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CRYOSOLS (CR)

The Reference Soil Group of the Cryosols comprises mineral soils formed in a permafrost environment. In these soils, water occurs primarily in the form of ice and 'cryogenic processes' are the dominant soil-forming processes. Cryosols are widely known as 'permafrost soils'. Other common international names are Gelisols, Cryozems, Cryomorphic soils and Polar Desert soils.

Definition of Cryosols

Soils having one or more cryic horizons within 100 cm from the soil surface.

Common soil units:
Turbic, Glacic, Histic, Lithic, Leptic, Salic, Gleyic, Andic, Natric, Mollic, Gypsic, Calcic, Umbric, Thionic, Stagnic, Yermic, Aridic, Oxyaquic, Haplic.

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Summary description of Cryosols

Connotation: frost-affected soils; from Gr. kraios, cold, ice.

Parent material: a wide variety of unconsolidated materials, including glacial till and eolian, alluvial, colluvial and residual materials.

Environment: flat to mountainous areas in Antarctic, Arctic, sub-arctic and boreal regions affected by permafrost, notably in depressions. Cryosols are associated with sparsely to continuously vegetated tundra, open-canopy lichen coniferous forest and closed-canopy coniferous or mixed coniferous and deciduous forest.

Profile development: A(B)C-profiles. Cryogenic processes produce cryoturbated horizons, frost heave, thermal cracking, ice segregation and patterned ground microrelief.

Use: Cryosols in their natural state support enough vegetation for extensive grazing of animals. Some areas are used for agriculture, especially in northern Russia and Siberia. Large-scale energy development (oil, gas and hydro), mining and, to a lesser extent, forestry have a negative impact on these soils.

Regional distribution of Cryosols

Geographically, Cryosols are circumpolar in both the northern and southern hemispheres. They cover an estimated 18 million km^2 or about 13% of the global area. Cryosols occur in the permafrost regions of the Arctic, and are widespread in the sub-arctic zone, discontinuous in the boreal zone and sporadic in more temperate mountainous regions. Major areas with Cryosols are found in Russia (10 million km^2), Canada (2.5 million km^2), China (1.9 million km^2) and Alaska (1.1 million km^2) and in parts of Mongolia. Smaller occurrences have been reported from permafrost regions in northern Europe, Greenland and the ice-free areas of Antarctica (Figure 1).

