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THE THREE KINGS RIDGE AND THE NORFOLK BASIN (SOUTHWEST PACIFIC): AN ATTEMPT AT STRUCTURAL INTERPRETATION

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ABSTRACT

Bathymetric, magnetic and seismic data collected during the AUSTRADEC and GEORSTOM cruises provide a structural interpretation in which the Three Kings Ridge is presumed to be a volcanic ridge extending from the Loyalty Ridge and linked to an extinct island arc (New Caledonia - Norfolk) due to Cretaceous subduction. The Norfolk Basin may have been formed by back-arc spreading as a consequence of this subduction.

INTRODUCTION

The eastern margin of the Austral-Indian plate is in contact with the Pacific plate at the Tonga-Kermadec, New Hebrides and Solomon subduction zones. This margin, which has a crust intermediate in thickness between normal continental and oceanic crusts, consists of a succession of rises and basins between the Australian continental area and the Pacific oceanic area. It is accepted that these structures originated by easterly migration of the plate boundary leaving behind these relict marginal rises and basins. It is within this regional context that an attempt is made to explain the existence of the Three Kings Ridge and the Norfolk Basin.

The Three Kings Ridge (Fig. 1), which lies between 28° and 33°S, running north/south along 173°E longitude, was first described by Van der Linden (1967, 1968). It is bounded to the north by the Cook Fracture Zone and to the south by the Vening Meinesz Fracture Zone, and lies between the Norfolk Basin to the west and the South Fiji Basin, or more precisely the Kupe abyssal plain, to the east.

Van der Linden (1969) states that "if the assumption is correct that the Three Kings Ridge is another example of an extinct mid-ocean ridge then the fracture zones most likely are transcurrent or transform faults which mark the actual spreading direction". Karig (1972) regards this Ridge as well as the southern extension of the Loyalty Chain as remnant arcs. Packham and Terrill (1975) report, in the northwest section of the South Fiji Basin, a north-south trending ridge which would appear to be an extension of the Three Kings Ridge displaced 100km westwards. We think it more likely that a NNW-SSE alignment of highs (Fig. 1) about 200km to the west constitutes the Three Kings Ridge extension formed before the opening of the Norfolk Basin. However, Lapouille (1977) links these highs to the Loyalty Chain.

The Norfolk Basin (Fig. 1) is bounded on the north and south by the fracture zones mentioned above and on the west and east by the Norfolk Ridge and the Three Kings Ridge. A bathymetric discontinuity (Figs. 1 and 3) marked by a series of topographic highs divides the basin into the North Norfolk Basin and the South Norfolk Basin (new names). Recent volcanic activity on the Norfolk Ridge (Aziz-Ur-Rahman and McDougall, 1973) and some seismic activity in the vicinity of Norfolk and Philip Islands (Adams, 1972) may be associated with this discontinuity.

MORPHOLOGY AND STRUCTURE (Figs. 1 and 2)

The region will be discussed in three sections, from east to west:

(a) Three Kings Ridge

The width of the Ridge decreases from about 250km in the north to approximately 100km in the south. Between 30° and 32°S insufficient data exist to allow the contours to be defined with confidence.

Structurally, the ridge appears, in the north, as a central ridge crest with synclinal flanks possessing a sedimentary series that is thicker and more regular in the west (1.5 seconds two way travel time) than in the east (0.5 seconds). On seismic profiles such as GEO 311 and AUS 203 (Fig. 2) there is a fairly distinct reflector located 1 second below this sedimentary series suggesting the upper level of another sedimentary layer which may, by its appearance, be deformed. Further south, the upper series has a seismic thickness of 1 second (AUS 202). The basement crops out in the north as massifs up to 10km wide while in the central portion our data show only one peak emerging from under the sedimentary cover. While relief on the flanks of the ridge is regular in the west, the eastern flank features many outcrops of faulted blocks. At the southern end, the basement is highly fractured (AUS 202) producing on the surface a very broken topography which contrasts with the northern portion.

