

54. LATE NEOGENE BIOSTRATIGRAPHIC AND MAGNETOSTRATIGRAPHIC SYNTHESIS, LEG 135¹

George C.H. Chaproniere,² Michael J. Styzen,³ William W. Sager,⁴ Hiroshi Nishi,⁵
Paula J. Quintero,⁶ and Niels Abrahamsen⁷

ABSTRACT

Integration of biostratigraphic and magnetostratigraphic results from Leg 135 sites has given additional information as to the position and reliability of various bioevents compared with previously published results. Two sites (834: Gilbert to Brunhes; and 836: Brunhes) provided excellent magnetic and biostratigraphic data. From these it is suggested that some bioevents are older than previously recorded: the first appearances (FAs) of *Emiliana huxleyi* (within the Brunhes Chron, at the same level as the FA of *Helicosphaera inversa*) and *Globorotalia (Truncorotalia) truncatulinoides* (within the upper Gauss Chron), and the last appearance (LA) of *Gr. (Tr.) tosaensis* (upper Matuyama Chron). The FA of *Gr. (Tr.) crassaformis hessi* is variable, but the oldest occurrence is just below the Cobb Mountain Subchron. Other key bioevents, such as the LAs of *Discoaster pentaradiatus* (just above the Réunion Subchron), *D. tamalis* (within the lower reversed part of the Matuyama Chron), *Sphenolithus* (lower Gauss Chron), and *Amaurolithus primus* (topmost Gilbert Chron) appear higher than previously recorded. Some key biostratigraphic taxa, such as *Globigerinoides quadrilobatus fistulosus*, *Pulleniatina finalis*, *P. primalis*, and *Sphaeroidinella dehiscens*, are either rare or their distribution is sporadic to the extent that they are unsuitable for biostratigraphic use in the area studied. Because of the rarity of *P. primalis*, the FA of *Globorotalia (Globorotalia) multicamerata* has been used to mark the base of Zone N17B. Though levels are present at most sites in which populations of *Pulleniatina* are sinistrally coiled, it is difficult to equate these coiling changes with previous records.

INTRODUCTION

Biostratigraphic events form the basis for the establishment of time scales (such as those of Berggren et al. [1985] and Haq et al. [1988]), when correlated with magnetostratigraphic events and oxygen isotope stages. Studies such as those of Berggren et al. (1985) are based on compilations of studies by many workers. In these compilations, however, the relationship between any bioevent and the magnetostratigraphy may be based on a single record, the reliability of which may not be known. Thus, any additional records of correlations between bioevents and magnetostratigraphy are of potential value for establishing global time scales by providing tests to assess their reliability.

This synthesis is based on the magnetostratigraphic and biostratigraphic results (planktonic foraminifers and calcareous nannofossils) obtained from the upper Miocene to the Pleistocene from Ocean Drilling Program (ODP) sites drilled during Leg 135 in the Lau Basin and Tongan Platform (Fig. 1), as reported in this volume (Chaproniere and Nishi; Quintero; and Styzen, all in this volume) as well as in the shipboard records (Parson, Hawkins, Allan, et al., 1992). Figure 2, which is based on Berggren et al. (1985), summarizes the biostratigraphy, magnetostratigraphy, and geochronology used in this paper. In general, the sites in the Lau Basin provided good biostratigraphic and fair to good magnetostratigraphic results, although core recovery was poor at some levels and abundant ash deposits at some sites made the recognition of magnetochrons difficult. In contrast, the magnetic signature and the biostratigraphic results obtained for the Quaternary and upper Pliocene sediments from Site 840 on the Tongan Platform proved

disappointing, to some extent because of the poor core recovery in the upper 260 m, and have not been used in this work. However, those for the upper Miocene were more satisfactory and have been included. Although the magnetostratigraphy from Site 841 can be interpreted back to the middle Miocene, many barren, or at best poorly, fossiliferous intervals yielded very poor biostratigraphic controls. Furthermore, the Miocene and older sections may have been remagnetized by hydrothermal metamorphism (Sager et al., this volume). For these reasons, Site 841 has not been used in this study.

Four samples were taken for each of the biostratigraphic groups studied from each core for the Lau Basin sites, with sample intervals being increased over critical intervals. Thus, on average, samples were taken over 2- or 3-m intervals. For Site 840, where the sequence was expanded by the volcanoclastic deposits, sampling intervals were greater than for the Lau Basin sites, with two samples per core being the norm, that is, a sample interval of approximately 4 m.

This paper is divided into two sections. The first part summarizes the foraminifer and nannofossil biostratigraphic results and the magnetostratigraphic results presented elsewhere in this volume, and then draws the three different studies together, making assessments of the reliability of the magnetic and biostratigraphic events with respect to previously published results, drawing on data presented in the second part, the Appendix. By using this strategy, the reader is spared detail that can be accessed by studying the Appendix.

MAGNETOSTRATIGRAPHIC SUMMARY

This part of the report is based on the shipboard results following Parson, Hawkins, Allan, et al. (1992).

Lau Basin Sites

A detailed magnetic polarity record was obtained from both the sediments and the underlying volcanic rocks at Site 834 (Fig. 3), with all polarity chrons and major subchrons being recognized back to the Cochiti Subchron of the Gilbert Chron (Zone N19-20, early Pliocene), a result in agreement with the biostratigraphy. At Site 835, the magnetostratigraphy is a complex pattern of reversals (Fig. 4), not readily

¹ Hawkins, J., Parson, L., Allan, J., et al., 1994. *Proc. ODP, Sci. Results*, 135: College Station, TX (Ocean Drilling Program).

² Marine Geoscience Program, Australian Geological Survey Organisation, P.O. Box 378, Canberra, A.C.T. 2601, Australia.

³ Shell Offshore Inc., P.O. Box 61933, New Orleans, LA 70161, U.S.A.

⁴ Department of Oceanography, Texas A&M University, College Station, TX 77843, U.S.A.

⁵ Department of Earth Sciences, Yamagata University, Yamagata, 990, Japan.

⁶ U.S. Geological Survey, 345 Middlefield Road, Menlo Park, CA 94025, U.S.A.

⁷ Geologisk Institut, Aarhus Universitet, Finlandsgade 6, DK-8200 Aarhus N., Denmark.

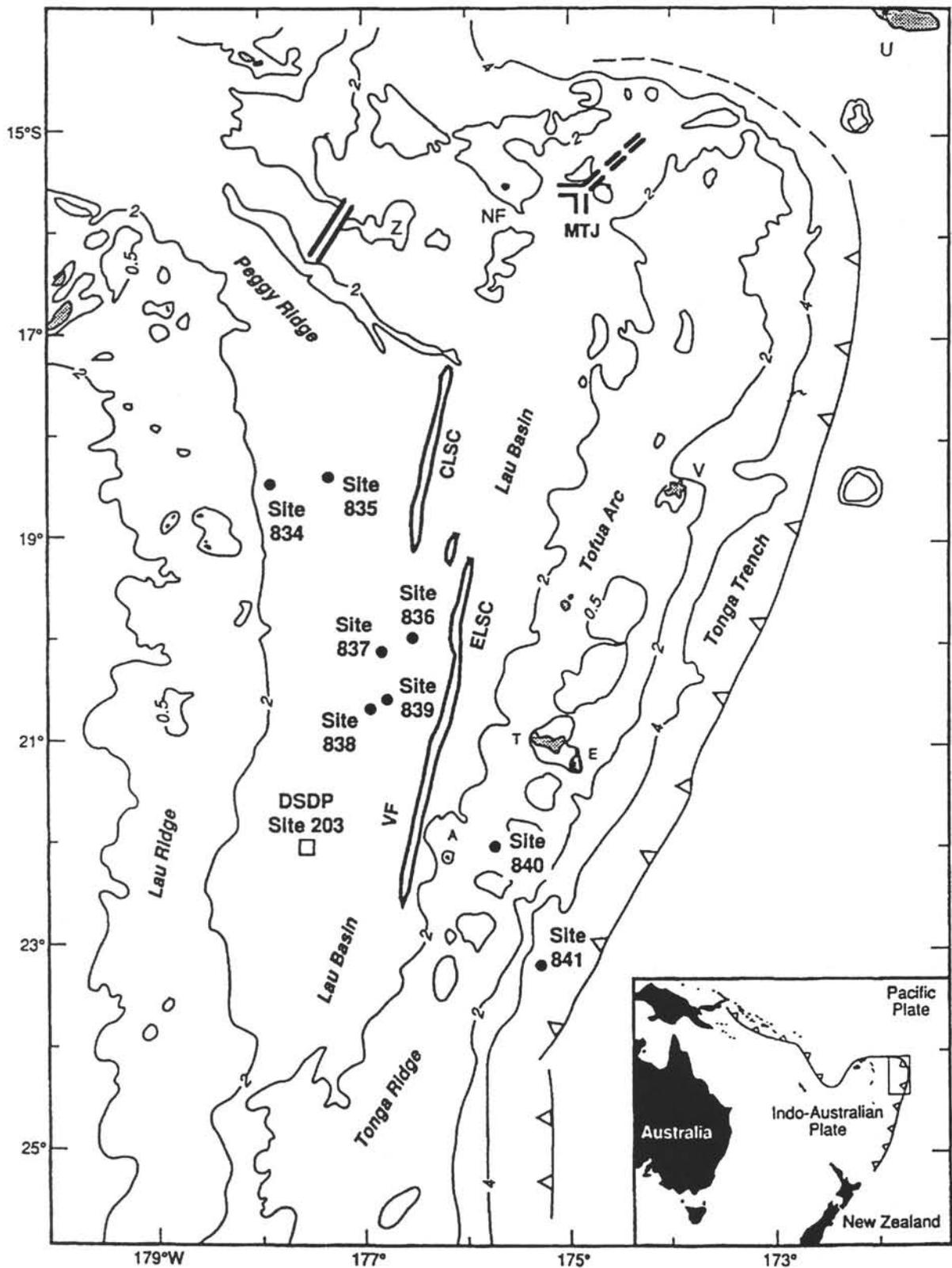


Figure 1. Map showing the bathymetry and locations of Sites 834–841 (after Parson, Hawkins, Allan, et al., 1992). CLSC = Central Lau Spreading Center, ELSC = Eastern Lau Spreading Center, MTJ = Mangatolu Triple Junction, Z = Zephyr Shoal, and VF = Valu Fa Ridge. Islands include 'Ata (A), 'Eua (E), Niufo'ou (NF), Tongatapu (T), Upolu (U), and Vava'u (V).

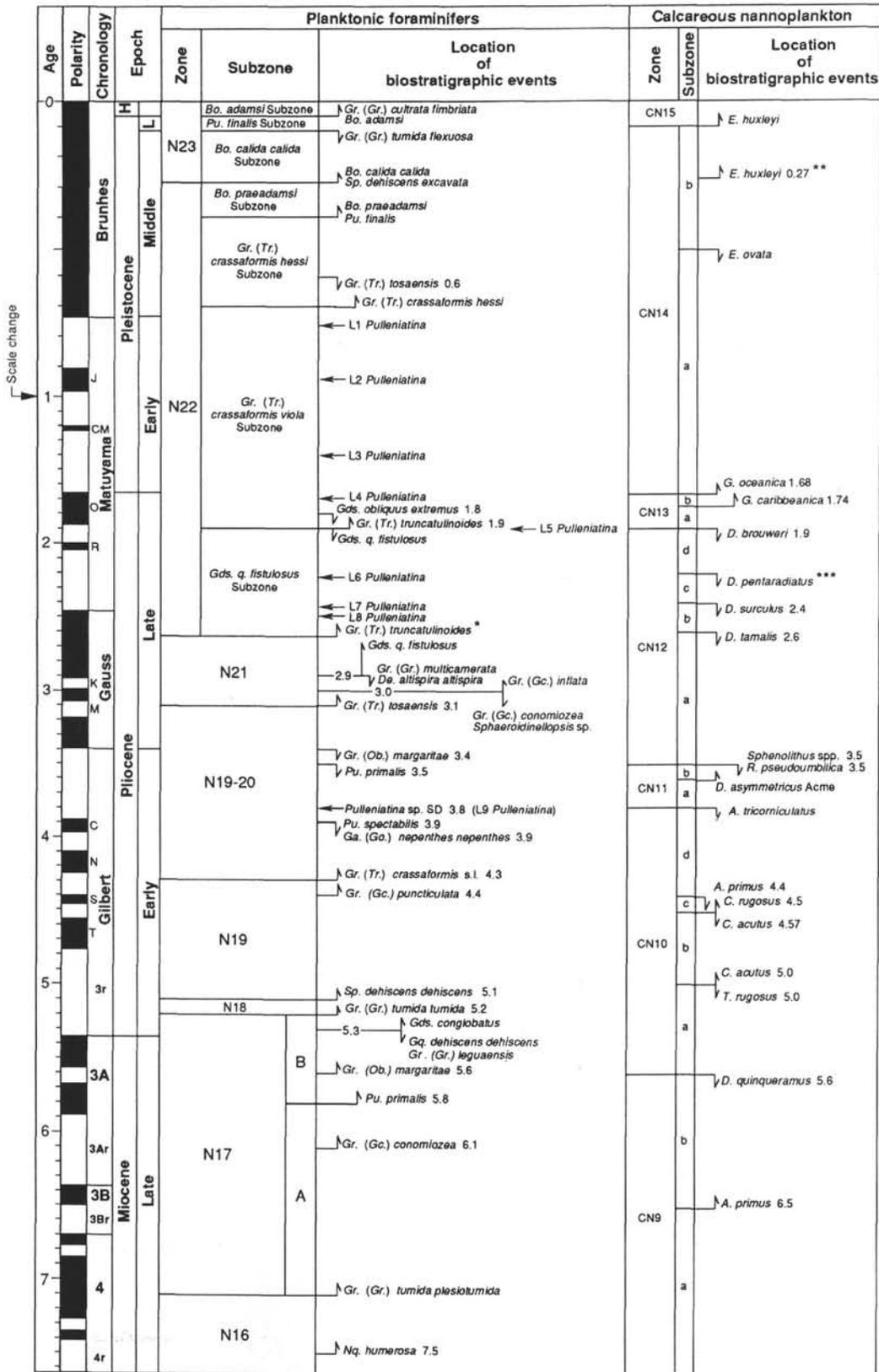


Figure 2. Biostratigraphic zonal scheme and the position of bioevents used in this study as given by Blow (1969), Saito, 1976, Berggren et al. (1985), and Chaproniere (1991). Time scale after Berggren et al. (1985); zonal scheme after Blow (1969), Kennett and Srinivasan (1983), and Chaproniere (1991); magnetic polarity scale nomenclature after Harland et al. (1982). Abbreviations for planktonic foraminifers: Bo. = *Bolliella*, De. = *Dentoglobigerina*, Ga. = *Globigerina*, Go. = *Globobulimina*, Gds. = *Globigerinoides*, Gq. = *Globoquadrina*, Gc. = *Globoconella*, Gr. = *Globorotalia*, Nq. = *Neoglobobulimina*, Ob. = *Obandylia*, Pu. = *Pulleniatina*, Sp. = *Sphaeroidinella*, Tr. = *Truncorotalia*. Abbreviations for calcareous nannoplankton: A. = *Amaurolithus*, C. = *Ceratolithus*, D. = *Discoaster*, E. = *Emiliania*, G. = *Gephyrocapsa*, R. = *Reticulofenestra*, S. = *Sphenolithus*, T. = *Triquetrorhabdulus*. Single asterisk (*) = location of bioevent as used in this study following Dowsett (1989); see Chaproniere et al., this volume; double asterisks (**) = from Berggren et al. (1985); and triple asterisks (***) = arbitrary placement of this bioevent because of conflict between Berggren et al. (1985) and Bukry (1975). L1-L9 are the levels at which sinistrally coiled populations of *Pulleniatina* have been recorded by Saito (1976).

