The Snowstreamer — a new device for acquisition of seismic data on land

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A new concept for seismic acquisition on snow, the Snowstreamer technology, has been developed. The concept is based on the same principles as for marine seismics and offers faster operations, reduced manpower and logistics and thereby reduced costs per kilometer, compared to conventional landseismics.

Introduction

In 1985 Norsk Hydro signed an agreement with Store Norske Spitsbergen Kulkompani to do hydrocarbon exploration on their claims onshore Svalbard. (Nøttvedt et al., this volume) Despite the relatively well known geology of Svalbard, it soon became clear that proper exploration demanded geophysical information.

Land seismic operations are in general very labor-intensive and time-consuming compared to marine seismic work. In conventional land seismics each geophone has to be manually put into the ground as well as manually moved from one position to another. The number of people needed is considerable and large amounts of equipment have to be carried along. Furthermore, the arctic climate of Svalbard would also add extra cost to the exploration budget and the total cost of covering the area of interest with seismics would be significant relative to the total exploration budget.

In order to speed up this operation and thereby reduce the cost, the Snowstreamer technology was proposed. This technique takes advantage of the operational efficiency achieved in marine seismics, by using geophones attached to a main cable. In this way the production rate may exceed conventional methods by several factors. At present, about 400 km of seismics have been shot onshore Spitsbergen, the largest island of the Svalbard archipelago, with the Snowstreamer technology.

General settings

Svalbard represents an uplifted part of the otherwise submerged Barents Shelf, with rock units of a similar age and composition as below the Barents Sea.

The geological basement of Svalbard consists of a complex series of different metasediments and crystalline rocks. Above this basement sits a more or less complete sedimentary section from Devonian to Tertiary, varying from clastic redbeds in the Devonian–middle Carboniferous, carbonates and evaporites in the upper Carboniferous–Permian, organic-rich clastic shale series in the Triassic–Jurassic to sandy clastic facies in the Cretaceous–Tertiary (Fig. 1).

Two main tectonic events caused structuring of the sedimentary cover sequence. Extension (possibly oblique slip) in the middle Carboniferous caused major subsidence and fault block rotation along the Billefjorden Fault Zone, whereas oblique compression in the Eocene, as Greenland moved northwards relative to Svalbard, caused the West Spitsbergen Orogenic Belt and formation of the Central Spitsbergen basin to the east of it (Fig. 1; Harland, 1969; Steel and Worsley, 1984). Up to 5 km of Carboniferous–Tertiary strata is preserved in the basin, probably overlying in addition several kilometers of Devonian sediments.

Decollement movements and thrust ramping related to the Eocene compressional event affected mainly the Mesozoic section, and are typically decoupled from the normal faulting in the Carboniferous below. This means that one cannot use the surface geology to predict which structures are present subsurface, and therefore seismics are needed in the general exploration of the area (Nøttvedt et al., this volume).

The subsurface seismic conditions at Svalbard are different from offshore Norway. The seismic velocities are very high and range from about 4000 m/s to

