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Seismic events in Hornsund, Spitsbergen

ABSTRACT: The distribution of earthquake foci around the Hornsund fiord, south Spitsbergen, suggest the presence in this region of a micronode of geotectonic structures, exhibiting moderate dynamic activity. Dislocation description was applied to the processes of motion of the glacier and crack formation. Long-period seismic waves generated by the glacier-substratum dynamic system and impulses generates by icebergs seated on the sea bottom have been discussed.

Key words: Arctic, Spitsbergen, seismicity, geotectonics, glaciology.

Introduction

The first observations of schocks associated with glacier dynamics were made by Teisseyre and Siedlecki in the summer season of 1962. The field works were performed on the Hans Glacier in Hornsund Fiord, south Spitsbergen (Lewandowska and Teisseyre 1964).

In 1970 the shock recording on the Hans glacier were carried out by Górski (1975). In 1971–1975 the work was continued by Czajkowski (1974; 1977a, b).

A seismological station has been operating in the Polish polar base in Isbjörnhamna since 1979. The station carries out continuous recording of tectonic shocks and shocks related to the dynamics of Hans Glacier (Górski 1986a, b; 1987; 1988) Górski and Perchuć 1987). In the summer of 1980, observations in the direct vicinity of the actually formed crack were performed by Cichowicz (1983). The theory to describe the dislocational formation of cracks and glacier motion has been developed by Teisseyre (1982; 1987a, b, c; 1988).

Tectonic shocks in the Hornsund fiord region

Seismicity observed in the region of Hornsund fiord is related to geotectonic situation in the Barents Sea shelf. The shelf is a young structural element of the earth's crust, of a platform character. The areas of the shelf nearby the continental slopes and areas densely traversed by faults are the sites of structural transformations responsible for considerable seismic activity.

Earthquakes in the Svalbard region are to be interpreted as a response — along local weakening zones — to regional stress field associated with the tectonics of lithospheric plates.

In the region of Spitsbergen there are three major zones of seismic activity (Górski 1990). Apart from these regions, some weak seismicity is observed in many places over Spitsbergen. Foci of these weak shocks are also located in the close vicinity of the station, in Hornsund fiord (Górski 1986a).

The seismological station in the Polish polar base in Isbjörnhamna records weak shocks of tectonic origin, with foci at a distance of a few to more than ten kilometers. An analysis was restricted to shocks the foci of which were localized. The location was possible owing to the fact that the seismometer sites in the station were distributed at distances of several hundred meters from each other (Górski, 1986a). In the location procedure the use was made of the difference in arrival times of P waves at different sites and the differences in the recording times of phases S and P. An example of recording of a shock the with a focus located in the Hornsund area is illustrated in Fig. 1.

The positions of shocks under study are indicated in the spatial map in Fig. 2. Among the localized shocks one can distinguish a group of shocks the foci of which, placed at approximately 10 km depth, are grouped about a plane (circles with a cross). The position of this plane was calculated with the method of least squares. It dips from east to west so that the intersection line with the earth's surface runs N-E at a distance of a few kilometers to the east of Treskelen Peninsula. If we take into account the curvature of the plane in question, we

