microtektites (ppm): Fe = 62,000; Mn = 770; Na = 14,000; K = 14,600.
10. S. R. Taylor, *Geochim. Cosmochim. Acta* **30**, 1121 (1966); W. H. Pinson and T. B. Griswold, *J. Geophys. Res.* **74**, 27 (1969); E. C. Chao, F. Cuttitta, M. K. Carron, C. Annell, P. Mount, *Trans. Amer. Geophys. Union* **40**, 427 (1965); W. Gentner, H. J. Lippolt, O. Muller, *Z. Naturforsch.* **19a**, 150 (1964); C. C. Schnetzler, W. H. Pinson, P. M. Hurley, *Science* **151**, 817 (1966); L. Rybach and J. A. S. Adams, *Geochim. Cosmochim. Acta* **33**, 1101 (1969); J. W. Morgan, *Earth Planet. Sci. Lett.* **7**, 53 (1969); C. C. Schnetzler and W. H. Pinson, *Geochim. Cosmochim. Acta* **28**, 953 (1964); W. Compston and D. R. Chapman, *ibid.* **33**, 1023 (1969).
11. C. C. Schnetzler, J. A. Philpotts, H. H. Thomas, *Geochim. Cosmochim. Acta* **31**, 1987 (1967).
12. J. W. Chase, C. C. Schnetzler, G. K. Czamanske, J. W. Winchester, *J. Geophys. Res.* **68**, 577 (1963); L. Haskin and M. A. Gehl, *Science* **139**, 1056 (1963).
13. L. A. Haskin, M. A. Haskin, F. A. Frey, T. R. Wildeman, in *Origin and Distribution of the Elements*, L. H. Ahrens, Ed. (Pergamon Press, New York, 1968), p. 889.
14. H. Wakita and R. A. Schmitt, *Earth and Planet. Sci. Lett.* **9**, 164 (1970); N. J. Hubbard, P. W. Gast, H. Wiesmann, *ibid.*, p. 181; C. C. Schnetzler, J. A. Philpotts, M. L. Bottino, *ibid.*, p. 185; J. C. Laul, R. R. Keays, R. Ganapathy, E. Anders, *ibid.*, p. 211.
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Hyalinea baltica and the Plio-Pleistocene Boundary in the Caribbean Sea

Abstract. *The foraminifer* Hyalinea baltica is found for the first time in sediments from the western Caribbean Sea. Its relationship to the Plio-Pleistocene boundary and to other criteria used to define this boundary is examined, with the result that a strict adherence to the classical definition is urged.

Gignoux (*1*, *2*) defined his Calabrian stage on the basis of the first appearance of northern marine invertebrates, including the pelecypod *Arctica islandica*, in late Cenozoic sections of southern Italy and Sicily. This stage, assigned by Gignoux to the Pliocene, was reassigned to the Pleistocene by the XVIIIth International Geological Congress (London, 1948). Therefore, the base of the Calabrian is, by definition, the Plio-Pleistocene boundary (*3*). While Gignoux placed the base of the Calabrian at the first appearance of *A. islandica*, Ruggieri and Selli (*4*) subsequently suggested that it be placed at the first appearance of the foraminifera *Hyalinea baltica*, which they found to occur above the first appearance of *A. islandica*. Emiliani *et al.* (*5*) ran paleotemperature analyses on pelagic and benthonic foraminifera and benthic mollusks from the continuous Plio-Pleistocene section at Le Castella, Calabria, southern Italy. In this section, which can be closely correlated with the section at Santa Maria di Cantanzaro (one of Gignoux's type sections) by means of the benthic microfauna, the base of the Pleistocene is clearly marked by the first appearance of *H. baltica*. (Fig. 1).

