Introduction

Quite often, we hear about large earthquakes causing significant damage. Tragic consequences of earthquakes occupy headlines for a short while. Unfortunately, we have a tendency to forget about it, until the next catastrophe strikes. Earthquakes, in fact, make up the largest part of natural disasters causing economic damage and loss of life. They therefore deserve our continuous attention, not only from the scientific community but also from society. We hope that an exhibition on earthquakes will help increase public awareness of this important natural phenomenon: a part of our living earth.

Why an exhibition about earthquakes in an apparently so quiet place like Bergen, Norway?

First of all, Norway is not as quiet as one might expect. Within mainland Norway near the coast, one can expect earthquakes of up to magnitude 6. If we include the arctic islands, we can even have volcanic eruptions and earthquakes up to magnitude 7. So compared to our Scandinavian neighbours, and even most countries in Northern Europe, Norway has more and larger earthquakes. This was recognized early on by one of the first Norwegian earth scientists, C.F. Kolderup, who managed to establish the first seismic station in Norway in this very museum exactly 100 year ago, in 1905.

The present exhibition "When the Earth Quakes" aims to give a general overview of the earthquake as a natural phenomenon, its consequences and how we can prepare our societies for future natural disasters. The basic principles of earthquakes are explained and demonstrated through examples, and a part of the exhibition allows visitors to participate interactively. We also take the opportunity to celebrate our centennial for the first seismograph station installed in Bergen, Norway. This is in itself a good reason for marking 100 years of instrumental seismology in Bergen. Since 1905, the Seismological Observatory (Jordskjelvstasjonen) in Bergen has evolved into a dynamic and productive scientific environment within the University of Bergen, with excellent monitoring, research and educational capabilities.

Seismology (the science of studying earthquakes) is often considered a rather obscure science with no relevance outside its field. This, however, is not an accurate view. Seismic waves generated by large earthquakes travel through the earth's interior and provide us with valuable information about the conditions deep inside the earth. Thanks to early investigations of records from seismographs around the world, we now know that the earth is composed of different layers: crust, mantle and the core, with different physical properties. Technological developments in the 21st century allow us to investigate the moon and remote planets. However, earthquake data remain the prime source of information for understanding the earth's interior. Modern instrumentation in seismology has been essential in testing and proving earlier scientific hypotheses. The theory of plate tectonics, which is the unifying theory behind our understanding of the geological processes on earth, was one of the remarkable success stories of seismology, where systematic observation of earthquake locations around the globe helped determine the plate boundaries and their deformation.

Seismology is also widely used in Norway, mainly because of its position as a key tool in the search for oil (dealt with in section on oil), an industry which has now become the backbone of Norway's prosperous economy. The Seismological Observatory at the University of Bergen is one of the key national institutions subjected to public inquiries about earthquakes whenever shaking has been felt or there has been large earthquake reported in the news. Two recent examples where there was significant public interest in seismology were: the large earthquake-generated tsunami in the Indian Ocean in December 2004, and the sinking of the cargo vessel "Rocknes" in January 2004. Both events were clearly recorded on our instruments and seismologists could contribute significantly with relevant information.

To understand the earthquake phenomenon, we have divided the exhibition in several themes. First, we present earthquakes as a natural phenomenon and explain the physical conditions leading to earthquakes. This is presented in the section about earthquakes as a natural phenomenon.

From a historical perspective, seismology has existed for more than 100 years. Important events leading to significant discoveries are outlined and shown in a section dedicated to the history of seismology. In addition to the international milestones in seismology, developments in Norway are presented chronologically in order to give the visitors a historical perspective on why there is such a strong interest in earthquakes in Bergen. Why did seismology get such a boost 100 years ago? Because the ground motion caused by earthquakes started to be recorded on seismographs, and thereby became available to make highly detailed studies of both the earthquake and the underground. It is the latter that has given Norway such a strong position in oil-exploration because there already existed, at the start of the oil age, many qualified Norwegian seismologists ready to participate in the oil adventure. So many, in fact, that it was hard to convince seismologists to work with traditional seismology, namely earthquakes. Later on, when oil platforms were built, earthquakes again became important since many of the oil fields are located in high seismicity areas, and the platforms have to be designed to withstand the highest possible earthquake in the area. So, more knowledge about Norwegian earthquakes was required. This is why the Norwegian oil industry has supported the operation of the National Seismic Network in Norway for the last 25 years, and the University of Bergen now has a modern seismic network of 30 stations covering all of Norway and nearby offshore areas, including the artic islands. Consequently, in this exhibition seismic instruments constitute an important section.

So, what began 100 years ago with a single seismograph station has developed into giving Norway a strong position in both seismology and oil exploration.
We hope that the exhibition not only attracts the interested individual, but also a younger generation wishing to take this opportunity to understand more about earthquakes.

Acknowledgements

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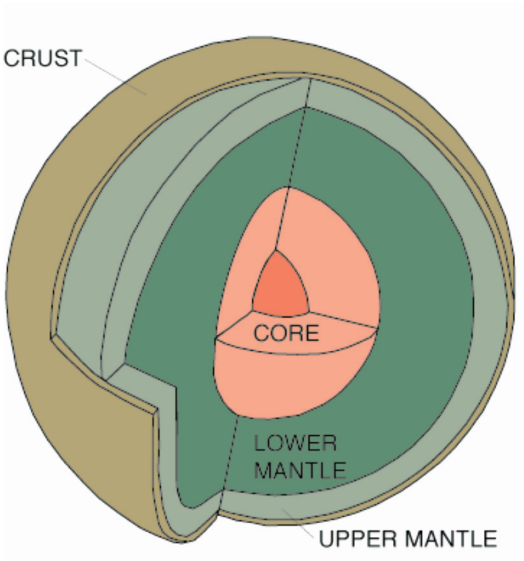
Earthquakes as a natural phenomenon

The earth is composed of a number of layers with different properties, see the figure below. Roughly, the earth can be divided into three layers: the core, the mantle and the crust. The core is the inner part of the earth and can be divided into the solid inner core and the liquid outer core. Similarly, the mantle can be divided into the upper and the lower mantle. The crust is the outermost part of earth. It is just 10-80 km thick and as such resembles in proportion the peel of an apple. The crust is composed of a number of plates, called continental plates, that are moving relative to each other. Most earthquakes occur as a result of these plate motions.

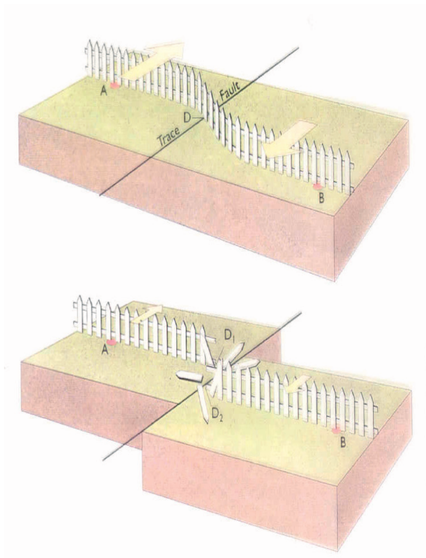


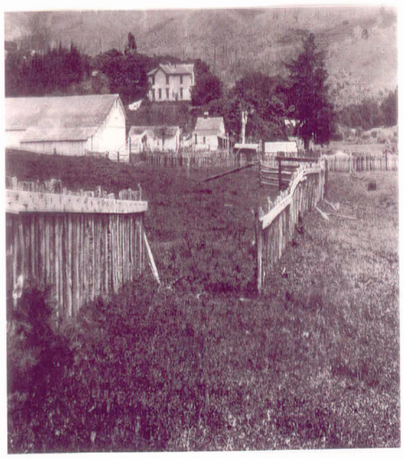
Cross section of the Earth

The map shows the earth at night. Densely populated areas are visible due to the enhanced light intensity. The green lines show plate boundaries where we have the largest earthquake activity. Earthquakes are shown as orange dots, volcanoes as red triangles. Future catastrophes will occur in places where earthquakes strike in densely populated areas.

Earthquake faults

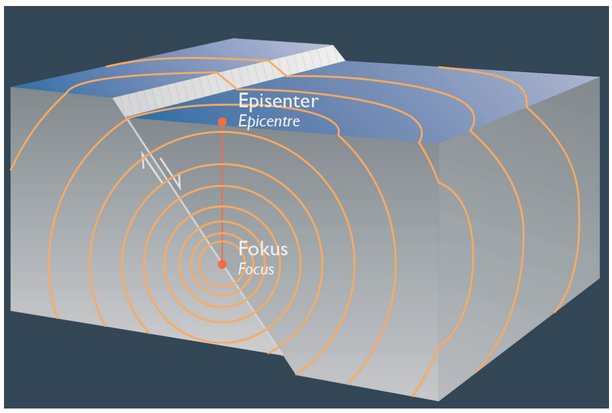
Stresses, which are built up in rocks due to for example plate motions, are released when the rocks can no longer withstand the stress. The result is a sudden displacement along a plane called a fault. This results in an earthquake, which is a sudden release of energy moving through the crust as seismic waves. The waves are felt as ground shaking at the surface.





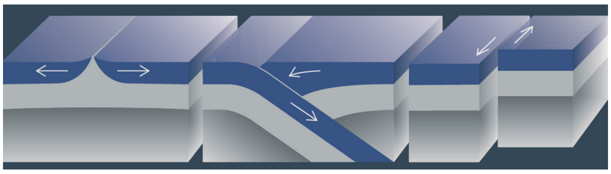
A fault

The focus (hypocenter) of an earthquake is the point on the fault plane where the rupture initiates. The epicentre is the point at the surface directly above the focus. The fault plane is defined from its direction at the surface, its slope and the direction of the slip. The slip is unevenly distributed depending on the roughness of the fault plane. Most of the energy is released in areas where the fault plane is rough. Such areas are called asperities.



