Subduction-obduction: a possible north-south transition along the west flank of the Three Kings Ridge

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ABSTRACT

The Three Kings Ridge has been reinterpreted as a west-facing island arc under which a significant amount of Norfolk Basin lithosphere may have been subducted. Examination of additional seismic reflection profiles adds credence to this interpretation and suggests the presence of a north-south transition from subduction under the northern half of the ridge, evidenced by well-preserved island-arc morphology, to obduction along the southern half of the ridge. This obduction probably obliterated the trench, resulting in overthrusting and severe deformation of the forearc basin as well as intense faulting of the volcanic arc.

INTRODUCTION

The Three Kings Ridge, a north-south trending feature, is part of the complex belt of subparallel basins and ridges that lies east of Australia, between New Zealand and New Caledonia. Jutting north from Northland, New Zealand, the Three Kings Ridge separates the South Fiji Basin to the east from the Norfolk Basin to the west (Fig. 1). Three Kings Ridge is offset from the Loyalty Ridge to the northwest by the Cook Fracture Zone [1].

Karig [2] suggested that the Three Kings Ridge is a remnant arc, left behind during the arc migration that formed the South Fiji Basin. Discovery of symmetric magnetic anomaly lineation patterns (anomalies 7–12) in the Minerva Abyssal Plain (Fig. 1) led Weissel and Watts [3] and Watts and others [4] to postulate a former R-R-R triple junction in the area. The lineations found to the south in the Kupe Abyssal Plain, however, represented only one side of the normally symmetric pattern formed on either side of a spreading center [5,6]. Westward subduction beneath the Three Kings Ridge was proposed to explain the missing lineations [4–6].

Kroenke and Eade [7], noting that there appears to be sufficient room within the South Fiji Basin to contain all of the missing anomaly lineations and that trench morphology appears to be missing on the eastern side of the Three Kings Ridge, suggested that the morphology present seems more characteristic of a backarc than a forearc region. They presented geophysical evidence for the existence of a trench and forearc basin on the western side of the ridge and concluded that a west-facing arc had been constructed on older (36 to 26 Ma) South Fiji Basin lithosphere. They also suggested that a significant amount of Norfolk Basin lithosphere could have been consumed in the eastward-dipping subduction zone.

As shown in Figure 1, the Norfolk Basin can be subdivided into two basins [8], termed North and South Norfolk basins. Both basins are characterized by complex physiography [7]. The Three Kings Ridge also seems to be comprised of two parts: a northern half that is steep, narrow and well defined, and a southern half that is less steep, broader, and less well defined but that is characterized by far more complex topography.

EXAMINATION OF REFLECTION PROFILES

In order to test the hypothesis that the Three Kings Ridge originally was a west-facing arc, four additional reflection profiles have been examined (GEO 311, AUS 203, AUS 202, and GC 21), all of which cross the north-south trend of the Three Kings Ridge. Profile GEO 311 is reproduced in Figure 2, and tracings of GEO 311, AUS 203, AUS 202 and GC 21 are shown

