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CRUSTAL SEISMIC STUDY OF AN ENSIALIC BACK-ARC BASIN (BAY OF PLENTY, NEW ZEALAND)

Abstract. The Central Volcanic Region of North Island (New Zealand) has been a zone of back-arc extension and arc volcanism, associated with the subduction of the Pacific plate under the Australian plate along the Hikurangi margin, for the past 4 Ma. Present activity (< 0.6 Ma) is concentrated on the 40 km wide Taupo Volcanic Zone along its eastern margin. Marine crustal seismic reflection measurements have been carried out across the Central Volcanic Region, providing new insight into the structure of this intracontinental back-arc basin. A broad, block faulted extensional basin is identified containing up to 2.5 seconds two-way time of sediments of presumed volcanogenic origin. Faulting is more intense along the eastern margin of the basin. Sedimentary structures are complex and two phases of sedimentation can be identified in some areas. In the presently active Taupo Volcanic Zone, sediment thickness increases towards its centre where a deep basement ridge occurs but cannot be unequivocally interpreted to be of volcanic origin. However, strong mid and lower crustal reflectors occur under the central part of Taupo Volcanic Zone and are interpreted to be associated with magma or volcanic sills. The deepest reflector is close to the refraction Moho.

INTRODUCTION

New Zealand lies along the obliquely convergent plate boundary between the Pacific and Australian plates (Fig. 1). In northern New Zealand, along eastern North Island, the oceanic Pacific plate is subducted westwards under the continental Australian plate to form the Taupo Hikurangi arc-trench system (Cole and Lewis, 1981). The latter comprise the Hikurangi margin, a trough and fore-arc system, and, to the west, the Taupo Volcanic Zone (TVZ; Healy, 1962; Cole, 1984), a zone of Quaternary calc-alkaline volcanism and intracontinental back-arc extension which is the latter, eastern, phase of a longer period of back-arc activity forming the Central Volcanic Region (CVR; Stern, 1985). The CVR is a region of thinned crust and extensive volcanism formed over the past 4 Ma with activity migrating eastwards with time.

To the north, the Hikurangi margin - CVR is contiguous with, and forms the southern margin of the Kermadec arc - Havre Trough system. The boundary between the active back-arc extension in the Havre Trough and in New Zealand being offset in an *en-echelon* manner just north of New Zealand (Wright, 1992).

To the south, subduction along the plate margin becomes more oblique and terminates in northern South Island where the plate boundary passes through the continental lithosphere

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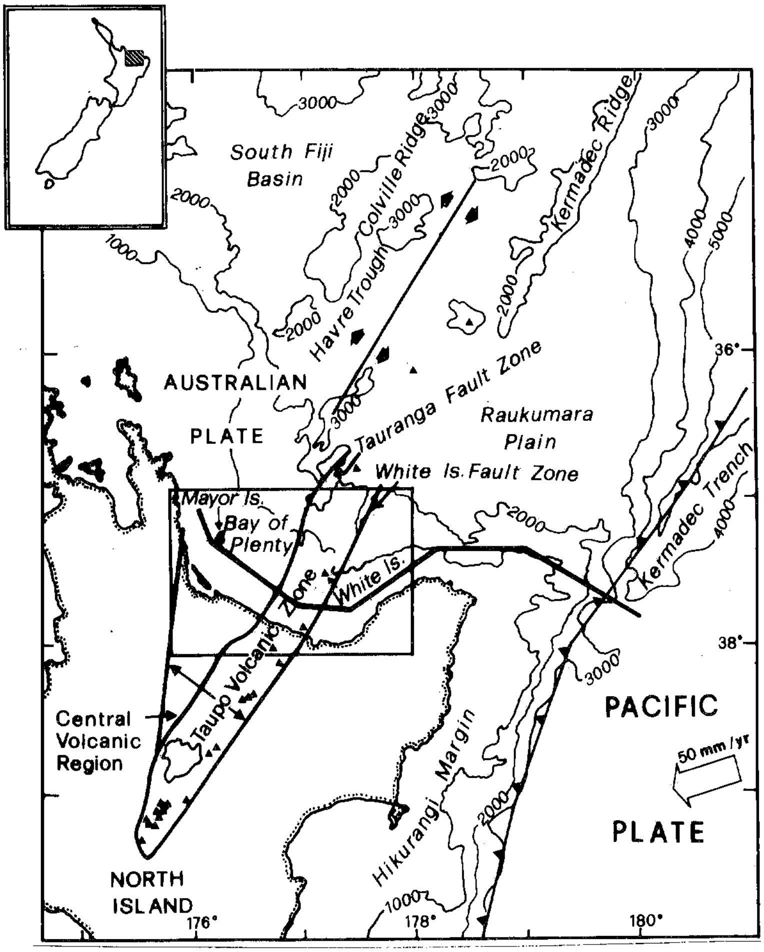

Fig. 1 - Main tectonic structures of North Island, New Zealand. The multichannel seismic profile is located by the thick line inside the box. The open arrow indicates the present rate of convergence (50 mm/yr) of the Pacific plate. Filled triangles represent active to recently active low-potash andesites.

of New Zealand and continental transpression occurs.

The present back-arc extensional tectonics of the TVZ terminates in central North Island and is replaced over southern North Island by back-arc downwarping (Davey and Stern, 1990).

The TVZ is the presently active zone of volcanism and extensive tectonism considered to comprise two major units: an andesitic arc to the east and a back-arc graben of rhyolitic volcanic centres to the west (Cole, 1984; 1986). However, extension occurs in both regions and Wright (1992), using an extensive set of morphological, shallow seismic and magnetic data, identifies three components to the back-arc system for the northern, offshore part of TVZ. These components are a back-arc graben, a volcanic ridge and a frontal graben.

