GLACIOLOGICAL AND GEOMORPHOLOGICAL RECONNAISSANCE IN THE ANTARCTIC IN 1956

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Abstract. This paper presents a preliminary account of the glaciological observations made by the Antarctic Expedition of the U.S.S.R. Academy of Sciences in Kaiser Wilhelm II Land, Queen Mary Land and Knox Coast in 1956. The topography of the edge of the ice sheet is described, and the ice regime is discussed, particularly in relation to the existence of ice-free areas such as "Bunger's oasis".

Zusammenfassung. Es wird ein einführender Bericht über die glaziologischen Beobachtungen übermittelt, die von der Antarkischen Expedition der Akadamie der Wissenschaften der U.d.S.S.R. im Kaiser Wilhelm II Land, Queen Mary Land und Knox Coast im Jahre 1956 gemacht wurden. Die Topographie der Kante des Inlandeises wird beschrieben, und der Eishaushalt wird besprochen, besonders in Bezug auf das Vorhandensein von eisfreien Gebieten wie z.B. die „Bunger's oasis".

Introduction

The programme of the Antarctic Expedition of the U.S.S.R. Academy of Sciences during the Antarctic summer of 1955–56 was to build a polar observatory and the "Mirnyy" settlement, and to commence studies on the sixth continent in order to obtain experience for the large-scale investigations in 1957–58 as part of the programme of the International Geophysical Year. The part of the Antarctic Coast assigned to the Soviet Union by the special I.G.Y. committee, Kaiser Wilhelm II Land and Queen Mary Land, between longs. 86° and 102° E., had been little studied and, to the best of our knowledge, presented great difficulties for landing and for setting up the expedition's base.

A group of glaciologists was included in the expedition to help in choosing the site for the observatory, to consult on building roads and constructions on the ice, to make reconnaissance studies and to work out the programme of glaciological research for 1956–58. The author was one of the members of this group.

We arrived at the Antarctic coast on 5 January 1956 on board the *Ob'* and spent 40 days on the continent. During this period I was able to observe from the air the coasts of Kaiser Wilhelm II Land, Queen Mary Land and Knox Coast for a distance of 880 km. and to carry out terrestrial investigations near Junction Corner at the western boundary of Shackleton Ice Shelf and the inland ice, in the Haswell Island district where the "Mirnyy" settlement was set up, in one place in the central part of the Shackleton Ice Shelf, and, together with other members of the expedition, in the "Bunger's oasis" area at the eastern end of Shackleton Ice Shelf. On 13 January, while flying in an aeroplane piloted by A. N. Kash, our group found the site which we recommended for the "Mirnyy" settlement; it was practically the only point suitable for this purpose in our entire sector.

By 13 February the observatory had been opened, the ships unloaded, and we had completed our main tasks. There was no possibility of continuing scientific studies before the construction work was completed, and so we left on 15 February on refrigerator ship No. 7, the first ship to return. After sailing some 4000 miles along the Antarctic coast, we transferred to the tanker *Kherson* in the Weddell Sea, and returned to Odessa on 5 April.

My stay in the Antarctic, though very brief, enabled me to become generally acquainted with its nature, to draw some scientific conclusions, and to work out a detailed programme of glaciological and geocryological* (permafrost) researches. My scientific results are being published at present; the main conclusions are reported here.

* Professor Shumskiy uses the word *geocryology* and its Russian equivalent *geokriologiya* to cover processes arising due to both temporary and "permanent" frost action in rocks and soil, which he prefers to the term *permafrost* or the Russian *merzlotovedeniye*. *Ed.*

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Topography

The area surveyed consists of Pre-Cambrian crystalline rocks primarily gneisses and granites. Mica schists and comparatively little altered conglomerates, possibly Palaeozoic, were also found in boulders. The volcanic cone of Gaussberg (370 m.), consisting of young, probably Tertiary, basalts, dominates the Pre-Cambrian shield in the west. This mountain is situated on the continuation of the Kerguelen-Gaussberg Ridge, a high submarine range.

