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THE ORIGIN AND CLASSIFICATION OF ICE FREE AREAS ('OASES') IN THE REGION OF THE ADMIRALTY BAY (KING GEORGE ISLAND, THE SOUTH SHETLAND ISLANDS, WEST ANTARCTICA)

ANDRZEJ A. MARSZ

Department of Meteorology and Nautical Oceanography, Gdynia Maritime Academy
81-345 Gdynia, Al.Zjednoczenia 3, Poland

ABSTRACT

This article deals with the origin and classification of ice-free area adjacent to Admiralty Bay. The ice-free area has been divided into nunataks and oases. The former comprises all the area where the occurrence of ice cover is impossible because of mechanical reasons, regardless climatic conditions observed there. There are, in most cases, small hills surrounded by ice. The oases are made up of larger areas and can be found almost always near the shore. The climatic conditions in the oases make the transformation of snow into glacier ice impossible (ablation > accumulation) and they are protected against covering by ice of the main glacier system on the island thanks to the type of ice movement in the vicinity and the elevation of area (O1), little ice transportation smaller than ablation (O2), extremely favourable conditions for sun radiation (O3) and sheltering by other ice-free areas (O4). Each of the above distinguished types of oases has its own characteristic geomorphologic conditions. Table of ice-free areas in the vicinity of Admiralty Bay and their typology have been presented in Table 1.

KEY WORDS: Antarctica - South Shetland Islands - King George Island - ice-free area - oases - origin of oases

INTRODUCTION

The areas ice and snow free in the region of the Admiralty Bay were examined by the author during his stay on King George Island in the years 1977/78, 1978/79 and in 1984. Further, supplementary studies were carried out during the summer season 1987/88. The characteristics of this region was for the first time presented in a written form in Polish and up to the present moment has been the only one (Marsz, Rakusa-Suszczewski, 1987).

The areas free from ice and snow in the region of the Admiralty Bay form enclaves of different dimensions which are separated from one another. Because on land areas they are separated from one another by ice zones of different width they are like 'oases' among ice on one side and in the waters of the Bransfield Strait and the Admiralty Bay on the other side. Most of the land area reaches the sea and the largest 'oases' - all of them - are located on the coast. Several of the land areas, mainly small ones, are surrounded on the described region by ice sheet forming nunataks.

The region being the topographical drainage basin of the Admiralty Bay is further called 'the Region of the Admiralty Bay'. The borders of the drainage area are mainly found in the area of ice caps system on the island. They are formed by icesheds. The area of the region of the Admiralty Bay defined in this way has 267.270 km^2. The areas free from ice and snow on the examined region cover 21.138 km^2 all together which is 7.909% of the land area

surrounding the Admiralty Bay[1]. The largest land area is the region place where the H. Arctowski Station is located with an area of 4.194 km^2. Altogether there are 40 places free form ice and snow in the described region with small average area of 0.5296 km^2. For full specification of their names, areas see table 1. The names of areas free from ice and snow were taken after the already existing geographical names. In case of coastal areas the 'oases' were called after the cape if such was found in a given area. Map No1 illustrates places where the ice and snow free areas are located and the number attached to a given area corresponds to number in Table 1.

THE ORIGIN OF THE ICE FREE AREAS

Before the classification of areas not covered with ice and snow is made, it seems to be reasonable to explain the reasons why in the region which is covered with thick ice sheet there are some places with surface being mineral ground.

Generally speaking, these are places with conditions enabling the occurrence of positive balance of snow masses, i.e. the amount of snow and ice output, in that area (ablation and transport) within a year is larger than their input (precipitation sum, snow occurring there but not originating from snow fall, flow of ice). The reasons which results in such effects are both complicated and varied.

