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AIRBORNE RADIO - GLACIOLOGICAL INVESTIGATIONS DURING THE 1969 BELGIAN ANTARCTIC EXPEDITION

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ABSTRACT. The 1969 Belgian Antarctic Expedition carried out a detailed airborne radio echo sounder survey of the Jelbartisen - Trolltunga area in Western Dronning Maud Land.
Ice thickness determinations by radio echo sounding, the equipment, the methods of navigation, the measurements of the velocity of propagation of radio waves in ice, the computation of the thickness and the precision of the survey are discussed.
The survey covers two ice shelves separated and limited by several ice rises, the marginal part of a major ice stream, and the junction with the inland ice sheet.
A map showing equal ice thickness contours, glacier cross profiles and examples of the obtained records are used to illustrate the relationship between the different morphological units, the ice thickness and the characteristics of the reflecting interfaces.

RÉSUMÉ. L'Expédition Antarctique Belge 1969 a effectué un lever aérien par radio écho sondage de la région Jelbartisen-Trolltunga dans le Dronning Maud Land Occidental.
Les déterminations des épaisseurs de glaces par radio echo sondage, les méthodes de navigation, les mesures de la vitesse de propagation des ondes électromagnétiques dans la glace, le calcul des épaisseurs et la précision du lever font l'objet du présent rapport.
Le lever couvre deux ice shelves séparés et limités par différents ice rises, la partie marginale d'un important fleuve de glace et la jonction avec le glacis continental.
Une carte des iso-épaisseurs de glace, des coupes à travers le glacier et des exemples des enregistrements obtenus illustrent les relations entre les différentes unités morphologiques, les épaisseurs de glace et les caractéristiques des interfaces réflectrices.

1. *Introduction*

The 1969 summer expedition was organized by the "Comité Antarctique Belge" (chairman: G. DE GERLACHE) in logistic collaboration with the South African Antarctic Expeditions (leader 1969: H. FULTON).

The Belgian expedition (leader: T. VAN AUTENBOER) consisted of eight members: one geologist, one geophysicist, two electronic technicians and four aircrew.

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The original programme adopted by the "Commission Scientifique" (chairman: P. BOURGEOIS) had to be modified and curtailed due to the mechanical failure of the bigger of the two aircraft of the expedition (one DHC3 Otter, one Cessna 180). This failure limited the radio echo sounder survey geographically to a smaller area around the base camp where oversnow transport could be relied upon for possible rescue operations. The use of the smaller Cessna further reduced the navigational equipment available on the flights, the number of personnel on board for the visual observations, and it affected the echo-strength of the radio signal.

The modified project enabled however a detailed ice thickness survey of an ice shelf and surrounding areas to be made. This survey was carried out in February 1969. Practically continuous records were obtained over some 1,500 km of flight lines and cover an area of some 6,000 km^2.

The techniques used in this survey and the preliminary results will be discussed here.

2. *Ice thickness determinations*

Before the International Geophysical Year (1957-58) little was known of the structure of Antarctica and even less of the ice sheet which covers 99 % of this continent. Following the example of the 1949-51 Norwegian-British-Swedish Expedition most expeditions since the I.G.Y. introduced studies of the ice-cover and determinations of the subglacial relief as a major item in their programme. These surveys are based upon seismic and gravimetric measurements and more recently on radio echo soundings. Considerable scientific and logistic effort is directed towards this fundamental aspect. A spectacular contribution was made by teams from the University of Wisconsin (C. BENTLEY, J. BEHRENDT, E. ROBINSON, E. THIEL and others). Supported by the National Science Foundation (USARP), they accomplished a long term programme of large scale oversnow traverses which enabled a first overall picture to be formed of the largest ice sheet that persists on earth.

Belgium included some ice thickness measurements in its more restricted operations. A 200 km seismic profile was determined between Base Roi Baudouin and the Sør-Rondane mountains to the south (DIETERLÉ and PETERSCHMITT, 1964). In the Sør-Rondane, gravimetric ice thickness determinations were combined with velocity measurements to calculate the discharge of the major plateau drainage glaciers. (VAN AUTENBOER and BLAIKLOCK, 1966; VAN AUTENBOER and H. DECLEIR, in preparation).

Seismic measurements require very costly and heavy equipment and lengthy preparation, including ice drilling. Interpretation of seismograms is difficult and some of the earlier results now appear doubtful (WOOLLARD, 1962).

Gravimeter techniques are less elaborate. However the interpretation of the observed anomaly requires accurate determinations of the height differences. It is based upon the density contrast between ice and rock used in the replacement of a slab of rock extending infinitely at right angles to the profile, by an identical slab of ice. It is therefore impossible to eliminate local geological anomalies, or to interpret local subglacial topographic irregularities which will be smoothed out over the profile.

Interpretation of the subglacial profiles by both techniques is based upon the interpolation between spot readings sometimes 50 km apart. Their major inconvenience is the dependance upon oversnow mechanical transport that under antarctic conditions remains very slow, often dangerous and requires major and expensive logistic support.

