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Letter Section

The termination of the southern New Hebrides subduction zone (southwestern Pacific)

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ABSTRACT

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Recent data (bathymetric map and petrological investigations) as well as reappraisal of local seismological events for more than 20 years allow us to present a new geodynamic interpretation of the southern New Hebrides subduction zone. A multidisciplinary approach to this complex area, where transform movements relay subduction process, clearly shows the interrelationships between intermediate seismicity, lithospheric plates tectonics and volcanic activity. According to our model, two hinge zones, tearing the downgoing slab along directions which parallel the convergence vector (N70° E), reasonably account for most seismological and petrological data from the region. The approach of the Loyalty islands ridge towards the trench and its increasing influence on the subduction regime is beginning to complicate this scheme.

INTRODUCTION

The New Hebrides island arc belongs to the southwestern Pacific arc—trench system, which marks lithospheric boundaries between the India—Australia and Pacific plates, and several related microplates. In the regional picture, subduction of the India—Australia plate occurs towards the ENE along the Solomon and Santa Cruz/New Hebrides arcs, and the Pacific plate is subducted towards WNW along the Tonga—Kermadec island arc.

Recent geophysical studies shed light on several unusual characteristics of the New Hebrides island arc (Daniel et al., 1982). Among them is the fact that in this area the India—Australia plate subduction does not directly take place under the Pacific plate, for an actively expanding structure — the North Fiji Basin — overlies the ENE-ward plunging slab. Linear N—S trending magnetic lineations (anomalies 0 to 2′) can be recognized in the southern part

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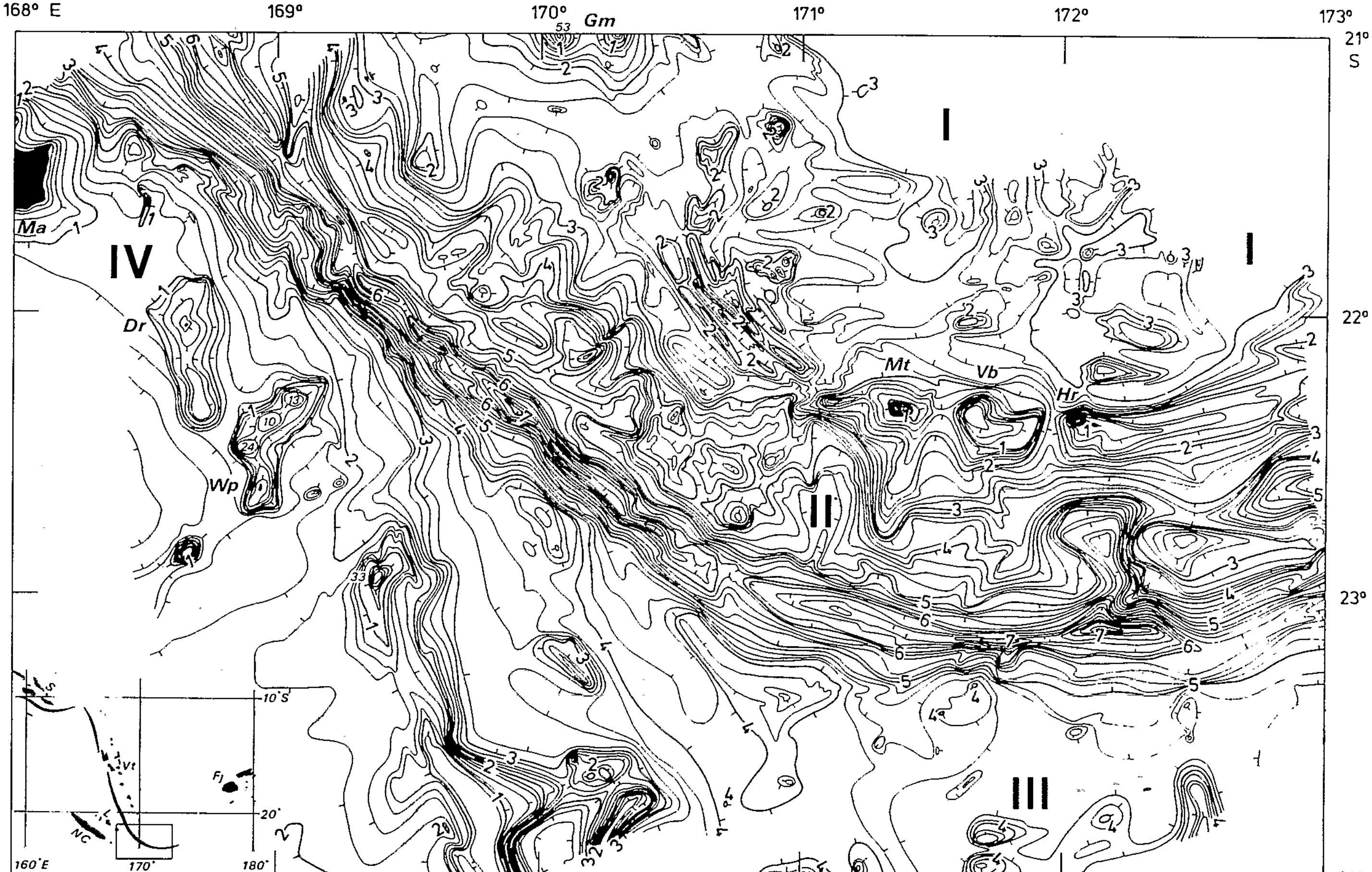
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of this basin, which support the hypothesis of active sea-floor spreading during the last 3.3 Ma (Cherkis, 1980). Furthermore, a triple junction may exist farther to the north, in the central part of the basin. Thus the presence of more than two microplates on the North Fiji Basin can not be excluded.

