6. PLANKTONIC FORAMINIFERAL BIOSTRATIGRAPHY, DEEP SEA DRILLING PROJECT LEG 81[1]

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ABSTRACT

Four sites on DSDP Leg 81 were cored at the southwestern margin of the Rockall Plateau. A composite but discontinuous section from the Holocene to the upper Paleocene was recovered from the cores. This Tertiary section can be divided into three parts: a lower, neritic, sedimentary–volcanogenic sequence in the upper Paleocene and lower Eocene; thin and discontinuous, deep-water, glauconitic chalks from the late Eocene through the early Miocene; and thicker, more continuous sections in the middle Miocene through Holocene. Because of sparsity of planktonic foraminifers in the upper Paleocene and lower Eocene, and because of solution problems in the planktonic foraminifers in addition to the thin and discontinuous sections in the upper Eocene through lower Miocene, the biostratigraphic zonation of this part of the section is incomplete.

Thirteen biostratigraphic intervals are described from the upper Paleocene through the Holocene, five from the upper Paleocene through early Miocene, and eight from the middle Miocene through Holocene. Three lineages of planktonic foraminifers are described that have moderately continuous representation in the Rockall Plateau area during the periods of their rapid differentiation: (1) a *Globorotalia* plexus (middle Miocene) that appears to have originated in *G. scitula praescitula*, and terminated in *G. menardii* and *G. conoidea* in the late Miocene in the Rockall Plateau area; (2) a plexus that originated in *G. challengeri*, and, in the late middle Miocene, evolved into the late Tertiary and Quaternary *Neogloboquadrina* plexus; and (3) a late Miocene *Globorotalia* plexus that originated in and included *G. scitula scitula*, and differentiated into *G. scitula scitula* and *G. margaritae* before the end of the late Miocene.

INTRODUCTION

The goals of DSDP Leg 81 were to determine the nature and details of the early Tertiary opening of the North Atlantic Ocean, and to determine the sequence of late Tertiary climatic events that culminated in northern hemisphere continental glaciation. Four sites (552, 553, 554, and 555) were cored on Leg 81; all from a small area on the southwestern margin of the Rockall Plateau. Most of the Tertiary, from the upper Paleocene through the Holocene, is represented at these sites. The upper Paleocene–middle Eocene section is characterized by interstratified volcanogenic rocks and neritic sandstones, mudstones, and shales that are mostly barren of planktonic foraminifers. The middle part of the Tertiary, from the upper Eocene through the lower Miocene, is characterized by nondepositional or erosional hiatus, with only irregularly occurring chalks. In terms of zonation or climatic trends, planktonic foraminifers are of little value in these parts of the section. It is only in the middle Miocene through Holocene that the nanno-foram oozes and chalks are sufficiently thick and continuous for a complete planktonic foraminiferal zonation and sequence of climatic events to be constructed.

Generally core-catcher samples were examined for this preliminary study. The core sections were sampled at closer intervals only in the condensed middle Miocene chalks and in a small part of the upper Miocene.

The planktonic foraminiferal assemblages on Leg 81 have been correlated as closely as possible with the established low-latitude zonation of Blow (1969). However, his zonation cannot be directly applied in the Rockall Plateau area either because of the lack of critical low-latitude zonal species or because of differing ranges of critical species in differing climatic regimes (also see Poore, 1979). Mid-latitude zonation schemes, or discussions of problems of mid-latitude zonations that have proved most useful, include Jenkins (1971), Poore and Berggren (1975), Bizon and Glacon (1978), Poore (1979), and Kennett and Srinivasan (1983). Because none of the above references produced a zonation that is readily applicable to the succession of planktonic foraminiferal assemblages in the Rockall Plateau area, I have developed an informal and highly tentative series of "biostratigraphic intervals" that is meant to be applicable only to the small area in question.

PLANKTONIC FORAMINIFERAL ZONATION

Thirteen biostratigraphic intervals from early Eocene to Holocene are recognized in this chapter (see Figs. 1-5). These intervals are not formal biostratigraphic zones in that they are based on local first and last occurrences from a small area, a coiling change in one taxon or plexus, and assemblages without defined boundary parameters. Although at least some of these biostratigraphic intervals appear to be identifiable regionally (cf. Poore and Berggren, 1975; Bizon and Glacon, 1978; Poore, 1979), no attempt is made here to apply these "zones" outside of the Rockall Plateau area. A discussion of these biostratigraphic intervals based on planktonic foraminifers follows.

