

Earthquake activity in Finland and the Russian North in December 1758: rare reports and their interpretation

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ABSTRACT

This investigation focuses on two historical earthquakes that occurred in the border region between Finland and Russian North in December 1758. They were close together in time and their magnitudes are among the largest observed in the region. We thoroughly searched for contemporary Russian and Scandinavian documentation on earthquake activity in several libraries in Moscow, Helsinki, Stockholm and Copenhagen. We found two primary reports, one from the Russian North and the other from Finland. The context and content of the reports indicate that they are independent and related to the dates of December 17 and December 31, 1758. The first occurrence was reportedly observed in Kandalaksha, Knyazhnaya Guba, Kovda, Chernaya reka and krest Vzista, and the second in Inari, Utsjoki, and Karasjok. We compiled macroseismic maps for both earthquakes and sets of possible parametric solutions that fit the sparse information available. We identified two types of uncertainty in epicenter and magnitude determination: one that stems from the ambiguity of intensity assessment at localities and the other from the spatial distribution of the data points. If no single solution is the best, we propose that all possible solutions be included in earthquake catalogs.

1. Introduction

Seismic hazard assessment is mostly based on seismic history. No sophisticated computer technology is able to fully compensate for inaccurate and short seismicity records. The problem is particularly challenging when there is a scarcity of documentary information on past earthquakes.

This investigation focuses on historical earthquake activity occurring in northern Europe, in the border region between Finland and Russian North. It is not characterized by a long cultural tradition of documentation: the native people led a nomadic way of life. It has had large areas of wilderness, and permanent settlements were mainly along waterways. The various state borders in the study region throughout the centuries have shown marked differences in language, religion, and

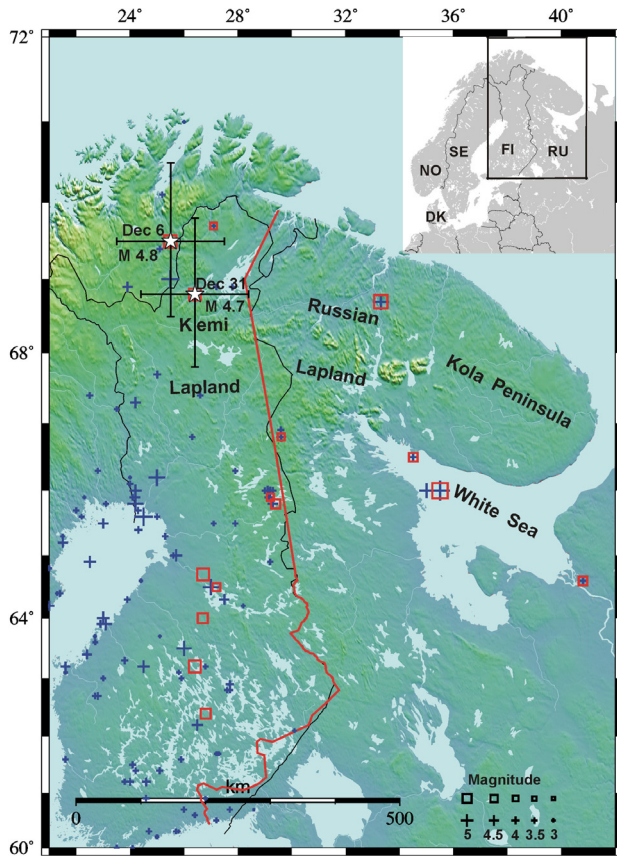
traditions, all of which pose obstacles in the study of historical earthquakes.

The seismicity rates in the study region situated in the intraplate Baltic (Fennoscandian) Shield are low in global terms: no historical earthquake of $M > 5.5$ is listed in available parametric catalogs (Figure 1). Earthquakes of $M > 4.5$ stand out from the seismicity records as the largest observed. They are particularly intriguing, when reported close together in time and space. Tatevossian et al. [2011] studied one such case, namely two earthquakes which occurred in the spring of 1626. Detailed analysis of written documentary accounts and historical background demonstrated that no unequivocal decision could be made, using the macroseismic data available. There may actually have been only one earthquake, which was split in two.

Another earthquake pair occurring in less than a month is listed in the parametric catalog of Kondorskaya and Shebalin [1977, 1982]: an earthquake on December 6, 1758 and another on December 31, 1758, both having magnitudes above 4 (Figure 1). However, the parametric catalog of Ahjos and Uski [1992] includes only one earthquake, on December 31, 1758. Nikonov [2004] also discussed only this earthquake in the region of interest. To obtain a better insight into the earthquake activity in the Finnish-Russian border region in December 1758, it is necessary to search for primary sources of information.

2. Search for primary sources

The parametric catalog of Kondorskaya and Shebalin [1977, 1982] gives explicit references for the earthquakes of December 6 and 31, 1758. We traced back these references (Appendix). The earthquakes of interest were listed in many seismological compilations that repeat or summarize information from earlier works; sometimes the place names differ.



The description of the first earthquake is more confused than that of the second. The main information came from Paris, where *Collection Académique* [1761] was published; it does not supply any reference

Figure 1 (left). Historical seismicity in the study region from 1542 to 1899. Earthquake epicenters were taken from the parametric catalogs of Kondorskaya and Shebalin [1977, 1982] (squares) and Ahjos and Uski [1992] (crosses). Symbol size is scaled to earthquake magnitude. Only earthquakes with $M \geq 3$ or $I_0 \geq 4$ are plotted. Stars are earthquake epicenters from Kondorskaya and Shebalin [1977, 1982] for Dec. 6 ($M = 4.8$) and Dec. 31, 1758 ($M = 4.7$); error bars correspond to location accuracy. Black lines are current state borders, while the thick red line approximates the border between the Kingdom of Sweden and Russia according to the Turku peace treaty in 1743.

for the communication. *Collection Académique* [1761] was used by Perrey [1845, 1846]. Renqvist [1930] reproduced the information from Perrey [1845] in French, while Mushketov and Orlov [1893] repeated the description from the Russian edition [Perrey 1846]. Thus, information from the Russian North in 1758, used before this study, was based only on a French journal not giving explicit references.

We searched for primary Russian documentation on earthquake activity in the Russian State Library in Moscow and the Slavonic Library of the National Library of Finland in Helsinki. To ensure the completeness of the search, several bibliographic indices of books and periodicals were used (Table 1). All works published in 1759, 1760, 1761, and partly in 1762 and cited in the bibliographic indices – a total of 19 titles – were checked (Table 2). Only one title included a primary account of an earthquake, namely the newspa-

Original title	Title in English	Place and date
Опыт российской библиографии или полный словарь сочинений и переводов, напечатанных на Славенском и Российском языках от начала заведения типографий до 1813 года..., собранный из достоверных источников Василием Сопиковым.	Experience of Russian bibliography or complete dictionary of opuses and translations in Slavonic and Russian languages from the beginning printing up to 1813..., collected from reliable sources by Vasily Sopikov.	St. Petersburg, 1813
Историческое разыскание о русских повременных изданиях и сборниках за 1703-1802 гг., библиографически и в хронологическом порядке описанных А.Н. Неустроевым.	Historical research on Russian periodicals and compilations for 1703-1802, bibliographically and chronologically described by A.N. Neustroev.	St. Petersburg, 1874
Материалы для русской библиографии. Хронологическое обозрение редких и замечательных русских книг XVIII столетия, напечатанных в России гражданским шрифтом. 1725-1800. Составил Н.В. Губерти. Вып. III.	Materials for Russian bibliography. Chronological review of rare and remarkable Russian books of the 18th century printed in Russia using civil fonts. 1725-1800. Compiled by N.V. Guberti. Issue III.	Moscow, 1891
Указатель к русским повременным изданиям и сборникам за 1703-1802 гг. и к историческому разысканию о них А.Н. Неустроева.	Index to Russian periodicals in 1703-1802 and to the historical research done by A.N. Neustroev.	St. Petersburg, 1898
Русская периодическая печать (1702-1894). Справочник.	Russian periodicals (1702-1894). Handbook.	Moscow, 1950
Сводный каталог русской книги гражданской печати XVIII века. 1725-1800.	Consolidated catalog of Russian books in the 18th century. 1725-1800.	Moscow, 1962

Table 1. Bibliographic indices of Russian books and periodicals relevant for 1758.

