11

Intraplate Seismicity and Seismic Hazard: The Gulf of Bothnia Area in Northern Europe Revisited

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1. Introduction

Intraplate seismicity is a challenging subject to study, because earthquake observations accumulate slowly in plate interiors. It is known that great earthquakes can occur in these regions and that shallow earthquakes may break the surface, but examples are limited to a dozen or so. This has obvious implications to seismic hazard and risk. England & Jackson (2011) pointed out that the unanticipated earthquakes in continental interiors have claimed more human lives than earthquakes at plate boundaries in the past 120 years.

The present investigation deals with intraplate seismicity of the Fennoscandian (Baltic) shield in northern Europe. The seismicity of the region has been discussed by several authors over the years (e.g., Bungum et al., 1986; Gregersen et al., 1991). The investigation focuses on the Gulf of Bothnia bordered by Finland to the east and Sweden to the west (Fig. 1). The Gulf of Bothnia has long been recognized as one area of enhanced seismicity in the region; even the oldest seismicity maps based on written documentary records show how earthquakes occur on its coasts. It is a seismicity area in miniature: the current seismograph networks register relatively frequent micro-earthquake activity down to magnitude below 0, while the largest observed earthquakes had magnitude above 4. It is not clear whether magnitude 5 has been exceeded during the last three centuries, the time span of the available seismicity record, because the largest earthquakes occurred during the non-instrumental era and their magnitudes are affected by uncertainties. The first short-period seismographs suited for the registration of local earthquakes were installed in the study area in the latter half of the 1950s. All earthquake information prior to that time is defined as historical.

Emphasis is laid on the historical data in this study. Many of the largest earthquakes known occurred adjacent to the Gulf of Bothnia, but only those in 1883, 1888 and 1898 have been subjected to a more detailed analysis (Mäntyniemi, 2005, 2008). New macroseismic maps are presented for earthquakes of 27 November 1757, 14 July 1765, 13 October 1780, 26 May 1907, 31 December 1908, and 9 March 1909. Many previously unknown reports of these earthquakes were brought to light, when scanning the contemporary press. In addition, attention is paid to the location of the largest historical earthquakes. They are compared with recent instrumental records and reviewed against the seismo-tectonic setting. Evidence for larger earthquakes is analyzed using historical data. The potential for larger earthquakes in the area and implications for seismic hazard are discussed.

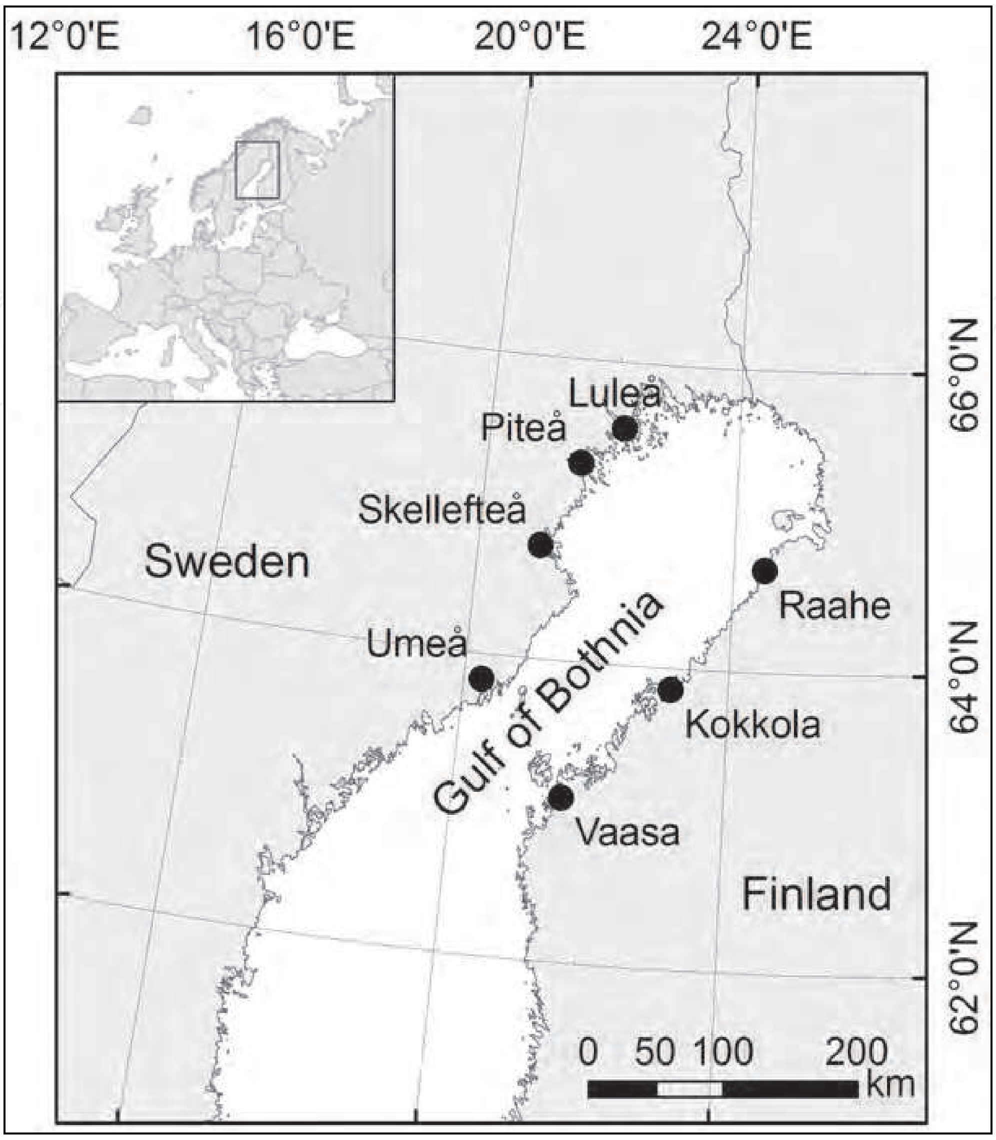

Fig. 1. Study area and place names mentioned in the text. Black dots denote towns. The light purple line in the north denotes the present-day state border between Sweden and Finland.