Fault plane

There are three main types of plate boundaries, depending on whether the plates are moving away from each other (divergent plate boundaries), towards each other (convergent plate boundaries) or sliding past each other (transcurrent plate boundaries).

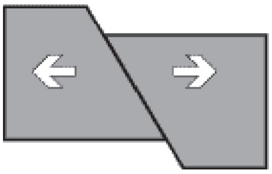


Different kinds of plate boundaries

There are three main types of faulting: normal, reverse and strike-slip. A combination of two of these results in oblique-slip faulting, which is quite common. The fault types are dependent upon tectonic stresses in rocks, which are mainly controlled by the regional stress field in connection with the plate motions. In the following, the three types of faulting are described and illustrated.

Normal faulting occurs in connection with an earthquake where rocks on both sides of the fault plane move away from each other, and one of the blocks is displaced downwards in relation to the other.

On divergent plate boundaries, two plates move away from each other and new material rises from the mantle. Earthquakes will usually occur on normal faults, and volcanoes are often seen in connection with divergent plate boundaries. One example of a divergent plate boundary is the mid-Atlantic ridge, where e.g. Iceland is affected by earthquakes and volcanoes.

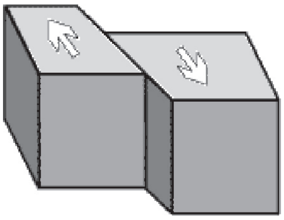


Normal fault

The picture shows a normal fault in connection with a destructive earthquake in November 1999, close to the city of Düzce, Turkey.

Reverse fault ruptures occur in connection with earthquakes where the rocks are pressed against each other and one of the blocks is displaced upwards along the fault plane.

On convergent plate boundaries, two plates collide. One plate moves down underneath the other and is pushed down into the mantle where it melts and dissolves. Earthquakes occurring in these regions usually have reverse mechanisms. Examples of convergent plate boundaries can be found in Alaska, Himalaya, Japan, Taiwan and western South America. It is along such so-called "subduction zones" the largest proportion of the earthquake activity occur globally

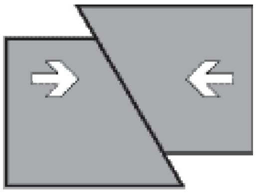


Reverse fault

The picture shows a reverse fault rupture in connection with the destructive Chi Chi earthquake in Taiwan in 1999. The small picture shows close-up picture.

Strike-slip faulting occurs in connection with an earthquake where the rocks on both sides of the fault plane are displaced in an opposite horizontal direction.

On a transcurrent plate boundary, plates are sliding past each other. This results in strike-slip faults. Examples of transcurrent plate boundaries are seen in California and in Turkey.

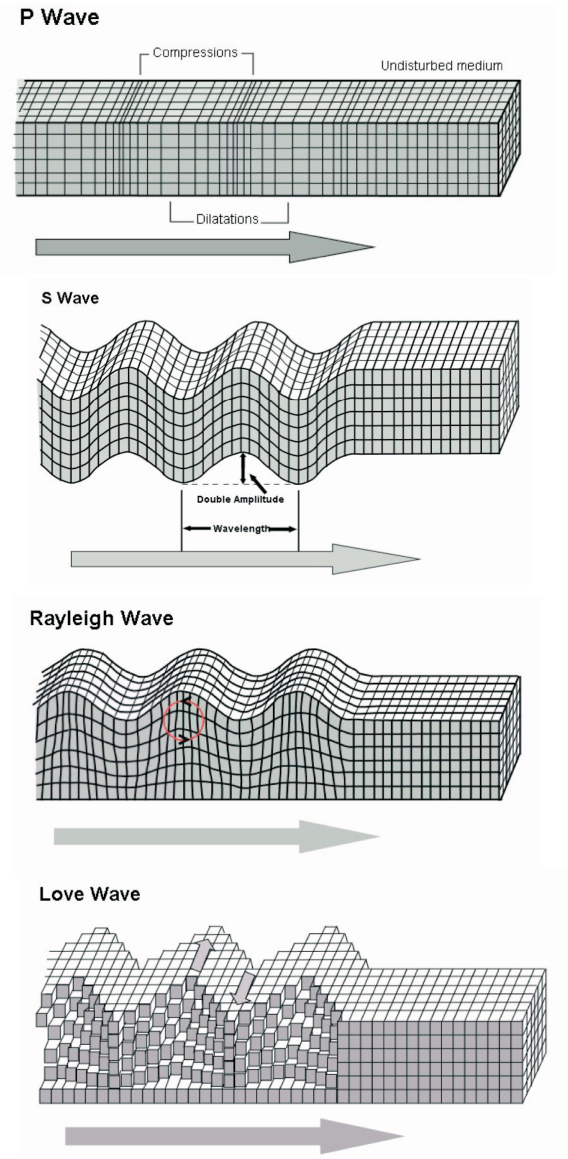


Strike-slip fault

The picture shows a strike-slip fault rupture, which displaces the railway line. The pictures are taken in connection with the earthquake in Izmit, Turkey, on August 17, 1999.

Seismic waves

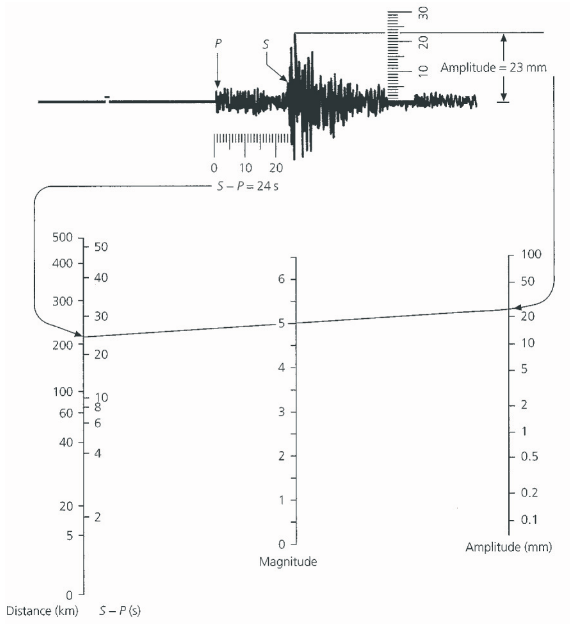
There are four main types of seismic waves. P waves (primary waves) have particle motion in the same direction as the wave propagates. S waves (secondary waves) have particle motion at a right angle to the direction of propagation. P and S waves are also called body waves because they propagate though the earth's interior. Surface waves (Love and Rayleigh waves), on the other hand, propagate only along the surface of earth. Love waves (named after A.E.H. Love (1863-1940)) have a particle motion at a right angle to the direction of propagation. Rayleigh waves (named after Lord Rayleigh (1842-1919)) have a retrograde particle motion, meaning that the particle motion is circular, opposite the direction of propagation.



Different types of seismic waves

Magnitudes of earthquakes

The traditional way to measure the magnitude of an earthquake is by using the Richter scale. The Richter magnitude is based on the amplitude of ground motion as it is registered on seismographs, and the distance to the earthquake. Charles Richter introduced the Richter scale in California in1935, where he assigned a magnitude of 3 to an earthquake at 100 km's distance, causing 1 mm amplitude of the ground motion as recorded on his special equipment (Wood-Anderson seismograph).



The magnitude is determined from the maximum amplitude as seen on the seismogram. In order to calculate the magnitude, the amplitude is corrected for the distance, as shown on the figure.

Magnitude scales like the Richter scale are logarithmic, which means that one unit increase corresponds to a 10 times increase in ground motion and ca. 32 times increase in the energy released by the earthquake. The Richter scale is still used by seismologists because of its popularity. However, seismologists today prefer to use another magnitude based on seismic moment. Seismic moment is determined from the size of the fault plane, the amount of slip, and the roughness of the fault plane.

How strong are the different magnitudes?

2 Rarely felt by humans
2.5 Energy similar to a moderate lightning bolt
3.5 Energy similar to a strong lightning bolt
4 Felt by humans, possibilities of damage
5 Energy similar to an average tornado
6 Energy similar to the Hiroshima atomic bomb
7 Damaging earthquake, often causing loss of life. Capable of creating a tsunami.
8 Energy similar to the world's largest nuclear explosion
9 Catastrophic earthquake causing great damage

How often do we have earthquakes?

Description	Magnitude	Average number pr year
Catastrophic	8 and higher	1
Very strong	7-7.9	18
Strong	6-6.9	120
Moderate	5-5.9	800
Weak	4-4.9	6200
Small	3-3.9	49000
Very small	Less than 3	Magnitude 2-3: ca 365000 Magnitude 1-2: ca 3000000

The table shows how often earthquakes with different magnitudes occur around the world on average.

