STRUCTURE AND HISTORY OF THE LOYALTY BASIN (SOUTH-WEST PACIFIC)

J. DANIEL [1], L.V. HAWKINS [2], J. RECY [1], F. DUGAS [1], R.J. WHITELEY [2],
B.D. JOHNSON [3].

1. O.R.S.T.O.M., Noumea, New Caledonia
2. University of New South Wales, Sydney, Australia.
3. Macquarie University, Sydney, Australia.

ABSTRACT

Seismic reflection, bathymetric and magnetic profiles across the Loyalty Basin and Ridge show the geological or sedimentary Loyalty Basin to be a restricted feature within the morphological basin. The basin contains a thick accumulation of sediment which in the centre exceeds a two-way reflection time of 4 sec, and thickens northwards. Three main sedimentary formations are recognised which rest on a basement which is correlated with the layer of about 5.9 km/sec velocity of the seismic refraction profile of Shor et al. (1971). The axes of sedimentation of these main sedimentary units and the respective areas of provenance vary between the different formations, with both the New Caledonia and Loyalty Ridges acting as important source areas at various times through the depositional history, giving three main phases of morphological and sedimentological history prior to the present time. Although only pelagic sedimentation is currently taking place within the Loyalty Basin, the large thickness of sediment within the basin implies a considerable amount of terrigenous and volcanoclastic sedimentation during earlier deposition.

Since the sedimentary formations within the basin do not appear to have been seriously deformed during the major orogenic phase associated with the emplacement of peridotites on New Caledonia in the Upper Eocene, deposition within the basin has occurred since the beginning of the Oligocene. A major unconformity surface which represents an old erosional platform, which occurs at the western margin of the basin, implies major subsidence of the platform and basin of about 2000 m. This appears to have occurred post Oligocene, possibly in the Miocene or Pliocene.

The Loyalty Ridge, which has acted as an important source of sediment during earlier phases of deposition within the basin and must have been in existence prior to the Oligocene, models magnetically as an essentially uniformly magnetised ridge of intermediate to basic composition. Since basaltic material from the ridge has been dated as 10 m.y. old, the ridge is either one of essentially basaltic composition which has suffered a number of phases

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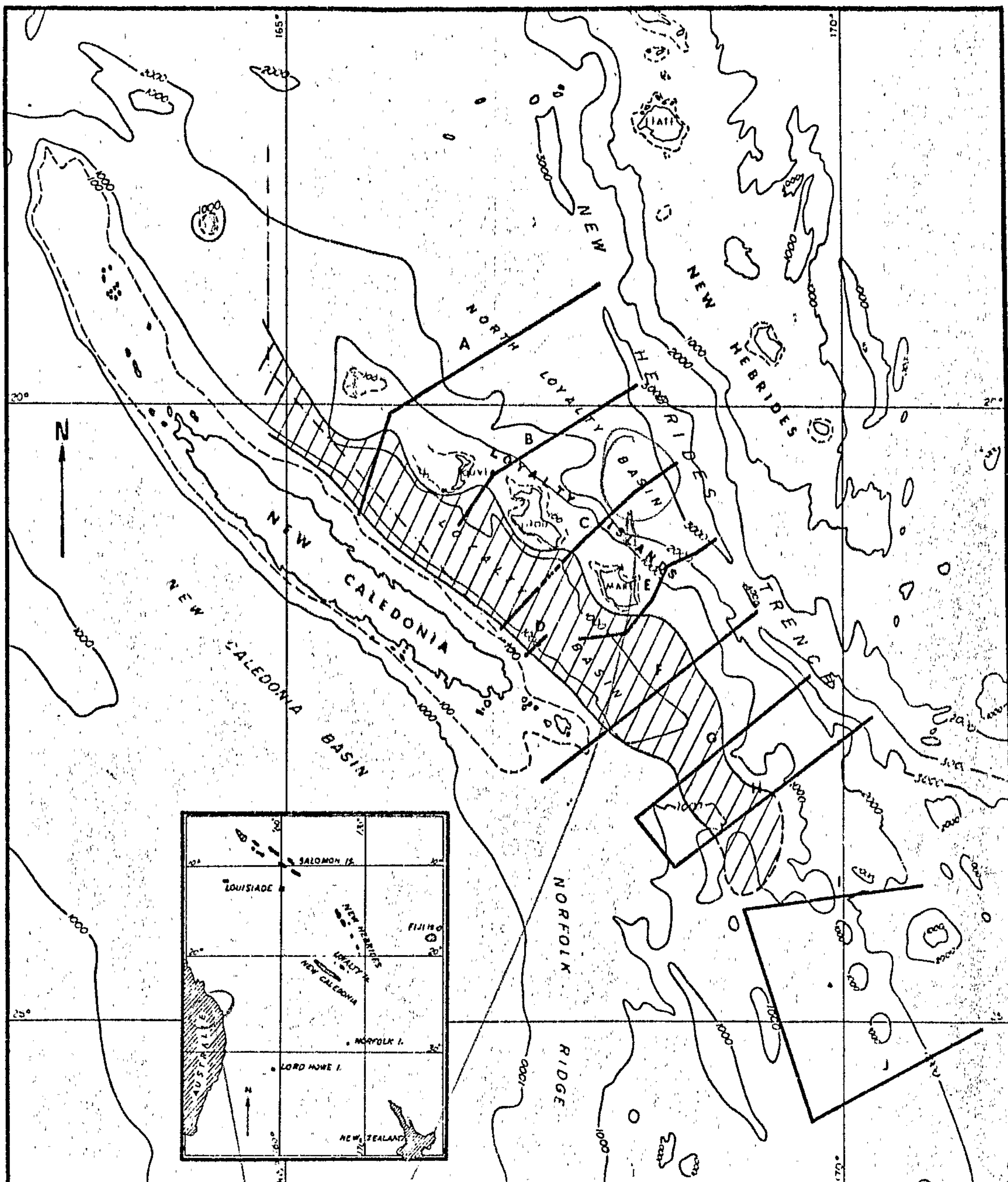

if possible

(1) australia

(2) North Loyalty PLATEAU

of volcanic activity, or it represents the old andesitic island arc related to the previous Benioff Zone of the inferred ancient New Caledonia Trench, which again has suffered subsequent phases of basaltic volcanicity probably related to major tensional block faulting during its subsequent history. The latter interpretation is preferred.

INTRODUCTION

Within a continuing, co-operative programme between the Office de la Recherche Scientifique et Technique Outre-Mer (O.R.S.T.O.M.) in Noumea, and the University of New South Wales, Australia, several continuous seismic reflection profiles were obtained across the Loyalty Basin, using a 650 cc (40 cu.in.) airgun seismic source. Continuous bathymetric (P.D.R.) and total field magnetic profiles from a proton magnetometer were also recorded. The locations of the profiles together with the general bathymetry of the aera, taken from the Scripp's Bathymetric map of the Southwest Pacific (1971) are shown in Fig. 1. These profiles were recorded during 1971 from H.M.A.S. Kimbla on cruises K3/71 and K4/71, and from O.S. Coriolis on cruise C1/1971.

Within the overall study, designed to contribute to an improved understanding of the geodynamic history of the Southwest Pacific, the purpose of these particular profiles was to study the Loyalty Basin, and its relation to New Caledonia to the southwest and to the Loyalty Island Archipelago to the northeast. These linear, parallel structural elements lie within the northeastern margin of the Indo-Australian Plate, close to the present plate boundary at the New Hebrides Trench where active subduction beneath the Pacific Plate is currently occurring. They also lie at the northeastern limit of a system of ridges and basins which extend back to the Australian continent with morphological trends generally paralleling the Australian continental margin.

This system of ridges and basins has the appearance of continental to intermediate crustal blocks rifted from the Australian continental margin.

