# Technosols of Hope Bay, Antarctic Peninsula: Century-old man made soils on Former Ornithogenic Environment

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**Abstract**
Technosols are anthopogenic soils that may be strongly impacted by heavy-metal deposition, which have not yet been described in Antarctica. In this paper, we present the chemical and physical study of what is supposedly the oldest man-made soil from Antartic Peninsula, developed in the vicinity of Trinity House and Nordenskjold Hut at Hope Bay. The soil morphology and chemistry indicates a former ornithogenic site (penguin rookery) further subjected to human disturbance, following exploration since 1903. We detected very high amounts of exchangeable Zn, Fe, Mn, Cu, all consistent with the human impacts and strong contamination. Also, the total contents of heavy metals such as Cd, Cu, Ni, Pb and Zn are extremely high. Strong positive correlation between the total concentrations of Cd, Cu, Mn, Ni, Pb and Zn indicates a similar source of pollution. These soils may represent the oldest Technosol in the Antarctic Continent.

## Introduction
The first report of human presence in Hope Bay (Antartctic Peninsula) date back to 1903, when J. Gunnar Andersson, a member of the Swedish expedition to the south pole (1901-1904), under the leadership of Otto Nordenskjöld, carried out the first exploration and mapping. Well-preserved ruins of the stone hut built by the swedish group can be seen at the harbour entrance. The United Kingdom first established at Hope Bay in 1945 (the so-called Base D – built as part of "Tabarin Operation"). The British station remained operational until 1964, being transferred to Uruguai in 1997. In 1951, Argentina also established an Army station in the region (Esperanza), with permanent operation to the present day. In the same area, remains of a former British Base (Trinity House), which burnt down in 1948, are situated 300 metres to the northeast of the Uruguayan base. The population of breeding birds of Hope Bay is well studied, and a large Adélie penguin (*Pygoscelis adeliae*) colony, numbering around 125,000 pairs, is situated about the same area (Woehler 1993). Soil morphological aspects indicating strong ornithogenic influence suggest that the extension of the penguin rookery was much larger prior to permanent human settlement. Other birds breeding at Hope Bay include gentoo penguins (*Pygoscelis papua*), brown skua (*Catharacta loennbergi*), Antarctic tern (*Sterna vittata*), Wilson's storm petrel (*Oceanites oceanicus*), kelp gull (*Larus dominicanus*), and sheathbill (*Chionis alba*).

The aim of this work was to study the occurrence and chemical composition of unusual Antartic soils under strong anthropogenic influence at the vicinity of Trinity House at Hope Bay, and relating chemical and morphological changes with the history of occupation of this area, as this possibly represents one of the oldest memories of anthropogenic impact of the Antarctic Continent. We hypothesized that these soils may represent Technosols (WRB, 2006). The last version of the World Reference Base for Soil Resources (IUSS Working Group WRB, 2006) developed appropriate taxa (Anthrosols and Technosols) for soils in urban/industrial areas (landfills, farming, earth movement, and heavy metal contamination), and agricultural areas (erosion, ripping, and land leveling).

## Methods
Soil profiles at selected anthopogenic sites were dug and collected at the vicinity of the ruins of the British depot of Trinity House, which burned down to complete destruction, leaving a widespread mantle of debris which was subjected to further pedological changes under a cold polar climate. This anthropic action left varied materials, such as semi-carbonized wood, bone, charcoal, bricks, charred organic materials, metallic materials, concrete, distributed at depths between 5 cm down to 30-40 cm.
The chemical extraction of nutrients and metals followed the procedure of Embrapa (1997): we determined pH in water; Mehlich 1-extractable amounts of P, $Na^+$, $K^+$, Zn, Fe, Mn and Cu; Available $Ca^{2+}$, $Mg^{2+}$ and exchangeable $Al^{3+}$ with KCl 1 mol $L^{-1}$. Total Organic carbon was estimated by wet combustion by the method of Yeomans and Bremner (1988).

