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Seismic crustal structure of the sedimentary basin of Central Spitsbergen (discussion of results)

ABSTRACT: Seismic refraction studies on Central Spitsbergen have shown that there is the fault systems with north-south strike directions, which divide the crust into western, central and eastern blocks. Thickness of the crust in this area varies from 35 to 40 km. Interpretation and modelling of seismic refraction data indicate that the Moho boundary beneath the Central Spitsbergen Basin is a complicated transition zone between crust and upper mantle with the thickness of about 5 km.

Key words: Arctic, Spitsbergen, crustal structure.

Introduction

The Svalbard Archipelago is the subject of the present discussion. It is located at the northwestern extreme of the Eurasian continental plate, and is separated from the landmass by the shallow epicontinental Barents Sea. The Knipovich Ridge spreading axis is located only 100—200 km west of the archipelago and of the Barents Sea continental margin (Fig. 1). Spitsbergen is the largest island within the Svalbard Archipelago.

Crustal refraction data of central part of Spitsbergen upon which this paper is based, were obtained during joint expeditions undertaken as a part of cooperative efforts between the following institutions: Bergen University, Norway; Hamburg and Münster Universities, FRG; Polish Academy of Sciences, Warsaw, Poland and Saint Louis University, USA. The main purpose of the expeditions were to investigate the crustal structure in the Spitsbergen region by explosion seismology method. Fieldworks were carried out in 1976 and 1978. Results of the study have been published earlier by Mitchell *et al.*

(1978); Guterch *et al.* (1978); Guterch *et al.* (1982), Pajchel *et al.* (1982) and Sellevoll (1982). The present discussion concentrates on the deep crustal structure of the sedimentary basin of Central Spitsbergen.

