
The Scandinavian Earthquakes of 22 December 1759 and 31 August 1819

ROBERT MUIR WOOD

The two largest known pre-1850 Scandinavian earthquakes are the 22 December 1759 Kattegat event (located at 57.7°N–11.1°E) and the 31 August 1819 Nordland event (located at 66.4°N–14.4°E), the latter being the largest north European near-shore earthquake of the past few centuries. The 22 December 1759 event caused minor damage to buildings (MMI VII) on either side of the Kattegat in Northern Jutland and in the Swedish province of Bohuslän, and was felt up to 600 km away. The 31 August 1819 earthquake caused widespread damage (MMI VIII) to stone components of wooden buildings in the sparsely populated region of Nordland Norway, as well as very extensive rockfalls, liquefaction phenomena and a remarkable variety of disturbances in fjords and in the sea. The earthquake was felt throughout northern Scandinavia over distances of up to 800 km.

INTRODUCTION

The western margin of Scandinavia (northern Europe) (see Figure 1) has a low to moderate seismicity, comparable with other intraplate regions, such as eastern North America. Earthquakes are recorded from 1073 in Denmark and 1570 in Norway (see Muir Wood and Woo, 1987). Yet for much of the post-Medieval period Norway was an underdeveloped northern colony of Denmark, and those regions with the highest seismicity (western coastal Norway) had few centres where such natural phenomena would be recorded. Communications were always very difficult along the rugged fjord coast and many of the details that have survived from the period 1570–1750 are fragmentary, and do not allow earthquake effects to be usefully mapped. Even for an earthquake

in the southwest Norwegian cathedral city of Stavanger on 16 March 1752, that “caused locked doors to burst open, glasses and crockery to fall, and stones from many houses to be thrown down” (Seyfart, 1756) no local sources have been found that might indicate the full geographical range of the shaking. However, at least in southern Sweden and Denmark, the start of newspapers and the greater spread of literacy make this mid 18th-century period the watershed after which major earthquakes can be adequately reconstructed.

Thus it proves possible to research, map and reconsider the significance of two of the most important events known from the region: the North Kattegat earthquake of 22 December 1759 and the Nordland, north Norway, earthquake of 31 August 1819.