The 5 largest earthquakes in the world since 1900

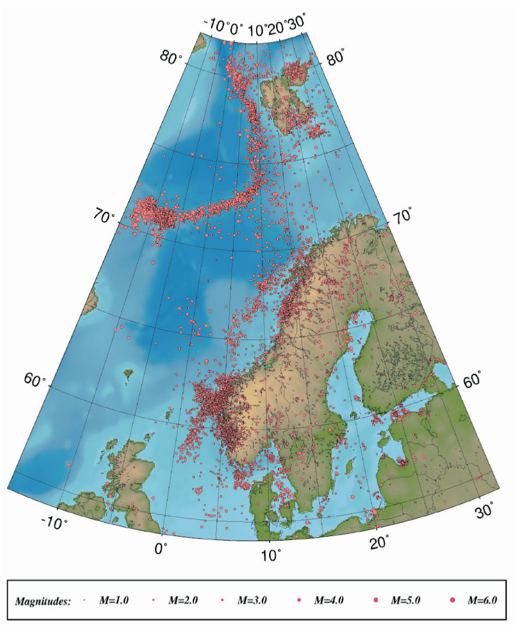
1. 1960, 22 May, Southern Chile, M=9.5
2. 1964, 28 March, Prince William Sound, Alaska, M=9.2
3. 1957, 9 Mach, Andreanoff Islands Alaska, M=9.1
4. 1952, 4 November, Kamchatka, M=9.0
5. 2004, 26 December, Sumatra, Indonesia, M=9.0

The 5 deadliest earthquakes in the world

1. 1556, 23 January, Senshi, China, 830 000 casualties (M=~8.0)
2. 2004, 26 December, Sumatra, Indonesia, 280 000 casualties (M=9.0)
3. 1976, 27 July, Tangshan, China, 255 000 casualties (M=7.5)
4. 1780, 28 February, Iran, 200 000 casualties (M=?)
5. 1920 16 December, Gansu, China, 200 000 casualties (M=8.6)

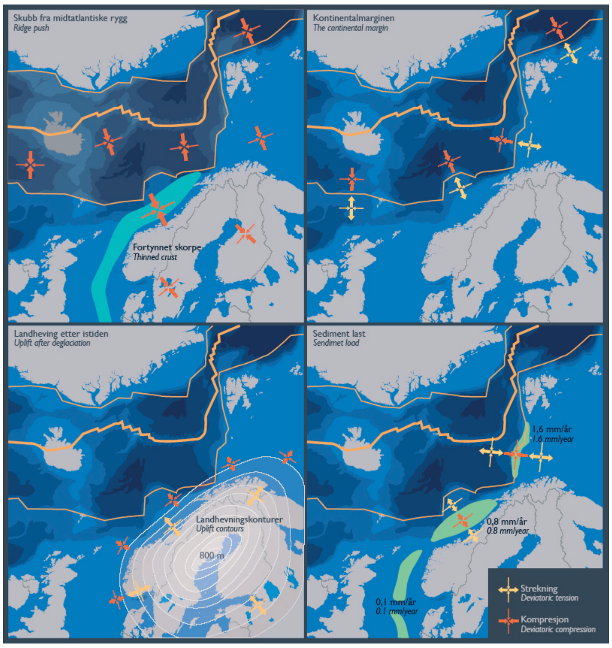
Earthquakes in Norway

Earthquake activity in Norway and surrounding offshore areas is connected to the geological structures. The plate boundary on the mid-Atlantic ridge is one of the most important elements. In addition, earthquakes occur along graben structures (normal fault systems) in the North Sea and along the continental margin. On land, the largest activity occurs in Sunnhordland and Nordland.



Earthquake epicenters 1980-2004

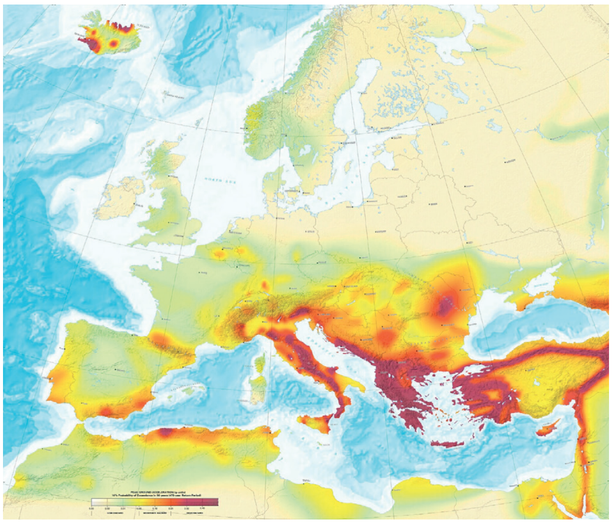
With the exception of the arctic areas around the mid-Atlantic ridge, Norway is situated far from plate boundaries, and one may ask why there are earthquakes here. The answer is that stresses build up in the crust due to other mechanisms. There are mainly four mechanisms causing stress build-up in the area around Norway. "Ridge-push" is associated with the divergent plate boundary in the North Atlantic and is considered an important source of regional stresses along the Norwegian coast and on land. Secondly, the continental margin plays an important role in the processes of stress build-up. Melting of ice and the following uplift after the latest ice age causes vertical stresses along the coast. Finally, vertical forces due to sediment loading on the sea bottom add to the stresses in the region.



Mechanism for stress build-up around the Norwegian Sea

On October 23rd, 1904, an earthquake in the Oslofjord made the front page of Aftenposten. The earthquake struck Oslo in the middle of church-time and had a magnitude of 5.4. The earthquake caused panic in several places, in addition to significant damage to buildings.

Earthquake hazard in Europe



This map shows earthquake hazard in Europe prepared by the European Seismological Commission. The strong red colours indicate increased hazard of strong shaking caused by future earthquakes. In Norway and surrounding areas, the risk of strong shaking is relatively small. The largest risk of strong earthquakes in Europe is in the Mediterranean area in countries like Greece, Turkey, Italy and Spain. These countries are situated close to plate boundaries and have large fault systems capable of generating large earthquakes.

High earthquake risk is a function of high earthquake hazard combined with high vulnerability. In other words, earthquake risk becomes higher when the location of epicentres for large earthquakes coincides with densely populated areas. One such recent example is in Turkey, where large destructive earthquakes frequently occur. On August 17th, 1999, a large earthquake occurred in Izmit in Turkey. The earthquake caused severe damage along the 150 km long fault and resulted in 19 000 casualties. Following this earthquake there is now an increased earthquake hazard in the Marmara Sea where a future large earthquake is expected to have catastrophic consequences in Istanbul, a city of almost 12 million inhabitants. In order to be as well prepared as possible for a future earthquake, scientists are working on the possible ground motion caused by such an earthquake. The calculations are based on assumptions of the magnitude (M=7.5) and the properties of the crust and the fault.

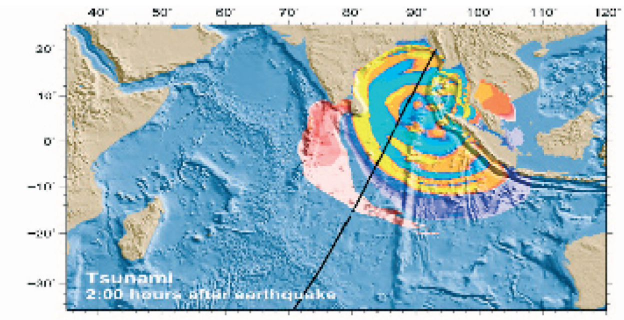
The pictures show the buildings that collapsed in connection with the catastrophic earthquake in Izmit, Turkey in 1999. Much of the damage was the result of bad construction practices.

Tsunami

Tsunami is a Japanese expression, which means "harbour wave". This is a large wave generated by sudden changes in the sea bottom due to for example an earthquake or a landslide. The change initiates the motion of enormous water masses. At the open sea, these waves can reach velocities of 800 km/h, but they are not felt by ships due to their long wavelength and shallow height. The water usually pulls back before the waves reach land. The velocity decreases and the waves increase dramatically in height, but the waves are still relatively long when they hit land, and they are therefore capable of reaching far inland. When the waves pull back they drag along all loose material towards the sea. Usually two-three waves reach the coast in this way with several minutes inbetween.

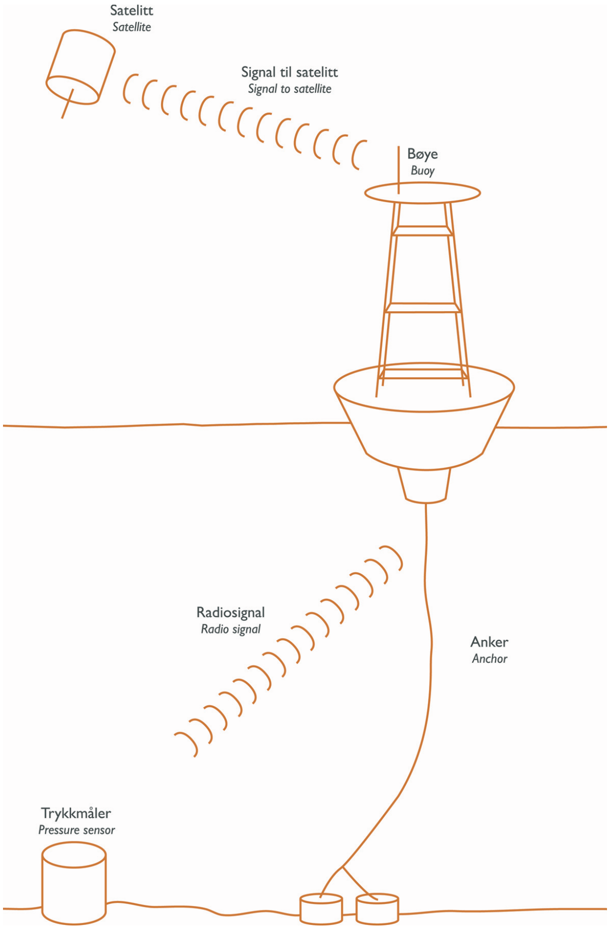
How a tsunami is generated

On December 26th, 2004, a catastrophic earthquake (M=9) occurred northwest of Sumatra in Indonesia. The epicentre of the earthquake was below the sea and a large tsunami was generated, causing severe damage in large areas around the Indian Ocean.

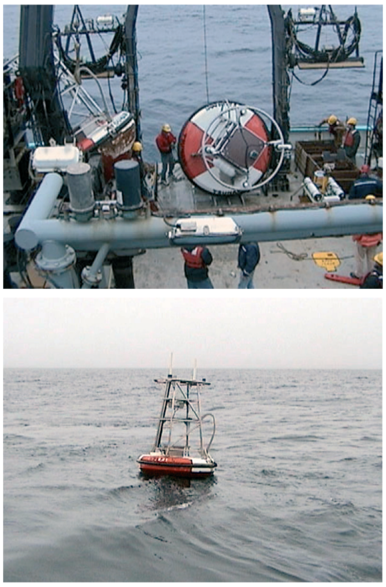


This picture, which is taken from the satellite Jason 1 (NOAA), shows the tsunami wave two hours after the earthquake. The colours show changes in the sea surface level, making wave propagation visible.