2. Seismicity features

Earthquake activity along plate boundaries is driven by tectonic forces. The study area undergoes postglacial uplift with a maximum uplift rate of about 10 mm/yr centered in the northern Gulf of Bothnia (e.g., Kakkuri, 1997). The uplift of land from the sea has been documented in Finland and Sweden for more than three centuries, so it appeared reasonable to explain the observed earthquake activity by land uplift, as many early geoscientists did. The advent of focal mechanism studies and stress observations provided arguments in favor of ridge-push from the mid Atlantic, because the NW-SE compression dominates in the region. Therefore the first-order stresses are generally attributed to forces at plate margins, the nearest plate margin being the mid-Atlantic ridge. The role of postglacial uplift in present seismicity remains an open question. Fjeldskaar et al. (2000) modeled the isostatic movements related to deglaciation and uplift. They concluded that, although the modeling fits the overall observations well, there are areas of misfit between them and the isostatic uplift model. The misfit was interpreted to reflect a tectonic component of the uplift. The Swedish east coast with the center northeast of the Gulf of Bothnia was one area of computed misfit. Also local features, such as sediment loading and topography, may affect the rupture of individual earthquakes, or different combinations of several factors.

2.1 Historical seismicity

Many towns were founded around the Gulf of Bothnia during the reign of king Gustavus II Adolphus of Sweden in 1611-1632. This increased the chances of documentation, and earthquakes felt on the shores of the Gulf of Bothnia are known since the 1700s. The oldest reports can be found in scientific essays and contemporary newspapers. They tend to be brief and sparse, so the historical method needs to be modified for observations stemming from the 1700s and most of the 1800s (Mäntyniemi et al., 2011). Local geologists started to use macroseismic questionnaires systematically in the 1880s.

The area of interest is quite challenging for macroseismic analyses, because it is crossed by sea, and also by a state border for more than two centuries. A crucial question in historical seismology is whether a paucity of observations in a given area in a given time interval results from an absence of earthquakes or earthquake reports. It is unclear how much earthquake reporting in the area was affected by the detachment of Finland from Sweden in 1809, when the Gulf of Bothnia became a border area. Interesting earthquake occurrences were reported in the latter half of the 1700s. After the separation, felt earthquake reports east of the Gulf of Bothnia ceased to be included in Swedish newspapers. Anyway, it is important to collect and display what is available, because not all available documentation on the effects of historical earthquakes has been used to date and macroseismic maps do not exist for every interesting earthquake in the area. Previously disregarded earthquake reports have been discovered in the contemporary press in particular. Below new macroseismic maps are presented for a selection of earthquakes felt on both coasts of the Gulf of Bothnia in the 1700s and 1900s. The maps consist of macroseismic data points (MDPs) that illustrate where effects of earthshaking were reported and indicate the strength of the effects, i.e. seismic intensity, when the available information is adequate.

2.1.1 Earthquakes in the latter half of the 1700s

An earthquake was felt at the bottom of the Gulf of Bothnia on 27 November 1757 between 6 and 7 am local time (Fig. 2). Reports about the felt effects have survived in local history and lore (cf. Sidenbladh, 1908; Renqvist, 1930). The use of oral accounts or reminiscences of earthquakes, not untypical of the study area, is discussed by Mäntyniemi et al. (2011). One macroseismic data point is uncertain. It may be related to another earthquake. However, the time of observation matches this earthquake except for the year (1752 instead of 1757). The time of day and time of year are considered the most reliable criteria of a genuine eyewitness report of an earthquake (Mäntyniemi et al., 2011).

Figure 3 shows the information available for the earthquake on the evening of 14 July 1765 (at about 9 pm local time). It is based on four letters from the surrounding provinces published in newspaper *Inrikes Tidningar* ("Domestic news") between 29 July and 23 September 1765. The intensity 1 (not felt) observation relies on a reminiscence published in the same newspaper on 6 November 1780. Only one observation is available for the earthquake on the morning of 13 October 1780, a situation sometimes encountered in historical seismology (Fig. 4). The assigned intensity is on the slightly damaging level, since fractured ovens were reported. The same town has sustained this kind of damages during other earthquakes as well (Mäntyniemi, 2007).

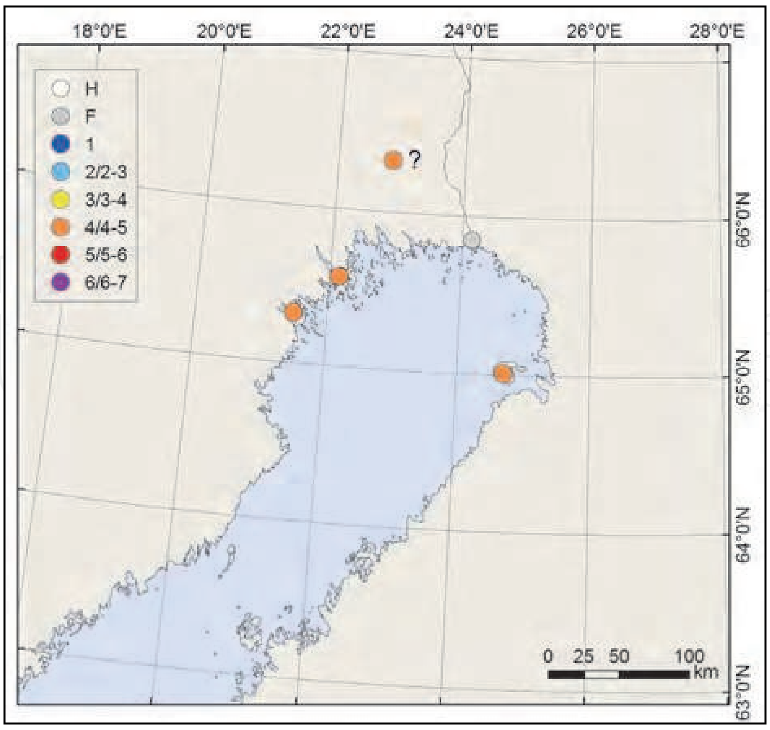

Fig. 2. A macroseismic map on the earthquake of 27 November 1757 between 6 and 7 am local time. Filled circles denote intensities given on the European Macroseismic Scale (Grünthal, 1998). The letter H stands for heard, F for felt. It is not certain whether the intensity point accompanied by a question mark belongs to this earthquake.

