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39. SYNTHESIS OF STRATIGRAPHIC CORRELATIONS OF THE AMAZON FAN[1]

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ABSTRACT

The older part of the Amazon Fan sequence penetrated on Leg 155 predates the last interglacial but is probably no older than oxygen isotopic Stage 8. The presence or absence of the zonal fossil *E. huxleyi* in sediments interpreted as isotopic Stage 7 appears variable, as the result of ecologic changes, dissolution, or reworking. Last interglacial highstand deposits are identified at Sites 942 and 946 from a microfossil assemblage, isotopic character, and the paleomagnetic Blake Event. They may have been removed by erosion by mass-transport deposits at other deep sites. The available data do not allow a consistent stratigraphy to be developed for the late Pleistocene (Stages 4 and 3) prior to the paleomagnetic Lake Mungo Excursion (32 ka).

A consistent correlation is developed for sequences younger than the Lake Mungo Excursion using oxygen isotopes of planktonic foraminifers, magnetic susceptibility, and paleomagnetic intensity and inclination. This correlation confirms that there is considerable variability in oxygen isotopic variations across the fan. The last glacial maximum is represented by the middle part of the Brown Channel-levee System. Shipboard seismic correlations are shown to be generally correct and confirm that major channel-levee systems formed sequentially. Several levees continued to accumulate mud with silt laminae, derived from flow-stripping of turbidity currents, after shifting of the active channel. A tentative age model is based on sparse ^{14}C dates and the correlation of paleomagnetic intensity events with the global stack.

INTRODUCTION

Stratigraphic correlation between sites (Fig. 1) and the development of a chronology for Leg 155 was based on a wide range of techniques, detailed in several chapters in this volume. This paper synthesizes the varied database, analyzes inconsistencies between the data sets, and presents a preferred stratigraphic and chronologic correlation. In some cases, data is insufficient to establish a correlation and in other cases, the correlations are somewhat speculative.

We first present a brief summary of the seismic stratigraphic framework of Amazon Fan developed prior to Leg 155. Then we briefly review the various data sets relevant to correlation and chronology. Discussion of these data and presentation of a correlation synthesis are presented in two separate sections: first, the correlation and age of the deeper sections on the fan, dating from the last interglacial (Stage 5) or older; and second, the correlation and age of the younger sediment on the fan that accumulated during the late Pleistocene glacial stage (isotopic Stages 2 through 4).

Seismo-stratigraphic Framework of Amazon Fan

The Amazon Fan (Fig. 1) has aggraded principally by the deposition of thick channel-levee deposits from turbidity currents (Manley and Flood, 1988). Periodic channel avulsion has resulted in the deposition of a series of overlapping channel-levee deposits. Previous workers on the Amazon Fan have assigned color names to all the recognized channel-levee systems (Table 1; Fig. 2), with the exception of the youngest, which is termed the Amazon Channel-levee System, and two systems on the eastern fan, termed Channels “5” and “6” (Damuth et al., 1983, 1988; Manley and Flood, 1988). On the upper fan, upstream from any particular avulsion point, two successive channel-levee systems may be contiguous, as is the case of the Amazon and preceding Brown levee in Figure 2. Individual channel-levee systems have been grouped into larger levee complexes: the Upper, Middle, Lower, and Bottom Levee Complexes (ULC, MLC, LLC, and BLC; Fig. 2).

The proportion of sand increases downfan. Sandy units interbedded with channel-levee systems appear as high-amplitude reflection packets (HARPs) on seismic reflection profiles. They were interpreted by Flood et al. (1991) as the first turbidite deposits following an avulsion across which the new channel-levee system prograded. HARPs are thus assigned the same color names as the overlying channel-levee deposits (Fig. 3).

Stratigraphic Data from Leg 155

No Leg 155 site completely penetrated the Brunhes magnetic epoch, an interpretation confirmed by foraminifer biostratigraphy. The lack of the coccolith *Pseudoemiliania lacunosa* indicates that no hole reached isotopic Stage 12 (ca. 475 ka). Deeply buried (≈130–400 meters below seafloor [mbsf]) calcareous clay units at several sites are lithologically similar to Holocene sediment deposited during a sea-level highstand when Amazon River sediment was advected northward along the continental shelf. All these carbonate-rich units contain an interglacial foraminifer assemblage. At Sites 942 and 946 the units spanned the paleomagnetic Blake Event (ca. 105 ka). All but one unit contain the nannofossil *Emiliania huxleyi*, with a first appearance datum (FAD) at 275 ka in the middle of isotopic Stage 8. The use of planktonic foraminifers and calcareous nannofossils for biostratigraphy is hindered by ecologically dependent variations in the presence and abundance of individual species and the lack of a continuous stratigraphic section (Mikkelsen et al., this volume).

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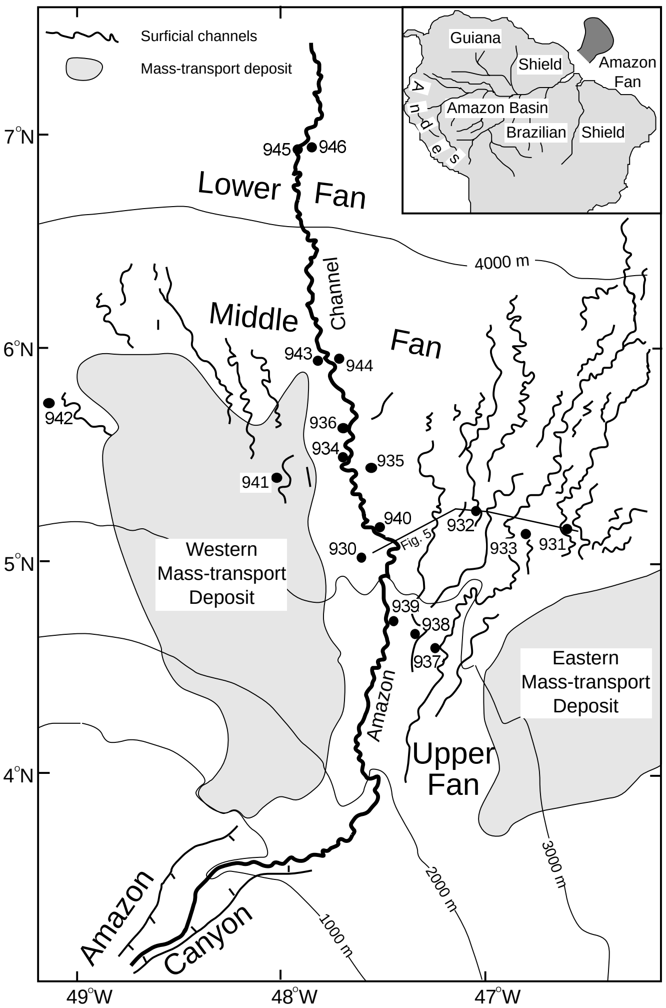

Figure 1. Map of the Amazon Fan showing the location of key stratigraphic sites discussed in the text and of the seismic-reflection profile in Figure 5. Modified from Flood et al., 1995; modified from Damuth et al., 1988, and Manley and Flood, 1988.

Stratigraphic continuity is broken by mass-transport deposits (MTDs; Fig. 2) that may have eroded underlying strata. Continuity is also reduced by lower sediment recovery and low microfossil abundance in sandier intervals.

In the upper Pleistocene, continuously sedimented sequences, correlation, and chronology are most readily determined using foraminifer abundance and species composition, variations in oxygen isotopes, and paleomagnetic data. Important chronostratigraphic markers are the downcore reappearance of the foraminifer *Pulleniatina obliquiloculata* at ~40 ka (Maslin et al., this volume) and the paleomagnetic Lake Mungo Excursion at 32 ka (Cisowski and Hall, this volume).

INTERGLACIAL CARBONATE-RICH UNITS

Nannofossil, Foraminifer, Paleomagnetic, Isotope, and Amino Acid Data

Foraminifer assemblages, oxygen isotopes, and lithology all indicate that the hemipelagic carbonate-rich muds that form the carbonate-rich units (Figs. 3, 4) accumulated under interglacial conditions, when a high sea level prevented much Amazon river sediment from crossing the continental shelf. At Site 942, three distinct carbonate-rich muds (Fig. 3) overlying fan sediments tentatively correlated with the MLC and are clearly assigned to oxygen isotopic Substages 5.1, 5.3, and 5.5 on the basis of a continuous oxygen isotope record (Showers et al., this volume), the paleomagnetic Blake Event, and the dominance of *E. huxleyi* in the uppermost carbonate-rich mud (Zone CN15b; Mikkelsen et al., this volume). A similar nannofossil assemblage and the Blake Event were also recognized in the carbonate-rich unit at 135–150 mbsf at Site 946 (Fig. 3).

Table 1. Summary of the nomenclature of the seismo-stratigraphic sequence on Amazon Fan (from Damuth et al., 1983, and Manley and Flood, 1988).

Eastern Mass-Transport Deposit (EMTD) and Western Mass-Transport Deposit (WMTD)
Upper Levee Complex (ULC)
Amazon (Am)
Brown (Br)
Aqua (Aq)
Purple (Pu)
Blue (Bl)
Yellow (Ye)
Channel “5” (Ch 5)
Orange (Or)
Channel “6” (Ch 6)
Unit R Mass-Transport Deposit (URMTD) and Bottom Mass-Transport Deposit (BMTD)
Middle Levee Complex (MLC)
Red (Re)
Lower Levee Complex (LLC)
Gold (Go)
Green (Gr)
Gray
Lime
Gray
Bottom Levee Complex (BLC)

The age control on other carbonate-rich units is less clear, principally because they lack an unequivocal nannofossil stratigraphy. The absence of *P. lacunosa* indicates that all are younger than isotopic Stage 12. Maslin and Mikkelsen and Mikkelsen et al. (both this volume) discuss biostratigraphic evidence for the age of these units, using the relative abundance of *E. huxleyi*, small *Gephyrocapsa,* and *G. caribbeanica* to distinguish Stages CN15a and CN14b. Globally, the FAD of *E. huxleyi* is in isotopic Stage 8 (260 ka), but it is rare in the South Atlantic before isotopic Stage 5 (Pujos and Giraudeau, 1993), and its abundance is probably influenced by ecological factors (Gartner, 1972) and dissolution (Thierstein et al., 1977). The absence of *E. huxleyi* therefore may not necessarily mean that a sample is older than isotope Stage 8. We summarize below all of the evidence bearing on the age of the carbonate-rich units and then use this data to present a synthesis.