In the case of the Tasman Sea Basin, Ringis (1972) and Hayes and Ringis (1973) have shown the Lord Howe Rise to have been rifted from Australia and displaced by a seafloor spreading accretion process at a now extinct mid-ocean ridge, between 80 and 60 m.y. B.P. The origin of the remaining basins and ridges in this area, and the ridges, plateaus and basins in the general area of this plate margin is still controversial. Several hypotheses have been advanced to explain the specific or general evolution of such features within the area. These include the evolution of complex arc systems (Geze, 1963; Dubois, 1969), arc migration and the development of marginal basins (Karig, 1971; Packham and Falvey 1971), and the creation of marginal basins by expansion due to second order adjustments at the limits of plates (Andrews et al., 1973a).

In the case of the Loyalty Basin and Loyalty Ridge, However, the situation is further complicated by an hypothesis which proposes the existence of a fossil trench system associated with the evolution of New Caledonia and emplacement of peridotites on the island. This was proposed by Geze in 1963, and the presence of an earlier subduction zone in this position, apparently during Eocene-Upper Oligocene time, has also been suggested by the seismological studies of Dubois (1969, 1971). The inferred presence of this previous subduction zone implies that the Loyalty Island chain could represent the ancient andesitic volcanic arc above the old Benioff zone. This aera of study is, therefore, one of particular interest within this broad area of significant geodynamic activity.

GEOLOGICAL BLACKGROUND

Regional setting

From northeast the southwest across the general area (Fig. 1), the major structural features are :

(i) The New Hebrides Trench which strikes in a direction of 170° from latitude 11°S to 22°S, but then bends sharply to acquire the easterly trend of the Hunter Fracture Zone.

(ii) The North Loyalty Plateau which is triangular in shape and lies between this trench and the Loyalty Islands.

(iii) The Loyalty Ridge which is largely submarine with its highest points forming the Loyalty Islands and supporting raised coral atolls.

(iv) The Loyalty Basin.

(v) The island of New Caledonia, the southeastern extension of which is essentially continuous with the northern part of the Norfolk Ridge which has a north-south trend in that area.

(vi) The New Caledonia Basin which separates the New Caledonia and Norfolk Ridge features from the Lord Howe Rise.

Crustal thickness and heat flow

The variations in the crustal thickness in this region underline its complexity. Seismological determinations of Dubois (1969) show the crust to reach a thickness of 35 km in New Caledonia and 17 km in the Loyalty Islands at Lifou Island. Marine seismic refraction profiles recorded during the Nova cruises (Shor *et al.*, 1971) show the following crustal thicknesses, with the depths to mantle shown in brackets :

12 (14) and 18 (20) km for the Loyalty Basin, 20 (21) and 21 (21) for the Norfolk Ridge immediately to the South of New Caledonia, 9 (13) and 11 (14) km for the New Caledonia Basin just to the southwest of New Caledonia, and 13 (17) and 7 (10) km in the New Caledonia Basin further to the south. On the Lord Howe Rise thicknesses of 16 (18) and 28 (29) km were calculated, while in the South Fiji Basin to the east of the Norfolk Ridge, calculated thicknesses were 11 (15) and 8 (12) km in the northeast and 6 (10) and 8 (13) km in the south central part of the basin. No crustal measurements have been made in the North Loyalty Plateau.

The heat flow measurements of MacDonald *et al.* (1973) show normal values for the Loyalty Basin of 1 to 2 HFU, whereas to the east of the New Hebrides Trench on the North Fiji Plateau, high values of up to 3 HFU were obtained.

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Results of Deep Sea Drilling Project

Several holes have been drilled into the sea floor within the area of the Southwest Pacific during legs 21 and 30 of the Deep Sea Drilling Project. The results obtained have been reported by Burns et al. (1972), Andrews et al. (1973a and 1973b) and Van der Lingen et al. (1973), and have led Andrews et al.(1973a) to divide the region into eastern and western provinces.

The western province consists essentially of the Lord Howe Rise, the New Caledonia Basin and the Norfolk Ridge. While the oldest sediments present in this province are of Upper Cretaceous age, its essential characteristic is the lack of sedimentation between the Upper Eocene and Middle Oligicene. The duration of this break in sedimentation is variable over the area and is greatest on the Lord Howe Rise. It is generally attributed to changes in the circulation of ocean currents resulting from the initial separation of Australia from Antarctica in the Eocene (55 m.y. B.P.).

The eastern province consists essentially to the South Fiji Basin, which is supposed to have come into existence in the Oligocene, and the North Loyalty Plateau which possibly formed in the Lower Eocene. The regional lack of Upper Eocene / Middle Oligocene sedimentation, characteristic of the western province, does not occur in this province, showing it to have been under different influences to the former.

Geology of New Caledonia

New Caledonia is an island of 400 km in length and 45 km in width, with a surface area od 18,000 km^2. It is flanked to both the west and the east by barrier reefs that extend some 200 km to the north of the most northern tip of the island. To the south, New Caledonia extends into the submarine Norfolk Ridge with which it appears continuous from seismological evidence (Dubois, 1971), as well as in morphological expression.

The oldest known formation in New Caledonia is a polycolour tuff which has been attributed to Permian age by Avias (1953) and Routhier (1953). From the Permian to the Upper Eocene, the rocks observed are pyroclastic and clastic sediments (greywackes, sandstones, pelites, argilites and flysch), accumulated in what has been inferred to be the ancient Melanesian or New Caledonian Trench. A number of different geotectonic phases have been observed on the island, the last of which was an alpine type orogeny which began subsequent to the deposits of Eocene flysch (Gonord, 1970). The peridotites and basalts which occur extensively over the island, appear to represent the overturned flank of a recumbent fold (Guillon, 1972) which was emplaced at the end of the major Alpine type origenesis, probably in Oligocene time (Guillon and Routhier, 1971). This episode represents the last orogenic event to which the island was subjected, after which only the effects of epirogenic movements have been observed. The latter are represented by the presence of peneplains and successive terraces (Davis, 1925; Trescases, 1969). The peridotites which cover some 7,000 km^2 of the island, may have covered a much larger area (Guillon and Routhier, 1971). They have, however, been submitted to considerable erosion, mainly chemical in nature, the residual lateritic deposits of which may be observed *in situ* or redistributed along the slopes, peneplains and terraces of the island.

Geology of the Loyalty Island Archipelago

The Loyalty Island Archipelago consists of coral atolls, which formed since the Pliocene (Chevalier, 1968), as cappings on the summits of a submarine ridge during a period of subsidence. These subsequently emerged during the Pleistocene to form the Loyalty Islands (Dubois et al. 1973), the emergence being produced by the lithospheric bulge resulting from the subduction of the Indo-Australian plate at the New Hebrides Trench (Dubois et al, 1974). The only observed basement of the atolls is on Maré Island where basaltic volcanics protrude through the bottom of an old lagoon. Potassium/Argon measurements made on these summital basaltic formations give an age of 10 m.y. (Baubron *et al.*, in press), which probably represents the last episode of volcanic activity of the submarine ridge. This ridge extends both to the north and south of the actual archipelago. Neither the age of the beginning of this volcanic activity, nor the number of phases of volcanism is known at this time. The structure of the ridge and the relative contributions of volcanic, volcano-clastic and sedimentary rocks to the formation of the ridge are also unknown.

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MORPHOLOGY

The bathymetric map published by the Scripps Institution of Oceanography (1971) for the Southwest Pacific, shows the Loyalty Basin as a depression between New Caledonia and the Loyalty Islands. This is elongated in a direction northwest-southeast between the latitudes of 20° and 23° S, and exceeds a depth of 2150 m. The bathymetric profiles across the Loyalty Basin obtained from the present study are shown in Fig. 2, and provide some further information on the morphology and extent of this basin.

Transverse profile

The most complete profile across the basin is profile F which passes immediately to the southeast of New Caledonia and the Isle of Pines. From southwest to northeast on this profile may be observed the extension of New Caledonia to the south of the Isle of Pines, the Loyalty Basin, the Loyalty Ridge, and the slope downwards to the New Hebrides Trench.

