DEVELOPING COMPOSITE REGIONAL CATALOGS OF THE SEISMICITY OF THE FORMER SOVIET UNION

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Sponsored by United States Geological Survey

ABSTRACT

Seismological studies by institutions of the former Soviet Union during the 20th century employed standard instrumentation and methods of data processing for determining standardized parameters to describe seismic sources, resulting in the production of regular summary publications. For most of the century, bulletin data were published only in Russian and were generally unavailable to the Western scientific community. Yet, for many regions of this vast territory, earthquakes with magnitudes less than 2 were routinely located and characterized, especially since the early 1960s. A great volume of data on the seismicity of the Eurasian land mass is therefore available, although to date only in scattered publications and for incomplete periods of time. To address this problem, we have undertaken a comprehensive compilation, documentation and evaluation of catalogs of seismicity of the former Soviet Union. These include four principal, Soviet-published catalog sources, supplemented by other publications. We view this as the first step in compiling a complete catalog of all known seismic events in this large and important region. To make these data more useful for regional seismic investigations, as well as to be consistent with their provenance, we have prepared *composite regional catalogs* in digital form, dividing the territory of the former Soviet Union into 24 regions. For each of these regions, all the data available from the basic and supplementary catalog sources have been combined and evaluated. For regions with low seismicity, we have included the historical, non-instrumental (macro-seismic) data. Completion of this work will require digitizing the remaining catalogs of the various regional seismological institutes.

OBJECTIVE

During the 20th century, seismological studies by institutions of the former Soviet Union employed standard instrumentation and methods of data processing for determining standardized parameters to describe seismic sources, resulting in the production of regular summary publications. For most of the century, event data were published only in Russian and were generally unavailable to the Western scientific community. Yet for many regions of this vast territory, earthquakes with magnitudes less than 2 were routinely located and characterized, especially since the early 1960s. A great volume of data on the seismicity of the Eurasian landmass is therefore available, although to date only in scattered publications and for incomplete periods of time.

To address this problem, we have undertaken a comprehensive compilation, documentation and evaluation of catalogs of seismicity of the former Soviet Union. These include four principal, Soviet-published catalog sources, supplemented by other publications. We view this as the first step in compiling a complete catalog of all known seismic events in this large and important region. Completion of this work will require digitizing the remaining catalogs of the various regional seismological institutes.

To make these data more useful for regional seismic investigations, as well as to be consistent with their provenance, we have prepared composite regional catalogs, dividing the territory of the former Soviet Union into 24 regions. For each of these regions, all the data available from the basic catalog sources (see below) have been combined and evaluated. Note that, for regions with low seismicity, the historical (non-instrumental, macro-seismic) data are of increased importance. Such information, if not included in any summary, were taken from various publications and marked as "historical".

RESEARCH ACCOMPLISHED

Brief History of Seismological Study in Russia and the Former Soviet Union

The first substantial summary of earthquakes in Russia and adjacent territories was the catalog of I.V. Mushketov and A.P. Orlov [1893; Figure 1], which was based solely on macroseismic data. The beginning of regular seismic observations in Russia was marked by the issuance of a noteworthy publication --the Bulletin of the Permanent Central Seismological Commission (or PCSK [2]), published from 1902-1908 under the direction of G.V. Levitskaya. Being aware of imperfections in the seismic instrumentation used at that time, the compilers of the PCSK Bulletin did everything possible to preserve the main quantitative characteristics of these records –the amplitude and duration of vibrations– in the most complete form. Macroseismic data were collected under the direction of the PCSK, and were combined with instrumental data in a separate publication, in order to simplify the use of the materials in the PCSK Bulletin.

From 1908 to 1928, periods and amplitudes were published in the first Soviet summary bulletin of the network of seismic stations [3]. Because of the exceptionally high quality of seismogram analysis, reflected in the individual bulletins of the best seismic stations (e.g., Pulkovo and the independent stations of Anapa, Grozniy, Pyatigorsk, Samarkand and others), it is still possible to calculate accurate earthquake magnitudes for events in this time period. Beginning in 1923, the bulletins of the individual seismic stations were published in Moscow by the Institute of Physics of the Earth.

By 1911, macroseismic observations were being separated from instrumental data, and their publication in the bulletins became of secondary importance. Macroseismic data were collected and analyzed, but published independently, without cross-reference. Eventually, however, the boom in construction brought to the forefront the problem of seismic risk, and aroused new interest in historic strong earthquakes. In these early years, the Caucasian seismologist Eu.I. Bius compiled an exceptionally detailed and complete catalog of Earthquakes In Transcaucasia [4], and a number of other data collections were published [5-8]. Changes were also made to the summaries of instrumental data. For example, the inability to accurately calculate true ground displacement was considered sufficient reason to remove the dynamic characteristics of waves from event summaries.

A landmark publication was the 1962 Atlas of Earthquakes in the U.S.S.R [9], a compilation and presentation of earthquakes that occurred in the period of 1911-1957. This volume, which included a catalog of seismicity and detailed maps, served to summarize this early period in the development of Soviet observational seismology.

After the 1948 devastating Ashkabad earthquake, the expansion of the seismic network was undertaken, as well as the replacement of the seismographs of the Nikiforov system with what were then the advanced broadband seismographs of the Kirnos system (CK). This created a new foundation for improving the analysis of observations. Substantially more precise calculation of amplitude of ground displacement soon made it possible to incorporate the earthquake magnitude into seismological practice. After 1956, the sensitivity of seismic stations was further increased and the dynamic and frequency

Figure 1. Cover of the first comprehensive catalog of earthquakes in Russia (Mushketov and Orlov, 1893, "*Catalog of the Earthquakes of the Russian Empire*").

ranges of the recorded signals were widened. Short-period seismographs of high sensitivity were installed at the network stations, as well as long-period instruments and seismographs for recording strong ground motions. In the 1970s, the sensitivity of the equipment was increased again, with the dynamic range of instruments increasing to 100 dB. An increase in the number of stations was accompanied by unification and standardization of seismic observations. With a few exceptions, the instrumental and macroseismic data were not cross-correlated or jointly analyzed.