We therefore postulate that the New Hebrides southern trench (at least between 18 and 21°S) marks the subduction of the India—Australia plate under a microplate which does not belong to the Pacific plate, but is related to the recent opening of the North Fiji Basin. Structural limits of this microplate still remain too blurred to constrain geotectonic reconstructions. The relative motion parameters between the India—Australia plate and this microplate (subduction strike: N76°E ± 11° between 11 and 21°S; N70°E ± 5° between 19 and 21°S; inferred rate: 12 cm/yr) have, however, been deduced from earthquake focal mechanisms and lithospheric bulge studies (Dubois et al., 1977; Coudert et al., 1981; Isacks et al., 1981).

SUBMARINE MORPHOLOGY

The bathymetric survey of the southern part of the New Hebrides subduction zone (Fig. 1) was completed by ORSTOM during the fall of 1981 cruises of R/V "CORIOLIS", using a ca. 10 mile-spaced profile array positioned by satellite navigation. We have also plotted on an extension of the bathymetric map (eastward up to 175°E) the seismic events recorded by more than 50 stations during the last 22 years (Fig. 2). Due to a lack of reliable bathymetric data east of 173°E, only main structural directions (Halunen, 1979) appear on Fig. 2.

Though structural interactions between the downgoing slab and the upper crust of the overriding plate still remain unclear, the following observations arise from Figs. 1 and 2.

The southern New Hebrides trench can, regardless of limited thresholds, be recognized up to 172.5°E, 23.1°S. At this point it ends in a sudden termination marked by its greatest depth (7575 m) in the central and southern New Hebrides. Also the 6-km isobath defines significant trench strike changes (from N to S: NNW—SSE, NW—SE, W—E) which persist in the main structural directions of the overriding plate; compare for instance, on Fig. 1, the Matthew—Hunter ridge direction to the ones apparent between Gemini seamounts and Matthew island. A superficial earthquake swarm at 170.4°E, 23°S (Fig. 2) may locate a zone of crustal weakness along which active trench disruption occurs. Perhaps causally this area also marks a change in trench direction.

Fig. 1. Bathymetric map (in km) of the southern New Hebrides island arc and related areas. Isobath spacing: 0.2 km. Soundings (in meters) are specified on some highs. Tickmarks run towards lows. *I* = North Fiji Basin, *II* = southern New Hebrides island arc, *III* = South Fiji Basin, *IV* = Loyalty Islands Ridge (LIR), *S* = Solomon islands, *Vt* = Vanuatu, *L* = Loyalty Islands, *NC* = New Caledonia, *Fj* = Fiji Islands, *Gm* = Gemini seamounts (previously unnamed), *Mt* = Matthew Island, *Vb* = Vauban seamount (previously unnamed), *Hr* = Hunter Island, *Ma* = Mare Island, *Dr* = Durand reef, *Wp* = Walpole Island.

