The seeds have a cylindrical sheath of viscous liquid material as they are ejected from the fruit (Fig. 1, *B, C*). The squarish shape of the seed in Fig. 1*B*, in comparison with seeds that have traveled further (Fig. 1, *F, G*), deserves mention. This sheath extends as a ring slightly behind the seed causing a slight central depression at the rear of the seed (Fig. 1*C*). The sheath usually disintegrates by the time the seed has traveled about 2 to 3 cm, although some liquid material seems to fall from the seeds for about the next 2 cm of flight (Fig. 1*G*). This viscous material thus does not remain attached to the seed to form a rudder, as some workers have postulated (*6*).

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"Pliocene-Pleistocene" Boundary in Deep-Sea Sediments

Abstract. *Changes in planktonic microfossil assemblages in Atlantic sediment cores, at approximately the beginning of the Quaternary, correspond in a general way with those recognized in Pacific cores. How closely the horizon marked by these changes approximates to the Pliocene-Pleistocene boundary is not yet established.*

Recently, Ericson, Ewing, and Wollin (*1*) proposed that the Pliocene-Pleistocene boundary be defined by certain paleontological criteria in deep-sea sediments (Fig. 1, B). It is necessary to consider how well the horizon they define agrees with the onset of the climatic deterioration which is generally accepted as marking the beginning of the Pleistocene epoch, and the distinction made between "Tertiary" and "Quaternary" in earlier publications on deep-sea sediments.

Recognition of the Pliocene-Pleistocene boundary in deep-sea sediments is particularly important because Quaternary sequences on the ocean floor are commonly more complete, and more easily correlated, than those on continents. After the limits of the Pleistocene have been recognized in pelagic sediments, geologic events recorded in the cores can be dated by isotopic methods more readily than those recorded in continental deposits. In cores 20 to 30 meters long from an appropriate region such as the north Atlantic Ocean, the earliest of the sequence of layers of ice-rafted material (*2*) could be established, and this horizon could be correlated in widely separated cores by means of wide-ranging planktonic microfossils.

Ericson *et al.* recognize a faunal boundary in seven cores from the Atlantic and one from an adjacent part of the Indian Ocean, and they contend that the evolutionary changes marked by their paleontological criteria (principally, extinction of discoasters and several foraminiferal species) are profound enough to indicate that they were caused by a marked and abrupt climatic change. This interpretation is open to question. Discoasters had been decreasing in number of species, if not of individuals, for a considerable time before their extinction. Perhaps five foraminiferal species became extinct at or near the "Pliocene-Pleistocene boundary," but a much greater number survived through it. The fact that micropaleontologists have hitherto found it difficult to define a Pliocene-Pleistocene boundary is in itself an indication that, among the total faunal assemblages, these changes are not particularly striking or profound. More pronounced faunal changes have occurred at intervals through geologic time, but many of them are not clearly attributable to marked climatic change, and fewer are attributable to the onset of glacial periods (*3*). Only one of the cores discussed by Ericson *et al.* contains ice-rafted detritus, and this lithologic evidence for the onset, or at least one of the intensifications, of antarctic glaciation occurs considerably lower in the core than the "Pliocene-Pleistocene" boundary they define paleontologically.

Thus the relation between the boundary defined by Ericson *et al.* and the generally accepted Pliocene-Pleistocene boundary remains uncertain. We next consider how their boundary relates to that previously used to distinguish tentatively between "late Tertiary" and "Quaternary" in Pacific sediments.

In two tropical Pacific cores, Arrhenius (*4*) based a distinction between Pliocene and Pleistocene on geochemical evidence—principally, changes in the rate of accumulation of calcium carbonate. Such changes in sedimentary characters are geographically restricted, and could be used to distinguish this horizon in only a portion of the tropical Pacific Ocean. However, to the extent that they are caused by significant changes in atmospheric circulation, it may be possible to correlate them with climate-dependent sedimentary characters in other regions.

Bramlette and Riedel (*5*) pointed out that discoasters, abundant throughout the Tertiary, are practically absent in Recent sediments. Bramlette (*6*) correlated a tentative "Tertiary-Quaternary" boundary in the aforementioned tropical Pacific cores described by Arrhenius, largely on the basis of the abrupt disappearance of discoasters, and partly on other changes in the calcareous nannoplankton.

