of eastern Russia, 1:200,000 Soviet military topographic maps, and 1:500,000 and 1:1,000,000 US air navigation charts.

One of the clearest regions of explosion contamination is the **Patom Highlands** (Area 1, Figure 3). Here, almost all of the seismicity is biased towards local daytime. This is an extensive region of placer gold mining (Shabad, 1969). The clusters of seismicity are centered on mining centers located at Marakan, Kropotkin, Svetlyi, Artemovsky, and Bodaibo. Additional areas of probable gold mining activity are located along the road between Perevoz and Chapaevo, near Bul'bukhta, and along the Pravyi Mamakan River. It is possible that some events could be related to construction of the dams on the Pravy Mamakan River. Analysis of events from the mid-1990s indicates that there is a tremendous bias with almost all events occurring between 2100 and 1400 UTC, and no events between 1400 and 2100 UTC (Figure 4). Events, however, appear to occur seven days a week, but with a peak in mid-week.

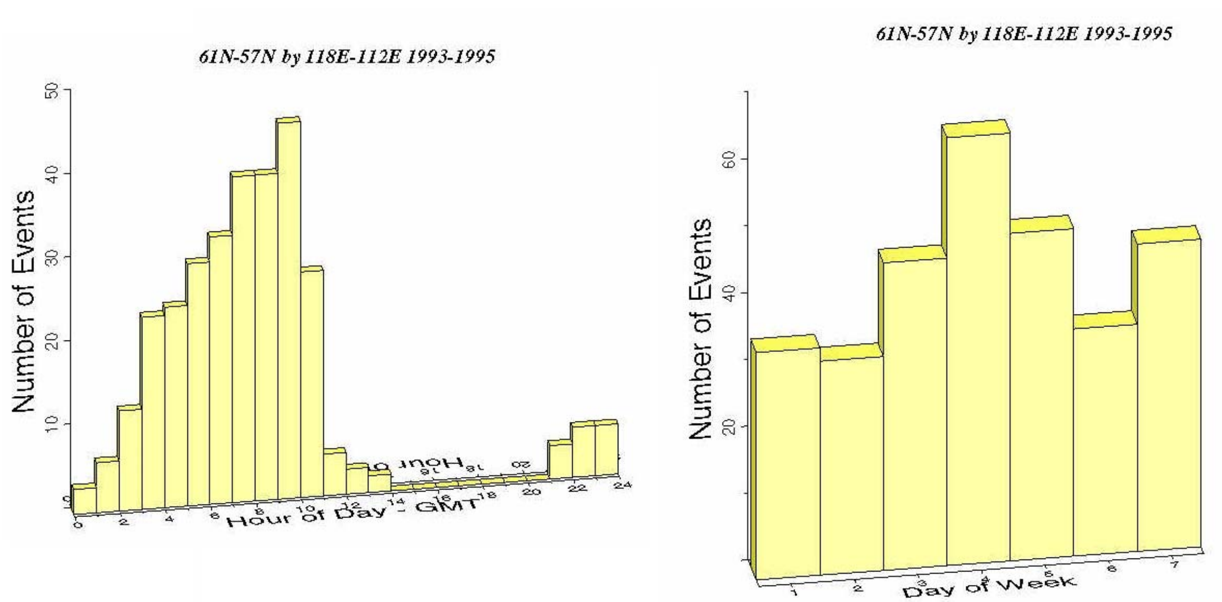


**Figure 4.** Histograms of reported earthquakes in the Patom Highlands region. The left histogram depicts number of events vs. time of day, with almost all events occurring during local day (GMT 0-11 hours). The right histogram depicts number of events vs. day of week, showing an increase in activity mid-week.

A series of phlogopite mica mines lies along the **Mama and Vitim Rivers** (area 2; Shabad, 1969). The northern part of this trend, near the Vitim River, shows no temporal seismicity bias, although events occur along the mining trend. A cluster of daytime biased events, however, occurs south and southeast of Gorno-Chuisk at the southern end of the mica mining district.

A series of grid squares located along the **BAM** (area 3) between Ust' Kut and Severo Baikal'sk show daytime biases. A small cluster at the eastern end near the now abandoned settlement of Granitnyi may be associated with the construction of the Del'bichinda Tunnel, which was completed in 1984 (Yates and Zvegintzov, 2001). Further west, a cluster of events is found slightly offset to the southwest of the BAM between Nebel' and Okunaisky. As no mining is known in this area and construction of the BAM here occurred in the late 1970s and early 1980s, these events are likely associated with construction, as is the cluster of events east of Ust' Kut.

A daytime biased cluster is also located near **Bratsk** (area 4), the site of the Bratsk hydroelectric station as well as a large industrial complex. As no nighttime events occur here, it is presumed that these represent explosions related either to construction or to other industrial activity; mining is not associated with this area.