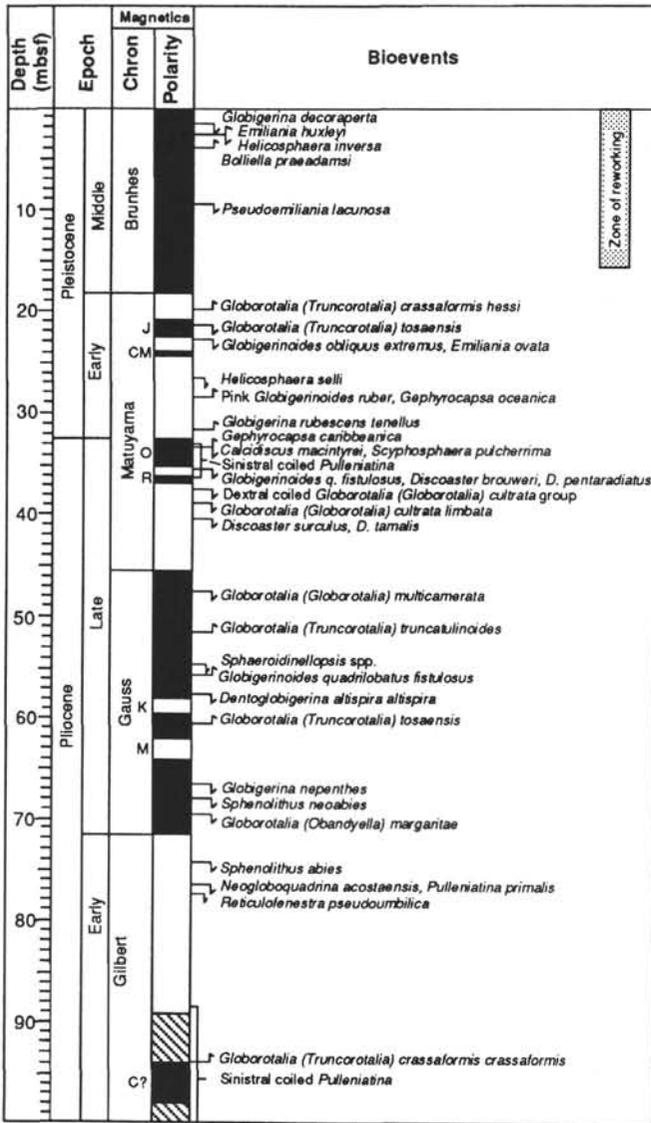


Figure 3. Bioevents and magnetostratigraphy at Site 834. Abbreviations for subchrons are as follows: J = Jaramillo, CM = Cobb Mountain, O = Olduvai, R = Réunion, K = Kaena, M = Mammoth, and C = Cochiti. Hatched intervals indicate intervals with uncertain magnetic polarity.

interpreted, in large part, because of the redeposition of large amounts of older material, as indicated by the biostratigraphic results. By combining the biostratigraphy and magnetostratigraphy, a coherent reversal record back to the Jaramillo Subchron was obtained. A section of slumped or allochthonous units shows truncated reversal sequences that cannot be readily interpreted. This chaotic sequence overlies an interval interpreted as the Gauss Chron. The sediments at Site 836 are all of normal polarity (Fig. 5), indicating that only the Brunhes Chron is present. At Site 837, magnetic polarity events down to the Cobb Mountain Subchron were recognized (Fig. 6). For the deeper parts of the site, two polarity models were proposed: Model A interprets a normal polarity as between the top of the Gauss Chron and the top of the reversed Kaena Subchron, and Model B interprets these depths as the Olduvai Subchron. The biostratigraphic evidence would support Model B (see below). The magnetic stratigraphy at Site 838 was hampered by thick ash layers, but the Brunhes, Jaramillo, and Cobb Mountain subchrons were distinguished (Fig. 7). The shortness of the Brunhes Chron suggests that part of it may be missing. An older magnetic record was not recognizable. At Site 839, the Brunhes,

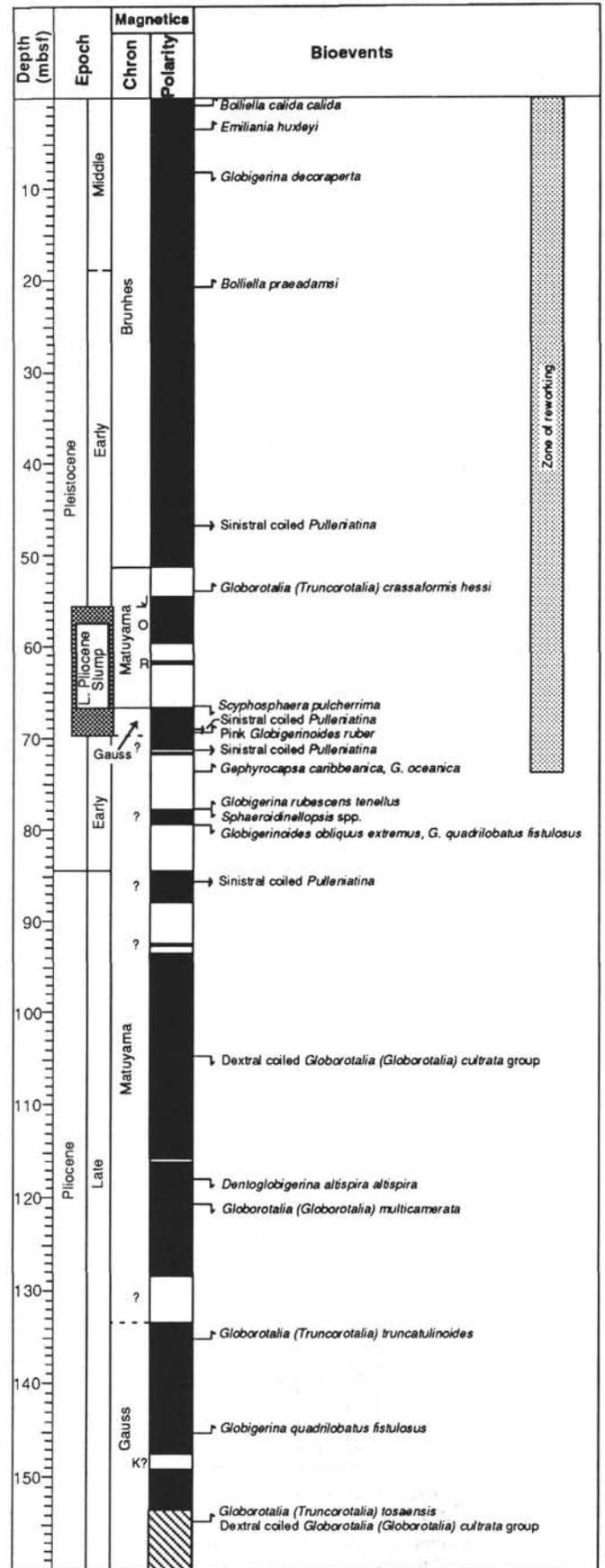


Figure 4. Bioevents and magnetostratigraphy at Site 835. Abbreviations as in Figure 3.

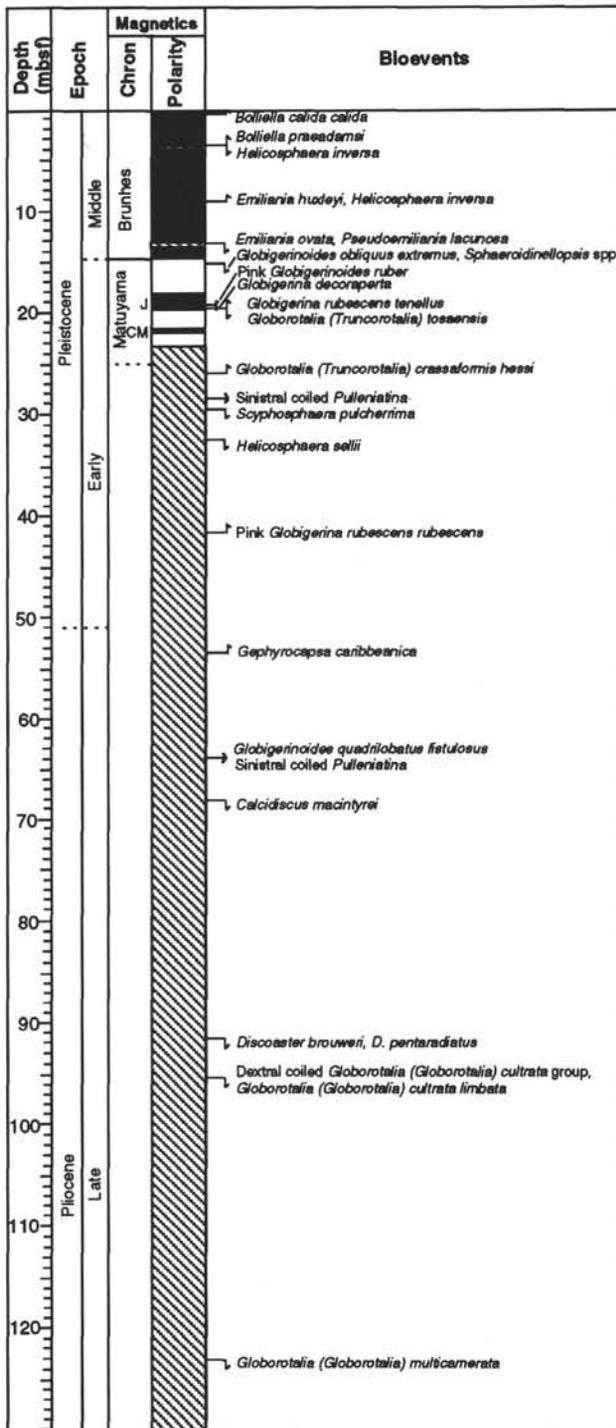


Figure 7. Bioevents and magnetostratigraphy at Site 838. Abbreviations as in Figure 3.

Sites 834 and 837. The sediments containing younger assemblages were probably removed during drilling operations.

Site 834 coring penetrated through a complete Quaternary to Pliocene sequence overlying basaltic basement and topmost Miocene (Zone N17B) sediments interbedded within the volcanic sequence. The upper part of this section contains faunal and floral elements that clearly originated from a late Pliocene, shallow-water environment, presumably on tectonic highs in the area adjacent to this site. Site 835 coring penetrated into the lower Pliocene (Zones N19 to N19-20) with considerable numbers of reworked upper Pliocene species present

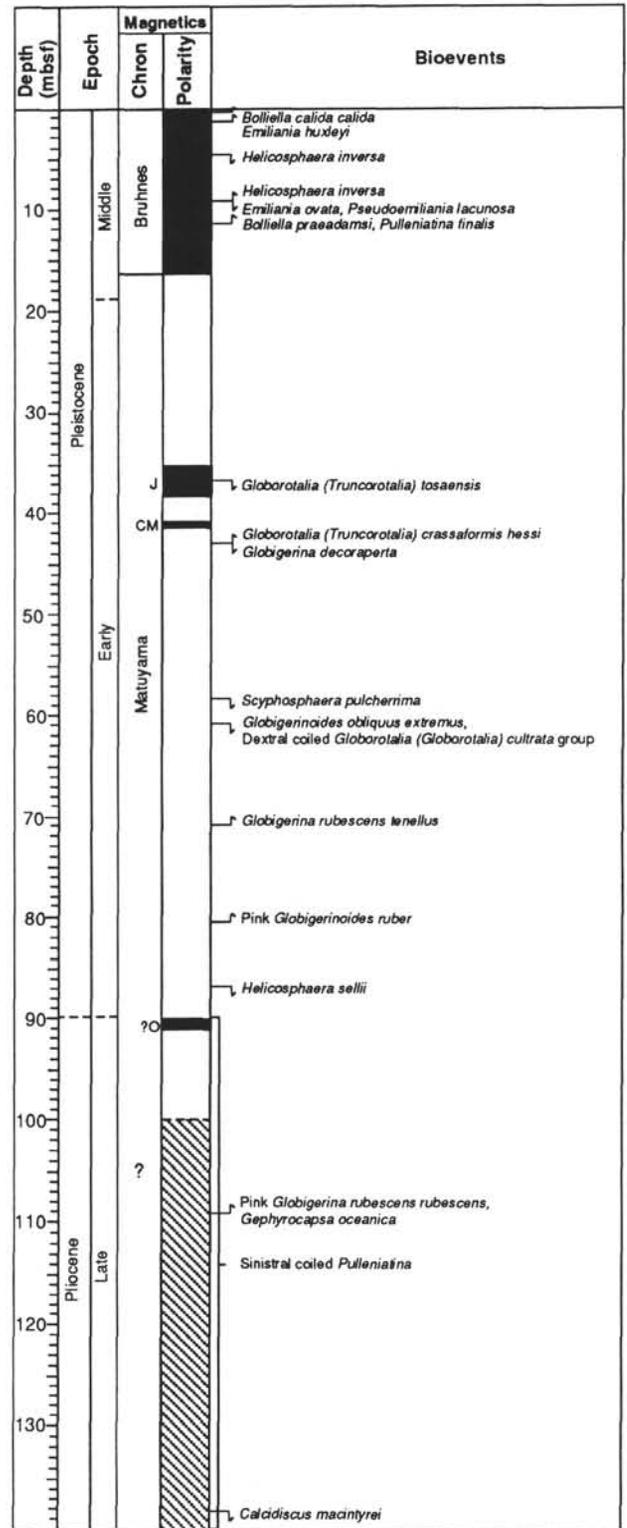


Figure 8. Bioevents and magnetostratigraphy at Site 839. Abbreviations as in Figure 3.

