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Excerpt
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Introduction

Sand dune formation has been studied for a long time (e.g. Sokolów 1894) and several excellent text books on that topic have been published recently (e.g. Greeley & Iversen 1985; Pye & Tsoar 1990; Nordstrom *et al.* 1990). Large sand seas and very high sand dunes in the deserts in low latitudes are such fascinating features that they have attracted students much more than cold environment features. Detailed surveys of aeolian landforms in tropical, subtropical and temperate environments are numerous. A very extensive literature exists on deserts, their morphology and climate (e.g. Cooke & Warren 1975; Mabbutt 1977; McKee 1979; Thomas 1989, 1997; Cooke *et al.* 1993; Abrahams & Parsons 1994) and coastal environments (e.g. Bakker *et al.* 1990; Carter *et al.* 1992).

Most presentations of aeolian landforms are limited to latitudes lower than 60°, with most close to the equator. In these studies the Polar world has been totally excluded. However, we find in the Polar regions real deserts with very limited or no vegetation. People seldom think of the regions with dry snow as white deserts (e.g. Giaever 1955). We can call Polar regions outside glaciers seasonal Polar deserts, without liquid water, with no vegetation, where snow cover melts away and with wind drifting granular material in an unlimited way. These seasonal cold deserts are limited to a zone where temperature in the winter is frequently fluctuating around 0 °C which means liquid water and hard pan in the snow cover. Occasionally wind there is also able to drift and pack snow especially when new. This book examines cold environments with respect to wind and its geomorphic impact in high latitudes. Much of what is presented here can be applied also in Alpine regions and in cold regions at lower latitudes (consider, for example, Mongolia). The topic has been studied earlier, for example by Hörner (1926) and Samuelsson (1926), but apparently since then there has been no review published of the geomorphic effects of wind in cold environments.

Extremely strong winds are well-known both from the Arctic and Antarctica. In South Victoria Land, Antarctica and on both sides of the peninsula of West Antarctica, ‘where rock is exposed denudation is powerful as a result of summer insolation, frost weathering, and strong winds. The violent wind acts as a formative agency on rock and snow surfaces. It transports snow, dust, and sand; creates small heaps of coarse detrital material like those in stony deserts; it polishes boulders and bed rock; it furrows the snow and shapes it into sharp-edged sastrugi' (Nordenskjöld & Mecking 1928: 287).

Hobbs (1931) called attention to the (according to him) erroneous conception regarding the conditions outside the Pleistocene continental glaciers of North America and Europe. He had observed in Greenland fierce storms which blew outward from the ice of continental glaciers and the restriction of drainage to a brief warmer season during which meltwater issued from beneath the glacier. In 1942 Hobbs wrote: 'As soon as the brief warm season has come to an end, the agent of extraglacial transportation is no longer running water but strong wind currents directed radially outward from the glacier, or nearly at right angles to the glacier front'. Wind takes over from the thaw water the work of transportation so totally that Hobbs (1942) considered wind as the dominant transportation agent within extra marginal zones to continental glaciers. He had found how 'dust, sand, and smaller pebbles are lifted and carried away, leaving behind an armour of pebble pavement to protect the material below, and in every way this pavement is similar to the *sêrir* of low-latitude deserts'.