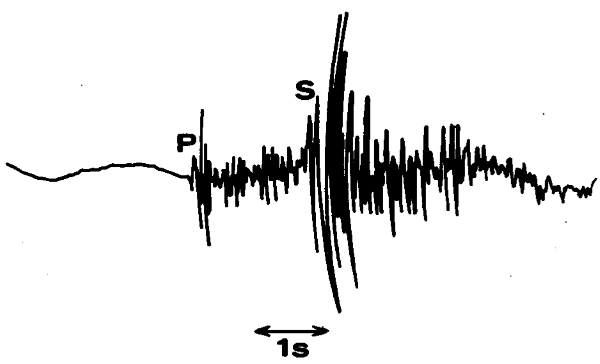

Fig. 1. Seismogram of a shock with a focus in the Hornsund area

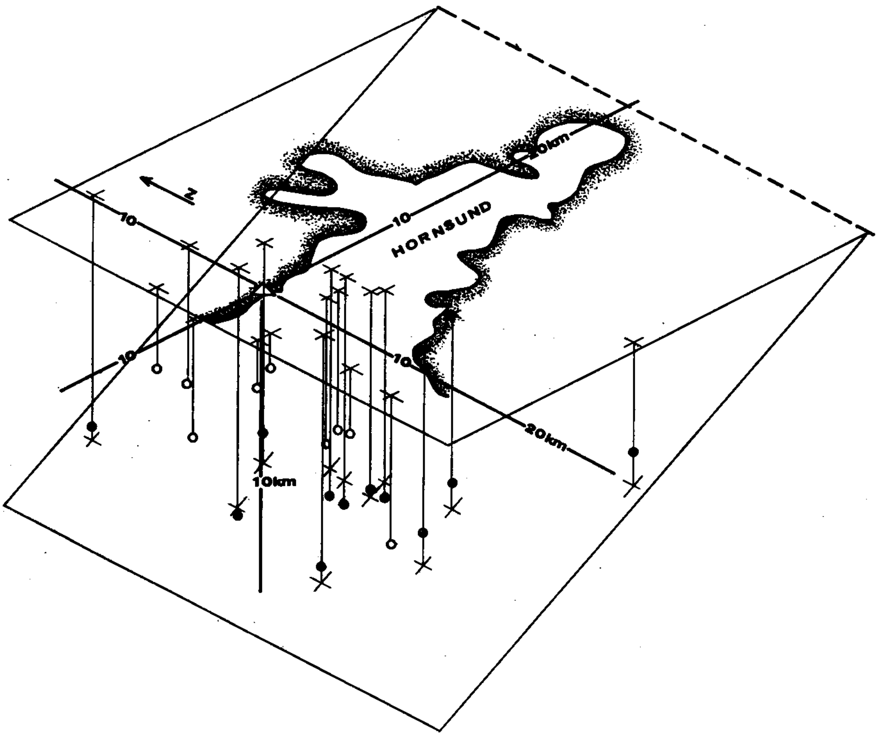

Fig. 2. Spatial map of Hornsund (circles — shock foci; circles with a cross — foci with determine a plane; triangle — the station)

obtain its good fit to the fault observed in this region (Ohta 1982). Therefore, one can expect that the fault has a deep-reaching continuation.

The group of shallower shocks in the direct vicinity of the station, marked circles in Fig. 2, does not show any distict ordering in space, though the shocks are related to a certain, rather well defined region.

The distribution of shock foci around the Hornsund area suggests the presence in this region of a certain micronode of geotectonic structures, exhibiting moderate dynamic activity.

Seismic effects associated with glacier dynamics

The problems of motion and deformation of a glacier are considered here from the point of view of an elastic medium containing a dislocation field and cracks. Describing plastic deformations of an elastic medium one should make use of the dislocation density field. It is therefore worthwhile to apply dislocational description to motion and plastic deformations of the glacier as well as to the crack formation processes in the glacier.

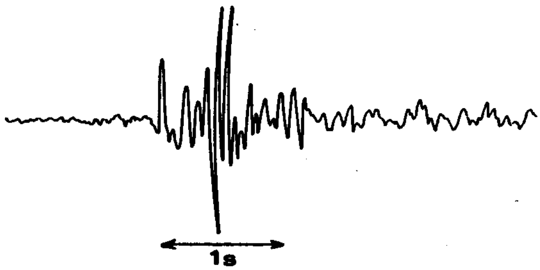

Fig. 3. Seismogram of a microtremor recorded on a glacier

Microseismological observations have shown that the dynamics of the glacier is accompanied by numerous microtremors and weak shocks (Fig. 3). The processes depend on rheological properties characteristic for the given range of deformation rates, stress field and temperature. Studies on the Hans Glacier, have shown that the number of microtremors quickly decreases with growing distance from the glacier front. In an obvious though not numerically exact way, this is correlated with the number of open cracks. The data on depth distribution of cracks in the glacier are even more scanty. Some relationships and characteristics, however, can be established theoretically.