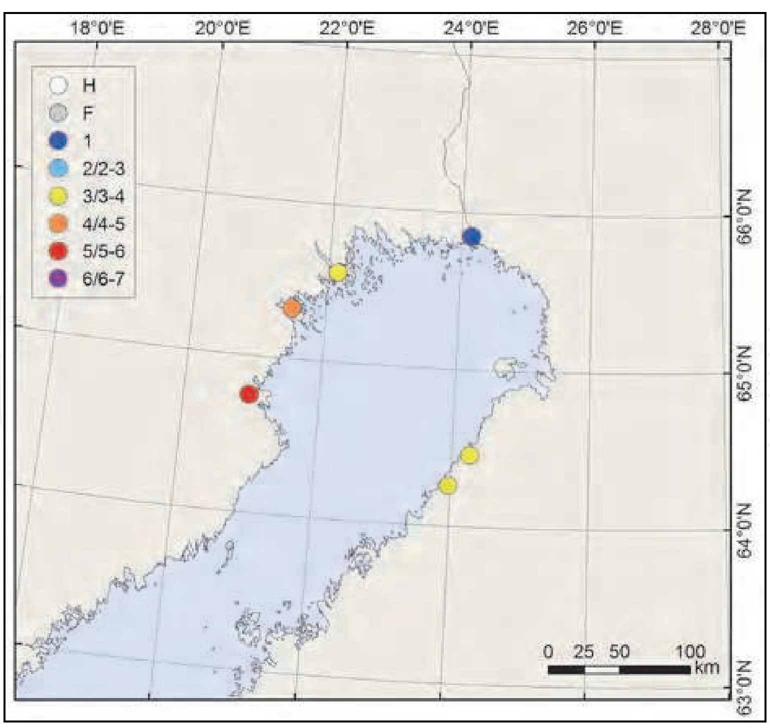

Fig. 3. A macroseismic map on the earthquake of 14 July 1765 at about 9 pm local time. Numbers are intensities given on the European Macroseismic Scale (Grünthal, 1998). At the time of the earthquake all area shown was Swedish territory.

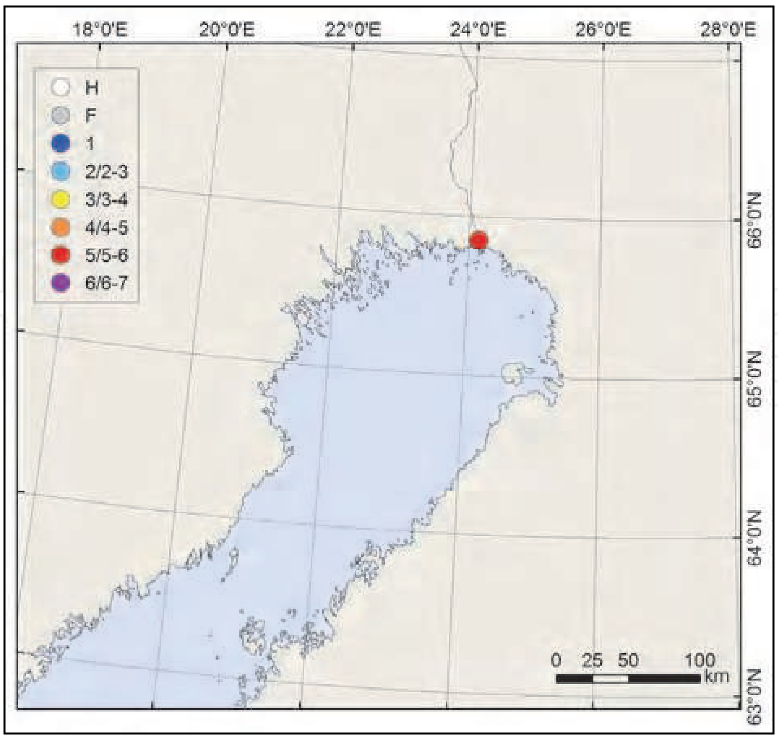

Fig. 4. A macroseismic map on the earthquake of 13 October 1780 at about 6:20 am local time. Filled circles denote intensities given on the European Macroseismic Scale (Grünthal, 1998). At the time of the earthquake all area shown was Swedish territory.

2.1.2 Earthquakes in the early 1900s

Swedish geologists and the Geographical Society of Finland were responsible for collecting felt reports of earthquakes in the study area in the first half of the 1900s. However, the activities were carried out parallel to each other and, as a rule, the outputs were not combined. There is usually little uncertainty about the timing of the observations in this century, so the chance of confusing different earthquakes with each other is rather low.

Sahlström (1911) described observations regarding the earthquake of 26 May 1907 (at about 11:33 am Swedish time) and draw the area of perceptibility. Later Renqvist (1930) reported that the event was felt in the archipelago and some locations east of the Gulf. Previously disregarded place names were found in the contemporary press in the present study. The new area of perceptibility is thus larger than that of Sahlström (1911). There are rather few classification criteria available at the lowest intensity values and thus the range of intensities is narrow (Fig. 5).

Sahlström (1911) named three communes where the earthquake of 31 December 1908 (at about 10:20 pm Swedish time) was felt west of the Gulf of Bothnia and outlined the respective area of perceptibility. Sederholm (1909, p. 65) reported that the event was felt on the eastern shore as well. More precise place names were uncovered in the contemporary press. They expanded the area of perceptibility westward; information about the eastern coast could not be augmented. The reports are not very detailed, so seismic intensity can be assessed only for a few places (Fig. 6). The reporting may have been overshadowed by the earthquake catastrophe in Messina, Sicily three days earlier, as news of the devastation there started to pour in at the beginning of the year 1909. The reportages were often accompanied by figures, which was not common for news coverage at that time.

