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

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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 [illegible]
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.

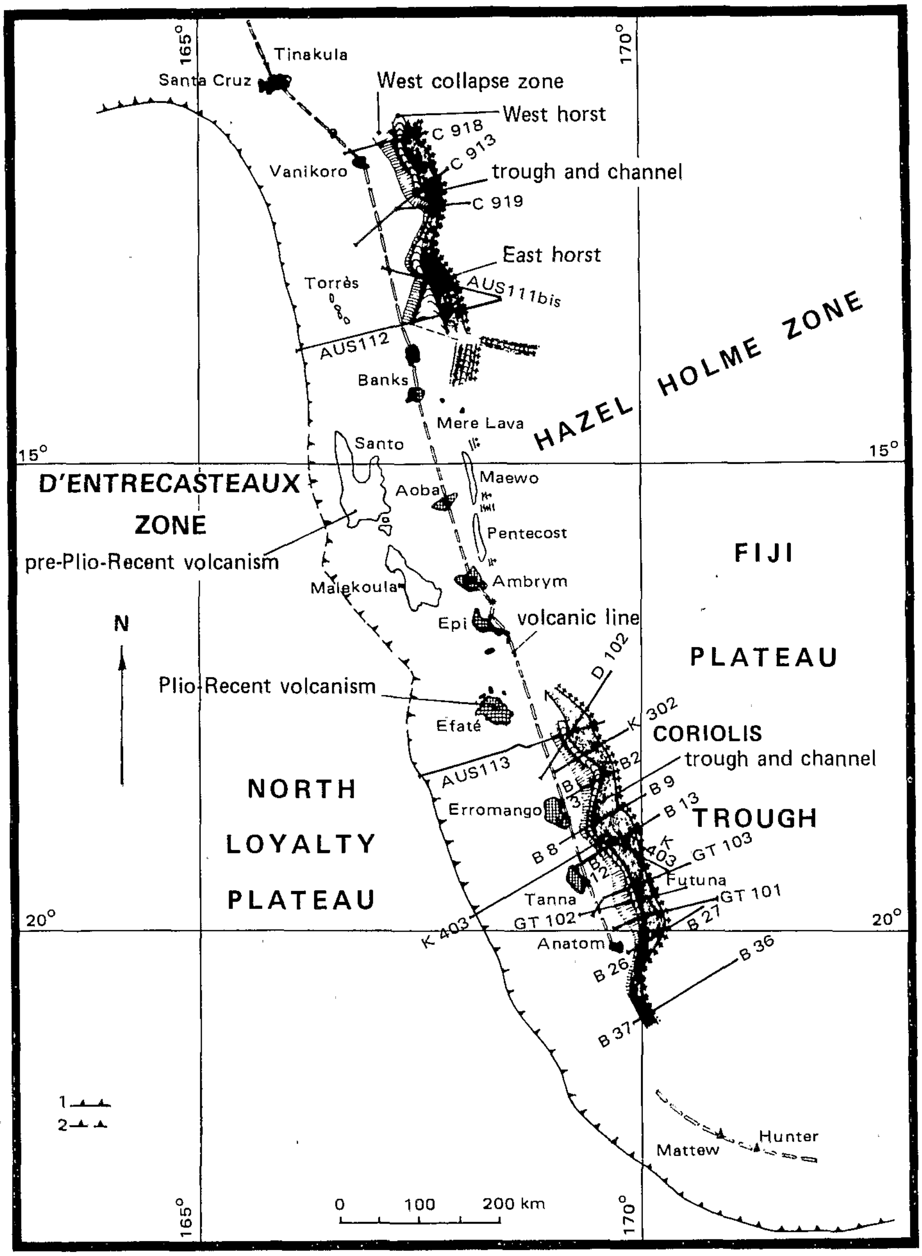
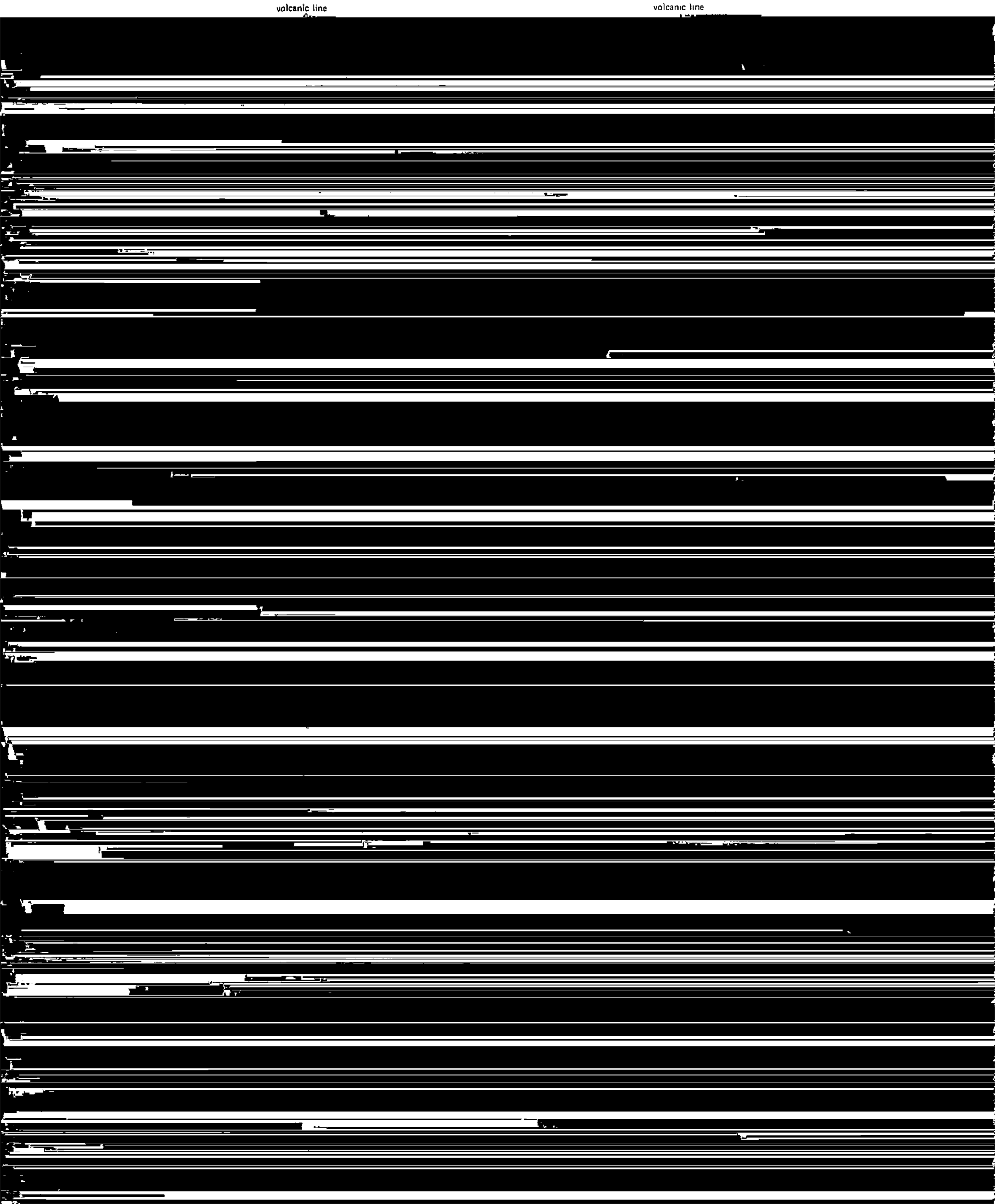


