Distribution of Soil Taxa in Antarctica: a Preliminary Analysis

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Abstract

Only 0.35% (49,500 km^2) of Antarctica is ice-free. These areas are scattered around the periphery of the continent and in interior mountain ranges, making soil mapping difficult. Here we compile the results of mapping in five of the nine ice-free areas that account for 29% of the ice-free area and interpret the distribution of soil subgroups in *Soil Taxonomy*. Soils of Antarctica are contained in four orders, dominantly Gelisols (84%), 13 suborders, 27, great groups, and 76 subgroups. Forty-four percent of the soils of Antarctica are Orthels, Gelisols that show minimal cryoturbation and occur in dry landscape positions; 36% of the soils are Turbels showing cryoturbation and occurring in more moist landscape positions. Only 16% of the soils of Antarctica lack permafrost in the control section and are classified as Entisols (Gel- great groups), Inceptisols (Gelepts suborder or Gelaquepts), or Histosols (Gel- great groups). These soils occur almost exclusively along the western Antarctic Peninsula and at elevations below 30 m in the South Shetland Islands (SSI) and South Orkney Islands (SOI). Typic Anhyorthels are the dominant soil subgroup comprising nearly 15,000 km^2, or 30% of the soils in Antarctica. These soils occur primarily in central and southern Victoria Land, but also occur in the Thiel and Pensacola Mountains and Shackleton Range, the Prince Charles Mountains, and the mountains of Queen Maud Land. Typic Haploturbels and Typic Anhyturbels occupy 14 and 13% of the soils of ice-free regions of Antarctica, respectively. Most abundant in central Victoria Land, they are common in most mountainous regions of Antarctica. Soils in lithic subgroups comprised only 15% of the soils; however, in the mountains of Antarctica, we were unable to differentiate the Rockland land type from soils in lithic subgroups so that we have probably underestimated the areal distribution of lithic soils. Typic Gelorthents occupy about 8% of the ice-free areas of

Antarctica, mainly in Palmer and Graham Lands but also in the SSI and SOI. Ornithogenic soils comprise less than 0.5% of the ice-free area.

Key words: soil classification, soil mapping, Antarctica

1. Introduction

Antarctica occupies an area of 14 million km^2 and according to the Antarctic Treaty (http://www.ats.aq/e/ats.htm) is comprised of the entire area south of 60°S. Only 0.35% of Antarctica is ice-free (Figure 1), with the Transantarctic Mountains and nunataks along the Antarctic Peninsula comprising 50% and 20% of the total ice-free area, respectively. During 1964 to 1975, a series of 19 Antarctic Map Folios were prepared by the American Geographical Society showing the distribution of vegetation, mammals, glaciers, and other natural resources of Antarctica (Bushnell, 1974); however, this series did not include maps of soil resources.

McCraw (1967) prepared the first soil map of Antarctica, a third-order (1:63,500) map of Taylor Valley based primarily on topography and parent material. Since the early map of McCraw (1967), several soil maps using units from *Soil Taxonomy* (Soil Survey Staff, 2014) have been published for portions of five of the nine ice-free areas at scales ranging from 1:1000 to 1:2 million (Table 1). A recent book, *Soils of Antarctica* (Bockheim, 2014), documents soils of each of the ice-free regions. The purpose of this study is to use the published maps and regional analyses to elucidate the distribution of soils in Antarctica.

2. Study area

Much of the following information is taken from a summary by Bockheim (2014). Antarctica is the world's fifth largest continent and is often subdivided based on two large ice sheets separated by the Transantarctic Mountains into East Antarctica and West Antarctica. The East Antarctic ice sheet is underlain at depths up to 4 km by a land mass with a network of sub-glacial lakes and streams and is believed to have been relatively stable throughout the Pleistocene. In contrast, the

West Antarctic ice sheet is marine-based, unstable, and has responded synchronously with Northern Hemisphere glaciations. These two ice sheets contain 70% of the Earth's freshwater.

Widespread glaciation began in Antarctica after the continent separated from South America approximately 35 to 40 million years ago during the Eocene or Oligocene. During the mid-Miocene the ice sheet had built up sufficiently to enable katabatic winds to pass from the polar plateau to mountain valleys causing a shift in climate from polar to polar-hyperarid.