Tsunami warning has proven to be a useful tool in avoiding catastrophes. A sensor measuring the water pressure is placed on the sea bottom and sends a signal to a buoy, which transmits the signal to land via satellite. Changes in water pressure indicate a passing tsunami wave. An essential requirement to generate a tsunami is that a large earthquake occurs on the sea bottom. This is registered at seismic stations on land, determining location and magnitude. A tsunami warning system then confirms if a tsunami wave is travelling towards land. Such a tsunami warning system is installed in the Pacific Ocean.



The figure shows schematically the different components of a tsunami warning system based on a sea-bottom sensor and satellite communication. Such a system is installed in the Pacific Ocean.



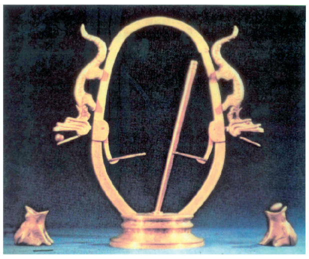
The pictures show the buoy, which enables satellite communication.

History of seismology

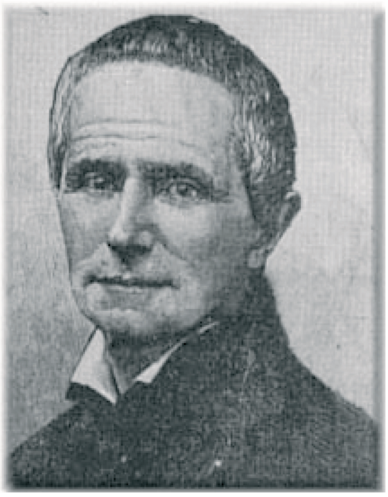
Milestones in seismology in the world

Far back in history, people have tried to explain why earthquakes occur. The Chinese were the first to build an instrument for registering earthquakes. This and following events are described in the following.

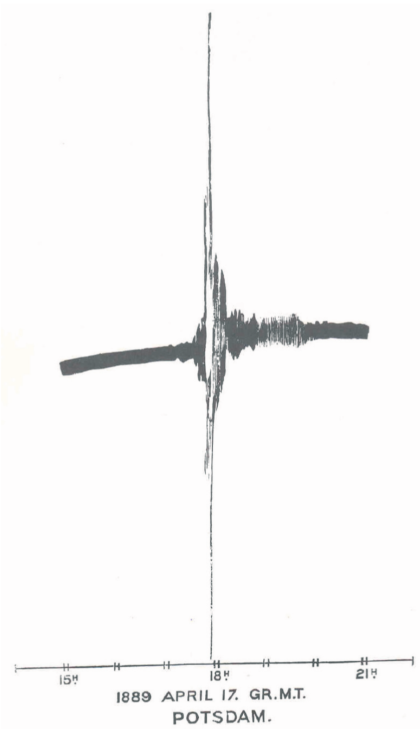
Ca 132 BC: First seismoscope, showing the direction of incoming earthquake waves, is developed in China



1875: The first seismometer is invented by Filippo Cecchi in Italy.



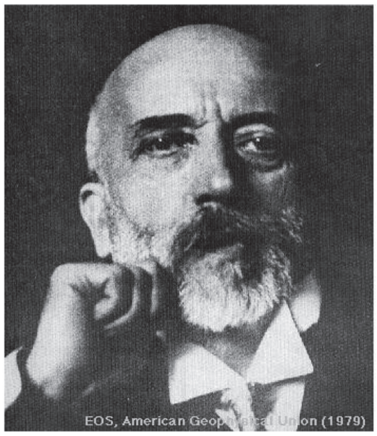
1889: A distant earthquake is recorded instrumentally for the first time. The recording is made in Potsdam, Germany of a Japanese earthquake.



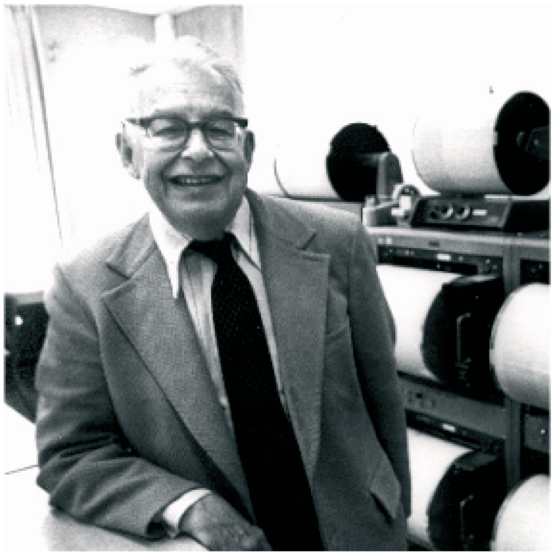
1892: John Milne develops a seismometer, which is installed at ca. 40 observatories around the world. This is the beginning of global earthquake monitoring.

1906: Richard Oldham discovers Earth's core by studying seismic waves.

1909: Andrija Mohorovicic discovers the moho discontinuity, which is the boundary between Earth's crust and mantle.



1935: Charles Richter develops the magnitude scale (the so-called "Richter's magnitude scale"), which is used for determining the size of earthquakes as applied in Southern California.



1936: Inge Lehmann from Denmark discovers the Earth's inner core.

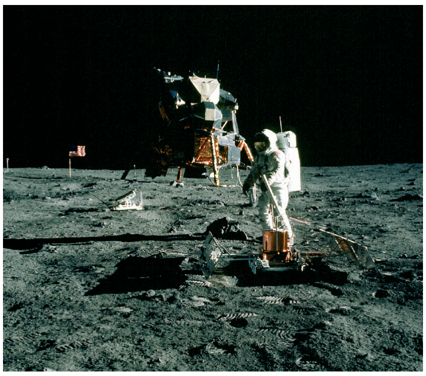
1946: A nuclear explosion is recorded by a seismograph for the first time.

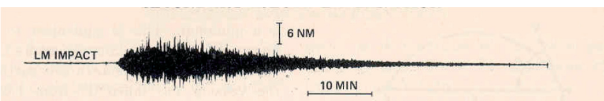
1960: The largest recorded earthquake occurs in Chile, with a magnitude M=9.5.

1961: The World-Wide Standardized Seismic Network (WWSSN) is established for monitoring both earthquakes and nuclear testing. The Norwegian station KONO at Kongsberg is installed as part of the network in 1962. WWSSN has played a central role in supplying data supporting the theory of continental drift and plate tectonics, which helps understanding the fundamental deformational processes of the Earth. WWSSN is later taken over by IRIS (Incorporated Research Institutions for Seismology) and now continues as the Global Seismic Network (GSN).

1966: Keiiti Aki defines seismic moment, which is a physical measure of the magnitude of an earthquake.

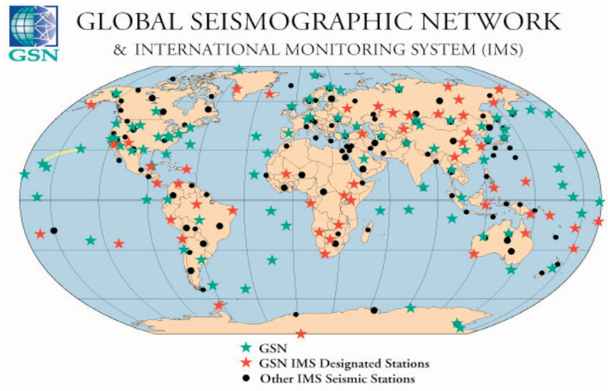
1969-72: The Apollo astronauts place a seismometer on the Moon, and the first 'moonquakes' are registered.





1977: Hiroo Kanamori establishes the moment magnitude scale, which is a measure of earthquake magnitude based on seismic moment. The moment magnitude scale is used by most seismologists today.

1996: The Comprehensive Nuclear-Test-Ban Treaty (CTBT) is established. As of 2005, the treaty is signed by 174 countries. At the same time, the International Data Center is established in Vienna, coordinating the monitoring in connection to the treaty. Seismic monitoring is done through the International Monitoring System (IMS). The map shows the global network of stations that are part of GSN and IMS.



Milestones in seismology in Norway

In Norway, seismology has been an active science since the 1830s where B.M. Keilhau started studying earthquakes. The most important events for seismology in Norway throughout the times are outlined below.

1819: On August 31st, a large earthquake is registered close to Lurøy, Northern Norway. This is the largest earthquake in NW-Europe in historical time with a magnitude of M=5.8.

1836: B.M. Keilhau publishes "Etterretninger om jordskjelv i Norge" describing Norwegian earthquakes until 1834.

1887: Hans Reusch, director of the Norwegian Geological Survey (NGU), starts systematic investigations of Norwegian earthquakes.

1888: T.Ch. Thomassen publishes "Berichte über die wesentlich seit 1834 in Norwegen eingetroffenen Erdbeben" covering Norwegian earthquakes in the time 1834-1887.

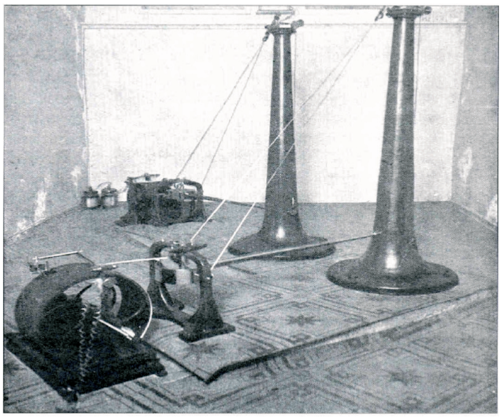
1899: Bergen Museum takes over the systematic investigations of earthquakes.

