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The hydrography of Admiralty Bay and its inlets, coves and lagoons (King George Island, Antarctica)

ABSTRACT: The environments of inlets, coves and lagoons varies widely. Climate warming has lead to retreat of glaciers directly entering the sea. In lagoons this is accompanied by exposure of an uncolonized substratum. Colonization processes in these lagoon appear to describe processes which have previously occurred in bays and fjords of glacial origin in the South Shetlands.

Key words: Antarctica, South Shetland Islands, environments (fjord, cove, lagoon).

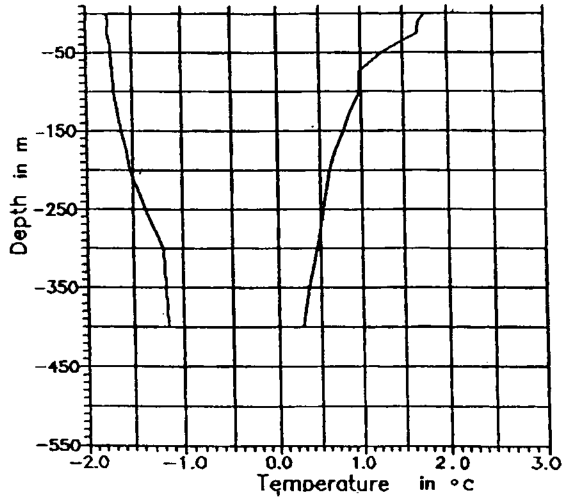
Admiralty Bay is fjord like in nature (Fig. 1), a straight line joining Demay Point and Syrezol Rocks is considered as the boundary of the bay, which is the largest in the South Shetlands.

The bay's shoreline extends 83.4 km of which Ezurra Inlet accounts for 25.3 km, and MacKellar and Martel inlets combined for 36.0 km. The ice shore is 38.9 km long, of which 16.4 and 2.4 are respectively submerged and emerged. Although the ice fronts are generally above 20 metres in height, large icebergs are not produced. Ice-free shores cover 44.5 km of which sandy/stony areas account for 42.7 km and rock cliffs for 1.8 km.

The bay covers some 122.08 km^2 (Battke 1990), of which the main body covers 52.3%, with MacKellar and Martel inlets together constituing 31.5%, and Ezcurra Inlet the remaining 16.2%. The bay's mean depth is 198.6 m, with the deepest part attaining some 535 m; Ezcurra, MacKellar, and Martel inlets are considerably shallower. These inlets from post-glacial hanging valleys (Marsz 1983) situated above the central basin of Admiralty Bay, the latter opening widely into the Bransfield Strait.

Of the bay's total volume of some 24.24 km^3, Ezcurra Inlet comprises only 1.96 km^3, and MacKellar and Martel inlets together 4.43 km^3. According to the bathymetric map produced by Szeliga (1991), and Szeliga and Rakusa-Suszczewski (1994), the mean depth of the Central Basin of the Bransfield Strait is 630 metres, and the surface area 30913.4 km². The volume therefore amounts to some 19477 km³. If we consider the volume of water in the Central Basin of the strait to a depth of 500 metres to be 3305 km³, the water in Admiralty Bay constitutes only 0.7% of this amount.

A full year's observations of the movement of icebergs in front of the entrance to the bay (Madejski and Rakusa-Suszczewski 1990), on the southern