The relationship of the CVR to the TVZ is also unclear. Cole (1990) considers that the CVR comprises the overlap of two distinct volcanic grabens - the Coromandel volcanic zone (4-0.8 Ma) and the Taupo Volcanic Zone (0.6-0 Ma) whereas Stern (1987) considers the CVR to be formed by an eastwards migrating arc-back arc extension during the past 4 Ma.

Deeper subsurface information is limited, both offshore and onshore, and this paper presents the results of a crustal seismic reflection profile across the CVR to constrain the larger scale structures forming the CVR and TVZ.

MULTICHANNEL SEISMIC REFLECTION DATA

A crustal seismic reflection profile was recorded across the CVR in December 1990 by the R/V *OGS-Explora*. A marine profile, close to the coast of northern New Zealand (Bay of Plenty, see Fig. 1), was chosen in view of the difficulties of getting good seismic data over the onshore volcanics of the CVR.

The objectives of the survey were to a) delineate the near surface sedimentary and basement structure and image the extensional tectonics inferred to form the CVR and the recent tectonics of the TVZ, b) image the lower crustal - upper mantle structure of the CVR, in particular define the base of crust inferred to occur at about 15 km under the CVR from seismic refraction data (Stern and Davey, 1987), and c) detect high reflectivity events which may be indicative of high temperature rock or magma which is the source of the recent volcanics in the region.

Data acquisition used a 120 channels, 3000 m long analogue streamer and a 2730 cu in (45.16 l) air-gun array. Shot spacing was 50 m (coverage 3000%), record length 16 seconds at 4 ms sampling.

Processing steps included a) spherical divergence and absorption correction, b) trace editing and despiking, c) two adjacent trace sum on the shot gathers applying a differential normal move out, d) sort, e) predictive deconvolution before stack, f) mute, g) constant velocity stack and semblance velocity analysis, h) common-depth-point (CDP) weighted stack, i) three traces time-variant running mix and time-variant filter, j) F-K domain filter, and k) finite-difference wave equation migration.

The resultant migrated profile, limited to 6 seconds two-way time (TWT) is shown in Fig. 2.

The data are of reasonable quality for the shallow, volcanogenic sedimentary section and clearly show the sequences and faulting in the section. Coherent dipping noise crosses the section and signal to noise is poor for the sub-sedimentary section. A relatively strong seafloor multiple in some places makes the interpretation of the shallow section difficult. The quality of the data varies significantly across the section. Dipping events, presumed to be diffraction associated with faulting, do not migrate out and are assumed to be out of plane reflections. Deeper events at CDP 3950 cross after migration and are discussed later. The complex shallow section indicates careful velocity analysis is needed.

The deeper reflectors are very weak apart from at CDP 3750-4400.

INTERPRETATION

The seismic section indicates that the structure across the CVR can be divided into three main parts (Fig. 2), a central trough of presumed volcanogenic sediments about 2 seconds TWT thick (3 km) from CDP 1000-5000, with flanking sub-basins containing up to 1 second TWT of sediments.

The central trough can be further subdivided into three sections by a basement high under the western portion (CDP 1900) and a deep basement high (CDP 3700) flanked by local sedimentary trough about 0.5 seconds TWT deeper than the adjacent sections. The whole section is highly faulted but east of this deep basement high the faults are of recent age and offset the seafloor. Beneath and to the east of the deep basement high, strong lower and middle crustal reflectors occur.

The section can be considered in parts corresponding to the tectonic units identified by Wright (1992) for the TVZ in the Bay of Plenty. These would be a) Central Volcanic Region west of the Mayor Island Fault Belt (Western CVR), b) Mayor Island Fault Belt, c) TVZ Back Graben, d) TVZ Volcanic Ridge, e) TVZ Frontal Graben, and f) Raukumara Plain to the east of the TVZ.

Strong reflectors (Fig. 3) occur at depth of 4.5 to 5.5 seconds TWT under the volcanic ridge and western frontal graben (CDP 3500-4450). The lower reflector lies close to refraction Moho of Stern and Davey (1987). The relatively strong reflectivity and coincidence with the

