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Correlation of Seismic Reflectors with the CRP-3 Drillhole, Victoria Land Basin, Antarctica

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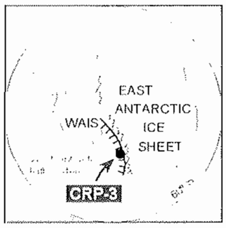

Abstract - Seismic reflection data collected in the region offshore Cape Roberts reveal a seaward dipping seismic sequence that thickens into the Victoria Land Basin. Drillhole CRP-3 cored this sequence to a depth of 939 mbsf (equivalent to 1025 ms two-way-time below the seafloor). This extended the total thickness of Cenozoic strata cored by CRP to 1500 m. The CRP-3 also cored 116 m into Devonian sandstone basement. At least 10 reflection events can be identified in the seismic data. These events are related to lithologic changes within CRP-3 core and down-hole electrical logs by deriving a time-depth relationship from whole-core velocity measurements. Data from a vertical seismic profile experiment in CRP-3, together with synthetic seismograms and the depth converted seismic section, enable the correlation of 9 key seismic reflection events (p-x) and 4 major seismic sequences (U-X) with sedimentary sequence boundaries and lithostratigraphic sub-units documented in the core. Seismic sequence U is correlated to sedimentary cycles 19 to 25 in the lower part of CRP-2/2A and to cycles 1 and 2 in upper part of CRP-3. Seismic sequence V corresponds to sedimentary cycles 3 to 6. Seismic sequences U and V are both dated at around 31 to 32 Ma. Sequence W includes the sedimentary cycles 7 to 23 beneath (*c.* 460 mbsf), and sequence X corresponds to the lowest part of the sedimentary section, including 40 m of dolerite breccia and conglomerate resting on the Devonian Beacon sandstone beneath. Sequences W and X are estimated to be around 33 Ma, and possibly as old as 34 Ma. The sequences, U-X, are all within V5 of Cooper et al. (1987) and RSS-1 of Brancolini et al. (1995) and dip >18° to the northeast.

INTRODUCTION

Seismic data provides essential spatial context for the high-resolution history of ice margin and water depth changes derived from drill hole data. For this reason an important component of the stratigraphic drilling project at Cape Roberts (CRP Project) is successfully correlating the Oligocene and Miocene stratigraphy from core to seismic reflection data (Cape Roberts Science Team, 1998, 1999, 2000). The seismic stratigraphic framework developed at CRP-1 and CRP-2/2A and integrated with seismic mapping in the Victoria Land Basin have been reported in Henrys et al., 2000 and Davey et al., 2000. A critical element of this analysis was the correlation between seismic sequences and equivalent lithostratigraphic and stratigraphic boundaries.

In this paper, we extend our analysis to drill site CRP-3 using synthetic seismograms derived from logs of CRP-3 drill core and the corresponding processed VSP, multi- and single- channel seismic reflection data that cross close to the drill site. We also establish the geometry of major seismic sequences by tracing them hundreds to thousands of meters in both coast-parallel and coast-orthogonal directions, and attempt to relate erosional and depositional features in the seismic records to core features. Throughout this paper we follow the nomenclature of Sheriff (1980) where seismic sequences are mappable seismic facies bounded by unconformities (onlap, toplap, and downlap). Where there is no evidence for an unconformity then we refer to these bounding packets as seismic units. Seismic sequences result from sediments within a time-stratigraphic depositional unit that implies a certain age interval.

Seismic stratigraphy of the Victoria Land Basin was first established by Cooper et al. (1987), who identified three major basin wide seismic units (V3-V5). In addition, Brancolini et al., (1995) extended the Victoria Land Basin stratigraphy developed by Cooper et al. (1987) by correlating the Ross Sea seismic sequences (RSS1-RSS8), from the central and eastern Ross Sea. In McMurdo Sound and Cape Roberts region this seismic stratigraphy was further refined into 10 seismic sequences (K – T) and the V3, V4, and V5 units could be identified as an