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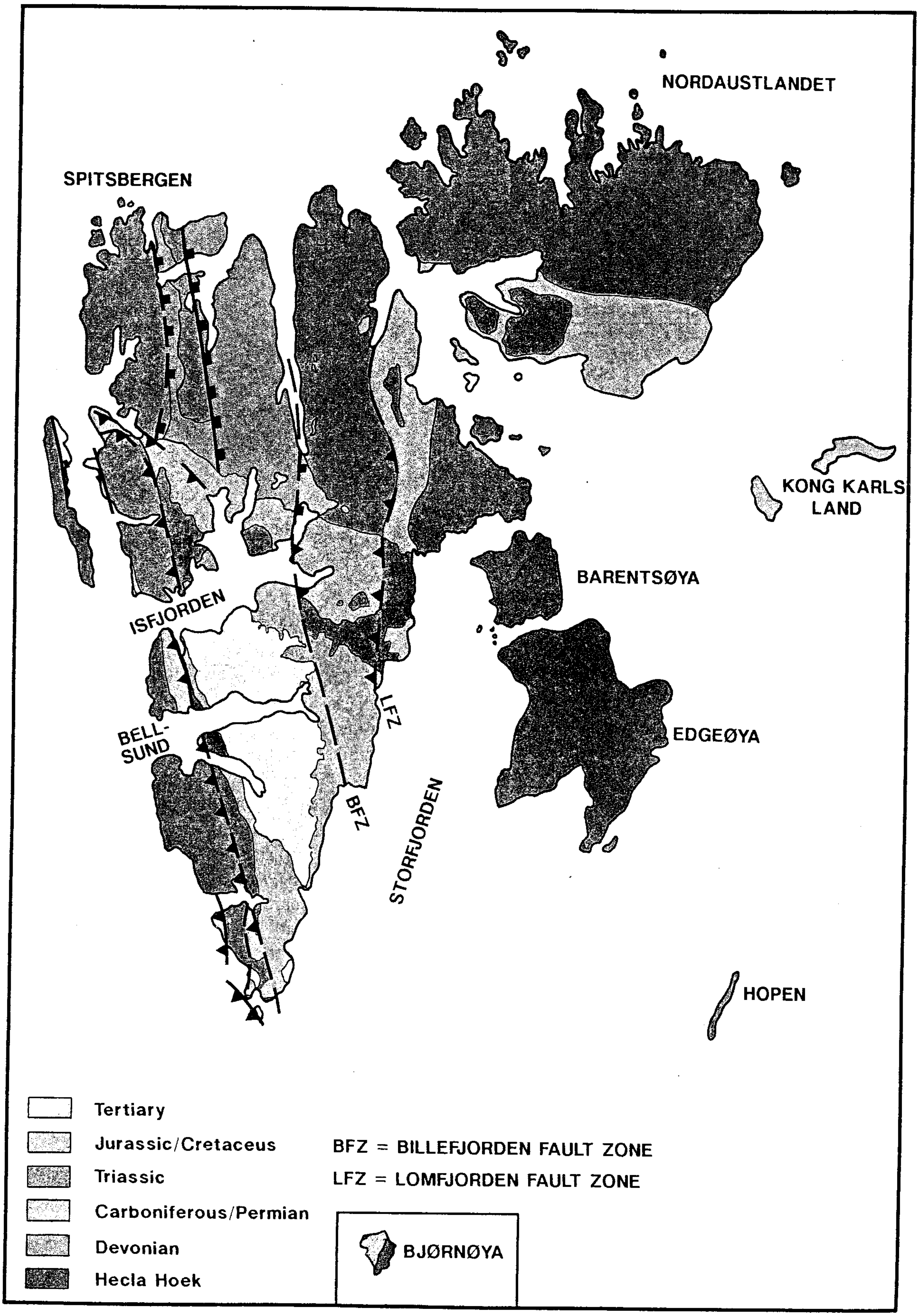

Fig. 1. Simplified geological map of Spitsbergen and adjacent areas.

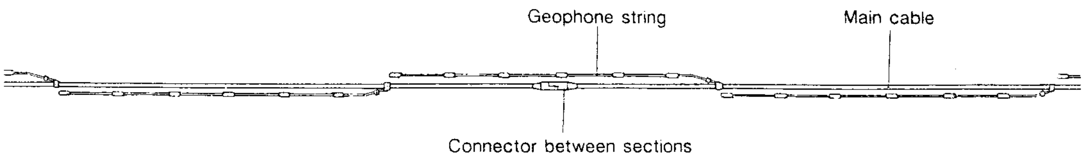

Fig. 2. Main cable and geophone strings.

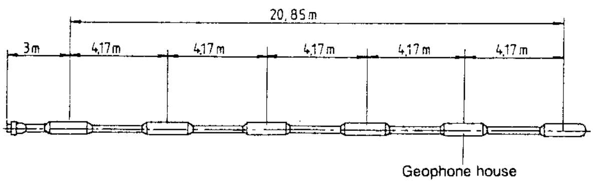

Fig. 3. Geophone string.

5000 m/s at the near surface, due to permafrost and significant burial succeeded by late Tertiary uplift in the area (see also Nøttvedt et al, this volume). In the fjords of Spitsbergen the large velocity contrast at the waterbottom causes severe penetration problems.

On land the permafrost does not seem to cause any problem for the seismic data quality. On the contrary, the fact that the near surface is frozen leads to a high velocity and the static problems are only minor. Since the seismic wavelengths are long in such an environment, the resolution will be reduced compared to offshore Norway, in particular for the shallow zone.