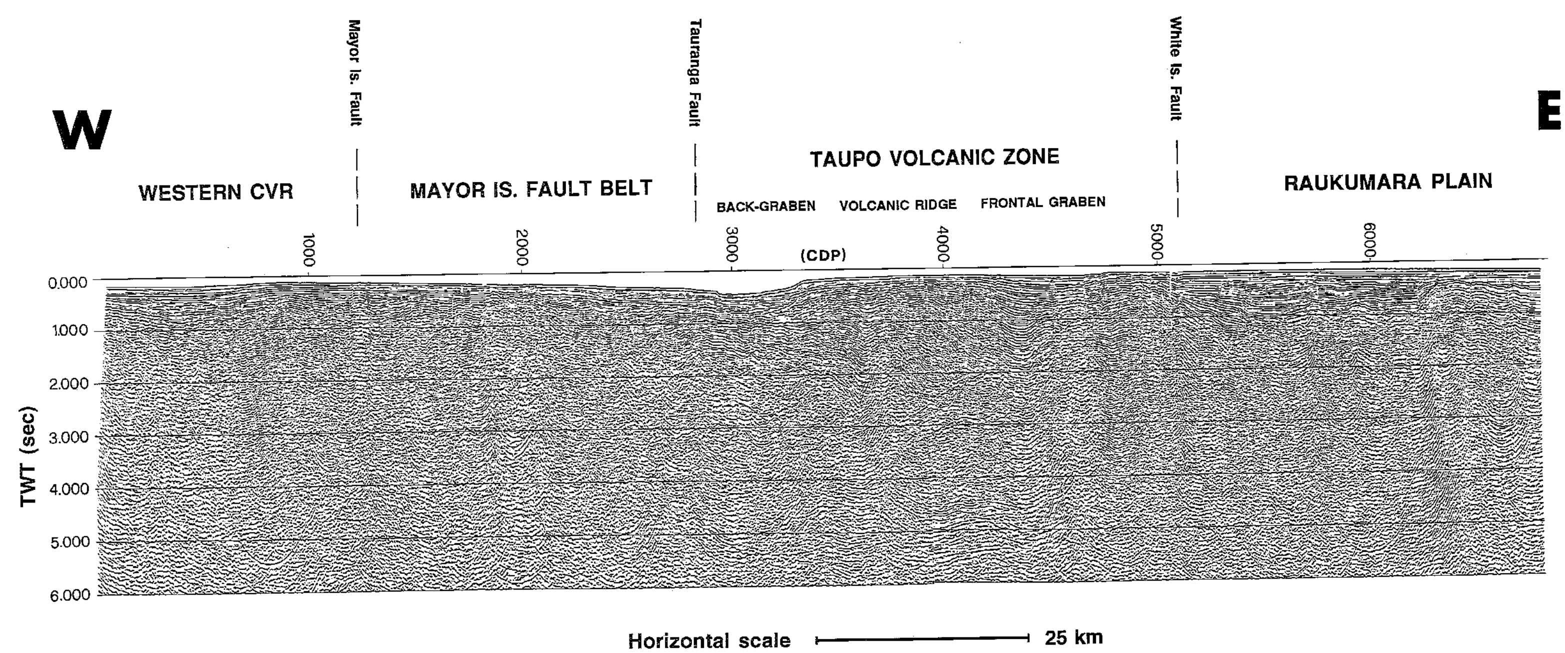

Fig. 2 - Migrated seismic profile across the Central Volcanic Region; on the top of the profile, the main tectonic units discussed in the text are indicated.

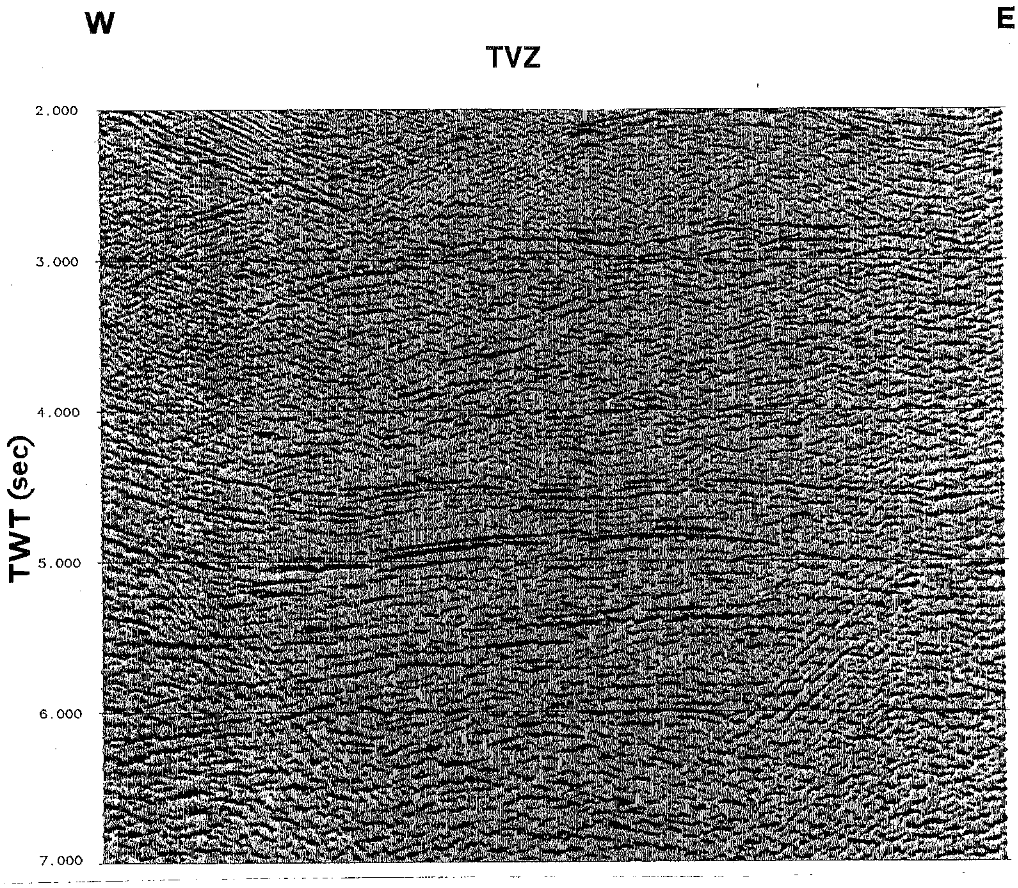

Fig. 3 - Stacked portion showing the strong reflectors below the central part of the Taupo Volcanic Zone (CDP 3800-4400). They are interpreted to be caused by magma and/or volcanic sills.

volcanic ridge would be consistent with the origin of the reflectors being of igneous origin, perhaps semi-molten rock or magma. Dipping reflectors overlying these deeper reflectors may indicate magma conduits to shallower levels.

