CIRCUM-PACIFIC MAP SERIES
MAP CP-45

U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY
Gordon P. Eaton, Director

INTERNATIONAL PERMAFROST ASSOCIATION

CIRCUM-ARCTIC MAP OF PERMAFROST AND GROUND ICE CONDITIONS

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Lambert Azimuthal Equal-Area Projection
Map Center Point: North Pole
SCALE 1:10 000 000

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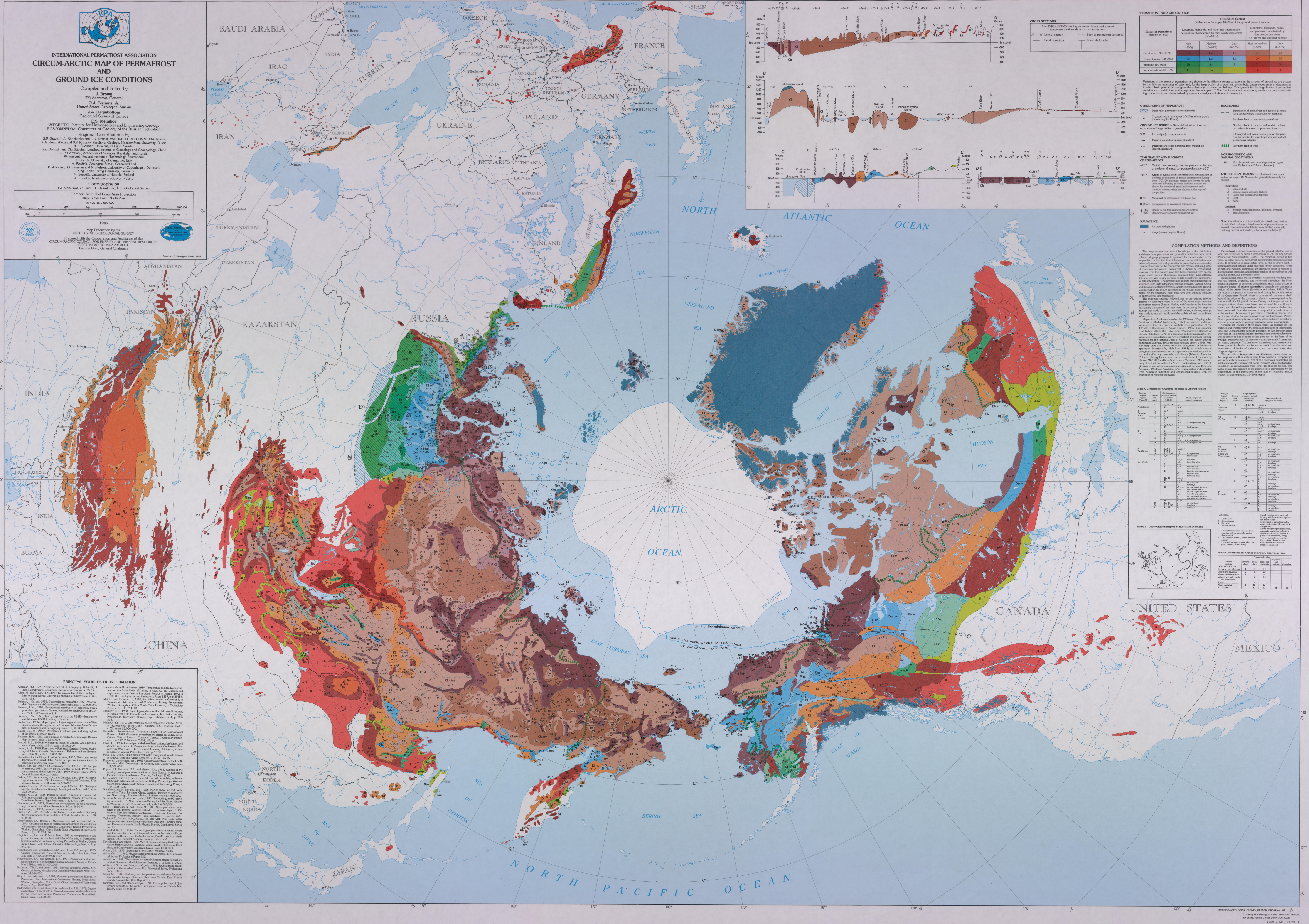

CROSS SECTIONS

See EXPLANATION for key to colors, labels and ground-temperature values shown on cross sections

A├─┤A′ Line of section
- - - - Base of permafrost (assumed)
Bend in section
Borehole location

