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The geoecosystem of polar oases within the ice drainage basin of Admiralty Bay, King George Island, Antarctica

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Introduction

The paper presents the results of a research into the geoecosystems of polar oases located on King George Island in the South Shetlands in the Maritime Antarctic. The recession of glaciers brings about an expansion of ice-free areas, landform metamorphoses, changes in land cover, redeposition of sedimentary covers, changes in the water cycle and mineral circulation, and finally a transformation of landscapes in the ice drainage basin of Admiralty Bay. The increase in ice-free areas observed in the 20th century is variable but quite rapid (Zwoliński 2007).

Corresponding to ice-free areas, the geoecosystems of polar oases have a relatively narrow range of geomorphic functioning since they are largely determined by the duration of snow and glacier covers and the accessibility and amount of solar energy reaching the Earth surface. The great significance of the geoecosystems of polar oases in the modern sub-Antarctic zone is due to the following:

– areas emerging from under ice, which are sites of a fast landform evolution, fast changes in the land cover and fast landscape transformations, and consequently of a rapid geosuccession due to the rebuilding of the internal structure of those geoecosystems,
– areas with distinct qualitative changes, mainly involving energy and matter,
– extensive, exposed areas susceptible to all morphogenetic factors such as sunshine, wind, water, snow, ice, gravitation and, increasingly, man,
– degraded periglacial landforms, highly sensitive to even the slightest climate change,
– manifestations of succession and biological colonisation, including communities of lichens, mosses and lower plants, and colonies of birds and pinnipeds as well as communities of the freshwater fauna,
– the potential space for settlement (at present mainly in the form of scientific stations and research sites), conducting of various types of economic activity (mainly mining), and a growing penetration by tourists.

Study area

The South Shetland Islands are located between two continents: Antarctica (the Antarctic Peninsula) in the south and South America (Tierra del Fuego) in the north, and between two ocean basins: the Pacific (the Bellingshausen Sea) in the west and the Atlantic (the Weddell Sea) in the east. This makes the waters surrounding the archipelago highly dynamic: they form a peculiar, internally mobile oceanographic junction which exerts a great influence on the dynamics of atmospheric and oceanic processes, and thus on the geomorphic processes within the terrestrial geoecosystems of polar oases.

In the drainage basin of Admiralty Bay within King George Island (Fig. 1), four morphogenetic microchores (types of terrain) were distinguished: 1. glacial, 2. postglacial and periglacial, 3. periglacial and 4. non-glacial, which belong to the category of paraglacial areas.

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Table 1. Area dynamic of polar oases within drainage basin of Admiralty Bay in years 1979–1988