Aqua regia extraction (pseudototal content) was done according to the German Norm (DIN 38414-S7)[1]. Three hundred milligram of dried soil samples, in triplicate, was weighed to digestor blocks tubes and 3 mL of aqua regia were added. The mixture was allow to stand at room temperature overnight. Then the tubes were transferred for a digestor block and a warming step of 3 hours at 120 ºC was done using a reflux apparatus. Finally the extracts were transferred to previously decontaminated tubes and the final volume was completed to 10 mL. In order to assess the bioavailable fraction of metals in these soil samples, a extraction with DTPA were performed. The DTPA extraction solution was prepared with 0.005 mol $L^{-1}$ of Diethylenetriamine-pentaacetic acid (DTPA), 0.01 mol $L^{-1}$ $CaCl_2$ buffered at pH=7.30 with triethanolamine[2]. One gram of each soil sample, in triplicate, were extracted with 5 mL of DTPA solution in a horizontal shaker end-over-end (Barnsteady, Iowa, USA) by 2 h. The supernatant was separated by centrifugation and it was transferred to previously decontaminated flasks. Spectrometric determinations of the elements Cd, Cr, Cu, Mn, Ni, Pb and Zn in the aqua regia and DTPA extracts were done using flame atomic absorption spectrometry. The accuracy of the aqua regia extraction was verified by the use of the certified reference material BCR 146 R (Sewage Sludge from Industrial Origin).

**Results**

These anthropogenic soils of Hope Bay showed mean values of Mehlich-1 extractable P of 996 mg $dm^{-3}$ (HB1) and 679 mg $dm^{-3}$ (HB2) (Table 1), and thus classified as strongly ornithogenic, according to criteria proposed by Simas et al. (2007). The parent materials of the Hope Bay Formation are generally chemically poor in bases and P (siliclastic tubidites and sandstones), indicating that the abnormal P values are related to a former penguin rookery, which was either went extinct or was forced to move away from the direct human influence following the swedish and british occupations in early XX century. In fact, slaughtering of penguins was described by O. Nordenskjöld at the 1903 season (SCAR, 2002), a fact which was possibly repeated in the following years of occupation, greatly reducing the original rookery.

Very high amounts of exchangeable Zn, Fe, Mn, Cu are consistent with the human impacts and strong contamination of the local soil following human occupation. It is also possible that the contamination and further pedogenesis and cryoturbation led to a larger extent of soil pollution, as indicated by morphological observation at the field. According to critical values for the Brazilian Law (Cetesb 2005), such Zn concentration of 987 mg $dm^{-3}$ (surface), and extractable Cu of 101 mg $dm^{-3}$ (subsurface), found in HB1 profile indicate urgent need for intervention, in view of imminent, direct or indirect, risk to human health. In this case, particular attention should be given to water pumping at nearby lake Boekella, used for the Argentinian Base. Furthermore, the pseudototal contents of heavy metals such as Cd, Cu, Ni, Pb and Zn are extremely high. For the most impacted sites (table 2), pseudototal levels of these elements were almost 36, 35, 26, 270 and 87times higher than the prevention value for soil quality prescribed by the CETESB, respectively. Regarding the bioavailable contents, great environmental concern was raised, especially the high Pb concentration in the more labile fraction, reaching 2094 mg $kg^{-1}$. A matrix correlation (table 3) was constructed using the pseudototal and bioavailable concentrations of the elements. Positive correlations were obtained between pseudototal and bioavailable concentration of each element, showing a good selectivity of the DTPA extractant. Nevertheless, the most important information obtained with that matrix was a good correlation between the pseudototal concentrations of Cd, Cu, Mn, Ni, Pb and Zn, which indicates a similar source of pollution.

Lower TOC are the result of poor vegetation development and little vestiges of the original penguin guano deposition, which was further mineralized and leached following abandonment. Present-day vegetation is restricted to a few crostose lichens (Acarospora) and matts of *Prasiola Crispa* (algae).

In the two soils, anthrosolization dominates the soil forming process, being man-made soils. They can be classified as Technosols, formed under the influence of deposited debris, without further direct anthropic interventions, nearly a century-old. Strong horizonation and redistribution of metals are indicating that cryoturbation under a polar climate did not prevent pedogenesis and sparse colonization of lower plants. Results also indicate an ability of these Antarctic Technosols to retain nutrients and heavy metals.