Maslin and Mikkelsen (this volume) show that the carbonate-rich units overlying the Bottom Levee Complex at Sites 931 and 933 (Fig. 4) contain *E. huxleyi.* At Site 931, *E. huxleyi* is restricted to a 20-cm, carbonate-rich interval (Unit IV) and is absent from the bioturbated muds beneath this (Subunit VA) despite the abundance of calcareous nannofossils. Two isotope determinations on *G. sacculifer* (Showers et al., this volume) from Subunit VA show $\delta^{18}O$ values similar to or lighter than Holocene values, suggesting interglacial conditions. The FAD of *E. huxleyi,* which is in the middle of glacial Stage 8, thus cannot be identified by the downcore disappearance of this taxon in Subunit VA at Site 931; rather, the disappearance must represent an abundance shift. The abundance of *G. caribbeanica* in the lower sediments at this site led Mikkelsen et al. (this volume) to suggest that they represent Zone CN14b (perhaps reworked), based on the acme zonation of Pujos and Giraudeau (1993). However, cores P6304-4 and P6304-9 of Gartner (1972) show considerable abundance of *G. caribbeanica* throughout isotopic Stage 7 (early zone CN15a), espe-

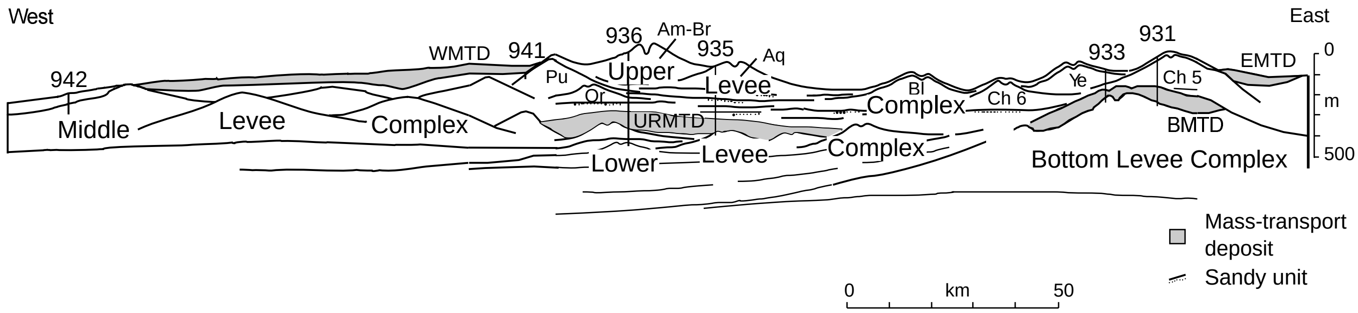

Figure 2. Schematic cross section of the Amazon Fan through selected ODP sites showing the major levee complexes and MTDs. The names of channel-levee systems (Ch 6, Ch 5, Or, Ye, Bl, Pu, Aq, and Am-Br) are summarized in Table 1. Modified from Flood et al. (1995).

cially the older part of the zone. Amino-acid racemization of foraminifers from Unit IV suggests an age of 200–300 ka (Wehmiller, this volume).

At Sites 931 and 933, >70 m of levee sediment was cored below the carbonate-rich unit (Figs. 3, 4). At both sites, there is a gradual lithologic transition from bioturbated carbonate-rich mud, downward through mud with thin silt laminae, to mud with thicker silts and fine sands (Fig. 4) similar to that found in the Holocene–uppermost Pleistocene sequence of the Amazon levee. This lithologic sequence is present at all sites on the levee of the late Pleistocene Amazon channel (e.g., Sites 939, 940, 944) and appears to represent the response of levee deposition to rising sea level. The possibility that the cores penetrated only a veneer of sediment overlying the main constructional phase of the Bottom Levee Complex can be excluded. At Site 931, coring was deep enough to penetrate strata equivalent to the upper parallel reflections of the Bottom Levee Complex (fig. 35 of Shipboard Scientific Party, 1995b), and sediment recovery was good. Using sedimentation rates estimated by Maslin et al. (this volume) for sediments on an abandoned levee at Site 932, the muddy sediments with silt laminae from 350 to 412 mbsf at this site, between the carbonate-rich unit and the levee sediments with abundant silt beds, are unlikely to represent more than 40 k.y. of accumulation. At Sites 931 and 933, the carbonate-rich unit is overlain by the Bottom Mass-Transport Deposit (BMTD), which may have eroded overlying sediment (Piper et al., Chapter 6, this volume).

Sites 935, 936, and 944 all penetrated the top of the Lower Levee Complex (Fig. 3). At Site 936, Cores 155-936A-44X and 45X contain an apparently continuous sequence of bioturbated mud (with at least 6% $CaCO_3$) passing down into mud with silt laminae (Fig. 4). As in Sites 931 and 933, the upper samples contain *E. huxleyi,* which is absent in the lower samples. In Core 155-936A-42X, carbonate-rich mud (11% $CaCO_3$) underlies levee muds with silt laminae and overlies a thin MTD. *E. huxleyi* was not found in the levee sediment, but is present in the underlying carbonate-rich mud, which has an interglacial planktonic foraminifer assemblage with lighter oxygen isotopes than in Cores 44X and 45X. It is possible that this upper carbonate-rich unit is a large clast in the underlying MTD, but its differences compared with the underlying carbonate unit do not support this interpretation.

At Site 944, carbonate-rich mud and bioturbated mud recovered from Core 155-944A-39X was located in an interval of very poor recovery, but logging data suggest that it is continuous with an underlying fining-up sequence of mud with silt laminae. The upper samples contain *E. huxleyi*, which is absent from the lower samples. Oxygen isotope determinations again indicate that the downcore disappearance of *E. huxleyi* cannot represent the FAD.

At Site 935, carbonate-rich mud with 10%–25% $CaCO_3$ overlies a fining-up sequence of mud with silt laminae. The rich nannofossil assemblage contains intervals with *E. huxleyi* alternating with a rich *G. caribbeanica* flora. Pujos and Giraudeau (1993) assign this acme (in the absence of *P. lacunosa*) to isotopic Stages 9 and 11, but as noted above, abundant *G. caribbeanica* persisted in the Caribbean through at least the early part of Stage 7 (Gartner, 1972). The presence of *E. huxleyi* suggests that either the *G. caribbeanica* is reworked (Mikkelsen et al., this volume) or that there were ecologically influenced fluctuations in its abundance.

Seismic Data

Previous studies, based on closely spaced single-channel seismic profiles centered around the Amazon Channel, have identified four discrete groupings of individual channel-levee systems: the ULC, MLC, LLC, and the BLC (Manley and Flood, 1988; Flood et al., 1991, Damuth et al., 1995; Pirmez and Flood, 1995). Each complex is composed of numerous channel-levee systems. The relative ages of individual systems and the levee complexes are determined as they stratigraphically overlie, overlap, or bury one another. The relative ages of the ULC, MLC, and LLC were determined by Manley and Flood (1988), but earlier single-channel seismic profiles could not resolve the relationship between the LLC and the BLC. During ODP Leg 155, a high-resolution seismic line (Fig. 5) tied the seismic surveys of the Amazon channel region to the BLC, which was sampled at Sites 931 and 933.

The top of the LLC beneath the Amazon Channel (Fig. 5) was defined by Manley and Flood (1988) and sampled at Sites 935 and 936. This interface can be traced eastward toward Sites 931 and 933. Seven kilometers east of Site 932, this interface clearly onlaps a strong reflector associated with the top of the BLC determined from the core-seismic correlation at Sites 931 and 933. Though slightly weaker, the interface which represents the top of the BLC can be observed to continue westward beneath the LLC. This stratigraphic relationship shows that the LLC is relatively younger than the BLC.

Stratigraphic correlation of the levee sediments underlying the carbonate-rich layer at Site 942 is uncertain because of poor seismic control, but a tentative correlation can be made with the MLC (as illustrated schematically in Fig. 2).

Discussion

The seismic and sedimentological evidence for the relative ages of the carbonate-rich units is clear. Buried carbonate-rich units consist of hemipelagic sediment with typically 5%–25% biogenic calcium carbonate that show a gradual sedimentological boundary with underlying levee sediments that is analogous to the transition from Holocene hemipelagic sediment to terrigenous turbidites of the Amazon Channel-levee System. Carbonate-rich units at Sites 931 and 933 overlying the BLC are older, on the basis of seismic stratigraphy, than the carbonate-rich units at Sites 935, 936, and 944 that overlie the LLC. These, in turn, are older than the isotopic Stage 5 carbonate-rich unit at Site 942, overlying the MLC. The position of the two car-