In the few places where bare rocks are exposed the topography is one of small hills with a difference of elevation of 100 to 150 m. between the peaks and depressions (Fig. 1, p. 54). The hills are *roches moutonnées*, and they are separated by depressions which show no signs of fluvial erosion. The elevation of the land along the greater part of the coast probably varies from 100 m. below to 100 or 200 m. above sea level. In the submerged sections the *roches moutonnées* form a skerry type of coast with numerous islets and straits. The coast near "Bunger's oasis" (long. 101° E.) is of this type, as is that at the "Mirnyy" settlement with Haswell Island and the surrounding islets.

In these regions there are also deeper valley-like depressions with hillocks on their surface. These are probably the remains of ancient pre-glacial erosional valleys, which have since been subjected to glacial action. Mountain *massifs* with heights of 1300 m. and more and cut through by deep valleys occur only between longs. 98° and 100° E. (Mt. Barr Smith, Mt. Strathcona, Mt. Amundsen and others).

Ice Cover

Almost the entire coast is covered by the inland ice sheet. The only places free of ice are some nunataks (Gaussberg and some peaks in Queen Mary Land), a few rocky precipices, three groups of coastal islands and the hilly region of 600 to 700 km.^{2} in eastern Queen Mary Land known as "Bunger's oasis". The mountain range which American airmen were reported as having seen 350 km. from the coast in 1947, was not found by the Soviet expedition during its aerial or terrestrial operations.

The surface of the ice sheet slopes gently northwards from the central ice plateau of the Antarctic, which is 3000–3500 m. high some several hundred km. from the coast. The gradient increases near the edge, and the surface becomes more uneven, hilly and crevassed, reflecting the relief of the glacier bed. At the coast itself the surface of the ice sheet descends more or less steeply from a height of 100 to 300 m. until it drops into the sea with an almost continuous wall which varies in height from place to place between 10 and 40 m.

The relief of the glacier bed causes variations in the flow of ice in the coastal regions. The ice flows round elevations of the bed and fills the depressions. As a result, thickness of ice and the flow velocity decrease above the elevations and increase above valley-like depressions, and this leads to variations in the height of the coastal ice walls and in some bands in the coastline. Protruding edges of the ice sheet or ice tongues emerge from the depressions and have a higher ice wall. The wide ice lobe by the side of the "Mirnyy" settlement and the Helen Glacier somewhat further east are examples of this, although the ice lobe near "Mirnyy" is due, not so much to the concentration of ice flow in a depression, as to its protection from the action of the sea by the archipelago of rocky islets on one of which the "Mirnyy" settlement is located.

Over most of the coast the variations in ice flow are not significant. The ice from the central regions of the continent moves towards the sea in a slab of more or less uniform thickness. Slipping of the ice over its bed is responsible for a large, if not predominant, part of the flow, and this enables the ice sheet to crawl over hills with a gradients opposite to the direction of movement. The author observed this phenomenon during his flight over Knox Coast.

Judging by the height of the ice walls and the reproduction of relatively small unevennesses of the bed on the ice surface, the thickness of the edge of the ice sheet in most places is 200 to 300 m., and probably nowhere exceeds 400 m. Whereas a man who sees polar glaciers for the first time is struck by the grandiose scale of the glacierization in this part of the Antarctic coast, the specialist is, on the contrary, surprised by its small thickness. This fact was unexpected since in remote

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inland regions the ice sheet undoubtedly reaches thicknesses of 2 to 3 km.* The smaller thickness on the coast cannot be, as in areas outside the Antarctic, the result of melting, because nourishment of the ice sheet continues right down to sea level, and in the coastal regions may be even more intensive than in the inland region. Radial spreading can hardly account for such a great decrease in thickness. A possible cause is that the upper part of the very thick ice sheet flows from the interior over the subglacial barrier which separates the central continental depression from the coast. To ascertain the specific features of the configuration and movement of the ice sheet in this part of the Antarctic is one of the aims of the glaciological studies during the International Geophysical Year.

