PERMAFROST

COMPRISES: PERENIALLY FROZEN GROUND

THERE MAY OR MAY NOT BE ICE IN THE GROUND.

IN ADDITION, THERE IS EXTENSIVE SEASONALLY-FROZEN GROUND.

ORGANIZATION: THE INTERNATIONAL PERMAFROST ASSOCIATION (IPA) – ESTABLISHED 1983, BUT FIRST INTERNATIONAL CONFERENCE 1963.

SEE:
http://www.geodata.soton.ac.uk:80/ipa/structure.html

WORKING GROUPS ON MountainPermafrost, Global Change etc and STANDING COMMITTEE ON Data Informationa and Communication.

MAJOR INITIATIVES:

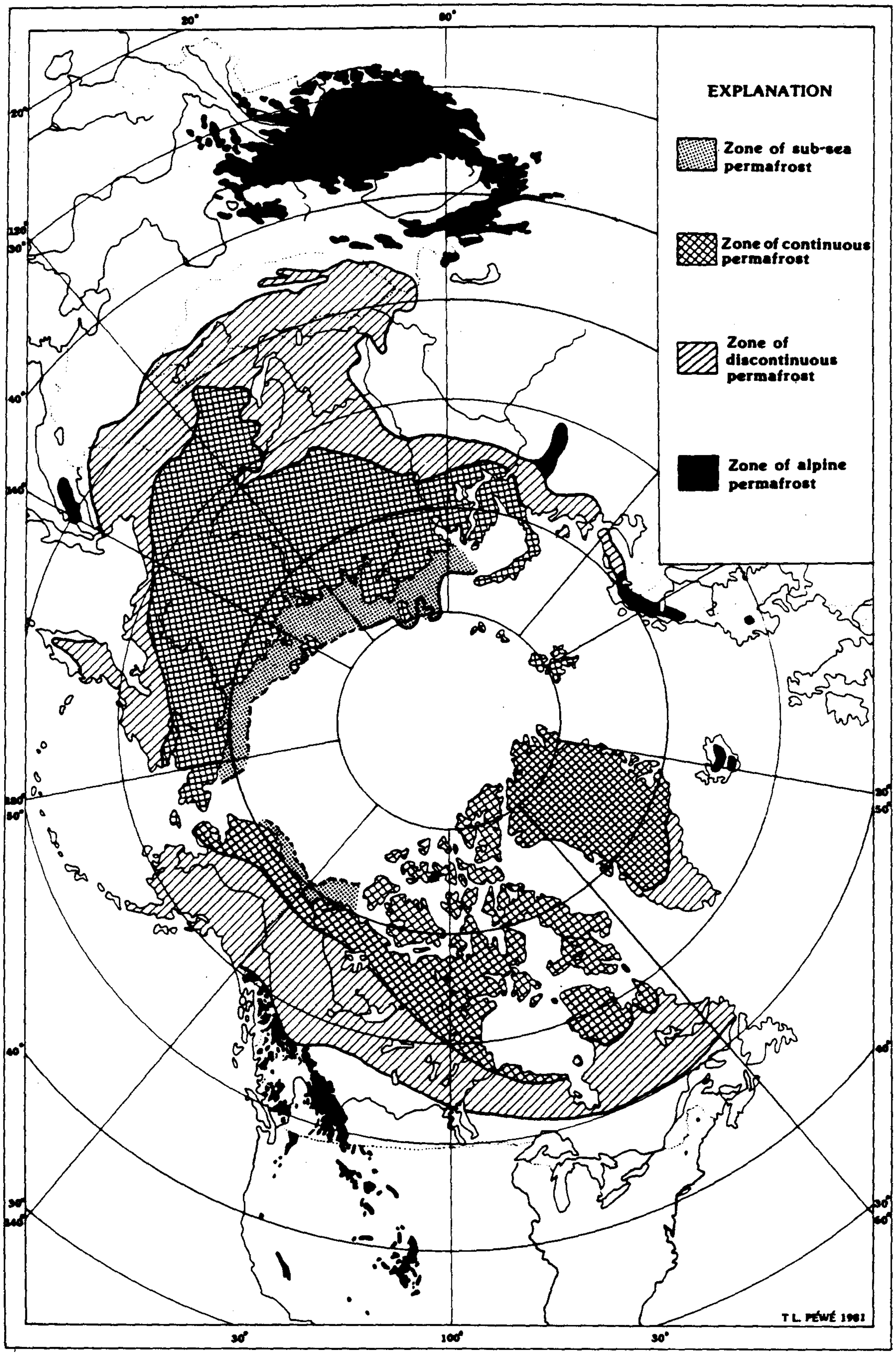
CIRCUMARCTIC MAP OF PERMAFROST (1998)

GLOBAL GEOCRYOLOGICAL DATABASE GGD)

Includes data on: Ground and soil temperature data sets
Borehole temperature data
Metadata on data sets and Russian maps.

contents on Circumpolar Active-Layer Permafrost System (CAPS)CD.

6.10


EXPLANATION
Zone of sub-sea permafrost
Zone of continuous permafrost
Zone of discontinuous permafrost
Zone of alpine permafrost
T L PÉWÉ 1981

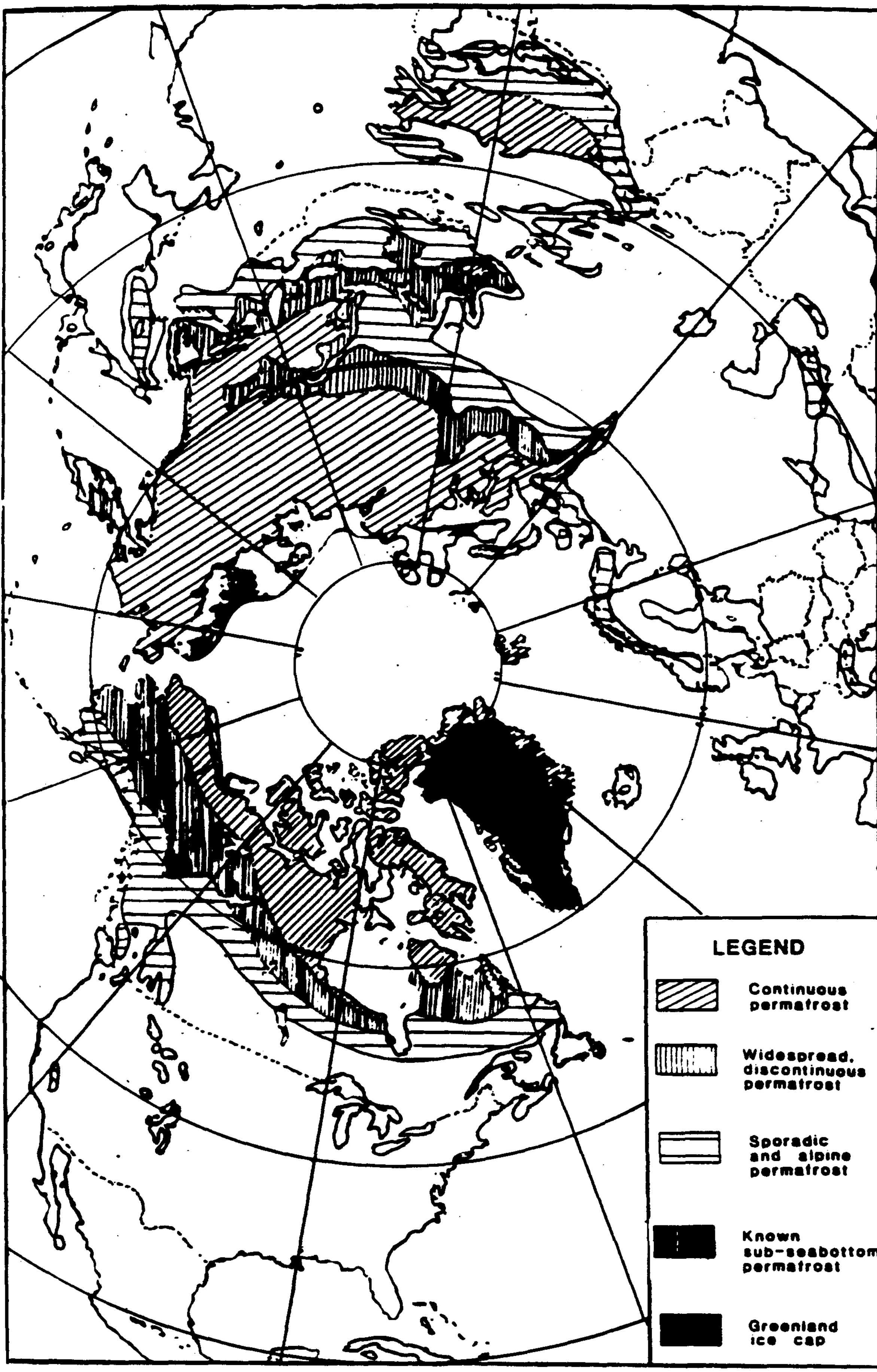
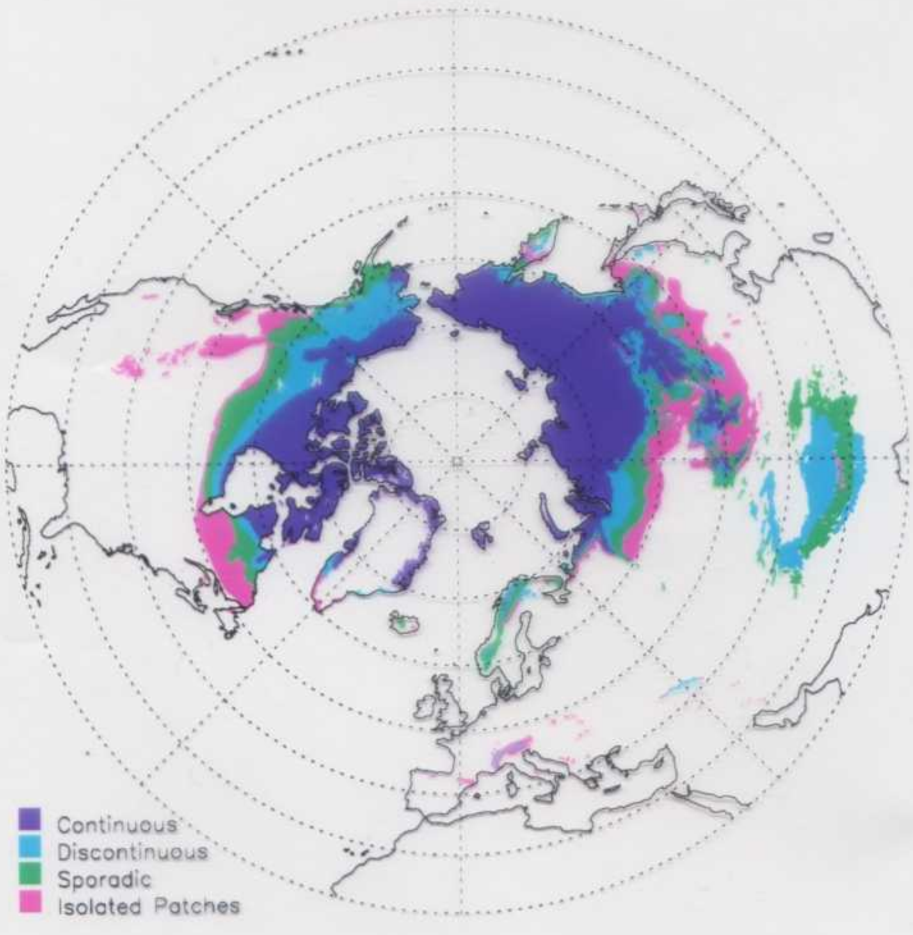


Fig. Generalized distribution of permafrost in the Northern Hemisphere (modified from Heginbottom, 1984)


Continuous
Discontinuous
Sporadic
Isolated Patches

Legend for IPA Permafrost and Ground Ice Map

Permafrost Extent (percent of area)	**Ground Ice Content** (visible ice in the upper 10-20 m of the ground; percent by volume				
	Lowlands, highlands, and intra-and intermontane depressions characterized by thick overburden cover (>5-10m)			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. Letter codes assist in determining to which basic permafrost and ground ice class any particular unit belongs.*

- Deep relict permafrost (where known)*
- Ice caps and glaciers
- Boundaries of permafrost and ground-ice units
- Northern limit of trees*
- ⊥⊥⊥ Southern limit of deep relict permafrost*
- Northern limit of the area within which subsea permafrost is known or presumed to occur*
- Limit of minimum sea ice edge*

*Not shown on this draft

Permafrost Characteristics in the N. Hemisphere
(from Zhang et al., 1999)

CATEGORY	EXTENT (10^6 KM^2)	% OF TOTAL	GROUND ICE VOL. (10^3 KM^3)
CONTINUOUS	10.69	46.9	4.85-9.93
DISCONTIN.	4.38	19.2	0.7-3.5
SPORADIC	3.90	17.1	0.1-1.5
ISOLATED	3.82	16.8	0-0.3
TOTAL	22.79	100	5.6-15.1
% of NH LAND	23.9%		

ACTUAL AREAS UNDERLAIN BY PERMAFROST (ZHANG et al. 2000)

			ΔMSL
CONTINUOUS	10.69 -9.62	24.06 -9.28	
DISCONTINUOUS	3.95 - 2.20	7.63 -1.40	
SPORADIC	1.96 -0.39	3.35 - 0.10	
ISOLATED	0.38	0.62 - 0	
TOTAL	16.98 -12.21	35.46 -10.8	3-9 cm EQUIVALENT
% of NH LAND ACTUALLY UNDERLAIN	17.8 -12.8%		

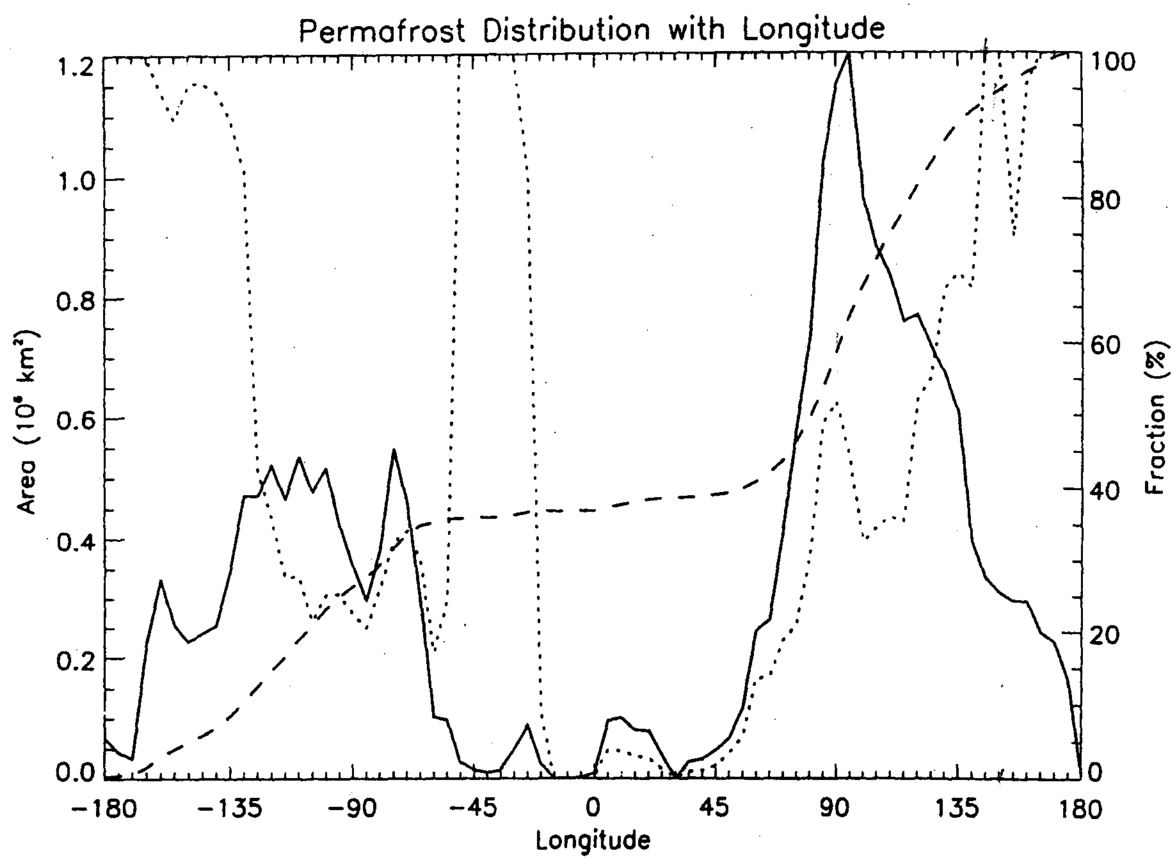


Fig. 6. Variations of permafrost area (solid line) and its fraction (short-dashed line) for the exposed land surface with respect to longitude. Negative values refer to the Western Hemisphere, positive values to the Eastern Hemisphere.

