The troughs at the rear of the New Hebrides island arc: Possible mechanisms of formation[1]

JACQUES DUBOIS, FRANÇOIS DUGAS, ANDRÉ LAPOUILLE AND RÉMY LOUAT
Office de la Recherche Scientifique et Technique Outre-Mer, B.P. A5, Cedex-Noumea, Nouvelle-Calédonie

Received July 5, 1977
Revision accepted October 7, 1977

A geomorphological description of the tectonic troughs behind the volcanic arc is provided from data gathered in the New Hebrides island arc. From bathymetry and seismic reflection profiles, a representative plan of these troughs is made. From front to rear, the arc sequence is generally a small depression, followed by a wide, deep depression with a narrow ridge along either side. Stratigraphy and tectonics clearly show that the troughs were induced by crustal stretching; sedimentary formations observed are thought to be Plio-Quaternary. Magnetic anomalies on several profiles, and some gravimetric data, show information on the deep structure and genesis of the troughs. We conclude from the data that these recently faulted basins are symmetrical about the longitudinal axis where rising magma is causing uplift.

Three possible mechanisms are suggested for the formation of the troughs. The most likely is that transcurrent faults occurred in the curved parts of the arcs, after which convection cells appeared in the asthenosphere above the Benioff zone. The rising columns of the convecting cells caused tensional tectonic movement beneath the troughs along pre-existing fault lines. Ascending material then formed intrusions, creating magnetic anomalies.

Les données obtenues dans l'arc insulaire des Nouvelles-Hébrides fournissent une description géomorphologique des fosses tectoniques en arrière d'un arc volcanique. A partir de la bathymétrie et des profils de sismique-réflexion, on présente un plan représentatif de ces fosses. De l'arrière à l'avant, la séquence d'arc insulaire consiste généralement en une petite dépression, suivie d'une dépression plus large et profonde avec une crête étroite de part et d'autre. La stratigraphie et la tectonique montrent clairement que ces fosses se sont formées par extension de la croûte; on croit que les formations sédimentaires de la région datent du Plio-Quaternaire. Les anomalies magnétiques sur plusieurs profils et quelques données gravimétriques ajoutent de l'information sur la structure profonde et la genèse de ces fosses. Nous concluons de ces données que ces bassins récemment faillés sont symétriques par rapport à l'axe longitudinal où la montée du magma cause en soulèvement.

On suggère trois mécanismes pour la formation de ces fosses. L'hypothèse la plus probable est que des failles transversales se sont produites dans les parties courbées des arcs et qu'ensuite des cellules de convection sont apparues dans l'asthénosphère au-dessus de la zone de Benioff. Les colonnes montantes des cellules de convection provoquent des mouvements tectoniques de tension sous les fosses le long de lignes de faille préexistantes. Le matériel ascendant a ainsi formé des intrusions qui créent des anomalies magnétiques.

[Traduit par le journal]

Can. J. Earth Sci., **15**, 351–360 (1978)

Introduction

In the southwest Pacific, the New Hebrides island arc is a 1400 km long structural complex curving towards the Solomon Islands in the north, and towards the Fijian islands in the south. Two large structures stretching east–west, the d'Entrecasteaux fracture zone on the Australian plate and the Hazel–Holme fracture zone on the Pacific plate, reach the central part of the arc at a point where large islands occur but no trench is found. At the trench axis the initial dip of the sinking plate is quite small; below a depth of 60 km the dip is much larger, about 70°. The direction of dipping is east-northeast and appears continuous, in large scale, from north to south except in the area of the central large islands (Pascal 1974). The volcanic line is delineated by active volcanoes that parallel the trench line. Along the arc east of the trench and the volcanic line but parallel to it, narrow troughs are observed, especially in the northern and southern parts. The troughs are patterned on Fig. 1.

Terminology for geological and geophysical features of insular arcs has been defined at the International Congress on Geosynclinal Sedimentation (Dickinson 1973) and by Karig and Sharman (1975). From trench to arc the following generalized sequence occurs: an accretionary prism with an inner-wall trench-slope break and an upper slope discontinuity, a frontal arc, a volcanic line and, at the rear, an active marginal basin, a remnant arc

---

[1]Paper presented at 13th Pacific Science Congress, Vancouver, British Columbia, Canada, August 1975, in a symposium organized by Working Group 1 (Western Pacific) of the Interunion Commission on Geodynamics. Publication coordinated by D. L. Tiffin and R. L. Chase.