The Loyalty Basin appears as a flat depression with a maximum depth of 2150 m which is remarkably constant over a distance of about 40 km. In general appearance, there is little asymmetry between the western and eastern flanks of the basin. In detail, however, two steps in the profile may be observed on the western flank. The first, between depths of 500 and 1000 m, connects the plateau which forms the southern extension of New Caledonia and the Isle of Pines, to an area gentler slope which extends down to 1800 m. At this level, the second rapid decrease or step in the profile occurs which passes diredtly to the level floor to the basin. Towards the eastern flank, the floor of the basin progressively rises until a single sharp step occurs at the margin of the Loyalty Ridge. Variations which occur in morphology across the basin both to the north and south of profile F, are also shown in Figure 2. To the north of profile F, the profiles A, B, C, D and E are incomplete, but show the western edge of the basin to slope up towards the margin of New Caledonia. In the east, the limit of the basin is formed by the Loyalty Ridge. However, depending on the position of the profiles relative to the various islands of the Loyalty group, they show different characteristics. For example, on profile E to the southeast of Maré Island, there occurs a plateau at a depth od 1500 m, whereas on profile A to the north, two distinct ridges occur, separated by a small basin which appears to lie within the ridge itself.

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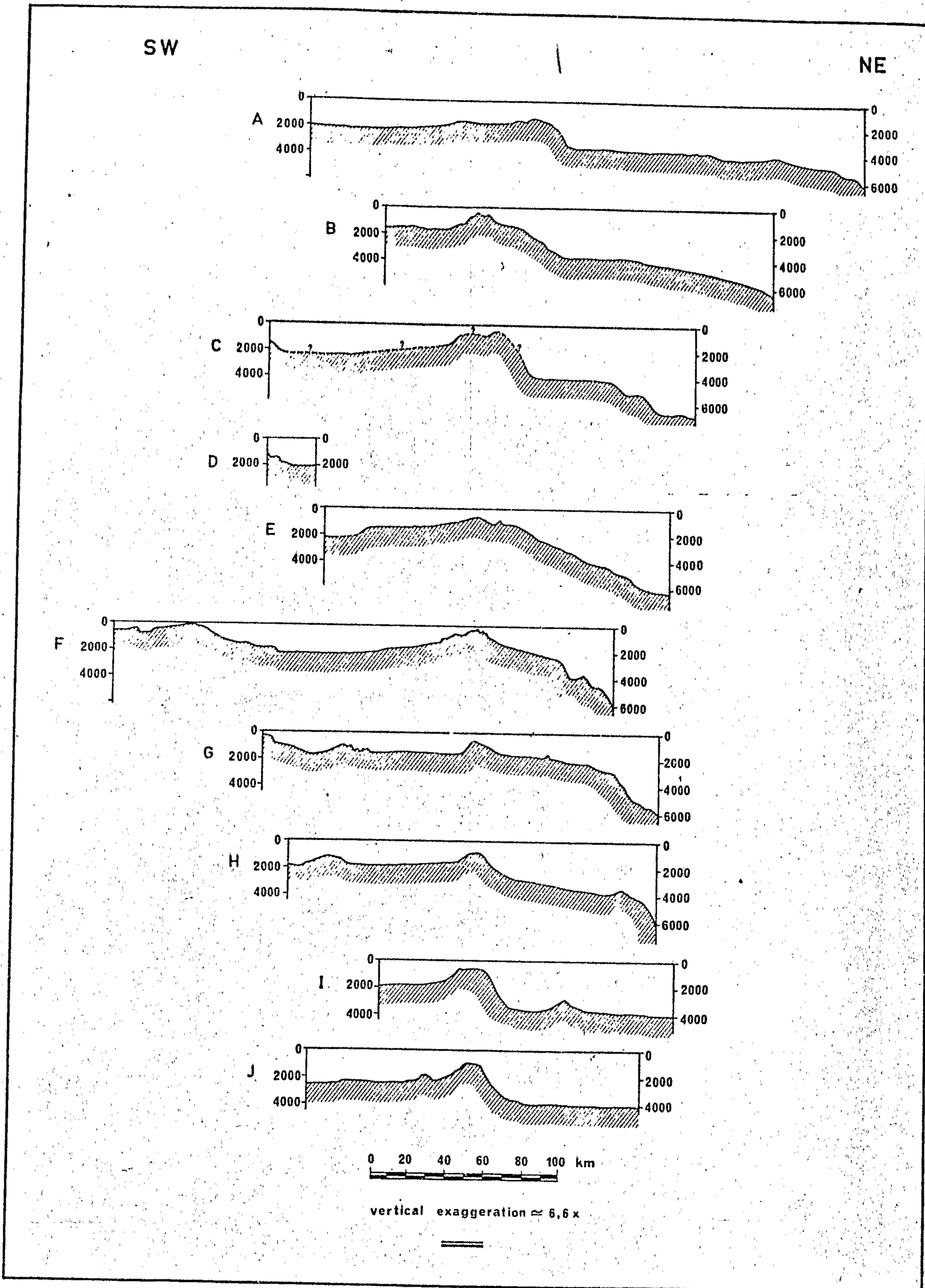
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From the bathymetric map, there appears to be a discontinuity in the ridge beyond the Astrolabe Reef. However, the profile of Coriolis/1966 (see Fig. 1) which passes well to the northwest of this reef and shows the ridge structure to continue with a relief of 1650 m above the sea floor between the latitudes of 19° and 20° S. This ridge appears to persist as far north as the Petrie Relief at a latitude of about 18° 30'S, and probably extends even further to the north.

To the east of the Loyalty Ridge, the sea floor slopes downwards towards the New Hebrides Trench but shows considerable variation in the different profiles. The slope is more regular on profile E than those further to the north, particularly on profiles A and C where distinct steps in the profiles occur.

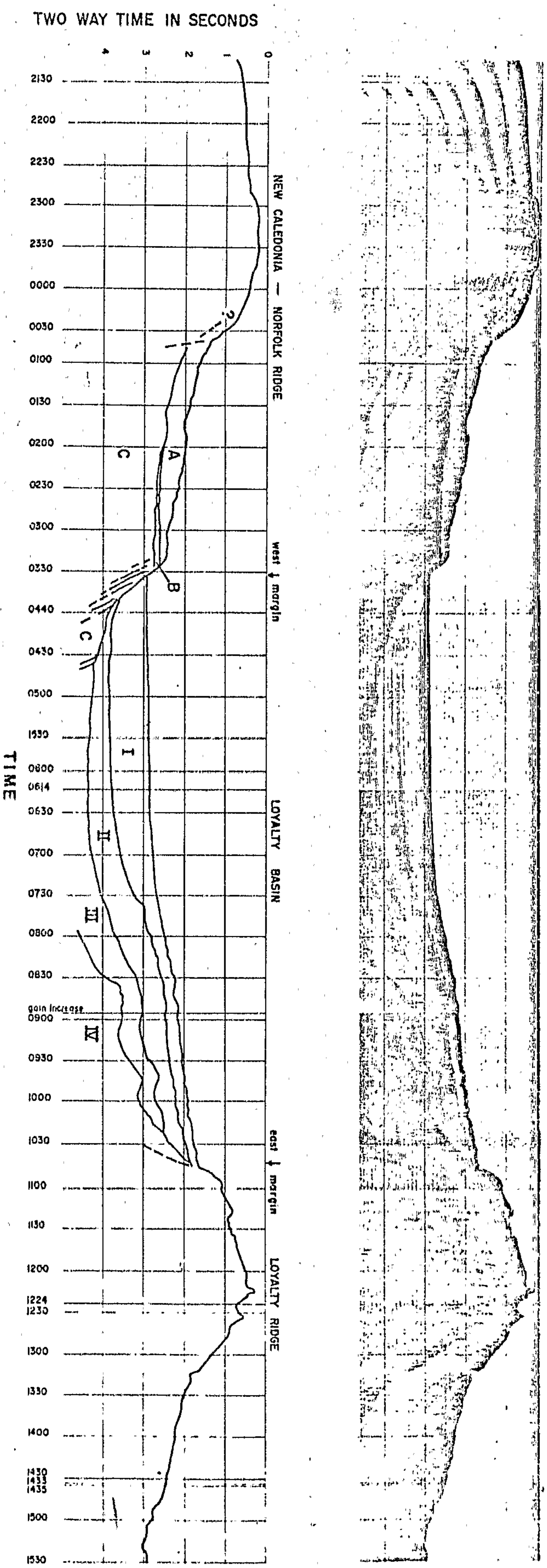
In the south, on profiles G, H, I and J, the eastern limit of the morphological basin is clearly marked by a ridge whose direction bends to the south without quite reaching the north-south trend of the Norfolk Ridge, which lies just to the west. From the bathymetry, there appears to be no reason why this former feature does not represent the southern extension of the Loyalty Ridge.

