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Continental Margins Near New Caledonia

J. Dubois, C. Ravenne, A. Aubertin, J. Louis, R. Guillaume,
J. Launay and L. Montadert

INTRODUCTION

A survey of the New Caledonian margins reveals several regions between the proper oceanic domain in the central Pacific and the continental domain forming the Australian continent. Earth physics and, in particular, seismology can be used to differentiate the following three units of the uppermost mantle and the crust: (1) the submerged continental zone (made up of subsea basins and ranges) to which New Caledonia and the Loyalty Islands belong; (2) the interarc expansion basins in which an oceanic lithosphere takes form (Lau Basin, North Fiji Plâteau); and (3) the island arcs (New Hebrides, Tonga-Kermadec). The relationships between these units are what determine the tectonics of these margins and enable their geological history to be better understood.

The main facts showed off by the seismic-reflection profiles are the following.

Structural Point of View

It is important that the existence of a Fairway rise can be interpreted as an outer arc related to New Caledonia-Loyalty island arc. The New Caledonian area, where the structural directions (northwest-southeast) are different from the Australian (north-south), is explained as a fossil island arc that was active at least during Oligocene and probably since Early Cretaceous.

Referring to the present patterns about island

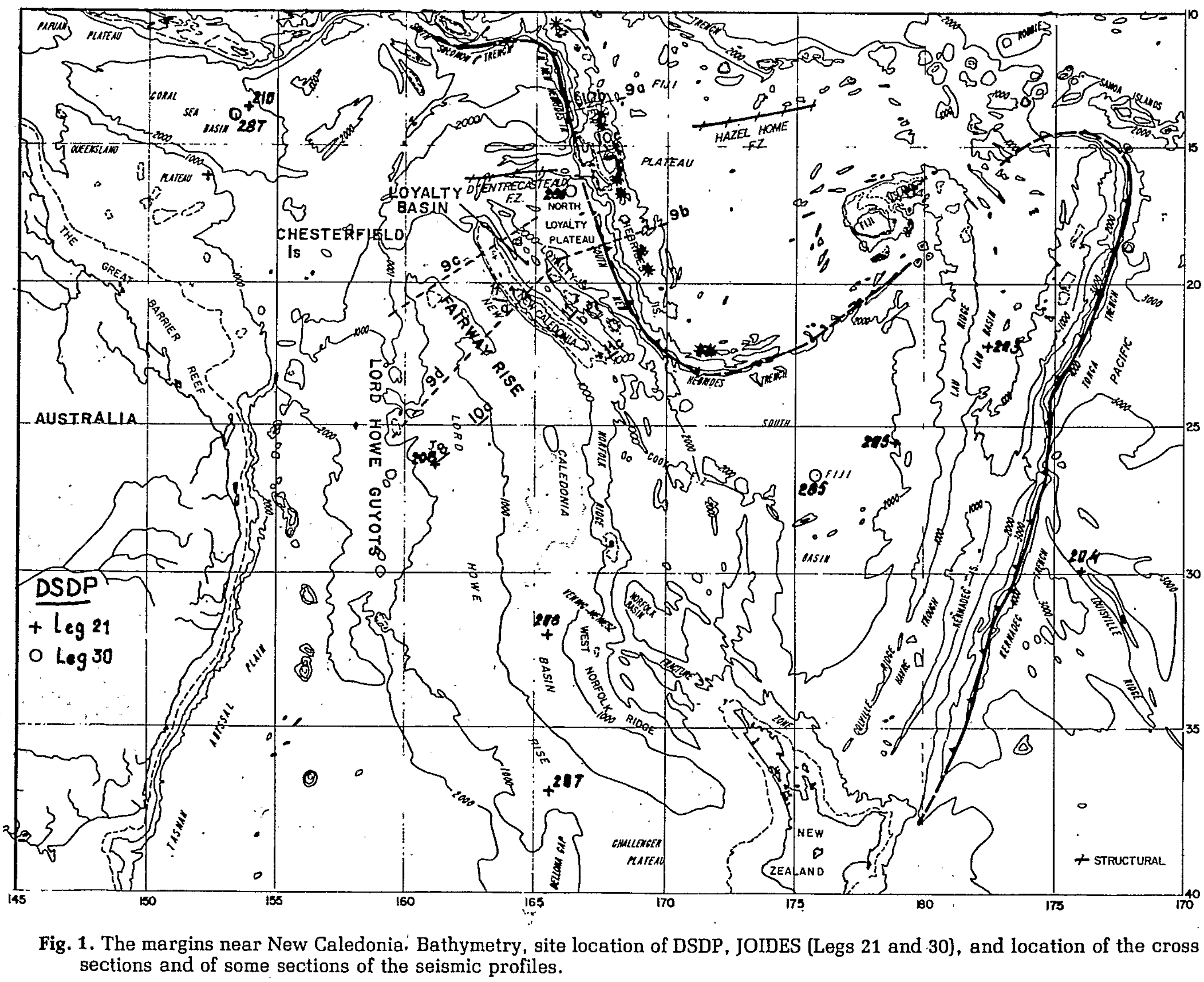

Fig. 1. The margins near New Caledonia. Bathymetry, site location of DSDP, JOIDES (Legs 21 and 30), and location of the cross sections and of some sections of the seismic profiles.

arcs, we put forward the following equivalence: (1) New Caledonia, nonvolcanic outer arc; (2) Loyalty Basin, inter deep basin; (3) Loyalty islands, volcanic inner arc; and (4) North Loyalty Plateau, interarc or marginal basin. The trench could have been located west of New Caledonia, in the deep basin.

Throughout the history of the area, vertical and horizontal movements occurred; the vertical ones are emphasized by the series of emergences and submergences and the great uplifting of the erosion terraces in the islands. The erosion disconformity, observed on Norfolk Ridge, connected with the Oligocene disconformity on Lord Howe Rise, appears to be synchronous with the Miocene peneplanation in New Caledonia. The horizontal movements are closely tied to the history of the remnant island arcs, as for New Caledonia, and active verse faults through the New Caledonia-Loyalty system.

Sedimentary Point of View

The sedimentary basins are conformable to the bathymetric basins. Thicknesses of sediments greater than 2.4 sec (two-way time, D.T.T.) occur in the Lord Howe Basin, New Caledonia Basin, and Loyalty Basin.

The erosion of the relief of New Caledonia seems responsible for the sedimentary filling of the New Caledonia Basin (where only the Neogene is important) and partly of the Loyalty Basin (which also received some volcano-clastic sediments from the Loyalty Chain). A strong subsidence zone runs along New Caledonia, and the thickness of sediments is far greater than 3 sec D.T.T.

We notice a thin thickness of sediments on the Fairway Rise and North Loyalty Plateau. There is a difference between the constitution of the Fairway Rise and Lord Howe Rise. The substratum of the Lord Howe Rise is sedimentary, for there are continuous coherent reflections at depth.

In the New Hebrides island arc, we observed a great thickness of sediments (more than 2 sec D.T.T.), especially in the broken-down basins in the north and the south. This is not compatible with the existence of an active interarc basin at this place. Difference between arc-trench gap in the New Caledonia and New Hebrides system can possibly be explained by difference in age.

DEEP STRUCTURE

New Caledonia and the regions around it are located in a zone halfway between the oceanic Pacific domain in the east and the continental Australian domain in the west. This continental margin area roughly corresponds to the zone west of the andesite line plotted by MacDonald et al. (1973). The sea floors surrounding New Caledonia have various structures (basins, trenches, rises, seamounts, etc.) (Fig. 1). An initial approach to a survey of these margins consists in considering the lateral heterogeneities that can be observed by earth physical/techniques, in defining the principal structural units in the region.