No.	Name of polar oasis	Area [km²]					Rates [km^2a^{-1}]	
		1979		1988	Difference			
		(A)	(B)	(C)	(C-A)	(C-B)	for (C-A)	for (C-B)
1	Red Hill	0,38750	0,29251	0,43315	0,04565	0,14064	0,00457	0,01406
2	Patelnia (Telephone Point)	0,13750	0,22959	0,22880	0,09130	-0,00079	0,00913	-0,00008
3	Blue Dyke	0,27875	0,41434	0,46547	0,18672	0,05113	0,01867	0,00511
4	Demay Point	1,48125	1,64770	1,62575	0,14450	-0,02195	0,01445	-0,00220
5	Bastion	0,08530	0,12383	0,13538	0,05008	0,01154	0,00501	0,00115
6	The Tower	0,04560	0,07556	0,08373	0,03813	0,00817	0,00381	0,00082
7	Brama	0,20000	0,10817	0,12763	-0,07237	0,01946	-0,00724	0,00195
8	Siodło	0,04125	0,02989	0,04296	0,00171	0,01306	0,00017	0,00131
9	Zamek	0,13125	0,24717	0,37457	0,24332	0,12740	0,02433	0,01274
10	Sphinx Hill + Błaszyk Moraine	0,58000	0,67765	0,73803	0,15803	0,06038	0,01580	0,00604
11	Rescuers Hills	0,46875	0,52326	0,62168	0,15293	0,09842	0,01529	0,00984
12	Arctowski Oasis	4,19375	4,48843	4,69146	0,49771	0,20303	0,04977	0,02030
13	Breccia Crag	0,26000	0,21332	0,24321	-0,01679	0,02989	-0,00168	0,00299
14	Cytadela	1,19375	1,13419	1,21059	0,01684	0,07640	0,00168	0,00764
15	Belweder	0,17708	0,28272	0,29423	0,11715	0,01151	0,01171	0,00115
16	Scalpel Point	0,04560	0,04719	0,08168	0,03608	0,03450	0,00361	0,00345
17	Pond Hill	0,41000	0,49514	0,51996	0,10996	0,02482	0,01100	0,00248
18	Dufayel Island	0,44380	0,45625	0,47801	0,03421	0,02176	0,00342	0,00218
19	Nunataki Emerald Icefall		0,61951	0,72125	0,72125	0,10174	0,07213	0,01017
20	Klekowski Crag	0,26250	0,30622	0,32367	0,06117	0,01746	0,00612	0,00175
21	Admiralen Peak	0,02060	0,06887	0,05050	0,02990	-0,01837	0,00299	-0,00184
22	Komandor Peak	0,11000	0,13457	0,14745	0,03745	0,01289	0,00375	0,00129
23	Crepin Point	0,44125	0,70141	0,75251	0,31126	0,05109	0,03113	0,00511
24	Cockscomb Hill	0,02500	0,01701	0,01434	-0,01066	-0,00267	-0,00107	-0,00027
25	Garnuszewski Peak	0,02680		0,03297	0,00617	0,03297	0,00062	0,00330
26	Keller Peninsula	4,18750	2,67146	3,15485	-1,03265	0,48339	-0,10327	0,04834

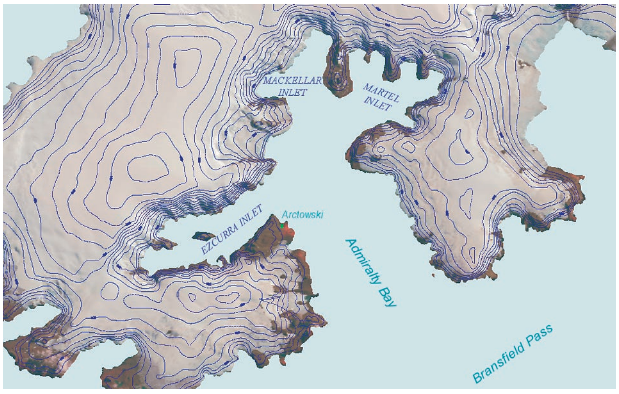

Fig. 1. Polar oases within drainage basin of Admiralty Bay on the background of ice caps' hypsometry (Project KGIS 2005, changed)

Overview of polar oases

The studies performed during a 4-year campaign corroborated the following regularities observed in polar areas (Zwoliński 2007):

– exceeding of the hitherto absolute maxima of air temperature at the Arctowski Station,
– an increase in annual precipitation totals at the Arctowski Station, first of all in the form of rain, also during the cold period,
– cold periods on King George Island becoming shorter and climatically milder,