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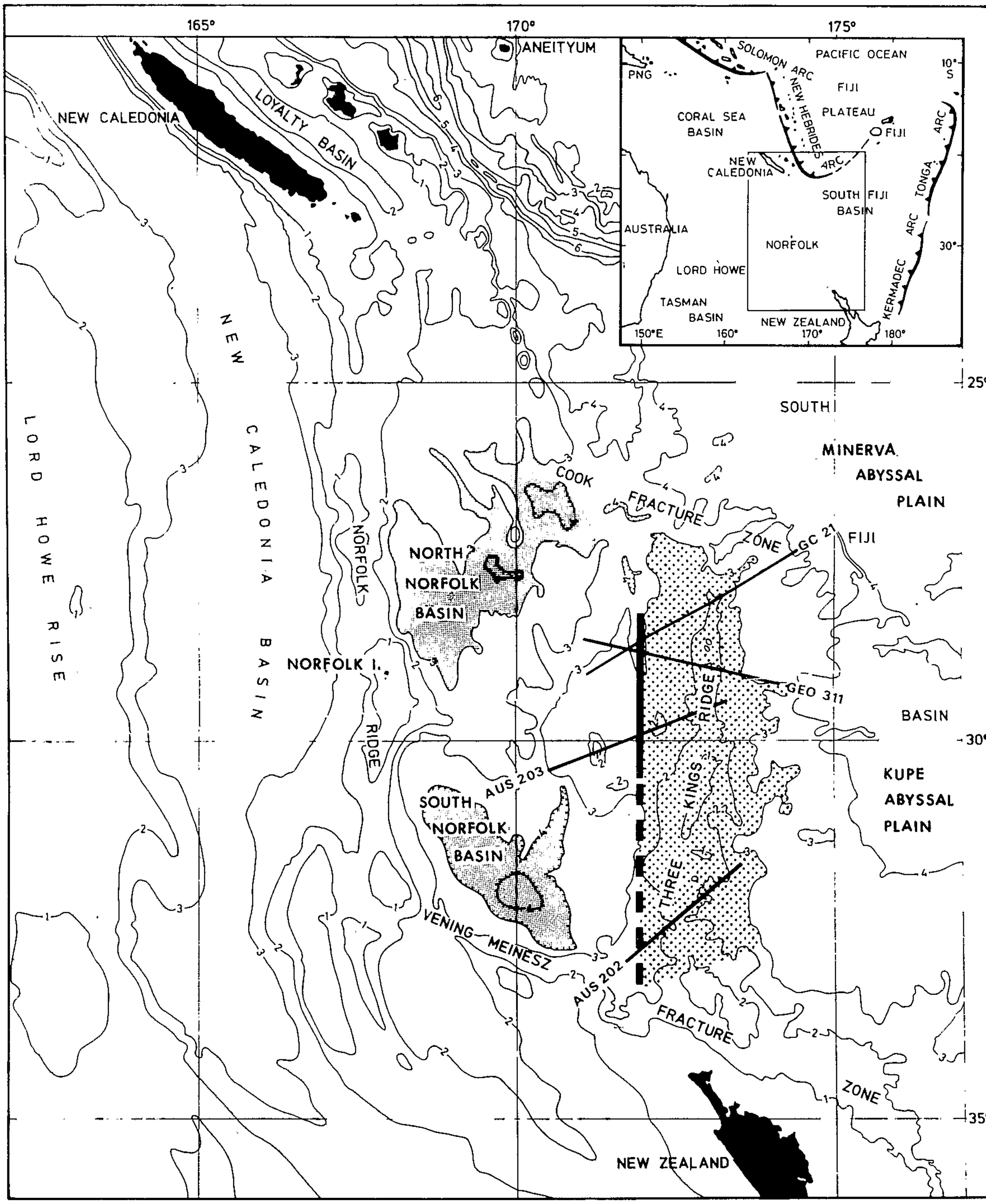

Figure 1. Location of Three Kings Ridge, showing locations of profiles referred to in the text. Contour interval 1 km. The wide vertical line indicates the trench axis: solid indicates subduction; dashed indicates obduction.

in Figure 3. It is apparent that the bottom morphology displayed in Figure 2 is very similar to that of the VEMA 33 profile farther to the north presented by Kroenke and Eade [7]. Below the blanket of transparent pelagic ooze in profile GEO 311, the seaward convergence of reflectors characteristic of a forearc basin [10] is clearly revealed.

In all of the profiles taken across the northern half of the Three Kings Ridge the forearc basin is the most distinguishing feature. In each of these profiles the spacing between the trench axis and the volcanic axis is approximately 110 km, within the normal range of spacing for an arc-trench gap [11,12].

In profile AUS 203, however, across the central part of the Three Kings Ridge, the arc-trench morphology is not as obvious. Here the relief of the volcanic arc is subdued; the forearc basin is structurally deformed and foreshortened, disrupted by a large horst which divides the basin in two; and the trench