EARTHQUAKES IN THE NORTH IN 1758

Title	Publishing town	Type of publication	Result of search
Novi Commentarii Academie Scientiarum Imperialis Petropolitanae, t. (VII-XI)	Petropolis (St. Petersburg)	academic summary	scanned from 1763 to 1767, no hits
Summariium Dissertationum quas continent novorum commentariorum, t. (VII-XI)	Petropolis (St. Petersburg)	academic summary	scanned from 1761 to 1767, no hits
Архангельская губерния по Статистическому описанию 1785 года (Arkhangel'skaya guberniya po Statisticheskomu opisaniyu 1785 goda)	Arkhangelsk	statistical summary	published in 1916, no hits
Декабрь 1759 год // Метеорологические наблюдения в Санкт Петербурге в 1758 году (Dekabr' 1759 // Meteorologicheskiye nablyudeniya v Sankt Peeterburge v 1758 godu)	St. Petersburg	annual meteorological report	scanned through 1759, no hits
Ежемесячные сочинения к пользе и увеселению служащие (Yezhemesyachnye sochineniya k pol'ze i uveseleniyu sluzhashchiye)	St. Petersburg	monthly	scanned from 1759 to 1761, no hits
Карманный календарь (Karmanniy kalendar')	St. Petersburg	calendar	scanned through 1759 and 1760, no hits
Московские Ведомости (Moskovskiye Vedomosti)	Moscow	national newspaper	scanned from 1759 to 1762; the earthquake was mentioned only in no. 11, 1759
Невинное упражнение (Nevinnoye uprazhneniye)	Moscow	monthly	scanned through 1763, no hits
Полезное увеселение (Poleznoye uveseleniye)	St. Petersburg	weekly magazine	scanned through 1760 and 1761, no hits
Полезное увеселение (Poleznoye uveseleniye)	St. Petersburg	monthly magazine	scanned through 1762, no hits
Праздное время (Prazdnoye vremya)	St. Petersburg	weekly magazine of interesting happenings	scanned through 1759, no hits
Роспись книгам, портретам и ландкартам, которые при Имп. Академии наук в Санкт Петербурге напечатаны и в книжной палате без переплета продаются. (Rospis' khigam, portretam i landkartam, kotorye pri Imp. Akademii nauk v Sankt Peterburge napechatany i v knizhnoy palate bez perepleta prodayutsya. 1759)	St. Petersburg	annotated index	scanned through 1759 and 1760, no hits
Санкт Петербургские Ведомости (Sankt Peterburgskiye Vedomosti)	St. Petersburg	national newspaper	scanned from 1759 to 1762; the earthquake was mentioned only in no. 8, 1759
Свободные часы (Svobodnye chasy)	St. Petersburg	monthly magazine	scanned through 1763, no hits

Title	Publishing town	Type of publication	Result of search
Собрание лучших сочинений к распространению знания и к произведению удовольствия, или Смешанная библиотека о разных физических, экономических, також до мануфактур и до коммерции принадлежащих вещах (Sobraniye luchshikh sochineniy k rasprostraneniyu znaniya i proizvedeniyu udovol'stviya, ili smeshannaya biblioteka o raznykh fizicheskikh, ekonomicheskikh, takozh do manufaktur i do kommertsii prinadlezhashchikh veshchakh)	Moscow	magazine (every three months)	scanned through 1762, no hits
Содержание ученых рассуждений Академии наук (Soderzhaniye uchenykh rassuzhdeniy Akademii nauk)	St. Petersburg	scientific journal	scanned through 1759, no hits
Сочинения и переводы к пользе и увеселению служащие (Sochineniya i perevody k pol'ze i uveseleniyu sluzhashchiya)	St. Petersburg	annual magazine of useful and amazing information	scanned from 1758 to 1762, no hits
СПб календарь на лето... (SPb kalendar' na leto..)	St. Petersburg	annual collection of exciting events	scanned from 1759 to 1761, no hits
Трудолюбивая пчела (Trudolubivaya pchela)	St. Petersburg	national monthly magazine edited by Sumarakov	scanned through 1759, no hits
Anmärckningar wid Swenske Post-Tidningarne	Stockholm	supplement to Stockholms Post-Tidningar	scanned through 1759 and 1760, no hits
Carlsronas Tidningar	Karlskrona	local newspaper	not scanned
Den Swänksa Mercurius	Stockholm	literature periodical	not scanned
Det Swenska Biblioteket	"	periodical on library issues	not scanned
Göteborgska Magasinet	Göteborg (Gothenburg)	local newspaper	not scanned
Hwad Nytt i Staden?	"	supplement to Göteborgska Magasinet	not scanned
Kongl. Maj:ts Befallningshafvandes i Jönköpings län Kungörelser	Stockholm	administrative issues	not scanned
Kongl. Vetenskaps Academiens Handlingar	"	Proceedings of the Royal Swedish Academy of Sciences	scanned from 1759 to 1762; 1759 volume, pp. 229-232 earthquake report by H. Wegelius
Kärnan af Swea Rikes Historia	"	history of Sweden until 1410, weekly publications	not scanned
Linköpings Stifts Tidningar	Linköping	diocese accounts	not scanned
Lärda Tidningar	Stockholm	scientific essays, academic dissertations, book reviews, etc.	scanned from 1759 to 1761; Nov 19, 1759 no. 91: summary of Wegelius [1759]
Norrköpings Weko-Tidningar	Norrköping	local newspaper	scanned until Oct 6, 1759, no hits

Title	Publishing town	Type of publication	Result of search
Stockholms Post-Tidningar	Stockholm	national newspaper	scanned through 1759 and 1760; 1759 no. 18: repeat of Russian account from Kandalaksha, slightly modified
Stockholms Stads Pris-Courant	“	buy-and-sell consumer prices	not scanned
Stockhoms Wekoblads	“	agricultural issues, some scientific writings	scanned through 1760, no hits
Kiøbenhavnske Danske Post-Tidender	Copenhagen	national newspaper	scanned through 1759: Mar 9, no. 20: repeat of Russian account from Kandalaksha, slightly modified
Nye Stats-Tidender	”	chronological overview of domestic accounts, consumer prices, etc. published monthly	scanned through 1759, no hits
Copenhagener Deutsche Post-Zeitungen	„	newspaper	scanned through 1759, no hits
Beytrag zu Den Copenhagener Deutsche Post-Zeitungen	”	supplement to Copenhagener Deutsche Post-Zeitungen	scanned through 1759 (published sporadically), no hits
Gazette Historique et Politique de Copenhague	“	newspaper	scanned through 1759, no hits

Table 2 (continued from the previous two pages). Publications in Denmark (including present-day Norway), Russia, and Sweden (including present-day Finland) scanned for reports related to the earthquakes of 1758. Literal translations of the titles can be found in the References.

per *Sankt-Peterburgskiy Vedomosti* [*St. Petersburg Gazette*] (no. 8, 1759, January 26, Tuesday). It reported an earthquake occurring in the North of Russia close to Kandalaksha on December 6, 1758. This piece of news was repeated in *Moskovskiy Vedomosti* [*Moscow Gazette*] (no. 11, 1759, February 5, Friday).