Antarctica currently features three contrasting climates: (i) a humid-maritime climate along the West Antarctic Peninsula (WAP) with a mean annual temperature (MAAT) of -1.7 to -3.4°C and mean annual precipitation (MAP) ranging from 400 to 1000 mm; (ii) a dry-maritime climate along the coast of East Antarctica with a MAAT of -9 to -11°C and a MAP of 200 to 250 mm; and (iii) a hyper-cold, hyper-arid inland, mountain climate with a MAAT of -17 to -35°C and a MAP of 100 mm or less. Antarctic currently is experiencing considerable warming, especially along the WAP.

Permafrost is continuous in continental Antarctica and discontinuous in the South Shetland Islands. Active-layer (seasonal thaw layer) depths commonly range from 1 to 6 m or more along Antarctic Peninsula, from 0.3 to 1.1 m along the coast of East Antarctica, and from 0.1 to 0.4 m in the inland mountains.

Plant life is restricted to mosses, lichens and algae in continental Antarctica, with vascular plants limited to two species (*Deschampsia antarctica* and *Colobanthus quitensis*) in the Antarctic islands north of 67°S, particularly in the South Orkney and South Shetland Islands. There are more than 400 species of lichens in Antarctica, 40% of which are endemic, and more than 130 species of bryophytes, mostly mosses. Seabirds and nesting birds constitute the dominant factor influencing soil organic carbon and nutrient levels in Antarctic soils.

Despite the small ice-free area, geologists have been able to map a large portion of the bedrock of the continent from nunataks, mountains that project above the ice. Ice-free regions 1 through 4 in East Antarctica (Fig. 1) feature primarily Precambrian gneisses and schists. The Transantarctic Mountains (region 5b) contain the Jurassic to Devonian age Beacon Group (sandstones intruded by dolerite) fronted by the Cambrian-Ordivician Granite Harbour Intrusives. The northern Transantarctic Mountains contain Upper and Older Precambrian metasedimentary rocks. The Pensacola Mountains (region 5a) are derived from Jurassic basaltic rocks, Upper Precambrian metasediments, and Paleozoic strata. The Ellsworth Mountains (region 6) contain Paleozoic strata. Ice-free areas in Marie Byrd Land are composed of Cenozoic volcanic rocks and Cretaceous intrusive rocks (granitic rocks). The Antarctic Peninsula is made up of a wide variety of rocks that are dominated by volcanic and granitic types.

The soil parent materials of Antarctica are primarily of glacial origin and include tills of various forms, outwash, and limited areas of glaciofluvial and glaciolacustrine deposits. Colluvium, talus and other deposits from mass-movement occur throughout Antarctica. Debris flows and gelifluction deposits are common along the Antarctic Peninsula and in East Antarctica. Aeolian deposits include sand dunes and mega-ripples, but not loess. Volcanic ash and lapilli are common in the SSI and SOI; and scoria and other tephra occur in the MDV. Residuum is common in the high mountains and nunataks of interior Antarctica.

3. Methods and Materials

Most of the information for this study was collected from maps identified in Table 1 and from summaries for each ice-free region contained in *Soils of Antarctica*, both of which use taxa from *Soil Taxonomy* (Soil Survey Staff, 2014). We used a set of three reconnaissance soil maps (1:1 million scale) prepared by McLeod et al. (2007) for the Transantarctic Mountains (region 5b). This region accounts for 40% of the ice-free area of Antarctica. Similar soil maps were prepared on 1:250,000 topographic map sheets for the Pensacola Mountains (region 5a) and the Ellsworth Mountains (region 6) (Bockheim and McLeod, unpublished).

The relative abundance of soil-map units from the Transantarctic Mountains was used for mountain regions elsewhere in Antarctica, including the mountains of Queen Maud Land (region 1; Matsuoka, 1995), the Prince Charles Mountains (region 3; Li et al., 2003), and the mountains of Marie Byrd Land (region 7). For Enderby Land (region 2), we used the interpretations of Mergelov et al. (2014) from the Larsemann Hills (region 3). The Antarctic Peninsula was divided into Graham-Palmer Lands and the SSI-SOI and interpretations were made from data by Haus et al. (2014) and Simas et al. (2014), respectively.

4. Results

From the areas of each region and the distribution of soil taxa within each region, we were able to determine the distribution of soils in Antarctica (Table 2). Antarctic soils are classified in four orders (Gelisols, Entisols, Inceptisols, and Histosols), 13 suborders, 27 great groups, and 76 subgroups. Typic Anhyorthels are the dominant soil subgroup comprising nearly 15,000 km^2, or 30% of the soils in Antarctica. These soils occur primarily in central and southern Victoria Land (region 5b), but also in the Thiel and Pensacola Mountains and Shackleton Range (region 5a), the Prince Charles Mountains (region 3) and the mountains of Queen Maud Land (region 1).