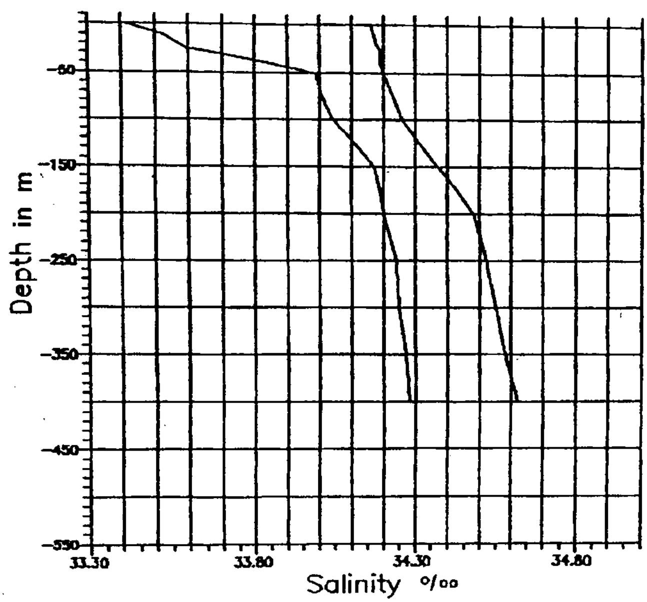


Fig. 2 a, b. Extreme values of temperature (a) and salinity (b) in the central part of Admiralty Bay 1979, according to Lipski (1987).