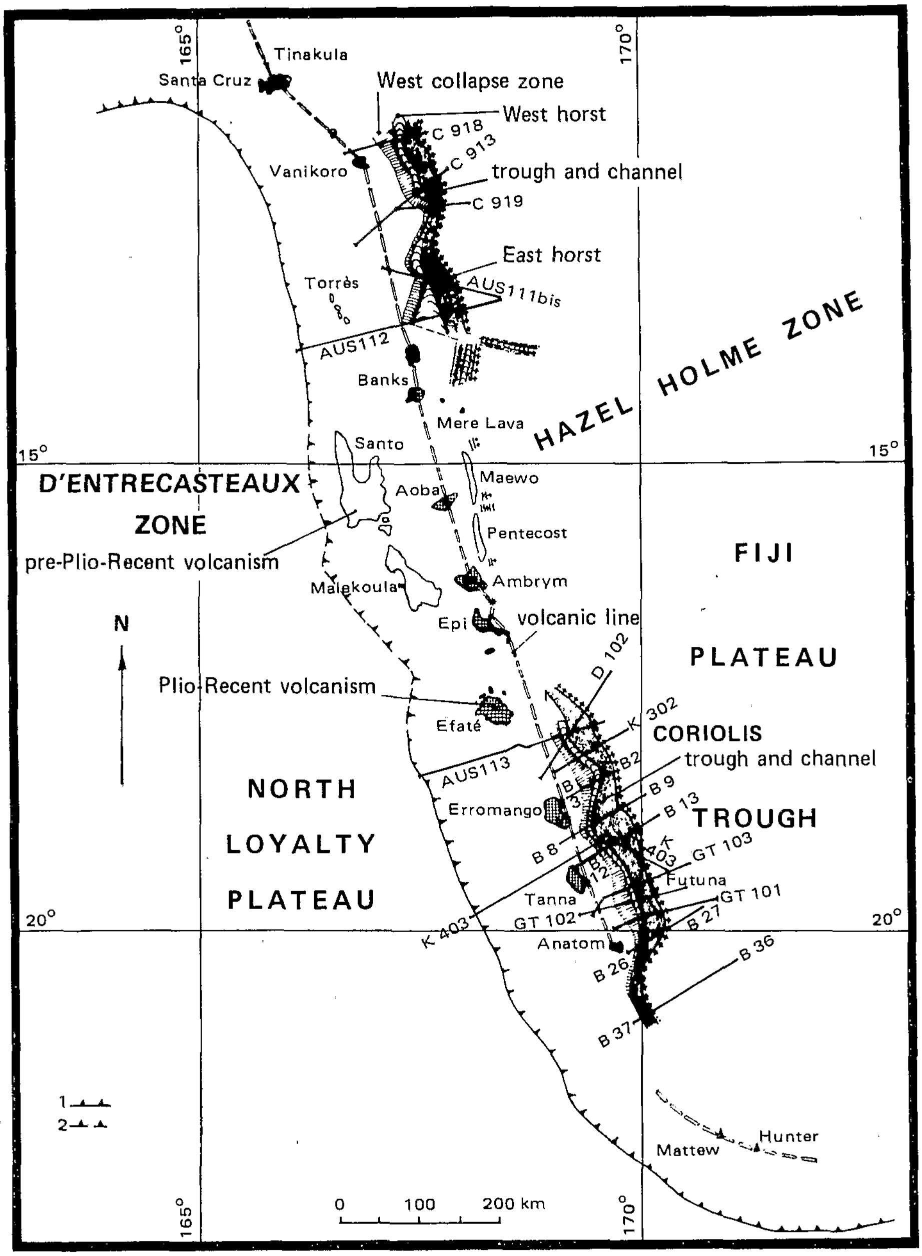

FIG. 1. Location of the troughs of the New Hebrides island arc, and positions of illustrated profiles over it. (1) outline of lithospheric dip where trench is present; (2) outline of lithospheric dip where trench is absent; (3) trench axis.

and an inactive marginal basin. Dickinson (1973) and Karig and Sharman (1975) have shown that these structures vary in time with a relationship between the trench – volcanic line distance and the age of subduction. In time an arc is widened by sedimentary accumulation (the accretionary prism) in front of the arc whereby the trench and the volcanic line appear to separate at a rate of about 1 km/Ma (Dickinson 1973).

The frontal structures of the New Hebrides arc with an accretionary prism and frontal arc with basin, illustrate this terminology, however, the structures situated at the rear of the volcanic line are more complex. Here a down-faulted trough between two horst-like rises is seen; the east horst that bounds the arc with the Fiji Plateau (Fig. 3) is Karig's third arc or remnant arc (Karig 1972; Karig and Mammerickx 1972).

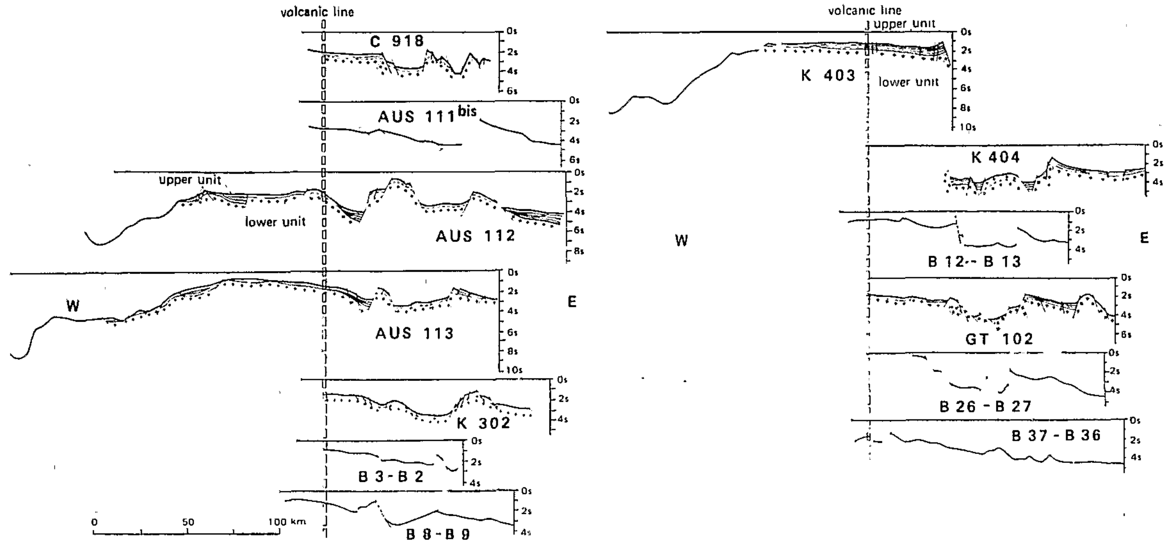

FIG. 2. Bathymetric and interpreted seismic reflection profiles showing cross sections of the trough along its length. Locations are given on Fig. 1.

We consider that the narrowness of the New Hebrides arc, less than 200 km wide, indicates that this arc is very young (10 Ma according to Dickinson (1973) or 3 Ma in the south according to Karig and Sharman (1975)). The trench – volcanic line distance of 125 km is one of the shortest known.

