MOUNTAIN PERMAFROST IN EUROPE

Lorenz King[1] and Jonas Åkerman[2]

[1] Geographical Institute, Justus Liebig University,
D-35390 Giessen, Germany
[2] Department of Physical Geography
University of Lund, S-233 62 Lund, Sweden

Abstract:

In several European countries a good knowledge about the properties and the distribution of mountain permafrost has been a vital factor for the development of these areas. This concerns particularly Svalbard (mining and construction activities), the Fennoscandian mountains and the Alps (traffic and protection measures). The distribution of mountain permafrost in Europe is displayed and the most important permafrost features for these mountain areas are mentioned. Whereas island permafrost is very common in many mountain areas, and sporadic permafrost, too, continuous or discontinuous permafrost is restricted to Svalbard, the Fennoscandian mountains and the Alps.

INTRODUCTION

A "Circumarctic Map of Permafrost and Ground Ice Conditions" at a scale 1:10 million has been recently prepared by different member countries of the International Permafrost Association (IPA) and a first draft map has been presented and discussed at the Sixth International Permafrost Conference in Peking 1993. In addition, the IPA Working Group on Mountain Permafrost prepared a special session with contributions from America, Europe and Asia (Haeberli 1993). This paper is part of these presentations and summarizes the knowledge concerning mountain permafrost in Europe.

Available information shows, that permafrost in Europe exists in:
a) Northern Europe (incl. Iceland, the Svalbard Archipelago and the Fennoscandian Mountains)
b) the Alps and
c) the Pyrénées.

To a smaller extent permafrost is also present in:
d) the Tatry Mountains (Poland, Slovakia),
e) the Carpathian Mountains (Romania),
f) the Abruzzi Mountains (Italy) and
g) Scotland.

Permafrost areas are small in Europe, when compared to the American Cordilleras or to Asia with their large areas of mountain and plateau permafrost. However, the European mountains are relatively densely populated or developed, and a good permafrost knowledge is a vital factor in and for these areas and their development (cp. Haeberli, 1992). Therefore, there is a good knowledge about mountain permafrost distribution and properties in quite a number of European countries. During the IPA sponsored international workshop on "Permafrost and Periglacial Environments in Mountain Areas" in Interlaken, Switzerland, 16-20 September, 1991, much of this knowledge has been presented and discussed together with American and Asian permafrost specialists, and research sites in the Alps have been visited before and after the workshop. Meanwhile, most presentations have been published in three issues of Permafrost and Periglacial Processes (volume 3, 1-3, 1992). The references to these papers form an excellent bibliography on mountain permafrost.

One of the sessions was also devoted to definition and classification of mountain permafrost. It was agreed there, that mountain permafrost is perennially frozen ground in mountain areas. This includes mountains in tropical, moderate and polar areas, and their common feature is a considerable altitudinal difference that produces special morphological forms. It is generally accepted today, that active rockglaciers are the most visible expression of mountain permafrost as creep of thick talus or morainic material. A great number of other geomorpholocical expressions for permafrost exist, too, and will be treated in this paper.

According to the considerable altitudinal differences, the distribution pattern of mountain permafrost is rather a vertical than a horizontal one, with many difficulties involved for its presentation on maps. In a short horizontal distance, permafrost may exist as continuous (90 - 100%), discontinuous (50 - 90 %), sporadic (10 - 50 %) or island (0 - 10%) permafrost.

Although these definitions have been used for the Permafrost Map of the Northern Hemisphere presented at the Sixth International Permafrost Conference in Peking, and have also been adopted by the authors for this paper, it should be realized, that these mentioned terms are also used in a different manner not only in Europe, but also in earlier studies in North America. Thus, e.g. the term "sporadic" is often used for areas with less than 10% occurrence, "patchy discontinuous" for 10 to 50% and so on. The addition of percentage values to these terms certainly is a good approach to definition problems and helps to avoid misunderstandings.

SVALBARD

The Svalbard Archipelago is mainly located between about 74° and 80° northern latitude and belongs to the area of continuous permafrost with a MAAT of about -4°C and lower (Åkerman 1980, 1987, King et al., in prep.). Permafrost thicknesses of about 100 m (along the west coast and the larger fiords) and 250 to 450 m (further inland) have been measured, especially in the existing coal mines (Liestøl 1980, 1986, Landvik et al. 1988). Large parts of Spitsbergen, the main island of the archipelago, are an area of rugged mountainous terrain with only narrow coastal plains.

The central parts of Spitsbergen and the large islands in the east are built by young sedimentary rocks and the mountains are plateaulike and divided by wide glacial valleys. 60% of the archipelago are covered by glaciers.

