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We recommend that the area be maintained as a pasture for cattle and other grazing animals. The quality of the forage could be greatly improved by the introduction of more nutritious grasses, however.

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The National Soil Survey Center Database for Permafrost-Affected Soils (Gelisols)

J. G. Bockheim, J. M. Kimble and C. L. Ping[1]

The National Soil Survey Center (NSSC) database contains 96 pedons with a pergelic soil temperature regime, half of which are classified as Pergelic, Histic Pergelic, or Pergelic Ruptic-Histic Cryaquepts. Eighty of the pedons satisfy the requirements of the recently proposed Gelisol order (permafrost within 100 cm of the soil surface, or gelic materials within 100 cm of the soil surface and permafrost within 200 cm of the soil surface), representing 12 of the 20 great groups. The morphological properties of these pedons are used to justify the approach used to classify Gelisols. For example, only seven of the Gelisol pedons have an active layer (depth of seasonal thawing) deeper than 100 cm (the average depth = 49 cm). More than two-thirds of the pedons feature cryoturbation (frost churn-

[1] Professor, Dep. of Soil Science, Univ. of Wisconsin, 1525 Observatory Dr., Madison, WI 53706-1299; Research Soil Scientist, National Soil Survey Center, 152 Federal Bldg., 100 Centennial Mall North, Lincoln, NE 68508-3866; Professor, Univ. of Alaska-Fairbanks, Palmer Research Center, 533 E. Fireweed Ave., Palmer, AK 99645.

ing), which is used to distinguish mineral soils at the suborder level. Although more than half (58%) of the pedons have an aquic soil moisture regime, the thickness of the organic layer is used as the first cut to distinguish Gelisols at the great-group level. The organic layer thickness is highly correlated (P = 0.006) with active layer thickness.

Introduction

Permafrost-affected soils comprise 18 million square kilometers or about 13% of the earth's land area, including 11 million square kilometers in Russia, 3.7 million square kilometers in Canada, and 1.3 million square kilometers in Alaska, USA (Bockheim et al., 1994). Permafrost is defined as a thermal condition in which a material remains below 0°C for two or more years in succession. Permafrost may be ice-cemented—or in the case of insufficient interstitial water—dry. In the frozen layer, a variety of ice lenses, vein ice, segregated ice crystals, and ice wedges are apparent. The permafrost table is in dynamic equilibrium with the environment.

With the exception of the Gelicryands, soils with permafrost are presently recognized in Soil Taxonomy (ST) as extragrades of soils with a cryic soil temperature regime (Soil Survey Staff, 1975, 1994). These soils may or may not have permafrost in the control section. Seven of the eleven orders in ST have cryic great groups and six of the orders have pergelic extragrades (Everett, 1992). Pergelic soils are recognized in the Histosols, Spodosols, Andisols, Mollisols, Inceptisols, and Entisols. Vertisols, Aridisols, and Alfisols that contain permafrost are not recognized in ST. In Alaska 20% of the mapped Spodosols are pergelic and 68% of the Histosols, 77% of the Inceptisols, and 95% of the Mollisols have a pergelic soil temperature regime. According to Moore et al. (1992), 65% of the pergelic soils mapped in Alaska fall into two subgroups: Histic Pergelic Cryaquepts and Pergelic Cryaquepts.

A main problem with ST is that permafrost-affected soils are differentiated primarily at the subgroup (extragrade) level, a criticism made repeated by pedologists working in the cold regions (Bockheim, 1980; Rieger, 1983; Moore and Ping, 1989; Bockheim and Burns, 1991; Everett, 1992). In ST, extragrades were intended to address local conditions. Although permafrost may be sporadic in distribution near its southern boundary, it is a regionally pervasive feature at the high latitudes. Another problem with ST in classifying permafrost-affected soils is the double or triple accounting of soil temperature, e.g., Pergelic Cryoborolls, which leaves little room for further differentiation of these soils. Most importantly, ST does not recognize cryopedogenic processes such as cryoturbation in permafrost-affected soils.

