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Ornithogenic soils on King George Island, South Shetland Islands (Maritime Antarctic Zone*)

ABSTRACT: Analysis was made of ornithogenic soils being formed around rookeries of krill-eating pygoscelid penguins on elevated volcanic island in Maritime Antarctic Zone. The profiles in the bird colony and in its close proximity have been described, explored chemically and characterized mineralogically, especially in the zone of deep metasomatic phosphatization of stony and clayish weathered covers. The semantics of ornithogenic soils was discussed in terms of their genesis and morphology as well as the dependence of phosphatization with species selectivity of breeding sites of the pygoscelid penguins.

Key words: Maritime Antarctic Zone, volcanic island, penguin guano, ornithogenic soils, phosphatized rocks

1. Introduction

The chemical data on ornithogenic soils in Maritime Antarctic Zone and in Subantarctic Zone concern solely surfacial layer of soil (Allen and Northover 1967, Boyd, Rothenburg and Boyd 1970, Everett 1976, Smith 1978a, 1978b, Wilson and Bain 1976). This is why no accumulation of substances deriving from decomposition of bird guano or products of guano reacting with the substrate rocks were observed below surface layer (Walton 1980). Therefore there is a common notion that the ornithogenic soils of Maritime Antarctic Zone appear to be similar to those reported for continental Antarctic (Allen and Heal 1970, Ugolini 1972). However, the existence of typical for land, organic layers

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of guano that would not have mixed and reacted with underlying rock is difficult to imagine in the zone where numerous scientists report on an intense and thorougly wash out of the whole mass of penguin faeces to the sea. There are after all, wast data on mineralization of ornithogenic materials associated with the deposits of guano in other warmer climatic zones (Hutchinson 1959, White and Warin 1964, Altschuler 1973).

To elucidate these ambiguidities studies were started aiming at description of the specific signs of ornithogenic soils, in Maritime Antarctic Zone. Special biass was laid on chemical and mineral characteristics of ornithogenic remains and the products of reactions of guano leachates with silicate rocks.

2. Study area

Studies were carried out during the Antarctic summer of 1979/1980 in the region of Admiralty Bay, King George Island, South Shetland Islands. In this season about 55 thousand pairs of pygoscelid penguins nested along the coast of Admiralty Bay (Jabłoński 1984). One of the largest rookery is situated at Llano Point. In the vicinity of the particular breeding groups the most differentiated geomorphological and hydrological situations was found (Fig. 1), therefore this terrain became the area of detailed studies.

In the seaside at Llano Point, behind vast about 100 m wide raised beach, craggy cliff is present. The raised beaches and stormridges are traces of subsequent stages of see regress. They are well preserved at a level from 3 to 6 m asl. and rudimentarily at about 11 m asl. Cliff is terminated at its apex with a platform — undulating gentle surface at a level from 20 to 50 m als. It is a flat area cut into bedrock by sea waving when the sea water surface was at that level. It is a geomorphological form commonly encountered at these heights in the region of South Shetland Islands, the vicinal Sphinx Hill area included (John and Sugden 1971). In the troughs finally formed within this platform by the glacial, the till were deposited. From the side of the outlet glacial the ridges of lateral moraines are present, and embed the adjoining rocks.

The youngest event determining the final configuration of the terrain was an abrupt progress in the processes of mechanical erosion which has covered the older formations (moraines, stormridges, peat banks, phosphates layer) with a talus or scree. Fresh stones occurring in them contrasting with weathered pebbles laying on the till surface. Mounts of pebbles around penguin rookeries can be partially ornithogenic. Penguins building their nests, bring small stones from the vicinity. Single exzotics and material selection could indicate such origin. Pebbles around rookeries consist mostly of fractions of small, flat stones several cm in size, just like those used by penguins at nest building. However recent cover of deluvial material can be also found outside the zone of penguins activity.

In the region of the Llano Point rookery in the season of 1979/1980 as many as 18335 pairs of penguins were nesting (Jabłoński 1984). They were mainly *Pygoscelis adeliae* (Hombron and Jaquinot) (15013 pairs). Besides smaller nesting groups of *P. papua* (Forster) (3008 pairs) and *P. antarctica* (Forster) (314 pairs) were present. The majority of nesting groups of *P. adeliae* (94.8% of pairs) was located on the hills covered with a thin layer of pebbles on the platform elevated to 20 — 45 m asl. These groups occurred foremostly on the area of one small catchment waters of which are gathered by a stream cutting off into a steep cliff between hills A and J (Fig. 1). All *P. papua*, on the other hand, nested on stony stormridges on the beach, below 8 m asl.

The area affected by penguins is hardly covered with permanent vegetation. Small plots of shallow peat (about 30 cm in thickness) became preserved at peripheries of penguins penetration. The remain of natural vegetation that had covered the surface of this region previously can be sometimes found in the vicinity of young and less numerous nesting groups. Nitrophilous lichens and ephemerous agglomerations of coprophilous algae are commonly found. During summer warm-up proliferous blooms in shallow pools with water enriched in nutrients can be observed. In total, however, the binding of nutrients by vegetation in the region of penguin rookeries has no substantial quantitative significance in their general biogeochemical cycle. Thus the situation is diverse from commonly found in the Arctic region.

3. Climatic conditions

King George Island lies in Maritime Antarctic Zone, in the region of wet marine climate. The ice caps of the South Shetland Islands may receive up to 1000 mm water equivalent in a year, while on the lee slopes precipitation may rise locally to 1500 mm (Robin and Adie 1964). Most of this precipitation falls in snow, which with coming summer melts completely on ice free plots of land.

Direct measurements give somewhat differented values (Moczydłowski 1978, Zubek 1980). At Soviet Bellingshausen Station, situated at southwest end of the island, average monthly values of precipitation in 1957—1970 were estimated as 70.4 mm. They were somewhat higher in winter (74 mm) than in summer (62 mm). At the Arctowski Station (3 m asl) in 1977-1978, as much as 800 mm of annual precipitation was noted with 241 days with precipitation. These data can be burdened with errors resulting from methodological difficulties when evaluating precipitation especially of snow at strong winds (average velocity of wind at the Arctowski Station amounts to 7.22 m/sec.) and diversified morphology. One can expect that when comparing with data by Robin and Adie (1964) they are understimated.

Precise measurements of temperature on King George Island were carried out in the years 1957-1970 at the English station at Admiralty Bay. Average annual temperature for this period was -3.9 C (−1.1 C in summer and — 6.7 C in winter). High humidity of air was maintained all the year round, amounting to 84% on the average. During the two year measurements at the Arctowski Station similar results were obtained. In the warmest month January, the temperature ranged from −10 C to +7 C (0. 2 C on the average). During a year only two days were totally cloudless and 9 days with little cloudiness.

4. Methods

During the Antarctic summer of 1979/1980 the samples from as many as 24 soil pits were collected in the region of Llano Point (Fig. 2). The samples of soil were gathered exclusively from fine material avoiding the fraction of stones whose number was only estimated.

During preparation of the samples all coherent phosphates and phosphatized parts of rocks were crumbled. In fraction that has been not analyzed chemically (grains with diameter over 1 mm) only parts of fresh volcanic rock remained.

All analyses were done only on fine earthy grains of soil (fraction below 1 mm diameter). H_2O^+ was assessed by heating air dry sample at a temperature of 110 C. The contents of carbon, nitrogen and hydrogen were assessed in pulverized subsamples by CHN analyzer of Carlo Erba Model 1102. The pH_{H_2O} reaction was determined by diluting air dry material with distilled water void of CO_2 in weight ratio 1:1. Decomposition of phosphates was obtained by boiling unpulverized samples for 30 min in a mixture (1:1) of hydrochloric and nitric acids (Belopol'skij et al. 1974). From the extract just obtained phosphorus was determined by colorimetric metavanadan method (Belopol'skij et al. 1974). Metals were determined by AAS method (Varian 1200) according to instruction of Varian techtron. In order to avoid interferention at determining of calcium and magnese a variant of determination in gas mixture of nitrous oxide and acetylene was used. As exemplified by several chosen samples no substantial (for interpretation) discrepancies were found between determination of metals with AAS method directly from the extract holding considerable amounts of phosphorus and metal determination from solution after their separation from phosphorous on jonites. The last method was used in work (Tatur and Barczuk 1984).

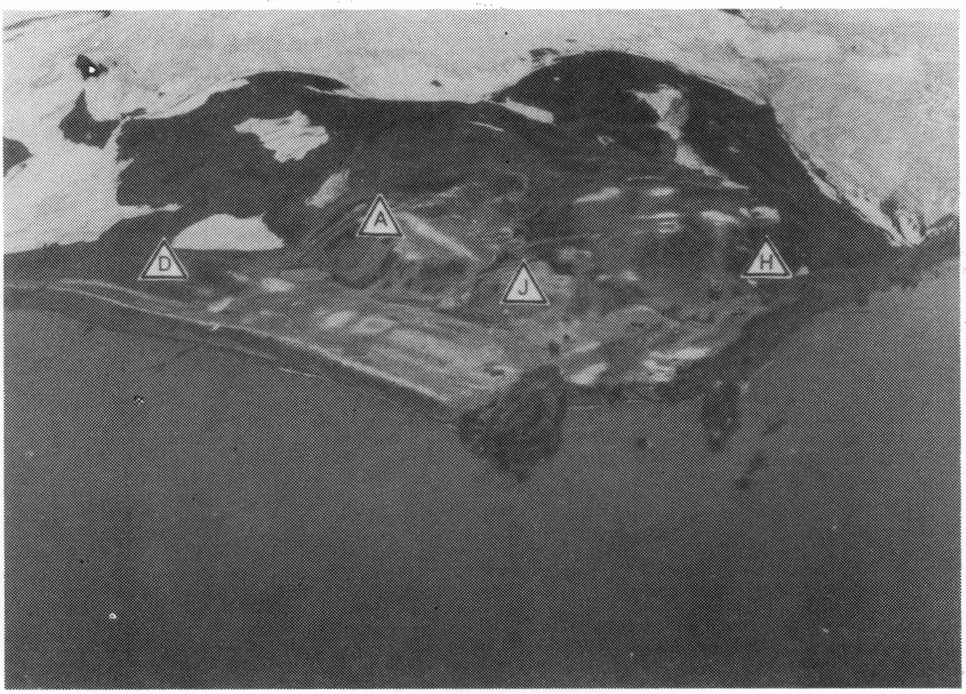

Fig. 1. Penguins rookery near Llano Point; nesting areas are surrounded with light coloured band of dry guano

A, J, H- hills, D- field base.