PERMAFROST AND GROUND ICE

Extent of Permafrost (percent of area)	Ground-Ice Content (visible ice in the upper 10–20m of the ground; percent volume)				
	Lowlands, highlands, and intra- and intermontane depressions characterized by thick overburden cover (>5–10 m)			Mountains, highlands, ridges, and plateaus characterized by thin overburden cover (<5–10 m) and exposed bedrock	
	High (>20%)	Medium (10–20%)	Low (0–10%)	High to medium (>10%)	Low (0–10%)
Continuous (90-100%)	Ch	Cm	Cl	Ch	Cl
Discontinuous (50-90%)	Dh	Dm	Dl	Dh	Dl
Sporadic (10-50%)	Sh	Sm	Sl	Sh	Sl
Isolated patches (0–10%)	Ih	Im	Il	Ih	Il

Variations in the extent of permafrost are shown by the different colors; variations in the amount of ground ice are shown by the different intensities of color and, for the large bodies of ground ice, by symbols. Letter codes assist in determining to which basic permafrost and ground-ice class any particular unit belongs. The symbols for the large bodies of ground ice contribute to the definition of the map units. For example, "Ch∇▬" indicates a unit underlain by continuous permafrost with high ice content, and characterized by sparse ice wedges and abundant massive ice.

OTHER FORMS OF PERMAFROST

- ▨ Deep relict permafrost (where known)
- χ Cryopegs within the upper 10–20 m of the ground; (shown only for Russia)

GROUND-ICE BODIES — General distribution of known occurrences of large bodies of ground ice

- ∇ ▼ Ice wedges (sparse, abundant)
- ▭ ▬ Massive ice bodies (sparse, abundant)
- ○ ● Pingo ice and other perennial frost mound ice (sparse, abundant)

TEMPERATURE AND THICKNESS OF PERMAFROST

−15.7	Typical mean annual ground temperature at the base of the layer of annual temperature fluctuations (°C)
−3/−7	Range of typical mean annual ground temperature at the base of the layer of annual temperature fluctuations (°C). On the map, ranges are shown for both units and subunits; on cross sections, ranges are shown for combined areas and represent end-member values; values are shown at the tops of the profiles
■ 16	Measured or interpolated thickness (m)
■ (197)	Extrapolated or calculated thickness (m)
♦ $\frac{150}{400}$	Depth to the top (numerator) and bottom (denominator) of relict permafrost (m)

SURFACE ICE

- ▇ Ice caps and glaciers
- ~ Icings (shown only for Russia)

BOUNDARIES

- ── Boundaries of permafrost and ground-ice units; long dashed where gradational or estimated
- ⊥ ⊥ ⊥ Southern limit of deep relict permafrost
- — — Northern limit of the area within which subsea permafrost is known or presumed to occur
- - - - - Lithological and mean annual ground temperature boundaries for morphogenetic and natural geosystems subunits
- ♣♣♣♣ Northern limit of trees

MORPHOGENETIC AND NATURAL GEOSYSTEMS

19 Morphogenetic and natural geosystem types (see Tables A and B for explanation)

LITHOLOGICAL CLASSES — Dominant rock types within the upper 10-20 m of the ground (shown only for Russia)

Unlithified:
- *c* Clay and silt
- *d* Coarse clastic deposits (debris)
- *l* Loess and eolian-sand deposits
- *p* Peat
- *s* Sand

Lithified:
- *k* Soluble rocks (limestone, dolomite, gypsum)
- *r* Insoluble rocks

Note: Combinations of letters indicate mixed composition of unlithified rocks (*pc*), listed in order of predominance, or layered composition of unlithified over lithified rocks (*c/k*). Saline ground is indicated by a bar above the letter ($\bar{s}$).

COMPILATION METHODS AND DEFINITIONS

This map summarizes current knowledge of the distribution and character of permafrost and ground ice in the Northern Hemisphere, using a physiographic approach for the delineation of the map units. For the first time, information on the distribution and extent of permafrost and ground ice is presented in a reasonably consistent manner for the continental land masses, including areas of mountain and plateau permafrost. It should be emphasized, however, that the present map has been compiled from source maps, which were in themselves compiled from quite different data sources, with varying densities of data and different approaches to data integration. The present map reflects these differences in approach. Map units in the major regions of Alaska, Canada, China, and Russia are defined differently, and the permafrost and ground-ice information are shown according to the relevant national source maps. Where necessary, map units have been adjusted adjacent to international land boundaries.

