POLISH POLAR RESEARCH	10	4	481—532	1989

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Ornithogenic soils of the maritime Antarctic

ABSTRACT: The paper deals with Recent and relic phosphatic soils of ornithogenic origin which occur in ice free oasis of the maritime Antarctic Zone (Antarctic Peninsula and King George Island regions). These soils form on rocky and clay weathering covers within and around of penguin rookeries. Their morphology strongly depends on petrological character of a substrate and climatic differentiation of a region. They are built of a surface layer of guano and underlying zone of a phosphatized rock. Except organic matter and unstable urates, the guano contains calcium phosphates (fluorapatite somtimes brushite) and magnesium-amonium phosphate (struvite). The phosphatized zone consists of phosphatic-silicate clays in which occur diversified aluminium-iron phosphates bearing potassium and ammonium ions (leucophosphite, minyulite, taranakite, amorphous aluminium phosphate). The guano layer is strongly reduced by erosion and weathering in ornithogenic relic soils left by penguins in areas abandoned by them during Holocene. Formation of a humus horizon of a plant origin may be observed under a vegetation cover in the relic soils. Clays of the phosphatized zone in these areas are transformed in the processes of chemical and mechanical weathering, by mass movements and frost processes.

Key words: Antarctica, ornithogenic soil, relic soil, phosphates.

Introduction

The maritime Antarctic forms a climatic zone, which surrounds the Antarctic Continent and includes South Sandwich Islands, South Shetland Islands and the west coast of Antarctic Peninsula (as far as 70° S), and the adjacent archipelagoes (Fig. 1). Some smaller islands around the Antarctic Continent (Scott, Balleny, Bouvetoya) are also included into this zone. The maritime Antarctic has softer climate than the continental part (Campbell and Claridge 1987. Antarctica 1985). Positive temperatures are common during

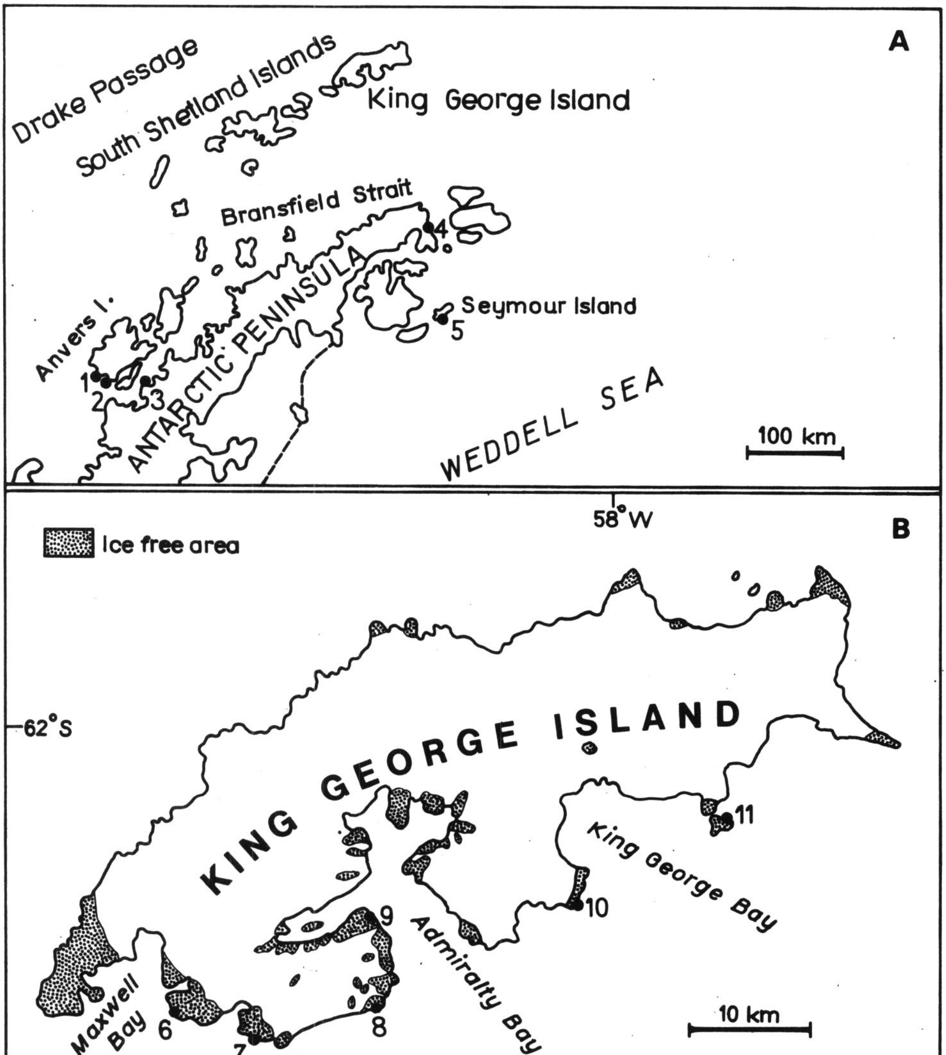

Fig. 1. Location of current and abandoned breeding areas included into the present investigations. A — Antarctic Peninsula sector, B — King George Island, 1 — Arthur Harbor, 2 — Cormorant Island, 3 — Southern Bryde Island, 4 — Hope Bay, 5 — Seymour Island, 6 — Penguin Point, Barton Peninsula, 7 — Petrels Rock, Potter Peninsula, 8 — Blue Dyke, 9 — Thomas Point on Penguin Ridge, 10 — Low Head, 11 — Penguin Island

summer, profuse rainfalls occur, and the average temperature of soil reaches positive values as down to a depth of below 1 meter (Cygan 1981).

Antarctic Peninsula and the adjacent islands are nearly totally covered with ice. Small, ice-free patches of land occur mainly in a coastal zone. During a short period of Antarctic summer they are places of gathering of great numbers of birds and seals. These animals live in an open ocean, and occupy ice-free oasis only during the breeding and moulting season. In this time they leave enormous amounts of excreta on the land. Penguins play, without doubts, the most important role in this natural manuring of a coastal area. It is so because of their numbers and their far inland penetration associated with nesting.

Penguins feed mainly on krill. The entire population of the genus *Pygoscelis* living in Antarctica delivers annually on the land, together with their nourishment during the nesting time, about $1.5—2.0 \times 10^4$ tons of phosphorus. This amount corresponds with 10^6 tons of dry mass of excreta (Tatur and Myrcha, *in press*). Intensity of manuring in areas of vast penguin rookeries reaches 10 kg of dry mass of penguin excreta with high protein contents per square meter per year (Tatur and Myrcha 1984).

Soils occurring on ice-free patches of continental Antarctica are generally nearly entirely devoid of organic matter, so that they were even called by Tedrov and Ugolini (1966) "ahumic soils". A higher amount of organic matter is accumulated only in coastal ornithogenic soils. A layer of mineralized guano, rich in calcium phosphates, occurs in areas of penguin rookeries. This guano layer covers weathered rock material but neither mixes nor reacts with it. In the areas abandoned by penguins the mineralized guano is winnowed by wind and eventually characteristic layer of loose pebbles collected by birds during nest construction is only left in the former breeding sites.

The ornithogenic soils of the Antarctic coastal areas are important source of nutrients for terrestrial ecosystems which surround penguin rookeries. Chemical weathering of rocks, the most important source of nutrients of other climatic zones, is strongly inhibited in severe climate of the Antarctic Continent. Weathering processes are hindered by negative temperatures, extreme poverty of liquid water and low air humidity.

The term "ornithogenic soils" was introduced by Syroyetschkovskiy (1959) and originally it was restricted only to the discussed above organic type of soils occurring on the Antarctic Continent. Processes of origin, development and disappearance of such soils were the subject of several Soviet (Glazowskaya 1958, Syroyetschovkiy 1959), New Zealand (Campbell and Claridge 1966, McCraw 1967, Spellerberg 1970, Speir and Cowling 1984, Campbell and Claridge 1987) and the US papers (Tedrov and Ugolini 1966, Ugolini 1972).

Initially, the distinct features of ornithogenic soils in the maritime Antarctic was not recognized, because of the absence of special investigations. Thus, their similarity to the ornithogenic soils from the continent was assumed a priori (Allen and Heal 1970, Ugolini 1972, Everett 1976, Campbell and Claridge 1987). Sometime it was even supposed, basing on cursory observations, that ornithogenic soils in this region do not exist, as summer rainfalls and melting snow wash guano out totally into the sea. This last opinion is often true in the case of rookeries located on rocky shores.

One should emphasize that despite the absence of detailed mineralogical and geochemical elaborations of soils around penguin rookeries in the maritime Antarctic, thorough and valuable geobotanical studies exist. They concern the influence of organic manuring by penguins on soil richness and further on development, productivity and chemical composition of vegetation assemblages which have developed around nesting places. Abstracts of numerous papers dealing with these problems can be found in the bibliography of Walton (1980). The results of British investigations, carried out on a large scale since many years, were synthetically treated by Smith (1985).

First suggestions concerning the distinct features of the ornithogenic soils of the maritime Antarctic appeared in the British papers by Wilson and Baim (1976), and by Brien, Romans and Robertson (1979). They described the occurrence of iron-aluminium phosphate containing ammonium and potassium ions, in soils from vicinity of penguin rookeries on Elephant Island. It was identified as leucophosphite. Only in eighties, however, ornithogenic soils of this region became the subject of detailed investigations by Polish expeditions. The present paper results from these studies.

The Polish investigations of ornithogenic soils around the occupied penguin rookeries in the maritime Antarctic, were initiated in 1979—1980 season and concerned a selected model area near Llano Point, King George Island. The microbiological decomposition of guano and excreta, as well as chemical changes occurring during this process were described by Pietr, Tatur and Myrcha (1983), and Pietr (1984). The mechanism of acidification of solutions leaching guano during percolation through soil was also elucidated by Tatur and Myrcha (1983). It permitted to explain processes of the rock substrate phosphatization, which lead to the formation of phosphatic ornithogenic soils specific for this region (Tatur and Myrcha 1984, Myrcha, Pietr and Tatur 1985). These soils have imprinted physicochemical conditions existing during their formation and alterations in the mineral composition of different genetic horizons (Tatur and Barczuk 1974, 1975, Tatur 1987). All the above studies covered, however, only a small area and did not allow for generalization for the entire region.

The investigations of ornithogenic soils were continued during the years 1984—1986, and the considerable part of the collected material is discussed in the present paper. The characteristics of diversity and specific features of ornithogenic soils in the entire maritime Antarctice developed on different rock substrates and in different sites, as far as to the climatically different continent, is the aim of the present studies. Ornithogenic soils of the abandoned breeding sites were also included into the studies. The term "ornithogenic relic soils of the maritime Antarctic" was proposed for them (Myrcha and Tatur, *in press*). Earlier, they were not recognized, as they are usually hidden under a dense cover of vegetation, and their common yellow-brown colour does not reveal enormous concentration of phosphates. The location, common occurrence and genesis of these soils were described in the preliminary reports by Tatur and del Valle (1986), and by Tatur and Myrcha (1988). The role played by these soils in the terrestrial ecosystems of the maritime Antarctic is discussed by Myrcha and Tatur (*in press*).

Methods

The soil investigations were carried out during the IXth Polish Antarctic Expedition to the *Arctowski* Station in the summer seasons of 1984/1985 and 1985/1986. A fine fraction, which is common among stones of a rubble, was only sampled. Samples were dried in the temperature of 25°C in laboratory, and next mechanically enriched in ornithogenic material by separation of clastic material. The clastic material was removed from guano with use of pincers. Soil samples were carefully ground with a rubber pestle; in effect, earthy phosphatic-silicate aggregates, and fine but relatively hard phosphatic crusts on clastic grains became totally ground leaving the clastic grains intact. Next, the samples were sieved on a nylon sieve of 1 mm grade. Most samples were additionally mechanically enriched by shaking off the clastic material on an inclined sheet of paper. That facilitated the separation of dark clastic material from a light phosphatic clay powder. The commonly used sedimentary method of separation could not be applied as many studied phosphate minerals ar soluble in water. On the other hand, the sieving alone gave unsatisfactory results of fractional and mineralogical separation. The concentrate received due to mechanical enrichment on the paper was optically devoid of clastic material and contained nearly exclusively clay and fine silt fraction. The material obtained by such sample treatment is called in this paper the "fine fraction free of clastic material" or simply clay. If the whole sample, or earthy fraction (below 1 mm), were analyzed, such a case is mentioned in the text.

Mineral crusts on rocks were sampled by scratching with use of a piece of quartz glass. After removing all contaminations with pincers, the powdered sample was analyzed.

Soil and crust samples were boiled in a mixture of HCl and HNO_3 to achieve total dissolution of phosphates (Bielopolskiy *et al.* 1974). Such a treatment permitted the total decomposition of phosphates, allowing rather sufficiently precise conclusions about their chemical composition. However, in the samples with high silicate clay contents, unidentified extracts from silicates formed, making interpretation sometimes difficult. The following determinations were made from this solution: P — by a colorimetric metavanadate method, Ca, Mg, Sr, Al — by AAS in the flame of nitrous oxide-

-acetylene in the presence of excess of the potassium buffer. Nearly identical results were obtained for Ca, Mg, and Sr in the control analysis in acetylene--air flame in the presence of the lanthanum buffer excess. Fe, Mn, Zn, Cu were determined by AAS method in acetylene-air flame K and Na were determined by the flame emission method. Chemical analyses of some selected phosphates were also carried according to original suggestions of Bielopolskiy *et al.* (1974), after removing phosphate ion on a ionite. The results do not differ from determinations made in solution without removing phosphate ion, reproducibility of determinations was not, however, satisfying.

The fact that the calculated molar ratio of main elements in differentiated chemically samples of pure phosphates (struvite, apatite, leucophosphite, minyulite, taranakite), on the basis of the obtained results, corresponds to the theoretical ratio known from a literature, is the crucial proof of a correctly made analysis. Determinations by AAS and the flame emission method were made on *Varian-1200* spectrometer. Determinations of C and N were carried in CHN Carlo-Erba analyzer.

X-ray analyses were performed in the Dron-1 diffractometer with the filtered radiation CoK_{α}, with anode current voltage 38 mV and intensity 10 mA. X-ray diffractograms of samples with phosphates were interpreted basing on criteria elaborated and discussed in earlier studies (Tatur and Barczuk 1984, 1985). Details of determination methods of some new phosphates will be presented elsewhere (Tatur, *in prep.*). X-ray analysis was used only for some selected samples, usually rich in phosphates.

In the discussion of results, the conclusions following from a chemical analysis are presented as a chemical formula of the phosphate salt. The results of X-ray analysis present mineralogical term (usually in parentheses). All chemically and mineralogically differentiated phosphates from the zone of phosphatized rocks with the chemical formula: iron–aluminium phosphates containing potassium and ammonium ions are described as "secondary phosphates". According to the proposed scheme primary phosphates originate as the result of guano mineralization.

Results

Penguin rookeries which are distributed in the whole region of the maritime Antarctic, were selected for the purpose of this study. They are located on Seymour Island, Wedell Sea, a territory being under the strong influence of a harsh continental climate, through the tip of Antarctic Peninsula (Hope Bay) and the adjacent west coast of Anvers Island (Arthur Harbor), to the King George Island (Thomas Point, Blue Dyke, Low Head, Penguin Island) which are under the influence of much softer marine climate.

The investigated sites were selected also to represent the total variability of rock substrates, as the processes of phosphatization of a substrate depend distinctly on its type. Among the selected sites, there are the rookeries founded on basic extrusives and their tuffs (Penguin Island, Blue Dyke, Thomas Point), on granite rocks (Arthur Harbor) and on granodiorites (Bryde Island), on strongly altered greywackes (Hope Bay), on moraine clays (Thomas Point) and on mixed volcanic–sedimentary rocks (Low Head), as well as on loose sands containing carbonate and ferruginous concretions (Seymour Island).

Every selected site displays specific character of ornithogenic soils, which needs a separate discussion. Both, the recent and relic ornithogenic soils are discussed in each case.

Arthur Harbor (near Anvers Island, west side of Antarctic Peninsula): Arthur Harbor (Fig. 2) is located near the US *Palmer* Station (64 46′S, 64 05′W) and surrounded by the archipelago of small and low islands, built of light granitic rocks. Adelie penguin rookeries occur on many islands. The entire penguin population is estimated as 20.000 breeding pairs (Poncet S. and Poncet J. 1987). Conditions of nesting are similar in the whole region. Changes of morphological characters of ornithogenic soils have been studied

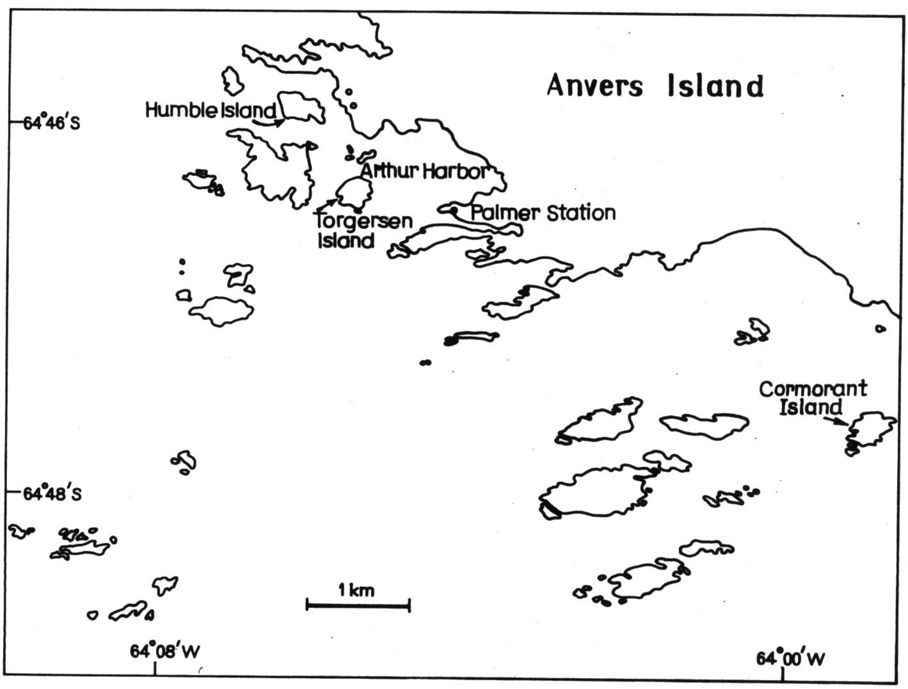

Fig. 2. Vicinity of Arthur Harbor near Anvers Island. The investigated islands arrowed

in the sequence of typical profiles P-1, P-2, P-3, P-4 which have been made at a different distance from the penguin rookery on Torgersen Island. The results of chemical analyses of ornithogenic soils are presented in Table 1.

