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# DEVELOPMENT AND PRESENT STATE OF GERMAN PERIGLACIAL RESEARCH IN ARCTIC AND ALPINE ENVIRONMENTS

## Abstract

After a short disscussion of the term *periglacial,* for which in German two versions, *periglazial* and *periglaziär* coexist, the development of periglacial research as reflected in the German literature is outlined. This paper focusses on research activities in arctic, subarctic and alpine environments after the Second World War, a phase in which most attention has been devoted to alpine periglacial studies in various parts of the world.

Regional studies rather than studies on specific periglacial phenomena prevail and show the geographical affiliations of German periglacial research. Traditionally a branch of descriptive climatic geomorphology, research in actuo-periglacial environments has experienced a gradual shift towards more ecological approaches. This is reflected by an increasing consideration of the whole range of periglacial environmental factors and their complex interrelation.

The next section focusses on periglacial micromorphodynamics and microrelief features. Results on patterned grounds, earth hummocks, seasonal frost crack polygons, palsas, depergelation forms (thermokarst) and gelifluction are briefly reviewed.

In the section on periglacial meso- and macromorphodynamics cryoplanation forms, convexo-concavo slope profiles, periglacial fluvial and eolian activity are discussed. Active cryoplanation forms have been described from a maritime non-permafrost environment.

Finnally, studies dealing with the spatial delimitation and regionalisation of the polar and alpine periglacial zone are summarized. It can be shown that the periglacial zone is not absolutely identical with the distribution of permafrost and can only be delimited and subdivided by means of climatic associations of periglacial microrelief features.

## Résumé de l'auteur

Après une courte discussion du terme *périglaciaire* (pour lequel deux versions *periglazial* et *periglaziär* coexistent en allemand), l'auteur donne une vue générale des recherches périglaciaires sur la base de l'étude des travaux allemands publiés après la dernière guerre. Les travaux considérés portent sur l'arctique, le subarctique et le domaine alpin. Cette synthése montre que beaucoup d'études ont porté sur les phénomènes périglaciaires de montagne dans le monde entier.

Les études régionales sont plus nombreuses que celles se rapportant à des phénomènes périglaciaires spécifiques; elles montrent la tendance proprement géographique des recherches périglaciaires allemandes. Ces études constituent traditionnellement une branche de la géomorphologie périglaciaire descriptive; la recherche sur les milieux périglaciaires actuels a cependant progressivement évolué vers des approches plus écologiques. Ceci apparaît par la prise en considération de plus en plus importante de l'ensemble des facteurs de l'environment et de la complexité de leurs interactions.

La section suivante est consacrée aux microprocessus et aux microreliefs. Les résultats sur les buttes de terre les fissures polygonales de gel saisonnier, les palsas, les formes de thermokarst et de gélifluxion sont également passés en revue.

Dans la partie consacrée aux phénomènes de taille moyenne et grande, les formes de cryoplanation, les profils de pente convexo-concave ainsi que les activités fluviatiles et éoliennes sont discuteés. Des formes de cryoplanation active ont été décrites dans un environnement maritime sans pergélisol.

Des études consacrées à la délimitation spatiale et à la régionlisation de la zone polaire et montrent que la zone périglaciaire ne recouvre pas exactement les régions ou existe un pérgélissol.

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## INTRODUCTION

Although Germany at present participates only insignificantly in the active alpine periglacial zone and although the major part of German periglacial studies is devoted to the Pleistocene periglacial environment research activities in actuoperiglacial environments, both polar and alpine, have a long tradition and have generated a voluminous literature.

In the German literature the term *periglacial* is used in two versions, *periglazial* which was originally introduced by ŁOZIŃSKI (1909) and *periglaziär* which was suggested by GRAHMANN (1951). *Periglazial* which is still more widespread is either used in a general and comprehensive or in a restricted temporal sense whereas *periglaziär* is rather used in a process oriented, ecological and spatial sense. In accordance with GRAHMANN (1951) the reviewer prefers the latter because of its general geomorphological and geographical meaning (KARTE, 1979).

The development of German periglacial research in Arctic and Alpine environments can roughly be divided into two phases the first of which started soon after the beginning of this century and received its main impulses from the 1910 International Geological Congress in Stockholm, the Spitsbergen field excursions and the evolution of „climatic geomorphology" in the 1920's for which periglacial research seemed to offer particularly rewarding opportunities (*cf.* POSER, 1977). Apart from Spitsbergen, Iceland and Greenland became the main research areas. The achievements of this early phase have been summarized by TROLL in his classic paper of 1944 which was later extended (1947, 1948) and is also available in English (1958). These studies are bench-marks within geographically and climatically oriented periglacial research which draws its conclusions concerning periglacial processes and environments primarily from an analysis of the spatial distribution of periglacial phenomena in relation to climatic and edaphic conditions.

Like in other countries the interest in research on actuoperiglacial environments has increased considerably in Germany since the Second World War. The role it has played since, within geomorphology as a whole, can be gathered from a review of the frequency of research subjects in geomorphological publications between 1950 and 1974 (BLUME, 1975). According to this survey almost 9% of the publications which were taken as a basis deal with periglacial topics. This is only exceeded by papers on glacial (13.6%) and fluvial geomorphology (13.7%).

It is the object of this paper to review the German periglacial literature of this phase and to outline the present state-of-the-art. This review is based on 250 publications between 1945 and 1979 dealing with the present polar and alpine periglacial environments. For reasons of space such an attempt will have to be incomplete and selective.

RESEARCH AREAS, TOPICS AND WAYS OF APPROACH

With regard to research areas in the Arctic and Subarctic, Greenland, Iceland and above all Spitsbergen remained classic areas of research interest. In recent years this has been extended to northern Canada, Alaska and the Antarctic. Within these the specific research areas and topics have often been selected from an actualistic point of view in order to gather information for paleogeographical reconstructions of the Pleistocene periglacial environment in Central Europe (BÜDEL, 1962; BARSCH, KING, 1979). However, this actualistic principle was restricted mainly to similarities of the topographical and geological situation whereas climatic considerations and preexisting geomorphic conditions have been largely neglected so far.

Table I

Classification by subject of 250 publications on periglacial research, 1945—1979

| Research topics | Percentage of papers | |
|---|---|---|
| Terminology | | 1.6 |
| Environmental factors including frozen ground, total | | 16.8 |
| Environmental factors | 4.8 | |
| Frozen ground, needle ice | 2.0 | |
| Polar permafrost | 2.0 | |
| Alpine permafrost, rock glaciers | 8.0 | |
| Microperiglacial morphodynamics, total | | 29.6 |
| Weathering | 2.0 | |
| Features related to thermal contraction | 0.8 | |
| Sorted forms | 12.8 | |
| Nonsorted circles | 0.4 | |
| Earth hummocks | 3.6 | |
| String bogs | 0.4 | |
| Pingos | 0.8 | |
| Palsas | 0.8 | |
| Depergelation forms | 2.4 | |
| Gelisolifluction | 5.6 | |
| Meso- and macroperiglacial morphodynamics, total | | 12.8 |
| Nivation, cryoplanation | 3.6 | |
| Slope forming processes | 3.6 | |
| Periglacial fluvial | 4.4 | |
| Periglacial eolian | 1.2 | |
| Regionalisation of the polar periglacial zone | | 5.6 |
| Regionalisation of the alpine periglacial zone, total (including permafrost and rock glaciers) | | 33.6 (41.6) |
| Subpolar | 3.2 | |
| Midlatitudes | 12.8 | |
| Subtropics | 9.2 | |
| Tropics | 4.4 | |
| Large-scale syntheses | 4.0 | |

Compared to the earlier phase of German periglacial research and to research in polar periglacial environments, considerably more attention has been devoted to high alpine environments in various parts of the world since the Second World War. Most work in this respect has been done in connection with a research project initiated by POSER on the delimitation and subdivision of the alpine periglacial zone along a meridional profile between the European Subarctic and equatorial Africa. These investigations have recently been supplemented by studies in the Andes and the North American Cordillera.