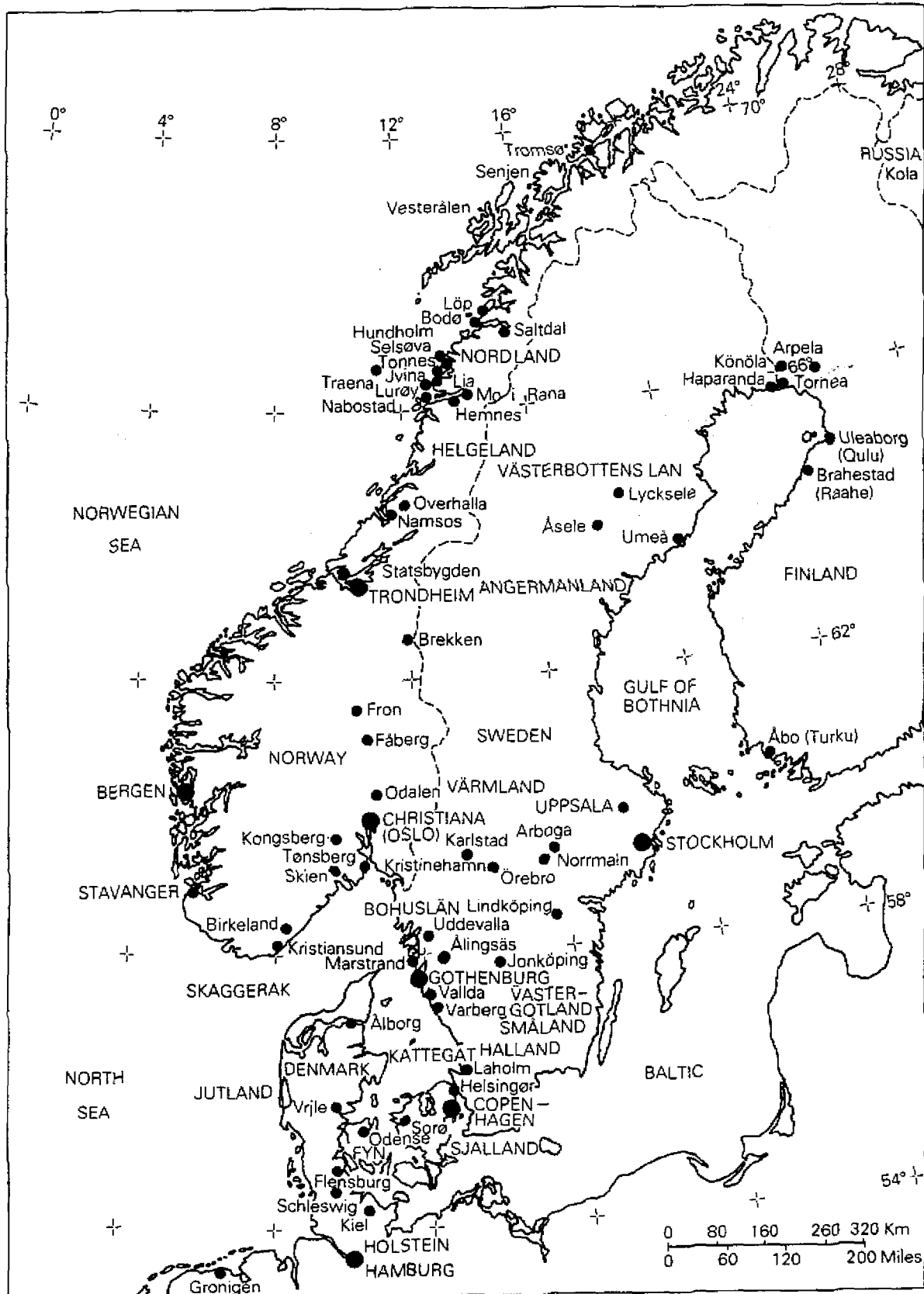


FIGURE 1 Location of places mentioned in the text Key: Brekken – locality/town; STOCKHOLM– major town/city; BOHUSLÄN = province/region/county

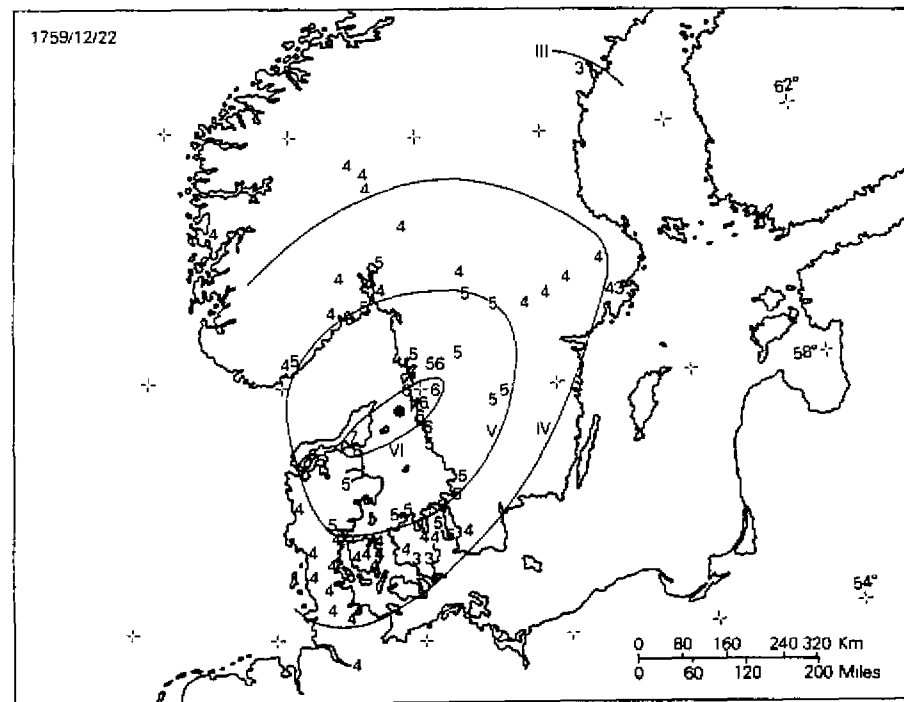


FIGURE 2 *Modified Mercalli intensities and approximate isoseismals for the 22 December 1759 North Kattegat earthquake*

22 DECEMBER 1759 NORTH KATTEGAT EARTHQUAKE

The earthquake occurred soon after midnight on the morning of 22 December 1759 and was widely felt throughout Denmark, Holstein, southern and central Sweden and southern Norway (see Figure 2). The most important contemporary accounts appeared in the new biweekly newspaper published in Copenhagen: the *Kjøbenhavnske Danske Post Tidende* (KDPT). The only other local periodical was published in Gothenburg: the weekly *Göteborgska Magasinet* (GM), which contained far less news. Other primary accounts appeared in Hamburg and Stockholm. There were no newspapers published in Norway at this period, although accounts from Norway passed into the Copenhagen newspaper. Within secondary catalogues the earthquake has often become conflated with earthquakes around the Holland–German border in January 1760.

The first Scandinavian earthquake survey was set up by the Bishop of Sjælland (Christian Horrebøw) who asked the priests of his island diocese (on which Copenhagen is located) to send in accounts of the shock, generating more than 70 replies which he analysed and discussed in a lengthy paper (Horrebøw, 1765). A number of letters recording the earthquake have been uncovered, and the event is reported in local topographical works.

The earthquake followed on only four years after the great Lisbon Earthquake that had an extraordinary impact on cultural and religious life throughout Europe. A heightened earthquake-consciousness is revealed by the several poems that the earthquake triggered – the longest of which, by Christian Biering (1760), was published in a thirty-two page pamphlet, liberally spiced with anecdotal footnotes.

Central Effects

In both western Sweden and Sjaelland the earthquake was claimed to have lasted between one and three minutes (KDPT, 24/12, 7/1/60). At Hamburg it lasted "about a minute". The time was somewhere between 12.30 and 12.45: one report from Sjaelland records the clock striking the quarter as the tremor ceased.