Riedel (*7*), investigating radiolarians in tropical Pacific cores, found that two (*Pterocanium prismatium* and *Eucyrtidium elongatum peregrinum*) became extinct approximately simultaneously, at a horizon approximately correlated with that believed to represent the end of the Pliocene in Arrhenius' paper. Therefore the upper limit of common occurrence of these two radiolarians was tentatively interpreted as indicating the "top of the Pliocene".

For some years these changes in discoasters (and other calcareous nannoplankton) and radiolarians were used to distinguish a boundary tentatively interpreted as separating "late Tertiary" from "Quaternary" in Pacific sediments (*8, 9*).

To determine whether these changes in nannoplankton could be recognized in a well-established Italian Pliocene-Pleistocene sequence, and whether they coincided with the onset of glacial conditions, Bramlette examined samples, made available by Emiliani and Selli (*10*), from the section at Le Castella (Calabria). However, the calcareous nannoplankton assemblages proved to be sparse, and reworking of older forms into younger deposits made difficult any determination of the true nannofossil sequence.

Among the planktonic Foraminifera, the change showing most promise as an aid in recognizing the Pliocene-Pleistocene boundary was the extinction of *Globigerinoides fistulosus*. This form, originally described from a New Guinea locality to which a Pliocene age was assigned on little apparent evidence, was later recorded by Cushman (*11*) from a Pacific sediment which he listed as Recent. Cushman's assignment of age was regarded with suspicion because the species is generally absent in Quaternary sediments, and Bramlette (*9*) concluded that *G. fistulosus* was probably restricted to the Pliocene. Subsequent correspondence with Ruth Todd established that Cushman's specimen was stained with manganese oxide (probably indicating considerable age) and that the sampling locality was in rough topography where reworked late Tertiary microfossils might be expected.

Below are presented results of our investigation of planktonic microfossils in the two cores which Arrhenius considered to contain an uninterrupted Quaternary record and to enter the Pliocene (Swedish Deep-Sea Expedition core No. 58, from 6°44′N, 129°28′W, 4440 m; and core No. 62, from 3°00′S, 136°26′W, 4511 m) (Fig. 1, A). The discussion is amplified by reference to other Pacific cores, collected by Scripps Institution of Oceanography.

There is considerable agreement between the horizon proposed by Ericson *et al.* as the Pliocene-Pleistocene boundary and that provisionally used by us to separate "Tertiary" from "Quater-