Bathymetry shows that this region is made up of a succession of submarine basins and ranges generally trending southeast, interrupted north of 16°S by the d'Entrecasteaux Fracture Zone. A deep trench runs along the New Hebrides Island arc, which is known for its great seismic and volcanic activity. It stops after curving eastward toward the Fiji Islands. Another arc farther eastward, the Tonga-Kermadec arc, bounds the area of the purely oceanic domain. Between these two arcs, monotonous plateaus (2,500 m), the North Fiji Plateau and the Lau Basin, stretch west and east of the Fiji Islands. The South Fiji Basin is deeper (4,500 m), as is the Tasman Sea in the southwestern part of the region, belonging to the oceanic domain.

The shape of the geoid (Guier and Newton, 1965) as determined from satellite tracking shows an appreciable swelling (+50 m) having its center in New Caledonia. The axis of this swelling runs southeast and generally covers the entire area being examined. The +40-mgal contour line follows the trend of the New Hebrides arc. We can thus expect to find an abnormal uppermost mantle in this region.

Magnetic anomalies such as those found during cruises in this area show that the deep-lying structural features of the crust closely follow those of the bathymetry, i.e., trending with the axes of the southeast anomalies (van der Linden, 1968; Lapouille and Henry, 1971). However, analysis of the seismicity (Fig. 2) and of the volume and surface-wave propagation are the most useful to distinguish the main units making up this region on the scale of the uppermost mantle and the crust. A separation is thus made between the zone directly surrounding New Caledonia, the interarc-basin region (North Fiji Plateau, Lau Basin) and the seismic arcs (New Hebrides and Tonga-Kermadec).

Area Surrounding New Caledonia and the Loyalty Islands

An analysis of Rayleigh-wave dispersion (Dubois, 1968, 1969, 1971) (Fig. 3) shows that the crustal structure in this area has a continental nature, even though it is underneath a deep-water layer (up to 3,500 m). A comparison between the observations made at Noumea, New Caledonia, and the theoretical dispersion curves of Rayleigh waves (Saito and Takeuchi, 1966) suggests that the crust here has a mean thickness of 20 km, that it becomes thicker underneath the ranges to attain 25 km (Norfolk Ridge and Lord Howe Rise), and then becomes thinner underneath the basins (New Caledonia Basin, Loyalty Basin, South Fiji Basin: Macquarie-Nouméa, New Zealand-Nouméa, and Kermadec-Nouméa ray paths). On the New Guinea-Noumea ray paths in the northwestern part, the crust appears to be the thickest, 25 km at the most.

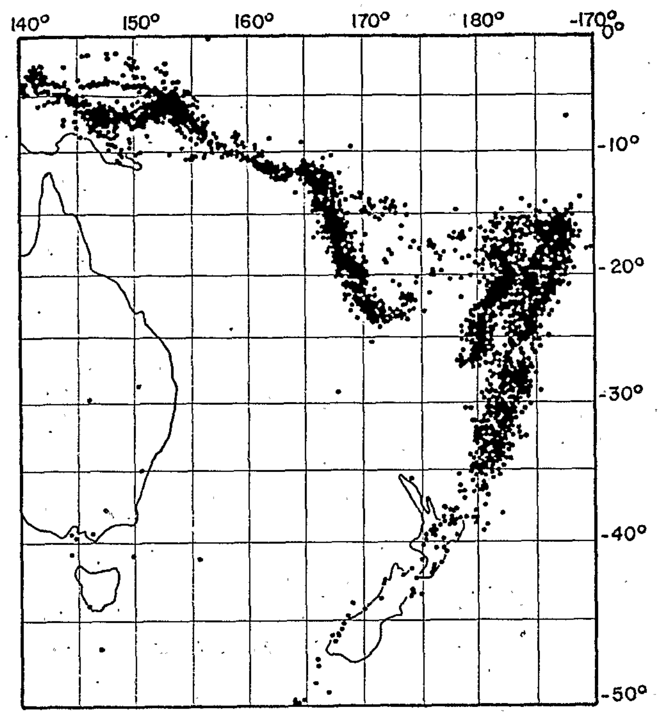

Fig. 2. Seismicity map from ESSA, Coast and Geodetic Survey. Epicenter data, 1961-1967, southwestern Pacific area.

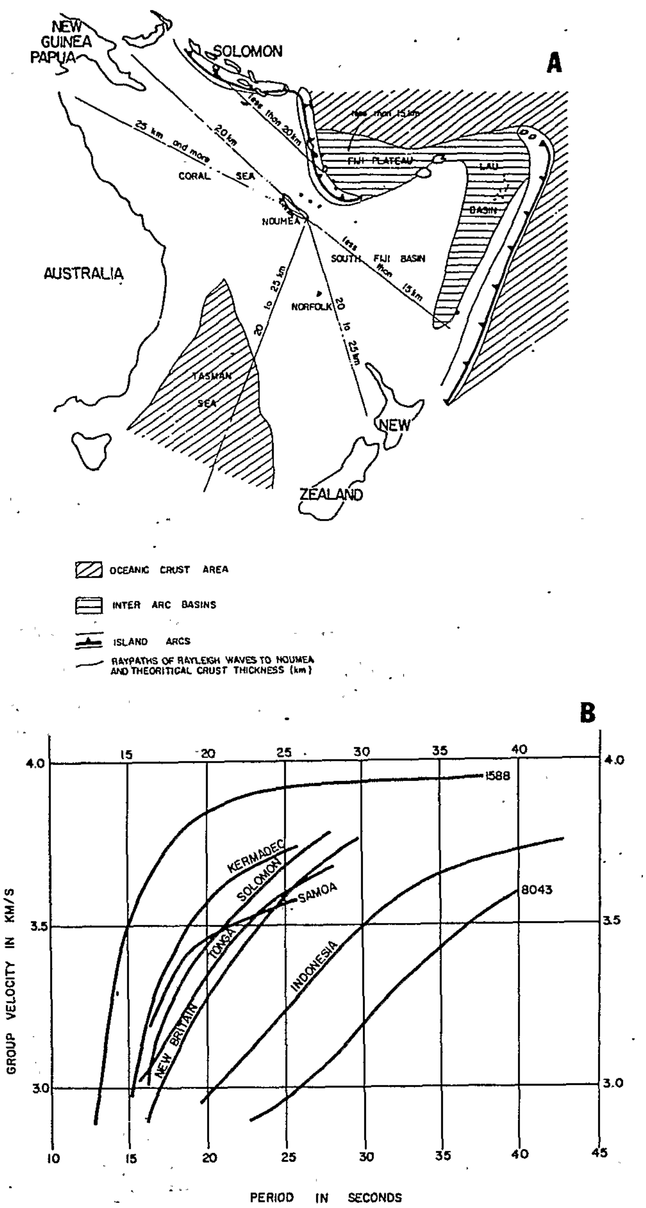

Fig. 3. New Caledonia-Fiji-Loyalty seismicity. (a) The four structural units: oceanic, continental, expansion basins, and four island arcs. Rayleigh-wave ray paths in the continental area and theoretical crust thickness (km). (b) Dispersion curves of Rayleigh waves to Noumea from different earthquakes belts. Comparison with oceanic 1588 and continental 8043 theoretical models.

The reason for this is that it crosses the Queensland Plateau, which is the submarine prolongation of Australia.

The Rayleigh-wave phase velocities between Noumea and Koumac, along the western coast of New Caledonia, suggest a crustal thickness of 18-20 km; whereas underneath the central range the residual time variations in the P waves, along the azimuth, reveals a thickening of the crust to 35 km (Dubois, 1969; Dubois et al., 1973). In addition, the relatively slow propagation velocities of the long Rayleigh wavelengths also show that, in this entire zone, the layer with the slowest S-wave velocity in the uppermost mantle is at a depth of about 60 km (Saito and Takeuchi, 1966; Dubois, 1969).

The sedimentary basins show negative smooth magnetic anomalies, while the subcontinental elevated structures produce long positive anomalies with smaller ones superimposed (Lapouille and Henry, 1973). Refraction and sonobuoy profiles complete the patterns given by seismology. In the Coral Sea, Shor (1967) finds a crust thickness of 15 km underneath 4 km of water. Layer 3, called the oceanic layer, reaches 11 km thickness there, and Raitt (1956) feels that there might be a transformation process whereby the oceanic crust turns into a continental crust.