FIG. 1. Location of the troughs of the New Hebrides island arc, and positions of illustrated profiles over it. (1) outline of lithospheric dip where trench is present; (2) outline of lithospheric dip where trench is absent; (3) trench axis.

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).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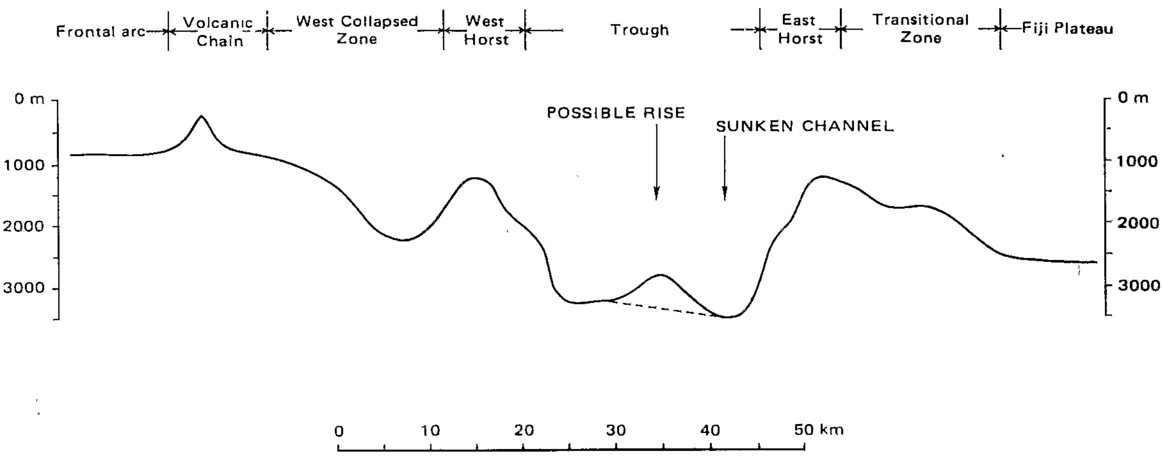


FIG. 3. Typical morphological cross section of the New Hebrides troughs.

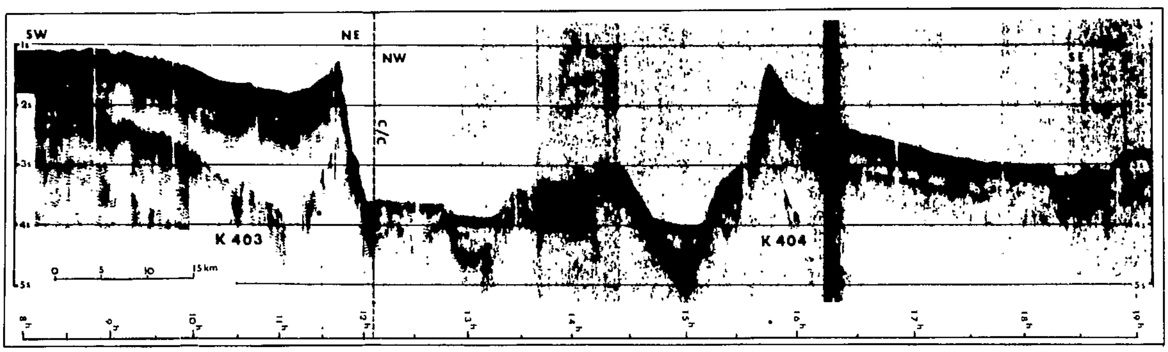


FIG. 4. Photograph of a seismic reflection profile across the trough (K 403 and K 404 profiles).