Profile P-1. This section has been made in a central part of the Adelie penguin rookery. This colony is founded on solid granitic rocks about 50 meters from the sea. In places, rocks have a thin cover of small pebbles collected by penguins during nests construction. The considered section has been made in such a place.

The layer of a fresh brown-red guano (0—5 cm) with a high content of an undecomposed fibrous organic matter occurs among small (an average diameter below 5 cm) stones. The content of phosphate is low. Black clay forming unstable aggregates occurs in an underlying layer (5—40 cm). It contains considerably less organic matter but more Ca phosphates (apatite). and Mg–NH_4 phosphate (struvite). Deeper (below 40 cm), the share of Ca phosphates (apatite) increases, struvite is absent, and chemical analysis shows that secondary phosphates may also be present. The material infilling interstices among stony rubble is also of the clay grain class and it keeps its black colour as far as the deepest levels, lying directly on hard granitic rocks.

Profile P-2. The soil profile is much better developed at the site occurring about 20 meters from the penguin rookery and from the above described profile. Fresh guano flowing on a soil surface (0—1 cm) is much more mineralized and desintegrated than within the rookery. Except decomposed and washed organic matter (high C/N ratio) and Ca phosphates, it contains small quantities of Mg–NH_4 phosphates. The light grey leached guano of the clay grain class with clear dominance of Ca phosphates occurs below (1—30 cm), among pebbles. Black clay containing apatite associated with Fe–Al phosphates occurs under this layer (30—40 cm) among large boulders. Struvite occurs also in the deepest layer (below 40 cm). Most probably it crystallizes from ground waters slowly flowing from the rookery at this level.

One can find minute, few millimeters in size, broken crusts of a pure Ca phosphate in the entire soil profile, at different depth. Seemingly they were formed during a dry season as the sand and gravel grains coatings. Next, after breaking off from the clasts by flowing water, they became dispersed in the soil (0—40 cm).

Profile P-3. The last outcrop in this sequences has been made near a beach, at the distance of 40 meters from the inland situated rookery. This site is located on a loose stone rubble, similarly as section P-2. Despite the fact that the soil is not thick, phosphates occurring in distinctly developed soil horizons evidence the phosphatization of the substrate.

Thin layer of fresh guano occurs on the soil surface: this guano is highly desintegrated and partly decomposed (0—1 cm). Ca phosphates predominate and Mg–NH_4 phosphate can be present, but only in trace quantities. The light–yellow mass of phosphate of the clay grain class occurs among stones under guano. It represents leached guano composed mainly of the earthy Ca phosphate (apatite) in the upper, a little darker part (1—15 cm). Exclusively secondary phosphates occur (among them leucophosphite was identified) in a deeper lighter part (15—20 cm), below the ground water table.

Profile P-4. The best developed soil profile of phosphatized rocks has been formed in a unique particular site, at the distance of 20 meters from the nearest rookery. It occurs on a small hummock, composed of loose not rounded pebbles few centimeters in diameter. During heavy rainfall this hummock could be entirely overflooded by solutions cyrrying guano suspension from the nearby penguin rookery. On the other hand, during low precipitation or its absence, the upper soil layer (0—70 m) is left relatively dry and oxygen–saturated. The guano suspension is then transported by ground waters at the depth below 70 cm. The above specific geomorphological situation causes the diversified morphology of ornithogenic soil in this site.

(0—1 cm) Surface flow of fresh guano with brown-red colour. Organic matter is strongly desintegrated. Mg-NH_4 phosphate (struvite) occurs in considerable quantities together with calcium phosphates (apatite).

(1—10 cm) The light-brown earthy mass of leached guano, rich in Ca phosphates (apatite), occurs among loose stone rubble. The content of Mg-NH_4 phosphate (struvite) is negligibile.

(10—30 cm) The light yellow-brown leached guano, still rich in Ca phosphate (apatite) and totally devoid of Mg-NH_4 (struvite), occurs among stones. Beside apatite, secondary phosphates also appear.

(30—70 cm) The white-yellow clay mass of apatite-absent phosphates occurs among stones. Only secondary phosphates: leucophosphite and minyulite are present. These minerals constitute nearly total mass of the most fine clay fraction (< 0.002 mm) separated sedimentary from the sample (30—70 c.cm).

(< 70 cm) The dark-brow clay material mixed composition with Ca phosphate as the most important component occurs among large boulders. It was transported by groundwater running from a side.

Surface accumulation. Ornithogenic soils as described above, commonly occur around Adelie penguin rookeries scattered on the islands around Arthur Harbor. They exist also near Bisco Point on the Anvers Island coast. Different forms of the surface accumulation of ornithogenic material are also conspicuous in the investigated area (surface Tab-1).

The sample (S—A) was collected from a small pool located within a penguin rookery (Humble Island). On a drying margin of the pool, thin light skin of a precipitate has been formed, which contained, beside Ca phosphates (apatite), high quantities of Mg-NH_4 phosphate (struvite).

Sedimentation of fine phosphate-silicate material (S—B) proceeded in a large pool existing below the penguin rookeries near Bisco Point. It forms the layer of a precipitate about 0.5 m thick. The mineral composition of this multicomponent mixture is difficult to determine. Similar poorly precised mineralogically accumulations are widespread around penguin rookeries.

After heavy rain, the finest mineral fractions of guano have been accumulated at the foot of a slope inhabited by penguins (Torgensen Island). They have been washed-out from the rookery as fine suspension and are composed mostly of Ca phosphates (S—C).

In short periods without rainfall, when soil, stones and rock surface become dry, liquid fractions of penguin excreta are drying on them. They form white patches of pure K, Mg and NH_4 urates (S—D, S—E). Thus, they represent physiological salts precipitated only due to evaporation. Similar urates commonly occur in small quantities around all rookeries in the maritime Antarctic. They are described in details by Tatur (1988).

Crust mineralization on rocks. Mineralization on rocks is characteristic for the Arthur Harbor region (Crust Tab. 1). It is much better developed here than in the other investigated areas. It forms thin phosphatic crusts coating the route of guano flow from rookeries. Samples were collected in different places located within and around rookeries on Humble and Torgersen islands.

Within the rookery itself, the crusts are usually pale rose and they form in rock troughs in which suspension of guano flows. They are composed mostly of Mg-NH_4 phosphates (struvite). Ca phosphate (apatite) appears at a certain distance from the rookery (C—B, C—C, C—D). These crusts are usually few mm thick but reaching sometime even 1 cm in thickness. Apatite occurs as the independent crystalline phase, and is concentrated in thin, white laminae of loose clay within thicker, hard and vitreous laminae

Table 1. Chemical composition of ornithogenic soils (fine fraction free of clastic material) from islands around Arthur Harbor.

Sample number depth (cm)	P (%)	Concentration of elements, Acid extract HCl + HNO_3 (1 : 1): Ca (%)	Al (%)	Fe (%)	K (%)	Mg (%)	Na (%)	Sr ppm	Mn ppm	Zn ppm	Cu ppm	C. (%)	Total N (%)	C/N
CURRENT														
Profile														
P-1														
0-5	4.49	4.99	0.10	0.10	1.50	2.07	1.94	1600	10	>90	250	13.13	6.58	2.0
5-40	9.63	12.82	0.21	1.03	0.21	4.65	0.39	1263	114	427	380	6.19	3.62	1.7
< 40	9.27	15.37	1.98	4.02	0.28	1.69	0.57	1616	436	734	298	4.27	1.83	2.3
P-2														
0-1	8.36	19.29	0.28	1.01	0.18	2.18	0.31	2374	178	574	445	14.53	3.35	4.3
1-30	7.95	23.16	0.58	0.44	0.11	0.31	0.29	2393	203	811	490	17.26	3.06	5.6
30-40	11.01	23.16	1.25	4.44	0.30	0.32	0.50	3040	290	1477	666	8.02	1.54	5.2
<40	11.31	21.51	0.78	2.29	0.16	2.90	0.38	1964	318	982	410	5.90	2.07	2.8
0-40c	12.13	33.16	0.31	1.06	0.09	0.27	0.33	1326	95	549	332	8.31	1.57	5.3
P-3														
0-1	8.51	22.98	0.56	0.62	0.11	0.57	0.25	2872	278	718	536	14.87	2.61	5.7
1-15	9.10	23.54	0.78	1.18	0.09	0.29	0.29	2413	314	942	580	12.74	2.11	6.0
15-25	5.49	0.47	2.13	6.70	0.23	0.28	0.02	97	194	281	126	3.32	1.14	2.9
P-4														
0-1	8.48	12.85	0.22	0.91	0.23	3.76	0.27	1572	99	395	306	11.87	4.19	2.8
1-10	8.54	19.66	0.60	0.78	0.20	1.30	0.34	2483	238	766	403	13.55	2.60	5.2
10-30	7.40	15.60	2.44	1.99	0.35	0.57	0.57	1815	302	663	195	10.12	1.96	5.2
35-70	6.58	0.50	4.59	4.69	1.67	0.05	0.23	113	93	361	72	3.87	1.28	3.0
35-70c	12.91	0.14	7.83	6.94	3.72	0.06	0.09	89	79	615	89	5.56	2.03	2.7
< 70	10.96	11.22	5.24	3.41	1.74	0.56	0.41	1431	1075	1421	271	3.49	1.52	2.3
P-5														
15 b	15.47	26.78	0.13	0.32	0.02	0.04	0.10	496	99	456	20	6.79	1.70	4.0
35 d	11.40	23.61	0.36	0.40	0.06	0.07	0.25	1033	305	1082	177	12.03	2.06	5.8
Crust														
C-A	12.05	1.77	0.10	0.52	0.07	8.93	0.08	208	73	73	3	2.11	4.72	0.5
C-B	11.60	2.59	0.05	0.88	0.10	8.38	0.08	399	50	110	1	1.64	4.78	0.4
C-C	11.74	4.01	<0.05	0.02	0.05	8.60	0.11	500	30	160	10	2.47	4.53	0.6
C-D	10.30	24.05	<0.05	0.43	0.17	5.89	0.62	1600	860	610	1	8.04	1.81	4.4
C-E	10.98	9.18	7.85	0.56	0.49	0.43	0.33	4589	591	2346	102	6.00	1.04	5.8
C-F	11.17	6.16	9.43	0.27	0.31	0.94	0.67	3500	337	1425	106	5.55	1.13	5.0
C-G	5.59	1.95	13.08	1.23	0.26	0.74	0.75	390	220	560	120	2.69	0.71	3.8
Surface														
S-A	9.41	19.52	0.40	0.90	0.29	4.96	0.62	5220	120	590	240	18.07	7.25	2.5
S-B	4.67	17.82	3.80	3.15	0.30	1.11	0.94	3840	1770	890	770	8.56	1.19	6.0
S-C	6.11	8.53	0.22	0.44	0.22	1.96	0.22	1569	118	500	363	16.54	4.30	3.8
S-D	0.30	0.69	0.20	0.59	1.26	0.35	0.42	30	0	30	0	28.82	31.52	0.9
S-E	0.46	0.00	<0.10	0.28	2.38	1.12	0.19	10	0	10	25	30.47	30.39	1.0
RELIC														
Profile														
P-6														
0-3	2.95	1.44	4.32	4.61	0.26	0.35	1.01	380	180	80	150	5.01	0.83	6.0
3-20	3.69	2.56	5.12	6.90	0.47	0.45	1.07	490	200	210	260	4.49	0.97	4.6
P-7														
0-1	0.89	0.49	0.90	1.49	0.12	0.08	0.20	300	40	130	150	27.44	5.19	5.5
< 1	5.78	0.24	2.33	6.69	0.16	0.07	0.04	179	89	506	40	5.13	2.07	2.5

of nearly pure struvite. Frequent intercalations of these two components lead to a characteristic banded structure of the crusts. The crusts have smooth surface, and only rarely, druses of struvite can be formed in protected places.

Thin snow-white crusts are observed on the walls of the rock troughs, but also on boulders, which are overflooded with rinsings by guano leachates at a larger distance from the rookeries (C—E, C—F). They are distinctly thinner than the earlier described rose crusts and they are composed of apatite and amorphous aluminium phosphate. These two components occur as optically homogeneous mixture and form the ideally smooth outer surface. The crusts most distant from the rookery are composed nearly exclusively of amorphous aluminium phosphate, usually with enhanced iron content (C—G).

Relic soils. Most of the islands around Arthur Harbor built of granitic rocks are covered with loose, coarse grained clastic material, almost totally devoid of clay fraction. Penguin's activity leads to the formation of phosphate-silicate clay, which infills interstices among the rocks rubble, thus forming suitable conditions for the development of soils and vegetation. The vegetation can develop, however, only in the areas abandoned by penguins.

Profile P-6. After a small moving of penguins in the rookery on Torgersen Island, they left the free surface of ornithogenic soil, where bright-green cover of the grass *Deschampsia antarctica* has grown. The soil is dark-grey and composed of mixed silicate-phosphate material in the zone of a root growth (0—3 cm). The high ratio C/N (as for ornithogenic soil) and colour indicate the beginning of plant-origin humus formation. The light phosphate-silicate clay, which is dominated by secondary phosphates, occurs in a deeper layer (3—20 cm), among fine grained rock rubble.

Profile P-7. Surface accumulation of phosphatic clay as well as well developed relic ornithogenic soils, have been found neither within the existing rookeries nor in their proximity. They are widespread on the entire small (500 meters long and 30 meters high) Torgersen Island, which currently is only in part occupied by breeding groups of penguins. Examples of relic phosphatic soils have been found far from the rookery on the top of the island under a thick vegetation cover of mosses and lichens. Thin horizon (0—1 cm) of humus has been formed by vegetation. Below it, the white clay rich in secondary phosphates occurs among stones.

Cormorant Island (near Anvers Island, west side of Antarctic Peninsula): rather interesting accumulation of guano has been noted on Cormorant Island (Fig. 2) near a large colony of piscivorous cormorants (*Phalacrocorax atriceps bransfieldensis*). This colony is located on the summit of a granitic cliff, at the height of 10 m a.s.l. Considerable part of guano is accumulated among rock blocks on a dry and flat area outside of the colony. The existing conditions did not allow for the formation of similar deposits around other cormorant colonies known to the author from the maritime Antarctic (Chag

Rock on the King George Island and Arctowski Peninsula, Danco Coast, Antarctic Peninsula).

Profile P-5. The profile of the ornithogenic soil is built of strongly mineralized leached guano composed nearly exclusively of Ca phosphates. The profile is 50 cm thick and any admixture of clastic material is absent. It displays characteristic patchy-banded colour pattern, which appears from intercalations of layers and bands of darker brown and lighter yellow--brown material. The lighter material (15/b. cm) is composed nearly entirely of brushite, the darker one (35/d. cm) is composed of apatite. The cormorant guano occurs directly on a clay covering hard granite rock. No traces of phosphatization have been found in clay material which contacts with guano.

The guano substrate around cormorant colonies is gradually invaded by a vegetation. The vegetation covers nearly totally the soil surface in marginal zones. Mosses occur in depressions, lichen *Usnea* sp. and grass *Colebantus quitensis* occur on small elevations.

Hope Bay (tip of Antarctic Peninsula): one of the largest penguin communities, in the entire Antarctic exists in the Hope Bay oasis (Fig. 3). In the year 1986, about 123 850 nesting pairs of Adelie penguins have been counted in this area (Myrcha, Tatur and del Valle 1988).

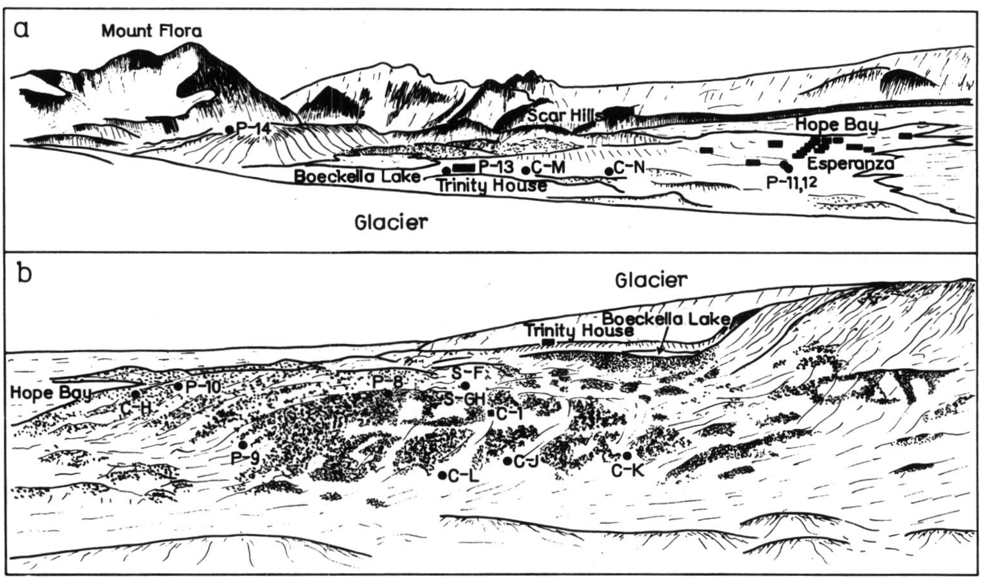

Fig. 3. Hope Bay Oasis. A — Abandoned breeding sites, eastern view from the glacier. Symbols indicate sampling sites of ornithogenic relic soils. Currently occupied penguin rokeries are stippled areas outside of Boeckella Lake. B — Current breeding sites (stippled) western view from Scar Hills. Symbols indicate sampling sites

The penguin rookery is located on rock rubble of the Trinity Formation, and in its east part, on stony-clayey moraine. The Trinity Formation is composed of strongly cemented greywackes. The silica cement makes these rocks very hard and weathering-resistant. Moraine clays contain mainly weathered material of bituminous shales of the fresh water origin (Mount Flora Formation). Stones come from hard volcanic rocks of the Antarctic Peninsula Volcanic Group (Fleming and Thompson 1979). The results of chemical analyses of relic and recent ornithogenic soils from the Hope Bay region are presented in the Table 2.