Principal Catalog Sources

By the end of the 20th century, four principal earthquake catalogs had been compiled and published (one electronically):

- The Obninsk Bulletin, issued every 10 days in the period from 1955 through 1999;
- The annual series, "Earthquakes in the USSR" (and since 1991, "Earthquakes in Northern Eurasia"), consisting of the regional catalogs of the ESSN, or Unified System of Seismic Observation. Published annually in Russian since 1962, a recent issue, published in 2000, was for earthquakes in 1994.
- The "New Catalog of Strong Earthquakes in the USSR," compiled by Shebalin and Kondorskaya [1974].
- The "General Catalog of Earthquakes in North Eurasia", compiled by the Institute of Physics of the Earth under the direction of W. Ulomov (and a nearly inclusive extension of the "New Catalog").

Additional event data were taken from the catalog published by *SevMorGeo* [10], the book, "The Seismic Regionalization of USSR Territory" [11], and various other publications. Some non-instrumental data were taken from a collection of felt earthquakes by Nikonov and Ananin (still being compiled). At present, not all of the available data are in digital format. For example, some of the most seismically active regions, such as Kopetdagh, Central Asia and the Far East, the smallest earthquakes (M < 3.5) are not yet available. A diagram illustrating the provenance and publication histories of the various catalogs is shown in Figure 2, and summarized in Table 1. A comparison of the number of events per year in the principal catalog sources and in the regional catalogs is shown in Figure 3.

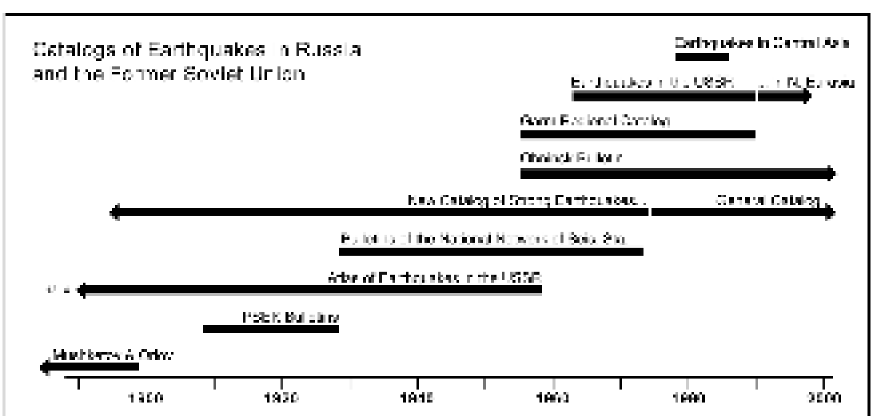

Figure 2. Time periods included in the various catalog sources of seismicity data for Russia and the Former Soviet Union.

Table 1. Summary of the principal catalogs of seismic events in the former USSR.

Short Name	Full Name (in translation)	Abbr.	Date Range Avail.
Obninsk Bulletin	Bulletin of the SEME GS RAS	OBN	1955-present
The Annuals	Earthquakes in the USSR Earthquakes in Northern Eurasia	ESSN	1962-1994
The New Catalog	New Catalog of Strong Earthquakes in the USSR [1973]	NEW	Historic through 1973
The General Catalog	General Catalog of Earthquakes in Northern Eurasia (digital)	GNRL	Historic through 1999

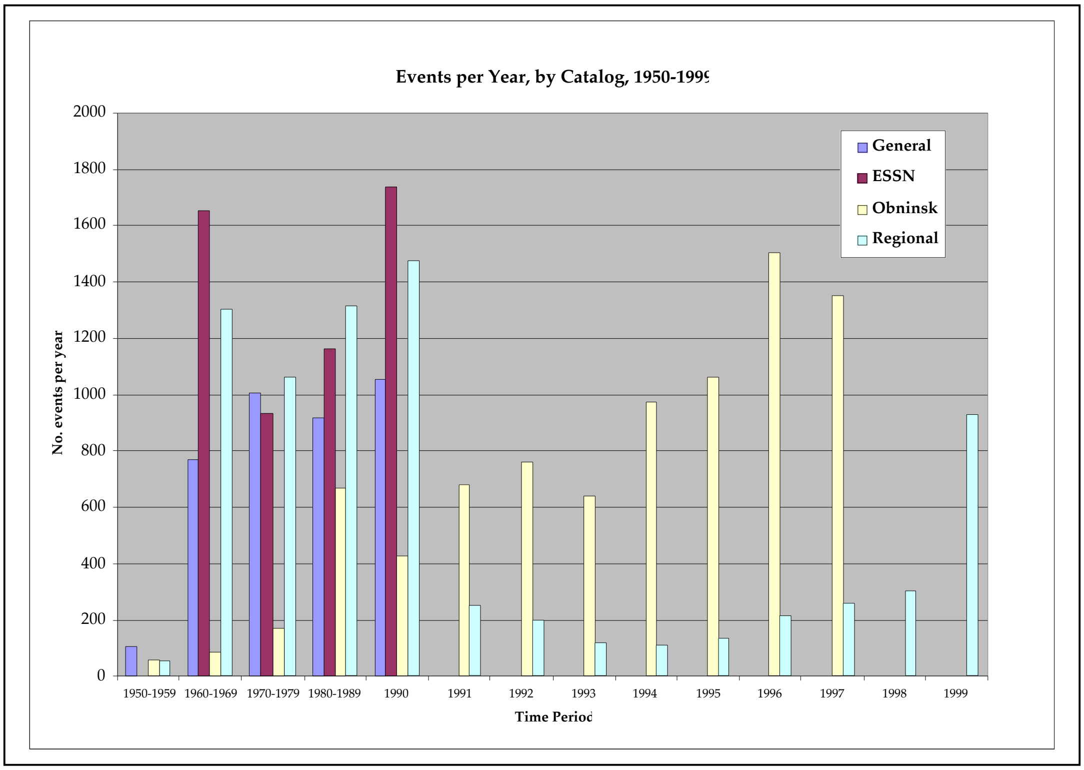

Figure 3. Numbers of events per year in the three principal catalog sources and in the regional catalogs we have compiled. Note that the Obninsk Bulletin is of earthquakes worldwide.