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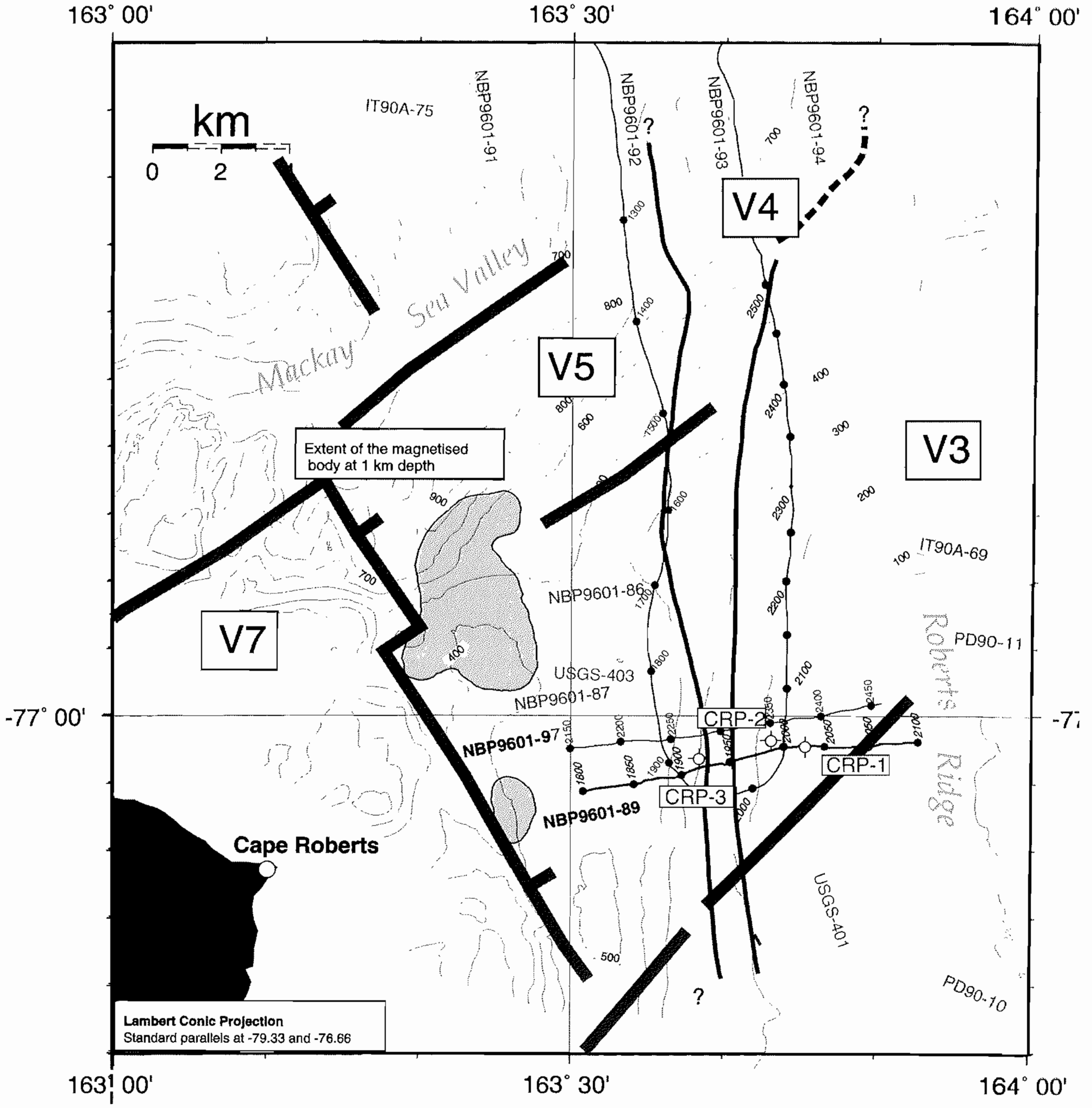
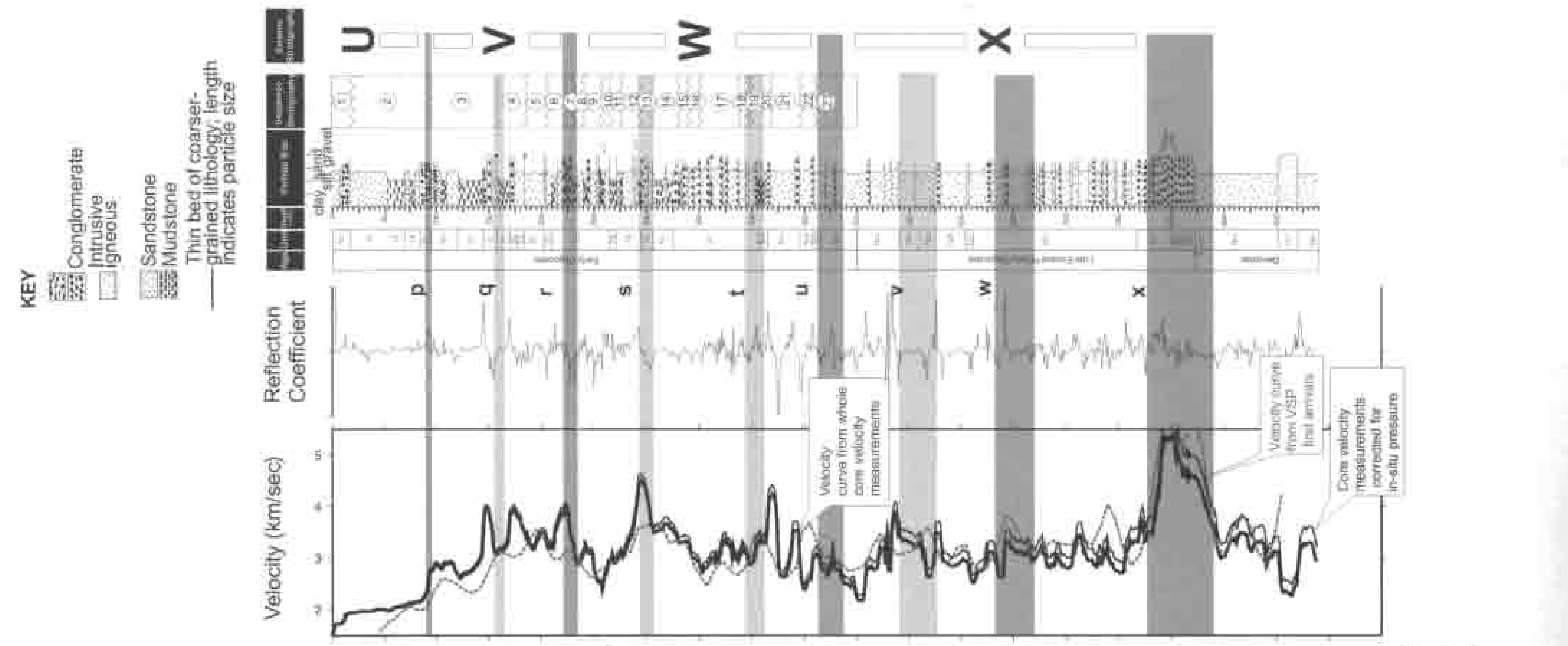


Fig. 1 - Location and bathymetry map of Cape Roberts showing the distribution of the sedimentary sequences (V3, V4, and V5). The heavy grey lines are magnetic anomaly lineaments interpreted as faults by Bozzo et al. (1997). West of Roberts Ridge, NW-SE trending lineaments coincide with mapped normal faults (Hamilton et al., 2001) and are proposed as the main boundary faults that separates the sedimentary sequence from the basement granitic rocks (V7), which crop out at the coast. The extent of shallow igneous bodies, inferred from magnetic data (Bozzo et. al., 1997) is also shown in the shaded pattern. Ship tracks of multi- and single-channel seismic data are grey lines – tracks named in the text are bold and annotated with shot points.

amalgamation of mappable sequences. For example, sequence R, S, and T were identified as part of the Cooper et al. (1987) "super sequence" V4 and inferred to correspond with early Oligocene and late Eocene rocks at depths greater than 366 m in CIROS-1 (Barrett et al., 1995; Bartek et al., 1996) - see Tab. 1 of Henrys et al. (1998) for correlation between the different nomenclatures. A number of these seismic sequences, including the three sub-seismic sequences of V4, were previously mapped across Roberts Ridge (Henrys et al., 1994, 1998) and identified in core recovered at CRP-2. Nine additional separate seismic events have been identified on SCS lines crossing the CRP-3 drill site and complete the mapping of V5 to basement in this region.