The mapping strategy followed was to use existing physiographic or landscape maps in each of the three major national permafrost regions (Russia, Alaska, and Canada) as the basis for delineating the permafrost map units. In preparing this map no attempt was made to conduct new field studies, and every attempt was made to use all readily available published and unpublished information.

Map units in Alaska are based on the 1965 map "Physiographic Divisions of Alaska" (Wahrhaftig, 1965) and contain additional information that has become available since publication of the 1:2,500,000-scale map of Alaska (Ferrians, 1965). The Canadian contribution utilizes the 1967 map "Physiographic Regions of Canada" (Bostock, 1970) as a base map and contains much of the information presented on the new permafrost and ground ice map prepared for the National Atlas of Canada, 5th edition (Heginbottom and Dubreuil, 1993; Heginbottom and others, 1995). Russian map units are derived from the geosystems or landscape approach described by Melnikov (1988), in which natural geosystems are delineated according to common relief, vegetation, soil and soilforming materials, and climate (Table A). Units for China and Mongolia are based on recompilations of the maps by Shi and Mi (1988) and from Sodnom and Yanshin (1990), respectively. Existing information for Nordic countries (Åkerman, 1993), Greenland, and other mountainous regions of Europe (King and Åkerman, 1993) and Asia (Qiu, 1993) was modified and compiled from numerous published and unpublished sources, with the assistance of regional specialists.

Permafrost is defined as a state of the ground, whether soil or rock, that remains at or below a temperature of 0°C for long periods (Permafrost Subcommittee, 1988). The minimum period is two years. In colder regions, permafrost occurs under essentially all land areas. It diminishes in areal extent until, at the southern limit, it occurs as isolated patches under favorable terrain conditions. Areas of high and medium ground ice are known to occur in regions of discontinuous, sporadic, and isolated patches of permafrost as well as in the continuous permafrost zone.

Beneath land areas, most permafrost has existed for a long time, and has formed, degraded, and re-formed throughout the Pleistocene. In addition to occurring beneath land areas, it also occurs as extensive bodies of **subsea permafrost** beneath the continental shelves of the Arctic Ocean (Zarkhidze and others, 1991). These are relics of the periods of lower sea level during the glacial maxima of the Quaternary Period, when large areas of continental shelf, beyond the edges of the continental glaciers, were exposed to the intense cold of a full glacial climate. During the interglacials and in postglacial time, these areas have been covered by a cold arctic ocean, and the **relict permafrost** of the continental shelves has been preserved. Extensive masses of deep relict permafrost occur at the southern boundary of permafrost in Western Siberia. This too formed during the glacial maxima of the Quaternary Period. Where ground freezing is prevented by saline sediment conditions, areas of ground with unfrozen groundwater occur as **cryopegs**.

Ground ice occurs in three main forms: as coatings on soil particles and crystals within the pores and fractures of sedimentary rocks and unconsolidated deposits (**pore ice**); as thin, lamellar lenses and veins of ice (**segregated ice, intrusive ice** and **reticulate ice**); and as larger bodies of more-or-less pure ice, in the form of **ice wedges**, extensive sheets of **massive ice**, and perennial frost mound ice, mainly **pingo ice**. The quantity of ice in the ground varies widely. Some ground ice bodies are known to result from the burial and preservation of bodies of surface ice, such as snow banks, river icings, and glacier ice.

The permafrost **temperature** and **thickness** values shown on the map were either determined from borehole temperature measurements or calculated. Not all the boreholes penetrated the full thickness of the permafrost; some thickness values are based on calculation or extrapolation from other geophysical profiles. The mean annual temperature of the permafrost is represented by the temperature of the permafrost at the level of negligible annual change, at approximately 15–20 m depth.