Comparison of the newspaper report from St. Petersburg with *Collection Académique* [1761] reveals some similar wording, which gives reason to assume that the information from Russia may have been available in France. However, the information became severely distorted in *Collection Académique* [1761]: Kola and Arkhangelsk were reported as localities experiencing the earthquake, while the place names given in the Russian newspaper were missing. Later compilations repeat the information rather accurately (Figure 2; Appendix).

At the time of interest, Scandinavia consisted of two kingdoms, namely Sweden including the present-day Finland (Figure 1) and Denmark including Norway [Derry 1979]. Possible accounts from Finland passed into the Swedish newspapers, and from Norway into the Danish newspapers; no newspapers were published in Finland or Norway [see Muir Wood et al. 1988]. We searched for primary Swedish and Danish documentation on earthquake activity in the National Library of Finland in Helsinki, the Royal Library of Denmark in Copenhagen and the Stadsarkivet (City Archives) in Stockholm.

A total of 16 newspapers and periodicals were issued in Sweden in 1758 and 14 the following year, according to the National Library of Sweden. The priority of the search was given to national newspapers and scientific journals, since local publications were not likely to contain news from abroad. The most important Danish newspapers were scanned as well (Table 2).

The Proceedings of the Royal Swedish Academy of Sciences contained a description of earthquake activity occurring in Utsjoki on December 31, 1758, known to Renqvist [1930]. In addition, the Swedish newspaper *Stockholms Post-Tidningar* (no. 18, 1759, March 1) included a slightly modified report of an earthquake occurring in the Russian North earlier the same month. The Danish newspaper *Kiøbenhavnske Danske Post-Tidender* repeated the Russian piece of news on March 9, 1759. The Swedish and Danish newspaper reproduced the Russian account quite accurately; in particular, the place names were given correctly, while this information was not present in later compilations (Figure 2).

3. Analysis of sources

3.1. Context and content of reports

Two earthquake reports, one from the North of Russia and the other from Swedish territory, could be classified as primary (Figure 2, Appendix). One origi-

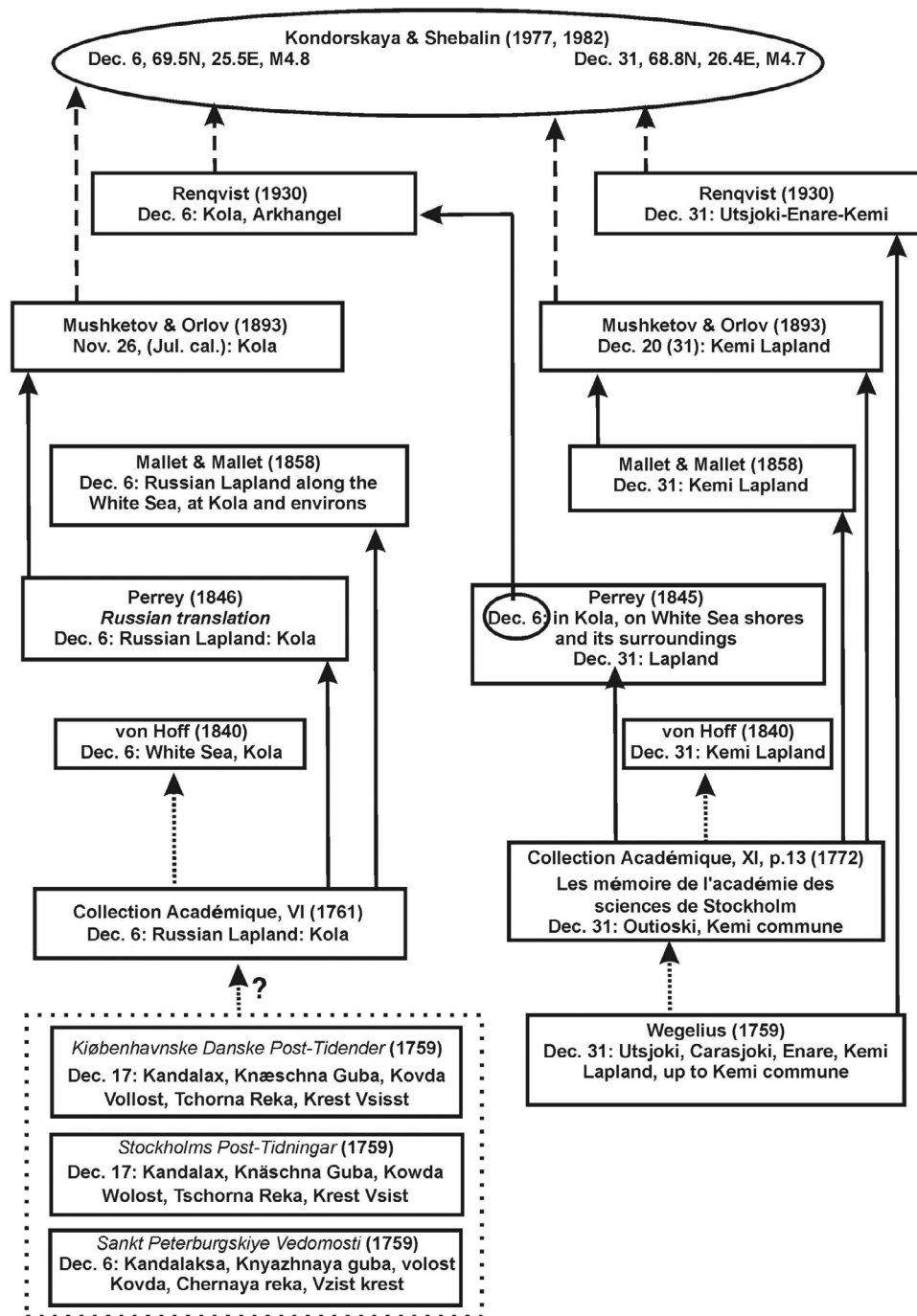


Figure 2. A flow chart of the relationships between different studies that refer to the earthquakes in Russian North and Sweden (present-day Finland) in December 1758. The dates and place names given in the studies are shown. The full original texts can be found in the Appendix.

nated from an eyewitness, the other was derived from an eyewitness' report. We cannot be sure whether the newspaper repeated the original account precisely; some distortion may have occurred at different stages, even if unintentionally. The context of the Russian report is rather unusual, but not incredible: the phenomena that occurred were observed by soldiers while they were on the road, they then reported what had happened when they reached their destination town of Arkhangelsk, from where the report passed to a newspaper published in St. Petersburg.

The Swedish author can be identified: Henrik

Wegelius (1735-1791) served as the second vicar in Utsjoki between 1758 and 1765 [Itkonen 1952]. The earthquake occurrence was included in his report of weather observations for 1758. Weather reports, besides statistics, were regarded as integral to the economic growth that began in the mid-1700s, and the clergy were taught how to make them at the Academy of Turku [Klinge 1990]. Wegelius' report [1759] was published in the Proceedings of the Royal Swedish Academy of Sciences, established in 1739.

The reports are given in the original language in the Appendix. They were translated into English:

– *Sankt-Peterburgskiyе Vedomosti*, on Tuesday, January 26, 1759:

“From the town of Arkhangelsk on December 30

A soldier who came here recently from Kola fortress (*ostrog*) orally reported that when he was on the way on December 6 late evening a very severe storm from the northwest started, and then such a strong earthquake followed, that not were both people and livestock not able to stand on their feet but also chimneys were partly damaged and partly collapsed. Because of the severity of the shaking he had together with his comrades, also soldiers, to fall into the snow because they could not stand any longer. This earthquake lasted together with the mentioned storm for three hours, and stopped when the wind ceased. It has started at Kandalaksa [modern spelling Kandalaksha] and the same time i.e. at day 6 in the evening was felt in Knyazhnaya Guba, Kovda region [*volost'*], at Chernaya reka and near krest Vzista”.