The refraction profiles by Shor et al. (1971) in the Lord Howe rise clearly reveal the thickening underneath the rise (Fig. 4), as brought out by seismology (thickness between 16.5 and 28 km), while Woodward and Hunt (1970) use gravimetry to determine a thickness of 26 km and qualify this crust as quasi-continental. Likewise, Layer 3 (P-wave velocity of 6.8 km/sec) is present underneath the rise, and so the problem is to determine whether the Lord Howe Rise is a fragment of the continental crust or a volcanic ridge built up on an oceanic foundation (see also Bentz, this volume). Underneath the Norfolk Ridge, the refraction profiles by Shor et al. (1967) show a thickness of 21 km, and Layer 3 is still present.

In the New Caledonia Basin, the uppermost mantle is at a depth between 10 and 16 km according to refraction profiling (Shor, 1971), whereas Solomon and Biehler (1969) use gravimetry to locate

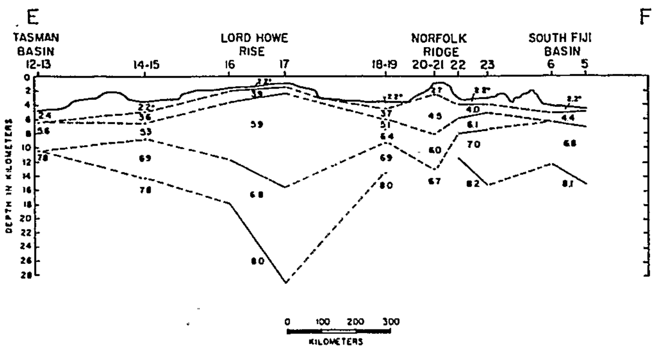

Fig. 4. Structure section across the western part of the Melanesian border (from Shor et al., 1971).

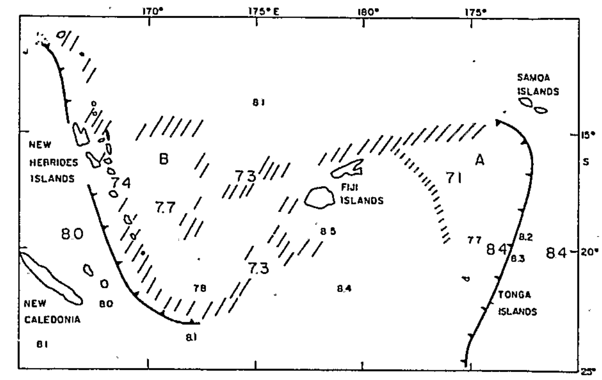

Fig. 5. Fiji Plateau and Lau Basin; P-wave velocities in the uppermost mantle, showing locations of shallow earthquakes (dashed lines). Data from Shor et al. (1971) (small numbers), Aggarwal et al. (1972), Dubois et al. (1973) (large numbers).

it at 17-18 km, and Woodward and Hunt (1970) find it between 9 and 16 km by gravimetry. In the Loyalty Basin crustal thickness appears to vary between 15 and 20 km (Shor, 1967). The South Fiji Basin has a more oceanic nature, but profiles by Raitt (1956) and Shor et al. (1971) show that the "oceanic" and sedimentary layers are thicker than usual there (6-12 km).

North Fiji Plateau

The structure of this basin is quite different from that of the regions described above; it is actively seismic, and the superficial and normal foci are distributed according to broad zones of deformation (Sykes et al., 1969; Chase, 1971; Dubois et al., 1973). Propagation of P and S waves in the uppermost mantle reveal the actual seismic plateau for which these velocities underneath the Moho are 7.6 and 4.3 km/sec (with attenuation of the *Ss*). The boundaries of the plateau are defined by a seismic belt made up of a line east of the New Hebrides, the Hunter Fracture Zone, a line west and north of Fiji, and the Hazel Home Fracture Zone, all of which are characterized by their low P-wave velocity (7.2 km/sec) and the very high attenuation of the *Ss* (Dubois et al., 1973; Barazangi et al., 1973) (Fig. 5). Likewise, the dispersion of Rayleigh waves from these earthquakes to the Port Vila seismological station clearly reveals these differences according to the azimuth considered. However, an analysis of P- and S-wave propagations does not show the existence of a thin crust underneath the Plateau. For Rayleigh wave propagation, the low S velocities in the mantle make up for the influence of the thin crust, and the dispersion curves are of a type halfway between oceanic and continental (Dubois, 1969). A refraction profile (Shor et al., 1971) and a sonobouy survey (Sutton et al., 1969) show a crust thickness of 5.5 km underneath a water layer of 2.5 km.

On the basis of these seismological data and considering observations on the high heat flow (Sclater and Menard, 1967; Sclater et al., 1972; MacDonald et al., 1973) on gravity measurements indicative of low-density uppermost mantle (Solomon and Biehler, 1969), as well as on the shallow-water depth (2.5 km) and the thinness of the sediments, we can deduce (Dubois et al., 1973) that the Fiji Plateau is not an oceanic lithosphere belonging to the Pacific Ocean, but a recently generated crust. The focal mechanisms of earthquakes on the Hunter Fracture Zone, with left-lateral strike-slip motion along the fracture (Johnson and Molnar, 1972), fit in with this pattern of opening up. The Lau Basin has the same features (Sykes et al., 1969; Karig, 1970; Barazangi and Isacks, 1971; Sclater et al., 1972a, 1972b; Mitronovas and Isacks, 1971).

Island Arcs

Between the two domains described above, the New Hebrides Island arc is situated. With regard to its seismicity, this arc is characterized by two singularities: (1) the eastward inclination of the seismic plane, i.e., toward the middle of the Pacific, as opposed to all the other circum-Pacific arcs (except the Solomon Islands arc); and (2) the seismic gap between the depths of 350 and 600 km (Fig. 6).

Structurally, the oceanic trench along the arc in the west is discontinuous. It breaks off at the latitude of Espiritu Santo at the level of the Hazel Fracture Zone and the d'Entrecasteaux Fracture Zone, both trending east-west. This break does not exist along the seismic plane, which is quite continuous from north to south. The major structural line appears as an active volcanic alignment parallel to the trench and perpendicular to the 200-km isodepth line of the seismic Benioff Zone (Fig. 6). The northern part of the volcanic line (north of Epi Island) crosses the basins bounded in the east and west by former volcanic islands. In the south the volcanic line is bounded in the east by en échelon troughs, of which the largest is the Coriolis Trough (Puech and Reichenfeld, 1969). The velocity of the P waves is high (7 km/sec) in a crust about 20 km thick, but it is low in the uppermost mantle (7.4 km/sec), i.e., in the part of the asthenosphere located between the

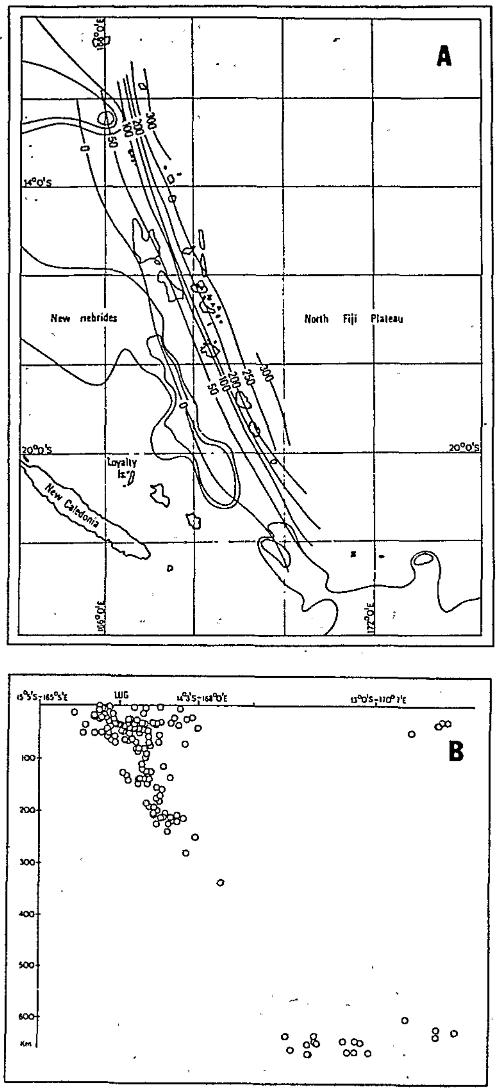

Fig. 6. New Hebrides island arc. (a) Map of isodepth lines that define Benioff Zone. (b) Typical cross section of earthquake hypocenters (Luganville, Espiritu Santo profile) (from Dubois, 1971).