## Conclusions

The soil pedons HB1 and HB2, are both anthropogenic, and previously developed under strong ornithogenesis before human arrival in 1903. At that time, the penguin rookery at Hope Bay was much larger than at present, having its size reduced following permanent settlement in this area.

Tentatively, these soils can be classified as Gelic, ornithogenic Anthosols. Very high exchangeable, pseudotototal and bioavailable amounts of heavy metals indicate contamination and disturbance, especially by debris left by the burning of the British Base Trinity House, close to the studied soil. This illustrates that the Hope Bay area needs to establish a permanent protected area in the remaining penguin rookery, allowing a long term recovery of the original landscape.

**Table 1. Chemical characterstics of Anthosols.**

| Hor. | Prof. (cm) | pH $H_2O$ | pH KCl | $Ca^{2+}$ | $Mg^{2+}$ | $K^+$ | $Na^+$ | $Al^{3+}$ | MO | P | $P_{rem}$ | Zn | Fe | Mn | Cu |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | ---------------cmol$_c$ dm$^{-3}$ | -------------- | | | | dag kg$^{-1}$ | mg dm$^{-3}$ | mg L$^{-1}$ | --------------mg dm$^{-3}$ | ------------- | | |
| HB1 - Gelic Ornithogenic Anthrosol | | | | | | | | | | | | | | | |
| A | 0-8 | 7,36 | 7,38 | 4,56 | 0,97 | 0,30 | 1,43 | 0,00 | 3,23 | 1156,10 | 26,00 | 987,00 | 302,30 | 200,40 | 94,20 |
| AC | 8-12 | 6,98 | 6,12 | 4,96 | 1,26 | 0,78 | 1,52 | 0,00 | 1,03 | 1921,50 | 33,00 | 184,50 | 576,20 | 61,80 | 101,90 |
| C2 | 12-27 | 5,11 | 3,60 | 1,16 | 0,63 | 0,85 | 0,56 | 1,05 | 0,52 | 480,50 | 48,80 | 14,49 | 1020,20 | 5,90 | 13,98 |
| C3 | 27-53 | 4,87 | 3,33 | 0,55 | 0,51 | 0,51 | 0,32 | 0,86 | 0,39 | 427,20 | 56,60 | 3,92 | 482,70 | 2,20 | 4,76 |
| HB2 -Gelic Ornithogenic Anthrosol | | | | | | | | | | | | | | | |
| A | 0-18 | 6,04 | 5,93 | 1,88 | 1,08 | 0,20 | 0,53 | 0,00 | 2,91 | 718,00 | 50,40 | 42,40 | 875,40 | 58,30 | 22,00 |
| C1 | 18-27 | 4,85 | 3,86 | 1,45 | 0,91 | 0,18 | 0,39 | 0,76 | 1,42 | 865,00 | 51,20 | 144,00 | 604,80 | 19,80 | 8,08 |
| C2 | 27-60 | 4,81 | 3,45 | 1,22 | 0,81 | 0,15 | 0,23 | 2,00 | 0,78 | 454,70 | 39,50 | 11,51 | 628,70 | 6,90 | 4,06 |