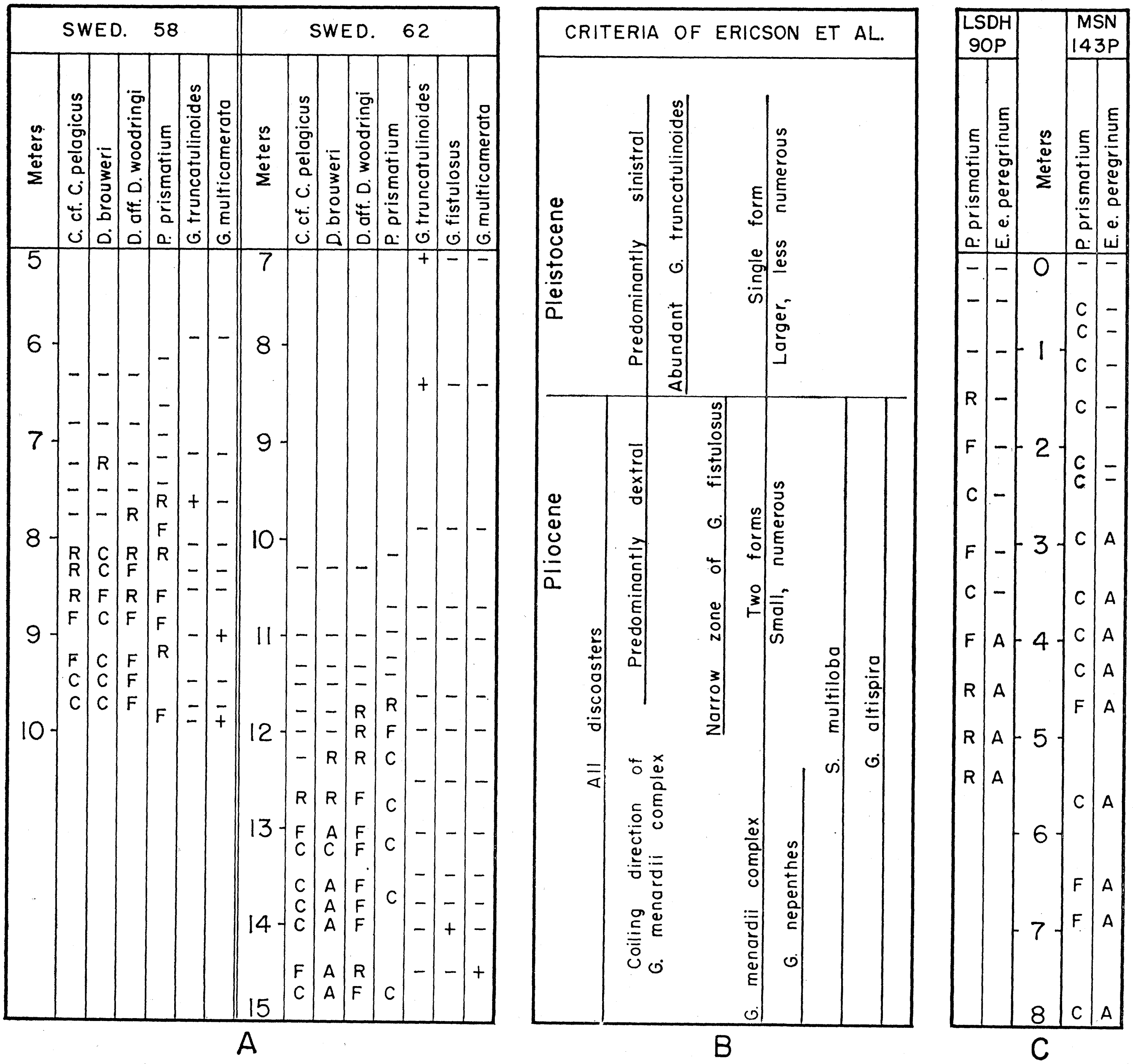

Fig. 1. A (left). Occurrence of some planktonic microfossils in two Swedish (Swed.) Deep-Sea Expedition cores. *A*, abundant; *C*, common; *F*, few; *R*, rare; +, present; —, absent. For generic names see text. B (middle). Summary of criteria used by Ericson *et al.* to distinguish the "Pliocene-Pleistocene" boundary. No vertical scale. C (right). Occurrence of two radiolarian species in Scripps cores LSDH 90P (approx. 7°20′N, 175°29′W; 5190 m) and MSN 143P (5°32′N, 146°09′W; 5100 m). These cores are practically noncalcareous.

nary". Most of the faunal changes described by Ericson *et al.* in Atlantic cores are recognizable in both oceans, but in the Pacific they do not all occur at precisely the same time. The interval through which these changes in the microplankton occur is applicable for correlation over a large part of the ocean floor, and although it apparently approximates to the Pliocene-Pleistocene boundary, the degree of this correspondence remains to be established.

Calcareous nannoplankton. In Swedish Deep-Sea Expedition core 62, the abrupt disappearance of abundant *Discoaster brouweri* is the most obvious change upward in the sequence, with coincident disappearance, in this region, of *Coccolithus* cf. *C. pelagicus.* This change occurs within the zone of relatively low carbonate between 12.3 and 13.0 m. *Discoaster* aff. *D. woodringi* is less common and disappears about 1 m higher.

In core 58 the same changes occur, although they are somewhat less obvious because dissolution has affected all the calcareous constituents more strongly than in the more rapidly accumulated core 62. The change in nannoplankton occurs near or within the zone of low carbonate between 7.9 and 8.1 m.

Reworked discoasters and radiolarians from various parts of the mid-Tertiary occur throughout both cores (more commonly in core 58), and several outcrops of such ages have been cored within 250 miles of the position where core 58 was taken. Other species of *Discoaster,* including *D. challengeri* and *D. pentaradiatus,* are common in some Pacific cores of earlier Pliocene age but do not persist to the "latest Pliocene" of cores 62 and 58. Thus the succession of discoasters described by Ericson *et al.* for the Atlantic seems to agree with that in the Pacific, particularly in the abrupt extinction of *D. brouweri.*

The number of species of *Discoaster* and coccolithophorids has gradually decreased since the middle Miocene, with some relatively abrupt extinctions within the Miocene. The most striking number of extinctions since that at the end of the Maestrichtian occurs near the end of the Eocene. Although abrupt and apparently widespread, the extinctions at the "end of the Pliocene" seem, per se, not sufficiently numerous to imply a drastic climatic change.

