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Core-log-seismic integration as a framework for determining the basin-wide significance of regional reflectors in the eastern equatorial Pacific

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Core-log-seismic integration as a framework for determining the basin-wide significance of regional reflectors in the eastern equatorial Pacific

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Abstract. ODP Leg 138 in the eastern equatorial Pacific (EEP) provided a unique opportunity to understand the paleoceanographic significance of seismic reflectors in this climatically sensitive region. Carefully offset multiple cores were spliced into a complete stratigraphic section for the upper 250 m at each site and accurate, astronomically tuned time scales were generated from these composites. Well log data provided a means to correct composite depths to true depths as well as density and velocity data for the generation of synthetic seismograms. These synthetic seismograms were used to determine the paleoceanographic significance of regionally traceable reflectors by linking variations in the core record to the seismic record. The EEP reflectors are due to changes in carbonate content, primarily due to variations in surface productivity, as indicated by the presence of mats of the upwelling diatom *Thalassiothrix longissima*. The EEP composite GRAPE records were successfully used as a tuning target for GRAPE records in the central equatorial Pacific (CEP), as a means to determine the basin-wide extent of EEP reflectors, and as a guide to the further interpretation of the CEP seismic record. It was found that EEP reflectors R3-t, R5, R6, R8-b, and Site 844 reflectors R10, R12-b and R13, correspond to reflectors in the CEP. However, some of the CEP reflectors, which were postulated to be due to periods of enhanced dissolution, also correspond to diatom mats, and hence the origin of these reflectors must be reconsidered.

Introduction

The goal of core-log-seismic integration in a pelagic setting is to relate paleoceanographic events found in the core record, to the seismic record, in order that the spatial and temporal extent of these events can be traced well beyond the borehole. In the course of this process, geophysical logging data acts as an intermediary in achieving this goal. ODP Leg 138, with over 5500 m of recovered sediment, 7000 m of borehole logged data, and 8800 km of single-channel digital seismic data from the eastern equatorial Pacific (EEP), provides a unique opportunity to perform such a study. Furthermore, each site was triple APC and double XCB offset cored with GRAPE density, magnetic susceptibility and color reflectance measured on all the cores (with sampling intervals between 1.5 and 4 cm), ensuring a continuous and complete stratigraphic section over the APC section (approximately the upper 250 m at each site) (Hagelberg et al., 1995). The

composite GRAPE records also provide the opportunity to develop an accurate, astronomically tuned time scale (Shackleton et al., 1995). However, these composites are typically 10% longer than the section drilled as measured by the length of the drill string. Although the source of this inconsistency is unresolved, inverse correlation of the GRAPE to the log density provides a means to correct back to true *in-situ* depths and check the validity of the composite (Harris et al., 1995).

Downhole log data also provides a means, through the generation of synthetic seismograms, of precisely relating paleoceanographic events found in the core record to the seismic record. Log density and velocity measurements (with core data supplementing the upper 75 m where log data do not exist), are combined to produce the downcore variations of acoustic impedance at each site. A series of reflection coefficients, related to the rate of change in the acoustic impedance, are convolved with a replica of the seismic source wavelet used during profiling, to produce synthetic seismograms. The synthetic seismogram is a model of the expected seismic record based on core and logging data and provides the basis for core-log-seismic integration.

Major Results of the EEP Study

Reflectors (or reflector packets) have been traced along 2000 km of profiles between the Leg 138 sites. The reflectors were chosen on the basis of amplitude, lateral continuity between the sites, and because the reflectors divided the section into zones having similar acoustic character. This paper will focus on the reflectors R3, R5, R6, and R8, (see Bloomer et al., 1995 Figures 4-8) which have been traced between the majority of Leg 138 sites and thus represent EEP wide events.

The first question to be investigated in this study is the cause of the reflectors, a question that the core-log-seismic integration process directly addresses. The reflectors are related to rapid changes in acoustic impedance (Figure 1), and in terms of physical property variations these correlate to rapid changes in grain density, porosity (not shown), and wet-bulk density. In terms of compositional variations, these major reflectors correspond to intervals with rapid changes in carbonate content. However, not all distinct changes in impedance result in laterally continuous reflectors. This may be due to lateral variability in the processes responsible for the changes in carbonate content or from destructive interference from numerous interfaces in deep-sea carbonate sequences, as demonstrated by Mayer (1979a).

