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# Geophysical investigations of the thickness of the ice and basement of the Hans Glacier in the area of the Hornsund Fiord in Spitsbergen

ABSTRACT: This paper discusses the results of gravimetric and magnetic investigations carried out on the Hans Glacier (Hansbreen) in the area of the Hornsund Fiord in Spitsbergen. These pilot investigations were performed in profiles running across to the extension of the glacier.

Analysis of the magnetic measurements permits the supposition that in the base of the glacier there are amphibolites assigned to the Skålfjellet series, one of the oldest links of the metamorphic complex in Spitsbergen. Fig. 3 shows the behaviour of the amphibolites determined from the qualitative and quantitative properties of the anomalies $\Delta T$.

This paper also determined the thickness of the glacier in a cross-section 1.5 km distant from its front. From interpretation of the gravity anomaly, thickness varies between several and more than 100 m, taking the highest values in the central part of the glacier.

Key words: Aretic, geophysical investigation, Spitsbergen

## 1. Introduction

For a number of years the Hans Glacier has been the object of numerous glaciological observations, but, despite this, relatively little is known of its thickness and the morphology of the basement. Such investigations were begun only recently, during a successive summer polar expedition to Spitsbergen in 1979. They were performed using several methods of prospective geophysics including the geoelektrical method (K. Żakowicz, and the radar one R. Czajkowski) at the front of the glacier where there is a net of reference points for the observation of the dynamics of the ablation processes and the horizontal motion of the glacier.

The investigations reported on in this paper were performed by the gravimetric and magnetic methods at the front of the glacier, between the Fugleberget and the Fannytoppen. Fig. 1 shows schematically the range of this region.

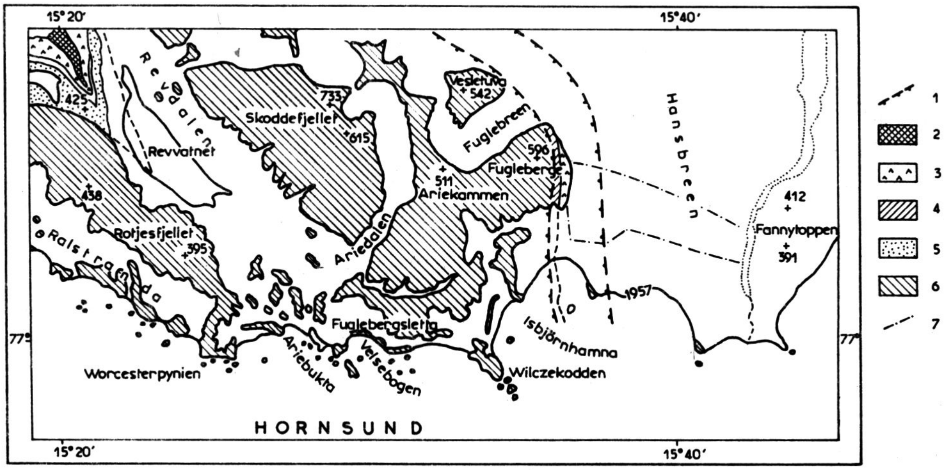


Fig. 1. Part of a geological plan of the northwestern boundary of the Hornsund Fiord. 1:50000 scale (according to Birkenmajer in Birkenmajer K., Narębski W., 1960) 1—overthrusts; 2—Gangpasset granitization zone; 3—Torbjörnsenfjellet amphibolites; 4—Steinvikskardet beds; 5—Gulliksenfjellet series; 6—Isbjörnhamna formation (not subdivided); 7—boundary of the area of the geophysical investigations

In the area of the geophysical investigations the basement of the glacier is built of strongly metamorphic Precambrian rocks. At the western boundary of the glacial valley the Precambrian rocks are mainly represented by quartizite and amphibolite series of the Eimfjellet Formation (K. Birkenmajer, W. Narębski, 1960). In the part where the glacier lies at the foot of the Fugleberget, this formation is represented, by the Skålfjellet series within which there occur Torbornsenfjellet amphibolites and Steinvikskardet beds. The amphibolite link is also known from a small peninsula near the front of the glacier. The rocks of the amphibolite "facies" in both parts enter under the glacier where their farther bahaviour has not been known to date.