Profile P-8. Section has been made on a stony ground, in the central part of a huge penguin rookery. On the surface among stones a layer of fresh (0—2 cm) and leached guano (2—5a cm) has been formed. Considerable quantities of $Mg\text{-}NH_4$ phosphate (struvite) and Ca phosphate (apatite) occur in this guano, together with decomposed organic matter. Deeper, the white clay composed of secondary phosphates (5—50 cm) occurs. In this layer leucophosphite has been recognized.

Profile P-9. This section has been made on a slope of a hill below a penguin breeding area on a loose rubble. A layer of decomposed guano (0—7 cm) is passing deeper on into silicate clay. It undergoes phosphatization, but the content of secondary phosphates is low (7—50 cm). Deeper sampling was impossible because of the permafrost.

Profile P-10. This section has been made in a stony ground on a slope of a small isolated hill, below a small penguin breeding group. The guano layer (0—15 cm) contains Ca phosphates and perhaps also $Mg\text{-}NH_4$ phosphates on the surface (0—1 cm). Nearly pure and chemically diversified Ca-Mg-Al-Fe phosphate or phosphates occur deeper. The mineral composition of this material is difficult to determine, despite strong X-ray reflections (15—20 cm). Gravel and sand occur in the deepest part, containing secondary phosphates and silicates. Small quantities of leucophosphite were identified (20—40 cm).

Surface accumulation. The investigations in the Hope Bay area were performed during the summer beginning, just before a new penguin breeding season. Guano from the previous season has been fractionally segregated on a soil surface due to a process of washing out from the nesting area. Coarse fraction was left in areas adjacent to the breeding places, close to the nests. It consists of still well-preserved organic fragments of krill, few millimeters in size (S—F).

Phosphatic clay, which is poorly soluble product of excreta mineralization, has been transported at a larger distance. This clay was accumulated in local depressions (S—G, S—H) within penguin breeding areas and in their vicinity. It is composed of compact aggregates of earthy clay, containing Ca phosphate and very fine chitin debris.

Crust mineralization on the rocks. Rock encrustations are also well developed around the penguin rookery in Hope Bay. The ground is well permeable here and this presumably caused the rarity of the struvit-apatite encrustations, which are so common within the rookery in Arthur Harbor (C—H). The white mineralization is distinctly common in Hope Bay. It occurs usually on stone surfaces which are located in flat depressions, through which guano solutions flow from the rookery. This hard and thin phosphate crusts are composed of a mixture of the variable proportions of amorphous aluminium phosphate and apatite (C—I, C—J, C—K, C—L).

Relic soils. Abandoned breeding areas, with relic phosphatic soils have been preserved on the whole large area between the glacier adjacent to Mount Flora and the Argentinian station *Esperanza* (Fig. 3). It is the area much larger than currently occupied by the rookery, and it seems that the human activity pushed penguins away toward the currently occupied locations (Tatur and Myrcha 1988).

Tab. 2. Chemical composition of ornithogenic soils (fine fraction free of clastic matrial) from Hope Bay Oasis

Sample number depth (cm)	Concentration of elements: Acid extract HCl + HNO_3 (1 : 1) P (%)	Ca (%)	Al (%)	Fe (%)	K (%)	Mg (%)	Na ppm	Sr ppm	Mn ppm	Zn ppm	Cu ppm	Total C	N	C/N
CURRENT														
Profile														
P-8														
0-2	7.72	7.73	0.20	0.24	0.35	3.00	0.39	1100	50	320	320	16.64	5.59	2.6
2-5	11.64	10.73	0.30	0.40	0.27	4.84	0.37	1300	80	490	350	6.77	3.54	1.9
5-20	7.93	0.59	4.35	3.95	2.17	0.67	0.50	200	120	270	160	4.12	1.98	2.1
20-50	7.41	0.19	3.78	4.27	1.97	0.13	0.18	200	200	220	150	2.83	1.33	2.1
P-9														
0-1	5.47	7.20	1.40	1.55	0.64	1.63	0.29	900	300	480	330	11.05	2.91	3.8
1-7	8.40	12.30	2.50	1.90	0.78	0.93	0.47	1600	400	820	280	3.81	0.92	4.1
7-10	2.08	1.25	2.41	3.28	0.78	1.28	0.19	800	350	270	120	1.92	0.43	4.5
10-50	1.34	0.77	2.30	3.41	0.74	1.48	0.08	500	370	190	110	1.52	0.32	4.7
P-10														
0-1	7.48	15.48	0.77	0.60	0.42	1.05	0.40	2000	0	670	320		3.18	
1-15	7.76	12.99	2.07	1.67	0.60	0.68	0.39	1500	90	720	610	11.94	2.64	4.5
15-20	11.67	4.54	4.73	2.86	0.55	3.03	0.27	400	110	560	180	4.16	4.01	1.0
20-40	4.17	0.29	2.50	3.27	1.08	0.23	0.08	200	20	320	190	2.91	0.91	3.2
Surface														
S-F	7.39	9.35	0.10	0.15	0.43	2.53	0.28	1200	50	440	430	21.01	5.55	3.8
S-G	10.37	23.96	1.36	1.21	0.28	0.41	0.31	2300	210	1110	600	17.39	3.36	5.2
S-H	8.15	15.81	0.87	1.06	0.25	0.66	0.31	2300	190	910	550	17.32	3.46	5.0
Crust														
C-H	13.79	5.18	0.00	0.10	0.12	8.35	0.23	900	100	150	60	3.63	4.46	0.8
C-I	12.84	19.09	4.95	0.32	0.33	0.47	0.41	4400	660	1630	140	5.37	1.18	4.5
C-J	13.94	17.23	6.38	0.48	0.41	0.52	0.31	4300	770	2010	190	3.66	0.68	5.4
C-K	12.80	13.80	7.79	0.66	0.47	0.98	0.46	5400	510	1990	120	1.93	0.48	4.0
C-L	12.77	11.81	8.28	0.44	0.72	0.54	0.47	5500	440	3360	110	2.87	0.68	4.2
RELIC														
Profile														
P-11														
10-20	9.45	18.50	0.90	0.77	0.31	0.40	0.39	2400	150	710	550	10.76	2.15	5.0
P-12														
10-15	8.79	18.73	1.08	0.86	0.30	0.30	0.38	2200	200	720	560	9.21	1.54	6.0
15-20	4.80	0.40	2.28	3.57	0.87	0.08	0.04	100	220	110	170	2.67	1.01	2.6
P-13														
0-0,1	17.76	27.03	3.61	4.39	1.32	0.55	0.92	4000	500	1630	660	2.15	0.60	3.6
0-2	11.48	22.56	1.30	1.45	0.34	0.27	0.51	2800	300	1190	380	6.77	1.05	6.4
2-5	8.08	8.72	2.28	4.26	0.75	0.19	0.27	1000	340	600	230	1.91	0.68	2.8
5-7	4.25	0.69	1.28	4.53	0.48	0.05	0.30	400	80	320	160	2.74	0.78	3.5
7-20	2.40	0.66	1.19	2.97	0.37	0.11	0.05	300	90	170	130	1.67	0.23	7.3
P-14														
10-20	10.76	25.18	0.76	0.62	0.27	0.37	0.35	3200	250	970	720	11.53	1.98	5.8
Crust														
C-M	11.42	26.90	0.40	1.11	0.30	0.36	0.64	800	990	320	100	1.88	0.07	27,
C-N	12.52	2.29	11.65	3.63	0.65	0.44	0.72	2200	220	680	140	1.02	0.17	6.0

Profile P-11. This section has been made on a top of a moraine hill, between the *Esperanza* station and the former station *Trinity House*, in the proximity of the Argentinian hangar. It is a former nesting place of penguins. At present, one can find only loose stone rubble covered with lichens (0—10 cm) at this site. Deeper (10—20 cm), a brown guano mass infills interstices between stones. The main component of this mass is Ca phosphate and weathered chitin detritus. Permafrost occurs below the depth of 20 cm.

Profile P-12. This section has been made on a slope of a hill, below the section P-11, and below the site formerly occupied by a breeding group. A light brown, leached guano (10—15 cm) appears among stones under a layer of loose stones covered with lichens. Sandy gravel containing light phosphatic-silicate clay occurs deeper (15—20 cm). Considerable amont of secondary phosphates occurs in it.

Profile P-13. This section has been made on a hill at the distance of 10 meters from the buildings of *Trinity House*. A rocky summit of the hill is built of greywackes and was formerly occupied by a penguin rookery. Human activity, in the proximity of the buildings, leads to the total destruction of vegetation. Strongly mineralized guano occurs among loose small stones (0—2 cm). It is considerably richer in Ca phosphates than in other sites. Also organic matter which is still present, displays distinctly higher C/N ratio. A very thin surface layer is locally especially enriched in Ca phosphates (0—0.1 cm, whole sample). These surface phosphatic efflorescences are devoid of organic matter and clastic material. Pale-grey clay with the high contents of secondary phosphates occurs among stones deeper (5—7 cm). X-ray analysis shows no determinable reflections of phosphates. Deeper the clay becomes darker and the share of phosphates decreases in it (7—20 cm).

Profile P-14. The highest abandoned nests are on stony moraine ridges at the altitude of about 150 meters. Thus they occur 20 meters higher than the highest located current breeding sites, and about 100 meters from it. The surface of a soil in the old nesting site is covered with vegetation, with lichen *Usnea* sp. playing a substantial role. Pale-brown guano, in which Ca phosphates reach very high level, occurs below the layer of loose stones (10—20 cm). Organic matter occurring in it is strongly weathered or/and it bears humus, and it displays relatively high C/N ratio. Remains of penguin feathers and bones are also present in guano. Moraine clays with stones occur under guano.

Relic mineralization on rocks. The mineralization on rocks is also preserved in regions of former penguin's activity. Rudimentary beige encrustations occurring on stones lying on the hill slope, near the old British base *Trinity House*, turned out to be pure Ca phosphate (C—M). White encrustations occurring on large boulders in the valley below Trinity House are composed almost exclusively of amorphous Al-Fe phosphate, and the share of Ca phosphate is negligible (C—N).

Bryde Island (near the west coast of Antarctic Peninsula): small and flat Bryde Island south, is located at the entrance to Paradise Cove in Fergusson Channel (64°54′S, 62°57′W). It is built of hard and resistant to weathering granodioritic rocks. The whole island is inhabited by papua penguins (*Pygoscelis papua*). Poncet S. and Poncet J. (1987) estimated that in 1987 it was inhabited by 500 nesting pairs. The island surface is devoid of vegetation. It is covered with a few dozen centimeters of guano resting directly on rocks. The results of soil analysis are presented in Tab. 3.

Profile 15. More important accumulations of sand and gravel on rocky substrate can be only found in few, lowest spots of the beach. This allowed to prepare somewhat deeper soil profile.

The fresh guano in a surface layer (0—1 cm) contains mostly decomposing organic remains together with apatite and struvite. In leached guano (1—9 cm), the content of organic matter is low, struvite is absent and chemical analysis indicates that beside apatite some quantities of Al-Fe phosphates may be also present. The amount of phosphates decreases with depth

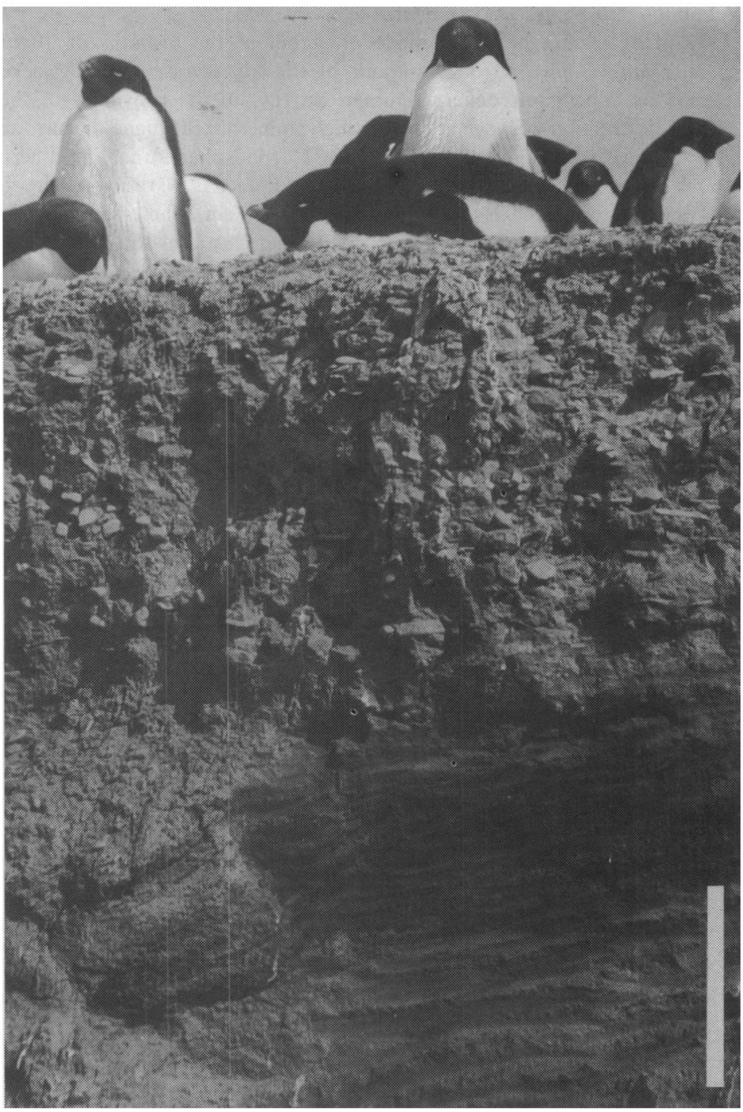

Fig. 4. Soil profile located in a central part of the penguin rookery on Seymour Island. Scale bar 10 cm

(9—10 cm and 10—20 cm) as the amount of apatite also decreases in favour of secondary phosphates. Their mineral composition is unknown because of their small contents in relation to silicates.

Surface accumulation. High concentration of struvite efflorescences exists on the surface of decomposed guano. It occurs in a small niche of rock, which is protected from rainfalls (S—J). The efflorescences form thin (few millimeters thick) but evidently crystalline crust.

Seymour Island (east side of Antarctic Peninsula): Seymour Island is located outside of the maritime Antarctica climatic zone. The Adeli penguin rookery, estimated at 21 954 breeding pairs, occurs near the Penguin Point on the Tertiary sedimentary rocks of the Sobral Formation (Myrcha, Tatur and del Valle 1988). This formation is composed of loose sands of shallow water origin, which are well sorted and rounded (fine to medium grained sand), and contains considerable amount of glauconite. These sands have profuse intercalations of dark bituminous clays. Carbonate concretions, often ideally spherical, are common. Irregular layers and lenses of ferruginous cement are common in a weathered zone. The results of the analysis of ornithogenic soils from Seymour Island are presented in Tab. 3.

Profile P-16. This section of ornithogenic soil has been exposed on a cliff formed by the sea erosion. The soil profile was done in a central part of the rookery (Fig. 4). A guano layer (0—25 cm) occurs among pebbles collected by penguins for nest construction. This guano is distinguished by a low degree of organic matter mineralization. Concentration of phosphorus in a coarse organic detritus of the guano equals 2.3% and is nearly two times lower than in other investigated samples of guano from the maritime Antarctic. The concentration of Ca phosphates is also relatively low in other, deeper guano layers (0—1 cm, 1—10 cm, 10—25 cm). The chemical composition of guano is very similar in all investigated sections of this region.

Pebbles which occur in the guano layer, are commonly fragments of carbonate concretions. They represent hard sandstones with crystalline carbonate cement. The concretion fragments are hard and not weathered in the upper layer of guano. Deeper the carbonate cement is gradually dissolved and phosphatized under the influence of water solutions leached guano. In effect, some fragments are transformed from hard rocks into a clayey-sandy mass. Carbonates are still present and the share of Ca phosphates is relatively small in the clay fraction separated from altered concretion fragments (R-1). P content was even lower in other five studied samples of the decomposing limestone.

Sands (R-2) with the high content of glauconite (R-3), and with yellow patches caused by weathering (R-4), occur below the depth of 25 centimeters. They are densely and rhythmically intercalated with bituminous clays (R-5). No phosphatization has been noted in any of the above mentioned rocks samples at the contact with guano (25—26 cm). One may only suspect the presence of traces of this process. Only clay fractions, mechanically separated from the rock, were analyzed.

Breeding sites in this area, quite often are situated on hard ferruginous cemented layers of weathering genesis. Their mineral composition is left unknown. In the ferruginous material, which occurs directly below guano, also only traces of phosphatization can be found (R-6).

Penguin Island (King George Bay, King George Island): a breeding group of penguins is situated on the wall of volcano, between Petrel Lake and the sea. Last eruption of the volcano, which has formed the present geomorphological situation, had place about 100 years ago (Birkenmajer 1982). Penguins nest there on dark brown and brick-red volcanic tuffs composed of gravel and sand fraction. During the summer season 1980/1981 the Antarctic penguin population was equal 451 breeding pairs (Jabłoński 1984b). The results of chemical analyses of ornithogenic soils are presented in Tab. 3.

Profile P-17. This section has been made just below the penguin breeding site, where extensive phosphatization of a substrate can be seen. Under fresh guano (0—2 cm) loose tuff glued by white clay of secondary phosphates occur (2—5 cm). Deeper (5—20 cm), its colour

Tab 3. Chemical composition of ornithogenic soils (fine fraction free of clastic material) from Bryde Island, Seymour Island Penguin Island, Barton Peninsula and Potter Peninsula.