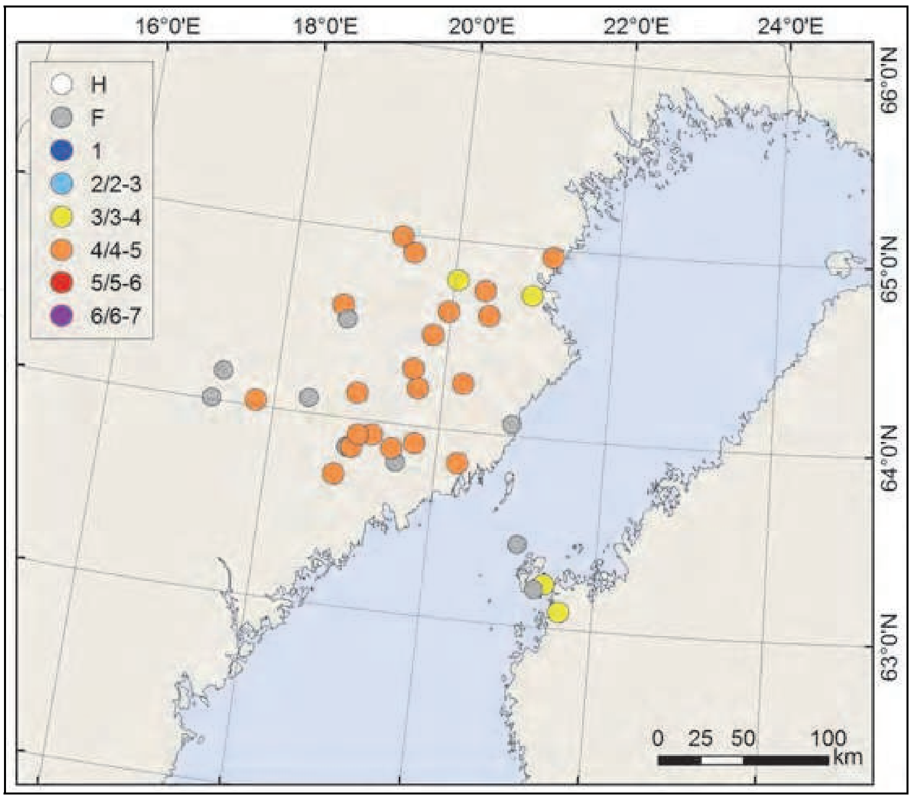

Fig. 5. A macroseismic map on the earthquake of 26 May 1907 at about 11:33 am Swedish time. Numbers are intensities on the European Macroseismic Scale (Grünthal, 1998). The letter H stands for heard, F for felt.

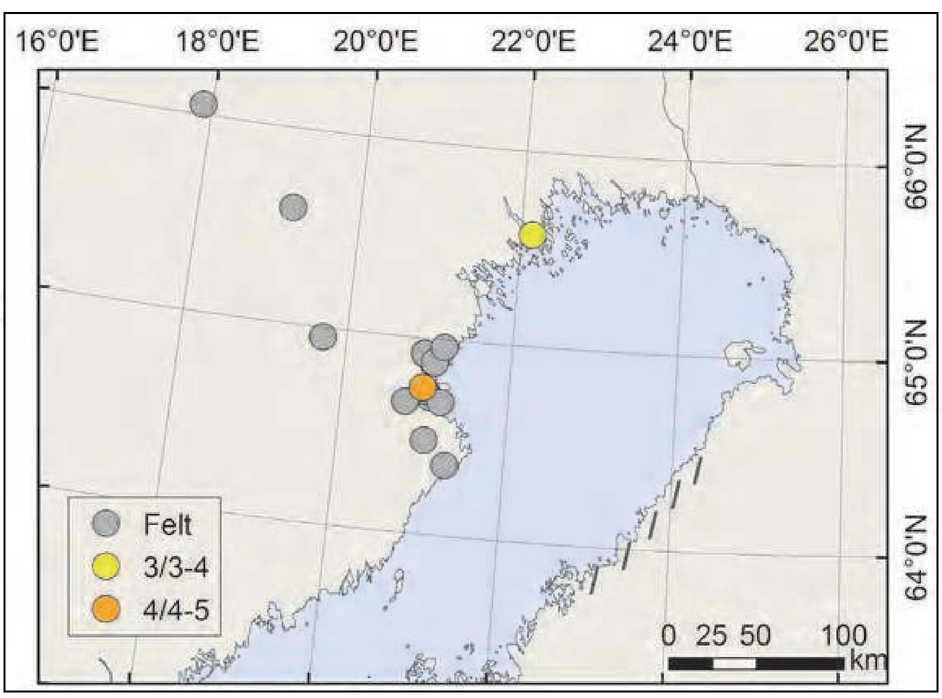

Fig. 6. A macroseismic map on the earthquake of 31 December 1908. Intensities are given on the European Macroseismic Scale (Grünthal, 1998). The earthquake was reportedly felt along the eastern coast (dashed area), but no specific locations can be named there.

The earthquake of 9 March 1909 was the largest event in the Gulf of Bothnia area in the 1900s (Fig. 7). The questionnaire data were presented and discussed by Sahlström (1911) for Sweden and by Rosberg (1912) for Finland. Both authors provided a map for the respective territory, but they were never combined. Båth (1956) gave the first parameters, including a magnitude estimate equal to 5, whereas Ahjos and Uski (1992) provided a macroseismic magnitude 4.6 for this event.

The contemporary press contained some letters from dwellers in the affected area, but most news were general descriptions of a given location. The newspaper reports were sometimes quite processed, providing the strength of earthquake effects relative to another location rather than the actual effects. The new map is thus based on the individual observations given on questionnaires and letters and the résumés prepared by unknown newspaper editors. However, the press provided helpful information in addition to the questionnaire data. The earthquake occurred at night (at about 1:20 am Swedish time), so information about the extent to which people were awakened was available. It is sometimes difficult to tell whether people were awakened by the accompanying earthquake sounds rather than actual

