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Tying seismic data to geologic information from core data: an example from ODP Leg 177

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Abstract The integration of seismic data with core data should provide ground-truth to a structural interpretation of seismic data. The main difficulty in such an integration effort is the correct translation of physical property measurements on cores to a form which can be used in seismostratigraphic interpretation. In the absence of down-hole well data and check-shots, required knowledge of the velocity structure at the drilling locations can be obtained directly from measurements of the physical properties of core samples. This involves upscaling of the data from physical properties of cores to the sample interval used in the seismic data. In the present study, three of the seven drill-sites of ODP (Ocean Drilling Program) Leg 177 in 1997/1998, located on the Agulhas Ridge in the south-eastern Atlantic (sites 1088–1090), were connected with eight seismic profiles. Physical properties data measured on the cores from the various holes at each site were combined to create a single continuous log and used to construct synthetic seismograms. The synthetics generally show a good agreement with real seismic data in terms of amplitude and waveform. Some reflections in these generated traces may have a time-shift due to sections with incomplete or spurious P-wave velocity measurements in the ODP datasets. The main reflectors identified in the real seismic data correspond to hiatuses or periods of reduced sedimentation rates, and correlate well with density variations. One particular hiatus, clearly observable in the real seismic data, was not unequivocally identifiable in the various types of core data, and tying core data to seismic data can confirm its existence in the core data, showing the benefit of including seismic data in an interpretation of core log data. On the other hand, core data provide a calibration tool for the geological timescale of seismic data and information about the lithology, needed in the interpretation of seismic data.

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Introduction

Understanding geological history generally requires the integration of data from different disciplines. When studying the activity of palaeo-currents, correlation of seismic with other geological data might offer insight into the coverage and the volume of sediment transport and erosion. Interpretation of reflectors in the seismic data can show how widespread associated hiatuses and the various facies identified in the cores are. Usually, down-hole logging measurements are used to link seismic and well data, supplemented by check-shots, i.e. a geophone is inserted in the well and records the traveltime of seismic waves generated by a source near the top of the hole, a procedure typically repeated at several marker horizons. In case no such well data are available but core samples exist, tools such as the P-wave logger (PWL), to generate P-wave velocity data, and the gamma ray attenuation porosity evaluator (GRAPE) for measurement of sediment density can be used to provide a velocity and density profile along the cored sections, which in turn can be used to create synthetic seismic data. These synthetic data can then be combined with real seismic data for a joint seismic interpretation. Various Deep Sea Drilling Program (DSDP) and Ocean Drilling Program (ODP) projects, but also the Cape Roberts Program, have successfully taken the approach of integrating physical property measurements on core samples with seismic data (Flood and Shor 1984;

Cooper et al. 1992; Bloomer and Mayer 1997; Kimura et al. 1997; Henrys et al. 2000; Zühlsdorff and Spiess 2001). The objective of this paper is to describe the steps needed, and the pitfalls encountered in a joint interpretation of AWI (Alfred Wegener Institute) seismic data and Leg 177 core data.

ODP data from Leg 177, run in the southern Atlantic Ocean in 1997/1998, provide an excellent dataset to assess core-to-seismic correlation. Core data at three locations of Leg 177 were supplemented by multi-channel seismic reflection data acquired by the Alfred Wegener Institute, Bremerhaven, for a seismostratigraphic interpretation of the study area. The aim of both Leg 177 and the seismic campaign was to document sedimentary processes under the influence of variations in ocean currents associated with climate change in the Antarctic region since the Cretaceous. Tying core data and seismic data provides the potential to extrapolate findings based on core information over a wider area, as well as the possibility to calibrate the depth of units in the seismic data.

The geological data from the cores need to exist in a form which is compatible with the available geophysical information—for example, seismics. This is accomplished through the petrophysical information extracted from physical properties measurements on core samples. Unfortunately, this can introduce serious bias, as in situ conditions in the well differ from those in the laboratory, due to the pressure release of the cores, pore-water modifications, material loss during drilling operations, and temperature changes (Boyce 1976; Hamilton 1976). Also, core sections are usually sampled at smaller intervals, in the centimetre range, and sometimes at irregular intervals, compared to intervals of several metres corresponding to sample rates typically applied in a seismic survey. To convert between the depth scale of the core data and the timescale of the seismic data, an integrated velocity profile along cores is used. Because errors can lead to a mismatch of reflectors between core-derived synthetics and real seismic data, this velocity profile needs to be accurate to unequivocally tie the core data with the seismostratigraphic units.

Study site, ODP data and seismic survey

ODP Leg 177 data

The cores of Leg 177 were collected, December 1997 through January 1998, with the objective of reconstructing the palaeo-oceanographic, biogeographic and biostratigraphic history of the Antarctic region in the Palaeogene and early Neogene (Gersonde et al. 1999). This is the timeframe during which the Antarctic ice sheet developed, associated with major changes in oceanographic currents (Lawver and Gahagan 1998).

The seven ODP Leg 177 core sites were situated in the eastern South Atlantic, several hundred kilometres southwest of Cape Town, South Africa. Three of the sites were located near the Agulhas Ridge, a ridge associated with the Falkland–Agulhas Fracture zone (Fig. 1a). The Agulhas Ridge separates the Cape Basin from the Agulhas Basin by a 2.5-km elevation of the seafloor above the adjacent ocean basins (Fig. 1b). Up to 400 m of mainly calcareous sediments was cored on the ridge and in the basins (Fig. 2). Site 1088, the northernmost site of Leg 177, is located on the Agulhas Ridge itself (Fig. 1b). The core (length 233 m) is constituted mainly of calcareous sediments of the middle Miocene to the present day, and shows several hiatuses (Gersonde et al. 1999). Site 1089 (length

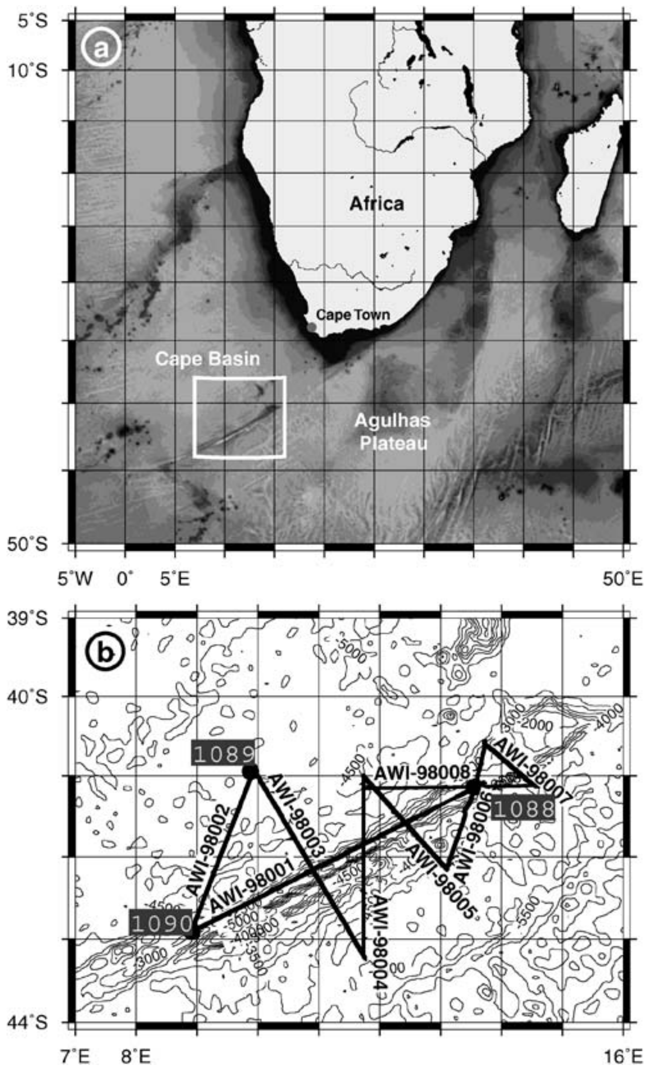


Fig. 1 **a** Bathymetry map of the Agulhas Ridge study area (*rectangle*; after Sandwell and Smith 1997). **b** Seismic profiles AWI-98001 through AWI-98008 and drilling locations of ODP Leg 177 sites 1088, 1089 and 1090 (*dots*)

