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PERIGLACIAL RESEARCH: JUMPING BETWEEN PROCESS AND ENVIRONMENT

Abstract

The generally progressing understanding of periglacial environments and processes results in the distinction of a rich diversity of processes taking place in different environmental and climatic conditions. This helps in turn to characterize specific types of periglacial environments and conditions. Efforts to increase the understanding of periglacial processes have to be pursued. But new challenges for periglacial research arise when the impacts of climatic changes on the periglacial environment have to be estimated more accurately. Modern techniques in the measurement of physical properties of freezing and thawing soils and data acquisition and management open new perspectives to achieve these goals.

INTRODUCTION

'Recent years have witnessed an accelerated progress of periglacial research. The approfoundation of the problems and the ever-increasing precision of methods tend to reinforce the conviction of the predominant importance of periglacial environment.' This statement seems an appropriate one when reviewing actual periglacial research. The remarkable fact, however, is that it is not a recent statement, but that it is from the hand of the editors of the first volume of *Biuletyn Peryglacjalny* in 1954. It was written at the time periglacial research was booming and a few years after that the first Periglacial Commission was established. If this statement held during the succeeding half century of periglacial research, and to what extent, is worth to discuss, but more important is to know the position of periglacial research nowadays in the study of the environment and in future environmental research.

Overviews of periglacial research have been made at several occasions in the past 20 years (e.g. WASHBURN, 1981; FRENCH, KARTE, 1987; FRENCH, 1987; BURN, SMITH, 1993). This is important in order to update the present lines of thinking and research evolution. But here I will focus primarily on progress obtained in the last decade in the understanding of specific periglacial processes, landforms and environments. Given the

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outcome of this analysis, I will give some personal views on the perspectives and challenges for future periglacial research in an international framework.

PROGRESS IN THE STUDY OF PERIGLACIAL PROCESSES AND ENVIRONMENTS

In its search to explain landforms and environments periglacial research got originally a strong impetus from the development of climatic geomorphology in the fifties and sixties, and later on from process studies. Both approaches contributed to interpret and characterize periglacial environments and to specify the involved climatic conditions. A number of topics in periglacial process, environmental and climate research has been selected which have received much attention in periglacial literature and in which substantial progress has been made in the last decade.

PROCESSES

It is striking that in the last decade new ideas have been developed with regard to some particular processes, while for other processes the traditional theories are still holding. Some specific advances with respect to the origin of periglacial phenomena are highlighted below:

One of the most expressive features of periglacial environments are *the thermal contraction cracks.* Substantial progress has been made in the study of ice-wedge growth thanks to field measurements and experiments of ice-wedge cracking. Especially the data obtained by MACKAY (1988) on the surface of a drained lake should be mentioned. Such studies are of considerable importance for the interpretation of relic forms, i.e. the direction and rate of cracking, and the relation of ice-wedge growth with vegetation and snow cover, temperature and humidity conditions.

As concerns the relation to climatic conditions ROMANOVSKY (1985) stressed the influence of local lithology. Coarse-grained sediments are less frost susceptible than fine-grained ones and thus ice-wedge casts that formed in gravels point to more severe climatic conditions than those formed in silts. These results as well are of utmost importance for palaeoclimatic reconstructions.

Illustrative was the interpretation of the *frost mound* relics on the Ardennes by PISSART. After comparison of these forms with frost hills in north Canada, this author was able to interpret them as palsas (PISSART, 1983). It proofs that such process research, not only in arctic regions but also in alpine areas and by experiments, is a necessary step to better understand the significance of periglacial phenomena and frost action.

Cryoturbations are quite important for reconstructing former periglacial conditions since they have wide occurrence in fossil form. Their origin was long and frequently debated, and still is (KASSE, this volume). One of the things on which I think all debaters will agree is that similarly looking cryoturbations may have had different origins. Most of the cryoturbations seem to be caused by density loading under periglacial conditions of oversaturation at the top of a thawing permafrost (VANDENBERGHE, VAN DE BROEK, 1982). It has taken a long time before cryoturbations have been found in present-day periglacial environments but MURTON and FRENCH (1993) described cryoturbations that formed by density loading on top of a partially thawed permafrost as a result of the warming during the Holocene maximum. Similarly looking cryoturbations may have had different origins, for instance the deformations from Gasebö (Svalbard) described by VAN VLIET-LANOË (1985) that were subject to different interpretations (VANDENBERGHE, 1988). Anyway, the study of such deformations in well-known periglacial environments is a major step forward. Substantial progress has also been obtained from the experimental side, where HARRIS *et al.* (in press) could initiate conditions of high pore-pressure by thawing of ice-rich sediments so that in certain conditions density loading originated.