One of the most important reasons for the presence of negative balance of ice-snow mass is the influence of climatic factors. The observations of glaciers in the region of the Admiralty Bay indicate that at the end of summer (March) the upper limit of ablation which led to complete disappearance of snow cover from the previous winter can be found at altitudes of 200 - 220 m above sea level. It means, that the precipitation which was deposited below those altitudes should melt completely within the summer season so now at altitudes lower than 200 - 220 m. above sea level there are no potential possibilities enabling the development of ice sheet. The amount of ablation at the sea level in this area can be calculated by the Khodakov formula (1965) as 152.1 g/cm^2 at the altitude 200 m. above sea level, with the vertical gradient of air temperature -1.2°C/100 m. (see Marsz, 1994) as about 85.7 g/cm^2.

When we go through elevations of a place of given areas free from ice it turns out that all larger areas do not reach such altitudes or they exceed such altitudes only in particular spots. At the same time vast areas placed below that limit are glaciated because the transfer of ice from higher located areas makes the ablation impossible to occur. A clear conclusion can be drawn that even in the areas which lack the potential possibilities of glaciation development a set of additional factors protecting the areas against 'flooding' them by ice flowing down from ice caps located higher must occur.

While analysing the conditions of land areas surrounded by the Admiralty Bay we can distinguish several basic reasons the influence of which resulted in the lack of ice cap in these areas. We can also classify these areas according to the set of factors occurring there, distinguishing in this way some genetic types. That classification is shown in a schematic way in Fig. 2.

Very generally speaking all the land areas can be divided into two categories, i.e. the areas without ice cap - the lack of ice cap is not influenced to any significant extent by present climatic conditions and the areas where the lack of ice caps is the effect of present climatic conditions.

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[1] The measurements were taken in 1984 from the transformed aerial photographs taken in January 1978. The present area (in 1999) of particular areas may differ from the given value due to very quick process of deglaciation occurring in this region.

CLASSIFICATION OF ICE AND SNOW FREE AREAS

Nunataks

The first group of ice and snow free area comprises areas where the climatic conditions leading to transformation of snow into glacial ice may (but do not have to) occur, i.e. areas where snow accumulation is bigger than ablation. These areas are free from ice cap as a result of some mechanic reasons acting, the climatic factor is of secondary importance.

They are known as nunataks. Within this category we can distinguish two types different from each other:

- *Nunataks which are conditioned hypsometrically.* These are areas which raise about dozens of meters or more above the surface of the surrounding glaciers or ice caps without any larger summit area allowing snow to accumulate. Their slopes are so steep that it is impossible for thick layer of snow to remain on them. The snow layer either falls off the rocky wall or slips down when becomes thicker. In such conditions the accumulation of snow and its further transformation into ice is impossible. At the same time the altitude protects these areas against being flooded by glacier ice. These areas remain free from ice regardless the climatic conditions. Classical nunataks found in the described area (regardless their altitude above sea level) are nunatacs such as Ternyck Needle, Tern Nunatak, Admiralen Peak, Czajkowski Needle, Cockscomb Hill, Dufayel Island, Brama and others.

- *Nunataks which are conditioned morphographically.* These are nunataks which generally do not raise high above the level of the surrounding ice and the relative altitude of one of their walls is low. Their summit area is flat or very often widespread with diversified sculpture of surface favourable for the accumulation of snow. The walls are characterised by different gradient of slope which very often is big. The snow falling on the summit surface is blown off by wind. It is also impossible for larger amount of snow to be drifted from a lower ice cap by lower snow-storms which prevail there. Also in such conditions a negative snow balance is observed so the summit area and side walls remain ice free. Bell Zygmunt, The Tower, Siodło, Bastion, Red Hill and others belong to that type of nunataks. The term morphographic with regard to conditions has been used because the fact whether a given part of the area will be uncovered or covered with ice is connected with the elevation of a place and ice level, with the size shape, the gradient of slope of the summit area, its orientation etc., i.e. with a set of morphographic features.

