CONTINUOUS SEISMIC PROFILING IN STORFJORDEN, NW NORWAY

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A continuous seismic profiler using an air gun transducer has been applied in a survey in Storfjorden, NW Norway. Four profiles were measured. It is shown that the sediment thickness reached 150 meter. There are indications of more reflectors between the fjord bottom and basement rock.

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In recent years the continuous seismic profiler has become an effective tool for seismic exploration at sea. It has been used in deep water as well as in continental shelf research and fjord surveys.

The profilers are now produced from a wide variety of principles and designs. In this paper the instrumentation of the Seismological Observatory, University of Bergen, will be considered. The main part of the paper, however, will deal with results obtained with the profiler in Storfjorden (Fig. 1).

The recordings were obtained by the research vessel 'Helland-Hansen' of the University of Bergen. On its way home from seismic research work on the Norwegian continental shelf in June 1968, time was available for running a few profiles in the fjord. The whole operation was part of a larger program, supported by Norges Teknisk-Naturvitenskapelige Forskningsråd (Royal Norwegian Council for Scientific and Industrial Research).

The purpose of the fjord survey was to examine the usefulness of this continuous seismic profiler in a narrow fjord, and to obtain information about the thickness of the sediments in Storfjorden.

Instrumentation

The seismic profiler consists of an air gun, a 100 feet long hydrophone eel, amplifiers, filters, and a graphic and a magnetic tape recorder.

The air gun (Bolt Ass. Model PAR 600 A) has a firing chamber 10 cubic
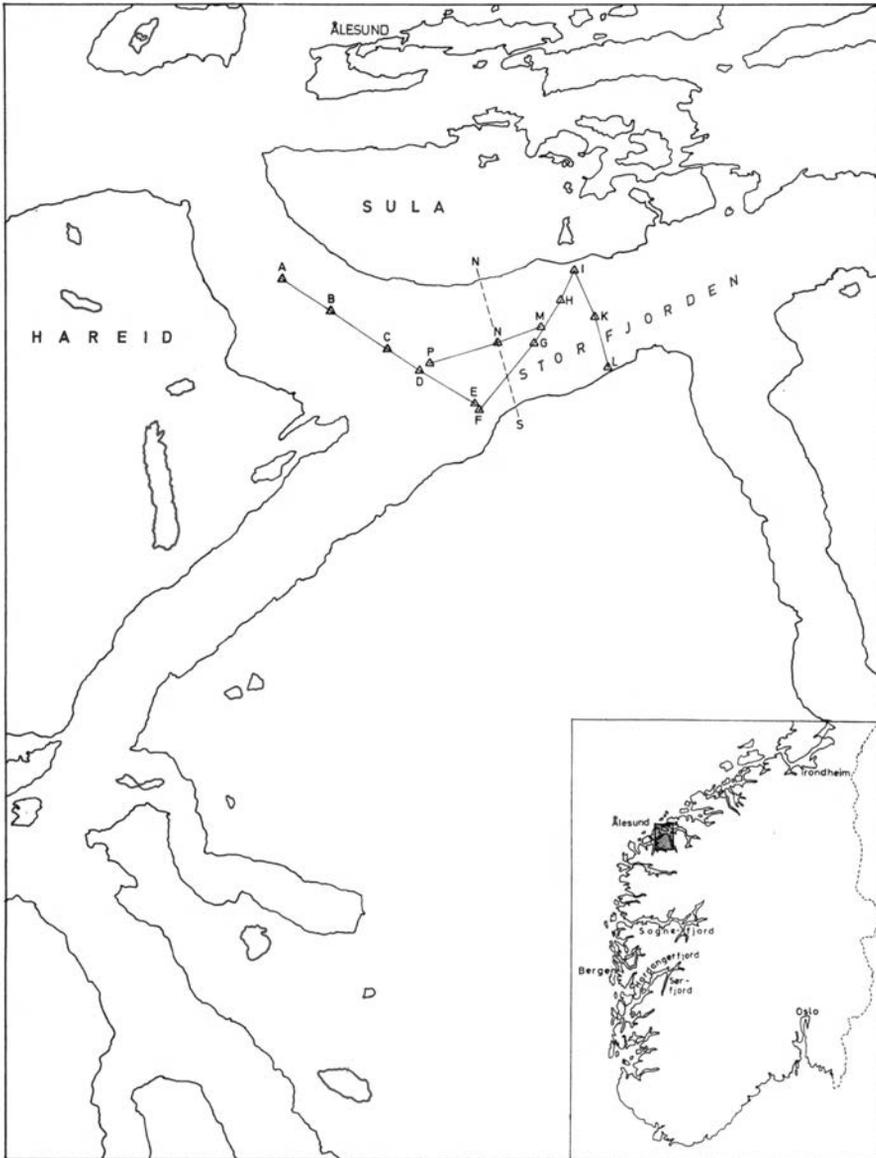
Fig. 1. Map of the Storfjorden area. Solid lines show the tracks of F/S Helland-Hansen. At lower right is a map of southern Norway showing location of surveyed area.