No events are associated with two large iron mining complexes in the area, at Zelenogorsk-Ilimsk and Rudnogorsk (Yates and Zvegintzov, 2001); thus, they must either be too small to be recorded at the network (the closest stations are 400-500 km away), or the operators are able to identify these events.

No strong signal is observed near the **Udokan** copper mines (area 5); however, they lie in an area of high tectonic activity. It is possible that a detailed search of the area would identify either exploratory blasting or blasting associated with infrastructure being built in the area (Yates and Zvegintzov, 2001).

An unexplained cluster of daytime events occurs near Bayandai (area 6) in the **Bayandaevskii Raion** of the Ust' Ordynskii Buryat Autonomus Okrug, which is close to a cluster of explosions identified by the Irkutsk network at the Kharanut coal mine (Gorkin, 1998). A smaller cluster is located northeast of Bayandai near the town of Khogot. The only mineral deposit reported in the Bayandai area consists of white clay (Gorkin, 1998).

A cluster of daytime activity occurs at **Onot** (area 7), the site of talc production (Sherbakov, 1991). There is no significant signal from the nearby coal mines in the Cheremkhovo area.

Daytime biases with a small amount of seismicity are associated with the industrial cities along the **Angara River** (area 8; Usol'e Sibirskoe, Angarsk, and Irkutsk). As no significant mining occurs in these areas, it is presumed that these are explosions related to industrial activity.

South of the active Baikal seismic belt, there are numerous areas of presumed explosion contamination. Many of them lie along the Trans-Siberian Railroad and along its two major branches, the Trans-Mongolian and Trans-Manchurian routes. We discuss these from west to east along the rail lines.

Although not identified in our statistical calculations, a cluster of daytime bias stands out just off of the eastern coast of Lake Baikal between **Bol'shaya Rechka** (area 9) and Selenga. The events trend to the east-southeast, but probably are due to an east-west striking chain of limestone quarries located south of the Selenga River.

A small cluster of events also identifies the town of **Ulan Ude** (area 10), a major manufacturing center, while an unattributed cluster of daytime events occurs near the settlement of **Khuramsha** (area 11), 40 km to the southwest; no mining or industrial activity has yet been attributed to this area.

To the northeast of Ulan Ude, a diffuse cluster is located in the southern part of the **Ulan Burgassy Range** (area 12). These may be associated with the Balbagar iron ore deposit (Thiel, 1957), but are offset to the north and west; alternatively they may be exploratory blasting.

The next cluster of presumed explosions is in the area to the west of **Petrovsk-Zabailak'sky** (area 13). There are a number of mining towns in this area associated with deposits of gold, tungsten, tin, lead, zinc, molybdenum, and lithium (Thomas, 1997). Specific clusters appear to center on the towns of Shabur, Kusoty, and Khonkholoi. There is no contamination associated with the coal mines along the Khilok River (e.g., Kataevo, Balyaga, Kuli, Tarbagatai, and the large pit at Novo Pavlovsk)

A cluster along the Trans-Siberian Railroad near Glinka and Zhipkhegen is elongated along the railroad line (area 14). However, the main locus of possible explosion activity is a mine just to the north of **Zhipkhegen**. Either the location procedures cause a smearing of the blast locations or there may have been expansion of the mining area along the foothills of the Tsagan-Kurtei Range. Resources in the region include sand, clay, gravel, coal, and some minerals (Gorkin, 1998).

To the southeast, daytime bias is found along the highway between Chita and Khilok along the upper **Ingoda** and **Arei Rivers**, including the settlement of Leninsk (area 15). Known mineral deposits in this area include gold ore, tungsten, uranium, and coal (Gorkin, 1998). Although the region was developed as an agricultural base, it is probable that there has been recent development or exploration in some of these deposits.

A very small and perhaps statistically marginal cluster of events is found around **Nerchinsk** and to the east (area 16). Nerchinsk is an old gold and silver mining area. No noticeable events are associated with gold mining at Balei to the south and Vershino-Darasunsky to the northwest (Shabad, 1969).

The largest cluster of daytime biased events occurs in the area of **Bushulei** (area 17), a gold and molybdenum mining district (Thomas, 1997) located on the Trans-Siberian railroad. The main mines are located to the east of the railroad. There is no significant signal from the coal mines at Bukachacha (Shabad, 1969) to the northwest of Bushulei .

A diffuse cluster of events lies along the **Chernaya River** valley (area 18), southeast of Sbega. As of about 1990, no development was known in this area. However, given the proximity of gold mining districts to the northeast and south, it is possible that this represents some exploratory activity. The compact cluster to the south is associated with the **Ust' Kansk** (area 19) gold mining district (Thomas, 1997).