Slopes have traditionally been considered to develop very specifically under periglacial conditions. Two examples are discussed:

The name *grèzes litées* is in use already for a long time indicating stratified slope deposits. Their origin, however, was quite disputed, which is not to wonder considering the wide range of facies which are grouped apparently under this name. It came out that these facies correspond indeed with different genetic processes of transport and deposition as has been shown by the studies of, amongst others, FRANCOU (1990), BERTRAN *et al.* (1993), BERTRAN and TEXIER (1994), HÉTU *et al.* (1994), VAN STEIJN *et al.* (1995). Deposition by solifluction, debris flow and dry grain flow are most common, but also niveo-aeolian action and frost-coated clast flow are reported from certain areas. For most of these processes periglacial conditions are not required. However, some of them, like stonebanked solifluction and frost-coated clast flow, require specific periglacial conditions, while others show an enhanced development under periglacial conditions.

Landslides are rapid movements which also occur in all climatic zones, but in a periglacial context they may be favoured by the presence of an underlying permafrost. In recent years, movements have been identified which are promoted by gliding of the soil over the permafrost table, especially when the ice near the base of the active layer is thawing, leading to minimal shear strength. Sediments at that level can even be liquefied by excess pore-water pressure due to artesian pressure or to thaw consolidation. As an example the 'detachment slides' should be mentioned which were studied extensively on Ellesmere Island (LEWKOWICZ, 1990; HARRIS, LEWKOWICZ, 1993). They are enhanced by the rapid advance of the thaw front towards the base of the active layer. Although the individual processes are of limited extent, they may represent an important geomorphic process in permafrost regions by their frequent occurrence.

Frost weathering has traditionally been considered in the general geomorphological literature to be responsible for the production of angular blocks as well as for fine silty material which is in turn estimated to be one of the main sources for loess supply. Experimentation started already in the fifties and is still going on. Long-lasting experiments, for instance at the Centre de Géomorphologie at Caen, have revealed numerous empirical relations between fragmentation and rock physical parameters (LAUTRIDOU, OZOUF, 1982; OZOUF, 1983; LAUTRIDOU, 1988). The role of moisture availability in the magnitude of frost action has been emphasised by laboratory experiments (PRICK, 1997) and also by new approaches in field monitoring by MATSUOKA *et al.* (1997). However, the process of gelifraction is not clear yet. More particularly, the frost-thaw mechanism is under serious discussion, especially for places where no water is available. At other places, the necessary multiple frost-thaw alternations are simply absent, for instance in the presence of a snow cover (THORN, 1979). Promising results for alternative mechanisms have been demonstrated by HALL (1997) who measured in the field marked differences in temperature over very short distances and also over very short time. Furthermore, there are indications that chemical weathering is significantly active, for instance by the very aggressive acids produced by lichens. Salt weathering may also play a role in rock fragmentation in certain circumstances, as well as alternating wetting and drying. So it appears that the predominant occurrence of angular clasts in periglacial environments may be due to different processes and even may be enhanced by the interaction of several mechanisms (HALL, 1992).

NATURAL ENVIRONMENTS

The concepts on *periglacial fluvial* activity have been quite deterministic in geomorphological literature. Braided rivers were considered to be typical for periglacial environments. Better insights in the processes of sediment transport by rivers in periglacial environments came up gradually for instance by the field measurements by the research team of WOO in northern Canada (e.g. WOO, MCCANN, 1994). Palaeohydrological studies have shown that river patterns and fluvial deposition are a function of vegetation cover, soil cohesion and discharge regime and not of temperature (VANDENBERGHE, 1993). So the whole range of braided, as well as meandering and anastomosed rivers are found in periglacial regions as well as a whole range of transitional forms (e.g. VAN HUISSTEDEN, 1990). Such a complex of patterns appears to coexist also in present-day periglacial environments where they may change their appearance even in very short time.

Traditionally *periglacial aeolian* deposits have been studied for their palaeogeomorphological or stratigraphic significance. It was only some ten years ago that aeolian process studies in present periglacial environments started (McKENNA-NEUMANN, GILBERT, 1986; KOSTER, DIJKMANS, 1988). From these studies it appeared for instance that combined sand and snow drift was not able to create the typical, finely laminated coversands, since such niveo-aeolian deposition leads to homogenization, sometimes accompanied with deformation structures. New perspectives were also introduced from detailed sedimentological studies. We mention the striking similarities between relict aeolian deposits in The Netherlands described by RUEGG (1983) and SCHWAN (1986) and subrecent deposits in Alaska described by LEA (1990). Different facies representing dunes, coversand sheets on dry or wet surfaces, fluvio-aeolian deposits and aeolian lacustrine fills were defined and are diagnostic elements in the reconstruction of past periglacial environments (SCHWAN, 1987). The characteristics of former periglacial aeolian activity have been shown to be the combined effect of geomorphological position, vegetation cover and permafrost as a determinant for moisture conditions (VANDENBERGHE, 1991; KASSE, 1997).

Mountainous regions are of the most sensitive ones to climatic change and much attention is paid nowadays to these environments. They do not only occur at high-latitude but also in semi-arid or subtropical zones. A characteristic feature in these environments are the rock glaciers which are slowly moving, tongue-shaped bodies of frozen debris. The debris may be derived from moraines or slope deposits. It is now clear that *rock glaciers* are completely different from ice glaciers covered by debris (e.g. BARSCH, 1988; HAEBERLI, VONDER MÜHLL, 1996). From their spatial distribution and topographic occurrence unique climatic information may be derived (HUMLUN, 1998). The knowledge of internal composition, structure and rheological properties is essential for a better understanding of the behaviour of rock glaciers. Geophysical measurements are useful methods in this respect: for instance the content of interstitial ice or ice lenses may be estimated by electrical resistivity soundings and borehole logging (VONDER MÜHLL, HAEBERLI, 1990; ASSIER *et al.*, 1996).