Variations in ice flow are much more pronounced in the dissected area of east Queen Mary Land and the adjacent part of Knox Coast. Here the deep valleys are filled with swift moving ice streams (Denman Glacier, Scott Glacier and others), which project far out to sea, while part of the edge of the ice sheet, isolated by them from the inland, is almost inactive and ends partly on land, leaving the territory of "Bunger's oasis" free of ice.

The ends of the glaciers which run out to sea west of the "oasis" spread out and merge with one another, forming the eastern part of the vast Shackleton Ice Shelf. Its western part is formed by the undifferentiated edge of the ice sheet which juts out to the sea. A considerable part of the ice shelf is afloat, but it is kept anchored by a number of islands covered with ice rises which merge with the ice shelf (Mill, David, Henderson, Masson and other islands). The shelf ice gets abundant nourishment from solid atmospheric precipitation, but the structure of ice in the cliffs shows that its base is formed by ice from the inland ice sheet and the glaciers. West Ice Shelf, which I was unable to examine in detail, probably presents a similar picture.

Ice Regime

Another phenomenon we had not anticipated was the thawing we observed on the Antarctic coast, which was however confined to a narrow coastal belt. In the Antarctic it is only during anticyclonic conditions that thawing occurs, caused by solar radiation and accompanied by a relatively low air temperature. Two metres above the ice surface the temperature very seldom rises to 3° or 4° C., while the mean temperature of the warmest month is about 1° to 2° C. below zero. Anticyclonic weather is characterized by calm or weak easterly winds of the föhn type, during which relative humidity often falls in daytime to 30 to 50 per cent (measurements by N. P. Rusin). In such conditions almost all the absorbed radiation causes evaporation of snow and ice and thawing is relatively weak. Cloudy, cyclonic weather causes a fall in temperature below freezing point and precipitation falls only in the solid state. Snowfall is accompanied by strong winds causing drift and very uneven deposition of snow. The mean annual precipitation, measured by the water content of the annual layers of firn and ice, reaches 600 to 750 mm. Consequently a large amount of precipitation in the solid state in the cold periods is combined on the coast with a great dryness of the air in warmer periods during summer.

The quantity of solid precipitation falling on the ice sheet down to sea level itself greatly exceeds ablation (melting, evaporation of melt water and sublimation) and a thick layer of firn is deposited annually on the surface. Consequently there is a cold infiltration† zone of ice formation on glaciers down to sea level, a zone which is many hundred metres above the climatic snow line. Thanks to such a low level of regional snow line, sea ice consists for the most part of snow. Perennial fast ice on the sea receiving abundant firn nourishment can reach great thickness, showing all transitions from seasonal sea ice cover to ice shelf. It is therefore often impossible to determine the exact boundary between land ice and sea ice—between land and sea.

However, on the convex surface near the edge of the ice sheet, where a considerable part of the snow is blown away during the melting season, melt water freezes in the pores of the snow which is transformed into a layer of ice. This part of the surface belongs to the infiltration-congelation† zone

* According to recent measurements the greatest thickness of ice is 2400 m. in Dronning Maud Land some 600 km. from the coast, and 3400 m. in Greenland.

† The terms "infiltration-congelation" and "cold infiltration" are those adopted by Professor G. Avsyuk in his Classification of Glaciers printed on p. 7 of this issue. *Ed.*

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of ice formation. In some sections, where the snow is swept off very intensively, ablation may even prevail over accumulation. The surface of nunataks and some small areas at the edge of the ice sheet belong to such ablation areas. In one place the marginal moraine of Farr Bay has been formed, the location originally planned for the "Mirnyy" settlement.