This primary interest in alpine periglacial environments can also be seen from a review of the topics of the publications on which this paper is based (Tab. I). On the whole regional studies prevail rather than studies on specific periglacial phenomena. This results from the predominantly geographical affiliations of German periglacial research. More than 40% of the reviewed publications focus on the present alpine periglacial zone and alpine frost action phenomena, particularly in midlatitudes (12.8%). With regard to periglacial processes and landforms, studies on periglacial micromorphodynamics prevailed (30%), but in recent years more attention has been devoted also to other geomorphic features like cryoplanation forms or rock glaciers which have been intensely studied in connection with alpine permafrost (8%). Although quantitatively few studies deal with fluvial or slope wash processes in the periglacial environment these have strongly influenced the formulation of general models in climatic geomorphology (BÜDEL, 1969, 1977).

There are still close links between periglacial research and climatic geomorphology but within the last ten years there has been a gradual shift towards a more ecological approach (POSER, 1977), which is manifested by an increasing consideration of the whole range of periglacial environmental factors and by a growth of interest in the exact measurements of processes and their environmental boundary conditions and by studies in small-scale geomorphic systems.

## PERIGLACIAL ENVIRONMENTAL FACTORS

Periglacial climatic conditions are usually approached at the scale of macroclimatic parameters although it is recognized that these may be of little relevance. Since TROLL'S (1944) investigations particular importance has been attached to the frequency and intensity of freeze—thaw cycles. Later studies in the Alps (HASTENRATH, 1960) and on Iceland (SCHUNKE, STINGL, 1973) have revealed that freeze—thaw cycles in the air near the ground are insignificant for periglacial morphodynamics and that the regional variability of freeze—thaw cycles in the air finds no correspondence in the ground.

Detailed soil climate studies were also carried out on Spitsbergen (BÜDEL, 1962, 1977; HERZ, ANDREAS, 1966; FURRER, 1969; STÄBLEIN, 1970), West Greenland (STÄBLEIN, 1977 c, d), East Greenland (SCHUNKE, 1979a) and in various parts of the Alps (VORNDRAN, 1972; KARRASCH, 1973). They focussed on the determination of the thickness and vertical differentiation of the active layer, the temperature and depth of the level of zero amplitude as well as on the correlation between the temporal course of weather and snowmelt and the annual course of temperature and moisture conditions in the active layer.

Other studies are related to polar permafrost. In an older study, GÖHRS (1951) had postulated that due to usually higher ground temperatures and the isolating effect of snow cover permafrost would only occur at a mean annual air temperature several degrees below the freezing point. Recently, STÄBLEIN (1977d) has investigated its distribution and regional subdivision in West Greenland. As a result the continuous and discontinuous permafrost can be delimited by the —7.5 °C and the —2° to —3 °C annual isotherms respectively. On the basis of available literature and partly conflicting maps STÄBLEIN (1979a) also produced a permafrost map of North America which, however, does not differ substantially from existing North American maps. Although permafrost presupposes a negative annual heat balance at its surface and within its thermal regime, heat balance, energy balance or radiation balance data have not been used for its spatial delimitation so far. The reviewer has compared existing permafrost maps with available radiation and energy balance data (BUDYKO, 1963; KELLEY, WEAVER, 1969; FRANZ, 1973; BARRY, HARE, 1974). As a result it could be shown that even continuous permafrost does not need a negative mean annual net radiation on the landsurface but may occur at positive values of $< 20$ kcal/cm$^{-2}$ (KARTE, 1979).

Up to now there have been only a few studies on the spatio-temporal development of polar permafrost. BÜDEL (1972) described a fossil active layer below the recent active layer on SE Spitsbergen which could be dated as 6000—5000 B.C. STÄBLEIN (1979a) mentions a similar development of permafrost in the Canadian Arctic. According to SCHUNKE (1975) the sporadic permafrost on Iceland is subfossil or fossil. By means of dated tephra layers it could be shown that permafrost was still formed after 1000 B.C. From the recent reactivation of subfossil periglacial geomorphic features such as palsas and frost crack polygons a recent aggradation of permafrost is postulated which can be related to a general climatic cooling in the Arctic and Subarctic since the 60's of this century. At the same time degradation as a result of warmer period between 1930 and 1960 still continues in places (PRIESNITZ, SCHUNKE, 1978). Although the climatic trend in SE Greenland is similar this is for unfavourable edaphic reasons not manifested in the periglacial microrelief (SCHUNKE, 1979a).

Alpine permafrost has been investigated in connection with studies on rock glaciers (BARSCH, 1969, 1977a, 1977b, 1978; FURRER, FITZE, 1970; HAEBERLI, 1975), which are regarded as the best indicators of alpine permafrost. In the Alps the active layer reaches a thickness between 1 and 3.5 m (BARSCH, 1973). A greater thickness indicates that the underlying permafrost body is not in equilibrium with present climatic conditions. Alpine permafrost occurrences have been studied by boring and direct temperature measurements (BARSCH, 1977a), refraction seismics (BARSCH, 1973; KING, 1976) and the determination of the temperature at the base of the winter snow cover as a sort of indirect heat flow measurement (HAEBERLI, 1973, 1978). Analogous to polar permafrost, alpine permafrost is vertically subdivided into continuous, discontinuous and sporadic permafrost with the continuous permafrost in the Alps being delimited by the −8 °C to −8,5 °C annual isotherm, the discontinuous permafrost by the −1 °C to −2 °C annual isotherm whereas sporadic permafrost can even occur at positive mean annual air temperatures.

Seasonally frozen ground has been studied in the Alps and in Iceland where SCHUNKE and STINGL (1973) make a distinction between a maritime type with shallow discontinuous freezing and frequent freeze—thaw cycles and a continental type with deep and long freezing and only few freeze—thaw cycles. According to SCHUNKE (1975) the latter resembles permafrost in its effects on periglacial meso- and macromorphodynamics.

On the whole frost climate conditions are now seen as minimum factor which determines the potential occurrence of periglacial processes and landforms. Within these climatic boundary conditions periglacial morphodynamics is primarily controlled by the preexisting relief, allochthonous sediments as well as local and edaphic factors (SCHUNKE, 1977a, 1979a; STÄBLEIN, 1977a) on which numerous observations are found widely dispersed in the regional studies and which have partly been summarized elsewhere (SCHUNKE, 1975; HÖLLERMANN, POSER, 1977; KARRASCH, 1977).

## PERIGLACIAL MICROMORPHODYNAMICS AND MICROFORMS

As in other environments weathering is an essential pre-requisite for the intensity of periglacial morphodynamics. Frost shattering is regarded as the prevailing type of weathering although examples of chemical weathering in the periglacial environment are also pointed out (HÖLLERMANN, 1964; SEMMEL, 1969; MECKELEIN, 1974). A distinction is made between surface weathering in the seasonally frozen ground and permafrost which according to STÄBLEIN (1977b) produces even silt and clay particles. BÜDEL (1969) pointed out that in the upper parts of ice-rich permafrost (which he calls „ice-crust") above the level of zero amplitude frost shattering is particularly intensive and an important precondition for intensive fluvial erosion in permafrost environments.