Oases in their strict sense

The other category of areas free from ice comprises areas with such climatic conditions that do not permit the snow originating from precipitation to transform into glacial ice[2] because accumulation there is smaller or equal to ablation. It means that in the climatic conditions present in these areas glaciation cannot occur, on the other hand a set of other factors causes that these areas have not been covered by ice onflowing from other regions. As opposed to nunataks such areas can by called 'oases' be analogy to Antarctica (Korotkevič, 1969).

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[2] This does not refer to a situation where as a result of a set of specific factors snow blowing, avalanche etc.) in certain parts of such areas abnormal amount of snow has been accumulated. The amount of snow is too big for ablation and therefore transforms into glaciers, small glaciers or snow-patches. These forms of glaciation are treated as those occurring in the ice free area, i.e. not occurring below the ice cap of the main glacial system of the island

Having analysed the reasons that led to the occurrence of oases in the region of the Admiralty Bay we can group them into four types, namely:

- *Oases conditioned by dynamic - morphological factors.* These are areas in the vicinity of which the system of sculpture of ice bed and the position of icesheds make the ice move in different directions. The ice flows in such a way that it does not reach a given area. On the border with the oasis area there is a cover of passive ice, i.e. ice with no horizontal motion component. Thus, we can state that the occurrence of the oasis is to some extent conditioned by dynamic features of ice (being more specific the lack of such features) forming the adjacent glacier. In the adjacent area a set of geomorphological features of the oasis itself is equally important, as the oasis creates conditions which are good either for blocking or divergence of ice movement. As a result ice flows round the oasis whereas within its area there are no conditions for glaciation.

The region of the Arctowski Station is a good example of oasis conditioned by dynamic - morphological factors. It is the largest oasis of this type in the described area. Its surface is rising up to 190 - 240 m. a.s.l. in considerable part of this area, reaching its highest point with a hill SW of Italia Valley adjacent to the ice cap. That hill is oriented more or less NW - SE, whereas its sides slope down gently towards the ice cap. The ice flowing down towards that hill from Warszawa Icefield probably reaches topographic lows on its way which change the directions of its flow. Some ice flows down towards the Ezcurra Inlet via Dera and Rościszewski icefalls some groups and first flows down southwards then turns south-eastwards and swells the upper part of the Ecology Glacier (see Fig. 3). So, as a consequence, the ice on the adjacent hill would have to flow upwards in order to reach the area of the Arctowski Oasis. The bordering zone of that part of the ice cap which is adjacent to the oasis has been made up of passive ice, partly of passive ice of a snowdrift glacier. In this way the movement has been broken up, reorganised and behind the above mentioned hill there is an area protected against the inflow of ice. Also, on the southern side, i.e. on the side of Ecology Glacier the movement of ice towards the Arctowski Oasis is extremely difficult because the surface of that area rises up, too. On border with the Arctowski Oasis the Ecology Glacier forms a zone of less active ice which ends up as a zone of well - formed marginal forms. There are more oases of this type in the described area. One of them is a large Keller Peninsula Oasis where nunataks Tokarski Peak and then Mount Birkenmajer massif crash the ice flowing down the Arctowski Icefield into a stream forming the eastern part of Domeyko Glacier and into a stream forming Stenhouse Glacier, another one is an oasis in the region of Crepin Point, where the ice flowing down the Arctowski Icefield is crashed by Wegger Peak massif into two glaciers (Domeyko Glacier and Znosko Glacier). Another oasis of this type is Hennequin Point Oasis, where Mount Wawel massif protects that place against ice. Some others to be mentioned here are the oases of the region of Demay Point, Vauréal Cape, Ulman Spur, Precious Peak, Pond Hill and some others. The largest oases in the region of the Admiralty Bay belong to that group.

- *Oases conditioned by dynamic - climatic factors* are formed in such areas where the shape of the ice bed and the position of icesheds are such that cause such a small onflow of ice to the area of the oasis that even in average topoclimatic conditions the ablation is larger than the precipitation sum and the amount of onflowing ice. As a result, in spite of good relief conditions, i.e. not obstructing the ice to cover that area, the area remains ice free. It is obvious that such situation may occur only in these regions where the coastal parts of ice cap are formed by less-active glacial ice originating from ice sheet. The biggest oasis of this type is Sphinx Hill Oasis where the ice of Sphinx Glacier is less active and it not only does not form a stationary front but also undergoes recession making the oasis area bigger.

