Aeolian Geomorphic Response to Latest Weichselian-Early Holocene Climate Change

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ABSTRACT. Parabolic and dome dunes developed at several locations in Moscow Oblast (Russia), Dalarna (Sweden), Churchill River valley (Labrador), Chalk River (Ontario), Estancia (New Mexico), and at other locations throughout boreal and taiga Canada preserve records of late-glacial climate shifts during the latest phases of the Late Weichselian and the Early Holocene. Although separated geographically, and formed under differing taiga, boreal, steppe, and high desert climates, development of these dune sequences is linked by similarities in the environments and in the geomorphic and sedimentologic responses. All of these dunes display numerous niveo-aeolian features. In contrast, younger adjacent dune sequences contain few or no niveo-aeolian structures. The dunes all formed under climates dominated by drier conditions than currently prevail in their localities, and were influenced by moderate to strongly gusting winds and periodic snowfall and hail events. Aeolian sedimentation patterns and geomorphology characteristic of the Mid- and Late Holocene environments of these regions differ from those of the Latest Weichselian and Early Holocene. The climatic conditions for dune development endemic to the late-glacial environment were not replicated during the later Holocene.

KEY WORDS: parabolic dunes, Late Weichselian, Early Holocene, climate change, aeolian geomorphology.

Introduction

The development of aeolian dunes in interior boreal and taiga environments is commonly considered as evidence of climate change. However, determination of the nature of climate change requires analysis of the internal sedimentology of the dune sequences, and consideration of the effects of sediment availability and variable sediment flux on the dune stratigraphy. Dunes developed under climate regimes as different as taiga (Koppen-Geiger Dfc) and high desert (BWk) may exhibit similar internal sedimentology and stratigraphy, as a result of the interplay of variable sediment supply, sediment flux, and differential rates of retention of aeolian sediment (Halsey et al., 1990; Catto, 1994; Halsey and Catto, 1994; Catto and Bachhuber, in press). Conversely, dunes developed under superficially similar climate regimes may exhibit significant geomorphological and sedimentological differences.

Parabolic, dome, and shield dunes developed at several locations in the Northern Hemisphere, including Beleopesotsk, Moscow Oblast, Russia (Drenova et al., 1997; Catto et al., 1999); Bönas, Dalarna, Sweden; Churchill River, Labrador, Canada; Chalk River, Ontario, Canada (Catto et al., 1982); Estancia, New Mexico, USA (Catto and Bachhuber, in press), and at other locations in Canada currently under boreal and taiga climates preserve records of late-glacial climate shifts during the latest phases of the Late Weichselian and the Early to Mid-Holocene. Although these dunes are widely separated geographically, and were formed under climates ranging from taiga to coastal boreal to high desert, development of these dune sequences is linked by similarities in the depositional environments and in the geomorphic and sedimentologic responses.

Dune geomorphology and sedimentology

Variations in sedimentology exist between these sites, as would be anticipated for such widely separated localities. However, at all sites where well-formed parabolic dunes in excess of 5 m high are preserved, planar tabular and convex-upwards cross-stratified medium-grained sands form the basal member of the dune sequences. These cross-strata were deposited by viscous grain flow. Overlying these sediments are planar tabular cross-stratified medium sands, produced by traction and saltation on slipface surfaces, coupled with locally extensive reworking by aeolian deflation, surface rilling, and niveo-aeolian processes. Adhesion warts, infilled rain/hail pit structures, and crenulated beds are common. Isolated thin lenses of rippled fine sand, overlying saucer blowout erosional surfaces, indicate episodic deflation of the dune surfaces by gusts. These sequences are frequently capped by fine-medium sands deposited by grainfall, or by coarse locally-derived loess.

Dome and shield dunes, and smaller parabolic dunes, preserve similar sequences, but were developed under conditions marked by lesser sand mobility and winds varying in velocity and direction. Smaller dune forms, developed under conditions of limited sand mobility, are commonly superimposed on the larger parabolic dunes. Dome dunes lack slipface cross-strata, indicating that viscous grain flow did not occur, but display medium to coarse sand deposits indicative of surface creep, involving seasonal freeze-thaw and niveo-aeolian processes. Traction and saltation deposits are present in the basal sequences of the shield and small parabolic dunes, but viscous grain flow deposits are absent.

All of these dunes, of latest Weichselian to early-mid Holocene age and located in latitudes extending from 34°N to 62°N, display numerous niveo-aeolian features. In contrast, younger adjacent dune sequences, even those developed under boreal and subarctic climate regimes, contain few or no niveo-aeolian structures. Smaller dunes superimposed on the larger and older parabolic and dome dunes in the Bönas, Beleopesotsk, Chalk River, Churchill River, and other Canadian boreal and taiga dune fields also display few or no niveo-aeolian features, in contrast to the prevalence of niveo-aeolian evidence in the underlying sediments.

