ANTPAS Guide for Describing, Sampling, Analyzing, and Classifying Soils of the Antarctic Region

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Introduction

The purpose of this manual is to identify key soil attributes and how they are measured. The manual seeks to provide a basis for soil data collection in Antarctica that can be utilized by all people working in the Antarctic environment who are contributing to the ANTPAS (Antarctic permafrost and soil) programme. Taking a uniform approach will ensure that the key minimum data are collected at all sites so it is easier to integrate data from the various regions of Antarctica when collating Antarctic-wide data-bases and maps. The manual identifies the key data that should be collected at all sites and a further list of attributes that it is desirable to record if possible.

The Antarctic region is defined by the Antarctic Treaty (http://www.scar.org/treaty) as all land and oceans ≥60ºS and, therefore, includes the sub-Antarctic islands (South Orkney and South Shetland Islands) and the entire Antarctic continent. Based on recent satellite imagery, only 0.3% of Antarctica (~420,000 km^2) is ice-free, primarily in the Transantarctic Mountains (TAM) and along the Antarctic Peninsula (AP), with smaller areas in Queen Maude Land, Enderby Land, Vestfold Hills, Wilkes Land, the Ellsworth Mountains, and Marie Byrd Land.

The Antarctic Permafrost and Soils (ANTPAS) website is managed by Waikato University in New Zealand (http://www.erth.waikato.ac.nz/antpas). Persons conducting soils investigations in Antarctica are encouraged to submit their data to Megan Balks, m.balks@waikato.ac.nz so that the data can be included as part of the Antarctic soils database for producing soil maps and other thematic maps, such as permafrost form and distribution, and active-layer depths, of the Antarctic region for general distribution.

Summary of Key Attributes to be recorded

 # = Minimum data set must be recorded if possible
*** = desirable attributes record if practicable.**

- Pedon number #
- Collector – affiliation, contact address or email #
- Date #
- GPS location #
- Map grid reference *
- Photos of site, soil profile, and ground surface#
- Profile sketch*
- Landform – including aspect and slope #

- o Parent material – lithology and form (eg ground moraine or bedrock) #
- o Patterned ground/cryoturbation description#
- o Climate regime*
- o Weather at time of sampling*
- o Vegetation/organisms#
- o Horizon name* or number#
    - o Depth to top of each soil layer or horizon #
    - o Thickness of each soil layer or horizon #
    - o Texture of <2mm fraction of each horizon #
    - o Percentage cobbles, boulders, etc for each horizon #
    - o Organic matter#
    - o Color of each horizon #
    - o Moisture status of each horizon #
    - o Horizon boundaries – shape and distinctiveness*
- o Weathering stage*
- o Salt stage and type of salt*
- o Presence/absence of ice cement# - depth to ice cement#
- o Depth to permafrost*
- o Human impacted site yes/no#
- o Soil classification – USDA*, WRB*
- o Samples colelected#

Methods for recording Key Attributes

In the following section, we indicate how the key attributes can be measured under Antarctic conditions. The attributes can be recorded on standard forms (Appendix 1).

SITE RECORD

Soil Excavation. Soil pits are normally excavated by hand at each site to a depth of at least 100 cm, unless bedrock, ice-cement, or large boulders prevented digging to that depth. Our soil pits are approximately 150 cm long by 80 cm wide. We always remove the desert pavement and store in on a tarpaulin or mat and place the removed soil (overburden) onto a second tarpaulin. After samples are collected, the soil is backfilled and the desert pavement is replaced. Under most national Antarctic programmes you will need to complete environmental impact assessments and acquire appropriate permits prior to undertaking any excavation or sampling of Antarctic soils.

Pedon Identification Number#. We prefer numbering sites by investigator (initials), year and consecutively by order of visit. For example, if Megan R. Balks (MRB) visited 38 sites in 2005, these would be labeled MRB-05-01 through MRB-05-38. Sample numbers for MRB-05-01 could be MRB-05-01-01, MRB-05-01-02, etc.

Date, Investigator, and Affiliation#. The date on which the data were collected should be indicated, along with the names and initials of the persons collecting the data, their full mailing and email addresses.

GPS Location#, Geographic Coordinates*, Map Sheet Location*, Elevation#. Geographic coordinates, including latitude and longitude, can be readily determined using a hand-held Global Positioning System (GPS). We prefer reporting coordinates in degrees with minutes and seconds given as a percentage of degrees, e.g. 74.68530ºS and 141.54318ºE. When using a hand-held GPS in Antarctica for data that is to be used in ANTPAS please ensure that it is set in terms of the **WGS84** geoid as many other co-ordinate systems will be inappropriate for use in the Antarctic a long way from their origins.

Please indicate which base/topographic map along with publisher, scale, and date if description and sampling points are put on a map.