Benioff plane and the crust. Attenuation of the S waves is great there (Barazangi et al., 1973).

The possible geometry and structure of an underthrusting slab were determined in detail from an analysis of the P and S propagations by the ray-tracing method between the deep foci underneath the Fiji Plateau and the seismological stations in the New Hebrides (Pascal et al., 1973). The break in seismicity at 350 km is interpreted (Barazangi et al., 1973) by a break in the oceanic lithospheric slab at this depth. Below that, the asthenosphere (low velocity of S waves, great attenuation) appears to extend to 600 km, and everything seems to indicate that the deep earthquakes in the Fiji Plateau are associated with a piece of the lithosphere that has become detached from the underthrusting oceanic slab.

Gravimetric measurements made on land (Malahoff and Woolard, 1969) and offshore (Luyendyk et al., 1973) show that the positive Bouguer anomaly in this area increases from 100 mgal in the west (Espiritu Santo, Malekula) to more than 200 mgal in the islands in the east. This is in good agreement with the presence of an upper mantle "corner" in the Benioff zone. The offshore profiles show this increase in the Bouguer anomaly from 100 mgal on the east coast of Vate (isodepth line 100 km) to 250 mgal 170 km offshore to the northeast.

The Tonga-Kermadec island arc has been the subject of a great many seismological and structural studies (Sykes, 1966; Oliver and Isacks, 1967; Isacks et al., 1967, 1969; Sykes et al., 1968, 1969; Mino et al., 1968; Barazangi et al., 1972; Mitronovas and Isacks, 1971; Isacks and Molnar, 1971; Barazangi and Isacks, 1971; Aggarwal et al., 1972; Karig, 1970). Its seismicity in its northern part extends continuously to 700 km depth, and an analysis of the wave propagation by Oliver and Isacks (1967) in this area is the basis for the fundamental hypothesis of the underthrusting of the oceanic lithosphere under the island arcs. Mention should be made of the symmetrical pattern, compared with the Fiji Islands, of both the New Hebrides and Tonga-Kermadec arcs with opposite-facing lithospheric consumption zones and the existence, in their concavity, of an expansion basin where the oceanic lithosphere is formed. Other important features are the basic difference in these two underthrusting systems with an oceanic lithosphere under a subcontinental lithosphere for the Tonga-Kermadec arc, and a continental lithosphere under a recently generated oceanic lithosphere for the Hebrides arc.

An analysis of the marine fossil levels in New Caledonia and the Loyalty Islands led us (Dubois et al., 1973) to try to interpret the uplifting of the atolls that form the Loyalty Islands in the lithospheric bulge of Australo-Tasmania, prior to its subduction at the New Hebrides. Indeed, the entire marginal area of New Caledonia and the Loyalty Islands appears to have been affected by this downthrust of the continental plate under the Fiji Plateau. In addition to topographic arguments (uplifted atolls) there are geophysical arguments (Bouguer anomaly corresponding to a bulge of the upper mantle and a magnetic anomaly) along with arguments of a dynamic nature (such as dating the different atolls at different stages of the uplifting according to their position in relation to the axis of the bulge).

Conclusions

These margins in the vicinity of New Caledonia have been classified in three main structural units on the basis of seismological data as well as of bathymetry, magnetism, gravimetry, heat flow, etc. These three units are as follows:

1. The oceanic region, with a continental-type crust, that surrounds New Caledonia and extends, via a succession of basins and ranges, from Australia to the New Hebrides and Tonga-Kermadec island arcs (except for the northern part of the Tasman Sea).

2. The North Fiji Plateau and the Lau Basin, in the concave parts of the island arcs, are highly singular areas at a shallow depth, with an oceanic crust and an abnormal uppermost mantle, that are interpreted as having been formed from the recently generated lithosphere (the Woodlark Plateau in the north appears comparable).

3. The island arcs make up the boundaries of these different zones and form two opposite-facing lithospheric consumption zones.

STRUCTURAL HISTORY AND SEDIMENTARY RECORD

New data on sediment distribution in the southwestern Pacific were obtained by seismic reflection during the Austradec cruises. These cruises were carried out by IFP, CFP, SNPA, and ELF-ERAP as part of a project sponsored by the Comité d'Etudes Pétrolières Marines in collaboration with ORSTOM and using CNEXO's vessels. The profiles were obtained with the IFP Flexichoc implosion source, a numerical recording laboratory and a 12-traces streamer for performing CDP shooting of 1,200 per 100. The profiles used in this report cover the area between the alignment of the Lord Howe Guyots and the Chesterfield Islands in the west, and the north Fiji Plateau in the east.

Historical Elements Provided by Onshore Geology

New Caledonia. The oldest formations identified are ante-Permian (Avias and Tonord, 1973). In the Permian, the sediments are made up of a volcanic series with a few calcareous interbeds and sandy deposits. The Triassic is marked by a marine transgression. The first graywackes appear and will go on to make up most of the Jurassic deposits. The absence of the Bathonian-Bajocian suggests, as in New Zealand, that the island emerged. The sedimentation changes abruptly in the Cretaceous, with argillaceous and sandy deposits. Also in the Cretaceous, there is a formation of emerged ridges with the presence of coal deposits and a thick conglomeratic and red arkosic formation encompassing the future Paleogene "sillon" (Routhier, 1953), in which the Cretaceous and Tertiary formations are well developed, folded but nonmetamorphic. The Eocene is present in three lithologic types: the external flysch facies (Tissot and Noesmoen, 1958) against the west coast; the internal facies (Tissot and Noesmoen, 1958), with sediments and fossils that are markers of deep sedimentation (phtanites, globigerinids) east of the external facies; and the basalt and dolerite volcanic outflows in two places—one in the "sillon" (Routhier, 1953) between the external facies and the middle range, and the other east of the island.

During the Eocene tectonic movements began. They went on to reach their climax in the Oligocene with the emplacment of peridotites. This compressional phase continued until the beginning of the Miocene. The Neogene and Quaternary are marked by vertical movements (transgressions and uplifts).

Loyalty Island Ridge. This range is volcanic and is topped off by reefs. The last major outflows date from the late Miocene (oral report by the ORSTOM Geology Section in Nouméa). This does not exclude an earlier date for this range, as shown by Chevalier's (1968) dating of a marine basalt indicating a late Oligocene age.

New Hebrides. These mountains are divided into three ranges (Dugas, 1971). The central range is the most recent (Plio-Quaternary) and is formed of still-active or recently active volcanoes. The eastern (Pentecost, Aurora) and western (Espiritu Santo, Malekoula, Torres) ranges are older. Andesite from Torres Island has been dated in the late Eocene (Warden, 1968), showing that the arc was already active there at that time. Pre-Miocene red argillites (Mitchell, 1970) are found west of Malekula. Their makeup reveals a deep-water environment located beneath the carbonate compensation depth. These two lateral ranges are essentially made up of volcano-sedimentary deposits with a few calcareous interbeds, linked to the existence of reefs in the early Miocene. The activity of the arc probably started later on the emerged folds in this part of the New Hebrides, around the Oligo-Miocene.

Bathymetry is of great interest for the area around New Caledonia because we find that the boundaries of the sedimentary and bathymetric basins are the same and that the isobath curves reflect structural features (Fig. 1).