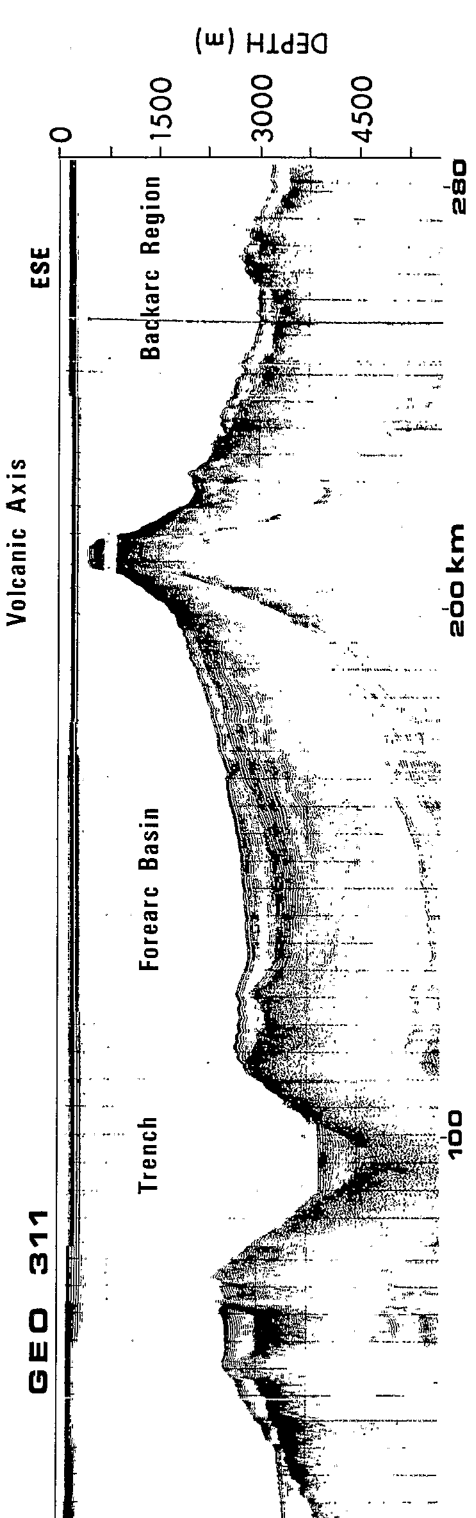

Figure 2. GEO 311 seismic reflection profile across the northern end of the Three Kings Ridge illustrating typical island arc morphology. The profile is a GEORSTOM single channel seismic reflection line, recorded by ORSTOM, using flexichoc (beginning) and 5-liter airgun sources. Location is shown in Figure 1.

morphology is almost completely obliterated, with only a vestige of underthrust oceanic crust discernible to indicate the presence of the former subduction zone and trench axis. The spacing between the inferred trench axis and the volcanic axis is still roughly 100 km, i.e., approximately that observed in the northern profiles, and is still within the range typical of an arc-trench gap. A large plateau is believed to have encroached on the trench and collided with the arc, causing deformation of the forearc region and partial obliteration of the trench.

In Profile AUS 202 the various elements of arc-trench morphology are more difficult to distinguish. The volcanic arc, although intensely faulted, is still recognizable; the forearc basin is so structurally deformed as to be almost unrecognizable; and there is no bathymetric expression of a trench. There is, however, a prominent deep, low-frequency reflector, as much as 6.3 sec of reflection time below sea level (more than 3.0 sec of reflection time below the seafloor) in the appropriate geographic position for the trench axis, i.e., roughly 110 km from the volcanic axis. This deep reflector is overlain by another low-frequency reflector 4.0 to 4.5 sec of reflection time below sea level (roughly 1.0 sec of reflection time below the seafloor), which we interpret to represent the top of basaltic basement. Thus, the origin for the deeper reflector, as much as 2.0 sec of reflection time below the "basement" reflector, becomes problematical.

A portion of the AUS 202 multichannel record across the critical region (indicated in Fig. 3) is shown in Figure 4a. Our interpretation is shown in Figure 4b. The deep, low-frequency reflection is highlighted in Figure 4b as is the overlying low-frequency reflection. Although Ravenne and others [13] apparently chose to interpret the deepest reflection as oceanic basement, attributing the entire overlying section to sedimentary basin infilling, we believe that the acoustic character of the shallower reflector is similar to that of oceanic basement observed elsewhere along the same profile (see for example, Austradec 202 bis, Fig. 6c, Ravenne and others [13]). Southwest of the trench axis (to the left of the arrow in Figs. 3 and 4), we interpret the deeper reflector to represent the M discontinuity (M reflection) at the base of Norfolk Basin oceanic crust. Northeast of the trench axis (to the right of the arrow in Figs. 3 and 4) we believe it signifies the presence of a decollement fault (D reflection) along which Norfolk Basin crust has been overthrust.