inches in volume. The firing interval is 3 sec. Both chamber-volume and firing interval can be changed.

Fig. 2 shows the air gun. Compressed air at 2000 psi is admitted to the operating chamber (1) through a filter (2). When the solenoid valve is closed as shown on the drawing, the shuttle is driven down. The pressure then rises in the firing chamber (3) and the unit is ready to be fired. Firing is accomplished by energizing the solenoidevalve (4) by a short current pulse.

Fig. 2. The PAR air gun. Explanations in text.
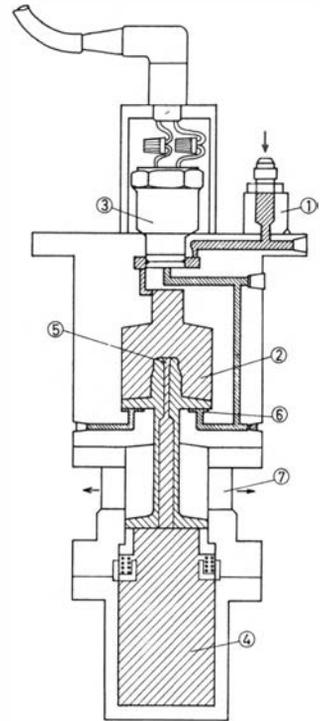
Compressed air is now admitted to the volume (5) causing the shuttle to move upwards and thus releasing the compressed air into the water, thereby generating an acoustic pulse.

The graphic recorder (Ocean Sonics. Type OSR – 19) is a single channel recorder using 19″ chart paper. It has a variety of sweep scales and paper feed speeds. The signals are also simultaneously recorded on an analogue magnetic tape deck (CEC Model PR – 3300).

The hydrophone eel has 16 dual hydrophones (Mark Prod. Inc. Type P – 24) installed at 5 feet intervals in a 100 feet oil-filled eel.

In addition, the instrumentation also consists of filters (Krohn Hite Model 335) and amplifiers (Fenlow Type A – 2).

A schematic diagram of the continuous profiler is shown in Fig. 3. The sound source is triggered from the recorder. To obtain the specified pulse for the gun, the trigger pulse is led through a pulse shaper. Compressed air is led from the compressor (Atlas Copco Type BP–3) via a reservoir and an adjustable reduction valve to the air gun.

The reflected signal is detected by the hydrophone eel and fed into the recorder via the amplifier and filter. Amplified signals are also fed via a broad band filter to the magnetic tape recorder. For play-back reasons, the tape deck receives a syncronizing signal from the paper recorder. The simultaneous recording on tape makes it possible to process laboratory data by playing back with different filter settings.