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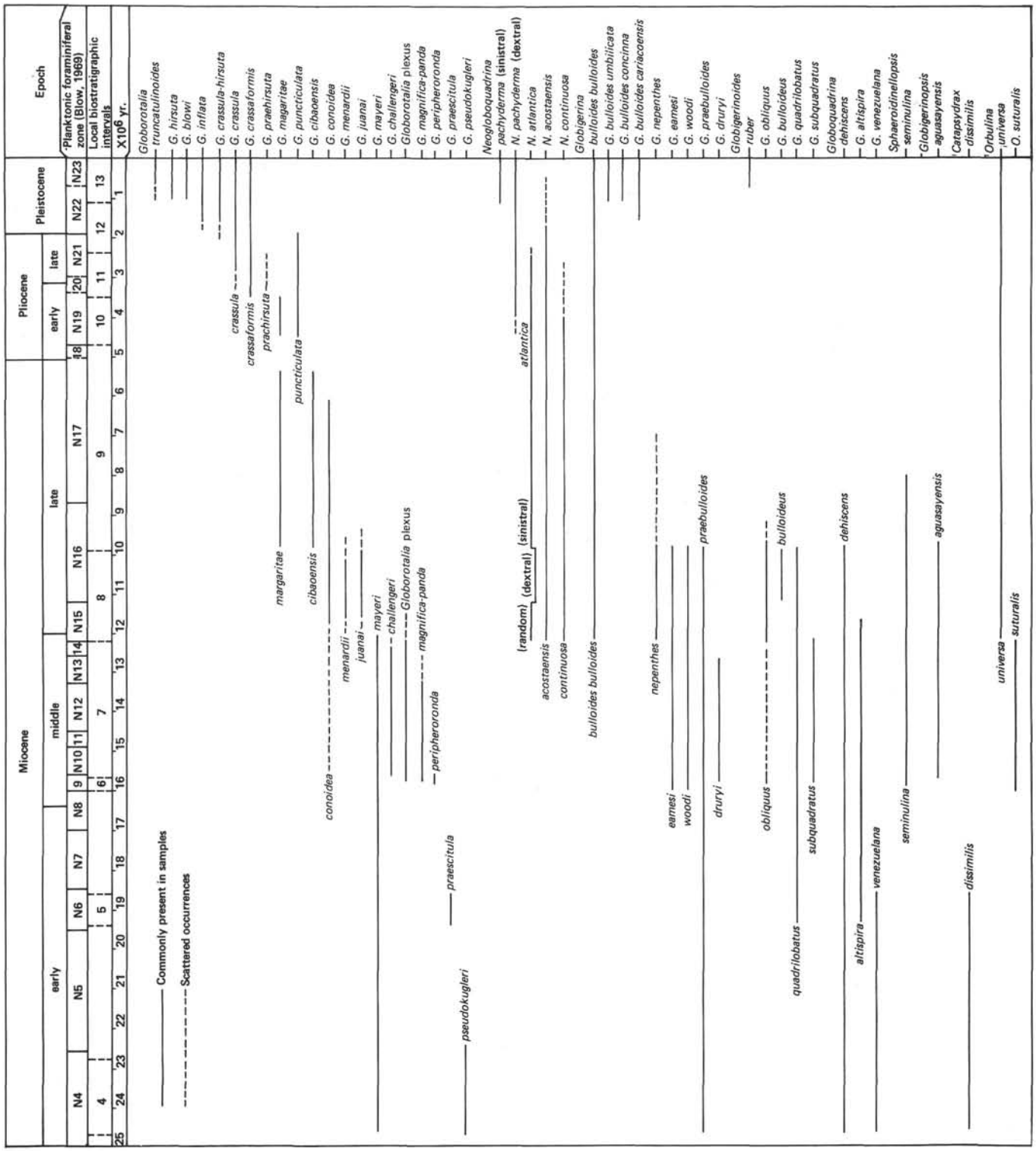

Figure 1. Composite range chart for selected planktonic foraminifers from Sites 552–555.

Early Eocene

Interval 1

Interval 1 is contained in the oldest sediments encountered on Leg 81 and consists of a very sparse planktonic foraminiferal fauna characterized by low diversity, high faunal dominance, and poor preservation. Most samples from this part of the section are barren or contain very few planktonic foraminifers. Of the planktonic foraminifers present, *Globigerina* cf. *patagonica* is the dominant species. Other species include *Pseudohastigerina wilcoxensis, Globigerina* cf. *primitiva, G. velascoensis,*