Sample number depth (cm)	Concentration of elements													
		Acid extrad HCL + HNO3 /1:1/										Total		
	P (%)	Ca (%)	Al (%)	Fe (%)	K (%)	Mg (%)	Na (%)	Sr ppm	Mn ppm	Zn ppm	Cu ppm	C (%)	N (%)	C/N
CURRENT														
BRYDE														
Profile P-15														
0-1	11.44	23.18	0.24	0.25	0.18	1.86	0.25	2050	110	760	270	9.09	2.17	4.2
1-9	10.83	16.82	1.27	2.64	0.26	0.18	0.42	2050	240	900	300	7.44	1.05	7.1
9-10	8.47	14.67	1.83	3.57	0.36	0.20	0.30	1350	280	610	190	4.88	0.80	6.0
10-20	2.41	1.59	1.69	3.18	0.37	0.29	0.17	200	170	100	40	1.26	0.14	9.0
Surface														
S-J	12.82	18.82	0.19	0.21	0.18	4.03	0.25	1260	70	550	210	8.12	3.21	2.5
SEYMOUR														
Profile P-16														
0	2.30	3.03	0.49	1.46	0.50	1.43	0.64	290	160	170	110	13.40	7.94	1.7
0-1	3.45	4.03	1.01	2.72	0.92	1.92	0.53	100	300	180	120	11.55	5.02	2.3
1-10	4.80	6.04	1.41	3.92	1.13	2.77	0.72	500	410	270	130	8.83	3.75	2.4
10-25	3.95	9.17	1.23	2.86	1.06	1.17	0.91	300	480	220	130	16.19	6.87	2.4
Rock														
R-1	2.70	15.33	1.21	3.01	0.94	1.28	0.40	390	420	200	120	3.07	1.06	2.9
R-2	0.00	0.39	1.25	2.41	0.94	0.43	0.13	100	140	50	10	1.20	0.20	6.0
R-3	0.25	0.50	1.59	4.87	1.95	0.80	0.41	100	40	60	40	1.27	0.97	1.3
R-4	0.20	0.59	0.79	7.89	2.34	0.37	0.28	300	60	80	60	0.91	0.60	1.5
R-5	0.60	0.29	1.24	1.86	1.03	0.75	0.40	100	70	90	100	1.48	1.25	1.2
R-6	1.25	1.03	1.85	17.44	0.09	0.16	0.07	100	100	100	30	0.62	0.08	7.6
PENGUIN														
Profile P-17														
0-2	4.39	7.28	1.99	2.09	0.39	2.23	0.67	1339	388	310	223	10.22	2.44	4.2
2-5	5.17	0.95	3.02	7.60	0.47	0.29	0.39	185	244	234	97	8.76	2.01	4.4
5-20	4.50	1.33	3.33	7.00	0.54	0.32	0.50	400	286	152	267	8.51	0.97	8.8
5-20cr	7.05	3.09	4.83	12.93	1.13	0.96	0.98	390	280	40	160	n.d.	n.d	n.d
RELIC														
BARTON														
Profile P-18														
5-15	0.51	1.19	0.73	1.71	0.12	0.84	0.21	100	160	90	150	29.67	1.76	17.
<15	4.52	0.43	1.64	6.49	0.48	0.10	0.05	100	130	170	170	4.57	1.13	4.0
POTTER														
Crust														
C-0	7.64	1.18	4.62	11.41	0.13	0.36	0.12	100	430	100	140	1.88	0.84	2.2

becomes darker, but chemical composition shows no changes. Grains of tuffs have thin brown coatings of phosphates (5—20/cr. cm). They are clearly richer in phosphates than the surrounding clay. Tuffs without traces of phosphatization occur below 120 cm.

Barton Peninsula (King George Island): a small colony of Antarctic and papua penguins exists near Penguin Point on Barton Peninsula. Ornithogenic soils covered with thick cover of mosses association occur on a small flat area above the rookery and below the colony of giant petrels. At present, this area is situated outside of any penguin's activity. The results of chemical analyses of soils from this location are presented in Tab. 3.

Profile 18. A cover of mosses (0—5 cm), in places with the alga Prasiola crispa, grows on a loose stony rubble with a small admixture of a dispersed humus (5—15 cm). The humus is of plant origin (C/N ratio equals 16.89) and is nearly devoid of phosphates. Angular gravel with a clay admixture occurs deeper, below 15 cm. The clay contains considerable amount of phosphates, which, when analysed, showed very clear X-ray reflections typical of leucophosphite, on the silicate background. The environment described above is clearly suitable for the formation of this mineral.

It is difficult to decide whether the described soil represents relic soil left by the penguin rookery, which migrated downhill, or it is being formed currently in effect of manuring by the giant petrel colony existing uphill.

Petrels Rock (near Stranger Point, King George Island): an old abandoned outflow from Rudy Lake exists on the east side of Three Brothers Hill. A former stream was deeply incised in rocks and marine terraces isostatically elevated to the altitude 16 meters (Tatur and del Valle 1986). A pebbly-gravel material occurring on the surface of the old elevated terrace (14—16 m a.s.l.) is cemented with a hard phosphatic cement, forming a hard and indurated conglomerate. The cement represents amorphous iron-aluminium phosphate (C—O in Tab. 3). The domination of Fe over Al is characteristic here and unknown in other samples.

At present, no traces of penguin's activity can be found. A giant petrels colony occurs, however, in a proximity and it is difficult to decide whether the described situation is an effect of their activity. It seems very probable, however, that it is a relic mineralization resulting from penguin presence when a different morphological situation of the shore in this area took place. Relic ornithogenic soils, formed by penguins, are common in the entire oasis near Stranger Point, above the present penguin rookery (Fabiszewski, Myrcha and Tatur, *in press*).

Thomas Point (King George Island): the name "Thomas Point" has a century tradition, at present being, however, not enough precise or even misleading. A mixed rookery of Adeli, antarctic and papua penguins, discussed in details below, was populated by 9 000 to 19 000 breeding pairs in years 1978—1981 (Jabłoński 1984a). It is situated near the Arctowski Station on

Penguin Ridge. The present breeding site is located on the old cliff built of volcanic rocks — andesites and basalts of the Arctowski Cove Formation (Birkenmajer 1980). The rocky cliff near Rakusa Point is surrounded by the Late Pleistocene moraines, which compose Penguin Ridge (Birkenmajer 1981a). The investigated area and location of the soil sampling points are shown on Fig. 4.

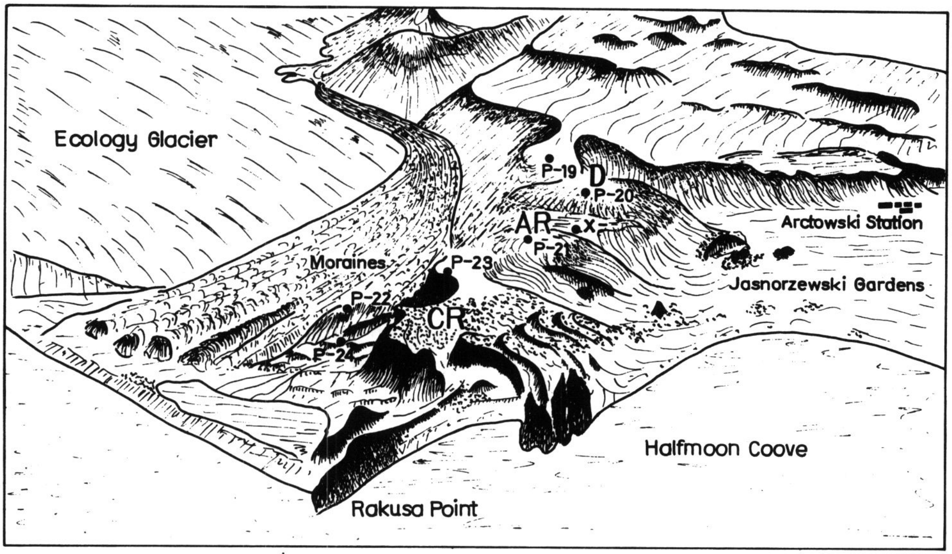

Fig. 5. Penguin breeding colony "Thomas Point" on the Penguin Ridge. The Penguin Ridge is composed of Current Rookery Hill (CR), 36.7 m a.s.l., Ancient Rookery Hill (AR), 53.3 m a.s.l. and Destiny Hill (D), 55.5 m a.s.l.
Location of soil profiles are indicated with P, and the trench is indicated with X. The stippled area is the present extent of penguin breeding sites

Solutions washing guano out of the present rookery flow over rock plates or among the rubble of large boulders. Thus, soil profiles are not developed or those which originate are inaccessible for investigations. Well developed ornithogenic soils can be only found in a belt of elevated marine terraces. A phosphatic clay, composed mostly of leucophosphite occurs among beach pebbles under a thin guano layer (Tatur and Barczuk 1984). No detailed investigations have been performed in the area of the present rookery, because of difficult conditions. Some partial observations have been made, however; especially concerning mineralization on rocks and surface mineralization. The results of chemical analyses of sample from the discussed area are presented in Tab. 4.

Small, slowly running spring has been found during the season 1979/1980 below the nesting site of penguins. Crystallization of nearly pure struvite took place from water of this spring. It is the only place known in the whole maritime Antarctic, where struvite was present without admixture of other minerals. Single free crystals of this mineral attained the size of several millimeters in length (Tatur and Barczuk 1984). The spring with the mineralization has existed without changes (as revealed an analysis S—K) also in the years 1984—1986. This suggests that the formation of struvite, which is very unstable geologically and easily dissolving in water mineral, is a continuous process in this place and not unusual and unique event.

After the long investigations, struvite/apatite mineralization similar to the commonly found on the islands around Arthur Harbor has been also found, in one point of a rock trough at the lower margin of the largest breeding group (C—P). On the other hand, the white mineralization of amorphous aluminium phosphate and apatite (S—L) is commonly found on the way of a guano flow through a stony beach. It is identical and equally common as in Hope Bay.

Relic soils. Much more attention has been paid here to the relic and burried soils existing in the investigated area, which occur above the present penguin rookery, in a moraine belt adjacent to the Late Pleistocene, forming Penguin Ridge (Fig. 4). This rookery, in effect of glaciisostatic elevating has moved downslope to the newly formed land, so leaving higher situated old breeding areas on the Destiny Hill and Ancient Rookery Hill (Tatur and Myrcha 1988). At present, these hills are ovegrown with a thick cover of diversified lichen and mosses. This vegetation hides phosphatic substrate from view.

Profile P-19. The section has been made in the highest and the most inland situated site of the relic ornithogenic soil occurrence in this region. White clay with the high phosphate content in clay fraction (5—10 cm) occurs on the top of the hill under a thin layer of the moraine clay composed mostly of silicates. The chemical analysis has shown that important role among phosphates is probably played by Ca phosphates. Despite the long investigations, no bones of penguins have been found at this site. One cannot exclude, however, that this site was occupied by giant petrels.

Profile P-20. Undoubtful traces of penguin nesting have been found on Destiny Hill. No ornithogenic soils have been investigated on the stony summit of the moraine which is covered with thick vegetation, as it was decided to avoid the environment degradation. Easily accessible traces of ornithogenic soils have been found, however, on a gentle slope below the summit and about 20 meters from the cross. Mosses, lichens *Usnea* sp. and the grass *Deschampsia antarctica* cover the soil in this area.

A peat-like humus mass occurs among loose pebbles and gravel (0—5) in the zone of roots spreading. Beside organic matter and silicates relatively small quantity of phosphates occurs in the finest fraction of this mass. Deeper (5—20 cm), a light clayey mass rich in phosphates (Ca phosphate domination over secondary phosphates) occurs among stones. Bones of penguins as well as remains of egg shells and egg membranes are present in the soil. Moraine clay showing no traces of phosphatization occurs below 20 centimeters.

Profile P-21. Much more clear traces of penguin nesting are present on the top of Ancient Rookery Hill. Numerous bones and egg membranes are present in the soil. This hill is composed of dark-brown moraine clays, with a high content of pebbles, gravel and sand fractions. The top of the hill is covered with a dense carpet of vegetation composed of the lichens *Usnea* sp., the grass *Deschampsia antarctica* and mosses. The vegetation in the section site was partly destroyed during the construction of the aerial mast.

A dark-grey humus has developed in the root zone. It is dispersed among stones and gravel. This horizon is up to 5 cm thick and has low contents of phosphates (0—2 cm). It is sharply separated from the light-brown lower horizon which is composed of strongly mineralized and leached guano. Earthy fractions (< 1 mm) (2—25/e. cm) contain much less phosphates than the clay fraction separated sedimentary (2—25/c. cm), in which Ca phosphate (apatite) is mostly concentrated. Pale-yellow earthy mass occurs below the guano layer, among small stones (25—30 cm). Besidé dominating silicates, it contains also secondary phosphates. Traces of phosphatization gradually disappear deeper in dark brown moraine clay.

Tab 4. Chemical composition of ornithogenic soils (fine fraction free of clastic material) from Thomas Point Rookery on Penguin Ridge

Sample	Concentration of elements													
number	Acid extrect HCl + HNO (1 : 1). I											Total		
depth	P	Ca	Al	Fe	K	Mg	Na	Sr	Mn	Zn	Cu	C	N	C/N
(cm)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	ppm	ppm	ppm	ppm	(%)	(%)	
CURRENT														
Surface														
S-K	12.75	0.12	0.00	0.07	0.03	9.36	0.00	0	5115	0	0	0.80	5.29	
S-L	12.95	4.30	10.56	0.59	0.82	0.29	0.29	2050	310	840	100	2.98	0.81	
Crust														
C-P	12.33	4.32	0.10	0.41	0.08	8.63	0.15	391	2056	82	8	2.23	4.70	
RELIC														
Profile														
P-19														
0-5	0.60	1.21	4.83	6.29	0.19	2.13	0.46	251	955	131	126	1.22	0.12	10.1
5-10	5.40	7.41	5.13	4.46	0.25	1.37	0.33	950	703	323	346	3.94	0.96	4.1
P-20														
0-5	2.20	2.72	4.09	3.99	0.23	1.41	0.29	438	409	136	141	12.45	2.09	5.9
5-10	7.00	11.15	4.50	3.33	0.27	0.63	0.47	1467	391	548	489	6.27	1.83.	3.4
P-21														
0-2	0.80	2.28	4.27	3.49	0.10	1.41	0.37	291	505	78	78	4.56	0.81	5.6
2-25s	5.80	9.32	4.56	3.11	0.44	0.53	0.48	1165	408	573	311	5.13	1.62	3.1
2-25c	8.05	11.93	4.59	2.96	0.44	0.43	0.56	1377	418	816	428	8.28	2.62	3.1
25-30	4.80	0.35	3.61	4.41	1.06	0.27	0.05	100	471	130	186	1.74	1.18	1.4
Surface														
S-M	6.10	0.19	5.17	5.03	0.91	0.25	0.08	1444	287	115	163	1.73	1.22	1.4
S-N	8.16	0.00	5.70	4.18	2.11	0.10	0.01	98	256	98	241	1.94	1.66	1.1
S-O	8.05	0.10	9.20	3.53	0.08	0.55	0.11	102	358	66	82	1.32	0.19	6.9
S-P	8.59	0.05	6.44	4.40	1.23	0.09	0.01	102	215	97	194	2.22	0.70	3.1
S-R	3.40	0.30	4.22	5.33	0.20	0.25	0.04	101	513	116	176	1.90	0.24	7.9
S-S	5.40	0.67	5.16	4.30	0.91	0.44	0.17	191	372	172	153	–	–	–
S-T	3.00	0.47	5.26	4.42	0.36	0.69	0.10	141	470	150	202	1.94	0.48	4.0
Crust														
C-R	5.60	0.24	8.52	4.74	0.09	1.06	0.16	97	639	150	111	1.43	0.15	0.8
Outcrop														
4t	4.40	0.98	6.36	3.24	0.33	0.32	0.08	687.	451	137	226	3.36	0.29	11.5
4c	5.10	0.54	5.98	4.39	1.03	0.31	0.08	286	372	220	267	3.08	0.50	6.1
4l	11.93	0.12	11.54	2.44	0.06	0.19	0.02	30	159	80	65	2.63	0.22	11.9
4d	11.45	0.19	10.88	6.83	0.20	0.16	0.10	67	193	39	87	2.39	0.22	10.8
4w	9.64	0.19	9.84	4.57	0.14	0.19	0.00	118	226	98	113	3.22	0.34	9.4
4b1	16.51	1.34	3.33	19.39	1.11	0.14	0.06	229	895	189	99	2.45	2.19	1.1
4b2	14.00	0.79	10.04	5.25	0.12	0.06	0.02	180	140	60	155	3.81	0.60	6.3
6c	2.40	0.49	5.83	6.50	0.22	0.69	0.06	230	1400	120	220	2.41	0.23	10.4
Profile														
P-22														
0-15	2.10	2.64	4.40	2.35	0.25	1.13	0.30	685	675	215	220	2.35	0.23	10.2
P-23														
0-20	6.55	0.20	5.00	4.95	1.55	0.23	0.10	98	324	118	162	3.63	0.98	3.7
20-60c	13.53	0.00	7.96	1.69	3.63	0.02	0.01	99	60	65	55	1.61	1.06	1.5
20-60d	3.80	0.20	4.75	1.14	0.36	0.25	0.05	99	475	109	138	1.82	0.31	5.9
P-24														
0-20	8.15	0.30	7.66	5.45	0.16	0.48	0.11	252	272	76	101	2.11	0.24	8.8
0-20cr	9.57	0.38	9.00	7.04	0.22	0.38	0.16	574	249	144	124	1.39	0.22	6.3

Mineralization on the surface of relic soils. The presence of penguins in the past has been marked not only in the described above top parts of the hills, which were the places of their nesting. Light soil surfaces with enhanced contents of secondary phosphates in the earthy fraction (S—M), and even more in clay (S—N), are common on the slopes of Ancient Rookery and Destiny Hill. In some places, one can find efflorescences of almost pure phosphates on the soil surface (S—O, total mass of the soil sample). These light ornithogenic soil surfaces are partly hidden under the rich vegetation and can be only seen in places exposed by erosion.