Ice-wedge polygons are frequent in the valley bottoms of the large wide valleys of central Nordenskjöld Land (Svensson 1976). However their distribution is not clear as they are often mixed up with the even more common and more widely distributed soil wedges. These soil wedges are mistakenly often classified as ice-wedges in maps and inventories, because their surficial appearance might be similar (Åkerman 1980, 1987). Pingos are common and found in the large wide valleys of central Nordenskjöld and Andrée Land and more rarely on Edgeøya and Barentsøya. A majority of the pingos are interpreted as open system pingos (Liestøl 1976) but a few have been classified as closed system pingos (Svensson 1973). Palsa-like frost mounds have been reported from Nordenskjöld Land and Nordaustlandet (Åkerman 1982, Salvigsen 1977). Icings of different origin are common all over the region (Åkerman 1980) and most commonly produced by the winter discharge from subpolar glaciers. An interesting form are icings produced in association with some of the surging glaciers.

Steep rock slopes often produce vast amounts of debris, that form rockglaciers in favoured places. These phenomena of mountain permafrost have been studied by Humlum (1982) and by Sollid and Sørbel (1992), also in cooperations with colleagues from ETH-Zürich (Hoelzle, in prep.). Push moraine formation is often favoured by the existence of permafrost in glaciofluvial or marine sediments in the valley floors. The mechanisms of push moraine formation has been studied by Van der Wateren (1992), Lehmann (1993; cp. also Gripp 1926, Sollid & Sørbel 1988).

Although Greenland belongs to the North American continent, it is also regarded as part of the "Nordic Countries" of Europe for historical reasons, and a large number of permafrost studies have been done by European scientists, especially from Denmark. References are compiled in Åkerman (in prep.).

ICELAND

Iceland experiences a mild and humid oceanic climate. Permafrost is limited to the central highlands above 450 m a.s.l. (Thorarinsson 1951, Schunke 1975). The majority of the permafrost observations in Iceland are connected with the flá-surfaces (Islandic bogs), that are characterised by numerous small ponds alternating with level surfaces of wet ground and by a multitude of large hummocks, called rúst (or dys). These rústs are the equivalent of "palsar" in the Scandinavian terminology and found between 400 m and 800 m a.s.l. Their lower limit corresponds fairly well with the 0°C isotherm. At higher altitudes the palsas (rústs) are larger, higher and more stable. Heights may reach 3 m and diameters up to 30-40 m are common.

Observations of permafrost in terminal moraines, rockglaciers and push moraines have been mentioned by Eyles (1978), Humlum (1985) and Rutten (1951). Permafrost is certainly also present in the glacier-free rockwalls and summits above 800 m a.s.l., but no systematic studies have been done.

FENNOSCANDIA

In Fennoscandia, the traditional opinion until recently was, that permafrost in Fennoscandia, even in the northernmost parts, basically was restricted to the palsa bogs (Fries & Bergström 1910, Hamberg 1905, Rapp & Rudberg 1960, Wramner 1973). However, recent studies made clear, that the extent of permafrost is much more widespread and that the majority of the permafrost areas belong to "mountain permafrost" (Østrem 1964, Svensson 1962b, Rapp & Clark 1971, King 1976, 1982, 1983, 1986, Rapp 1982, King & Seppälä 1987, Åkerman & Malmström 1986, Jeckel 1988, Sollid & Sørbel 1992, Ødegard et al. 1992, cp. also Åkerman, manus.). The distribution of permafrost in Fennoscandia is basically a vertical zonation as follows:

Island permafrost with a high or medium high ice content is common in and around the Fennoscandian mountains and is found from Hardangervidda and Dovre in southern Norway (Sollid & Sørbel 1974) up to the Varanger Peninsula in the north. Within this class permafrost is more or less restricted to organic soils, to bogs and to palsas or palsa-like features (Svensson 1962a, 1986, Åhman 1977, Meier 1985, Seppälä 1988). Annual and short-lived frost blisters are also common, here. Island permafrost is quite often observed at altitudes above 1000 m a.s.l. in the south, and reaches down to sea level altitude in the north. In the southernmost mountains of Hardangervidda (Norway) and Jämtland and Härjedalen (Sweden) it may even be found considerably lower than 1000 m a.s.l. at very selected places, mainly bogs. In Jämtland several sites between 650 and 750 m a.s.l. with palsa-like forms and small permafrost lenses have been reported by Smith (1911) or Lundquist (1962).

Sporadic permafrost occupies the mountain areas above 1.200 m a.s.l. in the south (Jotunheimen) and above 750 m a.s.l. in northern Sweden (Kebnekaise). Further north and inland, and due to increased continentality (cp. King & Seppälä 1987, Malmström 1988), this belt can also be found at lower altitudes of 300 m to 400 m. The strong gradient in continentality from west to east is displayed in Figure 1 (cp. also values in table 1). Icings, often in association with karst drainage in the mountains and with small groundwater springs are quite common in the sporadic permafrost belt. Pingo-like features regarded as transitional forms between palsas and pingos are found in the Abisko, Finnmarksvidda and Rastosjaure areas (Svensson 1969, Lagerbäck & Rohde 1985, Åkerman & Malmström 1986); in the lower levels these forms are often relict.