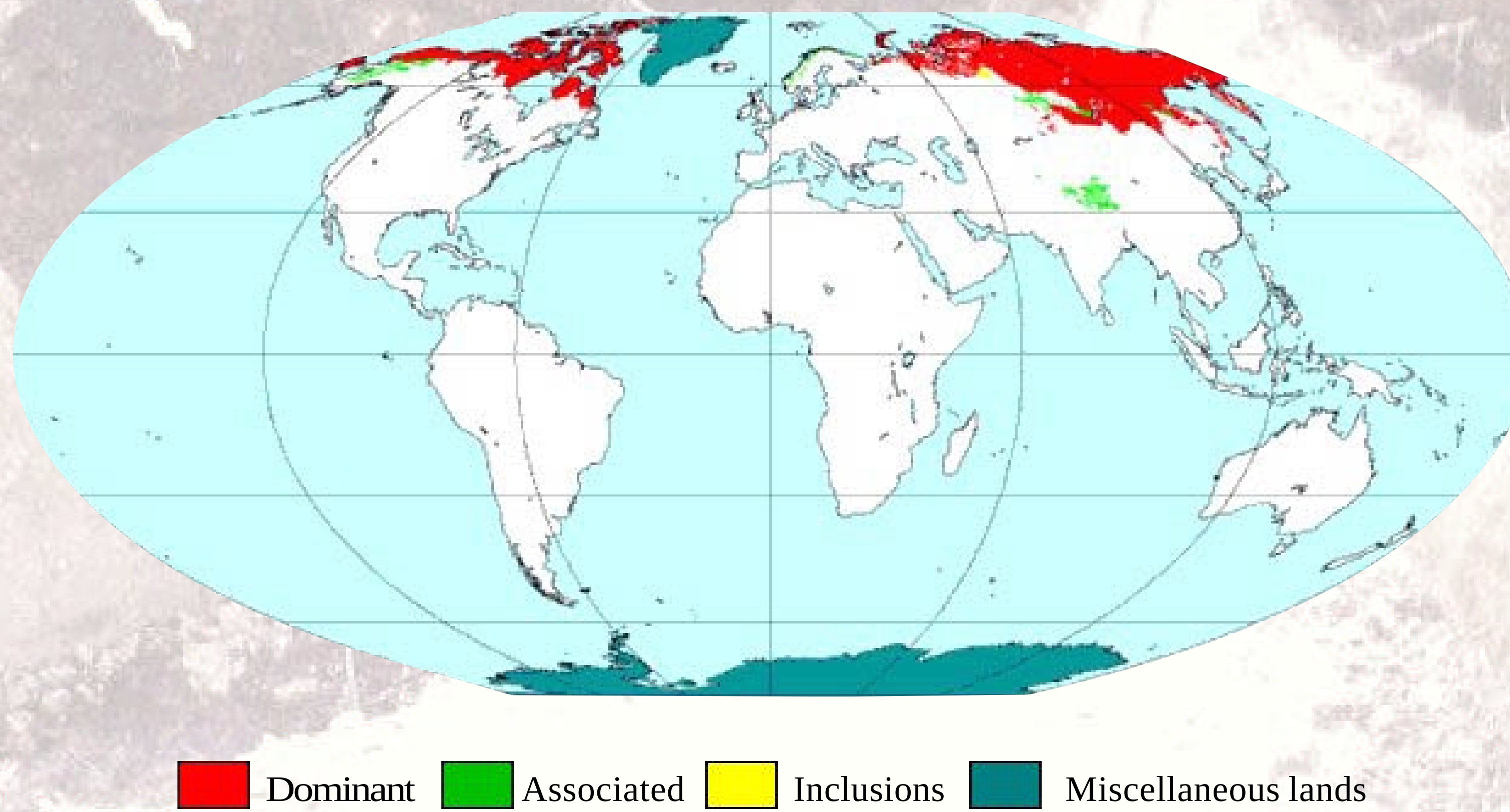

Figure 1. Cryosols Worldwide

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Associations with other Reference Soil Groups

Cryosols are often found adjacent to Histosols and Gleysols. Cryosols on coarse textured-materials and on recent alluvial or eolian deposits may occur together with Podzols, Planosols and/or Cambisols. In places, Cryosols occur on north-facing slopes in high elevation areas; south-facing slopes are normally associated with non-permafrost soils.

Genesis of Cryosols

'Cryogenic' processes are the dominant soil-forming processes for Cryosols. These processes are driven by unfrozen soil water as it migrates towards the frozen front along the thermal gradient (from warm to cold) in the system. Cryogenic processes include 'freeze-thaw' sequences, 'cryo-turbation', 'frost heave', 'cryogenic sorting', 'thermal cracking', and 'ice segregation'.

Freeze-thaw sequences
Repeated cycles of freezing and thawing of water in the soil are responsible for frost heave of coarse materials, cryoturbation (i.e. 'frost churning' of soil material), and mechanical weathering. During 'freeze-back' (the freezing portion of the cycle), freezing fronts move both from the soil surface downward and from the permafrost table upward. As this happens, moisture is removed from the unfrozen soil material between the two fronts ('frost desiccation'). Desiccation is responsible for the development of blocky structures in these soils; combination of cryoturbation and desiccation has caused the granular structure of many fine-textured Cryosols. The 'cryostatic pressure' that develops as the freezing fronts merge results in a higher bulk density of the soil.

Cryoturbation (frost churning)
Frost churning mixes the soil matrix and results in irregular or broken soil horizons, involutions, organic intrusions, organic matter occurrences in the subsoil, oriented rock fragments, silt-enriched layers, silt caps and oriented micro-fabrics. Two models have been suggested to explain the cryoturbation process.