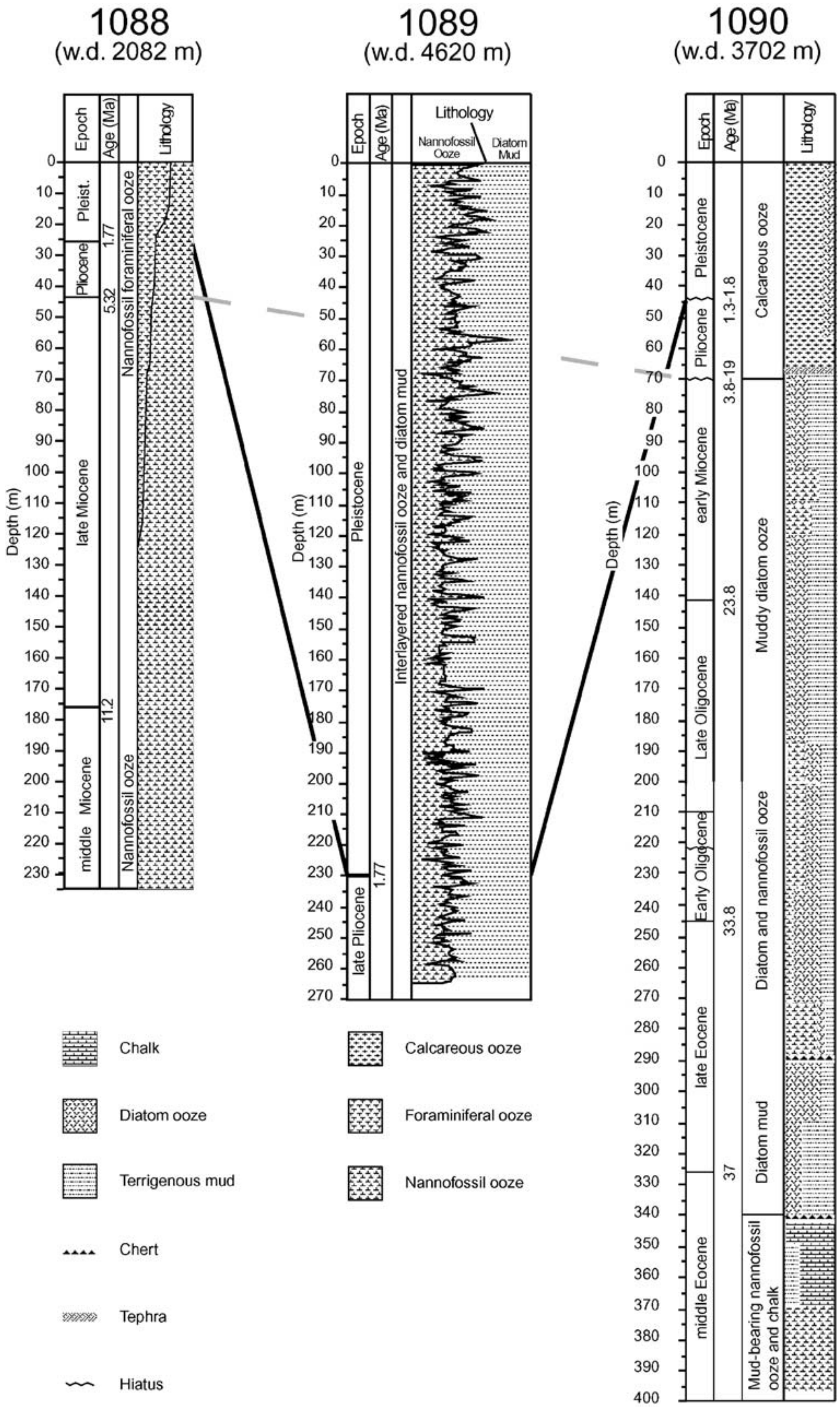


Fig. 2 Lithologies for ODP Leg 177 sites 1088, 1089 and 1090 (after Gersonde et al. 1999). *W.d.* Water depth

ca. 265 m) is located in the Cape Basin (Fig. 1b), and shows diatom ooze and nannofossil mud mainly younger than the Pliocene (Gersonde et al. 1999). In comparison with sites 1088 and 1090, this short geological time span is characterised by high sedimentation rates, which allows for millennial-scale temporal analysis. At site 1089, sediment porosity is higher than that at the other two sites. The oldest sediments were recovered at site 1090, in the south-western part of the Agulhas Ridge (Fig. 1b). The depth range of 406 m contains sediments up to the late Eocene, predominantly of calcareous composition. Cores from site 1090 show two major hiatuses, which have been linked to variations in deep water circulation. Between the lower Miocene and early Pliocene, an 11.7 Ma hiatus was recorded, possibly related to the emplacement of cold and corrosive bottom water masses (Galeotti et al. 2002). A possible hiatus between the Pliocene and Pleistocene (Gersonde et al. 1999) is likely due to variations in the depth and location of the boundary between various deep water masses (Venz and Hodell 2002).

Overall, there is a good agreement between moisture and density (MAD) and GRAPE densities for all three sites. At site 1088, a down-hole increase of density can be observed, which coincides with increasing carbonate content (Gersonde et al. 1999). The density data of site 1089 show an increase down-hole, implying compaction. Site 1089 bulk density data show a considerable cyclicity with a period of 120–140 ka (Gersonde et al. 1999). Similarly to site 1088, high density values at site 1090 correspond to low-porosity, carbonate-rich sediments. The lower density values correspond to intervals rich in diatom ooze (Gersonde et al. 1999). Remarkable is a strong drop in density at 70 m which coincides with a disconformity, below which biogenic opal content increases and carbonate content decreases (Fig. 3).

The P-wave velocity we used was measured by means of a P-wave logger mounted on the multi-sensor track (MST) but this device suffered from a calibration error in threshold detection (Gersonde et al. 1999). PWL data were of poor quality at all three sites, due to high signal attenuation and insufficient contact between the sediment and core liner, combined with a non-optimal threshold setting (Gersonde et al. 1999). As a result, a low signal can cause the auto-picker to trigger on the second wavelet, rather than the first. This artificially lowers the recorded traveltime, and yields low apparent velocities. Figure 4 shows that there are clearly two trends for the P-wave velocity at all three sites, one near and above 1,500 m/s and one which is lower and therefore unrealistic, as it is below the seismic velocity of water. The P-wave velocity was also measured with a P-wave velocity sensor 3 (PWS3) contact probe system at irregular intervals. Compared to the PWL velocities, the velocities recorded with this device are consistently higher for all three sites (Fig. 4) but, especially for site 1088 and the top 50 m of site 1090, the PWS3 data are too sparse and scattered to be useful for constructing a P-wave velocity record.

Seismic survey

During a seismic campaign in December 1997 and January 1998 carried out in the eastern South Atlantic by the Alfred Wegener Institute for Polar and Marine Research, seismic reflection profiles were collected with a total length of approx. 2,000 km along the Agulhas Ridge and in the adjacent parts of the Cape and Agulhas basins (Uenzelmann-Neben 1998), connecting the three locations of ODP Leg 177 near the Agulhas Ridge.

Materials and methods

An energy source of two GI-guns, of 45 cubic inch volume each and operating at a pressure of 150 bar, yielded seismic records with a bandwidth of approx. 150 Hz and a frequency maximum near 75 Hz (Fig. 5). This provided the necessary resolution within the sediments and a penetration reaching the basement. Data were recorded with a sample interval of 1 ms on a Syntron 96 channel streamer with 25 m spacing between the channels. The shot interval of 10 s approximates 25 m between successive shots.