The recognition of reflections originating from the top of the ocean crust/mantle interface in seismic profiles obtained using high-energy sources is not new and has been previously reported by others (see for example, Fig. 9 in Shepherd and Moberly [14]). Indeed, if the thickness of the basaltic crust is calculated along Profile AUS 202 southwest of the trench axis, using the two-way reflection time of 2.0 sec for the interval between the upper and lower low-frequency reflectors and a mean crustal velocity for average Pacific Basin crust of 6.6 km/sec [15], a thickness of 6.6 km is obtained. This thickness is roughly that of normal oceanic crust. Furthermore, the presence of semi-coherent acoustic stratification beneath the D reflection

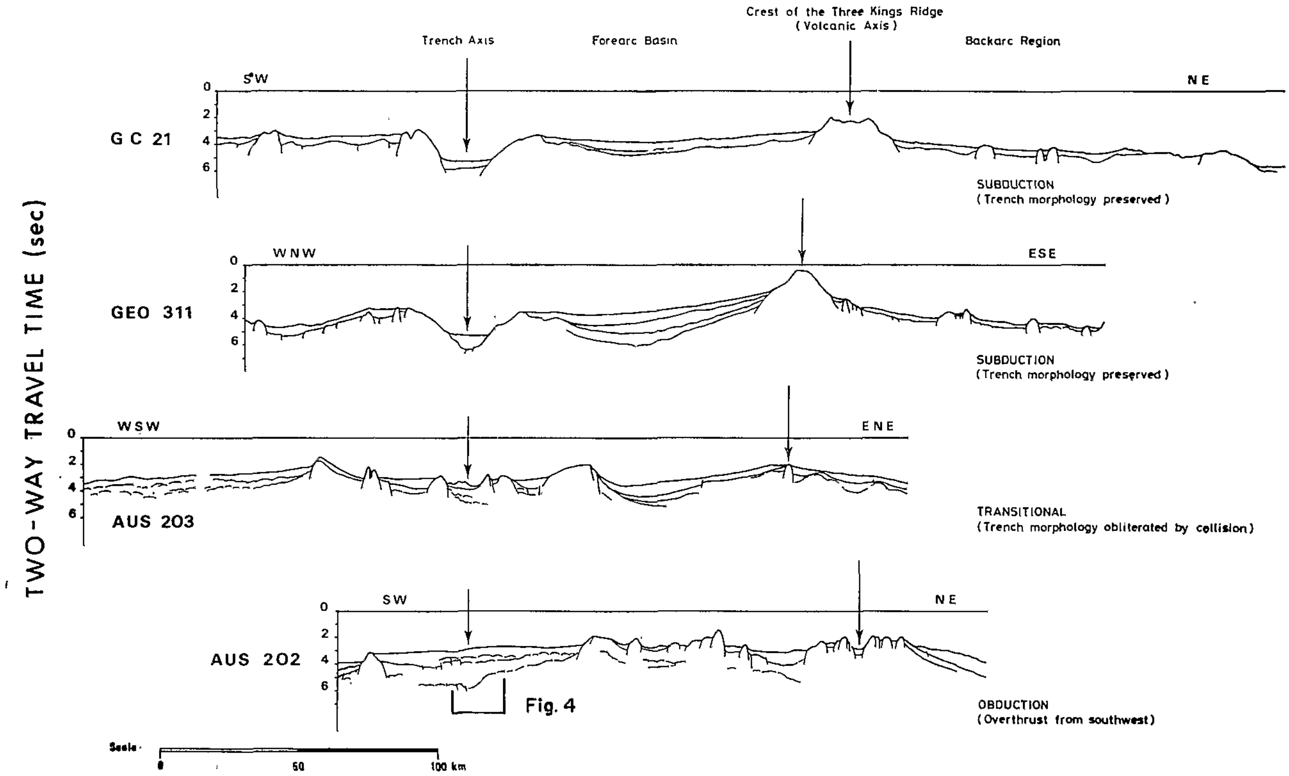

Figure 3. Line drawings of four profiles across the Three Kings Ridge showing variation in morphology and structure from that of subduction in the north to that of obduction in the south. The location of these profiles is shown in Figure 1. Profiles AUS 203 and 202 are Austradec multichannel seismic reflection lines, recorded by IFP-CEPM-ORSTOM (IFP: Institut François du Pétrole; CEPM: Comite d'Etudes Petrolieres Marines) using flexichoc which provides both deep penetration and high resolution. These profiles are so long and were recorded with such a small vertical exaggeration that only tracings are practical for illustrations. Profile GC 21 is from the GLOMAR CHALLENGER Leg 21 reflection record [9]. The location of the expanded section of the profile shown in Figure 4 is bracketed on the lowest profile. The arrow on the left indicates the trench axis, which is mainly obliterated in the south by the obducted sheet.

suggests that stratified trench slope deposits may underlie the postulated decollement surface.