- In the 'cryostatic model', freezing fronts moving downward from the surface and upward from the permafrost table cause pressure on the unfrozen material between the fronts.
- In the 'convective cell equilibrium model', heave-subsidence processes at the top of the active layer move material downward and outward, while those at the bottom move it upward and inward. This results in a slow upward cell-type circulation.

Frost heave

The soil volume expands upon freezing either because of the volume change that takes place when water is converted to ice or because ice build-up in the subsoil causes cracks to form in the soil.

Cryogenic sorting

Separation of coarse soil materials from fine materials takes place at both the macro- and micro-scale. At the macro-scale, cryogenic sorting produces sorted, 'patterned ground'; at the micro-scale it produces rounded and banded micro-fabrics.

Thermal cracking

Frozen materials contract under rapid cooling. The resulting cracks are typically several centimetres wide. They might become filled in with water or sand later to form ice or sand wedges. Since prior thermal cracks are zones of weakness, cracking recurs at the same place.

Ice segregation

This process of ice accumulation in cavities and hollows in the soil mass manifests itself in a variety of phenomena such as ice lenses, vein ice, ice crystals and some types of ground ice. The characteristic platy and blocky macro-structures of Cryosols result from vein ice development.

Other soil forming processes

Gleyic properties develop upon prolonged saturation of Cryosols with water (during the thaw period). (Weak) podzolization has been recorded in Haplic Cryosols in coarse-textured materials. Many Cryosols in cold desert environments are subject to salinization and/or alkalization or show signs of reddening ('*rubefaction*').

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Formation of a cryic horizon

Cryic horizons are perennially frozen soil horizons. They show evidence of cryogenic processes such as the phenomena discussed above and/or characteristic platy, blocky or vesicular macrostructures resulting from vein ice development, and banded microstructures originating from sorting of coarse matrix materials. If there is little interstitial water, thermal contraction of the frozen (dry) soil materials is weaker than that occurring in soil horizons of higher moisture content.

Formation of Cryosols

The subsoil of Cryosols remains frozen year after year (the ‘permafrost layer’) but the upper portion (the ‘active layer’) thaws in the summer. The maximum thaw depth of the seasonally frozen layer represents the depth of the active layer. Near-surface permafrost is highly dynamic; the active layer increases and decreases in depth in response to environmental and climatic changes. This explains why pedological features that developed when the permafrost table was deeper are sometimes found in the near-surface permafrost.

The active layer in Cryosols normally extends down to 40 to 80 cm below the soil surface; the actual depth depends on the physical environment of the soil and on soil texture, soil moisture regime and thickness of an organic surface layer. Cryosols in the more temperate part of the permafrost zone or at lower elevations tend to have deeper active layers than Cryosols in the High Arctic or at higher elevations. Coarse-textured soils tend to have deeper active layers than adjacent fine-textured soils. Soils with a thick (insulating) organic surface layer have a shallow active layer.

When the temperature drops, freeze-back occurs from the frost table upwards and from the soil surface downwards. The soil material between these freezing fronts comes under ‘cryostatic pressure’ and, as a result, unfrozen materials are displaced and soil horizons are contorted and broken. This causes characteristic ‘cryogenic structures’ and ‘cryoturbated’ soil horizons. Freeze-back also causes coarse fragments to be heaved and sorted, resulting in oriented features in the soil and a micro-topography of ‘patterned’, sorted and non-sorted, areas at the surface. Patterned ground is especially prominent in Arctic areas, with the most common patterned ground types being circles (including earth hummocks), nets, polygons, stripes and steps.

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Very low (winter) temperatures make the frozen soil mass shrink and crack, usually in a polygonal pattern. Ice builds up in these cracks, and ultimately forms ice wedges. In addition, water moving along the thermal gradient (warm to cold) in the frozen soil builds up to segregated ice (ice lenses, vein ice and pure ice layers) in the soil mass.

Weak leaching and translocation of materials occur in permafrost soils. Leached horizons are common; brownish B-horizons occur as well, in particular in the southern part of the permafrost region. The evidence for translocation of soil material is often partially or completely destroyed by cryoturbation, which mixes the soil materials in the active layer.