a) WESTERN CVR

This section (Fig. 4) is to the west of the Mayor Island fault that corresponds to a horst coming close to the seafloor. A presumably volcanogenic sedimentary sequence, up to 0.8 seconds TWT thick, overlies a poorly defined basement in the west and over an older sedimentary (?) sequence to the east where basement occurs about 1 second TWT deeper.

b) MAYOR ISLAND FAULT BELT

The Mayor Island Fault Belt (Thrasher, 1986; 1988) is considered to be part of the North Island shear belt which has been offset by extension of the Taupo Volcanic Zone (Cole, 1990; Wright, 1992). The section across this region (Fig. 5) is delineated by the Mayor Island fault (CDP 1275) to the west and the Tauranga fault to the east (CDP 2820). Up to 1.5 seconds TWT (2.0 km) of sediments overlie a poorly defined basement. A basement ridge uplifted, by a major fault (offset 2 km) to the west (at CDP 1860), to within 200 m of seafloor and a series of smaller faults to the east, separates this section into two. Along these faults, presumed magmatic material has been probably extruded to form the near surface intrusive feature at CDP 2000-2100. The sedimentary section here (and also to the west) can be divided into a younger gently deformed sequence over an older more highly deformed and faulted sequence.

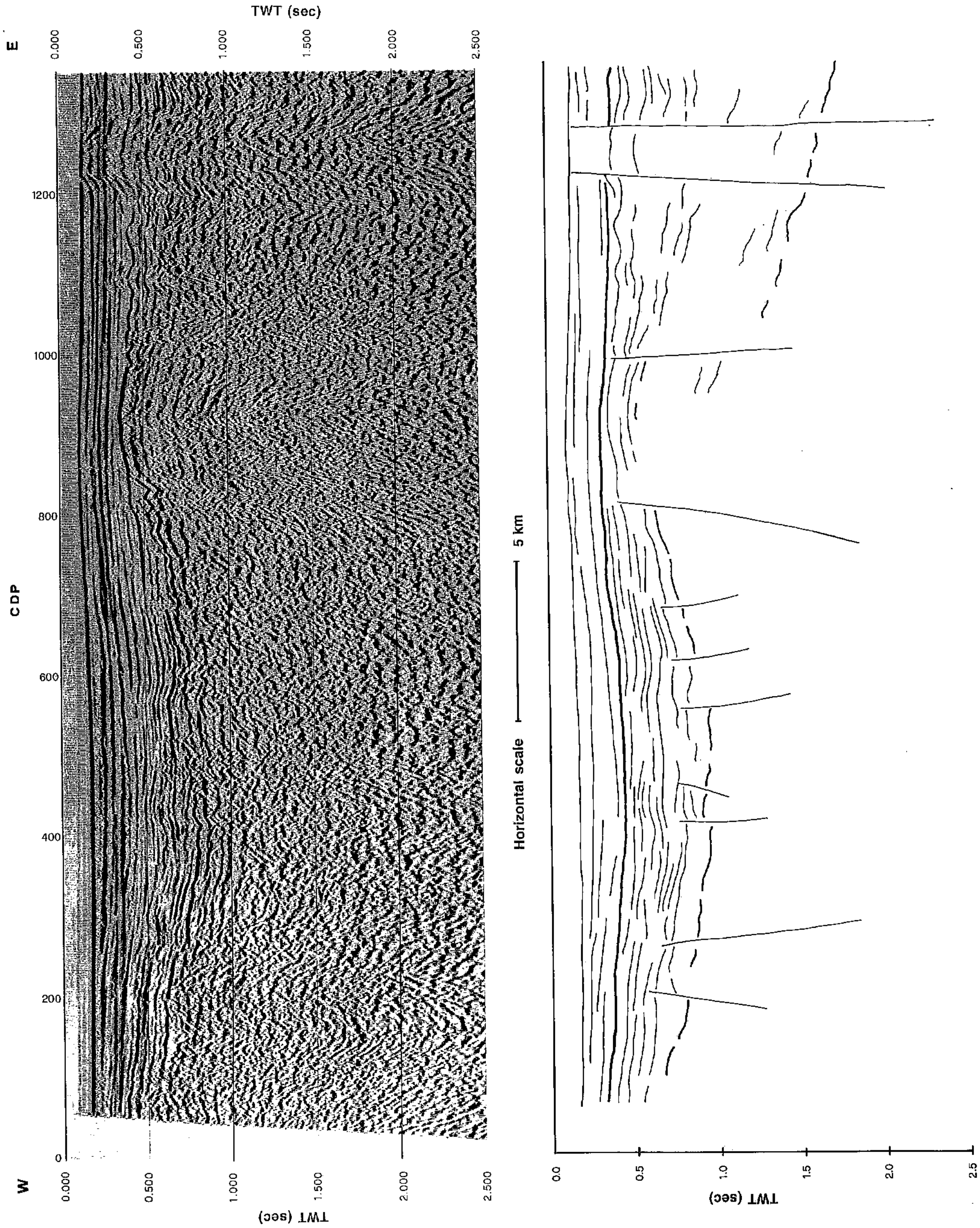

Fig. 4 - Migrated profile and line drawing across the western Central Volcanic Region.