Especially large secondary accumulation of phosphates can be seen in local depressions in which weathering microsprings occur. The clay material accumulated in such places may attain thickness of 20 cm and it is composed nearly totally of phosphates (S—P, whole sample). In the studied sample crystalline Al phosphate is the predominating mineral (unknown X-ray reflections). Dark brown sandy clay occurs under light phosphatic clay. It contains also small amounts of secondary phosphates in a clay fraction (S—R). Vegetation developed at the margins of these phosphate-rich areas with springs, displaying bright green colour contrasting with more pale colouration of vegetation growing in areas poorer in nutrients.

It seems that phosphates may be accumulated in such depressions in various ways. Beside washing out, and solifluction, also transportation of phosphates in suspension by ground water seems to be very probable. Direct precipitation from groundwater may also regarded as an important process. The easily soluble relic guano resting on the top of the hill could be in such case the source of phosphorus; Al, Fe and K could yield in water after reaction of the guano leachate with silicates. Precipitation on the pebble surfaces in the area of microsprings could result from rapid changes in aeration, or may be an effect of supersaturation caused by freezing and/or intensive evaporation due to strong wind. This is the most probable genesis of the mineralization occurring at the site where the sample (C—R) was collected.

A thin coat of a white phosphate mineralization has been formed, which covers the surface of stony ground within the area of microsprings. It represents crystallization composed of Al phosphates (X-ray reflections unknown).

Mass movements along the slope lead to the mixing of materials with different phosphate contents, thus causing patchy colouration of the soil. The lighter patches (S—S) contain more phosphates than the dark soil patches occurring several centimeters away (S—T).

Trench X. An interesting phosphatic clay accumulation of the ornithogenic origin exists in small Green Valley between the hills formerly inhabited by penguins (Fig. 4). The trench has been made in this site at the 45 meters altitude exposing the Holocene deposits 2 meters thick (Fig. 6).

The layer of rounded boulders (layer 2) occurs on the late glacial moraine clays (layer 1). They may represent the early Holocene beach (see Birkenmajer 1981a). The other possibility is that it is a stony pavement from the bed of stream which was running in this area during the time when Ecology Glacier was of larger size and blocked the present-day ways of outflow.

Clayey gravels (layer 3) occur on boulders. The clay contains considerable amount of secondary phosphates. Above one can find the white layer of sandy clayely mud 20 cm thick (layer 4), on average they contain 50% of secondary phosphates (4t). The phosphate content is even higher in the separated clay fraction (4c). Phosphate dominates in the sample collected from the very light (4l) and a little darker (4d) patches devoid of clastic material. Crystalline Al phosphate (unknown X-ray reflections) occurs in the sample 4l, collected from the periodically drying zone of the section. On the other hand, nearly pure Al phosphate, collected from the most humid zone of the layer 4, has been found to be amorphous to X-ray (4w).

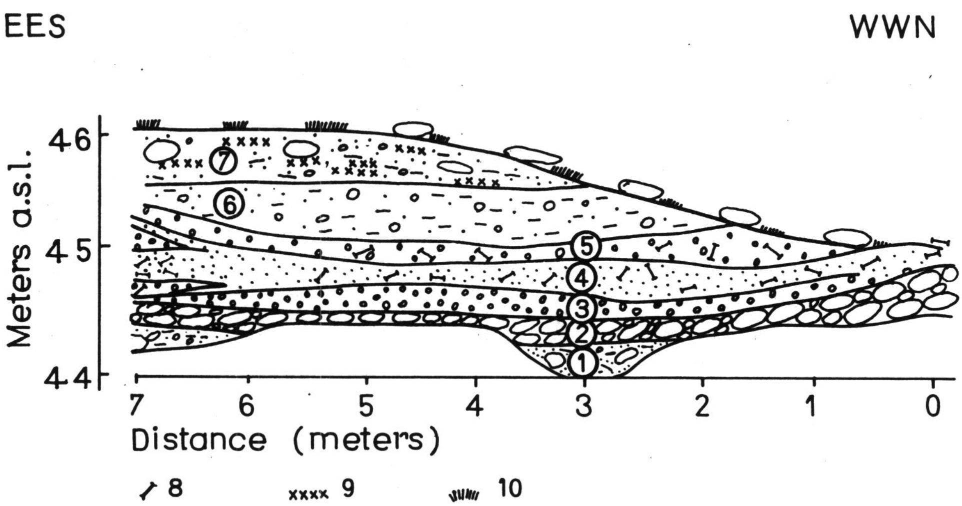

Fig. 6. Section of the Holocene deposits as cropping out in the trench X, Green Valley, near abandoned breeding sites on Ancient Rookery Hill (cf. Fig. 4). 1 — moraine clay, 2 — boulders and gravel, in eastern part penguin bones occur, 3 — gravels with penguin bones, 4 — fine sand and silt rich in phosphates, numerous penguin bones, 5 — sandy gravel with penguin bones, 6 — sandy clay, 7 — sand with peat intercalations

Both, clayey gravels (layer 3) and clayey silts (layer 4) contain enormous amounts of penguin bones. Basing on well preserved tarsometatarsi and humeri bones these penguins have been identified as juvenile forms of *Pygoscelis adeliae* and *P. antarctica*. Thus they represent the same species which compose also the main present-day rookery (Tatur and Myrcha 1988).

Subfossil penguin bones, although still having their former shape, have become completely new chemical composition. In the part of the profile cyclically flooded and dried, thus with alternating reducing and oxidizing conditios, the bones are darker, harder and they consist exclusively of leucophosphite. This leucoposphite represents iron-aluminium phosphate containing potassium and ammonium ions (4b1 — entire bone). That is the only known site in the whole maritime Antarctica where natural, nearly monomineral accumulation of this leucophosphite has been found. Although leucophosphite is commonly present in ornithogenic soils, it always occurs in multicomponent mixtures from which may be separated with use of special methods only (Wilson and Baim 1976). Entirely different alternations one can find in the penguin bones from the same level but from the permanently humid zone with reducing conditions. They are more delicate, fragile and have distinctly lighter colouration. They are composed of poorly crystalline Al phosphate (4b2 — whole bone) with unknown X-ray reflections.

Sandy gravels (layer 5) containing also small quantity of penguin bones occur above the phosphatic layer. Sandy clays of deluvial origin (layer 6) and alluvial sands with lenses of peat (layer 7) occur higher. Clays and sands also contain small amount of phosphates in the clay fraction (6c). The deepest peat lenses, which occur at the depth 40—50 cm were dated by Birkenmajer (1981a) as 4950± 500 years old. Thus, the colonization of this area by penguins took place earlier, but without doubts during the Holocene. The sea level at the beginning of Holocene had been located over 50 meters higher then at present while the described deposits occur at 45 meters a.s.l. The described site is the oldest documented in age site of the abandoned Holocene penguin rookery in the maritime Antarctic.

Profile 22. The penguin breeding sites and phosphatic ornithogenic soils occur also lower, along the whole Penguin Ridge and on the adjacent moraines. In the case of the farthest inland located sites one cannot exclude, however, that the observed effects may be caused by Antarctic skua commonly inhabiting this area. The described section has been made in such a place on the top of a moraine hill near the old shore in the belt of moraines adjacent directly to the Penguin Ridge. The layer (0—15) of light moraine clay occurs among pebbles under the vegetation cover *Usnea* sp. predominates. This clay gradually passes into the typical, darker, brown moraine clay. In the clay fraction of the lighter layer certain amount of phosphates, as well as fragments of penguin bones, are present.

Profile 23. Rather interesting ornithogenic soil in the area of former penguin rookery has been found on Penguin Ridge at the distance of about 60 meters from the present breeding site. The small hill is covered in 90% with vegetation (mostly *Deschampsia antarctica*, *Usnea* sp., and *Polytrichium* sp.).

A light clayey mass (0—20 cm) with a high phosphate content occurs in the earthy fraction directly under the vegetation. Darker, brown silicate-phosphate layer with fragments of phosphatized rocks exists below. Altered debris is coated with a white phosphate clay. This white clay is composed of pure taranakite — Al phosphate containing potassium and ammonium ions (20—60/c. cm — whole sample). The dark brown clay matrix also contains secondary phosphates in earthy fractions (20—60/d. cm), displaying, however, different composition. The presence of taranakite is rather excluded as the K and NH_4 concentration is small, thus one may expect the presence of simple Al and Fe phosphates.

Profile 24. Very distinct changes caused by the phosphatic mineralization have been also observed in the material composing the stony-gravel marine terrace situated at the 12 meters altitude. They are especially well visible in the place where the terrace is dissected by the stream producing deep incision.

At present, this terrace is situated outside the penguins activity area. Loose gravel which occurs in a surface layer, under a patch of *Deschampsia antarctica*, has been cemented into homogeneous conglomerate with the brown phosphatic cement (0—20 cm — separated mechanically cement, whole sample). Encrustations, which were carefully collected from particular grains, are very rich in amorphous Al-Fe phosphate (0—20/cr. cm). The phosphatic clay has been cemented, most probably, due to cyclic drying. The process of phosphatic cementation has been taking place during hundreds of years, what is indicated by the rate of the isostatic elevation of the island. The discussed terrace is built of permeable coarse grained clastic material and is situated at the cliff about 2 meters above the stream.

Similar old terraces, situated in the drainage places (which are indurated and cemented with phosphates), have been also found near Petrel Rock on Potter Peninsula (C—O, Tab. 3). On the other hand, old elevated terraces adjacent to Rakusa Point from the north, which are covered with permanently wet clayey weathered material about 1 meter thick, have not been indurated. The have soft clay composed mainly of Leucophosphite.

Blue Dyke (Admiralty Bay, King George Island): a small papua penguin rookery has been located formerly on the flat, small hill near Blue Dyke. Penguins of this species are changing their nesting sites more frequent than others, thus finding the area abandoned by them is not surprising. On the nearby moraine hills numerous surficial accumulations of penguin feathers remains has been noted. Similar material can be commonly found in feeding places of skua. It is formed by pellets of this species. Location of the breeding sites near Blue Dyke is presented on the Fig. 7, and chemical analyses in Tab. 5.

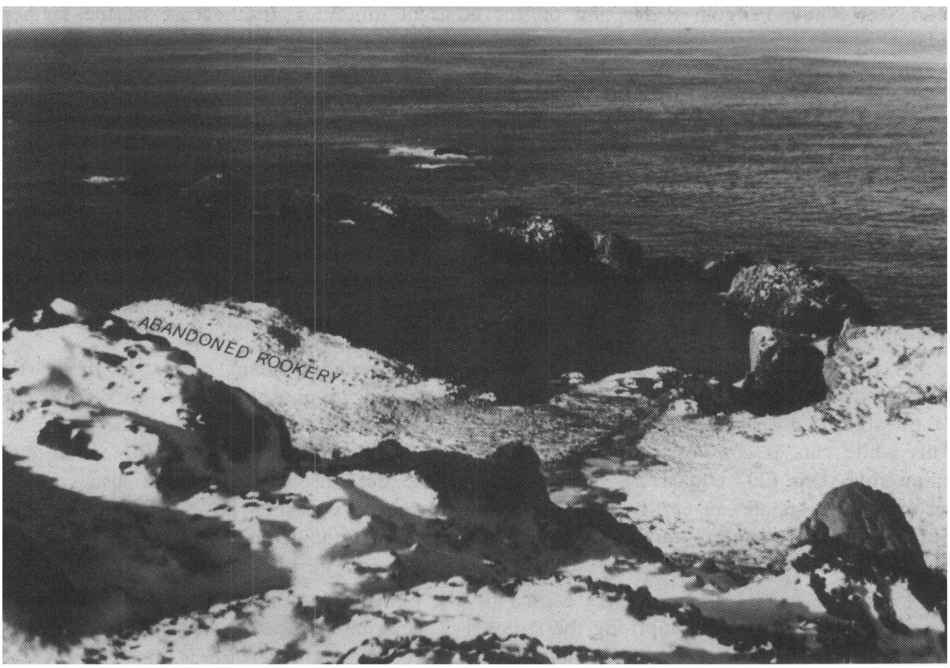

Fig. 7. Abandoned penguin rookeries near Blue Dyke

Profile 25. The entire surface of the former breeding site, located on a flat summit, is covered with thick vegetation. A black humus layer, locally thin (0—0.2 cm) and discontinous, occurs between the soil and the plants. It is nearly devoided of phosphates and displays high C/N ratio typical of plant material. Pale brown guano (0—20. g. cm) occurs usually directly under the vegetation among pebbles. Ca phosphate (apatite) predominates in it. Bones of penguins are also numerous. Ornithogenic macrodebris can be also found under the vegetation at the summit surface margins. It contains the most resistant organic remains as feather fragments, bones and chitin detritus (0—20 d. cm).

Profile 26. Light phosphatic clay, not more than 0.5 m thick, covers slopes of an old penguin rookery. The vegetation cover is sparse (not exceeding several surface percent) because of active solifluction processes. The described section has been made at the patch of vegetation composed mostly of *Usnea* sp. and *Deschampsia antarctica.* One may note the beginning of the black humus formation in a root zone (0—0.2 cm). The light, nearly white clay (0—20 cm) occurs directly under the vegetation. It is composed mostly of secondary phosphate (pure taranakite). The quantity of the rocky weathered material of the substrate increases deeper.

Surface accumulation. The alga *Prasiola crispa* is the only vegetation which is thriving on the surface of flowing phosphatic clays, covering the slope bellow the old penguin rookery. Phosphates constituting the clay are differentiated mineralogically. In the sample (L—A) only crystalline Al phosphate has been noted. It is concentrated in the white, clay coatings of stones in the surficial soil layer (L—B). An increase in Fe and K and decrease in Al have been observed in the clay matrix of surrounded stones.

The chemical and mineralogical composition of phosphatic clays, which cover slopes of the hill with the abandoned penguin rookery, is strongly differentiated. The samples of soil collected in sites distant from each other several meters often considerably differ in composition.

Low Head (King George Island): Low Head is a flat promontory about 200 meters long and 100 meters wide. It is built of diversified rocks of the Polonez Cove Formation (Birkenmajer 1982), *i.e.* volcanic rocks (andesites, basalts, rhyolites) and clastic sedimentary rocks. The large breeding colony has been formerly located at the promontory. Traces of it was noted earlier by Prof. K. Birkenmajer (Bocheński 1985). Only phosphatic ornithogenic soils, and feathers and bones remains, evidence this fact now. Accumulation of feather remains from pellets indicates activity of skua on adjacent moraines.

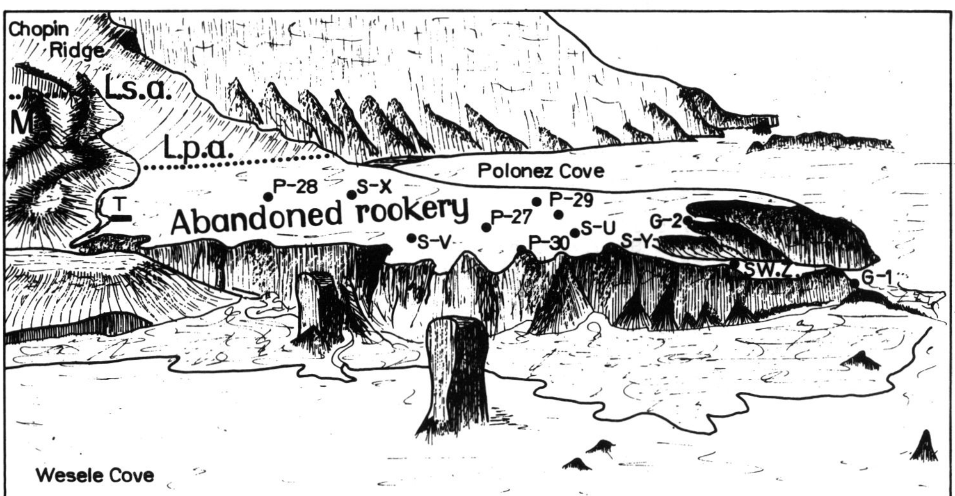

Fig. 8. Abandoned penguin rookery near Low Head, sampling sites marked. M — moraines, l.p.a. — extent of old penguin activity as revealed by the presence of phosphates in soil, l.s.a. extent of skua activity as marked by the presence of penguin feathers on the soil surface and remaints of pellets

Tab 5. Chemical composition of relic ornithogenic soils (fine fraction free of clastic material) from Blue Dyke and Low Head.