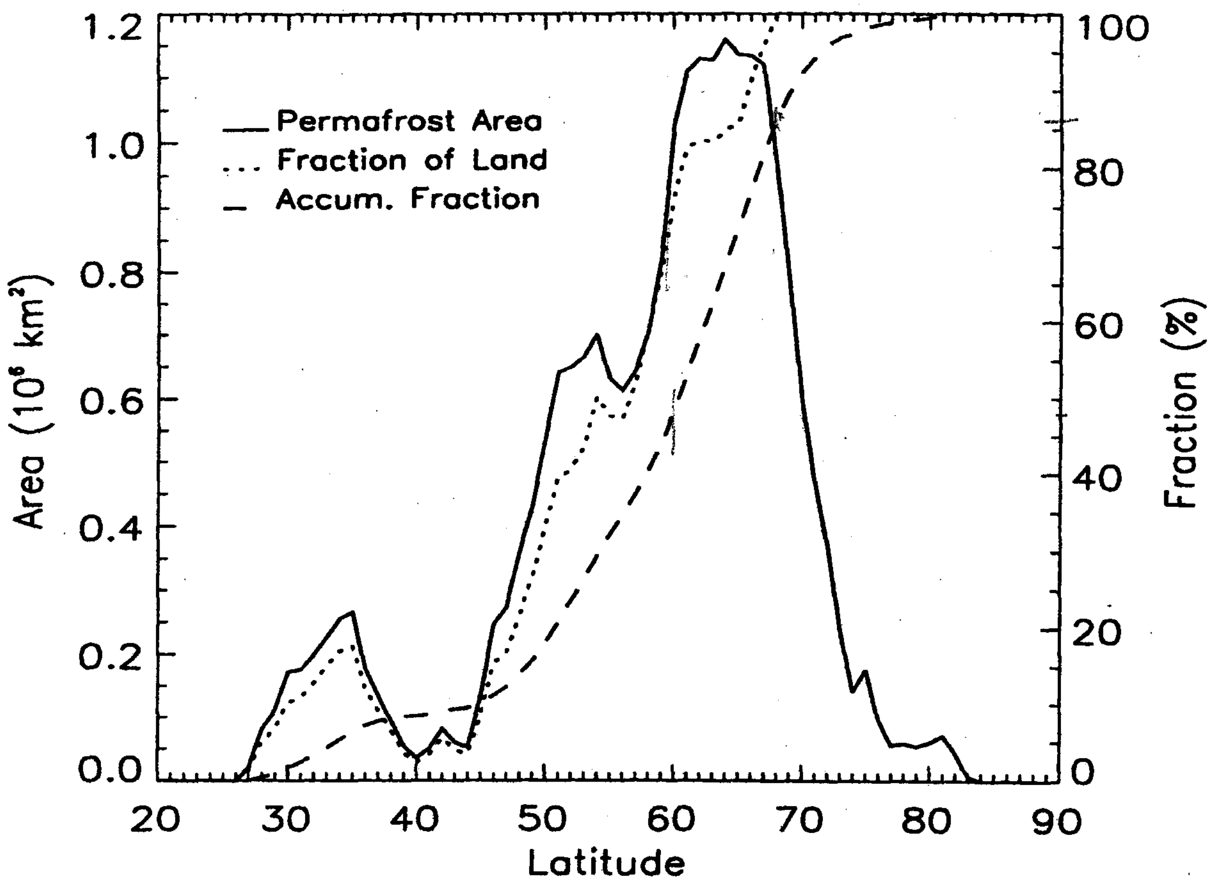


Fig. 4. Variations of the permafrost area (solid line) and its fraction (short dashed line) of the land surface at each latitude, and the accumulated fraction with latitudes (long dashed line) in the Northern Hemisphere.

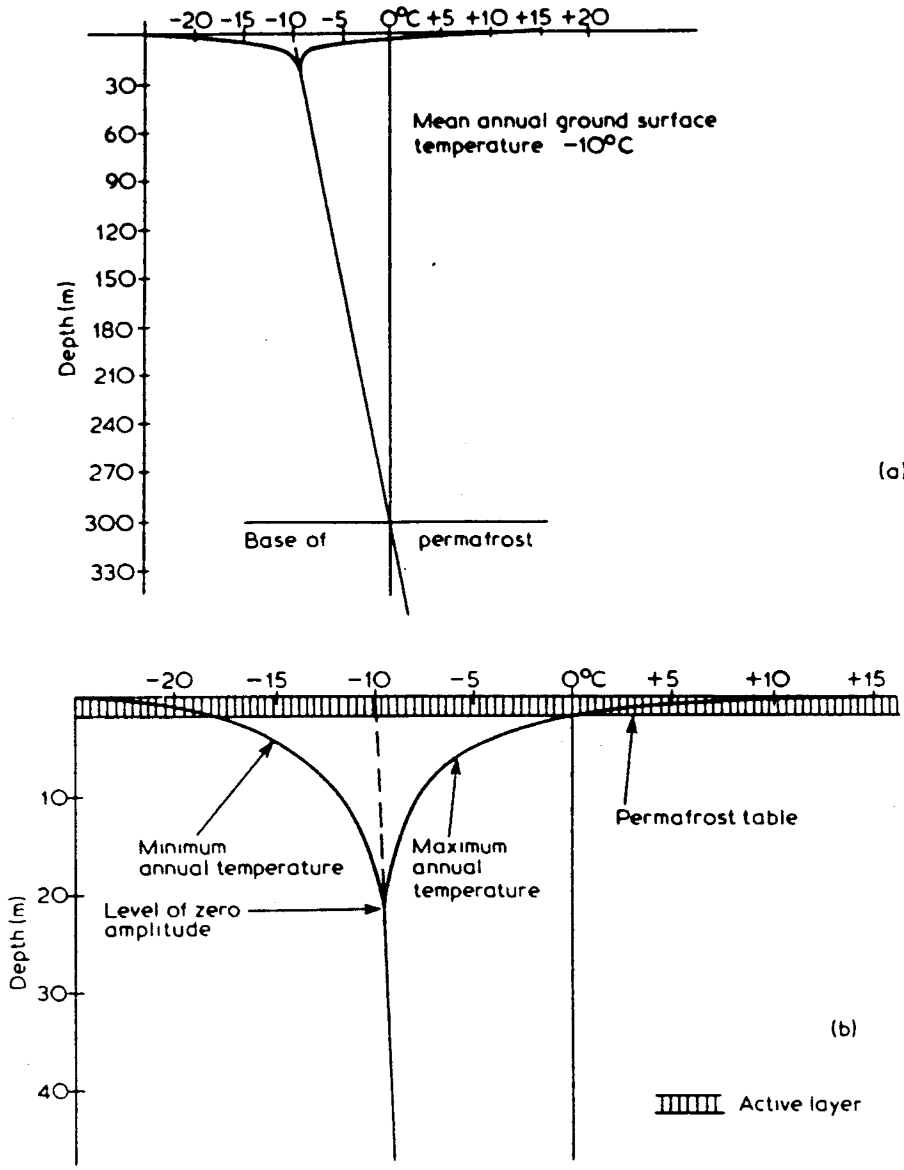


Fig. 4A.3. Schematic ground temperature profiles illustrating the relationships between (a) thermal gradient and the base of permafrost, and (b) the active layer and the level of zero amplitude.

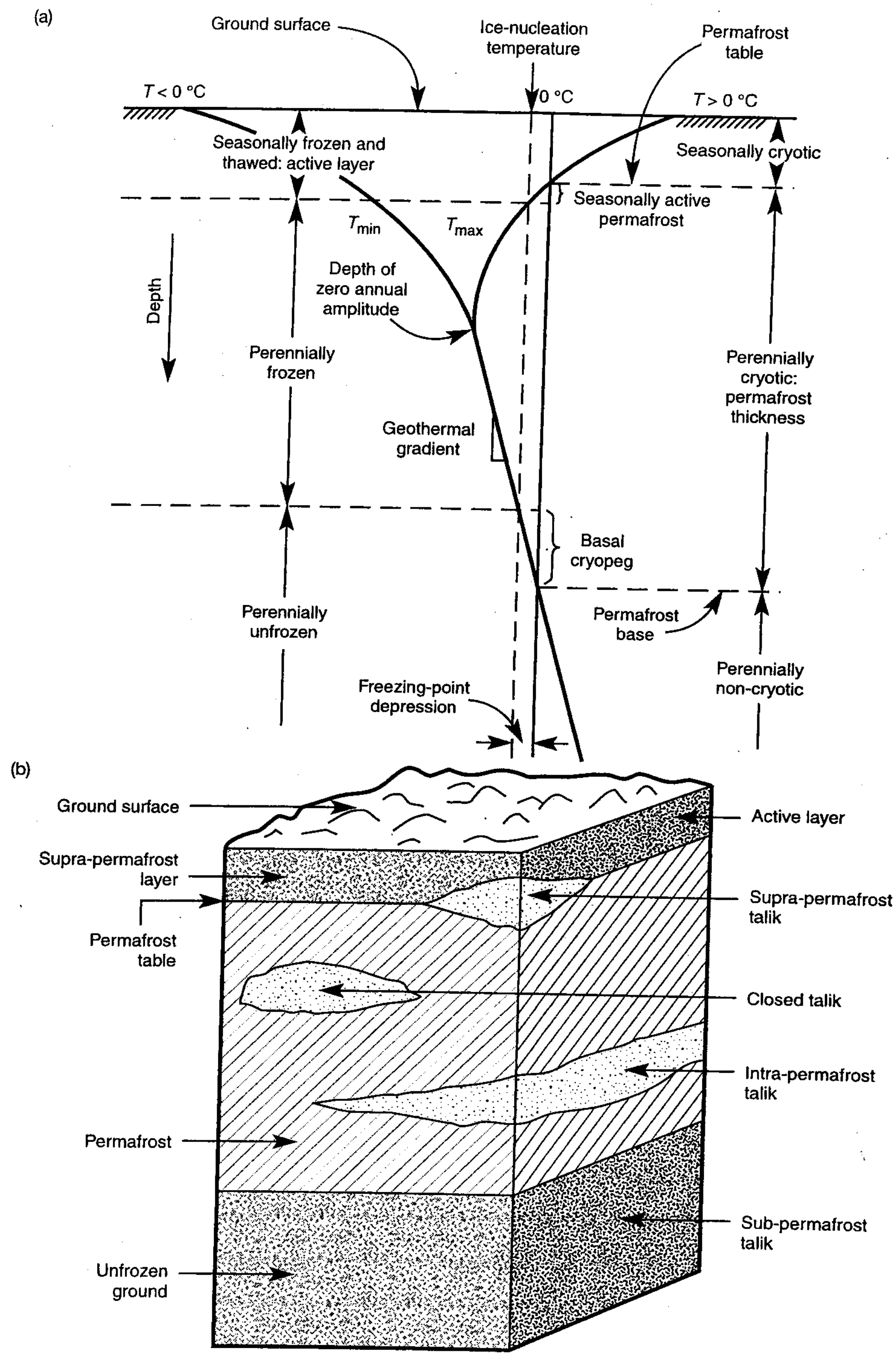


Figure 5.2 Permafrost terminology: (a) terms used to describe the ground temperature relative to 0 °C, and the state of the water, versus depth (modified from van Everdingen, 1985; from ACGR, 1988); (b) relationship between permafrost, the permafrost table, the active layer and supra, intra- and sub-permafrost taliks (modified from Ferrians *et al.*, 1969).