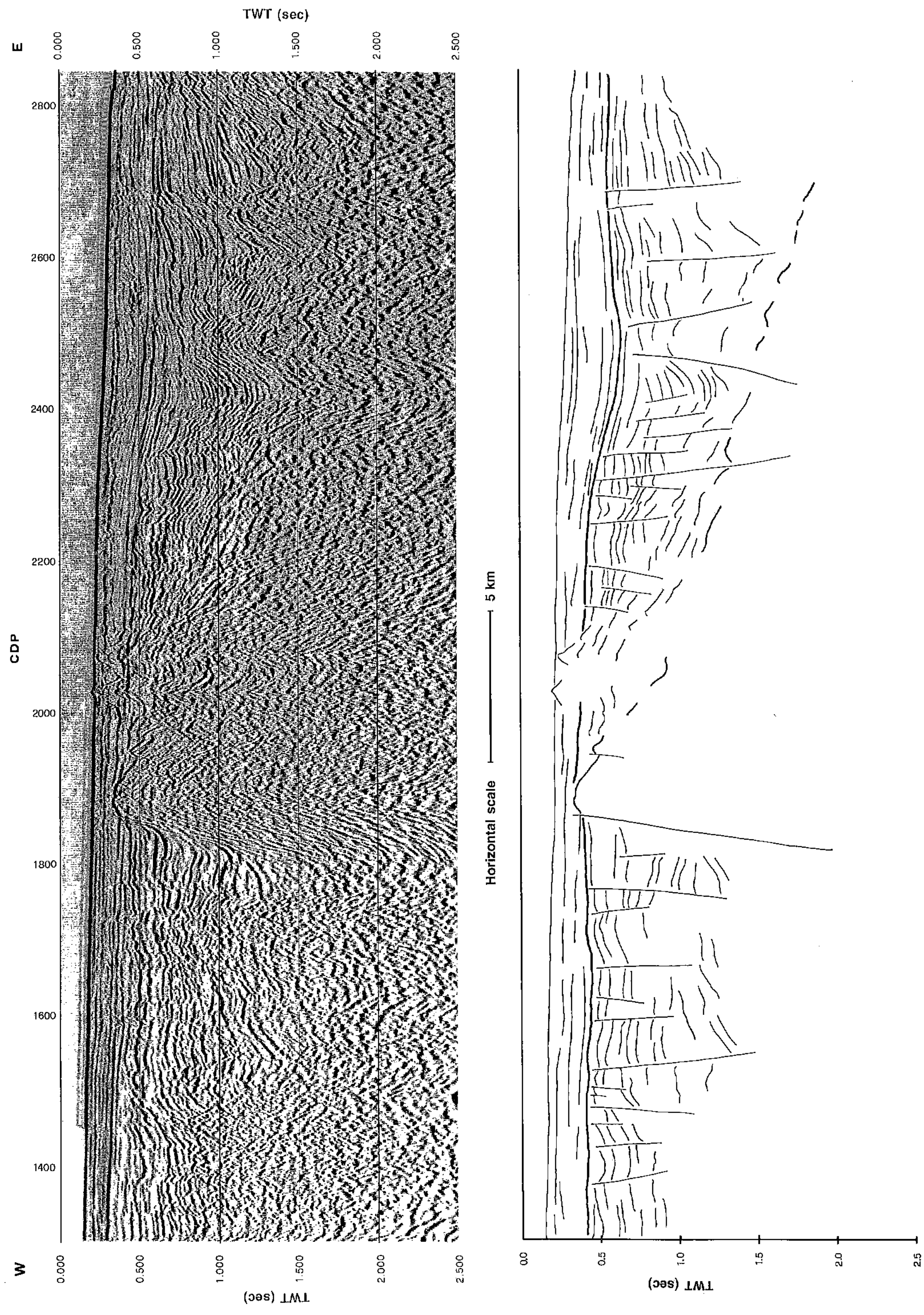

Fig. 5 - Migrated profile and line drawing across the Mayor Island Fault Belt.

