Géographie physique et Quaternaire

Geomorphology, Sedimentary Structures, and Genesis of Dome Dunes in Western Canada

Géomorphologie, structure sédimentaire et genèse des dunes en dôme dans l'ouest du Canada

Geomorphologie, Sedimentstrukturen und Genese der Kuppeldünen in West-Kanada

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Volume 48, Number 1, 1994

URI: https://id.erudit.org/iderudit/032975ar
DOI: https://doi.org/10.7202/032975ar

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Publisher(s)

Les Presses de l'Université de Montréal

ISSN

0705-7199 (print)
1492-143X (digital)

Explore this journal

Cite this article

Halsey, L. A. & Catto, N. R. (1994). Geomorphology, Sedimentary Structures, and Genesis of Dome Dunes in Western Canada. *Géographie physique et Quaternaire*, *48*(1), 97–105. https://doi.org/10.7202/032975ar

Article abstract

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Géographie physique et Quaternaire, 1994, vol. 48, n° 1, p. 97-105, 5 fig., 1 tabl.

GEOMORPHOLOGY, SEDIMENTARY STRUCTURES, AND GENESIS OF DOME DUNES IN WESTERN CANADA

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ABSTRACT Dome dunes in four stabilized, inland dune fields in western Canada are predominantly composed of horizontal to low-angle cross-strata, indicating that slip face development was rare. Dip angles of lee side deposits decrease upward in the dome dunes. The spread of dip directions increases with elevation in the dunes, spanning 360° for topset deposits. Sedimentary structures indicative of moisture (adhesion laminae) and vegetation (scour surfaces) occur in the dunes and denivation features are also present. Sediment adhesion is responsible for the maintenance of the dome morphology. Sediment sorting within the dome dunes is poorer than in other local dune types in the vicinity, suggesting that less reworking/ineffective selective transport occurred and that the dome dunes are more efficient in retaining sediment. The rarity of slip face and grainfall deposits and the abundance of low angle deposits indicate that preferential accumulation of sediment at the top of the lee side did not occur. Development of domal morphology is a consequence of the inhibition of slip face development. In inland, relatively moist boreal environments, the primary factor limiting or precluding sediment accumulation at the crest of the dunes is a low rate of sedimentation.

RÉSUMÉ *Géomorphologie, structure sédimentaire et genèse des dunes en dôme dans l'ouest du Canada*. Les dunes en dôme situées dans des champs de dunes stabilisés à l'intérieur des terres sont en grande partie constituées de stratifications entrecroisées subhorizontales, indiquant ainsi un faible développement de la face sous le vent. L'angle de pendage du versant sous le vent tend à diminuer vers la partie supérieure des dunes. Les directions de pendage s'étalent avec l'altitude, jusqu'à 360° dans les dépôts sommitaux. On trouve dans ces dunes des structures sédimentaires indicatrices de la présence d'humidité (feuillets adhérents) et de végétation (surface d'affouillement) ainsi que des formes de dénivation. La préservation de la morphologie des dunes est attribuable à l'adhésivité des sédiments. La granulométrie des dunes en dôme n'est pas aussi complète que dans les autres types de dunes de la région, indiquant ainsi que le remaniement des sédiments et leur transport sélectif ont été moins efficaces et qu'il y a eu meilleure rétention des sédiments. La faible accumulation par écoulement granulaire et sur la face sous le vent et la forte accumulation par strates subhorizontales montrent qu'il n'y a pas eu de mise en place préférentielle de sédiments au sommet du versant sous le vent. L'élaboration de la morphologie en dôme est attribuable au faible développement de la face sous le vent. À l'intérieur des terres, en milieu boréal relativement humide, l'accumulation des sédiments est minimeau sommet des dunes, surtout en raison du faible taux de sédimentation.

ZUSAMMENFASSUNG *Geomorphologie, Sedimentstrukturen und Genese der Kuppeldünen in West-Kanada*. Kuppeldünen in vier stabilisierten Inlanddünenfeldern in West-Kanada bestehen vor allem aus horizontalen bis gering geneigten Kreuzschichtungen, was darauf hinweist, dass abrutschende Entwicklung selten war. Die Neigungswinkel der Ablagerungen auf der Leeseite nehmen in den Kuppeldünen nach oben hin ab. Die Ausdehnung der Neigungsrichtungen nimmt mit der Höhe der Dünen zu, bis zu 360° in den höchsten Ablagerungen. Es gibt in den Dünen Sedimentstrukturen, die auf Feuchtigkeit (haftende Blätter) und Vegetation (Schleifoberflächen) hinweisen, und auch Denivationserscheinungen sind vorhanden. Der Sedimentadhäsion wird die Erhaltung der Kuppelmorphologie zugeschrieben. Die Sedimentsortierung innerhalb der Kuppeldünen ist geringer als in anderen lokalen Dünen-typen in der Nähe, so dass man annimmt, dass weniger Umarbeitung/ineffektiver selektiver Transport geschah und dass die Kuppeldünen erfolgreicher Sediment zurückhalten. Das seltene Vorkommen abrutschender und körniger Ablagerungen und die Fülle von gering geneigten Ablagerungen zeigen, dass bevorzugte Sedimentakkumulation an der Spitze der Leeseite nicht vorkam. Die Entwicklung der Kuppelmorphologie ergibt sich aus der Verhinderung abrutschender Entwicklung. Im Inland, in relativ feuchter nördlicher Umwelt ist der hauptsachliche Faktor der Begrenzung oder Verhinderung der Sedimentakkumulation an der Spitze der Dünen eine niedrige Sedimentierungsrate.