The region of strongest vibration and consequent damage extends across north-eastern Jutland, the northern fringe of Sjaelland, and the western edge of Bohuslän, Sweden. Around Gothenburg – "there are notes in various parish records that church walls had collapsed (cracked) in several places on the west coast" – Holmberg (1843). Several chimneys were knocked down in Ålingsås and Gothenburg (Gazette de France, 12 and 19 January 1760), where unsupported furniture moved around and porcelain and wood-burning stoves fell over or broke (KDPT, 7/1/60). At Walda (Valida), to the south of Gothenburg, a letter describes how glass and porcelain fell down, and tiles fell off the roof of the writer's house (GM, 5/1/60). On the road from Marstrand to Varberg (south of Gothenburg) slight cracks had formed between the bridges and the adjoining river banks (GM, 5/1/60). Holmberg describes a large earthfall into the Göta River (which passes through Gothenburg). At both Marstrand and Walda there were disturbances in the sea – at Walda "waves washed strongly at the foot of the cliff", and at Marstrand a party going home from a fishing trip on a flat sea, suddenly felt waves rocking the boat quite hard; water flew up on both sides into the boat, and the oars jumped out of their rollocks".

To the west of the Kattegat in Ålborg an upper storey of St. Bochs or Budolphi church fell down (KDPT, 31/12). This caused great damage to an extension of the building and the collapse of the two ends

of the church (Trap, 1961) which were only restored in 1764. Elsewhere in the town arches were cracked and several buildings moved on their "ground wall" foundations. At Ålborg the ice on the Limfjorden broke, as also at Vejle, where the following morning the ice was found to have been broken and lifted up. The same is told about many lakes and rivers in Sweden (KDPT, 28/12). At Walda ice on the lakes was broken, even where the lakes were frozen to the lake floor (GM, 5/1/60).

Further south in Jutland, at "Chatouller" (location unknown) some new buildings were cracked and ripped and doors were forced open, a phenomenon also observed at Odense "and other places". In Vejle objects fell and "people who were up could not stand still on the ground". A woman said that as she was walking along the street it was just as if she had become lifted off the ground and she became so confused in the head that she hardly knew where she was. The watchman says the same. A man who wanted to get out of bed fell back into it.

In Helsingør, on the north coast of Sjaelland, the hammer in the bell in Olai Church tower rang by itself, in the same way as when it chimes slowly (KDPT, 28/12). In the same place plaster came off the roofs and at Sorø rooftiles fell.

These observations suggest that Modified Mercalli intensity (MMI) VI effects were very widely distributed with MMI VII experienced locally around the coast of Bohuslän, Sweden and in Ålborg, northern Jutland. The spread of the region suffering minor building damage, from Ålborg to Ålingsås, is 150 km. No intensity VI effects are reported from Norway (although in Christiania (Oslo) panes of windows fell) and while isolated observations, such as the ringing of church bells, and fall of plaster at Helsingør, the fall of tiles at Sorø, and the bursting open of locked doors at Vejle, are all commensurate with intensity VI affects, these all appear

to be isolated observations within a prevailing intensity V region.

In Jutland the earthquake is mentioned as being generally felt in all the principal towns although stronger in north Jutland (KDPT, 31/12). Across Sjaelland, from where Horrebow collected his observations, the earthquake was "was not so strong as to cause building damage but it knocked over some objects, and knocked down some pictures in a church. The earth felt as if it were in a cradle. Houses were rattling - there was a loud noise of windows and doors, and doors sprang open, even those that were locked. Beds were moving as if in big waves - but quicker. Everything was creaking, plates and spoons rattling, furniture moving." Along the north and east coasts of Sjaelland it was strongest, while in the extreme southwest of the island it was only perceived by sensitive observers. A report from England that at Elsinor (Helsingør) "the sea was so agitated that several ships were driven from their anchors" (*Gentleman's Magazine*, January 1760) must be poetic license as it cannot be corroborated from local sources.

Within a few days information had arrived at Copenhagen from the whole of Jutland and within a week from southern Sweden, where the shaking had been felt in Värmland, Bohuslän, Halland, Västergötland and Småland, and more weakly in Stockholm, where it "could have been mistaken for a gust of wind" (KDPT, 7/1/1760). The shock was stronger in Arboga, Örebro and Kristinehamn than in Stockholm, and even stronger in towns over in the west: Karlstad, Lindköping, Uddevalla, Gothenburg, Ålingsås, Laholm and Jonköping.

The shaking was also strong around the southeast coast of Norway, at Tønsberg (KDPT, 4/1/60) and at Christianslund (Kristiansand?) near Birch (Birkeland?) where people thought the houses would collapse (*Morgenbladet*, 15 April 1894).

Further to the northeast the quake was felt around Scheen (Skien) and Kongsberg. A letter from Pastor Stokfleth, dated 29 January 1760, describes a fairly strong earthquake in the south of Gudbrandsdalen, at Fåberg, Fron and Odalen. The shock was also felt on the west coast of Norway - "news from Bergen that they have also felt the earthquake - which was preceded by a whistling and thundering noise and made the houses shake" (KDPT, 22/2/1760).