With the introduction of airborne radio echo sounding techniques, discussed below, glaciology has now a new and modern tool. Its major advantages are speed, range, safety, independance of terrain, economy, and last but not least the possibility of obtaining a continuous record. This allows even minor irregularities of the glacier profile to be registered and even weak and discontinuous echoes can be safely interpreted within the general pattern of the profile.

Such surveys now fall within the scope of the Belgian antarctic possibilities.

3. *Radio echo sounding*

3.1 Principles

Radio waves propagating in a dielectric medium are reflected on surfaces with different electromagnetic properties.

The use of radio altimeters in aircraft flying over ice sheets drew attention to the transparency of ice for radio waves and to the possibility — occasionally with catastrophic consequences for the airplane — of obtaining reflections at the ice-bedrock interface.

The use of these properties for measuring ice thicknesses was first suggested by American investigators. In 1957, A.H. WAITE conducted the first experiments in Antarctica using a standard SCR 718 radio altimeter operating on 440 MHz. The study of interference phenomena observed in records of ionosondes of ice shelf stations led to the same conclusion. This was further investigated by Evans (1961) who was responsible for the development at the Scott Polar Research Institute (England) of a 35 MHz radio echo sounder. At that frequency, absorption of radio waves is reduced and interference with ionospheric echoes is avoided (EVANS, 1963). Several field trials improved the instrumentation sufficiently to be used on a large scale during 1967 in a joint USA-UK Antarctic project. EVANS (1963 and 1966) gives a historic review of the development of radio echo sounding.

In practice the measurements consist of the determination of the time intervals between reflections at the air-glacier and at the glacier bedrock or glacier-sea interface. The ice thickness can then be computed by multiplying this time interval by the velocity of the radio waves in the glacier concerned.

3.2 Radio Echo Sounder

The Belgian Expedition used the 35 MHz S.P.R.I. MK II echo sounder (EVANS and SMITH, 1969) manufactured by Randall Electronics (HARPENDEN, England). It consists essentially of four units.

1) A crystal controlled pulse modulated 35 MHz transmitter with a pulse duration of 0,3 μsec and a pulse repetition interval of 64 μsec. Peak power is 500 watts.

2) A 35 MHz receiving unit. The receiver is suppressed during transmission. The duration of the suppression signal can be regulated so as to include the transmission pulse as the origin of the time scale. A manually operated attenuator allows for optimum reception of the signals, which vary widely in strength.

3) Monitoring and recording system. The receiver is coupled to two oscilloscopes (Tektronix 321 A), the first one displays the amplitude modulation and allows the operator to control the signal for optimum reception. The second displays the Z modulation or intensity. The cathode ray tube of this oscilloscope is continuously photographed by a modified 35 mm Shackmann camera. The camera speed can be modified thereby allowing the horizontal scale to be adapted to the speed with which the time interval between the two reflections (or the ice thickness) varies.

4) Timing unit. An electrical clock controls at one minute intervals the interruption of the receiver. This provides a time mark on the horizontal — or time-distance — scale of the record. The calibration marks generated by the crystal-controlled timing circuits of the transmitter are registered during this interruption. They provide a calibration of the vertical — or time interval - ice depth — scale of the film.

The equipment was originally installed in the Otter aircraft and operated from an additional battery. Two special, 1 m long, pylons mounted under the wing tips supported the folded dipole antenna and kept it away from the metallic mass of the wings. The same aerial served both receiver and transmitter. After the failure of the Otter, the same apparatus was fitted in the much smaller Cessna aircraft. This, as far as the operation of the sounder was concerned, caused a loss of 15 dB on the echo strength and much discomfort to the operator.

3.3 Determinations of the velocity of radio waves

The propagation of radio waves in ice is known to depend on the glaciological conditions (density and temperature distribution, impurities, stresses...). Velocity determinations in the area surveyed were therefore required. They were carried out on a line to the N-E of the base camp where the records already obtained, proved the ice thickness (h) and surface relief to be constant. Transmitter and receiver were separated and the time (t) necessary for the reflected signals to travel between the two instruments was obtained from the oscilloscope readings. The distance (d) between stations was measured by tellurometer.

Sixteen stations on a 2.5 km profile were occupied with the transmitter in a fixed position at one extremity and the receiver travelling along the profile. A second series of measurements was obtained with the position of the instruments reversed and the transmitter travelling along the line.

Simple geometrical considerations lead to the following equations in which v is the velocity in ice.

$$t^2 = \frac{d^2}{v^2} + \frac{4h^2}{v^2} \text{ for a single reflection}$$

$$t^2 = \frac{d^2}{v^2} + \frac{16h^2}{v^2} \text{ for a double reflection}$$

Plotting t^2 versus d^2 and fitting a straight line through the points we obtain the velocity from the slope $\frac{1}{v^2}$ of this line.

The linear correlation for the double reflection is better apparently because of stronger refraction affecting the path of the single reflection. The velocity used in this survey is therefore based upon the double reflection values and equals 175 $\pm$ 1 mμsec^{-1}.

4. *Navigation*

The location and altitude determination of the flight lines proved to be the more difficult part of the survey. A 1962 shipboard radar map of the coastline was found to be insufficiently accurate. Inland the smooth ice shelf provides few points identifiable from the air and even identification of points along the coast is not easy.

