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Seasonal Snowpack Variability and Alpine Periglacial Geomorphology

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Summary: Periglacial geomorphology needs a more systematic and holistic research model which focusses attention on absolute and relative rates of landscape evolution. Such an approach (1) emphasizes ground climate over the more traditional air climate, (2) substitutes the areal and temporal significance of processes for the common preoccupation with 'exotic' forms and (3) places periglacial geomorpholgy in a stronger theoretical context, both internally and externally. In the alpine tundra zone of Colorado, U. S. A., successful stratification of many periglacial process rates by seasonal snowpack distribution, and the concommitant tundra plant community distribution suggest that snowcover is a potentially useful tool in identifying both the internal linkage within alpine periglacial landscapes and the similarities/dissimilarities between these and other geomorphic regimes. The emergent step-function character of the alpine periglacial landscape parallels the general theoretical model for geomorphic development forwarded by SCHUMM (1977).

Zusammenfassung: Die Periglaziärgeomorphologie bedarf verstärkt eines umfassenden systematischen Forschungsansatzes, der auf die Erklärung absoluter und relativer Raten der Reliefentwicklung zielt. Diese Betrachtungsweise hebt 1) die Bedeutung des Bodenklimas gegenüber dem Luftklima hervor, ersetzt 2) die primäre Untersuchung „exotischer" Formen durch die Klärung der räumlichen und zeitlichen Bedeutung von Prozessen und stellt 3) die Periglaziärgeomorphologie in den Rahmen eines theoretischen Gesamtkonzepts. Am Beispiel der alpinen Mattenregion in den Hochgebirgen Colorados, USA, kann gezeigt werden, daß im Hinblick auf eine Überlagerung und Steuerung verschiedener periglaziärer Prozeßabläufe durch die jahreszeitliche Schneedeckenverteilung und die damit einhergehende Vegetationsverbreitung das Verhalten der Schneedecke gut dazu herangezogen werden kann, um wesentliche Merkmale des Periglaziärs und die Unterschiede zu anderen Formungsmilieus aufzuzeigen.

INTRODUCTION

"An appreciation of the value of operating within an appropriate general systematic model has emerged from the recognition that the interpretation of a given body of information depends as much upon the character of the model adopted as upon any inherent quality of the data itself." R. J. CHORLEY, 1962, page Bl in "Geomorphology and General Systems Theory".

Although the above citation might seem general and dated, it is particularly relevant to the needs of contemporary periglacial geomorphology. Presently, periglacial geomorphology requires a comprehensive framework that will create a context and perspective for periglacial research and serve as a focus that will permit researchers to identify the essential attributes of the science. The object of this paper is to suggest that, at some scales, the spatial and temporal patterns of seasonal snowpacks provide one useful framework within which important variations in alpine periglacial geomorphic processes may be fitted.

As with many entrenched concepts and terms in geomorphology, close examination of the term "periglacial" serves to confuse rather than enlighten. EMBLETON & KING (1975), FRENCH (1976) and WASHBURN (1980) all devote initial chapters to defining the concept precisely. Rather than review this topic the term is used broadly in this paper.

BACKGROUND

Many geomorphologists would argue that periglacial studies have been marked by a preoccupation with temperature rather than moisture regimes. Stemming from this has been a lengthy literature on air climate. Another characteristic has been the high proportion of periglacial literature that addresses exotica such as patterned ground, palsas and pingos, often in isolation. Such studies minimize our appreciation

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of the general significance of these phenomena. It follows that the selection of unifying themes in periglacial geomorphology is difficult. If literative citation frequency were used as the criterion, freeze-thaw cycles, permafrost and gelifluction (WASHBURN, 1980: 200—201) would probably emerge as strong focal concepts. However, it does not seem that any of these presently provides a suitable central theme.