within the Quaternary section. Site 836 coring penetrated the shortest section, in which Zone N22 (*Globorotalia (Truncorotalia) crassaformis hessi* Subzone) directly overlies basalts. Site 837 coring penetrated a complete section terminating in the basal part of Zone N22 (*Globigerinoides quadrilobatus fistulosus* Subzone) overlying basalt. Site 838 coring failed to encounter basalts, with the oldest sediment

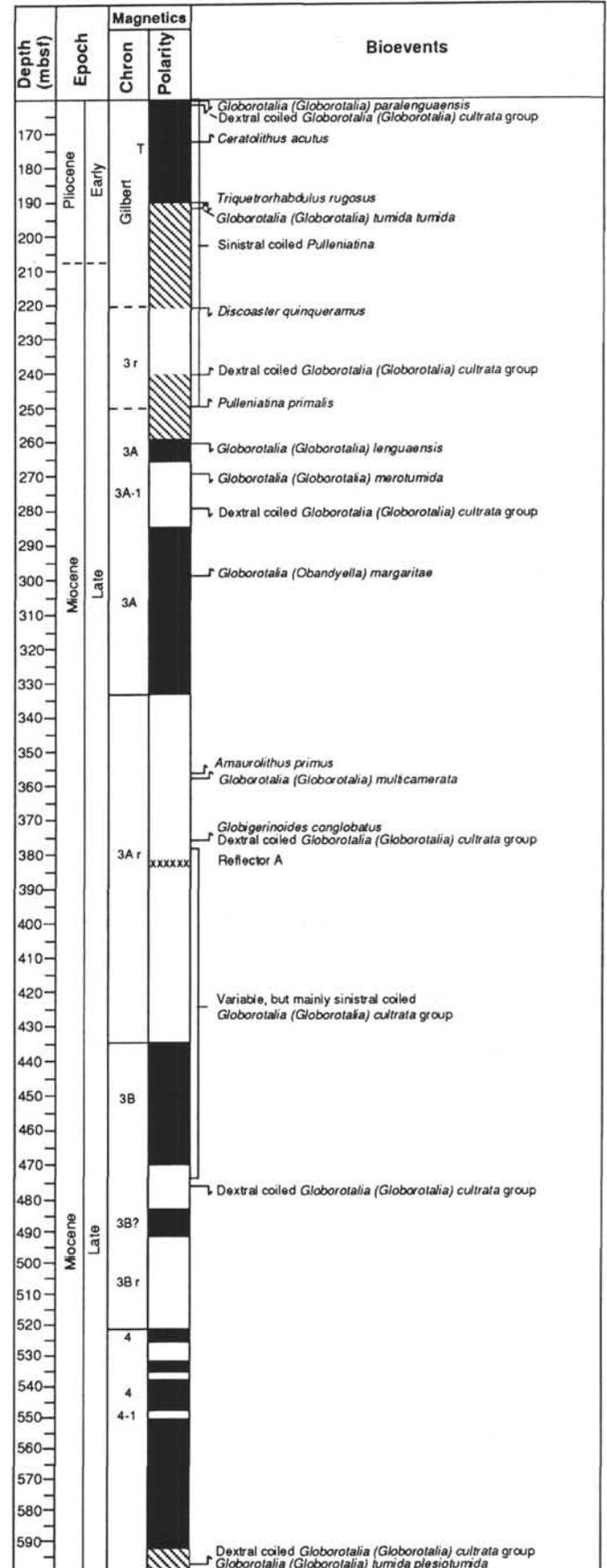
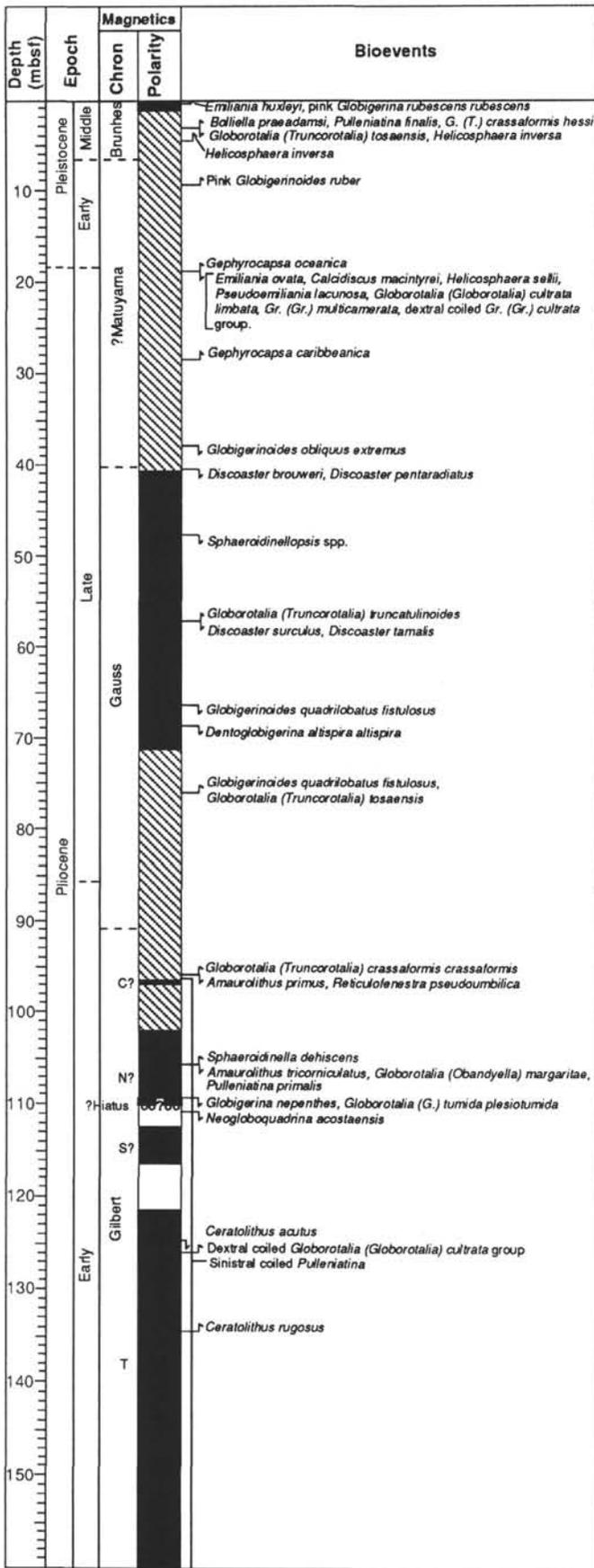


Figure 9. Bioevents and magnetostratigraphy at Site 840. Abbreviations as in Figure 3.

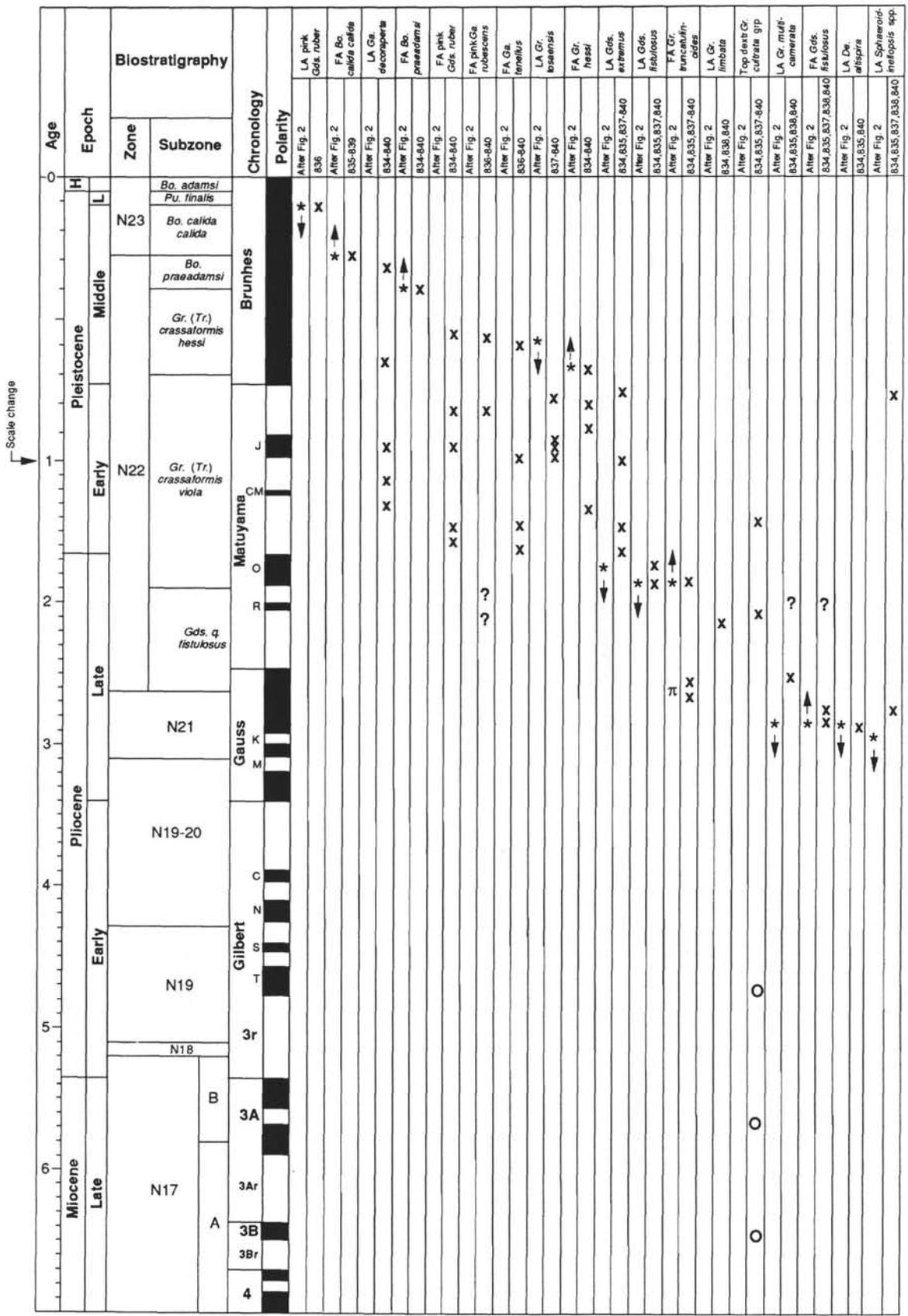


Figure 10. Summary of the relationship between planktonic foraminifer bioevents and magnetostratigraphy for Sites 834 through 840. Symbols are as follows: asterisk (*) = published record from Figure 2, after Berggren et al. (1985); π = published record from Figure 2, after Hills and Thierstein (1989); ∇ = LA bioevent; \blacktriangledown = FA bioevent; x = position within the ODP sites; o = position of change in coiling direction. Abbreviations for the magnetostratigraphy and microfossils as in Figure 2.

being from Zone N22 (*Globigerinoides quadrilobatus fistulosus* Subzone). Site 839 coring, within the same basin as Site 838, located Zone N22 (*Globigerinoides quadrilobatus fistulosus* Subzone) sediments directly overlying igneous basement. The oldest sediments in the Lau Basin sites are from Zone N17B, within and overlying the basalt sequence. This indicates that the formation of the Lau Basin began before 5.2 Ma.

Tongan Platform

The oldest sediments at Site 840 on the Tongan Platform are from Zone N17A. A hiatus may exist within the N19 to N19-20 zonal interval at this site at approximately 110 mbsf (Chaproniere and Nishi; and Quinterno, both in this volume). Reflector A, which is thought to be at approximately 383 mbsf, is based on a change in physical properties that corresponds to a zone of sediment alteration (Parson, Hawkins, Allan, et al., 1992) and not to a break in sedimentation.

At Site 841, the upper Miocene to Holocene sequence (Zones N17-N23) is mainly barren of calcareous microfossils, with rare, low-diversity assemblages recovered from some levels. This paucity of faunas is a result of the site having been below the calcium carbonate compensation depth (CCD) throughout this time. This poorly fossiliferous sequence is faulted against a middle Miocene unit (Zones N8-N9) that contains a diverse faunal assemblage and which must have been deposited above the CCD.

Calcareous Nannofossils

This section follows the results of Quinterno (this volume) for the Tongan Platform, and Styzen (this volume) for the Lau Basin. The biostratigraphic scheme followed is that of Bukry (1973, 1975) and Okada and Bukry (1980).

Lau Basin

In general, most sediments recovered from the Lau Basin sites contained well-preserved calcareous nannofloras. At Sites 834, 835, 836, and 839, the topmost sediments are referred to Zone CN15; however, at Site 837, the youngest sediments contain a CN14a Subzone nannoflora.

At Site 834, the sediments immediately above the basalts contain a Zone CN11 (latest early Pliocene) nannoflora. A sedimentary horizon within the basalt sequence contains an abundant but poorly preserved flora, devoid of any marker species, but the taxa are typical of Miocene assemblages. Samples from the upper part (0-74 m) of the sequence at Site 835 contain reworked floras. At this site, the lowest sample containing an identifiable nannoflora indicates Zone CN11 (top part of the early Pliocene). Pliocene reworked nannofossils are present in the lower part of the sequence at Site 836, but a flora no older than Subzone CN14a (early to middle Pleistocene) was present at this site. The oldest nannofossil flora at Site 838 is assigned to the top of Subzone CN12a (late Pliocene). At Site 839, the oldest sediments overlying the basaltic sequence are referred to Subzone CN13b (latest Pliocene), but a sample from within the volcanic sequence was assigned to Subzone CN12d (late Pliocene). Evidence of reworked nannofloras was present only at Sites 834, 835, and 836.

Tongan Platform

The lack of closely spaced, continuous samples and the presence of abundant volcanoclastic material at various intervals have limited the biostratigraphic resolution at Site 840, especially for the upper 260 m of the section. Nevertheless, a sequence from the late Pleistocene or Holocene Zone CN15 to the late Miocene Zone CN9 was identified. The sequence is broken by a possible hiatus at 110 mbsf, where Zone CN11 appears to be absent, even though Bukry (1985) has recorded the zonal assemblage from samples dredged from the Tongan Platform. As noted above, because the upper Miocene to Holocene sequence at Site 841 is mainly barren of calcareous microfossils, it has not been used in this synthesis.