"BUNGER'S OASIS"

"Bunger's oasis" and the adjacent region are the only large area of prevailing ablation along the entire coast we examined. The ablation zone surrounds the "oasis" in an asymmetrical strip, elongated down the prevailing wind towards the west and north-west for 50 to 60 km., but very narrow (100 to 200 m.) to windward (Fig. 2, p. 54). Thawing in this zone is much more intense than elsewhere, gradually decreasing away from the "oasis". Near the edge of the "oasis" the surface of the glaciers is indented with large potholes and is cut by deep channels of glacier streams (Fig. 3, p. 54). Farther from the edge the surface becomes more even and changes into the infiltration-congelation zone and then into the cold infiltration zone. Greater thawing is undoubtedly caused by the influence of the "oasis". Ice from the central part of the continent surrounds the "oasis" and flows into neighbouring valleys. The absence of glacierization in the oasis itself cannot be the result of snow being blown away, since the enclosed depressions and hollows of the "oasis" should be the first places to collect snow and ice. Obviously ablation prevails in the "oasis" notwithstanding the deposition of large quantities of solid precipitation. What is the source of such intensive ablation? This question is of great importance for solving the problem of numerous Antarctic "oases". Though differing in detail, all answers given until now can be divided into two main groups; in the opinion of some investigators the warmth of the "oasis" results from the heating of their surface by the sun, while in the opinion of others it is the result of heating by endogenetic, underground heat sources (volcanic activity, radioactivity, spontaneous combustion of coal).

Our observations allow us to assert that solar heat is the source of heating in the "oasis". This is attested not only by the geological structure, which provides no evidence of volcanic activity or coal combustion, but also by the preservation of permafrost everywhere at some depth under the surface at the end of the melting season, which is incompatible with heating from below. The question then arises as to how the existence of an "oasis" is compatible with the particularly severe climatic conditions in the Antarctic, and why there is such a sharp contrast in the water-substance and heat balance of the surface in the "oasis" and the surrounding ice, so that the former belongs to the zone of prevailing ablation while the latter is in the cold infiltration zone, which is usually located hundreds or even thousands of metres higher than the ablation zone, and why no such phenomena are observed in other areas now glacierized.

The solution of these problems is provided by the great difference in reflectivity between the surface of rocks in the "oasis" and the snow or firn surface of the ice sheet, and also by the exceedingly low air temperature due to the influence of the ice sheet under conditions when incoming solar radiation is very intense (about 700 calories per cm.^{2} per day according to Rusin's measurements). Under these conditions solar radiation is the only factor affecting ablation of the ice or snow cover, whereas everywhere else advective heat always plays a more or less important part in ablation. In the "oasis" there are many snow-free areas even in winter, for snow is blown away from the tops of the rocky hills. The dark surface of the "oasis" rocks, absorbing 80 to 85 per cent of the solar radiation (compared with 10 to 15 per cent on the surrounding glacier), is heated up in the summer to a temperature of 25° to 30° C. A considerable part of this heat is transmitted to the air layer above the surface, which becomes less saturated with water vapour (relative humidity 10 to 15 per cent), and thus more able to dry up the surface layer of disintegrated rocks, which are subjected to intensive deflation. The advective transfer of heat by the air layer above the rock surface and the intensive absorption of radiation by the dust covered surface leads to complete ablation of the snow cover in the "oasis". The only exceptions to this are snow drifts in the lee of hills, where permanent snow patches or immobile accumulations of ice and firn are formed. The same causes lead to the large amounts of ablation in the region near the leeward side of the "oasis". Thus the local absorption of radiation in the "oasis" results in a local climate being formed which is warmer and drier than that on the surrounding glaciers.

The prevalence of ablation over accumulation distinguishes the "oasis" from nunataks, whose surface is kept ice-free mainly by mechanical factors (blowing away of snow). This is why nunataks come into direct contact with the accumulation area of glaciers, whereas "oases" are separated from it by an ablation zone. Otherwise "oases" are similar in their nature to nunataks, but their desert features are more pronounced. The term "oasis" can be applied to the ice-free plains of the Antarctic only in a very relative sense, since in reality the Antarctic "oases" are very severe cold rocky deserts.