During winter and spring the surface on Svalbard is covered by high-density wind-packed snow. The snow depth varies from about 20 cm to several meters.

The snowstreamer

The Hydro prototype Snowstreamer is 1500 m long and has 60 seismic channels each with 6 geophones. The main features of the system are shown in Figs. 2 and 3. Each group is 25 m long and the Snowstreamer is divided into sections which are connected as shown in Fig. 2. The geophone strings (Fig. 3) consist of half-gimballed geophones mounted inside a housing so that they will always adjust to a vertical position and measure the vertical component of the ground velocity. Each geophone housing weighs 1 kg and the total weight of the system is about 1000 kg. The diameter of the main cable is 2 cm. The parameters of the prototype streamer are selected in order to satisfy the requirements on Svalbard, and may be changed in other areas.

Operations

Figure 4 shows the principle of the Snowstreamer technology during operations. The operational setup ahead of the tracked vehicle is similar to that of conventional seismics. The major difference is behind where no personnel are required for laying out the geophones.

The members of the crew are:

- Two surveyors to mark each shotpoint with a flag.
- Two persons to pull out the explosives.
- Two persons taking care of the shooting.
- Three persons inside the vehicle; driver and two field engineers.
- Two persons responsible for the explosive supplies.

This setup requires 11 persons, which is a reduction of a factor five compared to conventional operations.

Apart from the personnel inside the tracked vehicle, all members of the crew use snowmobiles. The shooters carry the instruments on the sledge and the explosives are also transported in this way. The cable is attached to the vehicle which also carries the recording instruments. Line shifts are easily made by using a hydraulic drum that can wind up the streamer in a short time. Owing to the main cable design, 180 degree turns can also be easily made if necessary.

During the seismic operations on Spitsbergen detonating cord laid on top of the snow has been used. This explosive is easy to handle and causes no

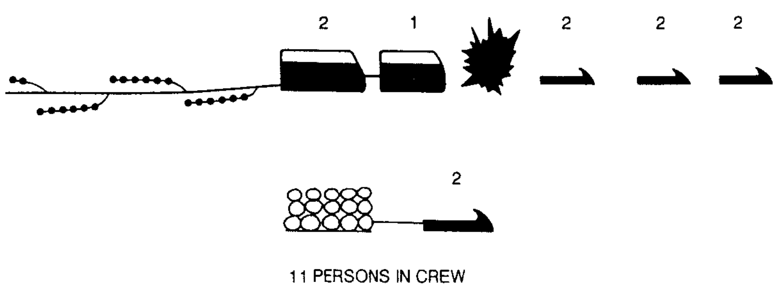

Fig. 4. Snowstreamer operations on the seismic line.