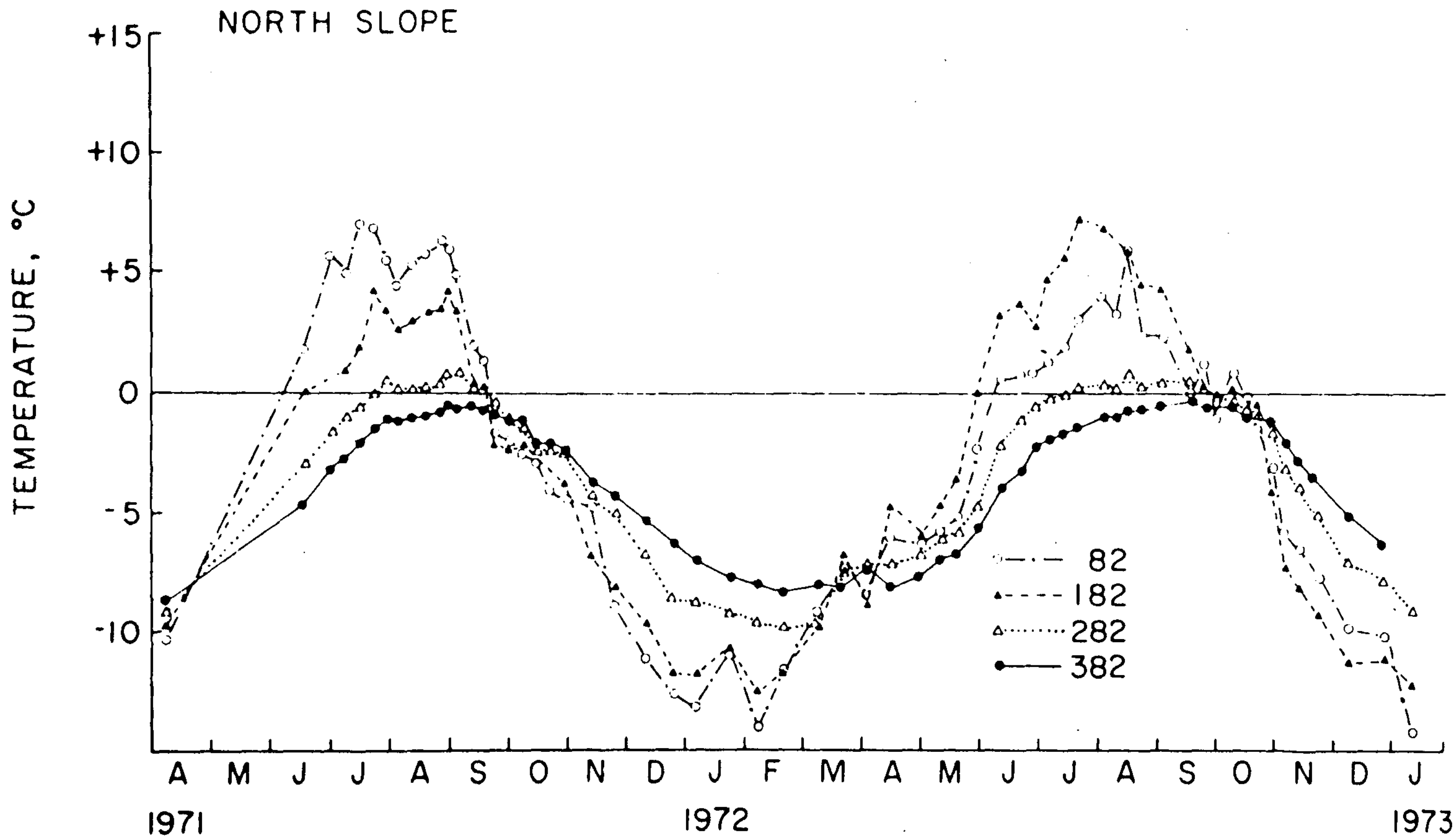
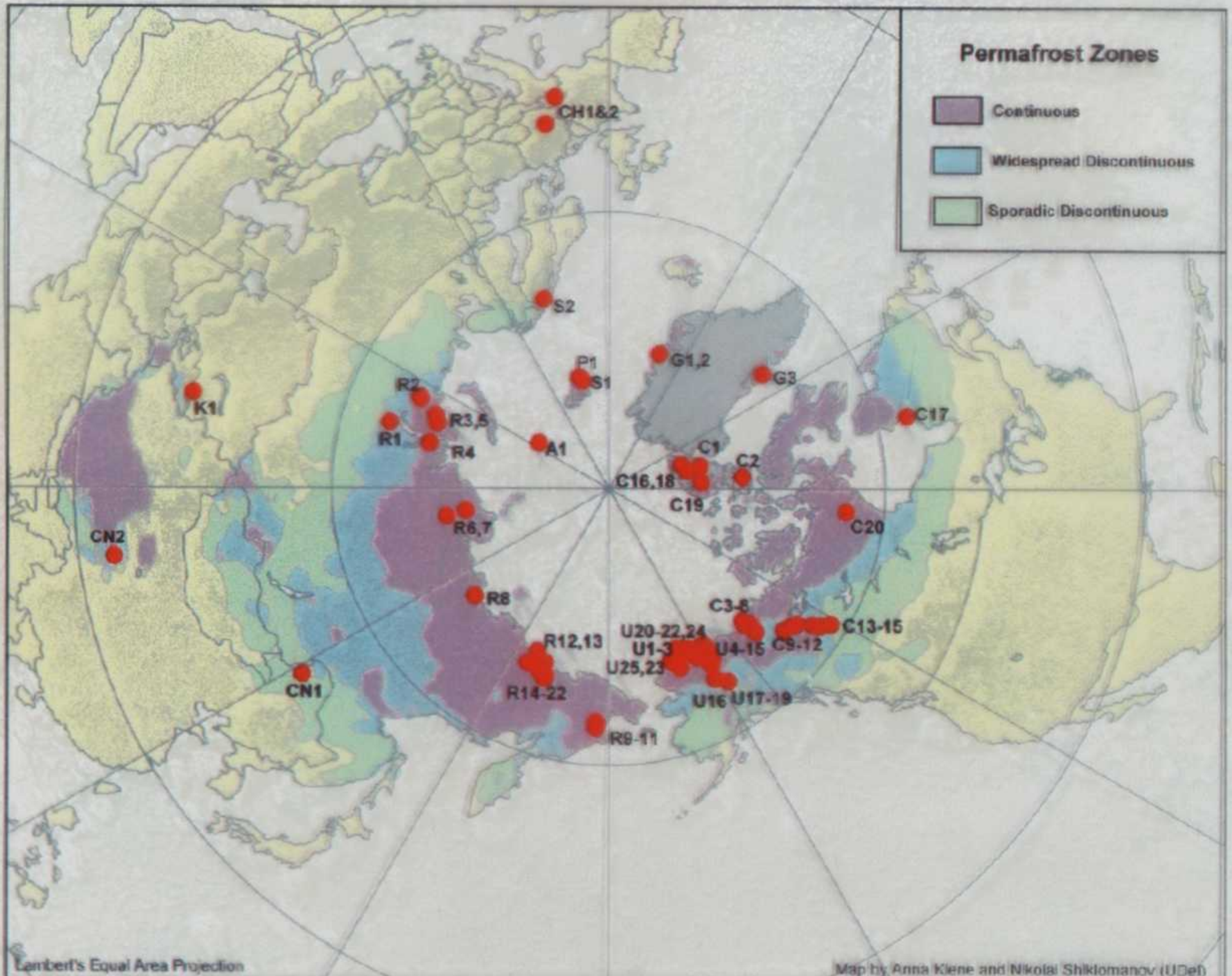
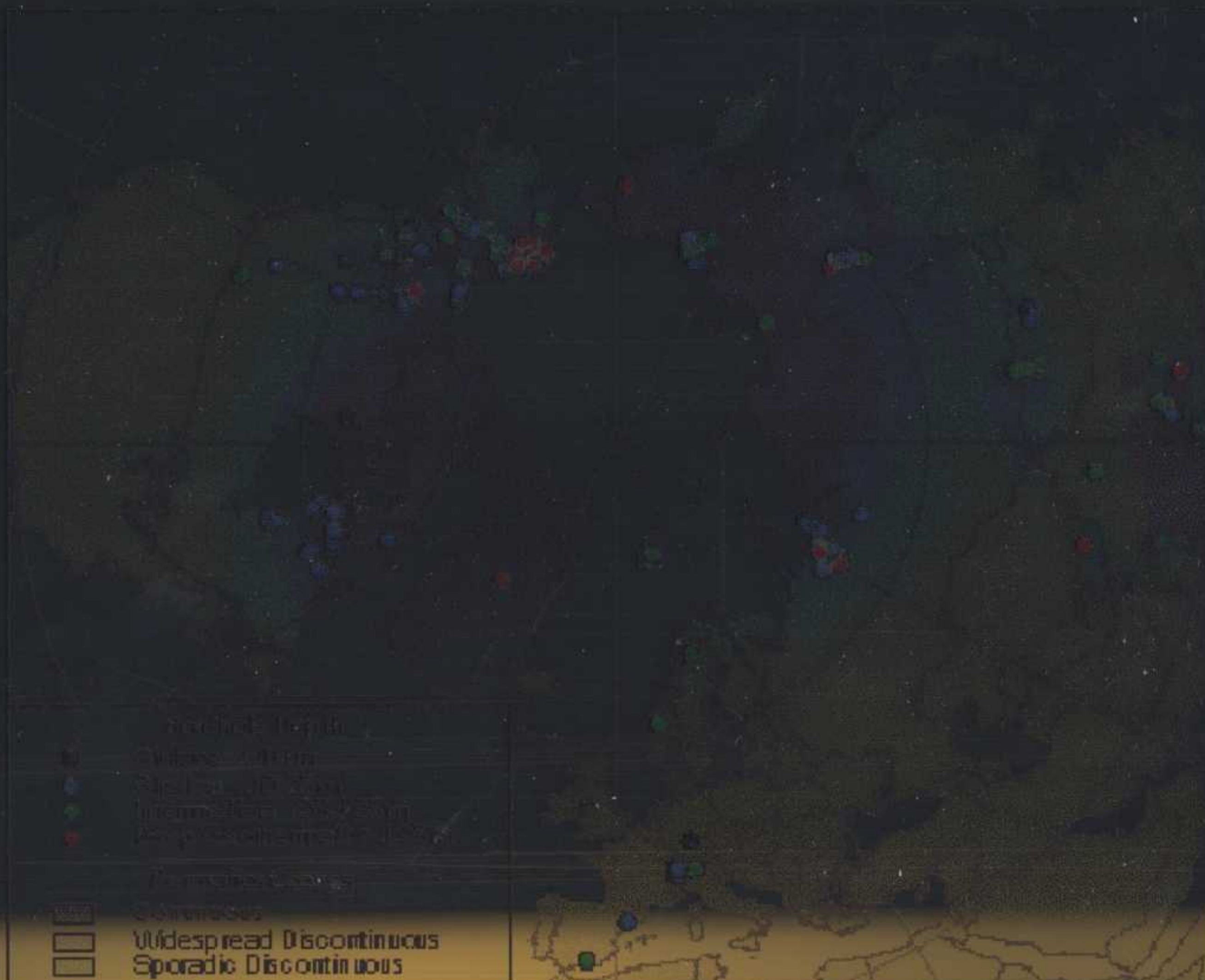


Fig. 4A.11. Ground temperature record from April 1971 to January 1973 for a north-facing site at 3750 m. Following June 1971, thermistors at 82, 182, 282 and 382 cm were read weekly during the summer and approximately once every 2 weeks during the winter. The 382-cm thermistor ceased to function in December 1972.

Circumpolar Active Layer Monitoring (CALM) Network



Permafrost zones (Brown et al. 1997) and eligible boreholes sites for the GTN-Permafrost



Map prepared by S.L. Smith, Geological Survey of Canada

Global Terrestrial Network for Permafrost (GTN-P)

- GCOS/GTOS INVITED IPA TO FORM A GLOBAL MONITORING NETWORK:
  - ACTIVE LAYER THICKNESS
  - PERMAFROST THERMAL STATE

- OVER 80 ACTIVE LAYER SITES (CALM and PACE)

* OVER 180 BOREHOLE SITES
  - SHALLOW (10—25m)
  - INTERMEDIATE (25-125m)
  - DEEP (> 125 m)

* PARTICIPATING COUNTRIES IDENTIFY REPRESENTATIVE SITES (GHOST 5 TIERS)

- FOLLOW STANDARDIZED DATA COLLECTION AND REPORTING PROCEDURES

* DATA MADE AVAILABLE ANNUALLY THROUGH CALM, PACE AND OTHER IPA COORDINATED PROGRAMS

http://www.geography.uc.edu/CALM

http://www.cf.ac.uk/uwc/earth/pace

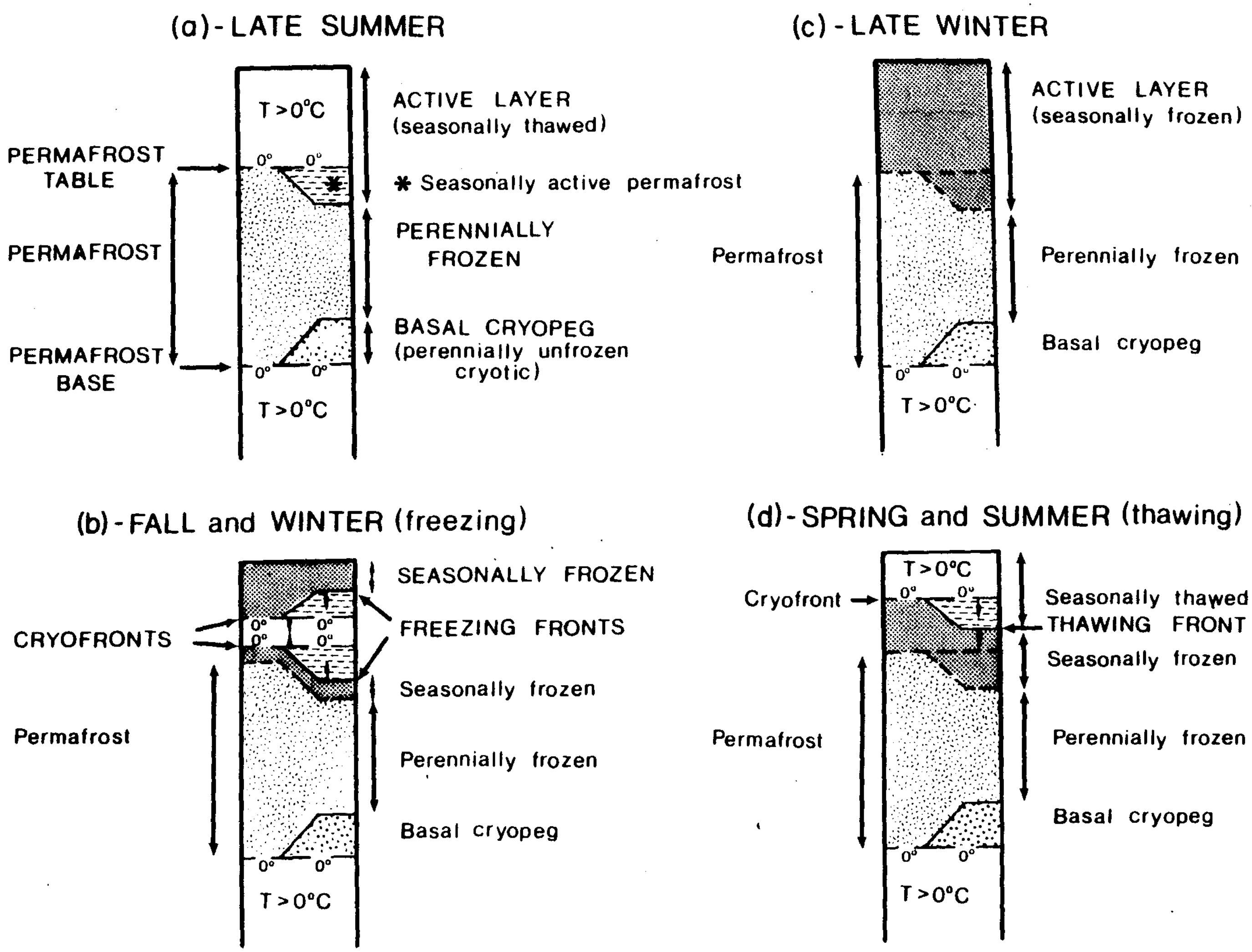


FIGURE 7.2 Seasonal changes in the active layer using geocryological terminology proposed by van Everdingen (1985). The temperature relative to 0°C and the state of water are also indicated. (A) Late summer. (B) Fall and early winter (freezing). (C) Late winter. (D) Spring and summer (thawing)

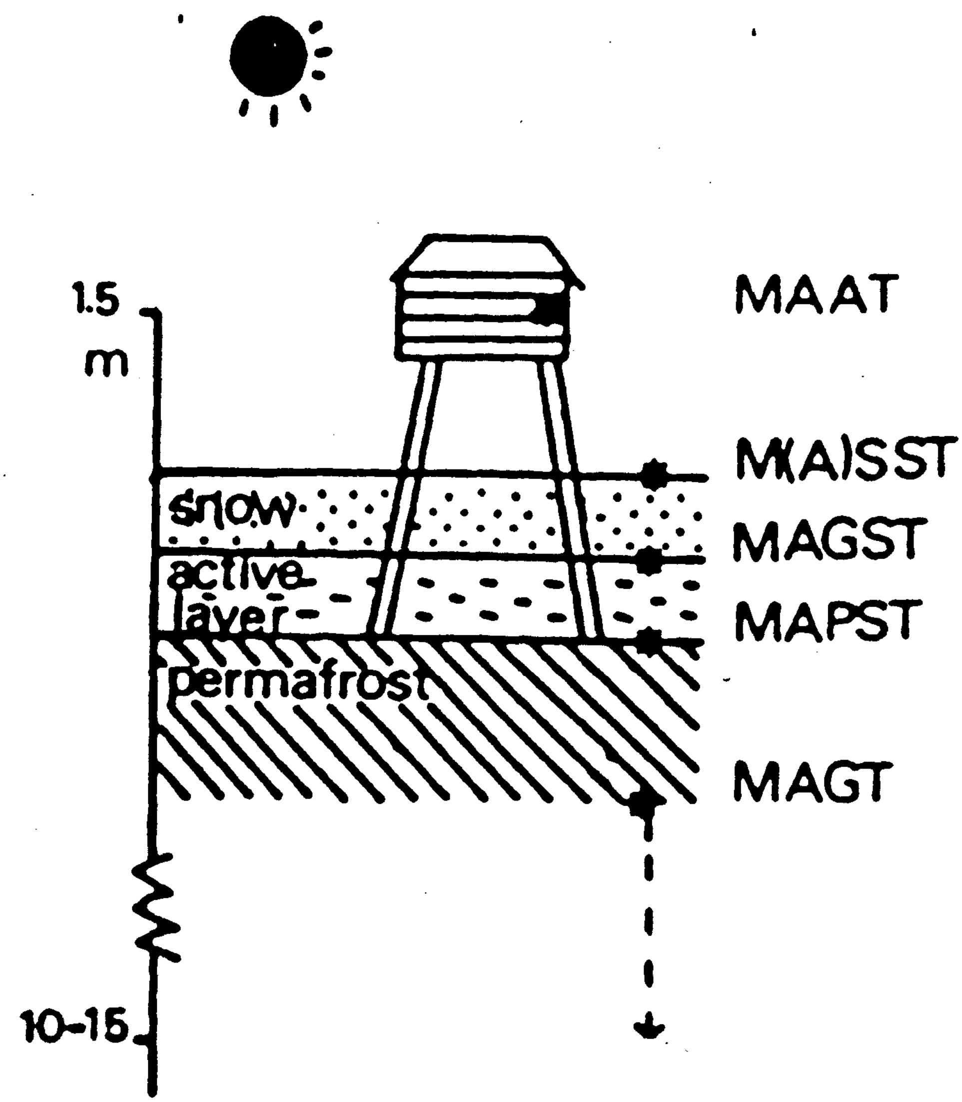


Fig. 3: Measurement sites for the different mean annual temperatures (adapted after LACHENBRUCH et al. 1988).