Typic Haploturbels and Typic Anhyturbels occupy 14 and 13% of the soils of ice-free regions of Antarctica, respectively. Most abundant in central Victoria Land, they are common in most mountainous regions of Antarctica. Soils in lithic subgroups comprised only 15% of the soils; however, in the mountains of Antarctica, especially regions 1, 3, 5a, 5b, 6, 7, and 8, we were unable to differentiate the Rockland land type from soils in lithic subgroups so that we have probably underestimated the areal distribution of lithic soils. Typic Gelorthents occupy about 8% of the ice-free areas of Antarctica, mainly in Palmer and Graham Lands but also in the SSI and SOI (region 8).

Forty-four percent of the soils of Antarctica are Orthels, Gelisols that show minimal evidence of cryoturbation and occur in dry landscape positions; 36% of the soils are Turbels showing cryoturbation in more moist landscape positions (Table 3). Only 16% of the soils of Antarctica lack permafrost in the control section and are classified as Entisols (Gelorthents), Inceptisols (Haplogelepts, Humigelepts, Dystrogelepts), or Histosols (Cryofibrists, Cryohemists, Cryosaprists, and Cryofolists). These soils occur almost exclusively along the western Antarctic Peninsula and at elevations below 50 m in the SSI and SOI; these organic soils may contain permafrost below 2 m. Ornithogenic soils occupy only 0.5% of ice-free areas in Antarctica.

5. **Discussion**

5.1 Evolution of soil taxa

5.1.1 Maritime Antarctica

The dominant soil processes of maritime Antarctica are cryoturbation, gleization, melanization, podzolization, paludization, and phosphatization (Figure 2). The presence of permafrost and gelic materials leads to the formation of Gelisols in maritime Antarctica. In areas devoid of permafrost, Gelorthents and Gelepts form. In poorly drained areas, Aquiturbels form in areas of permafrost, and Gelaquents and Gelaquepts develop in areas without permafrost. Melanization, or the accumulation of organic matter in the mineral soil, may lead to the development of Umbrothels and Umbriturbels in areas with permafrost and Humigelepts in areas without permafrost. Spodorthels (not officially recognized in ST) form in old penguin rookeries with thick active layers (Blume et al., 2002). Histosols and Histels result from paludization in areas without and with permafrost, respectively. Nesting and migratory birds, including penguins, may influence all of these soils through phosphatization (Simas et al., 2007).

5.1.2 Coastal East Antarctica

Soil taxa in coastal East Antarctica (regions 2 through 4) are derived from sandy outwash or weathered rock overlain by till (Figure 3). Spodorthels form on outwash materials and till devoid of cryoturbation (Beyer and Bölter, 2000), and Haplorthels form on loamy till devoid of cryoturbation. Haploturbels and Aquiturbels develop where cryoturbation occurs. Fibristels and Hemistels may also form on these deposits. Penguins contribute organic matter and contribute to the podsolization process.

5.1.3 Transantarctic Mountains

In the inland mountains of Antarctica, Glacic Haploturbels occur on sediments with an ice core and Typic Haploturbels on other glacial deposits of late Quaternary age (Figure 3). In environments where the ice table is not being recharged, Typic Anhyorthels occur on drift of late to mid-Quaternary age, Salic Anhyorthels on drift of early Quaternary age, and Petrosalic Anhyorthels on drift of Pliocene age or older. Salts originate primarily from marine aerosols (Bockheim, 2002).

5.2 Pedodiversity

An understanding of the distribution of soil taxa is important for identifying sites of special scientific interest (SSSI) and ASPs (Areas of Special Protection) that should be protected. Some of the most pedologically diverse areas in Antarctica include the South Shetland Islands (region 8) and Arena Valley in the McMurdo Dry Valleys (region 5b) (Table 4). Areas of low pedodiversity include southern Victoria Land (region 5b), and the Ellsworth Mountains (region 6).