The Obninsk Bulletin

The "decadal" (Russian for 10-day) catalog was first issued by the Moscow Institute of Physics of the Earth, beginning in 1955. This catalog was compiled by the Seismological Expedition of the Geophysical Survey of the Russian Academy of Sciences (SEME GS RAS). Its publication was delayed only a few months, issued in about 50 paper copies, and sent to all the seismological centers of the former USSR. The Obninsk Observatory later became responsible for preparing the publication (now referred to as the Obninsk Bulletin), and it is now available in electronic format in its entirety.

The Bulletin includes the earthquakes recorded by numerous seismic stations (45, as of Dec. 2000) belonging to the Geophysical Survey of the Russian Academy of Sciences. At present, these stations include: 19 digital broadband stations; 2 micro-arrays; and 24 analog, three-component stations equipped with short-period, middle-period and long-period seismometers with analog galvanometer recording on photo paper. The broadband digital stations include 12 IRIS GSN stations and seven stations of Russian manufacture, known as the Seismic Digital Acquisition Station (SDAS). The analog stations of the network are equipped with short period (SKM) and long period (SK and SKD) instruments. The data from the teleseismic network of analog stations are transferred to the Obninsk processing center in the form of station summaries in alert and operation modes by regular telephone and teletype lines. The quality of digital station operations is monitored continually, but only periodically for the analog stations. No seismic event parameters are automatically determined.

For the digital recordings, the processing and analysis are done at the Obninsk processing center (CEME GS RAS). For analog seismograms, the operator of the station(s) does the analysis with subsequent transfer of results to Obninsk. The decadal catalog is available after a delay of about 30 days. It includes earthquakes in Russia with M > ~4.5; for the whole of Northern Eurasia, M > ~5.0; and for the globe, with M > ~5.5. The Bulletin is sent throughout Russia and to foreign data centers (e.g., in the USA, the USGS National Earthquake Information Center (NEIC), and in the U.K., the International Seismological Center (ISC)). Currently, the Obninsk Bulletin (through 1999) consists of about 41,550 earthquakes, worldwide. About 16,600 events are in the region roughly from 34-90N and 00-195E, including the former USSR and surrounding areas. A comparison of the number of earthquakes in the Obninsk Bulletin in this region during three five-year periods is as follows:

Years	No_Eqs
1955-1959	258
1975-1979	1,011
1995-1999	6,055

The Obninsk Bulletin reports origin times, coordinates, depth and magnitudes. Three magnitudes are traditionally reported: a surface wave magnitude MLH; a P- wave magnitude from short-period instruments (Mpsp; earlier called MPVA) and a long-period P-wave magnitude (Mplp, earlier called MPVB). Most events have no magnitudes; these are usually at about 4 < M < 4.5. The intensity data published in the Obninsk Bulletin are taken only from seismic stations as “alert” information, and not included in our composite regional catalogs.

The Annual "Earthquakes In The USSR" (ESSN)

By 1962, the creation and development of regional seismic surveys lead to a tremendous increase in the number of earthquakes detected in northern Eurasia (see Figure 3). Subsequently, the Institute of Physics of the Earth began publication of a new yearly summary, "Earthquakes in USSR" (Zemletriasenniia v SSSR), which was a collection of bulletin data from the regional seismological institutes, along with articles on the seismicity of the various geographic regions of the USSR.

Increased coverage, as a result of using regional and local stations, resulted in catalogs that had lower detection thresholds and higher epicentral location accuracies than that of the global catalogs (such as the ISC and USGS), which were based only on teleseismic observations. The much greater resolution of the Annuals is evident the a comparison of these data with the ISC Bulletin made by Simpson and Lerner-Lam [1992] for the years 1962-1986, which showed that the annuals have about five times as many events as the ISC Bulletin in that time period.

The data in the Annuals is based on observations solely from stations located within the former USSR. Coverage therefore decreases to the south and southeast. Epicenters are also reported only to the nearest 0.1 or 0.01 degree (11 or 1.1 km), resulting in a gridded pattern on maps of high-seismicity areas when viewed at large scales. Another problem with the catalog is the lack of resolution in depth determinations, which is especially prominent near the boundaries of regions covered by the regional networks. Many events are given zero or no depth (i.e., blank).

<u>Recent Contributors to the Annual</u>

Current contributors to the annual include the Geophysical Survey Russian Academy of Sciences and its Central Experimental-Methodical Expedition, as well as ten regional surveys operated under the management of Obninsk:

- Kamchatka Experimental-Methodical Seismological Department Geophysical Survey Russian Academy of Sciences
- Sakhalin Experimental-Methodical Seismological Department Geophysical Survey Russian Academy of Sciences
- Magadan Experimental-Methodical Seismological Department Geophysical Survey Russian Academy of Sciences
- Dagestan Experimental-Methodical Seismological Department Geophysical Survey Russian Academy of Sciences
- Kola Regional Seismological Center Geophysical Survey Russian Academy of Sciences
- Siberian Geophysical Survey, Branch of Russian Academy of Sciences
- Baikal Experimental-Methodical Seismological Expedition Geophys Survey Siberian Branch Russian Academy of Sci.
- Yakutiya Experimental-Methodical Seismological Dept Geophysical Survey Siberian Branch Russian Academy of Sci.
- Altai-Sayans Exp-Methodical Seismological Expedition Geophys Survey Siberian Branch Russian Academy of Sci
- North Caucasus - Central Experimental-Methodical Expedition of Geophysical Survey Russian Academy of Sciences

The additional contributors from outside Russia to Obninsk are:

- Carpathian Institute of Geophysics of the Ukranian Academy of Sciences;
- Crimea Institute of Geophysics of the Ukranian Academy of Sciences;
- Kopetdag Institute of Seismology of the Academy of Sciences of Turkmenistan;

- Central Asian Institute of Seismology of the Academy of Sciences of Kyrgyzstan;
- Institute of Seismology of the Academy of Sciences of Kazakhstan;
- Institute of Seismology of the Academy of Sciences of Uzbekistan
- North Tien Shan Institute of Seismology of the Academy of Sciences of Kazakhstan;
- Gruziya Institute of Geophysics of the Academy of Sciences of Georgia;
- Institute of Geophysics and Engineering Seismology of the Academy of Sciences of Armenia;
- Institute of Geology of the Azerbaijan Republic.