Sample			Concentration of elements											
number			acid extract HCL + HNO3					(1 : 1)				I total		
depth	P	Ca	Al	Fe	K	Mg	Na	Sr	Mn	Zn	Cu	C	N	C/N
(cm)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	ppm	ppm	ppm	ppm	(%)	(%)	
BLUE DYKE														
Profile														
P-25														
0-0,2	0.74	2.90	3.39	3.34	0.13	0.81	0.30	500	610	120	190	11.95	1.10	10.9
0-20g	9.31	17.91	2.12	1.64	0.24	0.33	1.27	2100	500	770	760	13.80	2.33	5.9
0-20d	3.34	5.49	4.04	2.79	0.45	0.35	0.42	700	240	220	240	8.84	1.56	5.7
P-26														
0-0,2	5.09	1.20	3.60	4.10	0.62	0.23	0.18	100	200	200	360	12.90	1.27	10.2
0-20	12.02	0.19	5.71	4.53	3.44	0.05	0.09	100	150	40	190	3.15	0.88	3.6
Loam														
L-A	5.47	1.43	6.78	4.44	0.13	0.74	0.07	100	380	40	90	1.88	0.18	10.0
L-B	11.86	0.49	9.42	2.33	0.02	0.15	0.05	100	90	40	40	1.86	0.19	9.8
L-C	4.44	0.40	4.95	6.50	0.82	0.49	0.06	100	310	140	250	3.16	0.91	3.5
LOW HEAD														
Transect														
T-1	6.55	13.35	2.20	2.37	0.20	0.60	0.56	1500	470	1550	920	8.59	1.10	7.8
T-2	4.33	5.00	3.10	3.90	0.60	0.45	0.67	900	310	300	300	5.33	0.80	6.7
T-3	3.16	4.25	5.32	2.37	0.62	0.26	0.47	900	490	200	220	4.48	0.60	7.5
Guano														
G-1	3.57	4.13	5.91	6.58	1.25	0.54	1.05	310	290	320	330	13.64	2.36	5.8
G-2	8.35	19.95	1.90	2.04	0.30	0.61	0.85	2365	1026	1254	446	13.89	2.55	6.7
Profile														
P-27														
0-1	6.76	0.11	4.44	3.71	1.54	0.26	0.06	10	205	68	137	5.16	0.95	5.4
1-50a	8.56	0.04	5.15	4.32	1.82	0.12	0.03	10	137	78	137	3.68	0.61	6.3
1-50b	13.69	0.07	6.80	2.68	3.11	0.06	0.04	10	134	211	67	4.56	1.11	4.1
1-50c	3.96	0.42	3.38	4.16	0.80	0.59	0.10	39	382	156	113	4.61	0.60	7.7
<50 a	13.53	0.02	12.40	1.65	0.61	0.05	0.05	10	50	30	20	2.73	0.34	8.0
<50 b	0.79	3.07	7.50	7.14	0.36	2.17	1.00	50	690	70	100	1.30	0.09	14.4
P-28														
0-2	1.02	1.26	3.69	2.24	0.85	0.92	0.61	50	290	50	80	25.05	2.49	10.0
2-50a	5.45	0.34	4.59	3.77	1.49	0.39	0.07	20	313	157	215	2.53	5.38	3.2
2-50b	7.63	0.35	5.93	4.19	2.19	0.30	0.10	38	314	152	210	3.30	0.88	3.8
P-29														
0-20	3.40	0.47	2.69	3.63	0.83	0.25	0.19	179	236	75	94	4.04	0.37	10.9
20-40	3.97	4.38	3.64	3.43	0.42	0.65	0.35	1299	1668	380	317	8.79	0.75	11.7
40-50	4.44	4.22	3.61	4.61	0.48	0.62	0.14	1104	1056	413	384	8.21	1.16	7.1
P-30														
0-20	2.81	0.49	2.52	4.10	0.71	0.34	0.15	5	605	103	82	3.18	0.42	7.6
<20 a	5.05	0.39	2.67	7.79	0.70	0.57	0.20	80	221	111	231	4.82	0.48	10.0
<20 b	8.15	0.19	4.41	5.84	0.93	0.59	0.45	9	118	69	98			
<20 c	4.00	0.47	3.65	7.84	0.46	5.19	0.20	73	574	82	246	3.93	0.27	14.6
Surface														
S-U	5.28	0.65	4.07	5.29	0.92	0.43	0.15	336	569	488	467	6.11	1.23	5.0
S-V	1.94	1.35	7.68	4.81	0.71	0.59	0.48	190	290	50	200	8.08	0.49	16.5
S-W	14.02	0.40	6.52	2.27	3.59	0.19	0.26	100	30	170	200	7.60	1.21	6.3
S-Z	6.25	0.41	3.07	4.35	0.96	0.31	0.16	82	133	72	358	4.77	0.38	12.6
S-X	12.26	0.12	6.68	2.34	3.29	0.14	0.03	10	170	90	60	6.63	1.14	5.8
S-Y	13.88	0.09	6.66	1.88	3.94	0.09	0.12	100	220	10	80	5.05	1.12	4.5

Penguins have abandoned this breeding area, most probably in effect inconvenient for them shore evolution during the Holocene elevation of the island (Tatur and Myrcha 1988). The area formerly occupied by the breeding penguin colony near Low Head and sampling points were presented on Fig. 8. The results of chemical analyses of ornithogenic soils from Low Head are shown in Tab. 5.

Surface accumulation. Distinct traces of old penguin nesting places have been noted only at the top of a small hummock (T-transsect). Strongly mineralized pale brown guano (T-1) occurs at the top of the hill, which is partly covered with lichen *Usnea* sp. The guano contains in the clay fraction strongly weathered organic remains and Ca phosphate (apatite). Ca phosphate (apatite) is also an important component of clays with a mixed composition (T-2), occurring in the surficial soil layer on the slope.

Phosphatic clay of mixed mineralogical composition (T—3) accumulated here in a small pool at the hummock sole. It contains enormous amount of penguin bones. Basing on the well preserved tarsometatarsi and humeri bones from this site, the presence of Antarctic penguins (*P. antarctica* — 2 tarsometatarsi, 14 humeri) and chrysolopus penguin (*Eudyptes chrysolophus* — 1 tarsometatarsi 5 humeri) has been evidenced at Low Head (Tatur and Myrcha 1988).

The remains of leached organic debris can be found under vegetation, at the margins of a plateau. There are the most resistant parts of feathers and bones (G-1), often containing also considerable quantities of apatite (G-2). No distinct traces of nesting areas have been found on the hills as well as in the central part of Low Head despite the intensive searching. The flat surface on the summit is covered with an ornithogenic soil in which secondary phosphates predominate. Several soil sections have been made in this area.

Profile 27. This section has been made in a location where solifluction of phosphate took place. It happens despite the small inclination of the slope. The vegetation cover amounts to about 20% of the surface — *Usnea* sp. predominates and larger stones and boulders are covered with nitrophile crustlike lichens. Uncovered clay surfaces display abundant *Prasiola crispa.*

0—1 cm. Noncontinous layer of poorly developed humus occurs in places under the vegetation.

1—50 cm. Angular stony rubble occurs with interstices filled by nonhomogenous patchy clay mass (1—50/a. cm — mean sample). Lighter phosphatic patches contain mainly taranakite in a clay fraction (1—50/b. cm).

50—80 cm. The number of pebbles increases. They are commonly coated with compact white clay consisting of crystalline Al phosphate (50—80/a. cm — whole sample; X-ray reflections unknown). The weathering crust of rock fragments is weakly impregnated with phosphates (50—80/b. cm).

Below 80 cm. Increasing amount of large boulders precludes further excavation.

Profile 28. This section has been made under the dense cover of the lichen *Usnea* sp., on a flat and wide humock covered with pebbles. The pattern of the rock material on the surface resembles to some degree poorly developed polygonal soils. It could represent also strongly transformed (by freezing) outlines of former nests.

0—2 cm. Loose stony rubble overgrown with *Usnea* sp. Thin layer (several mm thick) of currently forming humus can be recognized in some places.

2—50 cm. Light phosphatic-silicate clay (2—50/a. cm) among loose pebbles of several centimeter in size. The concentration of white secondary phosphates coating took place (2—50/b. cm). Lecophosphite and taranakite have been identified among phosphates.

Below 50 cm. Increasing amount of stones precluded further excavation.

Profile 29. Soil surfaces characterized by a distinctly darker colour indicating lower share of phosphates and higher of silicate clay and vegetation humus occur in the investigated area. This situation is presumably caused by covering the ornithogenic soils with silicate soils and next partial mixing. The section made on the gentle slope of the hill, which is covered with diversified vegetation displaying *Usnea* sp. dominance, may serve as an example.

0—20 cm. Pale grey silicate-phosphate clay filling interstices among stony rubble. C/N ratio of the organic matter of the soil is equal to 10. This is the ratio characteristic for the humus of plant material.

20—40 cm. Grey-greenish silicate-phosphate clay displaying high C/N ratio occurs among stony rubble. Numerous bone and feather remains of penguins have been found in the sole of this horizon.

40—50 cm. Distinctly lighter clay with higher phosphates contents. C/N ratio is lower than in the overlying horizons. Large boulder precludes excavation below 50 cm.

Profile 30. Active processes of phosphatization of the substrate can be observed in this profile. The section has been made at the margin of the cliff nearly devoid of vegetation. Pale grey silicate-phosphate clay occurs among rubble of weathering basalts (0—20 cm), deeper this assemblage passes gradually (< 20 cm) in primary basalt.

Light, soft phosphate-silicate clay occurs in fissures of the weathered rock (< 20/a. cm). It contains important amounts of simple Fe-Al phosphate. Higher content of secondary phosphates exis in the hard glassy crusts of a dark brown colour, which cover rock fragments (< 20/b. cm). A weathering zone in rock fragments shows distinct traces of phosphatization (< 20/c.cm).

Surface accumulation. Common solifluction processes of phosphate clay (S—U, sedimentary separated clay) can be observed on the plateau in areas devoid of vegetation. The clay is composed mainly of secondary phosphates. Characteristic banded microstructure are common on the soil surface. They are composed of bands of phosphate clay separated each 5 centimeters by troughs infilled with gravel and pebbles (up to 3 cm wide), running consequently with the slope inclination. They resemble other well known macro forms.

Light clays with the relatively low contents of phosphates may occur also at the surface in this area. These clays, in some places, are derived from weathering of light sedimentary rocks, and often do not differ significantly in colour from the phosphate clays (S—V).

After rainfall, a process of washing out of phosphate clay from a weathered material has been observed at the margins of the plateau. Light yellow clay which was deposited in a small spring outflow from weathering cover (S—W), has been found to be nearly pure taranakite. Fine sand grains, included into this sediment, consisted of amorphous Al phosphate coating on a strongly phosphatized silicate core (S—Z).

Pebbles covering the soil surface are frequently coated with the white phosphate clay. It can be either nearly pure taranakite (S—X), or the mixture of taranakite and leucophosphite, as it is shown in the case of the profile 28.

The most pure tranakite has been found in a few meters deep fissures existing in the volcanic rocks of the substrate. The content of these fissures could be observed on the vertical wall of an old cliff (S—Y).

Trace elements in ornithogenic soils. — Krill eaten by penguins has the high F, Sr, Zn, and Cu contents (Mauchline and Fisher 1969, Adelung 1987). That is also the reason of an enhanced concentration of these elements in the mineralized guano. It has been noted in all examined profiles of recent soil and has been retained also in the relic guano apatite, Sr, Zn, Cu are bound in apatite by isomorphic substitution of Ca ions, and F substitute OH group (Altschuler 1973). Much less concentration of Sr, Zn and Cu has been noted in brushite (also Ca phosphate), which has been even accompanied in one case by apatite in guano of fish-eating cormorants.

Concentration of the above listed trace elements is usually less important in the phosphatized rock zone.

Fluorine is strongly bound only by minyulite (Tatur 1987). Presumably, it can be even regarded as indispensable in the process of minyulite formation. Metallic trace elements as Zn, Cu and Sr can be bound only by amorphous aluminium phosphate, which occurs in a superficial crust mineralization on rocks in paragensis with apatite. So it is rather difficult to estimate what is the partition of these elements between amorphous phosphate and apatite. On the other hand, Sr alone could be selectively sorbed, in high quantities, in amorphous aluminium phosphate coating clastic grains within a soil (Tatur and Myrcha 1984).

Discussion of results

Recent ornithogenic soils. — For the first time, the process of the recent ornithogenic soil formation in the maritime Antarctic has been studied in details by the Polish team during the 1979—1980 season in the region of Llano Point (Pietr, Tatur and Myrcha 1983, Tatur and Myrcha 1984, Myrcha, Pietr and Tatur 1985, Tatur and Barczuk 1985). The present paper is the continuation of these studies in the different climatically and geologically areas. It aims also to the synthetic description of ornithogenic soil problem.

Particular penguin species construct their nests in a diverse geomorphological situation of a shore in ice free Antarctic oasis. Adelie penguins nest in the studied area usually farthest inland. Diversified and widespread ornithogenic soil surfaces have been developed most commonly around their rookeries. Antarctic penguins occupy usually steep rocky shores, and papua penguins nest on stony beaches. The soils around rookeries of the last species cover smaller area and are less diversified.

Two processes control formation of ornithogenic soils within and around the currently inhabited rookeries. The first one is the mineralization process of guano left by birds on the land and the second one is the substrate phosphatization under the influence of guano solutions. Both these processes depend on the presence of water i.e. they need, at least periodically, positive temperatures.

Guano is easily and rapidly washed out into the sea from the rookeries located on shore rocks. However, if a rookery is located far inland, the guano is dispersed by rain and melt waters over a large area. In such a case, ornithogenic soils are formed not only within the rookery but also outside of it, especially in its proximity, usually on loose clastic rocks, stony rock rubble, pebbly, sandy and gravel beaches and moraine clays. This process is associated with infilling and impregnation of such loose deposits with the guano, phosphates and clay products of accelerated weathering. The phosphatization proceeds under the influence of the agressive guano solutions on way of their outflow to the sea. The morphology, chemical and mineral composition of ornithogenic soils are distinctly different in the rookery and in its surrounding.

The nesting area is covered with guano, which infills interstices among pebbles used by penguins for the nest construction. The thickness of this layer does not exceed usually 0.5 m. It is underlaid by a hard rock substrate, or by a layer of boulders. Only sometime clay composed of secondary phosphates may be found in the deepest horizon of the soil profile or in marginal parts of the colony. Accumulations of coarse grained organic detritus of ornithogenic genesis (feathers, bones, egg remains) may be observed locally, usually at the rookery margin (Tatur and Myrcha 1984).

The surficial part of the guano layer consists of decomposing penguin excreta (horizon of fresh guano). It contains mostly organic matter. Phosphates which are the products of guano mineralization process occur there only in small quantity. More important concentration of these phosphates may take sometime place in the form of superficial salt efflorescences. Struvite $Mg\ NH_4PO_4 \times 6H_2O$ and fluoroapatite $Ca_5(PO_4)_3F$ are the characteristic minerals in this horizon. They may be accompanied by unstable crystalline urates of K, Mg and NH_4 giving very strong X-ray reflections (Tatur 1988). Struvite accumulations on the guano surface have been more commonly observed on Antarctic Peninsula than on King George Island. It can result from a more dry and cold climate of Antarctic Peninsula.

The concentration of more stable fluoroapatite takes place in a lower part of a guano layer. Together with fine weathered chitin detritus it forms a pale-brown compact mass forming unstable aggregates (horizon of leached phosphatic guano). Struvite is absent in this horizon. Microbiological activity is much lower here in comparison with the higher level (Pieter 1984).

Only guano from the rookery on Seymour Island differs from this characteristics. It is rather homogeneous and less decomposed in the entire thickness of 25 cm. It seems to be more similar to the guano described from the continental Antarctic than to the guano from the maritime Antarctic (Tedrov and Ugolini 1966, Ugolini 1972, Campbell and Claridge 1987).

Guano from the vicity.of cormorant nests on Cormorants Island is also different due to its very characteristic mineral composition. This island is located off Anvers Island. Beside apatite, brushite $CaHPO_4 \times 2H_2O$ commonly forms in a layer of pure ornithogenic deposit of 0.5 m thick. The origin of brushite, instead of apatite, may result from the acid soil environment, what facilitates formation of this mineral. Brushite is more stable and less soluble than other phosphates in such conditions (Brown 1973). The finding of brushite only around cormorant nests suggests, however, that it may be also connected with the low F content in fish eaten by cormorants, and high F content in krill eaten by penguins. Brushite does not have to contain fluorine, whereas the most stable apatite variety, fluorapatite may form when F is available in concentration sufficient for binding into mineral structure.

Ornithogenic soils around of penguin nesting sites differ distinctly from the soils from within a colony. The best developed profiles of these soils occur just below the colony on a hill slope covered with thick weathering cover composed of pebbly clays. The thick and light colour zone of phosphatized rocks occurs under a thin guano layer. It has variable composition in a vertical section. The thickness of ornithogenic soil profiles does not exceed usually 1 m, but in some cases it may even reach over 2 meters.

A thin guano layer covering the slope below the penguin rookery is composed of a mixed organic-phosphatic material. This material has been washed out by rainfall or melting waters from the area of the rookery. It consists mostly of the finest fractions *i.e.* desintegrated chitin debris mixed with fluorapatite clay. Quantities of struvite and urates decrease in relation to the rookery area. Still proceeding microbiological decomposition of the guano releases ammonium which gives alkaline or neutral reaction. This material forms a thin layer permanently creeping down and gradually mineralized (horizon of guano run off). Phosphate ions, released in the process of the decomposition, react with a silicate substrate and form a thick zone of phosphatized rocks under the guano layer. It displays weakly acid reaction in the upper part, or strongly acid reaction in the lower part. Phosphatization is facilitated by the disintegration of a rock, high contents of easily weathering minerals, more humid climate and duration of the process itself. Moreover, climatic conditions and geological structures are variable in the maritime Antarctic Zone.

The investigated region of Antarctic Peninsula is built of rocks resistant to weathering (granite, granodiorite, strongly cemented greywackes, quartz sands). King George Island is built mainly of easily weathering basalts, andesites and andesitic tuffs. The climate is a little colder and more dry in a proximity of Antarctic Peninsula, especially on its east side. It results from the influence of the continental Antarctic. King George Island is situated about 140 km from the continent, in the warmer and more humid climatic zone (Antarctic 1985, Campbell and Claridge 1987).

Different climatic and geologic conditions cause that the phosphatized rock zone of ornithogenic soils is less developed near the Antarctic Peninsula (Arthur Harbor and Hope Bay Oasis) than on King George Island. In the case of Seymour Island, which is situated on the east side of Antarctic Peninsula, only fragments of carbonate rocks occurring in a guano layer reveal undistinct phosphatization. Phosphatization has not been observed in underlying sand, clay and ferrugineous concretions.

Situation is different in the case of the penguin rookeries on King George Island where phosphatization penetrates deeply in a substrate. Strong phosphatization leads to distinct differentiation of mineral composition of phosphates in a vertical section. The best developed profiles of recent ornithogenic soils have been described from the vicity of the rookery near Llano Point (Tatur and Myrcha 1984). The soil profile from Penguin Island, presented in this paper, indicates that the process of the substrate (fresh tephra) phosphatization may be very rapid, and well advanced already after several dozen years of penguins nesting.

Ornithogenic soils devoid or nearly devoid of a phosphatized rock zone are also common in the both compared regions of the maritime Antarctic. They occur within penguin rookeries located on hard and steep rocks close to the sea shore, where guano runs directly off to the sea. The penguin rookeries on Chabrier Rock, Uchatka Point or Lions Rump on King George Island are good examples. The same situation is illustrated by a considerable part of rookeries around Arthur Harbor, part of the breeding area in the Hope Bay Oasis and the rookery on Bryde Island.