– Henrik Wegelius [1759]:

“On the 31st of December last year, the weather here in Utsjoki was clear and pleasant until 4 o'clock in the afternoon, with a quiet southern wind. At 8 o'clock in the morning, the thermometer read 17 degrees, but at 10 o'clock in the afternoon it was 21 degrees below the freezing point. The barometer read 24 [Decimaltum, 7 liniers] height, all day.

At 4 o'clock in the afternoon the sky became rather misty everywhere, so that here in the vicarage the tops of the near-by hills could not be seen.

At about half past 10 in the evening, a strong underground roar began to be heard, it gradually became stronger, and seemed to approach. When it had lasted a couple of minutes, the ground began to swing, approximately like a boat in average conditions in the open sea. During that a few strong bangs were heard, close to the ground surface, which probably resulted from the fracturing of the frozen ground. The swinging lasted for 2 to 3 minutes, and the roar was still heard for a moment afterwards, until it finally came to an end.

Some 2 minutes later, the roar began to be heard again, and then a shaking followed, equally strong and long lasting as the previous one.

On the same night, at half past midnight on New Year's Day, an underground roar was still heard, however it was not as strong as the previous one and did not last that long; neither was any movement or swinging of the ground itself noticed.

During the first two tremors, and a little earlier, Northern Lights were seen on the sky (however, they were not that clear), stretching from SW to NE; it is noteworthy that all the Northern Lights seen this winter have appeared in the same direction. At 11 o'clock

in the night both the Northern Lights and the mist disappeared, and the sky was entirely clear.

I tried to observe the direction of these earthquakes carefully, but could not detect it with certainty. However, I thought that the roar and tremors moved from SW to NE.

A Lapp man reported that during the earthquake he noticed some fire on the sky, resembling a flash of lightning, but however carefully I tried to observe if anything out of the usual would appear on the sky, I could not see anything.

On the following day, or the 1st of January, the ground was fractured in many places along the road passing over the ice.

That the first two tremors were rather strong can be inferred from the fact that all those who had already fallen asleep were awakened and were very frightened. People ran out and were afraid that the houses would collapse over them. The fright of the Lappish people who had gathered here by the church cannot be described. They had never before noticed any earthquakes, and had heard no talk or very little talk about them. They came to me after they escaped, and had they not heard from me any explanation about this natural phenomenon, they would probably have very peculiar thoughts about what happened.

In Karasjok in Norway, which is located some 10 miles from here [Swedish mile = about 10 km], the earthquakes were so discernible that the ice on one lake was totally broken. Several tremors were noticed there too during the same night.

In Inari, located some 15 miles from here towards the SSE, everybody felt the first two tremors; however, they were not as strong as here in Utsjoki. In the market place there, the chimney of the cottage of the bailiff was broken because of the swinging. The earthquake was felt not only over the entire Kemi Lapland, but also in the parish of Kemi and, maybe, even further away”.

3.2. Were two earthquakes reported?

At that time, the Kingdom of Sweden had adopted the Gregorian calendar, while the Julian calendar was in use in Russia. The date of December 6 was given according to the Julian calendar. This was also confirmed by the newspaper from St. Petersburg; it was issued on January 26, 1758, Tuesday, a weekday that only accords with the Julian calendar. The Swedish newspaper *Stockholms Post-Tidningar*, in repeating the account from the Russian newspaper *Sankt-Peterburgskiyе Vedomosti*, converted the earthquake date correctly to December 17. The same applies to the Danish newspaper *Kjøbenhavnске Danske Post-Tidender*. It seems that the Danish and Swedish reports were unnoticed (Figure 2, Appendix).

The dates of December 17 and December 31, 1758



Figure 3. Map of Arkhangelsk Governorate in 1824 (close-up). Stations on the mail delivery road and distances between them are indicated. Both winter and summer roads are shown (www.kolamap.ru). Site locations are accurate to within 5 km.

are very close together. Could there have been any confusion here, so that both reports actually referred to the same occurrence? Wegelius [1759] is considered a reliable, literate eyewitness; in addition, he wrote *New Year's Day* in words, so a misprint is out of the question.

The date of the occurrence in Russian North warrants some reasoning. The road between Kola and Arkhangelsk was the only one connecting these two localities and was used for mail delivery. According to Figure 3, the distance from Arkhangelsk to Kandalaksha is 890 *versta*¹; according to a reference book [*Spravocnaya knizhka... 1850*], the distance is 870 *versta*.

The earthquake occurred on December 6, and the report sent from Arkhangelsk is dated on December 30, 1758, both according to the Julian calendar. This leaves 23 days at the most for the soldier and his comrades to travel from Kandalaksha, where they witnessed the event, to Arkhangelsk. If there is a confusion of dates and the report was related to the second earthquake, they would have at their disposal only 9 days to reach Arkhangelsk from Kandalaksha. By no means could one cover a distance of about 950 km in 9 days in 1758. For comparison, according to the same reference book, the distance from Arkhangelsk to St. Petersburg is 1103 *versta* (1179 km). The message from Arkhangelsk on December 30 was published in *Sankt-Peterburgskkiye Vedomosti* on January 26, i.e. more than 3 weeks later. Thus, the possibility that both primary

¹ *Versta* was a unit of distance before Russia adopted the metric system. 1 *versta* = 1.0668 km.

reports stemmed from the same event is excluded.

The origin of the occurrences on December 17 and 31, 1758 still remains open. The first earthquake report describes a strong storm and duration of 3 hours, which is unrealistic for an earthquake, but realistic for a storm. On the other hand, it describes features typical of an earthquake: severity of shaking after the storm had begun, people and livestock having difficulty standing due to the shaking and having to fall in the snow, chimneys partly damaged and partly destroyed. The masonry parts of the timber dwellings common in the study region are the most vulnerable to earthquakes. The uncovered, complete newspaper report includes place names that extend over a distance of almost 80 km (from Kandalaksha to Chernaya reka). It is possible that the duration was reported incorrectly either by the soldier or by the newspaper editor. It is known even from much more recent macroseismic reports that people's estimates of earthquake duration are often not reliable. Our interpretation is that the word "storm" possibly does not refer to a meteorological phenomenon, but to the earthquake sound: first an underground roar was heard, then the ground began to shake. This interpretation is perfectly analogous with other descriptions of local earthquakes in the Baltic Shield [e.g. Mäntyniemi and Wahlström 2013]. The earthquake roar is often described as resembling thunder and lasting as long as the ground shaking. Thus, we associate a lower probability to the event of December 17 being of non-seismic origin. Wegelius' [1759] description is very detailed and includes typical earthquake features and consequences: an underground roar, shaking, an earthquake light, cracks in the ground, aftershocks, and people awakened and being frightened.

4. Earthquake parameters

To determine possible locations and magnitudes for the earthquakes of December 1758, use was made of the attenuation relationship given for the Baltic Shield in Kondorskaya and Shebalin [1977]:

$$I_i = 1.5 M - 3 \log_{10} R + 3 \quad (1)$$

where, I_i is the intensity in the i^{th} locality at a distance R from the epicenter and M the earthquake magnitude. We assumed that attenuation was not dependent on the azimuth.