To the south of the affected region beyond the towns of southern Jutland the earthquake was felt widely across Holstein, in Sleswic (Schleswig), Flensburg, Kiel and other places. "It was felt very sharply and clearly by many reliable witnesses in Hamburg and in the neighbourhood, the shock lasting about a minute" (*Staats und Gelehrte ... Hamburg ...*, 28/12).

Earthquake lights were seen at a number of places: at Tønsberg, Norway there was a whistling in the air - and a ray of fire showed itself in all quadrants and drifted from south to north. In upper Fyn, Denmark after the movement and the thundering sound, those who ran out under an open sky said that there was not one but several powerful flashes of lightning.

An aftershock at 5.30 am was reported from Marstrand on the shores of the Kattegat. The epicentre was probably located offshore between Sweden and Jutland. The thick sedimentary deposits found beneath the towns to the west of the Kattegat (such as Ålborg) may reflect an asymmetric disposition of the highest intensities around the epicentral position.

Both Bergen and Hamburg are around 450 km from this epicentre in the Kattegat. In both towns the shock was widely felt, and was reported independent of news from Copenhagen. For numerous reports to have emerged from the middle of a (severely cold) night suggests that the intensities at Bergen and at Hamburg were predominately IV rather than III. However

the news from Stockholm suggests intensity III in that city. The most outlying observations are from Ångermanland almost 300 km to the north of Stockholm and more than 600 km from the epicentre (Kjellen, 1903). Subsequently the event was reported as having been felt in Holland, and while this has been dismissed as a confusion with the earthquakes around the lower Rhine a month later, it is not inconceivable that it was weakly felt around Groningen, at epicentral distances as low as 500 km, closer to the epicentre than Ångermanland. However no first hand accounts have been located to confirm this.

At the hour of the quake it is unlikely that intensity II would have been perceived. No single observations of people feeling the quake while at rest in upper storeys have survived. As in other moderately large earthquakes, pockets of high intensity exist at the outer bound. Therefore the outer intensities are generally III, and the averaged radius for this isoseismal is about 500 km.

THE 31 AUGUST 1819 EARTHQUAKE

The earthquake of 31 August 1819 had widespread felt effects, but an obscure epicentral location being subsequently claimed as Swedish (Ehrenheim, 1824; Kjellen 1903), Finnish (Renqvist, 1930), Russian (Musketoff and Orloff, 1893), and most recently allocated an epicentre on the border between Norway and Sweden (Ambraseys, 1985a). New primary and secondary descriptions of the earthquake have been uncovered in the course of this study, not used by any of the earlier cataloguers.

The most important eye-witness accounts were provided by two parson-naturalists who lived in Helgeland. The priest at Hemnes on Ranafjord from 1814 to 1842 was Iver Ancher Heltzen, who wrote seventeen books on the natural

history and economy of the region: while about 120 km to the northeast Søren Christian Sommerfeldt, the priest at Saltdal from 1818 until 1824, wrote works on the flora of northern Scandinavia and on the natural history of Saltdalen. Sommerfeldt sent two accounts of the earthquake to the *Norske Rigstinden* newspaper in Christiania (Oslo); the first written on the day of the mainshock, his writing interrupted by an aftershock. This letter is fairly similar to an account he later published in a local natural history (Sommerfeldt, 1827). A description of the effects of the earthquake around Hemnes and Mo i Rana, that also appeared in *Rigstidenden*, was probably from Heltzen, although there are a number of discrepancies in detail between this account and that published by him later (Heltzen, 1834).

Reports from a storekeeper and merchant on the island of Lurøy (Mr Dass) were collated by the local priest (Pastor Debes) and passed on to Norway's first earthquake cataloguer, Keilhau in 1827 (Keilhau, 1835, 1836). The powerful earthquake had such an impact on the lives of the people living around the Ranafjord and Lurøy that stories have passed down the generations, finding their way into local history books. Some of the detailed oral histories that had survived more than 160 years were collected together by Aasvik (1985).

Newspapers in Trondheim, Stockholm and Oslo reported local and some regional effects, and subsequently descriptions contained in letters from northern Sweden appeared in a Stockholm newspaper. Newspapers were not published north of Trondheim in Norway or Uppsala in Sweden in 1819. Local recollections of the earthquake were, however, reported in a newspaper at Tromsø more than 20 years later, and reports claiming to have emerged from Russian Kola passed into French and Swedish newspapers. In Swedish Finland there was only one newspaper published in

1819, from Åbo, now Finnish Turku.

Two travellers through northern Scandinavia reported earthquake effects. While the serialized memoirs of Lars Johan Prytz's summer journey from his hometown of Åbo to the North Cape (Prytz, 1821) were truncated by his death, a detailed account of the earthquake as perceived in Lapland and northern Bothnia (published in the *Åbo Tidningar*) is almost certainly his. In early summer 1820, a wealthy Englishman, A. de Capell Brooke MA, was rowed along the Norwegian coast en route to the North Cape (Brooke, 1823), and while more interested in stories of sea-serpents, gained some insight into the effects of the earthquake.