The New Hebrides troughs, after their discovery by de Chalvron *et al.* (1967) and Puech and Reichenfeld (1969), have been described as "en échelon inter-arc basins" or "extensional troughs" by Karig and Mammerickx (1972). These last authors have postulated as "inter-arc basins" the northern and southern troughs behind the frontal arc and the basins between the large islands in the central part. Later, Mallick (1973) postulated as "inter-arc basins" the large basins in the central part, keeping the term "intra-arc basins" for the troughs. Luyendyk *et al.* (1974) confirmed this differentiation, implying the possible existence (although they could not prove it) of new crust in the troughs, but not in the large central basins of the islands.

Detailed surveys (Puech and Reichenfeld 1969; and recent Office de la Recherche Scientifique et Technique Outre-Mer (ORSTOM) cruises) at about 15 km spacing in the southern part of the arc show that these troughs, at the rear of the arc, are continuous except in the central part of the arc. The distance from the trench to the west part of the trough is unvarying at about 170 km except at the extremities of the arc.

We have studied the character of the troughs to the rear of both the southern and northern parts of the arc from morphological and magnetic data, seismic-reflection profiles and seismicity. From this we postulate possible mechanisms of formation.

Physiography of Intra-arc Troughs

Position

These troughs are well developed at the rear of the arc in two 300 km long collapsed zones in the north and south with a 400 km long gap in between. As yet, we do not know precisely their north and south ends.

The distance between the volcanic line and the west part of the trough varies from 35 to 55 km (Fig. 1). The variations in trend of the axes of the troughs led Karig and Mammerickx (1972) and the authors of the Scripps Institution of Oceanography map to consider them "en échelon". However, having studied the previously mentioned detailed surveys, we believe that they are roughly parallel to the volcanic line and to the trench, but sinuous and distorted by transverse faulting. Only the deepest axis is seen laterally shifted.

Morphology

The troughs (Figs. 2, 5) are narrow complex valleys corresponding to the active marginal basin and the remnant arc of Karig and Sharman's (1975) model. We note from west to east (Fig. 3): (1) a collapsed section with down-faulted blocks. These are 20–45 km wide by 1.5–2.2 km, occasionally 3 km deep; (2) a narrow west horst 2–10 km wide with a top 0.8–1.5 km deep; (3) a trough with a channel 35 km wide and 2.5–3.3 km deep; and (4) a

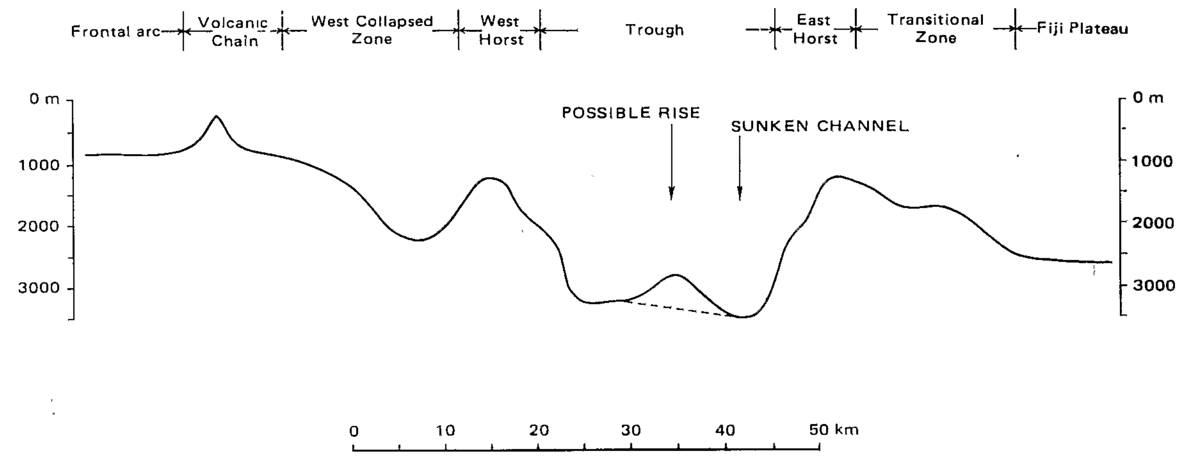

FIG. 3. Typical morphological cross section of the New Hebrides troughs.

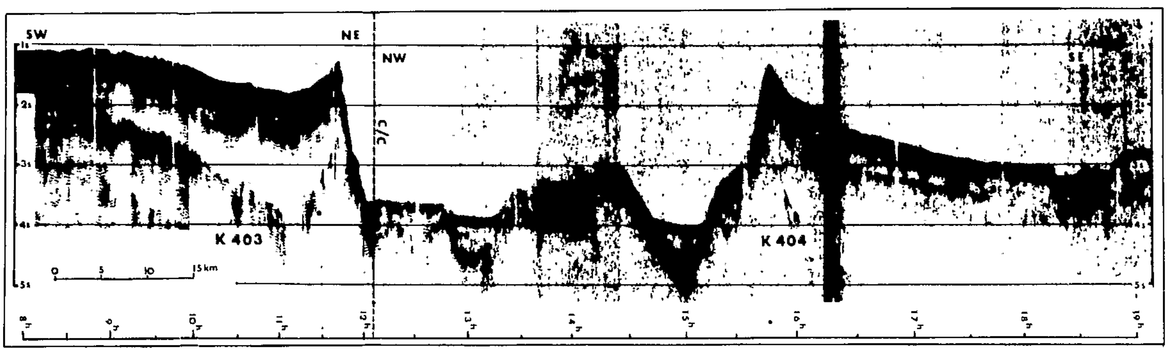

FIG. 4. Photograph of a seismic reflection profile across the trough (K 403 and K 404 profiles).

narrow horst at the east bounds the trough, which is 0–1.5 km deep, emergent at Futuna island (Fig. 1).