According to a more recent paper of Birkenmajer (cf. K. Birkenmajer 1978; Fig. 2), the eastern boundary of the glacier is also built of Precambrian rocks. In the area of the Fannytoppen they border on the Precambrian Sofiekammen Formation. The zone of this contact, however, lies in fact outside the area of our investigations.

In the geophysical investigations the aim was to determine the thickness of the glacier and the heterogeneity degree of its basement particularly the bahaviour of the amphibolite complex under the glacier, with measurements taken at profiles across to the direction of its extension. This was not always fully possible, in view of the well developed system of cracks on its surface. For this reason, the first two magnetic profiles, A–A and B–B, do not cut across the glacier, reaching only about 0.3 of its width.

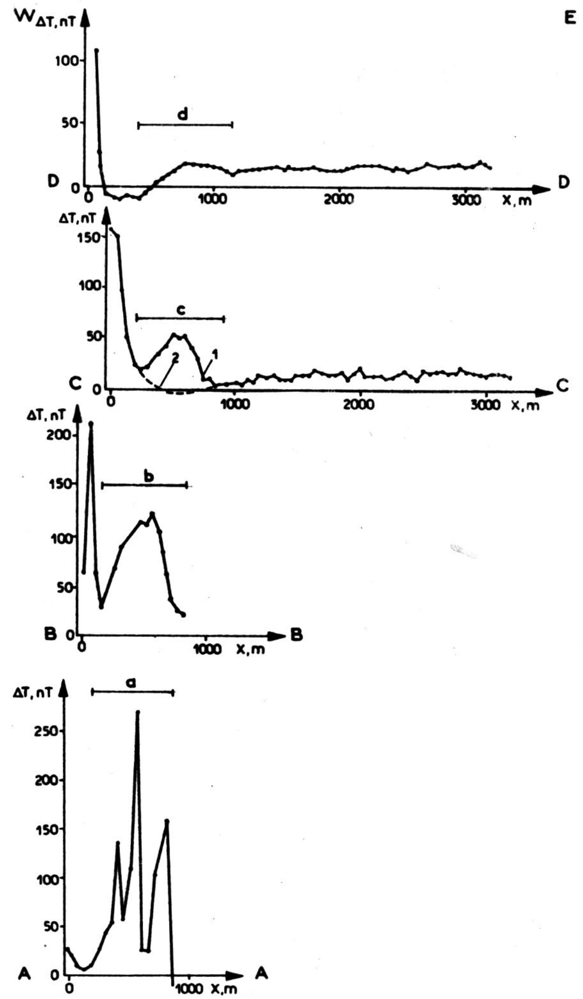


Fig. 2. The magnetic anomalies $\Delta T$ on the Hans Glacier
1—the measured values; 2—the approximated part

## 2. Magnetic investigations of the structure of the basement of the glacier

The magnetic measurements on the glacier were carried out by the method of synchronized observations with proton magnetometers, which was described in another paper of the present authors ("The method of magnetic investigations...", Polish Polar Research, no. 4). They were carried out along four profiles, marked with the indices A,B,C and D in Fig. 3.

The intervals between the profiles and their lengths are variable and depend on the topographic properties of the surface of the glacier mentioned above, whereas for all profiles the measurement step is constant, i.e. 50 m. At all measurement posts observations were repeated twenty times. Fig. 2 shows the anomalies $\Delta T$ calculated from these measurements. The anomalies were determined with error not exceeding 2 nT.