The use of a much smaller aircraft did not allow the use of the radio altimeter, the S.F.I.M. flight recorder and the navigational camera. An additional problem was the magnetic compass which proved less reliable for absolute readings than the gyrosynchronised Otter compass.

A satisfactory solution was found by basing all flights on three base lines of known azimuth and length (determinations: E. Bosmans). The well marked extremities of the base lines were intervisible from the aircraft.

Before each glaciological flight the airplane flew over one of the lines, at the height and in the direction of the planned flight.

The flying time between the two markers allowed a calculation of the ground speed. The compass heading on the reference flight was repeated on the glaciological flight thereby correcting for drift. The starting point of the glaciological flights were, whenever possible, points which could be identified from the air (a point of the coast line or markers placed by oversnow parties).

The return flight took place along the same track and the error estimated with regard to the point of departure allowed a supplementary correction to be made.

During February 1969, mv RSA carried out a radar coast line survey (McNish, personal communication). In addition handheld air photographs were taken of the coast and a few navigational flights — on the same principle as the glaciological flights — were carried out. All these data were combined to provide a new coast line map, which was then adapted to the grid survey based upon the reference lines and astronomical position of Sanae. Some barometric height determinations in the area surveyed were provided by Neethling (personal communication) and some were obtained from Norwegian reports and maps.

An indication of the height of the glacier surface can also be obtained from the radio echo sounder. The aircraft is kept at a constant barometric level indicated by the aneroïd altimeter (in general 4,000 ft). Height of the glacier surface can then be calculated as the difference between the aneroïd barometer reading and the height of the aircraft obtained from the echo sounder.

5. *Precision of the survey*

5.1 Evans (1966) compares radio echo sound-

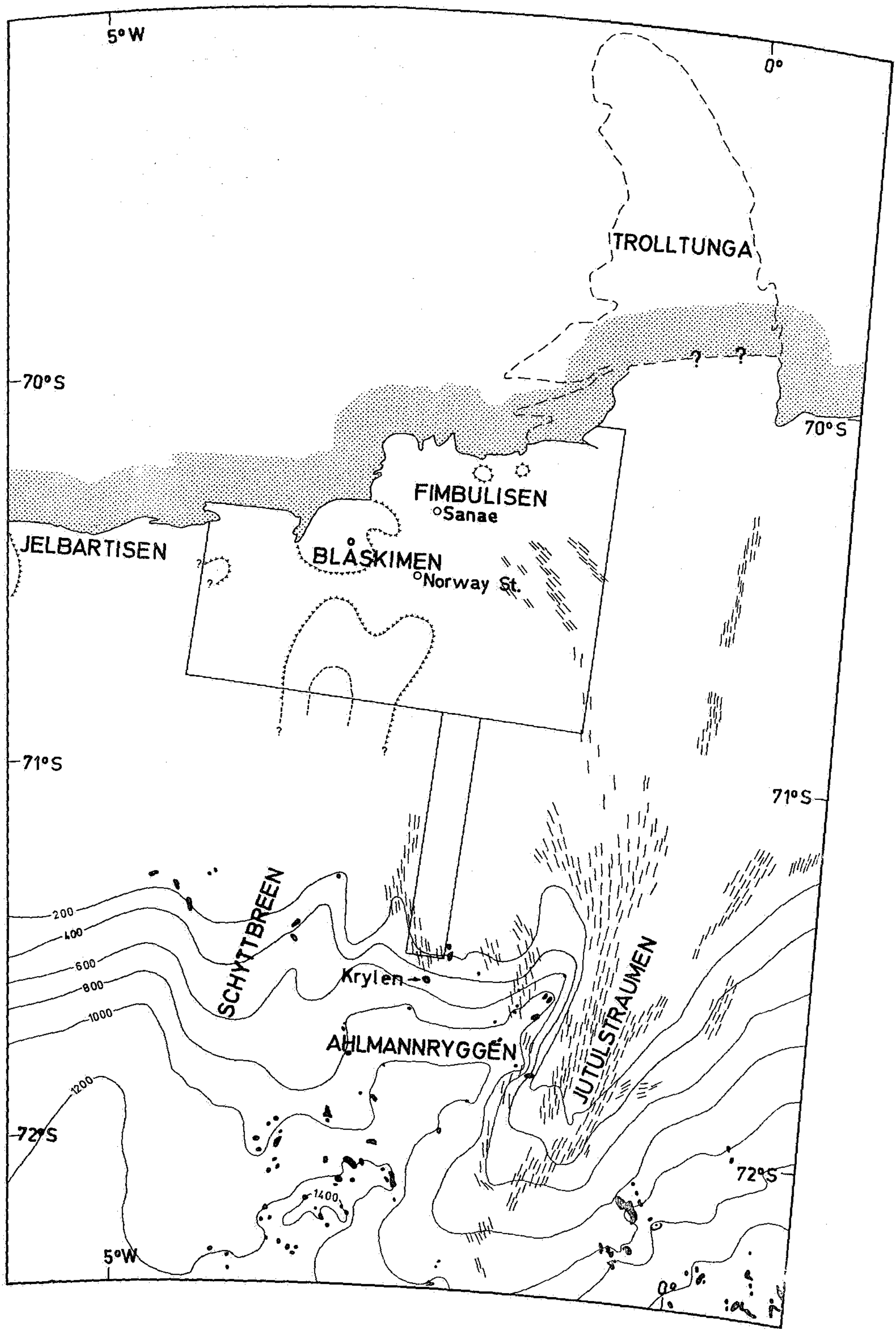


Fig. 1. Western Dronning Maud Land (compiled from different sources).

