



The concept of cryo-conditioning in landscape evolution

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ABSTRACT

Recent accounts suggest that periglacial processes are unimportant for large-scale landscape evolution and that true large-scale periglacial landscapes are rare or non-existent. The lack of a large-scale topographical fingerprint due to periglacial processes may be considered of little relevance, as linear process–landscape development relationships rarely can be substantiated. Instead, periglacial landscapes may be classified in terms of specific landform associations. We propose “cryo-conditioning”, defined as *the interaction of cryotic surface and subsurface thermal regimes and geomorphic processes*, as an overarching concept linking landform and landscape evolution in cold regions. By focusing on the controls on processes, this concept circumvents scaling problems in interpreting long-term landscape evolution derived from short-term processes. It also contributes to an unambiguous conceptualization of periglacial geomorphology. We propose that the development of several key elements in the Norwegian geomorphic landscape can be explained in terms of cryo-conditioning.

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Introduction

In contemporary geomorphology, the study of “landforms” constitutes the core of the discipline; however, there is little discussion on how “landform” is defined (Rhoads and Thorn, 1996) or what the basis for *classifying* landforms is. “Landscape” is another fundamental concept that lacks a proper definition in geomorphology. In its simplest sense, landscape is synonymous with topography, and can be considered either a continuous surface in space characterized by morphometric properties (Etzelmüller et al., 2007) or a specific assemblage of individual landforms. On the other hand, landscape as a term also includes biotic and anthropogenic patterns that lead to typical “landscape regions” such as vegetation and/or land-use patterns. Viewing the landscape as either continuous or a sum of discrete objects has very different philosophical implications (Rhoads and Thorn, 1996) and may yield complementary data in a landscape analysis.

Haschenburger and Souch (2004), based on a critical examination of seminal papers, propose six principles that create geomorphic landscapes. Their first principle is that landforms are the basic building blocks, while the remaining principles describe important structural and functional characteristics in a landscape. They state that a landscape is more than just an assemblage of landforms, and emphasize dynamic rather than static classifications. Landforms are essential features of a landscape, but it is not clear *a priori* if the

individual landforms that make up the landscape are or must be of the same scale as the landscape itself. Landforms would mainly be considered to be a smaller scale of the landscape even if, e.g. Ahnert (1994, 1996) in his hierarchical structure of landforms, includes all geomorphological objects from erosion rills to mountain chains into the term landform.

The “periglacial” concept was first used by von Lozinski (1912) and has evolved towards a definition of processes relating to “frost action” (Thorn, 1992; French 2004; French and Thorn, 2006), but with indistinct boundaries to azonal processes operating in cold climates. In this paper we refer to periglacial as the processes associated with seasonal and perennial ground ice as recommended by French and Thorn (2006).

The *periglacial landscape* is an interesting case-study of landscape development. First, the *periglacial landscape* is a focal point in science due to anticipated effects and feedbacks in global warming scenarios (French, 2007). Second, cold-climate landscapes have been regarded as being geomorphologically active. Third, the importance of periglacial processes for long-term large-scale landscape evolution has recently been questioned (André, 2003). Fourth, many cold-climate regions intersect with glacial domains in both space and time, thereby providing interesting examples of interactions and controls on landscape development (Zhang et al., 2001; Etzelmüller and Hagen, 2005).

In this paper we aim to develop an overarching concept for analysing cold-climate landforms and landscape evolution and control. The need for such a concept is further substantiated by the problems involved in defining periglacial geomorphology and periglacial landscapes. We argue for the importance of discussing

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the interaction of processes and controls on landscape evolution, rather than static landform assemblages or specific process domains. We claim that the relevant processes in cold-climate landscapes have one *common* control, namely a cryotic ground and surface thermal regime (at timescales ranging from diurnal to perennial [permafrost]). On that basis we suggest *cryo-conditioning* of landform and landscape development as a potential overarching concept, and discuss this within a theoretical geomorphologic framework. Finally, we apply this concept to attempt to explain some elements of the Norwegian landscape.

Periglacial geomorphology and landscapes

Thorn (1992), French (2004), and French and Thorn (2006) argue for a narrow description of periglacial processes and conclude that “the core of modern periglacial geomorphology should concern the study of both perennial and seasonal ground ice and related landscape development” (French and Thorn, 2006, p. 172). Despite the narrow definition of periglacial processes, their understanding of periglacial geomorphology is much broader. They state that “other components of periglacial geomorphology include the impact of seasonal freezing and the roles of seasonal snow and of fluvial, lacustrine, and sea-ice covers. Furthermore, the geomorphology of cold non-glacial regions must embrace (...) also the azonal processes that exhibit distinct behaviour and/or magnitude and frequency distributions” (French and Thorn, 2006, p. 172).

We agree with this holistic view on cold-climate geomorphology, but at the same time find it unfortunate to introduce ambiguity in the term periglacial. “Periglacial” should have the same sense for processes, landforms, landscapes, and environments. Defining periglacial processes in terms of ground-ice processes and conditions implies that periglacial geomorphology is about landforms and landscapes relating *only* to these processes and conditions. When periglacial geomorphologists seem reluctant to follow such a narrow definition, it is probably because, like Pissart (2005), they consider azonal processes to behave with distinctive characteristics in periglacial environments – in other words, that the azonal processes are somehow conditioned by the cold temperatures and ground ice, and that there are important interactions between periglacial and azonal processes.