New results present more detailed description of a morphology of a phosphatized zone. At first, silicate clay and phenocrysts of mafic minerals and feldspar undergo dissolution in rock fragments in effect of reaction with guano solutions. Ca, Mg, Na and sometimes also Fe are leached completely from the fine fraction of the forming phosphatized rock zone of an ornithogenic soil. Phosphate ions of guano solutions react with aluminium and iron ions (sometime also with potassium) delivered from silicate minerals, binding them into secondary phosphates. Ammonium and fluorine ions, as well as some undetermined simple organic compounds derived from guano solutions are also bound, in secondary phosphates. As it follows from the petrographic studies, organic compounds can be bound chemically with phosphates only in an amorphous mineraloid. However, they can be present as inclusions or superficially adsorbed admixtures on the surface of crystalline phosphates. Trace metals, released from guano (Zn, Cu, Sr), could be selectively bound mainly by amorphous Al phosphate in a phosphatized zone, what has been evidenced for the case of Sr in earlier papers (Tatur and Myrcha 1984, Tatur 1987). Fluorine is strongly bound by minyulite, sometime also by amorphous aluminium phosphate (Tatur 1986), and to a lesser degree also in leucophosphite (Keck and Tatur unpubl.).

Complete dissolution of silicates in the phosphatization process has been described from the upper part of a phosphatized zone in one profile from the Llano Point region (Tatur and Myrcha 1984). Both, silicates and silica have been totally removed, and only the spongy structure of hard phosphatic rock evidences the former presence of a fine clastic material. Soft silicate-clay pseudomorphs after fragments of volcanic rocks have remained in a deeper part of the discussed zone. The mode of phosphatization has been imprinted in the mentioned bizonal structure of soil profile. Leaching of the upper part of phosphatized zone with guano solutions of the variable, acid or alkaline, reaction. The lower part was only leached with acid solutions which did not remove silica. These conclusions follow from the analysis of the chemical composition of solutions flowing from the rookery and percolating through the soil (Tatur and Myrcha 1983).

Suitable conditions did not exist in other areas of the maritime Antarctic to imprint a clue of phosphatization process. Phosphatic clay, usually forming unstable aggregates, could be easily transported among loose stone rubble mixing soil horizons. Commonly, a guano horizon was also partialy mixed with underlying clay of secondary phosphates.

The described process of phosphatization becomes more clear if one considers also the mineral composition of a phosphatized zone. Various secondary phosphates (differing in physicochemical conditions necessary for their origin) occur under a thin guano layer in the zone of phosphatized rocks around rookeries (Tatur and Barczuk 1984. Tatur 1987). One should remember, that these phosphates have similar chemical composition, thus a determination of their mixture on the base of chemical analysis only is rather complicated. The problem may be solved by X-ray analysis. Under suitable conditions, secondary phosphates are regularly distributed in the vertical section, forming variously coloured genetic horizons of a soil. One or two of the four possible phosphates occur in every particular horizon.

Leucophosphite $(NH_4 > K)(Fe > > Al)_2(PO_4)_2\ (OH > F) \times 2H_2O$ in the most common mineral in the upper, weakly acid part of the phosphatized zone. It is commonly found in the entire maritime Antarctic. Its origin depends on periodic presence of Fe ^{2} ion in the soil solutions. Iron can be mobilized from a substrate by organic compounds of ornithogenic genesis reducing it to the mobile form. The total leaching of iron could sometimes take place when a soil is washed for a long time with guano solutions rich in organic compounds. It is also soil environment abundant in fluorine.

In such cases minyulite $KAL_2(F_{0.82}OH_{0.18})PO_4 \times 4H_2O$ can form. This mineral has been found only in two locations: near Llano Point (King George Island) and on Torgersen Island (off the west coast of Antarctic Peninsula). Taranakite $K_{1.9}(NH_4)_{1.1}Al_5H_6(PO_4) \times 18H_2O$ is very common in the deepest, most acid and always humid zone of the soil on King George Island. It has not been found in the shallow soils on Antarctic Peninsula. Amorphous aluminium phosphate is commonly found in the entire investigated region at different depths. Sometimes it contains considerable amount of iron and fluorine $(Al, Fe)_1(F.OH)_y(PO_4)_{1-y} \times nH_2O$, where y varies from 0.05 to 0.30. Possibly it represents the product of incongruent dissolution of phosphates containing potassium and ammonium, or can originate in a microenvironment with low alkalinity and high aluminium content. Vivianite $Fe_3^{II}(PO_4)_2 \times 8H_2O$, most probably of ornithogenic origin, has been only found in one spot near rookery on Llano Point, in clay intercalations in a peat bank (Tatur and Barczuk 1984).

Ornithogenic material is frequently accumulated on the surface of the soil in certain particular places within the areas of the penguin's activity. Commonly, fractionation of a fresh guano washed off the rookery can be observed. The coarsest fraction *i.e.* undigested chitin remains of krill is left in breeding areas. Finer, organic and phosphatic fractions are deposited in a proximity of breeding sites, but apatite clay washed from guano is transported on a larger distance. Sometimes it forms accumulations several centimeters thick, which periodically cover huge areas at the sole of hills inhabited by penguins.

Fine clastic material composed of a mixture of silicates and phosphates is accumulated in local pools formed on the way of streams draining the breeding areas. Such alluvial accumulations can be observed very frequently on flat beaches. They contain guano, clastic material of secondary phosphates, and clastic silicates.

Phosphatic efflorescences on a soil surface appear due to intensive evaporation of soil solutions. This process takes place under the influence of strong wind or/and in the dayly freezing and melting cycle in the summer time. This thin film of efflorescences occurs commonly but in negligible amount. During a dry period it causes very characteristic lighter colour of ornithogenic soils. It occurs both in the case of soils with apatite domination and in a case of soils containing only secondary iron-aluminium phosphates. Negligible amounts of this surficial film precluded chemical and mineralogical analysis.

Less common, but easier to observe and to study, are distinctly crystalline efflorescences of struvite and larger local accumulations of precipitated apatite. They can be found at the rookery area in places protected from rainfalls. During a dry season, thin struvite and apatite coatings occur on the guano surface at the margins of pools or in sites where guano leachates supersaturated in phosphate salts are slowly exude from a weathering cover.

During the period 1984—1986, a very interesting mineralization on rocks has been investigated for the first time. It occurs as thin and hard phosphatic crusts on the surface of solid rocks and pebbles located on the way of guano leachates flowing from the rookery. Struvite crystallizes first in the area of the rookery. The solution is alkaline in this moment and has an excess of ammonium ion. In the precipitate crystallizing a little further apatite is the main component. Amorphous aluminium phosphate crystallizes mainly at the largest distance from the rookery from acid solutions after reaction with silicates. Particular zones of crystallization overlap each other. Thus, the crusts consist of alternating laminae of the variable struvite/apatite proportion, or of the optically homogeneous mixture of apatite and amorphous aluminium phosphate. No monomineral crusts have been found. It indicates that the chemical composition of water, from which these minerals crystallize, changes continuously.

The first two zones of this crust mineralization (struvite apatite) are especially well developed within the areas of rookeries situated directly on hard cemented rocks, where supersaturated guano leachates do not sink into the substrate. It runs on the surface in rocky troughs leaving few millimeters thick layer of phosphates on their walls. The most suitable conditions for struvite-apatite mineralization had place within the breeding area on the islands around Arthur Harbor. The second zone (apatite-amorphous aluminium phosphate) of this crust mineralization is widerspread outside of the breeding area, on rocks or stones, often several dozen meters from a rookery. It is much more common than the first one and occurs in many investigated sites in the whole maritime Antarctic.

Relic ornithogenic soils. — The location and extent of penguin rookeries have been changing during the Holocene. Numerous examples of various soils have been described from the areas abandoned long ago by penguins (Tatur and Myrcha 1988). Despite their age of several hundreds or thousands of years, these soils preserved specific chemical and mineralogical features, which are only slightly transformed in the process of chemical and mechanical weathering, mass movements, frost processes and under the influence of a profuse vegetation.

The guano layer is the first to be removed and dissolved after a breeding site is abandoned by penguins. Remains of a strongly mineralized and leached guano with a high apatite content, can be only found in the area of the former nests, usually deeply hidden under a pavement of loose pebbles. This old guano is composed mostly of fluoroapatite, remains of feathers and bones, but unstable struvite is absent.

After the disappearance of a superficial guano layer, white clay containing secondary phosphates becomes much more visible on the surface of abandoned sites. One may also suppose, that it can partly originate, by guano dissolution after penguins left a rookery.

Areas of former penguins activity are covered with stony loams. Their clay fraction is composed usually of secondary aluminium-iron phosphates. These loams are slid and both mechanically and chemically segregated during gravity flows, erosion, solifluction, macro and micro sorting, frost processes, dissolution and recrystallization after a short transport in solution. They can be also included into lateral moraines by expansion of glaciers. Such processes are especially well marked and developed on Low Head and Penguin Ridge.

Those processes may lead to secondary concentration of phosphatic clay at the special levels and in special sites (*e.g.* secondary selective washing into local depressions and fissures cutting rocks, superficial efflorescences, secondary mineralization on rocks near weathering springs), and on the other hand, also to dispersion of phosphates in weathering covers as well as to a mixing (not always homogeneous) with nonphosphatic silicate clays. Often these processes may cause covering of ornithogenic soils with silicate weathering clays or alluvia.

Accumulations of ornithogenic material, which originated in local depression (Low Head, Penguin Ridge), are especially interesting. Their location protects them from mechanical erosion and they are usually well preserved, sometimes under the cover of the deluvial or alluvial deposits. In such situations a large accumulation of penguin bones often took place, thus permitting determination of species composition of a former rookery (Tatur and Myrcha 1988).

Penguin bones remaining hundreds and thousands of years in soil, may change distinctly their chemical and mineralogical composition. Primary calcium phosphate (apatite) could be in some cases replaced by simple crystalline forms of aluminium phosphate (X-ray reflections unknown), or by iron-aluminium phosphates containing ammonium and potassium ions (leucophosphite). They form perfect pseudomorphs preserving both outer shape of a bone and its internal structure.

Characteristic chemical-mineral alterations proceed in relic ornithogenic soils during longer time period. As it was already mentioned, guano is intensely destroyed mechanically and chemically in the abandoned breeding areas. The distinct concentration of apatite can be observed in preserved remnants, what indicates more rapid decomposition of organic matter than dissolution of apatite in guano.

Minyulite seems to be the most unstable mineral among secondary phosphates, as it has been never found in the relic soils. Leucophosphite is also less common than in recent soils. On the other hand, taranakite and aluminium phosphates (both amorphous and crystalline) are more commonly found in relic soils.

Simple crystalline Al phosphates have been never found in the recent ornithogenic soils. In the relic ornithogenic soils they have been noted as at least two different minerals, displaying X-ray reflections not described in the literature known to the author. Their chemical composition is similar to the composition of the amorphous mineraloid described by Tatur and Barczuk (1984). However, they contain less organic compounds. More detailed information on this subject is published elsewhere (Tatur and Keck 1988).

All secondary phosphates from the relic soils are poorer in organic matter than in recent ones but this matter has clearly higher C/N ratio. This indicates the presence of the permanent microbiological decomposition of less stable compounds richer in nitrogen. Such decrease in organic compounds occurs during the maturation of the ornithogenic soils. This indicates also that organic compounds are only mechanically associated or sorbed by phosphates and are not included into crystalline structure.

The fact that leucophosphite and taranakite of relic soil have not changed chemical formula during aging when compare them with recent occurrences, seems to be interesting. This concerns mostly the diadochy of K and NH_4 in the structure of tarankite and leucophosphite. Both, the recent and fossil taranakites display similar molar ratio of K and NH_4 (about 1.7 to 1.3). Also leucophosphite which was described from relic soils (sample 4b1, Tab. 4) contains even distinctly more ornithogenic NH_4 ($K:NH_4 = 0.18$) than leucophosphite from the recent soils ($K:NH_4 = 0.75$) described by Wilson and Baim (1976). If the processes of ion exchange occurred, one may expect the relative enrichment in potassium of taranakite and leucophosphite from relic soils. Potassium is the common element in a near shore soil environment whereas the decrease of the ammonium ion content may be expected due to its defficiency in the abandoned nesting sites.

Important conclusions follow from the analysis of remnant superficial mineralization on rocks in the Hope Bay Oasis. Phosphates which compose crusts on the rocks around the recent rookeries are characterized by variable solubilities. Struvite is dissolved first, next apatite and finally amorphous aluminium phosphate is dissolved. For this reason after a certain time only apatite remains of the struvite-apatite paragenesis. However, only amorphous aluminium phosphate can be left from the apatite-amorphous aluminium phosphate paragenesis. This way bimineral accumulations in recent soil can be transformed into monomineral ones in relic soil.

The observations presented in this paper permit to conclude that phosphates of the relic soils are relatively stable during the period of hundreds and thousands years. They could be slowly dissolved and/or altered into other more simple minerals in the process of weathering, but they do not reveal distinct ion exchange. Thus, a part of the phosphates can retain the unchanged chemical composition during hundreds and thousands years, thus being still the important source of phosphous and other nutrients for vegetation developing on phosphatic soils. The process of decomposition of leucophosphite, taranakite and minyulite delivers, beside P, also NH^{+} and K ions. Remnants of guano leached on hills deliver Ca^{2} ions as well as many other trace elements.

Origin of plant humus. Vegetation invades immediately ornithogenic soils in areas abandoned by penguins. It is absent only in the sites where erosion is active and mass movements or frost processes take place. The vegetation forms only a very thin (usually not exceeding several millimeters) pure humus horizon, displaying characteristic black colour and high (above 10) C/N ratio. This humus usually does not mix with the underlying phosphatic soil. Thus, the vegetation causes that beside organic matter of animal genesis, humus of plant origin appears also on the surface of soil. In effect, totally new type of soil forms in which the ornithogenic component interweaves with a different soil yielded from process, having no relation with penguins activity.

During transformation of recent soils into relic soils, total change of soil reaction takes place in a superficial layer. Reaction is alkaline or neutral (Tatur and Myrcha 1984) on a surface covered with fresh guano within and around of the current breeding areas. In the areas abandoned long ago, after erosion and/or dissolution of the superficial guano layer, the reaction changes to acid and pH usually reaches values close to 4 (Myrcha and Tatur 1988).

Comparative remarks

Extent of influence of penguin breeding groups on environment. — The manuring of a coast by nesting penguins covers considerable areas of ice-free oases of the maritime Antarctic. Commonly, rookeries are situated far inland, up to several hundred meters from the shore, and up to several dozen meters a.s.l. In some cases they have been even found as high as 100 meters a.s.l. Precipitation and melting waters wash out guano from hummocks occupied by penguin breeding colonies and distribute it over the entire surrounding area, thus forming ornithogenic soils. Other birds accompanying penguin (skua, sea-gull, and to a lesser degree sheathbills) participate in the manuring of adjacent areas, outside of the zone of guano washing. On the other hand, wind transports volatilized ammonia over a vast area with radius of several kilometers, thus extending the zone of penguin influence on the nutrient status of soils in whole oasis.

Penguins are characterized by strong ties to breeding site (Penny 1968). Two penguin species dominate in the investigated region *i.e. Pygoscelis adeliė* and *P. antarctica*. Each year, during the breeding season, they return to the same breeding colony, and only few specimens from a dozen thousand specimens from a big colony may inhabit the site of adjacent colonies (Trivelpiece, oral information).

Despite this fact, the shape and extent of a colony, as well as intensity of manuring by penguins, fluctuate in time. Each year the different number of penguins participates in breeding. Each year the number of birds in a colony is also different what may be caused by a variable breeding effect (Jabłoński 1984a, 1984b, S. Poncet and J. Poncet 1987). Many authors maintain that the recently noted increase of the penguin population follows from a food abundance (Croxal 1984, Myrcha, Tatur and del Valle 1988). In the case of penguins of this zone it is nearly exclusively krill (Volkman, Presler and Trivelpiece 1980). Large amounts of krill appeared in the oceans surrounding Antarctica in effect of exceptional reduction of the krill-eating whales number. This may be causing an expansion of penguins toward new breeding sites. Fluctuation of rookery shapes depend also on other factors as microclimate (Taylor 1962, Moczydłowski 1986, 1989), a pressure of predators, ice situation on the sea adjacent to breeding sites (Harrington and Keller 1958, Spellerberg 1970) and human activity (Antarctica 1985, S. Poncet and J. Poncet 1987, Tatur and Myrcha 1988).

However, development of geological events had the most important influence on a relocation of penguin rookeries during the Holocene. It caused considerable and final relocations. Numerous examples of these phenomena were presented elsewhere (Tatur and Myrcha 1988). Land areas of the investigated zone became elevated over 50 meters by glaciisostatic movements during Holocene (John and Sudgen 1971, Birkenmajer 1981b). The colonies have moved in this time down the slope, on a newly formed land, leaving the old higher nesting sites (*e.g.* Penguin Ridge, Stranger Point, Hope Bay). Specific development of morphological conditions as forming steep cliffs or uncovering more suitable nesting areas in a neighbourhood, caused sometimes total abandoning of the old breeding sites (*e.g.* Low Head, Blue Dyke). Glacial processes also play an important role in accessibility of land for penguins. Many times during Holocene glaciers changed morphology of the lateral moraines. Also current eruptions of volcanoes known from the investigated King George Island (Birkenmajer 1982, Tatur and del Valle 1986), had to exercise some influence on the distribution of the breeding colonies in the studied region (*e.g.* Penguin Island).

Thus, the course of geological events during the Holocene caused the definite abandonement by penguins of some areas with ornithogenic soils, which thus became relic soils. All searched sites with recent and relic ornithogenic soils were situated close to the present coast line, and at the altitude usually not exceeding 150 meters.

The oldest documented in age penguin rookery site is located on Penguin Ridge, near the Arctowski Station. Phosphatic clays with penguin bones occur there under peat, at the altitude 45 meters. The age of the oldest peat layer (Birkenmajer 1981a), as well as estimation of a rate of isostatic elevation justifies the suggestion that the age of these ornithogenic deposits, and thus the age of penguin colonization of Destiny Hills and Old Rookery Hill, is 5 000 to 8 000 years ago (Tatur and Myrcha 1988).