With increasing altitudes, the sporadic permafrost belt gradually changes into discontinuous permafrost at altitudes of about 1600 m a.s.l. in Jotunheimen, and 1200 m a.s.l. in the Kebnekaise mountains. This permafrost belt shows rockglaciers and ice-cored moraines in the steeper, alpine type mountains (Barsch 1971, Østrem 1964) and pronounced large-scale polygon patterns in the smoother Scandinavian fjell-type mountains (Rapp & Clark 1971, Rapp & Annersten 1969). Rock glaciers may reach down into the sporadic zone, especially in the more continental, eastern mountain areas (Barsch & Treter 1976), where the periglacial areas have quite a considerable vertical extent due to a high glaciation limit and relatively low mean annual air temperatures.

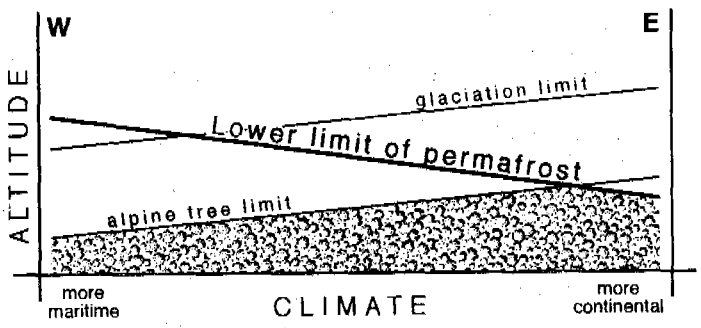

Figure 1: Schematic section across the Scandinavian mountain ranges. From west to east the lower permafrost limits drop considerably and the altitude of the glaciation limit increases. Thus permafrost is mainly found in the eastern (and northern) parts with a more continental climate; the western mountain ranges experience much precipitation and are often glacierized.

The continuous permafrost belt is found above 2060 m in Jotunheimen (Norway) and above 1600 m a.s.l. in northern Sweden (King 1984). It is an area where patterned ground is often as well developed as in many high arctic areas, if slope and sediment cover are favourable. Permafrost thicknesses of about 70 m have been measured even at the relatively low altitude of 1200 m a.s.l. (Ekman 1957) and the thickness of permafrost is estimated to be more than 100 m at about 1500 m a.s.l. and probably even 200 to 300 m in the highest elevations of the Kebnekaise mountain (2400 m a.s.l.) in northern Sweden (King 1984, 1986).

ALPS AND JURA

Research in mountain permafrost has a long tradition in Europe and started mainly in the Alps with the investigation of rockglaciers (Barsch 1978, Haeberli 1985). It is generally agreed today, that active rockglaciers are the most typical phenomena for widespread sporadic or discontinuous mountain permafrost (Barsch 1992). Rockglacier research is still continued in the Swiss, Italian, French and Austrain Alps, and there are a large number of thorougly investigated rockglaciers in all these mentioned countries (cp. Haeberli et al. 1992, Belloni et al. 1993, Evin et al. 1993). Research includes studies of rockglacier movement over a few and up to 25 years, rockglacier drilling and detailed geophysical borehole logging, as well as many geophysical sounding techniques (e.g. Francou et al. 1992, Haeberli et al. 1979, Von der Mühll et al. 1990, 1992). In more recent years, similar studies have also been conducted on Iceland, in the Fennoscandian mountains, as well as on Spitsbergen (cp. references in previous chapters). Freeze/thaw cycles in permafrost areas (e.g. King 1990) and creep of permafrost (Haeberli 1985, Wagner 1992) are other important research topics. Important methodological advances in mountain permafrost research also originated in the Alps: the BTS-method has become an accepted working tool for mapping permafrost very efficiently (e.g. Guglielmin et al. 1993, Hoelzle et al. 1993). Modelling of mountain permafrost distribution and its automated mapping will bring new knowledge and new ideas about permafrost distribution of large areas that have not been investigated detailedly until now (cp. Keller 1992). A methodological review concerning mapping and prospecting of mountain permafrost is given by King et al. (1992). It shows that the Alps represent an important research area for comparative studies in other mountain areas of the world (Cheng et al. 1992, Gorbunov 1978).