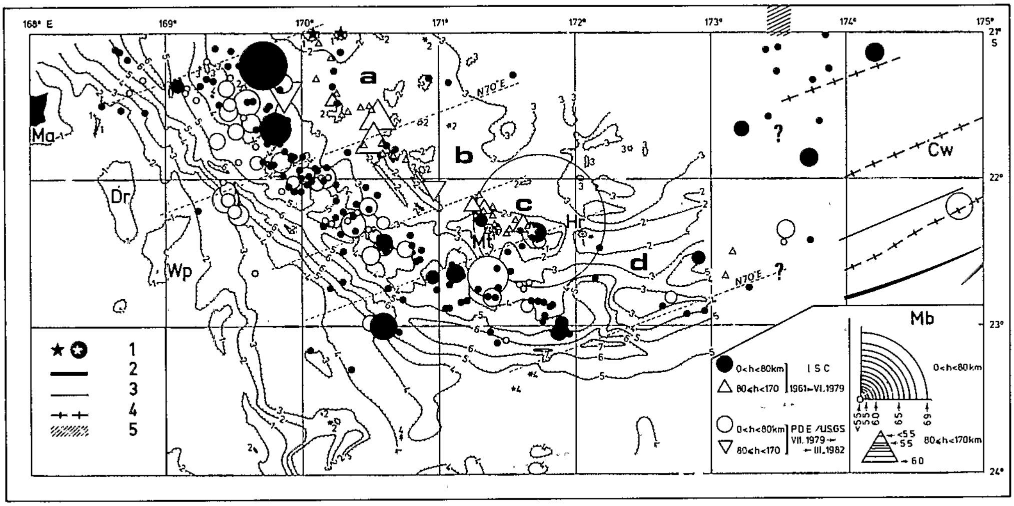

Fig. 2. 1961—1982 superficial (0—80 km) and intermediate (80—170 km) seismicity of the southern New Hebrides island arc and related areas. Only seismic events recorded by ⩾ 50 stations are plotted. Different symbols distinguish preliminary (*PDE*) and definitive (*ISC*) determinations of hypocenters. Events with a M_b magnitude ⩾ 5.5 appear with symbols proportional to the estimated released energy. Seismic zones (*a,b,c,d*) are reported from Fig. 3A. Halunen's (1979) and Cherkis's (1980) structural data have been added (eastward of 173° E) to the simplified bathymetry from Fig. 1 (same abbreviations, except for *Cw* = Conway Cay).
Features related to the New Hebrides island arc: *1* = seamounts. Features related to the Hunter Fracture Zone: *2* = major trough, *3* = minor trough, *4* = submarine ridges. Features related to the North Fiji Basin: *5* = spreading axis.

To the east of 172.5° E, submarine structures, although more complicated, display a definite ENE direction; this orientation (N70° E) corresponds to the western onset of the so-called Hunter Fracture Zone, which is the most conspicuous transform zone related to the opening of the North Fiji Basin.

In addition, the lobate and rough topography of the inner slope of the trench probably reflects severe fracturating, which may partly explain the significant concentration of shallow earthquakes all along it.

The New Hebrides central volcanic chain, which is related to the present subduction pattern, is not older than Late Pliocene (Carney and Macfarlane, 1979). In the studied area, it is represented by the Gemini seamounts to the north, and by Matthew and Hunter active volcanoes (plus the Vauban seamount ?) to the south. Between these two separate segments, the volcanic chain either never formed or at least has an unusual morphological pattern (narrow and elongate highs without any delineated volcanic edifice). We interpret this anomaly as the surface expression of the early stages of subduction of the easternmost wedge of the volcani Loyalty Island Ridge (LIR). The precise nature of this ridge still remains unclear (Baubron et al., 1976).