Studies on the lithological control of frost weathering have stressed that texture, porosity and permeability are far more important than petrographic hardness or mineralogical composition (HÖLLERMANN, 1964; STINGL, 1969). With regard to climatic controls it could be shown that the duration, depth and intensity of ground freezing and the availability of moisture are critical factors rather than the frequency of freeze — thaw cycles (HÖLLERMANN, 1964; SCHUNKE, 1975; MATHYS, 1974). Intensities have been approached via quantitative studies of debris production in a midlatitude alpine periglacial environment (VORNDRAN 1969).

With regard to periglacial micromorphodynamics and to patterned ground studies sorted forms have received most attention in German periglacial literature. They are regarded as typical polygenetic features. SCHENK (1955) stressed the importance of hydration and dehydration processes for their formation. In recent summarizing studies the following basic mechanisms are distinguished (STINGL, 1974; SCHUNKE, 1975; STINGL, HERRMANN, 1976):

1. cracking (frost, hydration or desiccation) in connection with actual frost sorting,

2. turbation movements of the fines in connection with vertical, lateral and centrifugal migration of the coarse material as a consequence of cryo- or/and hydrostatic pressure differences in the active layer or seasonally frozen ground.

Convection theory is rejected. While these concepts are discussed at length actual process studies have been neglected.

Since the studies of POSER (1933) and TROLL (1944, 1947, 1948) much attention has been focussed on a climatic classification of different types of sorted forms (KIM, 1967; STINGL, 1971; VORNDRAN, 1972; PREUSSER, 1973). Recent quantitative studies on Iceland and observations in the Alps have defeated this idea and stressed the role of edaphic factors as controlling the occurrence of different size types of sorted forms (HÖLLERMANN, 1964, 1967; STINGL, 1969, 1971, 1974; SCHUNKE, 1975; STINGL, HERRMANN, 1976). Quantitative studies on the micromorphometric variables have also confirmed the basic similarity of the internal structure of polar and alpine occurrences (HERZ, 1964; FURRER, 1968, 1969; ABT, BACHMANN, BÜHLER, FURRER, 1971; FREUND, 1971).

Compared with sorted forms nonsorted circles (mudpits) have not yet been studied in detail (SEMMEL, 1969; FITZE, 1975; STÄBLEIN, 1977a, 1977b). Earth hummocks have been described from high arctic (HABRICH, 1968), subarctic (MÜLLER, 1962; SCHUNKE, 1975, 1977b, 1977c, 1979a; STÄBLEIN, 1977a), various alpine localities (HÖLLERMANN, 1964, 1967; ELSASSER, 1967; STINGL, 1969; KELLETAT 1970; GARLEFF, 1970) and sporadic occurrences even from low altitudes in midlatitudes (KELLETAT, 1969b). The classical occurrences on Iceland are restricted to a narrow range of edaphic and hydrological conditions with a marked content of frost susceptible fines in the substrate, good water holding capacities and a closed vegetation cover.

Very few German studies exist on polygonal crack patterns. SCHENK'S (1955, 1966) theory of the formation of ice-wedges by Taber ice and not by thermal contraction can no longer be supported. Seasonal frost crack polygons on Iceland can be explained by thermal contraction or dehydration (SCHUNKE, 1974a, 1975) and are in many respects similar to the ground wedges described from other parts of the Arctic. On Iceland they occur without permafrost and are presently reactivated at a mean annual air temperature of $-1.6\,^{\circ}C$. This shows that on Iceland they occur close to their climatic boundary conditions. With regard to frost and ice mounds MÜLLER'S (1959) classic study of the formation and distinction between closed and open system pingos needs no further mention. Palsas have been studied in Lapland (QUITZOW, 1963), Greenland (STÄBLEIN, 1977a) and especially in Iceland where SCHUNKE (1973, 1975; PRIESNITZ, SCHUNKE, 1978) could identify aggradational and degradational forms resulting from the above mentioned climatic trends in the Arctic and Subarctic during the last five decades. The degradational forms are generally regarded as „thermokarst" features. The reviewer has rejected this popular though scientifically incorrect term and proposed with reference to BRYAN (1946) the term *depergelation forms* (KARTE, 1979). Such forms have been described from Northern Alaska (FÜRBRINGER, HAYDN, 1974), West Greenland and the Canadian Arctic (STÄBLEIN, 1977a, 1979a).

A voluminous literature relates to gelisolifluction which has also been the object of vivid terminological discussions (BÜDEL, 1959; ROHDENBURG, 1971; REICHMANN, 1978). As a result the term *gelisolifluction* should be reserved for frost induced slow mass movements on slopes and not include *in situ* movements of particles which TROLL (1944, 1947) called *microsolifluction*.

The following environmental factors have been stressed as critical for the occurrence and intensity of gelisolifluction: effective freeze — thaw cycles, amount of water-holding fines in the substrate, soil moisture content, degree of vegetation cover and inclination of slopes between 2° and 30° (BÜDEL, 1962; FITZE, 1971; FURRER, BACHMANN, 1972; SCHUNKE, 1975). Although the climatic boundary conditions are not yet well defined, permafrost is not regarded as a necessary pre-requisite.

Up to now most attention has been directed to gelisolifluction microforms and their distribution and differentiation. The boundary of regularly occurring gelisolifluction features („solifluction limit") is seen as an important criterion for the spatial delimitation of the periglacial environment as well as of high alpine regions (TROLL, 1955; HÖLLERMANN, 1967; KELLETAT, 1969a; FURRER, DORIGO, 1972). But it could be shown that the expression of the forms or the frequency of their occurrence are no valid indicators for the intensity of gelisolifluction.

Opinions on the intensity of gelisolifluction vary from region to region. Whereas BÜDEL (1962, 1977) assumes a high intensity for SE-Spitsbergen recent studies take a more conservative point of view (SEMMEL, 1969; SCHUNKE, 1975, 1979a; BIBUS, NAGEL, SEMMEL, 1976; STÄBLEIN, 1977a). Process rates which have been measured so far vary between 0.7 cm/year on gentle slopes (2.5°) in the arctic frost debris zone (BÜDEL, 1977) and 0.7 m within 34 days in the needle ice environment of the Bolivian Cordillera (GRAF, *cf.* FURRER, 1972). It should be noted that these values refer to measurements at the landsurface and thus represent maximum rates. They do not indicate the depth of the gelisolifluction movement and how much material is actually transported (FITZE, 1971). Apart from this, rates of gelisolifluction have been seen as primarily dependent on the inclination of slopes whereas the differentiation by local edaphic factors has been neglected so far.

## PERIGLACIAL MESO- AND MACROMORPHODYNAMICS

Periglacial morphodynamics at the meso- and macro-scale is understood as the combined action of micromorphodynamics and polyzonal processes, such as slopewash, fluvial or eolian processes in the periglacial environment which leads to the formation of valleys, slopes and various flat elements of relief. It is generally recognized that in most cases these forms are polygenetic, i.e. the result of various generations of geomorphic processes and thus not purely periglacial in origin (BÜDEL, 1971; WIRTHMANN, 1976, 1977; STÄBLEIN, 1977a, 1977b; SCHUNKE, 1977a, 1979a).