In the case of freeze-thaw cycles, there is little question concerning their effectiveness in promoting creep and sorting (WASHBURN, 1980). However, examination of the freeze-thaw weathering literature clearly reveals that neither the physics nor the natural spatial and temporal variability of the processes are yet understood (THORN, 1979a). The literature abounds with unverified assertions and although there have been several extensive reviews (KONISHCHEV, 1982; LAUTRIDOU & OZOUF, 1982; MCGREEVY, 1981; WHITE, 1976), freeze-thaw weathering remains a weak candidate in the search for disciplinary pillars.

The presence or absence of permafrost may be a fundamental criterion for subdividing subsurface periglacial environments. For certain periglacial forms (e. g., ice wedges, palsas, pingos) it is clearly an essential condition. Nevertheless, many other important processes such as solifluction and sorting may function on both seasonally and perennially frozen subsurfaces. Currently, there are no satisfactory gradational links between the presence or absence of permafrost and surface landforms although extremes in the spectrum may be identified. Finally, gelifluction is not a particularly appropriate central theme because it rarely, if ever, occurs in isolation. It is restricted to the wettest parts of the landscape and ultimately is a secondary conditon, since the primary one is soil moisture content.

THE HYDROLOGIC CYCLE

The hydrologic cycle, with all of its spatial and temporal variability, is at the heart of most process geomorphology. This is not to deny the importance of structural, tectonic or other sub-fields of geomorphology, but it is important to recognize that most periglacial geomorphologists focus upon surface and near-surface phenomena. On a Quaternary or Holocene time scale, let alone that of the average geomorphic study, many of the macro- and meso-scale landscape components are essentially constant.

Variation in effective precipitation input (THORN, 1978) has additional appeal to periglacial geomorphologists since seasonal snowpacks and their varability are tangible in a manner that rainfall variability is not. Furthermore, the potential energy in a snowfall regime is redistributed as blowing and drifting snow; this is important because neither of these processes does significant geomorphic work in the same way as overland flow and throughflow in a rainfall regime. Snowmelt represents a primary source of geomorphic energy and it is released over restricted areas for a limited period. On the other hand, the significance of rain-initiated processes, particularly convective rainstorms at high elevations (CAINE, 1978) complicate the issue.

SEASONAL SNOWPACK VARIABILITY

Snowpack variation is important in alpine environments not only because it modifies ground temperatures but also because it dominates ground moisture regimes. Therefore, it is a basic control of ground climate, a much more important geomorphic concept than the more commonly cited meteorological screen climate.

Several earlier papers have examined various aspects of the influence of snowpacks upon periglacial processes in the Colorado Front Range (THORN, 1979b, 1980). It is also known that mechanical weathering by freeze-thaw cycles requires coincidence of frost sensitive rocks, bulk water to create saturation $\geqq 50\%$

and some (uncertain) freezing amplitude (HUDEC, 1973). Snowpacks play an extremely complex role in these requirements, supplying not only essential bulk water during meltout, but also insulating and thereby reducing freezing amplitude. With respect to chemical weathering, meltwater is again a critical driving force. Initially, increasing snowpack depth probably promotes increasing weathering rates (e. g., THORN, 1975). However, very deep snowpacks reduce vegetation growth and eventually preclude it, thereby reducing the supply of organic compounds which appear to be vital to many weathering processes.

The entire question of absolute and relative weathering rates, and the processes involved, requires immediate attention in periglacial geomorphology. At the present time it is dominated by a theologic, rather than scientific, perspective. The data that are available (discussed in THORN, 1978) suggest that chemical weathering rates are moisture, rather than temperature, dependent and that chemical weathering dominates mechanical weathering in many (most?) periglacial environments. Stream solute/bed/suspended load studies made from one or two sites and extrapolated basin-wide offer no insight into weathering regimes. This is because they integrate unknown proportions of high and low solution activity and further confuse this with clastic transport which in many cases is dominated by reworking of floodplain alluvium; the latter is often paraglacial (CHURCH & RYDER, 1972) in periglacial environments.