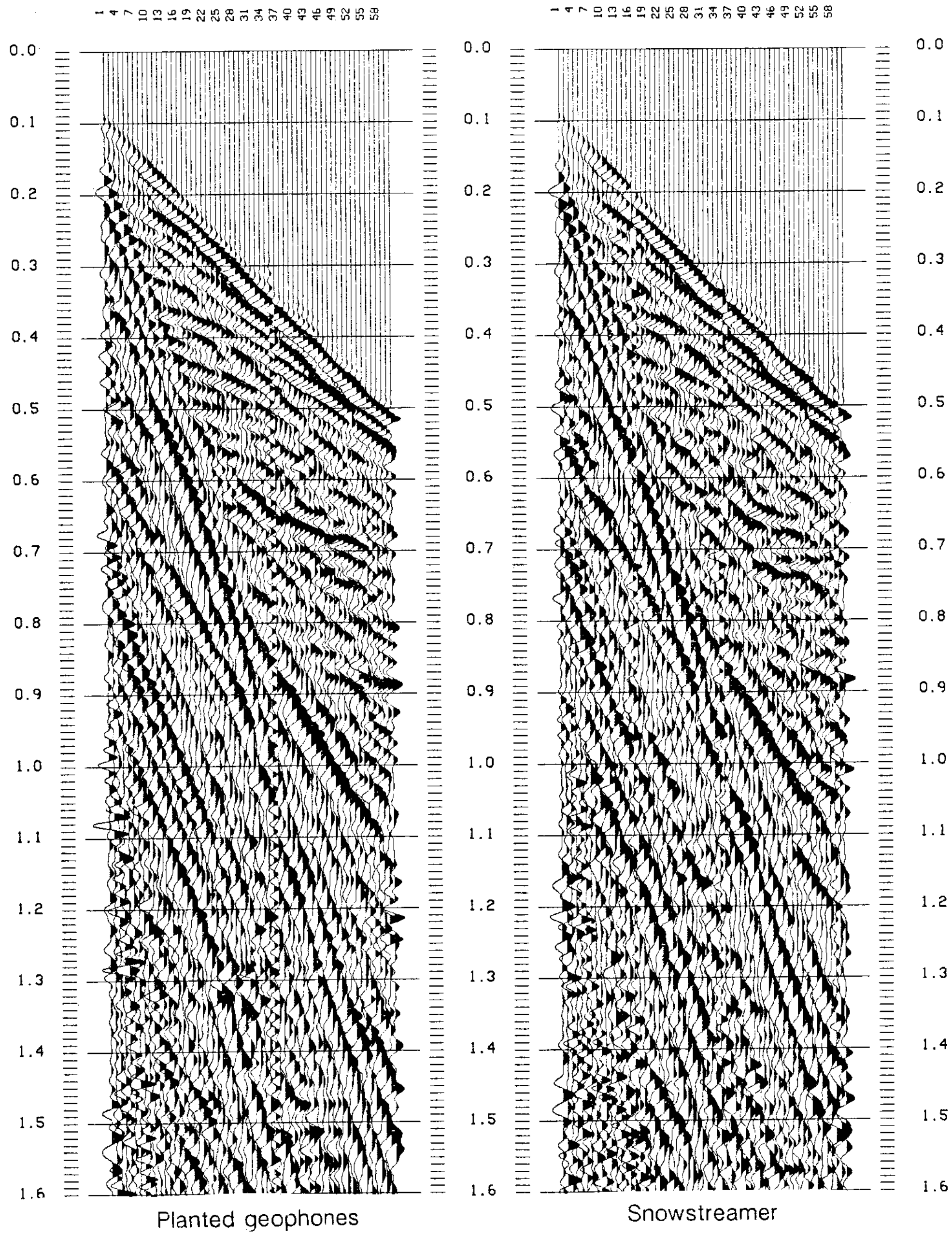

Fig. 5. Comparison of shot records.

damage to the environment, given a normal thin layer of snow on the ground. A total of 4 kg is used at each shotpoint, distributed in two parallel cords of 50 m length. This gives an explosive power of 40 g/m on the ground.

Data quality

In order to compare the Snowstreamer data with conventionally recorded data, several tests were carried out using different configurations and charge sizes. The most important test is a seismic line of about 4 km shot separately with the Snowstreamer and with planted geophones — all other parameters were identical (Rygg et al., 1989)

Figure 5 shows raw shots from this line, and as can be seen there are no significant differences. The final stacked sections are shown in Fig. 6 and they show data of equal quality. This result is also supported by coupling tests where single ordinary planted geophones were compared with gimballed geophones (Eiken et al., 1989). The measurements show that the coupling resonance frequency is above the seismic bandwidth of interest.

Seismic exploration onshore Svalbard

Norsk Hydro has collected and interpreted more than 400 km of seismic data onshore Spitsbergen.