In addition to scientific projects (Haeberli 1993), research in mountain permafrost has also been greatly promoted by construction measures. In the Alps, construction includes railways, cable cars, skilifts, restaurants and hotels, communication towers, hydropower installations, high power transmission lines, and protection measures against natural risks. Construction sites can be found in all permafrost belts, from the sporadic to the continuous one (Haeberli 1992). Many bedrock exposures have thus been created and allowed the study of ice-filled bedrock-joints or temperature gradients in tunnels. The scientific permafrost community is very grateful for these engineering activities, and should carefully follow these, wherever possible. Comparable development activities have only started in Northern Europe, Eastern Europe and the Pyrénées, and we will certainly learn much more about mountain permafrost distribution in Europe in the years to come.

In the Alps, permafrost occurs from the southern French and Italian Alps over the central Swiss Alps to the Austrian and German Alps. Predominantely sporadic permafrost with low ice content in bedrock and high ice-content in nonconsolidated sediments exists at altitudes between 2000 m and 2500 m a.s.l. Patchy vegetation and alpine meadows cover these areas and relict and inactive rockglaciers are typical and more numerous than active ones here. Island permafrost extends much further down, to altitudes considerably lower than the treeline in general. The occurrences are limited to special places, as e.g. snow-free rockwalls and slopes exposed to the north, long lasting avalanche deposits and ice-caves in limestone areas. There, the MAAT may be markedly higher than 0°C.

Discontinuous permafrost is common at altitudes above about 2500 m a.s.l. and gradually changes into continuous permafrost at altitudes above 3000 to 3500 m a.s.l. The mean permafrost temperature is -5° to -6°C at Jungfraujoch (3500 m a.s.l., northern Swiss Alps) and about -15°C with maximum permafrost thicknesses expected to exceed 1000 m on Monte Rosa (4,500 m a.s.l., southern Swiss Alps; cp. Haeberli & Funk 1991).

In contrast to the Fennoscandian mountains the Alps have not been shaped by a continental ice-sheet, and flat or rolling mountain landscapes are missing and steep slopes prevail. Due to this geomorphological characteristics of the Alps, the permafrost features so typical for the "Scandinavian fjell" (palsas, pingo-like features, ice-cored moraines, vast large scale polygon patterns) are missing in the Alps or are restricted to a few selected places. Active phenomena of creeping ice-supersaturated sediments from moraines and talus (rockglaciers) dominate instead, and the number of rockglaciers matches the number of glaciers. All forms of solifluction are quite widespread, too.

The Jura mountains are located in France and Switzerland, northwest of the Swiss Alps. For large areas, they consist of parallel folds of mesozoic sediments, often limestone. In the northeast, their continuation reaches to the cuesta-like Alb mountains in Germany. Alltogether, this mountain area is several hundred kilometers long and reaches above 1500 m a.s.l. at many points. Although the MAAT is above freezing point, ice-caves (island permafrost) may be found at many places even at altitudes below 1200 m a.s.l. (Pancza 1992).

OTHER EUROPEAN MOUNTAINS

Besides the main mountain ranges of continental Europe, the Alps and the Scandes, there are a great number of larger and smaller mountain ranges, where permafrost has been proven or where it can be expected, e.g. the Pyrénées, the Carpathians and the Appennine. Table 1 gives the approximate lower limits for island, sporadic and discontinuous mountain permafrost in the mountains of continental Europe.

The lowermost limits for island permafrost include areas of ice caves in karst areas, and the MAAT may therefore reach values considerably above the freezing point there. At the lower limit of sporadic permafrost the MAAT is in the order of -1°C to -1.5°C, and above the altitude of the -3.5°C MAAT discontinuous permafrost (> 50%) can be expected. The maximum altitude of the respective mountain range gives a first idea of the area affected by perennially frozen ground.

In the Pyrénées, geomorphological research has a long tradition, on the French side as well as on the Spanish one and the interest in mountain permafrost research is present, too (cp. Gutierrez et al. 1981). There are more than a dozen active rockglaciers in the Spanish Pyrénées in areas reaching above 2800 m a.s.l. (Agudo et al. 1992, San José et al. 1992, Serrano et al. 1991). According to David Palacios (written communication) the area above 2800 m a.s.l. is regarded as the altitudinal belt of sporadic permafrost (10 - 50 %). In addition to the studies of active permafrost, Chueca (1992) has mapped 170 rockglaciers as relict permafrost forms. The joining of the Spanish national body to the International Mountain Permafrost Association will certainly have a positive effect on more detailed mountain permafrost research in the Pyrénées, where more areas are expected to be underlaid by permafrost according to the existing MAAT of -1.5°C and lower.

In the central part of the Italian Appennine, the Abruzzi mountains, there are three small mountain areas where permafrost can be expected: Gran Sasso, Maiella and Monte Vellino (Dramis & Kotarba 1992).