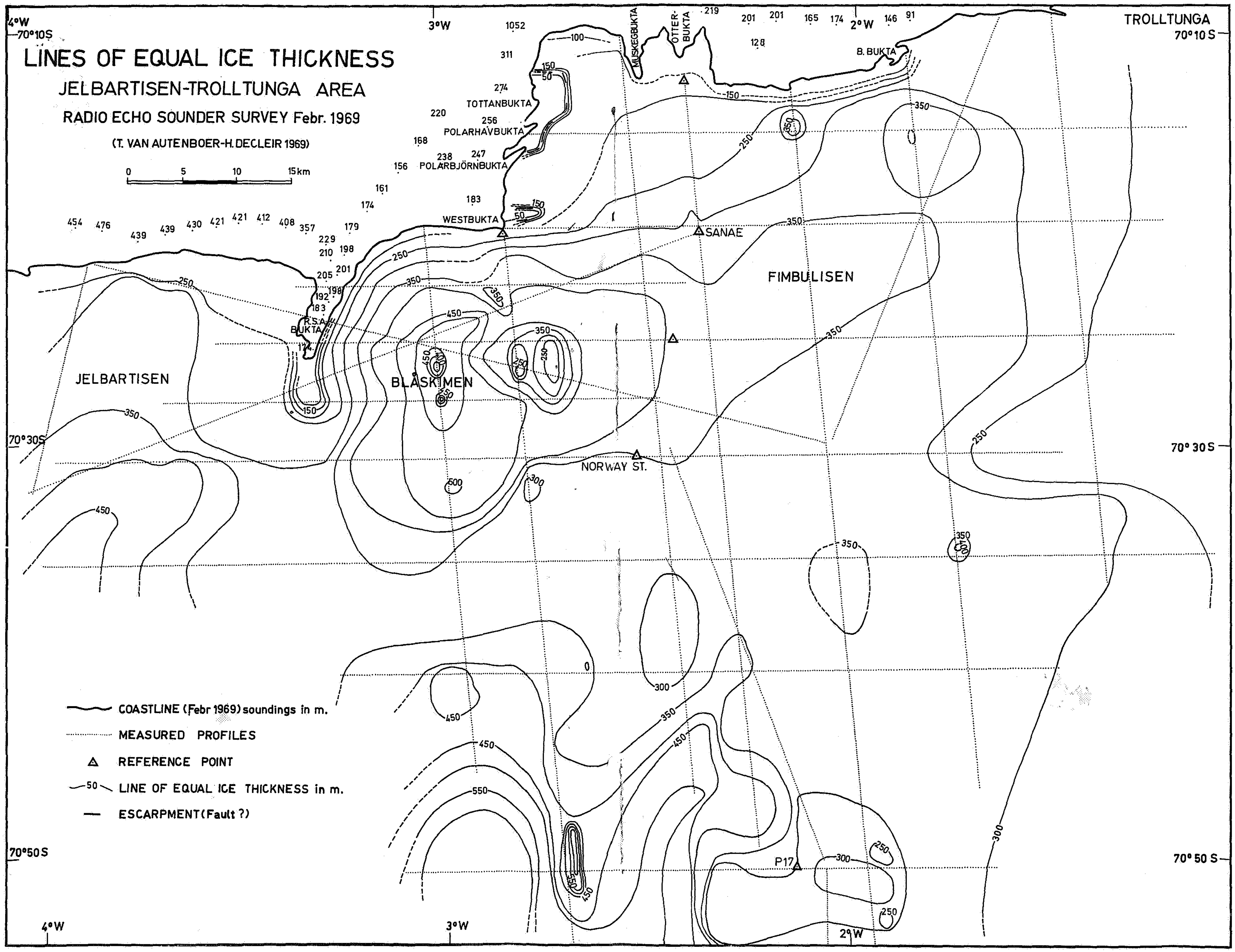


Fig. 2. Contour map equal ice thickness.

ings with depths measured by seismic techniques in Greenland. His results indicate a systematic difference of $\pm$ 15 m which for the thicknesses measured corresponds to less than 1%.

5.2 The enlarged films were read to 1/40 of μsec which corresponds to an error of approximately 2 m in thickness.

5.3 The error in absolute velocity as determined from the deviations of the linear function amounts to 1 mμsec^{-1}. On an average ice thickness of 350 m this means a possible error of 2 m.

Except for part of the Krylen flight all measurements were made in the same area and variations of the absolute velocity can not be expected to be large. However it is hoped to conduct some velocity measurements on the ice rises during a future expedition.