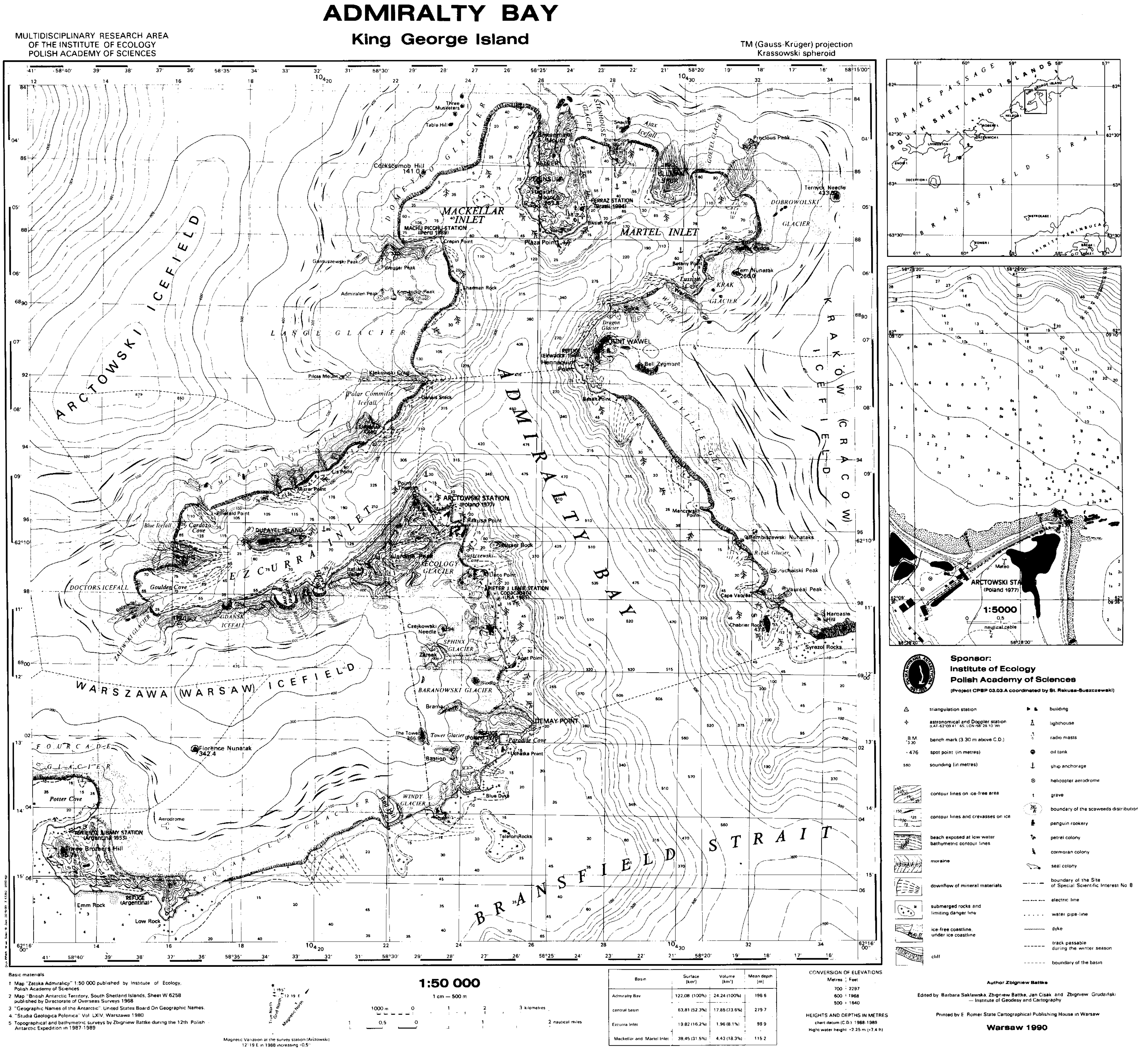


Fig. 1. Map of Admiralty Bay.

shores of King George Island, indicated the presence of a permanent current flowing in NE and ENE directions; its velocity between February–April, May–July, and August–September amounted to 60–90 cm s^{-1} 10 and 40–60 cm s^{-1} respectively. Through the Bransfield Strait these waters can also flow into Admiralty Bay.

About 30% of the bottom of Admiralty Bay is covered by macroalgae. Kelps are attached to the bottom to 90–100 m depth. The total biomass of macroalgae in the bay was estimated by Zieliński (1990) at approximately 74000 tons. Total zoobenthos biomass in Admiralty Bay was estimated by Jażdżewski and Siciński (1993) at about 67748 tons wet weight. The type of substrata in Admiralty Bay also affect the specific composition of benthic fauna (Siciński 1993, Jażdżewski *et al.* 1986).

During the year in the central part of Admiralty Bay, temperature and salinity of surface water vary (Fig. 2a–b) from −1.77° to 1.76° and 33.41‰ to 33.97‰ and at 400 m depth from −1.15° to 0.28° and 34.40‰ to 34.49‰ respectively (Lipski 1987, Sarukhanyan and Tokarczyk 1988). The mean annual temperature over the water column is −0.4°C. In summer, on windless days, water in the shore zones may warm to 5.3°C, but in the vicinity of glacier water, temperature remains negative. Water salinity changes markedly in summer because of the intensive inflow of water from land and glacial run-off. In surface layers of the nearshore zone salinity fluctuates between 16.4‰ to 34.16‰ (Szafrański and Lipski 1982). Oxygen concentration in Admiralty Bay changes in an annual cycle, with highest saturation in winter. Under a compact ice, oxygen content decreases until ice break-out.

In the intertidal zone rock pools are common. In such habitats temperature can exceed over 12°C and salinity varies from a few to more than 40‰ (Rakusa-Suszczewski 1993).

Inlets. Intensive deglaciation as a result of climate warming in the South Shetland (Martianov and Rakusa-Suszczewski 1990, Rakusa-Suszczewski *et al.* 1993a) has lead to retreat of those glaciers which directly enter the sea. Such a phenomenon has occurred in the past, as evidenced by the morphometry of Admiralty Bay (Marsz 1983, Battke 1990, Rakusa-Suszczewski *et al.* 1993b). Both in the central basin of the bay, as well as in front of glaciers flowing into its inlets, submerged terminal moraines are shown on the bathymetric chart (*cf.* Battke 1990, Fig. 1).

Hydrological and hydrochemical conditions in the inlets differ from those in the main basin of Admiralty Bay, Szafrański and Lipski (1982) reported that lowest temperatures and salinities occur at the surface in Ezcurra and MacKellar inlets in front of glaciers. Furthermore, both inlets contain the lowest levels of chlorophyll α (Tokarczyk 1986), but the highest quantities of silica (Table 1), possibly as a result of upwelling (Rakusa-Suszczewski 1980, Lipski 1987). Compared with bays such as Arthur Harbour or Paradise Harbour, Admiralty

Bay is charactized by about tenfold lower concentrations of chlorophyll during summer blooms. Throughout the bay, temperature, salinity, silica, and chlorophyll α show little variation due to mixing by winds and currents (Table 1).