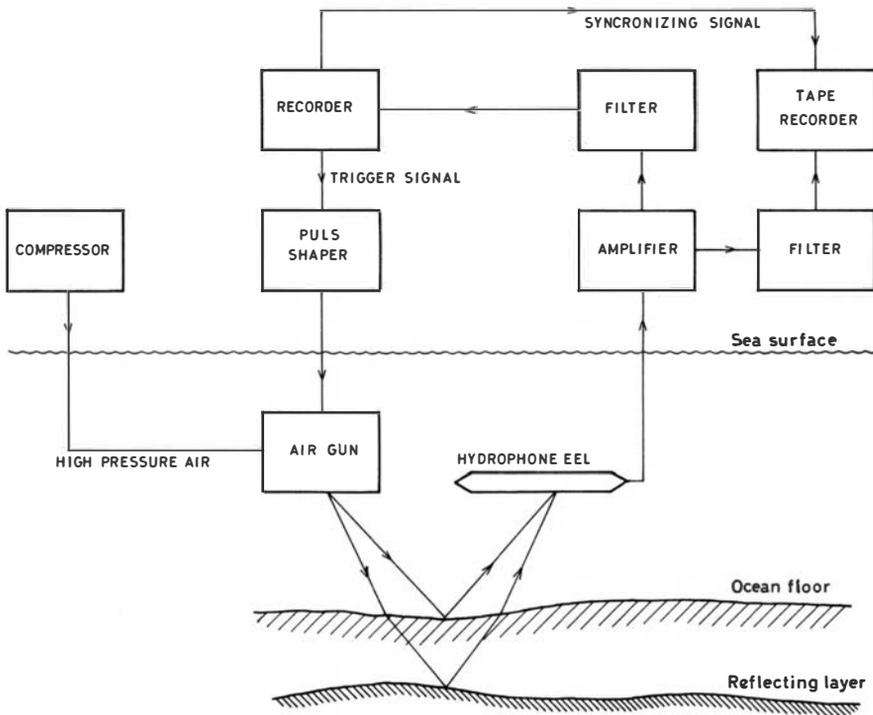The air gun is suspended in a float-gauge and thus kept at a constant

Fig. 3. Schematic diagram of the continuous seismic profiler.

depth. Actually this depth was 0.5 meter. The floater was towed from the stern and kept close to the ship. The hydrophone eel was kept about 30 meters behind the ship and at a depth between 1 and 3 meters. Tests showed
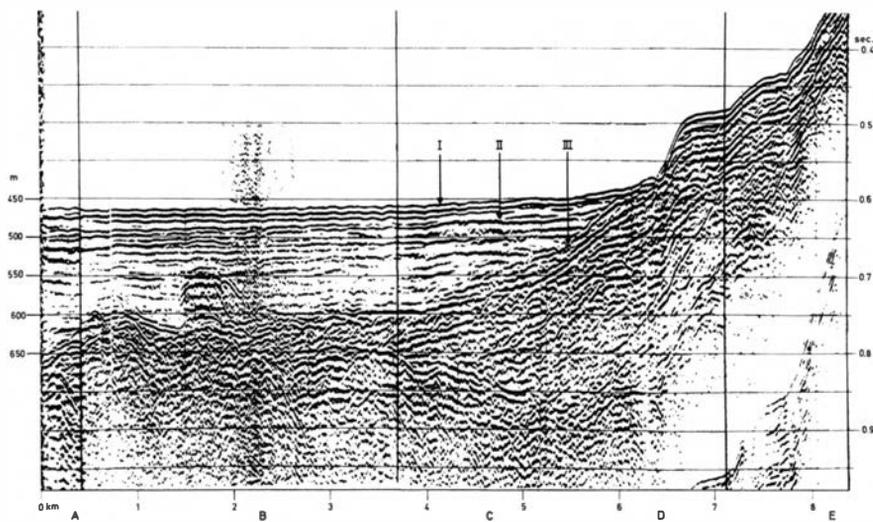