There are many lakes in the depressions of "Bunger's oasis", as in other Antarctic "oases". Their water level drops noticeably towards the end of summer. Most of these lakes are undrained and salty (Fig. 4, p. 54). Their shores have a white strip of salt efflorescences of different tastes—salty, bitter or tasting of soda.

The bare rocks and boulders in the "oasis" are subjected to temperature weathering associated with variations in the volume of rocks, especially desquamation, i.e. the separation of concentric shells of rock (exfoliation) (Figs. 5 and 6, p. 55). The dry surface layer of the loose rocks is intensively deflated, the particles being removed and blown away by the wind, so that the products of weathering and the redeposited moraines have almost no fine material. In many places cellular deflation of rocks and boulders of the kind associated with deserts can be seen (Fig. 5).

Geocryological processes are poorly developed, owing to the dryness of the loose deposits and their coarse-grained composition. Apart from frost weathering all the geocryological processes observed are associated with the thin moraine cover in the depressions which contain some silty material. The only widespread phenomenon is frost sorting leading to the formation of polygons (Fig. 7, p. 55). Frost heaving and solifluction were only observed occasionally and on a small scale.

Processes of chemical weathering are well developed, resulting in desert varnishes and salt efflorescences on the surface of rocks and boulders.

Plant life consisted of small patches of scum and lamellate lichens on rocks with very few bushy lichens, strips of green mosses along rivulets and blue-green algae in the salty lakes, which in some cases form bottom sediments. The only terrestrial animals were a few birds which get their food from the sea; McCormick Skuas, Snow Petrels and Wilson Petrels.

In former times the entire "oasis" was covered by ice. This is shown by glacial markings on the surface of rocks (polishing, striae and scars), by the presence of moraine cover and by erratic boulders. The "oasis" has, however, been in existence for not less than 10,000 years*, with its outside boundaries remaining more or less unchanged for a long time. This is indicated by the advanced state of physical and chemical weathering, cellular deflation of rocks, and frost sorting of loose sediments over its entire surface up to the very edge of the sheet. Probably the reduction of the Antarctic ice sheet which led to the formation of the "oasis", started about the same time as the recession of the ice sheets of the last glaciation in the northern hemisphere, under the influence of general climatic variation.

The presence of "oases" shows that two sharply differing water-substance and heat regimes—a glacier surface with firn nourishment and an ice-free surface—are both capable of stable existence in the coastal zone of the Antarctic. Ice-free surfaces arise if there is no influx of ice from the outside. Special conditions of relief are needed to resist the invasion of the ice, which is formed at a different latitude or altitude. It follows from this that the inland ice covers the edge of the Antarctic only because of its influx from the interior of the continent, where the conditions for ice accumulation are more favourable; the ice could not have formed on the spot. Consequently, the movement

* At the present intensity of ablation, even if accumulation of snow and the influx of ice to the edge of the ice sheet were to cease completely, about 4500 years would be necessary for an area as big as the "oasis" to be cleared of ice.

of the Antarctic ice sheet results in the invasion by ice of a region to which glacierization is not characteristic. This invasion of ice is accompanied by a sharp change in the water-substance and heat balance of the earth's surface and a considerable change in climatic conditions.

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GLACIER OBSERVATIONS IN NORTH-WEST SPITSBERGEN

By M. Mellor

(Leader, University of Nottingham Expedition to Vestspitsbergen, 1955)

Abstract. Results of observations on several glaciers in the Kongsfjord area are described, and comments are made concerning accumulation and ablation, glacier flow and the variation of glacier fronts. The findings are compared with those of previous workers in this district and, in particular, with those of H. W. Ahlmann. A history of the fluctuation of several ice fronts during the present century has been compiled from various sources, and some observations dating back to 1837 are mentioned.