Photo K. Furmańczyk

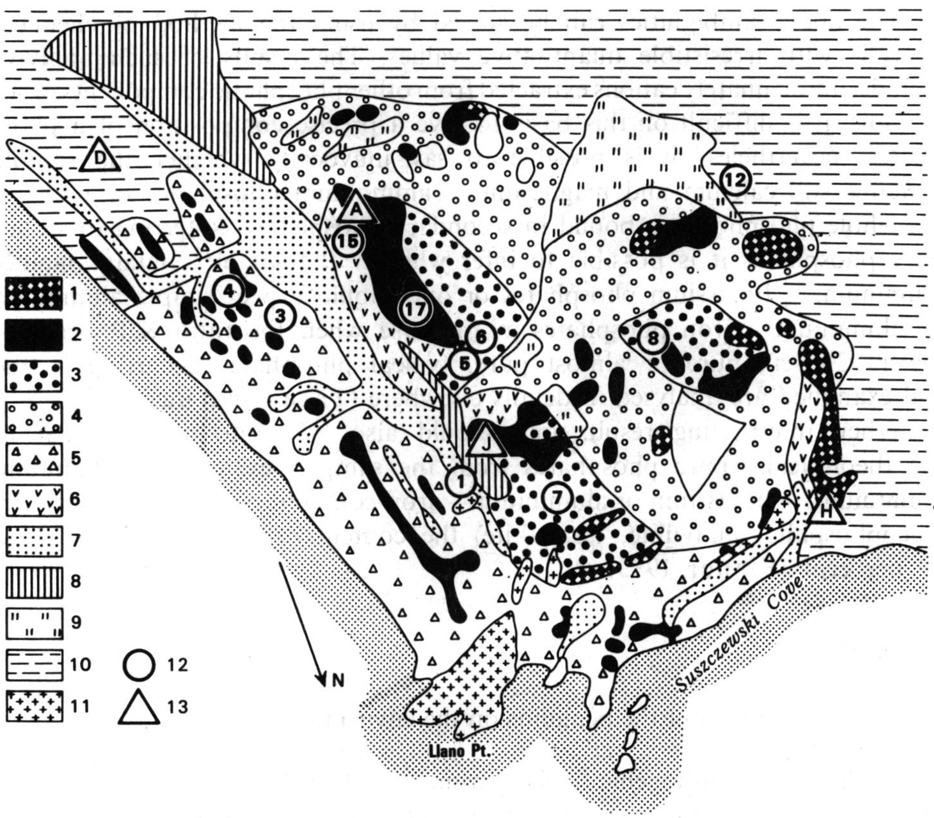

Fig. 2. Zones of impact of penguins on the environment (Llano Point rookery) (1 cm ≈ 55 m) 1 — area of young colonies, 2 — area of old colonies, 3 — zone of an intense deep phosphatization, 4 — zone of weakly marked phosphatization, 5 — zone of surfacial accumulation of guano and phosphates in the area of stony beaches, 6 — zone of guano and phosphates accumulation in bottom deposits of shallow small pools, 7 — zone of accumulation of feathers on the soil surface, 8 — plots of ice, 9 — area covered with vegetation, 10 — soils outside of zone of direct impact of solution washed out from the rookery, 11 — rocks, 12 — location and number of soil profiles, 13 — typical points (see Fig. 1).

The remarks pertaining to interpreting the chemical analyses of phosphates.

Microscopic observations enable in some cases to determine what phosphates occur in a given sample. However only cristals of magnese — ammonium phosphate can be thus identified with absolute certainty. On the other hand, it is impossible to determine calcium phosphates from other secondary phosphates: aluminium, aluminium-potassium and eventually aluminium-iron containing potassium. The petrografic analyses enable sometimes mineralogical identification of the secondary phosphates but such identification not always have value of quantitative analysis due to silicates background and various granulation as well as due to the presence of amorphic phosphates (aluminium phosphate).

The above ambiguities can be solved by using the method of chemical analysis with irresistible quantitative values. The results of such analyses include, unfortunately cations extracted from other phosphatic components of soil. Thus, it is difficult on this basis to give a precise composition of a phosphates, nevertheless it is possible to say univocally whether the sample contains still calcium and magnesium — ammonium phosphates or not and the whole phosphorus is bound in secondary phosphates. Referring to secondary phosphates it is possible to infer whether the sample contains mainly aluminium — potassium phosphates or one should expect simple aluminium or aluminium — iron phosphates in the case when the ratio K/P becomes lower. Chosen, pure or almost pure, typical phosphates occurring in the soil examined are analysed in details elsewhere (Tatur and Barczuk 1984).

When interpreting results one should also take into account that in the theoretically pure phosphates from the samples examined: aluminium, aluminium — potassium or aluminium — iron containing potassium (variscite, leucophosphite, minyulite, taranakite) the content of P ranges from 14 to 19 per cent (Fisher 1973).

5. Results

5.1. Zones of impact of the penguins on the environment

Studies of ornithogenic soils permit to distinguish several zones of differentiated impact of penguins on land environment. Their range on Llano Point is presented in Fig. 2. In general it is an area situated on the way of flow down of guano and products of its decomposition from the rookery to the sea (Fig. 1). These zones differ both in morphology and thickness of soil profile as well as in the extent and quality of the accumulation of ornithogenic materials.

Soils within the area of old colonies of *P. adeliae* (section 1 on Fig. 2) are totally bare of vegetation whereas in areas recently colonized (section 2) the remains of plant cover devastated by birds can be often seen. These vegetation used to cover these spots and at present it occurs commonly in uninhabited areas.

Around areas of old and numerous nesting groups located on rocks surrounded by large permeable weathered cover, a zone of deep phosphatization can be usually found (section 3). It reaches down to hard rock. Phosphatization due to guano leachates leads to alteration and decomposition of the fine mechanical fraction of soil and formation of a deep zone of occurrence of the secondary aluminium-iron phosphates containing potassium and ammonium. Further from the old colonies or around areas recently occupied by nesting groups chemical changes are less perceivable and are usually restricted to the surface layer of soil only (section 4).

On the area of rocky beaches the accumulation of secondary phosphates and fine phosphatic detritus occurs only in surface layer (section 5) and is restricted either by smaller permeability or constant humidity of deeper layers. The processes of phosphatization "*in situ*" in these soils are unperceivable. Especially high concentration of detrital phosphates occurs in fine sand of bottom sediments in shallow pools (section 6).

Near the nesting places situated on steep slopes between rocks the feathers often accumulate on the soil surface, especially on slopes where larger flows from the rookery do not occur (section 3). It is usually a layer of several centimeters in thickness.

As has been already mentioned the impact of penguins results from mechanical and chemical devastation of vegetation. Small patches of mosses and single tuffs of *Deschampsia antarctica* were preserved only in peripheral zones of penguins activity (section 8).

5.2. Description of soil profile in the area of old and numerous nesting colony [1])

These soils located on rocks covered with pebbles are described on the basis of a profile done within one of larger rookeries in the region of Admiralty Bay (in rookery on Llano Point) on a hill indicated with letter A (Fig. 1). It is situated on rocks of ancient cliff of a level 35 — 45 m asl. at a distance of about 100 m from the present sea shore and separated from it by stony beach. In this area which has been used for long time by *P. adeliae* for breeding as many as 8500 nests were counted in the season of 1979/1980.

In the profile one can distinguish black surface layer (0 — 10 cm under which there is clearly lighter layer: brown, or beige) 10 — 30 cm. The black colour of the upper layer comes from organic — mineral mass of decaying guano, occurring in spaces among pebbles. The carbon content in this material is about two times lower as compared with krill (taking into account the part unsoluble in acids).

Microscopic observations and analysis of X-ray (Tatur and Barczuk 1984) permit to distinguish in hydrated mass of decomposing guano earthy aggregates of calcium phosphate (poorly crystalized hydroxylapatite) glued to the soil skeleton as well as loose cristal of the magnesium — ammonium phosphate (besides fibrous shelling of fragments of particulated krill). The pH in surface layer as measured in the solution prepared from air dry sample is neutral. In a fresh sample it should be alkaline due to an excess of ammonium ion which becomes volatil while drying. When

[1]) Fig. 2, section 1, and 2 for chemical analysis see Table I.

comparing surrounding soils void almost completely ions of calcium and magnesium extracted by acids, the surface layers of soils in the nesting area contain such amounts of them that it is sufficient to bind the majority of present phosphorus into mineral phosphates — hydroxylapatite and struvite (Table I.).

In the upper layer, contrary to the lower one, the preponderance of phosphorus over calcium is characteristic. This results foremostly from the presence of considerable amount of phosphorus in struvite, which in turn, can be associated with the magnesium content. The presence of ammonium ion in the struvite structure as well as its tendency to enter in the form of isomorphic admixture into structure of other phosphates brings about that C/N ratio in decaying guano is lower than in krill. A characteristic trait of the soils from rookeries is also a high concentration of strontium of the krill origin.

In the lower brighter layer, uniform megascopically, mineral — organic material gathered in unstable aggregations fills in more fully free spaces among pebbles. The share of larger organic remains decreases clearly and they are much more crumbled. The cristals of magnesium — ammonium phosphate are rarely found there. The share of bright in colour, earthy mass of hydroxylapatite was found to increase. As comparing with surface layer the magnesium content is clearly smaller here and that of calcium — higher. The P/Ca ratio is also changed. Content of calcium is as high or higher as phosphorus. The strontium concentration is similar or even higher than in the upper layer.

5.3. Description of soil profiles in the zone of deep phosphatization [2])

In the close proximity to large rookeries the soils are being formed with a high accumulation of phosphates along the whole profile. It is the zone of an intense reaction of guano leachates with a loose underlaying sedimentary rock, clay, sand, gravel and to a lesser degree with stones. The prepondering process of phosphatization leads to formation of various secondary, hydrated aluminium-iron, phosphates containing potassium and ammonium ions. These phosphates become the most important quantitative component of fine fractions.

The changeable geomorphologic, hydrologic, and petrographic conditions and foremostly different intensity of manuring bring about that a high diversity of ornithogenic soils occurs in this zone. This diversity was shown in presentation of several chosen profiles. When choosing, little altered soils

[2]) Fig. 2, section 4, for chemical analyses see Table I.