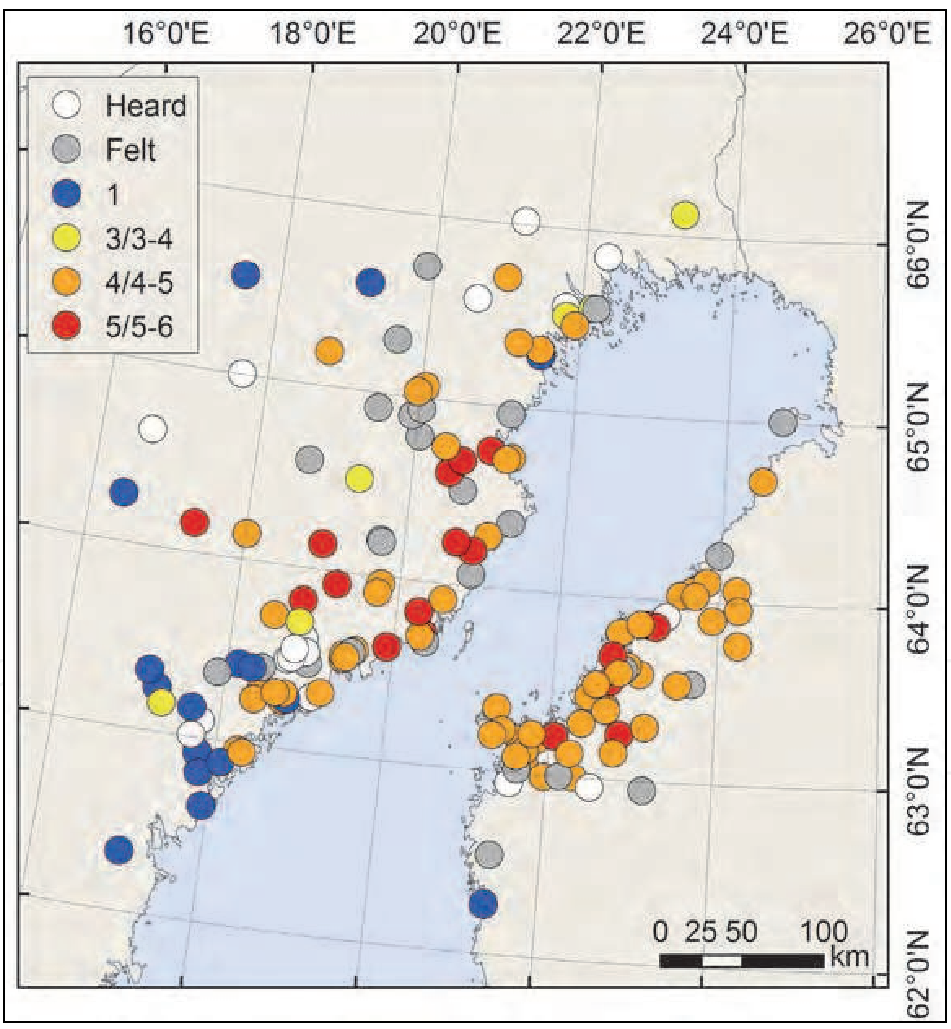

Fig. 7. Felt observations for the earthquake of 9 March 1909, the largest in the Gulf of Bothnia area in the 1900s. Filled circles show the villages and towns from where written documentary data are available. Numbers are seismic intensities on the European Macroseismic Scale (Grünthal, 1998).

ground shaking. Both shaking and sounds were often observed, whereas the heard-only observations tend to be located on the outskirts of the area of perceptibility (Fig. 7).
Estimation of epicenters for non-instrumental earthquakes relies on rather straightforward assumptions of symmetry – no strong dependency of ground motion on azimuth is assumed in the Gulf of Bothnia area until otherwise shown – and the proximity of the epicenter to the strongest effects. Symmetry assumptions may be hampered by the sea and incomplete area of perceptibility. It is commonly assumed that the strongest effects become included, in press reports in particular, as the possible damage is always a matter of concern. Since the density of population was low northward and inland of the Gulf in the early centuries, however, episodic strong ground motion could have been missed there. If reported, foreshocks and aftershocks may give insight into the location of the main shock.

2.2 Instrumental seismicity

Seven earthquakes of magnitude 3 or above occurred in the vicinity of the Gulf of Bothnia between 2001 and 2010 (Fig. 8). The largest had magnitude 3.5, the second largest magnitude

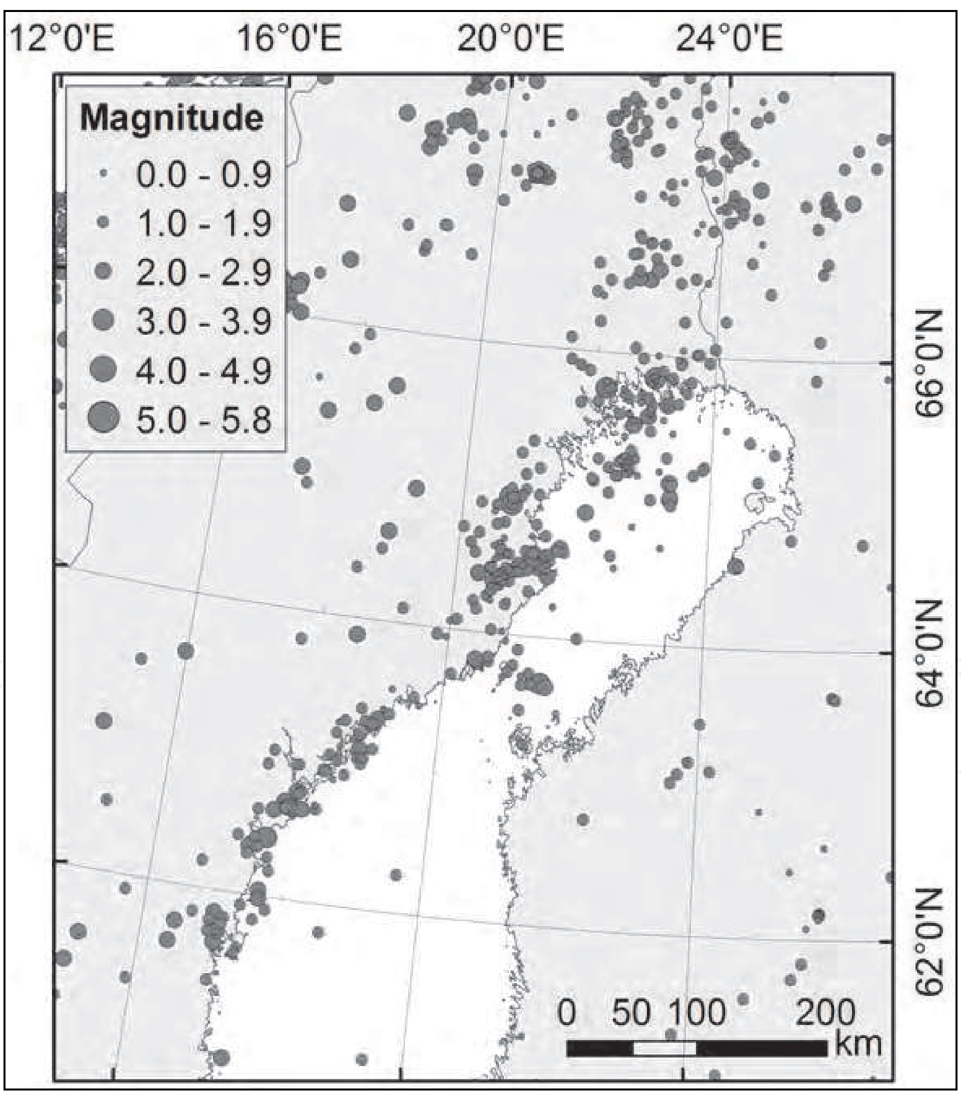

Fig. 8. Instrumental seismicity in the Gulf of Bothnia area between 2001 and 2010. Magnitude scale is M_L. Data: Institute of Seismology, University of Helsinki.

