15. BASE OF LARGE GEPHYROCAPSA AND ASTRONOMICAL CALIBRATION OF EARLY PLEISTOCENE SAPROPELS IN SITE 967 AND HOLE 969D: SOLVING THE CHRONOLOGY OF THE VRICA SECTION (CALABRIA, ITALY)1

L.J. Lourens,2 F.J. Hilgen,3 and I. Raffi4

ABSTRACT

Calcareaous plankton biochronology and the astronomical calibration of sapropels are presented for the early Pleistocene in Ocean Drilling Program (ODP) Site 967 and Hole 969D with the aim to solve the existing chronology problem in the Pliocene/Pleistocene boundary stratotype section of Vrica, Italy. Detailed sapropel correlations between these ODP sites and the Vrica and Singa sections, corroborated by calcareaous plankton biostratigraphy, indicate that the Vrica section is continuous and that the base of the large Gephyrocapsa is diachronous on a global scale.

INTRODUCTION

Recently, two alternative age models were presented for the Pleistocene part of the Pliocene/Pleistocene boundary stratotype section at Vrica (Calabria, southern Italy; Lourens et al., 1996a). The chronology of both models is based on the correlation of characteristic sapropel patterns to the average of the June and July (summer) insolation time series at 65°N of the La901,1 (Laskar et al., 1993) astronomical solution (Lourens et al., 1996a, 1996b). The first age model is based on the assumption that the succession at Vrica is continuous. According to this model, the position of almost all calcareaous plankton datum planes relative to the oxygen isotope stages is in good agreement with that found in the adjacent northern Atlantic. The only exception is the base of large Gephyrocapsa (blG), which is found in Stage 55 in the Vrica and Singa sections (Calabria, southern Italy), whereas it occurs in Stage 48 (or the top of 49) in the open ocean (Raffi et al., 1993). This unexpectedly large discrepancy in age of the blG in the eastern Mediterranean and the open ocean cast serious doubt on the validity of this age model. As a consequence, we developed an alternative age model based on the assumption that the blG is globally (near-)synchronous. This model implies a major hiatus between the top of Calcidiscus macintyrei (tCm) and the blG in the Vrica and Singa sections. Application of this alternative model, however, leads to significant discrepancies in the position of the other calcareaous plankton events.

In this paper, we aim to solve the astronomical calibration of the sapropels and thereby the existing problem of the two conflicting age models for the Pleistocene part of the Vrica section. For this purpose, we established a high-resolution biochronology for Ocean Drilling Program (ODP) Site 967 and Hole 969D for the same time interval based on an unambiguous correlation of sapropel patterns to the La901,1 summer insolation curve at 65°N. To explore the possibility of a blG diachronity, we also checked the position of this event in a high-resolution sample set of ODP Site 926 from the equatorial Atlantic.

SITE 967 AND HOLE 969D

Site 967 is situated south of Cyprus on the northern flank of a small (~300 m high) ridge near the foot of the northern slope of the Eratosthenes Seamount (34°04′N, 32°43′E) at a water depth of 2554 m (Fig. 1). The top 125 m of the section consists of early Pliocene to Holocene pelagic sediments and contains 80 sapropels and several intervals with mud turbidites. The sediments are relatively undisturbed, but show some small high-angle faulting and a slumped interval associated with an overlying debris-flow unit.

Hole 969D was drilled on the Mediterranean Ridge about 100 km south of the island of Crete (33°50′N, 24°53′E) at a water depth of 2192 m (Fig. 1). The sediments of Pliocene to Holocene age consist of nannofossil oozes and nannofossil clays and contain more than 80 sapropels. The sapropels occur in five distinct groups, which are separated by intervals of yellowish brown sediment that is commonly oxidized and does not contain (preserved) sapropels. In contrast to those of Holes 969A, 969B, and 969E, the sapropels recovered from Hole 969D are intact and undeformed.

BIOSTRATIGRAPHY

We carried out our own high-resolution biostratigraphic study for the tCm, blG, and the top of large Gephyrocapsa (l1G) and top of

---

2Faculty of Earth Sciences, Utrecht University, Budapestlaan 4, P.O. Box 80.021, Utrecht, The Netherlands. lourens@earth.ruu.nl
3Faculty of Earth Sciences, Utrecht University, Budapestlaan 4, P.O. Box 80.021, Utrecht, The Netherlands.
4Facoltà di Scienze Matematiche, Fisiche e Naturali, Università degli Studi G. D’Annunzio, Chieti Scalo, Italy.
*Helicosphaera sellii* (tHS) in Site 967 and Hole 969D to prevent the use of different taxonomic concepts in this study and that of the Vrica section. In addition, we determined the first occurrence (FO) of the benthic foraminifer species *Hyalinea balthica*, checked for short influxes of the planktonic foraminifer species *Globorotalia crassaformis* and *Globorotalia truncatulinoides*, and counted the number of left-coiling neogloboquadrinids relative to their right-coiling counterpart. Finally, we determined the top of *Discocoaster brouweri* (tDb) in Hole 969D and adopted the position of this event in Holes 967A and 967C from the initial shipboard scientific results (Emeis, Robertson, Richter, et al., 1996) and from Staerker (Chap. 31, this volume), respectively. All biostratigraphic data are reported in Figure 2 and Table 1.

