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Current tectonics of the Tonga–New Hebrides region

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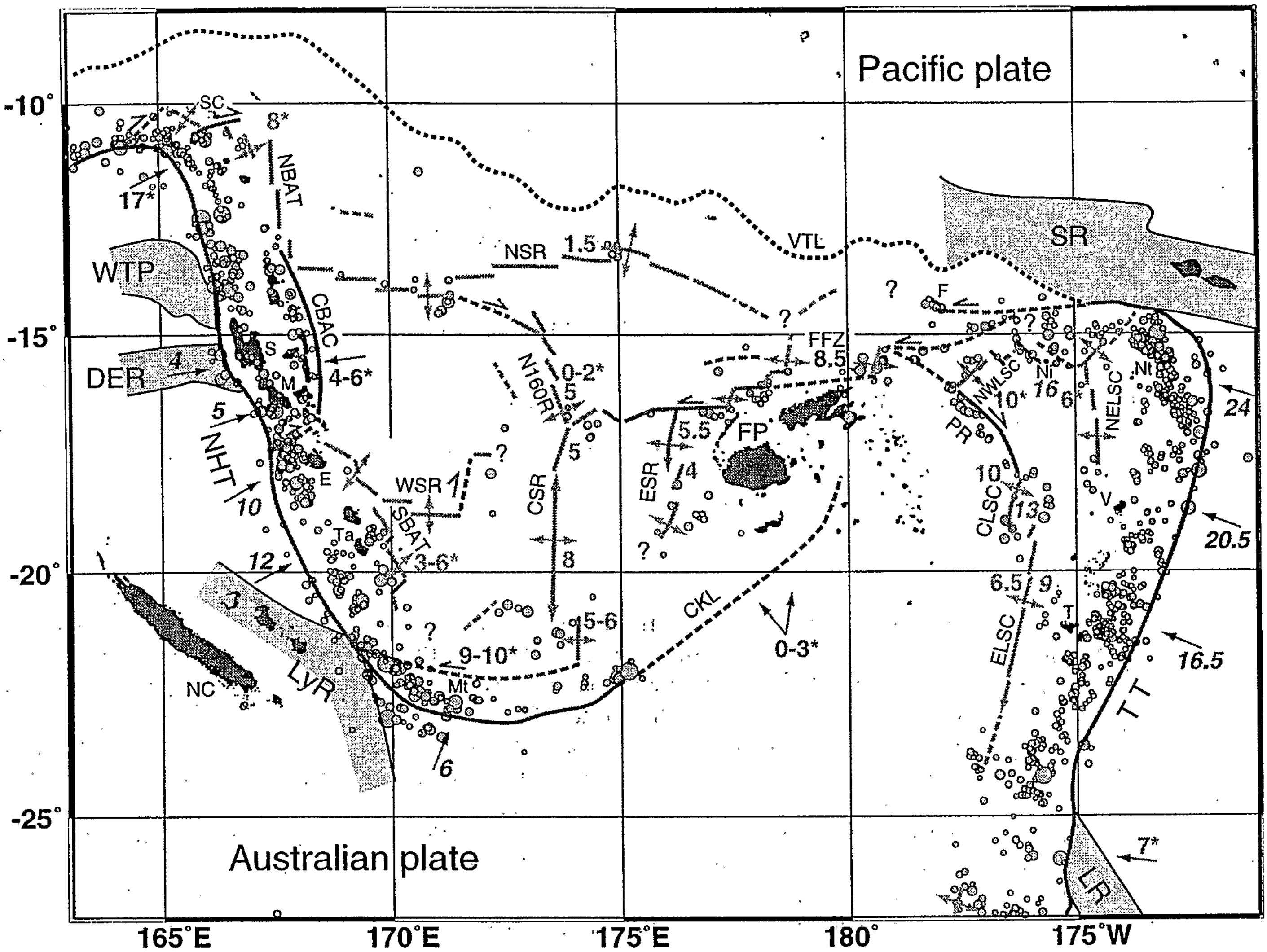