In response to deficiencies in ST with regards to permafrost-affected soils, a new order, the Gelisols, was recently proposed [Bockheim et al., 1994; International Committee on Permafrost-Affected Soils (ICOMPAS), 1996]. Gelisols are defined as soils containing permafrost within 100 cm of the soil surface, or gelic materials within 100 cm of the soil surface and permafrost within 200 cm of the soil surface. Gelic materials may be mineral or organic and are affected by cryoturbation (frost churning) and/or ice segregation. Gelic materials may occur in the active layer and/or the upper part of the permafrost. Cryopedogenic processes that lead to gelic materials are driven by the physical volume change of water to ice, moisture migration along a thermal gradient in the frozen system, or thermal contraction of the frozen material by rapid cooling. Characteristic structures associated with gelic material include platy, blocky, or granular structures in upper soil horizons and prismatic or massive structures in the subsoil. Cryopedogenic processes are also evident in soil thin-sections; orbiculic, conglomeric, banded, or vesicular microstructures are usually present.

Cryoturbation, especially that related to ice-wedge formation, is analogous to the vertic process. The difference is that turbation resulting from the vertic processes is hydrologically based, while that resulting from cryogenic processes (cryoturbation) is thermally based. Cryogenic processes produce somewhat similar landscape features and soil macro- and microstructures in areas with Gelisols to those observed in gilgai areas with Vertisols (Wilding and Tessier, 1988).

Gelisols contain three suborders: Histels (organic soils with permafrost within 100 cm of the surface), Turbels (mineral soils with gelic materials within 100 cm and permafrost within 200 cm of the soil surface), and Haplels (other soils with permafrost within 100 cm of the surface). In the Haplels, gelic materials may be represented by platy structure from ice lenses in the lower part of the active layer as well as cryoturbation and ice segregation in the upper part of the permafrost. The presence of other major features or diagnostic characteristics is used to delineate Histo-, Aqua-, Anhy-, Molli-, Umbri-, Argi-, Psammi-, and Haplo- great groups of Turbels and Haplels. Great groups within the Histels are comparable to suborders within the Histosols except that a Glacistel subgroup is added for soils that contain a layer ≥30 cm that contains ≥75% ice. Subgroups are defined using similar criteria as in ST, with some new terms.

Gelisols use the same family differentiae as the other 11 soil orders except that new soil temperature classes are used: subgelic (+1 to −3.9°C), pergelic (−4 to −9°C), and hypergelic (colder than −9°C). These soil temperature classes are intended to separate soils with "warm" permafrost that is subject to recession following a disturbance from "cold" permafrost that is more stable. The subgelic soil temperature regime will apply to alpine soils, as many of these soils have a mean annual soil temperature <0°C but do not have gelic materials and permafrost within 100 cm or 200 cm of the surface.

The pedon concept becomes extremely important in describing, sampling, and mapping Gelisols, because of the considerable spatial variability due to the presence of patterned ground. For Gelisols the pedon includes the full cycle of patterned ground within a 2-m linear interval, or a half-cycle with a 2- to 7-m linear interval. This interval is suitable for most patterned ground, such as earth hummocks and sorted and nonsorted circles, nets, steps, and polygons. In the case of large-scale patterned ground, such as large, ice-rich polygons, two pedons are identified, one in the polygon trough and rim and the other in the polygon center (Tarnocai and Smith, 1992; Bockheim et al., 1994). An analogous situation occurs with Vertisols (Wilding et al., 1991).

International Committee on Permafrost-Affected Soils (1996) has recommended several new soil horizon symbols, including restricting f for dry permafrost, and using fm for ice-cemented permafrost, Wfm for glacic material, and jj as a modifier for any horizon that is cryoturbated. Descriptions of Gelisols should include patterned ground form and size, the structure and ice content of permafrost, and a scaled drawing of cryoturbated pedons. For pedons showing intensive cryoturbation, the aerial percentage of each horizon is reported in soil

Table 1. Location of pergelic soils in the National Soil Survey Laboratory database.