Manuscrit reçu le 7 avril 1993; manuscrit révisé accepté le 7 décembre 1993

INTRODUCTION

Dome dunes are common features in the aeolian landscapes of the northwestern prairies and adjacent boreal forest of Alberta, Saskatchewan, and British Columbia. These dunes, currently inactive except where anthropogenically disturbed, formed after deglaciation, during the early and middle Holocene (Henderson, 1959; David, 1977; Halsey *et al.*, 1990). Despite the prevalence of these dunes in Canada, relatively little is known about their geomorphological, structural and sedimentological attributes and of their mode of genesis. Elsewhere, detailed studies of the sedimentology of dome dune successions have been restricted to sites in New Mexico (McKee, 1966), coastal Brazil (Bigarella and Popp, 1966; Bigarella *et al.*, 1969), and Wyoming (Ahlbrandt, 1973). Although each of these regions are located in different climatic and geomorphic environments, the dome dunes in them have varying internal structures. All the dome dunes are located in the upwind part of the corresponding dune fields formed by unimodal winds.

Under unimodal wind conditions, a downwind sequence of dome, transverse, barchan, and parabolic dunes has been observed (McKee, 1966, 1983). This succession has been interpreted to result from a progressive decrease in the volume of sediment in transport and available for dune construction with increasing distance from a restricted sand source (McKee, 1966; Ahlbrandt, 1975). Dome dunes have, consequently, been interpreted as the equilibrium dune form developed under strong unidirectional winds and from an abundant sand supply (McKee,1979).

In western Canada, numerous stabilized dune fields are present (David, 1977). These fields appear to have been active at various intervals throughout the Holocene when and where there were short periods marked by the absence of local arboreal vegetation (*i.e.* after deglaciation, fires, or alluviation). The dome dunes associated with these fields are presently situated in the downwind parts and contain internal structures with dip directions which suggest they have always been located in the downwind parts of the dune fields. This is in contrast to the upwind position reported in the above mentioned regions. The location of the dome dunes indicates that the assumptions that they require strong winds and a relatively abundant sediment supply to develop may not apply to western Canadian dune occurrences.

The objectives of this study are to: 1) describe the geomorphology of the dome dunes; 2) describe their internal structures and sedimentary sequences; 3) interpret the sedimentary processes and environments; 4) elucidate the controlling factors of dome dune development; 5) compare these dome dunes with those from other environments.

STUDY REGION

Dome dunes from four dune fields were examined: Grande Prairie and Fort Vermilion, Alberta; Maidstone, Saskatchewan; and Beatton River, British Columbia (Fig. 1). All the dune fields contain dome dunes. The Grande Prairie, Fort Vermilion and Maidstone fields contain parabolic dunes, and the Fort Vermilion field contains transverse dunes (David, 1977; Mulira, 1986). The dome dunes of Beatton River, British Columbia are located in a sand/loess sheet. The dune fields are generally restricted to river valleys, extending slightly outside the limits of Holocene river terraces.

GEOMORPHOLOGY

Dome dunes in the study region are circular to slightly elliptical having a modal eccentricity (short axis length/long axis length) of 0.85-0.95 in plan view. In each dune field, the principal axes of the elliptical forms are consistent in orientation, aligned within 15° of the dominant wind direction. Dome dunes vary in height from 1 to 7 m and are 15 to 200 m in maximum length. Smaller dunes tend to have higher height: maximum axis length ratios (modal 1:10 to 1:15) than the larger dunes (modal 1:20 to 1:30).

The dunes have rounded, smooth, upper surfaces, without deflation hollows. Steeper slopes are consistently present on the eastern part of the dunes corresponding to the highest dip directions internally. Thus, westerly winds formed these dome dunes with the stoss slopes on the western sides and the lee slopes on the eastern sides of the dunes. Stoss slopes are gentle, varying between 1° and 8°, and are commonly gently convex. The side slopes which parallel the elliptical dunes vary between 1° and 12°, and are generally gently

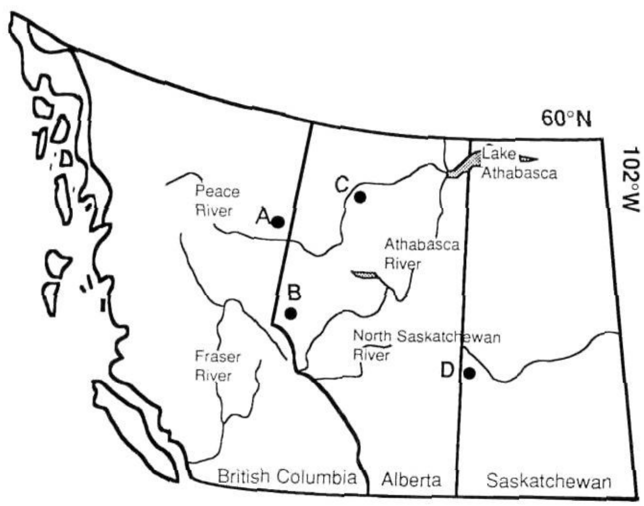

FIGURE 1. Location of the four studied dune fileds: A) Beatton River Dune Field, British Columbia; B) Grande Prairie Dune Field, Alberta; C) Fort Vermilion Dune Field, Alberta; D) Maidstone Dune Field, Saskatchewan.

Localisation des quatre champs de dunes à l'étude: A) Beatton River, British Columbia; B) Grande Prairie, Alberta; C) Fort Vermilion, Alberta; D) Maidstone, Saskatchewan.

convex. Lee side slopes are from 2° to 14°, although most slope at 6° or less. Lee slopes are generally convex, although some concave slopes are present on the lee sides of steeper dunes. Slip faces are generally absent on the dome dunes, although small slip faces are locally present near the top of some dunes.