SEISMIC REFLECTION DATA

The primary data set for drillhole correlation is the single-channel seismic (SCS) data from the NBP9601 cruise (Hamilton et al., 1998, 2001, and



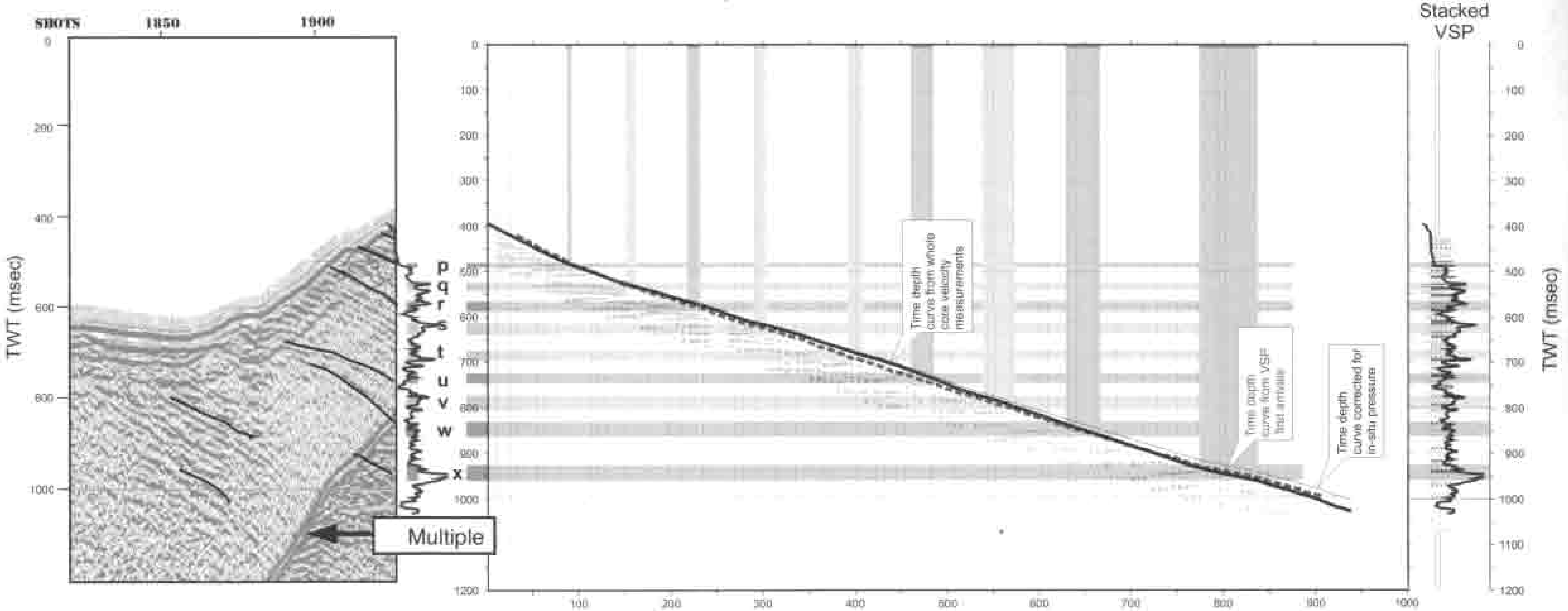


Fig. 2 - Composite figure showing cut away seismic reflection data (NBP9601-89), time-depth correlation, velocity reflectivity, VSP, and core-based lithology sequences. We have used the whole-core velocity and VSP data to derive time-depth conversion curves to map the seismic reflection section (top) to depth. These curves are overlaid on the time-aligned VSP. On the bottom, the stacked VSP data are compared to time-converted core velocity measurements. Core velocity and density data are used to derive a downhole reflection coefficient profile to associate the seismic data to the lithological logs. At least 9 of the most prominent seismic reflectors (p to x) can be identified down to 783.11 mbsf, (equivalent to 1030 msec twt bsl) in the SCS and VSP data. Individual seismic units and sequences bounded by seismic events u to x are grouped into larger sequences (U, V, W, and X).

Fig. 1). Two profiles cross close to the drill site: NBP9601-89 passes E-W and 300 m south of the drill hole and NBP9601-92 passes N-S, about 800 m east (Fig. 1). These data sets include a minimum amount of processing to preserve both true amplitude and relative trace-to-trace amplitudes, *i.e.*, no deconvolution or f-k filtering, or trace averaging were applied. However, the core at CRP-3 penetrated strata below the seafloor multiple. The use of multi-channel seismic data can significantly reduce seafloor multiple energy and improves the correlation of events below the multiple (Hamilton et. al., 1998). Whereas multi-channel seismic helped in the interpretation of CRP-2/2A, these data were found not to be useful for correlating data beneath the multiple near CRP-3. Also, reprocessing of NBP9601-89 failed to significantly improve the quality of data below the multiple in the vicinity of CRP-3 (*i.e.* below 92 sec two-way travel time). The reason for this is the high impedance at the seafloor and rapid decay of reflected energy after 2 sec.

The near-offset (normal incidence) seismic traces for NBP9601-89 were migrated using velocity information derived from our reprocessing and velocity measurements from cores. Near-offset data are displayed in all the figures 2 to 5 and both near-offset and migrated data are shown in figure 3. We noted that the effect of migrating data is to steepen dipping structures, but migration of water-bottom multiples causes artifacts - "smiles" - and, in particular, impairs interpretation of reflectors through the multiple (see Fig. 3b). To overcome this problem, and correctly position reflection events in depth, we depth-migrated (Fig. 4c) the line drawing of travel-time arrivals in figure 4b. However, we used all available seismic information, both near-trace and migrated images, in helping to refine our interpreted depth sections.

VERTICAL SEISMIC PROFILE AND MEASUREMENTS ON CORES

VERTICAL SEISMIC PROFILE (VSP)

VSP travel-time data can be used to determine velocities to serve as a basis for comparison with down-hole sonic and core measurements and can also be used to tie directly into marine seismic reflection data, resulting in reliable depth-time conversion for seismic reflection data.

Three separate three-component vertical seismic profiles (VSPs) were completed at CRP-3 (see Cape Roberts Science Team, 2000) but only the Z-component data for the near –offset VSP are reported here. Processing of the data includes trace display and editing. Down-going waves are marked by clear first arrivals and a low frequency (<10 Hz) complex coda that includes the source signature and shallow reverberations in the sea ice and reflections from the seafloor. This wavetrain masks up-going reflection arrivals. Separation of down-going and up-going waves was carried out by median filtering and polygon mute in the frequency-wavenumber (f-k) domain. To compare the VSP to two-way traveltime SCS data, the VSP traces have a static shift applied; equal to the first-arrival times. An 80 msec corridor after the first arrival is used to correlate well data to SCS reflection data (see Fig. 2). A detailed analysis of the three-component VSP data is to follow in a separate publication.