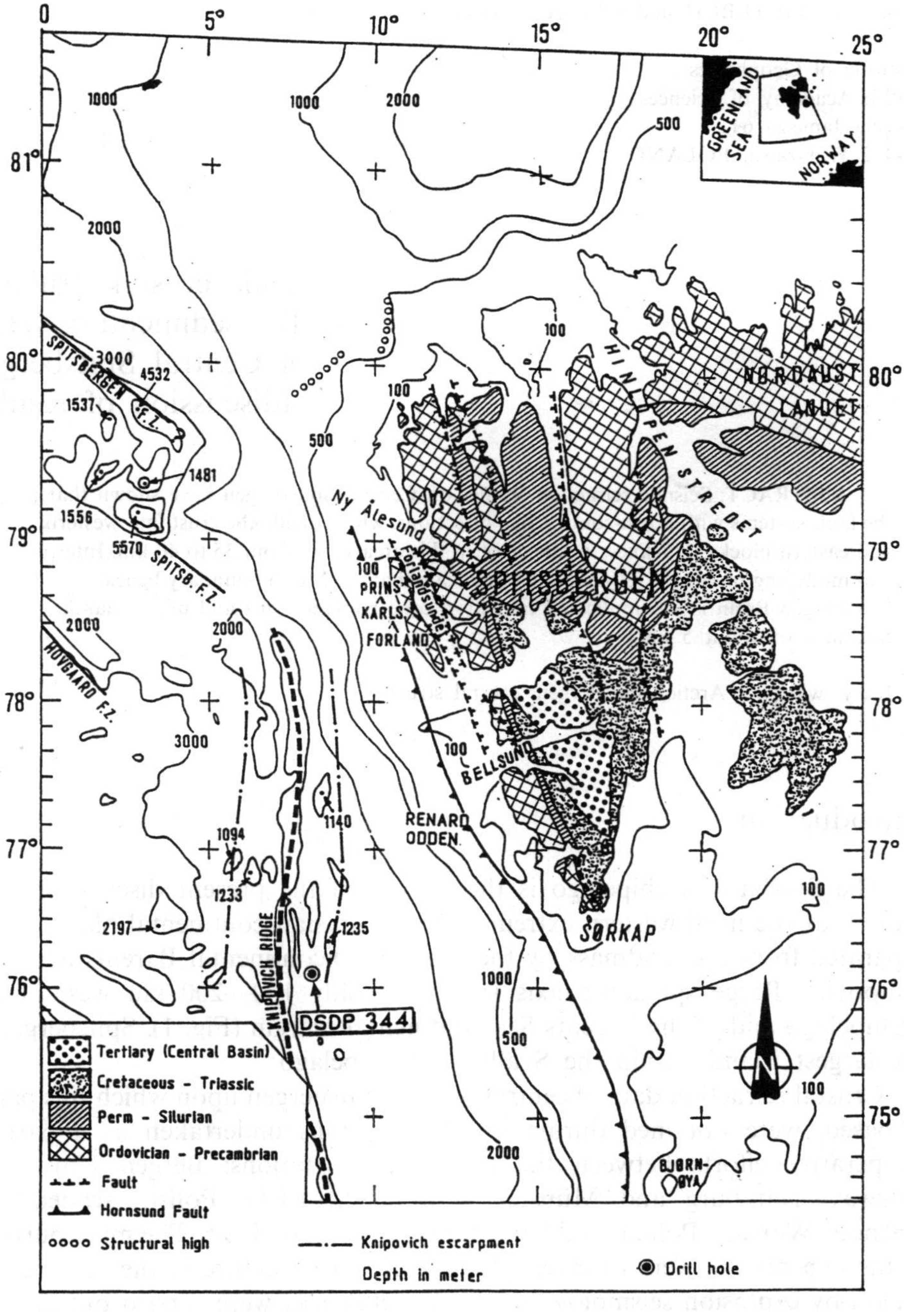

Fig. 1. Main geological features of the Svalbard region (*after* Sudvor *et al.* 1982)
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Area of investigation

Spitsbergen being the largest island within the Svalbard Archipelago, is composed of sedimentary, igneous and metamorphic rocks of Precambrian to Cenozoic age (Fig. 1). The tectonic development of the region is characterized by three major tectonic events.

The first major tectonic phase is related to the Early to Mid Paleozoic Ny Friesland Caledonian Orogenic event (Birkenmajer 1981), a pulse of intense tectonism whose effects are particularly well recognizable in the Eastern Svalbard, and to a lesser extent, in Western Svalbard. In the east the Hecla Hoek geosyncline was deformed and in the west the geosyncline suffered deformation possibly continuing through Silurian. The later Old Red Sandstone succession is a typical late-orogenic sequence formed in response to uplift of the Caledonic belt (Early and Middle Devonian).

The second major tectonic phase occured in the Late Devonian. Is has lately been interpreted in terms of major sinistral transcurrent faulting, during which Eastern Svalbard moved northward at least 200 km, and possibly more than 1000 km, from a position adjacent to the present east of Greenland to a point north of Greenland and near Queen Elisabeth Island. There it joined Western Svalbard which had moved from a lesser distance if it was not already there (Harland and Cutbill 1974).

The third important tectonic element in Svalbard history is of Cenozoic age and tended to reverse the second by dextral transcurrent movement along a zone somewhat west of the Paleozoic line. Accompanying this lateral movement, however, there was also compression and tension deforming the Greenland and Eurasian plates during the Palaeogene West Spitsbergen Orogeny (Harland and Cutbill 1974; Steel *et al.* 1985). During The West Spitsbergen Orogeny a narrow thrust and foldbelt developed along the west coast of Spitsbergen. This crustal shortening led to increased loading along Svalbard's Western margin, and turned the epicontinental, littoral basin of Central Spitsbergen into a rapidly subsiding foreland basin where more than 1.5 km of clastic sediments were accumulated and subsequently gently folded.

Crustal structure

Main seismic refraction profiles in the region of Spitsbergen are shown (Fig. 2). Results from the Isfjorden and Central profiles are discussed in this paper. Travel times branches obtained from phase correlation of seismic refraction sections and crustal section along Isfjorden profile are shown (Fig. 3).