These features are seen on most profiles but the western horst is sometimes not present. Variations in the collapsed zone are observed (Fig. 2): it is narrower on B3–B2 profiles because of a change in direction, and larger on B8–B9 profiles because of a valley that has been opened by inferred east–west sinistral strike-slip faulting. The western horst is most pronounced in the northern part (AUS 112, C 913, C 918) and to the east of Erromango (AUS 113, K 302, B3–B2, B8–B9). The slopes of the valley are about 24° and near its axis we see a peak on a few profiles (B26–B27).

Figure 3 is a typical composite profile proposed for the complex zone at the rear of the volcanic line.

Geological Aspects

Stratigraphy

On seismic reflection profiles two units are seen (Fig. 2). A superficial upper one is usually thin except in collapsed structures where it may be up to 1 s thick (two-way travel time). The upper unit shows regular strata nearly undeformed except in the trough, easy to penetrate and resting unconformably on the next unit. These sediments are accumulated in hollows, collapses and troughs. We also observe that in the trough (Fig. 4) the layers are deformed. The second unit is hard to penetrate and we do not know its thickness. It seems to be the upper part of a volcanic basement.

A dredge haul on the east slope of the valley near Futuna island (Geotransit) recovered black muds, medium to fine volcanoclastics and semi-consolidated tuffs with foraminifera, and manganese and ferruginous crusting.

Tectonics

The principal tectonic features of the troughs are tensional block faulting and lack of high amplitude warping. We recognise two types of faulting: vertical and transverse to the arc. The vertical faulting is most important, lifting horsts and troughs. The west and east horsts or rises, and the volcanic nature of Aniwa and Futuna islands (Williams and Warden 1964) suggest these may be extrusion dykes. Transverse faulting is implied at changes in trend of the trough. Offsets can reach 35 km as

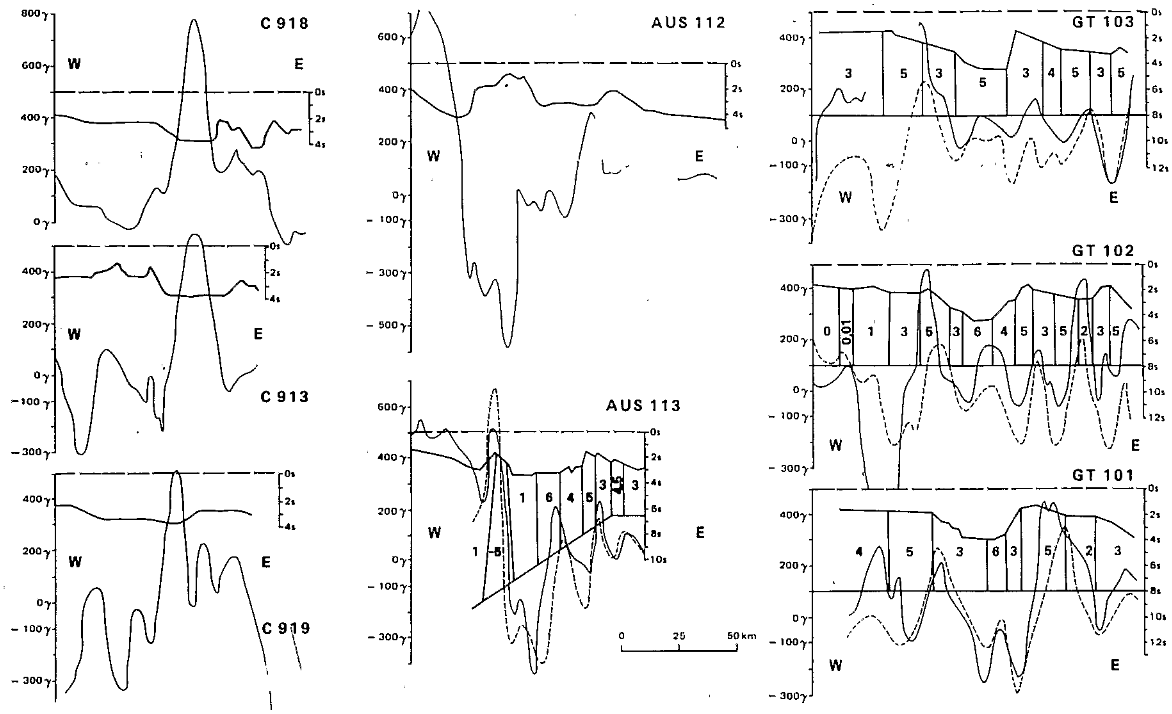

FIG. 5. Bathymetric and magnetic profiles of the troughs located on Fig. 1. Models of magnetic susceptibility (in 10^{-3} nH) on several profiles with calculated (dashed line) and observed (solid line) values.

between Erromango and Tanna islands, where seismicity is associated with the movement (see Seismicity).

Magnetic Study of the Troughs

The magnetic data are from cruises of ORSTOM, ORSTOM – University of New South Wales, Austradec and Woods Hole Oceanographic Institution. An International Geomagnetic Reference Field (Fabiano and Peddie 1969) was subtracted from total field measurements to derive magnetic anomalies.

The magnetic field in this area (Fig. 5) is characterized by short wavelength (about 20 km) and high amplitude (500 γ, occasionally 2 000 γ) anomalies indicating shallow causative bodies.

An important feature of the magnetics is the existence on several profiles (Fig. 5) of a positive anomaly in the center of the trough between two other positive anomalies over the horsts bounding the trough. This magnetic pattern is symmetrical on each side and is illustrated in Fig. 6. It is easy to correlate the magnetic anomalies of the edges of the trough with horsts but the central anomaly is less easily correlated with a morphological feature.

The magnetic anomalies in the troughs are not the same in amplitude along the arc. The central positive anomaly is highest in the north (700 γ east of Vanikoro), important in the central islands (400 γ east of Banks and 500 γ east of Efaté) and small in the south (200 γ in the Coriolis trough).