This type of oases comprises such oases as: Telefon Point Oasis (Patelnia), Blue Dyke Oasis, Sphinx Hill Oasis and Rescuers Hill Oasis. All of them are situated near the coast and their elevation above the sea level (apart from their rocky peaks) does not exceed 40 - 50 m.

- *Oases conditioned by topoclimatic factors* occur due to extremely good topoclimatic conditions. Apart from the fact, that scattered radiation is the main supply of radiant energy, the direct radiation may reach very big values in good weather and topographic conditions.

Such oases developed on slopes with northern i.e. warm and sunny exposition, generally on big rocky walls - sides of glacial troughs (U-shape) or fjord valley and above their crest ice caps are formed. Ice tongues go down the ice caps towards these slopes but in conditions with much bigger than average supply of radiant energy ablation reaches extremely big values and is larger than inflow of ice, so the glacial ice disappears (Styszyńska, 1995). Still, we can find there remnant ice tongues which were called hanging plateau glaciers.

Oases of this type are made us of rocky walls with big or very big gradient of slope. Very often the relative altitude of these walls exceeds 250 m. whereas horizontal extent 4 km (Cytadela). They are situated on the seaside (Cytadela, Szafer Ridge, Smok Hill) but also inlands (Klekowski Crag). The biggest oasis of this type is Cytadela extending on the southern slope of Ezcurra Inlet between Monsimet and Goulden coves.

- *Oases conditioned by topographic factors* most frequently are small forms of littoral accumulation. They appear in the beachy zone and are protected by places already ice free. If such protection did not appear it would be impossible for such forms to occur and exist. One can discuss whether the present dimensions of these forms justify calling them oases and incorporating them into this classification, especially as their bigger areas never appear individually.

Oases of this type at present appear and are formed independently and cover small areas (a few hectares). They are mobile forms, changing their dimensions and contours depending on the present direction and hight of waves and on the sea level. Some of them are of ephemeral character. One of example of such form can be hooked spit closing Denais Cove (Zabrze Cove) in Ezcurra Inlet.

Oases conditioned by dynamic - morphological, dynamic - climatic and topoclimatic factors are those areas which were formed long time ago in previous morfogenetic cycles. As ice covering them disappeared these areas were covered with forms of glacial accumulation and landforms corresponding to contemporary morfoclimatic ones such as nival, periglacial, corrasion and erosion landforms. Oases conditioned by topographic factors are new areas, which appeared only when this area experienced the process of deglaciation.

Forms of littoral accumulation which develop and join the areas free from ice in some places reached considerable areas and in some oasis make a big percentage of their areas. That is why some of the oases can be classed as a combined type made up of two types conditioned by dynamic - morphological factors with an oasis conditioned by topographic factors which joined them. They are oases such as Arctowski, Crepin Point, Keller Peninsula, Hennequin Point and Vaureal Peak. The buildings of the Arctowski Station are situated on the surface of an oasis conditioned by topographic factors which joined an oasis conditioned by dynamic - morphological factors.

This classification of areas free from ice did not incorporate different types of rocky reefs which permanently or periodically dry, tiny islets (e.g. Chabrier Rock) forming basset emerging above the water level and beaches along icy cliffs with their feet periodically submerged. This classification does not also cover areas of medial moraines, in which glacial ice is hidden below a stony cover.