No down-hole logging data had been collected at any of the holes of Leg 177 located near the Agulhas Ridge. Therefore, determinations of bulk density and seismic velocity were carried out by means of shipboard measurements on whole-round core sections run through an MST, and sampled at an interval of either 2 or 4 cm for analysis of physical properties (Gersonde et al. 1999). In general, data from core measurements are not sampled in a way which is directly comparable to that for seismic profiles. A basic problem is that seismic data are measured in the time-domain whereas core data are measured on a depth scale. Seismic data, sampled at 1 ms interval, are insensitive to very small-scale layering, equalling a sampling rate of 75 cm to 1 m in the depth-domain for assumed seismic velocities of 1,500 to 2,000 m/s. With a dominant frequency of the data from the seismic survey below 100 Hz, this means that the resolution of the data from the seismic survey is considerably lower than that for the ODP data. Detailed information on the relationship between depth and time is needed to perform a conversion, for which velocity information can be obtained from sonic logs or measured from core samples in case sonic log data are not available (Adcock 1993). Velocities measured on sediment cores originating from depths shallower than a few hundred metres tend to be up to 5% lower than corresponding down-hole measurements (Blum 1997). The

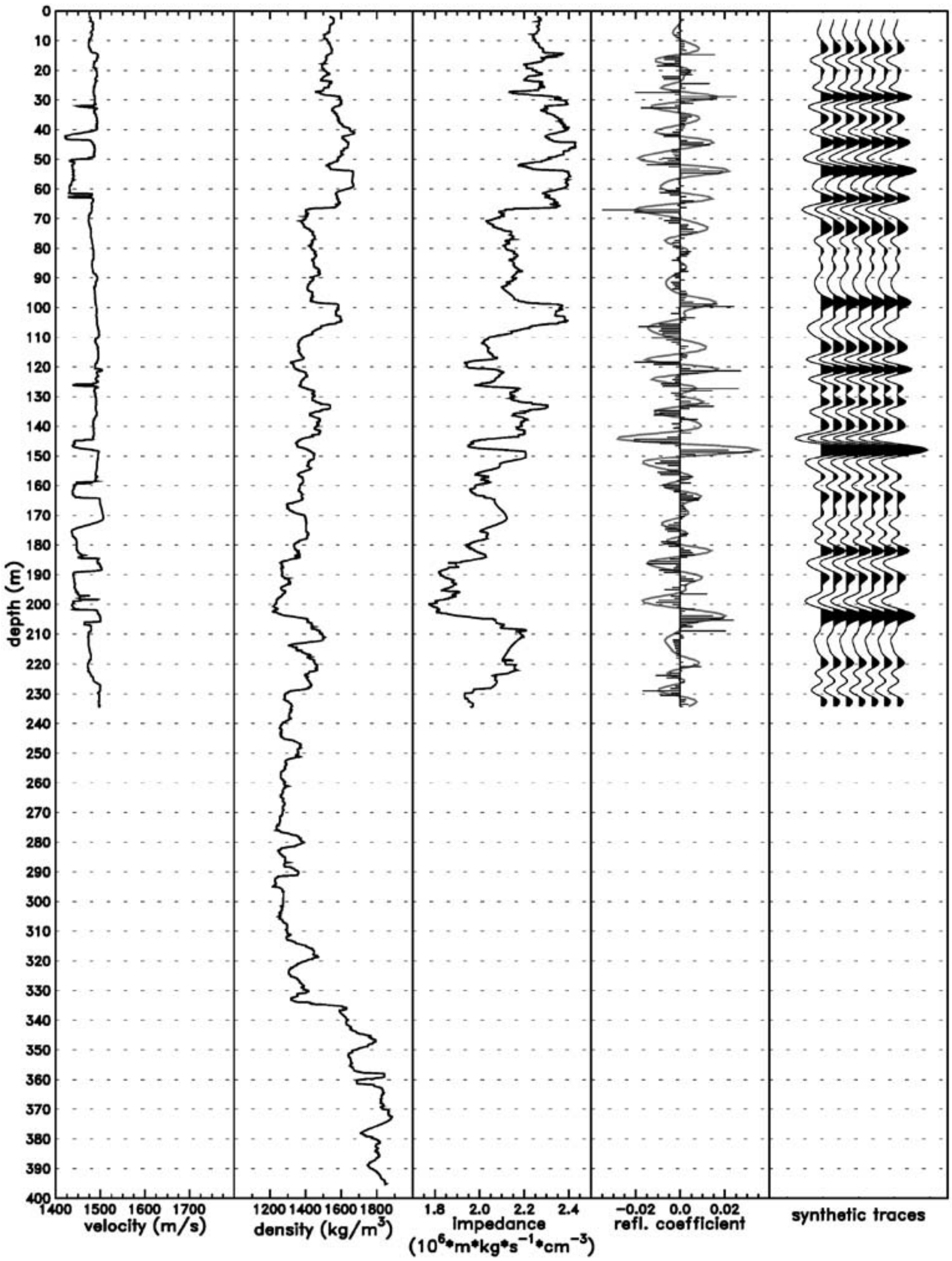


Fig. 3 Composite P-wave velocity log from PWL measurements and density log from GRAPE measurements for site 1090, used to calculate seismic impedance and reflectivity. Superimposed on the reflectivity record is the synthetic seismic trace (in *grey*) calculated from the reflectivity by convolution with a 75 Hz Ricker wavelet. The synthetic seismogram on the *right* consists of the same traces

accuracy of onboard gamma ray attenuation measurements for general sediment-water mixtures is such that the error in bulk density is less than 5% (Blum 1997). Data from previous ODP projects suffered from these problems, too, as discussed by several authors (Shipley 1983; Edwards 1998; Sun 2000; Delius et al. 2001).

Conversion of ODP logs to synthetic seismic data

We used the raw, unfiltered data supplied by the ODP to construct a composite P-wave and density record for each site. Figure 6 gives an overview of the depth ranges for which density and P-wave velocity values are available. Numerous intervals exist in which no measurements are available for either P-wave velocity or density or both, especially in the lower part of site 1089, e.g. at 150–160 and 195–207 m depths. The limited overlap in the depth range covered by the three holes of site 1088 explains why a hole-to-hole correlation was not possible (Gersonde et al. 1999). The density of the core samples was obtained by GRAPE measurements, and additionally weight and volume measurements on selected samples. The MAD measurements were generally conducted only once or twice per 10 m core section, resulting in a very sparsely sampled log