Western New Caledonia Region

Bathymetry is of great interest for the area around New Caledonia because we find that the boundaries of the sedimentary and bathymetric basins are the same and that the isobath curves reflect structural features (Fig. 1). Two zones can be distinguished according to the trend of the structural elements between 19°S and 24°S (Fig. 7):

1. A zone in which the trends are north-south, called the "Australian" zone because this trend is the same as that of the Australian continental slope as well as of the structures between this slope and the area studied. It includes the alignment of the Lord Howe Guyots, Lord Howe Basin, and Lord Howe Rise.

2. A New Caledonian zone, in which the trend is northwest-southeast and which includes Fairway Rise (previously unknown structural element), New Caledonia Basin, New Caledonia, Loyalty Basin, and the Loyalty Island Range.

Alignment of the Lord Howe Guyots. These guyots pierce into the Lord Howe Basin and represent an aspect of the volcanism that affected the southwest Pacific. Their age is unknown, but is probably at least middle Tertiary (Conolly, 1969). Several

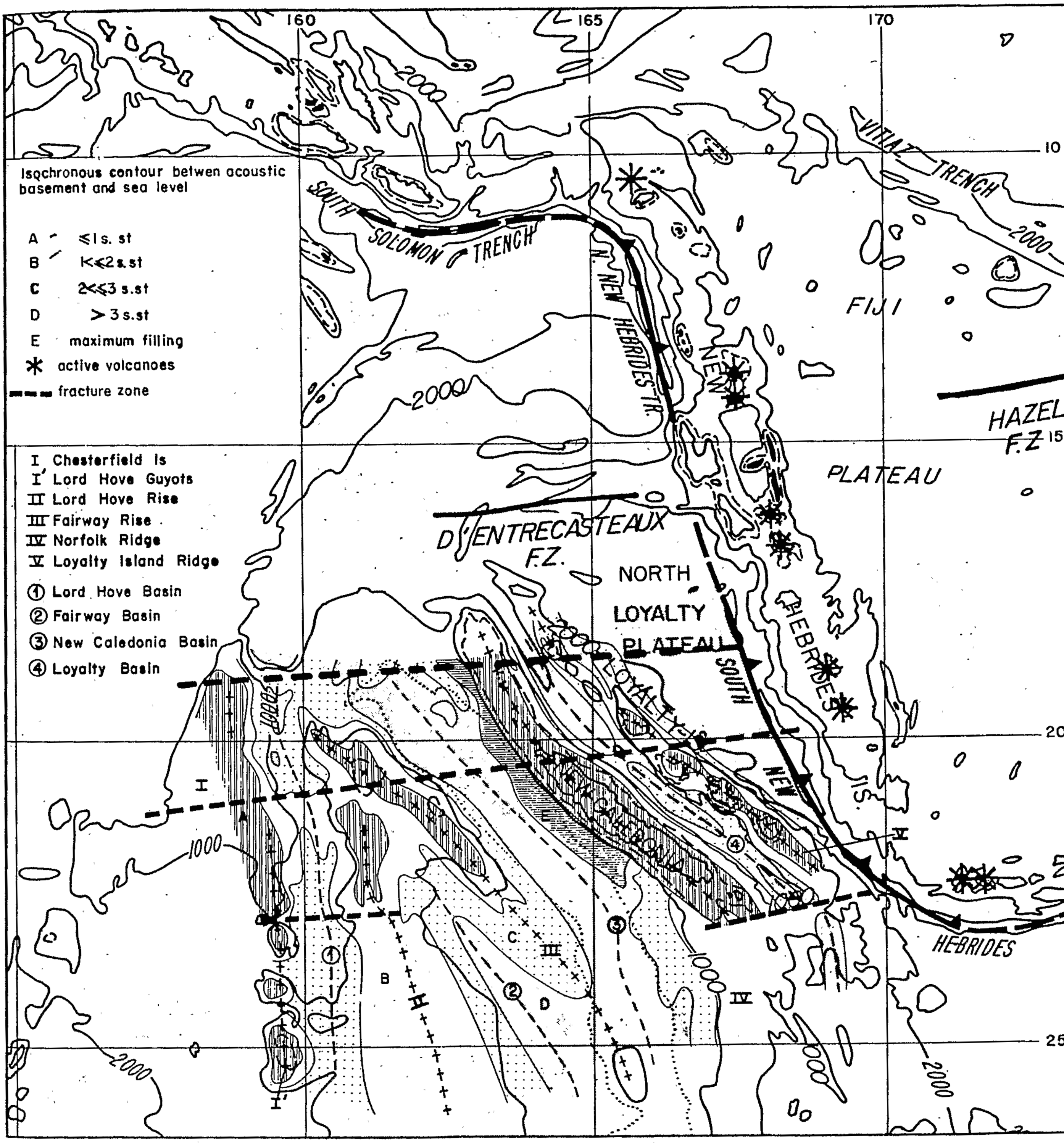

Fig. 7. Structural map of greater New Caledonia region.

authors (Vogt and Connely, 1971; van der Linden, 1969) have tried to explain the genesis of this alignment by the Wilson (1965)-Morgan (1972) theory (northward movement of the Australian plate on top of a fixed hot spot).

Lord Howe and Fairway Rises. The Fairway Rise extends at least from Fairway Reef to 25°S, and our more recent investigations apparently link it to West Norfolk Ridge (Figs. 1, 8, and 10A). The comparable morphological evolution of these two folds is the reason why they are studied together. From south to north they can be seen to shrink and grow progressively more shallow, until they emerge, because of the reefs which succeeded in forming on them. Lord Howe Rise disappears at 21°S against