VELOCITY *vs* DEPTH

An important application of VSP data is to provide accurate velocity-depth data for the formations penetrated by the well. Velocity measurements of the core provide substantially better depth resolution, but the VSP results are much less subject to borehole conditions. Indeed, they average over a much larger volume of the formation so that they provide velocities that are more representative of seismic reflection velocities than those obtained from core or core plugs. Interval velocities are calculated from travel times picked off first-arrivals of near-offset VSP data (±2 msec accuracy) and plotted as a function of depth together with core velocities (Cape Roberts Science Team, 2000; and Niessen, personal communication) in figure 2. The core velocities are median filtered over a sliding 10 m window of core. Our filter will also reject outliers if they are greater than 2.5 times the median value. A comparison of the velocity and time-depth curves (Fig. 2) show they are remarkably similar, with VSP velocities consistently about 0.2 km/s (or ~7%) higher than core velocities at depths greater than 450 meters below sea floor (mbsf). In contrast, VSP velocities are systematically slower than whole-core velocities in the top half of the hole. We do not know why there is a systematic mismatch in velocity values, or why it changes sign down the hole but we suspect temperature is one possibility. The whole-core velocities are normalized to 20°C, whereas in situ temperatures increase from about -1.8° at the sea floor to 23.0° at 870 mbsf. The sensitivity of CRP-3 velocities to temperature is not known. A 20-25°C temperature change produces a minor (<1%) decrease in velocity for very low-porosity rocks but a 5.0-5.5% velocity change for the very high-porosity sediments studied by Shumway (1958). The difference is attributable to mineral *vs.* water compressibilities. It follows that a correction for temperature should be applied to the whole core measurements but we have not done so here.

VSP velocities are dominated by anomalies of wavelengths greater than 50 m. High velocity peaks associated with thin (<20 m) conglomerate beds are not resolved in the VSP traveltime data. The dominance of high-velocity clasts within the core

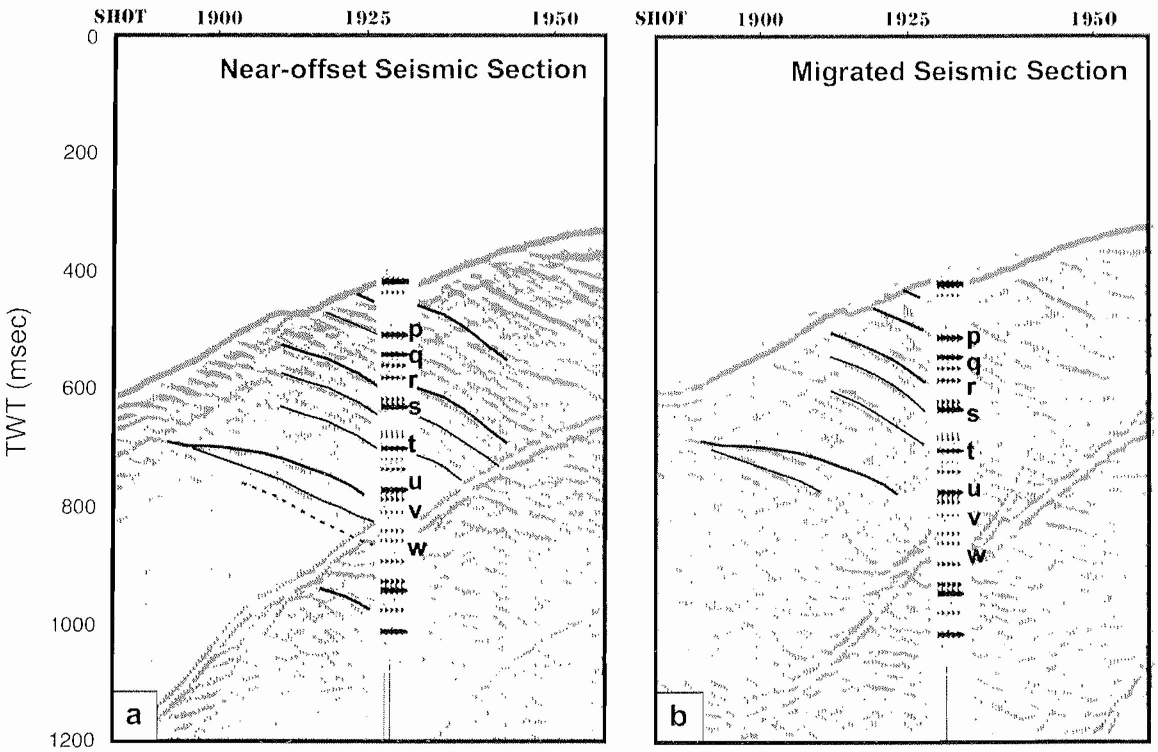


Fig. 3 - Cut away section NBP9601-89 with synthetic seismogram from CRP-3: (a) near-offset seismic data; (b), time-migrated seismic data. At least 9 of the most prominent seismic reflectors (p to x) can be identified down to 783.11 mbsf. (equivalent to 1030 msec twt bsl) in the SCS and VSP data.

results in the two-way traveltime to depth conversions differing by about 20 to 30 m between 300 and 500 mbsf (see Fig. 2). In general, velocities in CRP-3 are about 3.2 ±0.6 km/s, apart from the first 80 m of core, where velocity is close to 2.0 km/s, and a 50 m dolerite shear and conglomerate zone from 790 to 823 mbsf, where velocity is greater than 4.5 km/s. Wet bulk density values range from 1.63 to 3.16 Mg m^{-3} with the average value being 2.4 Mg m^{-3}. The intervals of the core corresponding to high velocities are also where measured densities are highest.

Core-plug measurements of velocity *vs.* pressure show that in situ velocities are higher than atmospheric-pressure velocities by a percentage that depends on depth. For example at 900 mbsf depth core velocities need to increase by 9% (Jarrard et al., this volume). We found that by making this rebound correction to core measurements produced core velocities that were closer to VSP velocities and a time-depth curve that matched the VSP first-arrival traveltime picks and therefore we used corrected velocities in subsequent analysis.