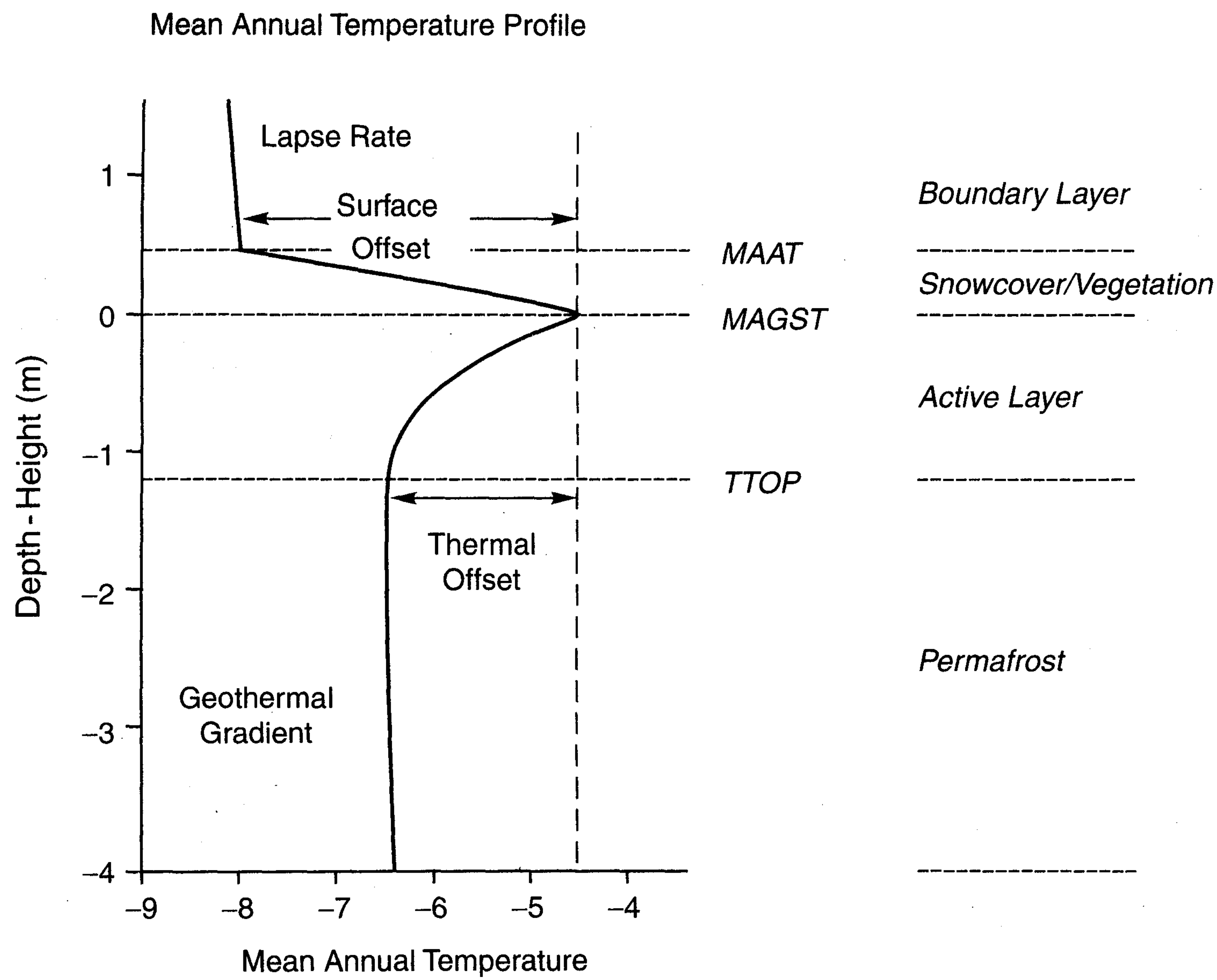
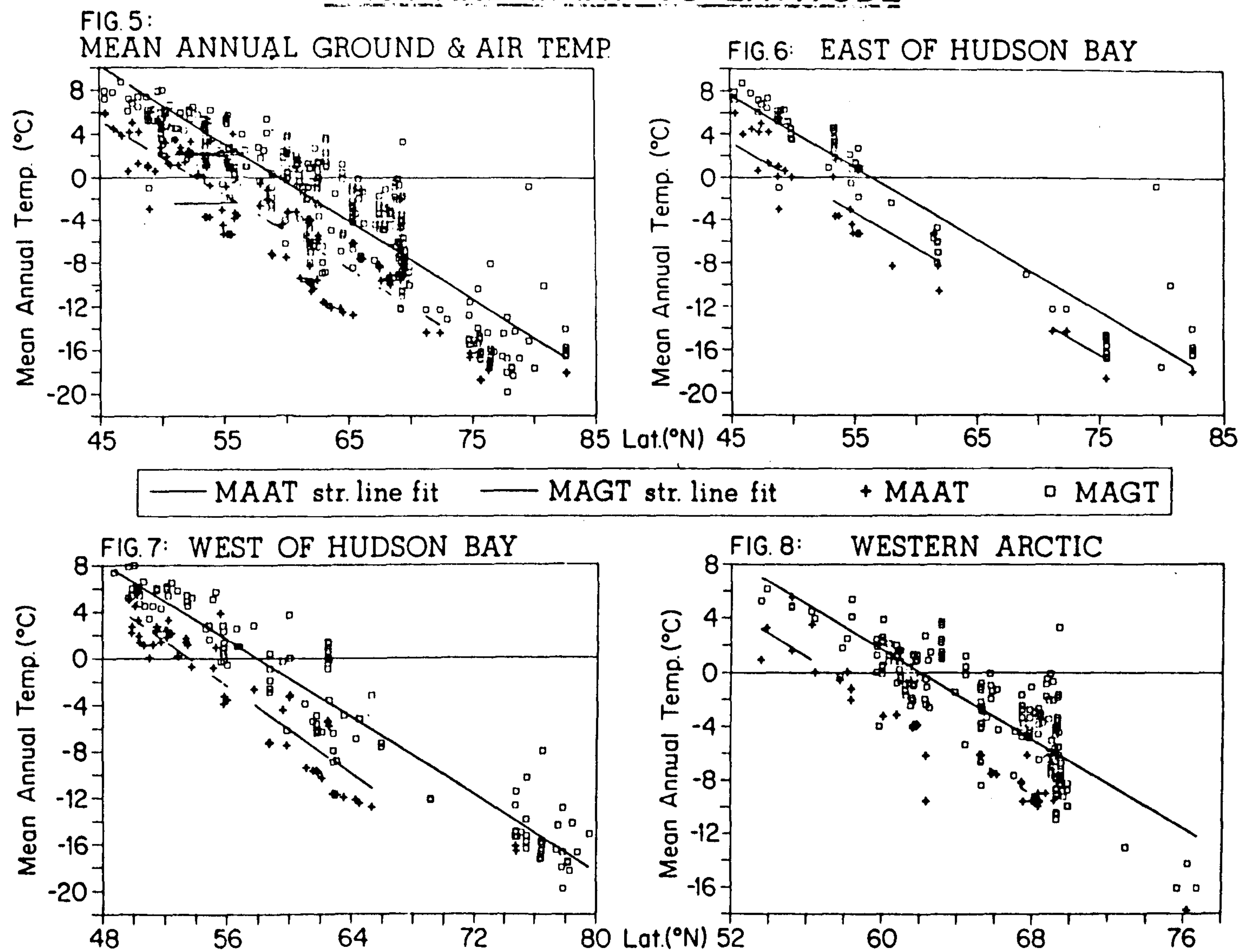


Figure 3 Schematic mean annual temperature profile through the surface boundary layer, showing the relation betwee
and permafrost temperature.

MAGT AND MAAT VS LATITUDE



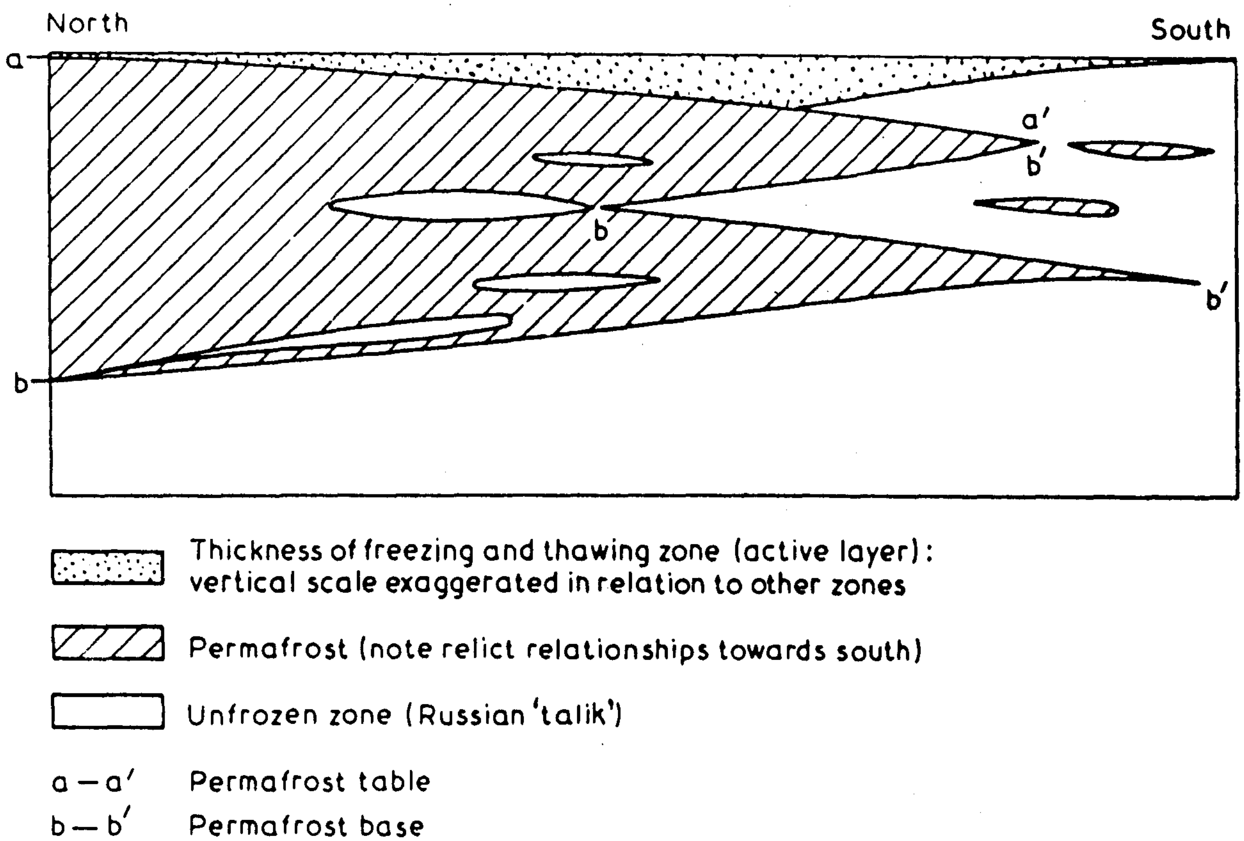
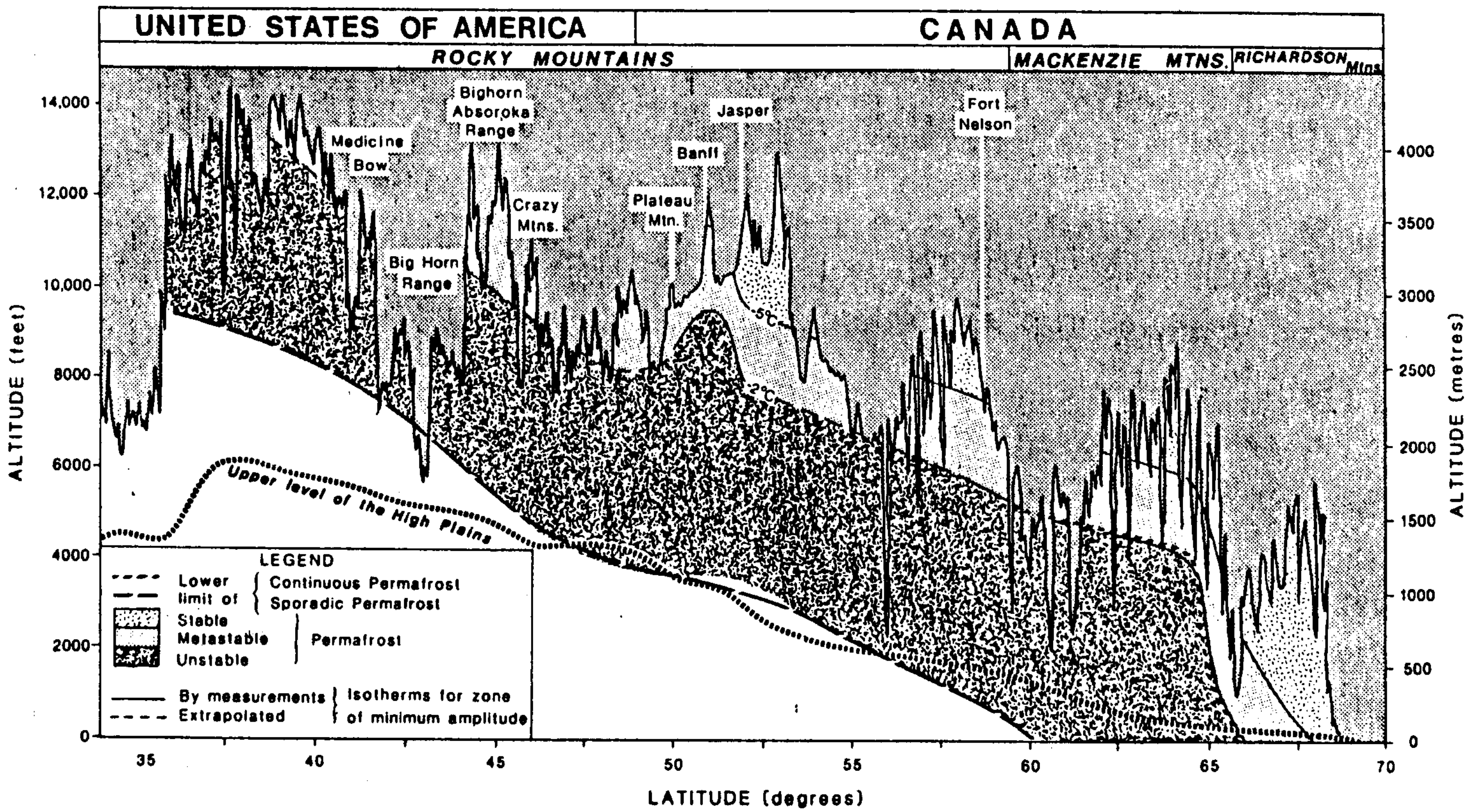


Fig. 4A.5. Schematic profile through high-latitude, continental interior illustrating the manner in which permafrost thins towards the south, the unfrozen zone, and deep, relict wedges of permafrost. Permafrost table $a - a'$; permafrost base $b - b'$.



UNITED STATES OF AMERICA
CANADA
ROCKY MOUNTAINS
MACKENZIE MTNS.
RICHARDSON Mtns.
Bighorn Absoroka Range
Medicine Bow
Big Horn Range
Crazy Mtns.
Plateau Mtn.
Banff
Jasper
Fort Nelson
5°C
2°C
Upper level of the High Plains
ALTITUDE (feet)
14,000
12,000
10,000
8000
6000
4000
2000
0
ALTITUDE (metres)
4000
3500
3000
2500
2000
1500
1000
500
0
LATITUDE (degrees)
35
40
45
50
55
60
65
70
LEGEND
Lower limit of { Continuous Permafrost
Sporadic Permafrost
Stable
Metastable
Unstable
Permafrost
By measurements
Extrapolated
Isotherms for zone of minimum amplitude