![Figure 2](image_url)

**Figure 2.** Biostratigraphic data of Site 967 and Hole 969D. Solid intervals in the lithology indicate sapropels, whereas the shaded areas indicate grey layers or less-distinct sapropels. The percentage of large-sized *Gephyrocapsa* (>5.5 µm) is related to 100 *Gephyrocapsa* >4 µm. The percentage of left-coiling neogloboquadrinids (N. sp. [sin.]) is related to the total of left and right-coiling neogloboquadrinids. The percentage of *Discocoaster triradiatus* (solid) is relative to the total of *Discocoaster brouweri* and *D. triradiatus*. Influxes of *Globorotalia crassaformis* and *Globorotalia truncatulinoides* are indicated by c and t, respectively. The jagged pattern at the bottom of the lithology column of Site 967 indicates a slumped interval.
6, 114–115 cm, and 125–127 cm. Finally, we placed the tDb and the associated drop in *Discocoaster triradiatus* between Samples 160-969D-5H-5, 85–87 cm, and 95–97 cm.

Benthic foraminifers are scarce in Hole 969D and rare specimens of *H. balthica* are present in one sample only. *H. balthica* occurs more frequently in Site 967, although still in very low numbers and discontinuously. *Islandiellla ionica*, another benthic foraminifer marker species (Verhulsen, 1991), was not found. Several short peak occurrences of *G. crassaformis* and *G. truncatulinoides* were found (Table 1). The first substantial increase of left-coiling neogloboquadrinids is found between Sapropels 34 and 35 in Hole 969D and at a correlatable level between Sapropels 46 and 47 in Site 967. An absence interval of this species is present between 26 and 29 revised meters composite depth (rcmd) in Hole 969D and between 40 and 44 rcmd in Site 967 (Fig. 2).

**SAPROPEL CHRONOLOGY**

A first-order calibration of sapropels to the astronomical record is based on the correlation of large groups or clusters of sapropels in Site 967 and Hole 969D to 400-k.y. maxima in the eccentricity of the Earth’s orbit. Four distinct clusters are found between 95 and 40 rcmd in Site 967, and between 90 and 20 rcmd in Hole 969D. Biostratigraphic data indicate that these clusters correspond to the large-scale O, A, B, and C clusters from classical marine sections in southern Italy (e.g., Hilgen, 1991).

The oldest sapropels of the C cluster (i.e., C1 – C9 in Singa and *-h in Vrica) can easily be identified in ODP Site 967 (i.e., Sapropels 44–52) and Hole 969D (i.e., Sapropels 30–42; Fig. 3). The next small-scale cluster displays a cyclic alternation of distinct and less-distinct sapropels (i.e., Sapropels 38–42) in Site 967 and of sapropels and grey layers (i.e., Sapropels 27–29) in Hole 969D. These alternating distinct and less-distinct (grey) sapropel patterns can be explained by the interference between precession and obliquity, which is clearly reflected in the La90 (1,1) summer insolation curve (Fig. 3): distinct sapropels are correlated to high-amplitude insolation maxima, and less-distinct (grey) sapropels are correlated to low-amplitude insolation maxima (Lourens et al., 1996b). Starting from this second-order calibration, all younger sapropels (i.e., 20–26 in Hole 969D and 27–37 in Site 967) can be correlated directly to the astronomical target curve (Fig. 3). The proposed astronomical calibration provides very accurate numerical ages not only for the sapropels (Table 2; Fig. 3B), but also for the recorded biostratigraphic datum planes (Table 1).

**DISCUSSION AND CONCLUSIONS**

In the Vrica section, complicating factors like the influence of obliquity, changes in sedimentation rate, and the increasing number of sapropels per large-scale cluster hinder a straightforward astro-
nomical calibration of the youngest (n−v) sapropels (Hilgen, 1991; Lourens et al., 1996a). A key problem in establishing a sapropel chronology for this part of the Vrica section is the interpretation of the small-scale sapropel cluster n-o-p. According to the continuous age model, as referred to in the introduction, this cluster is not related to a 100-k.y. eccentricity maximum, as could be expected from late Pleistocene phase relations, but reflects an interference pattern between precession and obliquity at the time of the 400-k.y. eccentricity minimum around 1.4 Ma. Starting from this age model, all sapropel correlations between the Vrica and Singa sections and ODP Site 967 and Hole 969D are straightforward and confirmed by biostratigraphic correlations (Fig. 4). The cyclostratigraphic correlation of Sapropels n-o-p with the characteristic interference pattern observed in Site 967 and Hole 969D is biostatigraphically confirmed by the position of tCm and bIG and by influxes of G. crassaformis (Fig. 4A). The short influx above this group of sapropels is substantiated by rare G. crassaformis in two successive samples above Sapropel C12 in the Singa section, but was not found in the Vrica section, possibly due to lack of sample resolution. Also, the correlation of the younger sapropels is easily accomplished. It shows that, as in the preceding interval, additional cycles are developed at the ODP sites either as grey layers or as thin indistinct sapropels. All correlations are confirmed by the position of tDb, tIG, tHS (Fig. 4A) and by the characteristic abundance pattern of left-coiling neogloboquadrids (Fig. 4B). Similar to the pattern observed in the Vrica section and North Atlantic Deep Sea Drilling Project (DSDP) Site 607, the peak occurrences of left-coiling neogloboquadrinids in Site 967 and Hole 969D are associated with glacial Stages 64 to 44, followed by an interval in which such (peak) occurrences are markedly absent. The next two younger peak occurrences, associated with glacial Stages 36 and 34 in the Atlantic (see Lourens et al., 1996a), are observed in the top part of the studied cores (Fig. 4B). The only remarkable difference between Vrica and