(b) The transition zone

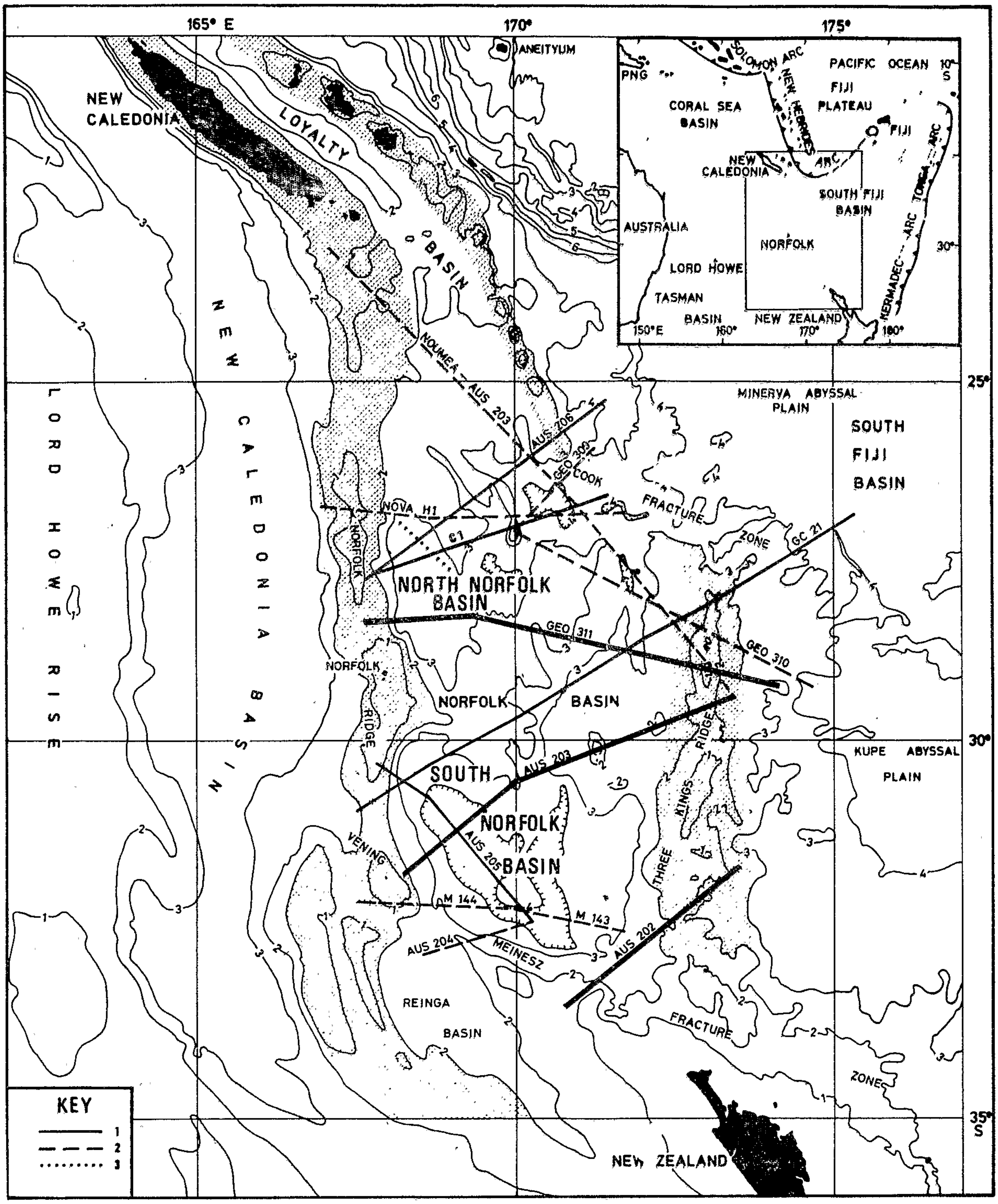
The transition zone does not possess any major morphological feature, but it nevertheless represents an important area distinct from the Norfolk Basin and the Three Kings Ridge. It is characterized by a very thin sedimentary cover (0.4 seconds) except in very small localized grabens. Basement horsts also crop out at many points as illustrated on profiles AUS 203 and GEO 311 (Fig. 2) as well as other seismic reflection profiles e.g. GC 21 (Fig. 1). On seismic and echo sounding profiles, the topography has a wavy appearance.

(c) The Norfolk Basin

The Norfolk Basin is flanked beyond the Vening Meinesz Fracture Zone in the South by the Reinga Basin, and beyond the Cook Fracture Zone in the North by the Loyalty Basin (Fig. 3). The eastern boundary of the basin is marked by a basement fault with vertical displacement of 750 to 1,500m. This NNW-SSE trending fault seems to be interrupted at the bathymetric discontinuity separating the north and south parts of the basin, but is present in both parts. The North Norfolk Basin is 60 to 100km wide and 350 to 400km long, while the South Norfolk Basin is 200km wide and about 500km long. The two basins differ in the depth and thickness of sediments: the northern one is shallower (2,500 to 3,300 metres water depth) with a thick sedimentary deposit (0.4 seconds); the southern one deeper (4,000 metres) with a mean sedimentary cover of 1 second. The topography of the southern basin is also smoother and more regular.