Table I

Chemical composition of ornithogenic soils

Profile number and depth (cm)		Estimated value of stones in profile (% vol.)	Mechanical fractions in taken samples (without stones)		Chemical composition of fraction (1 mm)															
					Aqua regia extract										Other analysis					
			1 mm	1 mm	part insol.	P	Ca	Mg	Al	K	Na	Fe	Mn	Sr	C	N	H	C/N	H_2O^+	pH
Krill		—	—	—	—	—	—	—	—	—	—	—	—	—	44.97	8.68	5.61	5.2	—	—
Ash of krill		—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
(550°C)					—	8.92	9.00	4.62	0.20	5.00	28.68	0.33	0.02	0.17	—	—	—	—	—	—
Prof. 17	0—10	80	58	42	19.23	7.44	5.70	3.30	2.10	0.20	1.08	1.40	0.02	0.12	16.79	4.15	3.20	4.1	16.51	6.5
	10—30	80	49	51	27.22	6.30	8.50	0.90	3.30	0.10	1.42	2.70	0.15	0.40	13.64	3.70	2.82	3.7	6.24	6.7
Prof. 5	0—2	90	30	70	25.88	6.80	6.10	1.61	2.90	0.75	0.78	1.70	0.02	0.13	13.85	2.33	2.24	5.9	11.74	6.9
	2—15	80	67	33	33.27	8.83	0.36	0.20	6.95	3.90	0.34	3.45	0.02	0.00	3.91	0.94	1.97	4.2	1.67	4.5
	15—45	20	10	90	8.89	13.32	0.34	0.17	11.20	6.60	0.35	0.95	0.01	0.00	3.60	0.84	2.22	4.3	4.25	5.0
	45—70	5	5	95	3.30	14.45	0.29	0.10	11.70	7.80	0.30	0.20	0.00	0.03	4.35	1.02	2.57	4.3	6.36	4.1
	70—90	10	13	87	5.96	12.17	1.20	0.08	10.90	2.60	0.40	0.50	0.01	0.15	5.75	0.93	2.91	6.0	17.99	4.3
	90—95	30	32	68	9.10	10.85	1.42	0.09	10.45	0.80	0.36	0.85	0.01	0.15	6.36	0.92	3.48	6.9	21.44	4.4
Prof. 6	0—5	90	27	73	23.14	6.85	5.90	2.20	2.10	0.65	0.52	1.25	0.02	0.11	15.36	3.08	2.70	5.0	15.23	6.5
	5—45	50	83	17	47.95	7.20	0.20	0.14	5.40	5.10	0.29	5.55	0.01	0.01	5.68	1.36	2.01	4.2	3.10	4.1
	45—60	30	51	49	42.73	8.32	0.12	0.16	5.70	2.50	0.18	5.00	0.01	0.01	5.60	1.38	1.83	4.1	3.53	4.6
	60—110	30	60	40	51.59	5.15	0.24	0.19	4.10	1.15	0.15	4.70	0.03	0.01	4.64	1.71	1.59	2.7	4.15	4.6
	110—150	50	29	71	32.45	10.36	0.06	0.08	6.20	2.15	0.18	5.10	0.01	0.01	3.54	1.42	2.46	2.5	15.48	4.4
Prof. 7	0—10	60	66	34	46.53	5.14	2.70	2.50	4.20	3.90	0.24	2.40	0.01	0.01	6.62	1.52	1.81	4.4	2.77	5.8
	10—80	60	45	55	40.92	7.60	0.85	0.11	5.80	3.90	0.24	2.40	0.01	0.01	4.10	0.96	2.12	4.3	2.20	4.5
Prof. 8	0—3	20	25	75	46.26	3.00	3.80	0.70	3.60	0.35	0.70	4.00	0.03	0.07	13.85	2.33	2.24	5.9	6.67	7.0
	3—20	70	79	21	49.49	5.44	3.40	0.19	3.70	0.75	0.28	5.40	0.02	0.06	18.15	2.88	3.14	6.3	4.85	3.8
	20—80	30	40	60	53.74	5.32	0.45	0.28	5.40	1.15	0.18	5.80	0.04	0.00	2.15	0.95	1.47	2.3	6.58	3.9
Prof. 1	0—12	0	10	90	32.98	4.86	4.80	0.41	4.20	0.30	0.38	2.20	0.05	0.13	14.51	2.01	2.87	7.2	11.26	5.9
	12—16	0	15	85	74.71	1.44	3.50	0.32	2.60	0.90	0.35	1.90	0.03	0.04	5.40	0.58	1.21	9.3	3.34	6.1
	16—20	0	39	61	43.14	3.68	4.40	0.34	3.40	0.35	0.24	3.50	0.04	0.10	16.10	2.15	2.72	7.5	6,90	5.9
Prof. 4	0—0 3	80	65	35	21.20	7.00	8.00	1.22	1.20	0.30	0.38	1.75	0.02	0.16	13.08	2.56	2.37	5.1	9.73	7.2
	0.3—10	80	65	35	44.35	4.38	2.90	0.33	1.80	0.40	0.20	6.55	0.02	0.03	14.83	2.53	2.43	5.9	3.91	4.3
	10	10	95	5	75.16	1.58	1.00	0.33	2.30	0.30	0.18	6.30	0.06	0.01	1.91	0.21	0.68	9.1	3.40	4.4
Prof.3	0—10	80	56	44	56.91	1.90	1.83	0.32	1.90	0.20	0.22	5.40	0.04	0.04	4.40	0.50	0.92	8.8	5.23	4.0
	10	0	98	2	78.99	0.82	0.60	0.43	1.50	0.10	0.15	6.50	0.07	0.01	1.74	0.11	0.58	15.8	2.71	3.7
Prof. 15	0—10	40	40	60	56.67	1.34	1.25	0.29	2.80	0.40	0.13	3.65	0.03	0.03	18.67	7.33	2.91	5.6	5.24	3.8
	10	60	50	50	70.65	0.38	0.70	0.65	4.60	0.05	0.11	5.45	0.04	0.01	4.46	0.43	1.44	10.4	6.32	3.9

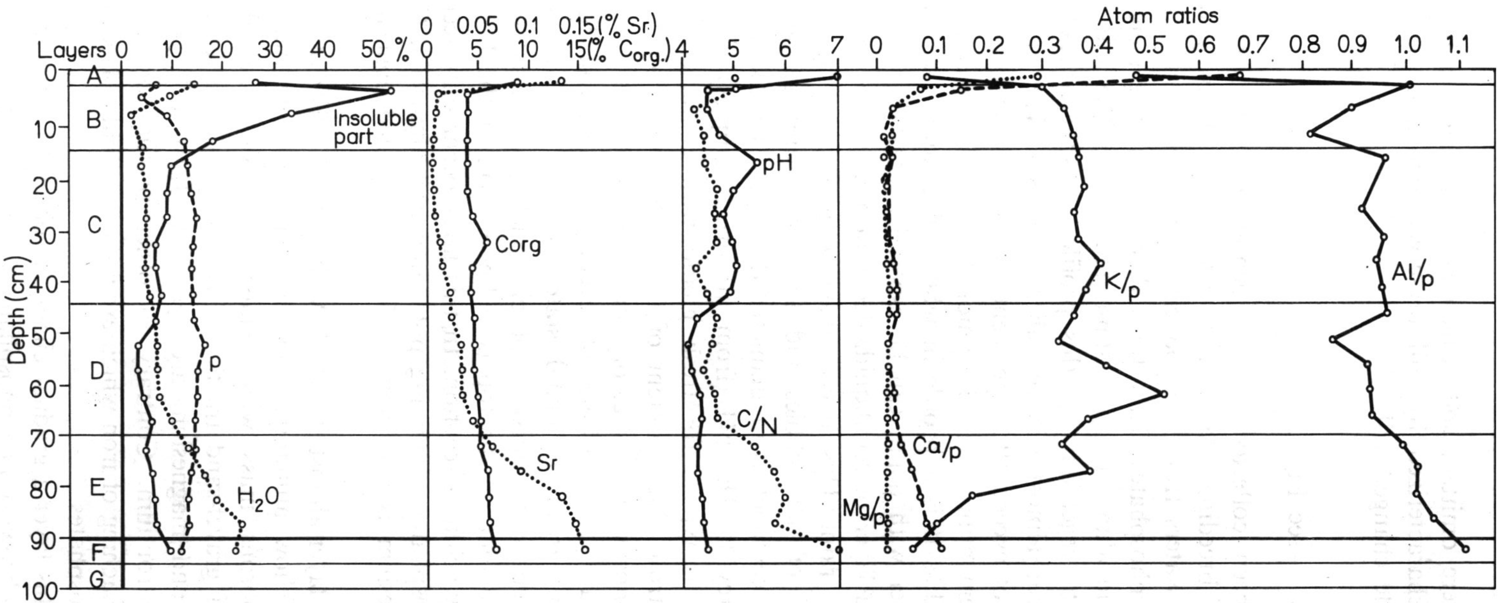

Fig. 3. Chemical composition of the soil in the profile No. 5

A — fresh guano, B — phospatic clay rich in leucophosphite among pebbles. C — indurate, vesicular minyulite; in the pores - weathered fragments of the rock, D - indurate, vesicular minyulite; in the pores - clay relicts after phosphatized fragments of the rock. D/E - level of permafrost in December 1979, E - indurate, vesicular minyulite containing grains of amorphous aluminium phosphates with silicate corn inside. E/F - level of ground water, F - gravel of grains consisting of amorphous aluminium phosphates with silicate corn inside by phosphatization were omitted, soils which occur around small or new rookeries. They are characterized by still preserved remnants of primary vegetation and by little changed soil.

Profile No. 5 (locality — see Fig. 2.)

This profile has been collected from a gentle slope a dozen or so meters below a large breeding group of *P. adeliae,* on the way of flow off of main mass of waters from the rookery. It is a place of especially high accumulation of phosphates. They form there almost one meter thick layer of aluminium and aluminium-potassium phosphates. The soil surface is completely devoid of vegetation. In this profile, phosphates (except for the surface layer) occur almost without silicates burden. The amount of clastic material does not exceed 10-20 per cent, and the phosphorus content from 10 to 17 per cent approaches the amounts of this element in pure phosphate minerals. Thus it is a profile in which all chemical and mineralogical changes together with depth can be especially clear (Fig. 3).

O — 2 cm — It is a layer of semiliquid, decomposing guano washed out from the rookery by rain. This mass mixed with fine clastic material lingers on the surface of flat pebbles and the spaces among them. The pebbles are of several centimeters in diameter (Fig. 4). The colour in wet state is dull brown-greyish. The pH (from air dried samples) is neutral. Chemical composition is typical for fresh guano with characteristic high content of organic detritus (high content of C and N), high concentration of calcium and phosphorus and indicatory strontium (Table I).

2 — 15 cm — It is a layer of pebbles of several centimeters in diameter. The free spaces among them in humid state are filled in with plastic, soft aggregates. They consist of mixture of phosphates with clay and fine mineral detritus. The colour on the top is yellow-brown, at the bottom — brown-yellow. Strongly acidious reaction. In this layer occur only secondary aluminium — iron phosphates containing potassium and ammonia. Content of calcium and magnesium is very low. Lack of augmented concentration of strontium.

15 — 45 cm — The layer almost stoneless. Main mass consists of coherent and uniform bright yellow aluminium — potassium phosphate (minyulite). It form a fragile, porous mass which embeds relatively less alterated fine silicate detritus of gravel-sand fraction. Reaction in this layer is acid. Amounts of calcium and magnesium are very low. It is a layer of the highest poorness in strontium. Contrary to other profiles one observes here almost complete leaching of iron which excludes possibility of occurrence of aluminium-iron phosphates.

45 — 70 cm — In this layer a gradual change is observed from the upper brighter part into darker brown-yellow phosphates with a harder, porous skeleton

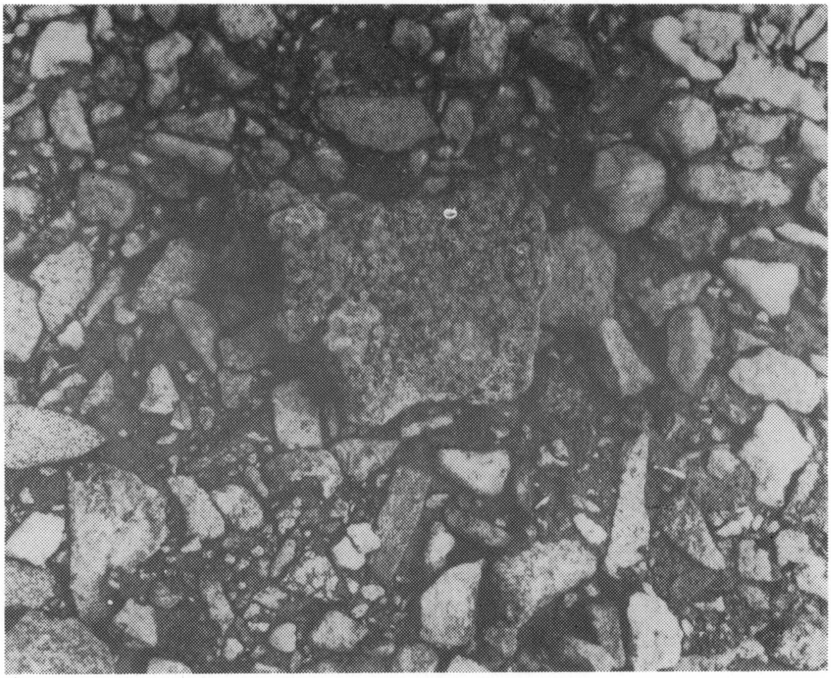

Fig. 4. Surface of the soil below penguins rookery (nearby profile No. 5)
Among pebbles - guano washed out from the rookery; in the central part fragment of the minyulite rock (profile No. 5, depth 30 cm)