SEISMOLOGY AND PETROLOGY

The high-gain/short period seismic station of Mt. Dzumac (New Caledonia) continuously records events from the whole area. All the shallow events located south of 21.5° S display high-frequency P waves (> 4 Hz). By contrast, most of P waves recorded from events located north of 21.5° S, i.e. related to the linear part of the New Hebrides island arc, show a dominant frequency ranging from 1 to 2 Hz. Since both P wave families travel the same oceanic ray path, only a source effect, linked to the stress regime existing within the contact zone between the two interacting plates, can account for these observations. Moreover, the location of this abrupt change in stress regime occurs precisely where the LIR interacts with the arc.

Thus we infer from the raw seismological data that the southern arcuate portion of the New Hebrides subduction zone marks a stress regime different from that associated with the linear part of the arc. Intermediate seismicity shows a change at about 20° S. South of this latitude the length of the Benioff zone abruptly shortens (from ca. 350 km to 220 km). This shortening presumably corresponds to a recent southward extension of subduction (Louat et al., 1982).

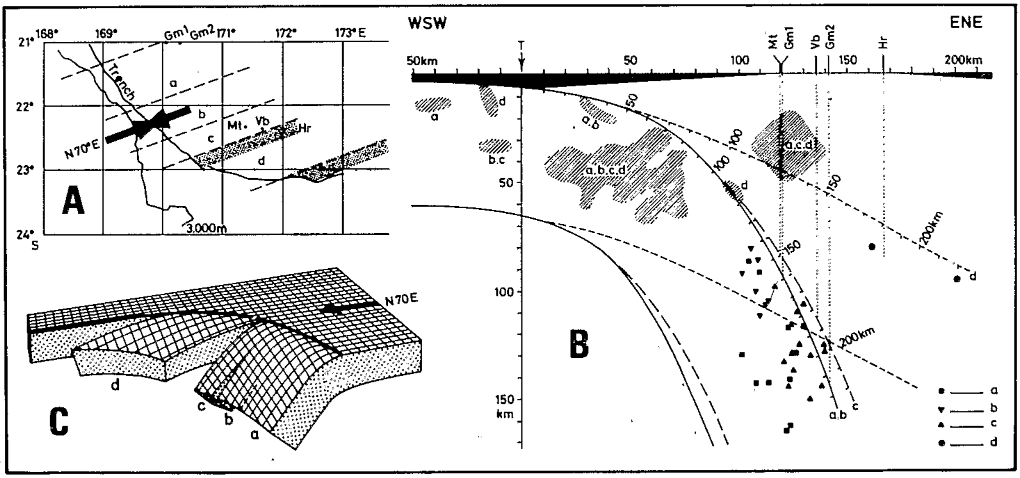

Fig. 3. A. Location of the four seismic zones (see text for discussion). Stippled areas delineate the two main hinge zones. The southern New Hebrides trench and the 3000 m-isobath bordering the Loyalty Islands Ridge have been drawn. Double arrow symbolizes the relative convergent plate motion. Abbreviated toponymy from Fig. 1.

B. Vertical composite cross-sections of the four seismic zones from Fig. 3A. The 0-km on the horizontal scale corresponds to the trench. Location of each seismic event is defined by the trench-epicenter distance along a N70° E direction, and the hypocenter depth. Locations of volcanoes and seamounts are determined using the same principle (same toponymy as in Fig. 3A). Intermediate seismicity of each composite cross-section is labelled with a distinctive symbol. Striped zones indicate superficial seismicity clusters. Inferred geometry of the 60-km thick slab appears on each cross-section.

C. Schematic model of the subducting plate along the southern New Hebrides arc.

Four cross-sections (located on Fig. 2) oriented N70°E, and exclusively defined using seismological arguments, show the inferred shape of the seismic zone (Fig. 3). Using this N70°E angle of convergence (instead of N76°E; cf. supra) produces a consistent representation of the data since no dramatic change occurs in the length of the seismic zone between 21.5° and 23°S.

Shallow seismicity in the four sections is primarily located beneath the inner slope of the trench. However, a noticeable swarm of great magnitude shallow earthquakes (1980—1981 seismic crisis) on the eastern flank of the LIR (169.5°E, 22.2°S; Fig. 2) is related to intense normal faulting apparent on seismic-reflection profiles (Launay, 1982).