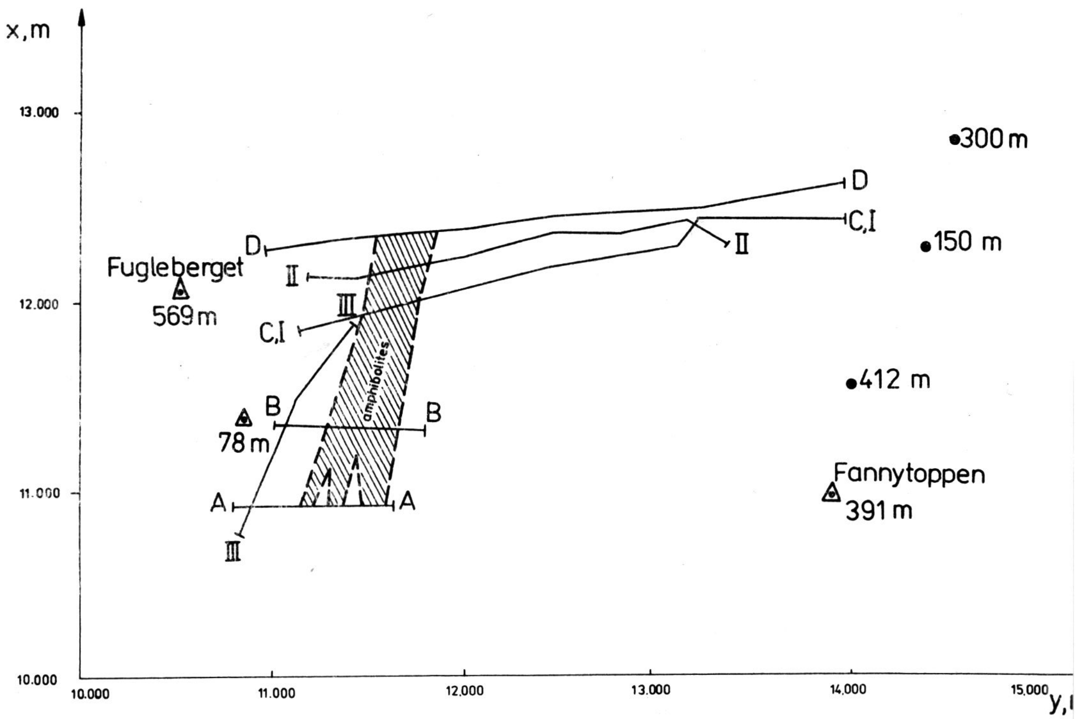


Fig. 3. Interpretation of the behaviour of the amphibolites under the glacier

In qualitative analysis of the magnetic measurements attention will be drawn to the possibility of there being a direct relation between the anomaly and the magnetic properlies of the amphibolites. Such a relation can be observed directly in the outcrop zones of these rocks where they are accompanied by positive anomalies with much larger amplitudes than those for the surrounding rocks. The strong magnetic properties of the amphibolites are related to their formation in the Hornsund area, according to Birkenmajer (op. cit.), as a result of long-term metamorphic processes, from originally alkaline rocks of basalt or diabase type. However, granitization processes occurred here in several phases and, depending on the degree of its advancement, the petrological and magnetic properties of the amphibolites vary. Therefore, in some cases, within the outcrops of rocks of this facies the amplitude of the anomaly can vary over a wide range of values from dozen-odd to several hundred ΔT. This is indicated by the measurements in the Baranowski peninsula, for example.

In the profile A–A, which as a whole lies outside the range of the front glacier and cuts across the penisula mentioned above, anomalies originate from petrological mhomogeneites in the complex of metamorphic rocks. In addition to fineand coarse-grained amphibolites, there are here (W. Smulikowski, 1965) also "porphyrylike" amphibolites and chlorite slates. Under the principle of extrapolation, the relationship which was found to exist here served to determine the behaviour of the amphibolites under the glacier.