No.	Name of polar oasis	Area [km^2]					Rates [km^{2}a^{-1}]	
		1979		1988	Difference			
		(A)	(B)	(C)	(C-A)	(C-B)	for (C-A)	for (C-B)
27	Shark Finn	0,01875	0,01830	0,04520	0,02645	0,02690	0,00264	0,00269
28	Stenhouse Bluff	0,08312	0,11265	0,09337	0,01025	-0,01928	0,00102	-0,00193
29	Ullman Spur	1,30375	1,22184	1,28726	-0,01649	0,06541	-0,00165	0,00654
30	Precious Peaks	0,63125	0,75084	0,74226	0,11101	-0,00858	0,01110	-0,00086
31	Ternyck Needle		0,03045	0,04183	0,04183	0,01138	0,00418	0,00114
32	Szafer Ridge	0,33250	0,31961	0,36199	0,02949	0,04238	0,00295	0,00424
33	Tern Nunatak	0,02280	0,01751	0,02194	-0,00086	0,00443	-0,00009	0,00044
34	Warkocz	0,20000	0,28403	0,30464	0,10464	0,02061	0,01046	0,00206
35	Smok Hill	0,50180	0,46810	0,44932	-0,05248	-0,01878	-0,00525	-0,00188
36	Mount Wawel (Hennequin Pt)	1,29750	1,02270	1,13405	-0,16345	0,11134	-0,01635	0,01113
37	Bell Zygmunt		0,05262	0,12136	0,12136	0,06875	0,01214	0,00687
38	Manczarski Point		0,06905		0,00000	-0,06905	0,00000	-0,00691
39	Rembiszewski Nunataks		0,03556	0,03658	0,03658	0,00102	0,00366	0,00010
40	Puchalski Peak		0,02056	0,02568	0,02568	0,00513	0,00257	0,00051
41	Vauréal Peak	0,20190	0,25391	0,28158	0,07968	0,02767	0,00797	0,00277
42	Harnasie	0,36620	0,51857	0,38814	0,02194	-0,13043	0,00219	-0,01304
43	Czajkowski Needle		0,03283	0,02430				
44	Northern Sphinx Hill		0,01697	0,10624				
45	Table Hill		0,00611	0,00984				
46	Three Musketers		0,02211	0,03496				
47	Krak Glacier		0,03726	0,07878				
48	Chabrier Rock		0,05548	0,06477				
49	Polar Club Glacier			0,02885				
50	Northern Blue Dyke			0,01844				
51	Baranowski Glacier			0,05901				
52	Ecology Glacier			0,06247				
53	Doctors Icefall			0,02799				
54	Dobrowolski Glacier			0,02145				
	Area of oases:	20,59435	21,37302	23,46612	Average rates:		0,00556	0,00411

- transitional periods in the South Shetland Islands becoming longer: spring comes earlier and autumn ends later,
- a decrease in the thickness, duration and spatial range of the sea-ice cover in Admiralty Bay,
- an increase in the temperature and a decrease in the salinity and density of the bay waters,
- an increase in the number of ice-floes and growlers from glaciers in the Admiralty Bay catchment,
- intense ablation and rapid recession of the majority of glaciers in the vicinity of Admiralty Bay,
- a decrease in the area of nival covers in the Admiralty Bay drainage basin,
- intensive thawing of the multi-year permafrost in the Admiralty Bay drainage basin,
- changes in the land water cycle manifested by an increase in the surface runoff in streams and a shortening of the freezing period for streams and lakes in the Admiralty Bay drainage basin,