6. Conclusions

Soils occur throughout ice-free areas of Antarctica (49,500 km^2) and include dominantly Gelisols (80%) but also Entisols, Inceptisols, and Histosols in areas where permafrost is lacking or is below 1 or 2 m. Although 76 subgroups have been identified in Antarctica, the dominant ones are Typic Anhyorthels (30%), Typic Haploturbels (14%), Typic Anhyturbels (13%), Typic Gelorthents (8%), and Glacic Haploturbels (6%). Schemes for time-related changes in soil development are presented for maritime Antarctica and the inland mountains. Soil diversity is greatest along the Antarctic Peninsula and lowest in the southern Transantarctic Mountains.

Acknowledgments

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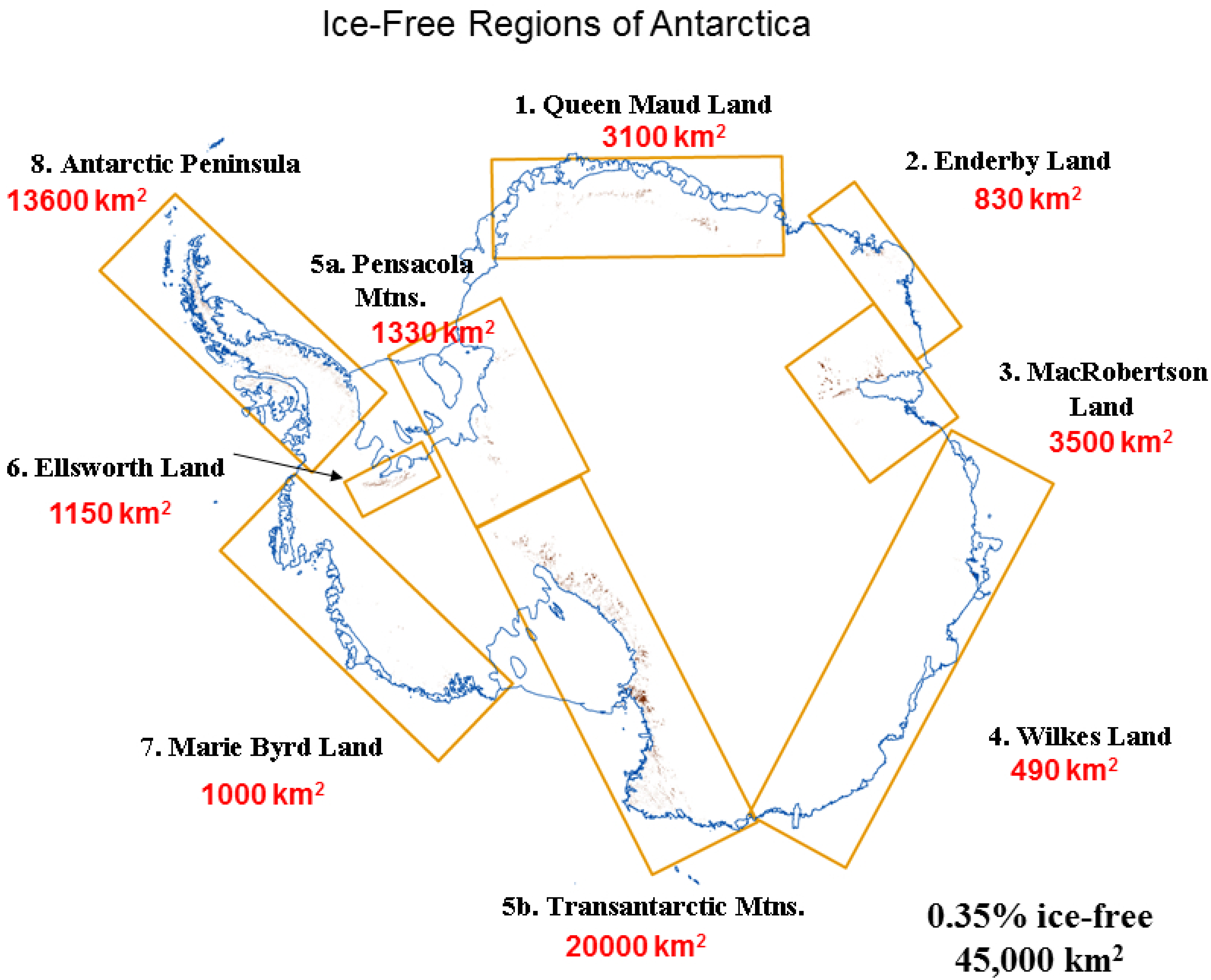
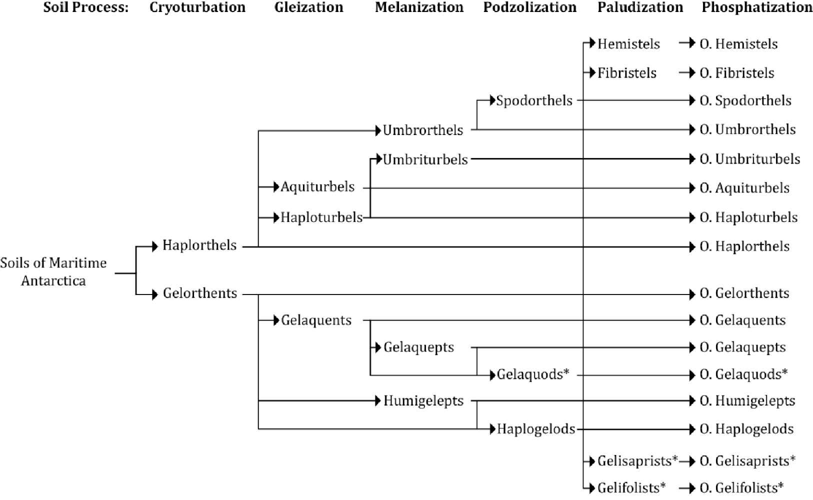
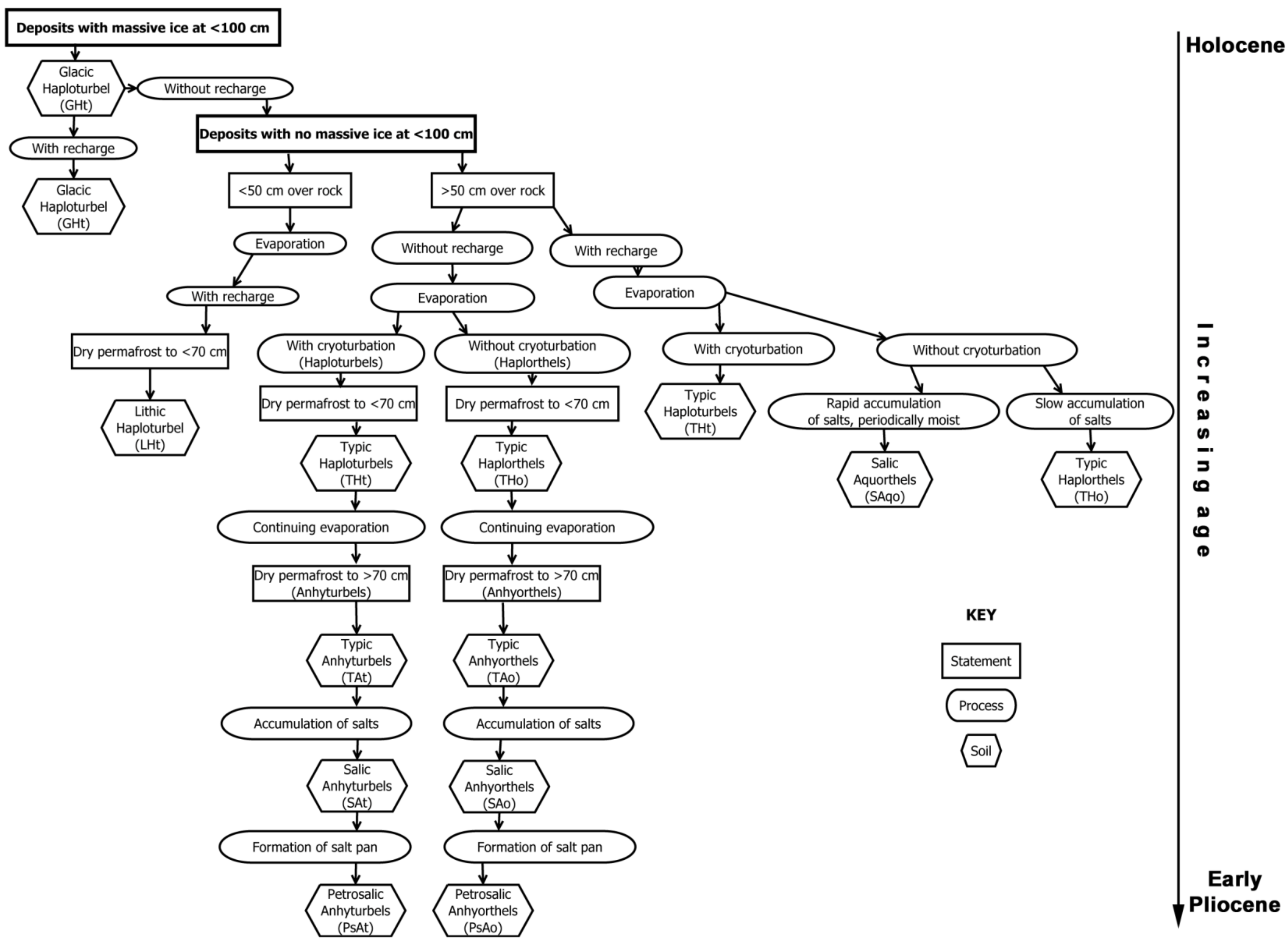