Effects of the earthquake

The earthquake occurred at about 2.30 pm local time and was strongest in the region on the borders between Nordland and Helgeland south of Bodö, close to the Norwegian coast (see Figure 1). The earthquake was variously estimated to last for c. 6 minutes at Saltdalen (Rigstidenden, 15/8/1819), 4 minutes shaking, 10 minutes noise at Hemnes (Rigstidenden, 10/12/1819), 5 minutes at Hemnes (Heltzen, 1834), 1.5 minutes at Hundholm (Bodö) (Brooke, 1823).

All the buildings in this region were constructed from wood, with stone chimneys and roof-weights and it was these latter features that were most susceptible to damage. Heltzen mentions that "in many places the walls on the roofs fell down", while "in some places chimneys were damaged" (Rigstidenden, 10/12/1819); and "chimneys fell down on Selsøen (Selsøya)" (Tromsø Tidende, 1/5/1842). However, shaking was strong enough to cause damage to some wooden frame structures: "some farms ... were thrown down" (Brooke, 1823) and "further up the (Saltdalen) valley ... some old walls fell

down" (Sommerfeldt, 1827; Rigstidenden, 22/10/1819). No casualties are recorded although this must reflect not just the resilience of the buildings but also the time of day and the weather, for this was the first fine day in three weeks and all the people were harvesting vegetation to feed the animals.

As the local buildings do not provide a susceptible measure of ground shaking, other indicators can be employed. A man working with the hay in Konsvik (Lurøy parish) "noticed the start of the earthquake (and) was going to hurry home, ... but the ground heaved so fiercely that he fell down several times, and found that it was impossible to run" (Aasvik, 1985). At Hemnes "people out in the fields couldn't stand up because their knees wouldn't bear up" (Heltzen, 1834). At Nabostad in Nesna parish "the shaking was so powerful that two horses which were ploughing a pasture fell over in their furrows" (Aasvik, 1985).

Further evidence for strong shaking comes from the evidence of superficial disturbances. Heltzen writing from Hemnes on Ranafjord, described how during the shaking "the mountains shook so very strongly that the stones from off the tops and sides, fell down with great noise and threw up a rain of dust that obscured the sun" (Heltzen, 1834). On the island of Lurøy "large-rocks became separated from the mountains and tumbled down providing such quantities of powdered rock that the island's heights became enveloped in fog" (Dass, in Keilhau, 1836). "In Traena ... stones fell down from the tops of the mountains" (Heltzen, 1834). In the Tonnes-Konsvik district (Lurøy parish) large boulders in Strupen half way between the two villages fell down from the mountainside during this earthquake (Aasvik, 1985). On the slopes around Liafjorden (next to the community of Lia) the damage caused by rockfalls was very extensive. "All the hillsides below Liaf-

jellet, from Haugen to the Upper Liamyrene, became covered by rocks which fell from the mountain . . . all cultivated land on this stretch became ruined" (Aasvik, 1985). Rockfalls were distributed even to the north of Bodø where at the foot of the mountains to the north of Løb (Löp), Brooke (1823) observed the crest of one rock greatly shattered in the earthquake.

The rock dust contributed to the clouding of streams that was noticed over a wide region. Heltzen (1834) reported that the streams became filled with soil and clay; Dass, as reported by Keilhau (1836), noted that at the foot of the mountains on Lurøy, "many streams were disturbed as though they had been mixed with milk, such that the water, smelling strongly of sulphur, remained undrinkable, even for the animals, for three days". At Saltdal the water emerging from two small springs at the foot of a mountain close to the parsonage, "became whitened with clay although there was no such material along the stream-banks" (Sommerfeldt, 1827; *Rigstidenden*, 15/10/1819).

Some of the most spectacular effects noted in the region of strongest shaking were the disturbances seen in large bodies of water. In the Ranafjord next to Hemnäes, where the water had been completely calm before the earthquake, the water "came up in jets, as high as the mast of a small sailing vessel, as if in a fierce storm. As the sea died down the water rose above its highest flood-level" (Heltzen, 1834). At the Storelven (mouth of the Rana river at Mo i Rana) the water "was disturbed as if in a storm" (*Rigstidenden*, 10/12/1819). In the sound between Traena and the mainland "columns of water were seen by many who were at sea, who thought their boats were going to capsize" (Heltzen, 1834). In the Aldersundet fjord below Lia "the waves on the sea were so big that it was impossible to get onto the water" (Aasvik, 1985).

These disturbances could reflect a

variety of submarine processes induced by strong vibration. They appear to be too widespread to be explained simply through submarine flow-slides, although such phenomena may provide a partial explanation. They are not simply restricted to delta-fronts as proposed by Ambraseys (1985a).

Heltzen offers a poignant description of liquefaction phenomena in an age before such features had gained any scientific description: "In some places thin sand came up from the earth. It seemed as if it came from the inside of the earth. In searching for the source of this sand afterwards it could not be found." These were evidently sand-blows.