In the Southern Carpathians, Romania, inactive and active rockglaciers have been reported in altitudes above 2000 m a.s.l. by Urdea (1992). In the Fagaras, the Paring and the Retezat mountain massifs many mountain tops and crests reach altitudes between 2300 and 2500 m a.s.l. and the MAAT at Omu

Table 1: Approximate lower limits for island (0 - 10%), sporadic (10 50%) and discontinuous (> 50%) permafrost in continental Europe. Continuous permafrost exists only in the Alps and in the highest parts of the Scandinavian mountains.

	0 - 10 %	10 - 50%	more than 50 %	Max. Altitude
Fennoscandia				
North / East	400 - 0 m	900 - 300 m	1300 - 700 m	2120 m
South	650 m	1400 - 1000 m	1900 - 1400 m	2470 m
Alps				
- Central, East	1500 m	2500 m	3000 m	4800 m
- South (France)	1750 m	> 2500 m	> 3000 m	3840 m / 4100 m
Jura Mtns.	1150 m	- - - -	- - - -	1720 m
Spain, Pyrénées	2000 m	> 2800 m	- - - -	3400 m
Italy, Abruzzi	2000 m	- - - -	- - - -	2900 m
Yugoslavia	> 2000 m	- - - -	- - - -	2520 m
Albania	> 2000 m	- - - -	- - - -	2760 m
Bulgaria	> 2000 m	- - - -	- - - -	2930 m
Carpathian Mtns.				
- South	2300 m	- - - -	- - - -	2540 m
- East	1900 m	- - - -	- - - -	2060 m
- West (Tatry)	1500 m	2400 m	- - - -	2650 m

(2505 m a.s.l.) is -2.6°C. Here again, a large number of relict rockglaciers exist below about 2000 m a.s.l. and proove former permafrost conditions (Ichim 1978, Urdea 1993).

The mean annual air temperature in the Northern Carpathians, especially in the Tatry mountains (Poland, Slovakia) is lower than -1.5°C, too, and these climatic conditions undoubtedly favour the development of sporadic permafrost. Whereas relict permafrost features have been studied, research on the distribution of active permafrost is still urgently needed (cp. Czudek, 1993).

In Scotland the existence of small permafrost island in the highlands cannot be excluded according to the existing temperatures.

ACKNOWLEDGEMENTS:

Additional contributions for this report came from the following colleagues: Matti Seppälä (northern Finland), Wilfried Haeberli (Switzerland), Michèle Evin (France), Francesco Dramis (Italy), David Palacios (Spain) , Adam Kotarba (Poland) and Petru Urdea (Romania).

REFERENCES:

SVALBARD

Åkerman, H.J. (1980): Studies on Periglacial Geomorphology in West Spitsbergen. PhD thesis. Lunds Universitets Geografiska Inst. Scr. Avh. LXXXIX: 297 pp.

Åkerman, H.J. (1982): Observations of palsas within the continuous permafrost zone in eastern Siberia and in Svalbard. Geografisk Tidsskrift 82: 45-51.

Åkerman, H.J. (1987): Periglacial forms of Svalbard - A review. In: Boardman, J. (ed.): Periglacial Processes and Landforms in Britain and Ireland, Cambridge University Press: 9-25.

Åkerman, H.J. (in prep.): Mountain permafrost in the Nordic countries, a review. - In preparation for Lunds Univ. Naturgeogr. Inst., rapporter och Notiser (1994).

Gripp, K. (1926): Über Frost und Strukturboden auf Spitzbergen. Zeitschr. Gesellsch. f. Erdkunde: 351-354.

Humlum, O. (1982): Rock Glaciers in Northern Spitsbergen: A discussion. Journ. Geol. 90: 214-218.

King L. & M. Volk (in prep.): Glaziologie und Glazialmorphologie des Liefde- und Bockfjordgebietes, Nordspitzbergen. - In preparation for Zeitschrift für Geomorphologie N.F., Suppl.-bd. (1994)

Landvik, J.Y. et al. (1988): Glacial history and permafrost in the Svalbard area. Permafrost, Fifth International Permafrost Conf. Proceedings 1: 194-198, Trondheim.

Lehmann, R. (1993): The Significance of Permafrost in the Formation and Appearance of Push Moraines, Examples of the Canadian Arctic and Spitsbergen. Sixth International Conference on Permafrost, Beijing 1993, Proceedings Vol. 1: 374-379.

Liestøl, O. (1976): Pingos, springs, and permafrost in Spitsbergen, Norsk Polarinstitutt Årbok 1975: 7-29.

Liestøl, O. (1980): Permafrost conditions in Spitsbergen. Frost i Jord 21: 23-28.

Liestøl, O. (1986): Permafrost på Svalbard og på fastlandet. Klimatiske forutsetninger, utbredelse og tykkelse. Fjellsprengningsteknikk, bergmekanikk, geoteknikk. Tapir.

