Pleistocene Glaciation: A Criterion for Recognition of Its Onset

Abstract. *The various biostratigraphic boundaries proposed for the base of the Pleistocene are not necessarily synchronous with the onset of continental glaciation. Electron-microscopic examination of surface textures of sand grains suggests a widely applicable rock-stratigraphic and geologic-climate boundary that may mark the point at which glaciers of continental proportions began to launch debris-carrying icebergs into the world's oceans.*

There is currently no general agreement as to whether the Pliocene-Pleistocene boundary should be based on faunal or floral changes, or on both, or whether it should be marked by the onset of continental glaciation. Flint (*1*) has argued that the boundary should be drawn on the basis of some of the many fossils that apparently reflect climatic changes. A committee of the 18th International Congress agreed that the marine Calabrian and its terrestrial equivalent, the Villafranchian, should be considered as the base of the Pleistocene, and that the boundary should be placed at the horizon of the first indication of climatic deterioration in the Italian Neogene succession (*2*); this is defined as the first appearance of the benthic foraminifer *Anomalina baltica* and the pelecypod *Cyprina islandica* at the base of the Calabrian stage in southern Italy. Emiliani *et al.* (*3*) reported the essentially simultaneous appearance of these two index fossils, but this conclusion is disputed (*4*). However, oxygen-isotopic analyses by Emiliani *et al.* (*3*) indicate that no major temperature change appears to have occurred across the Plio-Pleistocene boundary in Calabria as defined by the first appearance of *A. baltica*. A similar difficulty arises among those who choose to place the boundary at the first appearance of certain mammals; the most significant change in Pleistocene mammalian fauna did not occur until late in the Mindel ("second") glaciation (*1*). Anthropologists may define the commencement of the Pleistocene as the time of emergence of the genus *Homo*, but evidence now indicates that toolmaking *Homo* associated with an upper Villafranchian fauna that emerged some 1.75 to 2.00 $\times$ 10^6 years ago (*5*), indicating an early Pleistocene age.

Ericson *et al.*, among others, believe that glacial climate sets the Pleistocene apart from earlier epochs of the Cenozoic and that it seems logical to define the beginning of the Pleistocene as the time of onset of the first continental glaciation (*4, 6, 7*); they further believe that they have found a faunal transition zone marking this boundary. Other investigators who have critically examined Ericson's work confirm the existence of this faunal zone (*8*). However, at least one of the 11 deep-sea cores used by Ericson and his group shows evidence of continental glaciation earlier than their faunal boundary.

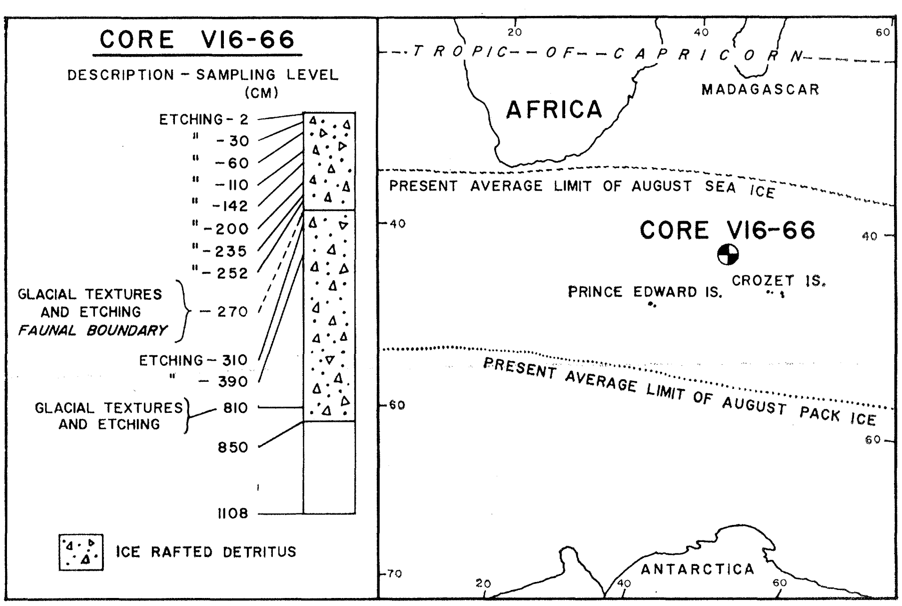

Fig. 1. Log and location map of core V16-66.