With such liquefaction in evidence it is unsurprising that there were larger-scale land-disturbances. Across the Ranafjord opposite Hemnes, on the eastern coast of the bay of Udskarpen, close to the Storstrand farm, there was a major landslide. "The dwelling houses were on a big hill and beneath that hill there was a large raised field cultivated with potatoes. When the earthquake happened this field fell down and the western part of the clay-hill on which the houses were built, fell down as well. A massive 30-40 fathom clay fall was created in this hill and the field below became submerged. The fjord bank, that was even deep enough to take the largest ships, was filled up with gravel so that it became difficult to get into the shore. One neighbour, with other people's help, had to move his farm. But what happened within one of the following earthquakes was that the above mentioned field that went underwater came up again to the place it was before, even though it was no longer level or smooth, due to the clayfall. It was strange that a bucket in which there was a dungfork came back with the field again. It belonged to an old woman who had been digging potatoes, but fortunately she had left the place before the accident" (Heltzen, 1834).

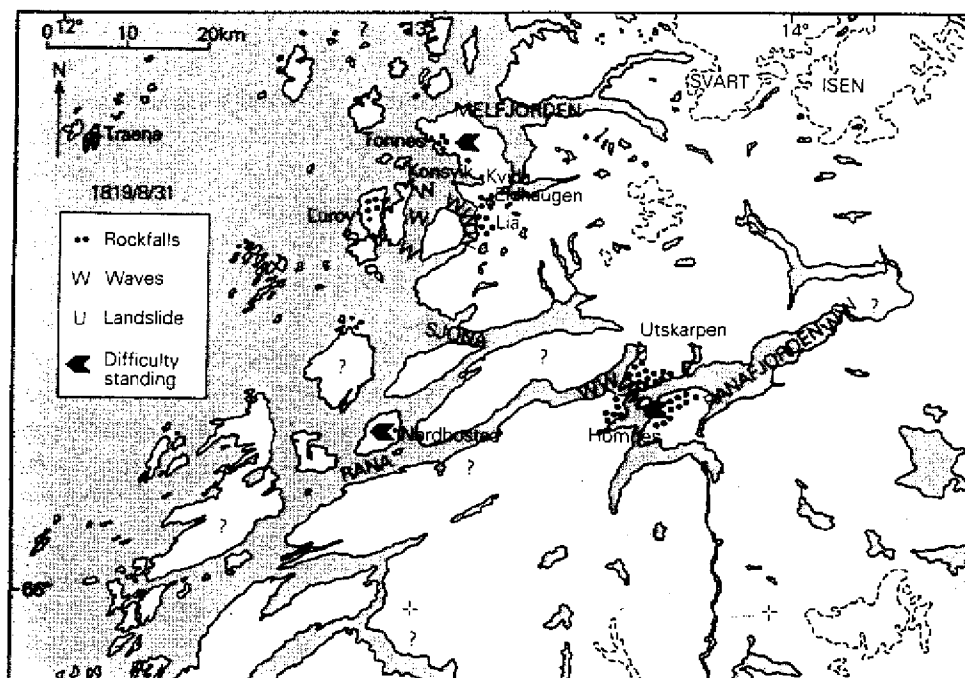


FIGURE 3 Effects of the 31 August 1819 earthquake in the epicentral region, around the parishes of Hemnes, Lurøy and Nesna

In the account in the *Rigstidenden* (10/12/1819) the landslide was solely attributed to an aftershock in the night following the earthquake, but this is corrected by Heltzen. At the time of the major earthquake, the slide moved the field underwater, presumably beneath the fjord, while at the time of a night-time aftershock, additional material was piled behind a rotational slump, elevating the field to a new subaerial location.

Another large landslide is suggested from accounts that have been passed down from Kvina farm (at the head of Kvinafjord, on the mainland in Lurøy parish) where it was claimed that the "water flooded the land around the same time, causing permanent damage so that the value of the farm was reduced" (Aasvik, 1985). A submarine landslide is suggested by reports of disturbance in the deltafront of the Glommåga river where it passes into the western end of the Langvatnet lake (a few km to the north of

Mo i Rana), although at the time this was blamed on an appearance of the monster of the lake – the "Langvasstrollet" (Coldevin, 1964).

Maximum intensity

There are a number of difficulties involved in attempting to estimate the highest intensity effects in this region of very low population (less than one person per square kilometre) and wooden houses. However the evidence of people and animals being thrown to the ground; the widespread and severe rockfalls, landslides, sand-blows, submarine flow-slides with probable seiching, and the evidence for the destruction of certain wooden buildings must reflect intensities of at least MMI VIII (see Figure 3). A regional intensity greater than VII extended from the island of Traena to the west, through Lurøy, Nesna and Hemnes parishes to Upper Saltdalen. The extent of this high

intensity region to both north and south is unknown as these regions are mountainous and unpopulated. High intensities (>VI) did not however extend to Lower Saltdalen where Sommerfeldt was based.

Confirmation that the region of highest intensities around the coast at the boundary of Lurøy and Nesna parishes, was the epicentre of the earthquake is provided by the distribution of the aftershocks. Following the mainshock an aftershock was felt at Lurøy "every hour until daybreak" (Dass, in Keilhau, 1836), of which only about half (7) were felt at Hemnes (Heltzen, 1834), and only two at Saltdalen. This allows the epicentre to be located with a probable precision better than 20 km, at 66.4°N–14.4°E.