During the Nova expedition conducted by Scripps Institution of Oceanography, a seismic refraction profile was carried out in the northwestern portion of the North Norfolk Basin, near Norfolk Ridge. The results published by Shor et al. (1971) show the following layers to be present:

- a layer 800m thick with a velocity of 2.15km/s
- a layer 1,600m thick with a velocity of 3.97 km/s
- a layer 2,200m thick with a velocity of 6.05km/s
- a layer 5,700m thick with a velocity of 7.04km/s



1 = bathymetric, magnetic and seismic profiles
2 = bathymetric and magnetic profiles
3 = seismic refraction profile in the North Norfolk Basin

AUS = AUSTRADEC		M = MOBIL	
GEO = GEORSTOM		C1 = CORIOLIS	
GC = GLOMAR CHALLENGER			

Fig. 1. Map showing the area of the Three Kings Ridge and Norfolk Basin in the Southwest Pacific and location of tracklines used in this study - profiles illustrated are marked by thick lines. Bathymetry is simplified with contours in kilometres - the stippled zones correspond to the New Caledonia - Norfolk Ridge and the Loyalty - Three Kings Ridge.

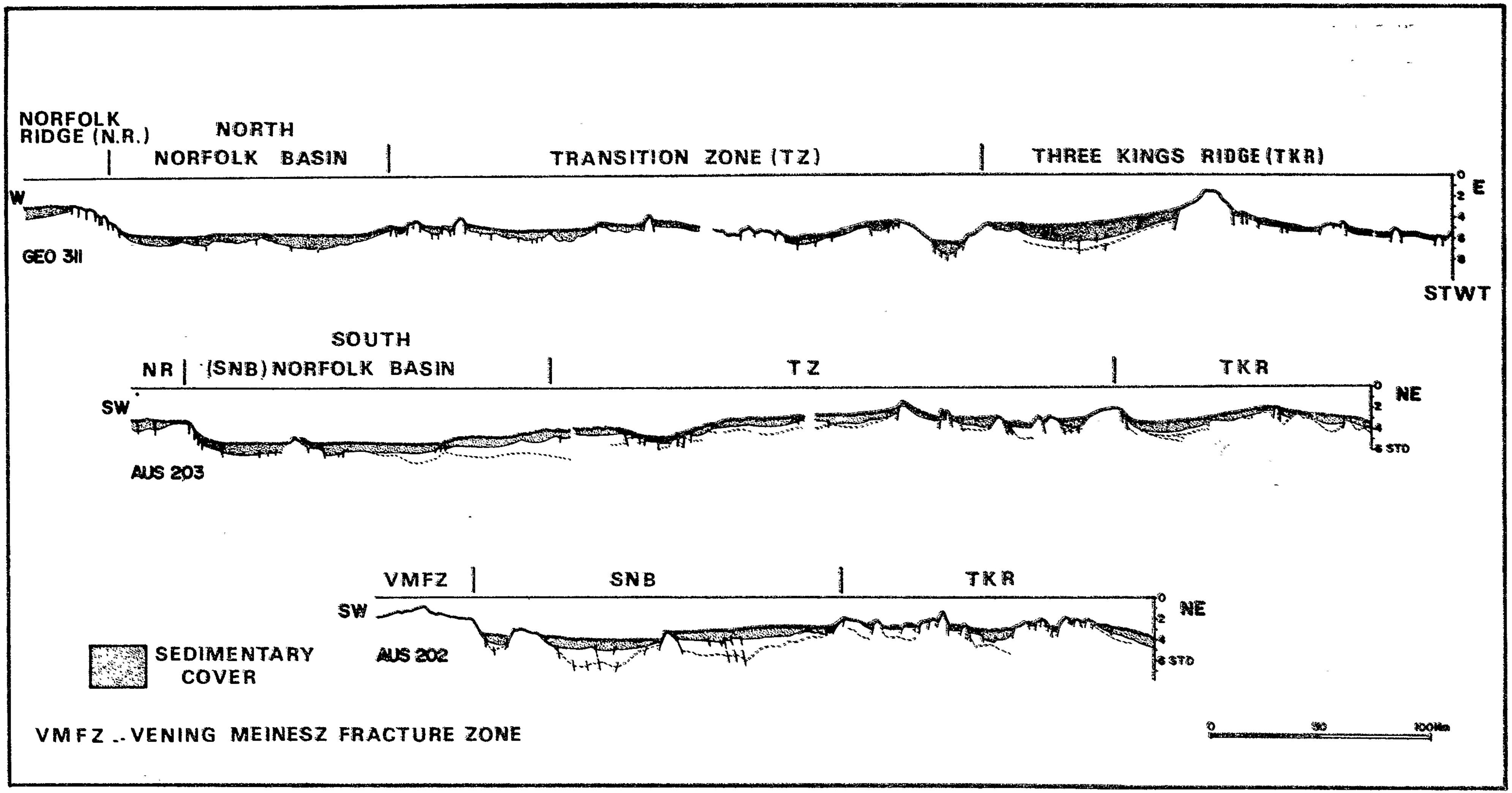


Fig. 2. Interpreted seismic cross sections across the Norfolk Basin and Three Kings Ridge. Locations are shown in Fig. 1.