Fig. 1. Proposed plate tectonic map for the Tonga–New Hebrides region. Shallow earthquakes (<50 km, NEIC location, period 1977–1996) having a focal mechanism solution are reported (size of shaded circles in function of magnitude). Lines or segments are recognised active plate boundaries. Dashed lines are inferred active plate boundaries. Dotted black line indicates fossil boundary. Directions of relative motions are indicated by arrows. Rates of motions are in cm/yr: numbers, numbers in italics and numbers with asterisks stand for magnetically derived rate (from [22–25,30] for the North Fiji basin and [6] for the Lau basin), GPS-derived rate (from [9] for the Tonga subduction and the Lau basin and from [10–13] for the New Hebrides subduction) and inferred rate, respectively. *NHT* = New Hebrides Trench; *TT* = Tonga Trench; *NBAT* and *SBAT* = resp. North and South New Hebrides Back-Arc Troughs; *CBAC* = Central New Hebrides Back-Arc Compressional zone; *ESR, CSR, WSR, NSR* and *N160R* = resp. East, Central, West, North and N160°E spreading ridges of the North Fiji basin; *ELSC, CLSC, NWLSC* and *NELSC* = resp. East, Central, North-West and North-East Lau Spreading Centres; *PR* = Peggy ridge; *FFZ* = Fiji fracture zone; *FP* = Fiji platform; *NC, SC, S, M, E, Ta, Mt, V, T, Nt, Ni* and *F* = resp. New Caledonia, Santa Cruz, Santo, Malekula, Efate, Tanna, Matthew, Vava'u, Tongatapu, Niuatoputapu, Niuafo'ou and Futuna Islands; *VTL*: Vitiaz trench lineament; *CKL* = Conway–Kandavu lineament; shaded areas indicate subducting ridges and plateaus; *DER, LyR, LR* and *SR* = resp. d'Entrecateaux, Loyalty, Louisville and Samoan Ridges; *WTP* = West Torres plateau.

for numerous references) and satellite-derived marine gravity anomalies [8] provided a global view of the ocean floor structures for the entire area. In addition GPS-derived crustal motions have been reported within the Tonga–Lau system [9] and at the New Hebrides trench [10–13].

The objective of this paper is to propose an updated present-day tectonic map of the Tonga–New Hebrides region. We then use this tectonic scheme, in which we try to reconcile the rate and direction of spreading in the Lau and North Fiji back-arc basins and the rate and direction of convergence at the Tonga and New Hebrides trenches, to assess the influence of the subduction of some aseis-