POSSIBILITIES OF FURTHER TRANSFORMATIONS

The change of the present climatic conditions leading towards the increase in precipitation sums or decrease in mean temperatures or concurrently both will result in the increase in the thickness of ice sheet, in the change of position of icesheds and in changes in ice dynamics. This will cause the increased inflow of ice to the area of the oases and gradual ice covering. The first oases to disappear will be those conditioned by dynamic - climatic factors because the balance present there is most unstable. We can assume that the area of oases conditioned by dynamic - morphological factors will experience local glaciation which with the passing time will join the main glacial system of the island. The longest lasting, as we may assume, will be oases conditioned by topoclimatic factors and high nunataks. Such scenario of transformations of oases areas in the region of the Admiralty Bay now is very unlikely to come true.

The climatic changes, as observed since the foundation of the Polish Antarctic Station, H. Arctowski (1977-1999) cause that the snow accumulation on ice caps decreases and the intensity of ablation increases (statistically significant decrease in precipitation sums (Marsz, 1999) and increase in air temperature; Kejna, in press). The shortening of the period of sea ice cover occurrence in the Admiralty Bay which is a consequence of large-scale hydrological processes occurring in the Bellingshausen Sea and the Bransfield Strait prolongs the period of thermic abrasion of ice cliffs. As a result these cliffs withdraw quickly and the slopes within the outlet glaciers increase. The increase in the gradient of slopes makes the ice movement faster and causes that the altitudes of ice caps become lower which leads their apical parts into higher temperature zone. Due to the action of possitive coupling between these processes intensive deglaciation in the region of the Admiralty Bay has been observed in the last 20 years, as a consequence both the area of the Admiralty Bay has increased and as well as the area of land free from ice.

List of the areas (in km^2) and some of physical and geographical features of these areas free from ice in the region of the Admiralty Bay noted in Table 1, perhaps after some time will make the analysis of changes, that occurred in that region possible.

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Tab. 1 List of areas and main features of areas ice free in the region of the Admiralty Bay: S – area (km^2), TG – genetic type of a given area, CP – location (A – coastal, B – inland), H – altitudes (m. a.s.l.); the occurrence within the area: streams (P), small lakes (J), local glaciers (LL), permanent snow patches (TS); symbol '+' means that a given element is present within the borders of the area, '±' means that a feature occurs periodically.

No	Name of the ice free area	S [km^2]	TG	CP	H [m. a.s.l.]	Presence			
						P	J	LL	TS
1	Red Hill	0.3875	O1	A	40 - 150	-	-	-	-
2	Patelnia (Telefon Point)	0.1375	O2	A	0 - 20	±	+	-	-
3	Blue Dyke	0.2788	O2	A	0 - 120	+	-	-	-
4	Demay Point	1.4813	O1	A	0 - 170	+	-	-	-
5	Bastion	0.0853	N2	B	160 - 250	-	-	-	-
6	The Tower	0.0456	N2	B	290 - 370	-	-	-	+
7	Brama	0.2000	N1	B	185 - 240	-	-	-	-
8	Siodło	0.0413	N2	B	80 - 155	-	-	-	+
9	Zamek	0.1313	N2	B	200 - 340	-	-	-	+
10	Sphinx Hill with Błaszyk Moraine	0.5800	O2	A	0 - 160	+	+	-	-
11	Rescuers Hills	0.4688	O2	A	0 - 125	±	+	-	+
12	Arctowski Station Oasis	4.1938	O1	A	0 - 284	+	+	+	+
13	Breccia Crag	0.2600	O2	A	0 - 200	-	-	-	-
14	Cytadela	1.1938	O3	A	0 - 290	+	-	-	-
15	Belweder	0.1771	N1	A	0 - 290	-	-	-	-
16	Scalpel Point	0.0456	N1	A	0 - 135	-	-	-	-
17	Pond Hill	0.4100	O1	A	0 - 190	-	+	-	+
18	Dufayel Island	0.4438	N1	A	0 - 205	-	-	-	-
19	Nunataks of the Ladies Icefall-Urbanek Crag	x	N1	B/A	0 - 315	-	-	-	-
20	Klekowski Crag	0.2625	O3	B	30 - 330	-	-	-	-
21	Admiralen Peak	0.0206	N1	B	270 - 340	-	-	-	+
22	Komandor Peak	0.1100	N1	B	180 - 305				+
23	Crepin Point	0.4413	O1	A	0 - 320	+	+	-	-
24	Cockscomb Hill	0.0250	N1	B	80 - 145	-	-	-	-
25	Garnuszewski Peak	0.0268	N1	B	300 - 340	-	-	-	-
26	Keller Peninsula	4.1875	O1	A	0 - 335	+	+	+	+
27	Shark Finn	0.0188	N1	B	120 - 220	-	-	-	-
28	Stenhouse Bluff	0.0831	O1	A	0 - 55	-	-	-	-
29	Ullman Spur	1.3038	O1	A	0 - 290	±	-	-	+
30	Precious Peaks	0.6313	O1	A	0 - 360	-	-	-	+
31	Ternyck Needle	x	N1	B	330 - 440	-	-	-	-
32	Szafer Rifge	0.3325	O3	A	0 - 240	-	-	-	+
33	Tern Nunatak	0.0228	N1	B	220 - 270	-	-	-	-
34	Warkocz	0.2000	O3	A	0 - 300	±	-	-	-
35	Smok Hill	0.5018	O3	A	0 - 260	+	-	-	-
36	Mount Wawel (Hennequin Point)	1.2975	O1	A	0 - 290	±	+	-	+
37	Bell Zygmunt	x	N2	B	150 - 220	-	-	-	+
38	Manczarski Point	x	O4	A	0 - 15	-	+	-	-
39	Rembiszewski Nunataks	x	N1	B	100 - 180	-	-	-	-
40	Puchalski Peak	x	N1	B	130 - 170	-	-	-	-
41	Vauréal Peak	0.2019	O1	A	0 - 185	±	+	-	-
42	Harnasie	0.3662	O3	A	0 - 120	±	-	-	-