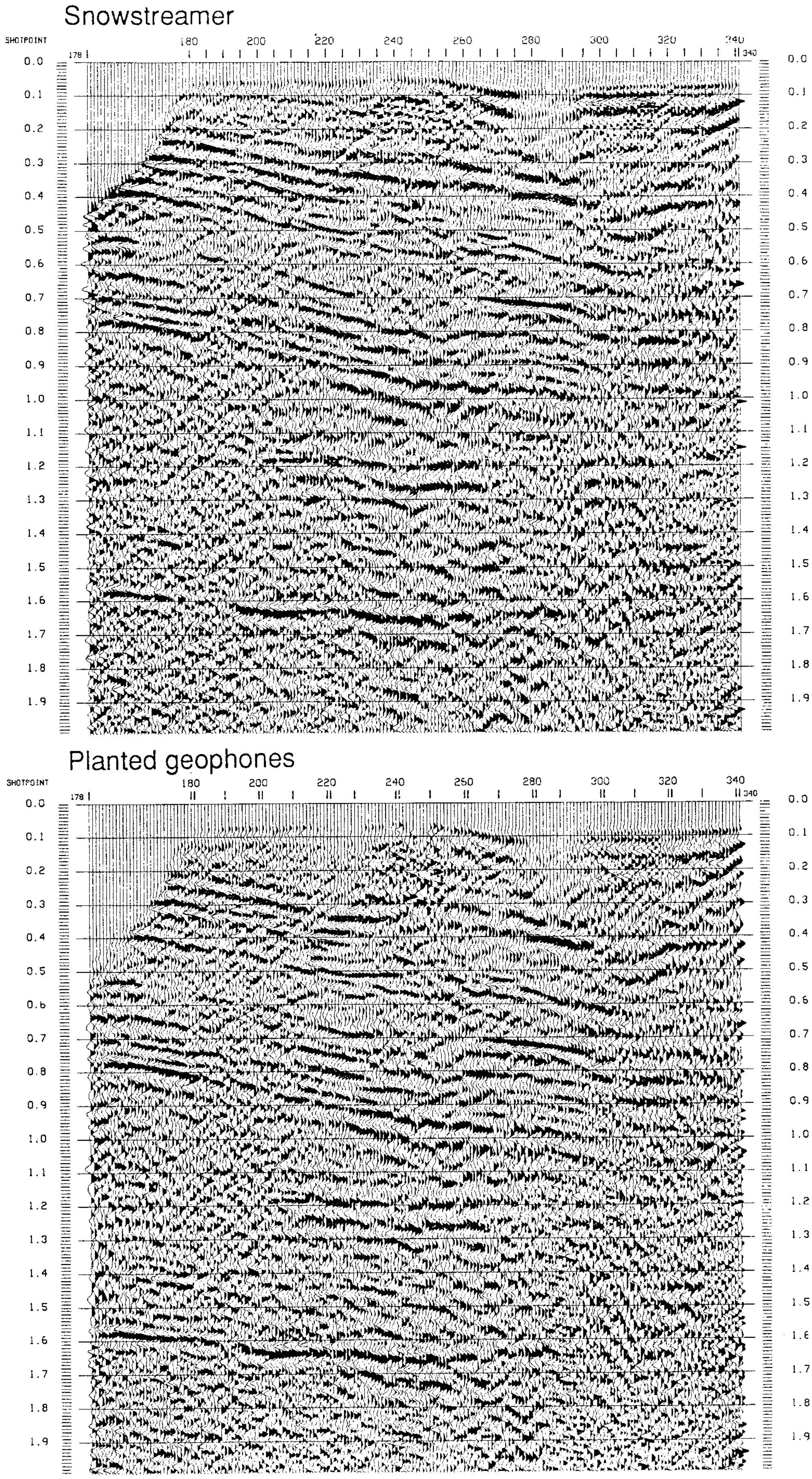

Fig. 6. Comparison of stacked sections.