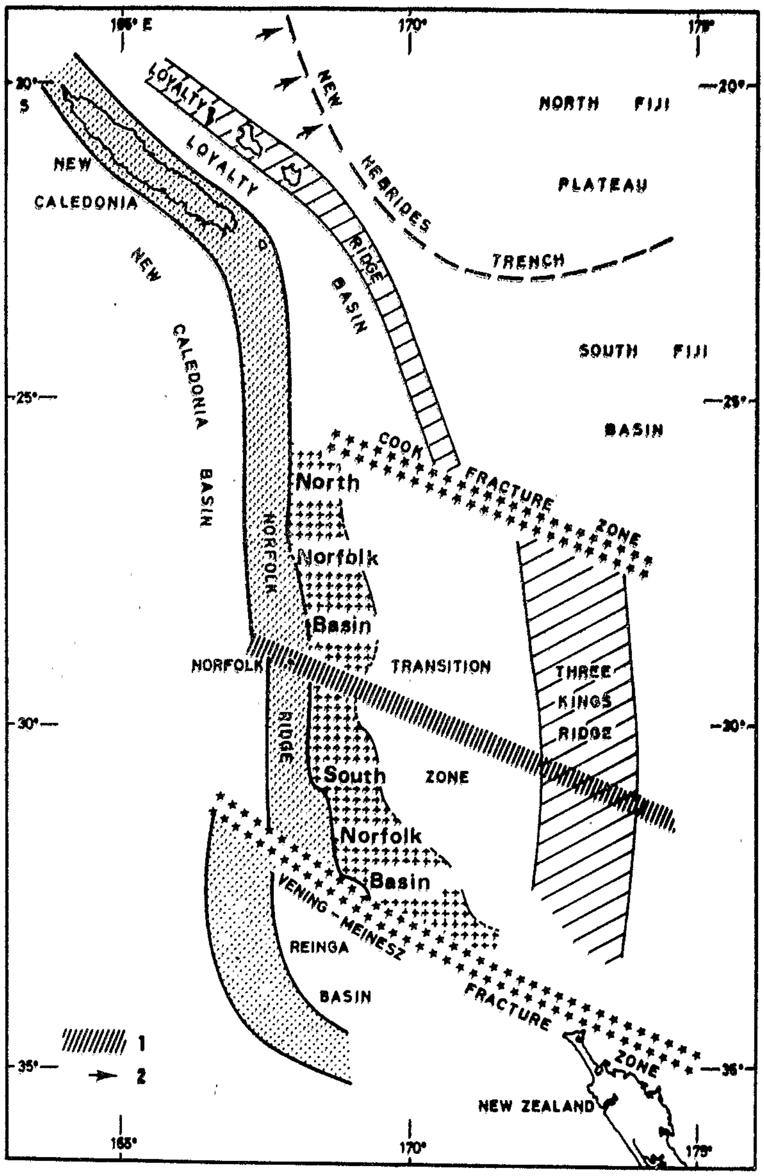


Fig. 3. Structural schematic showing the location of ;

1 = bathymetric discontinuity
2 = present subduction

This structural schematic emphasizes the separation of the Loyalty - Three Kings Ridge along the Cook Fracture Zone at the time of opening of the Norfolk Basin.

Below this, the authors indicate an upper mantle velocity of 8.17km/s. The overlying crust, about 10km thick, is interpreted by Shor et al. (1971) as "a slightly modified oceanic crust with the 'oceanic' and sedimentary layers thicker than normal and the Mohorovicic discontinuity depressed accordingly".

MAGNETIC FEATURES

The Three Kings Ridge displays a magnetic signature similar to that of the Loyalty Chain (Lapouille, 1977, 1978) and typical of most basaltic volcanic rises. It consists of a positive magnetic anomaly of 200 to 500 gammas in amplitude with wavelength equal to the width of the ridge (profiles GC 21, GEO 310, GEO 311, AUS 203, AUS 202, Fig. 4). This anomaly can be modelled by an oblong body with a magnetization close to that of basalt rocks, i.e. 10^{-2} e.m.u. (In this paper, all magnetization values are in c.g.s. units).