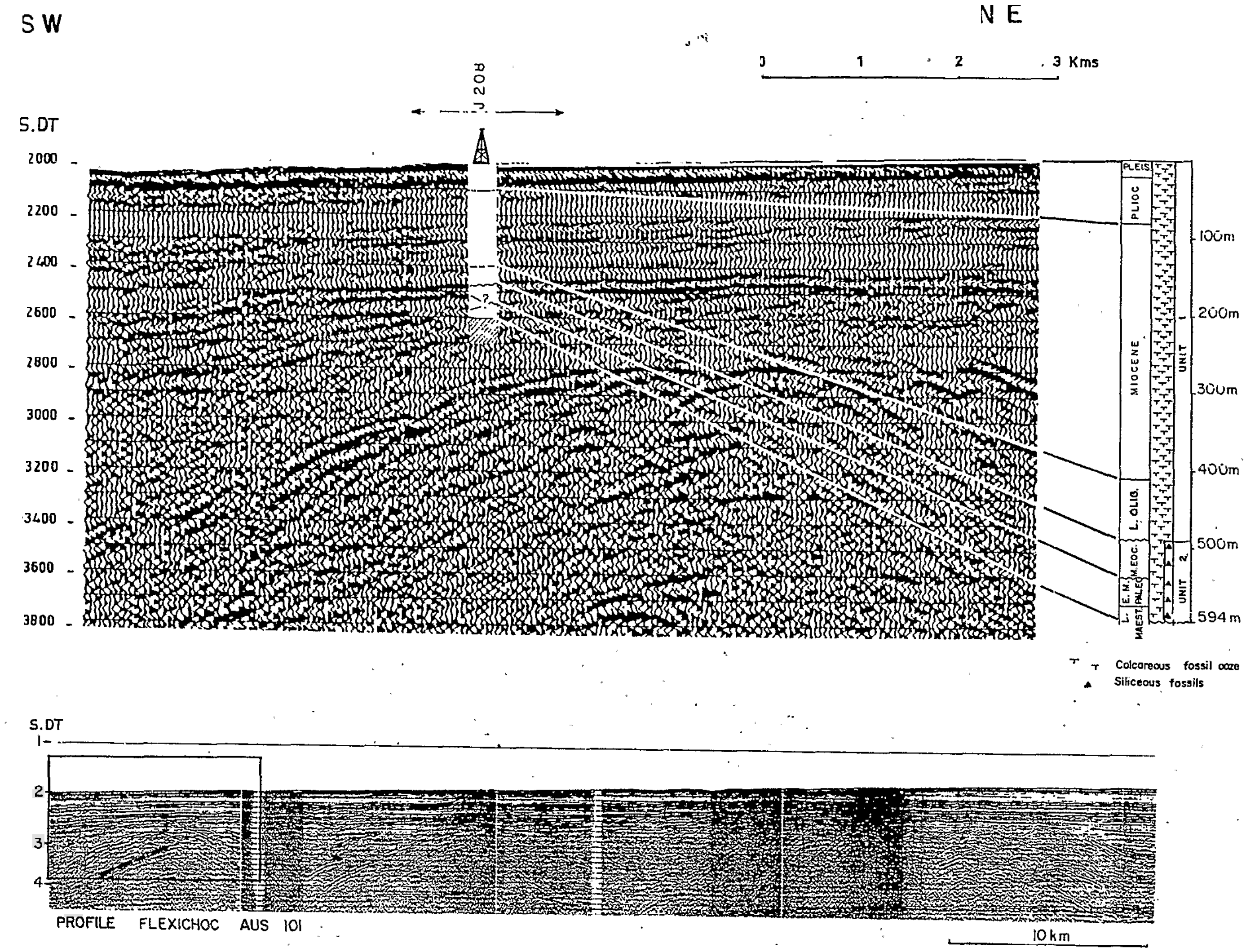

Fig. 8. Location of DSDP site 208 on the profile AUS-101; the relationship between the disconformities observed in the drill hole and in the reflectors of the seismic profiles is apparent.

the Fairway Rise, which extends northward to 20°S. Numerous volcanic outcrops can be seen at the end of Lord Howe Rise just before it disappears. The acoustic basements of these rises are different. The one for Lord Howe Rise is apparently made up of a folded sedimentary series, thus implying that this zone is quite old. Site 208 (DSDP, 1972) stopped in the Late Cretaceous at least 150 m above these folded formations that form a sedimentary substratum (Fig. 10), whereas the basement of Fairway Rise may possibly be a nonsedimentary substratum whose age and nature is unknown.

Seismic velocity obtained on Lord Howe Rise near site 208 by sonobuoy above the strong deepest reflector is 3 km/sec (Andrews et al., 1973), which is in good agreement with a substratum of sedimentary nature. Their sedimentary covering is not very thick but may be as much as 3 km in the small basins cutting into the rises (Fig. 8). Different tectonic episodes are revealed by vertical movements of the rises (unconformities observed in the sedimentary series) and by volcanism.

Basins. The fact that the boundaries of the bathymetric and sedimentary basins are the same is the result of fault movements on the boundaries of the sedimentary basin, causing a slope break in the bathymetry. There are four sedimentary series at the most, separated by major unconformities (Fig. 11A). Lord Howe and Fairway basins, which show that the lower series are well developed, are thus older than New Caledonia Basin, in which only the upper series (Series I) is well developed, if not the only one there. The New Caledonia Basin seems to have been filled in by debris from the erosion of the island, as shown by the maximum sediment thickness observed in the subsident trough along the west coast of New Caledonia. The deposits there are probably of the turbidite type, whereas west of Fairway Rise the data from JOIDES site 208 indicate the presence of pelagic deposits (chalk with nannofossils: van der Lingen et al., 1973), which apparently are widespread, as shown by the uniform seismic character of this series observed on the profiles in this area.

Age of the Sediments. JOIDES site 208 (Fig. 8) revealed two sedimentary gaps (DSDP, 1972; Webb, 1973). The upper is in the Oligocene, which appears to be worldwide and here extends to the late Eocene, and coincides with the major tectonic movements that affected New Caledonia. It corresponds to the bottom of "Series I." "Series II" is probably middle Eocene, while the second gap covers the middle and late Paleocene and the early Eocene. "Series III" is made up of Mesozoic; the DSDP hole stopped at the Late Cretaceous. There are older and relatively undeformed sediments, as well as orderly horizons, underneath the deepest mapable unconformity.

Norfolk Ridge

Several narrow and relatively calm sedimentary basins are visible (Fig. 1), but the successive tectonic phases and the volcanic episodes either deform the sediments or mask them and prevent any orderly seismic reflections. The numerous deformations affecting the sedimentary basins show that these latter are not entirely post-tectonic. They may have begun earlier in the Cretaceous, but apart from several horizons the visible levels are more probably post-Eocene (Fig. 11C).

A major subhorizontal erosional unconformity, covered with slightly undulated sediments, is attached to the Oligocene unconformity. This unconformity, at 24°S, is already at a depth of more than 1,000 m, thus implying that major vertical readjustments took place in the ridge. These vertical movements of the ridge are known on land since fragments of the Miocene peneplain (Davis, 1925) appear at an altitude of 1,000 m in the middle of New Caledonia. It is possible that the erosion unconformity seen in Norfolk Ridge may be connected with the Miocene peneplain since other fragments of the peneplain are found at an altitude of no more than 300 m on the edges of the island; hence the unconformity descends toward the edges.

The Oligocene age of the marine unconformity on Lord Howe Rise does not act as a boundary for the entire area of Lord Howe and Fairway rises. This unconformity disappears in New Caledonia Basin. On Norfolk Ridge it corresponds to the same event, and the angular unconformity between "Series I and II" is horizontal and continuous, implying that the unconformity there corresponds to an erosion phase later than the major Oligocene tectonic episode and that an identical phenomenon occurred at the same time on the Lord Howe Rise. It is possible that beneath this unconformity there may be all the formations known in New Caledonia, perhaps even with marine Cretaceous. Hence Neogene tectonics apparently operated by blocks, causing a rise of New Caledonia and a collapse of its edges. Profiles north of New Caledonia, in the "Grand Passage," reveal the existence of a central basin framed by two lateral ranges.

Loyalty Island Region

This region is bounded in the west by New Caledonia, in the north by the d'Entrecasteaux fracture zone, and in the east by the beginning of the New Hebrides trench (Fig. 9C, D). From west to east there are (Fig. 1) the Loyalty Basin, Loyalty Island Ridge, and North Loyalty Plateau.

Loyalty Basin. The sediments attain maximum thickness between New Caledonia and the Loyalty Islands. Rises of the basement divide the basin into several parts in the south. In the north, opposite Cook Reef, the shallow sedimentary fill reveals various secondary structures that trend north-northwest. From southwest to northeast we find the following (Figs. 11B, 11C): a graben disturbing the slope down to New Caledonia toward Loyalty Basin; a horst dividing the basin; a rise of the Loyalty Island Ridge via faults; and a large flexure fault that runs along the entire Loyalty Island Range.

The very thick sedimentary fill attains 6 km between the emerged land areas, thus showing that the fill comes partly from erosion of New Caledonia and partly from the Loyalty Island volcanoes. The upper series is particularly well represented. How-

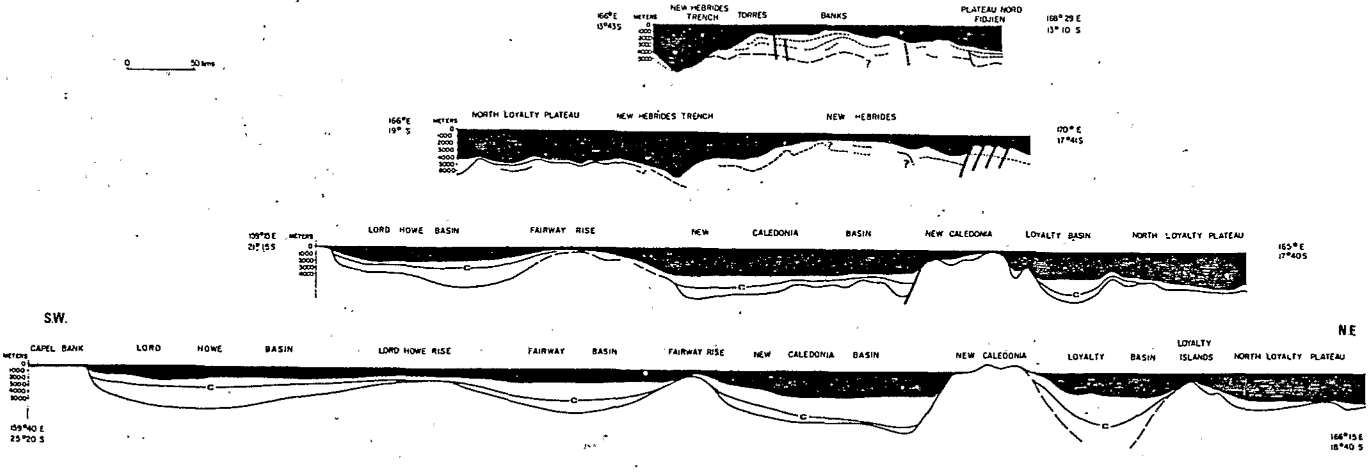

Fig. 9. Cross sections across New Hebrides Island arc and New Caledonia.

