and Alan Gillespie for reviewing the manuscript and suggesting improvements.

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QUATERNARY RESEARCH 17, 123–124 (1982)

LETTERS TO THE EDITOR

Comment on "New Evidence from Beneath the Western North Atlantic for the Depth of Glacial Erosion in Greenland and North America" by E. P. Laine

As a glacial geologist, I was delighted to read Laine's contribution (1980) to our scanty knowledge of long-term rates of glacial erosion within the southwest sector of the Laurentide Ice Sheet. The estimates of the volume of deep-sea sediment appear reasonably well founded, but I am disappointed that Laine has "exhumed" a theory of deep erosion of the central portion of the Laurentide Ice Sheet (White, 1977) which, as far as I was concerned, Sugden (1976) and Gravenor (1975) had seriously questioned and laid to rest. Laine appears not to be aware of, or at least believes it of no significance that:

1. The central interior basin of the Laurentide Ice Sheet, Hudson Bay, is primarily underlain by Paleozoic rocks. Furthermore, Paleozoic limestones and other "soft" sediments lie on the floor of Hudson Strait. Thus, "deep" erosion, if it occurred, must have primarily resulted in the extensive erosion of a Paleozoic cover. This implies that the process of deep erosion should have contributed a large amount of detrital carbonates to the deep sea.

2. The work of Higgs (1978) on the provenance of Mesozoic and Cenozoic rocks from the Labrador and western Greenland continental margins indicates that the "unroofing" of the Precambrian shield occurred "since the Paleocene, exposing progressively deeper levels of the crust" (Higgs, 1978, p. 1859). Post-Paleocene erosion of high-grade supracrustal rocks is implied. Moreover, even during the Paleocene, there is only scanty evidence for the contribution from sedimentary source rocks. This implies to me that the Paleozoic cover was already well removed from the continental margins and that the major erosional region was, in fact, outside the so-called arc of exhumation. This may have been concentrated along the fiords and sounds.

3. The flow lines of the Laurentide Ice Sheet (Laine, 1980, Fig. 4) are at variance with the consensus of field studies. There is no, and I repeat *no*, glacial geological evidence for radial overflow from Hudson Bay during the last glaciation (Shilts *et al.*, 1979; Shilts, 1980; Andrews and Miller, 1979; Hillaire-Marcel *et al.*, 1980). Instead, most Canadian glacial geologists view the Laurentide Ice Sheet as a complex of domes and saddles with the domes located over the land area.

4. If deep erosion characterizes the central region of an ice sheet, why does the area of southern Hudson Bay possess one of the longest multitill and nonglacial sediment records in northern Canada (Skinner, 1973; MacDonald 1971; Andrews *et al.*, 1980)?

In conclusion, I am conscious of the problems facing anyone in their attempts to equate the volume of sediment with rates and location of erosion. Thus, I strongly support the basic thrust of Laine's study, but I am totally unconvinced that these data can be used to say anything about "deep erosion," especially when we consider that the flow model employed is at variance with the known geological data (Shilts, 1980). It will be important to refine this initial study by: (1) working on the rates of erosion throughout the Quaternary, for example, was most of the erosion accomplished very early, possibly even during the first one or two glacial cycles (e.g., Andrews, 1979); and (2) expanding the work of Higgs (1978) to examine the provenance of the sedi-

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ments. Laine's work is clearly important, and this discussion is not meant to detract in any way from its overall significance.

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QUATERNARY RESEARCH **17**, 125–127 (1982)

Reply to Andrews' Comment

Laine (1980) emphasized that the deep-sea sediment record lent some support to the concept of deep glacial erosion within the Canadian Shield Province (White, 1972). White's hypothesis is more far reaching than the simple postulate of deep erosion in that it unites the concepts of stripping of Paleozoic cover and erosion of Shield rocks with a model to explain the geomorphic significance of major physiographic features. As with all controversial ideas it may undergo substantial revision as new studies are completed. While this revision may encompass reexamination of the geomorphic significance of particular physiographic features on and adjacent to the shield, it remains probable that portions of the Shield have been stripped of Paleozoic or younger cover and that portions have been deeply eroded by ice. The four points Andrews makes in his discussion serve to highlight this viewpoint.

Andrews suggests that a criterion for recognizing deep erosion of Hudson Bay and Hudson Strait might be the presence of detrital carbonates in the deep-sea sediments. At Deep Sea Drilling Project (DSDP) Sites 111, 112, and 113 in the Labrador Basin detrital carbonates have been inferred on the basis of dolomite in X-ray analysis of bulk sediment samples (Laughton *et al.*, 1972a,b,c; Perch-Nielsen, 1972). At all these sites dolomite is absent in the preglacial Pliocene. It first appears in the glacial Pliocene at Sites 111 and 112 and in the early Pleistocene at Site 113. It is difficult to estimate the volume of eroded terrestrial carbonate represented by this dolomite indicator since calcite is readily dissolved in corrosive bottom waters. Therefore much of the calcite delivered to the Labrador Basin may have been dissolved rather than deposited. Interestingly, the percentage of dolomite increases upcore at all sites reaching 11.2% at the top of Site 111. Perhaps this reflects a progressive increase in the volume of Paleozoic or younger sediments eroded during the Pleistocene.