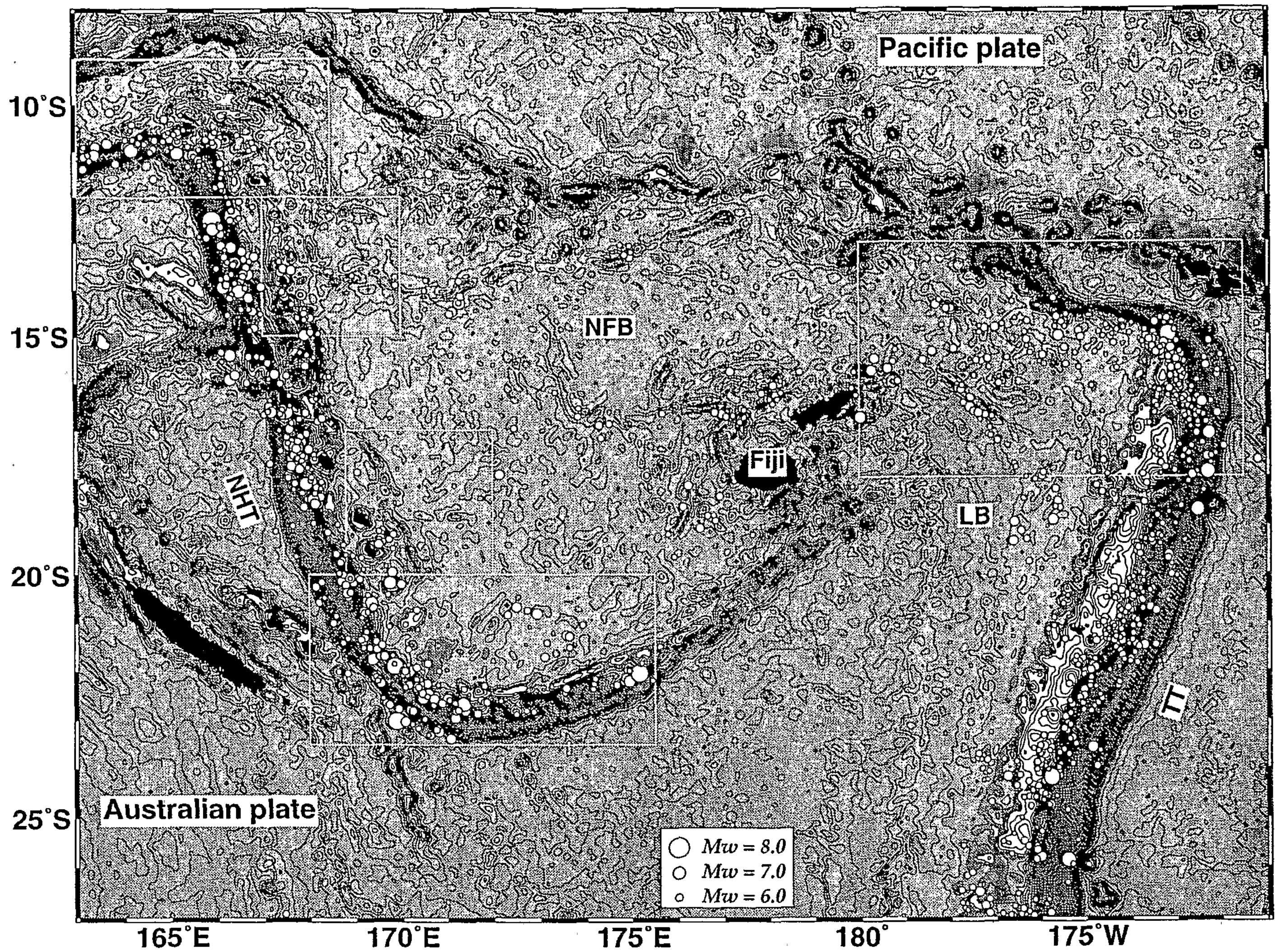

Fig. 2. Satellite-derived gravity anomaly map of the Tonga–New Hebrides region (from [8]). Anomalies are contoured at 20-mGa intervals. Grey levels change every 10 mGal between −100 (deep grey below) and +100 mGal (white above). Islands are in black Shallow earthquakes (source as in Fig. 1) are shown by white dots; *TT* = Tonga trench; *NHT* = New Hebrides trench; *NFB* = North Fij basin; *LB* = Lau basin. Locations of Figs. 5–9 are indicated.

mic ridges on the tectonics of arcs and back-arcs basins. This tectonic scheme (Fig. 1) is based on a compilation of new and earlier data and previously published results dealing with gravity, bathymetry, seismicity, magnetism and geodesy. Location and nature of plate boundaries are determined from satellite-derived gravity anomalies (Fig. 2), from bathymetric data mostly collected during the last decade with multibeam swath bathymetric systems in the back-arc basins (see the references in the following sections), and from the distribution and focal mechanism solutions of shallow earthquakes (Figs. 3 and 4). Compression (P) axes and slip vectors from thrust-type focal mechanisms are shown in the Fig. 3, while tension (T) axes from norma and strike-slip fault type mechanisms are reported ir Fig. 4. New bathymetric maps are only shown fo some selected parts of the area (Figs. 5 and 9), where new structures are proposed and questions remain unanswered. These maps result from a compilatio of marine data available from the National Geophys ical Data Center and from various institutions whicl carried out surveys in the selected areas (ORSTOM Institut Français de Recherche Scientifique pour l Développement en Coopération; RAN: Royal Aus tralian Navy; SOPAC: South Pacific Applied Geo science Commission). Crustal motions are derive from the opening rates as determined by magneti