Fig. 4. Continuous record section between positions A and E (vertical exaggeration about 8×).
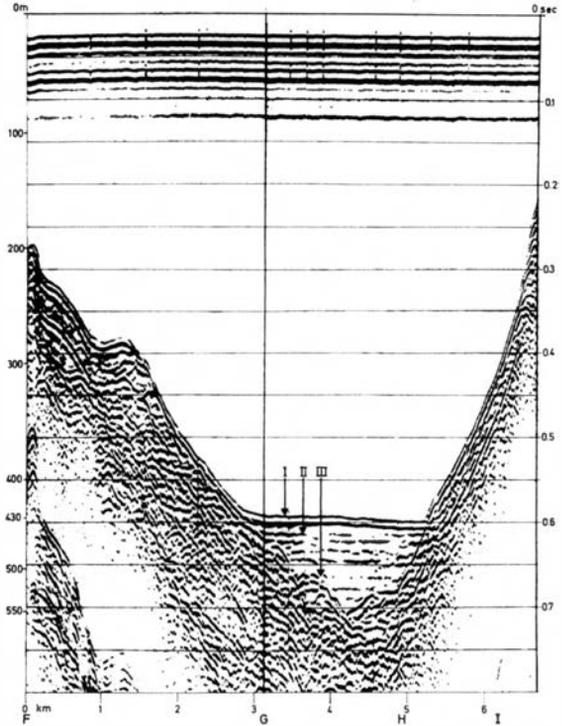
Fig. 5. Continuous record section between positions F and 1 (vertical exaggeration about 8×).

that the noise level decreased by increasing towing distance. Likewise the towing speed influenced the noise level. Random noise is always a problem, but it appears that in investigations like this, it is no serious problem. The filter had a band pass setting between 100 Hz and 260 Hz, and the main part of the noise has lower frequencies than this.

Interpretation

Continuous seismic profiles were taken along the tracks shown in Fig. 1. Total length of the profiles is 22 km.

The towing speed of the ship was held between 3 and 5 knots. With higher speed the noise became a considerable problem, due to streaming effects around the hydrophone eel. The noise could possibly be reduced by using other detecting systems. But the most effective way of improving the signal-tonoise ratio lies on the processing side by using modern signal handling techniques.

The present data are unprocessed. The filter setting and amplification were adapted to give the best picture on the record. The records show certain characteristics. From Fig. 6 it can be seen that the recorded signal has a complex form, shown by a double line. This is very well demonstrated by the
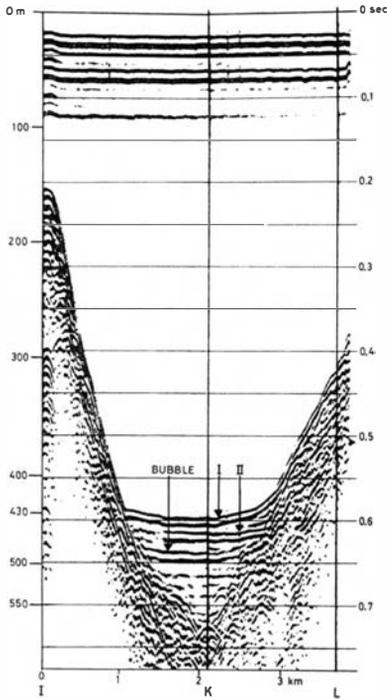
Fig. 6. Continuous record section between positions I and L (vertical exaggeration about 8×).

bottom reflection. One of the reasons for this is believed to be in the filter. Laboratory tests seem to confirm this assumption. In addition, the gun itself seems to contribute to this effect (H. Closs, personal communication). This complex signal will often mask the true signals and thus be an inconvenience, but sometimes it can be helpful in identifying weak signals.