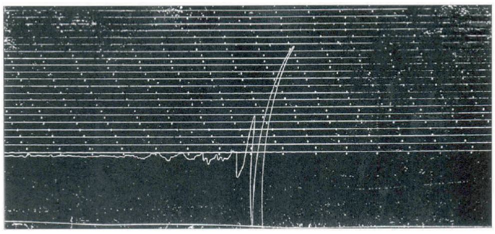
1900: C.F. Kolderup applies, for the first time, for funding of a seismograph in Bergen –the application is rejected.

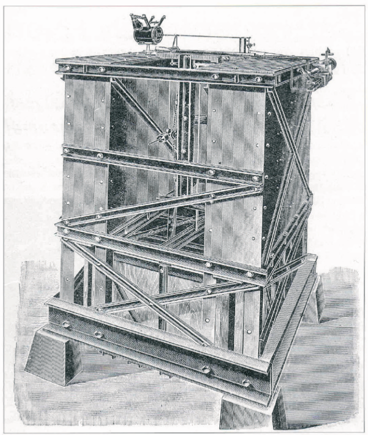
1904: On October 23rd a large earthquake occurs in the Oslofjord, M=5.4.

Norway joins the international convention of states for the advancement of earthquake research, and funding for the installation of a seismograph in Bergen is granted.

1905: The first seismic station in Norway, a two-component Bosch-Omori seismograph, is installed in the basement at Bergen Museum. The instrument is in use until 1959. During the first 10 years, ca. 70 earthquakes are recorded. The first earthquake (in Western Mongolia) is registered in Bergen on July 9th.







1921: A Wiechert horizontal seismograph (2 components) is installed in Bergen Museum.

1923: A vertical seismometer is installed in Bergen Museum.

The Seismological Observatory is established with its first office located at Joachim Frieles gate 1.

1946: April 9th: The Norwegian government decides to establish a university in Bergen.

The university takes over the systematic investigations of earthquakes from its opening.

1958: July: The first seismic station outside Bergen is installed with a Willmore vertical seismometer at Isfjorden on Svalbard (Spitsbergen).

1959: US Coast and Geodetic Survey donates a 3-component Benioff seismograpf with a film recorder, which is installed in Tromsø Museum.

The first homemade-seismograph is put in operation in Bergen.

1960: The Seismological Observatory (Jordskjelvstasjonen) becomes an independent university institute.

1961: The first seismic station in installed on Jan Mayen.

In March, the Seismological Observatory moves to Villaveien 9.

1962: During the Skagerrak project, the Seismological Observatory through a seismic survey detects for the first time rocks on the Norwegian Continental Margin, capable of containing oil and gas. This is the beginning of the Norwegian oil adventure.

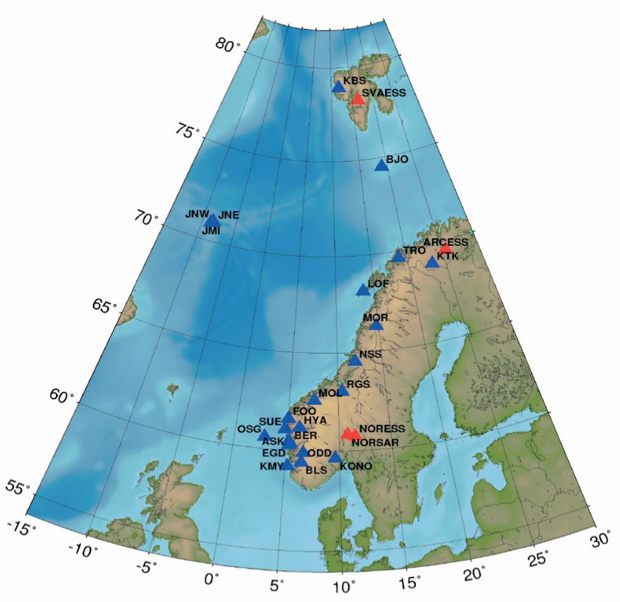
1963: US Coast and Geodetic Survey, in cooperation with UiB, installs a seismic array in Lillehammer for research on identification of explosions.

1968-70: NORSAR (Norwegian Seismic Array) is established with a seismic array at Mjøsa and data-/research center at Kjeller. NORSAR was established as a research institution in cooperation between the Seismological Observatory and the Foreign Department. NORSAR is mainly established for monitoring nuclear testing. NORSAR is today an independent institution which, in addition to operating arrays, also conducts consultant work in seismology.

1977: Jordskjelvstasjonen moves to the Science Building (Realfagbygget).

1990: Earthquake monitoring, seismological research and teaching move to the newly established

Department of Solid Earth Physics, which is created by joining the Seismological Observatory and part of the Geophysical Institute (Division on earth magnetism and paleomagnetism).



1992: The Norwegian National Seismic Network (NNSN) is established based on the former Western-, Southern- and Northern networks and single stations operated by the University of Bergen. The network is funded by the University of Bergen and the Norwegian Oil Industry Association (OLF). The map shows stations, which were part of the network when it was established. Blue triangles are NNSN stations, red triangles are NORSAR arrays.

2003: Earthquake monitoring and seismological teaching and research moves to the Department of Earth Science, which is established by merging the Institute of Solid Earth Physics and the Geological Institute.

The high competence in seismology in Norway has resulted in:

- Teaching programs for Norwegian and foreign students, today UiB has the largest seismology program in the Nordic countries.
- Oil related research and education had a 'flying start' with an important contribution from seismology when the large oil reserves were discovered on the Norwegian continental margin. These activities have been continued and today Norway is one of the World's leading countries in oil-related research.
- Many international projects in seismology are conducted by UiB and NORSAR
- Development of software at UiB, which is in use in more than 50 countries.
- Projects in developing countries with large seismic hazard.
- Research on Norwegian and global problems related to seismology.

Earlier in the catalogue a map is included, showing the countries in which Norwegian institutions have been collaborating and have had students from. The pictures below show some of our international activities.

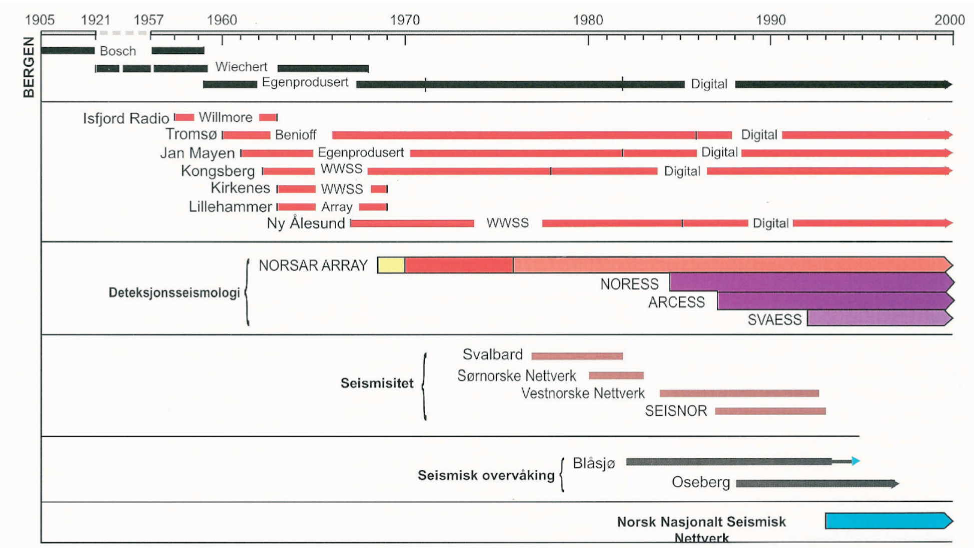
Seismic station in Iran

Teaching in Kuwait

Seismic station in Uganda

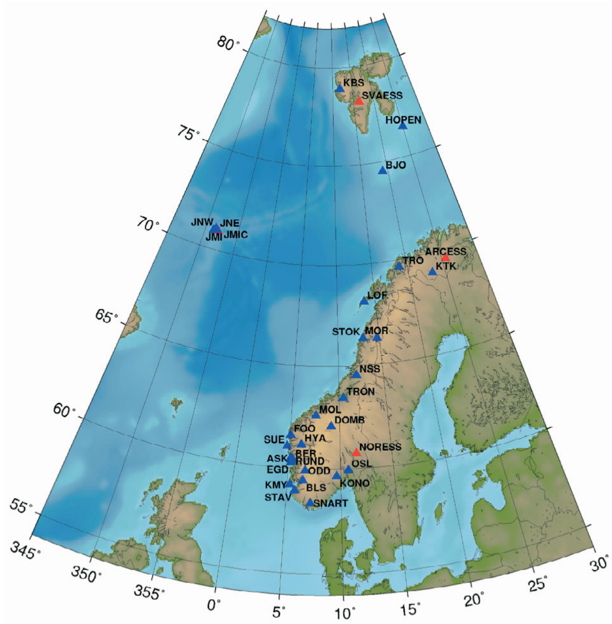
Seismic station in Tibet

Norwegian National Seismic Network



Seismic stations in Norway in time. From the top: black lines indicate stations in Bergen, thin red lines are other UiB stations, heavy red are NORSAR arrays and thin brown and black are time limited local network operated by both UiB and NORSAR. Abbreviations: WWSSN: World Wide Standardized Seismic Network. NORESS, ARCESS and SVAESS are NORSAR arrays.