On profiles G and H, there occurs a rise which forms the western limit on the basin. This drastically narrows the basin from a width of 90 km on the adjacent northern profile F, to a width of 47 km on these profiles. This narrowing coincides with the bending in basin trend direction towards the south.

With the change to an easterly trend of the New Hebrides Trench to the southeast of profile H, neither of the more southern profiles, I and J, display the downward slope towards this trench, but show the beginnings of the regular structure of the sea floor which constitutes the South Fiji Basin.

Longitudinal profile

In order to trace the longitudinal profile of the basin, a synthetic profile has been constructed from the profile of Coriolis/1966 and the maximum



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NEW CALEDONIA — NORFOLK RIDGE
west margin
LOYALTY BASIN
east margin
LOYALTY RIDGE
A
B
C
I
II
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IV

8 bis

depth points of the transverse profiles of the present survey. This is included in Fig. 4, from which it may be seen that there is a step of 750 m, at the level of the Astrolabe Reef, which raises the seafloor of the basin to a depth of 2300 m. This depth remains constant between profiles A and F, after which it decreases to 1500 m at profile G, before increasing again towards profile J.

In its general morphology, the Loyalty Basin appears as an elongated depression with a widening or bulge at the latitude of 23° S, where it bends towards the south, Neither the northern nor the southern limit of the basin is morphologically defined from the existing bathymetric data.

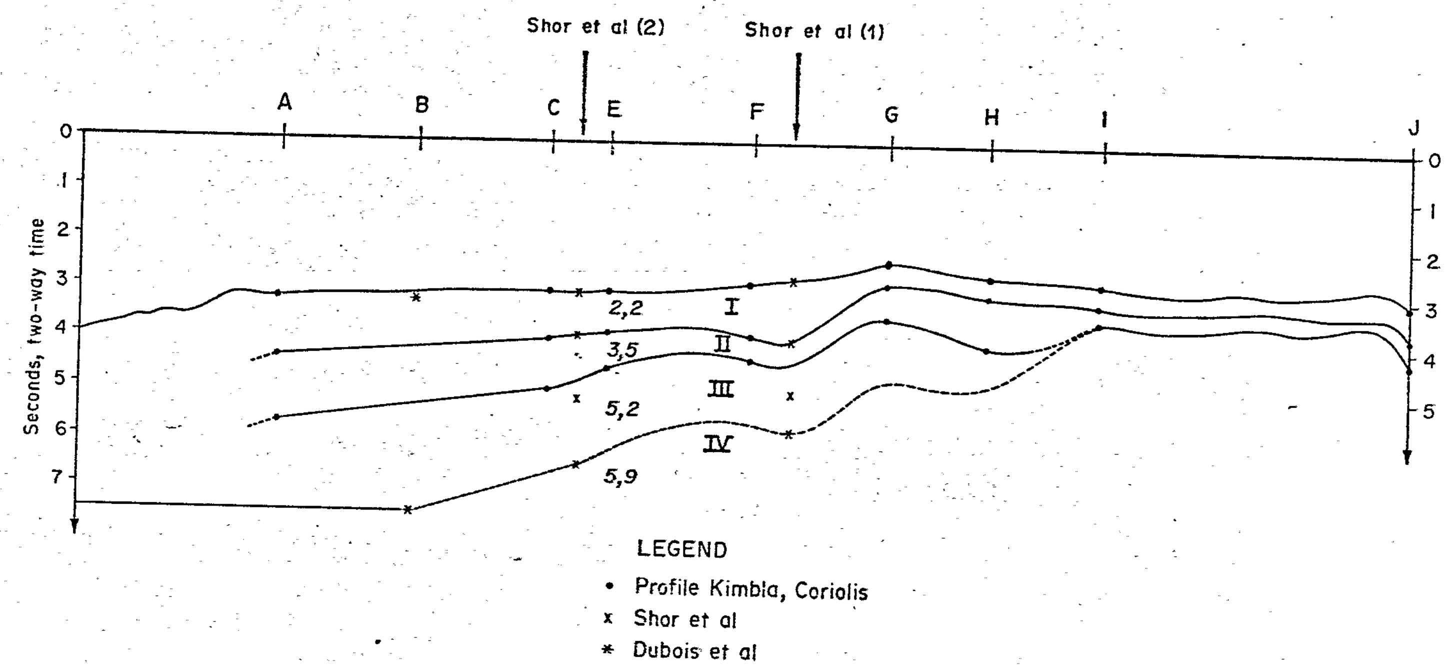
SEISMIC RESULTS

In this section, the geological structure across the basin is discussed, together with its southern extension, its western margin against New Caledonia, and its eastern margin against the Loyalty Ridge.

Geological structure across the Loyalty Basin

The seismic reflection profiles across the Loyalty Basin show that the deep structure of the basin is more accentuated than its morphological expression. The sediment cover over acoustic basement is very thin at the edges of the basin but at the centre, the depth to basement is greater than could be observed in the present survey despite a sub-bottom penetration in excess of 2.5 sec two-way reflection time on some of the profiles.

As in the discussion on morphology, since the northern profiles A, B, C, D, and E were incomplete, the main features of the seismic section will be described from the continuous section across the basin obtained on profile F (see Figure 3). In defining the limits of the geological basin, we take the western limit as the prominent step or scarp against which abut the almost horizontally layered sediments of the basin. The eastern limit is taken as the steep boundary between the basin sediments and the Loyalty Ridge.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Shor et al (1)
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LEGEND
• Profile Kimbla, Coriolis
x Shor et al
* Dubois et al

An important feature of the basin is its asymmetry. The total thickness of sediments within the basin is greater on the western side where they have a much more regular aspect than those to the east. On the eastern side, the sediments are raised relative to the west, and gently folded.

Within the sedimentary section, the seismic profiles show three disconformities, allowing four main units to be defined. They are shown in Fig. 3 as I, II, III and IV. The upper formation (I) has a maximum thickness corresponding to a two-way reflection time of 1.1 sec. This occurs in the deepest part of the morphological basin and is displaced towards the western margin of the geological basin as defined above. Towards the west, the numerous reflectors within this formation are nearly horizontal. Towards the east, where the thickness is much less (0.2 to 0.3 sec two-way time), only the first group of reflections may be observed due to the length of the bubble pulse sequence of the reflected signals. The lower boundary of this formation is, however, readily observed over the whole width of the basin. These sediments over the raised eastern part of the basin, show minor folding.

The second formation (II) has a maximum thickness corresponding to a two-way reflection time of 0.9 sec. This occurs at the point where the base of the formation begins to rise towards the east, and lies considerably further to the east than the maximum sediment accumulation in formation I. On the western part of the basin, the formation thins gradually to the west and appears to pinch out at the western margin of the basin. To the east, the layer becomes increasingly deformed and thins abruptly at the eastern margin near the Loyalty Ridge.