Reference number	Area	Latitude	Longitude	Number of pedons†
		°N		
1	Fairbanks, AK	64–67	145–148°W	7 (2)
2	Wrangell Mtns., AK	52	145°W	1
3	Koyukuk, AK	65	151°W	2
4	Barrow, AK	71	156°W	3
5	Prudhoe Bay, AK	70–71	149–150°W	13
6	N. Foothills, Brooks Range, AK	68–69	149–150°W	17 (2)
7	S. Brooks Range, AK	67	150°W	2
8	Seward Peninsula, AK	66	164–165°W	24 (8)
9	NWT, Canada	68	133°W	2
10	Yukon, Canada	64–67	136–139°W	5
11	Magadan, Russia	60–66	149–150°E	9 (3)
12	Cherskiy, Russia	68–69	159–162°E	10
13	Alpine zone, CO			1 (1)
				96 (16)

† Number of pedons that do not meet the requirements of a Gelisol is shown in parentheses.

descriptions rather than depth intervals, and composite samples are taken of equivalent broken horizons for laboratory characterization (Kimble et al., 1993; Bockheim and Tarnocai, 1996, unpublished data).

The purposes of the study are to: (i) summarize pedon descriptions for pergelic soils archived in the National Soil Survey Center (NSSC) database, (ii) classify these pedons according to the proposed Gelisol order, and (iii) illustrate the key morphological properties of these soils as a basis for constructing the Gelisol order.

National Soil Survey Center Database for Pergelic Soils

Since 1981, 96 pedons that are classified in pergelic subgroups are included in the NSSC computerized database. The pedons were described, sampled, characterized, and classified primarily by J.M. Kimble, C.L. Ping, D. Van Patten, and their colleagues. The pedons originate mostly from Alaska, including the Seward Peninsula (24 pedons), the arctic foothills drained by the Kuparuk and Sagavanirktok Rivers (17), the Prudhoe Bay region (13), and interior Alaska (10 pedons) (Table 1, Fig. 1). Nineteen of the pedons are from the Russian Far East and seven are from the Northwest and Yukon Territories of Canada. Of the 96 pedons, 80 contain gelic materials and permafrost in either the upper 100 cm or 200 cm and, therefore, meet the requirements of Gelisols.

In addition to the NSSC database, there are published data for permafrost-affected soils in Canada (Tarnocai and Smith, 1992), Greenland (Jakobsen, 1992), Russia (see reviews in Tedrow, 1977; Rieger, 1983; Bockheim et al., 1994), and Antarctica (Campbell and Claridge, 1987; Bockheim and Wilson, 1992).

The sampling localities for the 80 Gelisol pedons in the NSSC database were originally chosen for: (i) a soil mapping project on the Seward Peninsula, (ii) research projects such as the Long-Term Ecological Research (LTER) and International Tundra Experiment (ITEX), (iii) field tours such as the 1993 Meeting on the Classification, Correlation, and Management of Permafrost-

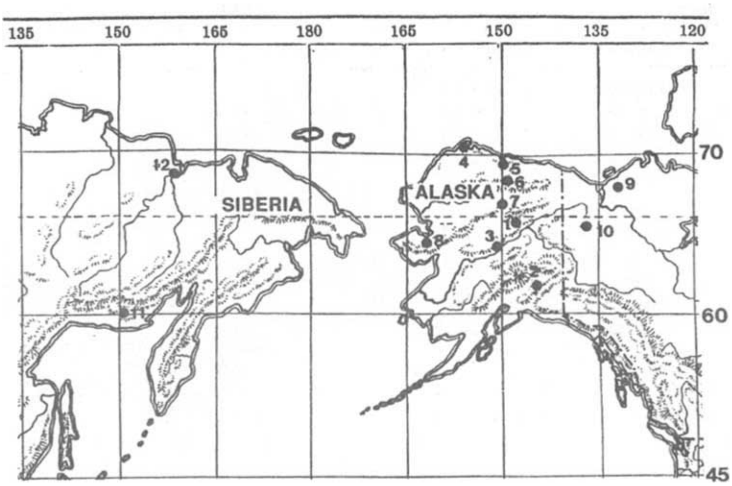

Fig. 1. Location of pergelic pedons in the National Soil Survey Laboratory database (see Table 1 for coordinates).

Affected Soils (Kimble and Ahrens, 1994), and (iv) international collaboration such as the 1994 trip to the Russian Far East (Smith et al., 1996).