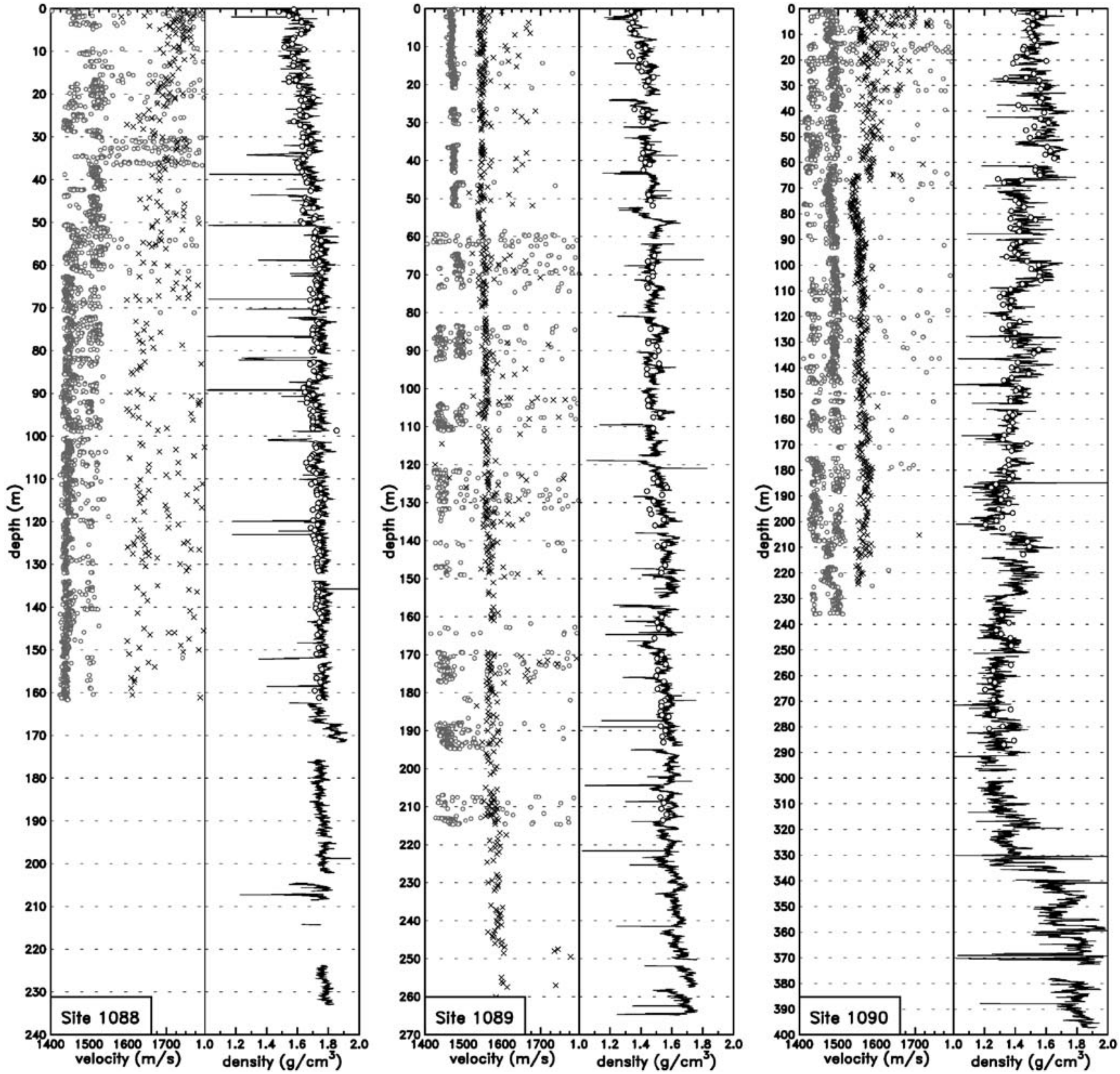


Fig. 4 P-wave velocity from PWL (*circles*) and PWS3 (*crosses*) measurements and density values from GRAPE measurements, with MAD density superimposed (*circles*), for sites 1088, 1089 and 1090 of Leg 177 (data extracted from the ODP Janus database at http://iodp.tamu.edu/janusweb/links/links_all.shtml)

(Fig. 6). The GRAPE density values, on the other hand, generally exist over the whole length of a hole (Fig. 6) and, combined in composite logs for the three sites (Fig. 4), they yield a series which we used in the construction of synthetic seismograms after filtering of spurious measurements.

Poor quality data resulting from device coupling problems usually necessitate filtering and interpolation for missing data. Interpolation is also necessary when seismic P-wave velocity and density are measured at different intervals on core sections. Median filtering is used to remove spurious values from the data series without affecting strong instantaneous contrasts, i.e. at buried erosional surfaces. A threshold value is used to remove the ambiguity in the velocity data caused by the auto-picking algorithm of the P-wave logger.

From the velocity and density profiles measured on the ODP cores, a reflectivity series was calculated after re-sampling and spline-interpolation to reduce the sensitivity to effects on a smaller scale than the real seismic data warrants, and to have a continuous and regularly sampled

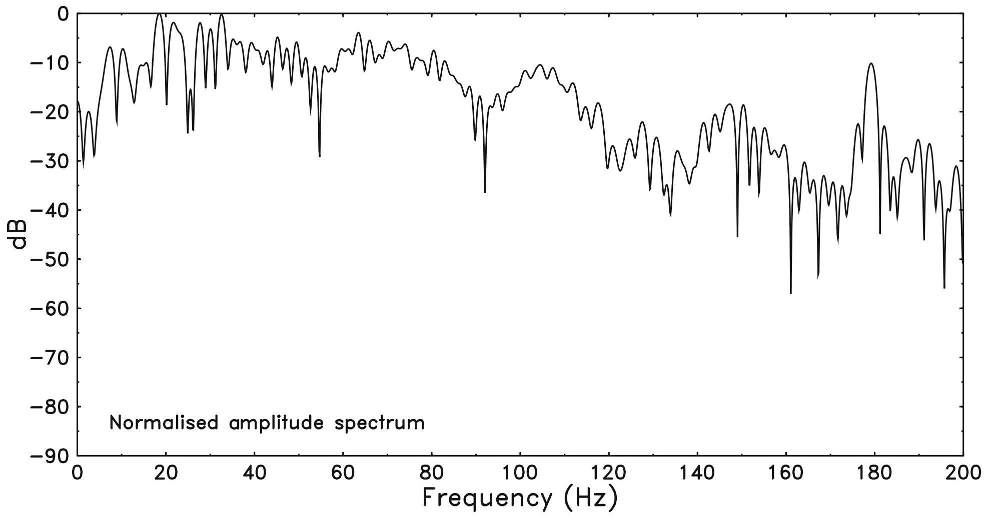


Fig. 5 Frequency spectrum of the seismic data (in dB) normalised to the maximum amplitude

series of data. For the deeper parts of the wells, however, only density information is available (Fig. 6), in which case an empirical relationship to estimate the missing variable, such as Gardner's (Gardner et al. 1974; Adcock 1993), has to be used. Internal reflections in the sediment layer were included in the calculation of the synthetic traces, although their influence is very small due to the small reflection coefficients.

The data from the seismic survey were processed to approximate a zero-phase section to facilitate interpretation. Spherical spreading was accounted for; other gain corrections, such as for attenuation loss, were not applied. Rough weather conditions necessitated extensive editing and filtering of noisy traces, especially for large offsets. A bandpass filter of 25 to 200 Hz was used for traces with offsets smaller than 700 m. The low-cut frequency was raised to 55 Hz for larger offsets where low-frequency contamination of the data dominates the signal. A residual source static correction proved to enhance trace-to-trace coherency significantly, necessary for a meaningful seismic velocity analysis. Additional processing steps were carried out to further improve the signal-to-noise ratio of the stacked sections, by improving lateral coherence within the CMP records. The processing did not involve deconvolu-