In other areas, different criteria have been used to define the Plio-Pleistocene boundary. Arrhenius (*6*) defined the boundary on the basis of a sharp increase in calcium carbonate content in cores recovered from the eastern Pacific by the Swedish Deep-Sea Expedition of 1947–1948. Riedel (*7*) correlated the level of extinction of two radiolarians, *Pterocanium prismatium* and *Eucyrtidium elongatum peregrinum*, in tropical Pacific cores with Arrhenius' boundary. Subsequently, Riedel *et al.* (*8*) used only the extinction of *P. prismatium* in defining the boundary. Ericson *et al.* (*9*) defined the Plio-Pleistocene boundary by using the following events in selected Atlantic deep-sea cores; extinction of *Discoaster challengeri, Discoaster pentaradiatus,* and *Discoaster brouweri*; change in coiling direction of *Globorotalia menardii* s.l. from predominantly dextral to predominantly sinistral; appearance of *Globorotalia truncatulinoides* in abundance; extinction of *Globigerinoides fistulosus*; reduction of the *G. menardii* group to a single, relatively uniform race; and an increase in size of *G. menardii*. Later, Ericson *et al.* (*10*) estimated this boundary to be 1.5×10^6 years. This boundary is believed by some to correlate roughly with that of Riedel (*7*) and Riedel *et al.* (*8*). Harrison and Funnel (*11*) related the last occurrence of *P. prismatium* to the Matuyama/Brunhes paleomagnetic reversal, correlated this with the extinction of discoasters in other Pacific cores, and dated it at 0.7×10^6 years.

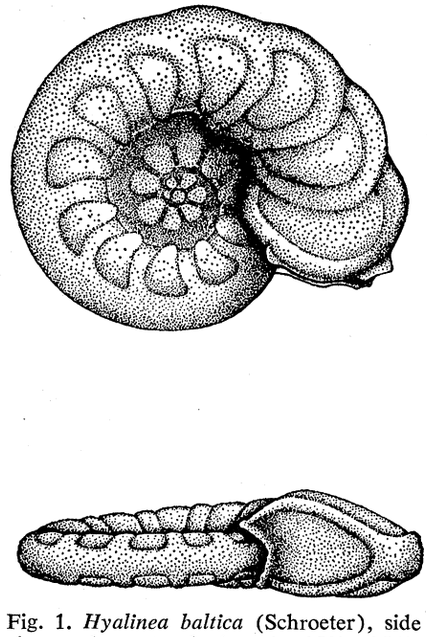

Fig. 1. *Hyalinea baltica* (Schroeter), side view and apertural view (× 150); 2560-cm level in the Submarex core.

Hays (*12*) recognized the boundary between the lower two of four faunal radiolarian zones in deep-sea cores from the Antarctic, marked by a change from red clay below to diatom ooze above, and correlated it with the Plio-Pleistocene boundary of Ericson *et al.* (*9*). Subsequently Opdyke *et al.* (*13*) related the radiolarian zones to paleomagnetic stratigraphy and found the boundary to coincide with the base of the Olduvai Event (1.9×10^6 years).

Berggren *et al.* (*14*) placed the Plio-Pleistocene boundary in a core from the south-central North Atlantic at the first evolutionary appearance of *Globorotalia truncatulinoides* from its immediate ancestor *G. tosaensis*. This boundary was found paleomagnetically to lie within the upper part of the Olduvai Event (1.85×10^6 years), and was correlated with the N21/N22 boundary of Banner and Blow (*15*) from the type Calabrian at Santa Maria di Cantanzaro. Berggren *et al.* (*14*) also suggested that the observed pronounced increase of *Globigerina inflata* and the general decrease and local disappearance of *Pulleniatina obliquiloculata* and *Sphaeroidinella dehiscens* lie within the Jaramillo Normal Event, dated at about 0.9×10^6 years, and correlated these events with the onset of glacial Pleistocene.

Wray and Ellis (*16*) noted that *D. pentaradiatus, D. surculus,* and *"D. variabilis"* (= *D. extensus*) all became extinct at about the same stratigraphic level off the Louisiana coast, while *D. brouweri* persisted longer. Akers (*17*) noted that *D. surculus* and *D. pentaradiatus* became extinct at about the same level as *Globoquadrina altispira*

s.l., while *Globorotalia truncatulinoides* changed from rare to abundant. The lingering presence of *D. brouweri* was confirmed. The extinction of *D. surculus* was thought to represent the Plio-Pleistocene boundary.