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Characteristics of Cryosols

Morphological characteristics

Most Cryosols show evidence of cryoturbation. Cryoturbated soil profiles have irregular or broken soil horizons and many have organic matter incorporated into the lower soil horizons, often concentrated along the top of the permafrost table. Cryoturbation is also accountable for oriented stones in the soil and sorted and non-sorted patterned ground features on the surface.

Freeze-thaw sequences and ice segregation are primarily responsible for the characteristic granular, platy, blocky and vesicular (i.e. 'net-shaped') structures of the mineral surface horizon(s). *Thixotropy*[1] is common in soils with high silt content. When thixotropic soils dry out, a characteristic vesicular structure develops. The subsurface horizons tend to be massive and densely packed as a consequence of the cryostatic pressure and desiccation that develop during freeze-back, especially in fine-textured soils.

Almost all Cryosols contain accumulations of ice such as ice crystals, ice lenses, ice layers (vein ice), ice wedges or massive ground ice, often to a thickness of several metres. Soil texture is one of the factors controlling ice content in mineral soils. Fine-textured Cryosols generally contain more ice than coarse-textured soils. Although coarse-textured soils have a relatively low ice-content, they are often associated with ice wedges in the form of polygons.

The 'active layer' in Cryosols supports biological activity and protects the underlying permafrost. Soil texture, moisture regime, thickness of an organic surface layer, vegetation cover, aspect and latitude are among the factors that control the thickness of the active layer.

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1. It is possible that the more accurate term for this process is dilatancy, but thixotropy is the more commonly used term. Dilatancy is defined as: "The increase in volume of a fixed amount of certain materials, as of wet sand, subjected to a deformation that alters the interparticle distances of its constituents from their minimum-value configuration". Alternatively: "Any of various related phenomena, such as increase in viscosity or solidification, resulting from such deformation.
Thixotropy, on the other hand, is defined as "The property exhibited by certain gels of liquefying when stirred or shaken and returning to the hardened state upon standing."

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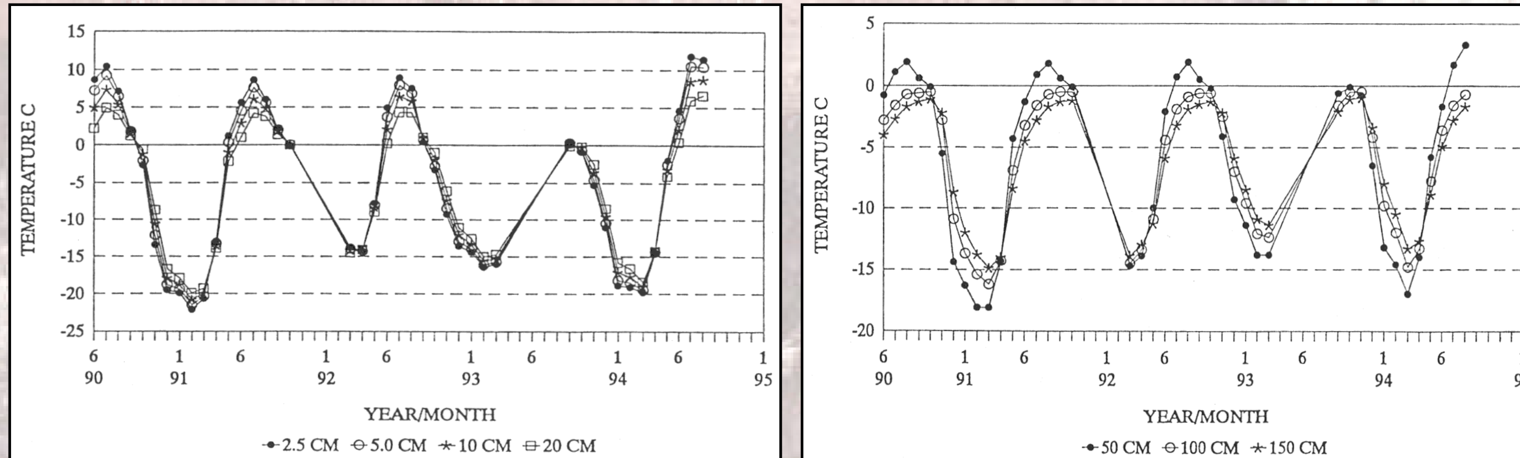
Salt crusts are common on soil surfaces on the High Arctic Islands of Canada and in Antarctica. These salt crusts develop during dry periods in the summer because of increased evaporation from the soil surface. Massive salt layers, up to 50 cm thick, have been reported from Antarctica.