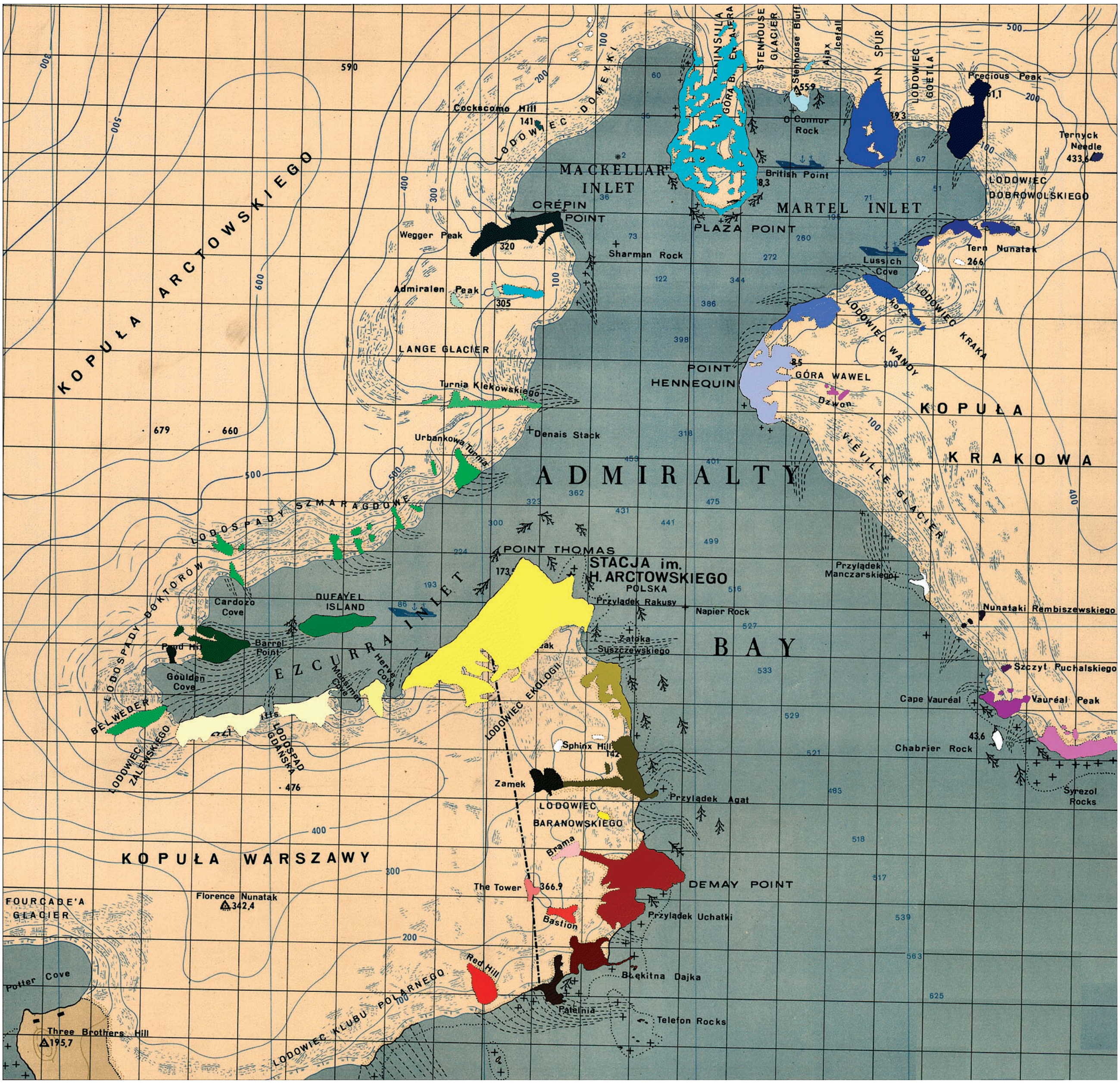

Fig. 2. Spatial pattern of polar oases on the topographic map „Zatoka Admiralicji" (ZBP IE PAN) in scale 1:50 000 according to data from January 1979

- a growing area of surfaces saturated with meltwater from degraded buried ice-cores in marginal zones of glaciers in the vicinity of the Admiralty Bay, and
- a shift of geoecological zones in the Admiralty Bay drainage basin.

The effect of the above set of causal and resultant tendencies is that an ever-growing amount of mineral matter (rock waste, morainic and diamicton covers) is transferred within areas newly exposed from beneath glaciers and ice caps. As a consequence, there is a rapid change in the initial topographic surface, the inclusion of mineral matter into the transport, a transformation of various types of cover deposits, and the formation of new landscapes, mainly postglacial/non-glacial hybrids. This makes landscape transformations a common phenomenon in the paraglacial zones.