In the New Hebrides area, as in any oceanic region, only thermo-remanent magnetization is important since it is up to 100 times higher than the induced magnetization (Fox and Opdyke 1973). We therefore neglect induced magnetization in this paper. We consider magnetic anomalies to be due to thermo-remanent magnetization of crustal oceanic rocks showing the earth's magnetic field at the time of their cooling.

Two dimensional structural block models (Fig. 5) were made and their calculated magnetic field compared to the measured magnetic anomalies. Because the north–south dimension of the troughs is much longer than the east–west one, we calculated models of east–west profiles with several juxtaposed polygons, each characterized by two geometric dimensions and a magnetization. Magnetic susceptibilities used in the models are typical of basic rocks, usual values being 5×10^{-3} nH and 3×10^{-3} nH, but range from 1×10^{-3} to 6×10^{-3} nH. Another block model constructed using alternate positive and negative magnetizations at the scale of earth's magnetic field inversions was a failure. An interpretation from only the bathymetry is not sufficient so we have given a variable mag-

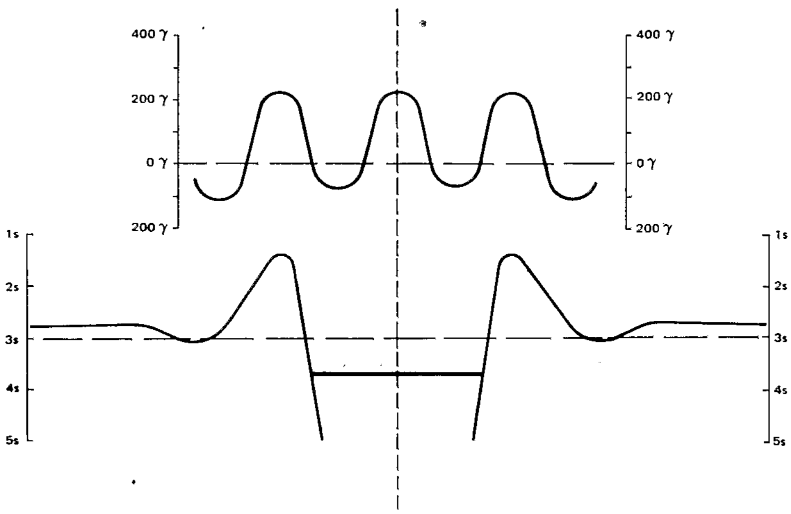

FIG. 6. Model of bathymetry and associated magnetic anomalies of the troughs.

netization (fictitious susceptibility) to different blocks. We chose the sea bottom for the upper surface of our models because of the thin sedimentary cover. For the lower surface, the Curie isotherm is the limit, estimated to be either constant at 5–6 km below sea level or variable with an increasing depth westward in the trough east of Efaté. It is likely that the orientation of the remanent magnetization is either identical to the present field or inverse. As the rocks have not been moved since cooling, and as the geomagnetic field has been roughly a north–south earth dipole, we assume a field identical to the present, although its intensity may have been variable in time, especially near field inversion times.

We suggest that after down faulting made the trough, the lateral horsts were uplifted and the valley was intruded by magma from the upper mantle. The higher amplitude of the northern troughs suggests that troughs are older in the northern part than in the southern part of the arc. Extensional troughs (Karig and Mammerickx 1972) seem to be an initial stage of a 'spreading marginal basin' such as Lau Basin in the Tonga arc system. Karig (1971) estimates the maximum spreading rate to be about 10 cm/year for larger troughs. However, according to Luyendyk *et al.* (1974) the existence of new oceanic crust in troughs is either negative or at best permissive.

Gravity data collected by Mobil Oil Corporation over Coriolis trough show a positive Bouguer anomaly (about 30 mGal) in the center of the trough in phase with the positive magnetic anomaly, while a negative Bouguer anomaly of the same value is in opposite phase with the positive magnetic anomalies on the lateral horsts. This character is found on similar structures such as over the Okhotsk Basin to the rear of the Kuril island arc where a positive amplitude of several dozen milligals is bounded by negative gravity anomalies on the edges of the trough (Kogan 1975).

Seismicity

Figure 7 shows earthquake epicenters from 0 to 50 km deep, located east of the volcanic line. In the southern part of the arc a good correlation exists between seismic activity and tectonic troughs but we do not know whether the hypocenters lie on recognized fault planes because they are poorly resolved. Between Erromango and Tanna, earthquakes are crowded (Fig. 8), crossing the arc from the trench of the Fiji Plateau. Towards Efaté the seismic activity does not correlate as well. In the northern part of the arc correlation is less obvious perhaps because the trough is at present inactive.

Mechanisms

Physiographic, geological, semsmic and magnetic studies show that these tectonic troughs are a feature of an island arc. Karig and Mammerickx (1972) have called them "extensional troughs" implying a mechanism of formation. They suggest that extensional troughs are characteristic of young island arcs in their opening phase, later becoming active marginal basins such as the Lau Basin. We propose three mechanisms to explain the origin of the tectonic troughs. They may be combined.

Secondary Spreading

Karig and Mammerickx (1972) consider that troughs are formed before becoming marginal inter-arc basins. Chase (1971) and Dubois *et al.*