Fig. 5 shows, for comparison, a magnetic profile over the Three Kings Ridge with a computed profile of a model of this ridge (5a), and also shows (5b) an observed magnetic profile over the Loyalty Chain with a computed profile of a model of that ridge. The models represent the normal sections of infinitely

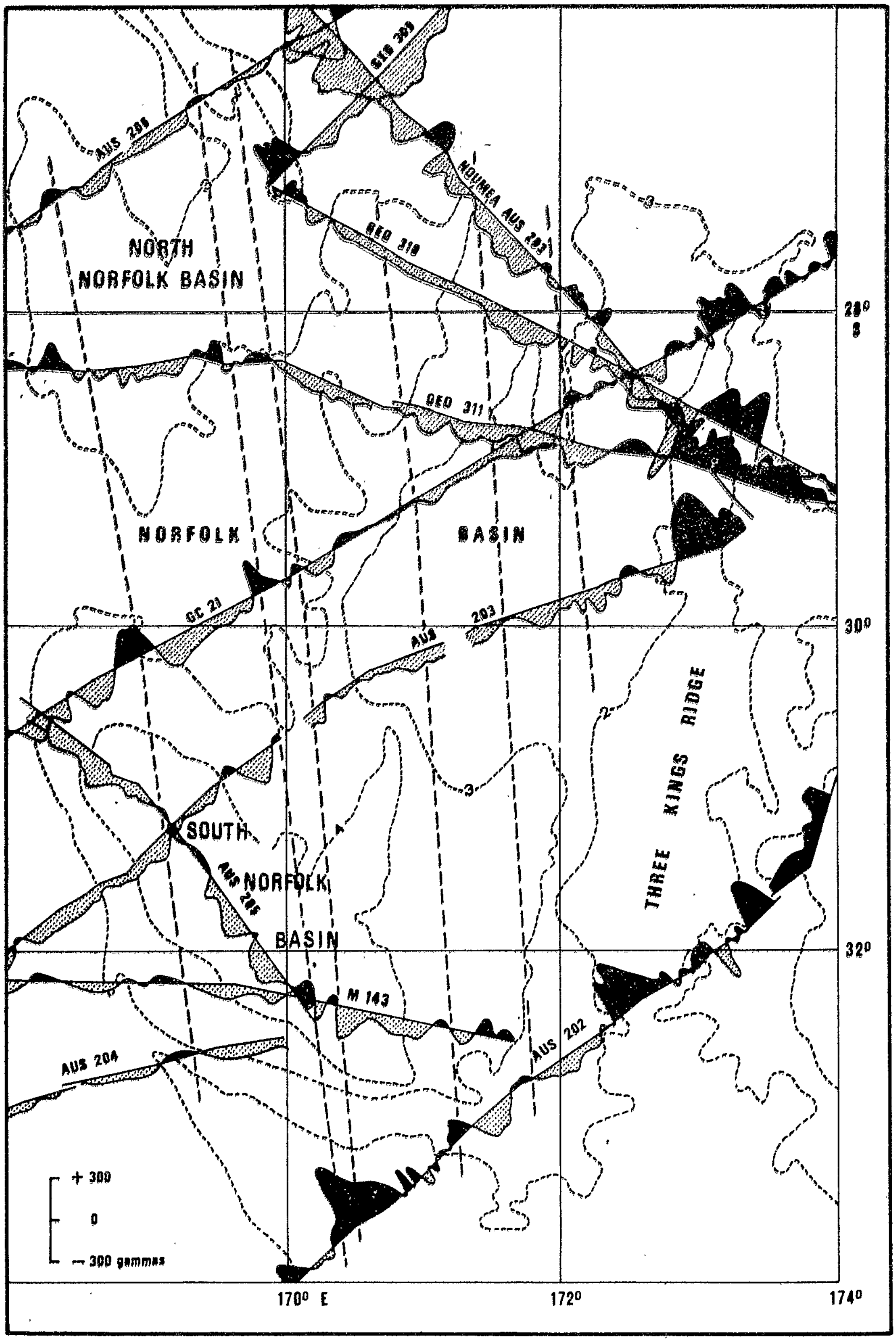


Fig. 4. Magnetic anomalies along the ship's tracks. Positive anomalies are coloured black, negative ones are stippled. Dashed lines show possible correlations of the anomalies (see Fig. 6). Bathymetric contours are in kilometres.

long two-dimensional bodies. We have deduced the top of the models, i.e. the basement underlying the sedimentary cover, from the seismic reflection records. Using Talwani and Heirtzler's (1964) method of computation of the magnetic field caused by two-dimensional bodies, we attribute to both models a remnant magnetization such that the computed field best fits the observed anomalies: so we have imposed on both Three Kings and Loyalty ridges a northern magnetization of 10^{-2} e.m.u. in contrast with a magnetization of 6.10^{-3} e.m.u., also directed northward, for their surroundings. (We added an intermediate magnetization of 8.10^{-3} e.m.u. to the Loyalty model to get a better fit to the computed profile).