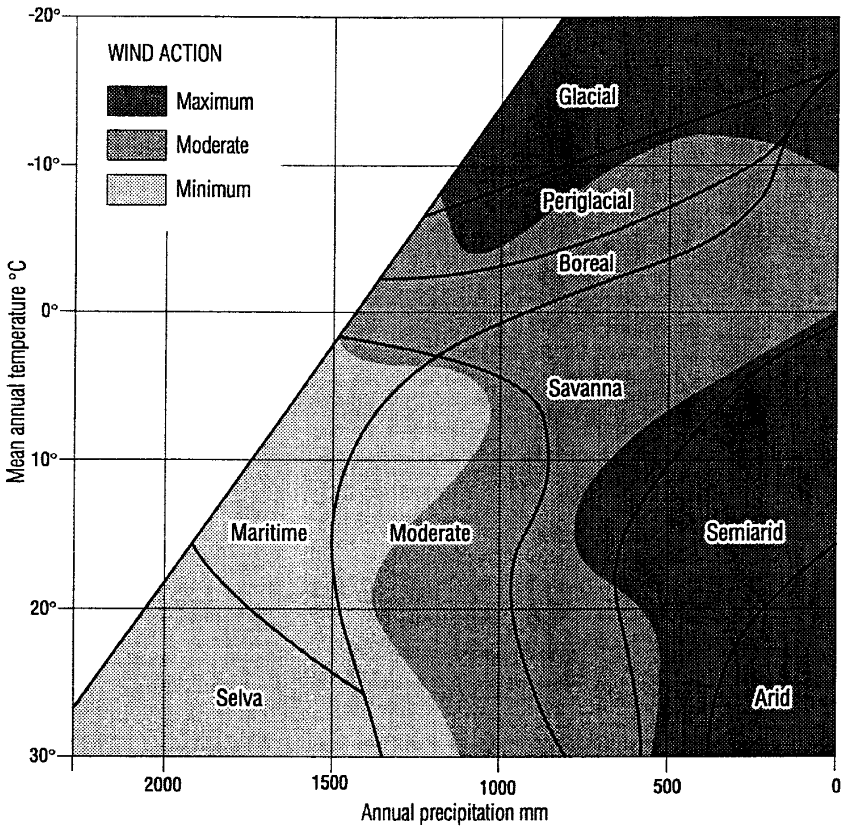
Thus an overall presentation of aeolian geomorphology from the cold regions was missing. Hamelin and Cook (1967: 129) wrote in their glossary of periglacial phenomena: 'The place of wind action in periglacial geomorphology is not fully understood. It does, however, contribute to both depositional and erosional features. Lack of vegetation in periglacial areas greatly increases the efficacy of the wind. The accumulative or depositional aspect is by far the most important. Some loess is of periglacial origin and is deposited by wind action. . . . Abrasion is performed by wind, both by blowing sand and snow.'

However, the importance of wind as a geomorphic agent in cold climates has been known a long time (e.g. Sapper 1909; Enquist 1916; Samuelsson 1926); the High Arctic deserts are rather seldom mentioned in literature (e.g. Passarge 1921; Fristrup 1952a, 1952b, 1952–53; Smiley & Zumberge 1974). In 1993 it was still possible to publish a book about *Canada's Cold Environments* (French & Slaymaker 1993) without mentioning the term wind erosion or deflation, although strong winds are pointed out. Tricart (1970) credits deflation with a greater transporting role than running water in periglacial areas. Periglacial environments are characterized by strong wind action. Climatic dryness and the sparse plant cover are only partly important for the aeolian processes, but above all the frost and melting glacial ice produce large quantities of unconsolidated sediments favourable for wind transport (Troll 1948). Peltier (1950: 221) believes that wind has a secondary role that increases in the later part of the periglacial cycle.

Maximum wind action occurs in morphogenetic regions with low annual precipitation and high or low mean annual temperatures (Peltier 1950: Fig. 6; Thornbury 1954: 60–65). In cold morphogenetic environments Peltier (1950: Fig. 7) considers glacial, periglacial, boreal and partly savana (sic! term used in unusual context) regions, which have from moderate to strong wind action (Fig. 1.1).

In the existing literature of the twentieth century we can find certain centres of periglacial aeolian studies. First a strong school of this aeolian geomorphology was established in Uppsala, Sweden (Enquist 1916, 1932; Hörner 1926; Högbom 1923; Samuelsson, 1921, 1925, 1926). The papers were published in a local journal: *Bulletin of the Geological Institution of the University of Upsala*. Then the centre of gravity moved to the central European sand belt and to Poland where many ancient late Pleistocene and Holocene sand dunes of cold climate origin appear (e.g. Dylikowa 1958; Galon 1958; Kobendza & Kobendza 1958;

Fig. 1.1 Morphoclimatic regions and the activity of aeolian processes according to mean annual air temperature and precipitation compiled after Peltier (1950: Figs. 6 and 7). © Association of American Geographers, Blackwell Publishing.



Mrózek 1958; Pernarowski 1959, 1966; Stankowski 1963; Wasylikowa 1964; Urbaniac 1969; Kozarski 1991). In Lódz the *Biuletyn Peryglacjalny*, founded by Jan Dylik, was published. Poser (1948, 1950), by continuing the old German tradition in late glacial sand dune studies (Sokolów 1894; Solger 1910), established in Göttingen, Germany, a study centre of periglacial processes in general and aeolian processes, too. Several studies were published in *Abhandlungen der Akademie der Wissenschaften* in Göttingen in the 1970s and 1980s. At present we have no very well specialized, leading cold environment research group studying cold environment aeolian processes but the interest seems to be split into several places (Seppälä 1975b; Niessen *et al.* 1984; Koster 1988, 1995). Recently a new journal in cold environment studies has been founded: *Permafrost and Periglacial Processes*, which contains some aeolian geomorphology, too.