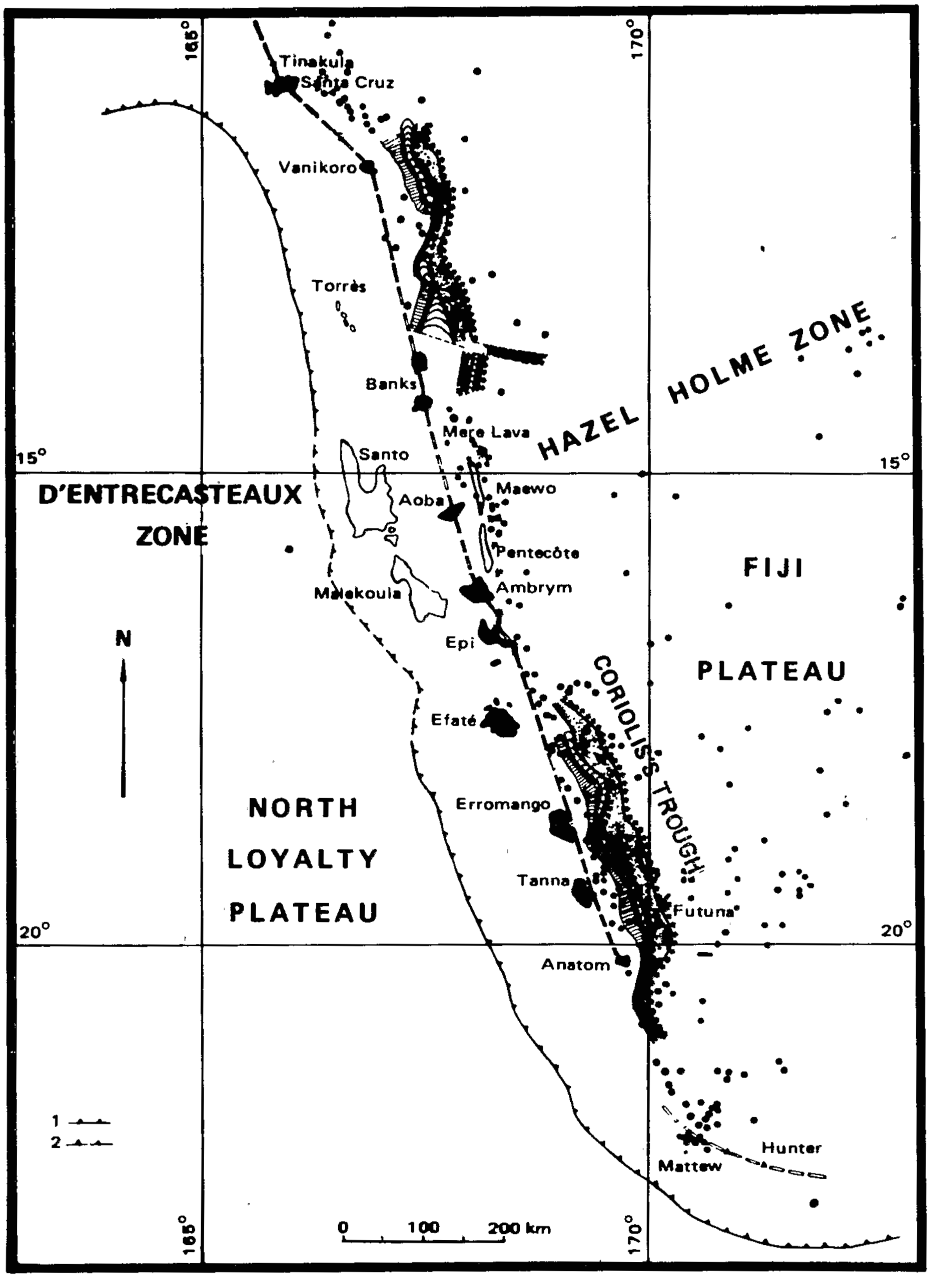

FIG. 7. Superficial seismicity (0–50 km deep) east of the volcanic line (after International Seismological Center Bulletin 1961–1970). Legend as for Fig. 1. Filled circles are epicentres.

(1973) have shown that a secondary expansion zone exists that created north Fiji Plateau in a way similar to the formation of Lau Basin. However, the narrow trough on the west side of this plateau does not seem to have been formed by the same process because magnetic lineations have been recorded from each side of horsts in the center of the trough and from its eastern edge. Besides, the magnetic anomalies associated with the troughs are not compatible with reversals of the earth's magnetic field over the last 10 Ma.

Faults Parallel to the Trench

This mechanism is very close to that proposed by Fitch (1972). In Fitch's theoretical scheme β is the angle of tensional direction with the trench axis

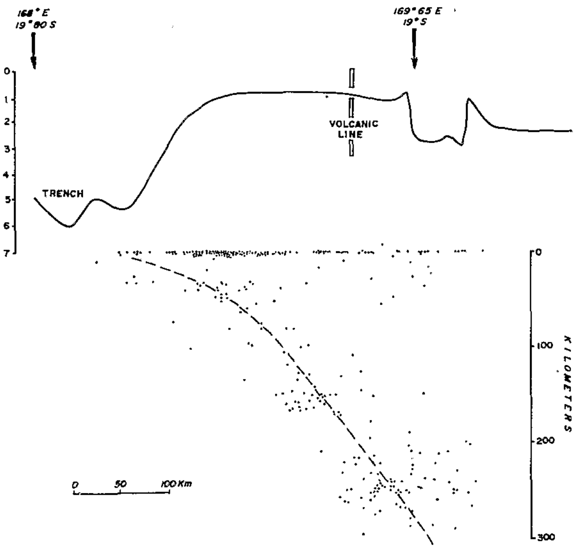

FIG. 8. New Hebrides arc. Bathymetry and seismicity along K 403 profile with projected hypocenters (ISC determinations) from 50 km each side of the profile.