Photo A. Tatur

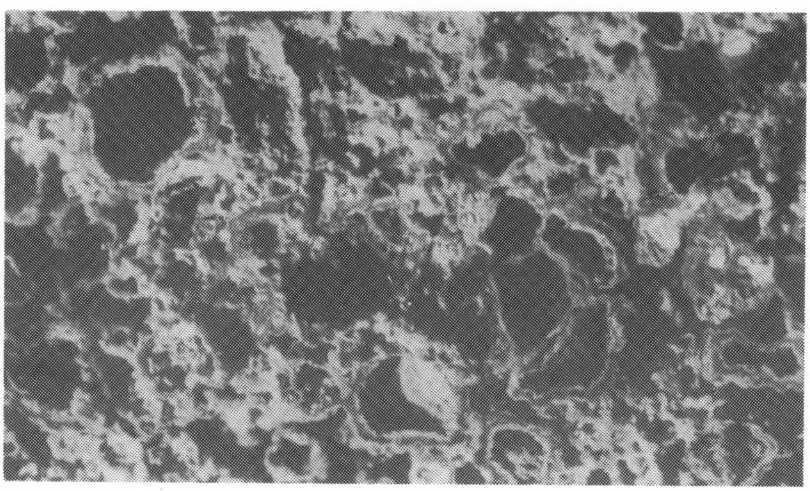

Fig. 5. Structure of the phosphates in profile No. 5 depth 45—70 cm Magnification 10x

Photo A. Tatur

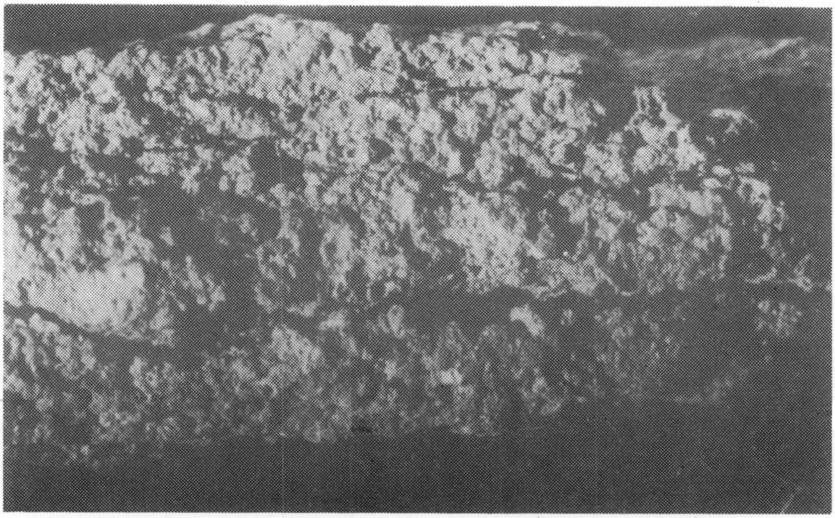

Fig. 6. Stratification in the profile No. 5 depth 45—70 cm Magnification 4x.
Photo A. Tatur

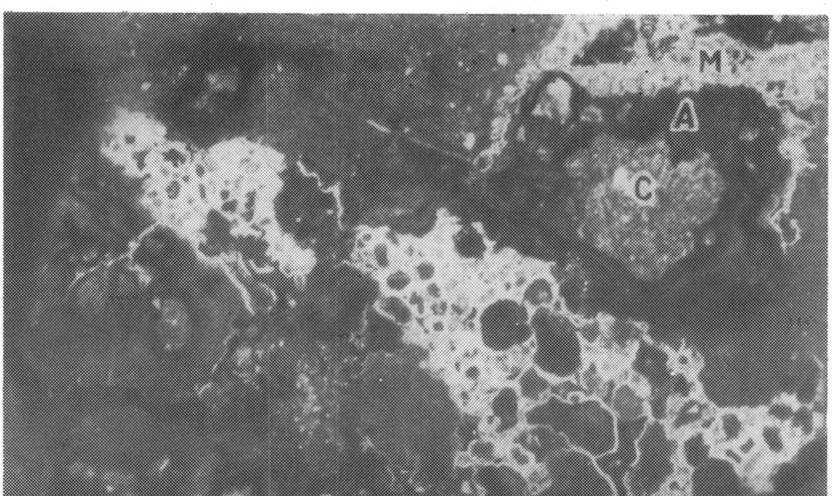

Fig. 7. Paragenesis of minyulite (M) with grains of amorphous aluminium phosphate (A). Inside grains — clay pseudomorphos (C) after phosphatized fragments of the rock
Polished section in reflected light. Magnification 20x
Photo A. Tatur

structure built from minyulite. Phosphates often form laminous coats (thin — brown, thick — bright yellow) on a fine clastic material. The grains of a clastic material are much more alterated than in the upper layer. Their phosphatic — clay remnants stick in much larger spaces. Often a void space is left by them (Fig. 5). Main mass in this layer consists of phosphates and the rock detritus (sand, gravel) form only several per cent of the soil weight. The content of clay material (part insoluble in HCl) does not exceed several per cent.

In this layer stratiform structure are found. The clearly perceivable thickness of single stratum amounts to about 0.5 cm. (Fig. 6I It is a layer permeable for water, often dried up since it is situated over the layer of capillary ascension of ground water. It is a layer of the lowest pH value (reaction strongly acid, almost by a unit lower than in the previous layer) and conspicuously poor in iron, magnesium and calcium. But it is enriched in strontium, probably selectively caught by phosphates from infiltrating solutions.

70 — 90 cm — The layer of phosphates. In porous, fragile, bright yellow mass of aluminium-potassium phosphate (minyulite) stick compact harder grains of glassy, amorphic dark brown aluminium-phosphate which form coherent coats on clastic material. Small fragments of rocks, on the contrary to upper layers, preserve its primary shapes although the material present in them is mostly strongly phosphatized. Thus there are tender pseudomorphs of clay — phosphates — silica material after fragments of volcanic rocks (Fig. 7). Some larger grains posses relatively less alterated core. This layer is usually wet. In the mid of warm summer it is within the reach of capillary ascension of ground water and by the remainig part of the season it is frozen up. Reaction in this layer is strongly acid. In the chemical analysis the concentration of strontium is clearly augmented due to selective catchment by amorphic aluminium phosphate. Some enrichment in calcium is also perceivable at the lack of increase in magnesium. The ratio C : N is also clearly higher in organic compounds bound (structurally?) with phosphate minerals.

90—95 cm — Loose dark, brown gravel which consists of glassy, amorphic, strongly hydrated aluminium phosphate coating phosphatized rocky detritus. Almost complete lack of potassium proves univocally lack of aluminium-potassium phosphate (minyulite). This gravel can be considered as grains sorted out from the upper phosphates most probably due to selective dissolving of minyulite. It lies in ground water. In the mid of summer, during an intense wash out of guano from the rookery the pH of water was strongly acid (pH 4) and concentrations of $N\text{-}NH_4$, $N\text{-}NO_3$ and $P\text{-}PO_4$ amounted to several hundreds mg/l (Tatur and Barczuk 1984). The reaction of the discussed layer is strongly acid, and the strongest secondary enrichment in strontium and calcium marked here. Concentration of calcium, as for strongly aciduous reaction, is relatively high. Ratio of Al to P exceeding 1 and some increase of iron concentration is probably brought about foremostly by augmented amount of clay material in phosphatized relicts after rocky detritus. Organic compounds entering the phosphates have the highest C/N ratio, close to those found commonly in organic matter of soils.

Below 95 cm — Hard layer of volcanic wock.

Profile No. 6 (locality — see Fig. 2.)

This is ornithogenic soil formed as a result of phosphatization of till, covered by a layer of pebbly delluvial material.

0 — 5 cm — Layer of semiliquid fresh guano with a high content of nitrogen, washed out from the rookery. Chemical composition similar as in profile 5. This mass lingers between loose, flat pebbles with a diameter of several cm, on the average.

5 — 45 cm — A layer of sharp-egded delluvial pebbles. The spaces among them are filled in with bright yellow-brown, soft mass clumped in unstable aggregations. This mass forms about 50% by volume of the whole soil and is built up mainly of secondary phosphates with phosphatized fine detrital material (sand, gravel). The detrital grains are often preserved only as thin dark brown shelling of secondary phosphates, which have appeared on the surface of rock chip whereas the silicates and aluminium silicates underwent strong phosphatization. Inside hard shellings there is either weathered crimp of rock or loose, pouring and fluffy material of phosphates and clay reminding the core of spoiled nut (Fig. 8).

From chemical analysis it results that among secondary phosphates a substantial quantitatively role is played by aluminium or aluminium-iron phosphates containing potassium. Calcium magnesium and strontium are almost completely leached. However the process of leaching did not remove iron (contrarily to profile no 5). This element occurs in amounts similar or even higher as in parent rock material. There is no enhanced concentration of ornithogenic strontium. The reaction is strongly acid.

45 — 60 cm — In this layer higher concentration of strongly phosphatized grains of clastic material is observed, these grains being joined together resemble layers of phosphates of profile no. 5. The colour of this level is clearly darker than in higher layer. From chemical analysis it results that higher content of darker simple aluminium phosphate or aluminium -rion phosphate. Reaction is acid. Similarly as in higher layer an intense leaching of calcium and magnesium occurs at the lack of leaching of iron and lack of higher concentration of strontium.

60 — 110 cm — The layer of boulder loam. The share of pebbles and cobbles is smaller whereas that of fine fraction among boulders — larger. The boulders are better rounded as in the upper layer. The layer is of brown colour coming from fluffy incoherent material, most often joined

Fig. 8. Phosphatization of the sand fraction in the profile No. 6 depth 5—45 cm
Clay pseudomorphs after fragments of the rock surrounded by hard coat of phosphates.
Magnification 40x

Photo A. Tatur

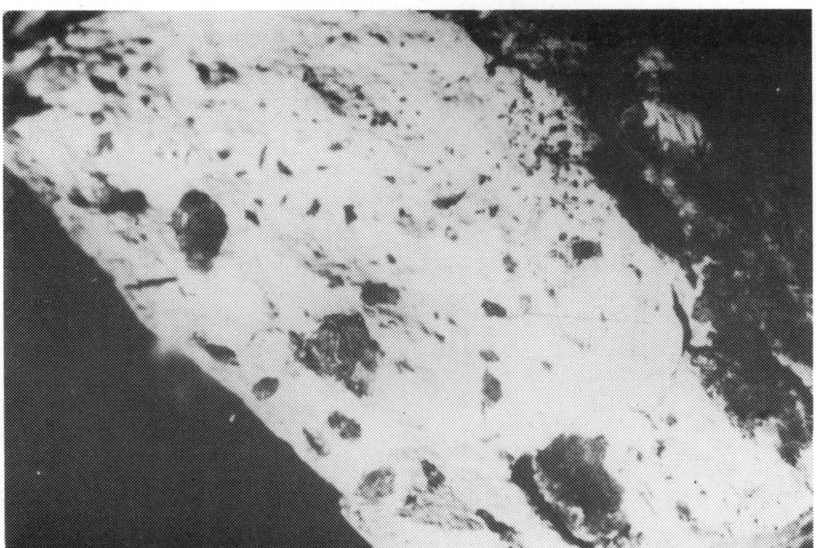

Fig. 9. Clay pseudomorphs after volcanic detritus of sand fraction in white clay of taranakite
Magnification 10x