The seismic measurements along Isfjorden have shown that there are two deep and distinct fault systems at distance of 60—70 km and 110 km from the

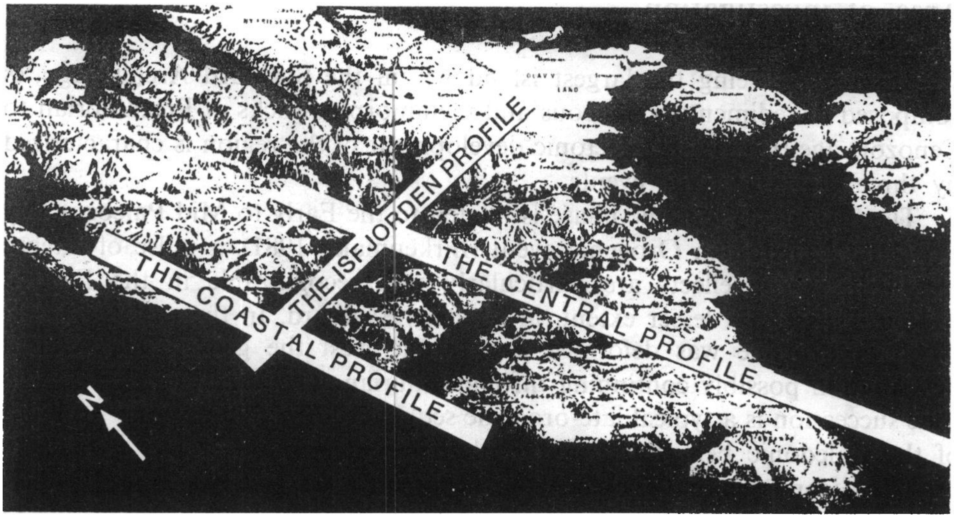

Fig. 2 The seismic profile lines on Spitsbergen

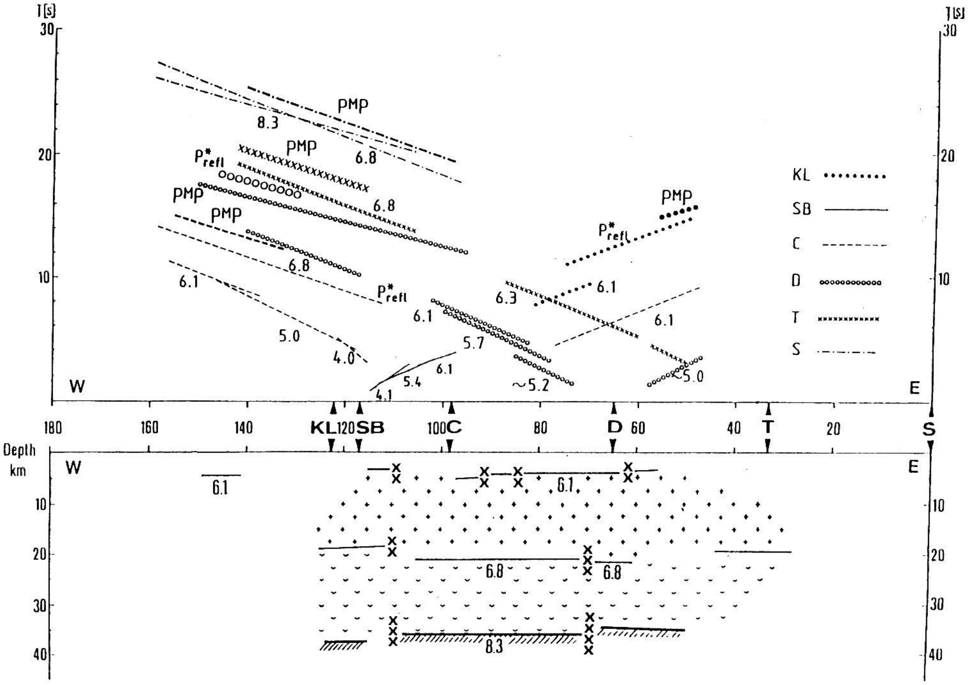

Fig. 3. Travel time branches and the crustal model along the Isfjorden profile; KL — Kapp Linne; SB — sonobuoy; C — Colesbukta; D — Deltaneset; T — Tempelfjorden; S — Svanebergfjellet

seismic station on Svanbergfjellet. These fault systems divide the crust along the profile into three main crustal blocks: a western, central and an eastern block. A consequence of the shots and station locations along Isfjorden is that the structure of the central block is the best known.

The P-wave velocities in the near surface layers vary between 3.8—5.4 km/s. These layers consist mainly of sedimentary rocks of Tertiary and Mesozoic ages. The maximum thickness of the sedimentary sequence is estimated to 5—6 km in the central region of the Tertiary Basin of Spitsbergen (between 85—110 km from Svanbergfjellet). Our observations concerning the depth to the crystalline basement beneath the sedimentary basin are in good agreement with what Nøttvedt (1982) has indicated on the basis of geological investigations.