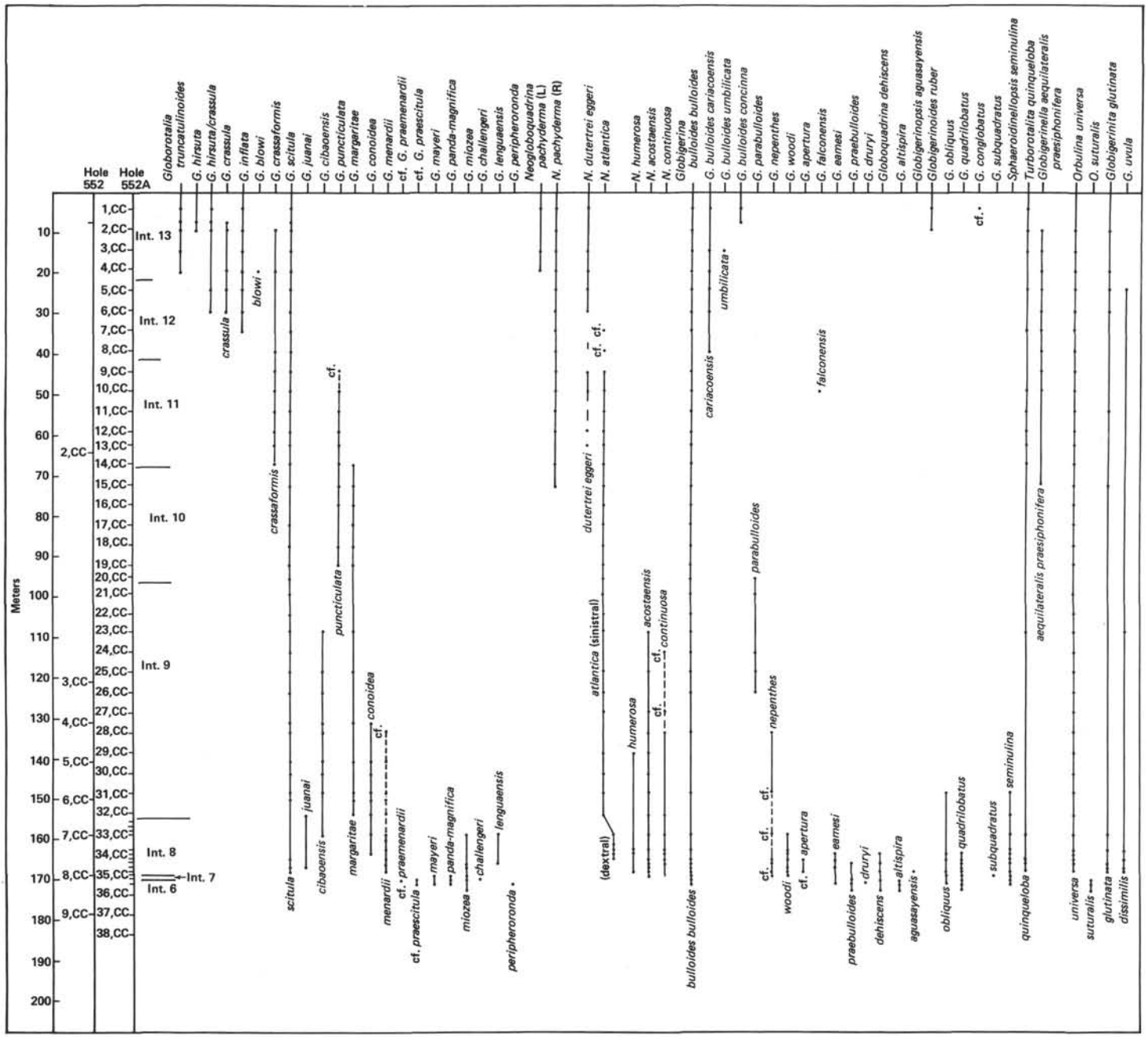

Figure 2. Range chart for selected planktonic foraminifers from Holes 552 and 552A.

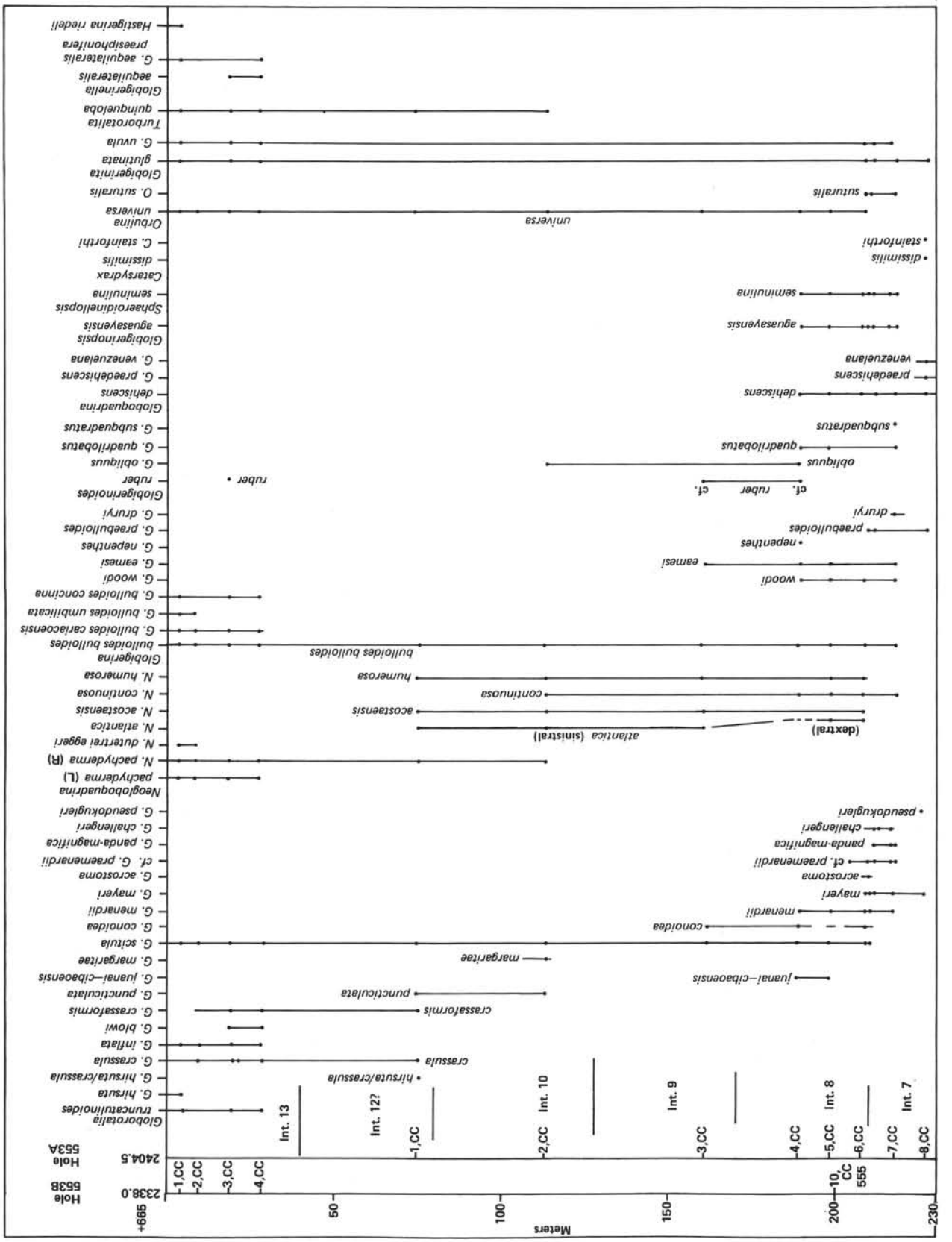

Figure 3. Range chart for selected planktonic foraminifers from Holes 553A and 553B.