Nivation and cryoplanation forms belong to this category but are still regarded as periglacial indicators (SCHUNKE, 1977a). The genesis of these forms is seen as resulting from similar complex geomorphic processes in which frost shattering, gelisolifluction, slopewash, congeliturbation and snow pressure operate together in connection with oval or longitudinal perennial snow patches. The resulting hollows, benches, terraces and cryopediments have been studied in midlatitude alpine periglacial environments (BERGER, 1967; KARRASCH, 1972) and especially in Iceland (SCHUNKE, 1974b, 1975; SCHUNKE, HECKENDORFF, 1976) and in SE Greenland (SCHUNKE, 1979a). These studies stress the lithological control and reveal that cryoplanation terraces can no longer be regarded as indicators of a continental frost climate (*cf.* RICHTER, HAASE, BARTHEL, 1963a, 1963b) and that they are active without permafrost at mean annual air temperatures between —1°C and —2°C.

As different from the international periglacial literature tripartite convexo-concavo slope forms have been described as widespread from Iceland, Spitsbergen, Greenland and Axel Heiberg, especially in palteau landscapes with flat lying sediments, showing typical zones of denudational processes (BÜDEL, 1960, 1962; WIRTHMANN, 1962, 1976, 1977; SCHUNKE, 1975; STÄBLEIN, 1977b; NAGEL, 1977). Three distinct sections can be recognized: the convex upper slope with combined action of gelisolifluction and slopewash, the middle section with prevailing slopewash, rillwash, gully erosion or with a free face and gravitational processes and the lower concave section with gelisolifluction, slopewash and transport of fines by subsurface drainage. According to BÜDEL (1960, 1977) intensive gully erosion in the middle section can lead to the formation of „triangular slopes".

With regard to the intensity of slope forming processes quantitative data are not yet available. Whereas BÜDEL (1962) assumed a high intensity for SE Spitsbergen, NAGEL (1977), STÄBLEIN (1977b) and SCHUNKE (1979a) pointed out that periglacial slope forming processes on W Spitsbergen, W and SE Greenland have only insignificantly changed the inherited, glacially eroded slope forms. Of particular geomorphic importance, however, are spontaneous and catastrophic mass transports in connection with heavy rain fall which has been reported from Spitsbergen (THIEDIG, KRESLING, 1973; THIEDIG, LEHMANN, 1973).

Opinions on periglacial fluvial activity are still controversial and contradictory. They are based on relief and sediment analysis rather than on process studies. BÜDEL (1960, 1969) believed that the ice-rich upper layer of permafrost (*ice-crust*) which he found in SE Spitsbergen was not only an effective agent of deep mechanical weathering but also a decisive pre-requisite of a very intensive vertical and lateral thermoerosion in river channels. He determined the average Holocene vertical erosion as amounting to 3 m/1000 years and called the polar frost debris zone a „zone of excessive valley formation".

According to recent studies in W Spitsbergen, in Greenland and on Ellesmere Island the model of very intensive fluvial erosion and valley formation in permafrost environments by means of the „ice-crust effect" cannot by generalized (Bibus, Nagel, Semmel, 1976; Stäblein, 1977b; Barsch, King, 1979; Schunke, 1979a). It could be shown that in the latter areas, accumulation from the slopes dominates over erosion in the valley bottoms. It is recognized though that periglacial fluvial systems may have a high sediment transport and erosion potential, but in the investigated areas the present periglacial rivers and their geomorphic activity are essentially controlled by the preexisting glacial landforms and sediments which they have not altered significantly so far. In order to clarify the problem of periglacial fluvial erosion it seems necessary to continue investigations in present periglacial environments which have not been glaciated during the Pleistocene (e. g. the Yukon Territory, Canada).

Compared to Pleistocene periglacial studies recent periglacial eolian activity has not received much attention in the German periglacial literature although a number of observations are to be found in regional studies. Troll (1973) has summarized the combined action of needle ice and deflation, *gelideflation*, which produced microforms of *turf exfoliation* occurring above all in subarctic maritime and high altitude tropical environments. Miotke (1979) has studied deflation and wind abrasion processes in South Victoria Land, Antarctica. It could be shown that ventifacts in the Dry Valleys can be formed within a few decades or at most, a few centuries. The geomorphic effect of blowing ice or snow crystals for abrasion processes should not be overestimated.

Like the opinions on partial macromorphodynamic processes in the periglacial environment the formulation of general models of geomorphic activity in the polar periglacial zone remains controversial. Whereas for Büdel (1977) it is a zone of excessive valley formation, for Dekov (1965) it is an area of intensive planation and for Stäblein (1977b) a zone of prevailing slope and only little valley formation.

## SPATIAL DELIMITATION AND REGIONALISATION OF THE PRESENT POLAR AND ALPINE PERIGLACIAL ZONE

As pointed out earlier regional studies are typified by geographically oriented German periglacial research. Most of these are small-scale studies pertaining to the alpine periglacial zone. Comparable studies on the regionalisation of the polar periglacial zone are few.

In a survey of the European-Atlantic Arctic and Subarctic Schunke (1977a) could show that most periglacial features occur ubiquitously depending on local conditions. Only at a large-scale approach and considering a large number of features is a planetary, altitudinal and peripheral-central regional variability recognisable.

Recently, the reviewer has attempted to delimit and regionalise both the polar and alpine periglacial zones (KARTE, 1979). In accordance with TROLL (1944, 1947, 1948) the periglacial zone is understood as geomorphic environment where frozen ground, no matter if diurnally or seasonally frozen ground or permafrost, is so intense that it entails conspicuous geomorphic effects. Against this background it could be shown that the periglacial zone is not absolutely identical with the spatial extent of permafrost but can only be delimited by the boundary of spatial and climatic associations of periglacial microrelief features and their specific climatic threshold values. As these associations are regionally variable the periglacial zone can only be delimited in a regionally differentiated way. As a consequence the climatic threshold values along the boundary of the periglacial zone are also variable and decrease from an annual air temperature mean of $-1\,°C$ in the subpolar maritime environment to a value of $-10\,°C$ in the extremely continental boreal environment. On the basis of the large-scale regional variability of spatial and climatic associations of periglacial microrelief features a subarctic maritime, subarctic continental, a boreal, an arctic tundra and an arctic as well as high arctic frost debris periglacial environment could be distinguished as regional types of the polar periglacial zone, which have been presented on a map of the northern hemisphere (KARTE, 1979; KARTE, LIEDTKE, 1981).

With regard to the delimitation and subdivision of the alpine periglacial zone one has to refer to the detailed studies of the Göttingen periglacial school around POSER which were carried out along a paradigmatic meridional profile between the European Subarctic and equatorial Africa (POSER, 1954; HÖLLERMANN, 1964, 1967, 1976; HAGEDORN, 1969, 1977; KELLETAT, 1969a, 1970, 1977a, 1977b; STINGL, 1969; GARLEFF, 1970; SCHUNKE, 1975; HÖLLERMANN, POSER, 1977; BROSCHE, 1977, 1978). They have been supplemented by individual studies in the high mountains of North and South America, in the Middle East and by studies from another periglacial school around FURRER in Switzerland.

There has been a long debate as to whether sorted forms (HÖLLERMANN, 1972) or gelisolifluction features are better criteria for the spatial delimitation of the alpine periglacial zone. According to recent studies (*cf.* HÖLLERMANN, 1976; HÖLLERMANN, POSER, 1977; KARTE, 1979) the lower limit of gelisolifluction, or in the opinion of the reviewer, the lower limit of the spatial association of various types of gelisolifluction features, has proved a suitable criterion for the delimitation of the alpine periglacial zone.

The lower boundary of the alpine periglacial zone rises with decreasing latitude and increasing continentality culminating in the respective highest parts of mountainous areas. Climatic threshold values along the lower limit are also regionally variable and need further research. The hypsometric subdivision, based on the hypsometric variability of spatial associations of periglacial microrelief features, shows a different picture from latitude to latitude.