The total area of ice free areas (without reefs and beaches emerging during ebbs, tiny islets, etc.) – 21.828 km^2 :

- the area of glaciers and snow patches present in that region – 1.8131 km^2,
- the area of lakes and small lakes – 0.0814 km^2

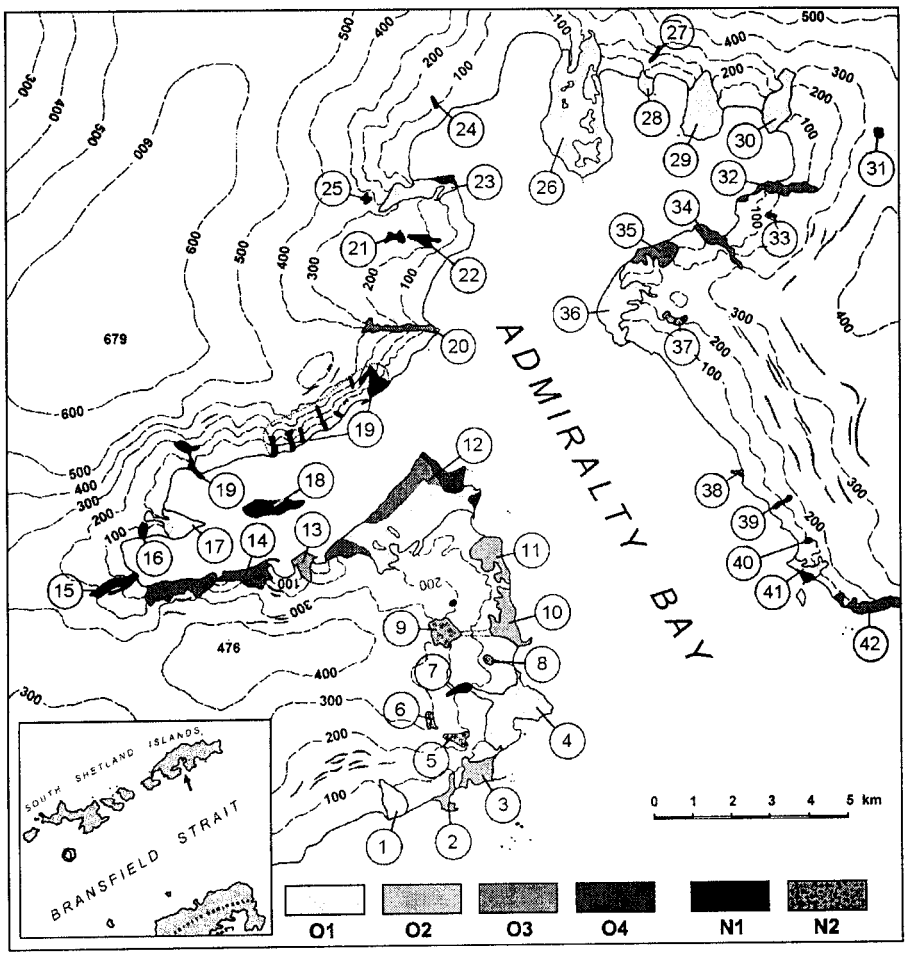

Fig. 1 The areas free from ice and snow in the region of the Admiralty Bay. Genetic types present in that area:

- nunataks conditioned by hypsometric factors (N1),
- nunataks conditioned by morphographic factors (N2),
- oases conditioned by dynamic – morphological factors (O1),
- oases conditioned by dynamic – climatic factors (O2),
- oases conditioned by topoclimatic factors (O3),
- parts of oases conditioned by topographic factors (O4),
- number of ice free area.