5.4 The biggest possibility of error remains the navigation. A check is provided at the junction of E-W and N-S flights where the same ice thickness should have been measured. In general the difference is of the order of 10 to 15 m. The biggest differences were found in areas of rapidly varying ice thickness where a small change in position causes a big difference. Differences also increase with the distance from the starting point because of increased navigational errors.

6. *The 1969 radio echo sounder survey*

The area surveyed by the 1969 expedition is shown in Fig. 1 while Fig. 2 shows the measured profiles. Records obtained on these flights, examples of which will be discussed below, can for all practical purposes be considered as continuous. The films have been scaled and ice thickness and navigational data computed. Plotted on a 1 : 50,000 horizontal and 1 : 5,000 vertical scale the different profiles have been assembled as maps to be published as a data report in the expedition series. Based upon these profiles is a map showing lines of equal ice thickness or isopachs (Fig. 2). Due to the differences in the measurements on the N-S and E-W flights and to discontinuous records on some flights, some subjective interpretation could not be avoided in the construction of this map.

The grid survey covers the following zones: the Fimbulisen ice shelf with its contact with the Jutulstraumen — Trolltunga ice stream and with its southwards continuation to the inland junction; part of the Jelbartisen ice shelf; the Blåskimen ice rise, the Southern ice rise and different minor ice rises.

6.1 *Ice shelves* are floating ice sheets that flow under their own weight. Limited areas may be aground (ice rises) (ZUMBERGE and SWITHINBANK, 1962). They are characteristic of the coastal areas of Antarctica of which they fringe more than one third with a total surface area of 1.4 10^6 km^2.

A morphological description of the ice shelves in western Dronning Maud Land has been given by SWITHINBANK (1957) and by KRUCHININ (1965). A comprehensive study of ice shelves — on which the following is based — can be found in SWITHINBANK and ZUMBERGE (1965).

The more conspicuous morphological features of the ice shelves are their gently undulating upper surface maintaining a near constant height over large areas and their 20-40 m high vertical cliff at the seaward end. Nourished by local accumulation [for example 50 cm/year of water equivalent at Norway Station (LUNDE 1961) and 38 cm at Base Roi Baudouin (TONGIORGI and others, 1962)], they maintain a constant height and compensate for the accumulation by continuous spreading and locally by melting at the ice-water interface. Free to creep in all directions an ice shelf would theoretically maintain a uniform thickness of the order of 200 m which is generally corroborated by the thickness of icebergs and of the coastal areas of ice shelves. Ice shelves are however generally confined by flanking arms of the inland ice-sheets or local grounded areas. The general pattern of bays and inlets is related to these factors and may be a permanent feature of the ice front. Free to float in one direction only their thickness increases considerably. It attains for example 1300 m at the inland junction of the Filchner Ice Shelf. Ice shelves are made up of snow firn and ice, and in the upper part display well stratified sections made up of fine grained winter and coarse summer layers. The mean crystal size and density increases with depth while the temperature varies from the mean annual temperature near the surface to the freezing point of sea water at the ice-water interface.

6.1.1 *The Fimbulisen Ice Shelf* is situated approximately between 2°25 W and 1°20 W. The area is limited in the west by ice rises, in the north by sea and some smaller ice rises, and in the east by the Jutulstraumen-Trolltunga ice stream (Fig. 1, Fig. 2).

The shelf can be considered as an embayed type. The surface is monotonously level or very slightly undulating and only careful observations can establish a deviation from the horizontal. Surface elevations vary between 50 m in the central part and 37 m near the ice front. Crevasses are on the whole rare.

1) The central part

The ice thickness (300-350 m) is very constant throughout a very large area. The ice thickness profiles are smooth and the recorded films are characterised by a continuous and very strong reflection on the ice-water interface (Fig. 3). Receiver attenuation is high. The ratio of ice thickness to surface altitude is 6, reflecting the hydrostatic equilibrium of the shelf in this area. Apparently due to the influence of the Blåskimen ice rise is the gradual increase in thickness of the floating shelf towards this grounded area. To what extent this increase reflects a direct influence of the grounded area or an indirect one affecting the rate of spreading is at present not yet clear.

At Sanae the isopachs show a pronounced deflection to the north-west which shows the ice to be some 25 m thicker that what would be expected from the general pattern of the map. The direction of the deflection seems to correspond with the main wind direction. An explanation can be found in the increased accumulation caused by the station and its disturbance of the accumulation over an 8 year period.

2) The coastal area

The coastline forming the northern limit of the shelf is strongly indented and related to the grounded areas. Apart from a slight decrease in elevation the physiography of the ice shelf as well as the characteristics of the echoes remain unchanged.

Characteristic of the coastal area are the 10 to 15 m deep depressions which form the landward extension of many small bays in the area. These depressions were investigated in detail in the Polarbjørn — Tottanbukta area. The equal thickness contours show the most conspicuous aspect of this area to be the very regular decrease in thickness towards the ice front. The minimum thickness measured (except for the depressions) was of the order of 100 m in the rounded cape between Tottan and Muskegbukta.