Zusammenfassung. Die Resultate von Beobachtungen an mehreren Gletschern in der Nähe von Kongsfjorden werden beschrieben, mit Bemerkungen über Zuwachs und Abtrag, Gletscherbewegung und die Änderung der Gletscherenden. Die Ergebnisse werden mit früheren aus derselben Gegend verglichen, vor allem mit denen von H. W. Ahlmann. Eine Geschichte der Schwankungen mehrerer Gletscherenden während dieses Jahrhunderts wird aus verschiedenen Quellen zusammengestellt, die zum Teil bis 1837 zurückgehen.

Introduction

During the summer of 1955 an expedition from Nottingham University visited the Kongsfjord area of Vestspitsbergen to examine the geology and glaciology of the region. Owing to a last minute disruption of transport arrangements the period spent in the field was much shorter than had been planned, and a comprehensive glaciological study became impossible.

The area is shown in Fig. 1 (p. 63). Names used in inverted commas are intended to facilitate reference. Two journeys to the accumulation areas of the Kongsbre system were made and the snouts of glaciers terminating in Kongsfjorden were mapped. During a boat journey to Krossfjorden the margin of Fjortende Julibreen was also surveyed. Flow measurements were made on two sections of Kongsbreen and on Blomstrandbreen.

Weather conditions generally were very poor.

Accumulation and Ablation

In 1934, during a detailed study of Fjortende Julibreen Glacier, H. W. Ahlmann[1] plotted a number of firn profiles on Isachsenfonna. A pit was dug in the same area and at the same altitude in August 1955, and the profile shown in Fig. 2 (p. 65) was drawn. The system of dates adopted is believed to be correct, but some mention of the uppermost ice band must be made. Although this might be expected to mark the 1954 surface, its occurrence without change of thickness in a series of small pits dug at altitudes from 850 m. down to a little above 600 m. leads to the belief that it is a false band. It may have been formed during a warm spell in December 1954. Specific gravity measurements were made at the points indicated by circles in Fig. 2, and the values were then adjusted for ice content in the manner mentioned by Ahlmann. In the lower, heavily-iced layers the values were taken to the lowest reasonable figure. The profile was plotted on 15 August and a generous allowance for ablation after that date was made (200 mm. of water, or about 14 days' steady ablation). Ahlmann took the snow surface on 15 August 1934 as the upper limit of the 1933–34 layer.

Fig. 1. "Bunger's oasis"

Fig. 2. The ablation zone on the slope of the Antarctic Ice Sheet near "Bunger's oasis"

Fig. 3. A glacier stream west of "Bunger's oasis"

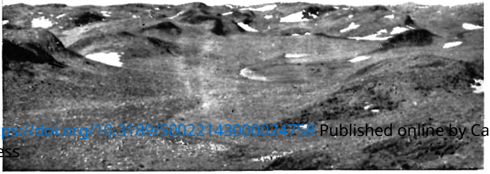

Fig. 4. Undrained salt lakes and solifluction stream in the "oasis"

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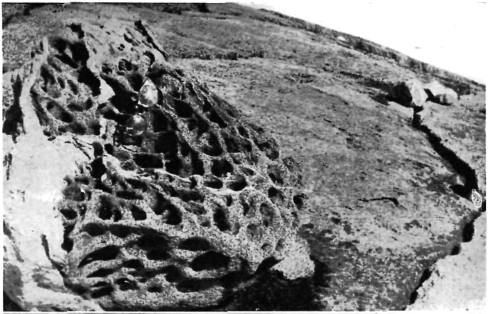

Fig. 5. Cellular deflation of a boulder and desquamation of rocks

Fig. 6. Desquamation of a roche moutonnée *in the "oasis"*

Fig. 7. A stone polygon—the product of frost sorting in the "oasis"

Photographs by K. K. Markov