The structure of the Annual

The catalogs completed by each regional survey are only a part of the Annual volume. It includes as well the papers describing the seismicity on each zone, special paper with detail study of macroseismic data of strong earthquakes with isoseismal maps, separate paper about large (M>6) earthquakes in the world, tables of fault plain solutions and spectral content. As an example of the typical content of the annual "Earthquakes in the USSR," the contents of the 1990 volume are given in Appendix I.

The number of earthquakes in the Annual

Because the monitored regions differ both in terms of their seismic activity and their areal extent, the yearly number of earthquakes in the various regional catalogs range from a few tens of events to thousands of events. Table 2 compares the number of earthquakes listed in each zone in 1990 and 1993:

Table 2. Comparison of numbers of earthquakes reported in two years of the Annual.

Zone	in 1990	1n 1993
Carpathians	50	37
Crimea	100	11
Caucasus	300	330
Kopetdag	270	263
Central Asia and Kazakhstan	970	617
North Tien Shan	330	475
Altai and Sayan	110	117
Baikal	230	263
Primorie	320	136
Sakhalin	40	24
Kuril-Okhotsk	630	667
Kamchatka and Komandorskaya Isl.	550	880
North-East	70	40
Yakutia	260	255
Baltic Shield and Arctic	53	2
Large earthquakes in the World	113	100
Total for the year is about	4,400	4,200

These numbers vary in time not only because of variations in seismicity and changes in the number of operating stations, but also because of changes in a cutoff value of the lower magnitude (or "Energy Class", *K* [12,13]) for earthquakes that were included in Annual Catalog. In 1967, a decision was made to raise the lower energy class limit of earthquakes from 7 to 9, in order to make the ESSN catalog "representative" (comparable) at all geographic zones. While the small events were still characterized at the regional seismic centers, they were not reported in this publication. For example, in 1990, the Altai & Sayan zone ESSN Catalog listed 110 earthquakes with Energy Class (K) of 8.5 or larger, while that year about 870 small earthquakes ($5 \le K \le 8$) were characterized but not published. In the Caucasus, about 1300 small earthquakes (K=5-8) were processed but not included in that year's ESSN publication. In the relatively small area monitored by the Garm expedition (100 by 150 km), more than 80,000 earthquakes were compiled in the expedition catalog for the time period from 1955 to 1990 (over 2200 per year). However, only a small fraction of these events were included in the ESSN catalog for Central Asia. For example, in 1964, only 84 earthquakes were reported with energy class, $K > 9$.

The parameters reported in regional ESSN catalogs

As a rule, the following data are included in the Regional Catalogs:

- Origin date and time to (GMT)
- Coordinates of epicenter

- Depth (in km)
- Energy Class, K = log E (in joules)

The Energy Class (from the Russian, Klass) determination is standard in most geographic zones (Carpathians, Caucasus, Kopetdag, Central Asia, Kazakhstan, Altai-Sayans, Baikal, Yakutia, and North East), but differs slightly in the catalogs for the Crimean region [14]. In the Far East, regional versions of K were created; these are KFS (after S.Fedotov, Kamchatka) and KC (for Sakhalin, after Soloviev & Solovieva [15]).

Unfortunately, when comparing these scales with the more widely used K (called KR, or K after Rautian) via teleseismic magnitudes, the regional versions were found to have a systematical discrepancy:

KR = KFS + 0.7
KR = KC + 1.6

In 1980, a new movement appeared in the regional seismological surveys, which begin to create their own versions of P-wave magnitude scales for regional distances. The MLH scale was extended to local and regional distances (10- 100s km), and the surveys begin to include values of these magnitudes in the Annual Catalogs. Unfortunately, these regional scales (MPVA) have the same name used for the classic teleseismic scale in the Obninsk Bulletin. It would be not bad if the values of regional MPVA were in a good accordance with traditional teleseismic MPVA. But our preliminary study shows, that it is not. It is well known that the P-wave, amplitude-distance dependence is extremely unstable at regional distances. Local MPVA is therefore not accordant with its teleseismic namesake, and is of high scattering in the correlation with other magnitude scale data. In contrast, the K scale, based on the maximum phase of P and S (mainly Lg) wave, is much more stable. The regional variation of amplitude-distance relation is small and negligible. To avoid confusion, the name MPVA now means regional P-wave scale. The teleseismic P wave scale is named Mpsp and Mplp (short- and long-period Mp). MPVA are not included in our Composite Regional Catalogs. The main scale used in ESSN was taken to be K (with its Far East and Crimean modifications [15,16]). K also determines the magnitudes of deep Hundu Kush earthquakes. Note that K was estimated for nearly 100 % of the earthquakes in the regional catalogs. For deep, Carpathian earthquakes the MSH scale was used, based on the max amplitude of the S wave (horizontal component of the short-period instrument).

The "New Catalog of Strong Earthquakes"

The New Catalog of Strong Earthquakes in the USSR (Shebalin and Kondorskaya, 1974), was the first attempt to collect all the data for strong earthquakes together, both for seismological and macroseismic observations. In 1984, data through 1977 were added and the New Catalog was translated in English [16].

The New Catalog consists of a huge volume of data, carefully collected and critically analyzed. The macroseismic and instrumental data were made compatible by development of the method of estimation of the epicenter, depth, and magnitudes from macroseismic data (details are explained in the New Catalog). When one uses data from the General Catalog, one can feel this methodical basis of the New Catalog.

Note that, in the General Catalog, the New Catalog was not used in its entirety. Of all the earthquakes that were taken, the format was nearly the same. However, not all the data from the New Catalog were included in the General Catalog. Specifically, no comments, references or information on macroseismic effects were included, and only some of the maximum intensity (Io) determinations.

<u>Sources of data</u>

The main principles used in preparing the New Catalog were to use all available information for each earthquake, and to estimate the most probable values for each of the basic focal parameters. The compilers did not limit themselves to using basic, well-known sources. Attempts were made to seek additional information, through research done in archives and elsewhere. Even for the period 1911- 1957, covered by the "Atlas of Earthquakes In the USSR", many “new” earthquakes were found. The list of references used as sources of data comprises 20 pages of the published Russian text, and about 30 pages in foreign-language versions.