In arriving at our interpretation, we initially considered the possibility that side echoes originated from nearby lineated topography. We believe, however, that a more compelling argument favors the overthrust interpretation: the observation that northeast of the trench axis, the D reflection appears to be phase-shifted 180°, indicating that the underlying section (trench slope deposits) is of lower velocity than the overlying section (oceanic crust). In contrast, southwest of the trench axis, the lack of a phase shift in the M reflection indicates that the underlying section (mantle material) is of higher velocity than the overlying section (oceanic crust).

CONCLUSIONS

From these arguments, we conclude that not only was the Three Kings Ridge a west-facing arc but also that there is a transition along the arc from formerly active subduction of oceanic crust under the northern half of the ridge to terminal obduction of oceanic crust over the southern half of the ridge. This transition is indicated by the change from well-preserved arc-trench morphology in the north (including the characteristic forearc basin as exemplified in GEO 311), through the partial obliteration of the trench and deformation and foreshortening of the forearc basin (revealed in Profile AUS 203), to the overthrusting and severe deformation of the forearc basin and the intense faulting of the volcanic arc (shown in Profile AUS 202). Although the timing of obduction is uncertain, it probably occurred contemporaneously with cessation of volcanism along the Three Kings Ridge, and it probably occurred after formation of the South Fiji Basin between 36 and 26 Ma [6].

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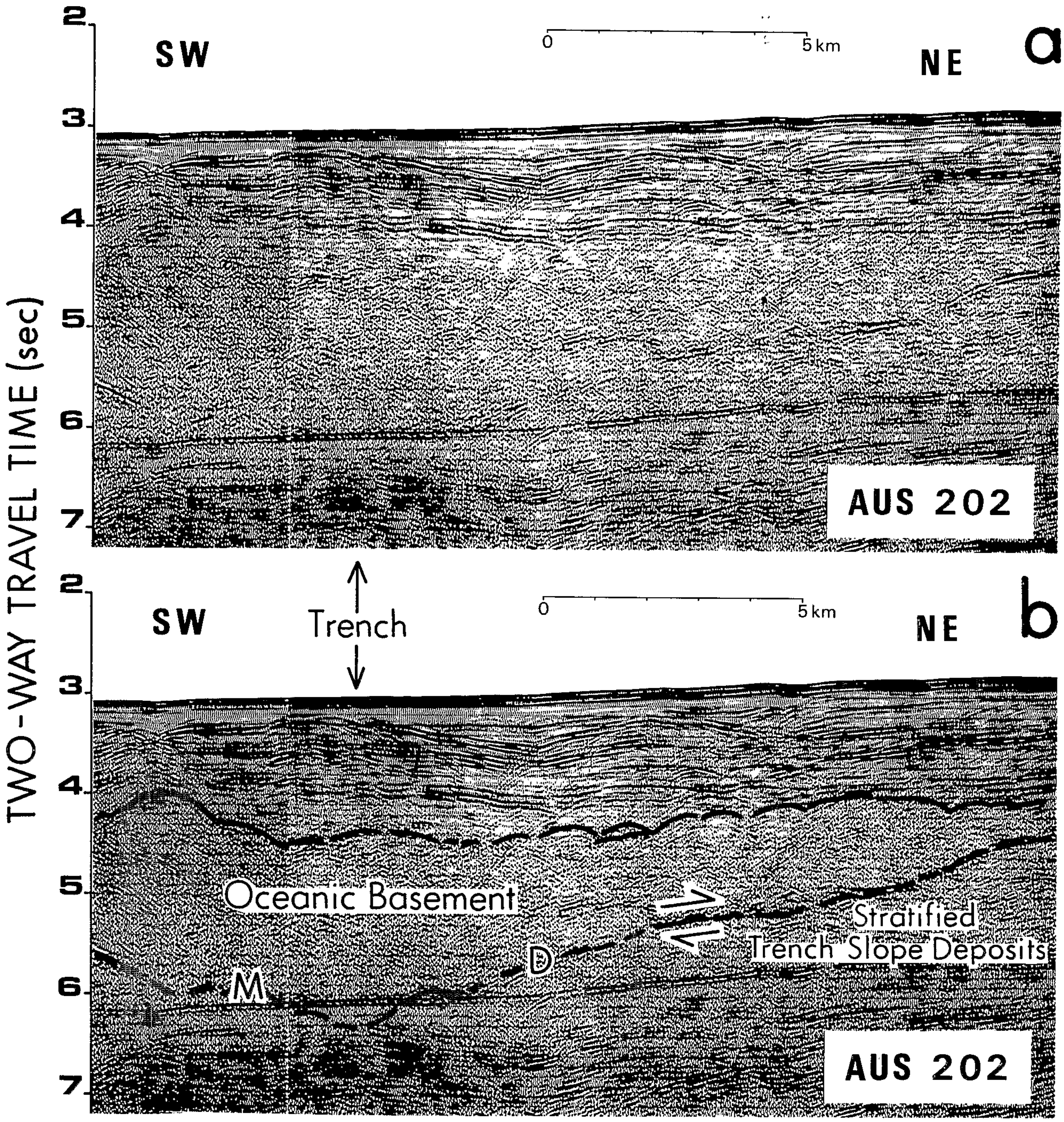