Ice-Free Regions of Antarctica
1. Queen Maud Land
3100 km²
2. Enderby Land
830 km²
3. MacRobertson Land
3500 km²
4. Wilkes Land
490 km²
5a. Pensacola Mtns.
1330 km²
5b. Transantarctic Mtns.
20000 km²
6. Ellsworth Land
1150 km²
7. Marie Byrd Land
1000 km²
8. Antarctic Peninsula
13600 km²
0.35% ice-free
45,000 km²



Soil Process:
Cryoturbation
Gleization
Melanization
Podzolization
Paludization
Phosphatization
Soils of Maritime Antarctica
Haplorthels
Gelorthents
Aquiturbels
Haploturbels
Umbrorthels
Umbriturbels
Spodorthels
Hemistels
Fibristels
Gelaquents
Gelaquepts
Gelaquods*
Humigelepts
Haplogelods
Gelisaprists*
Gelifolists*
O. Hemistels
O. Fibristels
O. Spodorthels
O. Umbrorthels
O. Umbriturbels
O. Aquiturbels
O. Haploturbels
O. Haplorthels
O. Gelorthents
O. Gelaquents
O. Gelaquepts
O. Gelaquods*
O. Humigelepts
O. Haplogelods
O. Gelisaprists*
O. Gelifolists*

outwash material
weathered rock or moraine deposit
penguin rookery
no cryoturbation
recent cryoturbation
Loamy Lithic Haploturbel
Loamy Lithic or Typic Aquaturbel
Sandy Lithic Haplorthel
Loamy Lithic or Typic Haplorthel
Loamy Lithic Haplorthel
podzolic
podzolic
rich in SOM
podzolic
Sandy Lithic Spodorthel*
Loamy Lithic Spodorthel*
Dysic Lithic Hemistel
Loamy Lithic Spodorthel*
dry
moist/wet
Dysic Typic Hemistel
Loamy Typic Spodorthel*
Dysic Lithic Hemistel
Euic Lithic Fibristel



Deposits with massive ice at <100 cm
Glacic Haploturbel (GHt)
Without recharge
With recharge
Glacic Haploturbel (GHt)
Deposits with no massive ice at <100 cm
<50 cm over rock
>50 cm over rock
Evaporation
With recharge
Dry permafrost to <70 cm
Lithic Haploturbel (LHt)
Without recharge
With recharge
Evaporation
Evaporation
With cryoturbation (Haploturbels)
Without cryoturbation (Haplorthels)
With cryoturbation
Without cryoturbation
Dry permafrost to <70 cm
Dry permafrost to <70 cm
Typic Haploturbels (THt)
Rapid accumulation of salts, periodically moist
Slow accumulation of salts
Typic Haploturbels (THt)
Typic Haplorthels (THo)
Salic Aquorthels (SAqo)
Typic Haplorthels (THo)
Continuing evaporation
Continuing evaporation
Dry permafrost to >70 cm (Anhyturbels)
Dry permafrost to >70 cm (Anhyorthels)
Typic Anhyturbels (TAt)
Typic Anhyorthels (TAo)
Accumulation of salts
Accumulation of salts
Salic Anhyturbels (SAt)
Salic Anhyorthels (SAo)
Formation of salt pan
Formation of salt pan
Petrosalic Anhyturbels (PsAt)
Petrosalic Anhyorthels (PsAo)
KEY
Statement
Process
Soil
Holocene
Increasing age
Early Pliocene

Table 1. Soil maps for Antarctica.