This implies that some relative uplift on the eastern side of the basin occurred between the deposition of formation II and formation I, with the main axis of sedimentation having migrated to the west before deposition of the latter. The gradual lensing out of formation II to the west, relative to the rapid thinning near the Loyalty Ridge to the east, also implies that the main area of provenance of sediment, during the deposition of formation II, was the Loyalty Ridge and therefore possibly volcanic in origin.

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Formation III is clearly marked over the whole width of the basin by the regularity of its upper reflector. At the western margin of the basin, the layer appears to ba faulted against what appears to be basement and which is labelled C in Figure 3. To the east, the layer thins gradually and becomes increasingly deformed until it terminates rather abruptly against the Loyalty Ridge.

The base of this layer was not observed in the centre of the basin. However, the minimum thickness of the layer on the western margin and the observed thickening towards the centre from the east suggest (i) that the axis of sedimentation during the deposition of layer III was again further to the west than during the deposition of layer II, and (ii) that the provenance of the sediment during the deposition of layer III was probably from both New Caledonia and the Loyalty Ridge, possibly with a greater contribution from the former.

Layer IV is only clearly observed in the eastern part of the profile but it may correspond to the basement on the western side which is shown as layer C on Figure 3. Layer IV is considered to represent basement in the eastern part of the basin.

The seismic refraction profile of Shor et al (1971), which is located along the axis of the basin between profiles D and E, provides a model for comparison with the results of the reflection profiles. Shor et al found three layers which overlie a layer with a velocity of about 5.9 km/sec, which deepens northward along the axis of the basin. This velocity is high and is consistent with a crystalline or highly metamorphosed basement. The refraction velocities for the three overlying layers were given as 2.2 km/sec, which was assumed for the surface layer, 3.5 km/sec, and 5.2 km/sec. The first two velocities are representative of poorly consolidated and well consolidated sedimentary material respectively, and the last of limestone, partly metamorphosed material or volcanic rock.

Although some differences occur between the depth determinations to the interpreted layers in the refraction data and that from the reflection profiles using the velocities of Shor et al., (see Figure 4), it appears

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possible to correlate the two. The difference in calculated depths may result in part from the rather poor control on the travel-time curve of Shor et al. (ibid, p. 2569) at the southern end of the refraction profile.

On this correlation, we assign layer IV as basement (the 5.9 km/sec layer) and layers I, II and III as sedimentary formations in-filling the basin. The deepening of the basin to the northwest along the axis of the basin, which was found by Shor et al, is supported by heavy seismic reflection data from Austradec cruise (Dubois et al., 1974). This shows that the total thickness of the first three formations increases in this direction to reach a two-way time of at least 4 sec. The above results have been combined into a longitudinal profile along the axis of the basin showing in addition to the bathymetry, the two-way reflection times or their equivalent from the refraction survey, as shown in Fig. 4.

Geological structure along the Loyalty Basin

The northern limit of the basin, which probably occurs at the position of the d'Entrecasteaux Fracture Zone, is not covered by the present survey. In the south, the thickness of formation I decreases considerably, having a two-way time of only 0.5 sec on profiles H and I. Formation II which is characterised by many internal reflectors, appears more variable in thickness but has also decreased at the level of profile I. Between profiles I and J there appears a very strong reflector at the base of formation II. This is interpreted as basement, with the rapid lensing out of formation III between the profiles H and I.

All three of the above sedimentary formations follow a rise in the morphology of the surface at the level of profile G. Although the basement (layer IV) probably also follows this rise, it is not recorded on profiles G and H, and is not observed until profile I where it appears to be quite shallow.

From the above, we place the southern limit of the geological Loyalty Basin at about the level of profile I. The northern limit of the basin remains underfined with the sedimentary fill within the basin thickening to the northwest in the area of the survey.

Western margin of the Loyalty Basin

Profile F passes just to the south of the Isle of Pines on which the southernmost exposures of the peridotites of New Caledonia occur. The position on the profile which is adjacent to the Isle of Pines, lies within the very shallow platform which represents the southeastern extension of the New Caledonia Ridge. Here, multiple reflections from the shallow seafloor obscure the seismic record from any coherent sub-surface structures which may be present. This ridge marks the western limit of the morphological basin but the limit of the geological or sedimentary basin occurs further to the east as indicated above.

The western boundary of the sedimentary basin appears to be controlled by major normal faulting with downward displacement to the east. Prominent faulting, probably as a series of closely spaced faults, is indicated in the basement at the edge of the sedimentary basin, with another parallel fault just within the limits of the basin. It is against this latter fault that the deepest sedimentary layer within the basin (formation III) appears to terminate. However, it is possible that this formation continues across the fault to rapidly pinch out against basement just to the west of the fault. This uncertainty in the interpretation arises from the disturbed nature of the reflections to the west of the fault.

On the eastern flank of the New Caledonia Ridge, between the crest of the ridge and the geological basin, three geological features are distinguished. The first is the uppermost formation, labelled A in Fig. 3. suggesting that some channelling of possibly slumping and minor internal faulting has occurred.

At the base of this formation there occurs a strong, sub-horizontal reflector which is particularly marked in the eastern part of the ridge flank towards the western limit of the geological basin. The strength of the reflection suggests an indurated surface at a major unconformity with the underlying layer. The reflections from below this surface are of an irregular and apparently dipping nature with sine in-filling on an older, irregular surface below the marked unconformity surface which was eroded to form a distinct platform. The unconformity surface and possible thin overlying layer are labelled B in Fig. 3.

The formation underlying this unconformity surface appears to have been subjected to some tectonic activity and faulting. It constitutes the basement at the unconformity and is correlated with the basement of the geological basin to the east. It is labelled C in Fig. 3. The basement and unconformity look to be exposed at what appears to be a fault scarp which marks the western limit of the sedimentary basin. Dredging at this position has recovered a large massive sample of highly ferruginous and cemented conglomerate containing basaltic pebbles. This is apparently a sample of the material from the marked unconformity surface which probably represents an old, very well developed coastal platform.

Within the basement below the unconformity, there occur a series of diffractions which line up to give the appearance of an almost plane dipping surface. This could be produced by primary layering within the basement or more probably, from a series of closely spaced faults within the basement at this western margin of the sedimentary basin.

To the north of profile F, the central part of the New Caledonia - Norfolk Ridge emerges to form the island of New Caledonia. However, only profiles C and D have extended far enough to the west to show the step or scarp that marks the western limit of the geological basin. On profile G to the south, formation C is again observed where it extends further to the east in the form of a bulge. Here, it is devoid of more recent sediment cover and formations I and II of the geological basin terminate at the eastern flank of the bulge. On profile H, however, both formation A and the possible formation at B are again present, which limits the extent of the depression found on profile C.

The western margin of the geological Loyalty Basin is therefore seen to run parallel in direction to that of the New Caledonia Ridge between profiles A and H. However, at the level of profiles G and H, it bends southward towards the north-south direction of the Norfolk Ridge in the area coinciding with the extension of formation C further to the west.

Further to the south on profiles I and J, the western margin of the morphological basin is not apparent and this basin may terminate between profiles H and I. It is of course possible, that the last two profiles did

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not extend far enough to the west to observe this margin. However, since the southern limit of the geological basin appears to occur between profiles H and I, it is likely that the morphological basin also terminates at this position.

In attempting to correlate the formations described above, it appears that in the west, formation III of the geological basin rests on basement (termed formation C), and that this probably correlates with formation IV to the east.

Formation A, to the west of the geological basin, is considered to be the equivalent of formation I. It is of course possible, that it is the equivalent of formation III, with the unconformity between formation III and layer IV corresponding to the pronounced unconformity at the top of layer C. However, the former interpretation is considered to be more likely. Also, since formation II of the basin pinches out at its western edge, it is likely that it is absent or only thinly represented above the marked unconformity surface of the western margin.