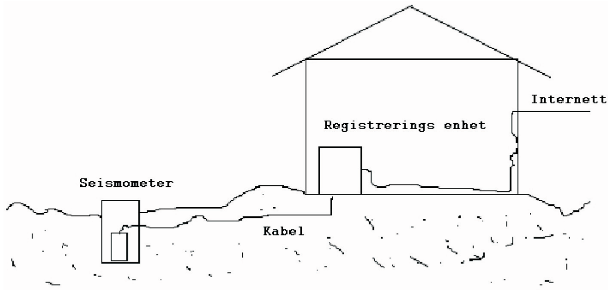
The seismograph installed in the Bergen Museum in 1905, marked the initiation of the Norwegian National Seismic Network (NNSN). Since then, there has been several single stations, small local networks and arrays (seismic antennas) in operation. From 1992, all stations except the NORSAR (Norwegian Seismic Array) arrays, were joined in the national network. The Norwegian oil industry has supported the operation of seismic stations at UiB since 1984. NNSN is today financed by the University of Bergen and the Norwegian Oil Industry Association and the operation takes place at Department of Earth Science, the University of Bergen.



Norwegian National Seismic Network (NNSN) and other seismic stations in Norway. Blue symbols are NNSN stations, and red are NORSAR arrays. Station JMIC is operated by NORSAR.

Typical NNSN station

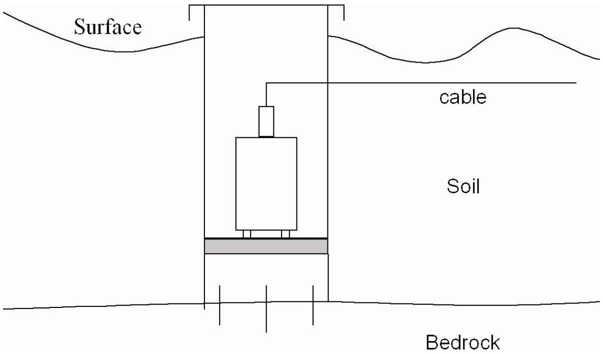
One or more seismometers are placed outside the house in order to avoid noise from the building. From the seismometer a cable ("Kabel") leads to the registration unit ("Registreringsenhet"), which is typically an analog to digital converter and a PC. From the PC, the data is transmitted to UiB using Internet.



Typical NNSN indoor installation of a station

Typical sensor installation

It is important that the seismometer is installed with contact to solid rock in order to avoid vibration noise from the uppermost soil layers. A typical NNSN station consists of a plastic tube cemented to the rock, and attached with iron bars. The installation is underground to avoid wind noise. This type of installation is used for measurement of signal down to 0.2 Hz and is well suited to detect Norwegian earthquakes.



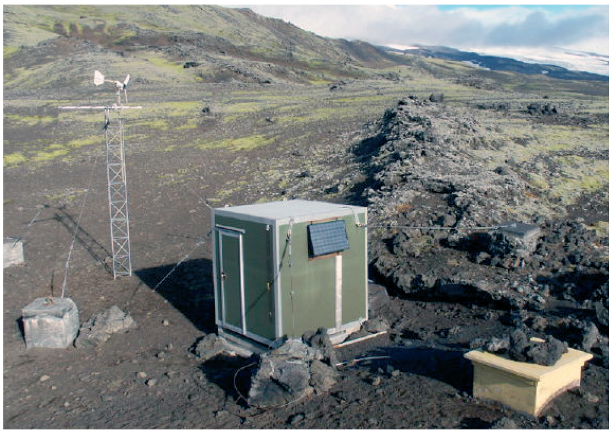
Schematical illustration of the installation. The installation is under the surface.

A short period sensor ready for installation

Seismic stations on Jan Mayen

Jan Mayen is our outpost in the Norwegian Sea. There we find Beerenberg, the only active volcano in Norway, and also the largest earthquakes. The data from Jan Mayen are transmitted via satellite so that Beerenberg can be monitored continually.

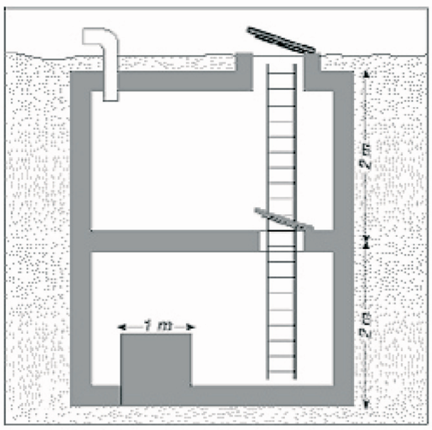
Beerenberg volcano



The station near Beerenberg gets electricity from a windmill and a solar panel. The seismometer is installed in the yellow box to the right. Data is sent by radio to the central base on Jan Mayen.

Broadband stations used by NNSN

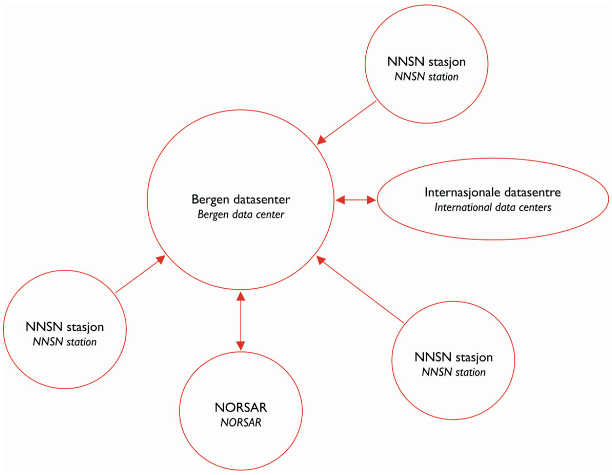
Broadband stations are particularly well suited to register earthquakes from the entire world. They must be able to register very low frequencies, down to 0.001 Hz, which is the same as an oscillation with a period of 1000 seconds. This requires very stable temperatures and there are special demands on the installation. There are 5 broadband stations in NNSN.



The station in Ny Ålesund, Svalbard. The uppermost picture shows the entrance to the station, the lowermost a schematic sketch. The seismometer is placed in the lower room to minimize the influence of pressure and temperature variations.

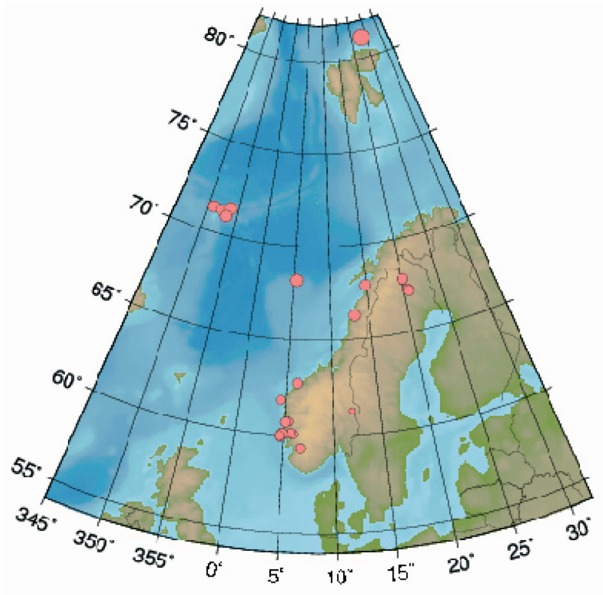
The station in Kongsberg old silver mine. This is one of the best stations in the world due to its location deep in a mine.

Flow of data in NNSN

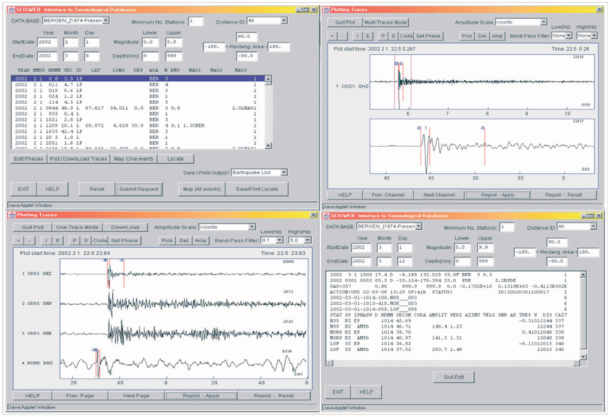


- Data is received from NNSN stations 24 hours a day
- Processed data are received from NORSAR and international data centers every day
- All Norwegian data and selected foreign data are processed together (calculate location and magnitude) and stored in a data base at UiB
- All data are available to the public and are also sent to international data centers.

NNSN and the public



NNSN is continually updating information about Norwegian earthquakes on our web page. The map shows events from the last 10 days.



On the NNSN webpage, everybody can inspect or copy data.


Makrosesimisk sporreskjema

i forbindelse med jordskjelv
01.11.2004 kl 22:26 GMT/UTC
(01.11.2004 kl 23:26 lokal tid)

Institutt for geovitenskap ved Universitetet i Bergen ønsker å kartlegge omfanget av rystelsene av dette skjelvet. Det er viktig at selv de som knapt merket jordskjelvet besvarer dette skjemaet.

Ble skjelvet merket?	◉ Ja	○ Nei		
Hvor var du?	○ Ute	◉ Inne		
Var du våken eller sov?	◉ Våken	○ Sov		
Bygningstype:	◉ Tre	○ Mur/lettbetong	○ Betong	
Antall etasjer i bygningen:	2			
Jordbunnstype:	◉ Fjell	○ Sand	○ Leire	○ Løsmasser

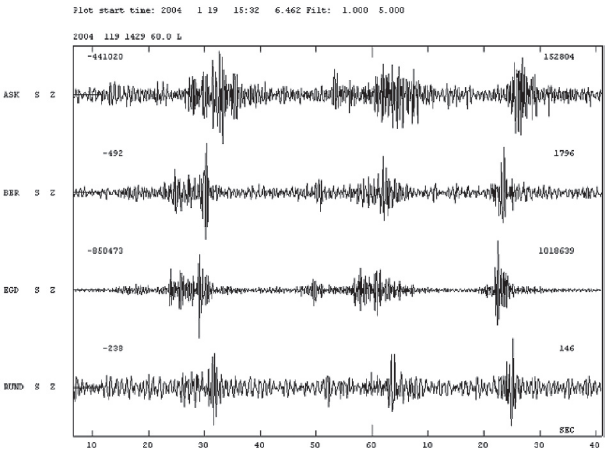
In case of felt earthquakes, NNSN will collect information from the public, manually and through the institute web page.