Sand grains from core V16-66, one of Ericson's 11 cores that penetrate the faunal boundary, were studied by electron microscopy. The core, 1108 cm long, came from a depth of 2995 m in the southern Indian Ocean (42°39′S, 45°40′E); the core and inferences based upon it have been described as follows (*6*):

> The sediment . . . is a silty burrow-mottled lutite, grayish-tan-to-light buff, containing abundant tests of Foraminifera and Radiolaria. From the *top 850 cm.* the sediment contains scattered heterogeneous mineral and rock fragments. This land-derived detritus is indicative of rafting by drifting ice. . . . Ice-rafted detritus in core V16-66 supports the faunal evidence for climatic deterioration during the final phase of the Pliocene. Presumably the drifting ice originated on the continent of Antarctica. The fact that the detritus first appears in core V16-66 at about 580 cm. below the Pliocene-Pleistocene boundary (850 cm. from the top of the core) indicates that the climate of Antarcita had become glacial some 250,000 years before the drastic climatic change that marked the end of the Pliocene epoch.

Samples from this core used by Ericson for his micropaleontologic examinations and containing land-derived and presumably ice-rafted debris were examined by us; quartz-sand grains were removed from various levels (see Fig. 1). Grains ranging in size from 0.0625 to 2 mm were found; sand-size material other than quartz included volcanic glass and rock fragments. Quartz grains prepared by the procedure of Krinsley *et al.* (*9*) were examined under both light and electron microscopes. Many of the replicated sand grains showed characteristic glacial surface textures such as Krinsley and Funnell described (*10*). These findings corroborate the belief of Ericson *et al.* (*6*) that the material originally derived from glaciers.

The surface texture of many of these grains indicates that some chemical alteration has occurred; many contain aligned pits that suggest chemical etching. Since the sediment consists almost entirely of pelagic foraminifers, with only a few sand grains, a resi-

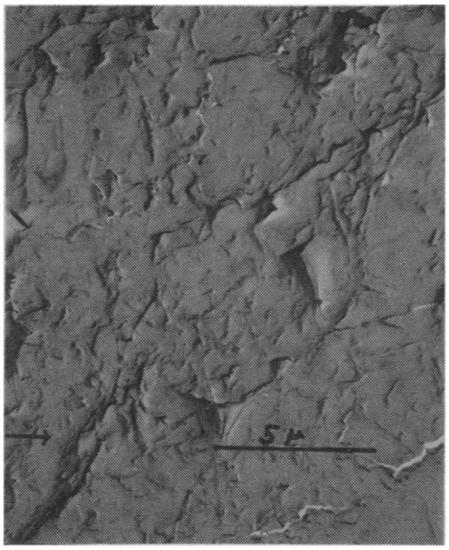

Fig. 2. Quartz-sand grain from core V15-107 taken approximately 110 miles due east of the eastern mouth of the Strait of Magellan in the South Atlantic Ocean; 65 cm from the top of the core. V-shaped mechanical breakage features characteristic of surf action are superimposed on glacial breakage patterns that have been somewhat worn; the latter were probably subjected to mechanical wear before burial. Arrow indicates the shadowing direction.

dence period of the order of 10^6 years might be expected to raise the pH of the solution in which both sand grains and foraminifers were immersed and to promote the etching and removal of silica. That chemical action does occur is evident when sand grains sampled from ancient sediments are examined; in almost every instance there is evidence of features that are not mechanical in origin. This is usually not true of Holocene marine sands.