The present position of the strong unconformity surface, which occurs at a depth of about 2000 m, indicates that subsidence of this amount has taken place. The above interpretation implies that this has occurred mainly since the deposition of formations III and II. This, together with the apparent changes in the axes of sedimentation and the related areas of provenance between the formations III, II and I of the Loyalty Basin, indicates considerable mobility of the earth's crust in this region. This is also suggested by the indications of faulting on the profiles, some of which probably represent major normal faulting of the crust.

Eastern margin of the Loyalty Basin

The eastern margin of both the morphological and geological basins is formed by the Loyalty Ridge. This ridge parallels the island of New Caledonia in the north, and at a latitude between 22° and 23° S, like the New Caledonia-Norfolk Ridge, it also bends towards the south. However, it diverges slightly from the north-south direction of the Norfolk Ridge.

The seismic profiles provide little information on the composition and structure of the ridge, or as to whether it is of sedimentary or volcanic origin. It does show, however, the development of a small, consistent

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basement high or ridge at its western edge. This becomes more pronounced to the north where a shallow intra-ridge basin is observed. This ancillary feature is magnetic (see below) and could be due to the effect of block faulting towards the basin along its western edge, or to a linear igneous feature which could be either primary or associated with a later stage of volcanic activity.

The formations I, II and III of the geological basin thin towards and terminate at the Loyalty Ridge. The relation between formation IV, which has been taken as the basement of these formations, and the ridge is not well defined. It is possible, however, that formation IV is of similar age to that of the Loyalty Ridge.

MAGNETIC RESULTS

Total field magnetic profiles which were obtained during the course of the seismic survey of the Loyalty features, are part of a wider coverage which is reported by Lapouille et al (in preparation). The magnetic profiles of the Loyalty Basin and Ridge are, however, given greater prominence here because they are part of an entily covered in this study. Also, in considering these results, greater emphasis has been placed on the magnetic modelling of the Loyalty Ridge feature. This was in order to test the consistency of the magnetic anomalies associated with the ridge, with that of either a predominantly sedimentary or volcanic composition. This determination is particularly important in regard to the evolution of the ridge and its possible relationship to New Caledonia.

The magnetic anomaly profiles after the removal of the I.G.R.F. are shown in Figure 5. Included in this figure are profiles within this area obtained by the Mobil Oil Corporation from the R/V Fred. H. Moore in July, 1972. These provide consistent anomaly profiles over the Loyalty features which are similar to those obtained from Kimbla and Coriolis.

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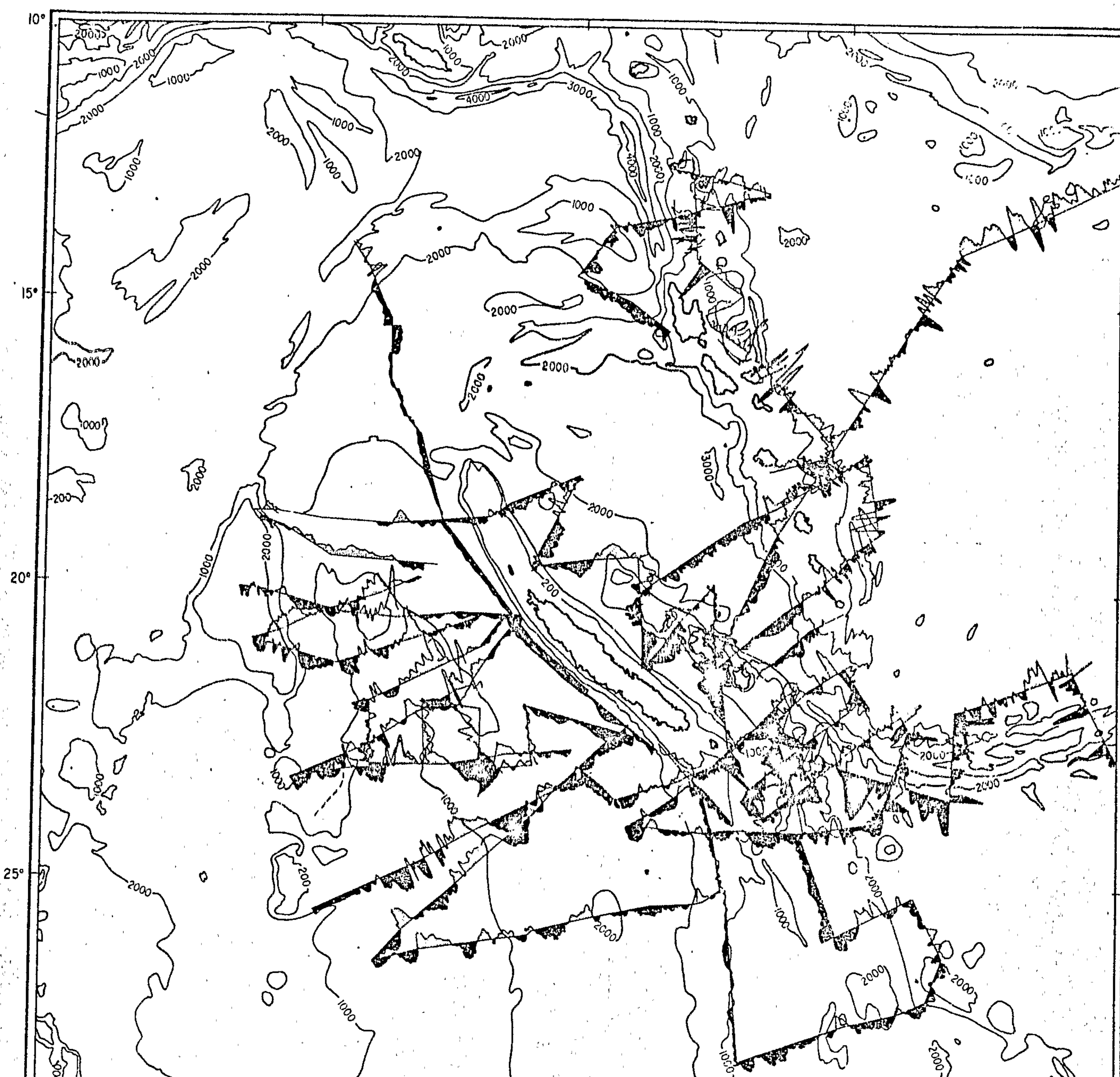
10°
15°
20°
25°
30°
155°
160°
165°
170°
175°
1000
2000
3000
4000

Loyalty Basin

A general observation, regarding the Loyalty Basin, is that it is characterised by a long wavelength, negative anomaly which may be readily correlated between profiles A and H. This is consistent with the thick accumulation of sediments within the basin which is shown by the seismic data.

South of profile I, the anomaly cannot be correlated and it is apparent that between profiles H and I, there exists a magnetic discontinuity which is probably related to a structural discontinuity across the strike of the basin. This coincides wi the position at which the southern limit of the geological basin has been taken.

Loyalty Ridge

A major, positive magnetic anomaly with an amplitude between about 800 and 1100 gammas strikes along the Loyalty Ridge. This anomaly and hence probably the ridge itself, appears to terminate to the north near 18° S. To the south, it becomes complex and poorly defined at about 24° S. The positive anomalies occur to the northeast of the islands and are centred on the northeastern edge of the ridge at about the position of the 2000 m bathymetric contour. The anomaly retains basically the same form along the length of the Loyalty Ridge. The amplitude of the major anomaly varies in response to changes in the water depth and broadens as the ship tracks become less perpendicular to the strike of the ridge. This suggests that the source of the anomaly is essentialy a single, uniformly magnetized body reasonably close to the sea floor.