Plant communities and by inference vegetation maps offer periglacial geomorphologists a surrogate measure of ground climate. To the uninitiated eye tundra surfaces may appear homogeneous but, in reality, they are extremely diverse as specialized communities adjusted to a highly stressful environment. Tundra biologists (e. g., WEBBER & MAY, 1977) recognize soil moisture, snow accumulation and soil disturbance as the primary controls on tundra plant communities. Given the intrinsically geomorphic character of these measures it is not surprising that geomorphic studies stratified by plant community have proven extremely rewarding.

BOVIS & THORN (1981) found surficial wasting rates to vary by two orders of magnitude (x100) between late-lying snow patch and dry fellfield sites on Niwot Ridge, Colorado Front Range. The availability of a vegetation map (KOMARKOVA & WEBBER, 1978) permitted calculation of the proportional contribution of the various surface types e. g., late-lying snow patch sites occupy 3% of the area but produce 50% of the sediment. In another study, stratified by plant community, THORN (1982) found that pocket gophers *(Thomomys talpoides)* whose destribution is closely tied to that of the snowpack produce localized maximum surficial wasting rates up to one order of magnitude greater than those in snowpatch sites.

Contemporary surficial periglacial processes, at least in the alpine zone, exhibit a distribution that is clearly akin to a step function (SCHUMM, 1977). Spatially, the landscape contains small areas that are extremely active and produce a high proportion of the sediment/solution yield. These active areas are "islands" in a much more extensive matrix of relative inactivity. As with non-periglacial environments unchannelized and channelized water is the driving force, but the periglacial landscape is much more poorly articulated because blowing and drifting snow do little geomorphic work in comparison to overland flow and throughflow (their rainfall regime equivalents).

The final spatial attribute of a snowfall-dominated regime is its strongly oriented or asymmetrical nature. Prevailing winds during the accumulation season produce oriented scouring and build-up of seasonal snow patches leading to uneven geomorphic activity (e. g., THORN, 1978); this important characteristic may be reoriented by climatic change (BENEDICT, 1970). Temporally, the periglacial landscape also exhibits step function behaviour as very high proportions of the annual geomorphic work are accomplished during a very brief part of the year.

CONCLUSIONS

Available data indicate that most microscale and many mesoscale surficial process rates are snowpack dependent in the alpine zone of the Colorado Front Range. This is an encouraging development because it is undoubtedly a periglacial environment with a mugh higher energy input from convective rainfall than higher latitude periglacial zones. The strength of viewing periglacial processes within a framework derived from seasonal snowpack patterns is that it embraces the entire landscape and the complete suite of contemporary processes while emphasizing the principal driving force — water.

At a temporal macroscale, periglacial geomorphologists must still confront the step function concept. On a priori grounds the kataglacial period (FARBRIDGE, 1972) should be one of intense geomorphic activity and CHURCH & RYDER's (1972) recognition of paraglaciation does much to confirm this notion. As a group, periglacial geomorphologists must pay close attention to the distinction between contemporary processes in steady state equilibrium over graded time and those that represent paraglaciation or ''glacial aftermath'' which are appropriately viewed as step components of dynamic metastable equilibrium during cyclic time (SCHUMM, 1977: 4—15). Spatially, one needs to abandon air climatology in periglacial geomorphology and focus attention on the variability of ground moisture regime, lithology and the interaction of the two. Finally, efforts should be made to create a precise binary vocabulary consisting of a set of non-genetic morphological terms complemented by a set of non-morphologic genetic terms. Available terminology is in large part dated, poorly conceived, ill-defined and loosely applied. The trauma in replacing an eclectic vocabulary and a largely item-specific field of study with a precise, and therefore liberating, vocabulary with which to study systematically the entirety of the periglacial environment will certainly be great. Nevertheless, these are essential prerequisites to determining the significance of periglacial phenomena.

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