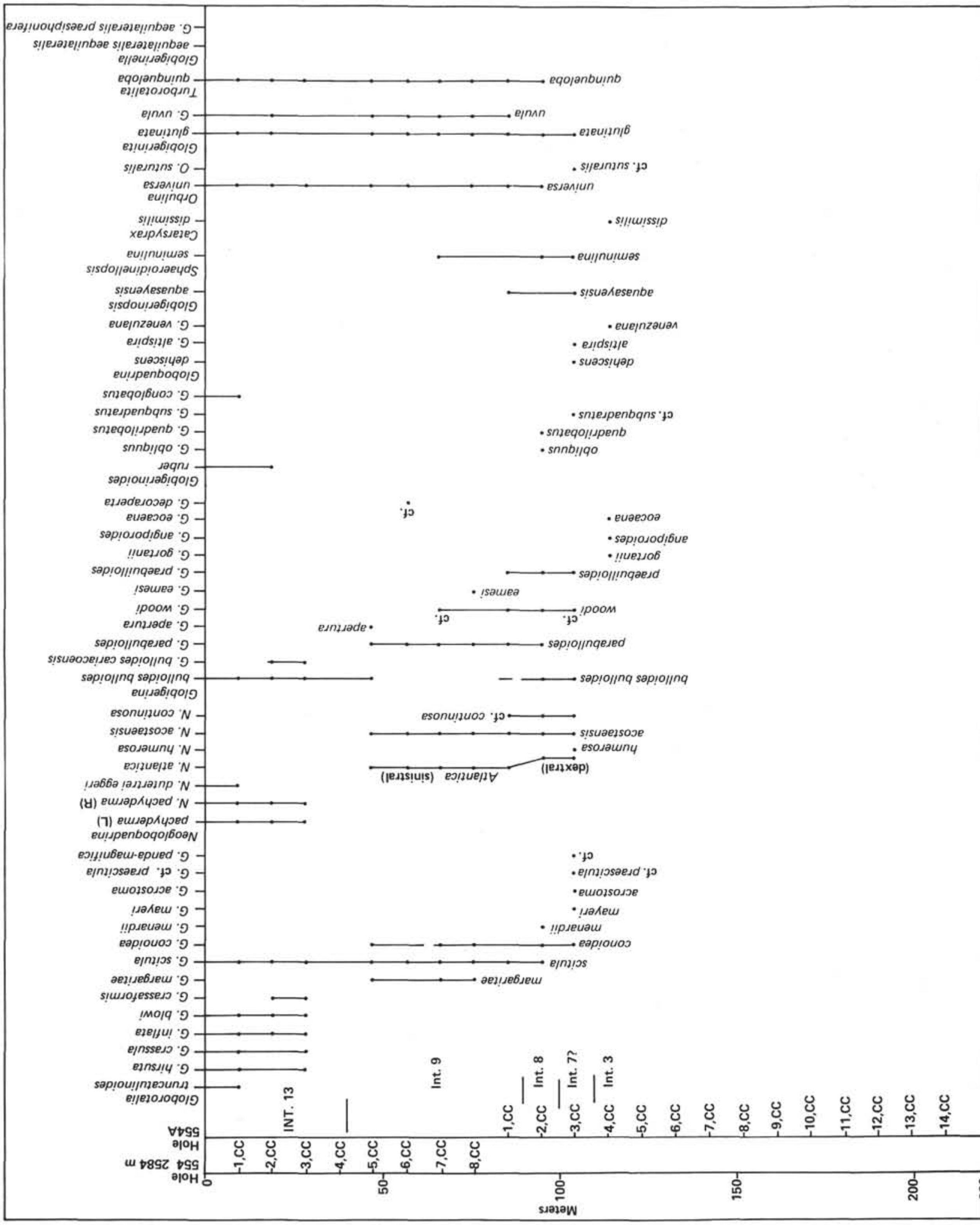

Figure 4. Range chart for selected planktonic foraminifers from Holes 554 and 554A.