Gary *et al.* (1972: 232) in the *Glossary of Geology* defined *aeolian* (=*eolian*) as ‘pertaining to the wind; especially said of rocks, soils, and deposits (such as loess, dune sand, and some volcanic tuffs) whose constituents were transported (blown) and laid down by atmospheric currents, or of landforms produced or eroded by the wind, or of sedimentary structures (such as ripple marks) made by the wind, or of geologic processes (such as erosion and deposition) accomplished by the wind’. Nevertheless, wind transport is a major part of sedimentology and perhaps it has received less attention than it deserves (Pettijohn *et al.* 1987: 310).

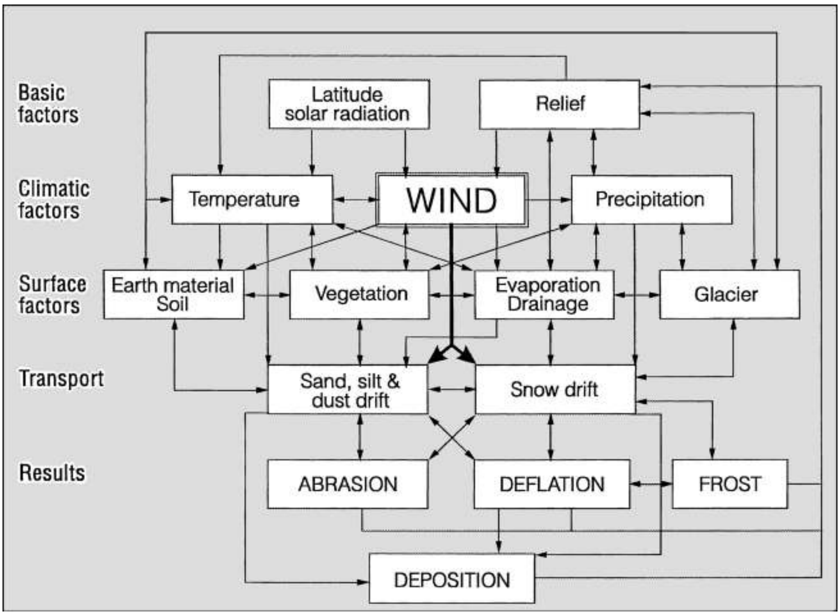
I would like to expand further the use of the term *aeolian* to the secondary effects of wind in cold environment. Then we are speaking of snow drift and accumulation, glacier formation, permafrost formation, deflation features which could later be lake basins, and deposition of mineral material together with snow, so called *niveo-haeolian* deposits. Deflation of snow cover can increase the thickness of permafrost, and form patterned ground which has connections with wind activity. Regions with glaciers and some other areas in middle latitudes have been included in this presentation as a part of the cold climate aeolian geomorphology.

Aeolian processes are environmentally controlled. The basic factors are the latitude which determines the amount of solar radiation and relief which both strongly affect climate (Fig. 1.2). Dominating meteorological factors from the aeolian point of view are temperature and precipitation which both affect the main limiting factors: vegetation and moisture of the soil surface and also soil formation. The special controlling factors of aeolian processes in the cold environments are frost, ice, snow, icing and meltwaters. Large quantities of meltwaters in spring and summer partly prevent the aeolian drift of mineral material and partly produce favourable sand surfaces to be deformed by wind. Most of the year snow cover and ground frost in certain parts of Polar regions can totally stop the deflation of the ground, but as contrast in some other regions the winter activity is the predominating one. As a result of favourable climatic factors wind can transport in cold environments sand, silt and dust, in some cases also small stones and especially large amounts of snow. Particle drift causes abrasion on rock surfaces and deflation forms. Material is deposited. Sand dune formation is only a small portion of the total aeolian activity in the cold environment. Snow deposition is probably much more important for landforms. A secondary effect of the thinning of snow cover is deep frost formation. Many of these processes and events have some kind of feedback on aeolian processes, for example, wind action drifts snow forming glaciers, which then affect wind pattern (Fig. 1.2).