The dunes are currently stabilized with an arboreal cover dominated by *Populus tremuloides*, with local occurrences of *Betula papyrifera, Picea glauca* and *Populus balsamifera*. The understory is mainly composed of *Alnus crispa, Salix* spp., *Rosa acicularis, Shepherida canadensis*. grasses and feather mosses. Many parts of the dune fields have been cleared for grazing by livestock.

Morphologically these dunes are similar to those of other regions; the smaller ones resemble those in the coastal regions of Brazil (Bigarella and Popp, 1966; Bigarella *et al.*, 1969), whereas the larger ones compare with those of New Mexico (McKee, 1966) and Wyoming (Ahlbrandt,1973).

SEDIMENTARY STRUCTURES

Sedimentary structures of dome dunes were described from the walls of active sand pits. Seventy eight textural analysis were conducted on bulk samples collected from finely laminated units while samples from strata thicker than 0.5 cm were collected from individual laminations or beds. Grain size was measured using sieve analysis at 1/4ø intervals. The graphic sorting of Folk and Ward (1957) was calculated for the 78 samples. The results compared to those from other dune types. A summary of textural analysis results is presented in Table I.

Seven sedimentary assemblages have been identified on the basis of their structure, texture, and unit morphology (Table I).

SEDIMENTARY ASSEMBLAGE A: SETS OF HIGH-ANGLE CROSS-LAMINAE

Description

Sedimentary assemblage A consists of sets of high-angle cross-laminae which interfinger or grade laterally into other units. The lower and upper boundaries of each set are marked by planar, horizontal surfaces. In cross-section, the strata are wedge- to lens-shaped and pinch out laterally down slope. In plan view, the beds have a lobate or tongue-like appearance, with the lobes aligned in the direction of dip parallel to the depositional slope. Blocks of brecciated cross-strata, with beds aligned at angles differing from the underlying depositional slope by 5°-20°, are infrequently present. The brecciated blocks are generally small, with maximum dimensions rarely exceeding 10 cm and thicknesses less than 5 cm.

The sediments of Assemblage A are generally medium grained and moderately well to well sorted. The thicker beds tend to be somewhat coarser grained, with the coarse sand particles concentrated at the downslope margins of the lobes. These cross-strata were present in the basal parts of one of the dome dunes examined in detail. This assemblage represents approximately 7% of examined sections.

Interpretation

The high dip angle of cross-laminae in Assemblage A suggests deposition on a steep slope. The lobate bed geometry (*cf.* Hunter, 1977), and the tendency for coarser grains to be

TABLE I

Descriptive summary of sediment assemblages observed in wet inland dome dunes of the study area

Facies	Description	Set/Bed Thickness (cm)	Laminae Thickness (cm)	Laminae Dip	Form of Laminae/ Bed	Range of mean grain size (Ø)	Range of graphic sorting index* (Ø)	Number of samples
A	Sets of high angle cross-strata	80-150	0.1-0.6	24°-36°	Tabular tounge shaped	2.35-2.70	0.66-0.72	3
B	Tabular sets of low-angle cross-laminae	10-60	0.1-.05	8°-15°	Tabular	2.37-2.70	0.60-0.67	11
C	Wedge sets of low-angle cross-laminae	2-20	0.1-.05	6°-12°	Wedge	2.37-2.65	0.59-0.61	7
D	Sets of planar parallel laminations	1-60	<0.1-1.2	0°-10°	Tabular	2.03-2.68	0.48-0.66	25
E	Tabular fine sand beds	1-3	—	0°-7°	Tabular	2.73-2.88	0.47-0.61	12
F	Sets of corrugated laminae	2-5	<0.1-0.5	Horizontal	Irregular	2.33-2.80	0.50-0.80	14
G	Unstratified coarse-medium sand beds	2-10	—	0°-10°	Irregular	1.52-1.72	0.58-0.67	6

* *From Folk and Ward, 1957*

concentrated at the downslope margins of the lobes suggest deposition by grainflow.

The brecciated blocks of this unit are the result of deformation during slumping of pre-existing cross-laminated sediments (*cf.* McKee *et al.*, 1972; Fryberger 1991). Moisture must have been present for the sediments to retain sufficient cohesion to preserve the cross-lamination.

Grainflow requires little humidity and noncohesive sands, while slumping and preservation needs humidity to produce cohesive sands. As both grainflow and brecciated blocks occur, moisture conditions on the slip faces varied.

SEDIMENTARY ASSEMBLAGE B: TABULAR SETS OF LOW-ANGLE CROSS-LAMINAE

Description

Sets of low-angle cross-laminae are bounded by planar tabular surfaces with dip angles of the sets ranging from 0°-5°. Azimuth trend orientations commonly span arcs of 150°-180° around the downwind direction. All of the cross-laminae are ungraded or inversely graded (Fig. 2a), with the contact surfaces commonly marked by heavy mineral accumulations. Sediments of Assemblage B are fine to medium grained and moderately to moderately well sorted. The finer-grained strata tend to be less well sorted than the medium-grained units. Assemblage B is present in the basal parts of all the dome dunes examined, and represents 10% of the examined sections.