COMPARISON BETWEEN THE MAGNETOSTRATIGRAPHIES AND BIOSTRATIGRAPHIES

In the Appendix, those bioevents that are of biostratigraphic importance are correlated with the magnetostratigraphic scale for each of the sites. An assessment also has been made with respect to the previously recorded results of Berggren et al. (1985), Dowsett (1989), and Hills and Thierstein (1989). Figures 10 and 11 summarize the relationship among these bioevents using the two fossil groupings and the magnetostratigraphy for the sites. The numerical ages assigned to the magnetostratigraphy, and then to the bioevents, are generally based on estimates (Berggren et al., 1985) because of the rarity of absolute ages. This factor would suggest that some of these age estimates may not be well constrained and could lead to some flexibility in the positioning of some bioevents with respect to the absolute time scale. For this reason, variations in the results shown in Figures 10 and 11 may be more apparent than real.

For the Lau Basin sites, with the exception of Sites 834 and 835, the magnetic signatures appear to be reliable only for the interval from within the upper Matuyama Chron (Cobb Mountain Subchron) to the Brunhes Chron. Below these levels, the magnetic signatures are questionable (Figs. 6-8). Complications arise because of reworking of older faunas or slumping at Sites 834 and 835. Although the magnetic sequence can be interpreted back to the lower part of the Gauss Chron at Site 835, a slumped section has added considerable complication to not only the interpretation of the magnetostratigraphy, but also to the biostratigraphy (Fig. 4). At Site 837, on the basis of the FAs of *Gephyrocapsa caribbeanica* and *G. oceanica*, the interval interpreted as the topmost Gauss in Model A may best be considered as the Olduvai Subchron (Matuyama Chron), as in the preferred Model B. In contrast, at Site 834, the sequence of bioevents compares well with the magnetostratigraphic sequence, suggesting that the record from this site is very reliable, even with an interval of reworked bioclasts covering much of the Brunhes Chron in the upper part of the section. Although the sequence from Site 836 is confined to the Brunhes Chron, it provides the best sequence for correlating the bioevents over this interval of all the Leg 135 sites. As noted above, the record at Site 840 cannot be used with the same degree of resolution, as, for example, Site 834; nevertheless, it can be used as a general guide to provide a correlation between the bioevents and the magnetostratigraphy on a scale similar to that offered by Berggren et al. (1985).

Figures 10 and 11 illustrate the positions of planktonic foraminifer and nannofossil bioevents, respectively, vs. the magnetostratigraphic scale for the Leg 135 sites, as discussed in the Appendix. Where possible, the previously published location of each event (as shown in Fig. 2) is also included. As can be seen, a wide range of variation exists among the sites for some of these bioevents, suggesting some unreliability. However, in all but a few cases, the ranges found are within the previously recorded biostratigraphic range for each taxon. A summary of the taxa that appear to differ from the previously published range is given below.

Planktonic Foraminifers

A number of planktonic foraminifer bioevents differ from previous records. The LA of *Globorotalia (Truncorotalia) tosaensis* appears to be earlier than previously recorded, being found within the top of the Matuyama Chron, which compares with the position within the lower Brunhes Chron given by Berggren et al. (1985). The lowest position of the FA of *Globorotalia (Truncorotalia) crassaformis hessi* is just below the Cobb Mountain Subchron. This result is somewhat older than that found by Chaproniere (1991) in the Coral Sea area. The LA of *Globigerinoides obliquus extremus* is shown to be consistently younger (from the top of the Olduvai Subchron to the base of the Brunhes Chron) than previously recorded (within the Olduvai Subchron). The position of the FA of *Globorotalia (Truncorotalia) trun-*

catulinoides is close to the location given by Dowsett (1989) and Hills and Thierstein (1989) for the southwest Pacific area (within the top part of the upper normal interval of the Gauss Chron), but it differs from that given by Berggren et al. (1985) (just below the base of the Olduvai Subchron). The LA of *Globorotalia* (*Globorotalia*) *multicamerata* appears higher in the Gauss Chron than previously recorded. This new level is found in Site 834, which has the most reliable magnetostratigraphic record of the sites studied. The LA of *Sphaeroidinellopsis* spp. appears considerably higher than previously recorded (topmost Matuyama Chron vs. topmost Mammoth Subchron). However, the small size of the specimens at these higher levels could cause them to be easily overlooked. The LA of *Globigerina* (*Globoturborotalita*) *nepenthes* is found within the lower normal interval of the Gauss Chron at Site 834, which is somewhat higher than that recorded by Berggren et al. (1985) (top of the Cochiti Subchron). As noted above, the magnetostratigraphy for Site 834 is considered to be the best of the Leg 135 sites, suggesting that the position of this bioevent is reliable.

The FAs of *Globorotalia* (*Truncorotalia*) *crassaformis*, *Gr.* (*Gr.*) *tumida tumida*, and *Sphaeroidinella dehiscens* appear to be a little higher, and that of *Globigerinoides conglobatus* lower, than recorded by Berggren et al. (1985) at both Sites 834 and 840. However, because the magnetostratigraphy at these levels is questionable at both sites, the position of these bioevents must be uncertain.

A number of bioevents that do not appear to have been correlated before with the magnetostratigraphic scale are noted here. These are the LAs of *Globigerina* (*Globoturborotalita*) *decoraperta* (middle Brunhes Chron), *Globorotalia* (*Globorotalia*) *cultrata limbata* (upper part of the lower reversed interval of the Matuyama Chron), *Gr.* (*Gr.*) *tumida plesiotumida* (within the middle normal interval of Chron 4), and *Neogloboquadrina acostaensis* (within the upper reversed interval of the Gilbert Chron).

The FAs of pink *Globigerinoides ruber*, pink *Globigerina* (*Globoturborotalita*) *rubescens*, and *Globigerina* (*Globoturborotalita*) *rubescens tenellus* have been previously recorded within the *Globigerinoides quadrilobatus fistulosus* Subzone of Zone N22 (Chaproniere, 1991) (lower part of the Matuyama Chron). These bioevents appear to be younger (middle Matuyama Chron) in the Leg 135 sites, and appear to be highly variable and so very unreliable.

The remaining bioevents (LAs of *Dentoglobigerina altispira*, pink *Globigerinoides ruber*, *Gds. quadrilobatus fistulosus*, *Globorotalia* (*Globorotalia*) *languaensis*, *Gr.* (*Obandyella*) *margaritae*, and *Pulleniatina primalis*; the FAs of *Bolliella calida calida*, *Bo. praeadamsi*, *Gds. quadrilobatus fistulosus*, *Globorotalia* (*Globorotalia*) *tumida plesiotumida*, and *Gr.* (*Truncorotalia*) *tosaensis*) appear to be at levels close to previous records and so appear to be reliable.

Calcareous Nannofossils

A number of nannofossil bioevents differ from previous records. The LA of *Pseudoemiliana lacunosa* appears younger (higher in the Brunhes Chron); the LA of *Calcidiscus macintyreii* appears to be older (within the Olduvai Subchron in Site 834) than previously recorded (between the Olduvai and Jaramillo subchrons); the LA of *Discoaster tamalis* is younger (within the lower reversed interval of the Matuyama Chron) than previously recorded (latest Gauss). The LA of *Sphenolithus neoabies* is within the lower normal interval of the Gauss Chron in Site 834, which is younger than the previous record of within the upper reversed interval of the Gilbert Chron.

The LAs of *Amaurolithus tricorniculatus* and *A. primus*, and the FAs of *Ceratolithus acutus* and *A. primus* at Site 840 appear to differ from previous records. However, because the magnetostratigraphy is questionable at these levels at this site, these results are uncertain.

A number of bioevents that do not appear to have been correlated with the magnetostratigraphic scale are noted here. These are the LAs of *Emiliana ovata* (middle Brunhes), *Helicosphaera inversa* (high in the Brunhes), and *Scyphosphaera pulcherrima* (within the middle

reversed interval of the Matuyama Chron), and the FA of *Helicosphaera inversa* (middle Brunhes).

Two bioevents (the LAs of *Triquetrorhabdulus rugosus* and *Discoaster quinqueramus*), which are recorded only from Site 840, are based on questionable specimens and so can only be regarded as uncertain.

The remaining bioevents (the LAs of *Ceratolithus acutus*; *Discoaster brouweri*, *D. pentaradiatus*, *D. surculus*, *Helicosphaera sellii*, *Reticulofenestra pseudoumbilica*, and *Sphenolithus abies*; and the FAs of *Ceratolithus rugosus*, *Emiliana huxleyi*, *Gephyrocapsa caribbeanica*, and *G. oceanica*) appear to be at levels close to previous records and so appear to be reliable.

COMPARISON BETWEEN THE FORAMINIFER AND NANNOFOSSIL BIOSTRATIGRAPHIES

Tables 1 through 3 give the levels at which the nannofossil and planktonic foraminifer bioevents illustrated in Figures 3 through 9 for the sites studied. From these, the relationship between the two groups can be observed and compared with the previously published findings that are illustrated in Figure 2.

Those planktonic foraminifer bioevents that are used for zonal definition appear in the same sequence in the Leg 135 sites as previously recorded, although, as can be seen for Site 840, the FAs of *Bolliella praeadamsi* and *Globorotalia* (*Truncorotalia*) *crassaformis hessi* occur at the same level, rather than being disjunct; this is probably related to sampling and has resulted in this part of the section not being used for this synthesis. A number of bioevents seem to vary among the sites (Figs. 10–11). The LA of *Globorotalia* (*Truncorotalia*) *tosaensis* has traditionally been found above the FA of *Globorotalia* (*Truncorotalia*) *crassaformis hessi*. At Site 834, however, this sequence is reversed, suggesting that the FA of *Globorotalia* (*Truncorotalia*) *crassaformis hessi* may be unreliable. The LA of *Globigerinoides obliquus extremus* is given by Berggren et al. (1985) as occurring approximately 0.1 Ma above that of *Globigerinoides quadrilobatus fistulosus*. At the Leg 135 sites, the relationship between these two bioevents is normally close, and certainly in the order previously recorded, but at some sites it appears much higher, occurring above the FA of *Globorotalia* (*Truncorotalia*) *crassaformis hessi*. Similar differences are discussed in the Appendix.

In general, the sequence of nannofossil bioevents conforms to that previously recorded (Fig. 11). However, some of these appear to occur at the same level at some sites. The LAs of *Discoaster brouweri* and *D. pentaradiatus* occur in the same level at Sites 834 and 840 as do the LAs of *D. surculus* and *D. tamalis*, but lower in the section. At Site 836, the FAs of *Gephyrocapsa caribbeanica* and *G. oceanica* are in the same sample. Other bioevents that should be at the same level but are separated are the LA of *Ceratolithus acutus* and the FA of *C. rugosus*.

As for the planktonic foraminifers, the relationships among those bioevents not used as traditional zonal markers are often variable. For example, the LAs of *Helicosphaera inversa* and *Pseudoemiliana lacunosa* may be either at the same level (Sites 834 and 837), separated (Site 838), or absent (Site 836).

CONCLUSIONS

Integration of the biostratigraphic and magnetostratigraphic results suggests that two of the Lau Basin sites provide results generally in keeping with previously published results. Figures 10 and 11 illustrate the variation in the location of the bioevents discussed in this synthesis with respect to the magnetostratigraphy. As one can see, most bioevents seem to be very variable among the sites, if in fact the magnetostratigraphy is reliable. As one can see from Figures 2 through 9, the magnetostratigraphy can only be reliably interpreted for the Brunhes Chron for Sites 835 and 836 (which is the best site for this interval), from what is probably the Olduvai Subchron for Sites 837 (Model B of Parson, Hawkins, Allan, et al., 1992, based on the bioevents), and 839, from the Cobb Mountain Subchron for Site 838, from the upper Gilbert

Table 1. Summary of the depths at which the major calcareous nannofossil bioevents occur at the Leg 135 sites.

Event	Bioevents	Age (Ma)	Depth level at hole (mbsf)											
			834A	835A	836A	837A	838A	838B	839A	839B	840A	840B	840C	
LA	<i>Helicosphaera inversa</i>		2.80			2.90	3.58			4.50		3.37	1.53	
FA	<i>Emiliana huxleyi</i>	0.275	2.80	0.35	0.66		9.20			1.40		0.45		
LA	<i>Pseudoemiliana lacunosa</i>	0.465	9.50		10.70	2.90	13.20			9.20			18.90	47.50
LA	<i>Emiliana ovata</i>		22.90		10.70	2.90	13.20			9.20			18.90	40.55
FA	<i>Helicosphaera inversa</i>		2.80			2.90	9.20			9.20		4.50	1.53	
LA	<i>Scyphosphaera pulcherrima</i>		33.20	66.50		41.70	29.60			58.40				
LA	<i>Helicosphaera sellii</i>	1.27	26.60		220.2	52.40	32.50			86.80			18.90**	47.50
LA	<i>Calcidiscus macintyreii</i>	1.45	33.20				68.10			138.20			18.90	40.55
FA	<i>Gephyrocapsa oceanica</i>	1.68	28.50	73.70		63.14	53.50			109.20		4.50	18.90	
FA	<i>Gephyrocapsa caribbeanica</i>	1.74	33.20	73.70		69.90				186.20		4.50	28.40	
LA	<i>Discoaster brouweri</i>	1.90	35.30			80.00	91.70				256.40		86.10**	40.55
LA	<i>Discoaster pentaradiatus</i>	2.29	35.30				91.70						86.10**	40.55
LA	<i>Discoaster surculus</i>	2.40	40.50										86.10**	57.28
LA	<i>Discoaster tamalis</i>	2.60	40.50					230.40					86.10	57.00
LA	<i>Sphenolithus neobabies</i>	3.50	68.00											
LA	<i>Sphenolithus abies</i>	3.50	74.20											
LA	<i>Reticulofenestra pseudoumbilica</i>	3.50	77.30										95.92	124.53
LA	<i>Amaurolithus tricorniculatus</i>	3.70											105.40	124.53
LA	<i>Amaurolithus primus</i>	4.40											95.92	181.00
FA	<i>Ceratolithus rugosus</i>	4.50										<3.37**	115.90	133.50
LA	<i>Ceratolithus acutus</i>	4.57											124.80	162.00*
FA	<i>Ceratolithus acutus</i>	5.00											172.20	181.00
LA	<i>Triquetrorhabdulus rugosus</i>	5.00											192.00**	190.50
LA	<i>Discoaster quinqueramus</i>	5.60											221.00	259.50
FA	<i>Amaurolithus primus</i>	6.50											356.80*	259.50

Notes: FA = first appearance and LA = last appearance. Single asterisk (*) indicates questionable occurrence beyond this identification, whereas double asterisks (**) indicate reworked specimens found at higher levels.

Table 2. Summary of the depths at which the major planktonic foraminifer bioevents occur at the Leg 135 sites.