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

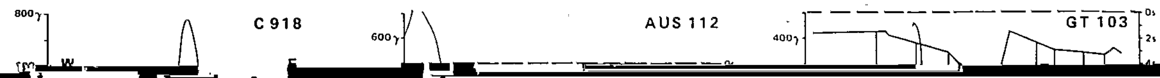
Stratigraphy

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


800γ
C 918
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AUS 112
400γ
GT 103

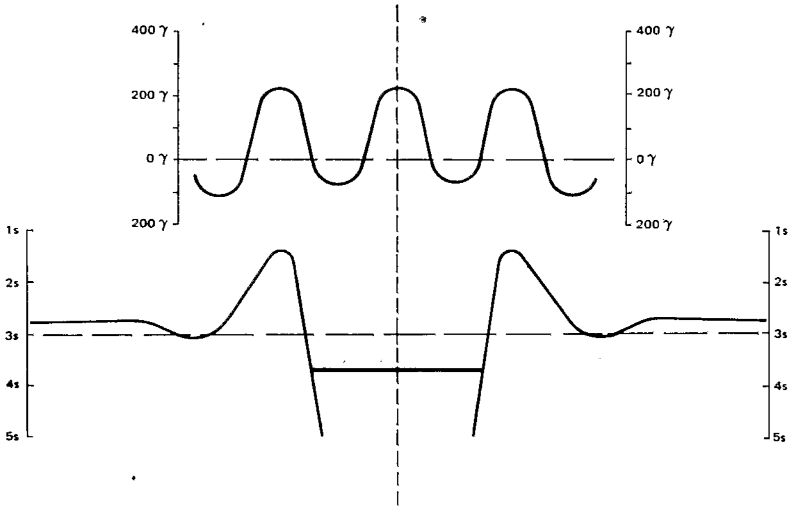


FIG. 6. Model of bathymetry and associated magnetic anomalies of the troughs.