The survey was limited to only a few profiles. Positions were determined by direct bearing to land and by radar fix. These positions are indicated by block letters in the map as well as on the sections (Figs. 4, 5, 6, and 7). The
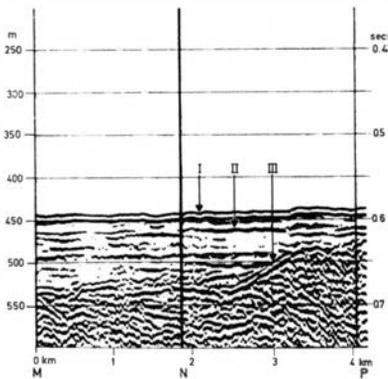

Fig. 7. Continuous record section between positions M and P (vertical exaggeration about 8×).

vertical axis on the sections represents reflection time, which is also indicated by horizontal lines for every 0.05 sec.

Depths to bottom and sub-bottom reflectors are also shown in the sections on a separate scale. These depths are based on a sound velocity of 1.50 km/sec in water, and 2.00 km/sec in the sediments. As we have no information about seismic velocities in Storfjorden, we had to choose an appropriate value. From a survey in Sørfjorden (Fig. 1), Behrens (1963) reports sediment velocity 2.28 km/sec and Eldholm (1967) from the same area reports an average velocity of 2.26 km/sec. Those velocities are in a range reported for similar sediments. F. Press (1966) gives the following velocities for water saturated alluvium and clay, respectively: 0.5 – 2.0 km/sec and 1.1 – 2.5 km/sec. From ocean surveys Nafe & Drake (1957) report compressional wave velocities covering the range from 1.8 to 2.2 km/sec for sediments in shallow sea areas. The chosen velocity 2.00 km/sec therefore seems to accord well with observations from related areas.

The bubble pulse (Dobrin 1960) is more or less visible in all sections. Its masking effect is always very troublesome. In the present data it can be clearly seen at position K (Fig. 7) where – as in all this material – it occurs 0.04 sec behind the first signal.

Three distinct reflectors can easily be identified in the sections (Figs. 4, 5, 6, and 7). They are named I, II, and III. I and III represent the bottom floor and basement rock respectively. Reflector II, though not so clear, is visible in all sections. It occurs about 0.02 – 0.03 sec after I. Seismograms from a seismic reflection survey in Storfjorden in 1965 (unpublished material) also show a clear signal at the same reflection time.

Though there is no doubt about where reflector III occurs in the records the 'III' reflection is generally not so distinct. This reflector, interpreted as basement rock, might be expected to give good reflection signals. On the other hand, if the reflector has an uneven surface, Dix (1952) has shown that such unevenness will diffract the wave energy – an effect which explains the weak basement reflections.

There are indications in the material of more reflectors. In Fig. 7, between positions N and P, there seems to be another reflector about 0.01 sec after 'I'. Though it is difficult to separate more reflection signals on the records, it seems that there must be a sequence of reflectors. From a similar survey in Hardangerfjorden (Cone, Neidell & Kenyon 1963), 4 layers have been reported, indicating a poor resolution in the instruments, which in fact was expected. The air gun transducer radiates wave energy in the range from 30 to 500 Hz, which is considered a low frequency for explorations like this. If the signal frequency is 100 Hz and the velocity 2 km/sec, wave length of 20 meters is given. The consequence of this is that layers with thickness less than 10 meters will not be detected. Leenhardt (1967) reports resolution better than 10 cm by a 12 kHz transducer.

The problem, however, is that a high resolution also means a low penetration. A higher resolution could have been obtained in this particular survey,
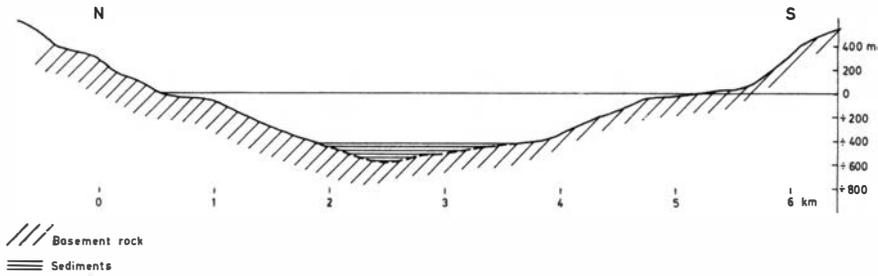
Fig. 8. Sketch showing a true topographic distribution along the profile NS in Fig. 1.

while also keeping the necessary penetration, by using a 1 cubic inch firing chamber instead of 10 cubic inches. The signal frequency should then rise and thus give a better picture of the sediment structure.