A refracted wave with an apparent phase velocity of 6.8—7.0 km/s is observed in the seismic sections from the stations in the Isfjorden area. The depth to the corresponding refractor varies between 18—22 km along the profile. This refractor correlates well with the reflection, $P^x_{refl.}$, which also is observed at several stations.

The data which we have obtained from the P_n and P^MP waves indicate that the Moho beneath the Central Sedimentary Basin is a transition zone at a depth of 32 to 37 km. The Moho (the 8.3 km/s refractor) is increasing depth from about 35 km for the eastern crustal block to 37 km for the central and about 40 km for the western crustal block. The eastern and western crustal blocks seem to differ from the central crustal block, concerning average crustal velocities as well as the nature of the crustal-mantle transition. Beneath the eastern and western blocks the Moho discontinuity is, according to our observations, best explained as a first order discontinuity, while a transition zone seems to occur between the crust and upper mantle in the central block region.

Travel times branches and seismic crustal section along the Central profile are shown (Fig. 4). At distances between 100 and 150 km a wave with an apparent velocity of 6.1 km/s is observed in the first arrival. At distances between 160 and 210 km a wave with an apparent velocity of 7.8 km/s is observed in the first arrival and from a distance of about 210 km the refracted wave with the apparent velocity of about 8.3 km/s arrives first. The existence of two refracted waves with apparent velocities close to the velocity of the P-waves at the Moho discontinuity makes the wave pattern highly complex. The determination of which of these waves corresponds to the Moho discontinuity and what is their nature becomes a main problem. An additional difficulty concerning the kinematic interpretation is the complicated relation of the fixed stations and mobile shot points.

Numerous reflected waves with distinct amplitudes are recorded as consecutive arrivals. The wave marked $P^x_{refl.}$, is reflected from a discontinuity within the crystalline crust. The onsets corresponding to this wave have been correlated at distances between 100 and 170 km. The wave reflected from