Salvigsen, O. (1977): An observation of palsa-like forms in Nordaustlandet, Svalbard. Norsk Polarinst. Årbok: 364-367.

Sollid, J.L. & L. Sørbel (1988): Influence of temperature conditions in formation of end moraines in Fennoscandia and Svalbard. Boreas 17: 553-558.

Sollid, J.L. & L. Sørbel (1992): Rock glaciers in Svalbard and Norway. Permafrost and Periglacial Processes 3, 3: 215-220.

Svensson, H. (1976): Iskilar som klimatindikator. Svensk Geogr. Årsbok 52: 46-57.

Van der Wateren, D. (1992): Structural Geology and Sedimentology of Push Moraines. Diss., Faculteit der Ruimtelijke Wetenschappen, Univ. van Amsterdam: 230 pp.

ICELAND

Eyles, N. (1978): Rock glaciers in Esjufjöll nunatak area, southeast Iceland. Jökull 28: 53-56.

Humlum, O. (1985): Genesis of an imbricate push moraine, Höfdabrekkujull, Iceland. Journal of Geology 93: 185-195.

Rutten, M.G. (1951): Polygon soils in Iceland. Geologie en Mijnbouw, Mai 1951

Schunke, E. (1975): Die Periglazialerscheinungen Islands in Abhängigkeit von Klima und Substrat. Abh. Akad. Wiss. Göttingen 30: 273 pp.

Thorarinsson, S. (1951): Notes on patterned ground in Iceland, with particular reference to the Icelandic "Fia's". Geogr. Ann. 33: 144-156.

FENNOSCANDIA

Åhman, R. (1977): Palsar i Nordnorge. Medd. Lunds Univ. Geogr. Inst. Scr. Avh. 78: 165 pp.

Åkerman, H.J. & B. Malmström (1986): Permafrost mounds in the Abisko area, Northern Sweden. Geogr. Ann. 68 A, 3: 155-165.

Åkerman, H.J. (in prep.): cp. section on Svalbard

Barsch, D. (1971): Rock glaciers and ice-cored moraines. Geogr. Ann. 53 A, 3-4: 203-206.

Barsch, D. & U. Treter (1976): Zur Verbreitung von Periglazialphänomenen in Rondane/Norwegen. Geogr. Ann. 58 A: 83-93.

Ekman, S. (1957): Die Gewässer des Abisko-Gebietes. Kungl. Vetenskapsakademiens Handlingar 4, e ser. 6, 6: 172 pp.

Fries, T. & E. Bergström (1910): Några iaktagelser öfver palsar och deras förekomst i nordligaste Sverige. Geol. Fören. Förhandl. Stockholm 32: 195-205.

Hamberg, A. (1905): Till frågan om alltid frusen mark i Sverige. Ymer 24: 87-93.

Jeckel, P.P. (1988): Permafrost and its altitudial zonation in N. Lapland. In: Permafrost, Fifth International Permafrost Conference, Proceedings Vol. 1: 170-175.

King, L. (1976): Permafrostuntersuchungen in Tarfala, Schwedisch Lappland, mit Hilfe der Hammerschlagseismik. Z. Gletscherk. u. Glazialgeol. 12, 2: 187-204.

King, L. (1982): Qualitative und quantitative Erfassung von Permafrost in Tarfala (Schwedisch Lappland) und Jotunheimen (Norwegen) mit Hilfe geoelektrischer Sondierungen. Z. Geomorph., Suppl.Bd. 43: 139-160.

King, L. (1983): High mountain permafrost in Scandinavia. In: Permafrost, Fourth International Conference, Proceedings Vol. 1: 612-617, Nat. Acad. Press, Washington, D.C.

King, L. (1984): Permafrost in Skandinavien, Untersuchungsergebnisse aus Lappland, Jotunheimen und Dovre/Rondane. Heidelberger Geogr. Arb.76: 174 pp.

King, L. (1986): Zonation and ecology of high mountain permafrost in Scandinavia. Geogr. Ann. 68 A: 131-139.

King, L. & M. Seppälä (1987): Permafrost thickness and distribution in Finnish Lapland - results of geoelectrical soundings. Polarforschung 57, 3: 127-147.

Lagerbäck, R. & L. Rodhe (1985): Pingos in northernmost Sweden. Geogr. Ann. 67 A, 3-4: 239-245.

Lundquist, J. (1962): Patterned ground and related frost phenomena in Sweden. Sveriges Geologiska Undersökning, Ser. C 55: 101 pp.

Malmström, B. (1988): Occurence of permafrost on the Varanger Peninsula, northernmost Norway. Norsk Geogr. Tidsskr. 42: 239-244.