Various magnitude values were used to calculate the distance to a corresponding epicenter. Each intensity data point was encompassed by a circle having a radius corresponding to the assumed magnitude, calculated using Equation (1). The magnitude was increased stepwise, using increments of 0.1 units. Since all the distances must fit simultaneously, a possible epicenter is

EARTHQUAKES IN THE NORTH IN 1758

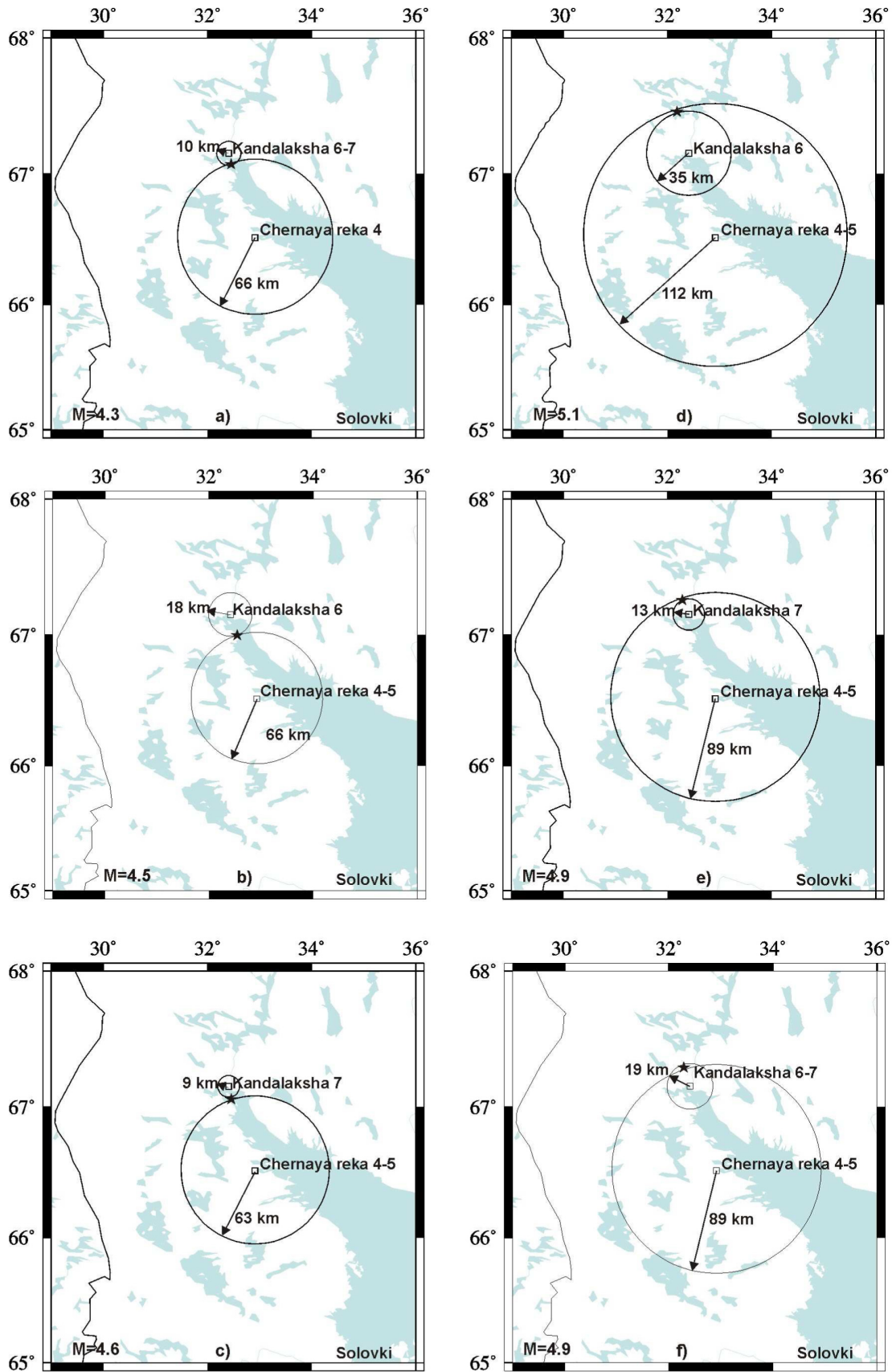


Figure 4. Stars denote possible epicenters for the earthquake of December 17, 1758 when magnitudes are assumed to be 4.3 (a), 4.5 (b), 4.6 (c), 5.1 (d), 4.9 (e), and 4.9 (f). Intensities in Kandalaksha and Chernaya reka were assessed according to the description in the newspaper *Sankt-Peterburgskiy Vedomosti* [1759] (see Table 3).

located at the point where the circles intersect. At the same time, the intersection area must have a minimum

size. Alternative solutions may exist, because the circles may intersect at more than one point.

Panel of Figure 4		Chernaya reka 4	Chernaya reka 4-5
a)	Kandalaksha 6	4.3	4.5
b)	Kandalaksha 6-7	4.3	4.6
c)	Kandalaksha 7	4.4	4.6
d)	Kandalaksha 6	4.6	5.1
e)	Kandalaksha 6-7	4.5	4.9
f)	Kandalaksha 7	4.5	4.9

Table 3. Earthquake of December 17, 1758: magnitudes corresponding to different combinations of intensities in Kandalaksha and Chernaya reka are shown. The best-fitting values are given in a bold font. They correspond to the epicenter solutions having the smallest intersection of circles illustrated in Figure 4. The corresponding epicentral intensity I_0 would be 6-7, 7, or 7-8 in cases a, b and c, and I_0 would be 7-8 or 8 in cases d, e and f.

4.1. Earthquake of December 17, 1758

On the way from Kola to Arkhangelsk, all travelers had to pass Kandalaksha, Knyazhnaya Guba, Kovda, Chernaya reka, and krest Vzista. The place names are given in order from the north toward the south in the newspaper account; krest Vzista was the only name we were not able to locate. It was reported that the earthquake was felt in all these localities.

All the details described are attributed to Kandalaksha. It was reported that the earthquake began near Kandalaksha; the group of soldiers could hardly have received information from there if they had already passed it. The intensity in Kandalaksha can be assessed at 6, 6-7, or 7 [EMS98, Grünthal 1998]. This was based on damage or even destruction of chimneys (suggesting an intensity of 7), but possible low-quality con-

struction may have reduced it to 6, and on having difficulty standing (6-7). No details are given for other places, so intensities were not assessed at Knyazhnaya Guba and Kovda. However, for Chernaya reka, which is furthest from the Kandalaksha locality at a distance of app. 80 km, we assumed different intensity values to limit the area of macroseismic effects reported and to be able to parameterize the earthquake. Alternative solutions for the epicenter are shown in Figure 4.

An important clerical and administrative center of documentation in the White Sea area at that time was the Solovki Monastery (Figure 4). We checked published monastery chronicles and did not find any information about ground shaking felt there in 1758. If this is taken to mean that the earthquake was not felt in Solovki, the upper limit of magnitude can be evaluated independently. This would give an upper limit of M 4.8, which agrees well with the values obtained using the intensities in Kandalaksha and Chernaya reka (Table 3).

Earthquake magnitudes of alternative solutions are presented in Table 3. In this case, the upper limit of magnitude, relying on the assumption that the earthquake was not felt at Solovki Monastery, would be 5.0, which agrees perfectly with the magnitudes obtained from the intensities in two localities. Actually, there are no grounds for preferring either of the two alternative solutions.