NNSN has a 24-hour telephone service where the public can get information about earthquakes. Office hours: 55 58 34 10, 55 58 36 00, outside office hours 55 14 00 98, 55 12 27 23 or 55 93 70 73 www.geo.uib.no

Use of data

- General information to the public about recent events; earthquakes or other events.
- Examples of other events than earthquakes are explosions, ship groundings (Rocknes), accidents (the Sleipner platform which sank), induced earthquakes (Ekofisk), or land slides.
- Seismic hazard: data from NNSN have been particularly important for offshore oil installations.
- Research

Rocknes accident



In connection with the Rocknes accident on January 19th 2004, the NNSN stations around Bergen registered an unusual signal. The seismograms show the registration of the strongest shaking at the stations: ASK: Askøy, BER: University of Bergen, EGD: Espegrend and RUND: Rundemannen. First time marking is at 15:32:10 GMT (16:32:10 local time). The time scale is seconds.

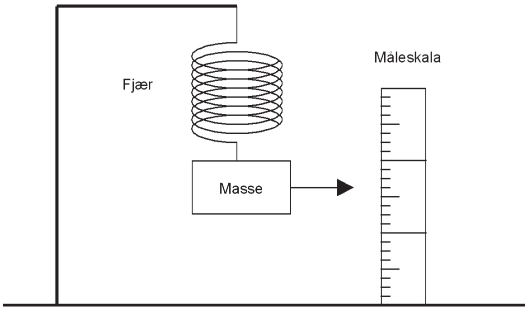
Seismic instruments

Seismic instruments used for registration of ground motion caused by earthquakes are essential for studying seismology. Without instruments, we would have little knowledge of earthquakes and the interior of the Earth. The following will describe a bit about seismic instruments, both those shown in the exhibition and a few others.

How does a seismometer function

The seismometer together with the unit recording the signal is called a seismograph.

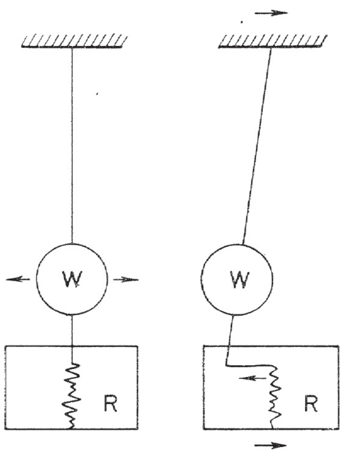
The seismometer senses the ground vibration and converts this to a signal that can be recorded. Modern seismographs can measure movements smaller than one nm (one millionth of a millimetre)



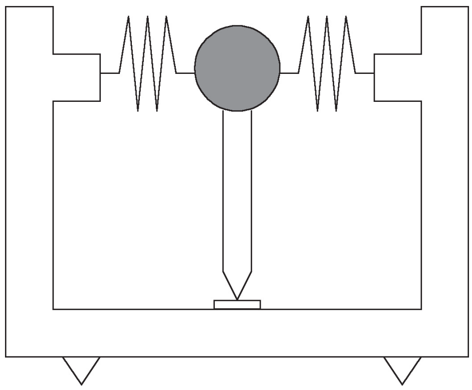
How it works: When the ground is moving rapidly, the spring ("Fjær") suspended mass ("Masse") will keep quiet due to inertia and we will get a measurement on the scale ("Måleskala") to the right. This is the principle of the mechanical seismograph. The seismograph in this figure measures the vertical ground motion. In newer seismometers there are electrical coils around the mass, which is magnetic, so that an electrical signal is generated when the mass moves.

Horizontal motion

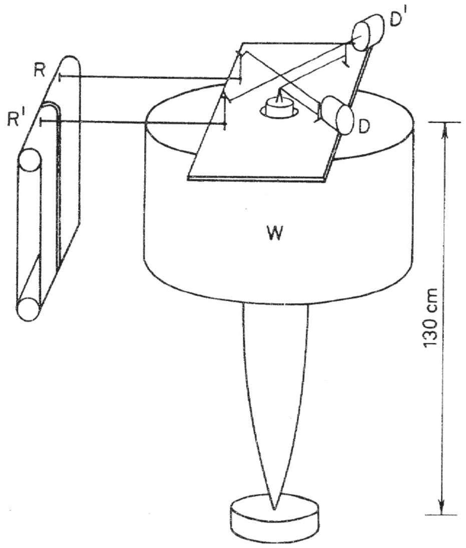
Earthquakes generate both vertical and horizontal motions. In order to measure a horizontal movement, we need a mass which can swing in the horizontal plane.



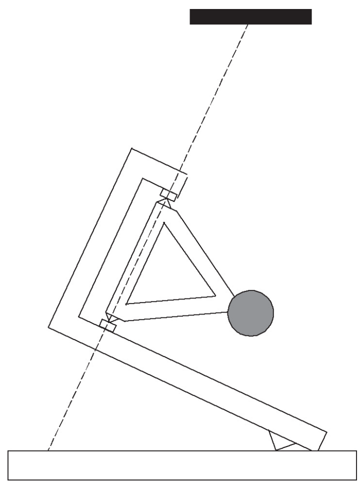
A simple horizontal pendulum. When the ground moves to the right, the mass will swing to the left and the ground motion will be recorded on the paper, which moves down. The mass can swing in all directions and must be suspended on a very long string in order to be able to record low frequencies. In order to avoid this, a 'garden gate' or inverted pendulum is used (see next figures).



Inverted pendulum. The mass can swing in all horizontal directions. This is the principle of the Wiechert seismograph used in Bergen from 1921 to 1968, see figure below.

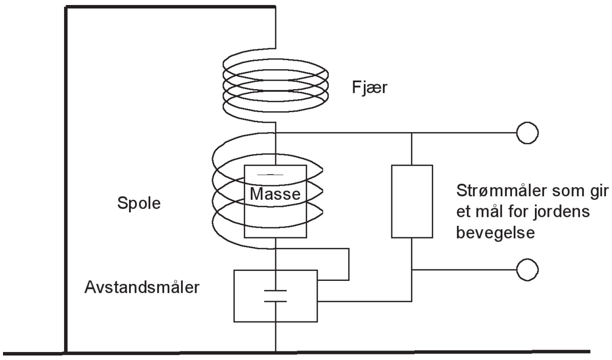


The Wiechert seismograph. The mass horizontal motion is captured by two arms that, by using a system of levers, can amplify the motion and record it on two rotating drums (R). The seismograph can record horizontal motions in East-West and North-South directions at the same time.

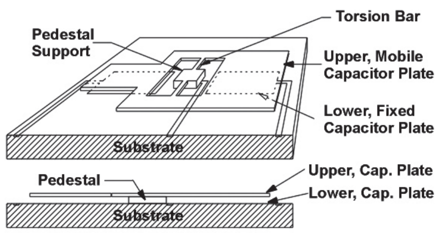


'Garden gate' pendulum. The mass only swings horizontally in one direction. It hangs at an inclined angle in order to make it swing more slowly (like a door hanging at an angle). This principle is used in the Bosch seismograph.

Moderen seismic sensors



In new sensors, the mass barely moves. The mass is suspended by a spring ("Fjær"). Departure from the mass center position is measured with a distance measurement device ("Avstandsmåler"). As soon as the mass tries to move, the distance measurement device will send a current through the coil ("Spole"), which will oppose the motion so that the mass remains stationary. The larger the force on the mass, the larger the current. The size of the current will therefore be a measure of the ground motion (more correctly the ground acceleration). Such instruments can be built compact and very sensitive and are called accelerometers. They are also widely used for other purposes, such as releasing



Accelerometer on an electronic chip. The distance measurement device is a capacitor, the spring is a torsion bar and the mass is the upper capacitor plate. The chip has a dimension of 2x2 mm.

Frequencies measured

Seismometers measure signals with frequencies between 0.001 Hz and 100 Hz

It is relatively simple to construct seismometers that measure the higher frequencies > 0.1 Hz (short period seismometer)

Seismometers that measure the low frequencies (< 0.1 Hz) are more difficult to make (long period seismometers)

Modern (and expensive) seismometers measure both low and high frequencies (broad band seismometers). Technically they are based on the principle of the accelerometer.

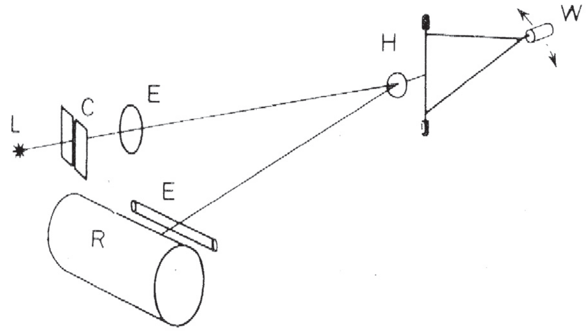
Recording of seismic signals

The sensor generates a signal. This was recorded mechanically on older seismographs. All modern sensors give out an electrical signal that can be recorded in several different ways. A recording on paper, usually lasting 24 hours, is called a seismogram.