For this purpose, at all profiles (Fig. 2), the relevant sections a,b,c, and d, in which the field has outstanding correlative properties, were determined. When they are compared with one another, it appears that the characteristic feature of this distribution is the gradual homogenization of the shape of the anomaly and the decay of its amplitude as the distance from the front of the glacier and its thickness increase.

In the profile B–B, of which only the initial part is outside the area of the glacier, in the correlated zone b with length comparable to a, the anomaly smooths out almost fully, whereas its amplitude decreases to about 100 nT. This change is related to the submersion of the source, which is probably heterogeneous, as in the profile A–A.

The tendencies suggested in the first two profiles are confirmed in the profiles C–C and D–D. The initial sections of these profiles, which are about 1,5 and 2.0 km distant from the front of the glacier, are within the active range of the exposed part of the Tornbjornsenfjellet amphibolites in the eastern slope of the Fugleberget. In turn, in sections c and d of interest, the amplitude of the anomaly decreases steadily to about 50 and 15 nT. In this zone the thickness of the glacier can reach about 100 m.

Beyond the zone of the anomalies discussed above, in these profiles the field varies slightly. From the 1.2 km point to the end of the measurement sequence, the curve of ΔT for the profile D–D is almost flat. In the light of the assumed interpretation model this may signify that the range of the amphibolite complex in the basement of the glacier ends with this zone, which reaches at most 1 km east of the foot of the Fugleberget.

On this basis of the above correlation, Fig. 3 shows the zones which are related to the behaviour of rocks of the amphibolite complex. The horizontal thickness of the "facies" is stable enough, whereas the meridional direction of its behaviour only partly deviates from the hypothetical geological overthrusts determined by K. Birkenmajer (see Fig. 1).

While qualitative interpretation of the magnetic anomalies does not raise any greater objections and proves relatively easy, there are serious difficulties in quantitative interpretation. This is so, since there is either insufficient sampling density, as in the profile A–A, or incomplete behaviour of the peripheral parts of the anomaly, as in the profile B–B. There are no laboratory data on the magnetic properties of amphibolites. Therefore, attempts at qualitative interpretation, irrespective of the ambiguity which is common in such cases, must be accepted with an additional qualification.

It follows from qualitative and quantitative analyses performed by direct methods that in all profiles the horizontal dimensions of the source of the anomaly are contained in the range 300–350 m. When evaluated under this principle, the depth to the ceiling of the body in the profile B–B is 50 m and 75 m in the profile C–C. In the profile C–C, where relatively best conditions exist for quantitative interpretation, verifying modelling was carried out by the method of selection.

On the basis of graphic estimation, in the section c the summary measurement effect was divided according to the principle in Fig. 2 and the body in the form of a vertical infinite layer was subordinated to the residual part. This model agrees with geological observations, whereas its vertical magnetization is justified by the meridional extension of the source of the anomaly.

Fig. 4 shows the modelling conditions. When it is assumed that the interpreted layer occurs directly in the ceiling of the rocks in the basement of the glacier, the determined depth to its ceiling is a direct reflection of its thickness.

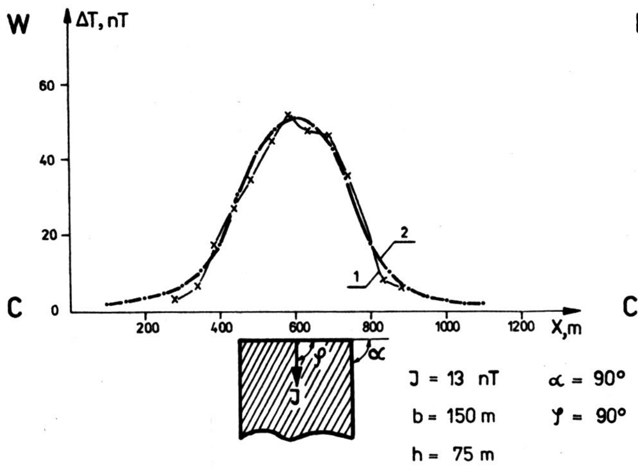


Fig. 4. Quantitative interpretation of the anomalies ΔT in the profile C–C
1—the measurement curve; 2—the theoretical distribution