In summary, data from core measurements, down-hole tools, and VSP agree very well and we are therefore confident in using the core velocity measurements that have been corrected for rebound for determining synthetic seismograms where there is an absence of sonic log data.

GENERATION OF SYNTHETIC SEISMOGRAMS

Reliable down-hole density and velocity data, as well as seismic impedances $z = \rho$ Vp, and reflection coefficients $R = (z_2 - z_1)/(z_2 + z_1)$, permitted synthetic seismograms to be calculated.

Synthetic seismograms were generated using a reflectivity algorithm (Kennett, 1981) for normal incidence data. The method used here is similar to that reported for CRP-2/2A (Henrys et al., 2000) and CIROS-1 (Bücker et al., 1998). Input is in terms of P-wave velocity, density, attenuation, and depth or thickness of horizontal layers. Attenuation is assumed to be near zero in all cases presented here. No attenuation measurements were made on core samples and, unless Q (seismic wave attenuation quality factor) is low, velocity dispersion effects are assumed to be small. Velocity and density values for the different layers, apart from the sediments immediately below the seafloor, were derived from measurements on core samples. The properties of the seafloor (density, velocity) were determined by trial-and-error matching of the observed and calculated water bottom reflections. To accurately match the sea floor and other reflection events, we convolved the synthetic impedance function with a source wavelet derived from the seismic data. An estimate of the source wavelet for SCS data can be derived by summing

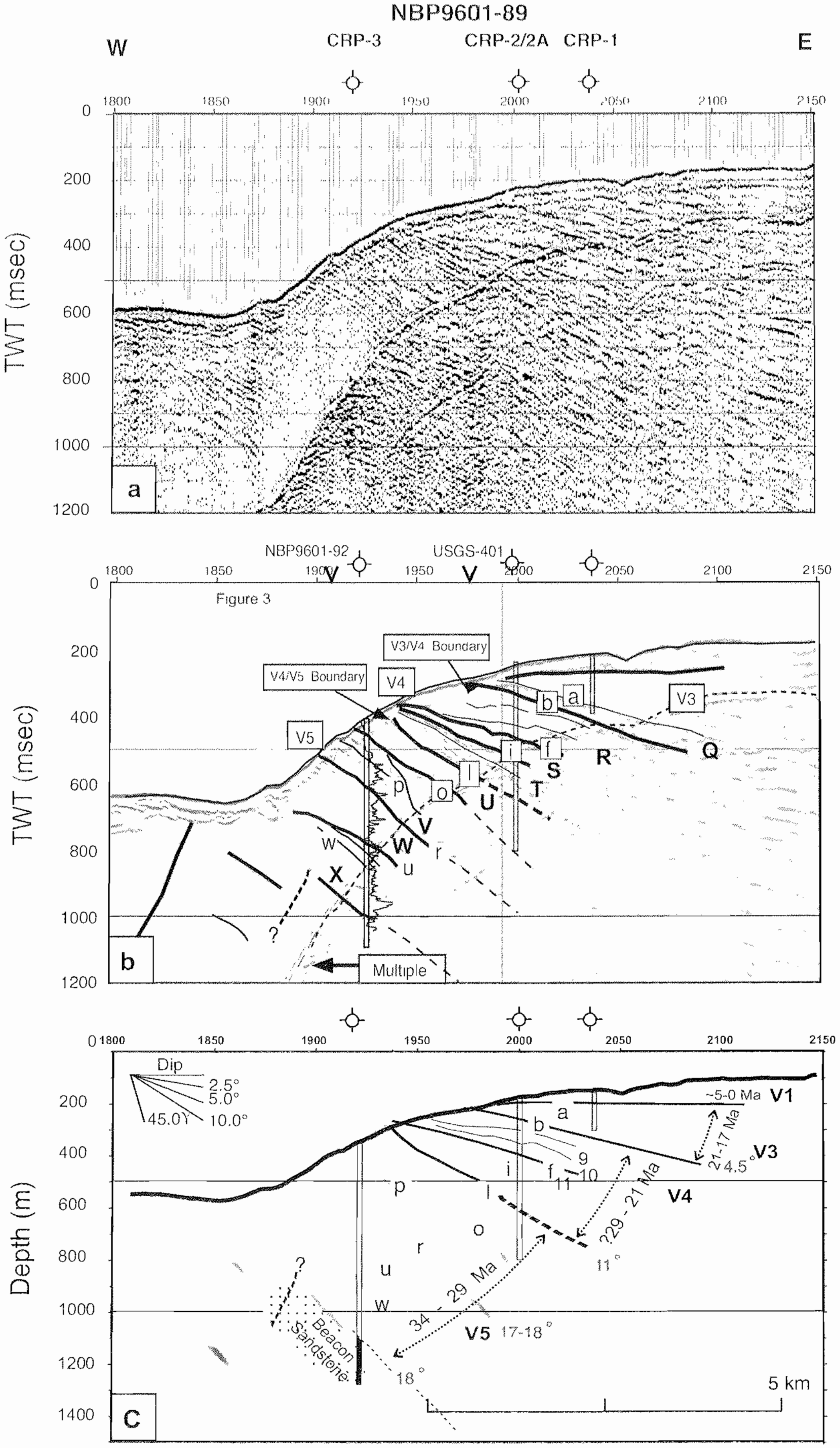


Fig. 4 - Seismic section for dip line NBP9601-89: (a) uninterpreted; (b). with interpretation of seismic stratigraphic sequence V5 and subsequences U, V, W, X together with major seismic reflector events identified in CRP-2/2A and CRP-3; (c). depth migrated section.

traces along the seafloor horizon. The convolved synthetic traces were subjected to the same processing sequence as the observed single-channel seismic data and shot gathers (*i.e.* same filter and gains) and displayed with identical plotting parameters.

RESULTS

CORRELATION OF SEISMIC REFLECTORS WITH CRP-3

An integrated seismic reflection, VSP, and core lithology plot is shown in figure 2. We have used the whole-core velocity and VSP data to derive time-depth conversion curves to map the seismic reflection section (top) to depth. These curves are overlaid on the time-aligned VSP. On the bottom, the stacked VSP data are compared to time-converted core velocity measurements. In addition, we have used core velocity and density data to derive a downhole reflection coefficient profile to associate the seismic data to the lithological logs (Fig. 2).