The next question to be addressed deals with the sedimentary processes responsible for the reflector-causing carbonate content variations. To the far left of Figure 1 are plotted the intervals in which mats of the upwelling diatom
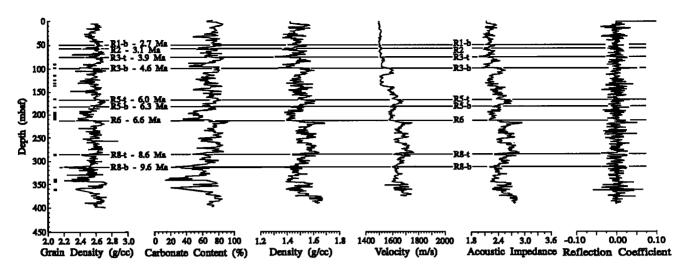
Figure 1. ODP Site 850 grain density, carbonate content, density, velocity, acoustic impedance and reflection coefficients with the location in the core and age of the major reflectors labeled. To the left of the grain density curve are the intervals where mats of the upwelling diatom *T. longissima* occur. Reflectors R3-b, R5, R6, and R8-t correspond to these mats are thus related to increases in surface productivity.

T. longissima (Pearce et al., 1995), an indicator of high-surface productivity (Sancetta, 1983), occur. The dominance of *T. longissima* (with a solid grain density of ~2.1 g/cm^3 as opposed to 2.6 g/cm^3 for carbonate) results in greatly reduced carbonate content. This, along with the higher porosity associated with siliceous tests (Mayer, 1979b), results in lower saturated bulk density in these diatom-rich intervals. This reduced density, in turn, produces an impedance contrast that is an excellent candidate for a major reflector. Reflectors R3-b, R5, R6, and R8-t correspond to these mats at Site 850, and it is inferred that these reflectors are caused by dilution of carbonate by opal due to a rapid increase in surface productivity. Not all reflectors are productivity events, however. Examination of the interval of reflector R8-b shows that it is associated with low nannofossil preservation indices and carbonate accumulation rates, as well as clay-rich sediment at the off-equator sites (Farrell et al., 1995).

Basin-wide Significance of EEP Reflectors

Based on the evidence presented above, many of the regionally traceable reflectors in the EEP are related to productivity events. By relating these reflectors to reflectors found in other studies, the basin-wide and potentially global significance of these events can be ascertained. Of particular interest are results from DSDP Leg 85 in the central equatorial Pacific (CEP), where the reflectors are thought to be related to periods of enhanced dissolution (Mayer et al., 1986).

To relate these two regions, the different timescales that formed the framework of these two studies must be resolved, as we are comparing the synchroneity of events in lieu of the direct tracing of digital seismic data between the two areas (such data do not exist). Bloomer et al. (1995) attempted to use biostratigraphic zonation to resolve this problem, but the age resolution of the zones is too coarse (coarser than the uncertainty due to limitations of seismic resolution), as is the depth resolution of the biostratigraphic markers (especially for the Leg 85 sites). However, a consistent time scale with a much finer resolution can be achieved by

correlating the GRAPE records from Leg 85 to the complete GRAPE stratigraphy from Leg 138. This process is similar to many of the earlier attempts to correlate Pacific carbonate events (for example Vincent, 1981; Dunn and Moore, 1981), except it is done at much finer resolution and against a complete stratigraphic section.

Correlation between the EEP and CEP GRAPE data was performed using the Analyseries CFR Macintosh software package from the Centre des Faibles Radioactivite. Figure 2 shows the results of this correlation process between EEP Site 851 and CEP Site 573 (0.498° N, 133.310° W, separated by ~2500 km) over the interval 0-5 Ma. Over this interval, complete composite GRAPE records from Sites 849, 850, and 851 exist. For DSDP Site 573, GRAPE data from
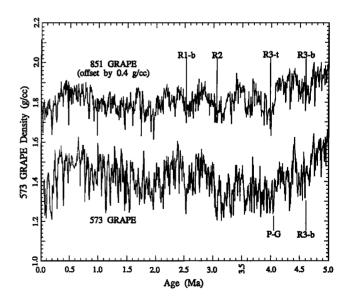

Figure 2. Results of GRAPE correlation between EEP Site 851 and CEP Site 573 over the interval 0-5 Ma with the locations in the core record of the reflectors found in Figure 3 labeled. Note that R3-t and R3-b correspond to paleoceanographic events with a lateral extent of ~2500 km.
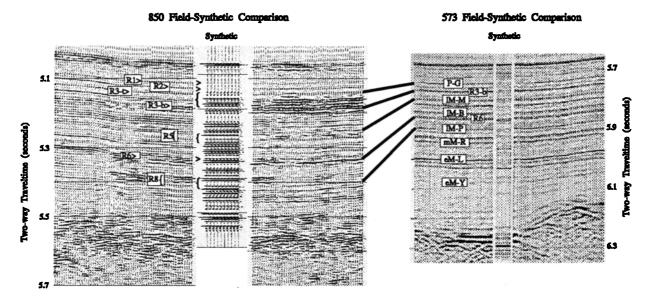
Figure 3. Interpreted Site 850 and 573 seismic profiles with the correlative reflectors between the two sites connected by solid lines. The consistent age model developed for Site 573 by GRAPE correlation aided the further interpretation of the Site 573 seismic record and other basin-wide reflectors were identified.

overlapping cores were used to create a composite section. The correlation process was constrained by the available Site 573 magnetic polarity reversals and biostratigraphic datums. The correlation coefficient between these two data sets is 0.68; for comparison, the correlation coefficient between 850 and 851 GRAPE over this interval is 0.78. This suggests that the age model developed for Site 573 is quite good and now consistent with the EEP time scale over this interval. Evolutionary spectra (Mayer, 1991) over this interval, revealing the change through time of the response of the system to orbital forcing, also confirms this conclusion.