3.4. Two occurred at the bottom of the Gulf nearby Swedish Luleå, three close to Skellefteå, including the largest earthquake. Its coordinates were given as (21.32 E, 64.49 N). It was felt distinctly on the eastern coast including Vaasa and Kokkola (Fig. 1). One of the seven M>3 earthquakes occurred offshore in the narrowest part of the Gulf between Swedish Umeå and Finnish Vaasa, and one further southward on the western coast.

The estimated depths of M>3 events ranged between 6 and 19 km. The depth distribution of all earthquakes during this decade was wider, since the deepest micro-earthquakes were located at a depth of about 40 km. Many of the deepest quakes occurred along the seismicity trend that extends from the bottom of the Gulf northward.

Good-quality instrumental locations discern between onshore and offshore earthquakes. Moreover, the improved location accuracy means that the fuzzy clouds of micro-earthquakes sharpen up: the previously more or less continuous earthquake activity along the western coast of the Gulf of Bothnia south of latitude 64 N seems to be concentrated in smaller clusters. The most pronounced clusters can be found in the northern part of the Gulf. Very frequent micro-earthquake activity occurs in the vicinity of the town of Skellefteå, where it seems to be divided into two main clusters. The earthquake activity nearby Luleå is more diffuse with epicenters both inland and beneath the sea. Thus, the spatial distribution of earthquakes in the vicinity of the Gulf of Bothnia suggests that the probability of earthquake occurrence is not equal over the area.

2.3 Comparisons

The time span of the available earthquake catalogue, about three centuries, is too short for fundamental changes in the local stress field that constrains the occurring seismicity rates. Therefore similarities between the historical and instrumental data can be anticipated. Indeed, seismicity maps relying on observations stemming from the 1700s show how earthquakes occur along the coasts of the Gulf of Bothnia, a feature that accords with instrumental data. The historical catalogue includes several low-magnitude events (M<3) that may actually be relatively well known because of the proximity of epicenters to population centers. The main criterion for a near-by earthquake is the accompanying sound, which is heard in the vicinity of the epicenter and attributed to the seismic P wave (Tosi et al., 2000). However, the historical catalogue is incomplete at the lowest magnitudes and may also contain other types of events such as weather-related noise.

On the other hand, the longer non-instrumental catalogue may include rare events that did not occur during the brief instrumental era. Rare events are, for instance, earthquakes at unusual sites (e.g., sites not anticipated on the basis of more recent instrumental locations) and large earthquakes that occur far more seldom than small ones. The obvious difficulty is to tell whether an incompletely known historical area of perceptibility is evidence for a rare earthquake occurrence. A report describing felt effects may belong to a local or distant earthquake; a sparse report may not include any clue as to the type of ground motion (low or high frequency). The events that occurred outside the study area constitute one category of rare events. A distant offshore earthquake may be hard or impossible to recognize from the seismicity record (e.g., Musson, 2008). It is known from the historical seismicity record that earthquakes with epicenters away from the Gulf of Bothnia area have been felt around it. An example is the Lurøy earthquake of 31 August 1819, located on the coast of northern Norway (e.g., Muir Wood, 1988).

The narrowest part of the Gulf of Bothnia from Umeå to Vaasa spans about 80 km. The Gulf gets wider towards north; it is about 160 km from Piteå to Raahe (Fig.1). The most frequent micro-earthquakes are not felt over very long distances, so an earthquake felt both on the eastern and western coast of the Gulf is noteworthy. This can be used as a handy rule of thumb for detecting a rare event, rare meaning larger than usual. An earthquake occurring on the northernmost western coast has to be above M3, possibly closer to M3.5, in order to be felt on the eastern coast. It has to be borne in mind, however, that the historical felt observations may also be explained by an offshore event.

The earthquakes of 27 November 1757 (Fig. 2) and 13 October 1780 (Fig. 4) may be examples of repeated seismic activity at the bottom of the Gulf of Bothnia. This feature accords well with the instrumental data. An earthquake in the vicinity of Luleå would explain the distribution of felt observations shown in Fig. 2. However, other options can easily be constructed around a small number of felt observations. The population centers were small at that time, the density of population particularly low outside the coastal areas and river valleys, and the native Lapp people nomads, so occasional ground motion in the area may have easily been missed. Size estimates are obviously prone to error when the area of perceptibility is incomplete known. Since these earthquake observations were accompanied by sounds, however, they are assumed to be local events.

The earthquakes of 14 July 1765 (Fig. 3) and 31 December 1908 (Fig. 6) may be related to seismic activity in the vicinity of Skellefteå on the western coast. A more recent earthquake occurred there on 15 June 2010. Its magnitude was estimated at M_L3.5, and it was felt distinctly on the eastern coast as well. The earthquakes of 26 May 1907 (Fig. 5) and 9 March 1909 (Fig. 7) may be related to seismicity southward from the other examples, possibly closer to Umeå. These historical earthquakes seem to support the notion that seismicity in the area has preferred locations.

3. Seismo-tectonic setting

All earthquakes occur on faults, but within the continental interiors the networks of faults may be less well defined than on plate boundaries. A tectonic model for the Paleoproterozoic evolution of the Fennoscandian shield was presented by Lahtinen et al. (2005), based on petrological, geochronological, potential-field, deep seismic reflection and refraction, and geoelectric data. Major crustal-scale boundaries were inferred from lineaments on magnetic, electromagnetic, and Bouguer anomaly maps, where seismic reflection and refraction data were lacking (Fig. 9).