Figure 4. Expanded section of AUS 202 profile; (a) is the original; (b) is interpreted. The upper highlighted reflection is interpreted to originate from oceanic basement. The lower highlighted reflection on the left-hand side (M reflection) is interpreted to originate from the M discontinuity. On the right-hand side (D reflection) it is interpreted to originate from a decollement beneath overthrust oceanic crust.

REFERENCES

[1] Lapouille, A., 1977. Magnetic surveys over the rises and basins in the south west Pacific. In: International Symposium of Geodynamics in Southwest Pacific, Noumea, 27 August–2 September 1976. Editions Technip, Paris, p. 15–28.

[2] Karig, D. E., 1970. Ridges and basins of the Tonga-Kermadec island arc system. Journal of Geophysical Research, v. 75, p. 239–254.

[3] Weissel, J. K., and Watts, A. B., 1975. Tectonic complexities in the South Fiji marginal basin. Earth and Planetary Science Letters, v. 28, p. 121–126.

[4] Watts, A. B., Weissel, J. K., and Larson, R. L., 1977. Seafloor spreading in marginal basins of the Western Pacific. Tectonophysics, v. 37, p. 167–181.
[5] Davey, F. J., 1982. The structure of the South Fiji Basin. Tectonophysics, v. 87, p. 185–241.
[6] Malahoff, A., Feden, R., and Fleming, H., 1982. Magnetic anomalies and tectonic fabric of marginal basins north of New Zealand. Journal of Geophysical Research, v. 87, p. 4109–4125.
[7] Kroenke, L. W., and Eade, J. V., 1982. Three Kings Ridge: A west-facing arc. Geo-Marine Letters, v. 2, p. 5–10.
[8] Launay, J., Dupont, J., and Lapouille, A., 1982. The Three Kings Ridge and Norfolk basin (Southwest Pacific): An attempt at structural interpretation. South Pacific Marine Geological Notes, v. 2, no. 8, p. 121–130.
[9] Burns, R. E., and Andrews, J. E., 1973. Regional aspects of deep sea drilling in the southwest Pacific. In: R. E. Burns, J. E. Andrews and others, Initial Reports of the Deep Sea Drilling Project, v. 21, U.S. Government Printing Office, Washington, DC, p. 897–906.
[10] Coulbourn, W. T., and Moberly, R., 1977. Structural evidence of the evolution of forearc basins off South America. Canadian Journal of Earth Science, v. 14, p. 102–116.
[11] Dickinson, W. R., 1973. Widths of modern arc-trench gaps proportional to past duration of igneous activity in associated magmatic arcs. Journal of Geophysical Research, v. 73, p. 3376–3389.
[12] Seely, D. R., and Dickinson, W. R., 1977. Structure and stratigraphy of forearc regions. In: Geology of Continental Margins. American Association of Petroleum Geologists Continuing Education Course Note 5.
[13] Ravenne, C., and others, 1977. New Caledonia Basin–Fairway Ridge: structural and sedimentary study. In: International Symposium of Geodynamics in Southwest Pacific, Noumea, 27 August–2 September 1976. Editions Technip, Paris, p. 145–154.
[14] Shepherd, G. L., and Moberly, R., 1981. Coastal structure of the continental margin, northwest Peru and southwest Ecuador. In: L. D. Kulm and others (eds.), Nazca Plate Crustal Formation and Andean Convergence, Geological Society of America Memoir 154, p. 351–391.
[15] Hussong, D. M., Wipperman, L. K., and Kroenke, L. W., 1979. The crustal structure of the Ontong Java and Manihiki oceanic plateaus. Journal of Geophysical Research, v. 84, p. 6003–6010.

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