Despite the long search no relic soils older than the Holocene ones have been found in the investigated area. Remains of such soils could be preserved on higher, more far inland situated erosional surfaces, formed by the sea during the Pleistocene or the Neogene.

It is established that penguins were present in this region so early as at the Eocene/Oligocene boundary. Sandstones of the La Meseta Formation, which occur on Seymour Island, contain numerous bones of fossil penguins. It is the only site found in the whole maritime Antarctic with well preserved pre-Holocene fossil penguin remains. In fact, outcrop with fossil penguin bones is known since the beginning of century, but only recently was more thoroughly investigated during Argentinian-Polish expedition, in which the author participated (Myrcha and Tatur 1988, Myrcha, Tatur and del Valle *in press*, Gaździcki, Myrcha, Tatur and del Valle *in press*).

Traces of the old, pre-Holocene activity of penguins were most probably destroyed, during multiple glaciations of the region. It concerns also the last glaciation which has finished about 10 000 years ago. This glaciation covered with ice the investigated islands and Antarctic Peninsula almost completely during its maximum expansion (Sudgen and Clapperton 1977, Birkenmajer 1987).

A considerable part of the relic ornithogenic soils has been found in areas which were abandoned by penguins undoubtedly in the Late Holocene. Largest surfaces of relic ornithogenic soils occur on flat areas (20—60 meters a.s.l.) above steep cliffs. The size of lichen *Usnea* sp. which grows in areas of old penguin rookeries indicates that the breeding sites were abandoned eventually over 500 years ago (Fabiszewski, Myrcha and Tatur *in press*). Independently of the direct cause, the movement of a rookery could only happen after uncovering a new land below the cliff, suitable for colonization. New land forming processes took place particularly during the last thousand years after the development of wide, elevated beaches reaching commonly the altitude of 16 meters. The process of relocation of penguin rookeries from a high cliff to easily accessible beaches proceeded most intensely between 1000 and 500 years ago and its traces are especially well visible in the sequence of abandoned breeding sites near Stranger Point (Tatur and Myrcha 1988, Fabiszewski, Myrcha and Tatur *in press*).

The presented above changes of the penguin influence on the environment, which have been taking place during the last several thousands years, caused wide distribution of both recent and relic phosphatic soils of ornithogenic origin in ice-free oases of maritime Antarctic. As it follows from the observations in the above described locations, relic ornithogenic soils occupy the area not less than the current ornithogenic soils. They occur in many areas located far inland and above the current rookeries, sometimes being also found in areas currently not inhabited by penguins.

Specific nature of ornithogenic soils in maritime Antarctic. — The data presented in this paper indicate that ornithogenic soils in the entire maritime Antarctic are distinctly different from such soils which occur on the Antarctic Continent. So far, this fact has not been recognized, because of the insufficient data collected. An opinion prevailed that these both areas have similar types of ornithogenic soils (Allen and Heal 1970, Ugolini 1972, Campbell and Claridge 1987). First signals about distinctness of ornithogenic soils of Elephant Island may be found in the paper by Wilson and Baim (1976). Much more detailed description of ornithogenic soils of King George Island was given by Tatur and Myrcha (1984). The results of the present study confirm the specific features of these soils in the whole area of climatically distinct maritime Antarctic.

Basing on the existing data of phosphatic guano exploitation (Hutchinson 1950), one may suppose that the type of ornithogenic soils described from the maritime Antarctic extends much more to the north, and should occur also on subantarctic islands, e.g. Falkland Islands (Islas Malvinas). They may be also expected in humid and cold temperate climate (Taranaki Island off the New Zealand coast, numerous islands near the southern end of South America). However, they play distinctly less important role in formation of the terrestrial ecosystems in those regions, in comparison with the maritime Antarctic (Tatur and Myrcha *in press*). Thus their mineralogy was not analyzed in details and with the presently used methods.

The processes of microbiological decomposition of excreta left by penguins on land are very rapid in climatic conditions of the maritime Antarctic (Pieter, Tatur and Myrcha 1983). The process of phosphatization of a substrate by guano leachates has been noted in the whole investigated region, though its intensity was very different and depended on the type of the substrate, the area morphology as well as on local differences of climate. Processes of excreta mineralization and substrate phosphatization are distinctly slower only on Seymour Island, which is protected by Antarctic Peninsula from the western winds carrying humid marine air and thus this island has more continental climate.

However, the phosphatized substrate is here completely different than in the other investigated areas. Hence, it is difficult to evaluate what factor, the substrate composition or the more severe climate, decreases stronger the rate of the phosphatization process.

Decomposition of excreta and guano is considerably slower on the Antarctic Continent. Because of more dry climate, highly soluble simple salts — chlorides and sulphates in addition to the commonly present Ca phosphates frequently occur in guano on the Antarctic Continent. The concentration of amorphous Ca phosphates during organic matter decomposition never becomes high as it happens in the maritime Antarctic. The absence of water precludes phosphatization of a substrate. The guano layer is sharply bordered from an underlying rocky substrate which displays no chemical or mineral changes (Campbell and Claridge 1966, Ugolini 1972, Speir and Cowling 1984, Campbel and Claridge 1987).

Relic ornithogenic soils of maritime Antarctic occur under a vegetation cover in the areas abandoned by penguins. Often they are only slightly changed after hundreds and thousands of years. They are composed mostly of loams bearing considerable amount of secondary Al-Fe phosphates in clay fraction. However, remains of guano with traces of Ca phosphates can be found under the cover of loose stones in old breeding sites. Numerous singular penguin bones, frequently of the juvenile forms, are found both in situ and relocated. The conditions do not permit the preservation of entire bodies or egs. The egg shells are dissolved and characteristic membranes are only left. So far, no relic soils of ornithogenic origin have been noted in this region, except for those described in the preliminary note by Tatur and Myrcha (1988).

The breeding areas abandoned by penguins on the Antarctic Continent have been noted by Debenham (1923) during the British Antarctic Expedition in years 1910—1913. They are covered with hard and dried layer of mineralized guano, which contains whole bodies of nestlings and unbroken eggs. Concentration of amorphous Ca phosphates in these relic soils is much lower than in the maritime Antarctic. Even traces of Al-Fe phosphates have not been found. After gradual guano mineralization and dispersion by winds, only loose pavement of pebbles, collected by penguins during nest construction, is left in the abandoned breeding areas. Relic guano rest on a silicate substrate without any traces of phosphatization. No one site with relic ornithogenic soils, described from the Continent, has a vegetation cover (Harrington and Keller 1958, Campbell and Claridge 1966, Spellerberger 1970, Ugolini 1972, Johnstone, Lugg and Brown 1973, Speir and Cowling 1984, Campbell and Claridge 1987).

Influence of penguin on the vegetation formation. — The soil surface around the existing rookeries is nearly devoid of vegetation. Primary vegetation, if existed at all, extincted due to toxic manuring and permanently wandering penguins. Only temporary, coprophile alga *Prasciola crispa* is present in some places on soil surfaces. Isolated patches of higher plants appear only in marginal zones. Productivity of the discussed ornithogenic soils usually reaches only the level of high microbiological activity (Pietr, Tatur and Myrcha 1983, Pietr 1974). Only assemblages of nitrophile crust-like lichens are profuse. They occur on rocks within and around penguin rookeries.

The areas abandoned by penguins are immediately invaded by vegetation. The succession of vegetation assemblages starts with an alga *Prasciola crispa* and reaches climax after several hundred years with dense and diversified vegetation cover, nearly totally covering the soil surface (Fabiszewski, Myrcha and Tatur *in press*). The pioneer alga *Prasciola crispa* has the turnover many times more rapid than other forms, thus it plays an important role in the humus formation in relic soils. It plays also a considerable role in the nutrient chain between the soils and higher plants, by forming humus.

Phytocenosis growing in the areas abandoned by penguins, may use directly or with *Prasciola crispa* intermediary role, the easily available nutrients accumulated in ornithogenic soils. The relation between the chemical composition of the grass *Deschampsia antarctica* and the content of different nutrients in ornithogenic soils have been described elsewhere (Myrcha and Tatur 1988). Samples of grass have been collected from the recent ornithogenic soils (isolated patches of *D. antarctica* from marginal zone of penguin activity) and ornithogenic relic soils (*D. antarctica* growing in soil) as well as from control stations outside of zone of seal and birds activity.

Deschampsia antarctica growing on the current and relic ornithogenic soils is generally richer in P, Ca, K, and Na. The contents of N, Sr, Zn and Cu are distinctly higher only in the grass growing on the current soils. On the other hand, Mg, Mn and Fe contents are much higher in grass from relic soils.

Thus a distinct correlation has been found between the high contents of some ornithogenic elements (P, Ca, K, N) in a soil, and in the investigated plants. Also an indirect relation exists following from specific physicochemical features (change of soil reaction to acid), which appear during maturation of the relic soils (Mg, Mn, Fe). Erosion and dissolution of alkaline guano in the areas abandoned by penguins cause exposition of acid clay of secondary aluminium-iron phosphates. Thus, the mineral composition of phosphates of relic soil is completely changed and their soil solutions have acid reaction. The availability of many elements is drastically changed also due to the new pH conditions. It differs distinctly from those on control surfaces, devoid of phosphates.

The penguin activity leads initially to the destruction of the primary vegetation cover in some areas, but later creates a new soil environment with new features, more suitable for recolonization by vegetation. New formed ornithogenic soil is much richer in clay and extremely rich in nutrients, being simultaneously very differentiated. Thus, the penguin's activity is the factor permitting a high trophic status and diversity of productivity and presumably also species diversity in the continental ecosystems of the maritime Antarctic.

High trophic differentiation of the soil environment which occurs in coastal areas of the maritime Antarctic (caused by birds and seals) is rather well known in the recent geobotanical and soil literature (Walton 1980, Smith 1985). No one considered, however, the specific geobotanical features of ecosystems from poor tundra, which originate in areas with relic ornithogenic soils.

Phosphates of ornithogenic soils. — The mineral composition of phosphates from ornithogenic soils is a key to their genesis. The diversity and chemical composition of phosphates, except for some special features as the presence of minyulite and fluoroapatite instead of hydroxylapatite, are comparable with that from ornithogenic soils in the humid temperate zone (Hutchinson 1950, Altschuler 1973, Flicoteaux and Lucas 1984). However, in the light of the present detailed investigations their composition seems to be even more diversified in the maritime Antarctic. One has to mention that the investigations had only general character in temperate and subantarctic zones.

Rather extensive mineralogical study of phosphates, presented by Tatur and Barczuk (1984) needs completion (Tatur and Keck 1988). The mineralogical problem is of general character, not only local. The phosphates which have been found in ornithogenic soils of the maritime Antarctic are the same which originate also under the influence of mineral phosphatic fertilization of cultivable soils around the world (Lindsay, Frazier and Stephenson 1962, Bache 1963, Taylor 1963). Nevertheless, the *in situ* investigations of these minerals in fertilized soils are difficult, because of low contents of the new-formed phosphates. Commonly undertaken laboratory simulations of natural processes, when phosphates originate synthetically in effect of rapid reactions between two solutions or between solutions and clay minerals, are extreme simplification of very complicated natural conditions (Haseman *et al.* 1950, Haseman *et al.* 1951, Cole and Jackson 1950, Hsu and Jackson 1960, Taylor, Gurney and Lindsay 1960, Taylor and Gurney 1961, 1962, Hsu 1982). The appropriate duration of certain processes necessary to complete some reactions is one of the most important conditions controlling the mineral composition of final products. This condition is difficult to fulfill in the laboratory studies.

The "natural Antarctic laboratory" delivers very valuable information concerning the genesis of soil phosphates, their composition, stability and conditions of dissolution. Detailed description of occurrence of the ten most common soil phosphates is given in the published papers, concerning the mineralogy of ornithogenic soils in the maritime Antarctic (Tatur and Barczuk 1984, 1985, Tatur 1986, Tatur and Keck 1988). The behaviour of phosphorus from fertilizing substances is the most complicated mineralogically among nutrients commonly used in agricultural practice. It is still not clear despite numerous existing studies, thus the present investigations have also a general value.

Acknowledgements. — The material, on which the present paper is based, has been collected with the invaluable help of many people staying in Antarctic during my visits there. Samples from Hope Bay, Seymour Island, Barton Peninsula and Stranger Point have been collected during the Argentinian-Polish Field Party in 1985 led by Dr. Rodolfo del Valle (IAA). Samples from the islands around of Arthur Harbor were collected during my stay at the US *Palmer* Station with the permission of Leader Don Wiggin and with the help of Dr. Wayne Trivelpiece. Samples from Bryde Island have been collected during the cruise of M/S *Koral* to the south, thanks to the benevolence of the Captain Jan Boruta. The Low Head Oasis and Penguin Island were accessible with the help of Brasilian, Chilean and FRG helicopters, Mr. Herman Fuchslochner, the Leader of Chilean *Teniente R. Marsh* Station was always ready to help. Understanding and invaluable help of Mr T. Wojciechowski, the Leader of IX Polish Antarctic Expedition of the Polish Academy of Sciences to *Arctowski* Station. as well as all other colleagues is also greatly appreciated. Field works were carried out together with Professor Andrzej Myrcha and Mr. Stanisław Żdżyłowski. I am very grateful to all these persons and institutions.

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Received October 10, 1988
Revised and accepted December 19, 1988

Streszczenie

Badania współczesnych i reliktowych gleb fosforanowych pochodzenia ornitogennego prowadzono w wolnych od lodu oazach Antarktyki, w rejonach Półwyspu Antarktycznego i Wyspy King George (fig. 1—8) w sezonach letnich 1984/85 i 1985/86. W pracy przedstawiono profile glebowe, warunki występowania naskalnej mineralizacji fosforanowej, wykwitów fosforanowych i innych form powierzchniowej akumulacji materiału ornitogennego. Przedstawiono wyniki analiz chemicznych wolnej od materiału klastycznego frakcji (ił i drobny pył) wyseparowanej mechanicznie z gleb, i różnorodnych próbek fosforanowych i organiczno-fosforanowych występujących na powierzchni gleb (tab. 1—5). Znaczna część próbek fosforanowych została zbadana mineralnie na podstawie rengenodyfraktogramów.

Gleby ornitogenne w rejonie czynnych kolonii pingwinów kształtowane są przez proces mineralizacji guana pozostawionego na lądzie przez ptaki, oraz przez proces fosfatyzacji podłoża skalnego w wyniku oddziaływania agresywnych roztworów płuczących guano. Na terenach opuszczonych przez pingwiny przed kilkuset i kilku tysiącami lat, gleby ornitogenne zachowały swoje specyficzne cechy chemiczne i mineralne, choć odpowiednio przeobrażone w procesie wietrzenia chemicznego, mechanicznego, ruchów masowych, procesów mrozowych, oraz pod wpływem szaty roślinnej bujnie rozwijającej się na opuszczonych powierzchniach.

Gleby ornitogenne morskiej Antarktyki tworzą się na kamienistych i gliniastych pokrywach zwietrzelinowych na terenie i w najbliższym otoczeniu kolonii pingwinów. Zbudowane są one z powierzchniowej warstwy guana, oraz podległej strefy sfosfatyzowanych skał. W skład guana oprócz urozmaiconej chemicznie materii organicznej i nietrwałych, krystalicznych moczanów, wchodzi również znaczna ilość fosforanów wapnia (fluoroapatyt), oraz magnezo-amonowych (struwit). Wyjątkowo wokół gniazd kormoranów znaleziony został brushyt.

Strefę sfosfatyzowaną tworzą urozmaicone mineralnie fosforany glinowo-żelaziste zawierające jony potasowe i amonowe. Bezpośrednio pod warstwą guana powszechny jest leukofosfit, pod którym można spotkać czasami minyulit. Dla stref głębszych gleb występujących na Wyspie King George charakterystyczny jest taranakit, którego nie znaleziono jednak w glebach w rejonie Półwyspu Antarktycznego. We wszystkich glebach na różnych głębokościach występuje amorficzny fosforan glinowo-żelazisty.

Wyżej wymienione minerały w sprzyjających warunkach układają się w profilu glebowym w sposób uporządkowany i tworzą różnobarwne poziomy genetyczne. Ornitogenne fosforany występują zwykle pomiędzy kamieniami w dwu- lub trój-składnikowych paragenezach wymie-

szanych z iłem krzemianowym albo materiałem organicznym. Jednak w pewnych przypadkach w głębi gleby, na jej powierzchni, oraz w naskorupieniach fosforanowych na skałach, może dojść do monomineralnych skupień czystych fosforanów.

Na terenach opuszczonych przez pingwiny w ornitogennych glebach reliktowych warstwa guana jest silnie zredukowana przez erozję chemiczną i mechaniczną. Wśród fosforanów zachowuje się jedynie fluoroapatyt, znikają natomiast moczany i struwit. Pod roślinnością obserwuje się tworzenie poziomu akumulacji humusu pochodzenia roślinnego. W wyniku wietrzenia fosforanów w reliktowej strefie sfosfatyzowanej dochodzi do zaniku minyulitu, zmniejszenia powszechności leukofosfitu, natomiast najczęściej spotykany jest taranakit, amorficzne fosforany glinu, oraz bliżej jeszcze nie opisane krystaliczne fosforany glinu, których występowanie stwierdzono wyłącznie w glebach reliktowych.

Skład chemiczny i mineralny gleb ornitogennych, a zwłaszcza wielkość i różnorodność mineralna strefy sfosfatyzowanej, silnie uzależnione są od cech petrologicznych podłoża i od warunków klimatycznych. Na stosunkowo cieplejszej i wilgotniejszej Wyspie King George, która zbudowana jest głównie z zasadowych skał wulkanicznych, spotykane są gleby głębsze i bardziej urozmaicone niż w chłodniejszym rejonie Półwyspu Antarktycznego, który zbudowany jest z kwaśnych skał głębinowych i osadowych odpornych na fosfatyzację.

Praca została wykonana w ramach tematu CPBP 03.03.