Although the ice rises complicate the general pattern of the isopachs one can estimate that this decrease starts some 20 km from the coast. The rate of decrease is of the order of 10 m/km in a N-S and of 6-7 m/km in an E-W direction. The ratio of the ice thickness to surface elevation has decreased from 6 to 5.

Since the accumulation is fairly constant over the entire shelf area (Lunde, 1961) this decrease is evidently explained by bottom melting and/or increase in the rate of spreading. It is thought that bottom melting is the more important cause for this decrease. This is indicated by the decrease in the ratio of ice thickness to surface elevation which appears to be due to a decrease in the overall density of the ice shelf. This decrease in its turn may be explained by the disappareance of the dense bottom layers of the ice shelf. An increase of spreading, on the other hand would maintain the same overall density and therefore the same ratio. The importance of bottom melting is further indicated by the close relationship between the coastline and the isopachs.

On the easternmost N-S profile no evidence of bottom melting can be found. The present coastline in that area is very recent and until last year formed part of the Trolltunga extending to the north. This apparently protected it from bottom melting.

Lunde (1965) has calculated the annual bottom melting at Norway Station as 0,76 m of ice, and similar figures have been obtained by Swithinbank (1962) and Crary (1961) for the Maudheim and Ross Ice shelves.

Assuming a constant rate of bottom melting — which one can however expect to increase towards the ocean — it becomes possible to calculate the minimum annual movement necessary to produce the observed decrease. This is of the order of 80 m/year.

The area within the ice shelf delimited by the Tottan-Polarhav- and Polarbjørn bukta depressions shows a reflection at a 50 m depth adjacent to the 150 m thick ice shelf, and separated from it by a 100 m high vertical discontinuity. An internal reflection at −50 m obscuring a bottom reflection can not be completely excluded. However it is felt that a fault-like escarpment forming the limit between a thinner ice shelf formed upon a sea ice base and the 150 m shelf is in better morphological agreement and explains the depression with its crevassed borders. It is also in agreement with the increased accumulation in similar depressions measured by Lunde (1961) and observations near Base Roi Baudouin where part of the depression inland of Baie Roi Léopold III breaks off regularly to be formed again by snow accumulation in the course of a single winter.

3) The southern area

To the south the limits of the ice shelf are not accurately known but different maps place these some 8 km north of the first nunataks. The surface heights remain within the 50 to 100 m range.

A profile from Norway Station to the south shows the ice thickness to increase very regularly to reach a maximum of 590 m. At the same time the echoes become weaker and more irregular. The contact of the floating ice with the grounded ice can not be readily distinguished as it can on other profiles. The glacier cross section constructed from the surface relief and the ice thickness, shows that in most parts of this area the bedrock lies well below the present sea level, and reaches a maximum of 490 m near Krylen (Fig. 3, Fig. 5).

Soviet glaciologists have found a deep trough to exist north of Novolazarevskaya. Future surveys might be able to confirm whether the depression measured here forms the westward extension of this so called Lazarev trench which is explained by crustal down warping caused by the Antarctic ice load (Frolov, 1965).

4) The eastern margin

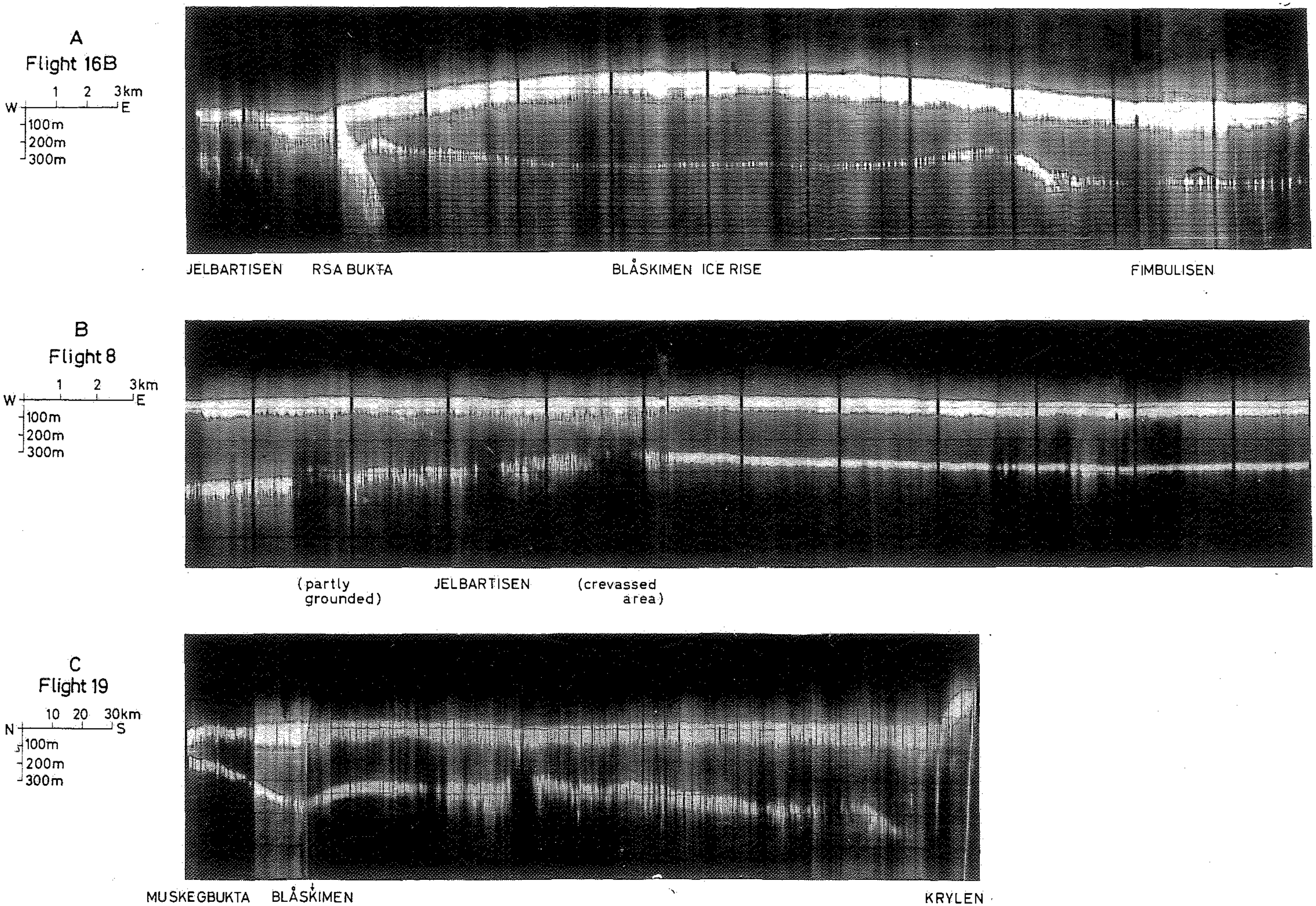
The eastern margin of Fimbulisen is formed by a major and very fast moving ice stream. The limit between ice shelf and ice stream is marked by a slightly depressed belt of crevasses in places 5 km wide (Lunde, 1961).