Fig 7

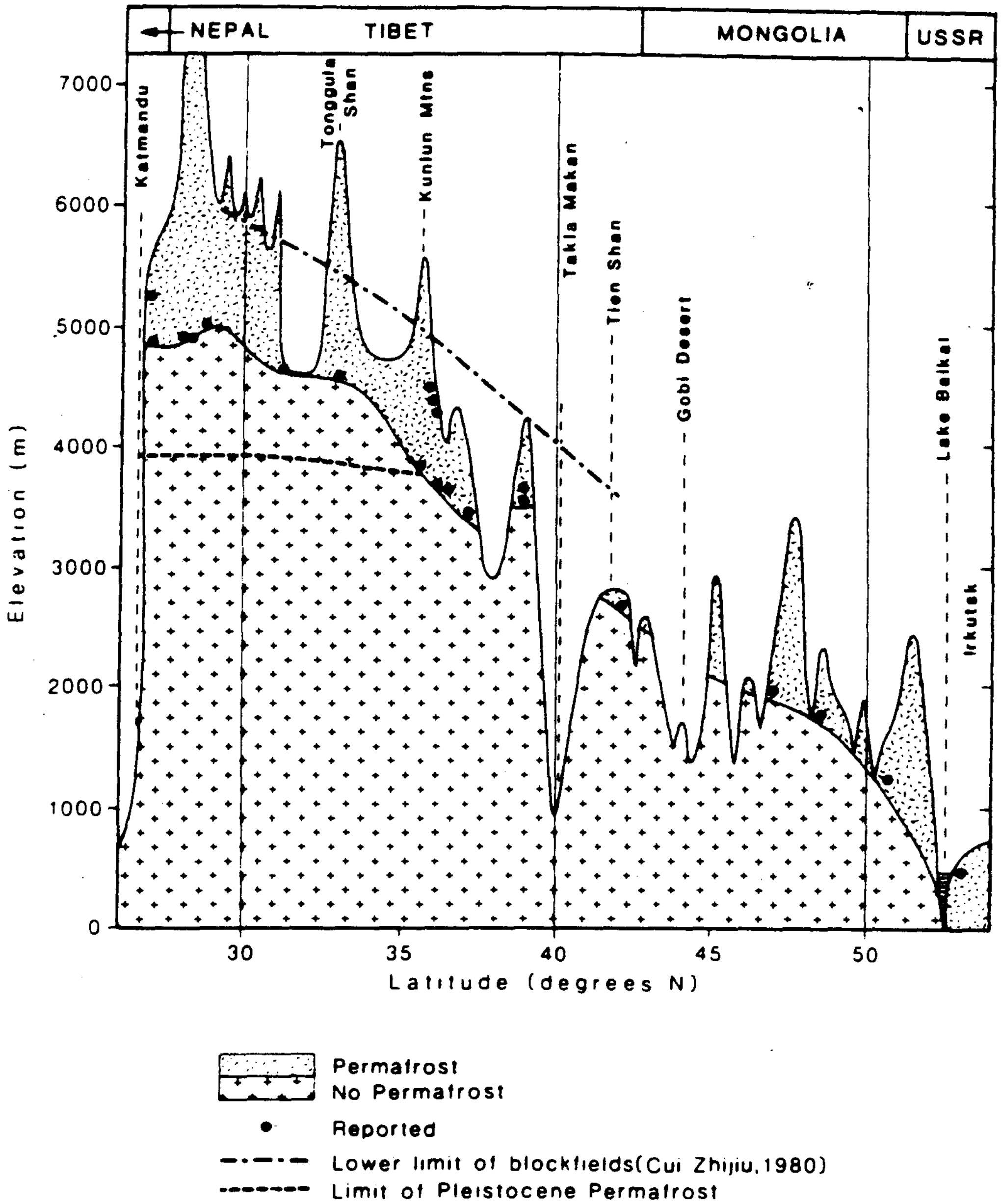


FIGURE 15.4 Lower limit of permafrost with latitude across the Tibetan Plateau and Himalayas from south-central Siberia to Nepal (from Harris, 1986, with permission). Data from Fujii and Huguchi (1976, 1978); Hsieh *et al.* (1975); Froehlich and Słupik (1978); RIGCDR (1975); Chou and Tu (1963); Chen Guodong (1984); and Chi Zhijiu (1980)

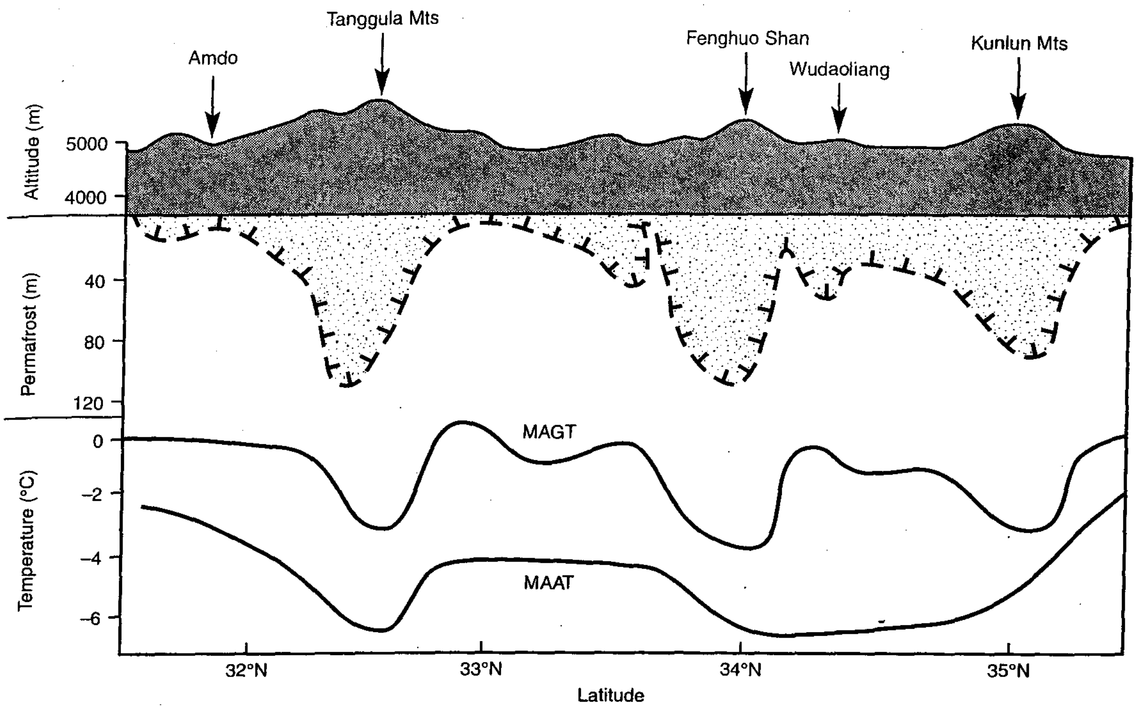


Figure 5.8 Graph showing changes in permafrost thickness, mean annual ground temperature (MAGT), mean annual air temperature (MAAT), and topography across the northern part of the Tibet Plateau (from Wang and French, 1995c).

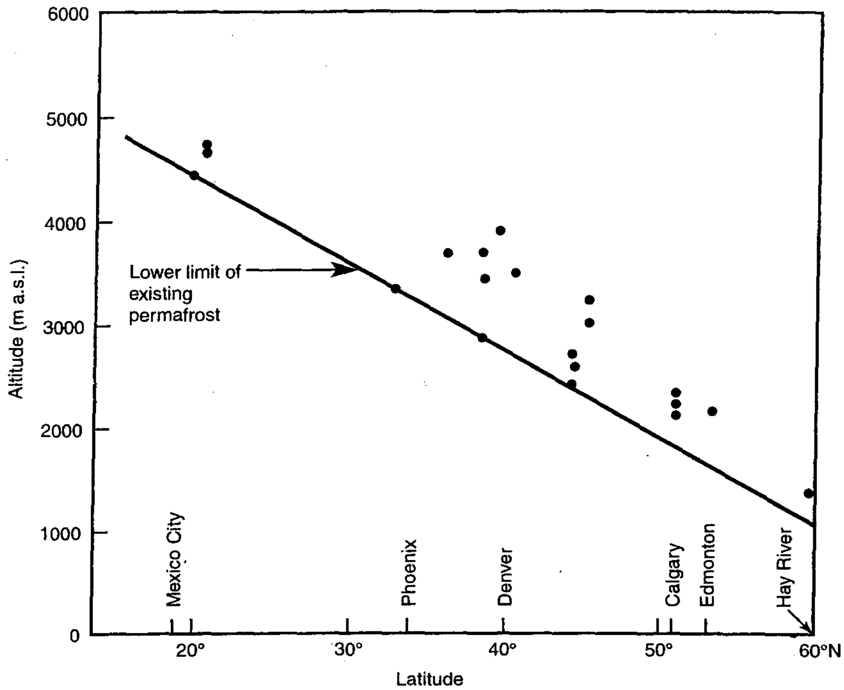


Figure 5.5 Graph showing relationship between latitude and altitude of reported localities of existing mountain permafrost in the cordillera of North America. Points indicate localities where permafrost has either been measured by ground temperatures, or inferred from local micro-climatic data or from geomorphic phenomena (ice-cemented rock glaciers, blockfields; from Péwé, 1983a).

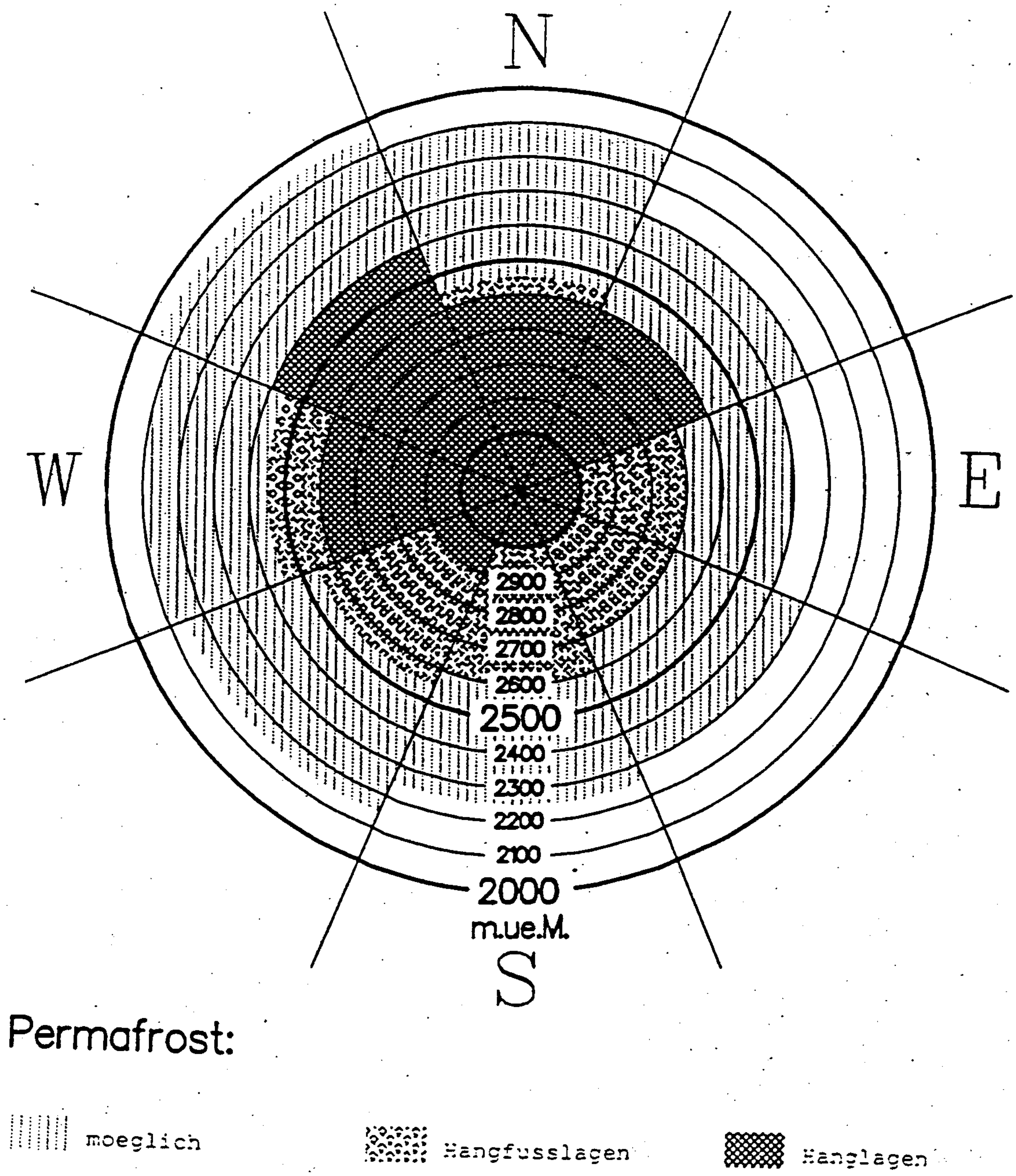
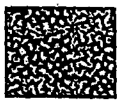
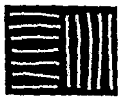
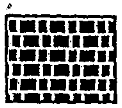
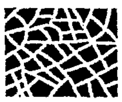
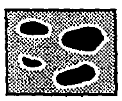
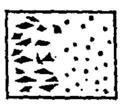


Fig. 1: Auftreten von Permafrost in den Alpen als Funktion der Meereshöhe, der Exposition und grober Hangcharakteristik (Hangfusslagen mit lang liegendem Lawinenschnee und oft grobblockigem Schutt). In Verflachungen tritt Permafrost oberhalb ca. 2700 m ü.M. (windexponierte Grate) und rund 3000 m ü.M. (windgeschützte Mulden) auf. Im Unsicherheitsbereich sind Permafrostvorkommen "möglich" aber nicht wahrscheinlich, es können auch tiefliegende Restvorkommen von Untergrundeis aus den vergangenen (kälteren) Jahrhunderten auftreten. Einzelne Permafrostvorkommen in extremen Schattenlagen sind gelegentlich auch in der Waldregion anzutreffen (Graphik: F. Keller).

(a)

Cryostructure and code		Sediment		Ice		Occurrence as or within	
	Structureless (Sl)	Sand Gravel		Pore		Ice in sand + gravel	
	Lenticular (Le)	Muddy peat Mud (Fine sand)	Sand	Segregated	Crack infill	Ice/sediment lenses Massive ice Icy sediments	(Ice wedges) (Composite sand-ice wedges) (Dilation-crack ice)
	Layered (La)	Muddy peat Mud (Fine sand)	Sand	Segregated Intrusive	Crack infill	Ice/sediment lenses Massive ice Icy sediments	Ice wedges Composite sand-ice wedges Dilation-crack ice
	Regular reticulate (Rr)	Mud		Segregated		Ice in mud	
	Irregular reticulate (Ri)	Mud		Segregated		Ice in mud	
	Crustal (Cr)	Mud Frost-susceptible clasts		Segregated			
	Suspended (Su)	Mud Sand Gravel	Mud Sand Gravel	Segregated Intrusive		Icy layer at top of permafrost Ice dykes in mud	Ice lenses Massive ice Icy sediments Ice dykes

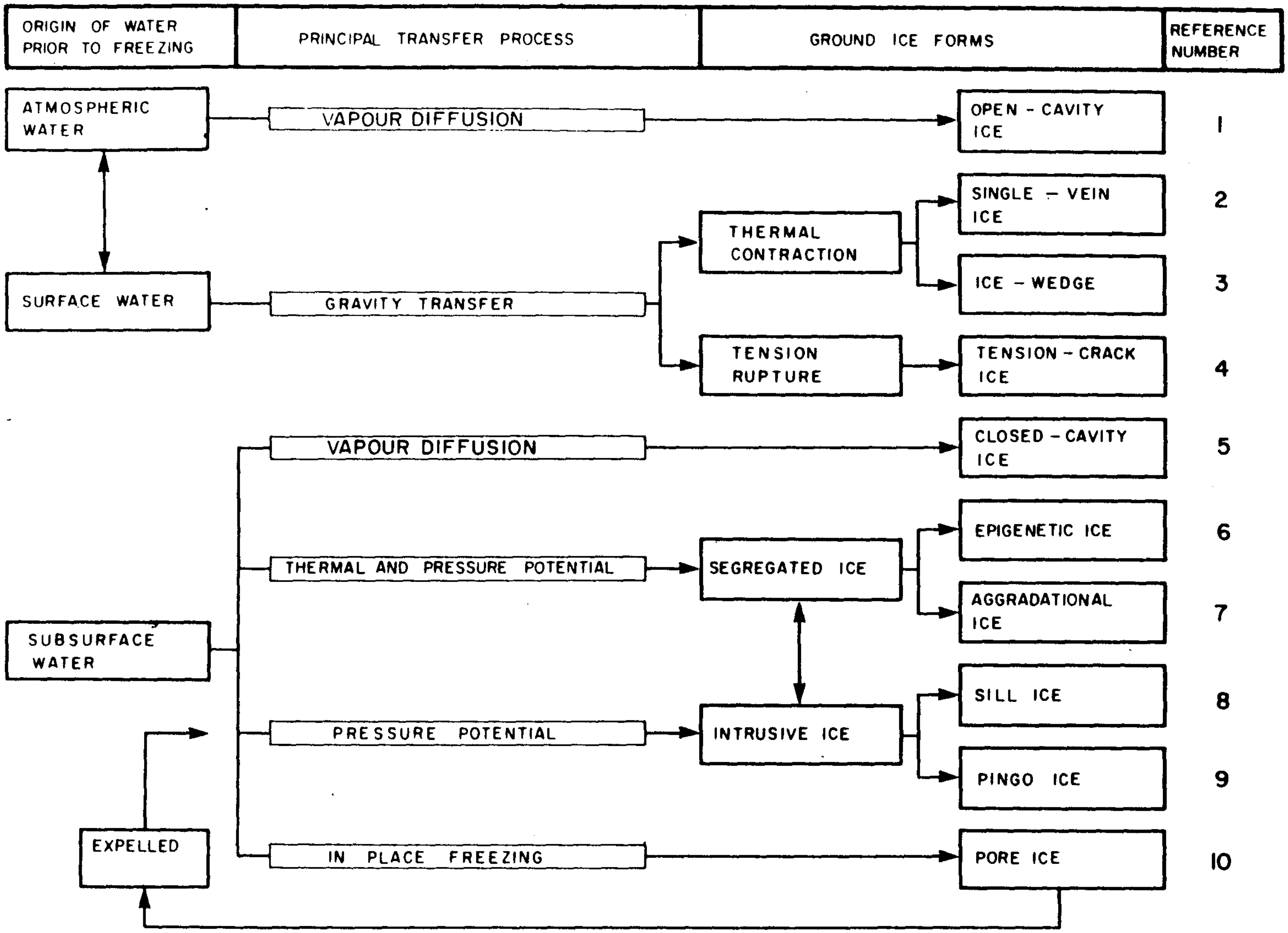


FIGURE 6.3 A genetic classification of ground ice. (After Mackay, 1972b). Reproduced by permission of the Annals of the Association of American Geographers