Interpretation

Tabular sets of low-angle cross-strata are common in dune deposits, and often develop from deposition of sediment downwind of the dune slip face (McKee, 1966) or in the plinth or apron areas (Nielson and Kocurek, 1987). Alternatively, the cross-strata can be formed by the migration or buildup of a bedform without the development of a slip face, as occurs

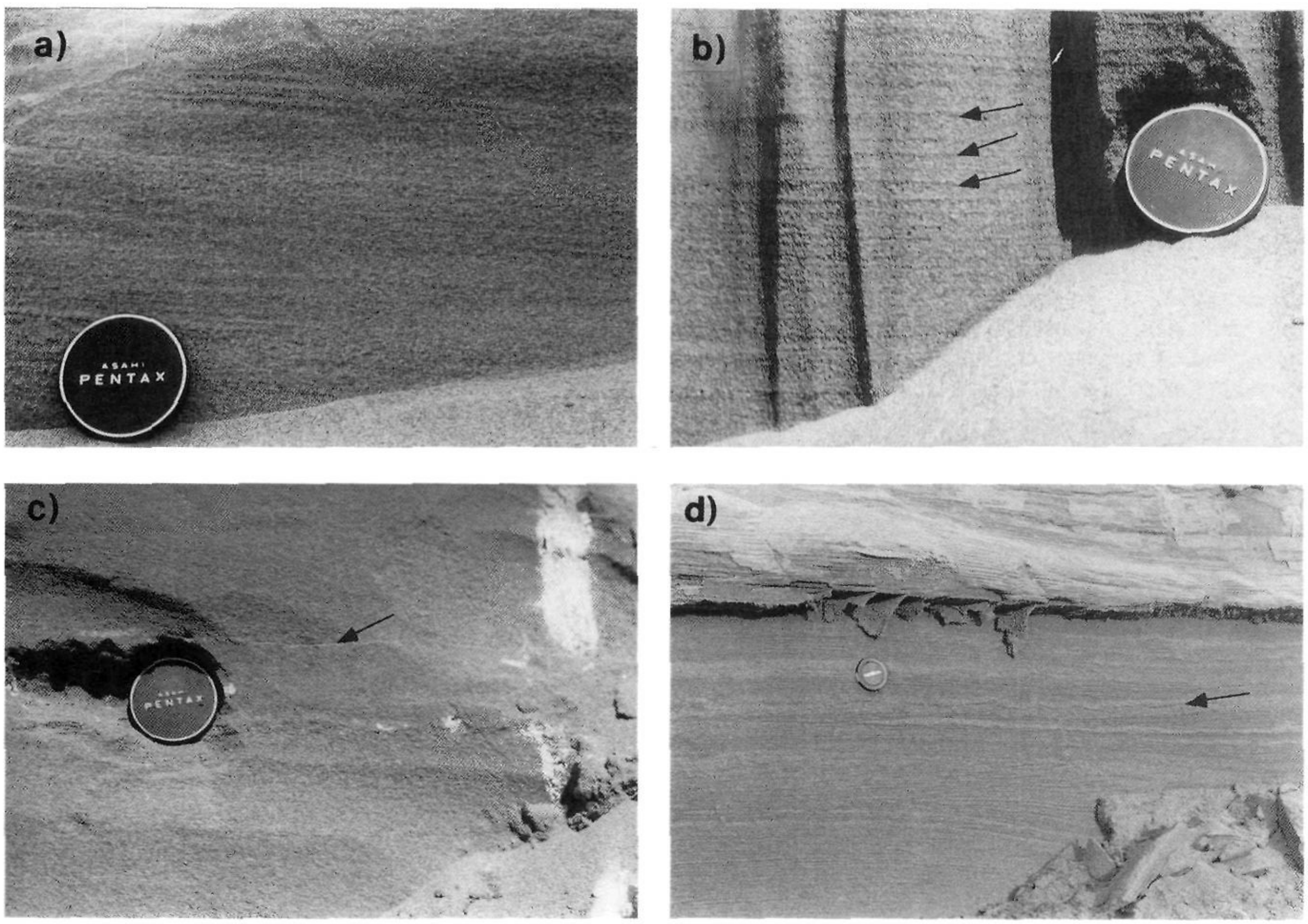

FIGURE 2. Photographs of some sediment assemblages observed in dome dunes. a) Photograph of sediment assemblage B taken perpendicular to the dip of laminations. b) Photograph of sediment assemblage D. c) Photograph of tabular fine sand bed (sediment assemblage E). Its lower contact grades from indistinct corrugated laminations of assemblage F. Note the rough uneven nature of the upper bed surface of sediment assemblage E indicated by the arrow. d) Photograph of unstratified coarse grained sand bed with an irregularly undulating upper contact indicated with an arrow underlain and overlain by sets of sediment assemblage D.

Photos de quelques faciès sédimentaires observés dans les dunes en dôme. a) Faciès sédimentaire B en vue perpendiculaire par rapport à l'inclinaison des feuillets. c) Faciès sédimentaire D. c) Couche tabulaire de sable fin (faciès sédimentaire E). Le contact inférieur se fait à partir des feuillets ondulés indistincts du faciès F. Noter la nature grossière inégale de la surface de la couche supérieure du faciès sédimentaire E montré par la flèche. d) Couche de sable grossier non stratifé dont le contact supérieur ondulé irrégulier (flèche) est susjacent et sousjacent à deux parties du faciès sédimentaire D.

on the crests and upper lee sides of some of the local parabolic dunes (Halsey *et al.*, 1990) and in low-relief periglacial eolian landforms (Lea, 1990). The morphology of the dome dunes and the presence of low-angle cross-laminae throughout the basal parts of the dunes, indicates that pronounced slip face development was not necessary for their formation. The spread of dip directions suggests that deposition resulted from the gradual migration and accumulation of ripple forms on the crests and lee sides of the developing dome dunes. Thin low-angle inversely graded laminae are generally produced by the migration of climbing ripples during net deposition from saltation and traction loads (Hunter, 1977; Fryberger *et al.*, 1979; Lea, 1990). The tendency for the finer grained units to be less well sorted, suggests that grainfall contributed some finer sand to the units. Multiple depositional processes are commonly involved in the formation and development of tabular low-angle cross-strata (Hunter,1977; Kocurek,1986; Halsey *et al.*,1990).