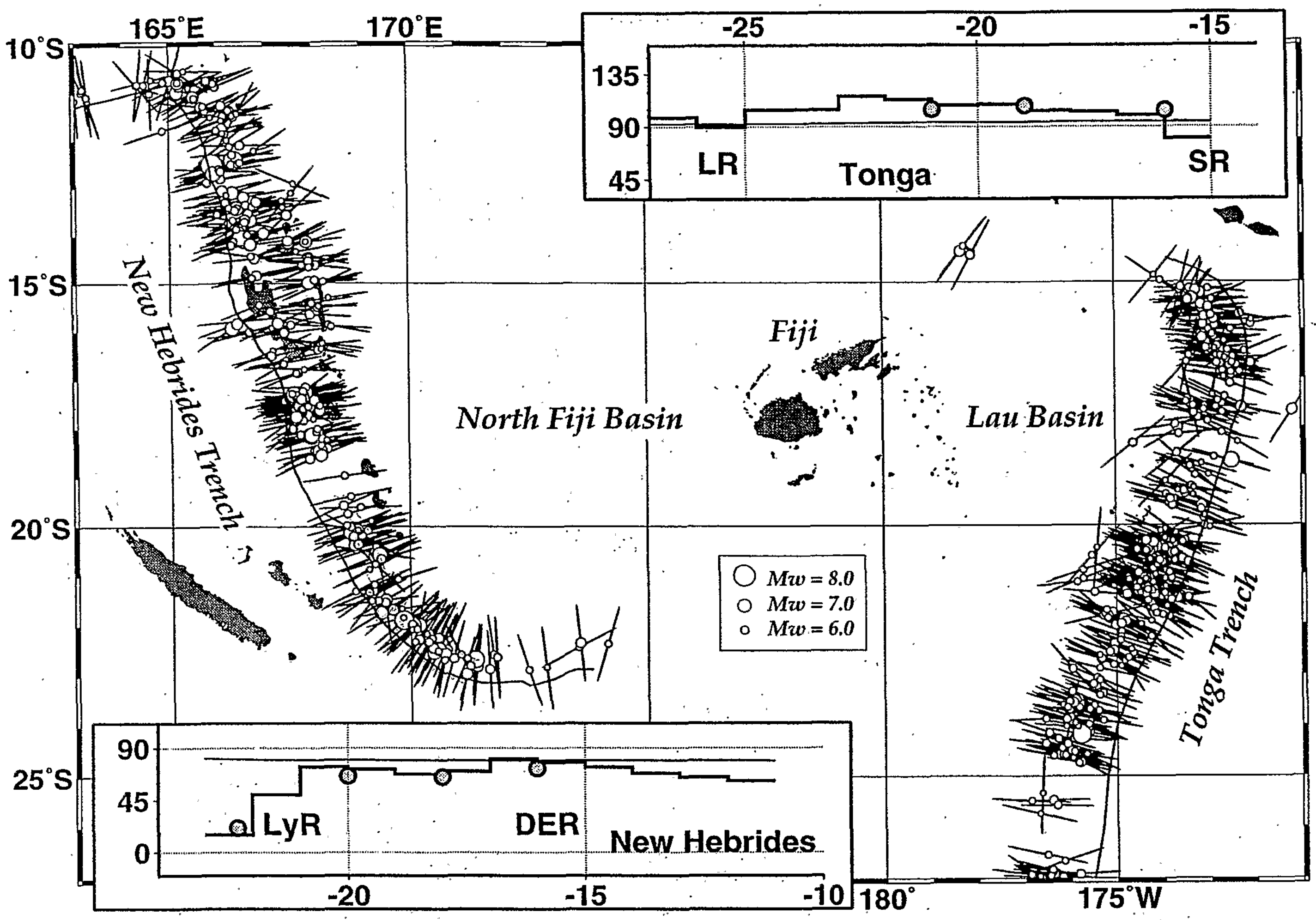

Fig. 3. Distribution (location from NEIC) and direction of *P* axis (bars) of shallow (<50 km) thrust-type earthquakes (from CMTS) for the period 1977–1996 in the Tonga–New Hebrides region. Circles are events at the rear of the arcs. Insets show the slip-vector azimuths averaged per degree of latitude along Tonga and New Hebrides (heavy segments). The continuous line indicates the NUVEL-1A predicted azimuth of the Pacific–Australian motion [14]. Grey circles indicate GPS-derived azimuths at trenches (from [9] for Tonga and [10–13] for New Hebrides). Junctions between trenches and subducting aseismic ridges are noted by *DER*, *LyR*, *LR* and *SR* for the d'Entrecateaux, Loyalty, Louisville and Samoan ridges, respectively.

anomalies along spreading centres in back-arc basins (see the following sections and Fig. 1 for references) and from direct GPS measurements of convergence and divergence collected since 1990 [10–13].