Within the polar frost debris zone a regular hypsometric subdivision is not recognizable. Obviously no geomorphologically significant climatic threshold values are exceeded with increasing altitude (Barsch, 1977c). The existing small--scale variability is primarily controlled by edaphic factors (Stäblein, 1977a, 1977b, 1977c; 1979b, 1979c). In the tundra and boreal periglacial zone the hypsometric subdivision is mainly determined by the vertically decreasing vegetation cover (Schunke, 1979b). This is also the critical differentiating factor in the middle and lower latitudes. In subpolar and middle latitudes a tripartite subdivision into a lower zone with prevailing microforms of vegetation-covered gelisolifluction, a middle zone where gelisolifluction microforms and sorted forms are associated and an upper zone with prevailing microforms of free gelisolifluction and sorted forms is typical. In the semi-humid and semi-arid subtropics a bipartite subdivision into a lower zone with the association of gelisolifluction features and sorted forms and an upper zone with forms of free gelisolifluction and sorted forms, is characteristic. In the high mountains of the inner tropics the alpine periglacial zone begins above the zone with vegetation cover and consists mainly of features of needle-ice microsolifluction and miniature sorted forms. A further subdivision has not been recognized so far. In the arid zone between the semi-arid subtropics and the semi-arid tropics there is no present periglacial zone, but only a thermally potential periglacial zone (Messerli, 1972, 1973; Mensching, 1977). The outlined picture of the delimitation and subdivision of the alpine periglacial zone has been summarized and presented on a schematic profile (Karte, 1979; Karte, Liedtke, 1981).

## CONCLUSIONS

It was the object of this paper to outline the development of German periglacial research in arctic and alpine environments and to review the main research results. From the multitude of mentioned aspects the following results may be summarized together with an outlook on remaining open questions:

1. Traditionally a branch of descriptive climatic geomorphology, geographically oriented German periglacial research has experienced a gradual shift towards a more ecological approach. This is manifested by an increasing interest in investigations of periglacial environmental factors. Whereas numerous important results on local climatic and edaphic factors have been achieved, from a geographical point of view the determination of the climatic boundary conditions of the periglacial environment as a whole, remains an important research object.

2. Permafrost has been mainly studied as to its geomorphic significance. In the future pragmatic permafrost research will become more and more important. It will be the task of geographers to make the ecological and economic role of permafrost and periglacial research for practical purposes transparent.

3. The intensive research of periglacial microrelief has produced numerous detailed results but in many cases their genesis is still not clear. The results have been mainly achieved through geographical approaches, i.e. by an analysis of the distribution and differentiation of periglacial features in relation to climatic and

edaphic environmental factors. Systematic process studies are still lacking. Whereas our knowledge of the edaphic boundary conditions of periglacial microforms has improved considerably the determination of the climatic threshold values of their genesis and spatial distribution needs further research. The edaphic and climatic indicator values (*cf.* KARTE, 1979) of periglacial microforms is of relevance for terrain evaluation in present periglacial environments as well as for palaeogeographical and palaeoclimatic reconstructions of the Pleistocene periglacial environment. In addition to this, more attention should be paid to periglacial structures which are known from the Pleistocene periglacial environment, such as involutions and cryoturbations, but which have hardly been studied in the present periglacial zone.

4. With regard to periglacial meso- and macromorphodynamics our knowledge has become more differentiated. Studies on periglacial denudational and periglacial fluvial activity remain controversial as to the intensity of these processes and their respective role within the periglacial geomorphic system. Systematic process studies are as necessary as comparative studies in other parts of the polar periglacial zone. In addition to this, investigations on processes like slopewash of which comparatively little is known should be carried out.

5. The regionalisation of the polar and alpine periglacial environment will remain an important object of the geographically orientated German periglacial research. In this respect many areas in the Arctic and Subarctic as well as many high alpine regions, especially in North America and Central Asia are virtually „terra incognita". According to POSER (1977) there is a particular need of regional studies which deal with the whole inventory of occurring periglacial phenomena.

With the foundation of a new central institute of polar research in the Federal Republic of Germany, the joining of the International Antarctic Treaty in 1978 and the construction of a research station in the Antarctic, German polar research will receive a new impetus (*cf.* KOHNEN, 1979). This may not only refer to periglacial research in the Antarctic, but periglacial research in the Arctic and Subarctic will also profit from this.

## References


ABT, P., BACHMANN, F., BÜHLER, J., FURRER, G., 1971 — Neue Beobachtungen an arktischen Strukturbodenformen. *Geogr. Helvetica*, 26; p. 115—121.

BARRY, G. R., HARE, K. F., 1974 — Arctic climate *In*: I. D. IVES, R. G. BARRY — Arctic and alpine environments. London. 1974.

BARSCH, D., 1969 — Permafrost in der oberen subnivalen Stufe der Alpen. *Geogr. Helvetica*, 24; p. 10—12.

BARSCH, D., 1973 — Refraktionsseismische Bestimmung der Obergrenze des gefrorenen Schuttkörpers in verschiedenen Blockgletschern Graubündens, Schweizer Alpen. *Ztschr. f. Gletscherkunde u. Glazialgeologie*, 9; p. 143—167.

BARSCH, D., 1977a — Alpiner Permafrost — ein Beitrag zur Verbreitung, zum Charakter und zur Ökologie am Beispiel der Schweizer Alpen. *Abhandl, Gött. Akad., Math.-Phys. Kl.*, 3 F. 31; p. 118—141.

BARSCH, D., 1977b — Nature and importance of mass-wasting by rock glaciers in alpine permafrost environments. *Earth Surface Processes*, 2; p. 231—245.

BARSCH, D., 1977c — Das Geomorphologische Symposium der Akademie der Wissenschaften in Göttingen vom 19 bis 23.9.76. *Ztschr. f. Geomorph.*, N.F., 21; p. 223—227.

BARSCH, D., 1978 — Active rock glaciers as indicators for discontinuous alpine permafrost. An example from the Swiss Alps. *Proc. Third Internat. Conf. on Permafrost, July* 10—13, 1978, *Edmonton, Alberta, Canada*, vol. 1, Ottawa; p. 349—353.

BARSCH, D., KING, L., 1979 — Die Heidelberg Ellesmere Island Expedition — Erster Bericht. *Marburger Geogr. Schriften*, 79; p. 45—56.

BERGER, H., 1967 — Vorgänge und Förmen der Nivation in den Alpen. *Buchreihe des Landesmuseums für Kärnten*, 17; Klagenfurt.

BIBUS, E., NAGEL, G., SEMMEL, A., 1976 — Periglaziale Reliefformung im zentralen Spitzbergen. *Catena*, 3; p. 29—44.

BLUME, H., 1975 — 25 Jahre geomorphologische Forschung in der Bundesrepublik Deutschland im Spiegel der Zeitschriften und Schriftenreihen 1950—1974. *Geogr. Rundschau*, 27; 361—364.

BROSCHE, K. U., 1977 — Formen, Formengesellschaften und Untergrenzen in den heutigen periglazialen Höhenstufen der Hochgebirge der Iberischen Halbinsel. *Abhandl. Göttingen Akad., Math.-Phys. Kl.*, 3 F. 31; p. 178—202.

BROSCHE, K. U., 1978 — Ergebnisse einer vergleichenden Studie zum rezenten und vorzeitlichen periglazialen Formenschatz auf der Iberischen Halbinsel. *Biul. Peryglacjalny*, 27; p. 53—103.