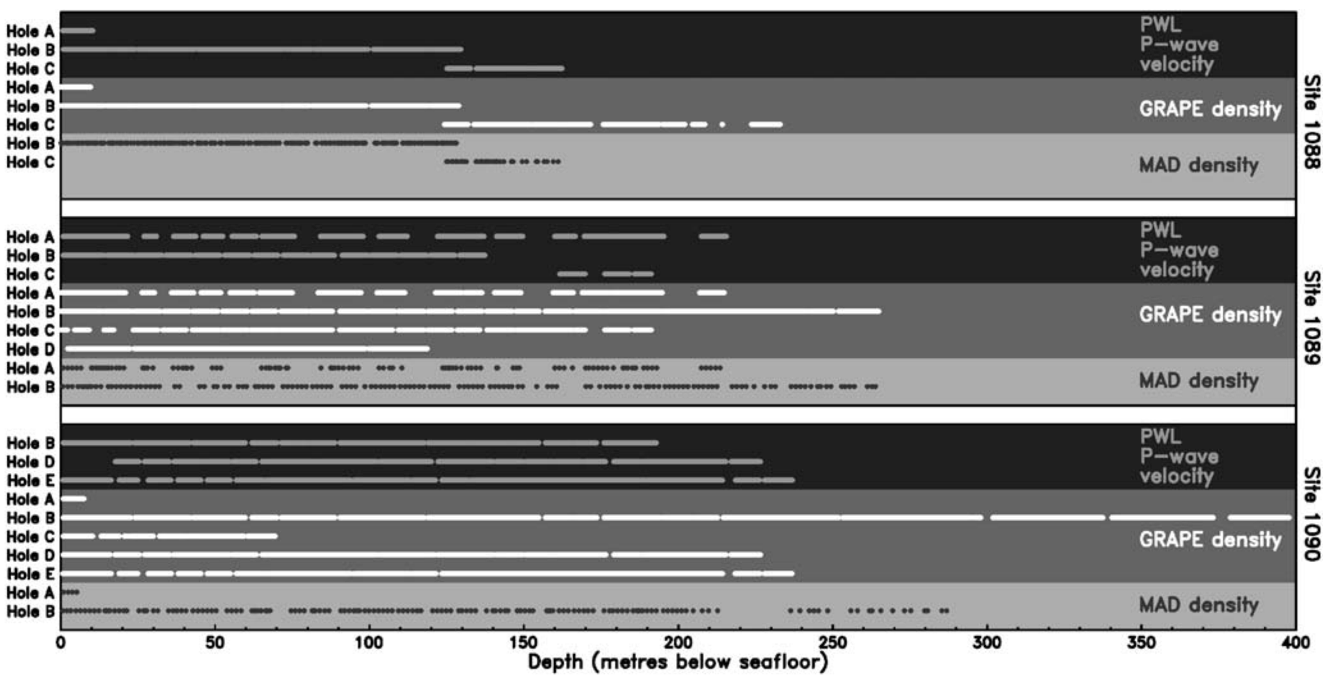


Fig. 6 Depth ranges for which physical properties measurements exist of P-wave logger (*PWL*)-derived seismic P-wave velocity, gamma ray porosity evaluator (*GRAPE*)-derived densities, and moisture and density (*MAD*) measurements. Not every type of measurement is always available for every hole of sites 1088, 1089 and 1090 (data extracted from the ODP Janus database)

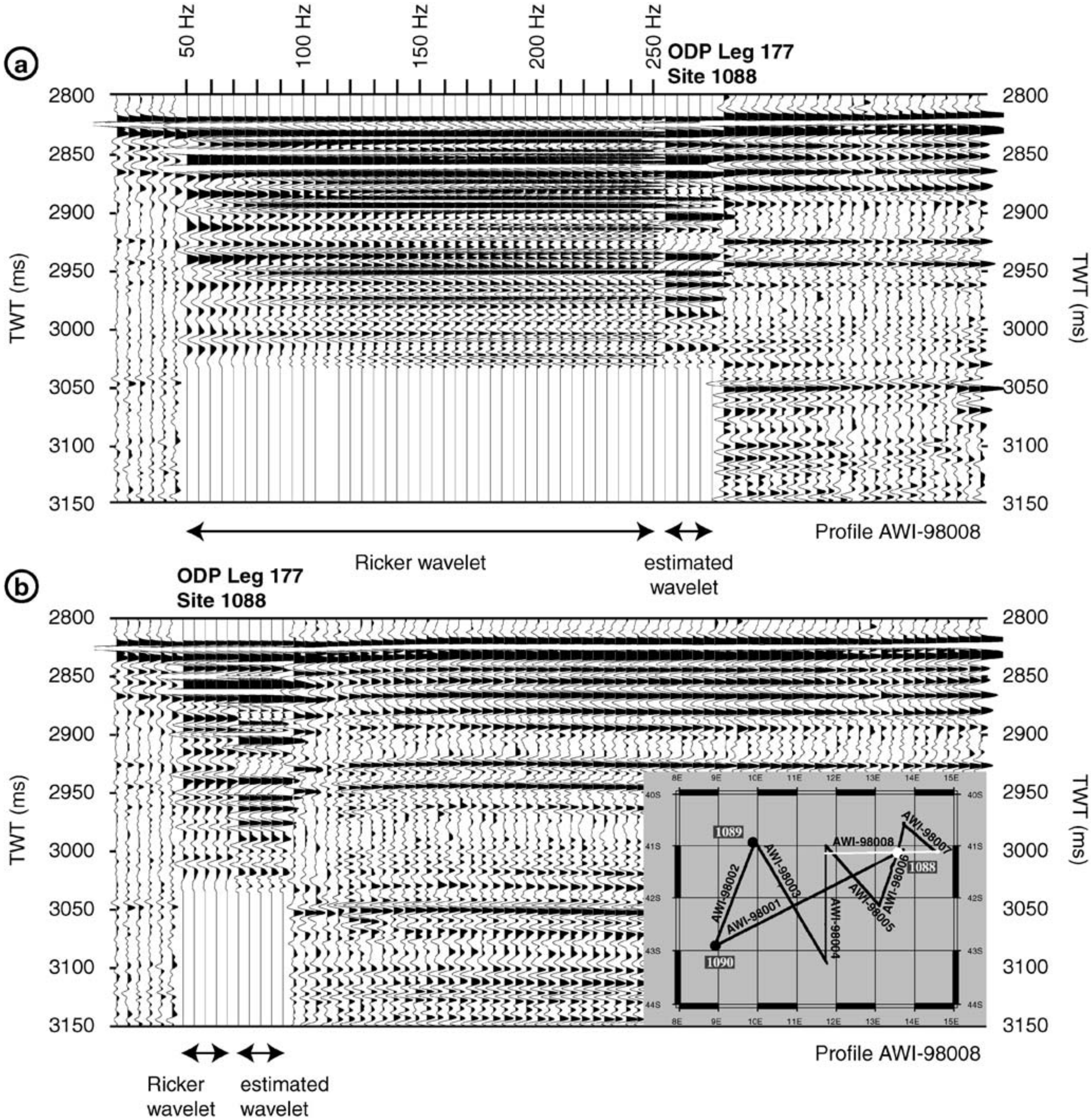


Fig. 7 **a** Comparison between the real seismic data (profile AWI-98008) and synthetic seismic data generated from ODP density and P-wave velocity data with a wavelet extracted from the real seismic data near site 1088, and a sequence of synthetic traces constructed with Ricker wavelets and ODP data. The dominant frequency of the Ricker wavelet increases in 10 Hz steps between 50 and 250 Hz. **b** Real seismic data from profile AWI-98008, with embedded synthetic traces constructed at the location of site 1088 along profile AWI-98008, using ODP density and P-wave velocity data and a 75 Hz Ricker wavelet next to synthetic traces constructed from ODP density and P-wave velocity data and a wavelet which was estimated from the real seismic data

tion to keep the data comparable to synthetic seismic data. This, however, is not a serious issue, as Shipley (1983) shows. Comparing different deconvolution models for deep-sea seismic sections in the Blake Bahama Basin, he did not obtain a much better result for seismic reflectors immediately below the seafloor.

A convolution of the reflectivity series with the source wavelet, as used in the seismic survey, is necessary to create

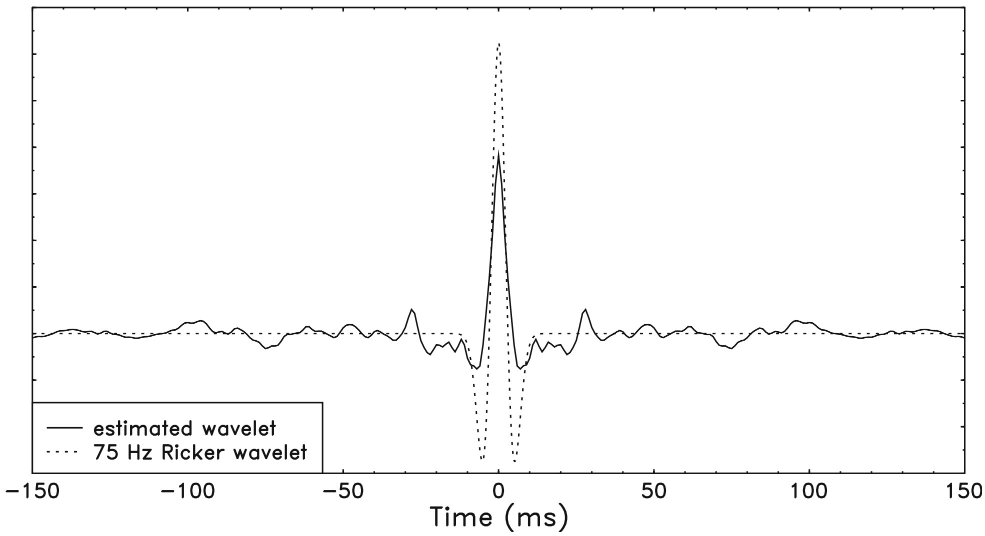


Fig. 8 Comparison of a zero-phase wavelet estimated from the seafloor reflection in the seismic data near site 1088 and a Ricker wavelet with a maximum amplitude at 75 Hz