4.2. Earthquake of December 31, 1758

According to Wegelius [1759], the intensity at Utsjoki can be assigned at 5 or 5-6 [EMS98]. Higher intensity values contrast with the absence of damage, while smaller values contrast with many people being awakened and frightened. The intensities in Karasjok (Karasjoki in Finnish) and Enare (Inari) cannot be eval-

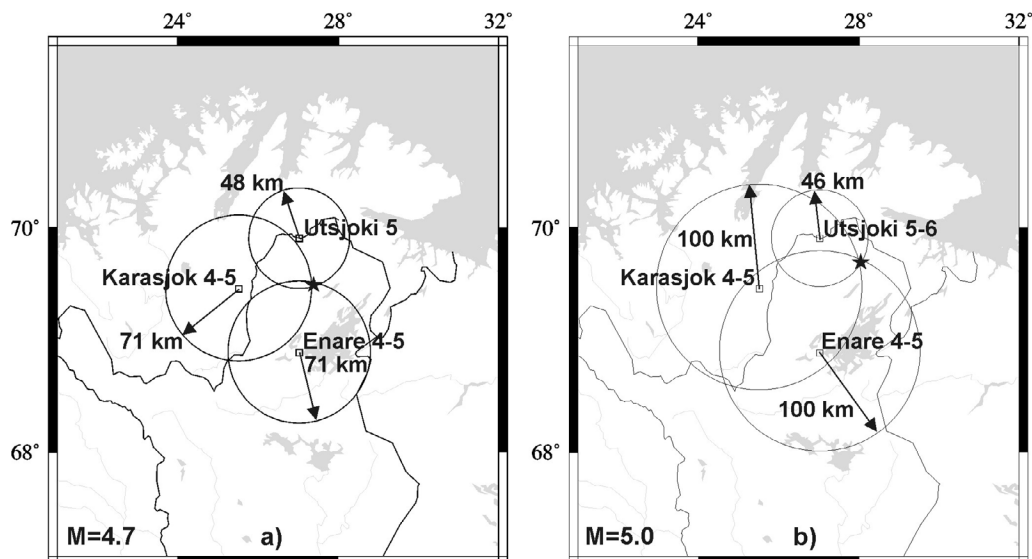


Figure 5. Stars denote possible epicenters for the earthquake of December 31, 1758 when magnitudes are assumed to be 4.7 (a) and 5.0 (b). Intensities at Utsjoki, Karasjok and Enare were assessed according to Wegelius [1759].

uated accurately, only that it was reported that ground shaking in these places was weaker than at Utsjoki.

Solutions corresponding to intensity values of 4-5 both in Karasjok and Enare and intensity 5 in Utsjoki (Figure 5a) or 5-6 (Figure 5b) for assumed magnitudes of 4.7 and 5.0 suggest the best fit. It follows that the intensity at the epicenter would be $I_0 = 7-8$ or 8. An independent check for the magnitude is given by the radius of perceptibility. The present-day town of Rovaniemi was chosen to represent the outskirts of 'Kemi Lapland' (meaning Finnish Lapland) where the earthquake was reportedly felt, and an intensity value of 3 was assigned to it.

For both locations (Figure 5a,b), the upper limit of magnitude is 5.1, which agrees well with the magnitudes derived from intensities at the localities given, especially with the solution based on intensities of 5-6 in Utsjoki. Information 'felt in Kemi Lapland' also constrains the solution. An alternative intersection of circles is located toward the northeast at more than 150 km from Utsjoki and will require a magnitude value of $M = 5.7$. It contrasts with the upper limit of magnitude ($M = 5.3$) for this epicenter location (distance 470 km from Rovaniemi) and also the underground roar heard in Utsjoki. Therefore, it is regarded as an alternative solution with a low probability.

5. Discussion and conclusions

Two primary reports of earthquake activity emerged in very sparsely settled, remote northernmost Europe at the turn of 1759. It is merely by chance that a group of soldiers experienced an earthquake on the way and that was heading toward Arkhangelsk, which was well connected to St. Petersburg where newspapers were published. Preconditions for records to appear in writing had improved only in the preceding years. A vicarage was founded in Utsjoki in 1747, making vicar Henrik Wegelius one of the very few learned persons over a large area in the far north. Interest in making systematic observations of nature was growing at that time.

The earthquake reports were distributed to other countries and appeared in many important seismological compilations (Figure 2, Appendix). However, the information was summarized, resulting in missing primary information, such as the Russian place names. Moreover, two explicitly given localities, Kola and Arkhangelsk, had nothing to do with the earthquake being felt. This supports well the principle of historians preferring sources created by eyewitnesses and contemporaries [e.g. Howell and Prevenir 2001]. In the 1758 case, the recommendation for searching for more ample data in archives and libraries [e.g. Guidoboni and Ebel 2009] did not lead to ample recoveries; instead, it is very fortuitous that as

many as two separate earthquake reports exist. The chance for earthquake observations to be recorded in writing is diminished in sparsely settled regions where illiteracy is prevalent [Mäntyniemi et al. 2011].

Solutions based on the macroseismic information available for the earthquakes of December 17 and 31, 1758 are summarized in Figure 6. Differences in location and magnitude within the same alternative solution (for example, V1) directly reflect the accuracy of the solution, which follows from the uncertainty of intensity assessment in different places. The largest scatter was for V3 and the difference in location was 33 km, while the smallest was for V1, only 9 km. The error for magnitudes was almost the same, app. 0.2-0.3 units, for the various solutions within the same alternative.

In addition, there was uncertainty reflecting the spatial distribution of the data points, so that there was more than one combination of epicenter and magnitude that ensured the same spatial distribution of intensities. This uncertainty could not be reduced for the given spatial distribution of data points by a more accurate intensity assessment. Sometimes, additional information can help to reduce the number of alternatives. For example, when taking into account the distance of perceptibility, one can quite confidently reject alternative V4 (Figure 6).

It is important to understand clearly what contributes to the accuracy of the solution and whether the uncertainty of parametric solutions can be reduced for the dataset given. If it is not possible to objectively

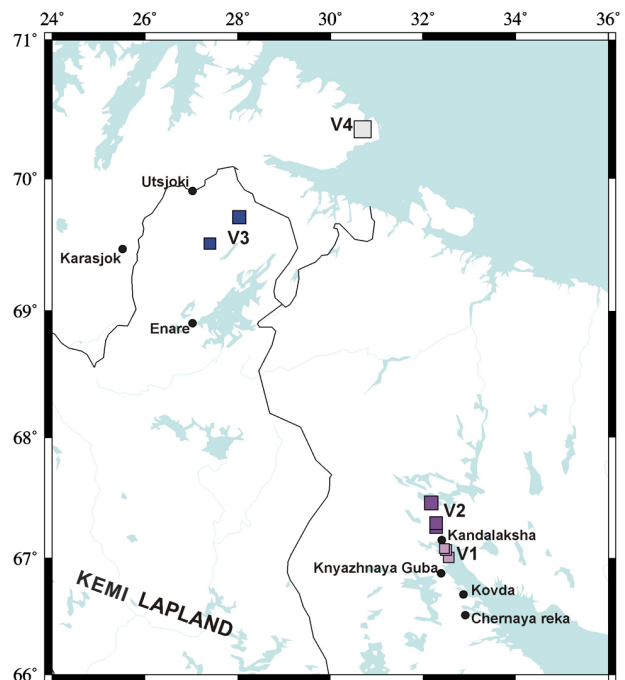


Figure 6. Squares denote possible epicenters associated with different magnitudes for the earthquakes of December 17 (V1 and V2) and 31 (V3 and V4), 1758.

choose a single primary parametric solution, it is better to include alternative solutions in the parametric earthquake catalogs. Such an approach to cataloguing earthquake activity in the same region in 1626 was proposed by Tatevossian et al. [2011]. In this case, it is even unclear whether one or two earthquakes occurred.

In conclusion, we agree with Kondorskaya and Shebalin [1977, 1982] in that two separate earthquakes occurred in the Russian North and present-day Finland in December 1758. However, the date of the first earthquake was December 17 according to the Gregorian calendar; there was less confusion about the second date of December 31, 1758. Both earthquakes were supported by a primary report. However, the epicenters were changed from the previous ones to the vicinity of the Bay of Kandalaksha and northernmost Lapland. The Bay of Kandalaksha is characterized by a graben structure and associated faults mapped in e.g. Sim et al. [2011]. Instrumental recordings of microearthquakes show a pronounced seismicity trend across the Finnish-Russian border toward Kandalaksha. More infrequent microearthquakes occur in the Finnish-Norwegian border region in the far north [Ahjos and Uski 1992 and updates]. The magnitudes of the two investigated earthquakes were within the range 4.3-5.0, which is rather large on the regional scale. This is quite an unusual pattern of seismicity in the region of interest.