Elevations can readily be determined from a 1:50,000 topographic map or from an altimeter or GPS.

SITE DESCRIPTION

Photo Documentation#. We recommend taking digital images (or prints or slides that can be scanned) of the following features: the landform showing the soil pit location, the soil profile with a readable scale, the desert pavement with an appropriate scale, and any special soil features such as evidence for cryoturbation, fossil sand wedge casts, ground ice, etc.

Profile sketch* An annotated sketch can be useful to record key profile features.

Landform# The main components of relief are landform, slope (reported in degrees or percent), and aspect (reported in degrees of azimuth or cardinal direction). Landforms could include end or ground moraine, outwash plain, river terrace, lake plain, etc.

Patterned ground/cryoturbation# The presence/absence and form of patterned ground should be described. The presence or absence of cryoturbation is important for classifying soils of Antarctica. Evidence for cryoturbation includes irregular or broken horizons, oriented stones on the surface or in the profile, patches of subsoil organic matter, etc. Cryoturbation or frost stirring is manifested on the surface of Antarctic soils by the presence of pattern ground. Most common forms include sorted and nonsorted stripes, circles, nets, and polygons (Appendix Table 3).

Surface weathering and surface topography/features* The degree and nature of weathering of the surface pavement materials should be noted and any specific surface features. A general description of the surface topography would also be useful.

<u>Parent material#</u> Parent material and lithology should be reported such as till from dolerite and sandstone, outwash from granitic materials, solifluction terrace from argillite, etc.

<u>Climate*</u>. Climate could include mean annual temperature, mean annual precipitation, etc. for the nearest weather/climate station. In the McMurdo Dry Valleys it is helpful to specify whether the soil climate is xerous (coastal), sub-xerous (interior valleys) or ultraxerous (high plateaus) using criteria established by Campbell and Claridge (1969), (Appendix 2).

The weather at the time of sampling should also be recorded and it is also useful to record the air temperature and soil temperature at the range of depths sampled using a hand-held temperature probe.

<u>Vegetation/organisms#</u> The vegetation and any fauna present should be described.

(Appendix Table 3). Any human impacts to the landscape or soils should be reported such as vehicular or foot trafficking, oil spills, etc.

<u>Horizon name* or number#.</u> Soil horizons are distinguished using standard soil horizon nomenclature (Soil Survey Staff, 1993), except that the symbol "D" is used for the desert pavement and the terms "Cn" and "Cox" are used for distinguishing between unoxidized and oxidized parent materials, respectively (ca. Birkeland, 1984). The depth of each horizon is determined from a control section representative of the four exposures in the soil pit.

<u>Horizon depth and thickness#</u> The depth to the top, and the thickness, of each soil horizon should be recorded in cm.

<u>Soil texture#</u> The soil texture (ie % sand, silt, and clay) of the < 2 mm fraction should be recorded for each horizon, estimated by hand texturing.

<u>Proportion of boulders/cobbles/gravel#</u> The proportion of stones/boulders (>25 cm diameter), cobbles (7.5-25 cm diameter), and gravel (2-75 mm diameter) should be estimated using comparative charts for each horizon. The degree of rounding, weathering and presence of salt coatings on rock materials should also be noted.

<u>Soil organic matter#</u> Soils in interior Antarctica contain very low concentrations of organic matter. However, soils in bird rookeries, along the outer Antarctic Peninsula, and in the sub-Antarctic islands may contain substantial amounts of organic matter. It is desirable to make some estimate of the amount of organic matter (low, medium, high), form (peat, muck), and the source of the organic matter (birds, mosses, lichens, higher plants). We recommend reporting whether the organic matter is fibric, hemic (mesic), or sapric, in increasing order of decomposition.
(Appendix Table 3).

Soil color# is determined on field samples, using Munsell soil colour comparative charts, and should be reported according to moisture content, e.g., dry, moist, or wet.

Soil moisture status# should be recorded at the time of sampling (as dry, slightly moist, moist, very moist, or saturated) for each horizon. The presence of soil moisture is important for biota, weathering processes, and cryoturbation in Antarctica.

Weathering stage* The weathering stage and any evidence of weathering should be reported such as the presence of ghosts (pseudomorphs), rubefication (reddening) of the soil, and alteration of surface boulders.

The weathering stage is intended to be an overall representation of the age of the landscape/material based on the degree of surface boulder weathering and soil morphology (Campbell and Claridge, 1975) (Table 2).

Weathering stage 1 has fresh, unstained and angular boulders, 5Y soil colors, minimal horizon development, stage 0 salts, very shallow ice-cemented permafrost, and moderate patterned ground development.

Weathering stage 2 has light staining of boulders with some disintegration, 10YR 6/3-2.5Y 6/2 soil colors, weak horizon development, stage 2 salts, shallow ice-cemented permafrost, weak soil horizon development, and strong patterned ground development.