The pedons were described and sampled using standard techniques (Soil Survey Division Staff, 1993). Samples were analyzed using standard techniques at the NSSC (Soil Conservation Service, 1992). The pedons were classified in the field and following laboratory characterization in ST (Soil Survey Staff, 1975, 1994) to the family level. In only a few cases did the laboratory data change the classification. The soils were also classified in the Gelisol order to the family level using keys in the International Committee on Permafrost-Affected Soils Circular Letter number 5 (ICOMPAS, 1996).

Results and Discussion

Soil Classification

The 96 pergelic pedons are classified into 6 orders, 10 suborders and great groups, and 12 subgroups (Table 2). Nearly half (49%) of the pedons are classified as Cryaquepts (Pergelic, Histic Pergelic, and Pergelic Ruptic-Histic), 16% as Pergelic Cryochrepts, and 13% as Histosols.

Sixteen of the pedons did not meet the Gelisol requirements. Although these pedons likely had a pergelic soil temperature regime, they did not contain gelic materials and permafrost in the upper 100 or 200 cm. All three suborders are represented by the remaining 80 pedons, with more than half (59%) classified as Turbels, 26% as Haplels, and 15% as Histels (Table 3). The pedons represent 12 of the 20 great groups recognized in the Gelisol order.

More than half (58%) of the pedons are in loamy or loamy-skeletal families. Many of the areas sampled contain loess or loess reworked by colluviation or collapse of thaw lakes. For this reason, 22% of the pedons have a fine- or coarse-silty particle-size class. These findings suggest that coarse-textured soil materials may not be as common as formerly thought in the arctic.

Table 2. Distribution of National Soil Survey Laboratory pergelic pedons in *Soil Taxonomy*.

Order	Suborder	Great Group	Supgroup	Number of pedons
Entisol	Orthent	Cryorthent	Pergelic	6
Inceptisol	Ochrept	Cryochrept	Pergelic	16
	Umbrept	Cryumbrept	Pergelic	6
	Aquept	Cryaquept	Pergelic	21
			Histic Pergelic	16
			Pergelic Ruptic-Histic	10
Alfisol	Boralf	Cryoboralf	Pergelic†	1
Mollisol	Boroll	Cryoboroll	Pergelic	5
Spodosol	Cryod	Haplocryod	Pergelic	2
Histosol	Fibrist	Cryofibrist	Pergelic	3
	Hemist	Cryohemist	Pergelic	2
	Saprist	Cryosaprist	Pergelic	8
				96

† Not officially recognized in Soil Taxonomy.

Morphological Properties

Arctic soils commonly have thick organic layers. The average thickness of the organic layer for mineral soils contained in the data set was 17 ± 18 cm (Fig. 2). This organic mat has a significant influence on the thermal and moisture regimes of arctic soils. For example, despite the variation in geography and soil-forming factors, there is a highly significant (R = 0.37, P = 0.006) correlation between organic layer thickness and active layer thickness for mineral soils and thin (≤60 cm) organic soils. The depth to the permafrost table ranged from 20 cm to about 160 cm and averaged 49 ± 19 cm (Fig. 3).

Table 3. Distribution of National Soil Survey Center pergelic pedons in the new Gelisol order.†

Suborder	Great Group	Subgroup	Number of pedons
Histels	Glacistels	Fibric	2
	Fibristels	Typic	1
		Terric	1
		Fluvaquentic	1
	Hemistels	Fluvaquentic	1
	Sapristels	Typic	3
		Terric	3
Turbels	Histoturbels	Typic	10
		Glacic	2
	Aquaturbels	Typic	9
		Ruptic-Histic	9
	Molliturbels	Typic	3
		Cumulic	1
	Umbriturbels	Typic	3
		Cumulic	1
	Haploturbels	Typic	8
Haplels	Histohaplels	Typic	8
		Glacic	1
	Aquahaplels	Typic	5
	Orthohaplels	Typic	5
		Glacic	1

† Sixteen of the 96 pergelic pedons failed to meet the criteria for Gelisols and are not included here, we were unable to classify two of the pedons because of lack of data.