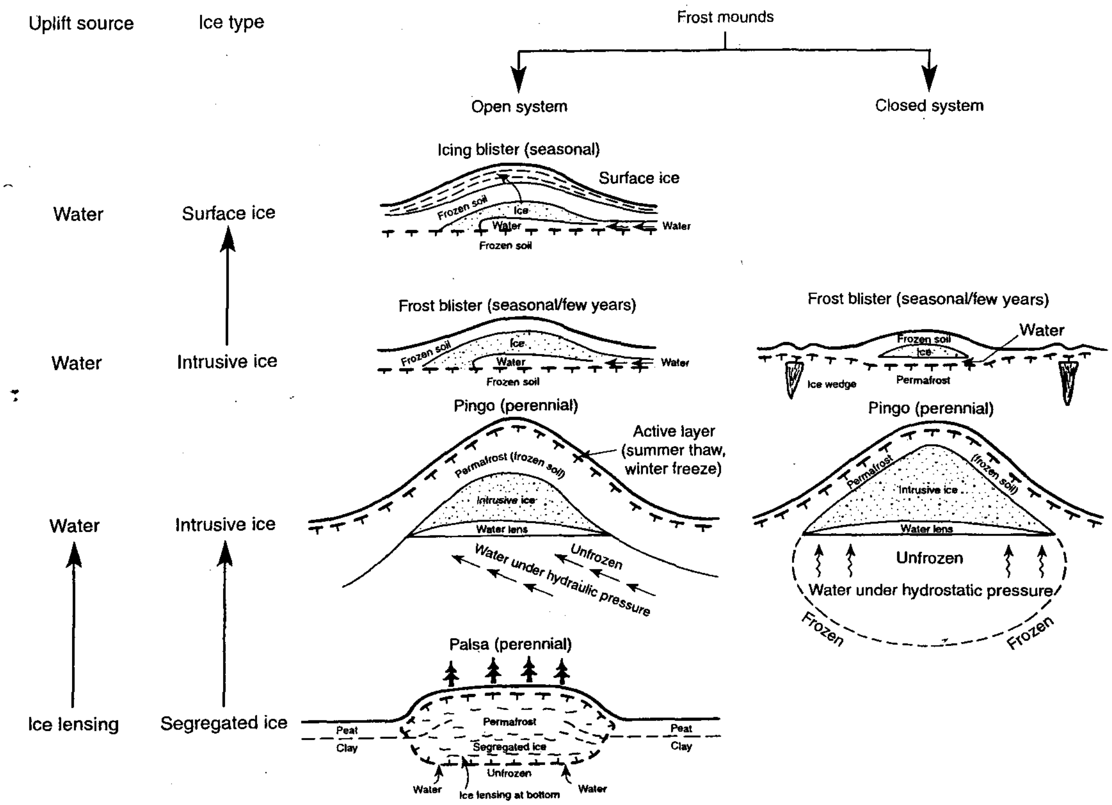
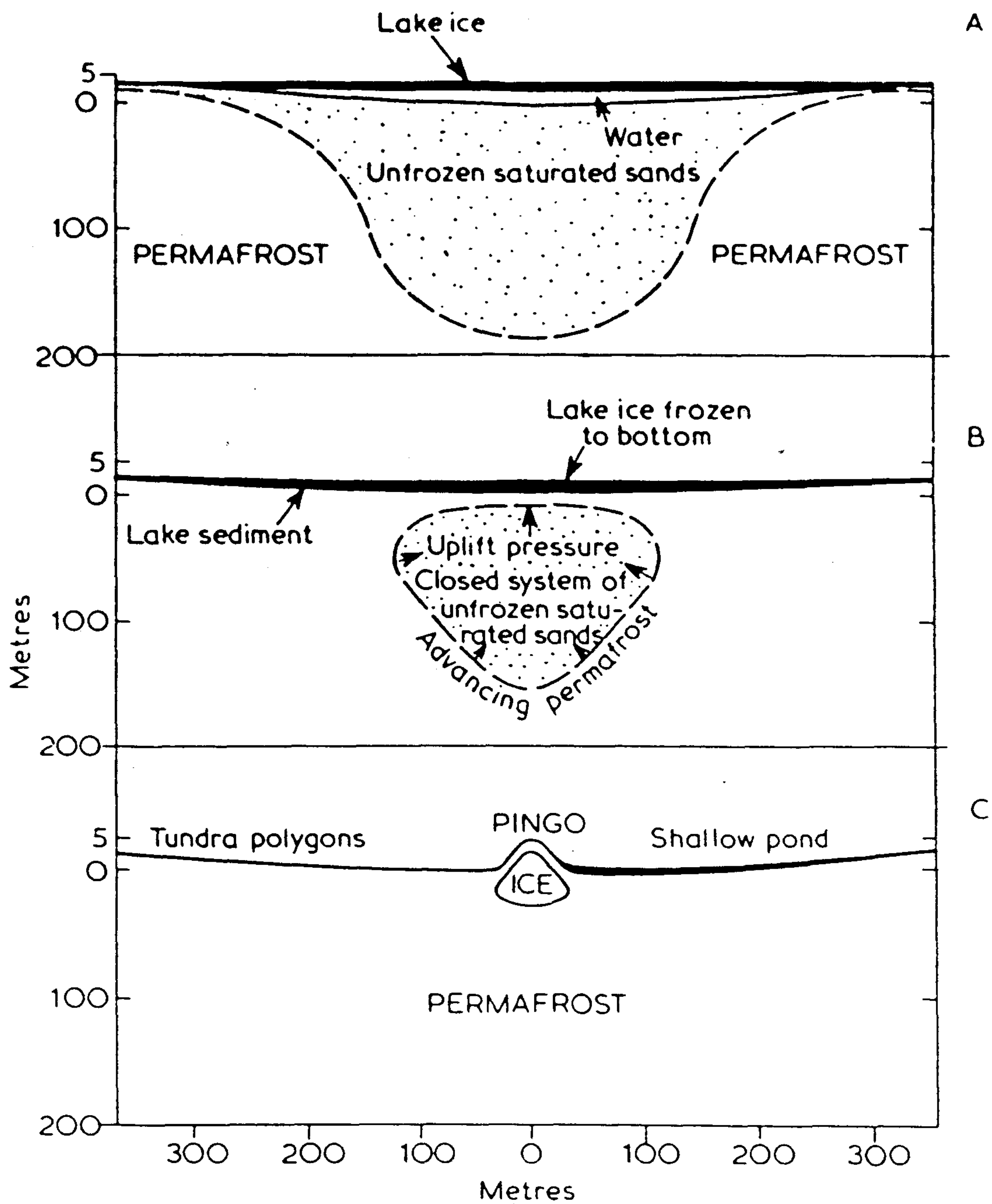


Figure 6.20 Diagram illustrating the various types of frost mounds and their origin (from Mackay, 1986c).



Lake ice
A
5
0
Water
Unfrozen saturated sands
100
PERMAFROST
PERMAFROST
200
Lake ice frozen
to bottom
B
5
0
Lake sediment
Uplift pressure
Closed system of
unfrozen satu-
rated sands
Advancing permafrost
Metres
100
200
C
5
0
Tundra polygons
PINGO
Shallow pond
ICE
100
PERMAFROST
200
300
200
100
0
100
200
300
Metres

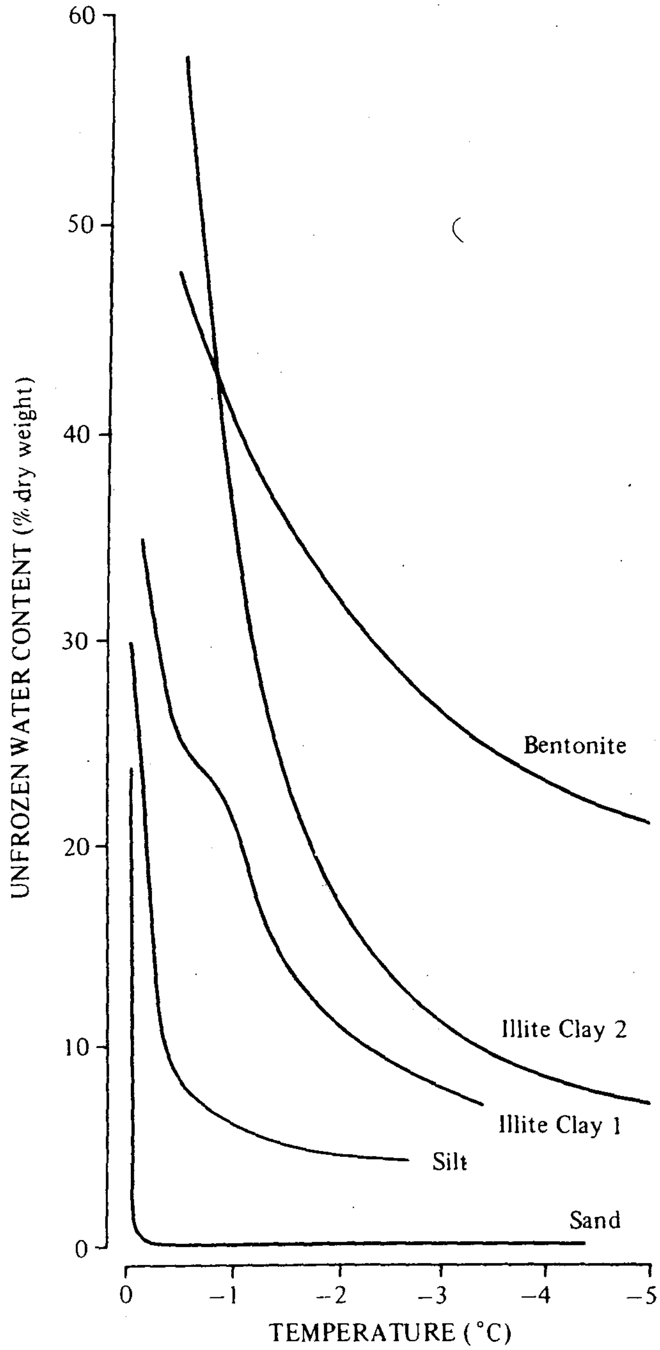


Figure 1.4 Amount of water remaining unfrozen at temperatures below 0 °C, various soils.

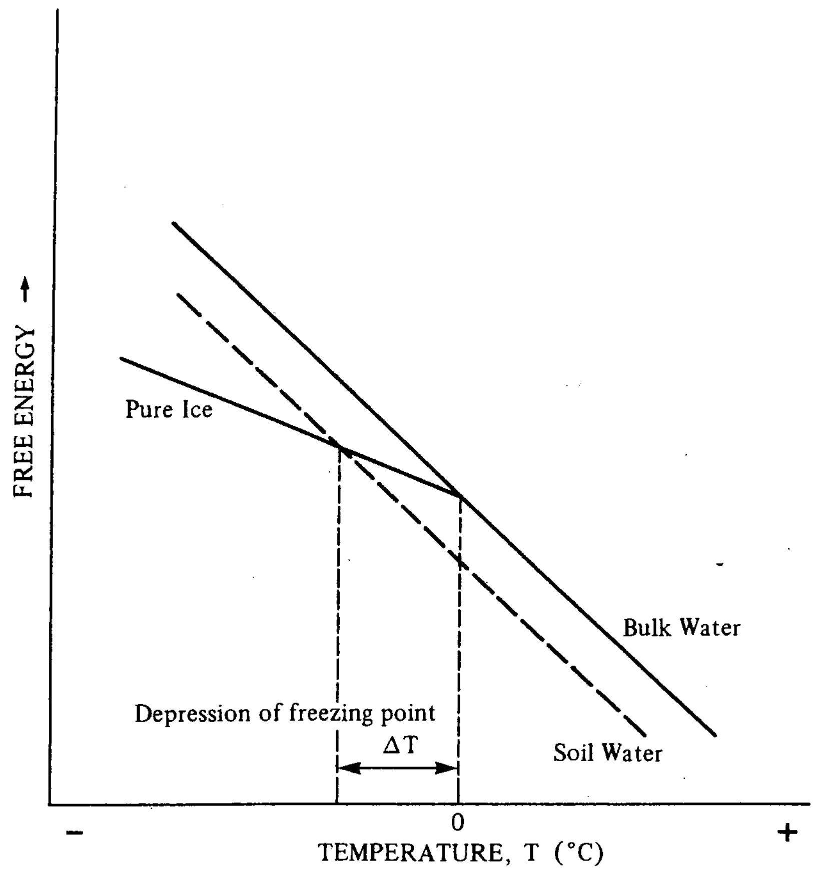


Figure 1.3 Ice and water normally coexist (have equal free energies) at 0 °C. But if the free energy of the water is reduced (dashed line) the freezing point is changed by ΔT (diagram modified after Everett 1961).

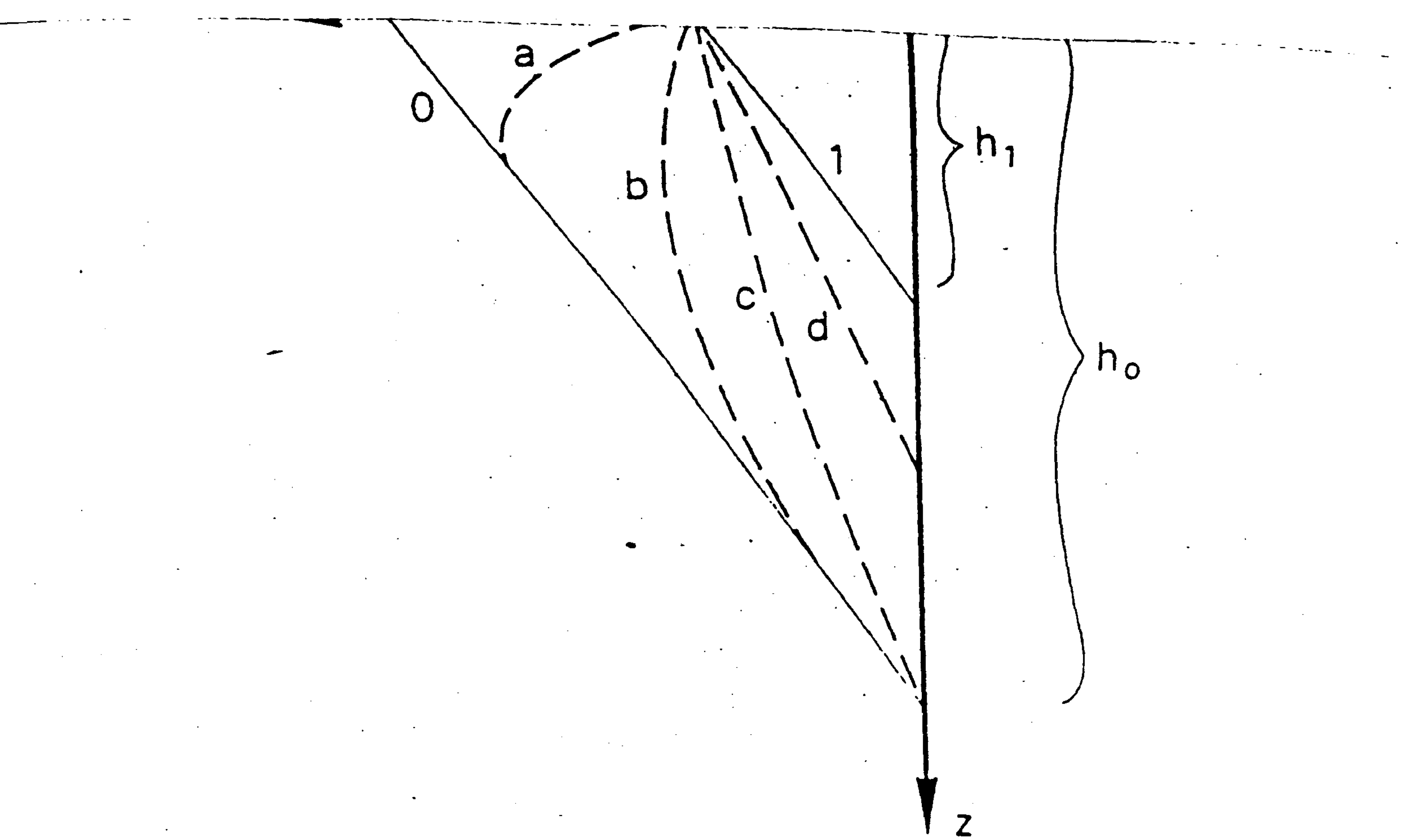


Fig. 5: Schema der Entwicklung eines Permafrost-Temperaturprofils als Folge eines stufenförmigen Temperaturanstieges von T_0 zu T_1: h_0 = Permafrostmächtigkeit im Ausgangsstadium (Gleichgewicht), h_1 = Permafrostmächtigkeit im Endzustand (neues Gleichgewicht).