Weathering stage 3 has boulders distinct polish, staining, and rounding, some cavernous weathering and ventifacts, 10YR 5/3-2.5Y 6/4 soil colors, distinct horizon development, stage 3 salts, moderately deep soil depth, and some ghosts.

Weathering stage 4 has boulders much reduced by rounding, crumbling and ventifaction, strongly developed cavernous weathering, well developed staining and polish, and some desert varnish; 10YR 5/4 soil colors; very distinct soil horizons; salt stage 4; deep soil profiles; and some ghosts.

Weathering stage 5 has few boulders, a well developed desert pavement with extensive crumbling, rounding, pitting and polish; 10YR 4/4-5YR 5/8 soil colors; very distinct soil horizon development; stage 5 salts; deep soil profiles; and some ghosts.

Weathering stage 6 has weathered and crumbled bedrock; very strongly stained residual materials; 7.5YR 5/6-5YR 4/8 or 2.5YR 3/6 soil colors; very distinct soil horizon development; stage 6 salts; shallow to deep profiles; and bedrock sometimes crumbled to 50 cm in depth.

Weathering Stages of Antarctic Landforms/Soils

Weathering stage	Boulder condition	Soil colors	Soil Horizon-ation	Salt stage	Permafrost depth
1	Fresh angular	5Y	minimal	0	shallow
2	Light staining, some disint.	10YR 6/3-2.5Y 6/2	weak	1 or 2	shallow
3	Polish, stained	10YR 5/3-2.5Y 6/4	distinct	3	Mod. deep
4	Ventif., strong cavern.	10YR 5/4	Very distinct	4	deep
5	Few boulders, strong pavement	10YR 4/4-5YR 5/8	Very distinct	5	deep
6	Residual pavement	7.5YR 5/6-5YR 4/8	Very distinct	6	Shallow-deep

Bockheim and Wilson, 1992 (modified from Campbell and Claridge, 1975)

Salt stage and type of salt* Salts are predominant in Cold Desert soils of interior Antarctica. The form of soluble salts reflects soil age and is related to total dissolved salts from electrical conductivity measurements (Table 1).

The salt stage of Bockheim (1997) should be recorded.

Salt stage 0 contains no visible salts;

Salt stage 1 has coatings on the bottom of stones;

Salt stage 2 has salt flecks 1-2 mm in diameter that cover <20% of the surface area of the horizon;

Salt stage 3 has salt flecks 1-2 mm in diameter that cover >20% of the surface area of the horizon;

Salt stage 4 has a weakly cemented salt pan;

Salt stage 5 has a strongly cemented salt pan; and

Salt stage 6 has an indurated salt pan.

Salt stages 4 through 6 reflect salt pans of differing degrees of cementation. Salt pans are designated in soil descriptions with the symbols “ym” or “zm” depending on whether the cementing agent is gypsum or a salt more soluble than gypsum such as NaCl or $NaNO_3$.

Morphogenetic Salt Stages in Antarctic Soils

Salt stage	Morphogenetic form	EC (dS/m)	Approx. age
0	None	<0.6	<10 ka
1	Coatings beneath stones	0.6-5.0	10-18 ka
2	<20% of horizon with flecks 1-2 mm	5.0-18	18-90 ka
3	>20% of horizon with flecks 1-2 mm	18-25	90-250 ka
4	Weakly cemented salt pan	25-40	250 ka - ~1.7 Ma
5	Strongly cemented salt pan	40-60	~1.7 – 3.9 Ma
6	Indurated salt pan	60-100+	~>3.9 Ma

Bockheim, 1997

Presence/absence, and depth, of ice-cement# The depth to an ice-cemented layer or ice core should be recorded where present. Much of the permafrost in the McMurdo Dry Valleys is "dry-frozen," i.e., there is insufficient interstitial moisture for the material to be cemented. Cementation by ice can occur with as little as 10% moisture content on a weight basis.

Depth to permafrost* The depth to permafrost is defined as the maximum depth reached by zero °C temperature measured over a two year period. Where such measurements are available this should be given. If you are sampling Antarctic soils in late December or Early January it can be assumed that, if ice cement is present, it will be at about the maximum depth of thaw so an inferred depth to permafrost can be given.

Human impacts at the site* Any previous human activities/impacts should be recorded, including extent and type of impact eg. Presence of spilled fuel materials, physical disturbance such as bulldozing or previous excavation.

Soil Classification*. It is useful to classify the soils of Antarctica into the Gelisol order to the family level (Soil Survey Staff, 2002). The Gelisols contain three subgroups: (1) Histels which contain permafrost in the upper 1 m and ≥80% organic matter in the upper 50 cm; (2) Turbels which are mineral soils and contain permafrost and one of more horizons that are cryoturbated in the upper 2 m; and (3) Orthels which are mineral soils with permafrost in the upper 1 m but show no evidence of cryoturbation.