Event	Bioevents	Age (Ma)	Age (Ma)	Depth level at hole (mbsf)											
				834A	834B	835A	836A	837A	838A	838B	839A	839B	840A	840B	840C
LA	Pink <i>Globigerinoides ruber</i>	0.12					0.83								
FA	<i>Bolliella calida calida</i>	0.20				1.04	1.20	2.92	0.36		0.21				
LA	<i>Globigerina (Globoturborotalita) decoraperta</i>			1.74		8.06	22.80	24.09	19.28		43.06			2.67	
FA	<i>Bolliella praeadamsi</i>			4.00		20.80	10.70	4.84	3.70		30.44			3.06	
FA	<i>Pulleniatina finalis</i>		0.40				19.96				30.44			3.06	
FA	Pink <i>Globigerinoides ruber</i>			28.84		69.58	18.50	18.49	19.28		80.50			9.50	
FA	Pink <i>Globigerina (Globoturborotalita) rubescens rubescens</i>						18.72	18.49	42.71		109.20			0.49	
FA	<i>Globigerina (Globoturborotalita) rubescens tenellus</i>						20.20	57.52	19.68		71.00			1.32	
LA	<i>Globorotalia (Truncorotalia) tosaensis</i>	0.60					15.92	19.68			36.69			3.06	18.90
FA	<i>Globorotalia (Truncorotalia) crassaformis hessi</i>		0.70	21.80		53.94	25.70	21.25	25.94		43.06			3.06	
LA	<i>Globigerinoides obliquus extremus</i>	1.80		26.50		79.55		68.27	15.18		60.73				37.90
LA	<i>Globigerinoides quadrilobatus fistulosus</i>	1.90		35.34		79.55		74.50	63.85						66.50
FA	<i>Globorotalia (Truncorotalia) truncatulinoidea</i>	1.90		52.62		135.60		78.20		259.20		266.40			57.00
LA	<i>Globorotalia (Globorotalia) cultrata limbata</i>			38.99					95.37						18.90
Top	Dextrally coiled <i>Globorotalia (Globorotalia) cultrata</i> group			37.24		104.50			95.37			60.86			18.90
LA	<i>Globorotalia (Globorotalia) multicamerata</i>	2.90		47.50		120.71			123.10						18.90
FA	<i>Globigerinoides quadrilobatus fistulosus</i>	2.90		55.69		145.09		78.20	63.85						76.00
LA	<i>Dentoglobigerina altispira altispira</i>	2.90		57.59		117.99									68.82
LA	<i>Sphaeroidinellopsis</i> spp.	3.00		54.52		77.98		75.75	15.18						47.85
FA	<i>Globorotalia (Truncorotalia) tosaensis</i>	3.10		60.62		154.66		81.01							76.00
LA	<i>Neoglobobadrina acostaensis</i>			76.00											110.83
LA	<i>Globorotalia (Obandayella) margaritae</i>	3.40		69.52											95.70
LA	<i>Pulleniatina primalis</i>	3.50		76.42											95.70
LA	<i>Globigerina (Globoturborotalita) nepenthes</i>	3.90		66.50											109.41
FA	<i>Globorotalia (Truncorotalia) crassaformis crassaformis</i>	4.30		93.96											95.70
LA	<i>Globorotalia (Globorotalia) tumida plesiotumida</i>				165.70										109.41
FA	<i>Sphaeroidinella dehiscentis dehiscentis</i>	5.10			116.40										105.40
LA	<i>Globorotalia (Globorotalia) merotumida</i>														269.92
FA	<i>Globorotalia (Globorotalia) multicamerata</i>				311.28										357.75
FA	<i>Globorotalia (Globorotalia) tumida tumida</i>	5.20			165.70										192.00
LA	<i>Globorotalia (Globorotalia) lenguaensis</i>	5.30													260.76
LA	<i>Globorotalia (Globorotalia) paralenguaensis</i>														161.22
FA	<i>Globigerinoides conglobatus</i>	5.30			165.70										376.20
FA	<i>Globorotalia (Obandayella) margaritae</i>	5.60			319.80										298.50
FA	<i>Pulleniatina primalis</i>	5.80			311.30										250.00
Base	Dextrally coiled <i>Globorotalia (Globorotalia) cultrata</i> group				311.47	154.63				249.79		189.70			
FA	<i>Globorotalia (Globorotalia) tumida plesiotumida</i>	7.10			319.80										597.30

Notes: Age in first column deduced from Berggren et al. (1985), and age in second column follows Chaproniere (1991). LA = last appearance and FA = first appearance.

Table 3. Depths over which populations of *Pulleniatina* are present at Leg 135 sites.

Event	Bioevent	Depth level at site (mbsf)						
		834	835	836	837	838	839	840
Top	Sinistral coiled <i>Pulleniatina</i>	33.00	46.86		74.50	28.51	90.00	95.70
Base	Sinistral coiled <i>Pulleniatina</i>	36.10			78.20		353.30	250.00
Top	Sinistral coiled <i>Pulleniatina</i>	83.60	69.29			63.85		
Base	Sinistral coiled <i>Pulleniatina</i>	311.47						
Top	Sinistral coiled <i>Pulleniatina</i>		71.45					
Base	Sinistral coiled <i>Pulleniatina</i>							
Top	Sinistral coiled <i>Pulleniatina</i>		86.56					

Notes: *Pulleniatina* are dominated by sinistrally coiled specimens in this sampling.

Chron at Site 834 (which is the best for this interval) for the Lau Basin sites. For the Tongan Platform, the magnetostratigraphy for Site 840 may not be reliable, especially for the upper 120 m; below this, the magnetic reversal pattern is similar to the that for the lower Gilbert Chron to Chron 4. Although most of the bioevents do appear to be unreliable within the local area, most do not contradict previously published results.

As one can see from the summaries presented in Figures 10 and 11, the major zonal indexes tend to occur in the same stratigraphic order and the same magnetostratigraphic levels as those recorded in the literature. It is obvious, however, that some bioevents, such as the FAs of *Emiliania huxleyi* and *Globorotalia (Truncorotalia) truncatulinoides* and the LA of *Gr. (Tr.) tosaensis* are older than those recorded by Berggren et al. (1985), being at similar levels to those recorded by Dowsett (1989) and Hills and Thierstein (1989). The FA of *Gr. (Tr.) crassaformis hessi* is variable, but the oldest occurrence is just below the Cobb Mountain Subchron.

Other key bioevents, such as the LAs of *Discoaster pentaradiatus*, *D. tamalis*, *Sphenolithus*, *Amaurolithus primus*, and the FA of *Sphaeroidinella dehiscens*, appear to be higher than recorded by Berggren et al. (1985). *Sphaeroidinella dehiscens* probably first appears in the Nunivak Subchron in the Gilbert Chron, but its rarity makes this appearance unreliable.

Some key biostratigraphic taxa, such as *Globigerinoides quadrilobatus fistulosus*, *Pulleniatina finalis*, *P. primalis*, and *Sphaeroidinella dehiscens*, are either rare or their distribution is sporadic to the extent that they are unsuitable for biostratigraphic use in the area studied. Because of the rarity of *P. primalis*, the FA of *Globorotalia (Globorotalia) multicamerata* has been used to mark the base of Zone N17B. Although levels are present at most sites in which populations of *Pulleniatina* are sinistrally coiled, it is difficult to equate these coiling changes with those recorded by Saito (1976).

ACKNOWLEDGMENTS

We thank Brian McGowran (University of Adelaide) and an anonymous reviewer for their constructive comments on the manuscript. G.C.H. Chaproniere publishes with the permission of the Executive Director, Australian Geological Survey Organisation.

REFERENCES*

- Berggren, W.A., Aubry, M.P., and Hamilton, N., 1983. Neogene magnetostratigraphy of Deep Sea Drilling Project Site 516 (Rio Grande Rise, South Atlantic). In Barker, P.F., Carlson, R.L., Johnson, D.A., et al., *Init. Repts. DSDP*, 72: Washington (U.S. Govt. Printing Office), 675–713.
- Berggren, W.A., Kent, D.V., and Van Couvering, J.A., 1985. The Neogene: Part 2. Neogene geochronology and chronostratigraphy. In Snelling, N.J. (Ed.), *The Chronology of the Geological Record*. Geol. Soc. London Mem., 10:211–260.
- Blow, W.H., 1969. Late middle Eocene to Recent planktonic foraminiferal biostratigraphy. In Brönniman, P., and Renz, H.H. (Eds.), *Proc. First Int. Conf. Planktonic Microfossils, Geneva, 1967*: Leiden (E.J. Brill), 1:199–422.
- Bolli, H.M., 1971. The direction of coiling in planktonic foraminifera. In Funnell, B.M., and Riedel, W.R. (Eds.), *The Micropalaeontology of Oceans*: Cambridge (Cambridge Univ. Press), 639–648.
- Bolli, H.M., and Premoli Silva, I., 1973. Oligocene to Recent planktonic foraminifera and stratigraphy of the Leg 15 Sites in the Caribbean Sea. In Edgar, N.T., Saunders, J.B., et al., *Init. Repts. DSDP*, 15: Washington (U.S. Govt. Printing Office), 475–497.
- Bukry, D., 1973. Low-latitude coccolith biostratigraphic zonation. In Edgar, N.T., Saunders, J.B., et al., *Init. Repts. DSDP*, 15: Washington (U.S. Govt. Printing Office), 685–703.
- , 1975. Coccolith and silicoflagellate stratigraphy, northwestern Pacific Ocean, Deep Sea Drilling Project Leg 32. In Larson, R.L., Moberly, R., et al., *Init. Repts. DSDP*, 32: Washington (U.S. Govt. Printing Office), 677–701.
- , 1985. Late Cenozoic coccoliths in dredge samples from the southern Tonga Platform. R/V S.P. LEE cruise L5-82-SP. In Scholl, D.W., and Vallier, T.L. (Eds.), *Geology and Offshore Resources of Pacific Island Arcs—Tonga Region*. Circum-Pac. Council. Energy Miner. Resour., Earth Sci. Ser., 2:141–148.
- Chaproniere, G.C.H., 1991. Pleistocene to Holocene planktic foraminiferal biostratigraphy of the Coral Sea, offshore Queensland, Australia. *BMR J. Aust. Geol. Geophys.*, 12:195–221.
- Dowsett, H.J., 1989. Application of the graphic correlation method to Pliocene marine sequences. *Mar. Micropaleontol.*, 14:3–32.
- Haq, B.U., Hardenbol, J., and Vail, P.R., 1988. Mesozoic and Cenozoic chronostratigraphy and cycles of sea-level change. In Wilgus, C.K., Hastings, B.S., Kendall, C.G.St.C., Posamentier, H.W., Ross, C.A., and Van Wagoner, J.C. (Eds.), *Sea-Level Changes—An Integrated Approach*. Spec. Publ.—Soc. Econ. Paleontol. Mineral., 42:72–108.
- Harland, W.B., Cox, A.V., Llewellyn, P.G., Pickton, C.A.G., Smith, D.G., and Walters, R., 1982. *A Geologic Time Scale*: Cambridge (Cambridge Univ. Press).
- Hays, J.D., Saito, T., Opdyke, N.D., and Burckle, L.R., 1969. Pliocene-Pleistocene sediments of the equatorial Pacific: their paleomagnetic, biostratigraphic, and climatic record. *Geol. Soc. Am. Bull.*, 80:1481–1513.
- Hills, S.J., and Thierstein, H.R., 1989. Plio-Pleistocene calcareous plankton biochronology. *Mar. Micropaleontol.*, 14:67–96.
- Jenkins, D.G., and Orr, W.N., 1972. Planktonic foraminiferal biostratigraphy of the eastern equatorial Pacific—DSDP Leg 9. In Hays, J.D., et al., *Init. Repts. DSDP*, 9: Washington (U.S. Govt. Printing Office), 1059–1193.
- Kennett, J.P., and Srinivasan, M.S., 1983. *Neogene Planktonic Foraminifera: A Phylogenetic Atlas*: Stroudsburg, PA (Hutchinson Ross).
- Lamb, J.L., and Beard, J.H., 1972. Late Neogene planktonic foraminifera in the Caribbean, Gulf of Mexico, and Italian stratotypes. *Univ. Kansas Paleontol. Contrib. Art.*, 57:1–67.
- Okada, H., and Bukry, D., 1980. Supplementary modification and introduction of code numbers to the low-latitude coccolith biostratigraphic zonation (Bukry, 1973; 1975). *Mar. Micropaleontol.*, 5:321–325.
- Parker, F.L., 1967. Late Tertiary biostratigraphy (planktonic Foraminifera) of tropical Indo-Pacific deep-sea cores. *Bull. Am. Paleontol.*, 52:115–208.
- Parson, L., Hawkins, J., Allan, J., et al., 1992. *Proc. ODP, Init. Repts.*, 135: College Station, TX (Ocean Drilling Program).
- Pujol, C., 1983. Cenozoic planktonic foraminiferal biostratigraphy of the Southwestern Atlantic (Rio Grande Rise), Deep Sea Drilling Project Leg 72. In Barker, P.F., Carlson, R.L., Johnson, D.A., et al., *Init. Repts. DSDP*, 72: Washington (U.S. Govt. Printing Office), 623–673.
- Rio, D., Sprovieri, R., and Raffi, I., 1984. Calcareous plankton biostratigraphy and biochronology of the Pliocene—lower Pleistocene succession of the Capo Rossello area, Sicily. *Mar. Micropaleontol.*, 9:135–180.
- Saito, T., 1976. Geologic significance of coiling direction in the planktonic foraminifer *Pulleniatina*. *Geology*, 4:305–309.
- Saito, T., Burckle, L.H., and Hays, J.D., 1975. Late Miocene to Pleistocene biostratigraphy of equatorial Pacific sediments. In Saito, T., and Burckle, L.H. (Eds.), *Late Neogene Epoch Boundaries*. Spec. Publ. Micropaleontol., 1:226–244.
- Thierstein, H.R., Geitzenauer, K., Molino, B., and Shackleton, N.J., 1977. Global synchronicity of late Quaternary coccolith datum levels: validation by oxygen isotopes. *Geology*, 5:400–404.
- Thompson, P.R., Bé, A.W.H., Duplessy, J.-C., and Shackleton, N.J., 1979. Disappearance of pink-pigmented *Globigerinoides ruber* at 120,000 yr BP in the Indian and Pacific oceans. *Nature*, 280:554–558.

* Abbreviations for names of organizations and publication titles in ODP reference lists follow the style given in *Chemical Abstracts Service Source Index* (published by American Chemical Society).

- Thompson, P.R., and Sciarrillo, J.R., 1978. Planktonic foraminiferal biostratigraphy in the equatorial Pacific. *Nature*, 276:29–33.
- Van Gorsel, J.T., and Troelstra, S.R., 1981. Late Neogene planktonic foraminiferal biostratigraphy and climatostratigraphy of the Solo River Section (lava, Indonesia). *Mar. Micropaleontol.*, 6:183–209.