Table 1

Temperature, salinity, silica, and chlorophyll α content, in the surface waters of Admiralty Bay at three stations; 18 — Goulden Cove; 8 — entrance to Ezcurra Inlet; 20 — exit from Admiralty Bay to the Bransfield Strait. (Lipski, *unpubl.*)

Station	Data	T °C	S‰	Si μgat.dm^{-3}	Chl. a mg·m^{-3}
18	25.01.1979	1.36	33.74	84.4	0.27
8		1.62	33.84	83.0	0.36
20		1.60	33.90	77.4	0.86
18	15.02.1979	1.06	33.92	88.7	0.82
8		1.38	33.96	86.0	1.59
20		1.65	34.01	80.4	2.05
18	12.05.1979	−0.84	33.95	84.1	0.21
8		−0.67	33.92	82.9	0.21
20		−0.98	33.96	81.8	0.23
18	12.09.1979	−1.70	34.05	87.5	0.17
8		−1.67	34.13	85.2	0.15
20		−1.64	34.13	86.5	0.13
18	23.11.1979	−0.62	34.05	87.5	0.30
8		−0.59	34.10	86.5	0.35
20		−0.57	34.09	84.0	0.48

Goulden, Cardozo, Monsimet and Herve coves in the western and southern part of Ezcurra Inlet are usually frozen during winter, with the duration of ice cover exceeding that usually seen in the rest of the bay.

Greatest local variation is noted in the amount of suspended mineral matter; this enters with freshwater, and as mud from below glaciers (Pęcherzewski 1980, Kozik 1982), and is carried by wind from the land (Krajewski 1986). According to observations carried out by Piechura (*personal commun.*), the amount of mineral matter transported as a result of aeolian processes seems to exceed that introduced in glacial meltwaters.

The amount of mineral matter determines water transparency, and this is considerably lower in the vicinity of glaciers than in the waters at the bay's opening to the Bransfield (Gurgul *et al.* 1992). According to Gurgul (1993) mineral particles suspended in the water of Ezcurra Inlet are generally of 2 – 3 μm diameter with the largest attaining 8 μm. Along a transect from the centre of the bay (station 5) to Goulden Cove (station 18) levels of suspended mineral matter may vary during summer from 10 to over 100 mg m^3 (Pęcherzewski 1980). The total amount of inorganic suspensions over the period of a year in Admiralty Bay varies from 32264 to 171000 tonnes (Rakusa-Suszczewski 1995).

In front of the glacier in MacKellar Inlet, there have been several instances noted of considerable amounts of dead and decomposing krill (as judged by the smell) at the bottom. The cause of this phenomenon is not quite clear, but it is possible that contact with freshwater, or perhaps high levels of suspended material interfere with the animals swimming or feeding ability, *etc.* This may lead to mass mortality of krill *E. superba.* Considerable quantities of mineral particles have been found by Ligowski (*personal commun.*) in krill (*E. superba*) stomach, a planktonic grazer.

The light regime is mainly influenced by living and dead particulate material and by dissolved organic matter. In Admiralty Bay, during summer, the mean of the 1% depth observations for PAR (Photosynthetically available radiation) UV-a and UV-b are 35 m, 29 m and 18 m respectively. Penetration of light in to the water columne is much deeper than in other coastal areas of the world (Vosjan and Pauptit 1992).