For the closure of the velocity vectors across the entire area we needed to use a model of the convergence between the Australian and Pacific plates. Numerous solutions are now available. Some are based on the inversion of geologic data (NUVEL-1A [14]), some rely on space geodesy techniques using VLBI [15], SLR [16], DORIS [17] or GPS [18]. Although all these solutions generally agree to within a few percent [17,18], discrepancies still exist for the noticeably poorly constrained Pacific–Australian pole of relative rotation. Tests performed using the NUVEL-1A, DORIS and GPS-derived poles show that the resulting velocity vectors never differ by more than 0.5 cm/yr in the study area. Because it is usually considered as the reference model, NUVEL-1A has been used in this study to derive reference values for the Pacific–Australian convergence motions.

The vectors derived from magnetic anomaly data, NUVEL-1A model or GPS measurements are calculated using different assumptions and over different time scales. In this study, we compared these different vectors in order to discuss possible recent variations of spreading rate. We used them together to estimate unknown rates across certain plate boundary segments. Our working hypothesis is partly supported by the fact that the motions predicted by

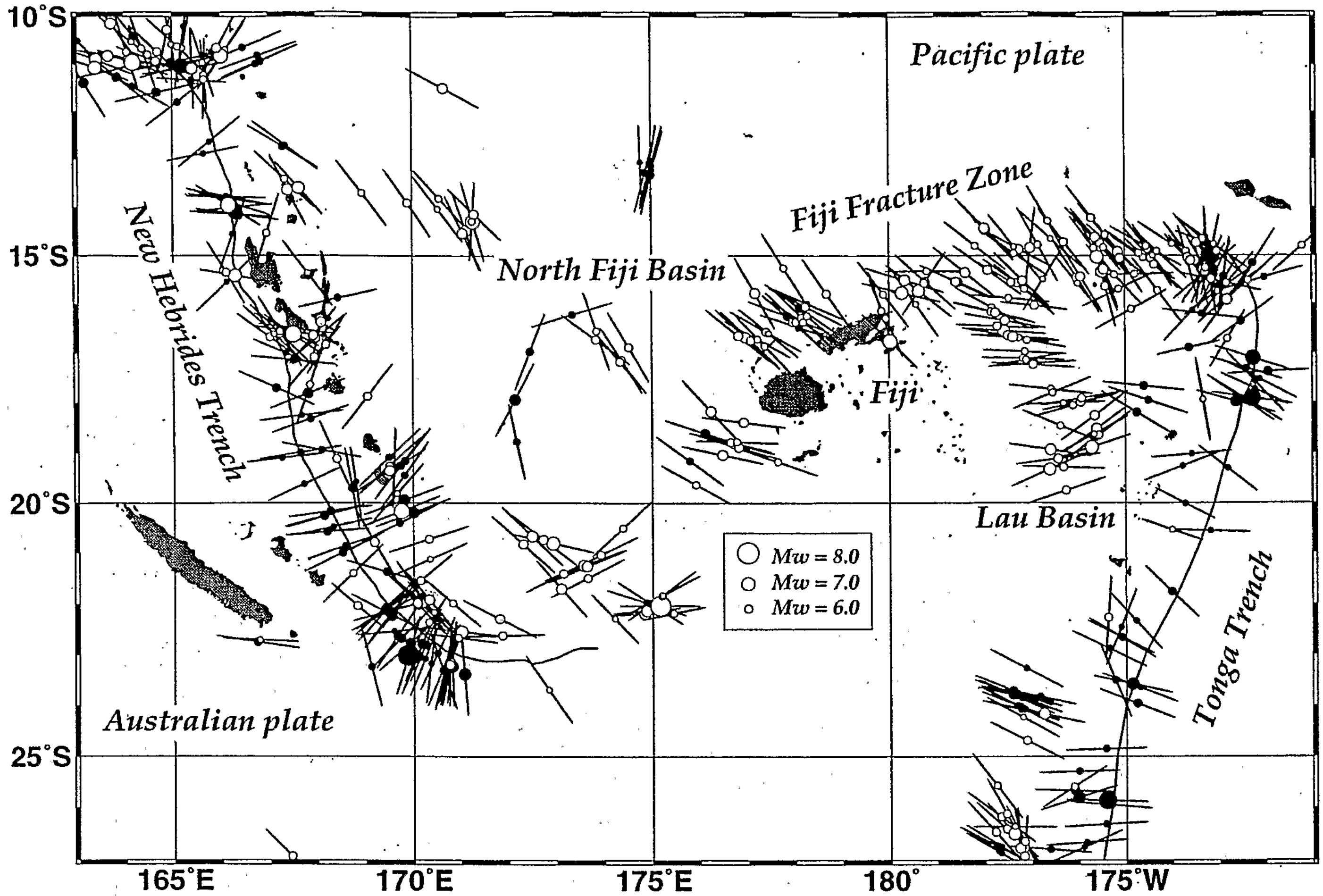

Fig. 4. Distribution (location from NEIC) and direction of T axis (bars) of shallow (<50 km) normal (dots) and strike-slip (circles) fault-type earthquakes (from CMTS) for the period 1977–1996 in the Tonga–New Hebrides region.