## 3. Interpretation of the thickness of the glacier from the distribution of the gravity anomaly

Gravity measurements on the glacier were taken along the three profiles which are marked with numbers I–III in Fig. 3. They were carried out using a Worden gravimeter by the method of indirect points, according to the following pattern: $p_0p_i...p_ip_0$. There were 50 m intervals between measurement points on the profile and the time of reference to base points ($p_0$) did not exceed 2 hours. These measurements were reduced to the mean level of the morphology of the glacier. The reduction used the local geodetic net and precision altitude levelling which was performed by Dr. Eng. W. Mizerski for the purposes of these measurements.

This paper presents only the results of interpretation of measurements in profile I. Since these also include magnetic, radar and geoelectrical measurements, this is then the most representative profile of geophysical investigations on the glacier. Fig. 5 shows the gravity anomaly distribution along this profile.

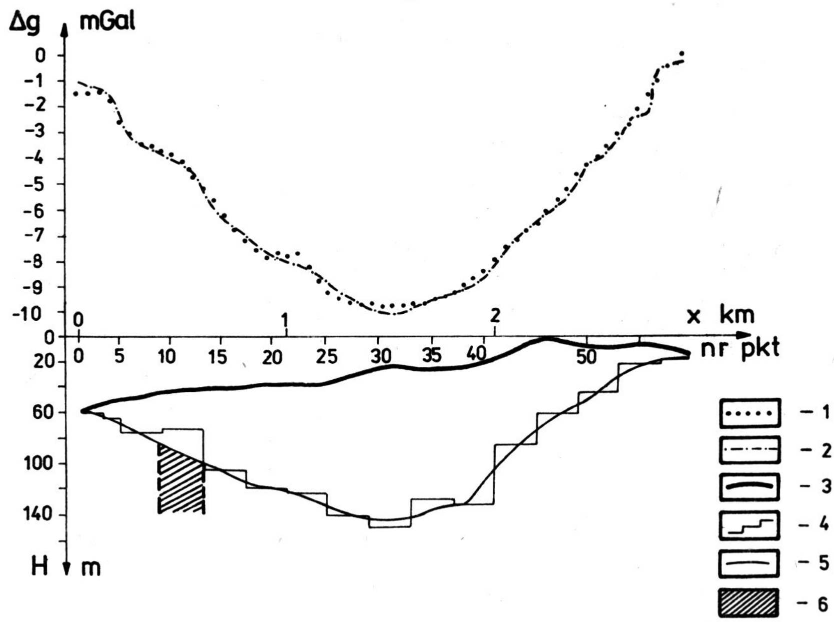


Fig. 5. Interpretation of the gravity anomaly in profile
1—the measurement curve; 2—the theoretical distribution; 3—the ceiling of the glacier; 4—the model of the density distribution boundary; 5—the probable shape of the boundary; 6—a local density change

On the basis of both geological and glaciological premises and the shape of the anomaly itself, a model of twodimensional boundary of density distribution was assumed for interpretation of the gravity distribution in this profile. This boundary occurs at the interface between the rocks of the basement and the glacier. The mean bulk density of the glacier was determined gravimetrically as $0.80 \times 10^3 \text{ kg m}^{-3}$, whereas for the rocks of the base it was assumed to be $2.8 \times 10^3 \text{ kg m}^{-3}$. Thus, the density jump at the interface is very large, i.e. $-2.0 \times 10^3 \text{ kg m}^{-3}$.

The preliminary morphology of this boundary was determined by the known method of direct qualitative interpretation proposed by Lukawchenko. This gave initial data for precision interpretation whose results are presented in Fig. 5.