**Table 2. Pseudototal and bioavailable contents of Cd, Cr, Cu, Mn, Ni, Pb and Zn of the soil samples.**

| Samples | Cd (mg kg$^{-1}$) | | Cr (mg kg$^{-1}$) | | Cu (mg kg$^{-1}$) | | Mn (mg kg$^{-1}$) | | Ni (mg kg$^{-1}$) | | Pb (mg kg$^{-1}$) | | Zn (mg kg$^{-1}$) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | pseudo | Bio | pseudo | bio | pseudo | bio | pseudo | bio | pseudo | bio | pseudo | bio | pseudo | bio |
| A1 | < LD | < LD | 34 | < LD | 105 | 0.48 | 195 | 6.0 | 10 | < LD | 129 | < LD | 405 | 17 |
| A2 | 7.2 | 0.49 | 225 | < LD | 159 | 1.0 | 326 | 12 | 106 | 2.8 | 437 | 22 | 3484 | 460 |
| A3 | 4.1 | 0.46 | 60 | < LD | 580 | 2.5 | 315 | 9.4 | 18 | 0.99 | 250 | 6.2 | 1554 | 84 |
| Gerador | < LD | < LD | 46 | < LD | 104 | 0.29 | 128 | 3.8 | 7.4 | < LD | 184 | < LD | 134 | 6.0 |
| 50 m | < LD | < LD | 74 | < LD | 150 | 0.62 | 73 | 1.7 | 4.2 | < LD | 250 | 7.8 | 151 | 6.0 |
| PERR | < LD | < LD | 35 | < LD | 195 | 0.49 | 202 | 5.6 | 12 | 1.22 | 103 | < LD | 263 | 10 |
| MOTOR | 47 | 1.9 | 90 | < LD | 2081 | 1.7 | 3197 | 5.4 | 336 | 1.69 | 18605 | 1817 | 5225 | 301 |
| CONST | 44 | 2.0 | 99 | < LD | 1836 | 3.2 | 2661 | 4.9 | 278 | 1.57 | 19381 | 2094 | 4422 | 242 |

**Table 3. Correlation matrix.**

| | Cd b | Ni b | Pb b | Cu b | Mn b | Zn b | Cd ps | Ni ps | Pb ps | Cu ps | Mn ps | Zn ps | Cr ps |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cd b | - | 0,39 | 0,97 | 0,96 | 0,01 | 0,60 | 0,99 | 0,98 | 0,98 | 0,98 | 0,98 | 0,92 | 0,27 |
| Ni b | - | - | 0,26 | 0,23 | 0,71 | 0,95 | 0,36 | 0,49 | 0,26 | 0,24 | 0,30 | 0,69 | 0,93 |
| Pb b | - | - | - | 0,96 | -0,18 | 0,46 | 0,98 | 0,95 | 0,99 | 0,97 | 0.98 | 0,83 | 0,12 |
| Cu b | - | - | - | - | -0,19 | 0,44 | 0,98 | 0,95 | 0,98 | 0,99 | 0,99 | 0,83 | 0,08 |
| Mn b | - | - | - | - | - | 0,65 | -0,07 | 0,03 | -0,18 | -0,11 | -0,12 | 0,33 | 0,67 |
| Zn b | - | - | - | - | - | - | 0,57 | 0,68 | 0,47 | 0,47 | 0,51 | 0,86 | 0.90 |
| Cd ps | - | - | - | - | - | - | - | 0,99 | 0,99 | 0,98 | 0,99 | 0,90 | 0,22 |
| Ni ps | - | - | - | - | - | - | - | - | 0,96 | 0,95 | 0,98 | 0,95 | 0,34 |
| Pb ps | - | - | - | - | - | - | - | - | - | 0,98 | 0,99 | 0,84 | 0,13 |
| Cu ps | - | - | - | - | - | - | - | - | - | - | 0,99 | 0,85 | 0,09 |
| Mn ps | - | - | - | - | - | - | - | - | - | - | - | 0,87 | 0,14 |
| Zn ps | - | - | - | - | - | - | - | - | - | - | - | - | 0,58 |
| Cr ps | - | - | - | - | - | - | - | - | - | - | - | - | - |

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**References**

Cetesb. Decisão da Diretoria n 195/2005. (2005) Aprovação dos valores orientadores para solos e águas subterrâneas no Estado de São Paulo, CETESB, São Paulo.
DIN 38 414 Part 7 (1983) German standard methods for the examination of water, waste water and sludge, sludge and sediment (Group S), Digestion using aqua regia for the subsequent determination of the acid-soluble portion of metals (S7).
Embrapa (1997) Manual de Métodos de Análises de Solos, 2nd edition. Rio de Janeiro.
Lindsay WL, Norvell WA (1978) *Soil Sci. Soc. Am. J.* **42**, 421-428.
Woehler EJ (1993) The distribution and abundance of Antartic and Subantarctic penguins. Cambridge: Scientific Committee on Antarctic Research.
WRB (2006) World Reference Base for Soil Resources. World Soil Resources Report 84, 2006. FAO, Rome, IT, EU.
Yeomans JC, Bremer JM (1988) A rapid and precise method for routine determination of organic carbon in soil. *Communications in Soil Science and Plant Anal*. **19**, 1467-1476.