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

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 exten-

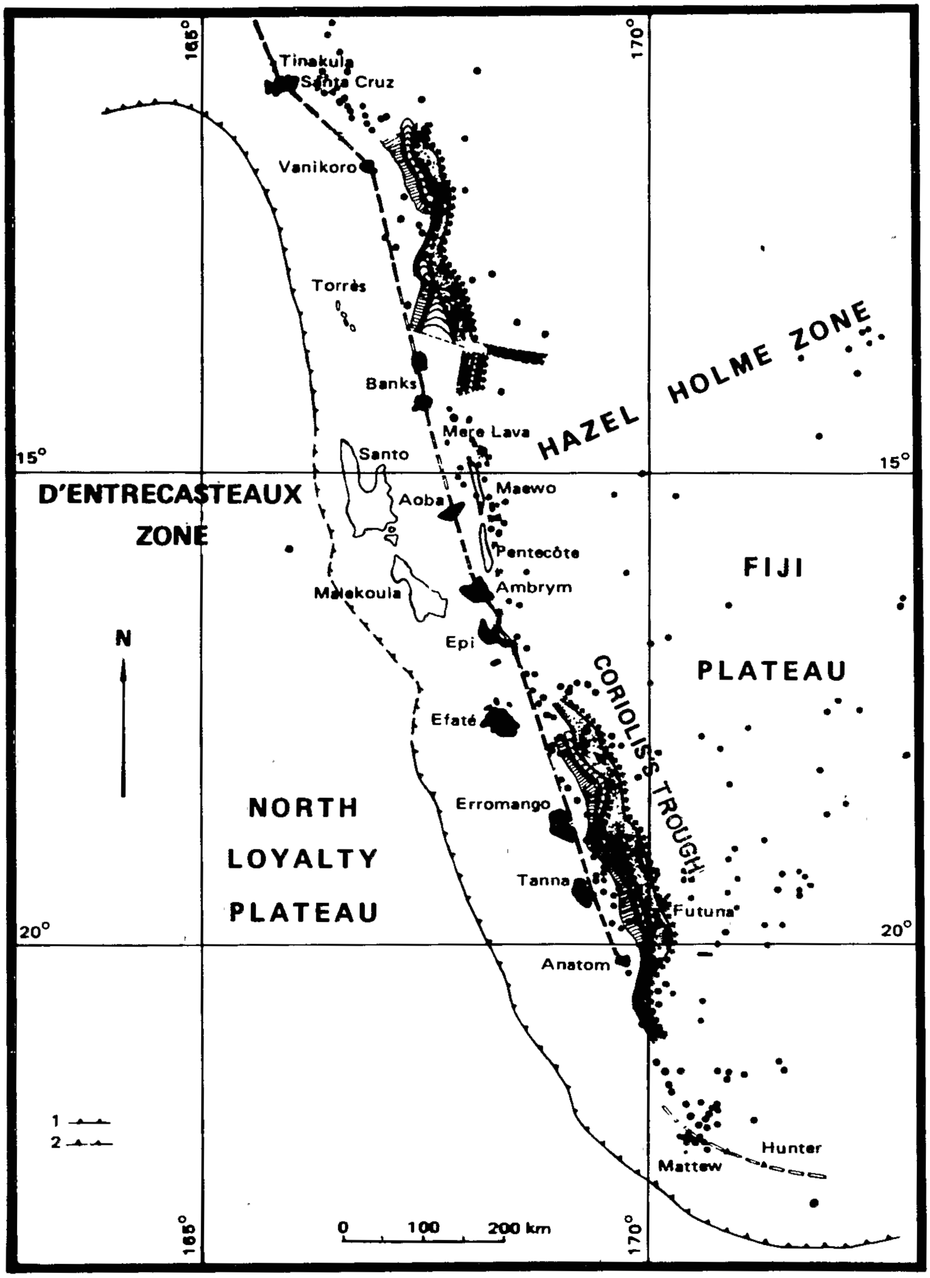


FIG. 7. Superficial seismicity (0–50 km deep) east of the volcanic line (after International Seismological Center Bulletin 1961–1970). Legend as for Fig. 1. Filled circles are epicentres.

(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

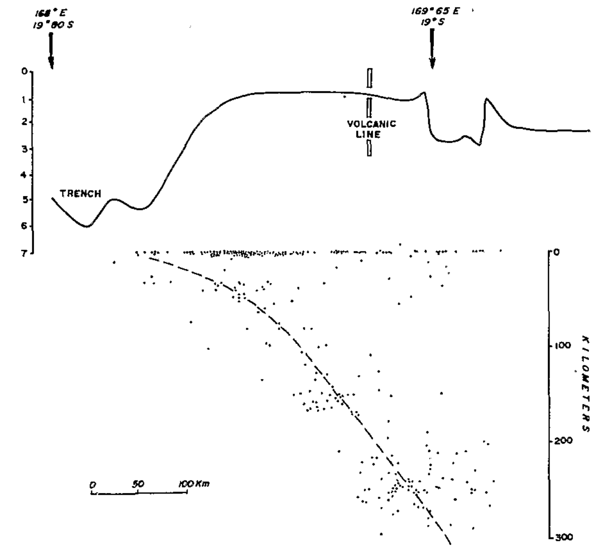
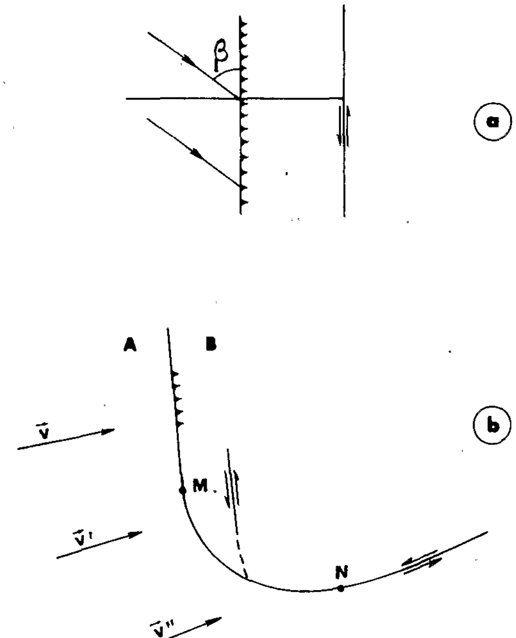


FIG. 8. New Hebrides arc. Bathymetry and seismicity along K 403 profile with projected hypocenters (ISC determinations) from 50 km each side of the profile.



between the plates A and B. If β is different from [redacted] 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

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