Table 2

Granulometric composition of bottom sediments in three areas of Ezcurra Inlet (Admiralty Bay) Goulden Cove (GC), Cardozo Cove (CC), Mirror Point (MP) (Błaszyk, *unpubl.*) and organic matter as a % of dry weight of sediments (combustion at 430° C, Wiśniewski, *unpubl.*)

Sample		Depth in m.	Fraction in % of dry weight Gravel 2 mm	 Sand 2–0.063 mm	 Mud <0.063 mm	Organic matter % of dry weight
1	GC	50	4.4	52.6	43.0	2.3
4	GC	33	14.9	55.1	30.0	1.3
6	GC	35	19.5	52.4	28.1	1.6
7	GC	35	9.8	67.9	22.3	1.3
10	GC	20	12.5	51.8	35.7	1.7
11	GC	18	20.8	43.8	35.4	1.4
12	GC	22	5.2	78.3	16.5	1.7
16	GC	68	29.2	43.2	27.6	2.3
18	GC	73	33.1	37.7	29.2	2.4
21	GC	68	15.4	53.0	31.6	1.9
25	GC	82	19.9	55.6	24.5	3.2
1	CC	31	14.0	64.8	21.2	2.2
3	CC	31	24.4	64.5	11.1	1.0
6	CC	50	21.2	65.7	13.1	0.9
8	CC	57	21.9	61.0	17.1	1.9
9	CC	48	18.2	61.4	20.4	0.9
14	CC	55	9.9	68.2	21.9	1.9
16	CC	53	19.3	67.5	13.2	2.1
23	CC	84	30.3	53.9	15.8	1.4
24	CC	85	18.3	63.4	18.3	1.6
12	MP	125	18.3	51.5	30.2	0.9
13	MP	125	41.8	35.2	23.0	2.0
14	MP	125	14.4	55.2	30.4	1.2
$\Sigma \pm$S.D.			19.0$\pm$8.5	56.7$\pm$10.2	24.0$\pm$8.1	1.7$\pm$0.6

Sediments in both the inlets and deeper parts of the bay contain gravel, sand, mud and clay. The granulometric composition of sedimented material in Ezcurra Inlet (analysed by J. Błaszyk — Table 2) is described as follows: 19% — gravel, 56.7% — sand, 24% — mud. The organic matter content of deposits in Ezcurra Inlet varied from 0.9% to 2.3% of its dry weight (Table 2). Sizes of mud and clay (50—95 μm) particles on the bottom exceed those of mineral particles in suspension (up to 8 μm) *see* Gurgul (1993).

Coves and lagoons. These are a characteristic feature of the shoreline in the South Shetlands Archipelago, being found mainly in the larger bays straits and