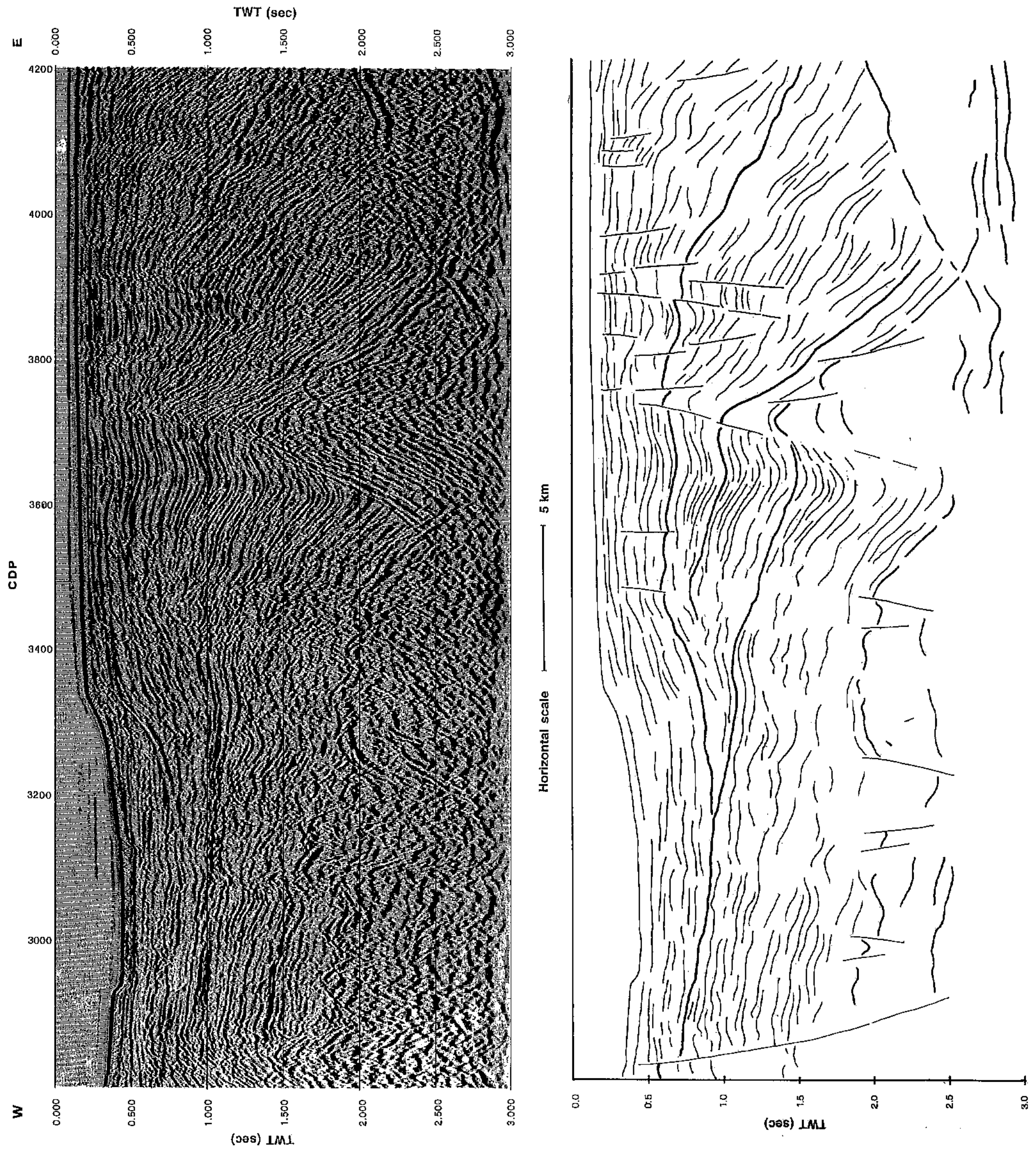

Fig. 6 - Migrated profile and line drawing across the Taupo Volcanic Zone back-graben and Taupo volcanic ridge.

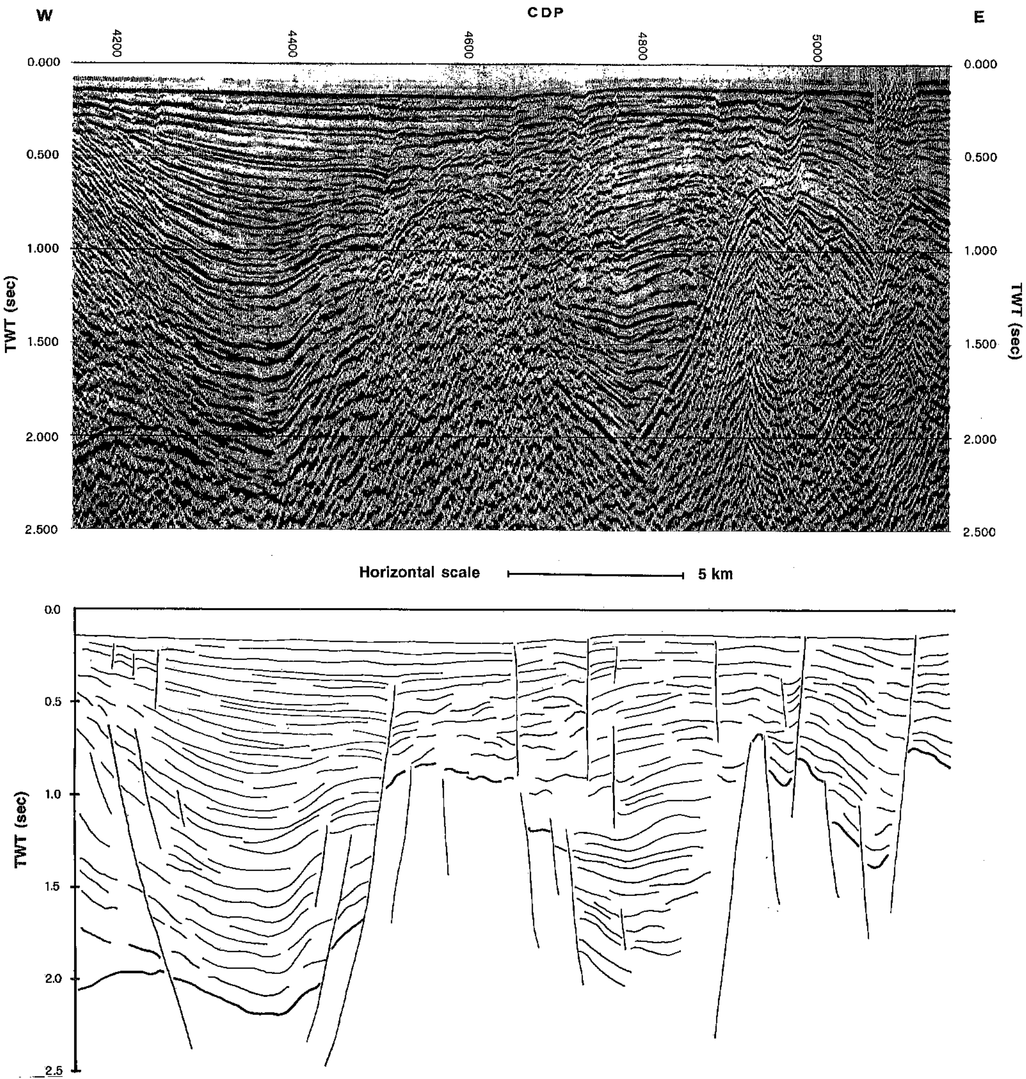

Fig. 7 - Migrated profile and line drawing across the Taupo Volcanic Zone frontal graben.