the NUVEL-1A model, which is also derived from a combination of geological time scale (magnetic) and instantaneous data (slip vectors), are generally in good agreement with global plate motions as measured by DORIS [17] or GPS [18]. The location of the Tonga and New Hebrides islands (i.e. the GPS benchmarks) being in general far enough from the seismogenic zones, and the lack of large shallow thrust earthquakes in the Tonga and New Hebrides subduction zones (few events with magnitude higher than 7.5 and none higher than 8 in the period of seismological records) also support the hypothesis that the short-term GPS-derived local rates do not differ significantly from the geological time scale rate. For example, even for the central New Hebrides which are very close to the interplate shallow seismogenic zone, Taylor et al. [11] showed that GPS measurements account for 85% of the total convergence and that a maximum of only 0.7 cm/yr of the convergence can be attributed to elastic strain accumulation. GPS-derived coordinates for several New Hebrides sites present co-seismic steps related to the largest quakes that occurred there during the time-series interval [12,13]. In these cases, a maximum velocity change of 0.75 cm/yr in the convergence rate can be attributed to elastic strain accumulation. The GPS vectors from [12,13] used in the discussions for the relationship between the New Hebrides arc and North Fiji basin are the strain-free convergence rates and thus are supposed to represent the long-term convergence rate.

2. The southern and central Lau basin and Tonga arc, and the Louisville ridge

At the Tonga trench, the convergence rate is the sum of the Pacific–Australian convergence and the