Spatial pattern of polar oases

In the distribution of oases in the surroundings of Admiralty Bay (Fig. 2 and 3) several regularities can be observed (Zwoliński 2002, 2007):

- most of the oases are located in maritime situations in which at least one of their sides meets the bay waters; only a few oases or nunataks occur in places surrounded on all sides by glacier ice;
- the greatest number of oases occur on north-facing slopes, e.g. the southern shores of the Ezcurra

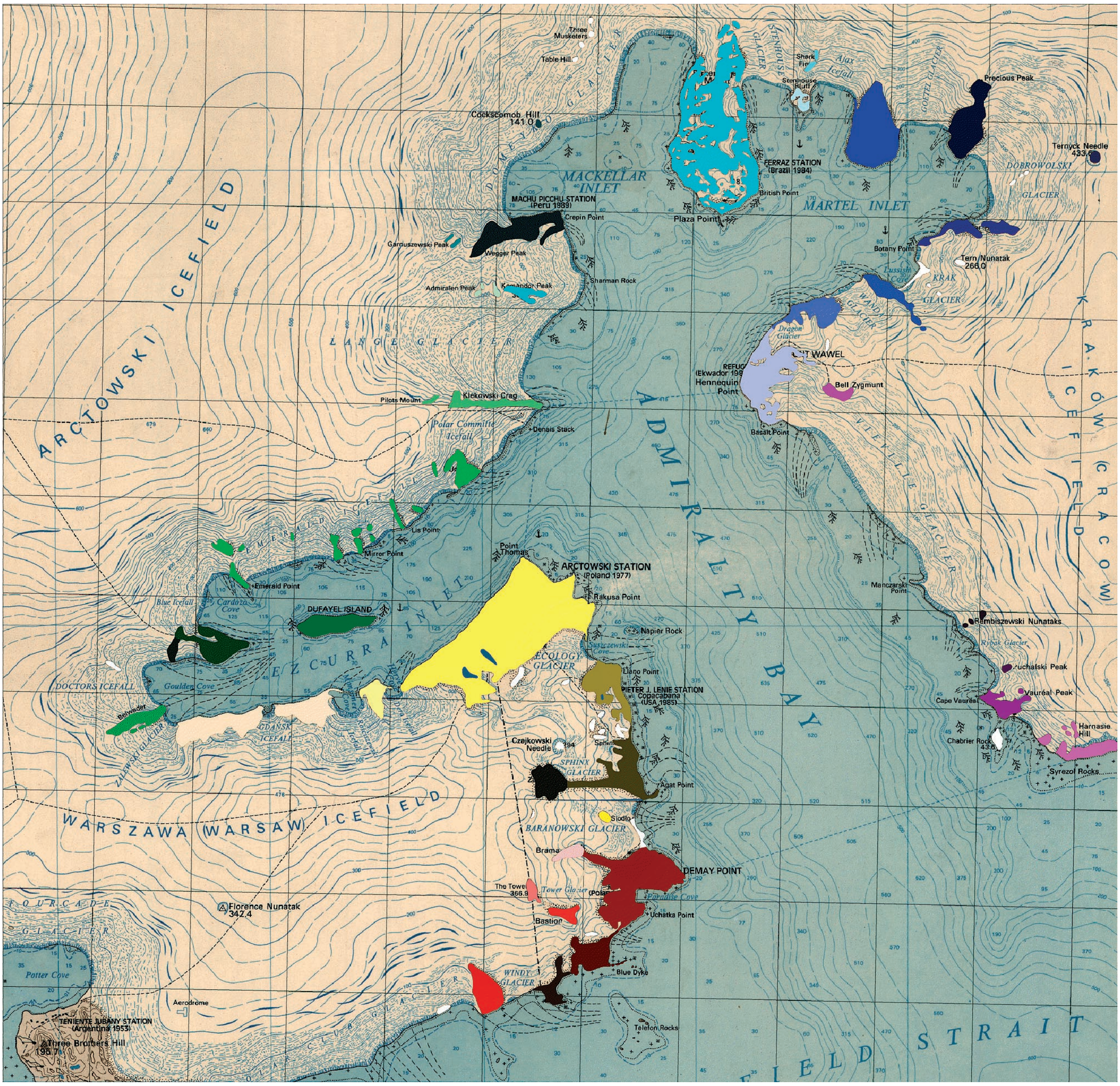

Fig. 3. Spatial pattern of polar oases on the topographic map „Admiralty Bay" (Battke 1990) in scale 1:50 000 according to data from 1988

and Martel Inlets; this is connected with the prevailing direction of incoming solar radiation irrespective of the season of the year;