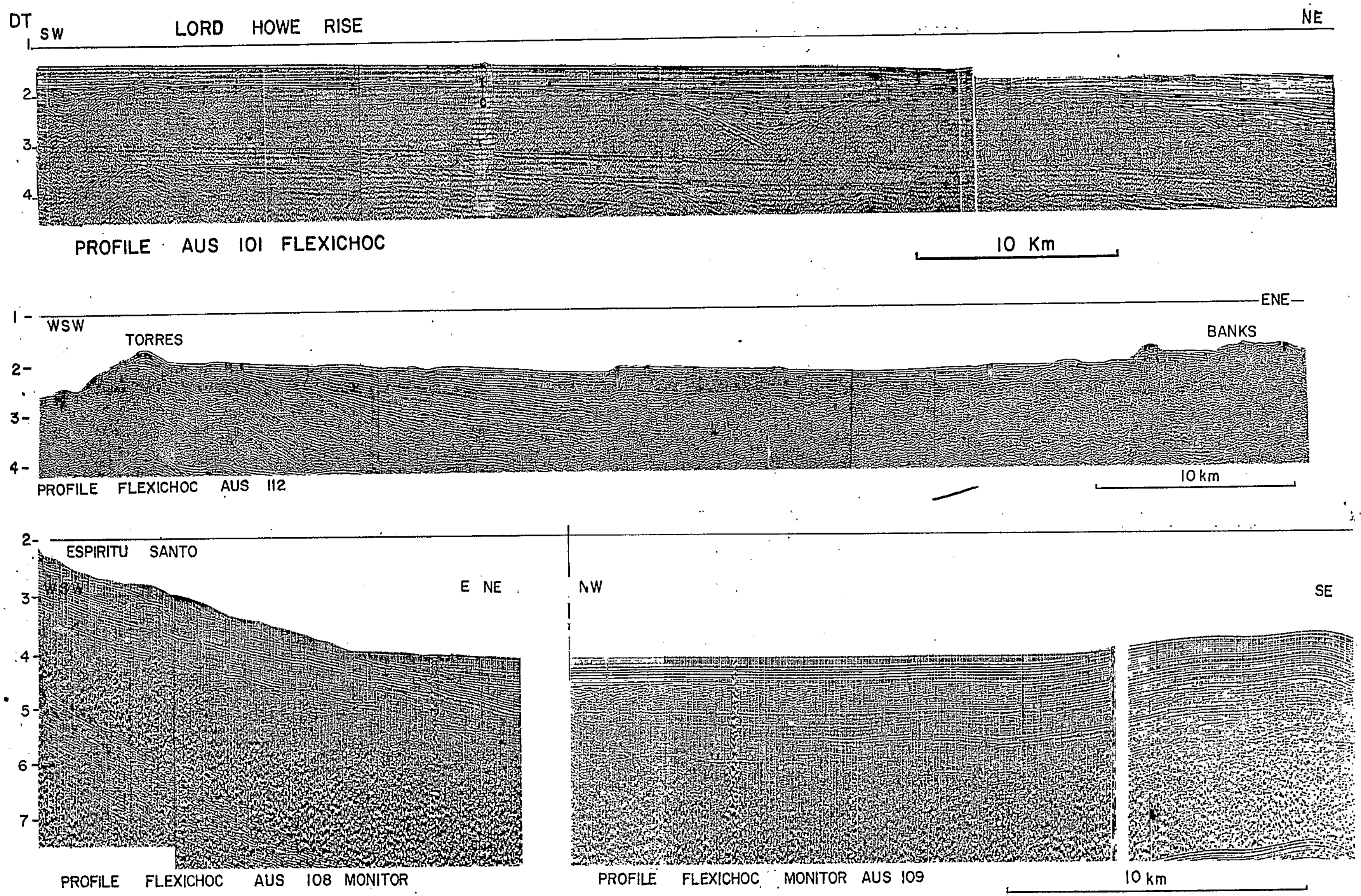

Fig. 10. Seismic-reflection profiles of (a) western New Caledonia area: Lord Howe Rise; (b) New Hebrides area, and between southern Torres and Banks islands; (c) between Espiritu Santo and Aurora.

ever, underneath the eastward prolongation of the erosion unconformity outlined on Norfolk Ridge, which quickly disappears, a thick series can still be seen, followed by a new and deeper unconformity.

Loyalty Island Ridge. Profiles in the submerged parts of this range show that it is divided by a central graben. The sedimentary covering is very thin here, except in the graben. In addition to volcanic elements, it probably contains calcareous elements coming from reefs.

North Loyalty Plateau. This plateau joins the Loyalty Island Range at the New Hebrides trench via a succession of faulted blocks having an opposite inclination from the general slope (Fig. 9B). The very thin sedimentary covering (maximum of 2 km) on this plateau appears to be recent. JOIDES site 286 on Leg 30 (DSDP, 1973) reached an intrusive gabbro inside a basalt, overlain by volcano-sedimentary deposits (450 km) of middle to late Eocene age, followed by chalks and muds with late Eocene to Oligocene nannofossils (110 m), in turn overlain by Oligocene red clays and then cinerites. The nature of the sediments shows that this area was already deep in the Oligocene (underneath the carbonate compensation zone). This plateau has an oceanic appearance because the substratum under the shallow sediments is highly diffracting and has a high velocity (5.5 km/sec).

Interpretation of the New Caledonian Zone

In the Southwest Pacific, the active island arcs highlight the convergence zone of the Australian and Pacific plates. The distinction between the north-south "Australian" structural directions and the northwest-southeast "New Caledonian" ones helps to bring out the individuality of the New Caledonian area. The island arc nature of this zone is supported by the thrust structure and overthrusting of the peridotites in New Caledonia (Guillon, 1973), the Loyalty Island volcanic arc, and the geographic arrangement of the different structural elements. Referring to the present concepts on island arcs (Karig, 1971, 1972; Uyeda, 1972), and even though the arc has probably been active previously, the following succession can be reconstructed at the end of the Paleogene (late Eocene, Oligocene).

New Caledonia apparently made up the external, nonvolcanic arc (supposed by Geze in 1963). The Loyalty Basin was the interdeep basin (more or less developed in the arc-trench gap; Dickinson, 1973); the Loyalty Island Ridge was the volcanic inner arc (Geze, 1963), and the North Loyalty Island Plateau was the interarc or marginal basin. This pattern assumes the existence of a subduction zone at that time, at the latitude of New Caledonia. The emplacement of peridotites complicates this pattern (obduction). The trench was probably located between the western edge of New Caledonia and the Loyalty Basin, and more certainly at the site of the subsequent trench along the west coast of the island. The polarity of the structural features implies that the Australian plate plunged underneath the Pacific plate at that time. Fairway Rise might be a vestige of the swell or outer arch that often seems to precede the trenches. The major disturbances roughly trending east-west (Fig. 7) that cut across and offset the structures also appear to be linked to the island arc history. The vertical movements later than this phase are probably readjustments. It should be mentioned that a system of ridges existed at the beginning of the Cretaceous at the site where New Caledonia is located.