Figure 3. Calibration of early Pleistocene sapropels in Site 967 and Hole 969D to the La90 (1,1) (Laskar et al., 1993) summer insolation curve at 65°N against (A) depth and (B) age. The color reflectance data of Hole 967A (dashed line in right column) has been shifted to the left with 10% relative to that of Hole 967C (solid line) for clarity. All color reflectance data are obtained from Sakamoto et al. (Chap. 24, this volume). The coding (i-cycle) indicated at the right side of the insolation curve is from Lourens et al. (1996b). The jagged pattern in the lithology column of Site 967 indicates a slumped interval.
the ODP sites is that the pattern of Sapropels q-r-s in the Vrica section (with r being thinner and less prominent)—thought to be indicative of interference between precession and obliquity—is not confirmed at Site 967 and Hole 969D where the three correlative sapropels are equally distinct. At present, we do not have an explanation for this difference.

On the contrary, serious inconsistencies are found if we start from the alternative age model for the Vrica section. This age model, which started from the assumption that blG is globally (near-)synchronous, implied that a major hiatus is present in the interval between tCm and blG (Lourens et al., 1996a). A hiatus, however, is no longer tenable, because the sapropel patterns and bioevents (e.g., the first appearance of large Gephyrocapsa, the absence interval of glacial-bound influxes of left-coiling neogloboquadrinids and the tIG and (HS) are remarkably consistent throughout the eastern Mediterranean (Fig. 4).

To investigate the potential global diachronity of blG, we checked the position of this event in a high-resolution sample set of ODP Site 926 (Ceara Rise, equatorial Atlantic). A comparison of our first results with the age model obtained from orbitally tuned susceptibility records (Bickert et al., 1997) reveals that the blG at this site is considerably older than the global estimate of 1.48 Ma for this event as well (Raffi et al., 1993). The age of 1.59 Ma at Site 926 is only 30 k.y. younger than our estimate for the blG at Sites 967 and 969 in the eastern Mediterranean. In conclusion, the alternative age model for the Pleistocene Vrica section is untenable. The Vrica section contains a continuous Pleistocene succession from 1.81 (i.e., the Pliocene/Pleistocene boundary) to 1.21 Ma.

More than 10 yr after its formal designation as a Pliocene/Pleistocene boundary stratotype, the Vrica section can now be considered as a (land based) standard reference section for the early Pleistocene, because it is shown to contain a continuous succession. In addition, the continuity makes Vrica an appropriate section for defining the Santernian/Emilian (S/E) boundary, even though the criterion proposed by Pasini and Colalongo (1994; i.e., the FO of H. balthica), is less suitable because of difficulties encountered in independently confirming its position in the Vrica section (see Lourens et al., 1996a) and the diachronous nature of this event even within the Mediterranean (Fig. 4B). In contrast, the blG is (near-)synchronous in at least the eastern Mediterranean and equatorial Atlantic, and, even on a global scale, it still gives a fair approximation of the position of the S/E boundary. Nevertheless, the observed blG diachronity of ±135 k.y. between the eastern Mediterranean and the North Atlantic DSDP Site 607 is almost half of the total duration (about 315 k.y.) of the Santernian as informally defined in the Vrica section. In the absence of an appropriate biostratigraphic datum plane or magnetic polarity reversal, cyclostratigraphy may guide the selection of the “golden spike” and therefore, a precession-related sapropel may represent a suitable position to define the S/E boundary. It would thereby follow the Pliocene/Pleistocene (Aguirre and Pasini, 1985), Piacenzian/Gela-
sian (Rio et al., 1994) and Zanclean/Piacenzian (Cita et al., 1996) boundary definitions.

ACKNOWLEDGMENTS

We thank G. Ittman and G.J. Van het Veld for preparing the numerous micropaleontological samples. The review and comments of D. Castradori and K.-C. Emeis are gratefully acknowledged.

REFERENCES


Date of initial receipt: 6 January 1997
Date of acceptance: 7 July 1997
Ms1665R-017

Figure 4. Comparison of the sapropel patterns and biostratigraphic datums between ODP Site 967 and Hole 969D, and the Vrica and Singa sections based on the continuous age model of Lourens et al. (1996a). See Figure 2 for definitions. A. Calcareous nanofossil events. B. Planktonic foraminifers and Hyalinea balthica. Numbers within the third column from right refer to oxygen isotopic stages.
Figure 4 (continued).