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Appendix

Source	When	Where	Text	Its references
Кондорская, Шибалин, 1977 [Kondorskaya and Shebalin 1977]	дек. 6			Мушкетов, Орлов, 1893; Renqvist, 1930; Sieberg, 1932; Горшков, 1947; Панасенко, 1969
	дек. 31			Мушкетов, Орлов, 1893; Renqvist, 1930; Панасенко, 1969
Панасенко, 1969 [Panascenko 1969]	дек. 6	К востоку от г. Колы	В русской Лапландии на берегах Белого моря, в г. Коле и его окрестностях произошло сильное землетрясение, продолжавшееся по одним известиям, 3 часа, а по другим – полчаса; в то же самое время разразился сильный ураган, разрушивший много домов и распространившийся до Архангельска [Мушкетов, Орлов, 1893, с. 165].	Мушкетов, Орлов, 1893; Renqvist, 1930; Sieberg, 1932; Горшков, 1947
	дек. 31 в 21:30 Гринвич	Карасйок	Раздались в Кеми, в Лапландии, два подземных удара, которым предшествовал шум. Одновременно с этим явлением были замечены сотрясения в Англии [Мушкетов, Орлов, 1893, с. 165]. Землетрясение ощущалось также на севере Финляндии – в Утсйоки, Инари и др. местах, в Норвегии – в районе Карасйоки [Renqvist, 1930]. Эпицентр, согласно Ренквисту, располагался вблизи Карасйоки.	Мушкетов, Орлов, 1893; Renqvist, 1930
Горшков, 1947 [Gorshkov 1947]	дек. 7	Кола	В Лапландии на Кольском полуострове, от Колы до берегов Белого моря – продолжительное землетрясение, продолжавшееся по одним источникам три часа, по другим – полчаса. Эпицентр, по-видимому, в районе Карасьюк – центре весьма активных сейсмических импульсов.	Мушкетов, Орлов, 1893. № 706, Sieberg, 1932
	дек. 31 20:30	Кеми	В Кеми два подземных удара, с предшествовавшим им шумом	Мушкетов, Орлов, 1893. № 707
Sieberg 1932	Dec. 6	Karasjok, Halbinsel Kola, Kuste des Weißen Meeres	1758. Dezember, 6. In Lappland, besonders zu Karasjok and auf der Halbinsel Kola bis zur Küste des Weißen Meeres ein Erdbeben.	
Renqvist 1930	Dec. 6	Kola och omnejd.	6 décembre, à Kola, sur les côtes de la mer Blanche et environs, tremblement de terre considérable; en même temps survint un gros ouragan qui renversa plusieurs maisons, et s'entendit jusqu'à Arkhangel; le trembelments n'y parvit pas. La durée de l'un et de l'autre a été de trois heures, selon les uns, et demi-heur seulement, selon d'autres.	Perrey, som citerar Coll. Acad., t. VI
	Dec. 31	Utsjoki – Enare – Kemi	Literal reproduction of the text from Wegelius, 1759, 229-232. see below.	Wegelius, 1759, 229-232

Source	When	Where	Text	Its references
Мушкетов, Орлов, 1893 [Mushketov and Orlov 1893]	ноябрь 26 (с. ст.)	Кола	В русской Лапландии на берегах Белого моря, в г. Коле и его окрестностях произошло сильное землетрясение, продолжавшееся по одним известиям, 3 часа, а по другим – полчаса; в то же самое время разразился сильный ураган, разрушивший много домов и распространившийся до Архангельска.	Перрей, Землетрясения [это Перрей 1846 г.]
	дек 20 (31) ок. 11:30 вечера	Кеми, Лапландия	В Кемии, Лапландия, раздалась два подземных удара, которым предшествовал шум. Одновременно с этим явлением были замечены сотрясения в Англии.	Collection Académique, XI, 13; Abhandlungen der Academie von Stockholm; R. Mallet, ib.
Mallet and Mallet 1858	Dec. 6	Russian Lapland along the White Sea, at Kola and environs	A considerable earthquake. It lasted 3 hours according to some or only half according to other accounts. A terrible tempest that lasted the same time as the earthquake that accompanied it. The storm threw down many houses in Archangel, where the earthquake was not felt.	Collection Académique; Abhandlungen der Academie von Stockholm (German translation), 1759, p. 221
	Dec. 31 about 11:30 p.m.	In Kemi Lapland. Also at the same time in England	Two shocks. Preceded by subterranean noise. Perrey suggests that the shock in England referred to may be of the 20th.	Collection Académique t. xi. P.13; Abhandlungen der Academie von Stockholm (German translation), loc. cit.
Перрей, 1846 [Perrey 1846]	дек. 6	Русская Лапландия	В Русской Лапландии на берегах Белого моря, в Коле (68° 58' широты) и ее окрестностях сильное землетрясение; в то же время сильный ураган, разрушивший много домов и распространившийся до Архангельска; землетрясение туда не дошло; то и другое продолжалось по одним 3 часа, а по другим полчаса (С. А.)	La Collection Académique t. VI part etrange
Perrey 1845	Dec. 6	à Kola, sur les côtes de la mer Blanche et aux environs	à Kola, sur les côtes de la mer Blanche et aux environs, tremblement de terre considérable; en même temps survint un gros ouragan qu'inversa plusieurs maisons, et s'étendit jusqu'à Archangel; le tremblement n'y parvint pas. La durée de l'un et de l'autre a été de trois heures, selon les uns, et de demi-heure seulement, selon d'autres	Collection Académique, t. VI
	Dec. 31	Laponie	vers onze heures et demie du soir, en Laponie, bruit souterrain suivi de deux secousses	Collection Académique, t. XI, p. 13
Collection Académique, 1772, t. XI, p. 13	Dec. 31	Ouïoski	Celui qui se fit sentir en 1758 à Ouïoski en Laponie, province de Kimi, fut tel à-peu-près que les précédents. Quatre jours auparavant le baromètre descendit jusqu'à ving- trois pouces neuf lignes un quart. Le 31 décembre l'air fut pur, le jour agréable. Un vent de midi fort doux régna jusques à quatre heures du soir. Il s'éleva pour lors un brouillard épais. A dix heures le thermomètre étoit à vingt et un degrés au-dessous de la glace : le baromètre fut tout le jour à vingt-quatre pouces sept lignes. Vers onze heures et demie on entendit un bruit souterrain qui s'augmenta par degrés et paroissoit approcher. (continues on following page)	Les mémoires de l'académie des sciences de Stockholm