SEDIMENTARY ASSEMBLAGE C: WEDGE SETS OF LOW-ANGLE CROSS-LAMINAE

Description

Assemblage C is composed of wedge-shaped sets of low angle cross-laminations. Lower bounding surfaces are planar and dip 8°-13°. Trend orientations commonly span arcs of 240°-270°. Upper bounding surfaces are planar or curved and truncate underlying laminations. Individual laminations decrease in dip upwards within an individual set. Laminae dip at lower angles than underlying bounding surfaces resulting in laminations which pinchout upslope. Sediments of Assemblage C are medium to fine grained and moderately sorted. Assemblage C represents 6% of the examined sections.

Interpretation

The wedge-shaped nature of the cross-lamination sets of Assemblage C is a result of preferential net deposition of sediment in the downslope direction during ripple migration. This process has been documented in wind tunnel experiments by Fryberger and Schenk (1981).

The wide range of trend orientations indicates that the ripples migrated freely over the downwind surface of the dune, without being concentrated perpendicular to slip faces. Slip face development, therefore, must have been limited or absent.

SEDIMENTARY ASSEMBLAGE D: SETS OF PLANAR PARALLEL LAMINATIONS

Description

Sets of strata which parallel lower bounding surfaces, and are draped over the underlying dome dune assemblages spanning 360°, represent Assemblage D. The strata are ungraded or inversely graded, with fine sand in the basal parts of the thicker laminations and medium sand along the upper contacts (Fig. 2b). The ungraded units of Assemblage D are moderately sorted, whereas sorting is better in the graded laminations. Medium grained laminae with isolated ripple forms up to 0.3-0.5 cm in height and 5-10 cm in length are present in some locations.

Small, scoop-shaped troughs, 0.4-0.8 cm deep and 5-15 cm wide, are also present. Many of these troughs are associated with calcareous tubules. The tubules occur at the heads of these troughs. The trend orientations of the troughs span 360°. Assemblage D represents 65% of the examined sections.

Interpretation

Assemblage D represents deposition from ripples migrating across the upper surfaces of the dunes. The migrating ripples were unconfined on the horizontal surfaces, as indicated by the trend orientations spanning 360°. Ripples oriented contrary to the prevailing wind direction suggest small-scale, shifting vortices, possibly developed as a result of interference with air flow by vegetation. Isolated ripples composed of medium-grained sand developed as a response either to a decrease in sand supply or to an increase in the shear velocity of the wind.

The influence of vegetation is also apparent in the development of the small, scoop-shaped troughs. The coincidence of the troughs and ripples indicates that vegetation was present and modified wind flow. Abrasion of cohesive sediment may also have played a role in creating these small, scoop-shaped troughs. McKenna Neuman (1989) describes the development of flutes, grooves and other large scour features in frozen sediments from abrasion during saltation. Abrasion of frozen sediment in conjunction with deflation of sediment around vegetation may have occurred on the dune surface.

SEDIMENTARY ASSEMBLAGE E: TABULAR FINE SAND BEDS

Description

Assemblage E consists of tabular, ungraded fine sand beds with trend orientations which span 100°-120°. The upper surfaces of the beds tend to be irregularly undulating, with minor pits up to 5 mm in depth and 1.3 mm in width. Sediments are moderately sorted. Many of the beds contain fine gypsum and calcareous mineral crystals. Assemblage E is generally found in association with sediments of Assemblages D and F, and is confined to the lee sides and topset deposits of the dome dunes. It represents 6% of the examined sections.

Interpretation

Tabular beds of fine sand similar to those of Assemblage E are commonly formed by grainfall, when the surface friction speed of the wind is decreased (Hunter, 1977). The irregularly undulating and pitted upper surfaces, however, indicate that grainfall was not solely responsible for bed formation. The presence of gypsum and calcareous material associated with the assemblage indicates that cementation has occurred. These minerals, originated from rainwater or snowmelt that infiltrated the dunes. Upon exfiltration cementation occurred (Nickling and Ecclestone, 1981; Nickling, 1984). This process develops a salt crust at ground surface, which then is susceptible to erosion and pitting by small-scale wind vortices. Vortices generate zones of differential pressure which fragment the crust (*cf.* Franzén,1989).

Alternatively, seasonal freezing of the dune surface could result in a cohesive layer which may be susceptible to pitting. Frozen sand surfaces, however, tend to respond elastically to grain impacts (McKenna-Neuman, 1989), resisting brittle failure and crustal fragmentation, and hence pitting. The presence of moisture-influenced sedimentary structures and features throughout the dome dune successions suggests that deposition occurred predominantly during periods when unfrozen water was present.

Alternately, pitting at the surface of dunes can develop and be preserved from hail stones falling on a wet dune surface (P. David, unpublished data), or during denivation of niveo-eolian deposits (Dijkmans 1990, Fig. 6)

SEDIMENTARY ASSEMBLAGE F: SETS OF CORRUGATED LAMINAE

Description

Assemblage F is composed of sets of indistinct corrugated laminae of well to moderately well sorted, fine sand. Laminae are horizontal and undulate irregularly on the millimeter scale (Fig. 2c). The contacts between assemblage F laminae and the underlying sediments are all either conformable or gradational. Assemblage F represents 5% of the examined sections.