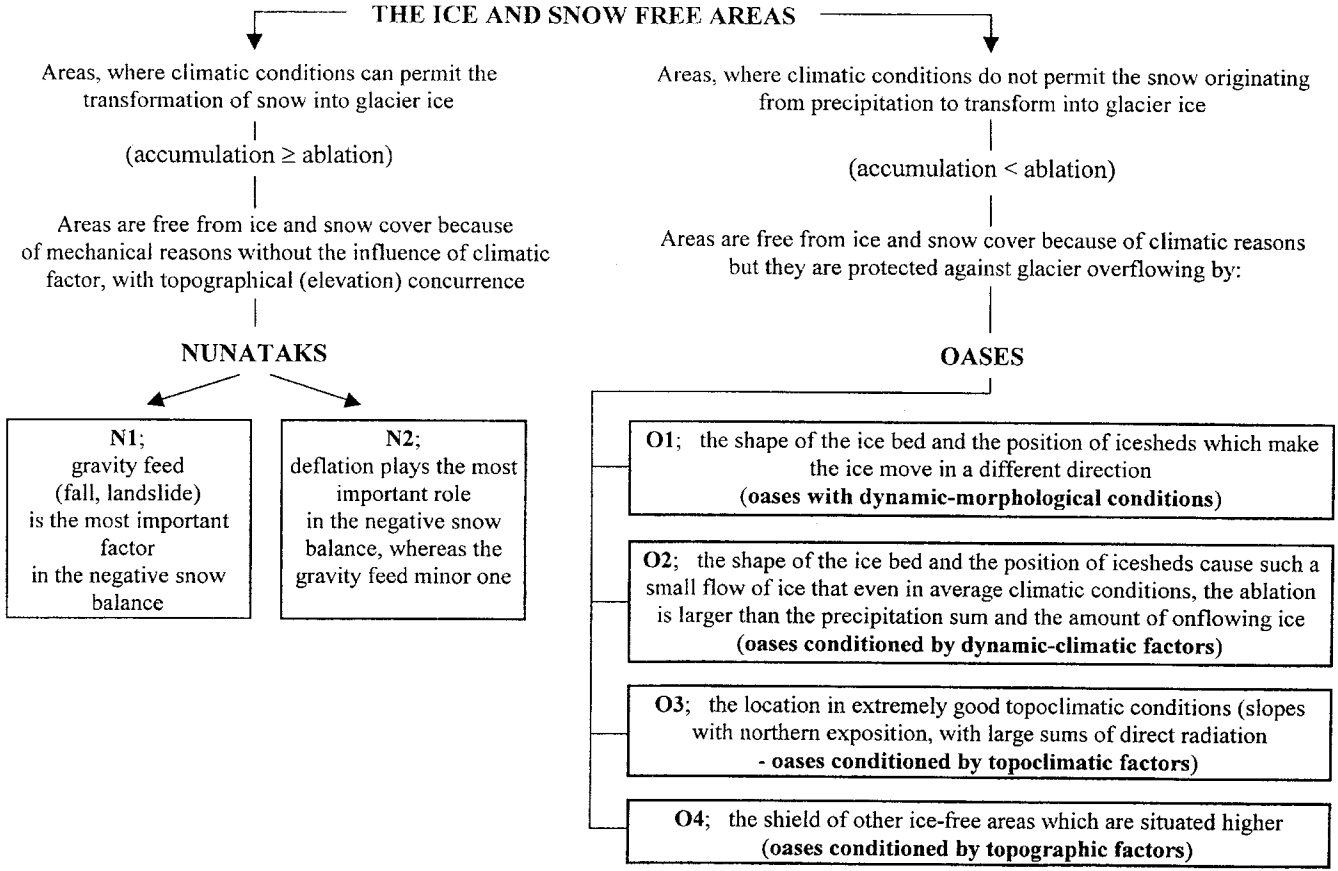

Fig. 2 Schematic diagram of classification of areas free from ice in the region of the Admiralty Bay.