This lower sequence, east of the basement high, appears to have undergone fault block rotation, although no listric faulting is detected, with subsequent sedimentation onlapping the older sediments (e.g. CDP 2760).

c) TVZ BACK-GRABEN

The western margin of the back graben of Wright (1992) coincides with a major fault (Tauranga fault) which marks a change to a thicker and simpler sedimentary section to the east (Fig 6). The section thickens steadily eastwards to reach a maximum (2.5 seconds TWT) in a trough marginal to a buried basement high. The younger sedimentary section has two major parts separated by an unconformity with the sediment sequences toplapping to the west and the overlying sediments downlapping to west over the central part of the graben. In the east the whole sedimentary sequence conformably dips to the east. Minor faulting occurs, particularly in the older section. The unconformity may mark the top of the sequence corresponding to the sediments further west and thus the overlying sediments are the graben infill since the development of the active back arc graben of the TVZ at 0.6 Ma. The sedimentary sequences underlying the unconformity show a much thicker gently deformed sequence than the sediments

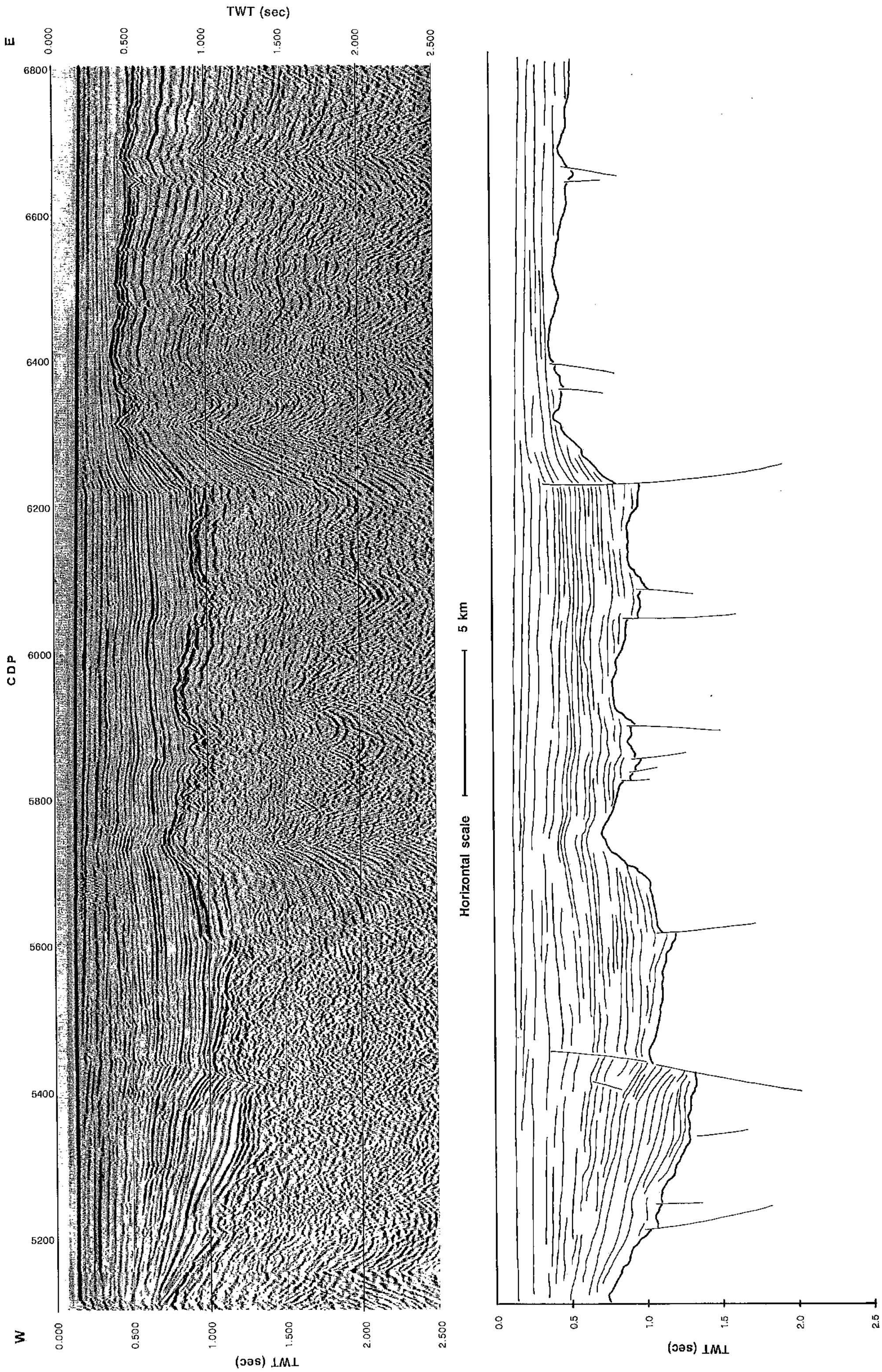

Fig. 8 - Migrated profile and line drawing across the eastern part of the Taupo Volcanic Zone.

to the west of the Tauranga fault indicating more extensive extension in this region when these sediments were laid down. The overall thickening of the younger sedimentary sequences eastwards across the TVZ back-graben indicates a movement in deformation (extension) eastwards.