Over the Norfolk Basin, the magnetic field shows variations of less than 200 gammas (Hochstein and Reilly, 1967) (Fig. 4). The high amplitude and short wavelength magnetic anomalies usually seen in other oceanic basins of the Southwest Pacific are not observed. However the magnetic field over the whole of the Norfolk Basin is generally negative with respect to the International Geomagnetic Reference Field, except for some positive values in the centre of the

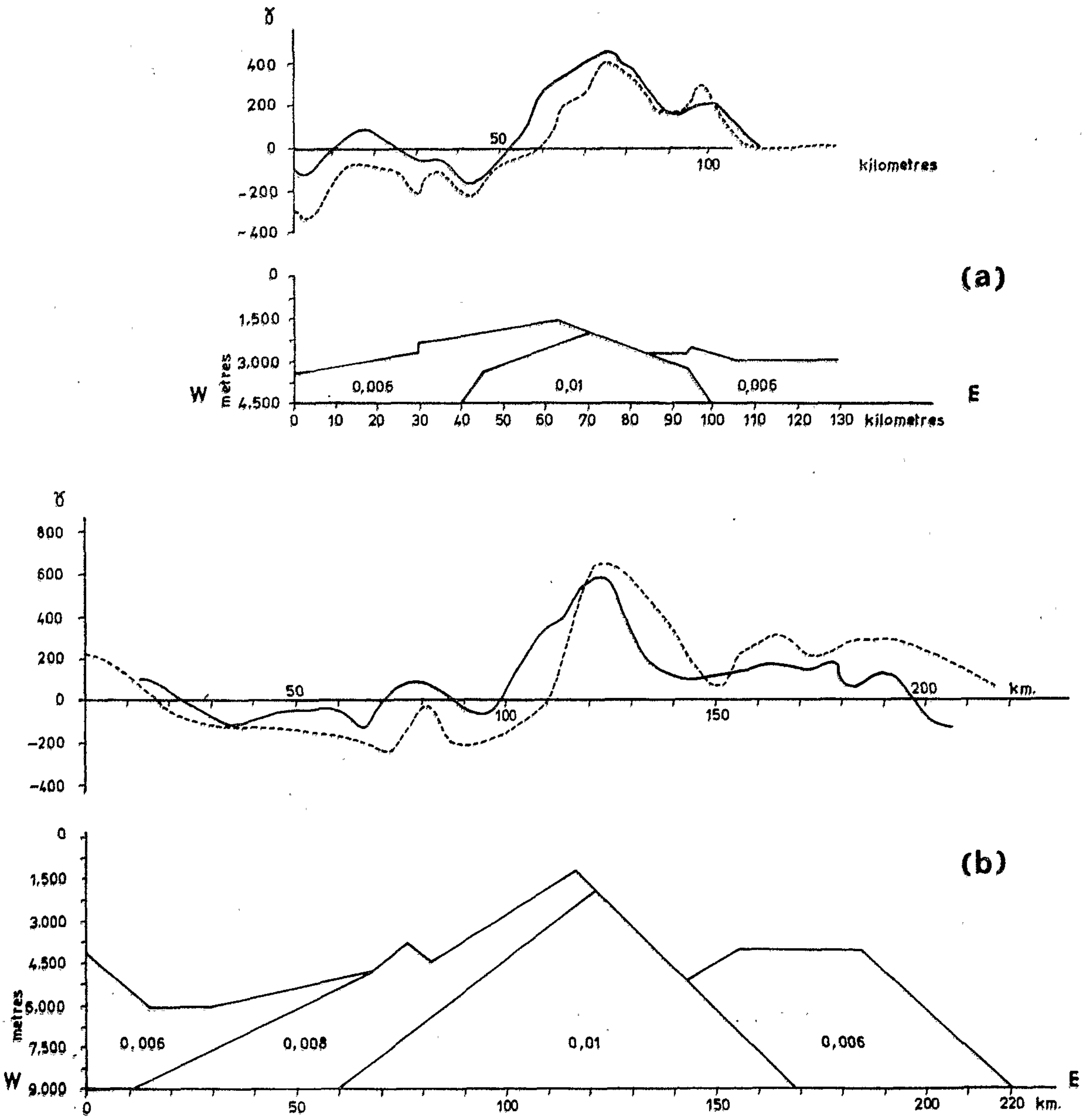


Fig. 5. Measured magnetic anomaly profiles (solid lines) compared to computed (dashed lines) profiles of schematic basement models of:

a) the Three Kings Ridge [AUS 203 magnetic profile] and
b) the Loyalty Ridge [AUS 114 magnetic profile] determined by their magnetization (intensity in e.m.u.; direction northwards).