Table A. Complexes of Cryogenic Processes in Different Regions

Geocryological regions (Figure 1)	Permafrost zones*	Morphogenetic groups of natural geosystems (Table B)	Basic complex of cryogenic processes*	
I Arctic Islands	C	*2, 12, 13*	*t, c*	
		17	*n, s, r*	
II European North of Russia	C	*1, 7*	*t, c, h*	
	D	*4*	*h, c, t*	
		7	*h*	
	S	*1, 3*	*h*	
		4	*h, t*	
		17	*n, h*	*h* in depressions only
	I	*1, 3, 4, 7*	*h*	
		17	*h*	in depressions
III Ural	C	*1*	*t, c, h*	
		14	*s, h*	
		19	*n, s, r, i, h*	*h* in depressions
	D	*17*	*i, s*	
		19	*n, s, r, i, h*	*h* in depressions
	S	*19*	*s, r, i, h*	*h* in depressions
	I	*7*	*h*	
IV West Siberia	C	*1, 2, 4*	*t, c, h, s*	
	D	*1, 2, 4*	*t,h*	
	S	*1, 2, 3, 4*	*t, h*	*h* in peatlands
	I	*2, 4*	*h*	in peatlands
V East Siberia	C	*2*	*t, c, h* *t, h, i*	in tundra in middle taiga
		3	*c, h*	
		7	*c, h, i* *h, i*	in north taiga in middle taiga
		11	*t* *d, c, h* *h*	in north taiga depressions in north taiga in middle taiga
		12, 14	*c, h, s*	
		13	*t, c, h, s*	
		17	*r, s, d* *h, i*	on interfluves in valleys
		18	*d, s, r, n* *c, h* *d, r* *c, h, i* *r* *h, i*	on mtn taiga interfluves in mtn taiga valleys on mtn taiga interfluves in north taiga valleys on mtn taiga interfluves in middle taiga valleys
		19	*n, r, s*	
	D	*11, 18*	*r*	on interfluves
	S	*7, 11, 18*	*h, i*	in valleys
	I	*11, 18*	*h, i*	in valleys

Geocryological regions (Figure 1)	Permafrost zones*	Morphogenetic groups of natural geosystems (Table B)	Basic complex of cryogenic processes*	
VI Northeast Siberia	C	*13, 15, 16*	*t, c, h, d*	
		17	*d, s*	
		19	*n, s, r* *i, c, h*	on interfluves in valleys
VII Far East	C	*13, 16*	*t, c, h*	
		14	*c, h, s*	
		17	*s, d*	
		19	*n, s, r* *i, c, h*	on interfluves in valleys
	D	*13, 16*	*h, c*	
		19	*s, n, r* *h, c, i*	on interfluves in valleys
	S	*19*	*r, n* *i, h*	on interfluves in valleys
	I	*13*	*h*	
		17, 19	*h*	in valleys
VIII Mountains of South Siberia and Transbaikalia	C	*13, 16*	*h, c*	
		17	*r* *h, i*	on interfluves in valleys
		19	*r, s, n* *i, h*	on interfluves in valleys
	D	*16*	*h, c, i*	
		17	*r* *i, h*	on interfluves in valleys
		19	*r, s, n* *i, h*	on interfluves in valleys
	S	*16*	*h*	
		17	*r* *h*	on interfluves in valleys
		19	*r, s, n* *h*	on interfluves in valleys
	I	*12, 13, 16* *17* *19*	*h* *h* *r* *h*	 in valleys on interfluves in valleys
IX Mongolia	C	*13*	*h, t*	
		19	*r, s, n* *h, i*	on interfluves in valleys
	D	*19*	*s* *h, i*	on interfluves in valleys
	S, I	*13, 16*	*h, i*	
		17	*h, i*	in valleys
		19	*n* *h, i*	on interfluves in valleys

* Definitions:

- C Continuous
- D Discontinuous
- S Sporadic
- I Isolated patches

- *c* Cracked-thermokarst complex (frost cracking with ice wedge formation, thermokarst)
- *d* Dale complex (furrow, ravine, thermal erosion)
- *h* Heaving-thermokarst (perennial cryogenic heaving, thermokarst)
- *i* Icing formation (icing, seasonal heaving with formation of injection ice, thermokarst)
- *n* Nival-glacial complex (destructive-accumulative action of snow bodies and glaciers)
- *r* Kurum (rock) complex (deserption, cryogenic weathering, suffosion)
- *s* Solifluctional complex (solifluction, gelifluction, deserption, creep)
- *t* Thermo-destructional complex (thermokarst, thermoerosion, thermosolifluction, thermoabrasion, landslides)

Figure 1. Geocryological Regions of Russia and Mongolia.

Table B. Morphogenetic Groups and Natural Geosystem Types

Genetic category	Physiographic class				
	Lowland plains	High plains	Basins and piedmonts	Highlands and plateaus	Mountains
ACCUMULATIONAL					
Marine and glacial marine	*1*	*5*	*12*		
Alluvial and lacustrine	*2*	*6*	*13*		
Glacial and fluvio-glacial	*3*	*7*	*14*		
Alluvial, proluvial, deluvial, and solifluctional		*8*	*15*		
Eolian		*9*			
Undifferentiated	*4*	*10*	*16*		
EROSIONAL		*11*	*17*	*18*	*19*

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