The boundary gravity effect in the form of a step curve (4), was determined by superposition of the elementary interactions of vertical finite layers. Calculations were carried out by the MINUIT programme, based on minimization procedures. The optimization parameters were the depths $h_i$ to the ceilings of particular layers.

The results of this interpretation indicate that the glacial valley is relatively plain and that the maximum thickness of the glacier in its centre reaches 120 m. It should be stressed, however, that not all elements of the source of anomaly have been represented with equal accuracy. This results from the method of the construction of the model and also from the assumption of the stable density contrast at the boundary. Analysing from this point of view the possible changes in its behaviour, only in one case were the modelling results complemented with qualitative interpretation. In the section where a local change in the gradient of gravimetric anomaly correlates with the magnetic anomaly $\Delta T$, an additional element (6) with density greater than that of the environment was introduced. This element, which has the form of a layer with parameters in agreement with the model of a magnetized body shown in Fig. 4, is marked on curve (5) which illustrates the probable shape of the basement of the glacier.

## 4. Summary

The geophysical research on the glacier was one of positive attempts to use magnetic and gravimetric methods to solve different geological and glaciological problems in Spitsbergen. Despite the greater difficulties related to the performance of measurements and their reduction, the accuracy of these measurements usually does not differ from the results obtained in other regions.

On the basis of the magnetic investigations, partly confirmed by the gravimetric results, the behaviour of the amphibolite rocks under the glacier was determined. These are probably Torbjornsenfjellet amphibolites, which Birkenmajer described (op. cit.) and which, in our interpretation, should be the easternmost part of the amphibolite complex of the Precambrian Eimfjellet Formation.

In addition to amphibolites, in the basement of the glacier there are also probably quartizites, slates and marbles. This strongly metamorphic complex is, however, so homogeneous in a geophysical sense (magnetization, density) that it is not reflected in measurements on the glacier in the form of separate, clearly distinct anomalies. In view of this, it was possible to use in interpretation of the gravity distribution the model of the boundary of density distribution. It seems that, despite some necessary simplifications this model describes well enough the form of the glacial valley and the thickness of the glacier.

## 5. Резюме

Обсуждаются результаты гравиметрических и магнетических исследований, проведенных на леднике (Гансбреен) в районе фиорда Горн зунд на Шпицбергене. Исследования носили разведывательный характер и были проведены на профилях перпендикулярных к леднику. Анализ магнетических измерений позволяет седелать предположение, что в основании ледника залегают амфиболитовые породы, относимые к свите Скальфьеллет, одному из найболее древних звеньев метаморфического комплекса на Шпицбергене. Простирание амфиболитов установлено (фиг. 3) на основании качественных и количественных черт аномалии $\Delta T$. Была определена также мощность ледника в поперечном разрезе на расстоянии около 1,5 км от края. Мощность эта, как следует из интерпретации аномалии силы тяготения, колеблется в границах от нескольких до свыше 100 м, приобретая найбольшие величины в центральной части ледника.

## 6. Streszczenie

W pracy omówiono wyniki grawimetrycznych i magnetycznych badań na lodowcu Hansa (Hansbreen) w rejonie fiordu Hornsund na Spitsbergenie. Badania miały charakter prac rekonesansowych, które wykonano na profilach usytuowanych prostopadle do rozciągłości lodowca. Analiza pomiarów magnetycznych pozwala przypuszczać, że w podłożu lodowca występują amfibolitowe utwory zaliczane do serii Skålfjellet, stanowiącej jedno z najstarszych ogniw kompleksu metamorficznego na Spitsbergenie. Przebieg amfibolitów wyznaczony został na Fig. 3 w oparciu o jakościowe i ilościowe cechy anomalii $\Delta T$. W pracy określona została również miąższość lodowca w przekroju poprzecznym, oddalonym od jego czoła o około 1,5 km. Miąższość ta, na podstawie interpretacji anomalii siły ciężjości, zmienia się w granicach od kilku do ponad 100 m, przyjmując wartości największe w środkowej części lodowca.

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