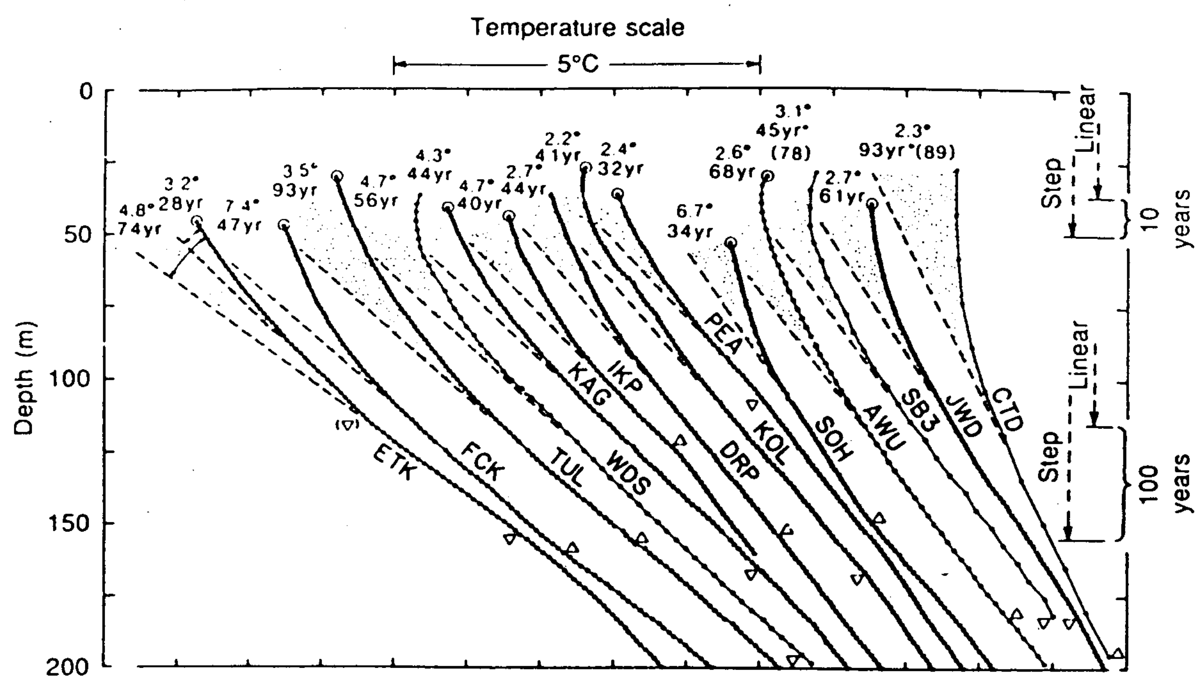


Fig. 6. Data from sites (denoted by ● in Fig. 2) with relatively smooth geotherms and indication of warming over several decades. Temperature origins are offset to avoid overlap. The stippled region for each curve is our interpretation of warming anomaly $T(z)$; numbers by curves indicate total temperature increase in Celsius degrees, and time in years before August 1984 for start-up in the best fitting model of linear change in surface temperature ($n = 2$, Eq. 8). Analyses performed on portion of each curve above the triangle, the region assumed to be homogeneous. Available shallow measurements have been deleted above circled dots for this analysis. Arrows at right-hand margin show depths at which step and linear changes in surface temperature, in progress for 10 or 100 years, become small (<5% of their surface value, assuming $\alpha = 10^{-6}$ m^2 sec^{-1}). Numbers in parentheses following asterisk are start-up times corrected for a diffusivity of 0.014 cm^2 sec^{-1} and a measurement date of 1961 for CTD, and for a measurement date of 1951 at SB3.

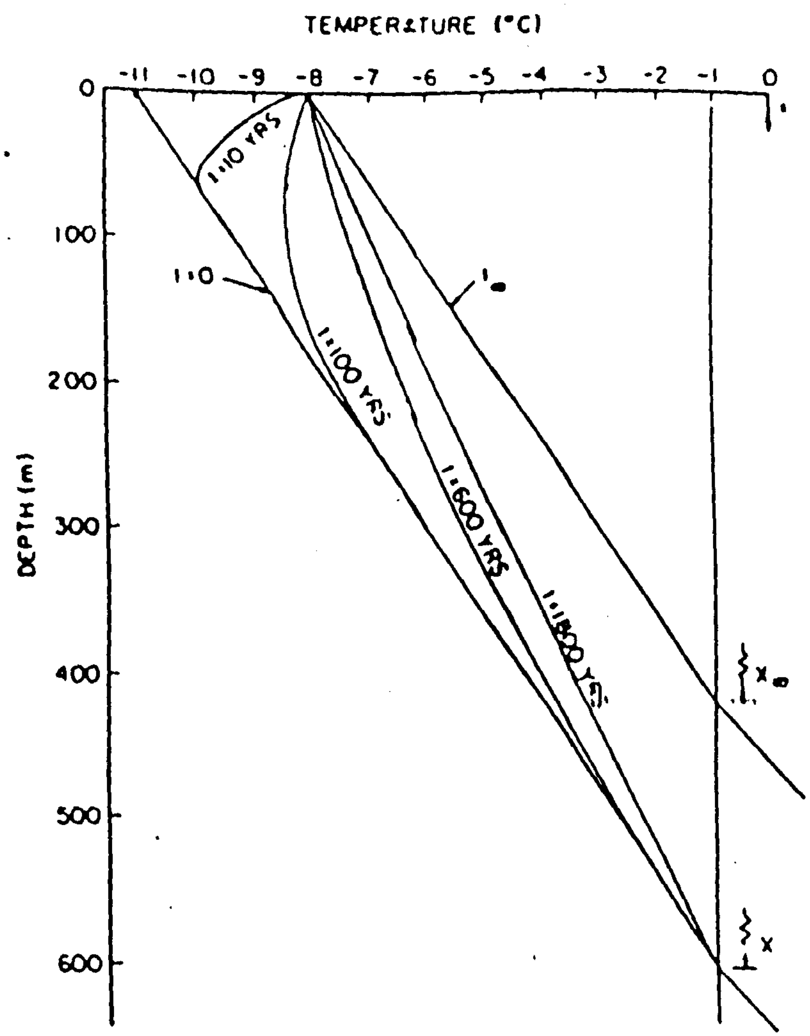
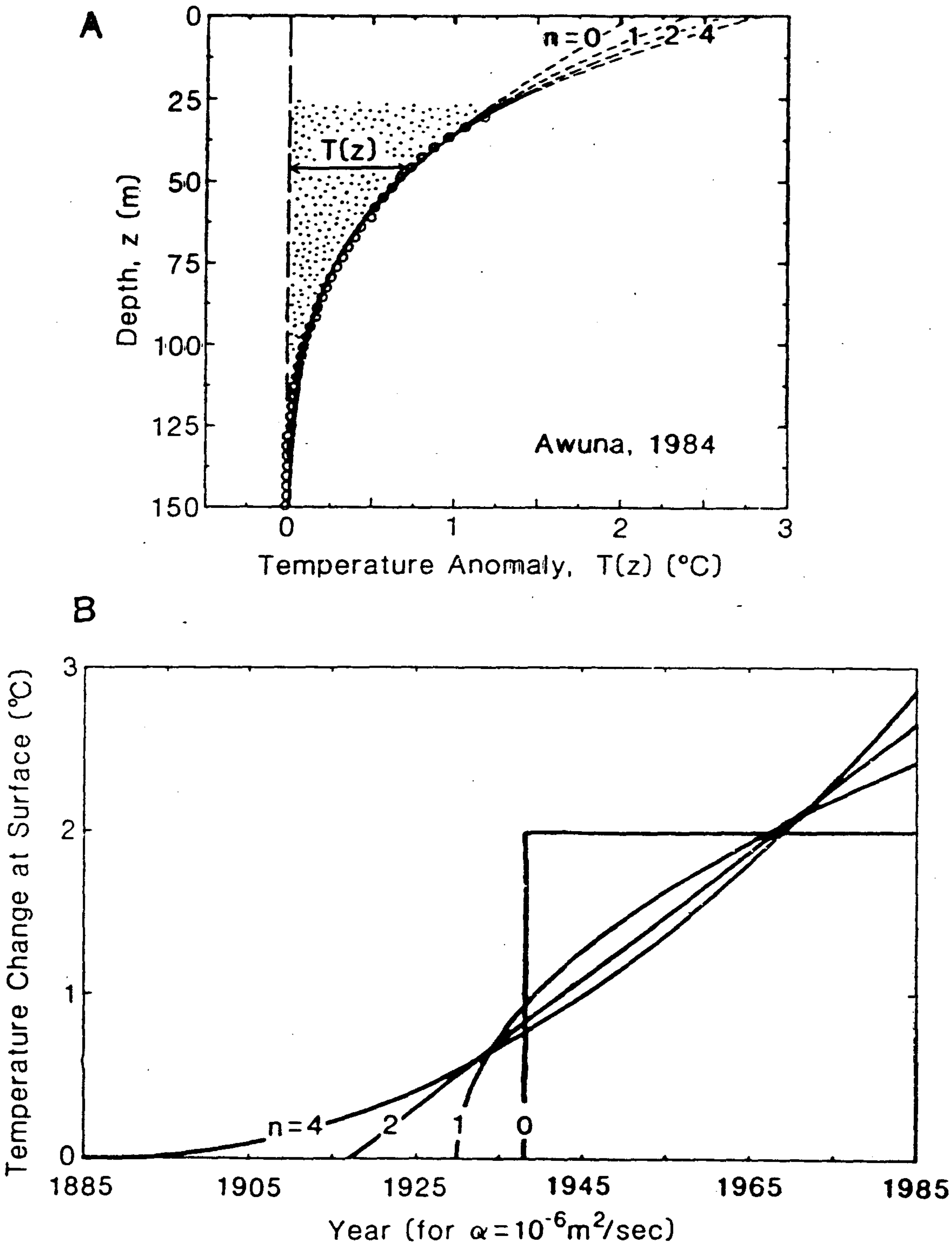


Fig. 6: Thermal warming model for the continuous permafrost zone. The assumed initial equilibrium temperature profile (t=0) and the final temperature profile at t=t∞, with a permafrost depth of X∞, are shown with the approximate temperature profiles for t=10, 100, 600 and 1800 years. Melting at the base of the permafrost amounts to ± 3.5 m during the first 1800 years and is neglected in this graph (after OSTERKAMP 1984a, b).



CALCULATED GEOTHERMAL HISTORIES

Figure 9: (A) Warming anomaly $T(z)$ obtained from AWU (Fig. 3). Circles are observations; curves are best-fitting geotherms calculated by Eq. 6 for the four forms of temperature history (Eq. 4) shown in (B).

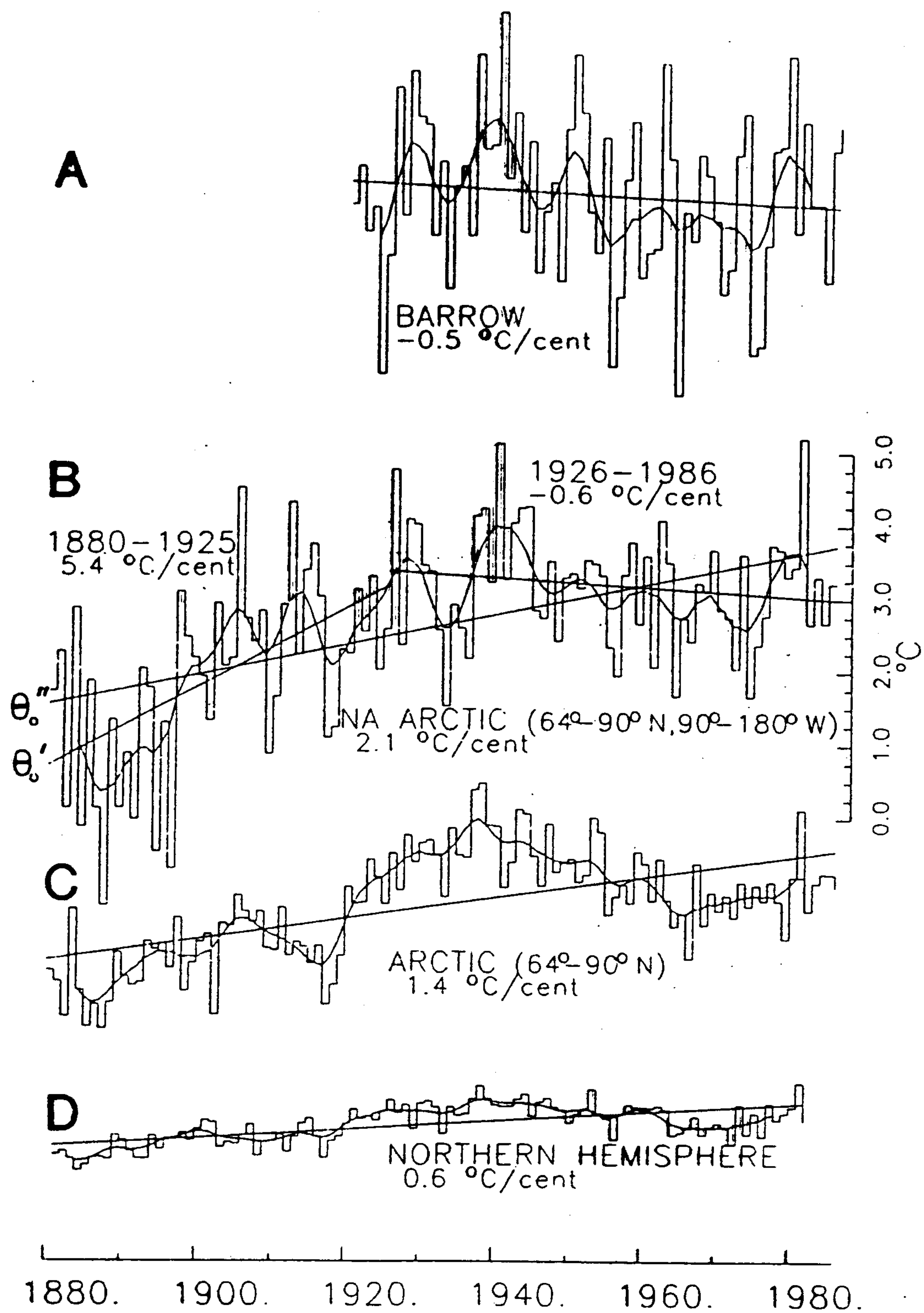
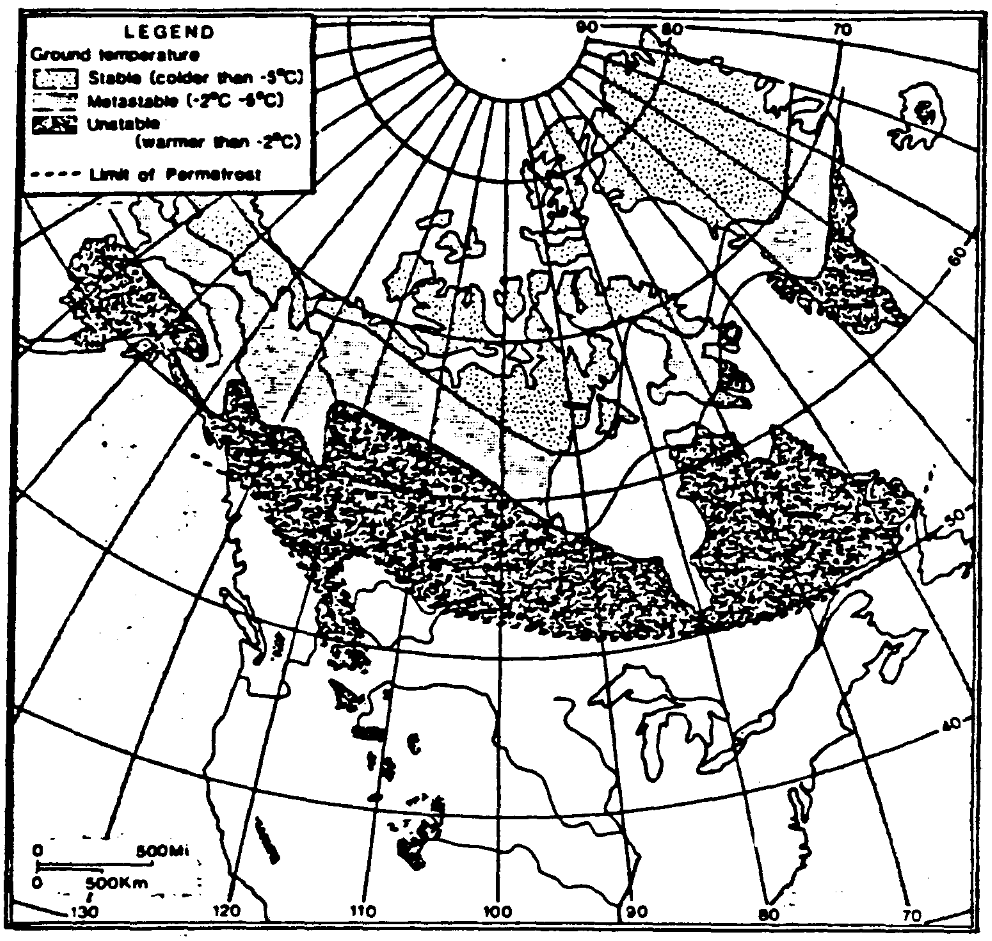


Figure 13: Mean annual temperatures from (A) U.S. Weather Bureau at Barrow, Alaska, and (B) from Hansen and Lebedeff (1987) for the North American quadrant of the Arctic; (C) the circumpolar Arctic, and (D) the Northern Hemisphere. Curves for nine-year weighted average and selected regression lines also shown.