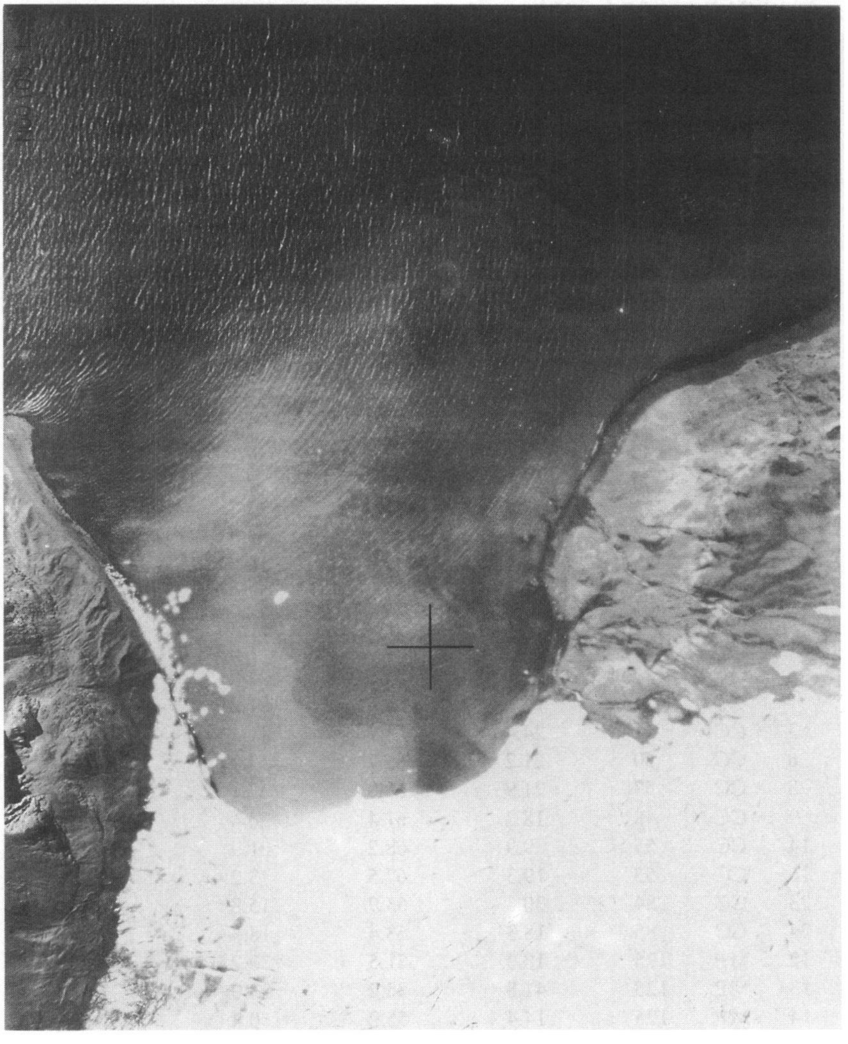


Fig.3. Aerial view of Herve Cove, (Admiralty Bay), summer 1979.

inlets. Examples of such lagoons are Johnson's Dock (62°40′ S, 60°22′ W) on Livingston Island (Madejski 1988, Base *Juan Carlos I* – map (1988), López-Martinez *et al.* 1992 a, b), Yankee Harbour (62°32′ S, 59°47′ W) in McFarlane Strait (Estrechos Nelson, Espora and McFarlane, chart, 1957), Potter Cove (Battke 1990, Klöser *et al.* 1994), Monsimet and Herve coves (Fig. 1). They also include lagoons which have recently formed, such as in front of Ecology Glacier and another in front of Baranowski Glacier on the western shore of Admiralty Bay.

According to Marsz (*personal commun.*), several glacier types line the Admiralty Bay shore (Battke 1990). In the area of Goulden Cove for example, the so called entering glacier is found, whilst in Cardozo, Monsimet and Herve coves there are ice-falls.

In front of ice falls, as in the case of Herve Cove (Fig. 3) or Johnson's Dock, lagoons are deeper (to 20 m), and there are submerged moraine arcs (Lopez-Martinez *et al.* 1992 a, b).

In front of quasi-valley glaciers like Ecology (Fig. 4) and Baranowski glaciers (Fig. 1), the formation of shallow (3–4 m) lagoons occurs. Mineral