Photo A. Tatur

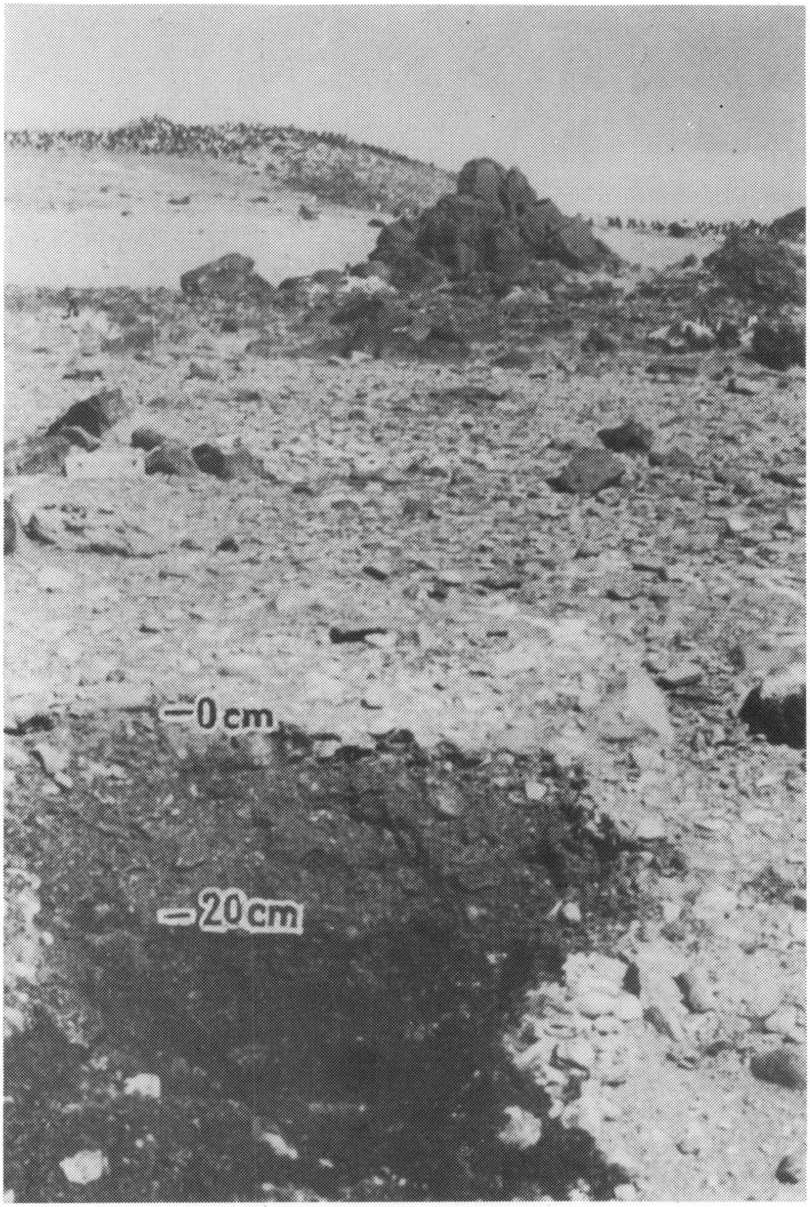

Fig. 10. Profile of the soil on the stony beach
0-20 cm — layer of phosphates accumulation among pebbles and cobbles

in unstable aggregates, consists of mixture of dark brown, secondary phosphates and clay material. The share of phosphates containing potassium is smaller which can be inferred from smaller concentration of potassium and lower ratio K/P in comparison with higher layer. That leads to the conclusion that beside phosphates containing potassium the simple aluminium and iron aluminium phosphates can be important.

Phosphatization of fine clastic material is still more strongly advanced in this layer. In the core of grains only small amounts of fluffy clay occur but often even void spaces. This layer have acid reaction and is strongly leached of calcium and magnesium. Neither leaching of iron nor enhanced concentration of strontium was observed.

110 — 150 cm — Gradual transition in a layer of wet boulder clay that lingers below the ground water level (130 cm). Among stony material especially among large stones, whose number is increasing in this layer together with depth there is white, plastic compact mass of pure alluminium phosphate containing potassium and ammonium (taranakite). In this mass there are unchanged shapes of red-brown soft pseudomorphs after phosphatized gritty rock material. This material consists of the mixture of clay, phosphates, silica and oxides. (Fig. 9). It is plastic, similarly as white mass surrounding them. In some spots, often around large stones, coats of pure white phosphate have dimensions of several centimeters. After drying up the white mass hardens. Similarly as in higher layers an intense leaching of calcium and magnesium, lack of iron leaching and lack of strontium enhanced concentration were ascertained. Iron occures only in pseudomorphs, probably in the form of hematite mainly. In white phosphatic mass only traces of iron occur (Tatur and Barczuk 1984).

Below 150 cm — Increasing amount of boulders and the presence of ground water make deeper digging impossible.

Profile No. 8 (locality — see Fig. 2.)

It is geologically non-uniform profile of soil derivating from the process of phosphatization of till covered by a layer of delluvial pebbles. The profile has been done just below a territory of old but less numerous group of nesting *P. adeliae*.

0 — 3 cm — A layer of semiliquid, decomposing guano with a large content of nitrogen, washed out from the rookery. The layer lies on pebbles. Reaction in this layer is neutral and chemical properties similar as in profile No. 5.

3 — 20 cm — A layer of poorly rounded pebbles, filled up with bright yellow brown, unstable aggregated, fluffy and soft mass. This mass consists of mixture of ornithogenic detritus and calcium phosphates (lack of magnesium phosphate) with fine clastic material of clear traces of an intense

phosphatization. These grains under a slight pressure go to pieces into loose, fluffy clay rich in in phosphates. There is lack of coatings around these grains, such as found in other profiles. According to chemical analysis some share in grains of aluminium phosphate containing potassium can be expected. In spite of strongly acid reaction this level containts relatively large number of elements susceptible for leaching (calcium, magnesium, strontium).

20 — 80 cm — Loamy layer with numerous larger boulders. The colour of this level is dark brown. It is uniform, by sight slighty durable and fluffy mass of aggregates. At magnifying over ten times it is visible that the mass is ununiform. Besides intensely phosphatized (as above) small rock crumbs, a brown, harder skeleton construction, probably of amorphic aluminium phosphate occurs in it filled up with white, loose mass of leucophosphite and taranakite (Tatur and Barczuk 1984). The pH is also strongly acid and calcium and strontium thoroughly leached.

Below 80 cm — Hard rock.

Profile No. 7 (for localization — see Fig. 2.)

The soil derived from the stony delluvial material below a large nesting group of *P. adeliae*. Lack of flow- off of guano along the soil surface.

0 — 10 cm — Layer of poorly rounded pebbles (several cm in diameter) with a brown mineral — organic mass between stones. It is a mixture of faeces washed out from the rookery with concentrated products of their mineralization (calcium and magnesium phosphates) and secondary phosphates (minyulite, leucophosphite). This material is mixed up with fine little phosphatized mineral detritus. The presence of calcium and magnesium phosphates is inferred from chemical analysis. X-ray identifications did not show diffraction spacing which could bee univocally identified as struvite or hydroxylapatite (Tatur and Barczuk 1984). The pH is slightly acid.

10 — 80 cm — The layer of pebbles filled up in free spaces with white-yellowish fluffy mass joined in soft aggregations of secondary phosphates (leucophosphite and minyulite were identified) mixed up with fine clastic material. Reaction is acid, and majority of calcium and strontium leached out.

Below 80 cm — Increasing number of large boulders make deeper digging impossible.

5.4. Description of soil profile in the zone of accumulation of ornithogenic materials in the area of stony beaches [3])

These soils are usually situated at certain distance from larger group of nesting penguins, thus they remain under lesser influence of organic

[3]) Fig. 2, section 6, chemical analyses — see Table I.

manuring. After heavier showers the waters washing guano out from more elevated soils inundate horizontally situated oversea terraces. Here reach solutions carrying nutrients diluted to a certain degree, often neutralized after passing through pools formed behind elevated storm-ridges.

In profiles of stony soils under a thin layer of fresh, decaying guano a bright zone of phosphate accumulation is observed. This accumulation is only found in surface layer of soil, a dozen or so centimeters thick and is restricted by a lower, permeability layer or by constant humidity (Fig. 10).

Characteristic for beaches are detrital agglomerations of fine grained sandy material with large share of ornithogenic detritus in bottom sediments of shallow pools located behind raised storm-ridges (Fig. 1).

Profile No. 4. (locality — see Fig. 2).

A typical profile through beach formations, stony pebbles and cobbles on gravels. The mass secondary phosphates filling the spaces between stones formes a waterproof level.

0 — 3 cm — A thin layer of decaying guano of a high content of nitrogen, covering the surface of the soil. The pH is neutral and chemical composition as in profile No. 5.

3 — 10 cm — Layer of beach pebbles and cobbles with plastic yellow-brown, unstable aggregated mass of secondary aluminium-iron phosphates containing potassium (mainly leucophosphite) mixed up with fine organic detritus and only slightly changed by phosphatation clastic material. The content of organic carbon is almost as high as in soils of rookeries but ratio C/N is higher than in krill. Reaction is strongly acid.

Below 10 cm — Loose beach gravel.

Profile No. 3. (locality — see Fig. 2.)

This profile is similarly shaped as profile 4, only surface layer of decaying faeces lacking, phosphates content lower,

Profile No. 1. (locality — see Fig. 2.)

It is typical profile of sediments in shallow pools formed behind eleveted storm-ridges. In central part of reservoirs the thickness of deposits reaches up to 0.5 m. This deposit consists of a mixture of various detritus components: rocky, organic and phosphatus with fraction below 0.5 mm. The organic detritus comprises fragments of feathers and chitinous krill skeleton. Phosphates are represented both by primary phosphates (distinguishable crystals of struvite, probable presence of calcium phosphate), as well as by various secondary phosphates washed out from higher elevated soils. Deposits are characterized by slightly acid reaction. They undergo mineralization processes, phosphatization and selective dissolving. These processes lead to differentation of profile into clear levels differing in colour.

0 — 10 cm — grey, fluffy consistency deposit,
12 — 16 cm — black, slightly compact deposit,
16 — 20 cm — brown, sligtly compact deposit.

5.5. Description of soil profile in the zone of feather accumulation [4])

The profile has been done in the vicinity of vast and old *P. adeliae* rookery on a steep slope between numerous little rocks. It is screened from wind place of moulting by penguins. Lack of guano flows from rookeries in this place is observed.

0 — 10 cm — Level of accumulation of strongly particulated and decaying feathers. Friable consistency mass with dark gray colour and numerous bigger fragments of feathers. Reaction strongly acid. In the chemical composition low content of phosphorus is worthy attention at a simultaneously high content of organic carbon and high C/N ratio, what is characteristic for such material (Williams and Berruti 1978).

10 — 50 cm — Redbrown weathering volcanic rock (tuffs with hematite?)

Below 50 cm — Hard volcanic rock.

6. Discussion

6.1. Description of guano forming processes

In the Maritime Antarctic Zone pygoscelid penguins feed almost exclusively upon krill (Volkman, Presler and Trivelpiece 1980). It is food clearly differing from the fish food consumed usually by brids that form guano in other geographical latitudes. Mature krill is characterized by a large content of chitin that forms on the average 15 per cent of dry weight of their biomass (Sitek, Kołodziej, and Stachowski 1975, Everson 1977) and fat (27 — 36 per cent of dry weight — Jackowska, unpublished data). Among trace elements a high concentration of fluorine, copper, strontium and zink is noteworthy what has been partially corroborated in this paper (Mauchline and Fisher 1969). The food of penguins by its high content of chitin reminds that of insectivorous bats that product guano in caves (Hutchinson 1950).

The breeding population of penguins in the Llano Point rookery was

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[4]) Fig. 2, section 7, chemical analyses — Table I.

leaving during each nesting season nearly 100 tons of dry weight of guano. One should keep in mind the fact that faeces form about 85 per cent of all ornithogenic deposits left by birds on the land (Burger, Lindeboom and Williams 1978). The majority of this material is deposed on the surface of about 10000 sq. m occupied by breeding penguins. Intensity of organic manuring can rich value of 10 kg dry weight of faeces per square meter of the rookery in the year.

The huge amounts of faeces undergo a rapid mineralization often checked by a low temperature but rarely by deficit of water (Petr, Tatur and Myrcha 1983). Under most favourable conditions in this region (temp. +16 C) about 50 per cent of organic matter is mineralized during 6 days and under less favourable conditions (open air *in situ*) — during 20 days. After 21-day incubation the guano becomes transformed in a uniform, semiliquid mass with ratio C : N : P close to that in fresh guano that forms surface layer on the soils in the rookery.