STABILITY OF PERMAFROST



STABILITY OF PERMAFROST

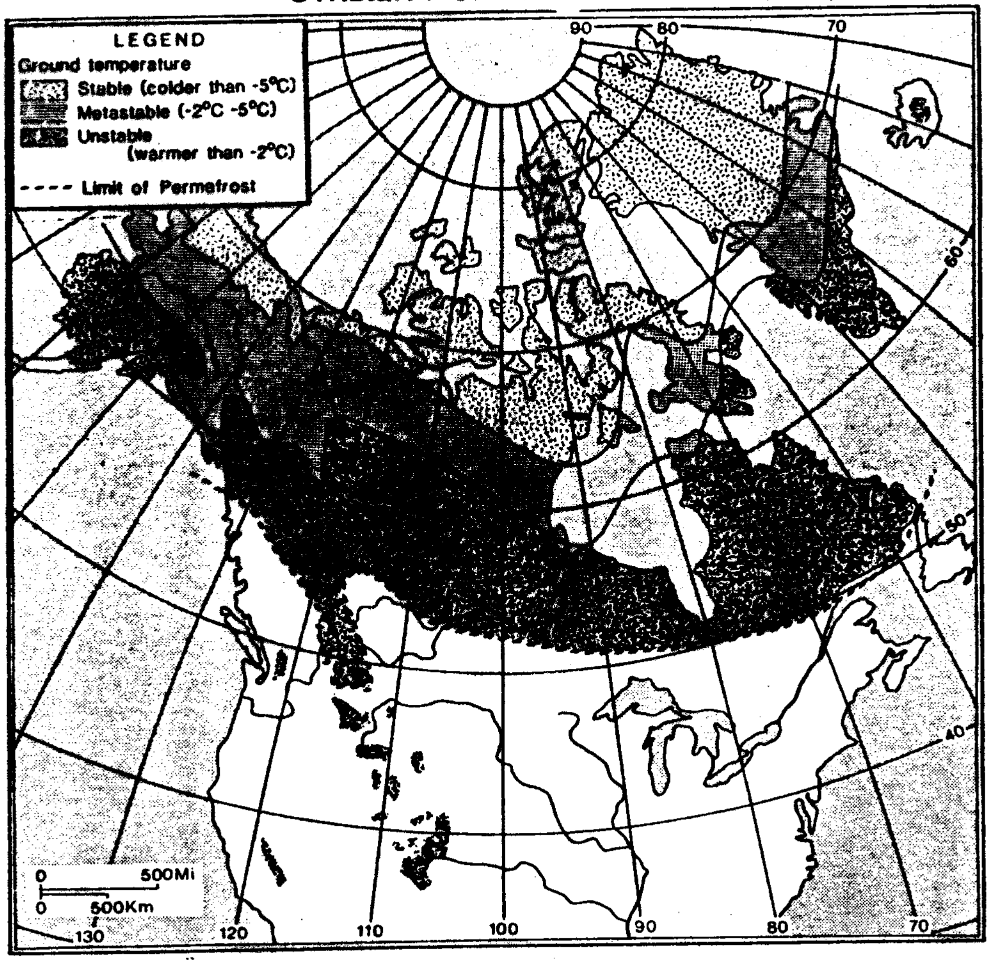


Fig 8

PERMAFROST ZONES

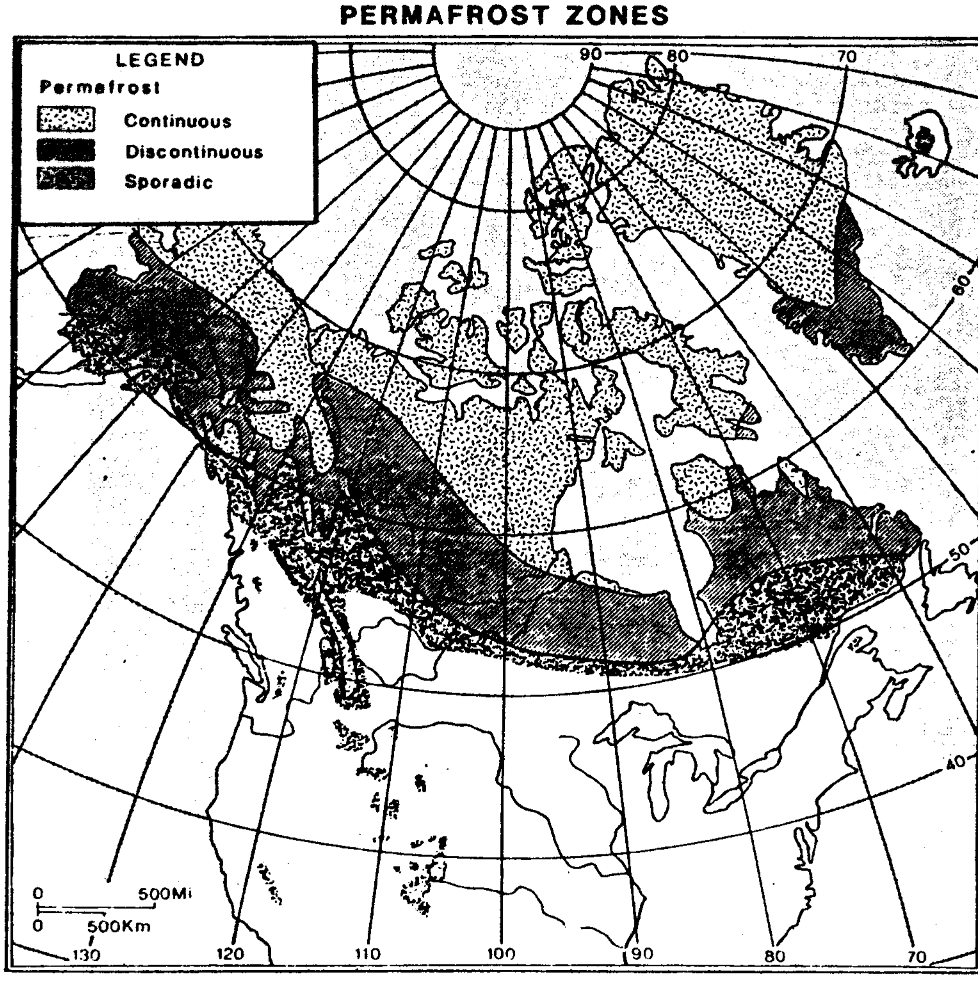


Fig 9

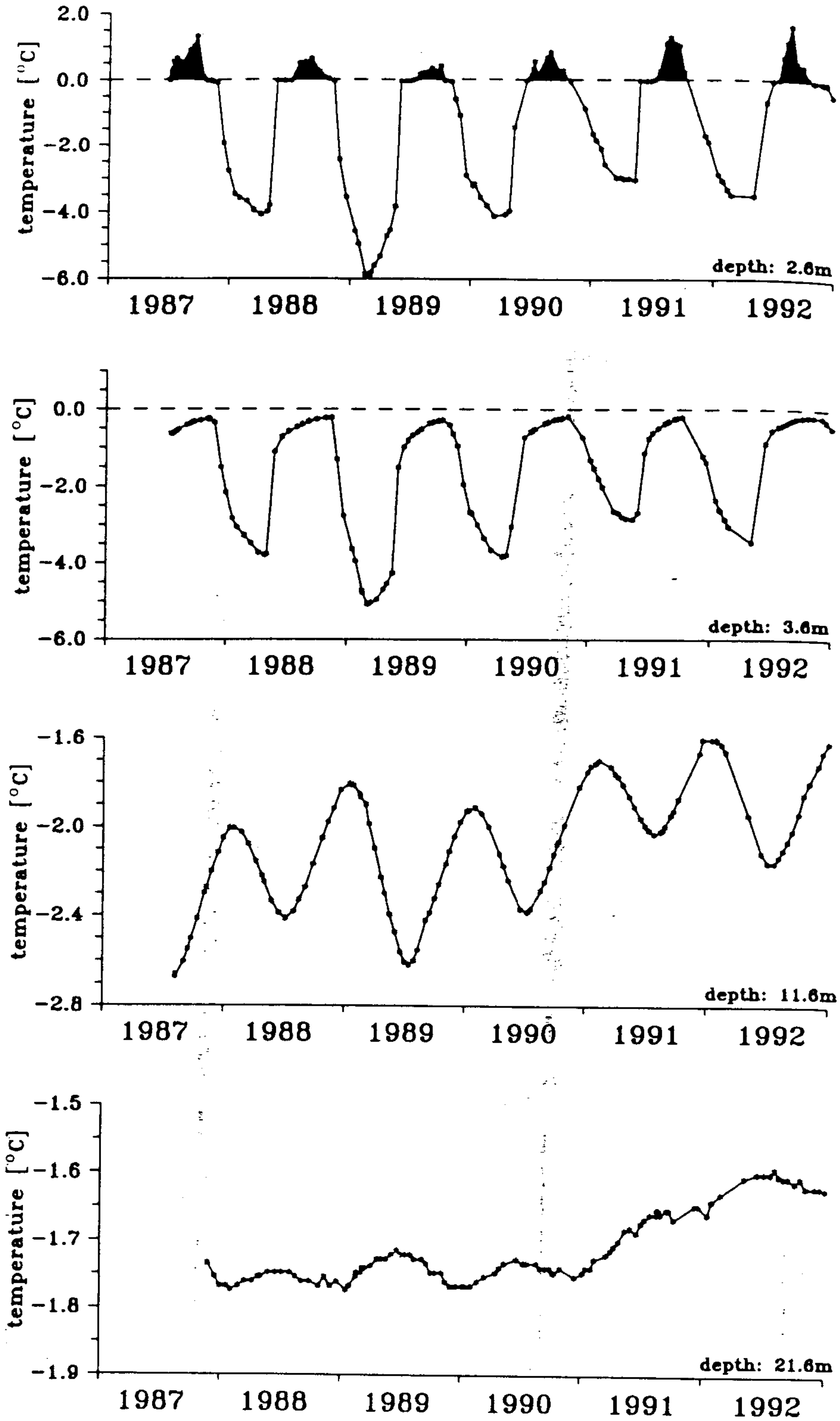


Figure 5.5 Borehole temperatures in the permafrost of the active rock glacier Murtèl/Corvatsch (Grisons) at various depths. The permafrost table is between 2.6 and 3.6 m depth. Recent warming trends from the exceptionally warm 1980s and early 1990s are most clearly visible at 10.6 and 21.6 m depth. The accuracy of the measurements is about ±0.05°C.

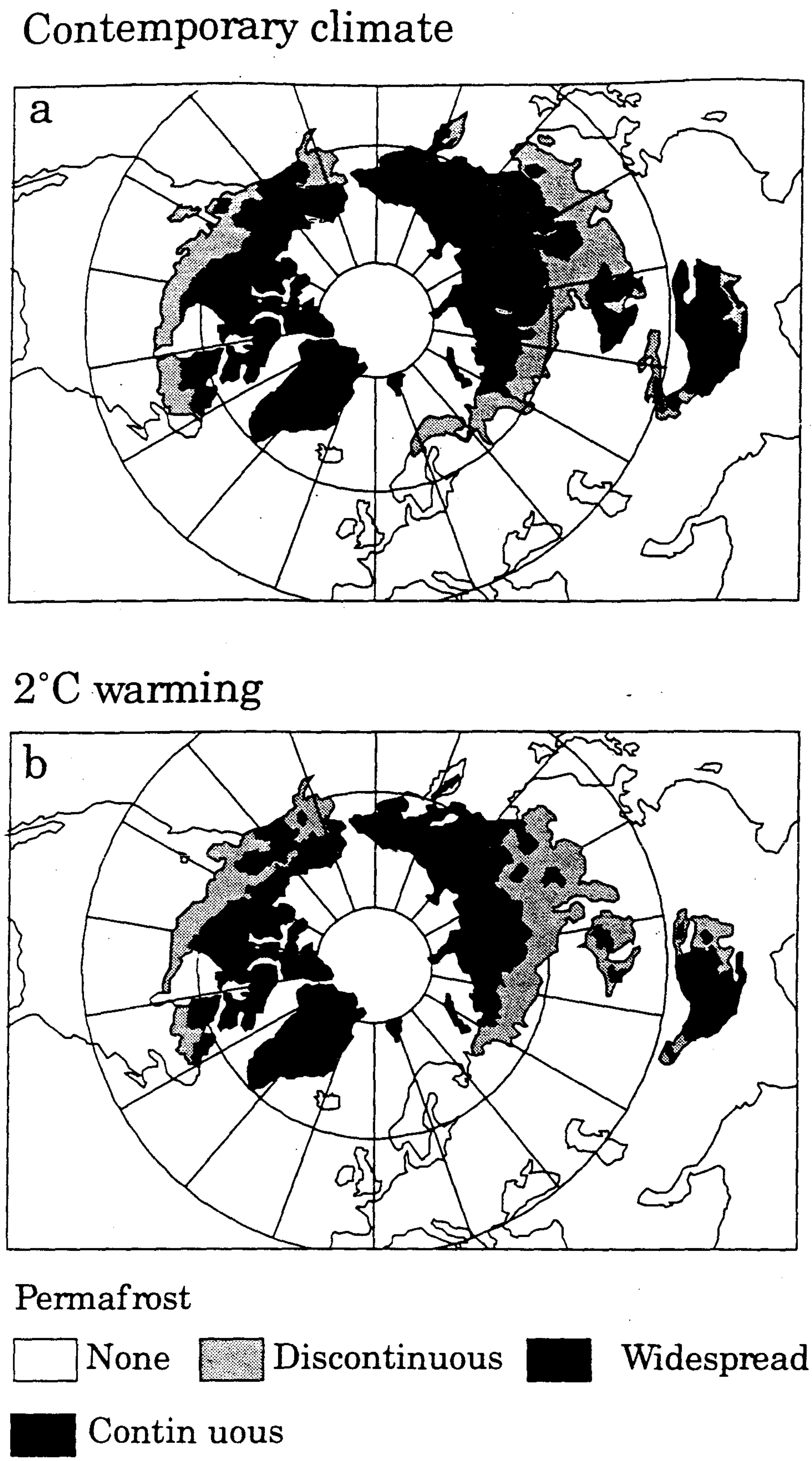


Figure 7-3: Distribution of Northern Hemisphere perma'rost for (a) the present and (b) 2050 (based on Nelson and Outcalt, 1987; Anisimov and Nelson, 1995).