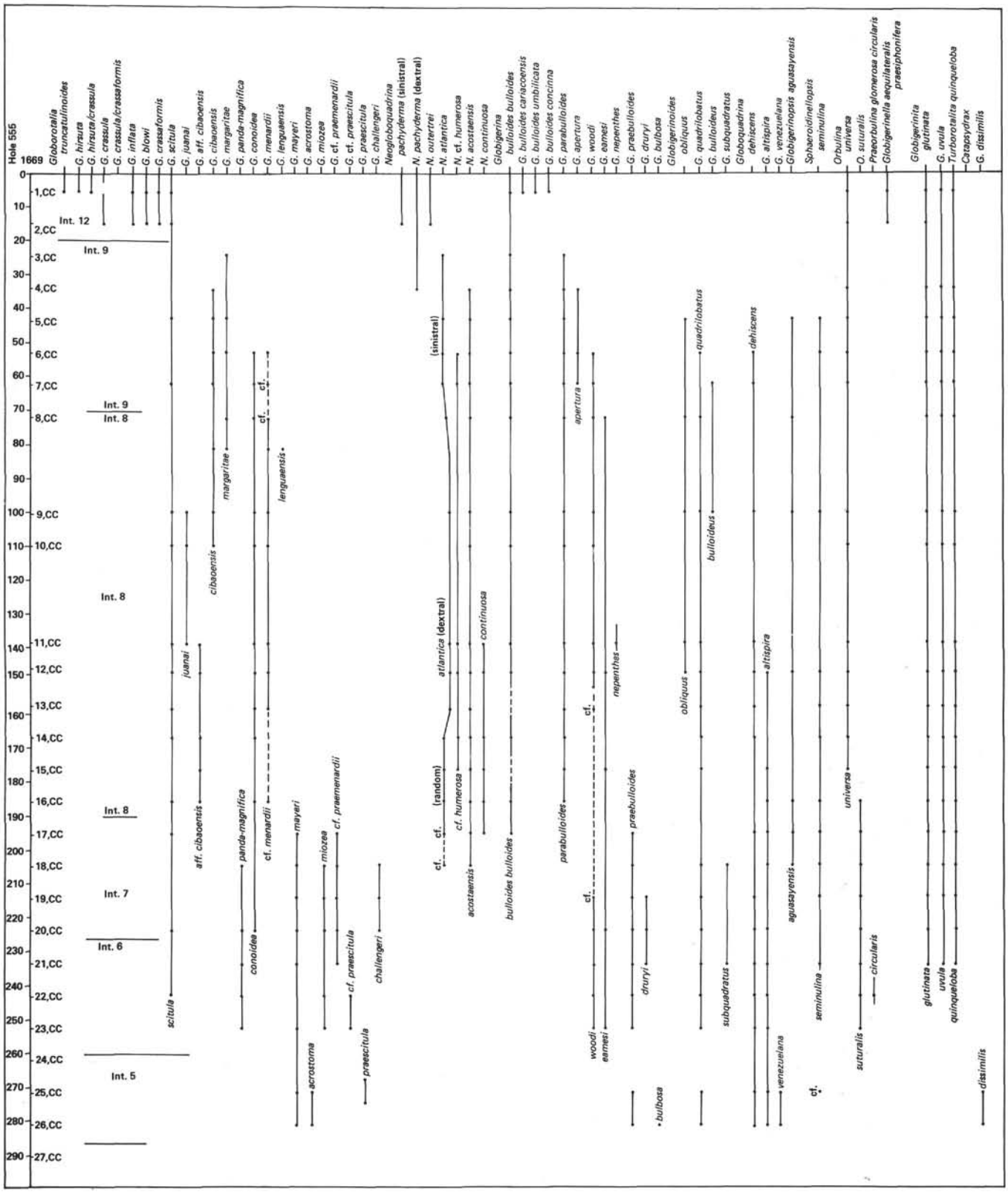

Figure 5. Range chart for selected planktonic foraminifers from Hole 555.

Acarinina wilcoxensis, A. cf. *broedermanni, A. pseudotopilensis, A.* cf. *soldadoensis*, and *Globorotalia* cf. *lensiformis*.

There are no critical zonal species in this interval. However, Interval 1 appears to be correlative with P7, P8, and P9 of the low-latitude zonation.

Middle Eocene

Interval 2

Interval 2 was identified in Sample 552-8,CC and 553A-9,CC. Like Interval 1 the planktonic foraminifers are characterized by low frequency, low diversity, and poor to moderate preservation. The species identified include *Pseudohastigerina* cf. *micra, Acarinina* cf. *bullbrooki, A.* cf. *pentacamerata*, and *Globigerina eocaena*. This interval is early middle Eocene in age, approximately correlative with the low-latitude planktonic foraminiferal Zones P10 and P11.

Late Eocene to Early Oligocene

Interval 3

Interval 3 was identified only in Sample 554A-4,CC and is characterized by the occurrence of *Globigerina gortanii, G. eocaena, G. angiporoides, Catapsydrax dissimilis*, and *Globoquadrina venezuelana*. This interval is approximately early Oligocene to late Eocene in age and is correlative with the broad range of Zones P17–P20.

Early Miocene

Interval 4

Interval 4 was identified only in Sample 553A-8,CC. It is characterized by the occurrence of *Globorotalia pseudokugleri, Globoquadrina dehiscens praedehiscens, G. dehiscens dehiscens, Catapsydrax dissimilis, G. stainforthi*, and *Globigerinita glutinata*. This interval is correlative with Zone N4 of the low-latitude zonation.

Interval 5

Interval 5 was identified only in Samples 555-25,CC and 555-26,CC. It is characterized by the occurrence of *Globigerinoides quadrilobatus, G. subquadratus, Catapsydrax dissimilis, Globorotalia praescitula*, and *Globoquadrina venezuelana*. Other species include *Sphaeroidinellopsis* cf. *seminulina, Globorotalia mayeri, G. acrostoma, Globoquadrina altispira, G. dehiscens, Globigerina praebulloides, G. bulbosa,* and *Globigerinita glutinata*. The above association is most compatible with Zone N6.