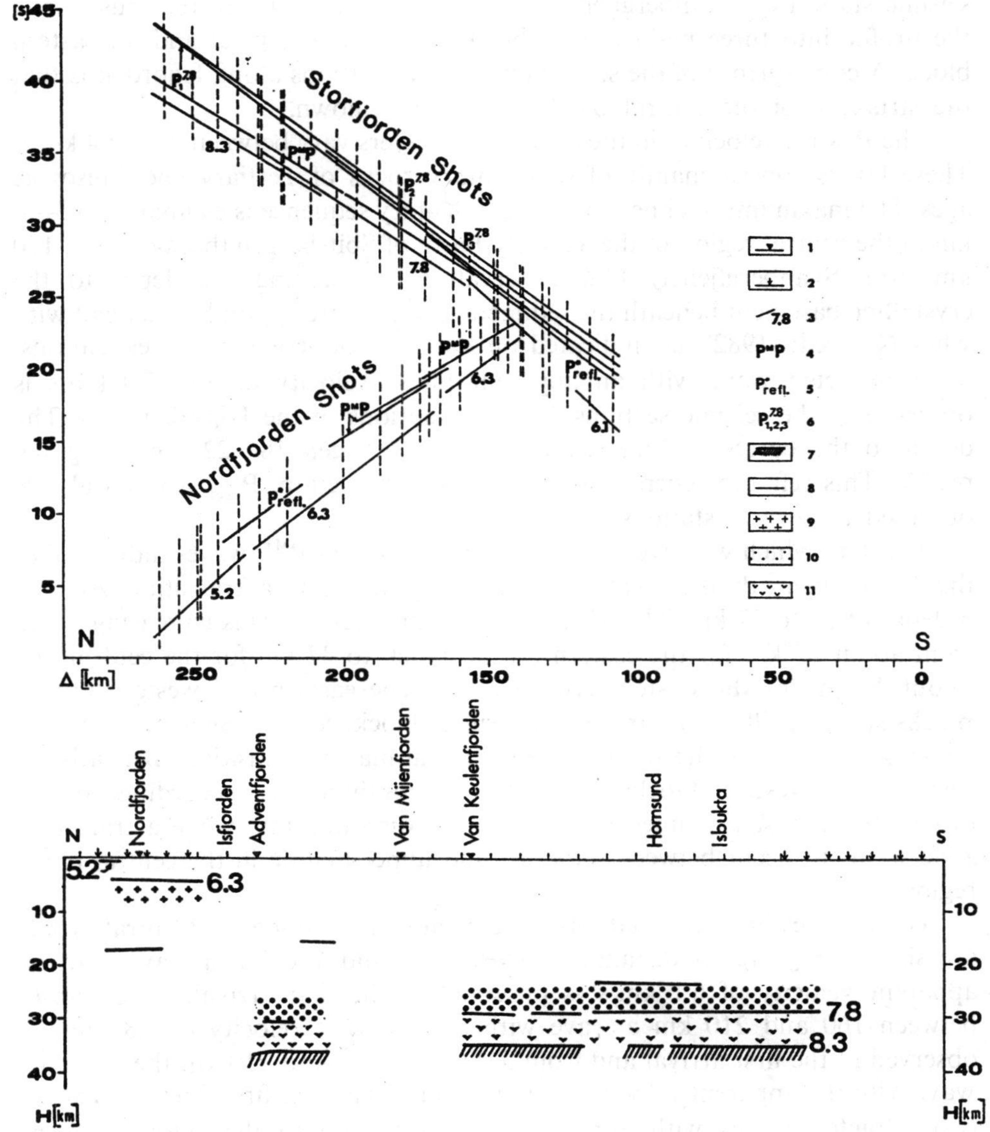

Fig. 4. Travel time branches of shots at Stordfjorden and Nordfjorden, along the Central profile and the corresponding crustal model. The distances are measured from the center of the Storfjorden shots (*see* Fig. 2). 1 — land stations; 2 — shot points; 3 — refraction boundaries; 4 — reflection from the Moho discontinuity; 5 — reflection from discontinuity in the middle of the crust; 6 — multiple reflections in the 7.8 km/s layer; 7 — Moho discontinuity; 8 — reflection boundaries; 9 — „granitic layer"; 10 — „basaltic layer"; 11 — crust-upper mantle transition zone

discontinuity 7.8 km/s $(P_1{}^{7.8}{}_{\mathrm{refl.}})$ was observed along the whole distance range of the profile from 100 to 270 km. This wave is characterized by very strong amplitudes. The depth to the boundary corresponding to this wave is in good agreement with that determined from refracted waves.

A reflected wave from the „8.3 km/s discontinuity" was correlated at distances between 155 and 270 km. This wave is interpreted as P^MP and the amplitude is distinctly smaller than that for the $P_1{}^{7.8}{}_{\mathrm{refl.}}$ wave. The correlation of P^MP wave is difficult especially at distances shorter than about 155 km because of the interference with the other waves. The depth of the Moho discontinuity found from the P^MP waves is in good agreement with the depth found from the P_n refracted wave (8.3 km/s).

The travel times of reflected waves $P^{7.8}{}_{\mathrm{refl.}}$ and P^MP and refracted wave $P^{7.8}$ and P_n form a typical kinematic system with distinct separated arrivals. The arrival times of these waves are clearly different, especially at greater distances. For example, at a distance of about 240 km the difference in arrival time between the P_n and P^MP wave is only about 1 s, while the difference between P_n and all three of the $P^{7.8}{}_{\mathrm{refl.}}$ waves is more than 4.5 s. These time differences made it possible to correlate all of the described waves. Model of the crust for the Central profile is shown (Fig. 5).

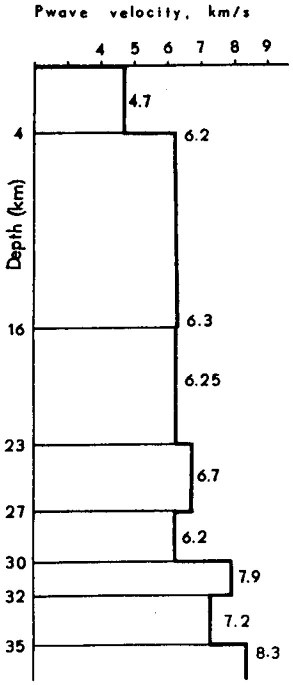

Fig. 5. Seismic model of the crust for the central part of Spitsbergen

The pattern of the S waves along the central profile is almost identical with the pattern of the described P waves. At distances between 100 and 150 km the S waves are recorded as the first arrivals. A refracted S-wave with an apparent velocity 4.4 km/s is observed. This wave corresponds to the $P^{7.8}$ wave and is denoted $S^{7.8}$. The S_n wave with apparent velocity 4.8 km/s is observed. Reflected waves, marked $S^{7.8}{}_{refl.}$ and S^MS in analogy to P waves, were correlated as the consecutive arrivals.