A cluster that does not appear in the grid search, but is apparent by inspection, is located south of the Trans-Siberian railroad in the area of the Davenda molybdenum mine and the **Klyuchevsky** gold mine (area 20; Shabad, 1969). The open pit mine at Klyuchevsky is a more likely site for larger explosions; however, in 1999-2000, the Irkutsk network identified activity as being dominantly from Davenda.

Along the Trans-Mongolian railroad south of Ulan Ude, a small cluster of daytime biased events is found near **Novoselenginsk** and southeast of Ozero Gusinoe (area 21). Although these events may be associated with coal mining at the Kholboldzhinsky mine on the southeast edge of Ozero Gusinoe, the fact that explosions from all other coal mines seem to have been excluded from the catalog makes it unlikely that events from this large complex would be included; thus, an alternate cause is suspected.

Further south, presumed mining and industrial events occur in **northern Mongolia**, in particular near the huge copper mine at Erdenet, and the industrial and mining towns of Ornon, Darkhan, and Sharyn Gol (area 22; Mayhew, 2001). The Irkutsk network has also identified numerous explosions from Darkhan and Erdenet in the past few years. However, a cluster in an uninhabited area of northeast Mongolia **north of Choibalsan** (area 23) is difficult to explain.

Several clusters of presumed industrial explosions are found along and near the route of the Trans-Manchurian Railroad. Southeast of Chita there is a cluster of activity near **Orlovsk** (area 24), the site of a tantalum mine (Shabad, 1969). Another cluster, which can not be attributed at this time, occurs near **Taptanai** (area 25); however, deposits of tungsten and gold are reported in the area (Gorkin, 1998).

A compact cluster of daytime events is located near **Mirnaya** (area 26), and a larger cluster near **Sherlovaya Gora** (area 27). Tin and coal mining is concentrated near the latter town (Shabad, 1969). Other mining in the area associated with flourspar (Kalangui and Klicha) and lithium (Akatui, Gornyi Zerentui, and others), do not register in our analysis.

Finally, several clusters of presumed industrial events are found north of the Trans-Siberian and south of BAM, mainly in the Buryat Autonomous Republic. Two centers of presumed explosions are located about 100 km northwest of Chita. These events cluster around the towns of **Sosnovo-Ozerskoe and Isinga** (area 28). Limestone quarrying is known in the Sosnovo-Ozerskoe area and polymetallic ores are found in the region (Gorkin, 1998).

A small cluster of daytime bias is noted near the settlement of **Karaftit** (area 29) where there is a gold mine (Shabad, 1969), although the search grid box is statistically dominated by the tectonic activity of the Baikal rift zone. Further east, large clusters of daytime events are located around **Tsipikan**, Bagdarin, Severnyi, Mongoi, and Rossoshino (area 30). These areas are alluvial deposits worked by dredging (Thiel, 1957).

Three grid squares (areas 31) with greater than 65% daytime events are found in the far northern part of the Chita oblast. None of these can be associated with mining or construction. Only one square, encompassing **Kalakan**, is associated with a populated point. These may be due to the small number of statistics or to exploratory drilling.

Finally two grid squares bracketing the BAM (area 32) are found around **Mururin**. It is surprising that these two grid squares alone along the tectonically active part of the BAM yielded strong daytime biases. Since there is a significant amount of nighttime seismicity here as well, there is likely both natural and anthropogenic activity. One possible explanation is that this section of the BAM is the highest (Yates and Zvegintzov, 2001) and considerable blasting was likely required in its construction.

Based on the above analysis, it is apparent that explosions at coal and iron mines have been fairly well filtered, even prior to the late-1990s, and are not included in the seismicity catalogs. Explosions associated with placer gold and construction, and some quarrying, however, are still prevalent in the catalogs.

## Digital networks and deployments

Our current research will incorporate data recorded by existing digital stations throughout eastern Russia. Currently the Irkutsk network operates 19 (excluding the IRIS station TLA) and the Yakutsk network four (excluding the IRIS stations YAK and TIXI) digital stations (Figure 5). We will also continue development of our digital station network in northeastern Russia to improve epicenter locations and begin a program to develop seismic discriminants in support of nuclear-explosion and treaty monitoring by digitally recording local explosions and earthquakes. Deployment of these stations began under a previous project (Mackey and Fujita, 2001a). At present, we have eight permanent stations deployed in and operated in conjunction with the Magadan and Yakutsk networks of northeast Russia (Figure 5). All stations are 3-component, with three stations recording broadband instruments. The remaining stations use short-period Russian seismometers (SKM-3 or SM3-KV). All seismometer outputs are digitized at 30 samples per second with 24-bit resolution and logged on a PC. Our current project will deploy additional digital stations throughout northeastern Russia, primarily supplementing existing digital stations in the Irkutsk and Yakutsk networks (Figure 5). Most of these new stations will use Geotech Instruments KS-2000 broadband seismometers. To aid in the acquisition of ground truth data, three additional portable digital stations will be maintained for temporary deployment at mine sites or in aftershock studies. Ultimately, one aspect of this project will be to combine digital waveform data from all digital stations in northeast Russia into a single database containing both earthquakes and explosions.