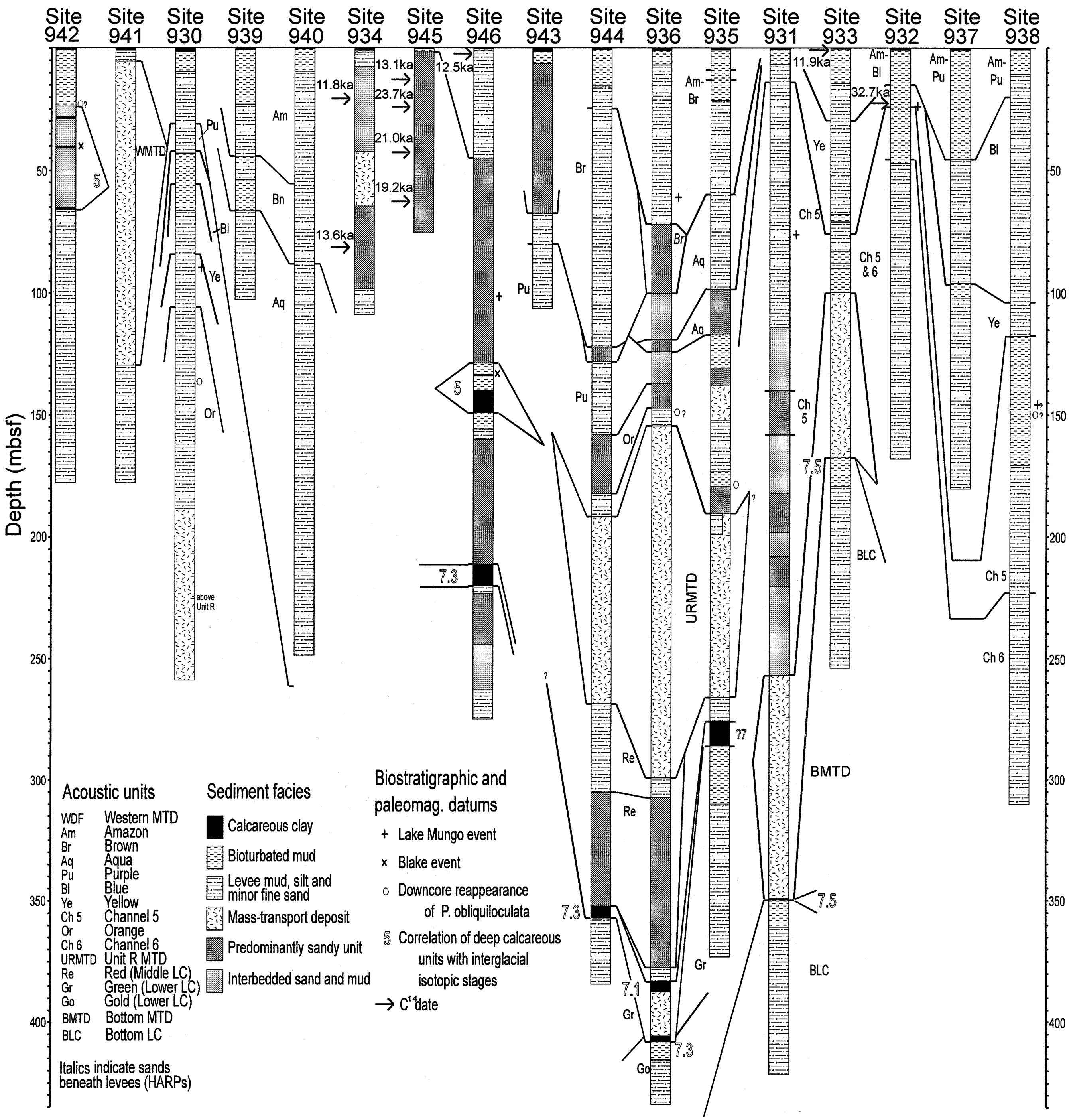

Figure 3. Summary stratigraphic columns for all sites (modified from Shipboard Scientific Party, 1995a), showing revised correlations discussed in this paper.

bonate-rich units at Site 946 relative to the seismic stratigraphy is not certain.

The nannofossil assemblages in the carbonate-rich units overlying the Bottom and Lower Levee Complexes are variable, with fluctuations in abundance of *E. huxleyi,* small *Gephyrocapsa,* and *G. caribbeanica.* The ubiquitous presence of *E. huxleyi* indicates that all the carbonate-rich units are younger than the *E. huxleyi* FAD in isotopic Stage 8. Mikkelsen et al. (this volume) suggest that abundant *G. caribbeanica* at some levels is a consequence of reworking. Alternatively, the abundance of nannofossil taxa may be ecologically determined and could be compared with cores P6304-4 and P6304-9 of Gartner (1972) in the southeastern Caribbean, where fluctuating abundances of *E. huxleyi,* open *Gephyrocapsa,* and *G. caribbeanica* are found throughout Stage 7.

Sedimentologically, the reworking hypothesis of Mikkelsen et al. (this volume) seems improbable. Coccolith-rich sediments make up a tiny fraction of the fine-grained sediment on the Amazon continental margin, and if there was sufficient resedimentation to give a rich *G. caribbeanica* assemblage, then a very high proportion of reworked glacial-age terrigenous sediment would be expected. Maslin and Mikkelsen (this volume) suggest that oxygen isotope determinations on benthic foraminifers provide evidence of reworking. However,

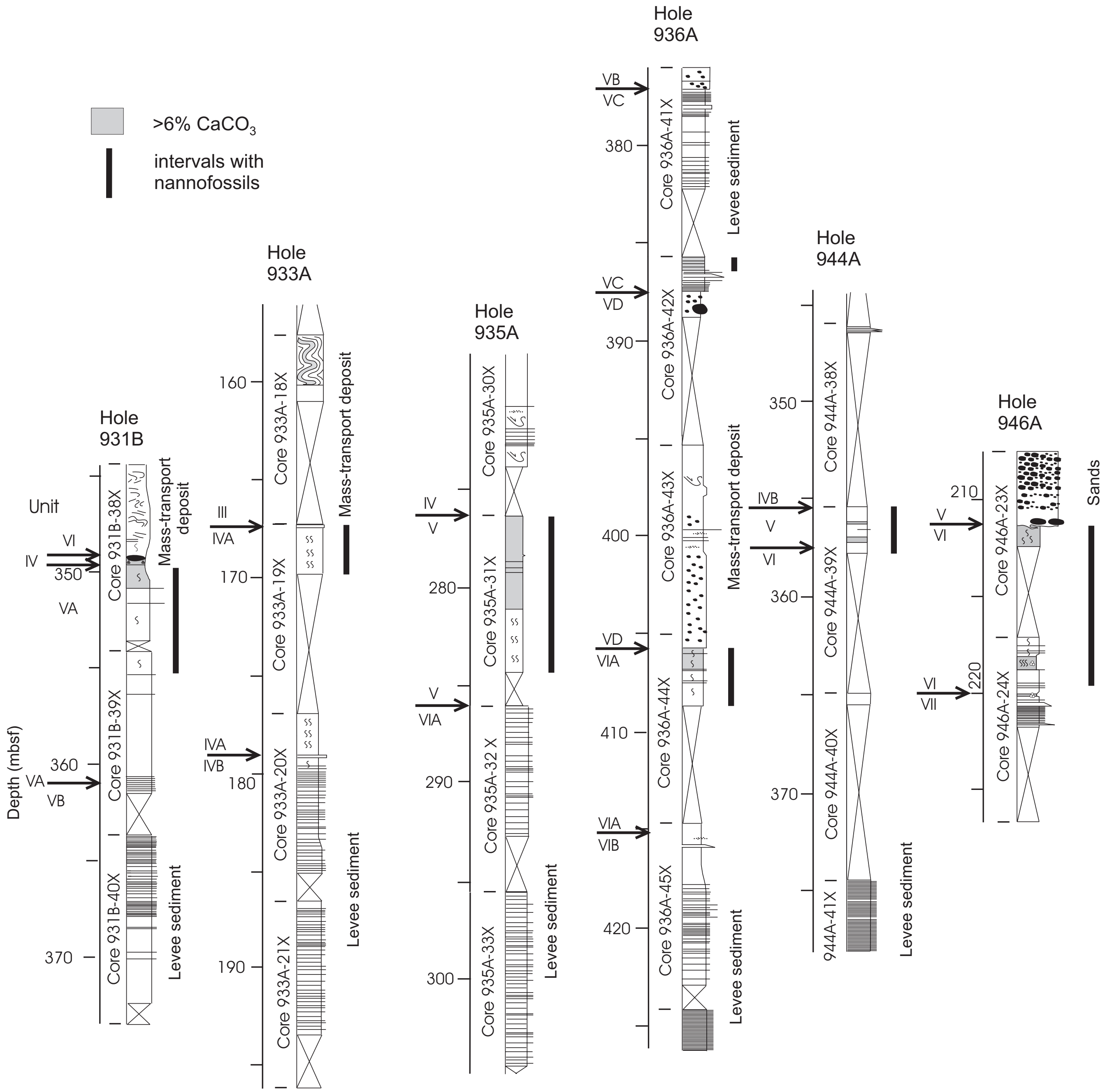

Figure 4. Lithologic setting of the buried carbonate-rich units older than Stage 5. Lithologic columns are taken from individual site chapters of Flood, Piper, Klaus, et al. (1995).

when integrated with sedimentological information, their data for *C. wuellerstorfi* from Site 933 is consistent with the sedimentological evidence that the sampled portion of the carbonate-rich unit represents the transition to the preceding glacial conditions, whereas at Site 936 (Core 155-936A-44X) it represents the transition to the subsequent glacial conditions. At neither site do either planktonic or benthic foraminifers show oxygen isotopes as light as in the Holocene. Some abraded *Uvigerina* spp. determinations at Site 933 are in the range of the last glacial maximum (LGM) values for Site 932; these may well be reworked. The substantial terrigenous component of the Holocene and buried carbonate-rich muds implies some “reworking” in the sense of a flux of sediment from the continental margin, resulting in a hemipelagic deposit, but most of this is probably from penecontemporaneous sediment rather than older deposits, which are rapidly buried in most areas.