Meier, K.-D. (1985): Studien zur Verbreitung, Morphologie, Morphodynamik und Ökologie von Palsas auf der Varanger-Halbinsel, Nord-Norwegen. Essener Geographische Arbeiten 10: 114-204.

Ødegård,R. et al. (1992): Ground temperature measurements in mountain permafrost, Jotunheimen, Southern Norway. Permafrost and Periglacial Processes 3: 231-234.

Østrem, G. (1964): Ice-cored moraines in Scandinavia. Geogr. Ann. 46: 282-337.

Rapp, A. (1982): Zonation of permafrost indicators in Swedish Lapland. Geogr. Tidsskrift 82: 37-58.

Rapp, A. & L. Annersten (1969): Permafrost and tundra polygons in northern Sweden. In: Péwé, T. (ed.): The periglacial environment. Montréal, Canada.

Rapp, A. & G.M. Clark (1971): Large nonsorted polygons in Padjelanta National Park, Swedish Lapland. Geogr. Ann. 53 A: 71-85.

Rapp, A. & S. Rudberg (1960): Recent periglacial phenomena in Sweden. Biul. Perigl. 8: 143-154.

Seppälä, M. (1988): Palsas and related forms. In: M.J. Clark (ed.): Advances in Periglacial Geomorphology: 247-278.

Smith, H. (1911): Postglaciala regionförskjutningar i norra Härjedalen och södra Jämtlands fjälltrakter. Geol. Fören. Stockholm Förh. 33: 503-530.

Sollid, J.L. & L. Sørbel (1974): Palsa bogs at Haugtjørnin, Dovrefjell, South Norway. Norsk Geografisk Tidsskrift 28,1: 53-60.

Sollid, J.L. & L. Sørbel (1988): Influence of temperature conditions in formation of end moraines in Fennoscandia and Svalbard. Boreas 17: 553-558.

Sollid, J.L. & L. Sørbel (1992): Rock glaciers in Svalbard and Norway. Permafrost and Periglacial Processes 3, 3: 215-220.

Svensson, H. (1962a): Några iaktagelser från pals områdon. Norsk Geogr. Tidsskrift 18, 5-6: 212-227.

Svensson, H. (1962b): Tundra polygons. Photographic interpretation and field studies in North Norwegian polygon areas. Arb. Norges Geol. Unders 223: 298-327.

Svensson, H. (1969): A type of circular lakes in northernmost Norway. Geogr. Ann. 51 A: 1.12.

Svensson, H. (1986): Some morphoclimatic aspects of periglacial features of northern Scandinavia. Geogr. Ann. 68 A:123-130.

Wramner, P. (1973): Palsmyrar i Taavavuoma, Lapland. Göteborgs Univ. Naturgeogr. Inst. Rapp. 3: 140 pp.

ALPS AND JURA

Barsch, (1978): Active Rock Glaciers as Indicators for Discontinous Alpine Permafrost, an Example from the Swiss Alps. Proceedings of the Third International Conference of Permafrost, July 10-13, 1978, Edmonton, Alberta, Canada. Vol. 1: 349-352, Ottawa.

Barsch, D. (1992): Permafrost creep and rockglaciers. Permafrost and Periglacial Processes 3, 3: 175-188.

Belloni, S., A. Carton, F. Dramis & C. Smiraglia (1993): Distribution of permafrost, glaciers and rock glaciers in the Italian mountains and correlations with climate: an attempt to sythesize. Sixth International Conference on Permafrost, Beijing 1993, Proceedings Vol. 1: 272-277.

Cheng, G. & F. Dramis (1992): Distribution of mountain permafrost and climate. Permafrost and Periglacial Processes 3, 2: 83-91.

Evin, M., D. Fabre, A. Assier & Ch. Guillain (1993): Les glaciers rocheux du Roure. Société hydrotechnique de France, section glaciologie, Grenoble: 6 pp.

Francou, B. & L. Reynaud (1992): 10 years surficial velocities on a rock glacier (Laurichard, French Alps). Permafrost and Periglacial Processes 3, 3: 209-214.

Gorbunov, A. P. (1978): Permafrost investigation in high mountain regions. Arctic and Alpine Research 10, 2: 283-294.

Guglielmin, M. & C. Tellini (1993): First example of permafrost mapping with BTS in the Italian Alps (Livigno, Sondrio, Italy). Acta-Naturalia de l'Ateneo Parmenese 29, NN. 1/2: 39-46.

Haeberli, W. (1985): Creep of mountain permafrost: internal structure and flow of alpine rock glaciers. Mitt. der Versuchsanstalt für Wasserbau, Hydrologie und Glaziologie 77, ETH Zürich: 142 pp.

Haeberli, W. (1992): Construction, environmental problems and natural hazards in periglacial mountain belts. Permafrost and Periglacial Processes 3, 2: 111-124.