CRP-3 reached a depth of 939.42 mbsf, equivalent to 1030 msec two-way travel time below sea level (twt bsl) based on core velocities and the VSP check shot survey. At least 10 of the most prominent seismic reflectors (seismic events) can be identified down to this depth or above in the SCS and VSP data. (o to w). Table 1 summarizes the correlation between seismic reflectors from line NBP9601-89 and lithostratigraphical units in CRP-3. Seismic events on SCS data (o, p, r, u, and v) were determined by correlating the highest positive amplitude wavelet, that

Tab. 1 - Correlation between seismic reflectors, reflectivity and velocity values from measurements on the core, and lithostratigraphical units in CRP-3.

Seismic Reflector		**Lithostratigraphical correlation and depth**	**Seismic Sequence**	***Comments and inferences***
	twt bsl (ms)			
p*	480-490	Base of LSU 2.1 at 95.48 mbsf and base of Sequence 2.	**Base of seismic sequence U**	Sandy Diamictite: corresponds to a major reflector traced to a 100-m wide bench on the seafloor
q+	530-545	Boundary between LSU 3.1 and LSU 4.1 at 144.67 mbsf and base of Sequence 3.		Major impedance change between sandy mudstone and conglomerate. Base of core–physical property unit 1.
r*	560-585	Within LSU 7.2 at *c* 225 mbsf and base of Sequence 6.	**Base of seismic sequence V**	A series of thin-bedded conglomerates gives a sharp change in velocity c 225 mbsf.
s+	610-640	Boundary between LSU 7.4 and LSU 7.5 at *c* 290 mbsf and base of Sequence 12.		Change in lithology from medium-grained sandstone to conglomerate. Corresponds to a significant velocity change.
t+	675-700	Within LSU 9.1 at *c* 360 mbsf and near base of Sequence 20.		Minor velocity increase associated with thin (up to 1.5 m thick) conglomerate beds.
u*	720-750	Near the base of LSU 11.1 at *c* 444 m and near base of Sequence 23.	**Base of seismic sequence W**	Corresponds to a strong reflector in VSP data and an increase in velocity. Base of core–physical property unit 2.
Sea floor multiple intersects CRP-3 at 770 ms bsl. Below this, interpretation of reflectors is more difficult.				
v*	770-800	Base of LSU 12.3 at c 540 mbsf.		Conglomerates near the top of LSU 12.3 mark an increase in core and VSP velocity. Near the base of core–physical property unit 3.
w	840-860	Within LSU 13.1 at *c* 640 mbsf.		Most likely conglomerates with LSU 13.1 and an increase in core and VSP velocity. A marked change in magnetic susceptibility occurs at 630 mbsf (base of core–physical property unit 3). A prominent unconformity on strike seismic reflection profiles.
x+	725-955	Top of conglomerate within LSU 13.2 at 783 mbsf.	**Base of seismic sequence X at 823 mbsf**	Top of dolerite breccia. Marked by >4.5 km/s velocity. Base of core–physical property unit 4. Dolerite breccia and conglomerate 40 m thick

Notes: LSU - Lithostratigraphical Sub-Unit: * strongest and most persistent reflectors: + not prominent on large scale near trace plot but observed in VSP data.

are laterally continuous away from the drill hole, and can be related to the cored section. However, detailed linkages are uncertain because of 1) the low resolution of the seismic signal (wavelength ~ 30 m), 2) uncertainty in the traveltime depth curve (estimated to be ±10-15 m), and 3) the surface seismic data are convolved with a complex source wavelet.

We have used VSP seismograms, core measurement impedance data (Fig. 2), and changes in physical properties that extend over about 20 m to refine our correlations. For example, the highest reflection coefficients are encountered in the highest velocity diamictites/conglomerates. Continuous layers of these lithologies will yield bright and laterally continuous reflectors.

In the synthetic seismograms (Fig. 3), the computed reflections represent only the information sampled in the borehole. Differences between the synthetic seismograms and the seismic reflection data (Fig. 3a,b) can arise because the Fresnel zone of the reflection data takes in a larger area than just the borehole (about 300 m radius at 1 s and 20 Hz) and therefore includes reflections generated by rocks and structures surrounding the borehole. Given the limitations of the data we have been able to establish that all of our 9 seismic events are close to or are associated with a lithostratigraphic sequence boundary (Fig. 2 and Tab. 1). Mapping of seismic data in the region by Cooper et al. (1987), has identified at least 3 major seismic unit boundaries (V3, V4, and V5) identified on the basis of regional unconformities and acoustic velocities - two of these unit boundaries (V3/V4 and V4/V5) were encountered in CRP-2/2A. In addition, these units have been further refined, into at least 10 seismic sequences, based on detailed mapping of SCS data (Henrys et al., 2000, Henrys et al, 1998; Bartek et al, 1996). We have chosen in this paper to continue the convention of grouping individual seismic units and sequences bounded by seismic events (p-x) into larger sequences (*e.g.*, U-X), because they offer the chance of highlighting significant basin-wide unconformities that could correspond to climate and tectonic episodes. However, not all lithostratigraphic sequences are detected as seismic sequences. Reflection data, for example, are blind to changes in magnetic and/or radiometric properties and where there is no significant accompanying variation in impedance (Bücker et al., this volume). The correspondence between the seismic sequences, and seismic reflector events, and lithostratigraphic units in the CRP3-3 drill site are summarized in table 1. The sequences, U-X, are all within V5 of Cooper et al. (1987) and RSS-1 of Brancolini et al. (1995).

Seismic Sequence V5 (sequence U)

The seismic sequence boundary V4/V5 (base of seismic sequence T) was recognized at about 440 mbsf in CRP-2/2A and is believed to be a significant chronostratigraphic break in CRP-2/2A at 29 Ma (Wilson et al. 2000). Differentiation into seismic sub-sequences and characterization of seismic facies within V5 was not made in Henrys et al. (2000). However, SCS seismic data along strike (NBP9601-93) and beneath the V4/V5 unconformity show laterally discontinuous and low amplitude reflectors. Sequence U is correlated to sedimentary sequences 19 and 25 in CRP-2/2A. In CRP-3 sequence U is correlated with the base of this sedimentary sequence 2 and is identified as a prominent reflector on VSP data ("p" at 95.48 mbsf). A marked velocity and density gradient is identified across this interval.