Date of initial receipt: 27 April 1993

Date of acceptance: 2 August 1993

Ms 135SR-116

APPENDIX BIOSTRATIGRAPHIC EVENTS

In this Appendix, the correlation of a number of bioevents with the magnetostratigraphic polarity scale are discussed as they occur within the sites studied and compared with previous records. By using this method, we hope to contribute to the global data base with this study. Some recent studies (Dowsett, 1989; Hills and Thierstein, 1989) have demonstrated that a number of biostratigraphically important bioevents are diachronous to some degree and so may be of doubtful value for correlation.

PLANKTONIC FORAMINIFER BIOEVENTS

Chaproniere (1991) recognized 14 planktonic foraminifer biostratigraphic events in the Quaternary of the Coral Sea area that appeared to have some biostratigraphic significance. This present study has helped to resolve some of the problems encountered in that earlier study. Comments have been made on some of these bioevents, but not for all; bioevents above the LA of the pink form of *Globigerinoides ruber* were not observed in this study, and others could not be evaluated because the taxa concerned were either absent or too rare in the Lau Basin–Tongan Platform area. Below, 36 bioevents are discussed from the late Miocene to middle Pleistocene; most of the bioevents have been given some biostratigraphic usefulness by previous authors. Because of the uncertainty of the magnetic polarity of the sediments in the upper parts of Site 840, and the general low diversity of the calcareous microfossil assemblages within the ash beds that make up this interval, this upper part of the sequence has not been used here. This interval of time is best covered by the Lau Basin sites. However, Site 840 penetrated an older sequence than that found in the Lau Basin; therefore, that part below the Gauss Chron has been used.

Brunhes Chron

LA pink *Globigerinoides ruber*

In the Indian and Pacific oceans, this bioevent is dated at 120,000 ka (Thompson et al., 1979), that is, after the FA of *Bolliella calida calida*. At Sites 834 and 835, this bioevent is masked by reworking; however, at Sites 838 and 839, it precedes the FA of *Bolliella calida calida*, and at Site 836 the opposite is recorded. It is difficult to explain this distribution, but in all cases pink specimens of *G. ruber* are rare, and so reworking or the burrowing activities of infaunal organisms may be responsible.

FA *Bolliella calida calida*

Bolli and Premoli Silva (1973) thought that this bioevent occurred at 200,000 ka, that is, within oxygen isotope Stage 7. Chaproniere (1991) found that this bioevent occurs in oxygen isotope Stage 8 in the Coral Sea area. According to Berggren et al. (1985), the nannofossil *Emiliana huxleyi* first appears at 275,000 ka, a level below that of *Bolliella calida calida* as recorded by Bolli and Premoli Silva (1973).

At Sites 834, 835, 838, and 839, *Bo. calida calida* appears below *Emiliana huxleyi*, agreeing with the Coral Sea results. At Site 837, *E. huxleyi* is not recorded, but at Site 836 *Bo. calida calida* appears a few centimeters above *E. huxleyi*, a record that may be the result of infaunal burrowing activities or the mixing of a top few centimeters of the core during drilling operations.

LA *Globigerina (Globoturbotalita) decoraperta*

In the Coral Sea area, this bioevent was found above the FA of *Bolliella praeadamsi*. Before this, Kennett and Srinivasan (1983) thought that the bioevent coincided with the Zone N21/N22 boundary. This same relationship was found at Sites 834 and 835, but at the remaining Lau Basin sites, it was found to occur at varying levels below FA of *Bolliella praeadamsi*. The reason for this variation in distribution is related in part to the difficulty in morphologically distinguishing *Globigerina (Globoturbotalita) decoraperta* from

its descendant, *Globigerina (Globoturbotalita) rubescens*, and to its rarity at the upper part of its stratigraphic range.

FA *Bolliella praeadamsi*

Chaproniere (1991) found that this bioevent occurred very close to that of the FA of *Pulleniatina finalis*. In the Leg 135 sequences, however, *Bolliella praeadamsi* is rare and *Pu. finalis* exceedingly rare; for this reason, the relationship between the two bioevents cannot be verified.

At all sites, the FA of *Bolliella praeadamsi* always precedes the FA of *Bo. calida calida*, the LA of *G. decoraperta* and the FA of *E. huxleyi*. It succeeds the LA of *Globoturbotalia (Truncorotalia) tosaensis*. With respect to nannofossil bioevents, it succeeds the LA of *E. ovata*, *Helicosphaera inversa*, and *Pseudoemiliana lacunosa* at all sites except Sites 837, 838, and 839. This variable relationship may suggest that either the FA of *Bo. praeadamsi* is not a reliable datum, or that the three nannofossil extinction bioevents are not reliable. More detailed studies using oxygen isotope and magnetostratigraphic studies are required to ascertain their reliability.

FA *Pulleniatina finalis*

As noted above, *Pulleniatina finalis* is too rare in the sections studied for any conclusions to be made. The distribution of this species seems to be related to environmental factors, possibly temperature.

Matuyama Chron

FAs pink forms of *Globigerinoides ruber* and *Globigerina (Globoturbotalita) rubescens rubescens*

Pink forms of both *Globigerinoides ruber* and *Globigerina (Globoturbotalita) rubescens rubescens* appear to develop within the Pleistocene (Parker, 1967; Jenkins and Orr, 1972). However, Chaproniere (1991) recorded pink specimens of *G. (Go.) rubescens* 20 cm above the FA of *Globorotalia (Truncorotalia) truncatulinoides*, within the range of *Globigerinoides quadrilobatus fistulosus* (i.e., within the late Pliocene).

Within the Lau Basin sites, the level of the FA of these two pink forms is variable. The oldest occurrences of pink *Gds. ruber* is between the Cobb Mountain and Olduvai subchrons at Sites 834 and 839, at Site 838 within the Jaramillo Subchron, and just above this subchron at Site 837. Within Site 835, pink *Gds. ruber* seems to occur within the basal part of a slumped interval, within the Gauss Chron; however, this record is uncertain as the specimens may have been derived from the underlying Matuyama sediments. In contrast, both forms appear within the Brunhes Chron at Site 836. Thus, as noted above, the Lau Basin occurrences of pink forms of both species shows that the levels of their first appearance are very variable.

LA *Globorotalia (Truncorotalia) tosaensis*

The results presented by Thompson and Sciarrillo (1978, fig. 2) indicate that the position of the LA of *Globorotalia (Truncorotalia) tosaensis* bioevent is variable, ranging from within the upper Matuyama Chron, above the Jaramillo Subchron, to within the lower Brunhes Chron (at 600,000 ka). Hills and Thierstein (1989) estimated the average age of this bioevent to be 0.89 Ma (immediately above the Jaramillo Subchron), but they also found it to be variable and therefore unreliable. From the data given in Hills and Thierstein (1989, table A11b) for the six sites analyzed, three were placed in the upper part of the Matuyama Chron, and the other three were well within the Brunhes Chron. No indication is given as to the influence of reworking or latitudinal change.

In the Lau Basin sites, the LA of *Globorotalia (Truncorotalia) tosaensis* ranges from within the Jaramillo Subchron (Sites 834, 838, and 839) to a level between the Jaramillo Subchron and below the Brunhes Chron. The only occurrence of specimens within the Brunhes Chron is at Site 835, where they are almost certainly reworked. No specimens were recorded at Site 836, which sampled only the Brunhes Chron. In the Tongan Platform site (Site 840), the highest occurrence of this species was found in samples from a level of uncertain magnetic signature.

For the Leg 135 sites, the position of the LA of *Globorotalia (Truncorotalia) tosaensis* bioevent seems less variable than that recorded by other workers, as it seems consistently to occur within the upper part of the Matuyama Chron.

FA *Globorotalia (Truncorotalia) crassaformis hessi*

Chaproniere (1991) placed the FA of *Globorotalia (Truncorotalia) crassaformis hessi* bioevent within oxygen isotope Stage 17, that is, within the lower part of the Brunhes Chron, and below the LA of *Globorotalia (Truncorotalia) tosaensis*.

Within the Lau Basin sites, only at Site 834 does this bioevent occur above the LA of *Globorotalia (Truncorotalia) tosaensis*. At Sites 837 through 839, the FA of *Globorotalia (Truncorotalia) crassaformis hessi* is placed within the Matuyama Chron immediately above the Jaramillo Subchron, whereas at Sites 838 and 839 it occurs below the Cobb Mountain Subchron. From this evidence this bioevent appears to be unreliable.

FA *Globigerina (Globoturborotalita) rubescens tenellus*

Kennett and Srinivasan (1983) thought that this bioevent occurred within the top part of Zone N21, that is, within the Gauss Chron. Rio et al. (1984) recorded this bioevent in the basal part of Zone N22, as did Chaproniere (1991).

Within the Leg 135 sites, *Globigerina (Globoturborotalita) rubescens tenellus* appears within the Matuyama Chron. At Sites 834, 837, and 839 this bioevent occurs between the Cobb Mountain and Olduvai subchrons; at Site 835, within an interval of confused lithostratigraphy, at Site 838, at the base of the Jaramillo Subchron; and at Site 836, within the Brunhes Chron.

The position of the FA of *Globigerina (Globoturborotalita) rubescens tenellus* varies, but in the Lau Basin-Coral Sea area it is not as old as that recorded by Kennett and Srinivasan (1983).

LA *Globigerinoides obliquus extremus*

Even though Kennett and Srinivasan (1983) equated this bioevent with the Zone N21/N22 boundary, Berggren et al. (1985) placed it within the Olduvai Subchron, a view supported by Chaproniere (1991). Dowsett (1989) concluded that this bioevent occurred just above the Olduvai Subchron, and Hills and Thierstein (1989) placed it close to the Matuyama/Gauss boundary.

This bioevent seems variable within the Lau Basin sites, ranging from a level above the questionable Olduvai Subchron at Site 837 to immediately below the Brunhes Chron at Site 838. This appears to be a little higher stratigraphically than previously recorded.

LA *Globigerinoides quadrilobatus fistulosus*

This taxon has a sporadic biostratigraphic distribution in the Leg 135 sites. For this reason, the reliability of this bioevent in this area can be questioned. However, at Site 834 it occurs just below the Olduvai Subchron, at Site 835 within an interval of uncertain lithostratigraphy, and at Site 837 within the probable Olduvai Subchron. These levels are similar to those recorded by Berggren et al. (1985), who recorded this bioevent as occurring just above the Olduvai Subchron, at approximately 1.6 Ma, and Hills and Thierstein (1989) found the bioevent to be at a similar level for the southwest Pacific area.

LA *Globorotalia (Globorotalia) cultrata limbata*

Populations of *Globorotalia (Globorotalia) cultrata limbata* in the Leg 135 samples are mainly dextrally coiled. Kennett and Srinivasan (1983) thought that this taxon disappeared within Zone N21. At Site 834, this bioevent occurs within the *Globigerinoides quadrilobatus fistulosus* Subzone of Zone N22, immediately below the Réunion Subchron. Records from the other sites are unclear with respect to the magnetostratigraphy; however, in all but Site 836, it occurs within the lower part of the range of *Globorotalia (Truncorotalia) truncatulinoides*. Thus, it occurs at a higher level than previously recorded.

Dextral coiling in *Globorotalia (Globorotalia) cultrata group*

Dextrally coiled populations are present within all the Leg 135 sites except for Sites 836 and 837. At Site 834, such populations range from the bottom of the sequence to a level immediately below the Réunion Subchron, and at Site 835 from the base of the section to within the upper part of the Gauss Chron. At Site 839, they range from the base of the sequence to a level midway between the possible Olduvai and Cobb Mountain subchrons, where the change in coiling direction to sinistral coincides with the LA of *Globigerinoides obliquus extremus*. Thus, for the Lau Basin sites, these dextrally coiled populations are restricted to the interval from Zone N19–20 (Site 834) to the *Globigerinoides quadrilobatus fistulosus* Subzone of Zone N22. Chaproniere and Nishi (this volume, table 7) show that four intervals of dextrally coiled populations, separated by either variable, but mainly sinistral coiled or sinistral coiled intervals, exist at Site 840. The lowest interval ranges from the bottom of the drilled sequence (within Chron 4—Zone N17A) to within the middle of Chron 3B (Zone N17A); this is followed by a variably, but mainly sinistral coiled interval, to within the middle of Subchron 3Ar (top of Zone N17A). Above this is a second dextrally coiled interval to within Subchron 3A-1 (Zone N17B). Sinistral coiled populations dominate the next interval to within Subchron 3r (Zone N17B), followed by a third interval of dextral coiling to within the Thvera Subchron of the Gilbert Chron (Zone N18), where they give way to dextrally coiled populations. This fourth interval of dextral coiling (from Zones N18 to N22) continues to within the Matuyama Chron,

but as noted above, the location with respect to the geomagnetic scale cannot be ascertained because of the low quality of the magnetic data in the upper levels of Site 840.

Bolli (1971) illustrated intervals over which populations of the *Globorotalia (Globorotalia) cultrata* group (as *Globorotalia menardii* sl.) were either dominantly dextrally or sinistral coiled. Bolli (1971, fig. 48.5) showed that this group was sinistral coiled for most of its stratigraphic range in the tropical Pacific area, but an interval (from within the *Globorotalia dutertrei* to the top of the *Globoquadrina altispira altispira* Zones) did occur over which the populations were dextrally coiled; for the Caribbean area, however, the coiling changes were more numerous. For the time interval over which dextral coiling is present in the Pacific area, two dextral coiling peaks were shown for the Caribbean. Lamb and Beard (1972, table 2), in a study based on the Gulf of Mexico and Caribbean regions, illustrated a similar result to that of Bolli (1971), but the two studies differ in that Lamb and Beard (1972) recognized only a single interval dominated by dextrally coiled populations (ranging from the *Globorotalia margaritae* to within the upper part of the *Globorotalia tosaensis* Subzone of the *Globorotalia truncatulinoides* Zone). Van Gorsel and Troelstra (1981, fig. 3) made a study of the Solo River section in Indonesia and found that from within the lower part of Zone N17 to within the lower part of Zone N19/20 the coiling direction in populations of *Globorotalia menardii* was variable, but that from within Zone N19/20 to within the upper part of Zone N21 coiling was dextral. They presented few data, but it appears that from the upper part of Zone N21 into Zone N22 coiling again became variable.

In terms of the biostratigraphic scheme used in this paper, the biostratigraphic interval given by Bolli (1971) over which populations of *Globorotalia menardii* were dextrally coiled for the Pacific region is equivalent to the interval from Zone N18 to within Zone N21. The range given by Lamb and Beard (1972) is from within Zone N19 to within the lower part of Zone N22 (*Globorotalia (Truncorotalia) crassaformis viola* Subzone) for the Caribbean and Gulf of Mexico regions.