Interpretation

The thinness, indistinctness, and corrugated nature of the laminae of Assemblage F all indicate that they were not deposited by grain segregation from ripple migration. Development of corrugated laminae has been attributed to adhesion of sand grains on moist dune surfaces by Hunter (1973, 1980) and Kocurek and Fielder (1982). Laminae of assemblage F developed from adhesion induced grainfall generated during wind gusts (*cf.* Lee, 1987). Small irregularities on the depositional surface, such as those produced by pitting of a chemically precipitated salt crust, will be draped by the fine sediments and result in the corrugated surfaces of the laminae. The depositional surface will effectively resist erosion if it is cohesive (Nickling, 1984) or water-saturated (Lee, 1987; McKenna-Neuman and Nickling, 1989).

SEDIMENTARY ASSEMBLAGE G: UNSTRATIFIED COARSE-MEDIUM SAND

Description

Assemblage G is composed of unstratified coarse and medium sand beds. Sorting varies from moderate to poor. The upper surfaces of the beds are invariably irregularly undulating, whereas the lower contacts are planar (Fig. 2d). Assemblage G sediments are rare in the dome dune successions, representing 1% of the examined sections.

Interpretation

Assemblage G sediments are interpreted as denivation deposits resulting from simultaneous deposition of windblown snow and sand. Niveo-aeolian sediments are generally more poorly sorted than most aeolian traction-load deposits (Schwan, 1986). Ablation of the incorporated snow results in the destruction of any primary bedding structure, producing internally structureless beds (Ballantyne and Whittington, 1987; Dijkmans and Mücher, 1989). Similar units are commonly associated with aeolian successions formed in boreal and arctic environments (Ruegg, 1983; Lea, 1990; Halsey *et al.*,1990).

SEQUENCE OF SEDIMENTARY ASSEMBLAGES

Dome dunes throughout the study region are predominantly composed of low-angle to horizontal strata separated by planar or concave-downwards bounding surfaces. Highest dip values are in the basal upwind part of the dunes (Fig. 3). Dip angles decrease upwards in the dunes while the span of dip directions increase as a result of the dune building up and out while remaining stationary.

One dune examined (Fig. 3, Section 1) had cross-strata in its basal upwind part dipping at or near the angle of repose (Assemblage A sediments). The spread of dip directions of these high-angle cross-laminae were unimodally oriented downwind, suggesting deposition on a slip face. This pattern of sedimentation was not observed in any of the other dome dunes. Assemblage A represents only 7% of the examined sections, occurring only at one site, suggesting that slip face development rarely occurred.

Other dunes show deposits of assemblages B in their upwind parts. These basal deposits have dip angles far below the angle of repose suggesting no slip face development. Grain avalaching/flow will be inhibited on the lee slope when sedimentation from grainfall does not accumulate near the crest. Sediment will not preferentially accumulate at the crest if it is quickly and efficiently redistributed. This will occur either if the sediment transport rate is low so there is little potential for accumulation, or if the wind velocity is sufficiently high to retain all the sediment in transport and preclude grainfall.

Sedimentary Assemblage B is rarely found in the upper half of the dunes examined, suggesting that once dome dunes are nucleated, sediment is deposited in a sheet like fashion draping the dome dune.

Sediments of Assemblage B are overlain by the horizontal to slightly inclined sediments of Assemblages D, E, F, and G (Fig. 3). The dominance of low angle sediment assemblages can be attributed to the successive accumulation of traction and saltation loads moving freely across the dune surfaces coupled with adhesion of sediment.

The presence of sedimentary structures indicative of deposition under moist conditions in Assemblages E, F, and G, indicates that moisture played an important role during dome dune development. These structures are more common in the basal part of dunes (Fig. 3). High surface moisture conditions enhances sedimentation as documented for various aeolian environments (Schwan, 1986; Lee, 1987; McKenna-Neuman and Nickling, 1989; Lea 1990), resulting in sheetlike deposits preserving the dome dune form. The presence of