Bolli *et al.* (*18*) placed the Plio-Pleistocene boundary at 2350 cm below the top in the Submarex drill core, based on the extinction of *D. brouweri* and the disappearance of *Coccolithus pelagicus*, which they thought approximated the level of appearance of *H. baltica* in the section of Le Castella. Other events noted in the 56.4-m-long drill core were: extinction of *Globoquadrina altispira altispira* at 4570 cm; disappearance of *Globorotalia multicamerata* at 4136 cm; disappearance of *Globigerinoides fistulosus* at 4066 cm; and an increase in abundance of *Globorotalia truncatulinoides* at 2380 cm. The Submarex core had surface contamination at the tops of each individual cored section which may have reworked some species from a higher level, but no reworking from below seems to exist.

I have now analyzed the benthonic foraminifera in the Submarex core in detail (*19*). This analysis has revealed the presence of *H. baltica* 210 cm below the extinction of *D. brouweri*, with 15 specimens in the 2460- to 2560-cm interval and two at the 2340-cm level. Apparently this is the first record of *H. baltica* in the Caribbean. As mentioned before, the Plio-Pleistocene boundary in the type section at Le Castella is defined on the basis of the first appearance of this foraminifer.

Hyalinea baltica has been reported from the Gulf Coast in sediments estimated to have been deposited in water several hundred meters deep. Akers and Dorman (*20*) recorded this species from South Block 41 Well in the Pleistocene of Louisiana and, more recently (personal communication), as being consistently abundant in the Gulf Coast below the *Sphenolithus abies* zone, below the extinction of *Globoquadrina altispira altispira*, and before the appearance of *Globorotalia truncatulinoides*. This species, in association with *Globigerina inflata* and *Globigerina bulloides*, is indicative of temperate to cool water on the Gulf Coast.

The first appearance of *H. baltica* in the Submarex core, 210 cm below the extinction of *D. brouweri*, suggests that the stratigraphic relationship between the two is not consistent at all locations. In the Submarex core, *H. baltica* appears above the *S. abies* zone, above the extinction of *Globoquadrina altispira altispira*, and below the increase in abundance of *Globorotalia truncatulinoides*. Bayliss (*21*) found the first appearance of *H. baltica* below the appearance of *G. truncatulinoides* in the type Calabrian at Santa Maria di Cantanzaro. The Submarex sediments containing *H. baltica* may be interpreted as having been deposited in water 500 to 600 m deep (*19*). There is no reported occurrence of this species in Recent interglacial sediments in either the Gulf Coast area or the Caribbean, so it appears likely that it is indeed indicative of climatic deterioration.

The extinction of *D. brouweri* and the disappearance of *C. pelagicus* were correlated by Bolli *et al.* (*18*) with the extinction of discoasters and the radiolarian *P. prismatium* in eastern Pacific cores 58 and 62, an event for which Emiliani (*22*) estimated an age of 0.8 $\times 10^6$ years. This age correlates well with the age of 0.7 $\times 10^6$ years for the disappearance of the same radiolarian in the Pacific core analyzed paleomagnetically by Harrison and Funnel (*11*).

Ericson *et al.* (*9*) correlated the extinction of discoasters in their Atlantic cores with the extinction in Swedish Deep-Sea cores 58 and 62, but estimated an age of 1.5 $\times 10^6$ years. This age approaches that of 1.85 $\times 10^6$ years for the Plio-Pleistocene boundary of Berggren *et al.* (*14*). Following the paleomagnetic data of Berggren *et al.* (*14*), Boudreaux and Hay (*23*) revised the estimate of the age of the boundary in the Submarex core to 1.8 $\times 10^6$ years. However, a brief reappearance of discoasters was noticed at 162 to 164 cm in the Atlantic core (*14*), coinciding with the upper part of the Jaramillo Event dated at 0.9 $\times 10^6$ years. If this correlates with the last occurrence of discoasters in the cores of Ericson *et al.* (*9*), in cores 58 and 62 of the Swedish Deep-Sea Expedition, in the Submarex core, in the Calabrian section at Le Castella, and with the extinction of the radiolarian *P. prismatium* in the Pacific, then there is close age agreement (0.7 to 0.9 $\times 10^6$ years) for all sections, except those of Ericson *et al.* (*9*). On the other hand, if the disappearance of abundant discoasters in the Atlantic core of Berggren *et al.* (*14*) correlates with the extinction of discoasters and the radiolarians in the other cores, then there is a large age discrepancy between the Atlantic cores (1.5 to 1.85 $\times 10^6$ years) and the Pacific cores (0.7 to 0.8 $\times 10^6$ years).