To compile a chronological foundation for the New Catalog, data were taken from:

- the "Atlas of Earthquakes in the U.S.S.R."
- the bulletins of the National Network of Seismic Stations for (1902-12) and (1928-73);
- the International Seismological Service (ISS);
- the bulletins of the BCIS and the Preliminary Determination of Epicenters of GSUS;
- publications of the International Seismological Centre (ISC);
- individual bulletins of domestic stations (1911-27) and foreign stations (1900-70);

- numerous summaries of macroseismic data, beginning with the catalogs of A. Perrey and A.P. Orlov (both as published and in manuscript form).

In addition, even more numerous papers and investigations dealing with individual earthquakes were reviewed, as well as archive materials, reports of seismic correspondents, extracts from geographic descriptions by travelers and regional specialists, reports in the Soviet and foreign newspapers, etc. One specific task of the work with the sources was the elimination of errors, mainly in dating, because every error in date, particularly in early sources, is then repeated in subsequent summaries making one earthquake appear as two events.

Processing of macroseismic data

In using historic and archival data, the help of historians was particularly important in evaluating the sources and separating true information from anachronisms and fabrications caused by emotional, political, and other factors. Special control of determination basic parameters from macroseismic data was used. Analysis of the earthquake was made first on the basis on macroseismic data only. Then the results compared with the basic parameters of the earthquake determined from instrumental data. This analysis showed that the procedure for treatment of macroseismic data does make it possible to determine the basic parameters of the focus with adequate reliability. The rigid formalism in choosing the parameter and estimation of its error is the most important for macroseismic data during the pre-instrumental period (as described in the New Catalog). The following general principles were used in selecting the final values for the basic parameters and in estimating their precision:

1) Each parameter was determined in several ways where possible;
2) The value of each parameter was chosen to eliminate or minimize contradictions with the raw data;
3) If estimates coincided, the value obtained for the parameter was taken as final, and its error was taken as the minimum of the errors determined by different methods;
4) If estimates differ and the ranges of error overlapped, the final value was chosen in the common range of errors and the value of the error was taken as the minimum;
5) If estimates differ and the ranges of error did not overlap, the one with the least error was taken as the final value and the spread of the determinations was taken as the error;
6) If direct calculation of a parameter was not possible, the realistic extreme possible values were taken as the limits, and the final value of the parameter was chosen as the mean In this interval;
7) All errors were rounded upward in a given system of gradations.

Intensity was estimated based on the European MSK-64 scale. If the data were originally given in the Rossi-Forel or JMA scale and the observational data were unavailable, a-priori re-determination of intensity was impossible. In such cases, the values of intensity were converted into MSK-64 by graphic relations compiled by Shebalin (see Figure 6). The range of error in intensity was assigned based on the quality and quantity of initial macroseismic data.

Origin Time. Using the macro-seismic data, origin times were assigned based on the individual reports. Dates were converted to modern format (accounting for differences from century to century), and dates according to the Muslim calendar were translated to the European chronology. Times were converted to Greenwich Mean Time. In this process, local time was taken to be that of the local time zone, which is not always accurate. Before the end of the 19th century, the time in nearby major cities was used as local time, with an error generally not more than 30 minutes. Because the quality of time estimates for older earthquakes were low, we ignored this difference. After the introduction of daylight-saving time in 1931, the corresponding 1-hour corrections were incorporated.

The epicenter, depth and magnitude of earthquake estimation was based on the so called "equation of the macroseismic field":

$$I = B*M - A \log R + C$$

where H is depth and R is hypocentral distance ($R = (H2 + D2)1/2$), with the empirical parameters A, B and C. These parameters were initially estimated as B = 1.5, A = 3.5, and C = 3.0. The epicenter of large earthquakes with rich data was taken as a center of first isoseismal with an error equal to its average radius. For poor data, and if there were no macroseismic information from epicenter (located at sea or in an uninhabited area, etc.), the Golenetski method was used. The equation:

$$Ii - Ik = a \log (Ri2/Rk2)$$

describes a circle as the locus of the possible position of the epicenter. If the coefficient a is known, the epicenter can be found with the Wadati method as the intersection of loci for several pairs of points. The error of epicenter, estimated this way, was taken from 0.2° to 0.5°, depending on magnitude. For earthquakes found by paleoseismic studies, the epicenter was taken as the center of the dislocation, with a location error of half of the dislocation length.

The focal depth was determined by two methods: from the decrease of intensity with distance (using a nomograph), and/or from magnitude and intensity "Io" at the epicenter. The magnitude was determined from intensity in epicenter Io if found from initial data and depth. If the depth cannot be estimated, the magnitude determined from the intensity far from the epicenter (where epicentral and hypocentral distances are similar). In this manner, the parameters of time, location, depth and magnitude were calculated and "non- instrumental" earthquakes became compatible with instrumental ones.

The New Catalog includes the radii of isoseismals and, in some cases, comments about destructive effects, such as landslides, collapse of ancient buildings (churches, fortress) and human loss, if these were mentioned in original sources. There are also comments about reliability or errors in the referenced sources (note that the latter were not included in the General Catalog, see below).

The "General" Catalog

As noted above, the "General Catalog of Earthquakes in North Eurasia" is an extension of the previous "New Catalog" by Shebalin and Kondorskaya (1974) It was compiled by the Institute of Physics of the Earth under the direction of W. Ulomov, but never published, and exists only in electronic form. As a source in our Composite Regional Catalogs, it is referred to as "General" (or shortened to "Gnrl").

The General Catalog provides data for 31,821 events that occurred during the time period from 1900 to 1990 in the region of Eurasia from 30°-90° N and 0°-190° E. Earthquakes that occurred before 1955, when Obninsk began to issue its Bulletin, are mostly taken from the New Catalog, supplemented by macroseismic information and from some local station Bulletins (the sources of data are not documented in the catalog).

The General Catalog contains a seismic magnitude M, which has been calculated from various kinds of data, as follows:

- the Soviet surface wave magnitude MLH (later renamed to Ms, but not identical to western Ms), which is determined not from amplitude but from A/T; both A and T correspond to the maximum A on surface wave records (and not necessarily to 20-second period waves).
- the p-wave magnitude, MPVA (taken from SKM instrumentation, at periods To=1.5-2 sec) and MPVB (taken from SD instrumentation, To=15-20 sec) were used for calculation of M.

The magnitudes of the smaller events were initially characterized by Energy Class (K) as determined by the local surveys. This makes the number of earthquakes in the General Catalog more than twice that of the Obninsk Bulletin; further, all events in the General Catalog have a value of M.