Conclusions

Biostratigraphic, isotopic, and paleomagnetic data suggest that the deep levee sediment is overlain by Stage 5 interglacial sediment at Site 942. The levee sediment has been seismically correlated with the MLC, suggesting that the MLC dates from glacial Stage 6. Stage 5 carbonates are also identified at Site 946 on the basis of the presence of the Blake Event and a diverse nannofossil assemblage of zone

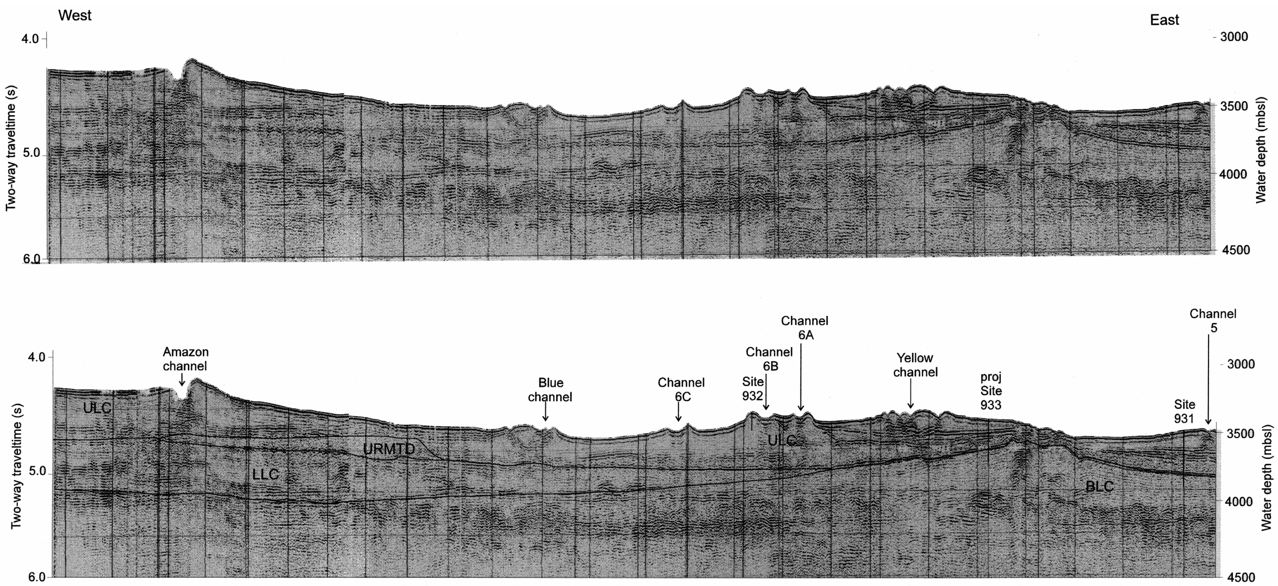

Figure 5. *JOIDES Resolution* seismic profile from the Amazon Channel to Site 931, showing the relationships of the Upper, Lower, and Bottom Levee Complexes.

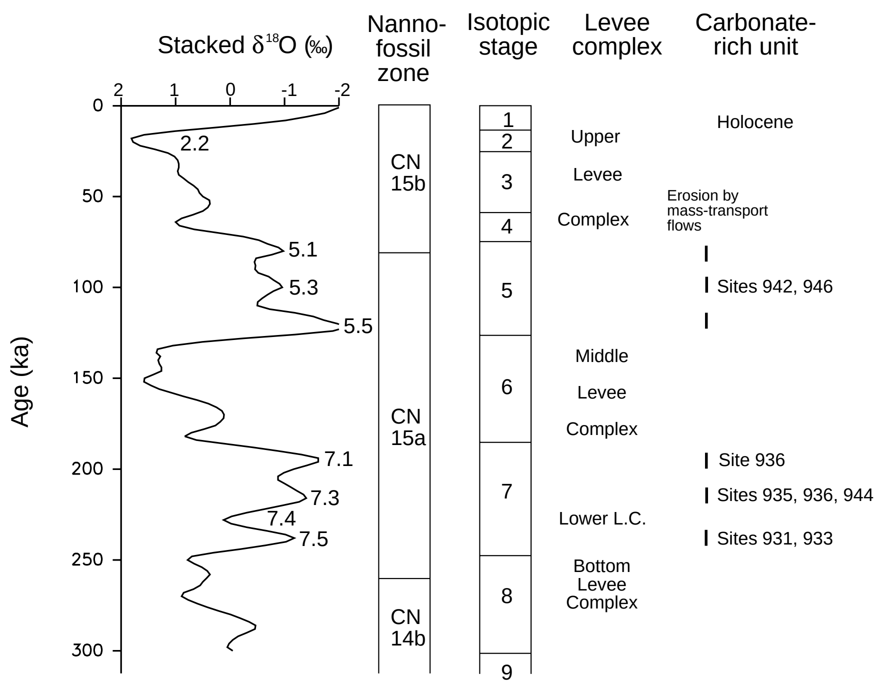

Figure 6. Tentative correlation of the carbonate-rich units with the stacked isotopic curve (proxy for eustatic sea level) of Martinson et al. (1987).

CN15a (Mikkelsen et al., this volume). At Sites 935, 936, and 944, carbonate-rich units overlie the LLC and at Sites 931 and 933, the Bottom Levee Complex. At all of these sites, nannofossils are of zone CN15a (interglacial Stages 5 or 7) and comparison of assemblages with known Stage 5 carbonates suggests that they probably represent Stage 7.

The seismic evidence presented shows that the LLC overlies the Bottom Levee Complex. Both are overlain by carbonate-rich units containing *E. huxleyi*, but lack the diverse nannofossil assemblage typical of Stage 5 (Mikkelsen et al., this volume). Our preferred interpretation (Figs. 6, 7) is that at Sites 931 and 933, the carbonate-rich unit represents the Substage 7.5 light-isotopic event (240 ka in the Martinson et al. 1987 chronology). Overlying hemipelagic sediments that accumulated during deposition of the LLC were removed by erosion by the BMTD (Figs. 3, 7). The LLC accumulated during the lowstand represented by the Substage 7.4 heavy-isotopic event, and the overlying hemipelagic sediments accumulated during the Substage 7.3 light-isotopic event (215 ka in the Martinson et al. 1987 chronology). The oxygen isotope data are consistent with the fact that neither 7.3 nor 7.5 was as isotopically light as the Holocene (Martinson et al. 1987; Fig. 6). The Substage 7.1 light-isotopic event may be represented by the upper carbonate-rich unit at Site 936 (Core 155-936A-

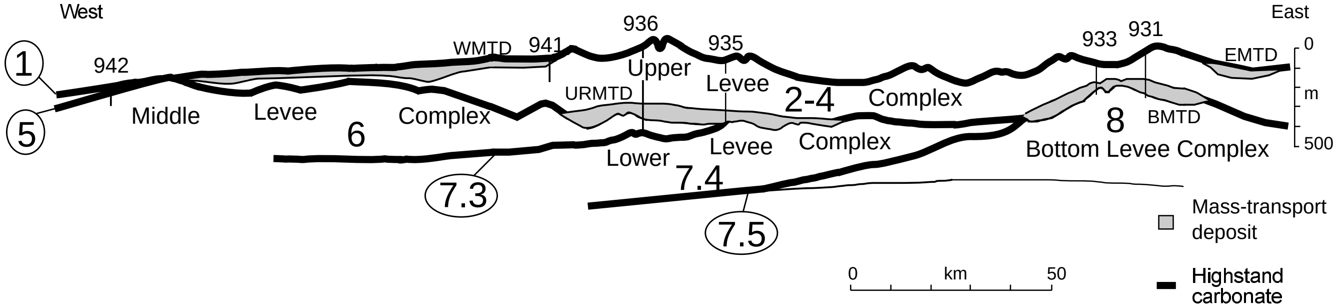

Figure 7. Schematic cross section of the Amazon Fan (cf. Fig. 2) showing the age assignment of the major levee complexes, MTDs, and highstand carbonate-rich units. Stages and substages are given in large, bold numbers.

42X) with very light oxygen isotopes. The preceding Substage 7.2, with only slightly heavier oxygen isotopes (Fig. 6), had a correspondingly small fall in sea level and may not have permitted the transport of significant Amazon river sediment across the shelf.

LATE PLEISTOCENE CORRELATION

Introduction

Sites 932 and 942 are important reference sites for isotope stratigraphy (Fig. 8). At both sites, Cisowski and Hall (this volume) correlated paleomagnetic intensity with the Mediterranean reference section of Tric et al. (1992). Isotopes at Site 942 were determined on *G. sacculifer* and correlated with the standard isotope curve (Showers et al., this volume). At Site 932, isotopes were determined separately for six species of planktonic foraminifers (Maslin et al., this volume). Heavy peaks in *G. sacculifer* are up to 1‰ greater than at Site 942. These heavy peaks are most pronounced in the *G. ruber* isotopic record (near-surface species), which was not determined at Site 942.

Correlation of isotopic records between sites is hindered by several factors. First, the Amazon Fan is an area of paleoceanographic complexity, as shown by the very different isotopic records at Sites 932 and 942. Second, whereas *G. sacculifer* has been analyzed from most sites, for some only *G. ruber* data are available. At Site 932, where both were analyzed, the two records show important differences (Fig. 4 of Maslin et al., this volume). Third, sedimentation rates are quite variable, and thus different sequences show varying degrees of resolution of the isotopic record.

Cisowski and Hall (this volume) used paleomagnetic data to derive an age model for Sites 932, 933, and 942 (Fig. 8). They correlated peaks in natural remanent magnetization (NRM) intensity normalized to anhysteretic remanent magnetization (ARM) intensity with the reference section of Tric et al. (1992) in the Mediterranean. Because of the relatively uniform sediment type and rock magnetic properties in most cores from Leg 155 (Hall et al., this volume), plots of raw NRM intensity show features similar to the normalized plots of Cisowski and Hall (this volume) and are illustrated in Figures 8 through 10. Variations in ARM have most effect on the record in the Holocene hemipelagic sediments compared with Pleistocene terrigenous sediments, but also result in differences between muddier and sandier Pleistocene sections. At Site 932, Cisowski and Hall (this volume) correlated a prominent normalized intensity peak at 5–6 mbsf with peak (A) of Tric et al. (1992), dated at 9 ka. However, the base of the Holocene hemipelagic sediment, which at most sites is at ~1 mbsf, appears to be ~9 ka on the basis of biostratigraphy (Fig. 11: discussed below), consistent with the isotopic record at Site 942 (Fig. 8) and the analysis of piston cores by Showers and Bevis (1988). The identification of peak A appears inconsistent with this data and with the isotopic record at Site 942, and it is therefore identified as peak A′ subsequently in this paper. Other peaks identified by Cisowski and Hall (this volume), however, are consistent with the isotope stratigraphy of Site 942 (Showers et al., this volume) and the radiocarbon dating of Site 932 (Maslin et al., this volume).