It appears that, if the Plio-Pleistocene boundary is defined in a way different from the classic one, then the age of the boundary is likely to be different depending on the criteria used. Four commonly used definitions of the boundary and their probable ages are: onset of the first major glaciation (Gunz-Nebraskan) at about 0.35 $\times 10^6$ years; micropaleontological changes in pelagic sediments at 0.8 or possibly 1.8 $\times 10^6$ years; appearance of *H. baltica* in the Submarex core and in the Mediterranean at about 1.0 $\times 10^6$ years; and the first appearance of the Villafranchian fauna at 3.2+ $\times 10^6$ years. Because of these different ages, students are strongly urged to adhere strictly to the classic definition of the Plio-Pleistocene boundary, representing a single event (first appearance of *H. baltica* at Le Castella) and, therefore, a single age.

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References and Notes

1. M. Gignoux, *C.R. Hebd. Seances Acad. Sci. Paris* **150**, 841 (1910).
2. ———, *Univ. Ann. Lyon n.s.* **36**, 693 (1913).
3. Unanimous decision, General Assembly, 7th INQUA Congress, Denver (1965).
4. G. Ruggieri and R. Selli, *XVIII Int. Geol. Congr. Rep.*, London, **9**, 85 (1950).
5. C. Emiliani, T. Mayeda, R. Selli, *Bull. Geol. Soc. Amer.* **72**, 679 (1961).
6. G. Arrhenius, *Rep. Swed. Deep-Sea Exped.*, Rep. 5 (1952).
7. W. R. Riedel, *ibid.*, Rep. 6 (1957).
8. ———, F. L. Parker, M. N. Bramlette, *Science* **140**, 1238 (1963).
9. D. B. Ericson, M. Ewing, G. Wollin, *ibid.* **139**, 727 (1963).
10. ———, *ibid.* **146**, 723 (1964).
11. C. G. A. Harrison and B. M. Funnel, *Nature* **204**, 566 (1964).
12. J. D. Hays, *Amer. Geophys. Union, Antarctic Res. Ser.* **5**, 125 (1965).
13. N. Opdyke, B. Glass, J. D. Hays, J. Foster, *Science* **154**, 349 (1966).
14. W. A. Berggren, J. D. Phillips, A. Bertels, D. Wall, *Nature* **216**, 253 (1967).
15. F. T. Banner and W. H. Blow, *ibid.* **208**, 1 (1965).
16. J. L. Wray and C. H. Ellis, *Amer. Ass. Petrol. Geol. Bull.* **49**, 98 (1965).
17. W. H. Akers, *Science* **149**, 741 (1965).
18. H. M. Bolli, J. E. Boudreaux, C. Emiliani, W. W. Hay, R. J. Hurley, J. I. Jones, *Bull. Geol. Soc. Amer.* **79**, 459 (1968).
19. W. D. Bock, *Micropaleontology*, in press.
20. W. H. Akers and J. H. Dorman, *Tulane Stud. Geol.* **3**, 1 (1964).
21. D. D. Bayliss, *Lethaia* **2**, 133 (1969).
22. C. Emiliani, *Science* **154**, 851 (1966).
23. J. E. Boudreaux and W. W. Hay, *Rev. Española Micropaleontologia* **1**, 249 (1969).
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