The General Catalog has been divided into regions, corresponding to those of the Obninsk Catalog (see Table 3). The table below shows the distribution of events versus regions and the magnitude range of earthquakes in each region. Note that the total number of events in all the regions listed below (23,467) are less than in the whole General Catalog, since no data for the active regions Central Asia and Turkmenia were included.

Table 3. Magnitude Ranges for Events in the GENERAL catalog, by region.

Region	N	Lat	Lon	M
Aldan	249	52-60	122-142	6.6-3.3
Alti	474	43-60	80-90	8.0-3.5
Arctic*	334	70-90	0-170	6.8-3.5
Baikal	1967	50-60	102-122	7.6-3.3
Baltic	12	52-60	20-30	4.7-3.5
Caucasus-East	1074	38-45	44-51	6.9-3.3
Caucasus-West	317	40-45	37-44	6.8-3.3
Central Asia	7662	35-44	65-80	8.3-3.2
Chukotka	37	59-70	165-190	5.8-3.5
Cremea	45	44-46	28-37	6.8-3.5
Kamchatka	6767	50-60	155-165	8.5-3.5
Kazakhstan NE	15	45-60	65-80	5.8-3.6
Kurile Islands	1954	45-51	145-164	

Table 3. Continued

Region	N	Lat	Lon	M
Primorie-E	649	42-52	131-142	7.8-3.2
Primorie-W	6	48-52	127-131	6.0-3.6
Russia Central	3	52-60	30-54	4.6-3.5
Russia North	13	60-70	30-54	4.9-3.0
Russia South	12	45-52	37-54	5.4-3.5
Sakhalin	660	46-55	142-146	7.0-3.3
Sayans	924	50-60	90-102	7.0-3.5
Siberia East	240	59-72	115-165	7.1-3.3
Siberia West	0	60-72	66-115	
Ukraine	45	46-52	20-37	5.5-3.4
Urals	15	45-70	54-66	5.5-3.2

*including the Laptev Sea

Sources of data

The General Catalog was converted to electronic format in the 1990s. The compilers at IPE combined data from the New Catalog, the Obninsk Bulletin and the annuals (ESSN data), with the goal of making the catalog as homogeneous as possible in terms of the magnitude distribution of events. If two of three sources reported the same event, only one version was included, as decided by the compiler. The origin time and coordinates were taken from these sources, choosing the most reliable version, or after revising the data. They converted all the various magnitude scales and energy classes as well as macroseismic data into unified magnitude M. The available information on errors was included for all the parameters. The parameters included in General Catalog are:

t_o, the origin time:
    Year, Mon, day, hour, min, sec;
Er-t:
    error in time, and units of measure the error (sec, min, etc.)
Latitude and Longitude:
    coordinates of epicenter, in degrees;
Er-ep:
    error in the epicenter, in degrees;
Dep:
    depth of origin, in km;
Er-D:
    Error in depth, measured in relation to depth and ranging from 0.05 to 2 times the depth

Meth:
    method of depth determination, as follows:
    (0) - instrumental
    (1) - macroseismic
    (2) - assumed

Earthquake energy and magnitude determinations

Earthquake magnitudes were determined by a number of methods, some of which have been described in earlier sections of this report. A full documentation of the magnitude relationships used by the various regions and for various event depths will be included in the final report. Note that, in our compilations of regional catalogs, if more than one estimation of magnitude is available, the following order of priority was established:

1) The magnitude, obtained from surface waves (with a correction for depth added)
2) The magnitude from seismic moment
3) The magnitude from P wave,
4) The magnitude from S wave

Composite Regional Catalogs

As described above, the compilers of the four principal source catalogs (New, Obninsk, ESSN, General) took different approaches in the compilation of their data, which are reflected in the content and scope of their products. For example, the New Catalog attempted to make instrumental and non-instrumental data mutually compatible, and the events therein are described with the same language. Macroseismic data are a significant part the New Catalog, since it was constructed as the home of strong earthquakes.

The Obninsk Bulletin can be considered to be “conservative”, in that only teleseismic data were used for characterizing events. The Bulletin therefore contains only moderate and large earthquakes and only classical (teleseismic) magnitudes. While growth in the number of stations over the second half of the 20th century greatly increased the number of earthquakes cataloged by Obninsk, it did not break the principle of stability and conservatism.

In contrast, the Regional (ESSN) surveys worked to characterize as many earthquakes as possible, with the goal of elucidating the detailed spatial distribution of regional seismicity and its relation with regional geological structure.

The General catalog was undertaken with the goal of merging all data into a single complete catalog. Adopting a “unified magnitude,” with the standard lower cutoff of M=3.5, was proposed as the basic description of seismicity for the territory.

Approach

Our principal goal in compiling the Composite Regional Catalogs is to archive as much of the available information as possible, with no lower magnitude cutoff and no “standardization” of magnitudes. When integrating the data from the various “ancestral” catalogs, the following approach was taken:

1. If, for particular seismic event, two (or three) source catalogs report identical origin time and coordinates, the event occupies a single record in the database. Other parameters are placed in different columns. In the column "Source" these two or three initial catalogs are pointed in "chronological order" of publication (OBN, ESSN, NEW/GNRL). Other parameters, from different surveys are placed in the same record, in different fields. They are:

from the ESSN:	K = energy class
	M(K) = magnitude calculated from K : M(K)=(K-4)/1.8]
from Obninsk:	MLH, Mpsp, and Mplp magnitudes
from General:	M = the "unified magnitude"
	M(_) = indicating the parameter used to calculate M
	Io = intensity at the epicenter
	Azim = azimuth

2. If the times and/or coordinates are different in initial catalogs (estimated independently), two events are reported, with each source data in a separate record.
3. Events are assigned to a geographic region. The “regionalization” of the Catalog does not precisely coincide with the zones for which each of the separate regional surveys is or was responsible. For example, the Baikal Survey processed and included in its catalog some events with longitudes less than 100°, they were incorporated into the Sayan Regional Catalog. Another example is the situation for Siberia, where the Yakutsk survey is responsible for the huge area, including the Aldan, East Siberia and Chukotka.
4. For several regions (Turkmenia, Central Asia, Primorie & Priamurie, Sakhalin, Kurile, Kamchatka), ESSN data are not yet available in digital form, so only the Obninsk and General catalogs were used in the compilations to date.