Maslin et al. (this volume) used detailed isotopic analyses from Sites 932 and 933, together with the NRM intensity record, to correlate the two sites. They demonstrated that isotopically heavy peaks correlate between the two sites and suggest that they result from times when there was a greater intrusion of saline South Atlantic water. In this section, we extend the methodology of Maslin et al. (this volume) to correlate between sites using heavy isotopic peaks and raw NRM intensity (mindful of its dependance on rock magnetic properties). Only those sites with sufficient data have been correlated. Where good data are available, we have also used the NRM inclination record. Our strategy in making correlations has been to use Site 932 as a reference site for downcore data, because of the large amount of isotopic data supported by ^{14}C dates and paleomagnetic data (all presented in Maslin et al., this volume). Comparison of oxygen isotope data at well-studied Sites 932 and 942 shows that patterns of isotopic variation in planktonic foraminifers are different on different parts of the fan, reflecting changes in the distribution and stratification of surface waters. There are insufficient foraminifers available to systematically determine isotopes on benthic species. For this reason, we have tried, where possible, to carry isotopic correlations between adjacent sites. Absolute values of oxygen isotopes may vary for the same stratigraphic level between slow and high sedimentation rate sites because of the increased effects of bioturbation in the former, but patterns should be similar. We have focused on correlating heavy isotopic peaks between sites and have termed these peaks *ha, hb, hc,* etc. We have accepted seismic correlation near levee crests, but have questioned seismic correlation in lower sedimentation rate sections more than 10 km from a channel. Where isotopic correlation is ambiguous, we have used NRM intensity to choose the most probable correlation.

Shipboard studies showed no simple correlations between changes in lithologic properties and magnetic susceptibility. At the same time, detailed correlations could be made between holes up to 500 m apart using magnetic susceptibility variations (Hall, this volume). In the case of Site 939, these variations were consistent with lithologic correlations, even though there was considerable lithologic variation between Holes 939A and 939B, 500 m apart. We show below that high-frequency variation in magnetic susceptibility can be correlated between nearby sites (e.g., dashed lines in Fig. 9B), provided that a general correlation is first developed using other techniques.

Slow Sedimentation-Rate Sites

At Site 932, Maslin et al. (this volume) identified four major heavy isotope peaks above the Lake Mungo paleomagnetic marker.

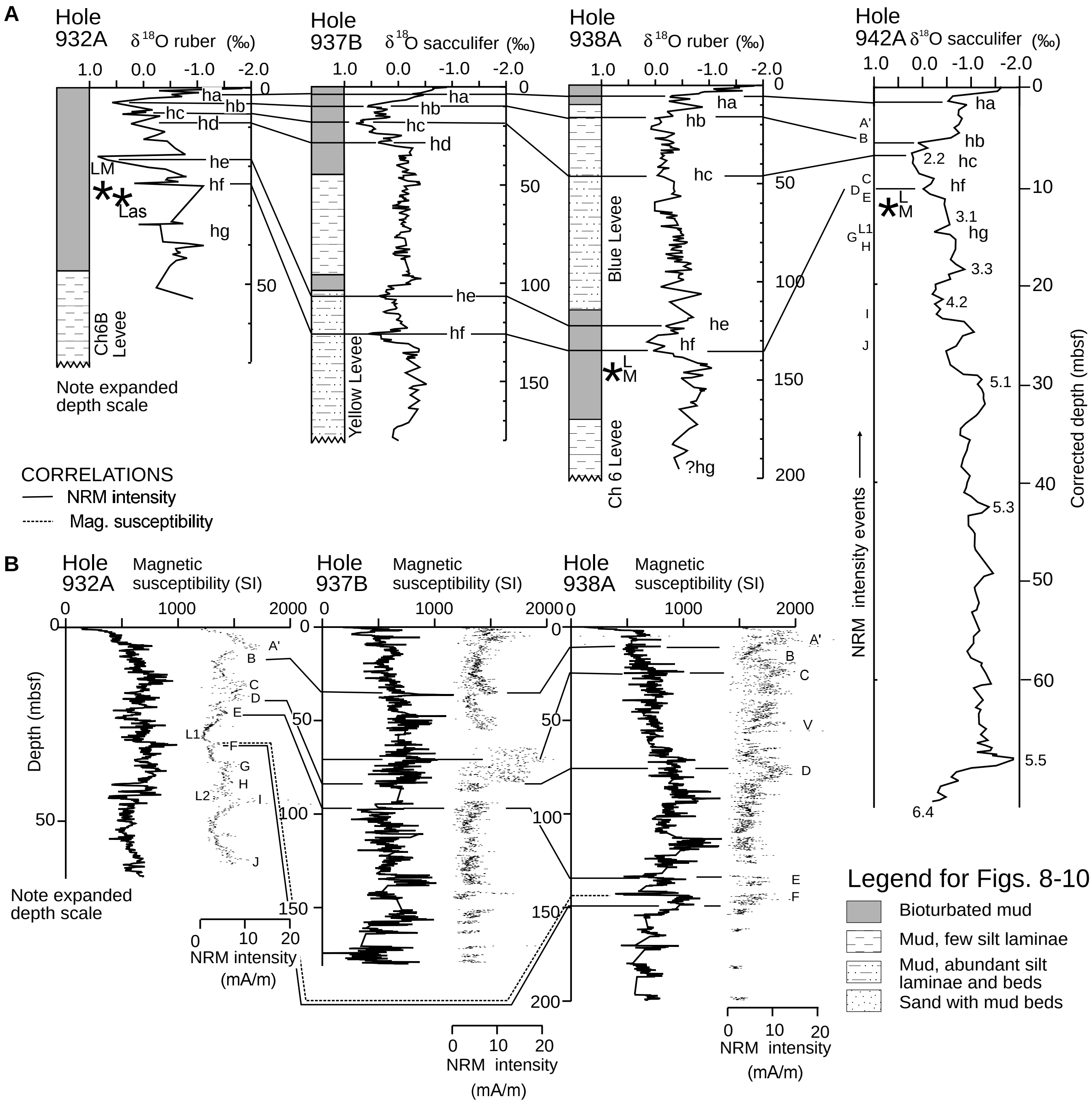

Figure 8. Downcore plots of (**A**) lithology and oxygen isotopes, (**B**) whole core magnetic susceptibility and raw NRM intensity, and (**C**) NRM inclination, showing the correlation of Sites 932, 937, and 938. Also shown is the oxygen isotope record for Site 942. In this figure, and in Figures 9 and 10, heavy isotopic peaks *ha* to *hg* are discussed in the text. LM = Lake Mungo Excursion; Las = Laschamps Event. A–J, L1, and L2 are the correlations of Cisowski and Hall (this volume) for Sites 932 and 942 with Tric et al. (1992); V–Z are additional peaks recognized in this study. All paleomagnetic data and the age model are from Cisowski and Hall (this volume). All isotope data are from Showers et al. (this volume). All magnetic susceptibility data (smoothed with a 3-point running average) are from Hall (this volume).

We have labelled these as *hb, hc, hd,* and *he* going downcore (Fig. 8). Maslin et al. (this volume) confirmed the presence of the Lake Mungo Excursion by radiocarbon dating. At Site 932, sedimentologic and seismic data both indicate the top of the Channel 6B levee crest occurs at 47 mbsf. Precise seismic correlation of the overlying succession is not possible because it is so thin.

Site 937 can be correlated by isotopes and magnetic properties with Site 932 (Fig. 8). The upper 10 m of both sites are similar, but below this the sedimentation rate is much higher at Site 937. The NRM intensity peak at 65–80 mbsf at Site 937 is correlated with intensity peaks C and D from 15 to 20 mbsf at Site 932. The heavy isotope peak from 120 to 130 mbsf at Site 937 is correlated with *hf* (24 mbsf) at Site 932.

The upper part of Site 938 can be correlated in detail with Site 937 (Fig. 8). General correlation is established using seismic correlation and the NRM inclination record (Fig. 8C). Once this framework is es-

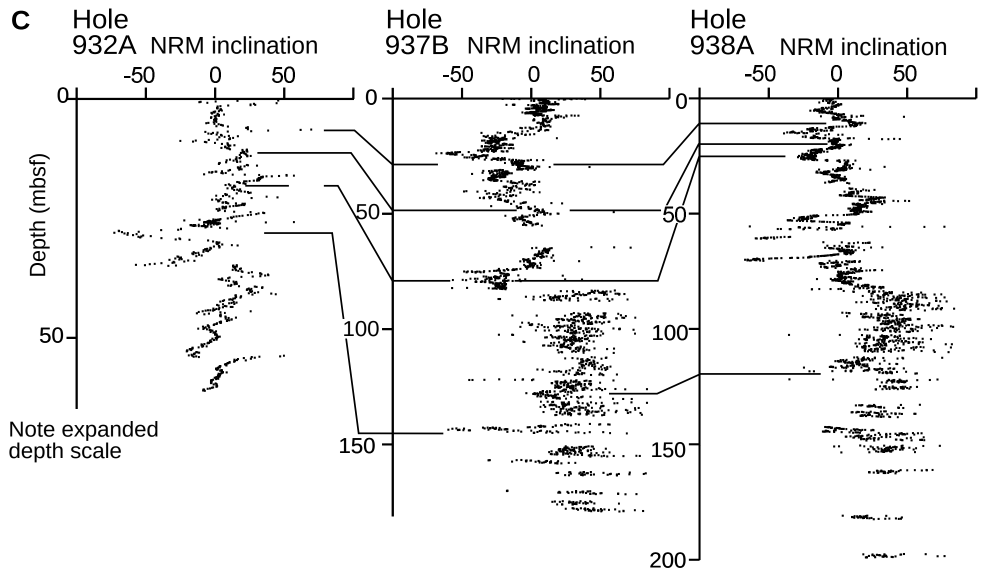

Figure 8 (continued).

tablished, correlations can be made on the basis of isotopes, NRM intensity, and magnetic susceptibility. Changes in seismic and sedimentologic character were used shipboard to identify the flank of the Blue Channel-levee System between 10 and 20 mbsf (top) and 117 mbsf (base). There is another sedimentological break at 171 mbsf, corresponding to the top of the Channel 6 levee crest.

Amazon Levee Sites

Initial correlation of Sites 935 and 936 is based on seismic stratigraphy. Site 935 has a thick Aqua levee sequence that underlies the Amazon and Brown levees at Site 936 (Figs. 3, 9). NRM inclination then provides a more precise correlation between the two sites (Fig. 9), which in turn allows NRM intensity and oxygen isotope peaks to be correlated between the two sites. Correlation can then be extended to Site 939 using the same techniques (Fig. 9).