The depth of the „7.8 km/s seismic discontinuity" is about 30 km, changing slightly along the profile. Similarly, the depth of the „8.3 km/s discontinuity" changes also slightly and it is about 35 km. This discontinuity is denoted as the Moho boundary. The depth of the other seismic boundaries found within the crystalline crust, changes from 18 to 25 km.

Conclusions

The Isfjorden profile is characterized by two deep and distinct fault systems at distances of 65 km and 110 km respectively from Svanbergfjellet (Fig. 3). The fault systems with north-south strike directions divide the crust into the western, central and eastern block. Fig. 6 shows a schematic crustal section as well as the Moho-depths and main faults between the Hornsund fault in the West and Svanbergfjellet in the East. The central block differs from the neighbouring blocks with respect to the average crustal velocities as well as to the nature of the transition zone between the crust and upper mantle. Depth of the Moho discontinuity increases successively from about 35 km in the eastern block to about 40 km beneath the western block.

Both P- and S- waves have been used for modelling the crustal structure along the Central profile (Guterch *et al.* 1982). A rather complex structure of the transition zone between the crust and upper mantle is observed along the profile line. The most characteristic element of the crustal section and the

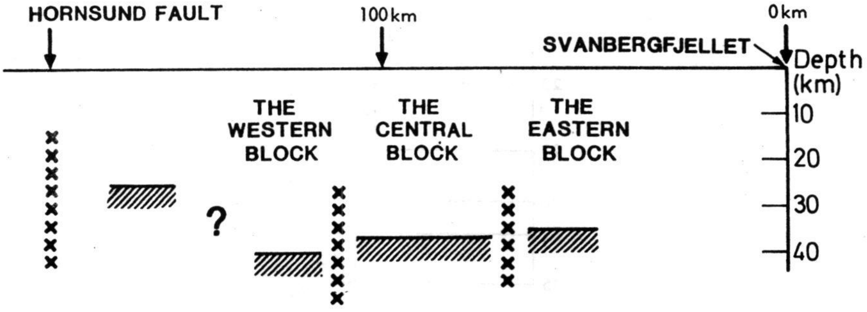

Fig. 6. Schematic crustal block section indicating the Moho-depths and main faults between the Hornsund fauld in the west and Svanbergfjellet in the east

crustal model from the southern part of the Central profile are two distinct seismic discontinuities with velocities of about 7.8 and 8.3 km/s, occurring at the basement of the crust. These discontinuities determine exactly the upper and lower boundaries of the transition zone between the crust and upper mantle. As evidenced by the form of the seismic signals, the shallower one of the two discontinuities is sharp, while the deeper one is of layered-diffuse type.

The structure at the base of the crust, which was found in the area of the sedimentary basin of Central Spitsbergen is very similar to structure of the aulacogene type. The structure of aulacogene type represents the old stage of a rift system, accompanied by high heat flow. The termal activity observed in the inner part of Woodfjorden and to the very south of Spitsbergen appears to confirm this hypothesis.

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Streszczenie

W pracy dyskutowane są wyniki badań głębokiej struktury skorupy ziemskiej wykonane na obszarze centalnego basenu osadowego Spitsbergenu Zachodniego (fig. 1—2). Miąższość skorupy ziemskiej w rejonie bloku centralnego, odpowiadającego centralnemu basenowi osadowemu, wynosi około 36—37 km (fig. 3—4). W podłożu skorupy ziemskiej tego obszaru, w rejonie nieciągłości Moho, występuje skomplikowana strefa przejścia między skorupą i górnym płaszczem o miąższości około 5 km. Strefa ta jest przedmiotem modelowania sejsmicznego i dyskusji wyników (fig. 5). Blokowy charakter budowy skorupy ziemskiej Spitsbergenu Zachodniego został przedstawiony schematycznie (fig. 6).