Aftershocks of the 1819/8/31 earthquake continued as a sound heard "daily for 4–5 weeks, though always accompanied by a weaker quake than the first" (Rigstidenden, 10/12/1819). This then passed into a period of swarm activity with an average of around ten shocks a year felt in Lurøy for the next decade.

Ambraseys (1985a) has proposed that there was a widely felt foreshock with the same epicentre, on 29 August at 10.45 am, but primary accounts indicate that this was only felt ("as a hard shake that rattled windows, made the pulpit seem to sway, and sent the chandelier into motion" – Inrikes Tidningar, 24/11/1819) at Åsele in Sweden, some 300 km to the southeast. The shock was not noticed by Heltzen, Dass or Sommerfeldt and hence had no connection with the earthquake of 31 August. (Ambraseys uses the evidence of this "foreshock" to justify the location for his epicentre of the Norway–Sweden border, some 100 km to the east of the maximum earthquake effects and concentration of aftershocks.)

Rockfalls are reported at least 100 km to the north of the epicentre (Brooke, 1823), and to the south the furthest extent of damage is from Overhalla near Namsos,

200 km from the epicentre where "an old chimney collapsed and people ran out of their houses for fear that they might fall down" (Trondheims Adr.-Cont. Eft. 21/9/1819). To the east the reports of old walls falling down in Upper Saltdalen are within about 100 km from the epicentre. At greater distances to the north there was strong shaking, in Senjen and the Vesterålen (300–350 km), causing chimney cowl to dance and furniture to move in the rooms (Tromsø Tidende, 1/5/1842).

The earthquake was widely felt offshore to the north and west: Heltzen (1834) notes "many of those who were on the sea thought that their boats were going to capsizes". In the isolated Traenan-archipelago, situated 30 km to the west of Lurøy, the shaking was, if not worse, just as strong as at Hemnes. Brooke (1823) reported that "the captain of a small Russian vessel off Hundholm received so great a shock that he instantly let fall both his anchors, and prepared to warp off, thinking the ship had run aground, when at the time, as he found afterwards, he was in 300 fathoms of water".

To the east reports from Åsele and Lycksele, in Västerbotten County, Sweden (300 km from the epicentre) suggest strong shaking: at Åsele, "the teacups and glasses on the table were moved from their places"; at Lycksele, "the houses shook, the roofs creaked, kitchen chairs in the rooms swung, the churchtower and the chimneys seemed to be swaying". Along the coast of the Gulf of Bothnia at Umeå parish (400 km) the shaking caused a "strong noise in the upper floors and the lofts of the houses and thereafter a shake which made lots of smaller objects start to fall down from the walls" (Post-Tidende, 22/12/1819). However the shaking was not universally felt: those farms on the eastern side of the river, close to Umeå, perceived nothing.

Prytz reported strong shaking in many towns at the head of the Gulf of

Bothnia around the modern border of Sweden and Finland and the event was generally considered to be a local earthquake. At Torneå, it was recounted "that the buildings shook for half a minute and the air smelt of smoke as if from a nearby woodfire" (Åbo Tidningar, No. 4, January 1820). The shaking was considered to have been stronger at Arpela and Könölä than in Torneå or Haparanda. The shock was also felt in the towns of Brahestad and Uleaborg on the eastern coast of the Gulf of Bothnia.

A number of accounts from Trondheim (Trondheims Adr. Cont. Eft. 14/9/1819, 21/9/1819) described the effects in towns in the immediate neighbourhood. From Statsbygden, on the north side of the fjord opposite Trondheim, it was reported that "we were eating in a large room on the second floor, when the table began to move. My daughter seemed to be dancing on the floor, which was not in keeping with her upbringing, yet I saw that it was a wavelike motion, which convinced me that it must be an earthquake."

To the south of Trondheim the earthquake is reported from Brekken, a community within Østerdalen, close to the Swedish border, and the earthquake was "said" to have been felt in Oslo (Keilhau, 1836). At the limits of the felt-area, reports from "Vrola" (Kola) in Russian Lapland that somehow passed to a Paris newspaper state that the shock was "sufficiently strong to overturn furniture and chairs" (Moniteur Universal, No. 324, November 1819). It is inconceivable that the earthquake could achieve such effects at a distance of 1000 km from the epicentre, and it is likely that news became scrambled, compounding the port of origin of some vessel with details picked up along its journey.

Following an account from the Rigstidenden, the translator for Allmanna Journalen (11/10/1819) inserted his own impressions in Stockholm: while seated he

had felt the room sway from north to south and heard the house timbers creak. However it was not noticed by others in the house. Subsequently (three months after the event, and following the arrival of all the Norwegian news) Inrikes Tidningar (24/11/1819) gave more details about the effects in the city where "many observed this phenomenon". "Two persons who sat in easy chairs with their backs towards the south felt . . . a shake or rocking from east to west, when their heads were thrown from one side to another. This went on for less than a minute, even so one of them noticed a break in between the shakes. Cracking was heard in walls and door-frames, chandeliers which hung from the ceiling were thrown from east to west; a woman who poured her coffee, had to hold onto the table and saw the coffee spill over the edges of the cup."