Initial correlation of Site 940 is also based on seismic stratigraphy, because the site is located on the composite Amazon-Brown-Aqua levee. There is a clear correlation of the upper 60 m with Site 939 based on NRM inclination and intensity variations. The deeper part of Hole 940A can be correlated with less certainty with Hole 935A, but the quality of the NRM data is degraded by XCB coring. NRM inclination and intensity variations are also used to correlate Site 940 northward with Site 944, also located on the Amazon-Brown levee.

Seismic correlation indicates that the top 30–50 m at Site 930 correlate with the composite Amazon-Brown-Aqua levee. The Lake Mungo Excursion at this site is a further tie with Sites 931, 932, and 938. The NRM inclination record at Site 930 is fragmentary, but correlation with Site 935 is possible using the NRM intensity record. This suggests that the base of the Aqua levee at Site 935 corresponds to ~20 mbsf at Site 930 (Fig. 10). It thus seems probable that the interval of silty levee sediment between 20 and 43 mbsf corresponds to sedimentation from the nearby Purple Channel. The top of the Orange Channel-levee System was picked seismically at 106 mbsf.

Older Upper Pleistocene Sections and Mass-Transport Deposits

In general, core recovery below the level of the Lake Mungo Excursion was not as continuous as higher in the stratigraphic section, making stratigraphic interpretation more difficult. In particular, the evidence is unclear as to whether the top of the BMTD at Sites 931 and 933 is younger than, or the same age as, the top of the Unit R MTD at Sites 935, 936, and 944. The various lines of evidence are discussed by Maslin and Mikkelsen (this volume) and Piper et al. (Chapter 6, this volume). We do not think this issue can be resolved with the available data.

Revised Correlation of Channel-Levee Systems

The correlations developed above are broadly consistent with the shipboard seismic correlations reported in detail by Flood, Piper, Klaus, et al., (1995) and summarized in figure 3 of Shipboard Scientific Party (1995a). We discuss below significant changes that are illustrated in Figure 3 of this paper. Detailed sedimentology of each site is summarized in individual site chapters of Flood, Piper, Klaus, et al. (1995).

The detailed correlation of Sites 935 and 936 (Fig. 9) corresponds in general to the shipboard seismic correlation. The base of the Brown levee at Site 936 at 72 mbsf corresponds to 57 mbsf at Site 935 (Fig. 9). Since the Brown HARP is also found at Site 936, the base of the Brown Channel-levee System may be a little deeper. This boundary corresponds to the uppermost part of the seismically recognized Aqua Channel-levee System. Correlation of Sites 939 and 940 is also generally consistent with shipboard seismic picks and can be extended to Site 944. This correlation shows that correlatable units in the levee crest sites thicken only slightly down-channel.

Correlation between Sites 937 and 938 (Fig. 8), based on both paleomagnetism and isotopes, indicates that the shipboard pick of the boundary between the Yellow and Blue Channel-levee Systems at Site 937 is incorrect. At Site 938, the Blue levee flank can be recognized seismically and corresponds to sediment immediately above and below NRM intensity peaks D. This interval corresponds to ~80 mbsf at Site 937. Based on this correlation, the base of Blue at Site 937 probably corresponds to the downcore change from mud with common silt laminae to bioturbated mud at 96 mbsf. About 50 m of levee overbank turbidites correlative with the Blue Channel-levee System thus are found on the crest of the Yellow levee at Site 937.

At Site 933 (Fig. 10), the top of the mud with silt laminae at 14 mbsf, previously identified as the top of the Yellow Channel-levee System, corresponds to an interval correlating with the Brown Channel-levee System at Sites 936 and 940 (Fig. 9). Regionally, the Yellow Channel-levee System appears to underlie the Blue Channel-

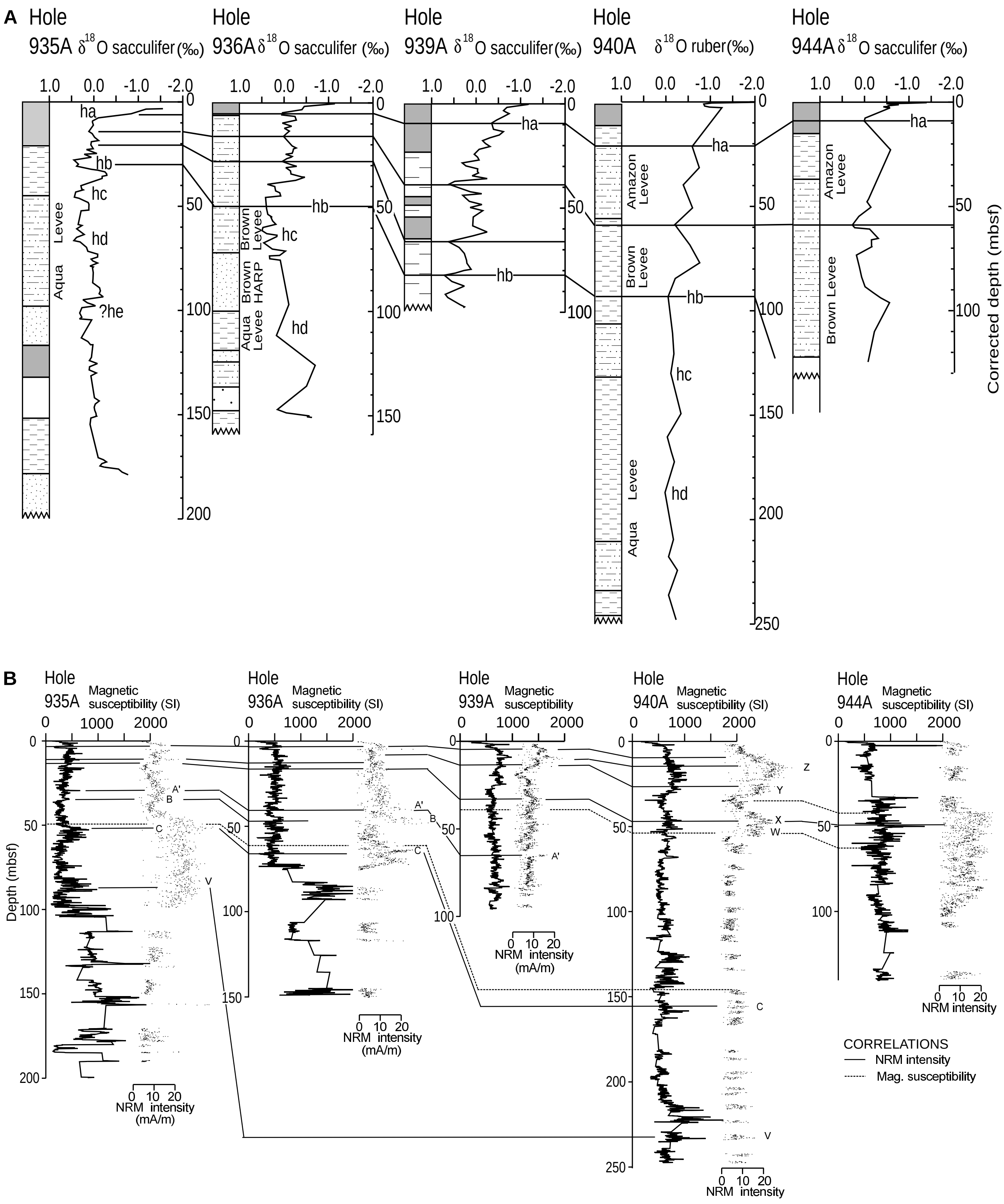

Figure 9. Downcore plots of (**A**) lithology and oxygen isotopes, (**B**) whole-core susceptibility and NRM intensity, and (**C**) NRM inclination showing the correlation of Sites 935, 936, 939, 940, and 944. Abbreviations and sources are the same as in Figure 8.

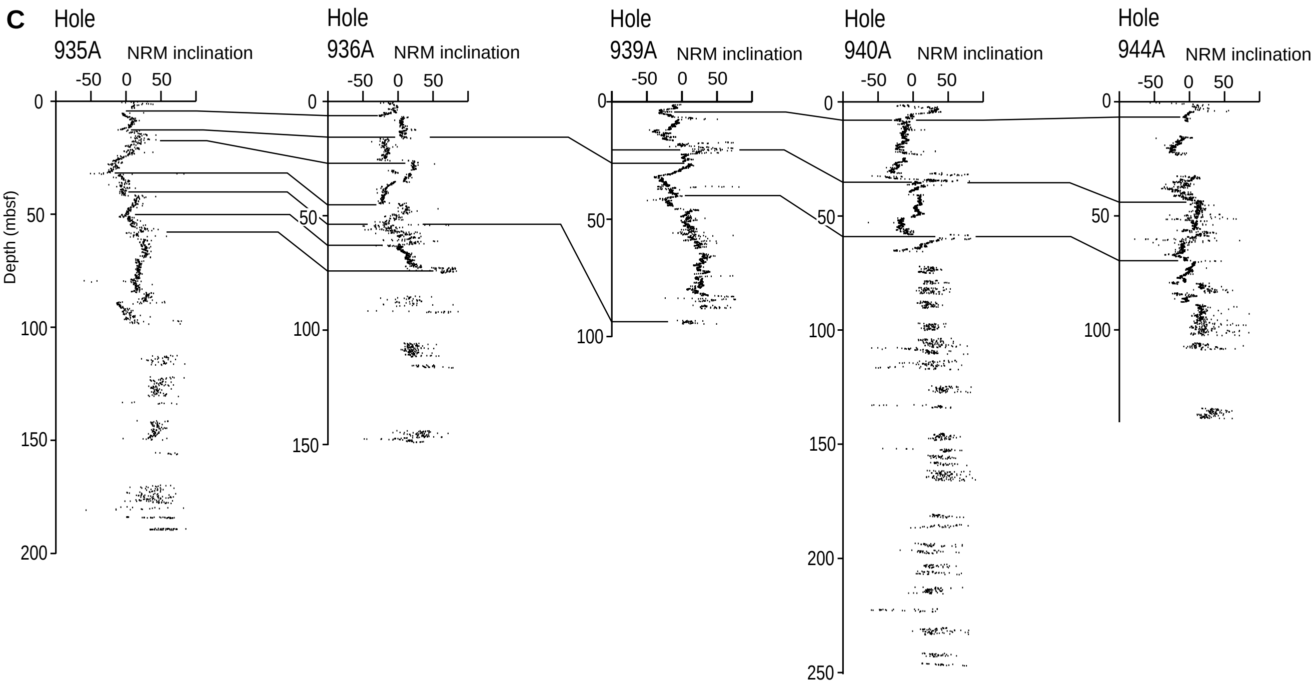

Figure 9 (continued).

levee System. The base of seismically identified Blue Channel-levee System at Site 938 at ~120 mbsf corresponds to an NRM inclination low between NRM intensity peaks E and F, and on this basis, appears to correlate precisely with the base of the Yellow Channel-levee System at Site 933. The base of the Blue Channel-levee System is probably either at an upsection increase in silt laminae at 103 mbsf or even higher in the section.