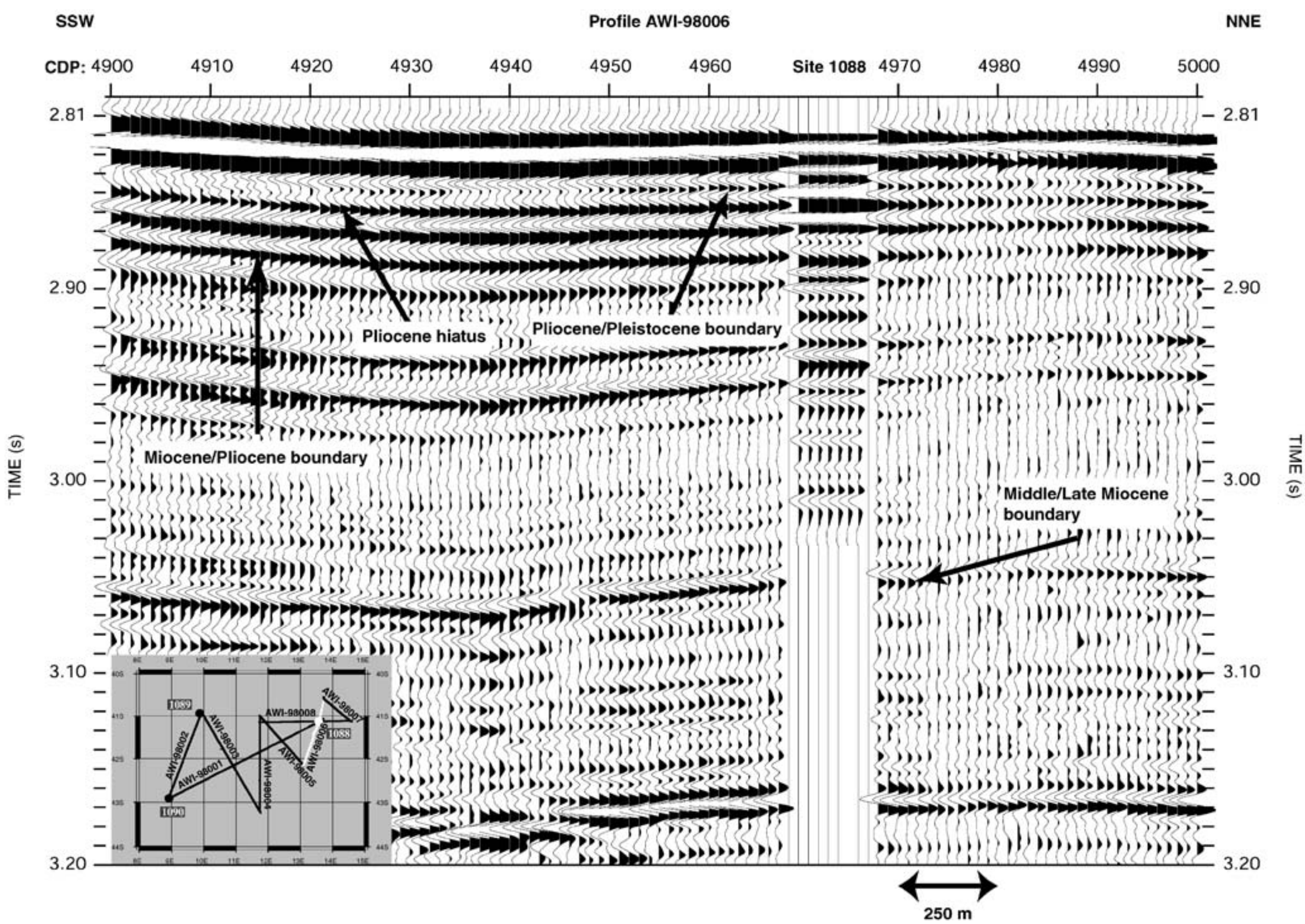


Fig. 9 Record showing the correlation between real seismic data (profile AWI-98006) and synthetic seismograms derived from site 1088 P-wave velocity and density data using a 75 Hz Ricker wavelet. Identification of seismic reflectors in the real seismic data caused by hiatuses in the biostratigraphic record (Fig. 2) is possible by using synthetic traces derived from physical properties (P-wave velocity and density) measured in core samples, combined with biostratigraphic analysis of the same samples. *CDP* Common depth point

a synthetic seismic trace, which can then be used in the interpretation of seismic profiles. If a measured source signature is not available, as in our case, then either a synthetic wavelet, e.g. a Ricker wavelet (Ricker 1953), or a wavelet estimated from the seafloor reflection in the real seismic data can be used. An estimated wavelet has the disadvantage that it itself is not a pure wavelet but contains geological information as well, and might be affected by attenuation effects and noise which can lead to an unsharp signature. An artificial wavelet, on the other hand, usually produces sharp signals in the synthetic data but has a different characteristic with respect to real data.

Results

Figure 7a shows a comparison between synthetic traces obtained using Ricker wavelets and by using a wavelet extracted from the seismic data for site 1088. Ricker wavelets having a maximum amplitude between frequencies of 50 and 250 Hz were applied to the reflectivity series. The synthetic traces constructed with Ricker wavelets in Fig. 7a exhibit a serious loss of resolution for low frequencies; the reflector at 2,900 ms, for instance, is not resolved in these traces. High-frequency wavelets introduce reflectors in the synthetic traces which are not resolved in the real seismic data, such as the series of reflections between 2,950 and 2,975 ms. Including small layers from the core data in the synthetic seismic by using a high-frequency wavelet would obscure, rather than aid a correlation with real seismic data in which a single strong reflector, e.g. the reflector at 2,850 ms, would split into multiple reflectors. A best correlation is obtained with a Ricker wavelet of 75 Hz, as shown by the comparison with the seismic data of profile AWI-98008 (Fig. 7b). Reflectors at 2,840 and 2,900 ms are still represented in the synthetic