basin. Numerous short wavelength and low amplitude variations are probably ascribable to the relief of the magnetic basement: the short wavelengths indicate indeed that their sources must be superficial (Redford and Sumner, 1964; Grant, 1972; Breiner, 1973).

Considering the width of the basin (several hundreds of kilometres), its opening at a rate in the order of 1 cm/yr must have required several million years. Using the reversal time scales of the earth's magnetic field of Heirtzler et al. (1968), Larson and Pitman (1972) and Labrecque et al. (1977), we consider that the long wavelength magnetic anomalies present could best be explained by the creation of the crust of the basin at a time when the frequency of the reversals of the magnetic field was very low. The only epoch with such low frequency reversals seems to be during the Upper Cretaceous. The computed magnetic field of a reasonable geological spreading model can be fitted to the observed magnetic anomalies by using a model representing the reversals of the magnetic field from 85 to 75 m.y. (anomalies 34 and 33 of the scale of Labrecque et al. (1977) (Fig. 6)). The model consists of a 500 metre thick layer, 4.0 to 4.5 kilometres deep, with a magnetization of 6.10^{-3} e.m.u. in intensity and directed alternately northwards and southwards. From this model we deduce a half spreading rate of 2.2 cm/yr.

INTERPRETATION

From their study of seismic reflection profiles, Coleman and Packham (1976) conclude that the Three Kings Ridge can be regarded as a remnant arc (thickly covered with sedimentary deposits built up since the Paleogene) which had become detached from the Lau Ridge when the South Fiji Basin was formed. These authors consider the Loyalty Chain to be different in that it is "part of the uplifted ocean floor that forms the South Fiji Basin - New Hebrides Basin".

Our own seismic data, obtained with a high-penetration (Flexichoc) source show, besides a slightly thicker sedimentary section on the west side of the Three Kings Ridge than on the Loyalty Chain, a greater regularity in the thickness of the sedimentary layers on the former. We believe that these slight sedimentary differences are insignificant in comparison with the similarities of basement and the magnetic signatures, which leads us to regard these two chains as being not only structurally similar but as having functioned as volcanic arcs during the same time (Fig. 3).

There may exist similarities in age between these chains, but the only information we have concerns Maré in the Loyalty islands. In 1968 Chevalier got one date of 29 m.y., but Baubron et al. (1976) reported an age between 9 to 11 m.y. New datings of Maré volcanites collected by Maillet and Monzier were