Foraminifera. Solution of the calcareous constituents, especially in core 58, has affected the Foraminifera as it has the nannoplankton. However, selected samples contain fairly representative faunas, although none of the more fragile species have survived.

In core 58, right-coiling *Globorotalia multicamerata* occurs rarely at 9.0 m and below. No typical *Globigerinoides fistulosus* were seen, and only one specimen of *Globorotalia truncatulinoides* (at 7.6 m). *Globorotalia cultrata-tumida* (part of the "*G. menardii* complex" of Ericson *et al.*) is left-coiling throughout the core and apparently constant in size, although no statistical measurements were made.

In core 62, also, *G. cultrata-tumida* is constantly left-coiling. *Globorotalia multicamerata* (right-coiling) occurs at 14.5 m. One specimen of *G. truncatulinoides* (left-coiling) was found at 8.4 m, and six specimens (right-coiling) at 7.0 m. Two specimens of *Globigerinoides fistulosus* were found at 14.0 m.

Globorotalia miocenica, Sphaeroidinella multiloba (and related species), and *Globoquadrina altispira* were not observed in these two cores, but the last two occur in other Pacific cores of presumably earlier Pliocene age. Funnell (*12*) has recorded *"Globigerina" nepenthes* in the lower part of a Pacific core containing Pliocene nannoplankton (Scripps core DWBG 118 C, 28°02′S, 96°20′W, depth 3400 m, core length 70 cm).

Thus, in cores 58 and 62 the Foraminifera offer little assistance in establishing a Pliocene-Pleistocene boundary, though most of the occurrences agree with those described by Ericson *et al.* Exceptions are the constant character of *Globorotalia cultrata-tumida,* both in coiling direction and general size of specimens, and the nonappearance of abundant *G. truncatulinoides* in the upper parts of the cores.

The statement by Ericson *et al.* that the Pliocene faunas have a "Miocene aspect" seems somewhat misleading. It might equally well be said that the faunas have a "Quaternary aspect," since many Quaternary species appear near the Miocene-Pliocene boundary (*Globigerina quinqueloba, Globoquadrina dutertrei, Globorotalia crassaformis,* and others). Although many Miocene species persist into the Pliocene, many Pliocene species also persist into the Quaternary.

Radiolaria. Although Riedel (*7*) originally regarded the upper limits of *Pterocanium prismatium* and *Eucyrtidium elongatum peregrinum* as approximately synchronous, the former has since been found to range higher than the latter, as for example in the two widely separated tropical Pacific cores shown in Fig. 1(C). The approximate synchroneity of their upper limits in Swedish Deep-Sea Expedition core 85 and the core-pair 73B-73 is probably due to truncation of the Pliocene section. In core 58 the upper limit of *P. prismatium* lies between 7.7 and 7.4 m, and in core 62 it is between 11.7 and 11.4 m; in neither core is this species accompanied by *E. elongatum peregrinum.*

Two supplementary Pliocene localities. The following selected Scripps cores illustrate Pacific Pliocene assemblages older than those of cores 58 and 62. (i) Chub. 30; 7°18′N, 127°25′W, depth 3640 m, core length 52 cm. Samples from near the bottom of the core contain *Discoaster brouweri, D. challengeri, D. pentaradiatus, Globorotalia multicamerata, G.* cf. *G. miocenica, Sphaeroidinella multiloba* (or related species), *Globoquadrina altispira,* and *Eucyrtidium elongatum peregrinum.* (ii) LSDH 78P; approximately 4°30′S, 168°03′E, depth 3208 m, core length 526 cm. A thin layer of Quaternary sediment disconformably covers early Pliocene containing *D. brouweri, D. challengeri, D. pentaradiatus, Globorotalia multicamerata, Sphaeroidinella multiloba* (or related species or both), *Globoquadrina altispira,* and *Eucyrtidium elongatum peregrinum* (*13*).

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