The process of plastic flow is described through a dislocation density growth. It was assumed that in the areas of active glacier motion the distribution of dislocations is close to a "saturated" system, which leads to the formation of fracture craks, perpendicular to the motion. Next, the mechanism of the dislocations ⇒ crack process and its depth range were examined. The above-mentioned saturation state corresponds here to a system of dislocations in mutual dynamic equilibrium. Such dislocation systems are characterized, like in the static case, by a large stress concentration around the so-called blocking or leading dislocation (the latter in the case of motion); the rest of dislocations are in equilibrium with each other. The obtained formulae reveal the relationship between the dislocation density growth and the deformation or displacement velocity. Stress around the leading dislocation increases according to the multiplier which is the number of dislocations in dynamic equilibrium along a certain dislocation plane. As a result, such a system leads to the situation in which the strength is exceeded and crack-type defects, notably the open cracks, are being formed. The dislocations ⇒ crack process produces a release of part of the elastic energy. Thus, such processes can be accompanied by the observed weak glacier shocks.

The method described above explains the important role of dislocations in the process of plastic flow of the glacier and gives a mechanism for the formation of defects in the form of cracks in the glacier structures.

The observations also show, however, that the flowing glacier generates seismic waves that strongly differ in character from typical waves accompanying

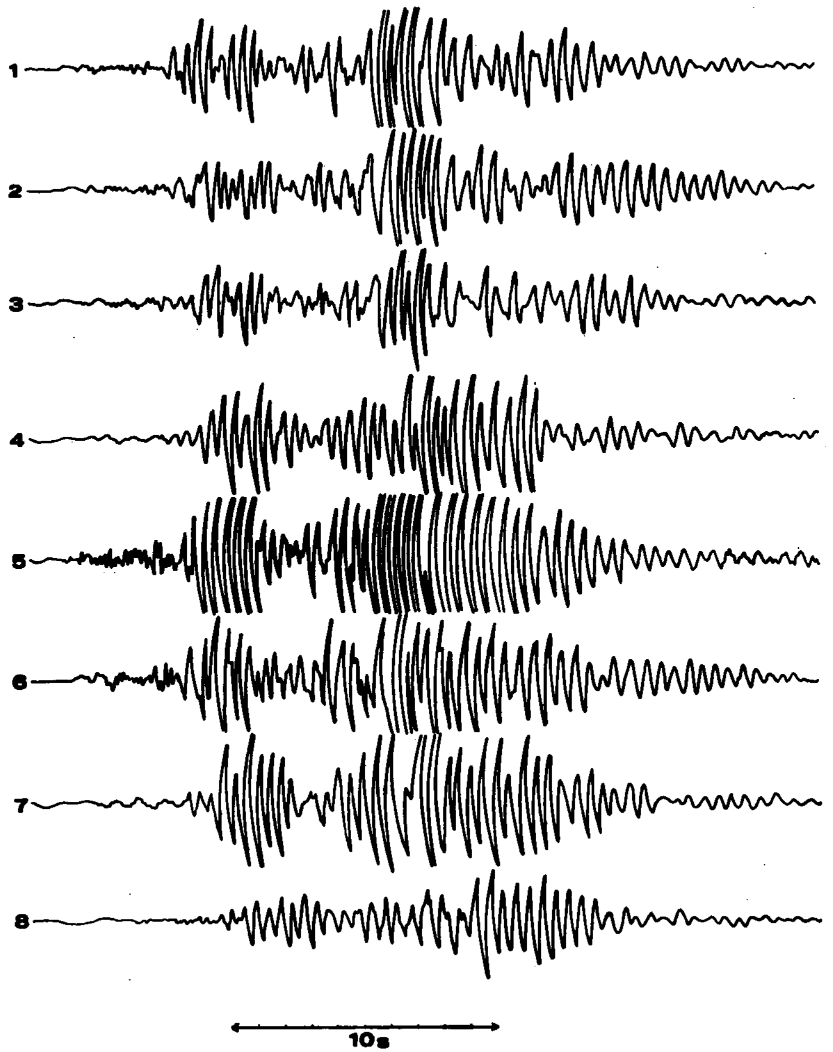

Fig. 4. Seismograms of waves generated during glacier motion (the numbers of channels correspond to seismometer sites of Fig. 5)

the formation of defects in the stress release process. Few kilometers away of the glacier we already do not record the microtremors related to the crack formation. Instead, we record characteristic wave packets of relatively high, decisively dominating period (about 0.5 s) and considerable amplitude (Fig. 4). Vibrations of higher frequencies which accompany these waves are recorded only by seismometers located relatively close to the active zone of the glacier.