In extreme conditions as in the Antarctic cold deserts, in the absence of contemporary fluvial and other geological and biological processes capable of removing weathered material from rock surface, aeolian abrasion acts as a controlling factor in the rate and magnitude of erosion (Malin 1992: 27).

Wind plays an important role in cold climate geomorphology. Tricart (1970: 143) enumerates the main reasons for this: (1) high frequency of strong winds and storms in the Arctic; (2) low precipitation; (3) reduction of the vegetation cover by the cold, which is increased (4) by the wind blowing away the snow and exposing the ground surface, leading to the destruction of the vegetation; and to (5) the concentration of water in the ground by freezing which tends to dry

Fig. 1.2 Flowage diagram of the aeolian processes and formations combined with other limiting and supporting factors in general.



out the surface layer of silty soils, and to the production of abundant fine debris, especially silt, by frost weathering. This material is suitable for long distance transport by wind.

Wind is everywhere and in the circumpolar environments and on high mountains it is strong. There its force is not much limited by high vegetation like forests. When considering the importance of aeolian processes in cold environments we have to keep in mind how vast areas of the earth are covered by snow permanently or seasonally. Dry snow is relatively light material and easily drifted. Snow as such does not form geomorphic features but when it is accumulated in big amounts and forming glaciers and snow patches or melting, then it produces erosional and depositional landforms of nival origin and wind drift is the primary reason for them. In certain places snow cover is thin and in other places thick and the controlling factor is wind. Blowing snow itself is a major problem in cold environments, e.g. Canada (French & Slaymaker 1993: 9). Accumulation and redistribution of snow in the mountains has considerable effects on snow transport, glacier dynamics, snow drifts and avalanche danger (Dyunin & Kotlyakov 1980).

Fig. 1.3 Wind piled sea ice blocks on the shore of the northern Gulf of Bothnia, Hailuoto, Finland. Photo by H. Tabuchi.

We should consider the winter conditions much more when studying the periglacial phenomena and the frost action on landforms. In the literature we can find a lot of knowledge of snow and of its physical characteristics which should be integrated into the geomorphic processes. In the summer time the periglacial phenomena are mainly in rest phase and melting. For example, data of freezing on the active layer and the impact of accumulating snow are limited. This book partly tries to open that gate a little.

In this book the stress of wind on sea ice (see Sverdrup 1957) and coastal processes is largely excluded, although cold environments give several characteristic features on beaches, too, such as rafted ice walls pressed up on the shores by wind (e.g. Alestalo & Häikiö 1976) (Fig. 1.3), ice-pushed boulders (Philip 1990) and boulder barricades on shores (e.g. Rosen 1979; Dionne 1994), permafrost degradation by wave action on Arctic coasts, buried ice blocks melting in beach sand, drifting of icebergs, ice scouring and plucking of rock surfaces on tidal flats (e.g. Dionne & Quessy 1995), etc.

By knowing the present-day wind action in cold environments we have a better chance of understanding also the ancient aeolian features found in the vicinity of the glaciated regions. The palaeoenvironment reconstructions deal mainly with temperatures and humidity, interpreted through plant remains, especially pollens, and through soil formation. Some wind regimes relating to the aeolian landforms are described in the literature but the winter conditions are almost totally neglected, with the exception of the evidence of permafrost. Occurrence of snow is considered mainly for niveo-aeolian deposits. It seems to be obvious that today's aeolian processes in cold regions are considerably weaker and scattered compared with the Pleistocene activity in North America, central Europe, Asia, Argentina and New Zealand when the glaciers reached their maximum stage.

2

Delimitation and characterization of cold environments

Polunin (1951: 308) pointed out the confusing matter of giving a precise definition or delimitation of the Arctic as a region. However, we should try to define the cold environment in the sense that cold has some impact on aeolian processes. We can easily find large regions where cold is limiting vegetation so totally that it provides no protection from the influence of wind. This applies in Antarctica and great parts of the Arctic. But in Arctic and Subarctic regions we also find totally scrub-, moss- and lichen-covered areas where the aeolian processes are limited even though it is cold enough for deep permafrost formation. On the other hand the cold season could be important for part of the year and give opportunity for wind action in environments which are not even in the Subarctic climatic zone. An example is the prairies where very cold, continental winters dominate with thin snow cover and extremely strong winds without limiting factors. In North America this type of seasonally cold aeolian environment is found as far south as Wyoming, for example. At present the aeolian processes are not extremely strong in Wyoming but we can find geomorphic evidence proving that wind has had a strong influence: ventifacts (Sharp 1949), periglacial soil wedge forms (Mears 1987), sand dunes, and mushroom rocks. Drifted snow even wears rock surfaces there locally. It means that if the climate gets somewhat more severe then the conditions are really favourable for aeolian processes again. We do not consider in depth the low latitude cold-supported aeolian regions, nor the mainly mountainous areas in low latitudes which have similar characteristics to high latitudes in spite of the strong solar radiation.