Middle Miocene

Interval 6

Interval 6 is that biostratigraphic interval between the first occurrence of *Orbulina suturalis* at the base, and the first local occurrence of *Globorotalia challengeri* Kennett and Srinivasan (= *G.* cf. *suterae* of Poore, 1979, pl. 6, figs. 4–7) at the top. This interval was identified in Samples 552A-36-2, 10–11 cm, 552A-36-3, 10–11 cm, 555-21,CC, 555-22,CC, and 555-23,CC. The planktonic foraminiferal association in this interval is rather variable, possibly resulting in part from poor sample control (five samples). A plexus of relatively large, commonly encrusted, noncarinate to carinate, morphologically variable *Globorotalia* is especially characteristic of this interval. The taxonomic position of this *Globorotalia* plexus appears to be between *G. scitula praescitula, G. miozea*, and *G. menardii*. It contains morphological characteristics of the three end member taxa. Previously it appears to have been in part included in *Globorotalia miozea* by Poore (1979, pl. 2, figs. 8–12), and has been included in *G. scitula praescitula* (pl. 2, figs. 1–4) and *G. archeomenardii* or "primitive *G. praemenardii*" (pl. 3, figs. 4–7) by Bizon and Glacon (1978) from the western Mediterranean Sea. A keel first becomes evident within this plexus in a morpho-type named *Globorotalia magnifica* Bizon and Glacon, but which is also morphologically close to *G. panda* and *G. praemenardii*. Keels become more prominent in this plexus in the upper part of Interval 6 but not all individuals display them. Some carinate morphotypes cannot be assigned to either *G. magnifica* or *G. praemenardii* because of heavy encrusting. In this respect they appear to have more in common with the mid-latitude species *G. miozea* and *G. conoidea*. This middle Miocene *Globorotalia* plexus was evidently widespread in the North Atlantic Ocean region because it has been well described by Bizon and Glacon (1978) from the western Mediterranean Sea. It is not clear, as a result of meager data, whether the first occurrence of this plexus in the Rockall Plateau area was gradual and sporadic or whether its introduction was abrupt and approximately defines an "event." Sample 555-23,CC from the lower part of Interval 6 is devoid of *Globorotalia* of this plexus.

Also characteristic of Interval 6 is the occurrence of *Globigerinoides quadrilobatus* and *Globoquadrina altispira* in relatively high frequencies and the scattered occurrence of *Globorotalia peripheroronda*. Species whose first occurrence is within this interval include *Orbulina suturalis, Praeorbulina glomerosa circularis, Globorotalia miozea, G. scitula, Globigerina druryi, G. eamesi, Globigerinopsis aguasayensis*, and *Globigerinoides obliquus*. Other species observed in this interval are *Globorotalia mayeri, Globoquadrina dehiscens, Globigerinoides subquadratus, Sphaeroidinellopsis seminulina, Globigerina praebulloides, G. woodi, Globigerinita glutinata, G. uvula*, and *Turborotalita quinqueloba*.

Based on the occurrence of *Globorotalia peripheroronda* and *Praeorbulina glomerosa circularis*, and the apparent evolutionary transition between *Globorotalia scitula praescitula* and *G. praemenardii archeomenardii*, it would appear that Interval 6 is approximately correlative with N9 of the low-latitude zonation.

Interval 7

The base of Interval 7 is defined on the first local occurrence of *Globorotalia challengeri* (= *G.* cf. *suterae* of Poore, 1979). The top of Interval 7 is defined on the extinction of *Globorotalia mayeri*. This interval was identified in Samples 552A-36-1, 10–11 cm, 553A-6,CC (re-

worked?), 553A-7,CC, 555-17,CC, 555-18,CC, 555-19,CC, and 555-20,CC.

The first occurrence of *Globorotalia challengeri* is abrupt, suggesting either disconformity or sudden introduction from outside areas. *Globorotalia challengeri* Kennett and Srinivasan has been a largely unreported species. To my knowledge, Poore (1979) made the only other reference to the species as *Globorotalia* cf. *suterae* (pl. 6, figs. 4–7). According to Kennett and Srinivasan (1983) *G. challengeri* evolved from *G. scitula praescitula* near the base of N9 and its last occurrence is near the top of N15. I have observed that *G. challengeri* is related morphologically to the middle Miocene *Globorotalia* plexus and therefore would appear to have evolved also from *G. scitula praescitula*. Some noncarinate variants of the *Globorotalia* plexus and morphologically primitive *G. challengeri* display marked resemblance. What is a significant departure from previous observations, however, is that *G. challengeri* evolved into the *Neogloboquadrina* plexus through *Neogloboquadrina atlantica* (primitive form) of Poore (1979, p. 472, pl. 16, figs. 10–12) near the extinction level of *G. mayeri*. Furthermore, all of the characteristic morphological variants of the *Neogloboquadrina* plexus are present within the *G. challengeri* range of variation. That is, *N. continuosa, N. acostaensis, N. humerosa*, and *N. atlantica* morphotypes are all latent within the taxon *G. challengeri*. The chief morphological differences between *G. challengeri* and *Neogloboquadrina* are the heavier construction and coarser wall structure of the test in *Neogloboquadrina*, and a slight asymmetry of the test chambers in *G. challengeri* in lateral view.

The *Globorotalia* plexus, as described under Interval 6, is dominated in Interval 7 by carinate *Globorotalia* that are especially variable morphologically. The most typical variant is reminiscent of *G. praemenardii* but is more robust and commonly thickened or encrusted. In appearance, the *Globorotalia* plexus is intermediate to *G. conoidea, G. praemenardii*, and *G. magnifica*. Although carinate variants dominate the assemblage, partially carinate, or even noncarinate, variants are still conspicuous through much of the interval. In the upper part of Interval 7, however, the morphology of the *Globorotalia* plexus appears to stabilize, with variants trending toward morphologically typical *G. menardii* on the one hand and *G. conoidea* on the other. The last occurrence of *G. magnifica* is in the upper part of Interval 7.

Other than *Globorotalia challengeri*, no other planktonic foraminifer has its first occurrence in the material studied in Interval 7. Those whose last occurrence is within Interval 7 include *G. magnifica, G. acrostoma, G. mayeri, Globigerina druryi, G. praebulloides*, and *Globigerinoides subquadratus*. Interval 7 appears to represent a long interval of time and is approximately correlative with Zones N10–N15.

Middle and Late Miocene

Interval 8

Interval 8 is that biostratigraphic interval above the last occurrence of *Globorotalia mayeri* and below the dextral to sinistral coiling change in the *Neogloboquadrina* plexus. This interval was identified in Samples 552-7,CC, 552-8,CC, 552A-33,CC, 552A-34,CC, 552A-35,CC, 553A-4,CC, 553A-5,CC, 554A-2,CC, and 555-8 through 555-16,CC.