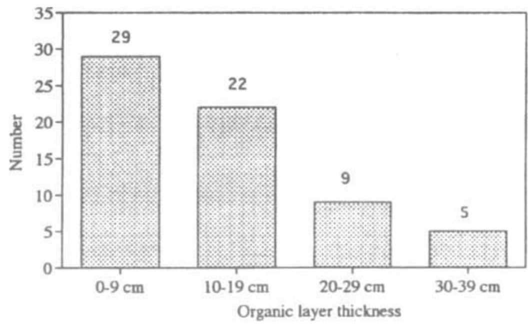

Fig. 2. Histogram of organic layer thickness for 80 Gelisols (mean = 17 ± 18 cm).

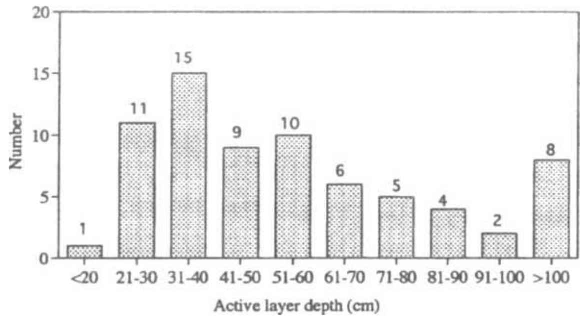

Fig. 3. Histogram of active layer thickness for 80 Gelisols (mean = 49 ± 19 cm).

Because of the thick organic layers and accumulation of moisture during melting of the active layer during the growing season, arctic soils often have an aquic soil moisture regime. More than half (58%) of the pedons analyzed in this study have an aquic soil moisture regime as manifested by standing water, gleying in the subsoil, and redoximorphic features such as mottles and concretions. More than two-thirds (68%) of the pedons (74% of the mineral soils) feature cryoturbation. The remaining pedons are either derived from organic materials (Histels) or contain gelic materials in the upper portion of the permafrost (Haplels).

For most of the orders in ST, soils with aquic soil moisture regimes key out first at the suborder level. Because Gelisols are almost universally aquic, we chose to separate suborders of mineral soils on the basis of whether or not cryoturbation was evident. The mineral soil suborders within the Gelisols (Turbels and Haplels) are delineated first into Histo- and then Aqua- great groups. This is because of the importance of the organic mat in controlling the position of the permafrost table and the magnitude of cryopedogenic processes, especially cryoturbation.

Because many of the soils are derived from calcareous loess or limestone materials, about 30% of the pedons are in the nonacidic reaction class. Mollisols are common in the Kuparuk River drainage of Alaska's North Slope (Walker and Everett, 1991; Walker et al., 1991) and may be common elsewhere in the arctic.

Proposed Future Efforts Regarding Gelisols

There are several areas of additional work that would enhance our understanding of Gelisols.

1. Incorporate published soil descriptions and laboratory data from Canada, Russia, China, Greenland, and Antarctica into the computerized Gelisol database, where the proper quality assurance/quality controls have been made, or make a comprehensive effort to characterize pedons from these areas.

2. Locate, describe and sample pedons representative of great groups for which no pedons have been described (Table 3), including Anhyturbels and Anhyhaplels in the Dry Valleys of Antarctica; and Psammiturbels and Psammihaplels in the Meade River-Atquasuk region of northeastern Alaska.

3. Prepare a circumarctic soil map at a scale of 1:10 million that has a multiple legend for Gelisols and soil map units in the Canadian and Russian soil taxonomies.

4. Work with the International Soil Science Society to classify permafrost-affected soils for the World Reference Base (WRB) for Soil Resources based on the Gelisol concept.

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Linking Ground-Penetrating Radar and Geographical Information Systems in West Florida

Andrew Williams[1]

The mission of the Natural Resources Conservation Service (NRCS) is to provide leadership and administer programs to help people conserve, improve, and sustain our natural resources and environment. As we enter the "information age," the NRCS in Florida is striving to keep up with changing technology to meet the needs of its customers. Two modern tools that are used to help provide special soil survey assistance to the citizens of Florida are ground-penetrating radar (GPR) and geographical information systems (GIS). In Santa Rosa County these two technologies have been linked to help assess sites for the suitability of using GPR.

A GIS system in the Milton, Florida, field office contains the digitized Soil Survey of Santa Rosa County. The soils in the county were rated as to their poten-

[1] Soil Scientist, USDA-NRCS, 451 West Street, Amherst MA 01002.