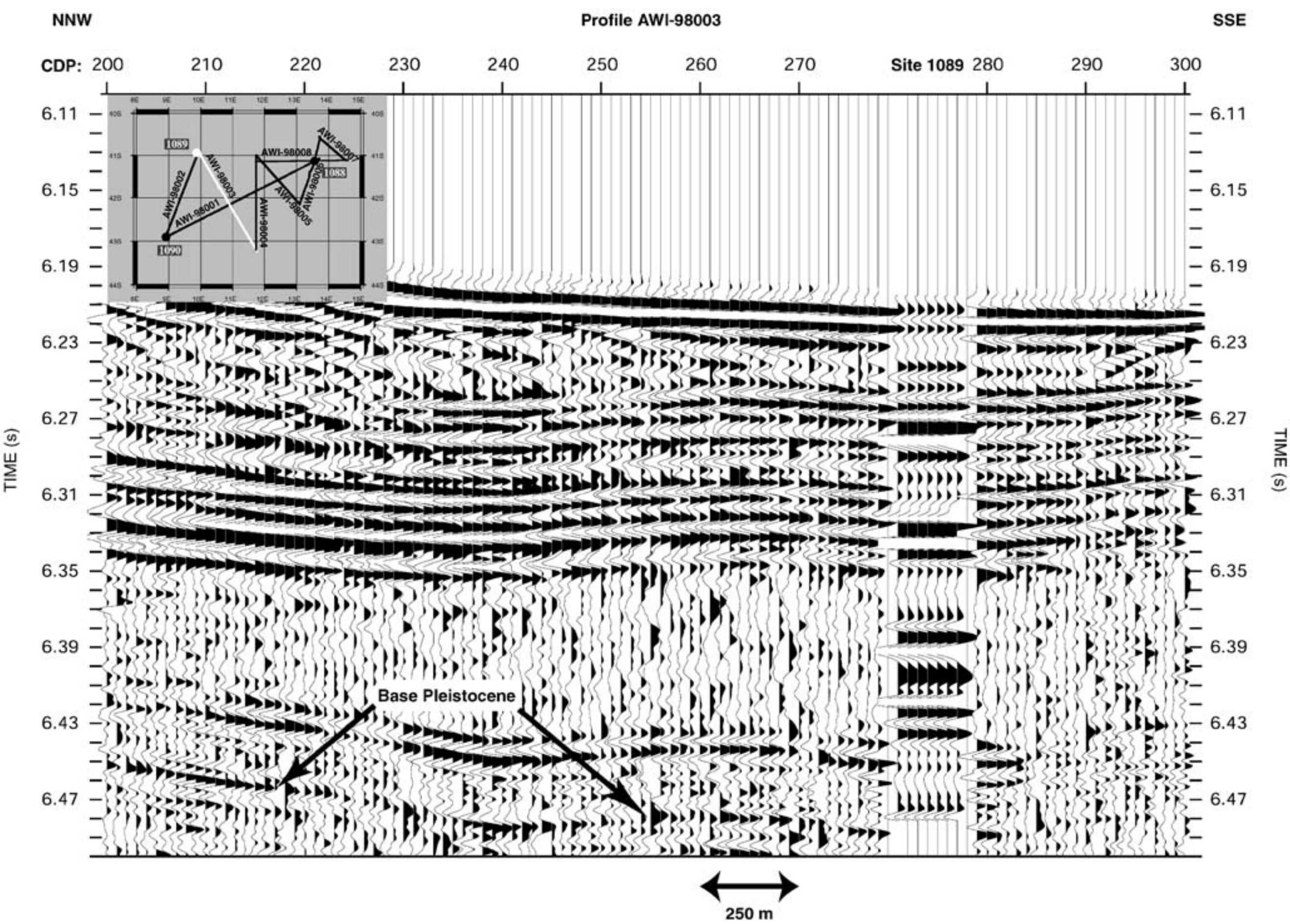


Fig. 10 Profile AWI-98003 shows that the lack of a high-quality series of P-wave velocity data, measured on core sediments from site 1089, is apparent in synthetic seismic traces constructed from these data and density data for sediments younger than base Pleistocene. Comparison of synthetic traces, created using a 75 Hz Ricker wavelet and inserted in a seismic section at the drilling location, shows that the amplitudes of the real seismic data are not adequately represented in the synthetic traces. This is evident below 6,350 ms, where the real seismic data are mostly transparent but the synthetic data show strong reflections

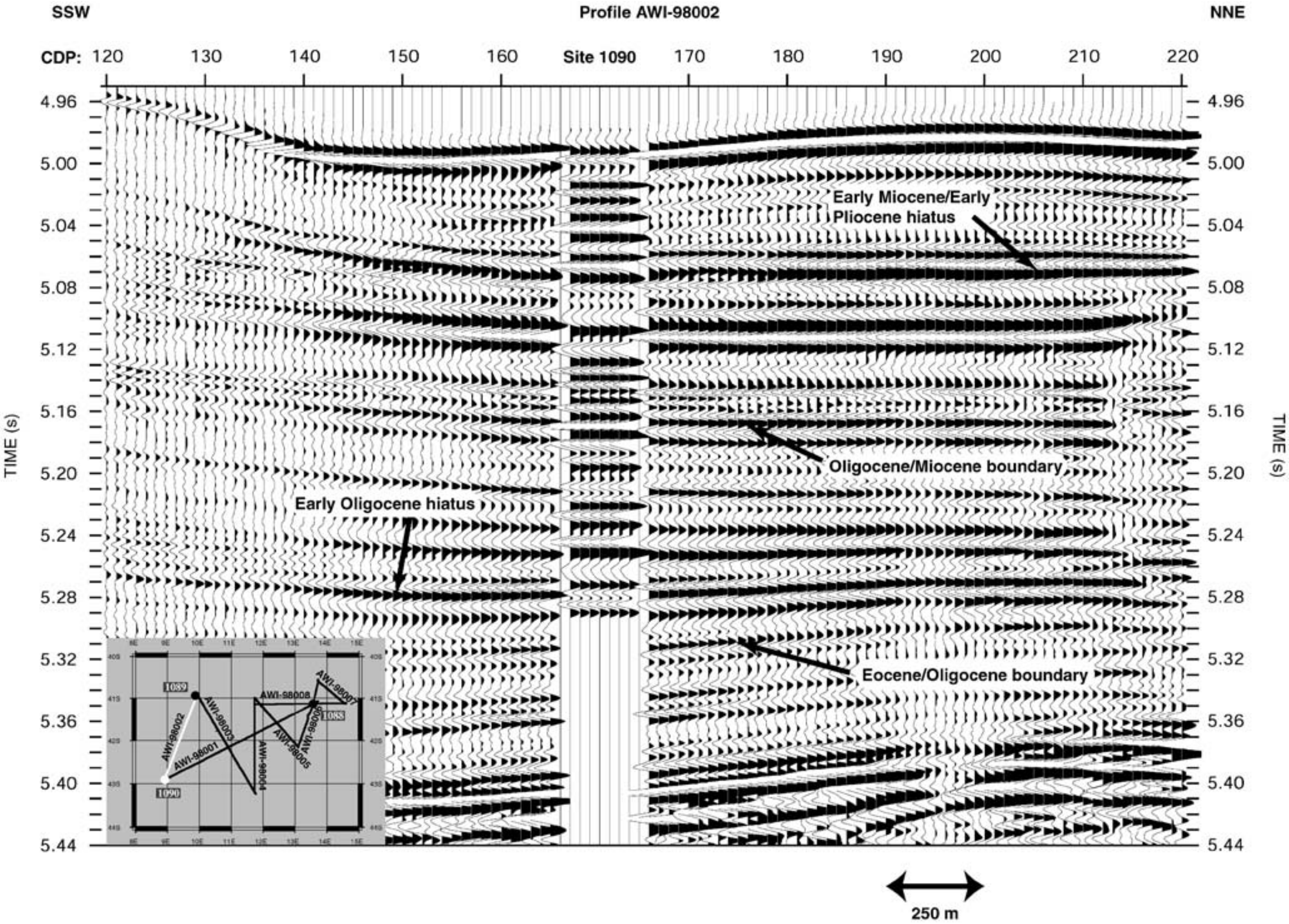
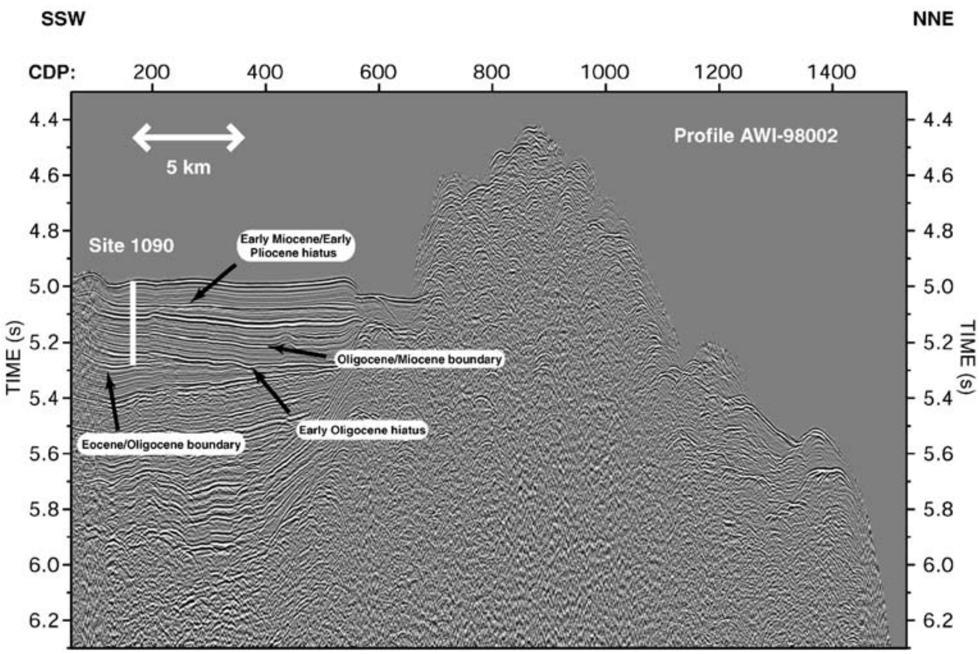