Organic soils underlain by permafrost are subdivided into great groups depending on the degree of decomposition, Fibristels, Hemistels, and Sapristels, from least decomposed to most decomposed. Mineral soils containing permafrost are divided into great groups on the basis of soil climate.

Where Antarctic soils have anhydrous conditions (i.e., the mean annual precipitation is less than 50 mm water equivalent), they are classified as Anhyturbels or Anhyorthels. Antarctic soils are further subdivided into subgroups on the basis of presence or absence of soluble salts. For example, soils containing a petrogypsic, gypsic, nitric, salic, or calcic horizon are designated as Petrogypsic Anhyturbels/Anhyorthels, Gypsic Anhyturbels/Anhyorthels, etc. Finally, the soils are classified into families on the basis of particle-size class, mineralogy class, and soil temperature class.

The World Reference Base (WRB) for Soil Resources, a soil classification system widely used in western Europe, identifies soils with permafrost as Cryosols and is currently undergoing revision.

Soil sample collection and storage# The samples collected, by whom, and where located should be recorded.

Laboratory Characterization of Antarctic Soils.

In accordance with the approach used for sodic and saline soils (U.S. Salinity Laboratory, 1954), 1:5 soil:(distilled) water extracts can be prepared and the following measurements performed on each sample: pH, electrical conductivity (EC), major cations, and major anions. pH can be measured potentiometrically using a pH meter, and EC can be determined using a conductivity bridge/cell (U.S. Salinity Laboratory, 1954). Cations can be measured using flame photometry (Na, K) and atomic absorption spectroscopy (Ca, Mg) (APHA et al., 1976). The anions, SO_4, and NO_3, and Cl can readily be measured by ion chromatography.

The anion chemistry of cold desert soils is controlled by air mass origin, i.e., McMurdo Sound or the polar plateau. Accordingly, we determine the $mmol_c$% of anion in the horizon of maximum salt concentration. Soils influenced by marine aerosols from McMurdo Sound are enriched in Na and Cl and soils along the polar plateau are dominated by Na and NO_3; soils intermediate from the coast and the plateau contain primarily Na or Ca and SO_4.We calculate profile quantities of salts to a depth of 70 cm from the equation: EC (dS/m) x thickness (cm) x 4.8 (Bockheim, 1979).

The amount of free iron was determined by extracting the soils with a citrate-dithionite-bicarbonate solution (Mehra and Jackson, 1960). Particle-size distribution can be determined from dry sieving and the hydrometer or pipette method (Day, 1965). The common soil fractions include very coarse sand (2-1 mm), coarse sand (1-0.5 mm), medium sand (0.5-0.25 mm), fine sand (0.25-0.10 mm), very fine sand (0.10-0.05 mm), coarse silt (0.05-0.02 mm), medium + fine silt (0.02-0.002 mm), and clay (<0.002 mm).

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Appendix 1: Soil Description Form

To be completed. If you want a copy of a draft immediately please contact m.balks@waikato.ac.nz or mcleodm@landcare.cri.nz .

Background information

Soils of Antarctica have attracted scientists for nearly 100 years, beginning with the Scott Expedition in 1907-9 (Jensen, 1916). Soils are important in Antarctica for reconstructing the glacial history and paleoclimate of the continent, understanding glacier dynamics, and examining life and biodiversity in extreme environments.

There is an extensive soils database put into a Geographic Information System (GIS) for the TAM from North Victoria Land (71-72ºS) through the McMurdo Dry Valleys (77-80ºS) to the Scott Glacier (86ºS) (Bockheim, 2005). Smaller databases that are not available electronically exist for the AP, the Ellsworth Mountains, and Queen Maud Land, but little information exists for the other regions cited above.

Weathering Stages, Antarctica

1 Unstained angular boulders; no horizonation (Cn); stage 0 or 1 salts; ice cement w/in 70 cm; patterned ground

2 Lightly stained subangular boulders; weak horizonation (Cox); stage 2 (few flecks) salts; may have ice cement; patterned ground common

3 Distinct polish and rounding, some cavernous weathering; distinct horizonation (Bw); stage 3 salts (many-common flecks); moderately deep profile

4 Strongly developed cavernous weathering; ventifaction; very distinct horizonation; stage 4 salts (weakly cemented salt pan); deep profile

5 Low surface boulder frequency; well developed desert pavement; very distinct horizonation; stage 5 salts (strongly cemented salt pan); deep profile

6 Low surface boulder frequency; well developed desert pavement; macro pits in dolerite; common “horns and hollows”; very distinct horizonation; stage 6 salts (indurated salt pan); shallow to deep profile; bedrock may occur in lower solum