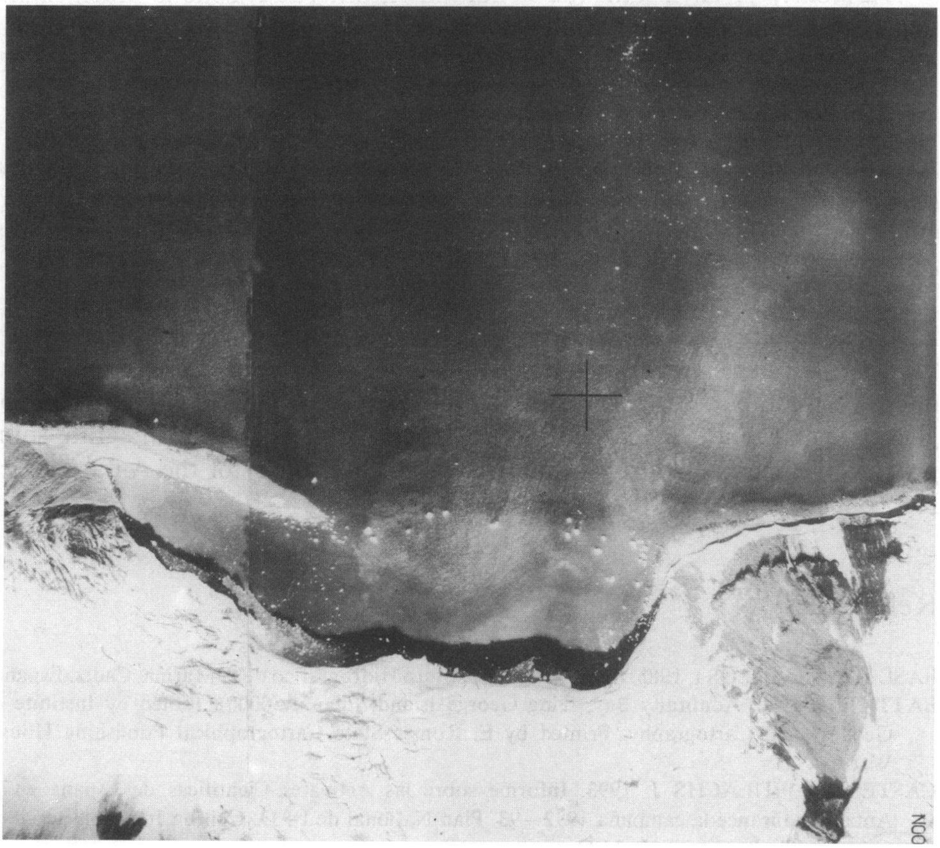


Fig. 4. Aerial view of lagoon in front of Ecology Glacier (Admiralty Bay), summer 1979.

matter is initially washed away, but with time there is deposition. The lagoon then forms, but is probably filled later.

Coves and recently formed lagoons are separated from Admiralty Bay by broken revy bars which may attain lengths of several hundred meters (*e.g.* Yankee Harbour, Monsimet Cove). Revy bars separating lagoons from the bay are broken, enabling an outflow of freshwater from the glacier, and an inflow of saltwater into the lagoon. By the latter, considerable amounts of organic matter enter the lagoon, particularly macroalgae as seen in front of Ecology Glacier. Deposition of organic matter at the bottom of lagoons may lead to its decomposition (Jażdżewski, *personal commun.*) and the development of anoxic conditions.

Salinity and temperature stratification in the lagoons are distinct and more stable (Castellvi Piulachs 1993) than in the bays and straits, the latter being strongly mixed by tides and wind. The lagoons also contain large amounts of suspended mineral matter. Quantities of this material in Herve Cove have been noted at 268 mg dm^{-3}, with a sedimentation rate of 2.1 g m^{-2} day^{-1} (Piechura *personal commun.*).

Variability of environmental conditions in intertidal zone is much higher than in the central part of Admiralty Bay. It is important to consider this in investigations of reaction and adaptation in plants and animals to temperature and salinity.

Glacial retread in a lagoon is accompanied by the exposure of an uncolonized substratum. Comparison of communities occuring in lagoons with previously described assemblages in Admiralty Bay (Zieliński 1990, Jażdżewski *et al.* 1986) will enable us to describe colonisation processes and formation of communities in such developing habitats.

Colonization processes in these lagoons appear to describe processes which have taken place in bays and fjords of glacial origin in the South Shetlands in the past. An assessement of colonisation rates in these waters may facilitate interesting comparisons with similar processes occurring on land exposed by glacial retreat, and such studies are therefore an ideal way to integrate some problems which are central to the Coastal-Shelf Ecology of the Antarctic Sea Ice Zone and BIOTAS programmes.

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Streszczenie

Zatoka Admiralicji (fig. 1) jest największą w rejonie Południowych Szetlandów (122.08 km^2, 24.24 km^3). Temperatura i zasolenie wahają się w zatoce nieznacznie (fig. 2a, b) w ciągu roku. Laguny (fig. 3–4) mają większe zróżnicowanie warunków hydrologicznych niż część centralna zatoki (tab. 1). Dno pokryte jest zróżnicowanym typem osadów (tab. 2). Współczesne zasiedlenie lagun związane z deglacjacją w rejonie Zatoki Admiralicji jest procesem, który w przeszłości przebiegał prawdopodobnie również w rejonie zatoki.