Initial magnetic modelling along tracks normal to the ridge and near the centre of the island chain, showed that the source of the magnetic anomaly could be roughly approximated by a two-dimensional, vertically sided prism centrally located beneath the ridge. The general configuration of this prism had a depth to the top of 1.9 km, a width of 22 km and a normal magnetization of 140 emu. To fit the anomaly profiles, a linear regional of about 2 gammas per km, with values increasing to the northeast was inserted. This is consistent w.th a generally shallower magnetic basement to the east of the ridge.

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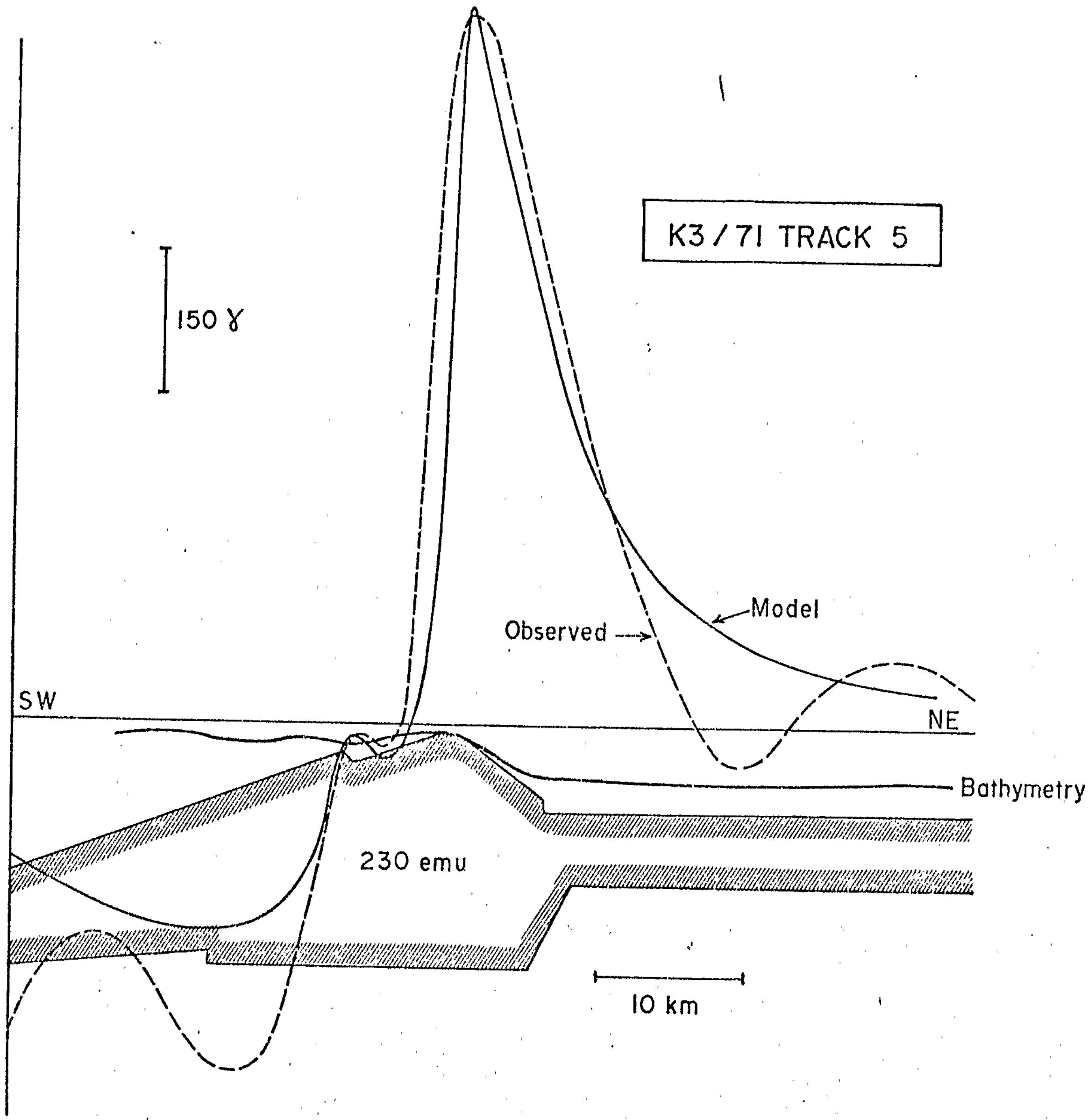
K3 / 71 TRACK 5
150 γ
Model
Observed
SW
NE
Bathymetry
230 emu
10 km

Detailed two-dimensional computer modelling on centrally located tracks, was carried out using the polygon method of Talwani and Heirtzler (1964). The magnetic data along essentially perpendicular tracks across the ridge were filtered to reduce the influence of local anomalies and processed using computer procedures developed at the University of N.S.W. for the treatment of marine geophysical data. The computed models were based on the initial magnetic interpretation and the existing seismic refraction and seismological information on the crustal thickness in the region of Shor et al. (1971) and Dubois (1971).

An example of this interpretation on a centrally located track at the position of profile B, is shown in Fig. 6. The measured magnetic anomaly can be closely fitted by adjusting the top surface of the model. Further minor adjustments could be made to achieve an even closer fit but these were considered unnecessary in the present study. For this model, a magnetisation of 230 emu was used.

The results of the modelling suggest that the source of the major anomalies over the Loyalty Ridge consists of intermediate to basic volcanic and / or volcano-clastic rock which makes up the bulk of the ridge. The Loyalty Ridge, therefore, appears to be essentially composed of andesitic or basaltic material rather than non-volcanic, sedimentary material. This is at least consistent with the hypothesis that the Loyalty Islands represents the ancient andesitic arc above an old Benioff zone which was associated with the inferred ancient New Caledonia Trench. However, since no measurements of magnetic susceptibility have yet been made on the basalts which have been reported from within the uplifted lagoon on Maré Island, it is not known whether their susceptibility is similar to that computed for the model.

Hence, the Loyalty Ridge may be essentially composed of rocks of either andesitic or basaltic composition, or of andesitic rocks intruded by basaltic volcanic of similar magnetic susceptibility, associated with major block faulting during the later history of the ridge. Certainly, the age of the basalt on Maré Island, which has been dated at 10 m.y. B.P., must be later than the ridge itself. This is apparent from the seismic data on the sedimentation within the basin, which indicates that the ridge acted as a major source of sediment at times which must have been considerably earlier than the age of these basalts.

A consistent feature of the magnetic profiles across the ridge is the smaller linear anomaly along its western margin. This anomaly models as a basement high or minor ridge along the edge of the feature. It is more developed in the northern part of the ridge as is also shown by the seismic results. Also observed was a single seamount protruding through the sediments of the Loyalty Basin near the western terminations of profile B. This shows a distinct magnetic anomaly and would appear to be associated with a late volcanic phase of the Loyalty Ridge.

Southern extension of the New Caledonia Ridge

Profile F, which passes near the Isle of Pines, shows a large negative anomaly of about 900 gammas to the south of the island. Since the island contains part of the mass of peridotites which occur on New Caledonia, this suggests that the anomaly may be produced by a submarine extension of the peridotites. The anomaly, however, is negative, which could be produced by either a reversed magnetisation or by an overturned normally polarised sheet of peridotite, as suggested by Guillon and Routhier, (1971).

PAST AND PRESENT SEDIMENTATION IN THE LOYALTY BASIN

A study of the actual phenomena of erosion of the peridotites on New Caledonia, and the transportation of the erosional products (Baltzer and Trescases, 1971), has shown the importance of chemical erosion, and of the transportation of dissolved material when compared with mechanical transportation. This occurs in the ratio of 4.5 to 1, with the products of mechanical erosion being actually less than the residual deposits of chemical erosion. The products of mechanical erosion are mainly transported during the cyclonic floods. These are deposited in the alluvial plains and in the mouths of river near the coast, where they are trapped by the

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mangrove vegetation which acts as a filter (Baltzer, 1972), with no terrigenous deposits reaching the lagoon area (Launay, 1972; Dugas, 1974). This explains the current absence of terrigenous sedimentation in the Loyalty Basin (see below).