d) TVZ VOLCANIC RIDGE

The volcanic ridge zone coincides with a deep basement high, to the east of which, the 4 km thick sequence of sediment dips steeply to the east (see Fig. 6). The sedimentary sequence has a prograding form but the attitude of the lower contact with basement is not clear. The strong deeper (2.0-3.0 seconds TWT) reflectors are difficult interpret. We interpret reflectors associated with the steeply dipping sedimentary layers as crossing the west dipping reflector at CDP 3900-4200 (2.0- 2.5 seconds TWT). This west dipping reflector we suggest is an out-of-plane reflector caused by a volcanic related dyke or sill. A reflector at about 3 seconds TWT is interpreted as basement in this region. The character of the reflections associated with the deep basement ridge are discontinuous and, in places, has similarities with out-of-plane reflectors. We would interpret this feature as being cause by volcanic intrusions associated with a volcanic ridge off to one side of this profile. The prograding sedimentary sequence to the east indicates the movement of the centre of extension and downwarp to the east. The toplapping and downlapping sequences over and to the west of the ridge are associated with the emplacement of the ridge.

e) TVZ FRONTAL GRABEN

The frontal graben of Wright (1992) is characterised in general by shallow dipping reflectors in contrast to the volcanic ridge section to the west (Fig. 7). The western margin of the frontal graben occurs at CDP 4200. The whole of the frontal graben is characterised by pervasive recent faulting with significant offsets seen at the seafloor. Basement, although difficult to identify in places, appears to very variable in depth. The White Island fault crosses obliquely the eastern end of the profile at a high angle and the complex structure recorded at CDP 4800-5100 probably includes out-of-plane reflectors.

f) EAST OF TVZ

There is a major change in character of the section on passing across the White Island fault from the frontal graben to the southern extremity of the Raukumara plain (Fig. 8). The section shows a well defined basement overlain by a flat sedimentary sequence, as seen further north (Gillies and Davey, 1986). Minor faulting occurs within the basin which is terminated at its western end (CDP 6220) by a high-angle reverse fault.

DISCUSSION

The data presented here are consistent with a broad model of Wright (1991) for the TVZ of a wide extensional zone with a higher degree of recent faulting along the eastern margin of the TVZ. In general terms the graben deepens towards the centre where a basement high may correspond to a volcanic/igneous body. This central area is underlain by strong reflectors at middle and lower crustal depths, interpreted to be caused by igneous intrusions or magma.

Faulting is pervasive across the whole CVR and the major faults define a tilted block fault terrane. Because of the difficulty of unequivocally identifying basement, a total extension factor for the basin cannot be determined. There is evidence in places of two phases of extension in the CVR suggesting an early phase associated with the 4 Ma et seq extension, and a later phase, also across the whole CVR, which is still ongoing with the extension of the TVZ. This is consistent with the geodetic results of Walcott (1987) who determined a present extensional rate of 12 mm/yr across the whole CVR. Within the TVZ the sedimentary structures are complex. The older sedimentary sequence of the CVR, which occurs to the west of the TVZ (Tauranga fault) is also inferred to occur in the lower part of western TVZ (back-graben) where it thins eastwards to the volcanic ridge. The overlying sediments are much thicker than in the CVR to the west, and these sediments thicken and may get younger towards the east. The geometry of the younger sedimentary sequences in the east of the back-arc graben can be interpreted to show uplift and erosion due to the intrusion of the volcanic ridge (older toplap beds) followed by regional downwarp and major extension east of the ridge (young downlap beds to the west and prograding sequences to the east) and in the frontal graben. Major, young, tectonic activity in the frontal graben is also supported by the increase in, and young age of, the faulting there.

Tectonic ablation along the eastern margin of the TVZ has been proposed by several workers (Healy, 1962; Stern, 1987; Wright, 1992). Stern (1987) deduced a relative rate of ablation of 8 mm/yr. This would give a total of about 5 km since the extension of the TVZ started 0.6 Ma ago and is consistent with the complex horst feature under the eastern part of the frontal graben (Fig. 8) being ablated (captured) into the TVZ.

The seismic profile supports the concept in asymmetric extension across the CVR. The younger sedimentary sequences and the total sediment thickness increase significantly to the east as the older sediments thin and disappear. The intensity of faulting appears to increase to the east and the faulting becomes younger, with faults displacing the seafloor. ODP results in the Lau Basin, at the north of the Tonga - Kermadec convergent plate boundary, has also derived a similar asymmetric extension history, but, in that case, for a back-arc basin where oceanic crust is being generated. A similar extensional mechanism probably occurs in both cases.

SUMMARY

Crustal seismic reflection data along the Bay of Plenty coast demonstrates that the Central Volcanic Region (back-arc and volcanic arc) is underlain by a complexly faulted sedimentary sequence up to 2.5 seconds TWT thick. In places the sequence forms two distinct units separated by an angular unconformity which may be related to an early extensional phase 4-0.8 Ma ago and a younger extensional phase (0.6-0 Ma ago) related to the formation of the Taupo Volcanic Zone. Within the TVZ there appears to be two extensional and depositional episodes associated with the intrusion of a volcanic ridge. Deformation is presently concentrated on the eastern margin of the region and the whole CVR appears to have been generated by asymmetric extension.

The presently active volcano-tectonic zone, the Taupo Volcanic Zone, in the east can be delineated by major faults, the Tauranga fault and the White Island fault. The major faults define a broad block faulted terrane. The three main elements of the TVZ identified by Wright (1991) can be identified but, particularly in the case of the volcanic ridge, they are not as distinctive as recognised by Wright.

The central part of the TVZ, coincident with the volcanic ridge region, is underlain by several strong mid-lower crustal reflectors which are interpreted to be caused by magma and/or volcanic sills, and are probably the source of the andesitic volcanoes.

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