The first evolutionary occurrence of *Neogloboquadrina* is near the base of Interval 8. In the material studied, the species *N. continuosa, N. acostaensis, N.* cf. *humerosa*, and *N. atlantica* emerge fully developed from *Globorotalia challengeri*. There are no precise morphological boundaries between the various *Neogloboquadrina* "species," and they appear to represent a morphological cline from *N. continuosa* through *N. atlantica*. As with its antecedent *G. challengeri*, the coiling of *Neogloboquadrina* is random in the lowest part of Interval 8. Below the middle of the interval, however, the coiling changes to dominantly dextral.

The middle Miocene *Globorotalia* plexus achieves differentiation in Interval 8. Only two clearly defined species continue into this interval: morphologically typical *Globorotalia menardii* and *G. conoidea*. Still, however, there are rare individuals in the assemblage that are difficult to assign to either *G. menardii* or *G. conoidea* with confidence. In addition, there are two variants of *G. conoidea:* the typical heavily encrusted variant, and a more delicate, thin-walled variant (*G. conomiozea* of Poore, 1979; not *G. conomiozea* of Kennett, 1966).

G. scitula, which is a minor component of the planktonic foraminiferal faunas of Interval 7, becomes morphologically more variable in Interval 8 and forms another *Globorotalia* plexus. This plexus consists of morphologically typical *G. scitula; G. scitula* variants that are partially, and rarely, fully carinate; and variants with relatively inflated chambers (*G. subscitula*); or strongly plano-convex, noncarinate variants (*G. juanai*). The occurrence of these variants is irregular and the only consistently occurring form is *G. scitula*. The partially carinate variants resemble *G. cibaoensis* except that they are more morphologically variable than is *G. cibaoensis*. Similarly the more rarely occurring, fully carinate variants resemble *G. panda, G. magnifica*, and *G. margaritae*. However, these carinate *G. scitula* in Interval 8 are more inflated and morphologically variable than *G. panda, G. magnifica,* or *G. margaritae*.

Those planktonic foraminifers making their first appearance in Interval 8 include *Neogloboquadrina continuosa, N. acostaensis, N.* cf. *humerosa, N. atlantica, Globorotalia menardii, G. juanai, G.* aff. *cibaoensis, Globigerina bulloides, G. nepenthes*, and *Globigerinoides bulloideus*. The last occurrence of *Globoquadrina altispira* is within Interval 8. Those planktonic foraminifers most characteristic of Interval 8 are *Globorotalia menardii, G. conoidea, G. juanai, Globigerina nepenthes, Globigerinoides obliquus* in low frequencies, and *Neogloboquadrina*.

Interval 8 is correlative with N15 and the lower part of N16 of the low-latitude planktonic forminiferal zonation. Poore and Berggren (1975) and Poore (1979) correlated the top of this interval, that is, the dextral to sinistral coiling change in *Neogloboquadrina atlantica*, with the top of the Miocene, the N17/N18 boundary. The

calcareous nannoplankton (Backman, this volume) indicate that the coiling change in *Neogloboquadrina* is within Zone NN11. The planktonic foraminifers are more compatible with an early late Miocene age for this coiling change than a latest Miocene age. *Globorotalia conomiozea*, a latest Miocene temperate species, is not present in the Rockall Plateau area. What Poore and Berggren (1975) and Poore (1979) identified as *G. conomiozea* is a thin-walled variant of *G. conoidea* that is not directly related to *G. conomiozea*. (Kennett, pers. comm., 1981). Furthermore, *Globorotalia margaritae* makes its first appearance near the coiling change in *Neogloboquadrina atlantica*, that is, near the base of Interval 9, and this first occurrence is probably near its evolutionary first occurrence. I believe that this is more accurate of the true range of *G. margaritae* and that the first occurrence of *G. margaritae* near the base of the Pliocene in the Mediterranean basin is only its first local occurrence in that area.

Late Miocene to Early Pliocene

Interval 9

Interval 9 is that biostratigraphic interval above the regional coiling change in the *Neogloboquadrina* plexus from dextral to sinistral, and below the first local occurrence of *Globorotalia puncticulata*. Interval 9 was identified in Samples 552-3,CC through 552-6,CC, 552A-21,CC through 552A-32,CC, 553A-3,CC, 554-5,CC through 554-8,CC, 554A-1,CC, and 555-3,CC through 555-7,CC.

The lower part of this interval contains the nonsynchronous local last occurrences of all the warm-water planktonic foraminifers. These include *Globorotalia menardii, G. conoidea, G. juanai, Globoquadrina dehiscens, Globigerinopsis aguasayensis, Globigerinoides quadrilobatus, Globigerina nepenthes, G. woodi, G. eamesi*, and *Sphaeroidinellopsis seminulina*. These species gradually disappear from the fauna and their disappearances can not be ascribed to any particular horizon or event.

The upper part of Interval 9 is characterized by the most impoverished planktonic foraminiferal fauna of the study material in the upper Tertiary (excluding the lower Miocene faunas that have been affected by dissolution). Likewise, the upper part of this interval is characterized by extreme faunal dominance by the *Neogloboquadrina* plexus and *Globigerina bulloides*. The only other species that occur in this part of the interval are *Globorotalia scitula, Orbulina universa, Turborotalita quinqueloba, Globigerinita uvula*, and *G. glutinata*.