An abrupt downcore increase in the abundance of silt laminae at 67 mbsf at Site 930 correlates with the base of the Yellow Channel-levee System at Site 933 (Fig. 10) and probably corresponds to a change in distributary channel at that stratigraphic level. The seismically recognized top of the Orange Channel-levee System at 106 mbsf underlies the Lake Mungo marker. The mud interval from 67 to 43 mbsf correlates with the Yellow and Blue Channel-levee Systems.

There are thus several examples where mud with silt laminae is deposited on a levee at a time when another channel was active and rapidly depositing mud with silt and sand beds. We have not found any unequivocal evidence for two channels being fully active at the same time, although the Blue and Yellow channel systems, sampled at Sites 938 and 933 respectively, might overlap in activity. In this case, the old Channel "6" channel may have been a pathway for turbidity currents detached by flow stripping upstream. Continued nourishment of turbidity current channels by flow stripping, particularly at abrupt avulsion bends, would allow levees to continue to accumulate mud with silt laminae long after the main channel had changed course.

The Holocene Section

Detailed foraminifer study at Site 934 (Shipboard Scientific Party, 1995c) showed that *G. fimbriata, G. tumida,* and *G. menardii* all reappeared at different stratigraphic levels (Fig. 11), which can be tentatively dated on the basis of reappearance of these taxa in the North Atlantic (G. Jones, pers. comm., 1994). This suggests that the prominent diagenetic "crust" at this site dates from 6 to 7 ka, approximately the time that the sea level stabilized near its present level. The base of the calcareous mud of Unit I is at ~8.5 ka.

An Age Model

Ages for the correlatable entities discussed above are based on sparse data. Ages within the range of ^{14}C dating are given in radiocarbon years: no calibration to calendar years has been attempted. Available consistent radiocarbon ages are shown in Figure 3. Paleomagnetic excursions have been dated elsewhere: we use an age of about 32 ka for the Lake Mungo Excursion, confirmed by a ^{14}C date by Maslin et al. (this volume). Well-developed variations in paleomagnetic intensity in Sites 932 and 942 have been correlated with those described by Tric et al. (1992) from the Mediterranean and by Cisowski and Hall (this volume).

The preferred age model is based largely on that presented by Cisowski and Hall (this volume) and Maslin et al. (this volume) and is shown in Figures 12 and 13. Comparison is made with the intensity curve of Guyodo and Valet (1996) and the more detailed curve of Menardier et al. (1992) (Fig. 12). The LGM (global sea level low and heavy peak in benthic foraminifer oxygen isotopes) is represented by NRM intensity peak B, an interval between heavy isotope peaks *hb* and *hc*, and corresponds to the middle of the Brown Channel-levee System. The base of the surficial carbonate-rich mud (Unit I) at most sites is taken as 9 ka, based on data from Site 934 (Fig. 12). Heavy oxygen isotope peak *ha* may represent the Younger Dryas event at about 11 ka, based on a ^{14}C date at Site 934 and the isotope curve shown by Showers et al. (this volume).

CONCLUSIONS

1. The deepest part of the stratigraphic section penetrated on Leg 155, the Bottom Levee Complex, is conformably overlain by interglacial sediment of nannofossil zone CN15a that may date from oxygen isotope Substage 7.5. The presence or absence of *E. huxleyi* is inferred Stage 7 sediment appears to be variable, perhaps due to ecological factors or dissolution, and the absence of *E. huxleyi* is not necessarily evidence that a sample is older than the FAD of *E. huxleyi* in isotopic Stage 8.

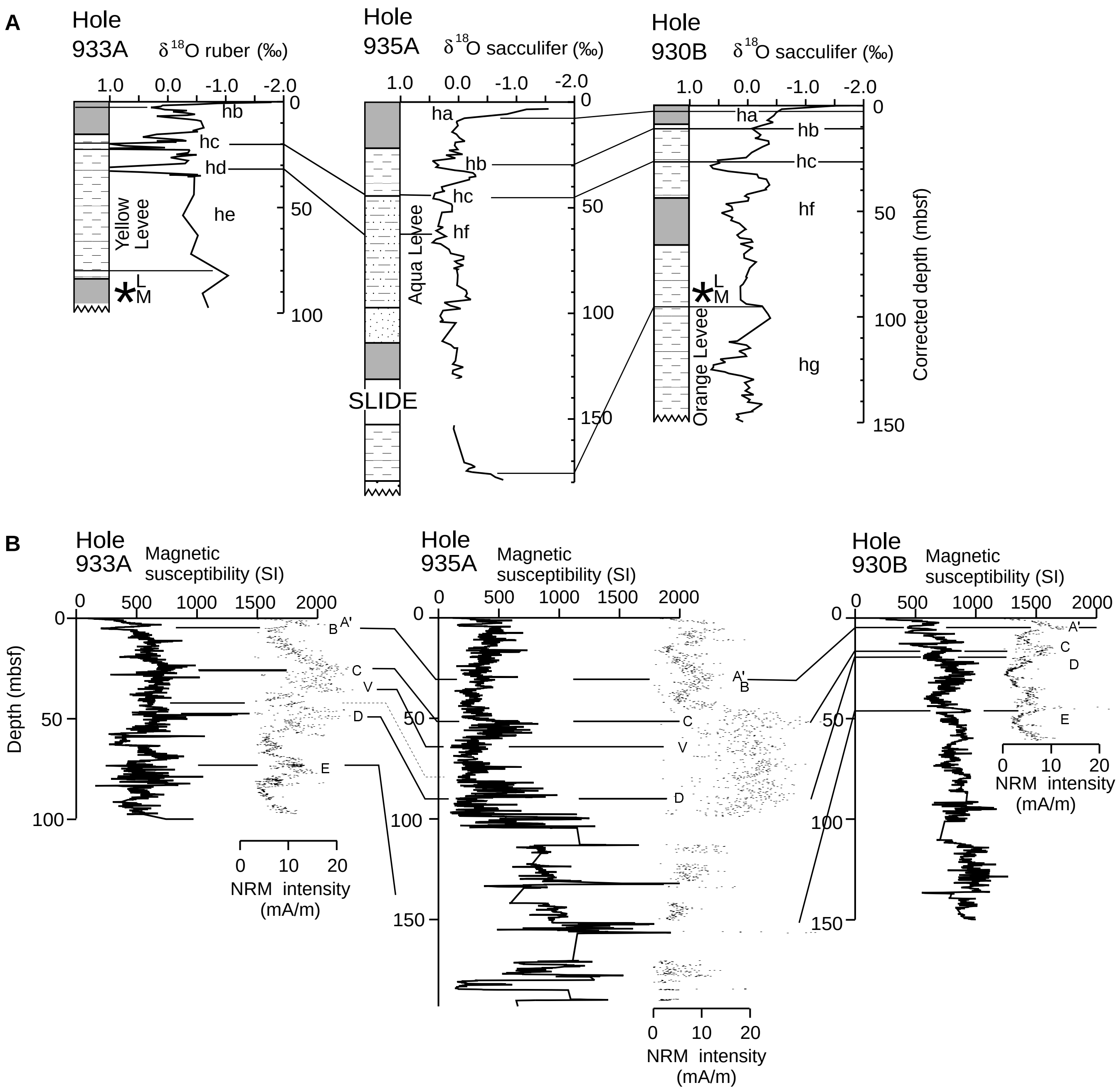

Figure 10. Downcore plots of (**A**) lithology and oxygen isotopes, (**B**) whole-core susceptibility and NRM intensity, and (**C**) NRM inclination showing the correlation of Sites 933, 935, and 930. Abbreviations and sources are the same as in Figure 8.

2. Isotopic Stage 5 highstand deposits are recognized at Sites 942 and 946. They may have been removed by erosion by mass-transport deposits at other deep sites. The available data do not allow a consistent stratigraphy to be developed for the late Pleistocene (Stages 4 and 3) prior to the Lake Mungo Excursion.
3. A consistent correlation is developed for sequences younger than the Lake Mungo Excursion, using oxygen isotopes, magnetic susceptibility and paleomagnetic intensity, and inclination. This correlation confirms that there is considerable variability in oxygen isotopes across the fan. The LGM is represented by the middle part of the Brown Channel-levee System. Shipboard seismic correlations are shown to be locally incorrect in detail. Several levees continued to accumulate mud with silt laminae, derived from flow-stripping of turbidity currents, after shifting of the active channel.