Parallel to the decomposition strong wash-out occurs of easily dissolved organic and mineral products of mineralization. Although the wash-out leads to concentration of the chitinous detritus and hydroxylapatite in fresh guano on the surface of the soil (Pietr, Tatur and Myrcha 1983, Tatur and Barczuk 1984), a large part of the nitrogenous matter of the original excreta is still present. Wishing to maintain the idea of classification proposed by Hutchinson (1950) one should call this matter nitrogenous guano.

To the high content of easily decomposable organic compounds in fresh guano points both direct chemical analysis and still high microbial activity of proteolytic and ammonifying bacteria (Pietr, Tatur and Myrcha 1983). High microbial activity ensures reducing conditions under which sulphur abundantly occurring in guano (1.1% according to Boyd, Rothenburg and Boyd 1970) is probably maintained in the form of sulphides that yield to wet layer of decaying faeces a typical black coloration. Black colour disappears at drying.

Under climatic conditions of Maritime Antarctic Zone the periods of an intense washing out of fresh guano leading to a fast removal of more soluble constituents are intermingled with short periods when solution that has passed through guano evaporates depositing various inorganic salts as minerals. The factor that enables evaporation and concentration of liquids on the soil surface in spite of low temperatures and ligh air humidities is probably strong wind. A substantial role in solution concentrating can be also played by freezing up. The most important phosphate in the layer of guano is hydroxylapatite.

Besides weakly crystalized hydroxylapatite, hydrated ammonium — magnesium phosphate (struvite) is commonly precipitated from concetrated solutions (Tatur and Barczuk 1984). It is one of several ammonium —

magnesium phosphates which were often found in guano. According to Hutchinson (1950) "leaching of somewhat more decomposed guanos commonly results in deposition of various magnesium phosphates". Both hydroxylapatite and struvite are durable minerals under neutral or alkaline reaction of soils. Such pH can be maintained due to a continuous influx of new portions of the organic matter that undergoes decomposition and releases alkaline ammonia (Gillham 1956).

In the rookeries and in their nearest vicinity under a thin layer of black fresh guano usually a layer bright in colour occurs which is named lechaed guano for stressing its genesis under the percolating water. The colour of the leached guano brighter than that of the upper level is most probably associated with smaller microbial activity. The share of easily decomposing organic compounds is clearly smaller. In the organic fraction further concentration of chitinous detritus occur (Pietr, Tatur and Myrcha 1983). Lack of struvite is characteristic for leached guano, as estimated by the magnesium content. The phosphates occur thus mainly in combination with calcium in the from of hydroxylapatite.

The lack of easily decomposing organic compounds Hutchinson (1950) considers one of criteria enabling to separate nitrogenous guano from phosphatic one. The leached guano described in the present paper could be compared to that described by the above-mentioned authors as leached phosphatic guano, however it differs from the latter by a large accumulation of chitinous detritus so typical for cave deposits of guano produced by insectivorous bats.

6.2. Description of phosphatized rocks

Fresh faeces, under the influence of rains became partly washed into stony, weathered cover in the area occupied by breeding group, but their considerable part became smeared in a thin layer on the area with flow of waters from the rookeries. Leachates of guano react on the other hand with stony loams that surround the breeding places forming thus a large zone of phosphatization with a high concentration of aluminium — iron phospates containing potassium and ammonium ions.

Such mineralization is commonly found where birds breeding in colonies nest on silicate rocks and where adequately high precipitation enables reaction between guano leachates and silicates. From the literature reviews published by Hutchinson (1950) and Altschuler (1973) it follows that phosphatization of silicate rocks occurs both in the warm zone with high precipitation and in temperate climatic zone with the most southwardly described place of its occurrence on subantarctic islands of New Zeland up to Antipodes (49 40'S). Among these islands the phosphatic deposits on Tarnacki Island (39°04'S) have been most thoroughly investigated and minerals tranakite so characteristic for wet, moderate climate has been found there (Hutchinson 1950).

Closely unidentified aluminium — iron phosphates can be also encountered in some deposits of Patagonia and on surrounding islands especially on Isla Leones (45°03'S) and Penguin Island (47°54,S). Layers of guano, even exploited in 19 century are also present in South Falkland Islands (51°40'S). The deposits described there consist mainly of calcium phosphates (Hutchinson 1950). In Maritime Antarctic Zone situated southwardly, where King George Island (62°11'S) is also situated Wilson and Bain (1976) have observed the occurrence of leucophosphite in surface layer of ornithogenic soils of Elephant Island (61°10'S).

The discovery of phosphatized rocks around rookeries of penguins on King George Island proves that ornithogenic mineralization in Maritime Antarctic zone can be compared with mineralization found in warmer regions, whereas it cannot be compared with organic deposits of ornithogenic soils decribed for Continental Antarctic (Ugolini 1972) in spite of suggestions reported by Allen and Heal (1970). This fact has been also mentioned by Wilson and Bain ((1976).

6.2.1. Alteration of the silicates in the phosphatization processes

Under the term phosphatization one understands the process by which phosphorus is emplaced in a host material. In assayed situation the alteration of rocky material takes place under the impact of chemically aggressive, rich in phosphorus guano solutions. In the area under study differentiated forms of rocks alteration have been observed. Accummulation of phosphates without any traces of "*in situ*" alteration of silicates is often noted as well.

Inferring from advanced alteration of rock fragments one can state that reaction between guano leachates and ground rocky material follows most intensely in deep and loose sedimentary rocks surrounding the rookeries and not in the surface layer of the breeding places and around them. Alteration is especially intense in situation when scattered mounds of pebbles stops guano run — off which enables waters leaching them a permanent aggresive penetration and phosphatization of lower situated layers. The phosphatization occurs most easily when in deeper layers there is finer but still permeable material. It corroborates a known notion than initial alteration facilitates phosphatization (Hutchinson 1950).

The processes of phosphatization can have different course at different depths of the soil profile, which was most conspicuously marked in profile No 5 (Fig. 3).

In more surfacial layer at a changeable oxidation and moisture the rock fragments undergo a thorough decomposition leaving only a void space in an as porous as a sponge mass of aluminium — potassium phosphates (Fig. 5). Such intense weathering leading to a complete disappearance of other substances than phosphates has been compared by Laroix after Hutchinson (1950) with weathering of laterite type. It is striking to be able to make such comparison for the soils of Maritime Antarctic Zone.

In a deeper always wet layer likewise below the level of ground water, phosphatization also leads to alteration of rock fragments but all by-products of phosphatization stay *in situ*. Thus soft pseudomorphs are being formed of clay-silica-phosphates material after fragments of volcanic rocks preserving however unchanged outer shapes of these grains (Fig. 7). Often there, are preserved characteristic for volcanic rocks, porphyritic structures which are underlined by the specific mineral composition of secondary filling mass. Differences are conspicuous not only between phenoecrysts and matrix but also between fine feldspats from matrix and matrix.

The discussed zone is very clearly developed in profile No 5 (depth of 70-90 cm), where clay pseudomorphs after volcanic rock fragments surrounded by hard, brown coat of aluminium phosphates form grains in fragile, light mass of minyulite (Fig. 7), or they form loose gravel at the level of ground water profile No 5 (depth 90-95 cm). In cores of greater grains one can often find still unweathered fragment of rocks. The pseudomorph consisting of phosphates — silica — clay after rock fragments are clearly preserved also in profile No. 6, at a depth of below 110 cm, below the level of ground water. These pseudomorphs stick in a compact, plastic clay of taranakite (Fig. 9).

The phosphatization in subsurface layers connected with a thorough removal of by-products of this reaction is probably caused by an alternating washing of this level with waters of different reaction, resulting mainly from changes in composition of the mineral forms of nitrogen (Tatur, and Myrcha 1983). At a low precipitation and at its lack solutions infiltrated through the soil contain the mineral nitrogen mainly in the nitrate form. There is enough time to lose alkaline ammonium ion as the result of volatilization to the atmosphere, sorption, binding in mineral structure and nitrification. The rate of nitrification increases with depth and time (Petr, Tatur and Myrcha 1983, Pietr in preparation). Nitrates with oxalic acid commonly occurring in the processes of decomposition of guano yield strongly acid reaction of those solutions (Tatur and Myrcha 1983). In strongly acid environment many silicates dissolve with liberating silica gel and in weathered clay silicates aluminium is transferred from structure of this minerals into exchangeable position, where it is substituted by hydrogenic ion, and aluminium itself goes to solution (Degens 1968).

At heavy rains the guano leachates rapidly percolating through soil are rich in ammonium ion (Tatur and Myrcha 1983) and they have alkaline reaction (Gillham 1956). These are conditions advantageous for dissolving silica that forms finally opal or chalcedone by-products during phosphatization processes (Altschuler 1973). To the deeper or less permeable layers the alkaline waters that dissolve silica cannot have an access due to acidification, neutralization and dilution at the contact with ground water. That is why in those layers by-products of phosphatization (silica, clay) stay in situ and are forming pseudomorphs after phosphatized rock fragments.

In the very surface layer of areas occupied by breeding groups and in their nearest vicinity as well as in shallow soils on beaches constant alkaline or neutral conditions at lack of strongly acid ones do not favour decomposition of silicates. However the aggressive guano leachates should not be considered as the only possible factor that is responsible for phosphatization although it is certainly the facilitating one. Analogous processes occur also without manuring at weathered of argiloceous phosphates in areas of intense ground water drainage (Altschuler 1973).

6.2.2. Formation of the phosphates

In the soils under study some of phosphates are formed as a result of phosphatization in situ or almost in situ within or around weathered rock fragments. This refers especially to brown-yellow layer occurring in deeper part of the zone of phosphatization where predominant mineral is minyulite or substituting amorphous aluminium phosphate. Phosphatization of this type leads to formation of typical indurated, porous phosphatic construction in soil. However, the other phosphates in the examined soils, including leucophospite characteristsic for the surface layer and taranakite, for the deepest layer are formed as a result of precipitation from solutions after transporting the ions through waters. Doubtless such is genesis of pure, crystalline efflorescence of aluminium — potassium phosphates observed sporadically around periodical springs of weathering cover that spray at the foot of hills below penguin rookeries. In the process of precipitation, aluminium can be considered as ion that precipitates probably the phosphatic ions and alkalist, remaining in excess (Tatur and Myrcha 1983). Factors that bring about precipitation can be both intense evaporation of water from the surface due to strong winds as well as concentration of solutions by freezing up. Precipitation can be the result of neutralizing of strongly acid (more rich in soluble aluminium) ornithogenic waters in the course of their flow through shallow pools. Considering conditions of precipitation, the mechanical transport of non-consolidated suspension of phosphates in flowing water should be also taken into account. Accumulation of secondary phosphates can thus occur far from the spot of its genesis among rocky materials without traces of such weathering (e.g. on beaches). Mechanical weathering of fragile or soft phosphates as well as secondary concentration of them in clastic bottom deposits of shallow pools below areas occupied by rookeries, occur commonly.

6.3. Mineral composition of the phosphates in the ornithogenic soils

The visual differentiation of soil profiles into genetic horizons finds its justification in their diverse mineral composition. Minerals characteristic for different levels are formed under specific physical and chemical conditions. Thus diversity of mineral composition between subsequent layers of soil profile can be considered as registered record proving their different origin (Tatur and Barczuk 1984).

The minerals of surface guano layer (struvite and hydroxylapatite) are formed and are durable under alkaline and neutral conditions. These reaction is mantained by organic manuring.