Polar regions in general are cold. The Polar Circles (66°33′03″ N and S; 2606 km from the poles) are simple criteria for defining cold regions lying poleward of the circles and they are governed by the presence of "midnight sun" or absence of "midwinter sun". The main reasons why the Polar regions are cold are: (1) Earth is a sphere which means that the sun shining in Polar regions is always at a low angle and does not bring much warmth to Polar areas; (2) the axis of the Earth is tilted in an oblique angle (23°27′) to its ecliptic, the plane on which the Earth circles the sun, such that the Polar areas lose the sun for part of the year and they do not receive direct solar heat the year round. At the poles the day is six months long and the sunless winter night lasts six months. (3) Snow covers the ground most of the time and with its very high albedo it reflects most of the incoming solar energy back into space so the warming effect of the sun is lost. (4) Polar air is very clean without many dust particles and it contains very little water vapour. This means very small storage of the outgoing long wave heat radiation.

The Antarctic Circle encloses a very cold region. Unfortunately such a single criterion in the case of the Arctic Circle is useless for the purpose of our delimitation. Because of its size, diversity, complexity, and the random and scattered manner, the Arctic is difficult to define. The experience and terms used to describe it have become part of our everyday language without a precise recognition of their meaning. For example, the 'limit' for cold for a person from middle or low latitudes means a different temperature than for a person living in the high latitudes. Cold is a relative term. Different plants grow in different temperatures. For many plants the growing starts when the temperature rises above +5 °C but some grow under snow (e.g. Salisbury 1985). Snowdrop (*Galanthus nivalis*), for example, blooms through the snow.

Good (1955) used Washburn's (1953: 271) definition of the Subarctic: the circumpolar belt of dominant coniferous forest (taiga) with the mean annual air temperature (MAAT) below 0 °C and where the average temperature of the warmest month is more than +10 °C, but with less than four months above this temperature. As a result the Subarctic region covers, for example, the whole of Finland except the south coast, and Sweden from the north almost to Stockholm (Fig. 2.1). From the aeolian geomorphological point of view this large Subarctic is less interesting. Thick forests stabilize snow and soils very effectively. Our opinion is that the Subarctic region is a much narrower zone close to the boreal forest limit, in which we can find at least sporadic permafrost (Fig. 2.2).

2.1 Climate

"Arctic" is usually defined with regard to environmental characteristics rather than simply to the Arctic Circle (66° 33′ N). Polunin (1951: 309) defined the Arctic in the following terms: treeless, with the winters largely dark and cold, with high windchill and less than 50 days between spring and fall frosts, the subsoil mostly permanently frozen with frost-heaving important; annual precipitation normally below 500 mm and "largely in the form of snow which drifts and is packed tightly by the wind"; the soils generally moist in summer but the air of low absolute humidity, and with sheltered salt and fresh water frozen in the winter. One of the definitions is determined by the Nordenskjöld formula [$w = 9 - 0.1k$] where w is the mean temperature of the warmest month and k is the mean temperature of the coldest month over a cycle of years. Nordenskjöld proposed that the southern limit of the Arctic should be the line along which the warmest month has a mean temperature equal to w in his formula. He also suggested that this line comes closer to the Arctic tree line than Köppen's 10 °C line (Fig. 2.2).

Hopkins (1959) made an attempt to show that there is a faithful correspondence between a temperature parameter (cumulative summer warmth) and the forest-tundra boundary in Alaska. He discovered a good correlation between the vegetation at the station and the number of degree-days above +10 °C and secondly the mean temperature of the coldest month (Hopkins 1959: 216).

Fig. 2.1 Arctic regions limited with the MMT isotherm 10 °C of the warmest month and Subarctic regions limited with MMT not higher than 10 °C for more than four months of the year according to the definitions by Washburn (1953). Source: Good (1955: Fig. 1). © The American Geographical Society.