This ice stream represents the northwards continuation across Fimbulisen of the Jutulstraumen glacier situated on the limits of an important tectonic structure. In the north the glacier stream gave rise to the Trolltunga ice tongue, until recently a very characteristic

Fig. 3. A. Horizontally compressed record obtained over Blåskimen ice rise.
Strong surface reflections, weak and discontinuous bottom reflections under the ice rise. The strong echo rising to the surface at the western end of the profile represents a forward reflection of RSAbukta.
The junction of the floating ice and the grounded area is not clearly marked. Note dissymetry of subglacial relief as compared with surface relief (see Fig. 4).

B. Idem over ice shelf between Blåskimen and Southern ice rise. Characteristic strong bottom reflection on the ice shelf in the eastern part. To the west the ice thickness increases and grounded areas appear.
The broadening of the surface reflections obscuring the bottom reflections 12 km from the western end is due to multiple scattering in a crevassed area.

C. Idem between the coast and the first nunatak in the south (Krylen). The record illustrates the thinning of the ice near the coast, the influence of Blåskimen (to the west of this flight) and the gradual thickening of the ice towards Krylen (see Fig. 5). →


A
Flight 16B
1 2 3km
W E
100m
200m
300m
JELBARTISEN
RSA BUKTA
BLÅSKIMEN ICE RISE
FIMBULISEN
B
Flight 8
1 2 3km
W E
100m
200m
300m
(partly grounded)
JELBARTISEN
(crevassed area)
C
Flight 19
10 20 30km
N S
100m
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BLÅSKIMEN
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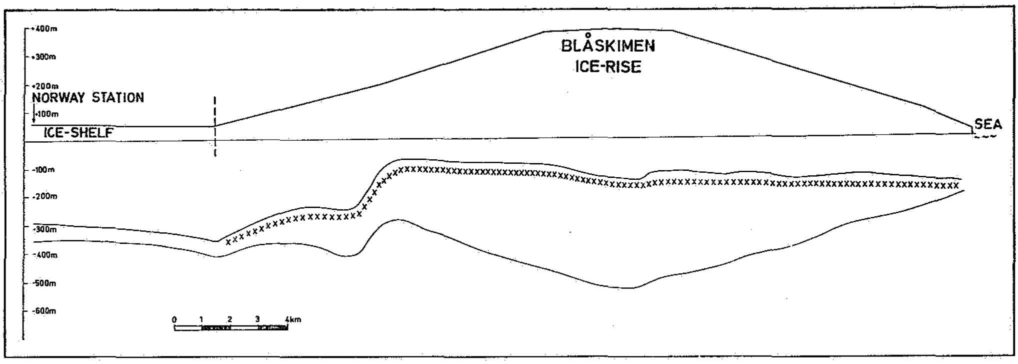

Fig. 4. Cross section through Blåskimen, constructed from surface elevation and ice thickness (the lowest line in the profile indicates ice thickness plotted from sea level). Note the asymmetry of the subglacial relief (see Fig. 3A.).

coastal feature of Dronning Maud Land. Aerial observations (in 1968 and 1969) proved that the southern part of this ice tongue calved off sometimes during 1968. ESSA satellite photographs show that the major part of the Trolltunga calved off before October 1967.