The catalogs can be divided into two time periods: “historical” (prior to 1962) and “modern (from 1962 through 1999). The first period includes the available data on errors, as estimated or assumed by the compilers of the New and General catalogs. In the so-called “modern observation period,” the errors are smaller then in the historical period. Note also that error estimates were not included in all of the regional catalogs, and when they were reported, they were mostly assumed values. For example, the density of seismic stations was generally not sufficient to discriminate a depth of 5, 10, or even from 15 km. Therefore, the depths of many events are presumed. The accuracy of these determinations can be evaluated by comparing separate analyses of the data for events that were recorded and processed by neighboring surveys, by regional and independent (e.g., Obninsk) determinations, or by comparing with the revised estimations by authors of the General Catalog or other special studies. For these reasons, the data about accuracy are not included in 1962-99 Catalogs.

Parameters included in Composite Catalog.

The catalogs for the early time periods have nearly the same parameters as those in the General catalog, and are included in the same format. But there is a difference: because the Obninsk Bulletin begins in 1955, the magnitudes MLH were included in it. Therefore, we have included an additional column, "MLH," in the Composite Regional Catalogs.

The recent part of catalogs consists of time, coordinates, depth, energy class (K, from the Annuals/ESSN), M(K) (calculated by us for completeness), M and M(K) from the General Catalog, the three classical magnitudes (MLH, Mpsp and Mplp) from the Obninsk Bulletin, and Io and Azim (from the General Catalog). The data from the Annuals are marked in the Composite Catalogs as "ESSN" (from the Russian abbreviation for "Unified Survey of Seismic Observation"). Note that the identifier, "ESSN," was used for all the regional data published in Annual “Earthquakes in the USSR” (described above), without mention of which regional center provided the data.

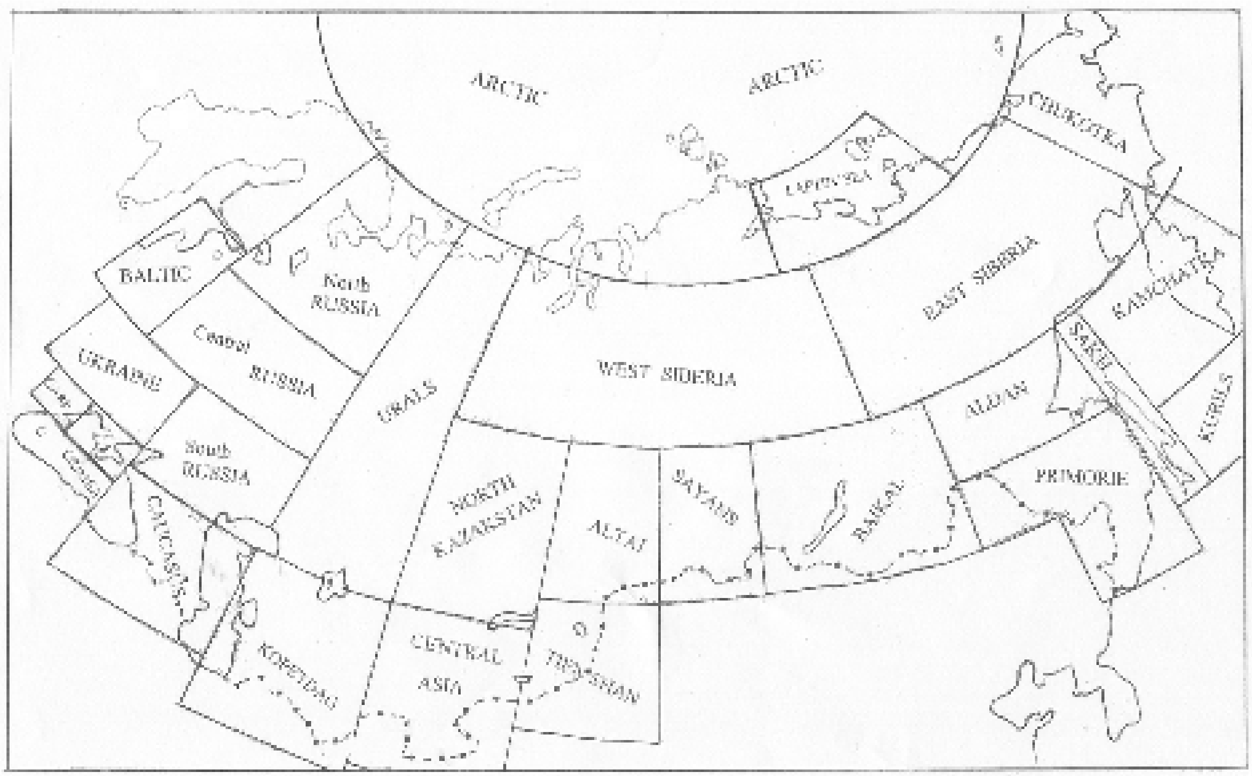

Figure 4. Sketch map of the former Soviet Union, showing the regions we have used in building the composite catalogs.

<u>The regionalization</u>

The system of regional networks, and the responsibilities of the regional seismological centers for monitoring the seismicity and characterizing events in their regions, was established mainly for political and administrative reasons. Some broad territories, like Central Russia and the Urals, were designated as one of the regions, but without any regional network or survey.

The boundaries between the various Soviet/Russian administrative regions were important for regional surveys, defining their areas of responsibility. However, these politically-based geographic divisions are not particularly useful to Earth scientists (“earthquakes know only natural boundaries”). Therefore, in the Composite Regional Catalogs, we have defined regions based not only on historical reporting responsibilities, network distributions and basic geographic features, but also on the spatial distribution of seismicity and tectonic features.

The entire territory of the former Soviet Union is divided into contiguous regions, although some low-seismicity regions are poorly reported in the available catalog sources and appear as “blank spots” on seismicity maps. Also, Russia, the Urals, West Siberia, and North Kazakhstan have a low and poorly-studied seismicity, but are known for intensive blasting. Most of the available information on events in these regions is for non-instrumentally recorded earthquakes. An example showing epicenters from the composite regional catalog for the Baykal region is shown in Figure 5.