Seismic Sequence V5 (sequence V)

Seismic facies that comprise V are characterized on both strike (north-south) and dip (east-east) lines by layers of high amplitude discontinuous and hummocky sub-horizontal reflectors separated by layers of low amplitude. To the north, the Mackay Sea Valley cuts through Roberts Ridge and exposes these older strata. On NBP9601-92 reflectors within sequence V appear as foresets and downlap onto a regional unconformity (reflector "r" and to the base of lithostratigraphic Sequences 6 at CRP-3). Also channels cut these layers, the widest being about 2 km and about 70 m deep (see Fig. 5). The character of this sequence is similar to younger sequences S and T (Fig. 4 of Henrys et al., 2000). In CRP-2/2A, "S" corresponds to a single lithostratigraphic sequence 11 and "T" to an amalgamation of 5 thin lithostratigraphic sequences. These sequences are interpreted as glaciomarine deposits each interpreted to record a cycle of glacial advance and retreat with attendant changes in palaeobathymetry (Fielding et al., 2000). Similarly, seismic sequence V is correlated to 4 thick lithostratigraphic sequences (sequences 3, 4, 5, and 6) in the CRP-3 drill site and may also be interpreted as cyclical glaciomarine strata that correspond to changes in glacio-eustatic sea-level (Fielding et al. this volume; Naish et al. this volume). The vertical resolution of the seismic data are not sufficient to resolve individual sequences recognized in the core but we infer, from synthetic seismograms, that the reflection signal in both CRP-2/2A and CRP-3 is dominated by high velocity and high density diamictites/conglomerates that occur at the base of depositional cycles (Fielding et al., this volume). Sedimentary sequences 1-7 have been dated by Sr/Sr analysis of molluscs (Lavelle, this volume), and correlation of magnetic polarity stratigraphy (Florindo et al., this volume; Hannah et al., this volume) to be *c.* 31 Ma.

Seismic Sequence V5 (sequence W)

Seismic sequence W is correlated to 16 thin (less than 28 m thick) lithostratigraphic sequences. The base of W ("u") is marked as a high amplitude

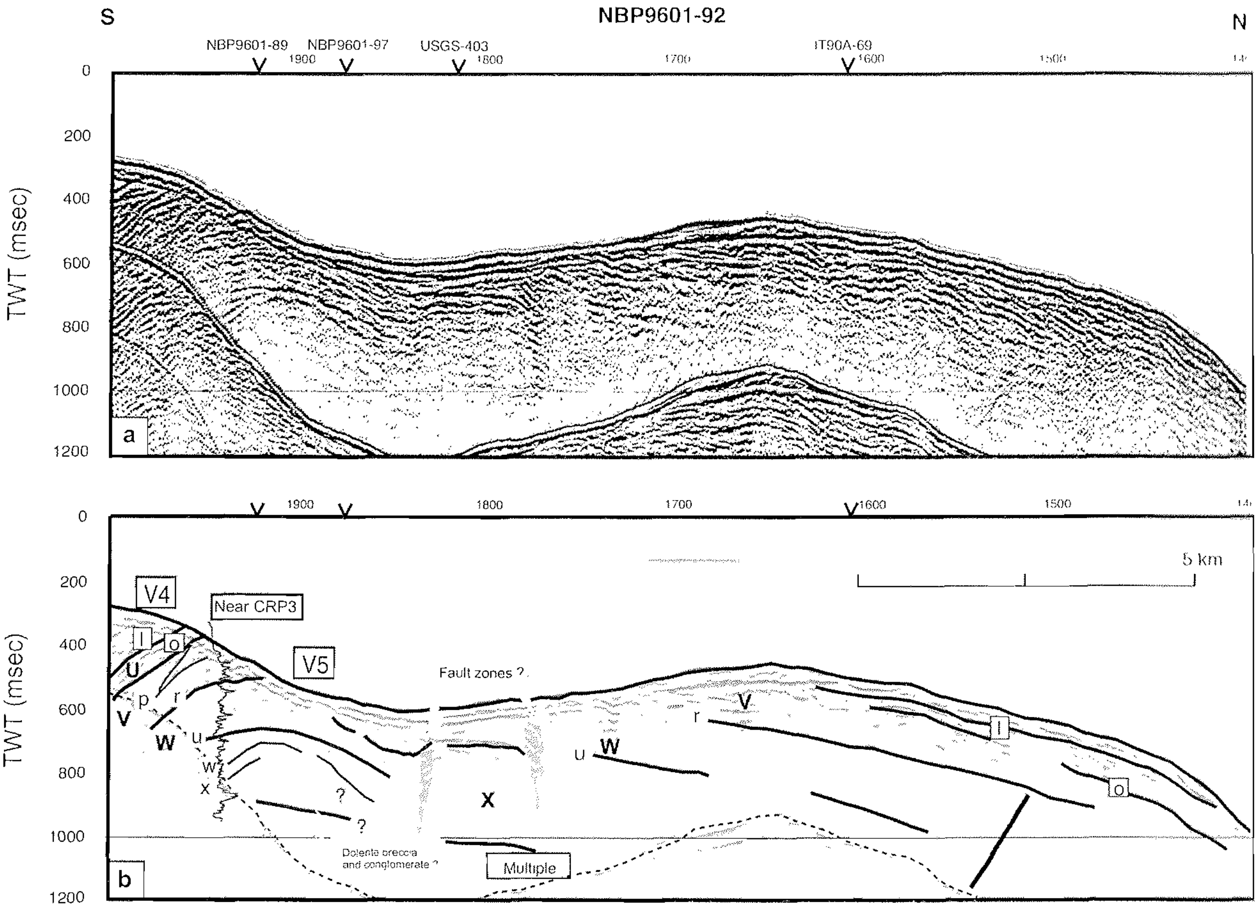


Fig. 5 - Seismic section for strike line NBP9601-92: (a) uninterpreted: (b), with interpretation of seismic stratigraphic unit V5 and subsequences U, V, W, X together with major seismic reflector events identified in CRP-3.

reflection corresponding to an erosional unconformity on NBP9601-92 (Fig. 5) and corresponds to the base of lithostratigraphic sequence 22 at CRP-3 (*c*. 460 mbsf; near the deepest of the interpreted sea-level driven cycles recognizable in the core (Naish et al., this volume). This boundary is also marked by a sharp change in magnetic susceptibility (Cape Roberts Science Team, 2000). Dip profiles showing sequence W also reveal layers with high amplitude reflections, similar to those observed in the overlying sequence, V. However, on strike profiles, amplitudes are low and the internal geometry of this sequence is poorly imaged. We are able to trace the base of sequence W approximately 7 km north of CRP-3, to shot point 1675 on line NBP9601-92, but further north these deeper sequences could not be confidently mapped. No clear age model has been established for the core spanning sedimentary sequences deeper that 7 but, seismic sequence W spans a normal/reverse polarity change (C12r/C13n) at *c*. 33 Ma (Florindo et al., this volume).