Region	Area	Area (km^2)	Scale	Reference
1	--			
2	--			
3	Broknes Peninsula, Larsemann Hills	1.3	1:1,000	Mergelov et al., 2014
4	Mable, Hill, Casey Stn.	0.06	1:1,250	Blume & Bölter, 2014
5a	--			
5b	Northern, Central & Southern Transantarctic Mtns. (3 sheets)	20,000	1:1 million	McLeod et al., 2007
	McMurdo Dry Valleys	6700	1:2 million	Bockheim & McLeod, 2008
	Taylor Valley	630	1:500,000	Bockheim et al., 2008
	Wright Valley	495	1:500,000	McLeod, 2013
	Darwin Glacier area	2000	1:900,000	Bockheim & McLeod, 2014
	Beardmore Glacier area	2700	1:600,000	Bockheim & McLeod, 2014
	Shackleton Glacier area	1200	1:400,000	Bockheim & McLeod, 2014
	Scott-Reedy Glacier area	3000	1:900,000	Bockheim & McLeod, 2014
	Seabee Hook, Cape Hallett, N. Victoria Land	1.1	1:12,500	Hofstee et al., 2006
6	--			
7	Russkaya Stn.	1.5	1:10,000	Lupachev et al., 2014
8	Hope Bay, Trinity Peninsula	2.4	1:18,000	Pereira et al., 2013; Haus et al., 2014
	Llano Point, Admiralty Bay, King George Island	1.2	1:3,000	Simas et al., 2014
	Lion's Rump, Admiralty Bay, King George Island	2.3	1:15,000	Simas et al., 2014

Table 17.1 Distribution (area and percentage of total area) of soil taxa[1] by region in Antarctica.

Region		Approx. area (km^2)		LHt	GHt	THt	AqHt	TAt	LAt	LAqt	LAo	TAo	THo	LHo	GHo	SAo	NAo	PnAo	TSpo	Orn	LHs	LFs	TGe	THi	LHi	TGqe
1	Queen Maud Land	**3400**	**%**	0	5	24	0	15	2	0	4	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			km^2	0	170	816	0	510	68	0	136	1530	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	Enderby Land	**1500**	**%**	25	4	30	0	0	0	3	0	3	0	30	0	0	0	0	0	3	2	0	0	0	0	0
			km^2	375	60	450	0	0	0	45	0	45	0	450	0	0	0	0	0	45	30	0	0	0	0	0
3	MacRobertson Land	**5400**	**%**	0	17	6	0	23	0	0	7	36	0	0	0	4	0	0	0	2	0	0	0	0	0	0
			km^2	0	918	324	0	1242	0	0	378	1944	0	0	0	216	0	0	0	108	0	0	0	0	0	0
4	Wilkes Land	**700**	**%**	0	0	7	0	0	0	7	0	0	0	58	0	0	0	0	14	7	7	0	0	0	0	0
			km^2	0	0	49	0	0	0	49	0	0	0	406	0	0	0	0	98	49	49	0	0	0	0	0
5a	Pensacola Mtns.	**1500**	**%**	0	7	9	0	17	0	0	4	47	0	0	3	0	3	3	0	0	0	0	0	0	0	0
			km^2	0	105	135	0	255	0	0	60	705	0	0	45	0	45	45	0	0	0	0	0	0	0	0
5b	Transantarctic Mtns.																									
	NVL	2420	**%**	0	36	0	0	36	0	0	14	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			km^2	0	871	0	0	871	0	0	339	339	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	CVL	10890	**%**	0	2	36	0	14	2	0	1	43	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			km^2	0	218	3920	0	1525	163	0	54	4683	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	SVL	10890	**%**	0	7	9	0	17	0	0	4	47	0	0	3	0	3	3	0	0	0	0	0	0	0	0
			km^2	0	762	980	0	1851	0	0	436	5118	0	0	327	0	327	327	0	0	0	0	0	0	0	0
	Subtotal	**24200**	km^2	0	1851	4901	0	4247	163	0	829	10140	0	0	327	0	327	327	0	0	0	0	0	0	0	0
6	Ellsworth Mtns.	**2100**	**%**	0	0	0	0	0	0	0	36	27	14	18	5	0	0	0	0	0	0	0	0	0	0	0
			km^2	0	0	0	0	0	0	0	756	567	294	378	105	0	0	0	0	0	0	0	0	0	0	0
7	Marie Byrd Land	**700**	**%**	0	0	0	10	0	40	0	40	0	0	0	0	0	0	0	0	0	0	10	0	0	0	0
			km^2	0	0	0	70	0	280	0	280	0	0	0	0	0	0	0	0	0	0	70	0	0	0	0
8	Antarctic Peninsula																									
	S. Orkney, S. Shetland Is.	645	**%**	4	0	4	2	0	0	0	0	0	41	0	0	0	0	0	1	8	2	2	23	6	0	2
			km^2	26	0	26	13	0	0	0	0	0	264	0	0	0	0	0	6	52	13	13	148	39	0	13
	Palmer, Graham Lands	9355	**%**	4	0	2	0	0	0	0	0	0	4	6	0	0	0	0	0	0	0	0	41	13	10	8
			km^2	374	0	187	0	0	0	0	0	0	374	561	0	0	0	0	0	0	0	0	3836	1216	936	748