The Gulf of Bothnia is situated in the central part of the Fennoscandian shield, composed of Paleoproterozoic rocks. The central part is often referred to as the Svecofennian domain. Identified major boundaries in the area include the Baltic-Bothnian megashear that extends from the bottom of the Gulf towards north (Berthelsen and Marker, 1986) and the Piteå-Raahe shear zone crossing its northern part (place names in Fig.1). The Hassela shear zone crosses the southernmost Gulf. Paleoproterozoic units in Sweden include the Skellefte district in the vicinity of the town of Skellefteå, and the Bothnian basin.

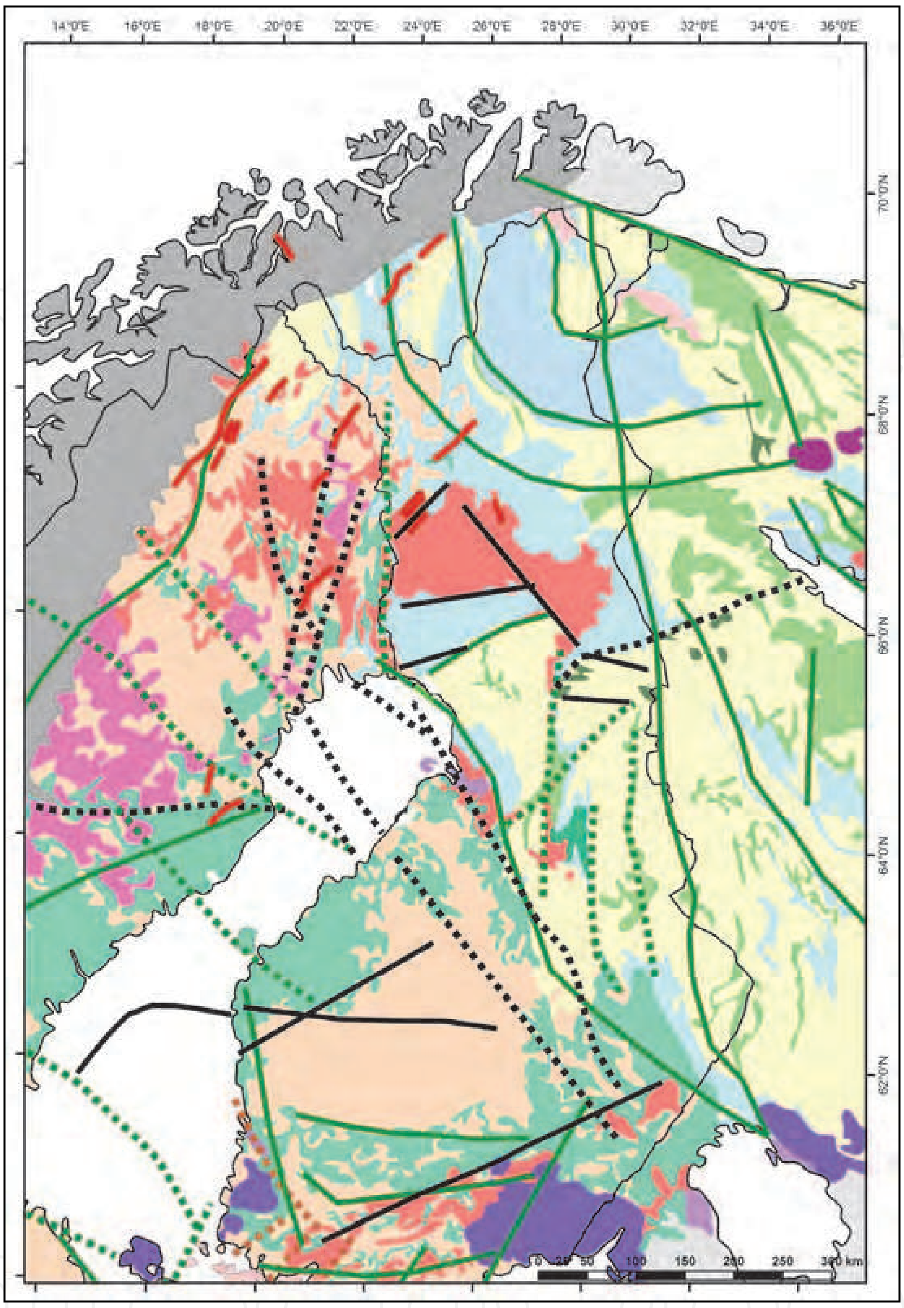

Fig. 9. Major aeromagnetic and Bouguer anomaly lineaments in the Fennoscandian shield. Continuous green lines denote magnetic lineaments, dotted green lines magnetic and Bouguer lineaments. Continuous black lines denote Bouguer lineaments, and dotted black lines Bouguer lineaments associated with shear zone at surface. Red lines denote mapped postglacial faults (from Lahtinen et al., 2005). The lineaments are shown on a simplified geological map. Igneous rocks and gneisses (denoted by light yellow) and supracrustal rocks (light green) are Archean rocks in the east. Supracrustal rocks of different ages (light and bright turquoise), the granulite belt (light blue), igneous rocks of different ages (light brown and pink), mafic intrusive rocks (spots of dark green), as well as granite and migmatite (reddish) are Paleoproterozoic rocks. The rapakivi granite association (purple) is Mesoproterozoic. The Caledonian orogenic belt (grey) and alkaline intrusions (bright purple) are Phanerozoic. Geology according to Koistinen et al. (2001).

4. Seismic hazard: how large magnitudes, where and when?

Seismic hazard assessment is confined to the location, time and maximum size of future earthquakes. Insufficient knowledge of ground motion is a secondary problem, if maximum magnitudes remain low. On many segments along plate boundaries, the location of the hazard is known with some probability, so the earthquake time constitutes the main concern. In contrast, in plate interiors even the locations may be poorly understood.

It is often assumed that the locations of small earthquakes are important indicators of the locations of future large earthquakes. Applying this scheme of things to the present study area means that the clusters of micro-earthquakes, discernible on the instrumental seismicity map (Fig. 8), should be looked at as sites where the hazard lies. As discussed in subchapter 2.3, there is some evidence of larger-than-usual earthquakes (at least M>3) that are located within the clusters, such as the earthquake of 15 June 2010 nearby Skellefteå. The historical epicenters cannot be pinpointed very accurately, but it is probable that the earthquakes of 14 July 1765 and 31 December 1908 are examples of repeat of M>3 events there. They have been given magnitudes of 3.9 and 3.7, respectively (Båth, 1956; Wahlström, 1990). These values were estimated using less information than presented in Figs. 3 and 6. However, the changes in the radius perceptibility affect the macroseismic magnitude slowly, because the dependency is logarithmic. The changes probably disappear within the magnitude uncertainty.