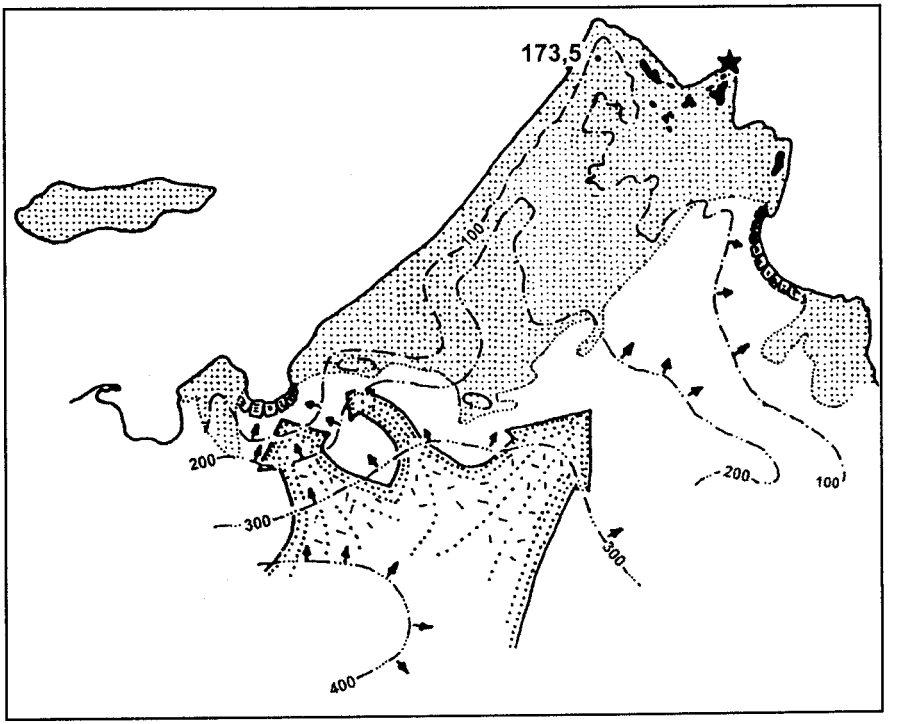

Fig. 3 Hypsometry and lay-out of ice movement protecting the area with Arctowski Station Oasis against 'flooding' by glacial ice.