	Subtotal	**10000**	km^2	400	0	213	13	0	0	0	0	0	638	561	0	0	0	0	6	52	13	13	3984	1255	936	761
	Grand total	**49500**	km^2	775	3104	6888	83	6254	511	94	2439	14931	932	1795	477	216	372	372	104	254	92	83	3984	1255	936	761
			%	2	6	14	0	13	1	0	5	30	2	4	1	0	1	1	0	1	0	0	8	3	2	2

[1] LHt = Lithic Haploturbels; GHt = Glacic Haploturbels; THt = Typic Haploturbels; AqHt = Aquic Haploturbels; TAt = Typic Anhyturbels; LAt = Lithic Anhyturbels; LAqt = Lithic Aquiturbels; LAo = Lithic Anhyorthels; TAo = Typic Anhyorthels; THo = Typic Haplorthels; LHo = Lithic Haplorthels; GHo = Glacic Haporthels; SAo = Salic Anhyorthels; NAo = Nitic Anhyorthels; PnAo = Petronitric Anyorthels; TSpo = Typic Spodorthels; Orn = Ornithogenic soils; LHs = Lithic Hemistels; LFs = Lithic Fibristels; TGe = Typic Gelorthents; THi = Typic Humigelepts; LHi = Lithic Humigelepts; TGqe = Typic Gelaquents; LCsh = Lithic Gelisaprists; Lcfoh = Lithic Gelifolists.

LCsh	LCfoh	Other	Total
0	0	5	
0	0	170	3400
0	0	0	
0	0	0	1500
0	0	5	
0	0	270	5400
0	0	0	
0	0	0	700
0	0	7	
0	0	105	1500
0	0	0	
0	0	0	2420
0	0	3	100
0	0	327	10890
0	0	7	
0	0	762	10890
0	0	1089	24200
0	0	0	
0	0	0	2100
0	0	0	
0	0	0	700
3	2	0	
19	13	0	645
5	5	2	100
468	468	187	9355

487	481	187	10000
487	481	1821	49500
1	1	4	100

Table 3. Influence of permafrost on distribution of soils in ice-free areas of Antarctica.

Group	Area (km^2)	Area (%)
With permafrost in upper 1-2 m		
Orthels	21639	43.7
Turbels	17708	35.8
Histels	175	0.4
Non-Gelisols	7903	16.0
Ornithogenic soils	254	0.5
Other	1821	3.7
Total	49500	100.0

Table 4. Pedodiversity in ice-free regions of Antarctica.

Region	Area	Ice-free area mapped (km^2)	Number of subgroups	Reference
4	Casey Stn., Windmill Is.	1.3	5	Beyer & Bölter, 2000
5b	Taylor Valley	545	7	Bockheim et al., 2008
5b	Wright Valley	495	13	McLeod et al., 2008
5b	Arena Valley	68	13	Bockheim, 2007
5b	Beacon Valley	215	3	Bockheim, 2007
5b	Seabee Hook, Hallett	1.6	3	Hofstee et al., 2006
5b	Darwin Glacier area	2,000	10	Bockheim & McLeod, 2014
5b	Beardmore Glacier area	2,700	10	Bockheim & McLeod, 2014
5b	Shackleton Glacier area	3,000	10	Bockheim & McLeod, 2014
7	Russkaya Stn., M. Byrd Land	11.5	6	Lupachev et al., 2014
8	Lion's Rump, King George Island	2.3	10	Simas et al., 2014
8	Llano Point, King George Island	1.2	15	Simas et al., 2014