Discussion

The material is limited and thus does not permit any wide discussion. It is not possible to give any relief of the fjord bottom or the other reflectors. The discussion must be based upon the sections, which are all reproduced (Figs. 4, 5, 6, and 7). In all the sections, vertical exaggeration is approximately 8. To show a true picture of the distribution along a profile crossing the fjord, a sketch is presented in Fig. 8.

In the central parts of the fjord the sediment depths reach 100 meters. Towards the sides the sediment thickness reduces as the basement rock rises. Thus the sediments form an even and almost horizontal floor over wide areas of the fjord.

Why are the reflected signals from the basement rock so weak? If the fjord, as generally accepted, is formed by glacial and glacifluvial erosion, it could be expected that the rock surface would be even over wide areas. If so, it should also be an excellent reflector. This is not so, and the answer may be that the bottom is covered with morainal material. Blocks and boulders would have the effect of scattering the wave energy and thus make the bottom a poor reflector (Dix op. cit.).

In Fig. 4, near position B, the reflector III abruptly rises about 50 meters. In this area the total sediment thickness reaches up to 150 meters. How can this 'heap' be explained? Its horizontal extent along the profile is about 600 meters, and the height is 50 meters. Its extent normal to the profile is unknown. It is possible that this rise is basement rock. At position A, the depth of the fjord bottom is 460 meters, with basement rock about 600 meters below sea surface. According to the map, the bottom rises to about 330 meters only 1.5 km NW of position A. This fact shows that an expected threshold is situated in this area. If so, the rise at B is possibly a part of the threshold area.

Another explanation of the rise, and possibly one of the more probable, is

that it is a morain. Many authors have suggested that the thresholds are morainal accumulations. This is a possibility which cannot be excluded. Recent studies of Sognefjorden and Hardangerfjorden indicate very clearly that the thresholds are rocky (Holtedahl 1967). This supports the supposition, which we believe in fact to be the case, that the rise is rocky.

The survey is, as mentioned above, very limited. Many questions must be left open about the sediment accumulation and structure, the fjord formation in general and the history of Storfjorden in particular. A continuation of this study seems to be of great interest.

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REFERENCES

Behrens, J. 1963: Refraktionsseismische Messungen im Sörfjord. *Dissertation*. Clausthal.
Cone, R. A., Neidell N. S. & Kenyon, K. E. 1963: Studies of the deep water sediments with the continuous seismic profiler. *Sarsia 14,* Bergen.
Dix, C. H. 1952: *Seismic Prospecting for Oil*. Harper Bros, New York.
Dobrin, M. B. 1960: *Introduction to Geophysical Prospecting*. McGraw Hill, London.
Eldholm, O. 1967: Seismiske undersökelser i Sörfjorden, Hardanger. *Unpublished thesis* for the degree of cand. real., University of Bergen.
Holtedahl, H. 1967: Notes on the formation of fjords and fjord-valleys. *Geografiska annaler, 49, Ser. A.*
Leenhardt, O. 1967: Topics on seismic research at the Monaco Oceanographic Museum. *Geophysical Prospecting, AV, No. 3.*
Nafe, J. E. & Drake, C. L. 1957: Variation with depth in shallow and deep water marine sediments of porosity, density and the velocities of compressional and shear waves. *Geophysics 22.*
Press, F. 1966: *Seismic Velocities. Handbook of Physical Constants.* Ed. Sydney P. Clark jr. The Geological Society of America.