Fig. 11 This seismic section from the south-western end of profile AWI-98002 shows a comparison between real data and synthetic data obtained from convolution of a reflectivity series from P-wave velocity and density core data of site 1090 with a 75 Hz Ricker wavelet. Major hiatuses in Oligocene and Miocene sequences, causing pronounced reflectors in the real seismic data, are resolved in the synthetic seismic data

Fig. 12 Seismic data of profile AWI-98002 on the top of the Agulhas Ridge over the location of site 1090, showing a hiatus in the early Oligocene which is covered by the cores of site 1090



seismogram, and the reflector at 2,880 ms appears as a single reflector—the same as in the real seismic data. Figure 8 shows the time-domain characteristic of both the 75 Hz Ricker wavelet and a zero-phase wavelet, estimated from data near the location of site 1088. The 75 Hz Ricker wavelet shows a better result than synthetics obtained by application of a wavelet estimated from the seismic data, due to the difficulty to accurately estimate such a signature when there are strong reflectors immediately below the seafloor, and when processing steps such as normal move-out correction may have introduced a significant distortion in the multi-channel data.

The computation of the synthetic seismograms is followed by their use in the interpretation of the seismic sections. The ODP team has analysed the cored samples not only for physical properties but also for micro-palaeontological, sedimentological and petrological properties. Known erosional contacts in the cores can be traced to a unique location in the synthetic seismogram, and extrapolated into the real seismic data. In this way, seismic units can be assigned a petrophysical or palaeontological stratigraphy as well as a timescale.

For site 1088, there is a very good correlation between the seismic data and synthetic seismograms. The lithology at this site (Fig. 2) is quite uniform throughout the section (Gersonde et al. 1999). Indeed, profile AWI-98006 in Fig. 9 shows that the major reflections in both the synthetic data as well as in the real seismic data coincide with a Pliocene hiatus at 2,860 ms, and the Pliocene/Pleistocene (at 2,850 ms) and Miocene/Pliocene (at 2,880 ms) boundaries, as marked by geological core analysis. Also, the upper/middle Miocene boundary observed in the cored material correlates roughly with the reflector at 3,050 ms in the seismic section, although it should be noted that this observation is based on extrapolation of the data, since only density data are available down to this depth, whereas there is no seismic velocity information (Fig. 6) and therefore no accurate timescale.

Site 1089 in Fig. 10 shows that it is difficult to construct accurate synthetic seismic data if the P-wave velocity data are unreliable, and density data are missing and spurious (Fig. 4), even after filtering the density logs. This results in unrealistically high amplitudes, especially in a seismic transparent zone between 6,350 and 6,440 ms. The synthetic data correlate well with the real seismic section for the upper 70 ms (Fig. 10) but, below 6,270 ms, the synthetic data seem to be shifted downwards, indicating that the velocities used in the depth-to-time conversion are too low. Some of the misfit might be accounted for by the slight offset from the seismic profile AWI-98003 (Fig. 1).

Figure 11 shows a visual correlation of synthetic and real data at site 1090, where the major reflectors in the seismic data (Fig. 12) are linked to geological units, with a hiatus at the Miocene/Pliocene boundary at 5,070 ms and at the Oligocene/Miocene boundary at 5,170 ms. At the Pliocene/Pleistocene boundary, a relatively strong reflector is present in the synthetic seismic data at 5,050 ms (Fig. 11) but the corresponding reflector in the real seismic data is much weaker. One of the dominant reflectors in the seismic profile is a hiatus found in the early Oligocene (at 5,255 ms in Fig. 11).

Discussion

Leg 177 velocity and density data are far from complete and hampered with calibration errors of the equipment, which introduces a serious bias in the computation of synthetic seismic data and the subsequent interpretation of seismic sections. Biased density or velocity values lead to incorrect reflection coefficients, which in turn causes over- or under-estimated amplitudes. Site 1088 data show that the amplitudes of the synthetic traces correlate very well with the real seismic data, even though the velocity record is not very good, suggesting that a core-seismic correlation is more sensitive to an inadequate density record than to errors in the velocity record. A more serious problem is that, in the conversion between time and depth, every deviation adds up to what could result in conversion errors of up to tens of metres. Therefore, a visual correlation or adjustment of the synthetic data remains necessary to identify the geological units of the core data on the seismic sections. For site 1090, the PWS3 velocities are consistently higher than the PWL velocities. This difference would cause a maximum upward shift of 14 ms in the synthetic seismogram over the length of 234 m for which the velocity records are available, if the PWS3 velocities were used, rather than the PWL velocities. Both site 1088 and site 1090 show that the hiatuses can be resolved by synthetic seismic data and extrapolated to real seismic data. Site 1090 shows that other reflectors in the real seismic data are attributable to changes in lithology, such as the reflectors at 5,110 and 5,120 ms in the early Miocene. Site 1088, which has a uniform lithology, has several outstanding reflectors which are not attributed to hiatuses. In this case, an increase in density is caused by sudden variations in sedimentation rates, such as the reflector at 2,950 ms (Fig. 9) which coincides with an increase in sedimentation from 17 to 30 m/10^6 years.

The analysis of seismic profile AWI-98002 shows a clear stratigraphic discontinuity which, however, was initially not evident on the basis of geological core analysis alone, and is a relatively weak reflector in the synthetic seismic data. An early Oligocene hiatus could be identified in the cores at 220 m from calcareous nannofossils (Marino and Flores 2002; Diekmann et al. 2004) whereas other types of core data did not show a hiatus at this depth. The seismic profiles subsequently positively identified the existence of this hiatus, and the seismic interpretation shows that this hiatus can be traced over a wide area in the Southern Cape Basin (Wildeboer Schut et al. 2002). On the other hand, a timescale and lithology can be defined for the reflectors which cross the location of the drill-site, revealing the location of the Pliocene–Pleistocene boundary in the seismic data, which would not have been identifiable without the information from the cores. Remarkable is the phase shift between the real and synthetic data at 5,120 ms (Fig. 11), associated with a lithologic change from an episode with increased carbonate accumulation and preservation to an episode of relatively strong input of terrigenous matter (Diekmann et al. 2004; Fig. 2). This phase shift, and the differences in reflection strength of the reflectors at 5,220 ms depth and near the early Oligocene hiatus at 5,280 ms, are indicators that the Ricker source signature does not completely describe the real source signature used in the seismic survey. Because site 1090 was located on the northern flank of the Agulhas Ridge, which has a strong relief, the possibility also exists that parts of the phase shifts are actually in the seismic sections due to oblique incidence of the seismic waves on the tilted layers. The deeper parts of the synthetic data, roughly the lower half, might be slightly displaced due to the time-depth conversion using the velocity log, which suffers from problems with the P-wave logger.

Conclusions

ODP Leg 177 data show that the quality of synthetic seismograms mainly depends on the accuracy of measured density information, which appears to be the dominant factor in the deep-sea environment of the South Atlantic Ocean. If the synthetic data are constructed from the reflectivity series with a wavelet which adequately represents the signature used in the seismic survey, then most reflectors match quite well with the real seismic data. Because velocity data from core samples are incomplete due to recovery losses or measurement problems, it remains necessary to visually inspect whether reflectors in the generated synthetic traces are stretched or condensed in the conversion process between the time- and depth-domain. Site 1090 of Leg 177 shows that a prominent reflector in the seismic data can be identified in the core data, and identified as a hiatus in the early Oligocene with the assistance of synthetic seismograms from physical properties measurements. This shows that valuable structural information available through seismic interpretation can arise even from slight variations in some properties of the sediments which are not always evident from core data alone.

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