(click to enlarge) (click to enlarge)

Figure 2. Mean monthly soil temperatures at the 2.5, 5, 10, 20, 50, 100 and 150 cm depths between 1990 and 1995. The site is located in the Northwest Territories, Canada, at Lat. 68° 58' 09" N, Long. 133° 32' 54" W. (Tarnocai, 1995)

Thermal characteristics

Figure 2 presents soil temperatures in a Cryosol north of the arctic tree line in Canada. The unique thermal characteristic that separates Cryosols from all other soils is the presence of a perennially frozen layer, usually deeper than 50 cm. Because of this frozen layer, Cryosols have a steep vertical temperature gradient. If these soils are associated with certain types of patterned ground, the horizontal temperature gradient can also be considerable. For example, Cryosols associated with earth hummocks, may have a summer soil temperature at the centre of the hummock that decreases from 12°C at the surface to 0°C at 50 cm depth. Soil temperatures at comparable depths but measured under the depression between adjacent hummocks, can be 5° to 7°C lower.

Physical characteristics

The physical properties of Cryosol surface soils vary strongly with the season. Thixotropic silt soils are poorly trafficable during the thaw season. The subsoil is always solid with various amounts of ice in the form of segregated ice crystals, ice lenses, ice layers and ice wedges.

Chemical characteristics

The pH of Cryosols varies greatly and depends in part on the composition of the parent material; Cryosols developed in calcareous parent material have a higher soil-pH than soils in non-calcareous material. The similarity of the soil-pH to that of the parent material is also caused, in part, by cryoturbation, which mixes soil materials not only between horizons but also with the parent material.

The nitrogen, potassium and phosphorous contents of Cryosols are generally low. Most plant nutrients are locked into compounds that form the surface organic matter. Salt accumulation is not uncommon in Cryosols in the dry, cold areas of the Antarctic. Many Cryosols, especially Turbic Cryosols, contain large amounts of organic carbon. Kimble et al. (1993) found organic carbon contents of 27.2 to 72.6 kg/m^3 in Turbic Cryosols whereas the carbon contents of non-cryoturbated Cryosols were 3.9 tot 5.4 kg/m^3.

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Management and use of Cryosols

Human activities

Natural and man-induced biological activity in Cryosols is confined to the active surface layer that also protects the underlying permafrost. Removal of the peat layer on top of the soil or of the vegetation and/or disturbance of the surface soil often lead to rapid and drastic environmental change, with possible damage to man-made structures.

Most areas of Cryosols in North America and Eurasia are in the natural state and support sufficient vegetation for grazing animals such as caribou, reindeer and musk oxen. Large herds of caribou still migrate seasonally in the northern part of North America; reindeer herding is an important industry in the vast northern areas, especially in northern Europe. Overgrazing leads rapidly to erosion and other environmental damage.

Human activities, mainly relating to agriculture, oil and gas production and mining, have had a major impact on these soils. Severe ‘thermokarsting’ has occurred on land cleared for agriculture. Improper management of pipelines and mining can cause oil spills and chemical pollution that affect large areas.

Global warming and Cryosols

It has been predicted that climate warming will cause a significant temperature increase in northern areas. Cryosols contain large amounts of organic carbon and act as carbon sinks under the present climate. If the CO_2 content of the atmosphere would double, warming of the circumpolar regions would alter the thermal regime of the soils and increase the depth of the active layer. This would strongly enhance the decomposition of soil organic matter; previously ‘fixed’ carbon would be released to the atmosphere as carbon dioxide and methane and accelerate global warming even more.