The Fig. 5 illustrates location of seismometer sites and the active zone of Hans Glacier. Comparing the seismograms (Fig. 4) from different seismometer

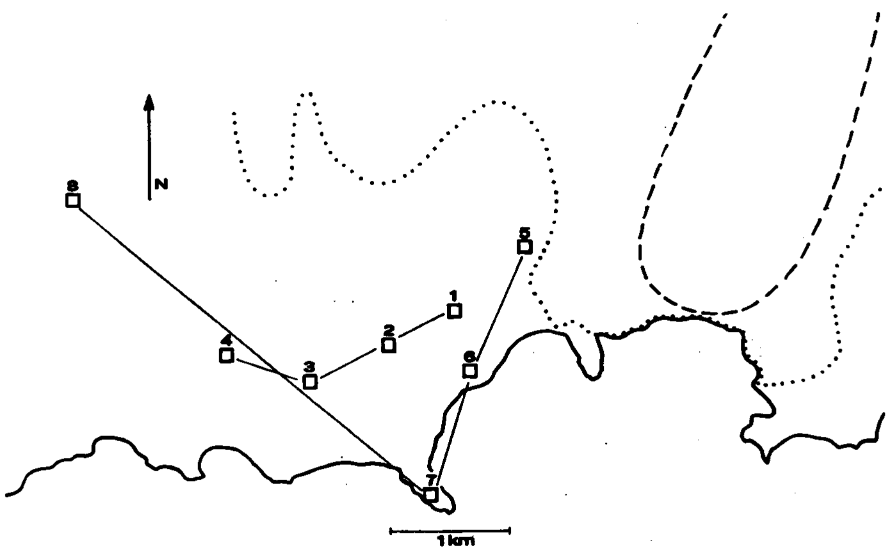

Fig. 5. Location of seismometer sites (sqares) and the active zone of Hans glacier (dashed line). The doted line shows the boundary of ice

Fig. 6. Seismogram of an impulse generated by an iceberg seated on the sea bottom

sites (Fig. 5) we can observe their changes with growing distance from the source. Worth noting is the fact that the generated group of waves consitutes a time sequence that does not change with growing distance from the source only their amplitude decreases. The waves described above are generated by the glacier-substratum dynamic system during glacier flow. Similar sequences of long-period waves have been recorded by seismometers placed in the vicinity of glaciers in the Antarctic Peninsula region.

An iceberg seated on the sea bottom in the shore region and subjected to the influence of sea waves is a similar seismic wave-generating dynamic system. The waves produced in such a system have been recorded in Hornsund and in the Antarctica (Fig. 6).

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Streszczenie

Pierwsze pomiary mikrowstrząsów lodowca Hansa rozpoczęli Siedlecki i Teisseyre w roku 1962 (*zob.* Lewandowska i Teisseyre 1964). Następnie badania te znacznie wykroczyły poza pierwotne zamierzenia obejmując problemy tektoniki Spitsbergenu (Górski 1990).

Analiza wstrząsów tektonicznych w rejonie fiordu Hornsund, zarejestrowanych w stacji w Isbjörnhamna (fig. 1), wskazuje na istnienie w tym rejonie umiarkowanie aktywnych struktur geotektonicznych (fig. 2).

Problemy ruchu lodowca są rozpatrywane w niniejszej pracy jako procesy w ośrodku elastycznym zawierającym dyslokacje. Mechanizm tworzenia się szczelin łączony jest z obserwowanym występowaniem mikrowstrząsów lodowca (fig. 3).

Ruchowi lodowca towarzyszy generowanie fal sejsmicznych o stosunkowo długim czasie (fig. 4 i 5). Fale te generowane są na styku lodowca z podłożem. Podobnie powstają impulsy sejsmiczne wytwarzane przez osadzone na dnie morza góry lodowe w strefie brzegowej (fig. 6).