Main mineral of the subsurface yellow layer of the phosphatized rock leucophosphite forms as a precipitate in neutral or slightly acid conditions. Deeper, harder brown layer with minyulite forms in greater part as product "*in situ*" phosphatization under acid conditions by high phosphorus and fluor ions content. Amorphous aluminium phosphate is typical mineral for deeper part of this layer as well. It is forming in alkali-poor ground water either by incongruent dissolution of minyulite, or as precipitate from solution.

Taranakite forms in deepest part of the soil as a white, pure precipitate under ground water level from strong acid solution with lower phosphorus but enough high alkali content.

In the examined soil there only sporadically follows accumulation of pure monomineral phosphates. Usually it is a mixture of two, three phosphates with silicates. The presence of several phosphates proves changeable physical and chemical conditions during genesis. Vertical distribution of the phosphates in ornithogenic soils in a close connection with earlier described (Tatur and Myrcha 1983) dynamic metamorphosis of guano leachates during percolation through the soil.

6.4. Morphology of the ornithogenic soils in Maritime Antarctic Zone

The discussion on main soil forming processes given above led to generalization of the facts observed in natural environment and found in the laboratory. The result of this considerations concerning morphology of the ornithogenic soils is presented in Fig. 11.

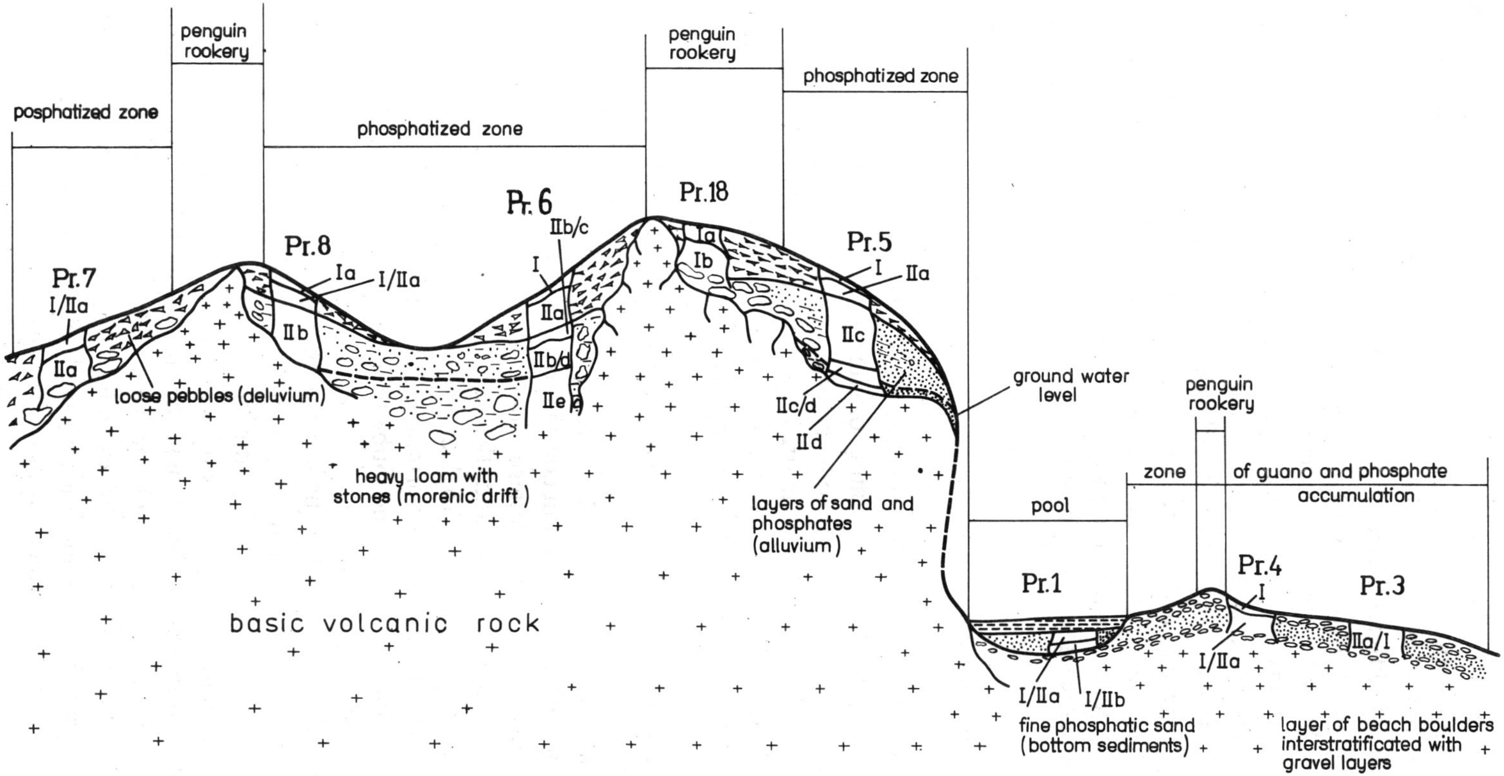

Fig. 11. Morphology of the ornithogenic soil I — guano horizon, a- black fresh organic matter with struvite and hydroxylapatite among stones, b- yellow-brown, leached organic matter (chitine) with hydroxylapatite among stones, II- phosphatized rock horizon, a- yellow, mainly leucophosphite in flaffy loamy aggregates among pebbles, b- brown-yellow, mainly minyulite or its substitute amorphous aluminium phosphate in weakly indurated phosphatized loam, c- brown-yellow, pure hard vesicular layer of minyulite, d- dark brown, loose gravel of armohpous aluminium phosphates, e- white plastic clay of pure taranakite and small phosphatized fragments of rock among boulders.

The morphology of these soils is described on the background of idealized geomorphological transection, referring to a real geomorphological situation found in the area of Llano Point (Fig. 1 and Fig. 2). The distinguished zones of differentiated impact of penguins on the environment were determined in accordance with sections presented in Fig. 2.

The genetic horizons of ornithogenic soils were determined in field basing on observations of their colour and structure. Visual dividing into horizons also agree with chemical and mineral differentiation (Tatur and Barczuk 1984). It seems that mineral differentiation is especially important at description of levels within the chemically monotonous phosphatized rocks. It should be also stressed that three fundamental phosphates (leucophosphite, minyulite, taranakite) typical for the distinguished levels could have a very similar chemical composition.

6.5. The term "ornithogenic soils"

The term "ornithogenic soils" proposed by Syroečkovskij (1959) has been generally accepted for determining organic soils of birds colonies on the Continental Antarctic. These soils consist of layer of guano resting sharp on mineral soil. Due to a limited amount of leaching caused by low temperatures no chemical reactions are observed between guano constituents and underlaying rocks (Campbell and Claridge 1966, Ugolini 1972).

Allen and Heal (1970) probably mainly per analogiam with Continental Antarctic distinguish ornithogenic soils, around the colonies of sea birds also in Maritime Antarctic Zone. Ugolini (1972) also is of opinion that "ornithogenic soils which are found in coastal areas of continental Antarctic ... are also widespread along the western coast of the Antarctic Peninsula, the islands of the Scotia Ridge and the subantarctic Islands". However, these authors most probably due to lack of relevant data neither precize specific morphological features of ornithogenic soils under conditions of humid Maritime Antarctic Zone and Subantarctic, nor the territorial range of these soils.

Everett (1976), on the other hand, basing on one soil profile done in an active rookery down to a depth of 30 cm considers that "since the term of ornithogenic was originally applied to soils in areas essentially devoid of organic matter other than bird droppings it should be restricted to rookery soils (principially penguins) and in West Antarctica perhaps even further restricted to include only active rookeries". By narrowing the meaning of term "ornithogenic", he excludes often vast surfaces of soils surrounding rookeries that are under the impact of solutions coming from them.

In numerous pedological papers from the vicinity of rookeries in Maritime

Antarctic Zone profound effect of the manuring on the poor vegetation in the neighbourhood is stressed but the standard soil analyses applied usually in these studies refer only to abundance of surface layer of soil in extractable or available forms of nutrients and they neither precize specific chemical composition, nor stress a special role of phosphate minerals, in these soils (Allen and Northover 1967, Boyd, Rothenburg and Boyd 1970, Smith 1978a, 1978b). The above-mentioned authors do not use the term "ornithogenic soils".

In petrological literature similar zones found in warmer regions are called as phosphatized or residual soils due to dominant process of phosphatization, and at sedimentary accumulation on depressions — phosphatic clay (Hutchinson 1950, White and Warin 1964, Altschuler 1973).

In the present paper in accordance with intentions reported by Allen and Heal (1970) although against restrictions by Everett (1976), the term "ornithogenic soils" has been applied in *sensu lato* covering besides the rookery area also surrounding soils being influenced by solutions flowing from the rookery. Thus a complete dependence of genesis and morphology of these soils, both organic (rookery area) and phosphatic (rookery vicinity), on organic manuring by birds has been underlined. According to Syroečovskij (1959) it is a condition of introduction of the term "ornithogenic". This author does not restrict the term for Continental Antarctic by writing that ornithogenic soils can be also formed in less severe climatic conditions.

The ornithogenic soils of Maritime Antarctic Zone are different than those of the Continent. In a wet, periodically abounding in rain zone the substances washed out from decomposing guano react with substrate forming a vast zone of phosphatization and sedimentary accumulation. In phosphatized, weathered materials characteristic for soils genetic levels occur. The surface of ornithogenic soils under study due to an excess of nutrients and tramping by birds besides ephemeral agglomeration of coprophilous algae is usually totally devoid of vegetation in the nearest vicinity of the rookery. Their productivity thus is most probably restricted to exquisitely high microbial activity (Pietr, Tatur and Myrcha 1983).

6.6. Influences of species preference of the penguin breeding places on formation of the ornithogenic soils

The present studies have corroborated finding by Smith (1978a) that the effect of bird manuring on surrounding soils is connected with species preference to rookeries. On King George Island in the region of Admiralty Bay three species of penguins occur: *P. adeliae*, *P. antarctica* and *P. papua*. *P. adeliae* are more agile and breed further inland than the other penguin species do. The way of water running down from their rookeries is longer and more complicated during percolation through permeable weathered rocks and they have a better chance to phosphatize them, all the more so as metamorphosis of the chemical composition of these water during percolation (Tatur and Myrcha 1983) makes them more aggressive towards silicates.

Chinstrap penguins prefer steep, bare coastal rocks. *P. papua*, on the other hand, nest usually on the stormridges present on beaches. Droppings of these bird species are quickly washed out into ocean by the high rainfall.

Therefore, zones of deep, metasomatic phosphatization in the region of Admiralty Bay are formed mainly around rookeries of *P. adeliae*.

The authors would like to thank Jacek Goździewicz for his kind company and help in the field work.

7. Резюме

Исследование орнитогенных почв проводилось в период антарктического лета 1979/1980 в пределах и вокруг выводковых колоний пингвинов из рода *Pygoscelis* в районе Лано поинт, остров Кинг Джордж (рис. 1). Зоны воздействия пингвинов на окружающую среду представлены на рис. 2, а попытка синтеза морфологических свойств названных почв — на рис. 11. Проведенное на местах визуальное выделение почвенных уровней на основании цветной и текстуральной дифференциации подтверждено химическими (таблица I) и минералогическими анализами (Татур и Барчук 1984).

Мелкие, каменистые почвы с территории колоний состоят из черного поверхностного слоя (свежее гуано), под которым находится светлый слой. Оба слои характеризуются высоким содержанием органической материи. В верхнем слое это интенсивно разлагаемые свежие выделения, в нижнем слое происходит концентрация сильно раздробленного хитинового детрита, который трудно разлагается. Почвы с территории колонии и особенно более глубокий слой, отличаются концентрацией гидроксилапатита $Ca_5(PO_4)_3 \cdot OH$, образующегося с элементов, которые освобождаются в ходе минерализации гуано. Верхний слой характеризуется наличием кристаллического струвита $Mg(NH_4)PO_4 \cdot 6H_2O$ который осаждается из поверхностных орнитогенных вод. После разведения воздушно-сухих проб реакция этих почв оказалась нейтральной. В свежих пробах из-за высокого содержания аммиака следует ожидать щелочной реакции.