The CLIMAP reconstruction of the Laurentide Ice Sheet was used to model flow lines because of its simplicity and because it maximized the source area in calculations. Using the more complex, multidome reconstruction suggested by Andrews decreases the source area and increases the average amount of erosion to about 140 m. If one accepts this newer reconstruction as accurately portraying average ice flow lines for the entire period of Northern Hemisphere glaciation, then it would appear to concentrate erosion around the periphery of eastern North America. There is evidence, however, which suggests that those areas south of Hudson Bay and west of the Nouveau Quebec-Labrador ice center may have experienced a similar magnitude of erosion. The volume of glacial-age terrigenous sediment in the Gulf of Mexico has been estimated (Bell, 1980; Bell and Laine, 1980; Bell and Laine, in preparation) and added to the estimates of Laine (1980). This work shows an average of about 130–150 m of erosion from the entire source which fed the Gulf of Mexico and the western North Atlantic and indicates that erosion south and west of southern Hudson Bay was of equal magnitude to that to the east and north.

These new estimates suggest that the central portion of North America has been eroded by ice sheets to a similar average depth as the eastern margins. The presence of thick multitill and nonglacial sediment records in the southern Hudson Bay region cited by Andrews does not necessarily have

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to contradict this finding since this record spans only the last 5% of the period of Northern Hemisphere glaciation (Andrews, 1980). It is very possible that most erosion was completed before the deposition of the Bell Sea and younger sediments to which Andrews refers. This implies that during the glacial Pliocene and perhaps early Pleistocene, ice sheet geometry and flow may have differed from that of the Laurentide Ice Sheet.

The evidence of Higgs (1978) which Andrews cites indicates that Labrador was stripped of Paleozoic cover by the Paleocene. Higgs also suggests, however, that the Shield rocks within this province have been extensively eroded since the Paleocene. Judging by the large volume of glacial-age terrigenous material in the Labrador Basin (Laine, 1980) this erosion probably occurred during the glacial Pliocene and Pleistocene. The work of Grant (1972) on the Labrador margin suggests that Tertiary sediments have been stripped from beneath the shelf by glaciation. Whether these sediments once blanketed those portions of Labrador considered by Higgs in a fashion similar to Coastal Plain deposits on the southeastern Atlantic coastline is not known, however, this possibility does suggest caution in using rocks from the Paleocene to infer exposure of Shield rocks during the early Pliocene. A better basis for determining whether a cover of Paleozoic or perhaps Tertiary sediments was stripped from Labrador would be through analysis of the provenance of glacial-age sediments at DSDP Sites 111, 112, or at 113. Such work is now underway.

Andrews' suggestion that the major volume of erosion may have occurred in the early phases of Northern Hemisphere glaciation is supported by the results at Site 113 where glacial-Pliocene sedimentation rates of 35 cm/1000 yr were recorded with the subsequent Pleistocene rates being about 10 cm/1000 yr (Laughton *et al.*, 1972c). Less reliable estimates at Sites 111 and 112 show higher rates in the Pleistocene than in the glacial Pliocene (Laughton *et al.*, 1972a,b). Because the sediments at 113 were primarily deposited by turbidity currents and those at 111 and 112 from floating ice and bottom currents, respectively, the apparent contradiction between the two sets of results may be simply due to mode of transport or deposition. Thus, at Sites 111 and 112 increases in ice rafting or bottom current activity might control sedimentation rates, whereas at Site 113 sedimentation rates were controlled primarily by the rates of erosion.

In summary, we would like to suggest that Andrews' main points form the basis for modifying White's hypothesis rather than abandoning it. There is evidence for stripping of Paleozoic and perhaps younger sediments from the Shield. There is evidence for erosion of Shield rocks themselves, though not in the same areas. There is evidence for equally deep erosion in both the eastern and central portions of the Shield. Each of these pieces of evidence supports major expressed or implied elements of White (1972). If the multidome reconstruction is valid for the entire history of Northern Hemisphere glaciation, then the key element which must be reconsidered is the geomorphic significance of the physiographic features of the Shield. Several factors may have to be taken into account in making this revision. Erosion may have been more rapid during the early phases of Northern Hemisphere glaciation; however, stripping of Paleozoic carbonates may now be progressing at rates faster than those during the late Pliocene. Current loci of erosion and nonerosion may not accurately reflect the general pattern for the last several million years. This implies a shifting pattern of domes and "conditioning" of the land's surface by this evolution.

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