We attempt to reconcile these perspectives. Glacial processes are also conditioned by cold environments and interact with periglacial processes. Within glaciology, the importance of permafrost conditions for the glacial and glacial geomorphic system is now being recognized (Etzelmüller et al., 1996; Etzelmüller and Hagen, 2005; Haeberli, 2005; Fitzsimons et al., 2008; King et al., 2008). The co-occurrence of permafrost and glaciers in space and time, such as in many high mountains and polar areas, or the former existence of glaciers in present permafrost areas, may cause distinctive characteristics of landforms and sediments. As geomorphologists, we seek explanations to these landforms and sediments. In our view, there should be no reason to include azonal processes in the periglacial domain and at the same time exclude glacial processes.

French (2007) concludes that the few landscapes that experienced cold, nonglacial conditions throughout the Pleistocene can be regarded equilibrium periglacial landscapes, but that they do not show significant development during this time with respect to bedrock topography. Where a clear periglacial imprint is visible in bedrock topography, such as the chalk areas of England and France, the bedrock has been particularly susceptible to frost weathering. Apart from André (2003), no contemporary papers present data in which scale is taken into account in the discussion of process rates against long-term “periglacial landscape” development. Where the term “periglacial landscape” is used in recent papers, it is mainly to denote a landscape where periglacial processes are or have been operating (e.g., Hättestrand, 1994; Luoto and Hjort, 2004; Fortier

and Aubé-Maurice, 2008), or where periglacial landforms are developing (Rossi et al., 2008). When scientists use the term “periglacial landscape” they often relate this to a particular feature such as ice-wedge polygons or rock glaciers. Then, a “periglacial landscape” can be regarded as a *specific association of landforms, superimposed on larger scale topography*. This is in accordance with Haschenburger and Souch (2004, Table 1) principle #2: “Landscapes are organized assemblages of interconnected landforms”, where they explicitly state that landscapes can include both inherited and exhumed landforms.

It is commonly accepted that periglacial processes do not produce a large-scale topographic fingerprint. This is partly due to the differences in spatial scale that different processes operate upon. Glacial landforms are caused by processes operating at scales up to that of continental ice streams and ice sheets, while periglacial process–form systems do not exceed the scale of rock glaciers, open-system pingos, and thaw lakes, and more often operate on scales below 10¹ m such as in patterned ground. In addition, periglacial processes contribute to sediment production (in the case of frost weathering and thermokarst), but other processes will be responsible for sediment export from the catchment. It is therefore reasonable that any periglacial landscape will exhibit dominant landform elements related to either fluvial or glacial processes. Thus, in a very strict sense, there should be no large-scale “periglacial landscapes”.

However, the lack of specific large-scale topography is not necessarily a relevant criterion for determining the importance of periglacial conditions. First, a specific end product of landscape development can generally not be substantiated, given the nonlinear nature of geomorphic systems (e.g., Phillips, 2006). Second, the importance of periglacial processes should be discussed also in terms of geomorphic work, and this is seldom recorded in landforms. Third, an important point for explaining palimpsest landscapes is to clarify what controls inheritance. From a geomorphological point of view, the evolution of this landscape, both regarding the processes involved and the relevant controls, thresholds and other sources of nonlinearity, is more interesting than its present state in terms of landform assemblage.

Cryo-conditioning of landscape development

The concept

In cold-climate regions, slope, fluvial, marine, and aeolian processes exhibit certain “zonal” characteristics (cf. French, 2007). For fluvial processes, permafrost hydrology is a term used (Woo et al., 2008), and hydrological models have been developed specifically for cold regions (Pomeroy et al., 2007). Frozen ground influences hydrological regimes and runoff generation and the interactions with freezing and thawing ground will further influence fluvial geomorphology and sediment yield. Modelling by Boogart et al. (2003) showed that a change from non-permafrost to permafrost conditions leads to network expansion and a (temporary) peak in sediment yield. A freeze–thaw regime may also be very important for riverbank erosion (Yumoto et al., 2006). On slopes, Davies et al. (2001) demonstrate that the stability of frozen jointed bedrock is temperature-dependent, and the importance of cryotic temperature regimes for mass movements from rock walls has been revealed by, for example, Anderson (1998), Gruber and Haeberli (2007) and Hales and Roering (2007). Interconnection between active layer creep (solifluction) and active layer slope failures was demonstrated by Harris and Lewkowicz (2000), and the role of permafrost or seasonal frozen layer in facilitating detachment slides and debris flows is well recognized (Larsson, 1982; Lewkowicz and Harris, 2005). Also in the case of weathering, the ground temperature regime (rather than just freeze–thaw) is considered essential (Hallet, 1983; Hallet et al., 1991; Ødegård et al., 1995; Hall and André, 2001; Hall et al., 2002).

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