It is difficult to correlate the changes in coiling direction at Site 840 with those found at the Solo River section (Van Gorsel and Troelstra, 1981). However, it is apparent that the lowest level of dextral coiling matches a similar interval at the Solo River section. Above this, little correspondence is present until the Zone N19 part of the Solo River section, where a good match occurs with Site 840. However, it is noted that the highest level of dextral coiling at Site 840 begins within Zone N18, a lower level than at the Solo River. As noted above, Bolli (1971) considered that the interval over which populations of *Gr. (Gr.) cultrata* group were dominated by dextral forms was from Zone N18 to the top of Zone N21, which is similar to that for the highest level at Site 840. Bolli (1971) shows a number of dextral zones in the Caribbean region below Zone N18, which may be comparable with what is seen in the Zone N17A and N17B intervals at Site 840. Lamb and Beard's (1972) interval of dextral coiling ranges from within Zone N19, younger than that seen at Site 840, but almost identical with that seen in the Solo River section. The sudden change from dextral coiling to sinistral coiling within the lower part of Zone N22 appears to be similar for all sections, and thus may provide a useful datum; however, it is obvious that the great variations in coiling direction in populations below Zone N19 shows that the biostratigraphic usefulness of these coiling changes at these older levels is low. Bolli (1971) and Van Gorsel and Troelstra (1981) considered that water temperature related to climatic factors controlled the coiling changes.

Gauss Chron

LA *Globorotalia (Globorotalia) multicamerata*

Berggren et al. (1983), based on a study by Pujol (1983) of the Rio Grande Rise in the South Atlantic, concluded that the age of the LA *Globorotalia (Globorotalia) multicamerata* was 2.5 Ma (i.e., within the Matuyama Chron). However, Berggren et al. (1985) reassessed the earlier result to be an age of 2.9 Ma within the Gauss Chron. Hills and Thierstein (1989) placed this bioevent in the lower part of the Matuyama Chron, below the Olduvai Subchron (within Zone N21).

Globorotalia (Globorotalia) multicamerata has been recorded from only three sites (Chaproniere and Nishi, this volume). At Site 834, this bioevent occurs within the upper part of the Gauss Chron, within the lower part of Zone N22 [*Globorotalia (Truncorotalia) crassaformis viola* Subzone]. At Site 835, its location is confused by the uncertainty caused by the confused lithostratigraphy. At Site 840, the poor results from the magnetostratigraphy do not allow any conclusions to be made, except that this extinction event may be as high as the Matuyama Chron.

These results agree closely with those found in the South Atlantic by Berggren et al. (1983) and in the Pacific by Hills and Thierstein (1989).

FA Globorotalia (Truncorotalia) truncatulinoides

The FA of *Globorotalia (Truncorotalia) truncatulinoides*, which marks the base of Zone N22, was observed at only three sites. At Site 834, it occurs high within the Gauss Chron. At Site 835, it probably occurs at a similar level as at Site 834. At Site 840, the magnetic resolution is such as to permit only a generalized position within the Gauss Chron.

Berggren et al. (1985) thought that this bioevent occurred just below the base of the Olduvai Subchron (Matuyama Chron), considerably higher than that found in the Lau Basin. More recently, however, Dowsett (1989) and Hills and Thierstein (1989) have questioned the reliability of this bioevent, finding evidence that it is diachronous, at least in the southwestern Pacific, appearing between 2.7 and 2.4 Ma (i.e., within the upper part of the Gauss Chron). This is in close agreement with the results found for Site 834 and probably for Site 835. Thus, these results suggest that *Gr. (Tr.) truncatulinoides* does appear somewhat earlier in the southwest Pacific area.

FA Globigerinoides quadrilobatus fistulosus

Berggren et al. (1985) considered that this bioevent occurred between the Kaena and Mammoth subchrons (within Zone N21), based on Hays et al. (1969) for the equatorial Pacific. Dowsett (1989) recorded the bioevent from just below the Mammoth Subchron (within Zone N19–20) for the Pacific and from between the Mammoth and Kaena subchrons in the Atlantic.

Only two sites contain an adequate record of *Globigerinoides quadrilobatus fistulosus*. At Site 834, the FA of this taxon occurs within the Gauss Chron, just above the Kaena Subchron (within Zone N21), which is probably also the case at Site 835. At Site 840, this species is confined to the Gauss Chron (Zone N21), but the poor magnetic record does not permit an accurate placement.

Thus, the records obtained from the Leg 135 sites are in close agreement with the previous assessments (Berggren et al., 1985; Dowsett, 1989), although a little younger than that obtained by Dowsett (1989).

LA Dentoglobigerina altispira altispira

Berggren et al. (1985) placed the LA of *Dentoglobigerina altispira altispira* between the Kaena and Mammoth subchrons (within Zone N21). Dowsett (1989) found that this bioevent varied from within the upper part of the Gilbert Chron to within the Kaena Subchron (Zone N19–20 to N21) in the Pacific region. Hills and Thierstein (1989) also found this bioevent to be variable in the Pacific area, ranging from between the Kaena and Mammoth subchrons to the upper part of the Gauss Chron (within Zone N21).

De. altispira altispira has not been recorded at Sites 836–839. At the other sites, the LA of this taxon falls within the Gauss Chron. At Site 834, it occurs immediately above the Kaena Subchron (within Zone N21) and a little higher at Site 835 (within Zone N22). These results are similar to those recorded elsewhere.

LA Sphaeroidinellopsis spp.

Berggren et al. (1985) gave the age of this bioevent as 3.0 Ma, within the top of the Mammoth Subchron (within Zone N21). Hills and Thierstein (1989) found that it ranged from below the Mammoth Subchron to the upper part of the Gauss Chron above the Mammoth Subchron, a finding similar to that of Berggren et al. (1985).

Most of the Leg 135 sites provided similar results to those noted above, but at Site 835 small specimens of *Sphaeroidinellopsis* spp. (probably reworked, as they occur within a probable slumped interval) were recorded from within an interval of confused lithostratigraphy, and at Site 837 from within the probable Olduvai Subchron (within Zone N22). These records are somewhat higher than previously recorded, but it should be noted that the specimens are small and show no development of spiral apertures.

FA Globorotalia (Truncorotalia) tosaensis

This important datum, which marks the base of Zone N21, has been regarded as occurring within the Mammoth Chron (Berggren et al., 1985). Hills and Thierstein (1989) found that this datum was variable. In contrast, for the southwest Pacific, evidence from DSDP Leg 90 sites (Sites 587, 588, 590, 591) shows a remarkable concordance, occurring within the lower Gauss Chron, close to the lower boundary of the Mammoth Subchron, similar to that recorded by Berggren et al. (1985).

In the three Leg 135 sites where this bioevent was recorded (Sites 834, 835, and 840), it occurs between the Mammoth and Kaena subchrons (Site 834), below the probable Kaena Subchron (Site 835), and within the lower Gauss Chron (Site 840). Thus, its consistency with previous records indicates its high reliability.

Gilbert Chron**LA Neogloboquadrina acostaensis**

This bioevent, which was placed within Zone N19–20 by Kennett and Srinivasan (1983), was found at only two Leg 135 sites. At Site 834 it was placed near the top of the Gilbert Chron, above the Cochiti Subchron. At Site 840, it was placed at a level within the Gilbert Chron, between the Nunivak and Sidufjall subchrons. These results place it within Zone N19–20, in close agreement with published records.

LA Globorotalia (Obandyella) margaritae

This bioevent was considered by Berggren et al. (1985) to be just below the Gauss/Gilbert boundary (within Zone N19–20) in the Caribbean. Dowsett (1989) found this bioevent to be variable in the Pacific, ranging from just above the top of the Sidufjall Subchron (within Zone N19) to the lower part of the Gauss Chron below the Mammoth Subchron (within Zone N19–20). In contrast, Hills and Thierstein (1989) found this bioevent to be much less variable and to be between the Cochiti Subchron and the top of the Gilbert Chron (within Zone N19–20), close to that recorded by Berggren et al. (1985).

At Site 834, the highest occurrence of *Globorotalia (Obandyella) margaritae* is in the basal part of the Gauss Chron (within Zone N19–20). At Site 840, however, it is within the Gilbert Chron, possibly within the Nunivak Subchron (within Zone N19). Thus, this bioevent is slightly higher and is close to the highest record documented by Dowsett (1989).

LA Pulleniatina primalis

The LA of *Pulleniatina primalis* was recorded by Berggren et al. (1985) as occurring within the latest part of the Gilbert Chron.

At Site 834, this bioevent is placed within the upper Gilbert Chron, just above the possible position of the Cochiti Subchron (within Zone N19–20), and within the questionable Nunivak Subchron (within Zone N19) at Site 840. This is in general agreement with Berggren et al. (1985).

LA Globigerina (Globoturborotalita) nepenthes

Berggren et al. (1985) thought that this bioevent occurred within the upper Cochiti Subchron (within Zone N19–20), but Dowsett (1989) found that it occurred within the Nunivak Subchron.

This bioevent was recorded from within the lower normal interval of the Gauss Chron (within Zone N19–20) at Site 834; however, at Site 840, it is placed within the Gilbert Chron, possibly within the Nunivak Subchron (within Zone N19). This difference between the results from Leg 135 and those previously recorded is a result, in part, of the difficulty in separating ancestral (*nepenthes*) from descendent (*rubescens*) species, and of differentiating morphotypes in a complex phylogenetic/phenotypic series (*nepenthes-decoraperta-rubescens*). The specimens referred to *nepenthes* are small, but they show the typical features of the taxon.

FA Globorotalia (Truncorotalia) crassaformis crassaformis

The FA of *Globorotalia (Truncorotalia) crassaformis crassaformis* is an important biostratigraphic event marking the base of Zone N19–20 (Kennett and Srinivasan, 1983). Berggren et al. (1985) placed this bioevent just above the Sidufjall Subchron. Dowsett (1989) found the position of the bioevent to be similar in both the Pacific and Atlantic oceans (within the Thvera Subchron), but it varies between the North and South Pacific (Cochiti and Thvera subchrons, respectively).

At Site 834, *Gr. (Tr.) crassaformis crassaformis* appears in what is probably the Gilbert Chron below the Nunivak Subchron. At Site 840, it appears at a level probably within the base of the Gauss Chron.

This taxon is most common in the warm subtropical and temperate regions of modern seas and appears to have maintained this range throughout its history (Kennett and Srinivasan, 1983). Thus, climatic and sea temperature variations may be responsible for its variable abundance and distribution. Even so, the position of the bioevent in the middle part of the probable Gilbert Chron in Site 834 is close to that previously recorded.

LA Globorotalia (Globorotalia) tumida plesiotumida

The LA of *Globorotalia (Globorotalia) tumida plesiotumida* was placed within Zone N19 by Kennett and Srinivasan (1983). This taxon is recorded from the basal part of the sequence in Site 834, but no magnetic records exist for this level. At Site 840 this bioevent occurs within the upper part of the Gauss Chron, probably in the basal part of the Nunivak Subchron. At both sites, this bioevent is within the upper part of Zone N18.

FA *Sphaeroidinella dehiscentis dehiscentis*

The FA of *Sphaeroidinella dehiscentis dehiscentis* marks the base of Zone N19 (Blow, 1969; Kennett and Srinivasan, 1983); thus, it was placed in the middle of the lower reversed interval of the Gilbert Chron (Berggren et al., 1985). Dowsett (1989, tables II and IV) gave the position of this bioevent within the Cochiti Subchron at DSDP Hole 577A (northwest Pacific) and in the upper reversed interval of the Gilbert Chron at DSDP Site 502 (Caribbean Sea), positions somewhat higher than given by Berggren et al. (1985).

At Site 840 this bioevent appears to occur within the upper part of the Gilbert Chron, possibly within the Nunivak Subchron, a level close to that recorded by Dowsett (1989).

LA *Globorotalia (Globorotalia) merotumida*

Kennett and Srinivasan (1983) considered that *Globorotalia (Globorotalia) merotumida* became extinct within Zone N18 (i.e., that is within the lowest part of the Gilbert Chron). At Site 840, this bioevent occurs within the reversed interval of Chron 3A (in Zone N17B).

FA *Globorotalia (Globorotalia) tumida tumida*

Blow (1969) used the FA of *Globorotalia (Globorotalia) tumida tumida* to define the base of Zone N18. Berggren et al. (1985) placed this bioevent within the lower reversed interval of the Gilbert Chron (Subchron 3r). At Site 840, this datum is placed within the lower part of the Gilbert Chron, in a zone of uncertain polarity, but which is probably near the base of the Thvera Subchron. This record appears to be higher than that noted above.

Pre-Gilbert Chron**LA *Globorotalia (Globorotalia) languaensis***

The LA of *Globorotalia (Globorotalia) languaensis*, which was considered to be within Zone N17A (Kennett and Srinivasan, 1983), is placed by Berggren et al. (1985) within the lowest part of the Gilbert Chron (within Zone N17B). At Site 840 it is placed within the upper normal interval of Chron 3A (also within Zone N17B), somewhat lower than previously recorded from the Atlantic.

FA *Globorotalia (Globorotalia) multicamerata*

Kennett and Srinivasan (1983) considered that the FA of *Globorotalia (Globorotalia) multicamerata* occurred within Zone N17B. Chaproniere and Nishi (this volume) used this bioevent to define the base of Zone N17B because of the rarity of the index *Pulleniatina primalis*. In Site 840 this bioevent is placed within the upper part of Subchron 3Ar.

LA *Globorotalia (Globorotalia) paralanguaensis*

Kennett and Srinivasan (1983) thought that the LA of *Globorotalia (Globorotalia) paralanguaensis* was within Zone N17A, below that of *Gr. (Gr.) languaensis*. In Site 840, this species overlaps *Gr. (Gr.) tumida tumida* but is below the FA of *Sphaeroidinella dehiscentis*, suggesting a level within Zone N18. However, the part of the section where the LA of *Globorotalia (Globorotalia) paralanguaensis* occurs appears to be within the lower part of the Thvera Subchron of the Gilbert Chron, which according to Berggren et al. (1985) should be within Zone N19 (Fig. 2). The presence of *Ceratolithus acutus* at these levels also suggests a level within Zone N19. Thus, at this site, the LA of *Gr. (Gr.) paralanguaensis* is higher than previously recorded, and it also occurs above that for *Gr. (Gr.) languaensis*.

FA *Globigerinoides conglobatus*

According to Berggren et al. (1985), this bioevent occurs within the lowest part of the Gilbert Chron, within the uppermost part of Zone N17B. At Site 840, it is placed within Subchron 3Ar (Zone N17A), below the LA of *Globorotalia (Globorotalia) languaensis*, and so lower than previously recorded.