BRYAN, K., 1946 — Cryopedology — the study of frozen ground and intensive frost action with suggestions on nomenclature. *Amer. Jour. Sci,*. 244; p. 622—642.

BUDYKO, M. I., 1963 — Atlas teplovogo balansa zemnogo šara (Atlas of the earth heat balance). Moscow (in Russian).

BÜDEL, J., 1959 — Periodische und episodische Solifluktion im Rahmen der klimatischen Solifluktionstypen. *Erdkunde*, 13; p. 297—314.

BÜDEL, J., 1960 — Die Frostschutt-Zone Südost-Spitzbergens. *Colloq. Geogr.*, 6; Bonn.

BÜDEL, J., 1962 — Die Abtragungsvorgänge auf Spitzbergen im Umkreis der Barents-Insel aufgrund der Stauferlandexpedition 1959/60. *Verh. d. Deutschen Geographentages. Tagungsberichte u. wiss. Abhandl.*, 33; p. 337—375.

BÜDEL, J., 1969 — Der Eisrinden-Effekt als Motor der Tiefenerosion in der exzessiven Talbildungszone. *Würzb. Geogr. Arb.*, 25.

BÜDEL, J., 1971 — Das natürliche System der Geomorphologie mit kritischen Gängen zum Formenschatz der Tropen. *Würzb. Geogr. Arb.*, 34.

BÜDEL, J., 1972 — Geomorphologische Polarforschung in Spitzbergen. *Ztschr. f. Gletscherkunde u. Glazialgeologie*, 8; p. 283—294.

BÜDEL, J., 1977 — Klima-Geomorphologie. Berlin.

DEDKOV, A., 1965 — Das Problem der Oberflächenverebnungen. *Petermanns Geogr. Mitt.*, 109; p. 258—264.

ELSASSER, H., 1967 — Untersuchungen an Erdbülten im Avers, *Geogr. Helvetica*, 22; p. 27—30.

FITZE, P., 1971 — Messungen von Bodenbewegungen auf West-Spitzbergen. *Geogr. Helvetica*, 26; p. 148—152.

FITZE, P., 1975 — Nonsorted circles — Ein Vergleich zwischen arktischen und alpinen Formen. *Geogr. Helvetica*, 30; p. 75—82,

FRANZ, H.—J., 1973 — Physische Geographie der Sowjetunion. Gotha-Leipzig.

FREUND, R., 1971 — Die Kleinformen der Frostumsterböden. Vergleich Arktis-Alpen — tropisches Hochgebirge. *Geogr. Helvetica*, 26; p. 142—147.

FÜRBRINGER, W., HAYDN, R., 1974 — Zur Frage der Orientierung nordalaskischer Seen mit Hilfe des Satellitenbildes. *Polarforschung;* p. 47-53.

FURRER, G., 1968 — Untersuchungen an Strukturböden in Ostspitzbergen, ihre Bedeutung für die Erforschung rezenter und fossiler Frostmusterformen in den Alpen bzw. im Alpenvorland. *Polarforschung,* 6; p. 202—206.

FURRER, G., 1969 — Vergleichende Beobachtungen am subnivalen Formenschatz in Ostspitzbergen und in den Schweizer Alpen. *Ergeb. Stauferland-Exped.* 1967, 9; Wiesbaden.

FURRER, G., 1972 — Bewegungsmessungen auf Solifluktionsdecken. *Ztschr. f. Geomorph.,* N. F., Suppl. Bd., 13; p. 87—101.

FURRER, G., BACHMANN, F., 1972 — Solifluktionsdecken im schweizerischen Hochgebirge als Spiegel der postglazialen Landschaftsentwicklung. *Ztschr. f. Geomorph.,* N.F., Suppl. Bd., 13; p. 163—172.

FURRER, G., DORIGO, G., 1972 — Abgrenzung und Gliederung der Hochgebirgsstufe der Alpen mit Hilfe von Solifluktionsformen. *Erdkunde,* 26; p. 98—107.

FURRER, G., FITZE, P., 1970 — Beitrag zum Permafrostproblem in den Alpen. *Viertlejahresschrift d. Naturforsch. Gesell. in Zürich.* 115; p. 353—368.

GARLEFF, K., 1970 — Verbreitung und Vergesellschaftung rezenter Periglazialerscheinungen in Skandinavien. *Gött. Geogr. Abhandl.,* 51.

GÖHRS, I., 1951 — Die Klimate der ewigen Gefrornis. *Diss. Göttingen.*

GRAHMANN, R., 1951 — Begriffe in der Quartärforschung. *Eiszeitalter u. Gegenwart,* 1; p. 69—73.

HABRICH, W. v., 1968 — Vegetationshöcker auf steilgeneigten Terrassenhängen in der Frostschuttzone Nordostkanadas. *Polarforschung,* 6; p. 212—215.

HAEBERLI, W., 1973 — Die Basis-Temperatur der winterlichen Schneedecke als möglicher Indikator für die Verbreitung von Permafrost in den Alpen. *Ztschr. f. Gletscherkunde u. Glazialgeologie,* 9; p. 221—227.

HAEBERLI, W., 1975 — Eistemperaturen in den Alpen. *Ztschr. f. Gletscherkunde u. Glazialgeologie,* 11; p. 203—220.

HAEBERLI, W., 1978 — Special aspects of high mountain permafrost methodology and zonation in the Alps. *Proc. Third Internat. Conf. on Permafrost, July 10—13, 1978, Edmonton, Alberta, Canada,* vol. 1, Ottawa; p. 378—384.

HAGEDORN, J., 1969 — Beiträge zur Quartär-Geomorphologie griechischer Hochgebirge. *Gött. Geogr. Abhandl.,* 50.

HAGEDORN, J., 1977 — Probleme der periglazialen Höhenstufung in Griechenland. *Abhandl. Gött. Akad., Math,-Phys.* Kl., 3 F. 31; p. 223—237.

HASTENRATH, S., 1960 — Zur vertikalen Verteilung der Frostwechsel- und Schneedeckenverhältnisse in den Alpen. Diss., Bonn.

HERZ, K., 1964 — Ergebnisse mikromorphologischer Untersuchungen im Kingsbay-Gebiet (Westspitzbergen). *Petermanns Geogr. Mitt.,* 108; p. 45—53.

HERZ, K., ANDREAS, G., 1966 — Untersuchungen zur Ökologie der periglazialen Auftauschicht im Kongsfjord (Westspitzbergen). *Petermanns Geogr. Mitt.,* 110; p. 260—272.

HÖLLERMANN, P., 1964 — Rezente Verwitterung, Abtragung und Formenschatz in den Zentralalpen am Beispiel des oberen Suldentales (Ortlergruppe). *Ztschr. f. Geomorph.,* N.F., Suppl. Bd., 4.

HÖLLERMANN, P., 1967 — Zur Verbreitung rezenter periglazialer Kleinformen in den Pyrenäen und Ostalpen. *Gött. Geogr. Abhandl.,* 40.

HÖLLERMANN, P., 1972 — Beiträge zur Problematik der rezenten Strukturbodengrenze. *Gött. Geogr. Abhandl.,* 60; p. 235—260.

HÖLLERMANN, P., 1976 — Probleme der rezenten geomorphologischen Höhenstufung im Rahmen einer vergleichenden Hochgebirgsgeographie. *Verh. d. Deutschen Geographentages. Tagungsber. u. wiss. Abhandl.*, 40; p. 61—75.