Haeberli, W. (1993): Research on permafrost and periglacial processes in mountain areas - status and perspectives. (This volume)

Haeberli, W., M. Evin, G. Tenthorey, H.R. Keusen, M. Hoelzle, F. Keller, D. Vonder Mühll, S. Wagner, M. Pelfini & C. Smiraglia (1992): Permafrost research sites in the Alps: excursions of the International Workshop on Permafrost and Periglacial Environments in Mountain Areas. Periglacial Processes 3, 3: 189-202.

Haeberli, W. & M. Funk (1991): Borehole temperatures at the Colle Gnifetti core-drilling site (Monte Rosa, Swiss Alps): Journal of Glaciology 37, 125: 37-46.

Haeberli, W., L. King & A. Flotron (1979): Surface movements and lichen-cover studies at the active rock glacier near the Grubengletscher, Wallis, Swiss Alps. Arctic and Alpine Res. 11, 4: 421-441.

Hoelzle, M., W. Haeberli & F. Keller (1993): Application of BTS-measurements for modelling mountain permafrost distribution. Sixth International Conference on Permafrost, Beijing 1993, Proceedings Vol. I: 272-277.

Keller, F. (1992): Automated mapping of mountain permafrost using the program PERMAKART within the geographical information system ARC/INFO. Permafrost and Periglacial Processes 3, 2: 133-138.

King, L. (1990): Soil and rock temperatures in discontinuous permafrost: Gornergrat and Unterrothorn, Wallis, Swiss Alps. Permafrost and Periglacial Processes 1,2: 177-188.

King, L., A. P. Gorbunov & M. Evin (1992): Prospecting and mapping of mountain permafrost and associated phenomena. Permafrost and Periglacial Processes 3,2: 73-81.

Pancza, A. (1992): La gélivation des parois rocheuses dans une glacière du Jura Neuchâtelois. Permafrost and Periglacial Processes 3, 2: 49-54.

Vonder Mühll, D. & W. Haeberli (1990): Thermal characteristics of the permafrost within an active rock glacier (Murtèl/Corvatsch, Grisons, Swiss Alps). Journal of Glaciology 36, 123: 151-158.

Vonder Mühll, D. & P. Holub (1992): Borehole logging in Alpine permafrost, Upper Engadin, Swiss Alps. Permafrost and Periglacial Processes 3, 2: 125-132.

Wagner, S. (1992): Creep of Alpine permafrost, investigated on the Murtèl rock glacier. Permafrost and Periglacial Processes 3, 2: 157-162.

OTHER EUROPEAN AREAS

Agudo, C., E. Serrano & E. Martinez de Pison (1989): El glaciar rocoso activo de Los Gemelos en el Macizo de Posets (Pirinéo Aragones): Cuaternario y geomorfología. Vol. 3: 83-91.

Chueca, J. (1992): A statistical analysis of the spatial distribution of rock glaciers, Spanish Central Pyrenees. Permafrost and Periglacial Processes 3, 3: 261-265.

Czudek, T. (1993): Pleistocene Periglacial Structures and Landforms in Western Czechoslovakia. Permafrost and Periglacial Processes 4, 1: 65-76.

Dramis, F. & A. Kotarba (1992): Southern limit of relict rock glaciers, Central Appennines, Italy. Permafrost and Periglacial Processes 3, 3: 257-260.

Gutierrez, M. & J.L. Peña (1981): Los glaciares rocosos y el modelado acompañante en el área de la Bonaigua (Pirinéo de Lérida). Bol. Geol. Minéro 92: 11-20.

Ichim, I. (1978): Preliminary observations on the rock glacier phenomenon in the Romanian Carpathians. Revue Roumaine Géol. Géof. Géogr., Géographie 23, 2: 295-299.

San José, J.J. De, C. Agudo, E. Serrano & F. Silio (1992): Auscultación topografica y fotogrametrica del glaciar rocoso de Las Argualas (Pirinéo Aragones): datos preliminares. In: F. Lopez Bermudez, C. Conesa Garcia & M.A. Romero Diaz (eds.): Estudios de geomorfología en España, actas de la reunion de la II reunion nacional de GEO: 423-431, Murcia.

Serrano, E., E. Martinez de Pison et al. (1991): El glaciar noroccidental del Besiberri (Pirinéo de Lérida). Pirinéos 137: 95-109

Urdea, P. (1992): Rock Glaciers and Periglacial Phenomena in the Southern Carpathians. Permafrost and Periglacial Processes 3, 3: 267-273.

Urdea, P. (1993): Permafrost and Periglacial forms in the Romanian Carpathians. Sixth International Conference on Permafrost, Beijing 1993, Proceedings Vol. 1: 631-637.