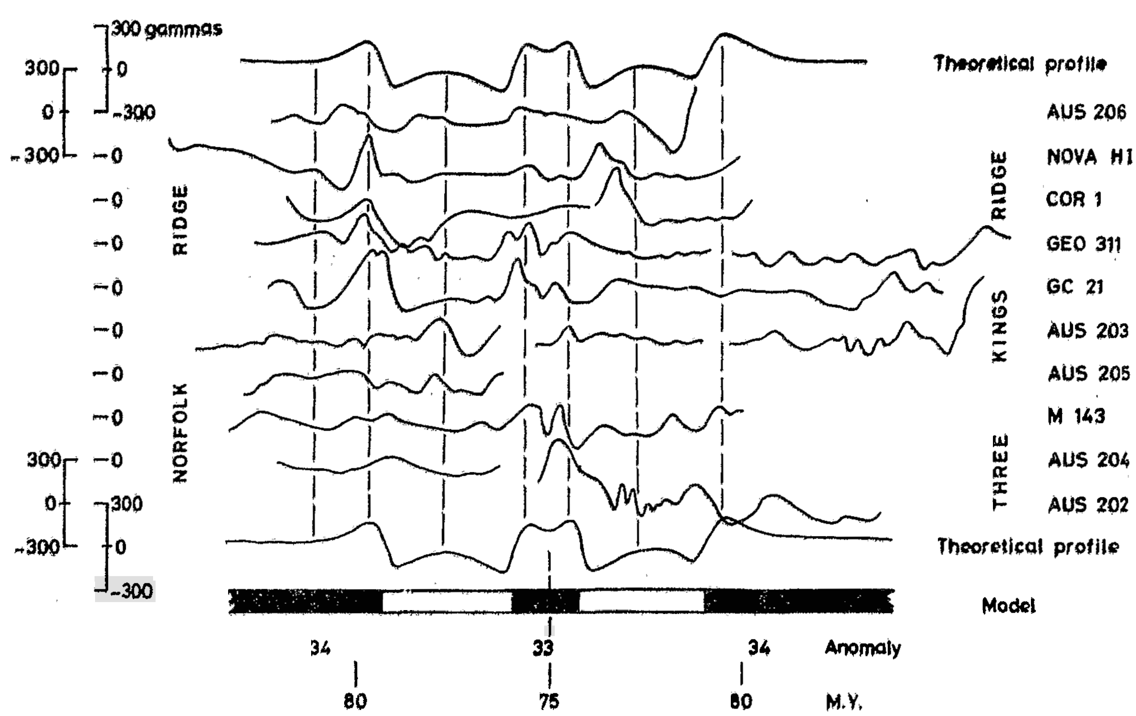


Fig. 6. Magnetic anomalies compared with a computed theoretical profile based on a spreading model for the opening of the Norfolk Basin. Magnetization directed northwards is in black blocks, and southwards in white blocks.

recently carried out by Bonhomme (1979) who found ages between 13.5 m.y. and 9.6 m.y. Obviously, that only represents the end of the emissions whose beginning is not dated.

In the same way, we consider the Norfolk Basin as being the extension of the Loyalty Basin though the sedimentary thickness of the latter is greater than 4 seconds (Ravenne et al. 1973). Volcanoclastics from the Three Kings Ridge were deposited in the Norfolk Basin and those from the Loyalty Chain in the Loyalty Basin. However, the infilling of the Loyalty Basin due to the degradation and erosion of the huge New Caledonian peridotitic mass was on a much larger scale, which explains the great difference in sedimentary thickness between the two basins.

By analogy with the New Caledonia - Loyalty part of the structural unit (Dubois et al. 1974), one can assume a Cretaceous-Eocene island arc model that includes the New Caledonia - Norfolk Ridge and the Loyalty - Three Kings arc. The associated subduction zone would have been situated west of the Norfolk Ridge, the Austral - Indian plate dipping easterly under the ridge. This subduction may have been caused by the opening of the Tasman Sea during the Cretaceous (Hayes and Ringis, 1973). A polarity reversal of the subduction resulting from the opening of the South Fiji Basin in the Oligocene (Watts et al. 1977) is in agreement with a general outline of subduction suggested by Brothers (1974), who extrapolates to the Southwest Pacific the Kaikoura orogeny of the North Island of New Zealand.

The Norfolk Basin, even though the velocities and thickness of its crustal layers are atypical, seems to be of the oceanic type (refraction profile N 22-23; Fig. 1; Shor et al. 1971). The presence of magnetic anomalies 34 and 33 would infer the formation of this basin during the Upper Cretaceous, i.e. from 85 to 75 m.y., using the magnetic reversal time scale of Labrecque et al. (1977). The formation of the Norfolk Basin could then be explained in the regional geodynamic context as follows: the opening of the Tasman Sea Basin induced a subduction in the New Caledonia Basin, which Ringis (1972) suggested was as old as Late Cretaceous. The Norfolk Basin was created as a back arc basin at the rear of the New Caledonia - Norfolk Island arc. The opening of the Norfolk Basin is thought to have been accompanied by transform faulting along the Cook and Vening Meinesz Fracture Zones. An approximately north - south direction for the spreading axis (Fig. 4) is demonstrated by the magnetic data.

CONCLUSION

The seismic profiles show considerable sedimentary thickness on the flanks of the Three Kings Ridge, but the sedimentary cover grows thinner in the Norfolk Basin, suggesting an oceanic type origin for this basin. The magnetic data show similarities between the Three Kings Ridge and the Loyalty Chain and, for the Norfolk Basin, suggest an opening at an epoch of low frequency magnetic reversals. From all these data, we conclude that the Three Kings Ridge is a regionally large structure consisting of volcanic sedimentary deposits on the flanks of a basaltic volcanic ridge crest. It can be regarded as an extinct Cretaceous-Eocene volcanic arc previously linked to the Loyalty arc within a huge island arc system including New Caledonia - Norfolk, Loyalty - Three Kings Ridges. The displacement of the Three Kings Ridge in relation to the Loyalty Ridge is thought to have occurred as a result of transform faulting along the Cook and Vening Meinesz Zones during the opening of the Norfolk Basin. This opening of the Norfolk Basin, as a back arc basin, is thought to have taken place in the Late Cretaceous.

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