В зоне аккумуляции перья, чаще всего на крутых склонах среди небольших скал, укрытых от ветра и расположенных в стороне от стока с выводковых мест, образуются мелкие почвы с характерным слоем бурого, разлагающегося перья, расположенных на минеральном основании (дресва или скала). Эти почвы, при высоком содержании органического вещества и довольно высокой величине C/N, в отличие от других орнитогенных почв характеризуются низким содержанием фосфора, а также кальция, магнеза и стронция. Это результат химического отличия исходного материала, каким в этом случае являются перья.

Выступающие часто вокруг выводковых колоний силикатные дресвеные покровы подлежат фосфатизации под влиянием растворов, вымытых из гуано. В почвах зоны глубокой фозфатизации под тонким слоем гуано с нейтральной реакцией выступает толстый слой фосфатизированных скал с реакцией всегда кислой или даже сульно кислой. Наблюдается

почти полное выщелачивание кальция и магнеза, а также отсутствие повышенной концентрации стронция. В этой зоне выступает как правило несколько уровней с разным минеральным составом.

Прямо под тонким слоем гуано, среди каменистой россыпи выступает бледно-желтая илисто-фосфатная масса в форме мягких агрегатов. Доминирующим фосфатом является здесь лейкофосфит $(K, NH_4)(Fe^{III}, Al)_2(PO_4)_2(OH) \cdot 2H_2O$. Он образуется в нейтральной или слабо кислой среде при высоких концентрациях щелочных катионов.

Более глубокий слой темнее, бурого или буро-желтого цвета. Он обычно содержит менее камней. В твердой глинистой массе главным минералом является миньюлит $KAl_1(PO_4)_2(OH, F) \cdot 4H_2O$, который придает ей характерную отверделую структуру, или его инконгруентный заменитель, аморфный фосфат алюминия $AlPO_4 \cdot 5H_2O$. Эти минералы сопровождаются обычно другими алюмино-железистыми фосфатами, содержащими калий и аммониевый ион. Преобладающие в этом слое фосфаты образуются в более кислой среде при изменчивом содержании щелочных катионов. При высокой концентрации ^+K и NH_4^+ образуется миньюлит, который в результате промывки водой, содержащей мало щелочных соединений, растворяется до алюминевого фосфата. Верхняя часть этого слоя характеризуется фосфатизацией наряду с полным устранением побочных, силикатовых продуктов этого процесса (рис. 5). В более глубоких партиях эти продукты остаются "*in situ*", образуя илисто-фосфатно-кремнистые псевдоморфозы в месте скальных обрывов (рис. 7). Иногда случается, что в почве этого слоя алюмине-калийные фосфаты вымываются. Происходит тогда концентрация одних только алюминевых фосфатов, что в результатах химического анализа очень четко обозначается убытком калия (рис. 3).

В одном из профилей была обнаружена интересная минерализация, являющаяся найболее глубоким уровнем в секвенции описанных. Под бурым слоем, ниже уровня грунтовых вод (120 см), в свободных пространствах между каменистой дресвой был установелн связный, белый, пластический ил, который оказался быть чистым таранакитом $(KNH_4)_3Al_5H_6(PO_4)_8 \cdot 18H_2O$. Это минерал образующийся при самых низких значениях pH и должно быть при низких концентрациях фосфора в растворах.

Почвы в зоне аккумуляции гуано и фосфатов на пляжах обладают значительно простейшей морфологией. Между лежащими на поверхности грунта голышами, часто под тонким слоем свежего гуано, наблюдается мягкое, светло-желтое глинистое вещество, выступающее в форме агрегатов (рис. 10). Это смесь ила, гуано и вторичных фосфатов, среди которых преобладает лейкофосфит.

Значительное количество орнитогенного материала накопляется в алеурытого-песчаных донных отложениях мелких водоемов, образующихся у подножья возвышенностей, на которых находятся выводковые колонии пингвинов (рис. 1). Среди мелкого, детритического материала (фракция алеурыт-мелкий песок), выступают как мелкие крупинки скал основания, так и частицы вторичных фосфатов (струвита), а также значительное количество органического детрита (перья, хитина).

Главным фактором, ответственным за минеральную дифференцияцию и различный ход фосфатизации в изучаемых почвах, следует признать динамически изменяющийся химический состав и реакцию вод, вымывающих гуано и просачивающихся сквозь дресвы, окружающие выводковые колоний шингвинов (Татур и Мырха 1983).

8. Streszczenie

Badania gleb ornitogennych prowadzono w czasie lata antarktycznego 1979/80 na obszarze i wokół kolonii lęgowych pingwinów z rodzaju *Pygoscelis* w rejonie Llano Point, Wyspa Króla Jerzego (rys. 1). Strefy oddziaływania pingwinów na środowisko przedstawiono na rys. 2, a próbę syntezy cech morfologicznych wyróżnionych gleb na rys. 11. Dokonane w terenie wizualne wydzielania poziomów glebowych na podstawie zróżnicowania barwnego i teksturalnego znajdują uzasadnienie w analizie chemicznej (tabela I) i mineralogicznej (Tatur i Barczuk 1984).

Płytkie, kamieniste gleby z obszaru kolonii składają się z czarnej warstwy powierzchniowej (świeże guano), pod którą znajduje się warstwa jaśniejsza. Obie warstwy charakteryzują się wysoką zawartością materii organicznej.. W górnej warstwie są to intensywnie rozkładane świeże odchody, w dolnej natomiast następuje koncentracja silnie rozdrobnionego detrytusu chitynowego, mało podatnego na rozkład. Gleby z obszaru kolonii, a zwłaszcza ich głębszą warstwę cechuje koncentracja hydroksylapatytu — $Ca_5(PO_4)_3 \cdot OH$, powstającego z pierwiastków uwalnianych w wyniku mineralizacji guana. Dla warstwy górnej charakterystyczna jest obecność krystalicznego struwitu — $Mg(NH_4)PO_4 \cdot 6H_2O$, wytrąconego z powierzchniowych wód ornitogennych. Odczyn tych gleb po rozcieńczeniu próbek powietrznie suchych jest obojętny. W próbkach świeżych, ze względu na nadmiar amoniaku, należy oczekiwać odczynu alkalicznego.

W strefie akumulacji pierza, najczęściej na stromych zboczach wśród skałek osłoniętych od wiatru i omijanych przez spływy z obszarów lęgowych, tworzą się płytkie gleby z charakterystyczną warstwą brunatnego, rozkładającego się pierza, zalegającego na mineralnym (zwietrzelina lub skała) podłożu. Gleby te, przy wysokiej zawartości materii organicznej i dość wysokim stosunku C/N, w odróżnieniu od innych gleb ornitogennych, cechują się niską zawartością fosforu, a także wapnia, magnezu i strontu. Jest to wynik odmienności chemicznej materiału wyjściowego, jakim są w tym przypadku pióra.

Występujące często wokół kolonii lęgowych krzemianowe pokrywy zwietrzelinowe ulegają fosfatyzacji pod wpływem roztworów wypłukanych z guana. W glebach strefy głębokiej fosfatyzacji, pod cienką warstwą guana o odczynie obojętnym, występuje gruba warstwa sfosfatyzowanych skał o odczynie zawsze kwaśnym lub silnie kwaśnym. Zwraca uwagę niemal całkowicie wyługowanie wapnia i magnezu oraz brak podwyższonej koncentracji strontu. W strefie tej występuje zwykle kilka poziomów o różnym składzie mineralnym.

Bezpośrednio pod cienką warstwą guana, wśród kamienistego rumoszu, występuje bladożółta ilasto-fosforanowa masa skupiona w miękkich agregatach. Dominującym fosforanem jest tu leukofosfit $(K,NH)_4\ (Fe,^{III}\ Al)_2\ (PO_4)_2\ (OH) \cdot 2H_2O$. Tworzy się on w środowisku obojętnym lub słabo kwaśnym przy wysokich koncentracjach jonów metali alkalicznych w roztworach.

Warstwa głębsza jest ciemniejsza, brunatna, ewentualnie brunatno-żółtawa. Zawiera ona zwykle mniej kamieni. W utwardzonej gliniastej warstwie głównym minerałem jest minyulit — $KAL_2\ (PO_4)_2(OH,F) \cdot 4H_2O$, który nadaje jej charakterystyczną utwardzoną strukturę, lub jego inkongruentny zamiennik amorficzny fosforanu glinu $AlPO_4 \cdot 5H_2O$. Minerałom tym towarzyszą zazwyczaj inne fosforany glinowo-żelaziste zawierające potas i jon amonowy. Dominujące w tej warstwie fosforany tworzą się w środowisku kwaśniejszym przy zmiennej zasobności w roztworach kationów metali alkalicznych. Przy wysokiej koncentracji K^+ i $NH^+{}_4$ tworzy się minyulit, który przy przemywaniu go ubogimi w alkalia wodami rozpuszcza się do fosforanu glinowego. Górną część tej warstwy cechuje fosfatyzacja połączona z całkowitym usuwaniem ubocznych, krzemianowych produktów tego procesu (rys. 5). W głębszych partiach produkty te pozostają *"in situ"* tworząc ilasto-fosforanowo-krzemionkowe pseudomorfozy po okruchach skalnych (rys. 7). Czasami w spągu tej warstwy może dojść do selektywnego wypłukania fosforanów glinowo-potasowych. Następuje wówczas koncentracja samych fosforanów glinowych, co w wyniku analizy chemicznej zaznacza się bardzo wyraźnie ubytkiem potasu (rys. 3).

W jednym z profili natrafiono na interesującą mineralizację będącą najgłębszym poziomem w sekwencji opisywanych. Pod warstwą brunatną poniżej poziomu wody gruntowej (120 cm), w wolnych przestrzeniach między kamienistą zwietrzeliną stwierdzono występowanie zwięzłego, białego i plastycznego iłu, który okazał się czystym taranakitem — $(KNH_4)_3Al_5H_6(PO_4)_8 \cdot 18H_2O$. Jest to minerał tworzący się przy najniższych wartościach pH i prawdopodobnie przy niższych koncentracjach fosforu w roztworach.

Gleby w strefie akumulacji guana i fosforanów na terenie plaż mają znacznie prostszą budowę. Między leżącymi na powierzchni gruntu otoczakami, często pod cienką warstewką świeżego guana, występuje miękkie, jasnożółte spoiwo gliniaste, skupione w nietrwałe agregaty (rys. 10). Jest to mieszanina iłu, guana i wtórnych fosforanów, wśród których dominuje leukofosfit.

Szczególnie duże nagromadzenie materiału ornitogennego występują w pylasto-piaszczystych osadach dennych płytkich zbiorników wodnych, tworzących się u podłoża wzgórz, na których znajdują się kolonie lęgowe pingwinów (rys. 1). Wśród drobnego materiału detrytycznego (frakcja pył — drobny piach), występują zarówno drobne okruchy skał podłoża jak i okruchy wtórnych fosforanów (struwitu) oraz znaczne ilości detrytusu organicznego (pióra, chityna).

Za główny czynnik odpowiedzialny za zróżnicowanie mineralne oraz różny przebieg fosfatyzacji w badanych glebach należy uznać dynamicznie zmieniający się skład chemiczny i odczyn wód płuczących guano i przesiąkających przez zwietrzeliny otaczające tereny lęgowe pingwinów (Tatur i Myrcha 1983).

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