Radio echo sounding records show discontinuous and/or weak reflections due to multiple scattering in the crevassed belts. The ice thickness in the ice stream area decreases to the east by thinning of the ice in the faster moving ice stream. Although only the marginal parts of the ice stream have been investigated it seems safe to accept a general 250 m thickness.

The gulflike indentation shown by the isopachs around 70°30′S and 2°20′W is not fully understood. Heavily crevassed this feature seems related to a S-W - N-E orientated line of ice rises or shoaled areas.

6.1.2 *Jelbartisen ice shelf*

This area was only partly surveyed. It is limited east and west by ice rises, the eastern one being Blåskimen and related RSA bukta. A comparison with Swithinbank (1957) shows that the northern free floating part of the shelf has calved off since 1951. The S-E limit is shown by the isopachs map to be formed by another ice rise. The same author already described the conspicuous E-W orientated crevasse-lined depressions running across the shelf. The average thickness of the shelf seems to be around 300-350 m and the decrease in thickness to the north is also noted. Internal reflections and the related discontinuous record on a N-S flight at right angles to the depressions and crevasses are still being analysed.

6.2 *Ice rises* are dome shaped glaciers — or part of glaciers — resting on rock and occuring within an ice shelf area. They condition the general distribution and form of the floating ice shelves of which they are sometimes considered to form part. Their coastal outline seems a stable feature and can often be recognized within the very rapidly changing pattern of the ice shelf front over long periods (see Van Autenboer, 1964 p. 14-15).

6.2.1 *The Blåskimen ice* rise limits the Fimbulisen ice shelf to the north-west. Its surface relief shows a typically symmetrical dome approximately 400 m high. The coastline to the north of Blåskimen follows the contours of the ice rise and forms a rounded smooth coast, the present outline of which can be readily compared with the 17 year old map of Swithinbank (1957). The grounding of the glacier in the area is proved by independent observations: gravimeter profiles (by H. Decleir in 1968), the bathymetric survey off the coast which proves a shoaled area to continue the ice rise to the north and the nature of the return echoes which will be discussed later. The isopachs in Fig. 2 show Blåskimen to be completely surrounded by floating ice

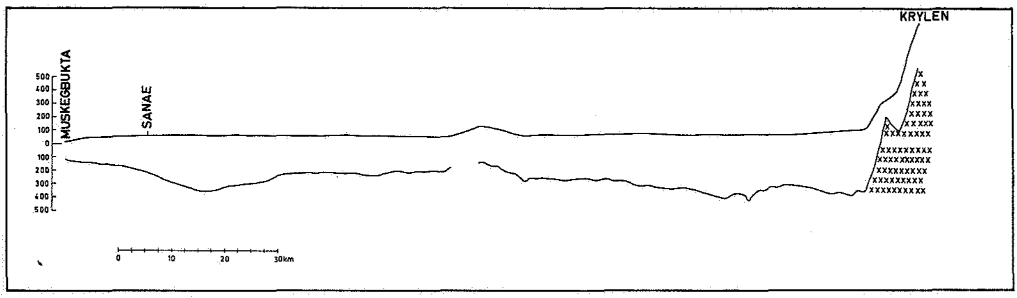

Fig. 5. Muskegbukta — Krylen Cross section.

shelves. Accumulation measured by LUNDE (1961) is nearly 5 times that of the ice shelf at Norway Station.

Echo strength diminishes considerably and receiver attenuation is locally at a minimum. This is related to the poorer reflecting characteristics of the ice-rock interface. The records are discontinuous in places although interpretation on the whole remains easy. The records and isopachs show the most conspicuous features of the ice rise to be the general increase in thickness of the ice reaching a maximum of 500 m. The symmetry of the surface of the dome is not reflected by the sub-ice topography as can be seen from the isopachs and from a cross section based upon the surface relief (Fig. 3, Fig. 4). The ratio of ice thickness to surface elevation varies, and can not be related to the hydrostatic equilibrium ratio's as found on the floating ice shelf.

6.2.2 *Two minor ice rises* were discovered by radio echo sounding along the coastline. Both are close to shoaled areas off the coast and have higher surface elevations. Both are characterized by an increase in ice thickness, the records are similar to the ones already described for Blåskimen. It is well possibly that a more detailed survey reveals the existence of several of these minor domes.

6.2.3 *The Southern ice rise*

The south western limit of Fimbulisen is formed by an elongated N-S oriented dome the long axis of which continues to a point close to the Blåskimen ice rise. Norwegian, British and South African maps show this dome to continue in the same direction towards the first nunataks in the south. This is confirmed by the flights towards Krylen (Fig. 3, Fig. 5). This flanking arm of the inland ice sheet seems therefore to form the western limit of Fimbulisen.

7. *Further interpretation*

Further analysis of the records and interpretation of the surface elevations will allow the construction of different cross profiles. These will lead towards the construction of a three-dimensional model of the glacier coverage in the surveyed area and allow more detailed interpretation. Further studies are being made of the internal and multiple reflections, the receiver attenuation and the characteristics of the reflections in the different areas.

8. *Acknowledgement*

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