HÖLLERMANN, P., POSER, H., 1977 — Grundzüge der räumlichen Ordnung in der heutigen periglazialen Höhenstufe der Gebirge Europas und Afrikas. Rückblick und Ausblick. *Abhandl. Gött. Akad., Math.-Phys. Kl.*, 3, F. 31; p. 333—354.

KARRASCH, H., 1972 — Flächenbildung unter periglazialen Klimabedingungen. *Gött. Geogr. Abhandl.*, 60; p. 155—168.

KARRASCH, H., 1973 — Microclimatic conditions in the Alps. *Arctic and Alpine Research*, 5; p. 55—64.

KARRASCH, H., 1977 — Die klimatischen und aklimatischen Varianzfaktoren der periglazialen Höhenstufe in den Gebirgen West- und Mitteleuropas. *Abhandl. Gött. Akad., Math.-Phys. Kl.*, 3, F. 31; p. 157—177.

KARTE, J., 1979 — Räumliche Abgrenzung und regionale Differenzierung des Periglaziärs. *Bochumer Geogr. Arb.*, 35.

KARTE, J., LIEDTKE, H., 1981 — The theoretical and practical definition of the term „periglacial" in its geographical and geological meaning. *Biul. Peryglacjalny*, 28; p. 123-135.

KELLETAT, D., 1969a — Verbreitung und Vergesellschaftung rezenter Periglazialerscheinungen im Appenin. *Gött. Geogr. Abhandl.*, 48.

KELLETAT, D., 1969b — Erdbülten als Frühjahrsformen im Raum um Göttingen. *Eiszeitalter u. Gegenwart*, 20; p. 131—137.

KELLETAT, D., 1970 — Rezente Periglazialerscheinungen im Schottischen Hochland. Untersuchungen zu ihrer Verbreitung und Vergesellschaftung. *Gött. Geogr. Abhandl.*, 51; p. 67—140.

KELLETAT, D., 1977a — Die rezente periglaziale Höhenstufe in den Gebirgen der nördlichen Mittelbreiten Europas. *Abhandl. Gött. Akad., Math.-Phys. Kl.*, 3, F. 31; p. 105—117.

KELLETAT, D., 1977b — Die rezente periglaziale Höhenstufe des Apennin: geomorphologische Ausstattung, gegenwärtige Formungsprozesse und Probleme der Abgrenzung. *Abhandl. Gött. Akad., Math.-Phys. Kl.*, 3, F. 31; p. 203—222.

KELLEY, J.J., WEAVER, D. F., 1969 — Physical processes at the surface of the Arctic tundra. *Arctic*, 22; p. 425—437.

KIM, D. J., 1967 — Die dreidimensionale Verteilung der Strukturböden auf Island in ihrer klimatischen Abhängigkeit. Diss., Bonn.

KING, L., 1976 — Permafrostuntersuchungen in Tarfala (Schwedisch Lappland) mit Hilfe der Hammerschlagseismik. *Ztschr. f. Gletscherkunde u. Glazialgeologie*, 12; p. 187—204.

KOHNEN, H., 1979 — Ein neuer Anfang in der deutschen Antarktisforschung. *Polarforschung*, 49; p. 80—83.

ŁOZIŃSKI, W,, 1909 — Über die mechanische Verwitterung der Sandsteine im gemässigten Klima. *Bull. Internat. Acad. Sci. de Cracovie, Cl. Sci. Math. et Nat.*, 1; p. 1—25.

MATHYS, H., 1974 — Klimatische Aspekte zur Frostverwitterung in der Hochgebirgsregion. *Mitt. d. Naturforsch. Gesell. in Bern*, N.F., 31; p. 49—62.

MECKELEIN, W., 1974 — Aride Verwitterung in Polargebieten im Vergleich zum subtropischen Wüstengürtel. *Ztschr. f. Geomorph.*, N.F., Suppl. Bd., 20; p. 178—188.

MENSCHING, H., 1977 — Bemerkungen zum Problem einer „periglazialen" Höhenstufe in den Gebirgen der ariden Zone in nördlichen Afrika. *Abhandl. Gött. Akad., Math.-Phys. Kl.*, 3 F., 31; p. 290—299.

MESSERLI, B., 1972 — Formen und Formungsprozesse in der Hochgebirgsregion des Tibesti. *Hochgebirgsforschung*, 2; p. 23—86.

MESSERLI, B., 1973 — Problems of vertical and horizontal arrangement in the high mountains of the extreme arid zone (Central Sahara). *Arctic and Alpine Research*, 5; p. 139—147.

MIOTKE, F. D., 1979 — Die Formung und Formungsgeschwindigkeit von Windkantern in Victoria--Land, Antarktis. *Polarforschung*, 49; p. 30—43.

MÜLLER, F., 1959 — Beobachtungen über Pingos. *Medd. om Grønland*, 153.

MÜLLER, S., 1962 — Isländische Thufur und alpine Buckelwiesen — ein genetischer Vergleich. *Natur u. Museum*, 92; p. 267—274.

NAGEL, G., 1977 — Vergleichende Beobachtungen zur periglazialen Hangabtragung in Spitzbergen und Axel Heiberg Island — NWT, Kanada. *Ztschr. f. Geomorph.*, N.F., Suppl. Bd., 28; p. 200—212.

POSER, H., 1933 — Das Problem des Strukturbodens *Geol. Rundschau*, 24; p. 105—121.

POSER, H., 1954 — Die Periglazial-Erscheinungen in der Umgebung der Gletscher des Zemmgrundes (Zillertaler Alpen). *Gött. Geogr. Abhandl.*, 15; p. 125—180.

POSER, H., 1977 — Bericht und Einführung. *In :* POSER, H. — Formen, Formengesellschaften und Untergrenzen in den heutigen periglazialen Höhenstufen der Hochgebirge Europas und Afrikas zwischem Arktis und Äquator. *Abhandl. Gött. Akad., Math.-Phys. Kl.*, 3 F., 31; p. 7—17.

PREUSSER, H., 1973 — Hypsometrischer Formenwandel der Polygone in Island. *Ztschr. f. Geomorph.*, N.F., Suppl. Bd., 16; p. 155—160.

PRIESNITZ, K., SCHUNKE, E., 1978 — An approach to the ecology of permafrost in Central Iceland. *Proc. Third Internat. Conf. on Permafrost, July* 10—13, 1978, *Edmonton, Alberta, Canada, vol.* 1; *p.* 474—479.

QUITZOW, H. W., 1963 — Beobachtungen in einem isländischen Palsen-Moor. *Natur u. Museum*, 93; p. 133—140.

REICHMANN, H., 1978 — Kriechen, Solifluktion, Gelifluktion, Kongelifluktion. Ein terminologischer Irrgarten. *Geol. Jahrbuch Hessen*, 106; p. 409—418.

RICHTER, H., HAASE, G., BARTHEL, H., 1963a — Die Golezterrassen. *Petermanns Geogr. Mitt.*, 107; p. 183—192.

RICHTER, H., HAASE, G., BARTHEL, H., 1963b — Besonderheiten des Periglazials unter kontinentalen Klimaverhältinissen Zentralasiens. *Wiss. Z. d. Techn. Univ. Dresden*, 12; p. 1153—1158.

ROHDENBURG, H., 1971 — Einführung in die klimagenetische Geomorphologie. Giessen.

SCHENK, E., 1955 — Die Mechanik derperigl azialen Strukturböden. *Abhandl. d. Hess. Landesamtes f. Bodenforschung*, 13.

SCHENK, E., 1966 — Origin of ice-wedges. *Proc. Permafrost Internat. Conf.* 1963, *Nat. Acad. Sci., Nat. Res. Council Publ.*, 1287, Washington; p. 82—87.

