TRANSACTIONS, ILL. STATE ACAD. SCI.
Vol. 69, No. 4 (1977)

GLACIAL LOESS--IS IT REALLY GLACIAL?*

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ABSTRACT - Glacial-non-glacial climatic shifts exhibit an episodic or square-wave behavior, while the growth-decay response of glacial ice approximates a normal curve. If this model is realistic, Laurentide melt-water discharge and alluviation along proglacial drainageways peaked several thousand years after the last major Wisconsinan climatic shift from dominantly glacial to dominantly non-glacial regimes. This also implies that the principal period of wind erosion of floodplain deposits (and loess accumulation) occurred during climatic episodes that were distinctly non-glacial.

Glacial loess primarily consists of moderately well-sorted, unconsolidated, locally laminated blankets of silt. Although dominant (40% to 50%) grain size is 0.01 mm to 0.05 mm, deposits generally are accompanied by significant clayey (5% to 30%) and sandy (5% to 10%) fractions (Pecsi, 1968). Typically, glacial loess is porous and permeable, yellow to buff, and is exposed in nearly vertical cliffs. In the nation's midsection late Wisconsin loess occurs in two convergent belts: One deposit thins eastward from Nebraska and Kansas through Iowa, Missouri, Wisconsin, Illinois, Indiana and into southern Ohio. The second belt is east of the Mississippi River and south of the Ohio River from Mississippi through western Tennessee and Kentucky.

Loess units of the Great Plains and South are eolian in origin with the bulk of loess derived by wind erosion of glacial outwash floodplain and channel bar deposits (Flint, 1971, p. 250). In Nebraska and adjacent areas, however, this mechanism may have played a secondary role to deflation in the Sand Hills of west-central Nebraska (Lugn, 1968). Additionally, in the narrow periglacial zone adjacent to the Laurentide ice sheet, frost heaving and churning of soils probably provided minor sources of silt for subsequent redeposition as loess (Davies, 1972).

*The substance of this paper was presented at the 1976 Annual Meeting of the Illinois State Academy of Science. At the time the author was a Visiting Associate Professor in the Department of Geography, University of Illinois at Urbana-Champaign.

Loess deposits in the Central United States are traditionally described as glacial--a designation that some construe to indicate deposition during periods of severe climate. Although most late Wisconsinan loess was deposited in close association in time and place with extensive continental glaciation, there are reasons to believe that the bulk of loess accumulated during climatic episodes that were distinctly non-glacial.

LOESS AND CLIMATE

A simple glacier-climate model proposed by Bryson and Wendland (1967) sheds some light on the general relationship between loess deposition and climatic regimes (Figure 1). The Bryson-Wendland model depicts the large scale climatic behavior during the Quaternary as a square wave, *i.e.*, a sequence of glacial and non-glacial episodes punctuated by abrupt shifts between episodes. This abrupt change nature of Quaternary climates is confirmed by studies of pollen stratigraphy and by other paleoenvironmental indices (Bryson, 1974). Prevailing atmospheric circulation patterns favor glacial expansion (positive mass balance) during glacial climatic episodes and glacial recession (negative mass balance) during non-glacial climatic episodes. This model, however, is concerned with prevailing climatic conditions, and thus does not exclude periods of ablation during glacial episodes and periods of glacial growth during non-glacial episodes.

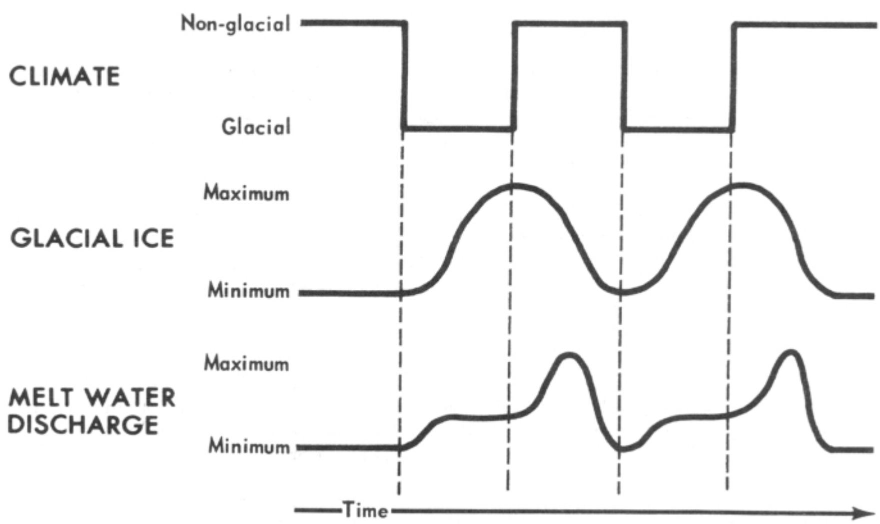

Figure 1. Schematic representation of climatic forcing and the responses of glacial ice volume (modified after Bryson and Wendland, 1967) and meltwater discharge. Note that this diagram portrays in exaggerated fashion general phase relations and does not indicate absolute magnitudes of either lag times or glacial-interglacial intervals.