Determining the spatial distribution of the largest (M>4) earthquakes in the study area is hampered by uncertainties. When relying on the assumptions that the strongest earthquake effects, as well as foreshocks and aftershocks, occur in the vicinity of the epicenter, some of the largest historical earthquakes are located within or close to the clusters. For instance, Mäntyniemi (2008) proposed that the earthquake of 4 November 1898 may have occurred within the northern extension of the seismicity around the Gulf of Bothnia, which runs parallel to the Baltic-Bothnian megashear.

Båth (1956) gave the epicenter of the 9 March 1909 earthquake as (21.6 E, 64.0 N), with uncertainty in the range of 0.2-1.0 degrees (borders exclusive). This location is slightly offshore; Ahjos and Uski (1992) moved the epicenter eastward to (22.0 E, 64.0 N), which is clearly offshore. The previously unknown newspaper reports contain some remarks about small quakes preceding the main shock. If emphasis is placed on the foreshocks, the earthquake epicenter is shifted inland, to around longitude 19 E, while the latitude remains about the same. The distribution of felt effects shown in Fig. 7 could be explained by an inland epicenter: the westward portion of the area of perceptibility is larger than that eastward. There is no clear cluster of the strongest seismic intensities, which may indicate that the earthquake did not occur close to the ground surface. However, the modified epicenter is within one area of the largest seismic intensities. The modified epicenter seems to coincide with a crustal-scale boundary such as a magnetic lineament or a shear zone (Fig. 9), but the exact location remains uncertain. The possible connection to the enhanced seismicity around the postglacial fault north of the modified epicenter is unclear.

Magnitude 4 was not exceeded in the vicinity of the study area in seventy-four years until the Solberg earthquake of 29 September 1983. Kim et al. (1985) estimated its magnitude at

M_L=4.1, depth at 39 km, and located the epicenter near (17.5 E, 63.8N). This location is distant from the most pronounced micro-earthquake clusters; the Solberg earthquake did not occur where small quakes are frequent. Also instrumental locations are affected by uncertainties, but it is possible that the epicenter coincides with a mapped shear zone that commences (or ends) in the Skellefteå area.

Average recurrence time is somewhat conceptual in the case of M>4 earthquakes in the study area. There was a rather remarkable temporal cluster of these events in the late 1800s and early 1900s. It came to an end in 1909, and was followed only by the Solberg earthquake in 1983. The significance of this time variation of seismicity increases as more time passes and magnitudes remain low. Except for the 1909 earthquake, whose area of perceptibility totally covers that of the 1907 earthquake, the few available cases of M>4 occurred at different sites; the respective areas of perceptibility overlap scantily or partially. The seismic potential for M>4 earthquakes seems to be distributed widely over the area. It can be speculated whether earthquakes in this category will be repeated at the same sites in the future.

The seismicity in the study area follows the Gutenberg-Richter magnitude-frequency relationship with a large number of tiny earthquakes and a tiny number of "large" earthquakes. Earthquakes larger than shown by the short historical record could possibly occur. The discussion of the maximum magnitude in the area tends to be somewhat twofold. Great earthquakes (M>7 or above) have been associated to some of the mapped postglacial faults, especially in the north and north-west (Fig. 9). They have been dated to be less than 10 Ka old and have been explained by changes in the stress field due to deglaciation after the last glaciation. It is difficult to argue convincingly about the upper limit of magnitude in the current tectonic regime. However, it is known from areas of stable continental crust that earthquakes exceeding the largest observed magnitude have occurred. Such an example is known from east of Svalbard, northern Europe, where an M6.2 earthquake occurred on 21 February 2008.

5. Conclusion

The intraplate seismicity in the Gulf of Bothnia area, northern Europe exhibits enhanced micro-earthquake activity. The most pronounced clusters of micro-earthquakes are situated in places where several shear zones meet, for instance in the vicinity of the town of Skellefteå on the western coast. Earthquakes of M>3 have occurred within the clusters during the brief instrumental era, during the most recent decade as well, but earthquakes above magnitude 3.5 appear rare. Macroseismic maps of earthquakes felt on both the eastern and western shore of the Gulf are a practical means of detecting unusually large earthquakes. New maps making use of previously disregarded newspaper reports were prepared for a selection of earthquakes in the late 1700s and early 1900s. Some of the investigated earthquakes are interpreted to be repeat events within the clusters. For instance, the earthquakes of 14 July 1765 and 31 December 1908 are associated with the Skellefteå cluster. Their magnitude estimates are probably in the range 3.5-3.9. The earthquakes of 27 November 1757 and 13 October 1780 are regarded as local events at the bottom of the Gulf, where the pattern of instrumental seismicity is rather diffuse.

The few known earthquakes of magnitude M>4 stem mostly from the non-instrumental era. Some of the respective locations possibly coincide with the enhanced seismicity trends, but at least one M>4 earthquake occurred where small earthquakes are not that frequent. The location uncertainty precludes associating the historical epicenters with smaller structural features than crustal-scale boundaries, such as postglacial faults. It appears that the clusters of micro-earthquakes should not be looked at as the only sites where large earthquakes may occur in the area in the future.

6. Acknowledgment

The author thanks Kati Oinonen for plotting figures 1 and 6-8, Outi Valtonen for plotting figures 2-5, and Annakaisa Korja for permission to use figure 9.

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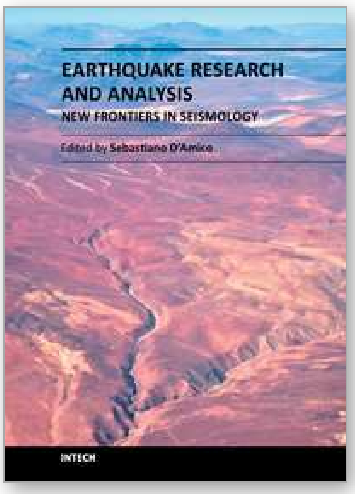

Earthquake Research and Analysis - New Frontiers in Seismology

Edited by Dr Sebastiano D'Amico

ISBN 978-953-307-840-3

Hard cover, 380 pages

Publisher InTech

Published online 27, January, 2012

Published in print edition January, 2012

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