The earthquake was particularly felt in upper storeys – in Normalm (at the centre of Stockholm) two persons described "a push or shake of enormous nature. A low sound was followed by a shaking of the house so strong that a tea-tray on the wall started to swing and a book in one hand almost fell to the floor. The earthquake lasted 30 to 40 seconds and its direction seemed to be northwest to southeast. It started with a perpendicular push and finished with a horizontal swinging which later became so noticeable that the tray finally flew 50 cm from the wall. The earthquake was felt on the third floor but in the lower parts of the house was hardly noticed."

Stockholm is about 800 km from the epicentre, and these reports are convincing evidence of long-period affects at the margins of the intensity III felt area, indicating a major earthquake. However the anecdotal intensity at Oslo, 750 km from the epicentre, cannot have been above intensity II. While the surviving information is too thinly spread to map accurate isoseismals (see Figure 4) it is

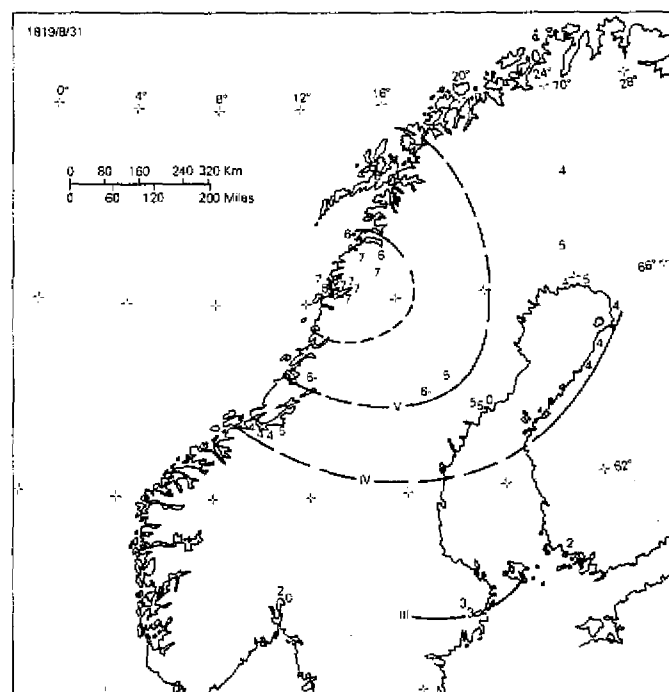


FIGURE 4 *Modified Mercalli intensities and approximate isoseismals for the 31 August 1819 Nordland, Norway, earthquake*

easier to estimate felt area radii, which are around 800 km for intensity III, 350 km for intensity V and 150 km for intensity VI.

MAGNITUDES

The magnitude of these two earthquakes can only be estimated through comparison with 20th-century events from this same area for which both instrumental and macroseismic data are available. The 22 December 1759 earthquake has a comparable macroseismic field to the 23 October 1904 Oslofjord (59.2°N–10.5°E) earthquake ($R_{III} = 450$ km, Muir Wood and Woo, 1987) located 150 km further to the north and to the 7 June 1931 Dogger Bank (54.1°N–01.5°E), southern North Sea earthquake (M_s 5.5, $R_{III} = 500$ km, Woo and Muir Wood, 1986). While the Oslofjord earthquake generated numerous scientific articles, detailing the macroseismic effects not just in Norway, Sweden and Denmark but also in the lands around the eastern

edge of the Baltic, some details of the two suggest that the 1759 shock may have been the larger. While the 1904 earthquake was scarcely felt in coastal western Norway, at greater epicentral distances, the 1759 earthquake caused houses to shake in Bergen. Low intensity shaking around the eastern Baltic from the 1759 earthquake was relatively unlikely to have been felt in the middle of the night and has not been reported. The 1759 earthquake has a macroseismic field suggesting a magnitude M_s 5.4–5.6.

The 1819 earthquake has a larger felt area than any near-shore event in northern Europe over the past few centuries. Earthquakes of comparable felt areas in this region have all had offshore epicentres. The pre-instrumental 9 March 1866 event caused damage around Kristiansund, was felt across much of Norway and Sweden, and even very weakly at Banffshire, Scotland at an epicentral distance of 1000 km ($R_{III} = 600$ km). The estimated location is

at 65.2°N–6.0°E, around 100 km offshore Møre. The largest 20th-century event in this region is that of 10 June 1929 located at 70.9°N–9.2°E in the Norwegian Sea, with an instrumental magnitude M_s of 6.1 (Ambraseys, 1985b). From the available small sector of its eastern onland macroseismic field, this had an R_{III} of around 700 km. Uncertainties in the complete macroseismic field for both this event, and the 1819/8/31 earthquake, suggest that the 1819 event had a magnitude in the range M_s 5.8–6.2

CONCLUSIONS

The western coast of Scandinavia, formerly a region of poor isolated farming and fishing communities, has in the past two decades become economically transformed, principally through the discovery and exploitation of large offshore reserves of oil and gas. The construction of important engineered structures both onland and offshore and the expansion of coastal towns, has considerably increased the vulnerability of this area to the impact of future earthquakes.

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<p>Robert Muir Wood 20 Emery Street Cambridge CB1 2AX</p>