Changes in glacial ice volume accompanying climatic shifts govern meltwater discharge into proglacial drainageways. Meltwater discharge, in turn, controls floodplain sedimentation and, hence, the amount of alluvium available for deflation and redeposition as loess. It follows that meltwater (and, therefore, loess) is primarily generated following a shift from glacial to non-glacial climate.

In contrast to the abrupt glacial climatic transition, the concurrent response of glacial ice volume is gradual. In fact, the time constant of glaciers is considerably longer than that of atmospheric circulation patterns, so that the growth-decay of glaciers approximates a normal curve (Figure 1). During a glacial climatic episode, it simply takes time for glacial ice to accumulate to a volume that is in equilibrium with the climate. Initiation of a continental ice sheet may involve either slow growth from one or more nuclear centers or "instantaneous" glacierization of a large plateau area (Ives et al., 1975). In either event, once glacial ice covers an extensive region, its preservative characteristics (e.g., high reflectivity for solar radiation) become meteorologically significant, and its growth rate accelerates. The accelerated growth rate, however, is temporary because, as the ice sheet expands into lower latitudes (altitudes), it encounters more intense radiation and higher temperatures which slow glacial growth.

After a shift from glacial climatic episode to a non-glacial climatic episode, the high albedo of the ice surface, coupled with the tremendous heat required to melt ice, retards for some time the rate of ice wastage. Then, when the thermal regime of the glacier is modified and the surface albedo drops with the wetting of the ice surface, ablation proceeds more rapidly (Pounder, 1965, p. 142-143). This ultimately leads to a melting back of the glacier to colder latitudes (altitudes) and hence, a slowing in the rate of ice wastage.

The lag time of glacier response to climatic forcing implies that great masses of glacial ice may remain long after a shift from glacial to non-glacial climate. For example, during Wisconsinan time, the last major climatic shift from glacial to non-glacial conditions occurred about 18,000 BP; yet, vestiges of Laurentide ice remained in North America until after 6,000 BP (Bryson et al., 1969). Although there were numerous reversals of this climatic amelioration, as evidenced by the deposition of more than thirty marginal moraines during this period in Illinois and Wisconsin (Frye et al., 1965), cooling episodes were short-lived, and prevailing climatic regimes favored glacial ablation.

The time lag of glacier response to climatic forcing also suggests that meltwater discharge peaks sometime after a major glacial to non-glacial climatic shift (Figure 1). This interpretation is confirmed for the late Wisconsinan disintegration of Laurentide ice by oxygen isotopic analysis of planktonic foraminiferans in deep-sea cores from the Gulf of Mexico (Kennett and Shackleton, 1975). These studies indicate that influx of meltwater reached dramatic proportions by 15,000 BP--three thousand years after the onset of climatic amelioration. The flow of meltwater into the Gulf of Mexico tapered off rapidly after 13,500 BP, when the principal drainage shifted away from the Mississippi River to the St. Lawrence. Furthermore, the most rapid rate of eustatic sea-level rise apparently began thousands of years after 18,000 BP, reflecting a delay in the major period of meltwater generation (Walcott, 1975).

Regardless of climate, as long as there was glacial ice on the North American continent, there was some seasonal ablation. Hence, proglacial floodplain deposition and some loess generation occurred during both glacial and non-glacial climatic episodes. This is confirmed, for example, by the ^{14}C dates of late Wisconsinan Peorian loess in Illinois, which range from 20,300 BP to 13,700 BP (Willman and Frye, 1970). If, however, meltwater discharge is a reasonable indicator of the volume of sediment available for loess generation, then the bulk of loess deposition took place during non-glacial climatic episodes; long after the shift from glacial to non-glacial climate.

Assignment of peak loess deposition to periods of non-glacial climate is compatible with the faunal content of late Wisconsinan loess. For example, in Illinois, Frye and Willman (1958) report abundant terrestrial snails in Peorian loess--in some cases within fifteen kilometers of the former glacier margin.

PALEOCLIMATIC IMPLICATIONS

Certain physical properties of loess units may be examined to reconstruct the character of depositional winds (Handy, 1976). If the bulk of loess deposition occurred during non-glacial climatic episodes, then the inferred winds are components of non-glacial atmospheric circulation patterns. Further, the seasonal nature of loess deposition is tied to an annual glacial ablation cycle. In winter, ablation was minimal and frozen soil and snowcover shielded floodplains from eolian activity. With the onset of spring and continuing through the summer, ablation was vigorous and proglacial rivers and streams overflowed their banks, depositing alluvium on their floodplains. As temperatures began to fall during late summer and early autumn, ablation waned and the rivers withdrew to their channels, thus exposing fresh silt deposits to dessication and wind erosion. Hence, in those regions where floodplains served as the major source of silt, it is likely that loess was deposited primarily by autumnal winds.

SUMMARY

In the Central United States, loess owes its origin primarily to wind erosion of glacial outwash floodplain deposits. Hence, loess is intimately associated in time and place with continental glaciation. Because generation of meltwater is a key requisite to floodplain deposition, however, it is likely that loess was generated primarily during non-glacial climatic episodes. Further, it is likely that the bulk of loess was deposited long after the glacial to non-glacial climatic shift and that loess was deposited primarily by autumnal winds.

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