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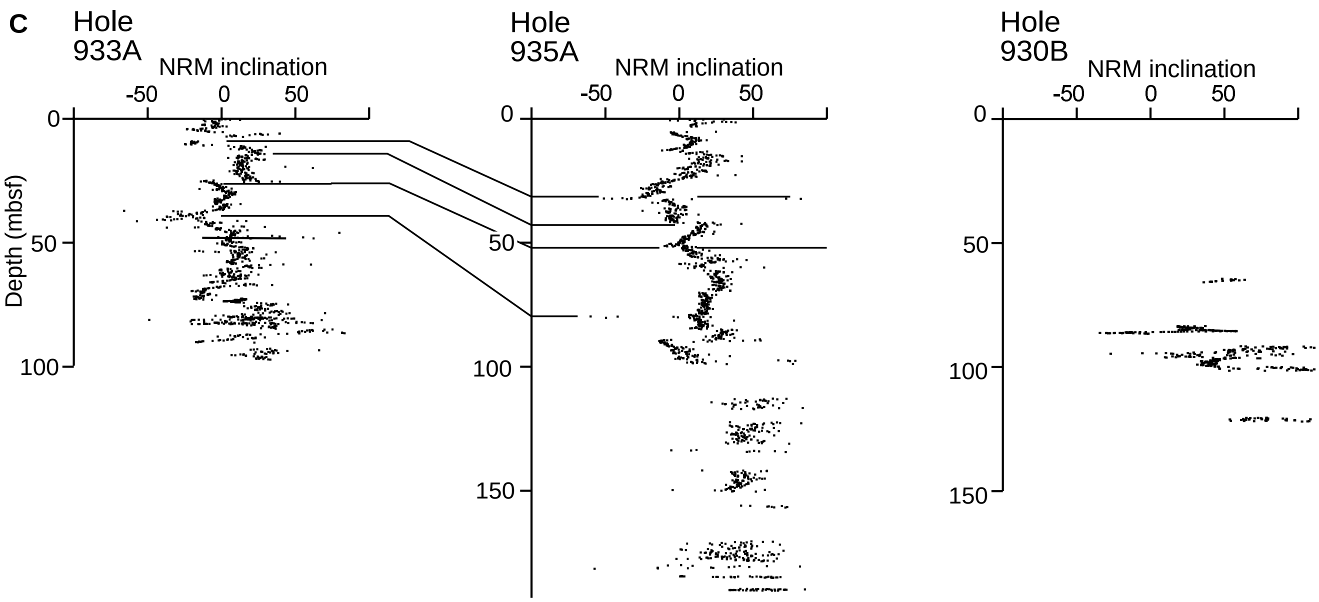

Figure 10 (continued).

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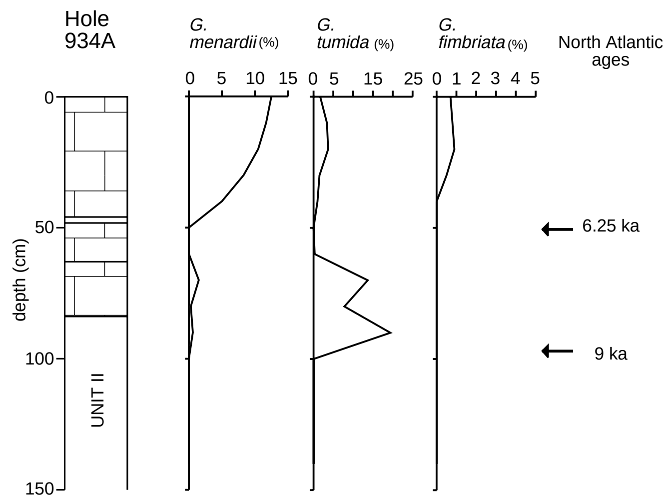

Figure 11. Foraminifer abundances at Site 934 and their relationship to lithologic features. Ages are those of the reappearance of species in the South Atlantic, based on ^{14}C dating by G. Jones (pers. comm., 1994).

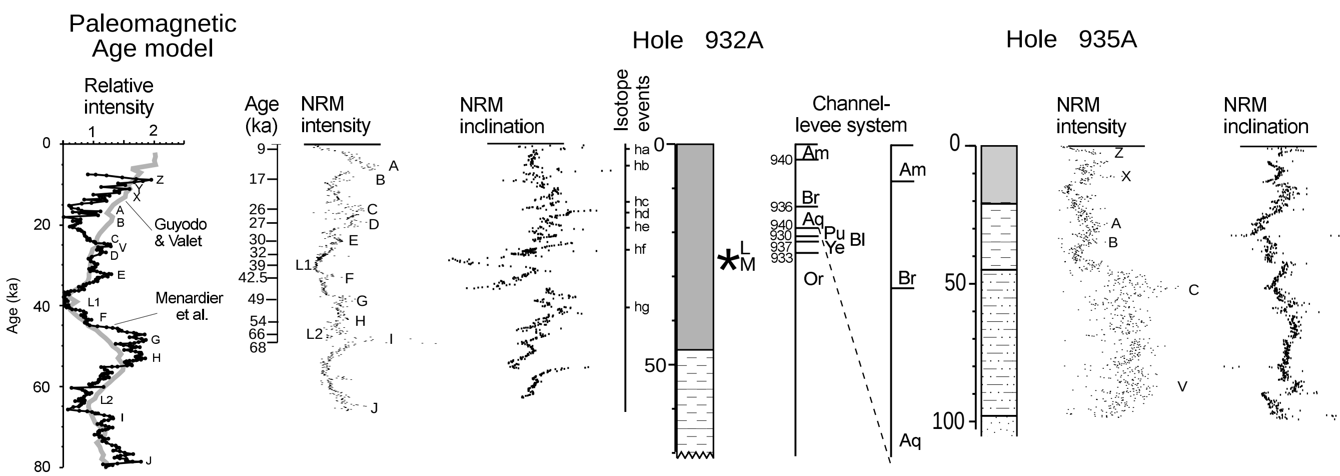

Figure 12. Lithology, NRM intensity, and NRM inclinations for Holes 932A and 935A. Channel-levee system boundaries indicated are based on correlation from Sites 932 and 935 to the sites indicated; abbreviations are as in Table 1. A–J, L1, L2 are the correlations of Cisowski and Hall (this volume) for Sites 932 and 942 with Tric et al. (1992); V–Z are additional peaks recognized in this study. The age model for Hole 932A is based on this correlation with Tric et al. (1992), except for the 9 ka age, which is based on radiocarbon and biostratigraphic dating of the base of the Holocene hemipelagic sediment at other sites. For comparison, we show the global NRM intensity stack normalized for the rock magnetic properties of Guyodo and Valet (1996) and the more detailed record of Menardier et al. (1992).

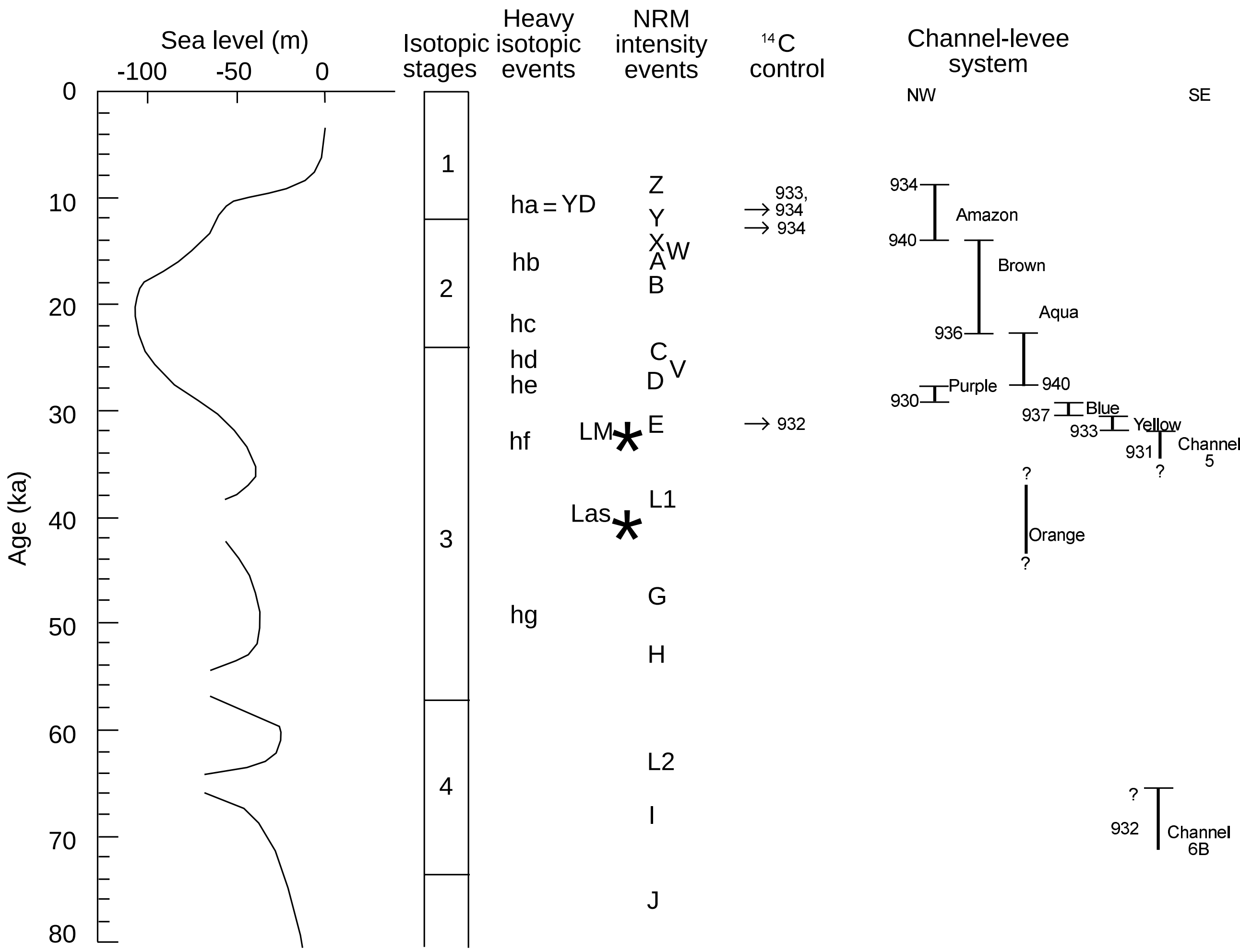

Figure 13. Summary of correlation of isotopic records, paleomagnetic events, and seismic unit boundaries, with a tentative age model for isotopic Stages 1–4 on the Amazon Fan. Sea-level curve is taken from Flood et al. (1995). Paleomagnetic events summarized by Cisowski and Hall (this volume) are shown in Figure 12. Site numbers identify those sites that provide control on ^{14}C ages and the activity of channel systems. YD = Younger Dryas.

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