Influence of climate change

The parabolic, shield, and dome dunes all formed under climates dominated by drier conditions than currently prevail at their localities. All were developed under the influence of moderate to strongly gusting winds and periodic snowfall and hail events. The variability in wind regimes recorded in the sediments at most of the sites was substantially in excess of that characteristic of the modern climates at each locality. Wind gustiness and consequent variability in sediment flux, and variations in the rate of retention due primarily to surface moisture conditions, were generally more in evidence during the latest Weichselian and early Holocene than they are currently.

At several localities, buried palaeosols indicate that the climatic shifts of the latest Weichselian - earliest Holocene, particularly those surrounding the Middle and Younger Dryas events, were sufficient to interrupt or change the style of aeolian sedimentation. At Beleopesotsk, Moscow Oblast, a buried palaeosol has been ^{14}C dated at 12,680 ± 512 BP (IG-1051; uncorrected), indicating formation during the Bölling Interstadial. A second, locally discontinuous palaeosol is separated from the first by 1 m of underlying aeolian sediment, attributed to the preceding Middle Dryas event. The upper palaeosol is dated at 10,500 ± 170 BP (GIN-9922; uncorrected), indicative of formation during the Alleröd Interstadial. Renewed aeolian sedimentation marked the Younger Dryas.

These responses to variations in sediment availability and flux, changes in wind regime, and increased vegetation cover are replicated in many other boreal and steppe aeolian sequences. In contrast, Younger Dryas aeolian sedimentation was precluded in areas marked by extensive permafrost development, such as coastal Newfoundland (Liverman et al., 2000). In these regions, initiation of aeolian sedimentation was associated with climate amelioration following the Younger Dryas, during the Early or Mid-Holocene.

Discussion

Aeolian sedimentation patterns and geomorphology characteristic of the Mid- and Late Holocene environments of the regions considered here differ from those of the Latest Weichselian and Early Holocene. In all of the study regions, the climatic conditions for dune development endemic to the late-glacial and Early Holocene environments were not replicated during the subsequent phases of the Holocene. In steppe and high desert regions, increased vegetation cover on the dune surfaces led to increases in sediment trapping efficiency, locally leading to the formation of loess caps in preference to renewed dune-building (Catto and Bachhuber, in press). In taiga and boreal regions, the sedimentological successions indicate that deposition under variably gusting winds and niveo-aeolian influences was replaced during the Mid- and Late Holocene by episodic deposition reflecting variations in sediment flux resulting from climate warming and drying, as well as removal of vegetation cover by fire. Aeolian sedimentation and dune response to changes in the moisture regime and fire frequency, indicative of climate changes over broad regions, is more in evidence in Late Holocene deposits than in earlier successions. Latest Weichselian and early Holocene aeolian successions provide excellent indications of local climate conditions, but may be not as representative of broad regional conditions as are aeolian events recorded in Late Holocene dunefields. Thus, although dune development did continue in many regions throughout the Holocene, the patterns of sedimentation, depositional processes, and geomorphic responses differ between older and younger aeolian successions within the same region.

References

CATTO N.R., 1994. Anthropogenic Pressures and the Dunal Coasts of Newfoundland. Coastal Zone 1994, Halifax, Nova Scotia, Bedford Institute of Oceanography, pp. 2266-2286.

CATTO N.R. and BACHHUBER F.W., in press. Aeolian geomorphic response to climate change: an example from the Estancia Valley, Central New Mexico, U.S.A. In: S. McLAREN and D. KNIVETON (Editors), Linking Climate Change to Land Surface Change, Kluwer Academic, Dordrecht, The Netherlands.

CATTO N.R., PATTERSON R.J. and GORMAN W.A., 1982. The Late Quaternary Geology of the Chalk River region, Ontario and Quebec. *Can. J. Earth Sci.*, 19: 1218-1231.

CATTO N.R., VELICHKO A.A., DRENOVA A.N., TIMIREVA S.N., LITTLE E.C. and RUTTER N.W., 1999. Parabolic Dunes of the Oka River valley, Russia: Geomorphology, Sedimentology, and Climatic Significance. Canadian Geophysical Union, Abstr., Banff, Alberta.

DRENOVA A.N., TIMIREVA S.N., and CHIKOLINI N.I., 1997. Late Glacial Dune-Building in the Russian Plain. *Quat. Int.*, 41/42: 59-66.

HALSEY L.A., CATTO N.R. and RUTTER N.W., 1990. Sedimentology and development of parabolic dunes, Grande Prairie dune field, Alberta. *Can. J. Earth Sci.*, 27: 1762-1772.

HALSEY L.A. and CATTO N.R., 1994. Geomorphology of Dome Dunes. *Géog. Phys. et Quat.*, 48: 97-105.

LIVERMAN D.G.E., CATTO N.R., BATTERSON M.J., MACKENZIE C., MUNRO-STASIUK M., SCOTT S. and SOMMERVILLE A., 2000 Evidence of late-glacial permafrost in Newfoundland. *Quat. Int.*, 68/69.