Source	When	Where	Text	Its references
Collection Academique, 1761, t. VI, p. 648	Dec. 6	Laponie Moscovite	<p>(continued from previous page)</p> <p>Il fut bien-tôt suivi de deux secousses assez fortes qui durèrent chacune deux ou trois minutes. Elles s'étendirent nord-est et sud-ouest, de même que l'aurore boréale qui parut un peu auparavant : presque toutes les aurores boréales de cet hiver eurent la même direction. Un lapon dit avoir vu pendant la secousse des especes d'éclairs: l'observateur qui rend compte de ce phénomène n'en aperçut pas : on trouva le lendemain des crevasses dans plusieurs endroits.</p> <p>Le six Décembre, tremblement de considérable dans la Laponie Moscovite, sur la côtes du Golfe de la mer blanche à Kola, petite Ville au soixante-huitieme degré cinquante-huit minutes de latitude & dans les environs ; en même temps survint un gros ouragan qui renversa plusieurs maisons, & s'étendit jusqu'à Arkhangel; le trembelments n'y parvit pas : la durée de l'un & l'autre a été de trois heurs, selon les uns, & demi-heur, selon les autres.</p>	
Wegelius 1759	Dec. 31	Utsjoki, Carasjoki, Enare, Kimi Lappmark, utan och til Kimi socken	<p>Den 31. December sistledet år, var väderleken här i Utsjoki klar och behagelig, alt til kl. 4 efter middagen, med sakta sydlig vind. Kl. 8 för middagen stod Thermometern 17 gr. men kl. 10 efter midd. 21 gr. under frysuncten. Barometern stod hela dagen til 24 Decimal tum, 7 liniers högd. Kl. 4 efter midd. blef himmelen öfveralt ganska töknig, så att man här vid Prästegården, icke kunde se topparne af de Fjäll, som ligga helt nära intil.</p> <p>Inmot kl. half 11 efter middagen, började et starkt underjordiskt dån att höras, hvilket småningom blef starkare, och tycktes komma närmare. Sedan det påstått et par minuter, begynte jorden gunga, ungefär som en båt i medelmåttig sjö-gång på vida hafvet. Där under hördes några starka smällar, nära til jordens yta, hvilka förmodeligen härrörde däraf, at den tilfrusna marken remnade. Gungningen påstod i 2 à 3 minuter, och hördes dån et en stund efter, uti sakta aftagande, til dess det aldeles uphöorde.</p> <p>Vid pass 2 minuter därefter, begynte dån et åter höras, hvarpå fölgde en lika stark och långvarig skakning, som den förra.</p> <p>Samma natt, kl. half et om morgonen på Nyårs-dagen, hördes än et underjordiskt dån, hvilket likväl icke var så starkt och långvarigt, som den förra, icke heller märktes då någon rörelse eller gungning på sjelfva marken.</p> <p>Under de tvänne första skakningarna, och äfven litet förut, syntes Norrskan på himmelen (hvilka likväl ej voro nog tydeliga) til sträckningen ifrån SV. til NO; varande märkligt, at mäst alla Norrskan, som visat sig i denna vinter, haft samma sträckning. Kl. 11 om natten försvunno så väl Norrskanen som töknet, och var himmelen sedan alldeles klar.</p> <p>Ehuru uppmärksam jag var at i akt taga sträckningen af dessa Jordbäfningar, kunde jag likväl icke utröna den med full visshet. Dock tyckte jag, at dån et och skakningarna gingo ifrån SV. til NO.</p> <p>En Lappman berättade, at han under Jordbäfningen märkt på himmelen någon eld, som liknat ljungelden; men ehuru noga aktning jag gaf, om något besymmerligt skulle yppa sig på himmelen, blef jag dock ej något sådant varse.</p> <p>Dagen efter, eller d. 1 Januarii, befants marken, där is-gatan var, på många ställen remnad.</p> <p>At de tvänne första skakningarna voro tämmeligen starka, kan däraf slutas, at alle, som humnit somna, upvaknade med mycken förskräckelse. Folket sprang ut, och befarade, at husen skulle ramla öfverända. Den förskräckelse, som öfverföll Lapparna, hvilke då voro här vid Kyrkan församlade, kan ej beskrifvas. De hade aldrig tilföre märkt någon Jordbäfning, och ganska litet eller intet hört talas därom. De togo til mig sin tilflykt, och om de icke fått någon underrättelse af mig om denna Naturens verkning, hade de säkert fallit på mycket underliga tankar däröfver.</p> <p>Uti Carasjoki i Norrige, som ligger vid pass 10 mil härifrån, hafva Jordbäfningarna varit så känbara, att isen uti en Sjö blifvit aldeles sönderkrossad. (continues on following page)</p>	Eyewitness

Source	When	Where	Text	Its references
			<i>(continued from previous page)</i> Där hafva ock flera skakningar samma natt blifvit kände. I Enare, som ligger 15 mil här ifrån åt SSO, hafva alle kända de tvänne första skakningarna, dock hafva de där ej varit så starka, som här i Utsjoki. På marknads platsen därstädes, har likväl skorstenen uti Fogdens stuga blifvit bräckt af gungningarna. Jordbäfningen har sträckt sig icke allenast öfver hela Kimi Lappmark, utan ock til Kimi Socken, samt, kan hända, ändå vidare.	
newspaper Kjöbenhavnske Danske Post-Tidender, no.20, Mar 9, 1759	Dec. 17	Kandalax, Knäschma Guba, Kowda Wolost, Tschorna Reka, Krest Vsisst	Archangel, den 10 Jan. En Expresser er her anlangt fra Kola, som har medbragt den Efterretning, at da han var paa Benen til Archangel, den 17de Dec. 1758 reiste sig, da det var mørk Aften, en meget stor Orcan, paa hvilken fulgte et sa heftigt Jordskielv, at hverken Menneske eller Fæe kunde staae paa Beenene, ja, endog Ovne og skorsteene bleve deels spaltede, og deels ligesom knusede. Jordskielvet vedvarede 3 hele Timer, og holdte ikke op, førend den heftige Storm tillige ophørte. Jordskielvet begyndte til Kandalax, og blev paa samme Tid paa det heftigste fornummet Klokken 6. om Aftenen til Knäschma Guba, Kowda Wollost, Tschorna Reka og Krest Vsisst.	
newspaper Stockholms Post-Tidningar, no. 18, Mar 1, 1759	Dec. 17	Kandalax, Knäschma Guba, Kowda Wolost, Tschorna Reka, Krest Vsisst	Archangel, den 9 Januarii. En ifrån Kola hitkommen Express berättar, at då han varit på vägen til Archangel har den 17 nästled. upkommit en owanligt häftig Nordwest Storm, och därpå följt en så häftig Jordbäfning, at hwarken Menniskjor eller Boskap kunnat stå på föttern, och Ugnar samt Skorstenar dels rämnat, dels aldeles omkullfallit. Expressen hade tillika med de honom åtföljande Soldater måst kasta sig i Snön, emedan de icke förmått at stå. Jordbäfningen har wid påstående Storm warat 3 hela timar, och icke förr uphört, än sedan Stormen sackt sig. Jordbäfningen hade tagit sin början wid Kandalax, och wid samma tid försports lika häftig uti Knäschma Guba, Kowda Wolost, Tschorna Reka, och Krest Vsisst.	
Московские Ведомости, 1759, no.11, фев. 5, пятница [Moskovskije Vedomosti, 1759, 11]	дек. 6	Кандалакса, Княжная губа, волость Ковда, при Черной реке и у креста Взиста	Literal reproduction of the text from newspaper Sankt-Peterburgskije Vedomosti, 1759, 8. see below.	
СПб, Ведомости 1759, no. 8, янв. 26, вторник [Sankt-Peterburgskije Vedomosti, 1759, 8]	дек. 6	Кандалакса, Княжная губа, волость Ковда, при Черной реке и у креста Взиста	От города Архангельского от 30 декабря. Пришедший сюда недавно из Кольского острога солдат сказкою показал, что во время бытности его в дороге декабря 6 дня поздно в вечеру востала презрестокая и весьма чрезвычайная буря от северозапада, и потом последовало столь сильное землетрясение, что не токмо люди и скот не могли на ногах устоять, но и печи и трубы отчасти разселись, а отчасти повалились. При такой жестокости трясения принужден он был с товарищами своими солдатамиж броситься в снег, потому что им не можно было на ногах стоять долее. Землетрясение сие продолжалось при упоминутой буре три часа, а перестало уже по утишении ветра. Оно началось при Кандалаксе, и в то же самое время т.е. 6 же числа в вечеру чувствуемо было в ù губе. в волости Ковде, при Черной реке и у креста Взиста.	Derived from an eyewitness

The references for the earthquakes of 1758 from Kondorskaya and Shebalin [1977, 1982] traced back and completed with primary information. The references are given in the original languages. The flow of information, including place names and dates, is summarised in Figure 2.