FA *Globorotalia (Obandyella) margaritae*

Berggren et al. (1985) placed this bioevent within the middle of Chron 3A, between subchrons a and b in the Atlantic Ocean (DSDP Hole 516A) and from the equatorial Pacific (Saito et al., 1975), although it was recorded also from the lower Gilbert Chron at DSDP Site 502 (Caribbean). These occurrences are within Zone N17B, but Kennett and Srinivasan (1983) thought it to be within the base of Zone N19. At Site 840, this bioevent occurs within the lower normal interval of Chron 3A, within Zone N17B, which appears to be a little earlier than given by Berggren et al. (1985), but considerably below the level suggested by Kennett and Srinivasan (1983).

FA *Pulleniatina primalis*

The FA of *Pulleniatina primalis* marks the base of Zone N17B (Kennett and Srinivasan, 1983); it was placed within the lower part of Chron 3A. At Site 840, this bioevent occurs within a section of uncertain polarity, either at the top of Chron 3A or within the lower part of the Gilbert Chron (Subchron 3r), somewhat higher than previously recorded. *Pu. primalis* is rare and sporadic in its distribution in Site 840, forcing Chaproniere and Nishi (this volume) to use the FA of *Globorotalia (Globorotalia) multicamerata* to mark the base of Zone N17B.

FA *Globorotalia (Globorotalia) tumida plesiotumida*

The FA of *Globorotalia (Globorotalia) tumida plesiotumida* marks the base of Zone N17A (Blow, 1969; Kennett and Srinivasan, 1983). Berggren et al. (1985) did not show the relationship of this bioevent to the magnetostratigraphic scale. At Site 840, this species is present from the base of the sequence (within Chron 4).

Coiling Changes in *Pulleniatina*

Saito (1976) recognized nine levels over the biostratigraphic range of *Pulleniatina* in which the populations are sinistrally coiled (L1–L9), spread over an interval from the early Pliocene to the early Pleistocene. Chaproniere (1991) recognized one of these, interpreted as being L5, in the Coral Sea area. Berggren et al. (1985) recognized a coiling change from dominant sinistral to dextral coiling just above the Cochiti Subchron, within Zone N19–20. This bioevent was also recognized by van Gorsel and Troelstra (1981) in the Solo River section, Indonesia.

Within both the Coral Sea area and the Leg 135 sites, most of the populations of *Pulleniatina* are dominated by dextrally coiled specimens. At Site 834, two sinistrally coiled intervals were detected. The upper one was spread over the interval from the top of the Réunion Subchron to the upper part of the Olduvai Subchron within the Matuyama Chron (lower Zone N22); this appears to equate to the L4 and L5 changes of Saito (1976). The lower sinistrally coiling interval was found within the Gilbert Chron, ending within the base of the presumed Nunivak Subchron, which appears to be the change noted by Berggren et al. (1985), but at a lower level. At Site 835 *Pulleniatina* is rare, but three populations were found to be sinistral. The highest is in the lower part of the Brunhes Chron, which is a little higher than the L1 level, but within an interval that contains large numbers of reworked, older taxa. The second sinistrally coiled population is within the bottom of a slumped interval interpreted as the top part of the Gauss Chron, which seems to be the same level as L8. The lowest sinistrally coiled population falls within the Olduvai Subchron, probably equivalent to L4. At Site 836, all populations are dextrally coiled. At Site 837, a single interval of sinistral coiling is present, which is within the Olduvai Subchron and is probably L4. At Site 838, *Pulleniatina* is rare, and two populations are sinistrally coiled, but the lack of good magnetic data precludes correlation with the magnetic reversal scale. The upper one is probably within the lower Matuyama Chron and may be equivalent to L3, and the lower to one of either L6, L7, or L8. At Site 839, a single sinistral population was detected, which is at the same level as the lower population at Site 838 and may match one of L6, L7, or L8. At Site 840, a single interval of sinistrally coiled populations of *Pulleniatina* extends from the FA of *Pu. primalis* (within Zone N17B) to a level at the top of the Gauss Chron (top of Zone N19), at a level of uncertain magnetic signature; this appears to be the bioevent placed at the top of the Cochiti Subchron by Berggren et al. (1985).

Pulleniatina has a sporadic distribution within the Leg 135 sites, so it is difficult to correlate the sinistrally coiled levels with those of Saito (1976), and Berggren et al. (1985). The questionable L1 population at Site 835 is probably a result of reworking. The L3 population may be present at Site 838; the L4 or L5 population at Sites 834, 835, and 837; and the L8 population at Site 835. At Sites 838 and 839, a sinistrally coiled interval equates to one of either L6, L7, or L8. The S-D change recorded by Berggren et al. (1985) is represented at Sites 834 and 840; however, because of the poor magnetic data, it is difficult to make a close comparison. Nevertheless, the change appears to be at a level close to that recorded by Berggren et al. (1985).

CALCAREOUS NANNOFOSSIL BIOEVENTS**Brunhes Chron****FA *Emiliania huxleyi***

Berggren et al. (1985) placed this bioevent high in the Brunhes Chron, at 0.275 Ma. Hills and Thierstein (1989) found the bioevent to be reliable and a little younger at 0.23 Ma. At all sites from the Lau Basin, with the exception

of Sites 837 and 838, the bioevent occurs high in the sequence, well above the LA of *Helicosphaera inversa*. *E. huxleyi* was not recorded at Site 837, but at Site 838 it overlaps with *Helicosphaera inversa* suggesting that the latter extends to higher levels than previously recorded.

LA *Helicosphaera inversa*

At Sites 834, 837, 838, 839, and 840, this bioevent occurs within the middle part of the Brunhes Chron. *Helicosphaera inversa* was not recorded from Site 836.

Matuyama Chron

LA *Pseudoemiliana lacunosa*

Berggren et al. (1985) placed this bioevent at 0.474 Ma. Thierstein et al. (1977) and Hills and Thierstein (1989) considered that this bioevent was reliable, based on studies from the Atlantic, Indian, and Pacific oceans. The LA of *Pseudoemiliana lacunosa* was recorded from all Leg 135 sites, except Site 835 (where it was not recorded), at levels within the middle part of the Brunhes Chron, apparently in agreement with earlier studies.

LA *Emiliana ovata*

This bioevent, which marks the base of Subzone CN14b, is variable, occurring between the Jaramillo and Cobb Mountain subchrons (Matuyama Chron) at Site 834, in the middle of the Brunhes Chron below the LA of *Pseudoemiliana lacunosa* at Site 836, at the same level as the LA of *Pseudoemiliana lacunosa* at Sites 837 and 839.

FA *Helicosphaera inversa*

This bioevent is present only at Site 839, where it occurs within the middle part of the Brunhes Chron at the same level as the LA of *Pseudoemiliana lacunosa* and the LA of *Emiliana ovata*.

LA *Scyphosphaera pulcherrima*

This bioevent appears to occur within the Matuyama Chron, varying as low as the base of the lower reversed interval of that chron (Site 835) to the middle part of the reversed interval between the Cobb Mountain and probable Olduvai subchrons at Sites 837 and 839.

LA *Helicosphaera sellii*

Berggren et al. (1985) placed this bioevent between the Olduvai and Jaramillo subchrons, a position supported by Dowsett (1989). This bioevent has been recorded at most of the Leg 135 sites between the Cobb Mountain and Jaramillo subchrons. However, a questionable specimen of *Helicosphaera sellii* was recorded from Site 836 from a level within the Brunhes Chron (Styzen, this volume). Thus, these results are close to those previously recorded.

LA *Calcidiscus macintyreii*

Berggren et al. (1985) and Dowsett (1989) place the highest record of *Calcidiscus macintyreii* between the Olduvai and Jaramillo subchrons, a little below that of *Helicosphaera sellii*. It appears to be a useful datum for general biostratigraphic correlation (Dowsett, 1989). In contrast, Hills and Thierstein (1989) found this datum to be statistically unreliable, even though it generally occurred in a similar position to that recorded by Berggren et al. (1985) and Dowsett (1989). This bioevent can only be correlated with the magnetic scale at Site 834, where it occurs within the Olduvai Subchron, somewhat lower than traditionally recorded.

FA *Gephyrocapsa oceanica*

This bioevent marks the base of Subzone CN14a, and was placed by Berggren et al. (1985) just above the Olduvai Subchron. At Site 834 this bioevent has been placed between the Cobb Mountain and Olduvai subchrons, at Site 835 within the interval of confused lithostratigraphy, and at Site 837 within the probable Olduvai Subchron. At Site 839 it is possible that the FA of *Gephyrocapsa oceanica* occurs lower, below a possible Olduvai Subchron. However, as the magnetic record at these levels at Site 839 is uncertain, this record may be unreliable.

FA *Gephyrocapsa caribbeanica*

This bioevent, which marks the base of Zone CN13b, was correlated with a level just below the top of the Olduvai Subchron by Berggren et al. (1985). This level is the same as that from Sites 834 and 837, whereas at Site 835 this

bioevent is at the same level as *G. oceanica*, but within an interval of uncertain magnetostratigraphy.

LA *Discoaster brouweri*

The LA of *Discoaster brouweri* marks the base of Subzone CN13a. Berggren et al. (1985) placed this bioevent just below the Olduvai Subchron, a position supported by Dowsett (1989) and Hills and Thierstein (1989). The LA of *Discoaster brouweri* was found to be the same level at Sites 834 and 837.

LA *Discoaster pentaradiatus*

This bioevent marks the base of Subzone CN12d, and was placed by Berggren et al. (1985) within the reversed interval between the Réunion Subchron and the top of the Gauss Chron. Dowsett (1989) and Hills and Thierstein (1989) made similar findings. This bioevent is found higher than previously recorded at Site 834 where it coincides with the LA of *Discoaster brouweri*, immediately above the Réunion Subchron.

LA *Discoaster surculus*

Berggren et al. (1985) suggested that this bioevent occurred in the reversed interval between the Réunion Subchron and the top of the Gauss Chron, which has been supported by both Dowsett (1989) and Hills and Thierstein (1989). This bioevent marks the base of Subzone CN12c. At Site 834 the LA of *Discoaster surculus* was placed at the same level as that of *Discoaster tamalis*, between the Réunion Subchron and the top of the Gauss Chron, similar to what has been recorded by previous authors. At Site 840, however, this bioevent has been placed within the upper Gauss Chron.

Gauss Chron

LA *Discoaster tamalis*

The LA of *Discoaster tamalis* marks the base of Subzone CN12b, and was placed within the latest Gauss by Berggren et al. (1985), in agreement with the findings of Dowsett (1989) and Hills and Thierstein (1989). At Site 834, this bioevent was found within the interval between the top of the Gauss Chron and the base of the Réunion Subchron, higher than previously recorded. At Site 840, however, this bioevent was placed within the upper Gauss Chron.

Gilbert Chron

LA *Sphenolithus abies* and LA *S. neoabies*

The last *Sphenolithus* spp., together with the last occurrence of *Reticulofenestra pseudoumbilica*, marks the base of Subzone CN12a. Berggren et al. (1985) placed the LAs of both *Sphenolithus abies* and *S. neoabies* within the top of the Gilbert Chron. At Site 834, the two bioevents are separated, with the LA of *S. neoabies* occurring within the lower part of the Gauss Chron and that of *S. abies* within the upper part of the Gilbert Chron. Thus, this bioevent appears to be slightly higher than previously recorded.

LA *Reticulofenestra pseudoumbilica*

This bioevent, which marks the base of Subzone CN12a, was placed by Berggren et al. (1985) and Hills and Thierstein (1989) between the base of the Gauss and the upper part of the Gilbert Chrons. Dowsett (1989) was in general agreement with this, but found that it occurred at a level within the Cochiti Chron at DSDP Site 577, east of Japan. At Sites 834 and 840 the LA of *Reticulofenestra pseudoumbilica* occurs immediately above the probable Cochiti Subchron. These occurrences are in general agreement with previous findings.

LA *Amaurolithus primus*

Berggren et al. (1985) placed this bioevent, which marks the base of Subzone CN10d, near the top of the Sidufjall Subchron. At Site 840, the LA of *Amaurolithus primus* is bracketed with the LA of *Reticulofenestra pseudoumbilica*, and was placed at the top of the possible Cochiti Subchron, near the top of the Gilbert Chron, which is somewhat higher than recorded by Berggren et al. (1985).

LA *Amaurolithus tricorniculatus*

The LA of *Amaurolithus tricorniculatus* was thought by Berggren et al. (1985) to occur between the Mammoth and Cochiti subchrons. Dowsett (1989) found this bioevent to be a little older, occurring from between the Sidufjall and Nunivak subchrons to within the Nunivak Subchron. At Site 840, this

bioevent occurs within the interval questionably assigned to the Nunivak Subchron, which is in agreement with Dowsett (1989).

FA *Ceratolithus rugosus*

The FA of *Ceratolithus rugosus*, which marks the base of Subzone CN10c, was placed by Berggren et al. (1985) between the Sidufjall and Thvera subchrons, whereas Dowsett (1989) placed it within the Thvera Subchron. At Site 840, this bioevent has been found within the Thvera Subchron.

LA *Ceratolithus acutus*

The LA of *Ceratolithus acutus*, a bioevent used to mark the base of Subzone CN10c, was placed by Berggren et al. (1985) between the Sidufjall and Thvera subchrons, at a slightly lower level than the FA of *Ceratolithus rugosus*. Dowsett considered that this bioevent occurred within the Thvera Subchron. At Site 840, this bioevent occurs within the upper part of the Thvera Subchron.

FA *Ceratolithus acutus*

Dowsett (1989) placed the FA of *Ceratolithus acutus*, a bioevent used to mark the base of Subzone CN10b, in the early part of the Gilbert Chron, below the Thvera Subchron, in agreement with Berggren et al. (1985). At Site 840, this bioevent was placed within the lower part of the Thvera Subchron, a little higher than previously recorded.

LA *Triquetrorhabdulus rugosus*

The LA of *Triquetrorhabdulus rugosus* was placed within the early part of the Gilbert Chron by Berggren et al. (1985). At Site 840, this bioevent occurs within the lower part of the Gilbert Chron, within an interval of uncertain polarity just below the Thvera Subchron.

Pre-Gilbert Chron

LA *Discoaster quinqueramus*

The LA of *Discoaster quinqueramus*, which marks the base of Subzone CN10a, was placed by Berggren et al. (1985) within the middle part of Chron 3A. At Site 840 this bioevent has been placed near the top of Subchron 3r, which is higher than previously recorded.

FA *Amaurolithus primus*

The bioevent used to mark the base of Subzone CN9b was placed by Berggren et al. (1985) within Chron 3B. At Site 840, the lowest definite occurrence of this bioevent is found within the upper part of Subchron 3Ar, although a questionable occurrence of *Amaurolithus primus* is present at 481.4 mbsf, within Chron 3B.