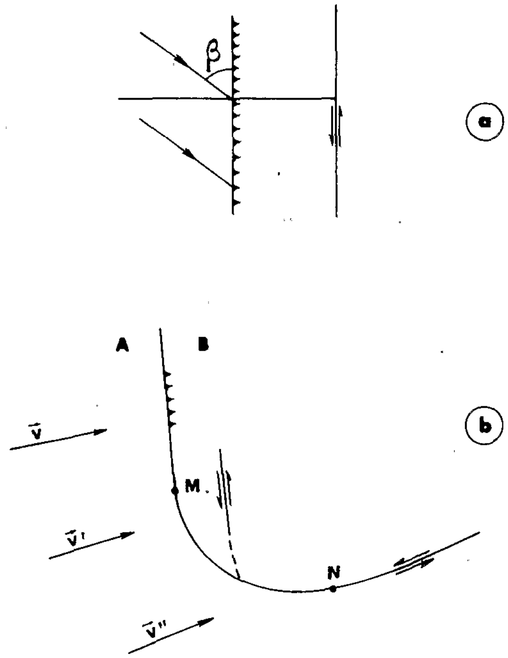

FIG. 9. (a) Creation of transcurrent faults after Fitch (1972) if the direction of relative motion makes an angle β with the strike of the trench. (b) Application to New Hebrides: V, V', V'' are the vectors of relative motion of A to B: dip to the edge of M, sinistral transform fault to the east of N, appearance of a sinistral transcurrent fault between M and N.

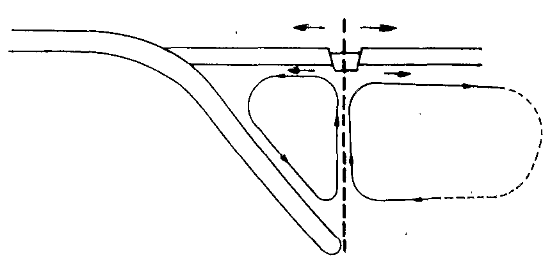

FIG. 10. Proposed theoretical model: convective cells in asthenosphere on Benioff zone, ascending column of hot material vertically from the end of the down-going lithosphere. Possible result: down-faulting of the troughs and intrusions.

between the plates A and B. If β is different from 90°, tension parallel to the trench causes faulting in weak zones of plate B (transcurrent faults). We consider the limit of the two plates A and B (Fig. 9) whose vector directions of relative motion V, V', V'' are centered on a rotational pole situated on 58°S, 179°E (McKenzie and Sclater 1971). Along the arc from northern point M to eastern point N, the plate will dip on an axis perpendicular to the vector V (this is confirmed by focal mechanisms according to Johnson and Molnar (1972)), while a transcurrent motion occurs parallel to V'' east of N.

On the other hand, between M and N the situation is comparable to that described by Fitch (1972). The angle β, between V' and the trench axis on the edge of B, different from 90° creates shear forces increasing towards the south, resulting in transcurrent faults in weak zones of the crust. In the New Hebrides arc these faults should appear at the rear of the volcanic line in the thinner lithosphere (Malahoff 1970).

Some observations support this view, i.e. that troughs are seen only in curved parts of the arc (northern and southern) and are associated with seismicity, although two discrepancies should be noted: there is no evidence of slip along the presumed faults, and channel offsets seem to correspond to perpendicular trend faulting.

Deep Mechanism

The tectonic troughs are positioned directly above the deepest earthquakes, or vertical to the end of the down-going lithosphere (Fig. 10).

High attenuation of seismic waves above the Benioff zone may be characteristic of young arcs. This is only true in the New Hebrides, Mariana and Tonga arc systems, not in the Ryukyu arc (Barazangi and Pennington 1973).

A model of the upper mantle with convective cells in the viscous asthenosphere (Coulomb 1969; Dubois 1969) leads us to propose a mechanism of creation of the troughs. After Sleep (1973), we think that the dipping lithosphere becomes viscous in the asthenosphere in a mixed zone where viscosity is intermediate between lithosphere and asthenosphere. The flux of hot viscous material rises vertically from the end of the dipping lithosphere. A less viscous and less hot material then replaces the former. Once one cell is formed, a second opposite cell is formed immediately (Fig. 10). Tensions appear in the crust above the upward convecting zone creating tectonic troughs. A consequence of this rising up of material is the possibility of dense material intrusions into the crust beneath the troughs. Artemjev and Artyushkov (1971) explain the origin of the Lake Baïkal rift by a similar tensional process.

This model is confirmed by the following: the physiography and geology of the trough imply extensional tectonics, the position of the trough is related to the deepest earthquakes, the trough is missing in the central part of the New Hebrides arc where deep earthquakes are also missing, an intrusion of high density magnetic material explains both the magnetic anomaly in the center of the trough and its associated high gravity anomaly, and there is a high heat flow measured in the troughs (Yasui *et al.* 1968, 1970; Luyendyk *et al.* 1974).

A few observations cannot be explained by this mechanism: the low attenuation of seismic waves in the Ryukyu arc system (Barazangi and Pennington 1973), and the differences in seismic activity between northern and southern troughs in the New Hebrides arc.

Conclusion

As a working hypothesis we suppose that the third mechanism (possibly with the second one as complementary) has created the troughs. In curved parts of the seismic arc and weak zones of the lithosphere transcurrent faults are formed as previously described by Fitch (1972). Then a slow opening and down faulting made the troughs above the end of the dipping lithosphere, which is presumed to have created convective cells. The irregular intrusions of dense material underneath the troughs can explain the high amplitudes of magnetic anomalies.

This mechanism is comparable to the creation of spreading ridges but it is much less important. We agree with Karig's (1971) hypothesis on inter-arc basins but we cannot explain the evolution from troughs to basins such as the Lau Basin in an arc system.

Acknowledgments

We thank B. P. Luyendyk (Woods Hole Oceanographic Institution) and Mobil Oil Corporation for allowing us to see their magnetic and seismic profiles over the area. We also thank D. Karig, B. P. Luyendyk, J. Goguel and J. Coulomb for their review of this paper. The assistance of CNEXO (Centre National pour l'Exploitation des Océans), IFP (Institut Français du Pétrole), SNPA (Société Nationale des Pétroles d'Aquitaine), ELF–ERAP (Société pour la Recherche et l'Exploitation des Hydrocarbures), CFP (Compagnie Française des Pétroles) and of the marine geophysics group at the University of New South Wales is gratefully acknowledged.

ARTEMJEV, M. E., and ARTYUSHKOV, E. V. 1971. Structure and isostasy of the Baïkal Rift and the mechanism of rifting. Journal of Geophysical Research, **76**, pp. 1197–1211.