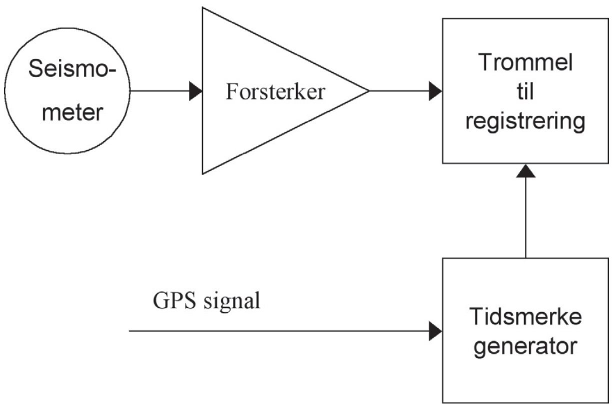
Optical recording. The electrical signal is sent to a galvanometer with a mirror. A light beam is reflected from the mirror and recorded on a rotating drum with light-sensitive paper. This system was used from early 1900 up to a few years ago.

Pen recording. Instead of a 'lightbeam' pen, an electrical pen, also recording on paper on a rotating drum, is used. The pen can record with ink, scratch on smoked paper, or develop heat and write on heat-sensitive paper.

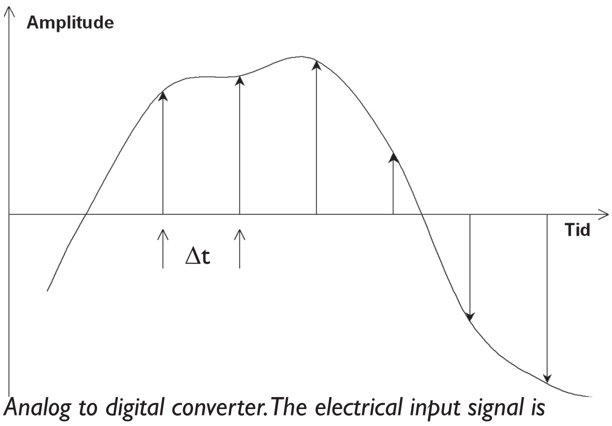
Digital recording. Today, nearly all seismographs record digitally. The electrical signal is transformed to a digital signal that can be recorded by a computer.



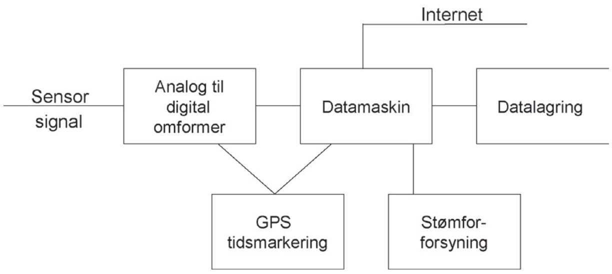
Optical recording. The electrical signal is sent to a galvanometer with a mirror (H). A light beam (L) is reflected from the mirror (H), and recorded on a drum with optical paper (R). In front of the drum, there is an optical lens focusing the beam.



Pen recording of seismic signals. The signal from the seismometer is amplified ("Forsterker") and sent to a drum recorder ("Trommel til registrering"). The time signal from a GPS (Global Positioning System) receiver is used to generate minute and hour pulses recorded together with the signal. Before time signals were available by radio, time pulses were generated by a mechanical clock.



Analog to digital converter. The electrical input signal is continuous: In other words, we know the size (amplitude) of the signal at any time. The analog to digital converter (AD) measures the amplitude at regular time intervals (Δt) and gives out the numerical values for the amplitude as a sequence of numbers. These are then read by the computer. For seismic signals, the amplitudes are usually read 100 times per second. For digital music recorded on CD, we have ca 44 000 values per second.



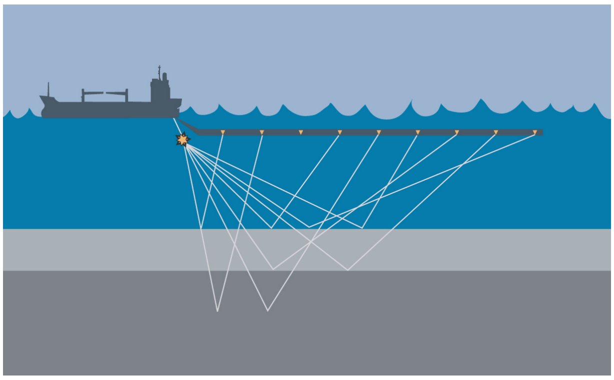
Digitial seismic station. The signal is sent to the analog to digital converter ("Analog til digital omformer"), which converts the signal to a digital signal. It is then transferred to a computer ("Datamaskin"), where it is recorded and stored ("Datalagring"). Via Internet, the signal is sent from there to a central data center. "GPS tidsmarkering" means making a time stamping by GPS, and "Strømforsyning", power supply.

Seismology and oil

The methods for searching for oil are based on seismological principles. The Seismological Observatory has from 1960 played a central role both in connection with the investigation of the Norwegian continental shelf, and in educating candidates for Norwegian and foreign oil industries.

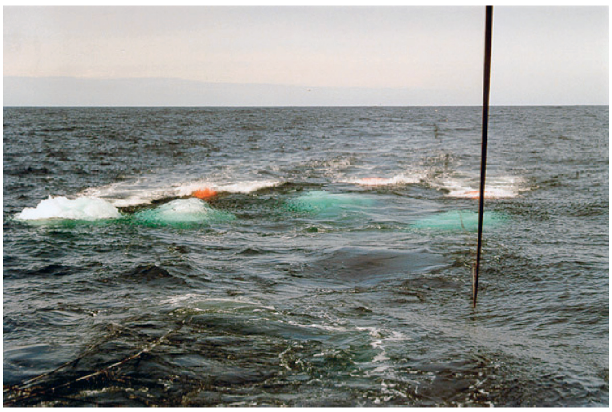
Hydrocarbons (oil and gas) are formed by the breakdown and transformation of organic materials under high pressure and temperatures in sedimentary rocks (oil bearing rocks). Oil and gas have then migrated from the oil bearing layer to a porous layer and have finally been captured in a trap consisting of an overlaying impenetrable sediment.

In seismic investigations, the sedimentary layers are mapped in search of traps where oil and gas can be found. In the early days, explosives were used in order to generate seismic waves. This, however, lead to large-scale protests from fishermen claiming that it was greatly harming the fish stocks. This resulted in an extensive search for alternative energy sources. In the late 1960s, the use of compressed air was introduced as a replacement, and today the so-called airguns are dominating.

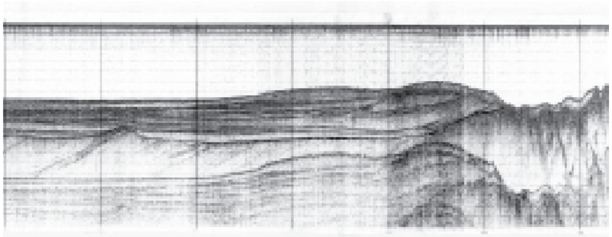


Reflections from layers in the underground are recorded by sensors placed in seismic cables that are towed after the ship.

Modern seismic ship.

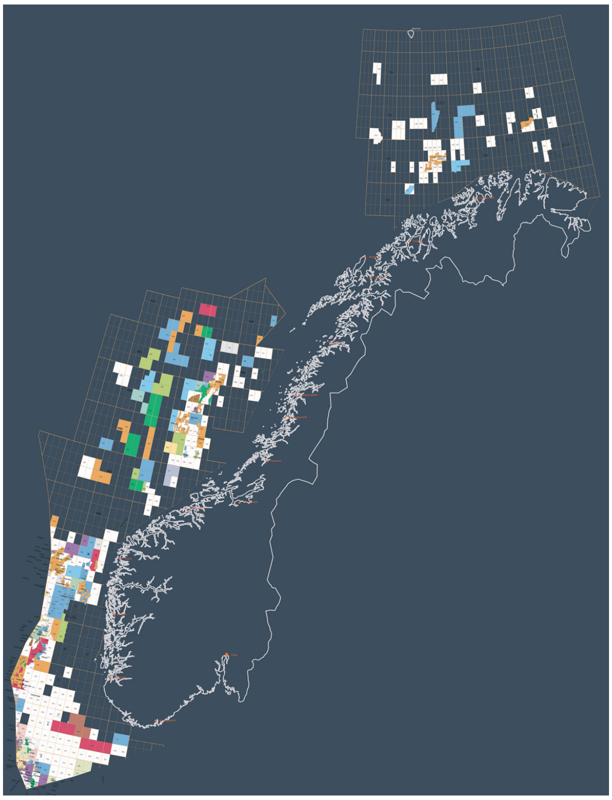


Air guns being fired



An example of a seismic section going from the area west of Bergen and crossing Norskerennen. The layers under the seabed are visible as lines in the seismic section.

It was early known that the southern parts of the North Sea were covered by sedimentary rocks. However, many geologists believed that these were confined to the south by a line between Shetland and southern Norway where old granite rocks were exposed. It therefore came as a surprise to many experts when the Seismological Observatory demonstrated, in seismic investigations, that massive sedimentary layers (several kilometers thick) existed along the entire continental shelf, including the Barents Sea and the area around Svalbard. As a result, candidates from the Seismological Observatory were highly in demand and central to the establishment of the Norwegian oil industry in the early 1970s.



This map shows oil fields on the Norwegian continental shelf. The colored areas indicate fields where oil is being explored.

The first discovery of oil on the Norwegian shelf was at Ekofisk in the North Sea. This happened in 1969, and the production started in 1971. The Ekofisk oil field has been sinking for many years due to the oil extraction, and water is being pumped into the reservoir to compensate for this. Due to a damaged well, water was pumped into the layer above the oil reservoir, resulting in a manmade earthquake of magnitude 5 in May, 2000. NNSN recordings were essential in explaining what had happened.

The Ekofisk field.