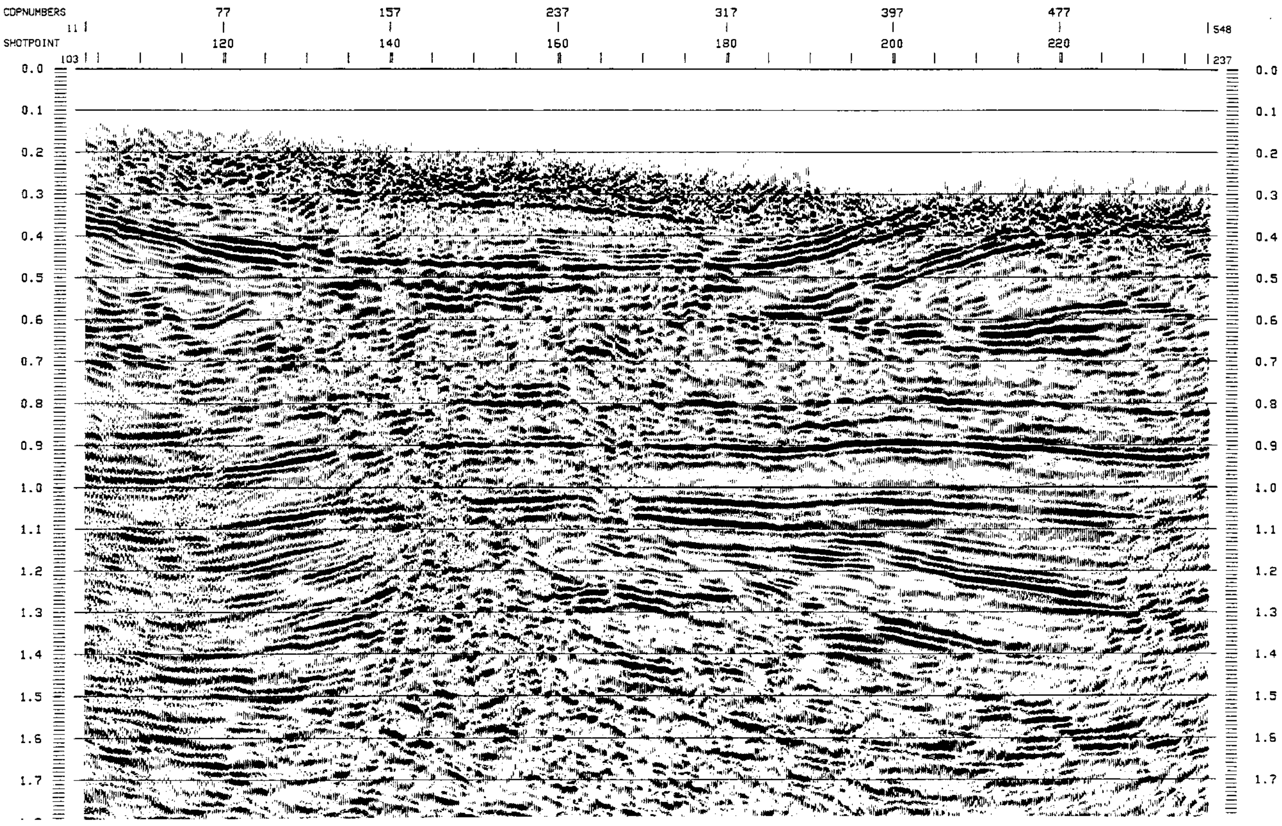

Fig. 7. Seismic line from production acquisition.

The large valleys of the eastern part of the Central Spitsbergen Basin have been covered, but the Snowstreamer technology is not restricted to the flat valley bottoms. It has also proved successful on glaciers and moraine areas. An example of processed seismic data from rough terrain is shown in Fig. 7. The line starts on the top of a glacier and ends in a valley 500 m below. The line is oblique to the regional dip and is shown in dual polarity display. The well defined syncline in the upper 5–600 ms represents a broad compressional fold structure, forced by decollement movements and thrust ramping in the Mesozoic beds. The syncline overlies, and is clearly decoupled from, a low relief anticline in the Paleozoic section below. At about 1.1 s, an unconformity terminates a package of slightly rotated, normal faulted Carboniferous beds, representing a subsurface continuation of the well defined Billefjorden Graben to the north (see also Nøttvedt et al., this volume). This line emphasizes the need for geophysical information to resolve the subsurface structuring — i.e. sound prospect mapping cannot be done solely by the use of surface structural contouring and subsurface extrapolation.

Data processing

The seismic data have been processed at a contractor, but several lines, such as the line shown in Fig. 7, have been specially processed at Norsk Hydro Research Centre Bergen.

In land data processing we are often confronted with two problems; surface waves and statics due to a low velocity weathering layer. On Spitsbergen there are strong surface waves with area dependent characteristics, but they can be attenuated by FK filtering on shot records in most cases. The well known statics problem is not pronounced on Spitsbergen, mainly due to the permafrost which causes high near surface velocities. Therefore the data have been processed without residual statics and only elevation statics have been applied. For lines with large elevation differences, for instance the line shown in Fig. 7, datum has been selected as the largest altitude in the area.

Due to the combination of high velocities and relatively short offsets, the stack response is not sensitive to selection of stacking velocities. However, the large dynamic range means that scaling must be done with care.

Conclusion

The Snowstreamer technology has been shown to produce seismic data of equal quality to conventionally acquired data at a large reduction in cost. During production shooting on Spitsbergen the

Snowstreamer has proven to be a robust and reliable device for Arctic seismic operations. It is believed that the concept is applicable worldwide under similar winter conditions.

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