Over the interval 5-10 Ma, a similar correlation was attempted by matching GRAPE minima while attempting to satisfy the available diatom datums. Previous correlation of Pacific carbonate events by Vincent (1981) and Dunn and Moore (1981) in the late Miocene suggest that a fundamental correlation between the GRAPE records should also exist. However, the lack of overlapping core and log data, as well as · poorer recovery downhole, make construction of composite sections (and precise time control) for this interval deficient and thus hampers attempts to correlate the EEP and CEP sections. The correlation coefficient between the EEP and CEP GRAPE records over this interval is 0.5; we interpret this as the result of incomplete sections although a there may be a fundamental lack of correlation between the two sites.

Armed with relatively consistent timescales from 0-10 Ma from the EEP (Site 850) and CEP (Site 573), more accurate comparisons of the reflectors can now be attempted (Figure 3). Synthetic seismograms demonstrate that reflectors at both sites are related to rapid changes in density (Mayer et al., 1986; Bloomer et al., 1995). The occurrence of these reflector-causing changes were dated using our consistent timescale and it was found that the green, magenta, and purple reflectors of the CEP (Mayer et al, 1986) correspond to reflectors R3-t, R5-t and R8-b (Figures 2 and 3). Therefore, these reflectors represent paleoceanographic events spanning both the EEP and CEP.

The consistent time scale also aids the further interpretation of untraced reflectors in the CEP to determine the connection (if any) between other EEP reflectors and the CEP. For instance, R6, which represents a major change from high to low carbonate content in the EEP (Figure 1), is associated with an untraced reflector in the CEP. This reflector also corresponds to a major change in density (carbonate content), as well as mats of *T. longissima* (Kemp, personal communication), at Site 573, suggesting that productivity, and not solely dissolution, plays a role in forming CEP reflectors.

For many of the DSDP 85 sites the stratigraphic section is relatively expanded in the mid and early Miocene relative to the last 10 Ma (for instance at Site 574, the average sedimentation rate is ~8 cm/kyr over the last 10 Ma, ~20 cm/kyr for the early to mid Miocene (Theyer et al., 1985)). For a similar comparison of mid-Miocene reflectors, EEP Site 844 (7.921° N, 90.461°W) and CEP Site 574 (4.209° N, 133.330° W) were chosen. Site 844 represents the most expanded and complete mid-Miocene record of the Leg 138 sites. Again density minima were correlated between Sites 574 and 844 while trying to satisfy the known biostratigraphic datums. Figure 4 shows the results of the correlation of the GRAPE records from these two sites. Over the period 7.5-14.5 Ma, a correlation coefficient of 0.82 was obtained, an amazing correlation given that these two sites are presently 5000 km apart.

Site 844 reflectors R10, R12, and R13 are related to *T. longissima* mats and thus are productivity events while the EEP reflector R8-b is associated with clay minerals and is thus a dissolution event. The main result is that the CEP red reflector, as well as the further interpreted CEP reflectors corresponding to R10 and R12-b (Figure 4) also correspond to these diatom mats, further demonstrating the role that productivity has played in forming seismic reflectors in the CEP.

Berger and Mayer (1986) stated that "if event mapping is to reach its potential as a tool for addressing the fundamental problems of the oceans response to forcing, a concerted
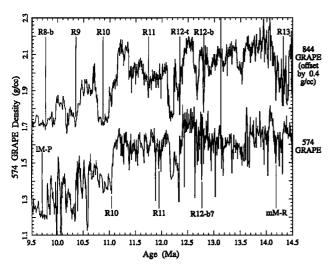
Figure 4. Results of GRAPE correlation between EEP Site 844 and CEP Site 574 over the interval 9.5-14.5 Ma (mid-Miocene) with the locations in the core record of the reflectors found in the seismic record at each site (not shown). Note that R10, R12, and R13 correspond to paleoceanographic events with a lateral extent of ~5000 km. These 3 reflectors correspond to diatom mats at both sites, suggesting that increases in surface productivity, and not solely enhanced dissolution, are responsible for CEP reflectors.

effort is necessary to generate a generalized, high-resolution marine stratigraphy." Our ability to relate the GRAPE and seismic records of the CEP to the long, carefully-tuned EEP stratigraphy of Leg 138 demonstrates that we are approaching this point.

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