The question arises as to whether these erosional processes have been constant in the past. During the Quaternary, both in the lagoon (Launay, 1972), and to a depth of 600 m on the continental slope of New Caledonia (ORSTOM, Noumea, 1971; Anglada et al., in press), terrigenous deposits are not an important factor in sedimentation, although some episodic ferruginous, terrigenous deposits do occur. Also, from drilling on the western barrier reef, which extended down to basement at 226 m (Avias and Coudray, 1967), reefal and parareefal formations of Quaternary age occur without any important terrigenous phase (Coudray, 1971).

It therefore appears that New Caledonia has not been a source of terrigenous deposits throughout the Quaternary. However, since the deposits both in the Loyalty Basin and in the New Caledonia Basin to the west, are thickest near New Caledonia (Dubois et al., 1974) it is reasonable to suppose that New Caledonia has been an important source area of detrital sediment in the past. Similarly, since volcanic activity occurred in the Loyalty Islands up until at least 10 m.y. B.P. (Baubron et al, in press), it is likely that the Loyalty Ridge acted as a source of volcanic and detrital material prior to its subsidence.

Dredging from the surface of formation A where it meets the slope of New Caledonia, obtained calcareous ooze containing pelagic and benthic micro-fauna but no terrigenous material. Other dredging in the Loyalty Basin, obtained muds with less globigerina and no benthic micro-fauna or terrigenous material. Hence, present sedimentation within the Loyalty Basin is purely pelagic without terrigenous or neritic material, despite the proximity of the reefal formations of New Caledonia and the Loyalty Islands.

Since the total thickness of formations I, II and III attain a two-way reflection time in excess of 4 sec, a purely pelagic sedimentation regime cannot have been in existence since the Oligocene. For comparison, drillhole 206 of Leg 21 of D.S.D.P. (Burns et al., 1972; Andrews et al., 1973 a) found the top of the Oligocene under 420 m of purely pelagic sediments. It is therefore clear that previously, considerable terrigenous material was added to the pelagic sedimentation in the Loyalty Basin. These deposits appear to have come from both the New Caledonia Ridge and the Loyalty Ridge at various times during the history of sedimentation.

CONCLUSIONS

Within the morphological basin between New Caledonia and the Loyalty Islands, seismic reflection profiles reveal a thick accumulation of sediments in a restricted basin within the broad morphological feature. This geological or sedimentary basin is limited in the east by the submarine flank of the Loyalty Ridge, and in the west by an exposed basement scarp. Between this scarp and the continental slope of New Caledonia, the basement of the geological Loyalty Basin to the east, rises to form a well developed platform which represents a marked unconformity with a relatively thin overlying sediment cover. Dredging from the exposed scarp has obtained samples of a well-cemented ferruginous conglomerate which contains basaltic pebbles from New Caledonia.

The width of the geological basin is roughly 80 km while the total width of the morphological basin in which it occurs is about 110 km. The northern limit of the geological Loyalty Basin remains undefined from the present survey, with the thick accumulation of sediment continuing northward, perhaps until the position of the d'Entrecasteaux Fracture Zone. The southern limit of this basin is marked where the deep sediments of the basin terminate at a latitude of about 24° S, which lies to the south of where the axis of the basin bends southwards.

Within the geological basin, three principal formations have been identified. These formations (labelled I, II and III) have been laid down on a basement which was too deep to be observed in the central part of the basin. The basement to the west, (formation C) on which the marked unconformity surface is located, is correlated with formation IV to the east. The latter appears to correlate with the basement found by Shor et al., (1971), which has a velocity of about 5.9 km/sec from the marine refraction data. This basement rises towards the Loyalty Ridge and is possibly of similar age to the formations of that feature.

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The relatively thin sediment overlying the marked unconformity to the west of the geological basin, is interpreted to be essentially equivalent to formation I within the basin and therefore relatively young. The very strong reflections occurring at or near the unconformity surface, may mask the existence of a very thin overlying layer. If present, such a layer could represent the equivalent of formation II and possibly formation III. However, irrespective of whether a very thin layer is present overlying the strong unconformity, it is clear that this old erosional surface must have submerged by about 2000 m to its present position, and that it appears to have been at or near sea level at or since the time of deposition of formations III and II. This implied subsidence of the erosional platform and basin, appears likely to be due to major normal faulting along the eastern continental slope of New Caledonia.

It is known that a major orogenic phase affected the region of New Caledonia and the Loyalty Islands during the Upper Eocene. Since the formations I, II and III within the Loyalty Basin have not suffered any serious deformations, it must be concluded that they were not affected by that major orogeny. It follows that they were deposited after this phase, that is since the beginning of the Oligocene, although the precise age of the onset of this sedimentation is not known. Also, subsidence of the old erosional platform would therefore appear to be post Oligocene, possibly in the Miocene or even the Pliocene.

Although sedimentation in the Loyalty Basin has been restricted to pelagic sedimentation during the Quaternary, the large accumulation of sediment in the basin and the varying distribution of the sediment within the different layers, points to both the New Caledonia and the Loyalty Ridges as having been important sources of sediment at various times from the Oligocene. Also, the presence of three major sedimentary formations separated by disconformities implies the existence of three different morpho-tectonic and sedimentological phases in the development of the Loyalty Basin.

Because the Loyalty Ridge as well as the New Caledonia Ridge, clearly appears to have acted as an important source of sediment during the deposition of formation III and particularly formation II, it is implied that it cannot be considered only as a basaltic volcanic chain developed over a relatively

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short period prior to the dated volcanic activity of 10 m.y. B.P. The ridge must have been in existence prior to the Oligocene and we prefer the interpretation that it probably represents the andesitic volcanic or volcanoclastic island arc associated with an inferred Benioff zone of an ancient New Caledonia Trench but which has suffered subsequent phases of basaltic volcanicity probably related to major, tensional block faulting during its subsequent history up until 10 m.y. ago.

The results of precise magnetic modelling of the anomalies over the Loyalty Ridge show it as being essentially composed of material with a uniform magnetization which is appropriate to rocks of intermediate to basic composition, which is consistent with the above hypothesis. The alternative interpretation is that it is a ridge of basaltic composition which again must have been in existence over the same period as above, and subjected to various phases of volcanicity.

Finally, from the magnetic profiles across the Loyalty Ridge and the precise modelling of these profiles, it emerges that not only is the ridge composed essentially of uniformly magnetised material of intermediate to basic composition, but that there is a consistent though minor associated ridge of similar magnetisation within but on the western edge of the main ridge. This gives the ridge a double aspect with the minor associated ridge on its western side providing an intra-ridge basin which has been clearly observed on seismic profiles in the northern part of the ridge. The development of the ancilliary ridge could be due to tilted block faulting at the western margin at the main ridge, or have an igneous origin of a primary or subsequent nature.

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FIGURE CAPTIONS

Figure 1. Bathymetric map of the Loyalty Basin and surrounding areas (after Scripps Institution of Oceanography Bathymetric Map of the Southwest Pacific, 1971), showing the location of profiles across the Loyalty Basin.

Figure 2. Bathymetric profiles across the Loyalty Basin.

Figure 3. Seismic reflection section across the Loyalty Basin along profile F.

Figure 4. Profile of two-way reflection time along the axis of the Loyalty Basin showing the bathymetric profile, compounded from the results of the cruise of Coriolis 1966, and the maximum bathymetric depths from profiles across the basin together with the reflection times for sedimentary layers from the present seismic profiles across the basin and their equivalent from the refraction results of Shor et al., 1971.

Figure 5. Magnetic anomaly profiles across the Loyalty Basin and Ridge.

Figure 6. Interpretational model of representative magnetic profile across the Loyalty Ridge.