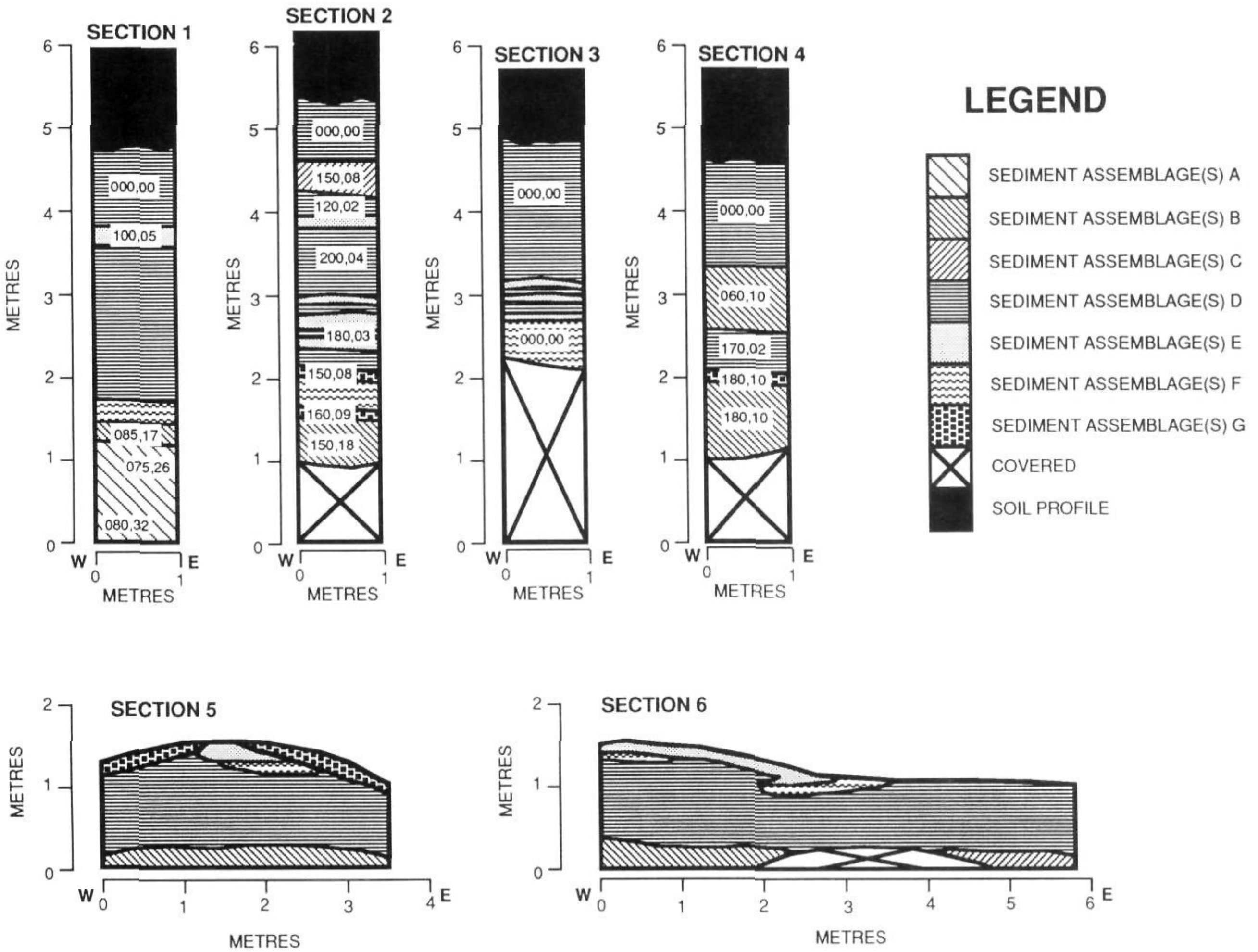

FIGURE 3. Representative sequences of sediment assemblages observed in dome dunes with representative strike and dip measurements given. Sections 1 to 4 are located in the Grande Prarie Dune Field with latitudes and longitudes (section 1:55°12′N, 118°12′W; section 2:55°13′N, 118°13′W; section 3:55°14′N, 118°12′W; section 4:55°22′N, 118°7′W). Section 5 is from the Beatton River Dune Field (26°29′N, 120°34′W), while section 6 is from the Maidstone Dune Field (53°5′N, 109°14′W).

Séquences représentatives des faciès sédimentaires observés dans les dunes en dôme avec les mesures d'orientation et de pendage. Les coupes 1 à 4 proviennent du champ de dunes de Grande Prairie (coupe 1:55°12′N, 118°12′W; coupe 2:55°13′N, 118°13′W; coupe 3:55°14′N, 118°12′W; coupe 4:55°22′N, 118°7′W). La coupe 5 provient du champ de dunes de Beatton River (26°29′N, 120°34′W, et la coupe 5, du champ de dunes de Maidstone (53°5′N, 109°14′W).

beds of sediment assemblage E conforming to the dune topography was apparent (see Fig. 4).

Dome dunes of the region thus represent constructional forms initiated by the development of a bedform generally without the development of a slip face. Further deposition of sediment occurs in a sheetlike fashion, draping the initial bedform. Adhesion of sediment will preserve the dome dune morphology. This occurs as grain motion along the dune is reduced by particle adhesion reducing sedimentation at the crest. As preferential accumulation of sediment at the crest is reduced, slip face development does not occur and flow separation is limited. The interplay of these mechanisms reinforces slip face inhibition and results in the dome dune morphology.

GRAIN SIZE OF SEDIMENTS IN DOME DUNES

The dome dunes of the study area have finer-grained sediments than other dunes situated in the same dune fields (Fig. 5). Sediments in the dome dunes of an area are more poorly sorted than the same sized sediments located upwind in other dune types. The finer grained nature of the sediment coupled with a poorer sorting implies less reworking of the sediment by the wind. Less reworking may be a function of lower wind velocities, and/or from ineffective sediment transport generated by cohesion of sediment. Regardless of the mechanism, sediment retention in dome dunes is more efficient than in other associated dune types.

FACTORS CONTROLLING DOME DUNE GENESIS

Dome dunes can be divided into two broad groups based on their geographic position and internal structures. Dome dunes present along the upwind margins of inland dune fields are typically composed of high-angle, planar tabular cross-strata which dip downwind, suggesting development from pre-existing transverse dunes (see McKee, 1966; Ahlbrandt, 1973). These cross-strata are draped by a thin layer of nearly

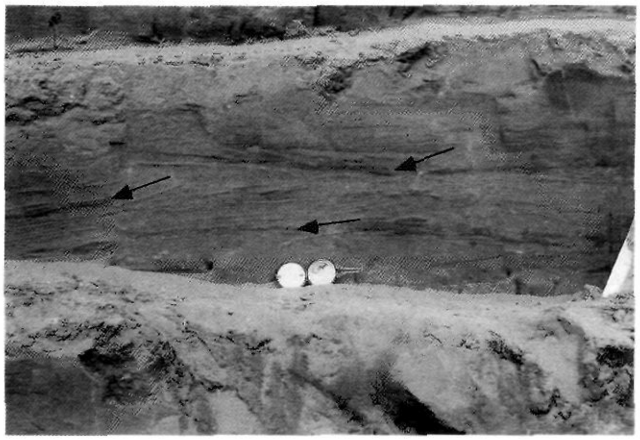

FIGURE 4. Topset deposits of a dome dune in the Grande Prairie Dune Field. Massive fine grained sand beds of sediment assemblage E indicated by arrows are interbedded with sediment assemblage D. Three massive fine sand beds are domes conforming to the topography of the dune.