SCHUNKE, E., 1973 — Palsen und Kryokarst in Zentral-Island. *Nachrichten d. Gött. Akad., Math.--Phys. Kl.;* p. 65—102.

SCHUNKE, E., 1974a — Frostspaltenmakropolygone im westlichen Zentral-Island — ihre klimatischen und edaphischen Bedingungen. *Eiszeitalter u. Gegenwart*, 25; p. 157—165.

SCHUNKE, E., 1974b — Formungsvorgänge an Schneeflecken im isländischen Hochland. *Abhandl. Gött. Akad., Math.-Phys. Kl.*, 3 F., 29; p. 274—286.

SCHUNKE, E., 1975 — Die Periglazialerscheinungen Islands in Abhängigkeit von Klima und Substrat. *Abhandl. Gött. Akad., Math.-Phys. Kl.*, 3 F., 30.

SCHUNKE, E., 1977a — Periglazialformen und — formengesellschaften in der europäisch-atlantischen Arktis und Subarktis. *Abhandl. Gött. Akad., Math.-Phys. Kl.*, 3 F., 31; p. 39—62.

SCHUNKE, E., 1977b — Zur Ökologie der Thufur Islands. *Berichte aus der Forschungsstelle Nedri As, Hveragerdi (Island)*, 26.

SCHUNKE, E., 1977c — Zur Genese der Thufur Islands und Ost-Grönlands. *Erdkunde*, 31; p. 279——287.

SCHUNKE, E., 1979a — Rezente periglaziäre Morphodynamik auf Angmassalik, SE-Grönland. *Polarforschung*, 49; p. 1—19.

SCHUNKE, E., 1979b — Aktuelle Morphodynamik in den periglazären Höhenstufen der Subarktis. *Arb. Geogr. Inst. Univ. Saarlandes* (in press).

SCHUNKE, E., HECKENDORFF, W. D., 1976 — Resistenzstufen und Kryoplanation — Beobachtungen aus dem periglaziären Milieu Islands. *Ztschr. f. Geomorph.*, N. F., Suppl. Bd., 24; p. 88—98.

SCHUNKE, E., STINGL, H., 1973 — Neue Beobachtungen zum Luft- und Bodenfrostklima Islands. *Geogr. Ann.*, 55 A; p. 1-23.

SEMMEL, A., 1969 — Verwitterungs- und Abtragungserscheinungen in rezenten Periglazialgebieten (Lappland und Spitzbergen). *Würz. Geogr. Arb.*, 1969.

STÄBLEIN, G., 1970 — Untersuchung der Auftauschicht über Dauerfrostboden in Spitzbergen. *Eiszeitalter u. Gegenwart.* 21; p. 47—57.

STÄBLEIN, G., 1977a — Periglaziale Formengesellschaften und rezente Formungsbedingungen in Grönland. *Abhandl. Gött. Akad., Math.-Phys. Kl.*, 3 F., 31; p. 18-33.

STÄBLEIN, G., 1977b — Rezente Morphodynamik und Vorzeitreliefinfluenz bei der Hang- und Talentwicklung in Westgrönland. *Ztschr. f. Geomorph.*, N.F., Suppl. Bd., 28; p. 181—199.

STÄBLEIN, G., 1977c — Periglaziale Höhenstufen zwischen Subarktis und Äquator. *Die Erde,*, 108; p. 151—153.

STÄBLEIN, G., 1977d — Permafrost im periglazialen Westgrönland. *Erdkunde*, 31; p. 272—279.

STÄBLEIN, G., 1979a — Verbreitung und Probleme des Permafrostes im nördlichen Kanada. *Marburger Geogr. Schriften*, 79; p. 27—43.

STÄBLEIN, G., 1979b — Böden und Relief in Westgrönland. *Ztschr. f. Geomorph.*, N.F., Suppl. Bd., 33; p. 232-245.

STÄBLEIN, G., 1979c — Höhenwandel kryogener Prozesse im arktisch-alpinen Milieu. *Arb. Geogr. Inst Univ. Saarlandes* (in press).

STINGL, H., 1969 — Ein periglazialmorphologisches Nord-Süd-Profil durch die Ostalpen. *Gott. Geogr. Abhandl.*, 49.

STINGL, H., 1971 — Zur Verteilung von Gross- und Miniaturformen von Strukturböden in den Ostalpen. *Nachrichten Gött. Akad., Math.-Phys. Kl.*, 2; p. 25—40.

STINGL, H., 1974 — Zur Genese und Entwicklung von Strukturbodenformen. *Abhandl. Gött. Akad., Math.-Phys. Kl.*, 3 F., 29; p. 249—262.

STINGL, H., HERRMANN, R., 1976 — Untersuchungen zum Strukturbodenproblem auf Island. Geländebeobachtungen und statistische Auswertung. *Ztschr. f. Geomorph.*, N.F., 20; p. 205—266.

THIEDIG, F., KRESLING, A., 1973 — Meteorologische und geologische Bedingungen bei der Entstehung von Muren im Juli 1972 auf Spitzbergen. *Polarforschung*, 43; p. 40—49.

THIEDIG, F., LEHMANN, U., 1973 — Die Entstehung von Muren als säkulares Ereignis auf Spitzbergen (Svalbard) und ihre Bedeutung für die Denudation in der Frostschuttzone. *Mitt. Geol. Paläontol. Inst. Univ. Hamburg*, 42; p. 71—80.

TROLL, C., 1944 — Strukturböden, Solifluktion und Frostklimate der Erde. *Geol. Rundschau*, 34; p. 545—694.

TROLL, C., 1947 — Die Formen der Solifluktion und die periglaziale Bodenabtragung. *Erdkunde*, 1; p. 4—6, 162—175.

TROLL, C., 1948 — Der subnivale oder periglaziale Zyklus der Denudation. *Erdkunde*, 2; p. 1—21.

TROLL, C., 1955 — Über das Wesen der Hochgebirgsnatur. *Jahrbuch d. Deutschen Alpenvereins*, 80; p. 142—157.

TROLL, C., 1958 — Structure soils, solifluction and frost climates of the earth. *U.S. Army Snow, Ice and Permafrost Research Establishment Transl.*, 43.

TROLL, C., 1973 — Rasenabschälung (turf exfoliation) als periglaziales Phänomen der subpolaren Zonen und der Hochgebirge. *Ztschr. f. Geomorph.*, N.F., Suppl. Bd., 17; p. 1—32.

VORNDRAN, E., 1969 — Untersuchungen über Schuttentstehung und Ablagerungsformen in der Hochregion der Silvretta (Ostalpen). *Schriften Geogr. Inst. Univ. Kiel.* 29.

VORNDRAN, G., 1972 — Kryopedologische Untersuchungen mit Hilfe von Bodentemperaturmessungen (an einem zonalen Strukturbodenvorkommen in der Sivrettagruppe). *Münchener Geogr. Abhandl.*, 6.

WIRTHMANN, A., 1962 — Zur Morphologie der Edge-Insel in Südostspitzbergen aufgrund der Stauferlandexpedition 1959/60. *Verh. d. Deutschen Geographentages. Tagungsbericht u. wiss. Abhandl.*, 33; p. 394—399.

WIRTHMANN, A., 1976 — Reliefgenerationen im unvergletscherten Polargebiet. *Ztschr. f. Geomorph.*, N.F., 20; p. 391—404.

WIRTHMANN, A., 1977 — Erosive Hangentwicklung in verschiedenen Klimaten. *Ztschr. f. Geomorph.*, N.F., Suppl. Bd., 28; p. 42—61.