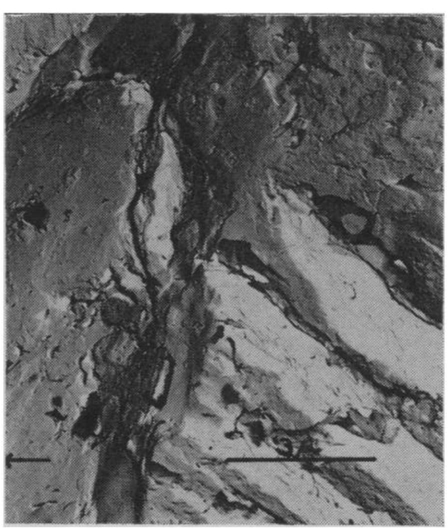

Fig. 3. Grain of quartz sand from core V16-66 at the 810-cm level. Large-scale, somewhat irregular breakage blocks along with imbricate breakage-patterns characteristic of glacial action are seen; some rounding has taken place, probably resulting from postdepositional action. Arrow indicates the shadowing direction.

Two periods of mechanical breakage on the surface of a single grain of sand have been observed on samples from various parts of the world (*10*). Grains taken from cores from off the eastern coast of South America, near the Falkland Islands, show two breakage sequences, one superimposed on the other (Fig. 2). The initial pattern is glacial and is followed by surf action, suggesting that the grains were first subjected to glacial grinding, were then rolled about in the surf, and were finally transported into deeper water. Pleistocene sands from many other areas show the same sequence. Sand grains from the 270-cm level in core V16-66 show mostly glacial features, but several portions of three grains examined show weakly indented mechanical beach patterns suggesting beach action after glacial grinding. Nichols has shown that beaches developed directly on Antarctic ice (*11*) and that beach processes have been active. However, the beach patterns there are not as common as those found on beaches at lower latitudes; this is to be expected, because beaches in Antarctica are for various reasons not well developed (*11*). Sand grains from the 810-cm level of core V16-66 contain glacial but not beach textures (Fig. 3). Generally, the grains of quartz sand from core V16-66 do not include a beach phase, suggesting that they were carried out to sea by icebergs launched from glaciers of continental proportions.

We believe that examination of sand grains in deep-sea cores from most of the oceans could lead to identification of the point at which glaciers of continental proportions began to launch debris-carrying icebergs into the world's oceans. It seems to us that a good demarcation for the beginning of the Pleistocene would be such a point, because equating any currently known faunal or floral boundary (or both) with the onset of continental glaciation may not be possible. Unfortunately, very few cores representing the approximate Plio-Pleistocene boundary exist at present, but when longer deep-sea cores are taken in the North Atlantic, North Pacific, Arctic, and southern oceans a rock-stratigraphic and geologic-climate boundary (*12*) will probably be delineated for the beginning of the Pleistocene.

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11. R. L. Nichols, *Amer. J. Sci.* **259**, 694 (1961); see especially plate 1*B*.
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13. We thank D. B. Erickson for his samples. Craig Munsart drew Fig. 1.

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Optical Activity in the Orgueil Meteorite

Abstract. *Nagy's report of an optical rotation of −0.023° to −0.084° in the Orgueil meteorite has not been confirmed. The highest rotation found in several fatty-acid and hydrocarbon fractions isolated from the meteorite was −0.002°, less than that of optically inactive controls. The "rotations" observed by Nagy may have been caused by scattered depolarized light from colloidal particles, reduced instrument sensitivity due to low transmittance of the solutions, or a combination of both.*

Nagy *et al.* (*1*) have reported the discovery of optical activity in the Orgueil carbonaceous chondrite. They observed a rotation of −0.023° ± 0.005° in an extract consisting mainly of organic acids and hydrocarbons, and concluded: "It seems reasonable to