Dépôts sommitaux d'une dune en dôme du champ de dunes de Grande Prairie. Les couches massives de sable fin du faciès sédimentaire E montré par les flèches sont intercalés dans le faciès sédimentaire D. Les trois couches massives de sable fin sont des dômes qui se conforment à la topographie de la dune.

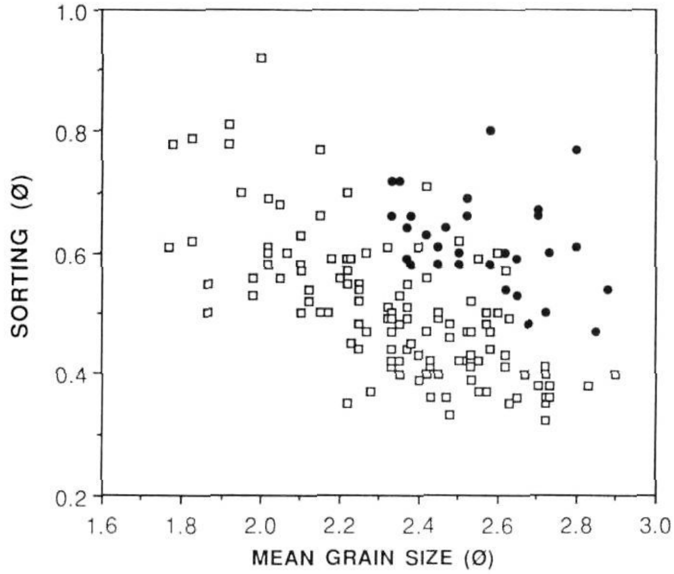

FIGURE 5. Mean grain size and sorting from parabolic and dome dunes in the Grande Prairie Dune Field. Circles represent dome dunes. Squares represent parabolic dunes. Sediments of assemblage G are excluded. Sorting values calculated according to Folk and Ward (1957).

Granulométrie et granoclassement (Folk et Ward, 1957) des dunes paraboliques et en dôme du champ de dunes de Grande Prairie. Les cercles représentent les dunes en dôme. Les sédiments du faciès G sont exclus.

horizontal topset strata, which grade downwind into low-angle cross-strata. Cut-and-fill structures which parallel the dominant wind direction are also present (McKee, 1966). The change in depositional style from transverse to dome dune deposition has been suggested by McKee (1979) to have resulted from strong winds which bevelled the dunes, impeding slip face development.

In contrast, dome dunes present along the upwind margins of coastal dune fields contain near-horizontal to low-angle cross-strata, separated by concave-downwards bounding surfaces. Very few slip face deposits are present (Bigarella and Popp, 1966; Bigarella *et al*, 1969; Bigarella, 1972). The dune morphology is attributed to variations in wind flow direction, with erosion being inhibited by both vegetation and/or moisture.

In the dunes of this study, the primary cause for the establishment of dome dunes appears to be the inhibition of slip face development or maintenance. This results when preferential accumulation of sediment at the top of the dune is reduced or precluded by low sedimentation rates. It has been suggested by other workers that dome dune morphology has been developed by either: 1) high wind velocities (as in the dry inland environments of New Mexico and Wyoming) or 2) variations in wind flow directions (as in the tropic coastal environments of Brazil).

High wind velocities (McKee, 1966), and variations in wind flow directions (Bigarella, 1972) have also been speculated to impede slip face development. If the concept of slip face inhibition is correct, the depositional processes and environmental conditions which resulted in slip face inhibition differ from area to area. Dry inland environments have high wind velocities which periodically remove the slip face (McKee, 1979), while tropic coastal environments have large variations in wind flow directions which result in erosion (McKee, 1979). Wet inland dome dunes such as those present in western Canada have a restricted sand supply such that any sediment which does preferentially accumulate at the top of the lee face is efficiently reworked downslope. Other mechanisms are probably also responsible for slip face inhibition. Vegetation, for example, can exert strong controls on dune development in humid environments, coupled with moisture and low sedimentation rates, vegetation would probably also result in the inhibition of slip face development. It is possible that as in the dunes examined in this study inhibition of slip face deposits resulted in the development of a dome dune, with the processes causing the lack of slip face development being different.

SUMMARY

Extensive dune fields are present in the northwestern prairies and boreal forest of Alberta, Saskatchewan, and British Columbia. Dome dunes are present in the downwind parts of these dune fields, or in intercalated sand/loess sheets located along the foothills of British Colombia and Alberta. The location of these dome dunes suggests that the sequence of dome, transverse, barchan, and parabolic landforms does not hold for western Canadian dune fields.

This study suggests that dome dunes are the equilibrium landform which develops under slip face inhibition. An increase in the net accumulation rate of sediment on the top of the lee face resulting in the buildup of a stable slip face results in the development of another dune type.

ACKNOWLEDGMENTS

Thanks are extended to G. Bradbury, G. Thistle, and M. Ashby who provided diligent and competent assistance in the field and lab. Funding was provided by grants from the Canadian Circumpolar Institute to L. Halsey and NSERC grants to Drs. N. Catto and N. W. Rutter. The authors would also like to gratefully thank Drs. N. W. Rutter and D. Liverman for numerous discussions and helpful comments made throughout the span of this project. The helpful and thought provoking comments of Dr. P.P. David and an anonymous referee greatly improved this manuscript and are very much appreciated.

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