A map of the epicenters of events in the General and composite regional catalogs is shown in Figure 6. In this presentation, the epicenters of events in the regional catalogs overlay the epicenters of events in the general catalog. This emphasizes the spatial distribution of events in the regional catalogs.

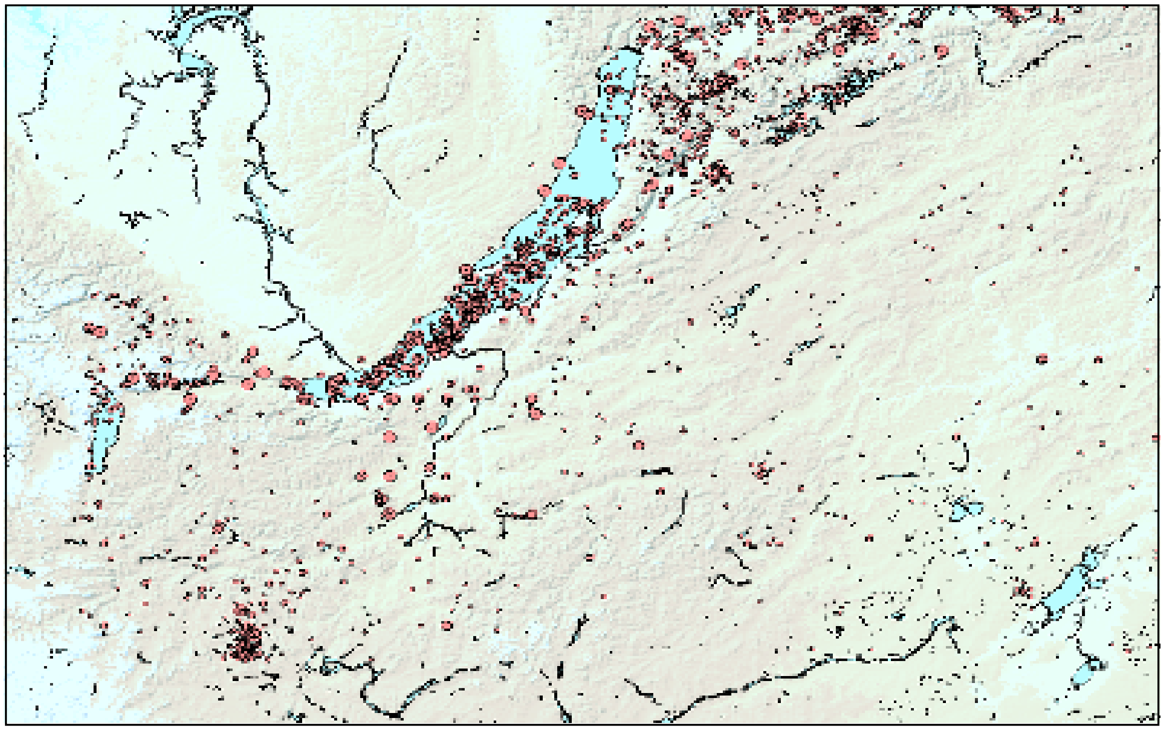

Figure 5. Map of epicenters in the Baykal Lake region, from the composite regional catalog of seismicity of that region.

CONCLUSIONS AND RECOMMENDATIONS

We have made substantial progress toward the goal of completing uniform regional catalogs of seismicity of Russian and the former Soviet Union, using and documenting all the available major catalog sources, with no standardization of magnitudes and no lower magnitude cutoff. These catalogs therefore contain the best available representation of the seismicity of the former Soviet Union, particularly at low magnitudes. Completion of this work will require digitizing the remaining catalogs of the various regional seismological institutes. A prototype web site for the distribution of these data is available through the U.S. Geological Survey, at: http://geology.er.usgs.gov/gmapeast/kaz/.

ACKNOWLEDGEMENTS

We gratefully acknowledge support from the U.S. Geological Survey. This work benefited greatly from the expertise, contributions and reviews of Vitaliy Khalturin, and from the contribution of papers by and discussions with David Simpson. We also thank Kim Buttleman and Steve Schindler, for assistance in building and maintaining the web site.

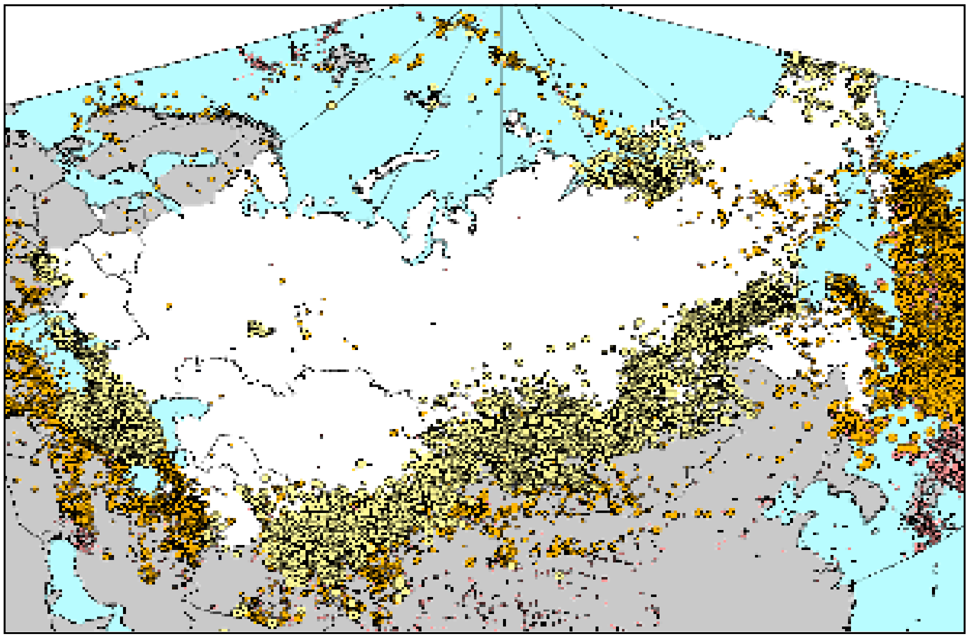

Figure 6. Map of the epicenters in the Obninsk Bulletin (pink), overlain by those of the General Catalog (ochre), overlain by epicenters of events in the Annual (ESSN) catalogs (yellow).

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