The first occurrence of *Globorotalia margaritae* and *G. cibaoensis* is at or near the base of Interval 9. The range of *G. margaritae* is much lower in this region than it is in the Mediterranean Sea where its first local occurrence is near the base of the Pliocene. Neither *G. margaritae* nor *G. cibaoensis* range locally through the zone of low diversity in the upper part of Interval 9. They do, however, range higher in the interval than the other warm-water species.

Interval 9 is approximately correlative with the upper part of N16 through the lowest part of N19 of the low-latitude zonation. The Miocene/Pliocene boundary falls within the upper part of the interval, in the zone of low diversity.

Interval 10

Interval 10 is that biostratigraphic interval above the first occurrence of *Globorotalia puncticulata* and below the last local occurrence of *G. margaritae*. Interval 10 was identified in Samples 552A-14,CC through 552A-19,CC and 553A-2,CC. This interval is reminiscent of the older Interval 9 in that the planktonic foraminiferal fauna is characterized by low diversity and high faunal dominance. The *Neogloboquadrina* plexus and *Globigerina bulloides* continue to dominate the fauna. However, the reappearance of *Globorotalia margaritae* along with the occurrence of *G. puncticulata* adds a slightly greater diversity to the assemblage.

Since the appearance of the genus *Neogloboquadrina* near the base of Interval 8, the plexus has consisted of morphotypes or variants that include *N. continuosa, N. acostaensis, N.* cf. *humerosa*, and *N. atlantica*. The range of variation is richer than this, however, in that forms referrable to *N. acostaensis pseudopima* in addition to unnamed variants are present in scattered samples or in low frequencies. *Neogloboquadrina pachyderma* has not been included in this list of variants because the typical encrusted, sinistral-coiled form is not found in the study material below the Pleistocene. The nonencrusted, dextral form that is characteristic of warmer water masses cannot be differentiated from *N. continuosa* and *N. acostaensis* in this area. In addition, the coiling direction of the plexus is uniform throughout the Miocene and through Interval 9, all *Neogloboquadrina* is sinistral.

This situation is altered slightly in Interval 10 where some of the smaller variants of the *Neogloboquadrina* plexus assume dextral coiling. These variants may be considered to be *N. pachyderma* (dextral) except they are not obviously different morphologically from the small *N. continuosa* or *N. acostaensis* of Intervals 8 and 9.

Interval 10 is approximately correlative with the lower to middle part of N19 of the low-latitude zonation.

Late Pliocene

Interval 11

Interval 11 is that biostratigraphic interval above the last local occurrence of *Globorotalia margaritae* and below the last occurrence of *Neogloboquadrina atlantica*. Interval 11 was identified in Samples 552-2,CC, 552A-9,CC through 552A-13,CC, and 553A-1,CC.

The planktonic foraminiferal fauna of Interval 11 indicates a recovery from the zone of low diversity in the late Miocene and early Pliocene. The assemblage is still overwhelmingly dominated by *Neogloboquadrina* and *Globigerina bulloides* but a number of species make their first appearance in this interval. These include *Globorotalia crassaformis, G. crassula, G. praehirsuta, Globi-*

gerina apertura, and *Globigerinella aequilateralis praesiphonifera*.

Interval 11 is approximately equivalent to the uppermost part of N19 through the lower part of N21.

Late Pliocene to Early Pleistocene

Interval 12

Interval 12 is that biostratigraphic interval above the last occurrence of *Neogloboquadrina atlantica* and below the first local occurrence of typical *Neogloboquadrina pachyderma* (sinistral). Interval 12 was identified in Samples 552A-5,CC through 552A-8,CC, and 553A-1,CC. The interval is missing at Sites 554 and 555 as a result of a hiatus in the record. Planktonic foraminifers whose first local occurrence is within this interval include *Globorotalia inflata, G. crassula* trans. *hirsuta, Globigerina bulloides cariacoensis*, and *Hastigerinella digitata. Neogloboquadrina atlantica* is reduced drastically between Samples 552A-8,CC and 552A-7,CC. However, small individuals close to *N. atlantica* persist in trace amounts in Sample 552A-7,CC.

Interval 12 appears to be correlative with the upper part of N21 and the lower part of N22. The Pliocene/Pleistocene boundary appears to fall within this interval. However, as with the Miocene/Pliocene boundary, none of the critical low-latitude planktonic foraminifers are present in the area to define the boundaries.

Early Pleistocene to Holocene

Interval 13

Interval 13 is that biostratigraphic interval above the first local occurrence of *Neogloboquadrina pachyderma* (sinistral and encrusted). Interval 13 continues to the present. This interval was identified in Samples 552-1,CC, 552A-1,CC through 552A-6,CC, 553-1,CC, 553B-1,CC through 553B-4,CC, 554-1,CC through 554-3,CC, 555-1,CC, and 555-2,CC. The first local occurrence of *Globorotalia truncatulinoides* also appears to be near the base of this interval but its occurrence within the cores is too sporadic and the stratigraphic control in the area is too limited for one to be certain of its lower limit. Other species that make their first local appearance in Interval 13 include *Globorotalia hirsuta, G. blowi, Neogloboquadrina dutertrei, Globigerina bulloides umbilicata, G. bulloides concinna, Hastigerinopsis riedeli, Globigerinoides* cf. *conglobatus, G. ruber*, and *Globigerinella aequilateralis aequilateralis*. The diversity of the planktonic foraminifers in Interval 13 is the greatest since the early part of the late Miocene in the Rockall Plateau area. In contrast, however, few warm-water species are present in the assemblage.

Interval 13 is approximately middle Pleistocene to Holocene in age. It appears to include the upper part of N22 and N23 of the low-latitude zonation.

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Date of Acceptance: December 14, 1983