PALAEOCLIMATIC RECONSTRUCTIONS

Much progress has been made in recent years in the use of periglacial phenomena as proxy-indicators for palaeoclimatic reconstructions (VANDENBERGHE, 1988; ISARIN, 1997). By comparison with their present-day climatic constraints, specific periglacial phenomena enable to derive especially palaeo-temperatures, and more particularly mean annual air temperatures (MAAT), provided that these phenomena have also good preservation chances and taking into account their geomorphological and hydrological setting, soil conditions and vegetation or snow cover (PISSART, 1987; HUIJZER, ISARIN, 1997). The quality of the data, expressed in the reliability, climatic significance and dating of the forms, is of utmost importance. The use of such data in combination with a relatively wide spatial distribution enables the production of palaeoclimatic maps (e.g. HUIJZER, VANDENBERGHE, 1998; ISARIN *et al.,* 1998) and curves showing the climatic evolution through time (e.g. VANDENBERGHE, PISSART, 1991). Most of the present-day analogs are documented in maps which present climatic and environmental conditions in combination with the occurrence of periglacial phenomena and permafrost (e.g. BROWN *et al.*, 1997; ROMANOVSKY, 1985).

The relation between climate and subsoil temperature can also be used for ground temperature history estimates. Heat at the surface propagates slowly by diffusion in permafrost so that major changes in temperature take place in the permafrost after some time. Temperature records in boreholes in Alaska show that there can be little doubt about a marked increase in temperature at the top of the permafrost of a few degrees in the last century (LACHENBRUCH *et al.*, 1988). Recently, geothermal data have been successfully combined with oxygen isotope data from ice cores which have higher resolution but lower possibility for climatic interpretation (BELTRAMI, TAYLOR, 1995).

It is very important to stress that such studies of past climatic environments will help to assess the impacts on morphology, sedimentary and hydrological processes and physical soil conditions induced by near-future climatic changes.

CHALLENGES FOR THE FUTURE

What can we learn from these historic and recent developments?

1. Further progress in a better understanding of the processes that shape landforms and affect the periglacial environment is of utmost importance. This is true from an academic point of view as many processes as well as their impacts are still poorly understood. But this is certainly also significant from a societal point of view when considering constructional and environmental problems and natural hazards.

2. Periglacial environments are most vulnerable. Therefore the risks for irreversible damage and the measures to protect against them should be investigated thoroughly. Negative effects in present-day periglacial environments are due to exploration, mining and constructions, while soils on permafrost are especially sensitive to disturbances. Therefore, a good understanding of the characteristics of tundra ecosystems and soils, as well as engineering constraints is necessary. In this way sensitive habitats and areas with endangered species may be avoided.

3. With respect to a (possible) climatic warming there is an urgent need to evaluate and quantify the effects of climatic changes on periglacial environments and especially the regions with permafrost. The effects of global climatic change are supposed to have their greatest impact in the periglacial environment. The permafrost limit may retreat by 100 km per degree temperature increase (JUDGE, PILON, 1983). At some places in Russia a retreat of the permafrost limit of almost 400 m per year has been reported from the last decades. Also the second Assessment Report of the IPCC (1995) recognizes the vulnerability of permafrost geo- and ecosystems to climatic change for instance by a thickening of the active layer, thaw settlement in areas of massive ground ice, slope instability, and the possible release of methane.

4. The use of modern techniques opens new perspectives for research. Most important is the possibility to carry out quantitative and automatic measurements in the field as well as in the laboratory. The acquisition of important series of field measurements and (palaeo)climatic data should lead to storage and documentation in global standardized archives or data-bases, enabling the exchange of information for different purposes.

CONCLUSIONS

The development of ideas on the few selected topics which are presented, allow to appreciate the considerable progress which has been made in periglacial research in the last half century. Thanks to the increased knowledge of periglacial processes we are now able to come back to some of the original objectives of the Commission, namely to better understand the essentials and specificity's of periglacial environments.

From the given analysis two main conclusions may be made:

1. there is the need for a better knowledge of physical processes in freezing and thawing soils in relation to climatic conditions by field measurements and laboratory experiments, and

2. there is the significance of relic periglacial phenomena for palaeoclimatic reconstructions and for evaluating the impact of climate on periglacial environments. These points will be the main challenge for future periglacial research which should respond both to academic questions and societal demands. Periglacial research is at the cross of geocryology, geomorphology and climatology, considering respectively the periglacial processes, landform development and environmental conditions. Considering the growing awareness of the vulnerability of periglacial environments with regard to changing climatic conditions and the impact of man, makes the IGU the most appropriate niche to continue periglacial research.

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