Seismic Sequence V5 (sequence X)

Low amplitude, almost opaque, seismic facies characterize seismic sequence X on both dip and strike reflection profiles. At CRP-3, the sequence X corresponds to the interval *c*. 460 to 783 mbsf and comprises a thick succession of seismically monotonous sandstone intervals punctuated by fining-upward conglomerate-sandstone units. However, in this interval synthetic seismograms show that weak amplitude reflections dominate. A 40 m thick high-velocity dolerite breccia and conglomerate occurring at the base of the sandstones is calculated to give a high-amplitude reflection, which is absent on strike and dip seismic profiles. We infer from this that either the dolerite layer is local to the vicinity of CRP-3 or is extensive and masks a coherent basement wide reflector. If the dolerite is local then brecciated rocks may be associated with a shear zone in faulted basement rocks and implies deposition near the fault escarpment. On the other hand, strike line reflection data (Fig. 5) reveals an opaque mound structure near shot point 1900 extending up to 2 km north of CRP-3 that points to a more extensive feature. The base of the sequence X is dated at 34 Ma (Cape Roberts Science Team, 2000) and is the contact with mid Devonian sandstones of the Beacon Supergroup. The observation that the base of this sequence is a weak reflector, on seismic data away from the drill hole, can also be explained by the small difference in velocity between Beacon rocks and those sandstones of the overlying Cenozoic (see Bücker et al. this volume and Barrett and Froggatt, 1978).

Basement

Seismic sequence V7 is acoustic basement for the region, and comprises rocks that pre-dated the Victoria Land Basin. This unit was interpreted by Cooper et al. (1987) to include igneous and metamorphic rocks of Ordovician and older age, and probably the sedimentary Beacon Supergroup. The top of V7 was inferred to lie at approximately 1500 mbsf (1.0 sec twt-bsf; see Figure 22 of Cooper et al., 1987) beneath the western margin of Roberts Ridge, but CRP-3 cored the Beacon Supergroup at 823.11 mbsf. Beacon strata, and the unconformity corresponding to the Cenozoic and older rocks, therefore, lie within sequence V5 identified by Cooper et al. (1987). Indeed, our correlation has identified a reflector, about 300 msec (450 m) above the V5/V7 boundary (identified in as the reflector intersecting the sea floor near shot point 300 in plate 2 of Cooper at al. 1987) as the Devonian/Cenozoic unconformity (see Fig. 5). Further, we suggest that the reflector identified by Cooper et al. (1987) as representing the top of V7, marks an igneous and metamorphic basement underlying the Beacon strata and close to the top of sheet-like magnetic bodies modeled by Bozzo et al. (1997).

Seismic data collected to date, including high-resolution seismic data from NBP9601, are not able to add significantly new information about the basement structure and the Cenozoic/Beacon unconformity since the region beneath 770 mbsf is obscured by a strong multiple. However, depth conversion of the seismic data (Fig. 4c) shows the steeping dip with depth trend, observed in CRP-2/2A, continues in CRP-3 where dips steepen from *c.* 11° up to 18° above the conformity truncating the Beacon strata. North-south striking reflection profiles (NBP9601-92 and Figure 5) appear to show that the Beacon/Cenozoic basement unconformity dips to the east-northeast, in agreement with dipmeter and borehole televiewer data (Jarrard et al., this volume).

CONCLUSION

Seismic data provides essential spatial context for the high-resolution history of ice margin and water depth changes from drill hole data (Henrys et al., 2000). Although the resolution of reflecting horizons in the NBP9601 data is limited to around 20 m, in the best case, individual horizons could be traced several kilometers along strike (parallel to the ancient coastline), and many hundreds of meters along dip (normal to the coast). The internal geometry of the stratal packages has been investigated to establish the lateral continuity of seismic facies and sequence architecture.

Data from a vertical seismic profile experiment in CRP-3, together with synthetic seismograms and the depth converted seismic section, enable the correlation of 9 key seismic reflection events (p-x) and 4 major north easterly dipping (up to 18°) seismic sequences (U-X) with sedimentary sequence boundaries and lithostratigraphic sub-units documented in the core. Sequence U is correlated to sedimentary sequences 19 and 25 in CRP-2/2A and 1 and 2 in CRP-3; the base of which is at 96 mbsf. Seismic sequence V corresponds to sedimentary sequences 3 to 6. U and V are both dated at *c.* 31 Ma. Sequence W represents an amalgamation of the remaining sedimentary cycles present in CRP-3 (7 to 23) to 444 mbsf. The age model is not well determined in this interval but W is most likely early Oligocene in age (*c.* 32-33 Ma). The remaining sequence, X, is interpreted as early Oligocene to late Eocene in age. The base of X at 923 mbsf in CRP-3 is the base of a 40 m thick dolerite breccia and conglomerate that separates underlying Devonian age Beacon sediments from Cenozoic strata and dated at 34 Ma. The sequences, U-X, are all within V5 of Cooper et al. (1987) and RSS-1 of Brancolini et al. (1995).

The oldest Cenozoic strata beneath Roberts Ridge, which comprise the upper part of V5 and were cored in CRP-2/2A and CRP-3, have now been dated as early Oligocene (or possibly latest Eocene) to early Miocene. They are thus much younger that Palaeocene or Cretaceous, as interpreted by Cooper & Davey (1985) and Cooper et al. (1987).. Furthermore, the lower part of V5, deeper than 823.11 mbsf in CRP-3 and extending to a depth of approximately 1280 mbsf, are most likely Devonian age Beacon rocks. The V5/V7 boundary of Cooper et al. (1987) lies approximately 340 m below the base of CRP-3 (from the intersection of NBP96-89 and USGS-401) and contrary to what is reported by Hamilton et al. (2001), probably marks an igneous and metamorphic basement underlying the Devonian Beacon strata and close to the top of sheet-like magnetic bodies modeled by Bozzo et al. (1997).

Finally, the absence of any core strata of Paleocene or Cretaceous age, requires a reassessment of seismic data in the western Ross Sea along with a reevaluation of the evolution of the Victoria Land Basin.

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