- on south-facing slopes the oases are sporadic and small because solar radiation either does not reach them at all or its access is limited, e.g. the northern shores of the Ezcurra and MacKellar Inlets;
- generally, on the eastern shore of Admiralty Bay there are no oases due to intensive glacier alimentation from the Cracow Cap; and
- on the western shore numerous small oases have developed as an effect of the dying out of the Warsaw Cap, which is not directly supplied from the centrally located Arctowski Cap.

The above distribution of oases clearly indicates that it is dependent on the climatic and topoclimatic conditions, primarily on the exposure and ice balance of the icefields. Superimposed on these characteristic features of oases throughout the whole area is its geological-morphological aspect, i.e. the occurrence on the bedrock of rock ranges and massifs resistant to denudation processes and hence being natural places for oases to develop. The spatial pattern of oases in the Admiralty Bay drainage basin can be considered a regularity in the polar sub-Antarctic zone because similar locations can also be observed in the whole of King George Island as well as the other islands of the South Shetland archipelago.

Matter flux in polar oases

From the point of view of the mobility of mineral matter, the following properties of the geoecosystems of polar oases in sub-Antarctic islands should be emphasised:

– the occurrence of a debris, morainic or waste cover under which glacier ice may be buried,
– frequent changes in the morphological surface, including hypsometric changes,
– a climate distinct from that of the surroundings,
– air and ground temperatures above 0°C, at least at the height of the warm period,
– the occurrence of water flow in the systems of streams and lakes which thaw during summer, but also the occurrence of water as ground moisture,
– the formation of initial soil covers, and
– a gradual appearance of conditions for the succession and development of biological life.

The system of mineral matter cycle within modern terrestrial sub-Antarctic geoecosystems is third in importance in the Admiralty Bay drainage basin after the climatic and hydrological systems. The boundaries of the matter cycle system are fuzzy, zonal and permeable in any direction and through any medium. This makes it susceptible to a dynamic exchange of energy and matter with the adjacent systems. That is why the thickness of a 3–dimensional solid representing the matter cycle varies spatially and in the case of the Admiralty Bay drainage basin depends on at least three factors:

– the altitude of the bedrock, which is a resultant of the geological history of the Scotia Arc and the previous and modern history of volcanism, tectonic and isostatic movements,
– the thickness of the ice caps, which is the effect of the snow-ice mass balance, and hence of the alternate advances and recessions of glaciers,
– the occurrence of coastal and inland oases and their areal expansion.

Concluding remarks

The glacier recession, expansion of ice-free areas, and paraglacial transformations of the land cover, water cycle, mineral matter circulation, sedimentary covers, landforms, and finally of the landscapes in the Admiralty Bay drainage basin, became an inspiration for the formulation and development of the conception of geosuccession and its justification in theoretical and application terms. The result of a geosuccession is an overlap of qualitative and quantitative changes in the weathering, denudation, transport and deposition processes occurring at any spatial-temporal scale and leading to transformations in the style of functioning of morphogenetic domains. The change in morphogenetic domains expresses changes in the nature of the relief and its forms, and as a consequence, changes in the landscape caused by the interchangeability of dominant and secondary processes. The sensitivity of these domains is evidence of an enrichment or impoverishment of the geodiversity of the given polar area.

Among the key features of the presently forming paraglacial areas within the geoecosystems of polar oases are high-energy, fast morphological and depositional changes as well as the freshness and youth of landforms and sedimentary covers, hence great geomorphic dynamics. The modern environments of polar oases are highly tender geoecosystems sensitive to changes in and variability of geographical conditions, from the local through regional to the global scale. Therefore features of areas in the sub-Antarctic zone may be treated as very precise geoindicators and bioindicators of present-day environmental changes, showing the direction and rate of transformations in the abiotic (Table 1) and biotic environments.

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