Seismic data have shown that the substratum of Lord Howe Rise is made up of ancient sedimentary formations: the disappearance of the Lord Howe Rise in the north, in front of Fairway Rise, which cuts across it, is a result of the more recent island arc history of New Caledonia. Distribution of the Neogene sediments around New Caledonia is controlled by the structures formed when this island arc was active. Hence the erosion of New Caledonia is responsible for the fill in New Caledonia Basin and for part of the fill in Loyalty Basin, with the other part being provided by the volcano-clastic deposits from the Loyalty Islands. The "old series" appear clearly only in the "Australian" zone (Lord Howe Basin, Lord Howe Rise), which was not touched by this tectonic episode. The lower part of these series is older than the Late Maestrichtian. The erosional discordance revealed on Lord Howe Rise and Norfolk Ridge, separating the "upper series (I)" from the lower ones, and dated in the Oligocene by DSDP site 208, should apparently be attached to the New Caledonia Miocene peneplain.

New Hebrides. The seismic-reflection profiles (see Figs. 1, 9a, 9b, 10b, and 10c) reveal that the sediments on the arc itself are quite thick (more than 2 sec D.D.T.), especially in the collapsed basins between the two lateral ranges. In connection with what is known on land, these are thought to be volcano-sedimentary formations with interstratified calcareous series coming from the reefs on top of the rises. The layers observed are subhorizontal, but blocks with a different seismic nature succeed one another laterally (Fig. 10b). As at Malekula (Mitchell, 1970), major faults apparently bring different layers in contact with one another. These faults were again active recently as shown by offsets visible in the bathymetry. Few reflections are visible on the western flank of the arc, except in the small basin located at mid-slope (see Bentz, this volume).

One of the problems raised by the plate tectonics theory is that of interarc basins, as defined by Karig (1970). Studies of the Tonga, Kermadec, and New Hebrides arcs has led Dubois et al. (1972) to consider the grabens in the southern New Hebrides (studied during the Coriolis cruises in 1968; Puech and Reichenfeld, 1969) as en échelon grabens that can be assimilated with interarc basins. The Kimbla and Coriolis cruises (1971), especially the

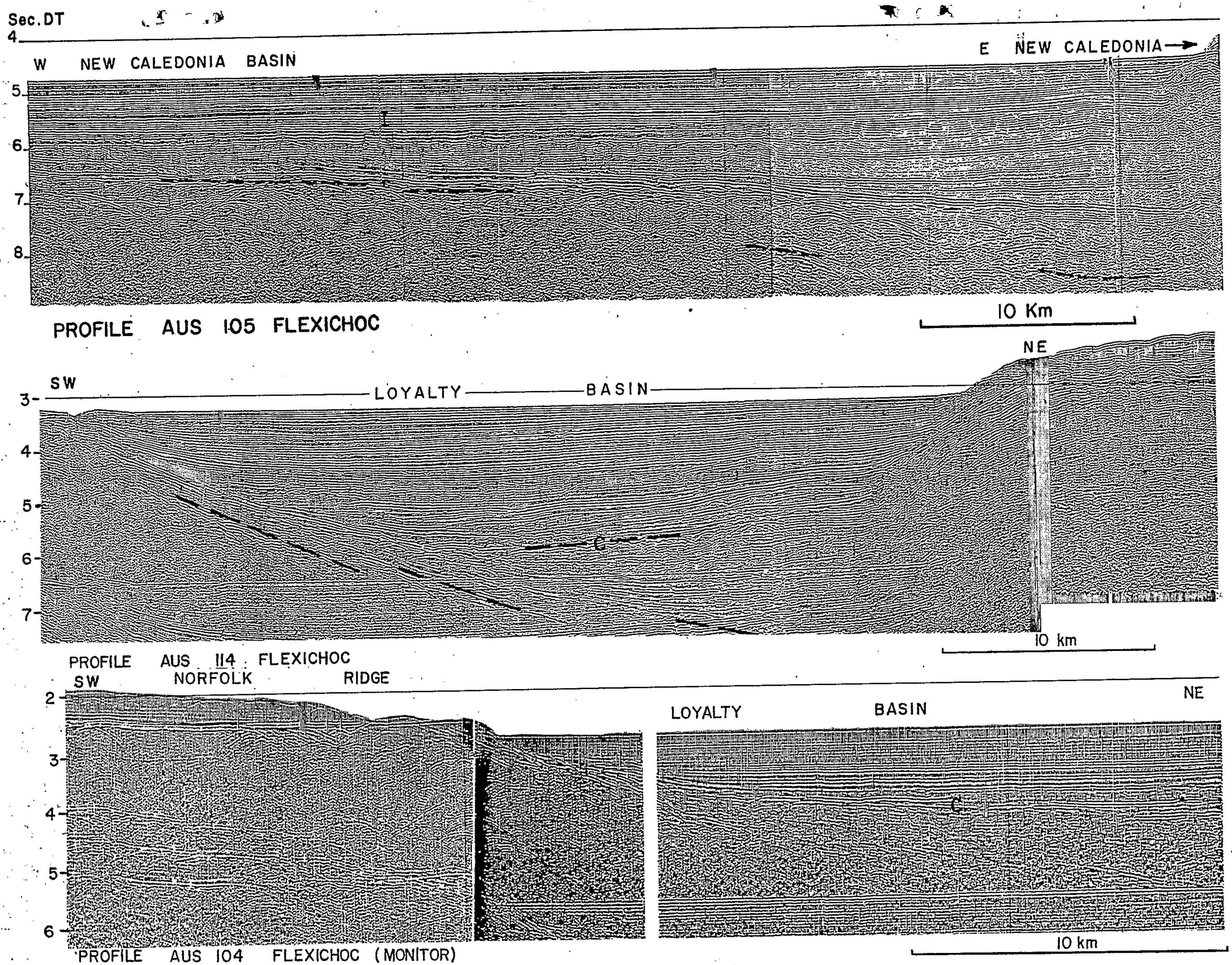

Fig. 11. Seismic-reflection profiles of (a) western New Caledonia area (axis of maximum filling); (b) Loyalty Islands area, and Loyalty Basin in its central part; (c) Norfolk Ridge extending to southern New Caledonia.

first Austradec cruise, enabled two sorts of collapse basins to be distinguished in this region: the narrow grabens in the south are certainly quite recent and are poor in sediments; the much wider basins north and south of Aoba contain thick, old sediments. We feel that these collapse basins, of which both kinds could be caused by a slight opening up, are not comparable to the Tonga and Kermadec interarc basins, but that they possibly represent recent secondary disturbances or grabens as often described inside volcanic arcs. Indeed, we have already seen that an analysis of seismic-wave propagations and attenuations appears to show that the opening up, in the concave part of the New Hebrides, should be sought for in the North Fiji Plateau, which probably played the same role as the Lau interarc basin for Tonga-Kermadec.

CONCLUSION

The deep structure and distribution of sediments in the New Caledonia-New Hebrides region can be explained within the context of fossil or active island arcs. But on the contrary, the Lord Howe Rise belongs to an older domain, and its origin is still unexplained.

Following this interpretation, the same tectonic characteristics of an arc-trench system seem to exist in both the New Caledonia and New Hebrides systems, but with a different development of the arc-trench, i.e., the distance between outer nonvolcanic arc and inner volcanic arc. In the New Hebrides the gap is very small and these two tectonic components are close together, with no interdeep basin well developed; here the outer nonvolcanic arc is similar to the mid-slope basement high described by Karig (1971). On the contrary, in the New Caledonia system the arc-trench gap is very large, with a very well developed interdeep basin (ref. APEA). Following Dickinson (1973), this could be related to the different age of these two island-arc systems. Indeed, the New Hebrides island arc seems to be of early Miocene age, while the New Caledonia island arc could be as old as Late Jurassic-Early Cretaceous. Using Dickinson's relation between age and arc-trench gap, we obtain for the beginning of New Caledonia island-arc activity an age of 125 my, which is in good agreement with land geology.

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