BARAZANGI, M., and PENNINGTON, W. 1973. Global study of seismic wave attenuation behind Island Arcs and above inclined seismic zones using P and pP waves. EOS, Transactions of the American Geophysical Union, **54**, p. 364.

CHALVRON M. DE, DUBOIS, J., MERLE, J., PUECH, J. L., and REICHENFELD, C. 1967. Croisière bathymétrique aux Nouvelles Hébrides à bord du Coriolis. Office de la Recherche Scientifique et Technique Outre-Mer, Nouméa, Nouvelle-Calédonie.

CHASE, C. 1971. Tectonic history of the Fiji Plateau. Geological Society of America Bulletin, **82**, pp. 3087–3110.

COULOMB, J. 1969. L'expansion des fonds océaniques et la dérive des continents. Presses Universitaires de Paris. France, 224 p.

DICKINSON, W. R. 1973. Widths of modern arc–trench gaps proportional to past duration of igneous activity in associated magmatic arcs. Journal of Geophysical Research. **78**, pp. 3376–3389.

DUBOIS, J. 1969. Contribution à l'étude structurale du sud-ouest Pacifique d'après les ondes sismiques observées en Nouvelle Calédonie et aux Nouvelles Hébrides. Thèse, Paris, France. *Also* Annals of Geophysics, **25**, pp. 923–972.

DUBOIS, J., LARUE, B., PASCAL, G., and REICHENFELD, C. 1973. Seismology and structure of the New Hebrides. *In* The Western Pacific island arcs, marginal seas and geochemistry. *Edited by* P. J. Coleman. Western Australia Press, Perth, Australia. pp. 213–222.

FABIANO, I. B., and PEDDIE, N. W. 1969. Grid values of total magnetic intensity IGRF — 1965. ESSA Technical Reports C and GS, **38**. 55 p.

FITCH, T. J. 1972. Plate convergence, transcurrent faults and internal deformation adjacent to Southwest Asia and the Western Pacific. Journal of Geophysical Research, **77**, pp. 4432–4460.

FOX, P. J., and OPDYKE, N. D. 1973. Geology of the oceanic crust: Magnetic properties of oceanic rocks. Journal of Geophysical Research, **78**, pp. 5139–5154.

INTERNATIONAL SEISMOLOGICAL CENTRE BULLETIN. 1961–1970. Edinburgh, Scotland.

JOHNSON, T., and MOLNAR, P. 1972. Focal mechanism and plate tectonics in the Southwest Pacific. Journal of Geophysical Research, **77**, pp. 5000–5032.

KARIG, D. E. 1971. Origin and development of marginal basins in the western Pacific. Journal of Geophysical Research **76**, pp. 2542–2561.

KARIG, D. E. 1972. Remnant arcs. Geological Society of America Bulletin, **83**, pp. 1057–1068.

KARIG, D. E., and MAMMERICKX, J. 1972. Tectonic framework of the New Hebrides Island Arc. Marine Geology, **12**, pp. 187–206.

KARIG, D. E., and SHARMAN, G. S. 1975. Subduction and accretion in trenches. Geological Society of America Bulletin, **86**, pp. 377–389.

KOGAN, M. G. 1975. Gravity field of the Kuril–Kamchatka arc and its relation to thermal regime of the lithosphere. Journal of Geophysical Research, **80**, pp. 1381–1390.

LUYENDYK, B. P., BRYAN, W. B., and JEZEK, P. A. 1974. Shallow structure of the New Hebrides Island Arc. Bulletin of the Geological Society of America, **85**, pp. 1287–1400.

MCKENZIE, D., and SCLATER, J. G. 1971. The Indian Ocean since the late Cretaceous. Geophysical Journal of the Royal Astronomical Society, **25**, pp. 437–528.

MALAHOFF, A. 1970. Gravity and magnetic studies of the New Hebrides Island Arc. New Hebrides Geological Survey, Regional Report. 67 p.

MALLICK, D. I. J. 1973. Some petrological and structural variations in the New Hebrides. *In* The Western Pacific island arcs, marginal seas and geochemistry. *Edited by* P. J. Coleman. Western Australian Press, Perth, Australia. pp. 195–211.

PASCAL, G. 1974. Contribution à l'étude de la seismicité des Nouvelles Hébrides. Thèse, Office de la Recherche Scientifique et Technique Outre-Mer, Paris, France.

PUECH, J. L., and REICHENFELD, C. 1969. Etudes bathymétriques dans la région des iles Erromango, Tanna et Anatom (Nouvelles Hebrides). C.R. Academie des Sciences, Paris, **268**, pp. 1259–1261.

SLEEP, N. H. 1973. Induced flow beneath island arcs and intra-arcs spreading. EOS, Transactions of the American Geophysical Union, **54**, p. 467.

WILLIAMS, C. E. F., and WARDEN, A. J. 1964. Futuna. *In* Progress Report for 1959–1962. New Hebrides Geological Survey. p. 28.

YASUI, M., NAGASAKA, K., and KISHII, T. 1968. Terrestrial heat flow in the Okhotsk Sea (2). Oceanographical Magizine, **20**, pp. 73–86.

YASUI, M., EPP, D., NAGASAKA, K., and KISHI, T. 1970. Terrestrial heat flow in the seas around Nansei shoto (Ryukyu Island). Tectonophysics, **10**, pp. 225–234.

Reprinted from

Canadian Journal of Earth Sciences

Réimpression du

Journal canadien des sciences de la terre

The troughs at the rear of the New Hebrides island arc: Possible mechanisms of formation

JACQUES DUBOIS, FRANÇOIS DUGAS,
ANDRÉ LAPOUILLE AND RÉMY LOUAT

Volume 15 • Number 3 • 1978

Pages 351–360

National Research Council Canada
Conseil national de recherches Canada