Using the existing deployed stations in the Magadan network, we have thus far recorded several hundred earthquakes, and mine blasts from many locations throughout the Magadan region with yields ranging up to or exceeding 40 T. To obtain ground truth information on explosions, we have either visited or deployed temporary stations at mine sites, and we have been able to obtain information on blast size and location. Additional information and seismograms from early stages of this deployment can be found in Mackey and Fujita, 2000, and Mackey and Fujita, 2001 a,b. In addition, we plan to deploy our temporary stations at mine sites as we expand our digital network and use data acquired for ground truth studies.

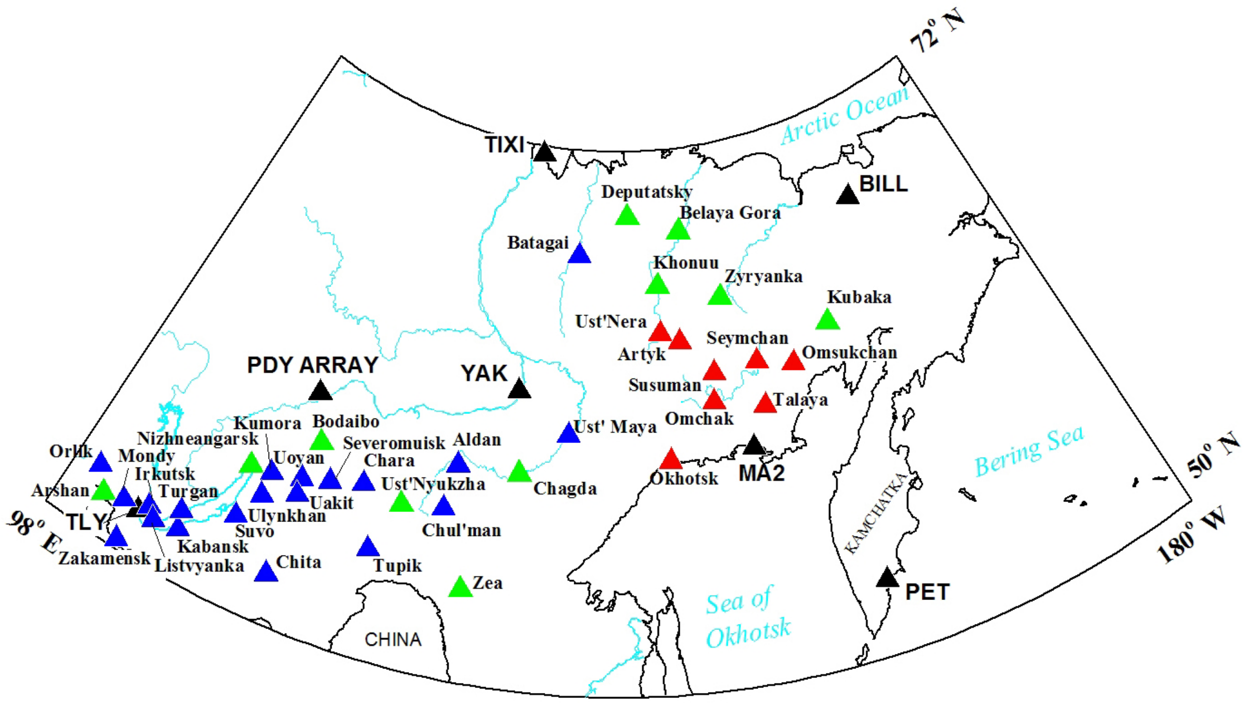


**Figure 5.** Digital stations in northeastern Russia to be used in this study. Red triangles – digital stations operated jointly between Michigan State University and local seismic networks. Black triangles – IRIS and International Monitoring System stations. Blue triangles – digital stations operated by Russian seismic networks. Green triangles – preliminary sites for additional stations to be deployed as a part of this study.

## CONCLUSIONS AND RECOMMENDATIONS

We have begun an ambitious project to compile a complete seismic catalog and bulletin for northeast Russia to use for ground truth studies and develop velocity models for the region. We are also in the process of deploying a digital seismic network in northeast Russia in cooperation with local network operators. Waveform data from our network will be combined with that from other existing digital stations to improve monitoring in the area and develop seismic discriminants. Additional portable digital stations will be maintained in the region for rapid deployment at active mine sites to record explosions or to record aftershocks from large events if the opportunity arises.

## ACKNOWLEDGEMENTS

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