Intermediate seismicity typically defines an envelope which roughly parallels (and sometimes overlaps) the shallow earthquake epicenters, but a seismic gap usually occurs in the descending slab (Figs. 2 and 3B).

The seismic cross-sections delineate two main subducting slab patterns. The first one corresponds to sections *a*, *b* and *c* (Figs. 3A and 3B) which look quite similar in shape and dip. However, intermediate hypocenters shallow distinctly in *b* compared to *a* and *c*. Although this peculiarity in *b* may be due to a too short recording time span, it more probably reflects the consequence of the early subduction of the LIR. The deepest part of the slab is still present (but seismically inactive) in *b*, and the slab length does not vary throughout the three sections *a*, *b*, and *c* (ca. 220 km). If the position of the inferred slab is correct, then it underlies the Gemini seamounts at a depth ranging from 90 to 145 km, and the Matthew active volcano at ca. 85 km.

In contrast, the section *d* (Figs. 3A and 3B) shows less active intermediate seismicity (some intermediate earthquakes determined using 47 stations do not appear in Figs. 2 and 3B; however, their hypocenter location strengthens the following conclusion). Besides section *d* displays a significantly lower dip of the seismic zone (30° vs. 70°). The length of the zone, however, remains similar to that observed on sections *a*, *b* and *c* (ca. 220 km). These two distinctive hinge characteristics of section *d* support the hypothesis of a major lithospheric zone between sections *a*, *b*, *c* and section *d*, as shown schematically in Figs. 3A and 3C. Consequently, the active Hunter volcano — i.e. the southernmost edifice of the New Hebrides central chain — would overlie this major tear zone in the subducting plate. Furthermore the petrological resemblances between the Matthew and Hunter volcanics (xenolith-rich, high-silica, medium-K orogenic andesites) favor a similar depth of the slab beneath both islands (Fig. 3B) (Maillet and Gill, 1980; Maillet and Monzier, 1982; Maillet et al., 1982; Lefèvre et al., 1982).

Finally a second hinge zone is supposed to be located southward (Figs. 3A and 3C), beyond which only transform movements occur.

CONCLUSIONS

The most important conclusions from our study are:

(1) The India—Australia plate is subducted under the New Hebrides island

arc with a relative N70°E convergence direction. South of the 21.5°S latitude, which marks the beginning of the arcuate termination of the arc, an abrupt change occurs in the intraplate stress régime. In addition, two main hinge zones, parallel to the plate-motion vector, permit a dynamic transition between subduction and transform movements. Since the slab length (220 km) remains constant along the N70°E direction all the way to the southeasternmost tear zone, a ca. 2 Ma age for the onset of the subduction in this area can be deduced from a 12 cm/yr inferred rate of plate motion.

(2) The Gemini seamounts and the Matthew and Hunter active volcanoes (plus Vauban seamount ?) represent the southernmost edifices of the New Hebrides central volcanic chain. Only bathymetric data reflect the volcanic nature of Gemini seamounts, which overlie the downgoing slab at 90 and 145 km, respectively. On the other hand a recent petrological study of the Matthew and Hunter islands emphasizes the close petrographic and geochemical similarities between their xenolith-rich, high-silicic, medium-K andesitic volcanics. The proposed geodynamic model is consistent with these similarities. According to the model, Hunter Island would overlie one of the hinge zones. This would account for a comparable depth of the slab below both volcanoes (ca. 85 km). Moreover the distinctly low dip of the slab between the two hinge zones may partly explain the absence of arc volcanism to the east of Hunter.

(3) The impingement of the Loyalty Islands Ridge on the trench is already disturbing the subduction mechanism. Limited modifications in the location of shallow and intermediate seismicity, as well as the lack of a definite volcanic ridge between the Gemini seamounts and Matthew Island argue for the recent and progressively increasing influence of this ongoing collision.

Finally, the southern New Hebrides subduction zone displays a step-by-step change from a convergent to a conservative plate boundary, in which a local external influence — i.e. the collision of the Loyalty Islands Ridge — tends to become more and more prominent.

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