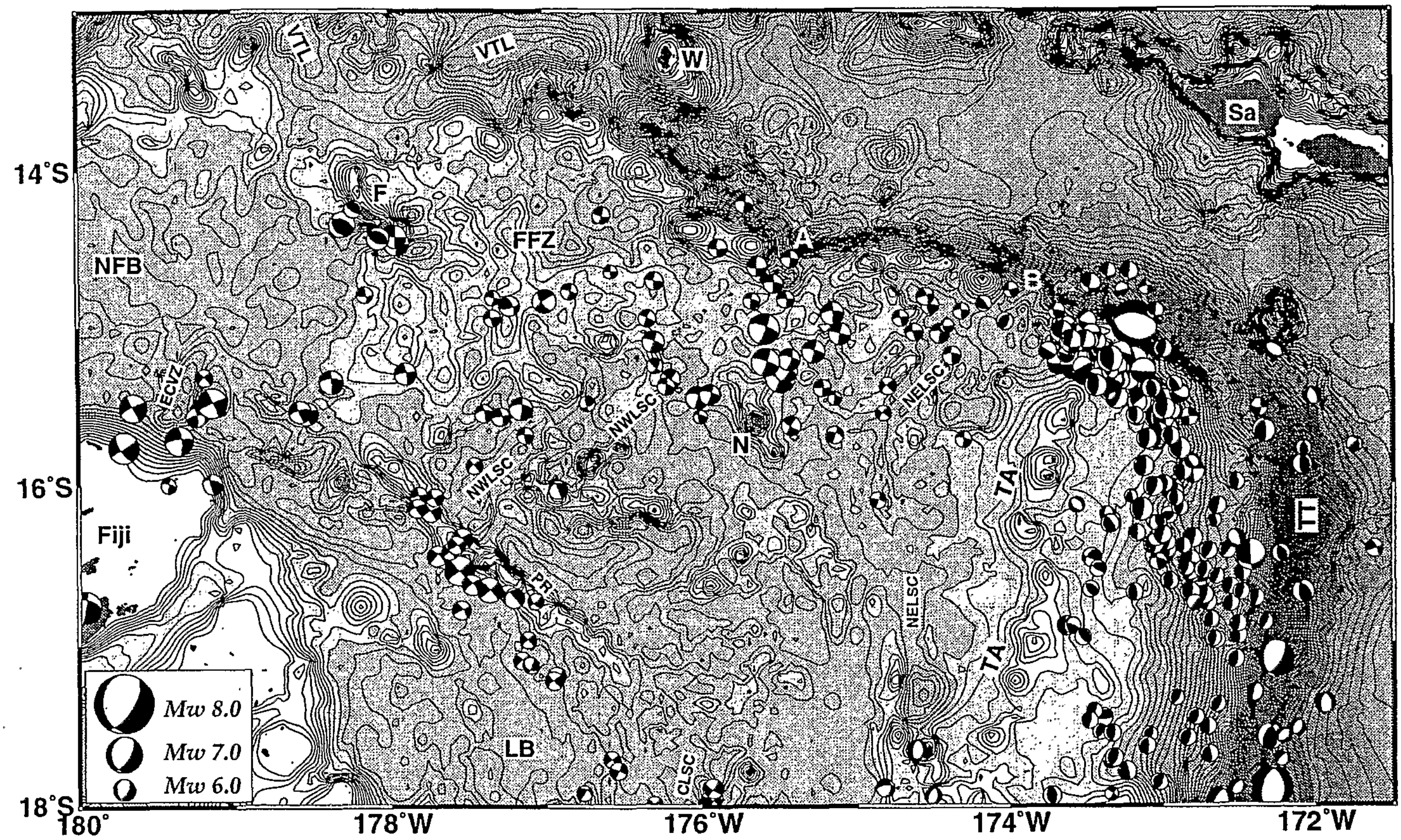

Fig. 5. Bathymetric map of the northern parts of the Lau basin and Tonga arc. Contour interval is 200 m. Grey scale interval is 1000 m. Focal mechanism solutions (CMTS) for shallow earthquakes (source as in Fig. 1) are reported. *LB* = Lau basin; *NFB* = North Fiji basin; *TT* = Tonga trench; *TA* = Tonga arc; *CLSC, NWLSC* and *NELSC* = resp. Central, North-West and North-East Lau Spreading Centres; *PR* = Peggy ridge; *ECVZ* = East Cikobia volcanic zone; *FFZ* = Fiji fracture zone; *VTL* = Vitiaz trench lineament; *Sa, W, F, N* = resp. Samoa, Wallis, Futuna and Niuafo'ou islands.

Lau basin opening. GPS measurements [9] indicate a convergence rate of 16.4 ± 0.5 cm/yr at 21°S, 20.5 ± 1 cm/yr at 19°S and 24 ± 1.1 cm/yr at 16°S. No geodetic measurement is available at the latitude of the junction between the Louisville aseismic ridge and the Tonga trench. However the convergence rate there is likely to be much lower than the 16–24 cm/yr observed further north, possibly only as much as 7 cm/yr predicted by the NUVEL-1A model. Indeed, the fact that the East Lau Spreading Centre ends just north of the Louisville ridge–trench junction (Fig. 1) and the relatively good fit between earthquake slip vectors azimuths and the NUVEL-1A predicted direction for the Pacific–Australian motion near the junction (Fig. 3) suggest that there is little or no extension in the back-arc domain in front of the ridge–trench intersection.

In the southern and central Lau basin, from 23°S to 18°S, opening occurs along a single spreading system composed of two overlapping centres propagating southward: the East (from 23°S to 19°S) and Central (from 19°20′S to 18°S) Lau Spreading Centres [6,19]. Except a few strike-slip earthquakes near the Central Lau Spreading Centre and normal fault earthquakes south of the East Lau Spreading Centre, indicating that active rifting continues southward to 24°S, no earthquakes are associated with back-arc opening along the whole East Lau Spreading Centre from 19°30′S to 23°30′S. Unexpected events with thrust-type mechanism solutions cluster west of the Vava'u and Tongatapu Islands, at the rear of the Tonga platform and below the active arc. These thrust-type mechanisms with NE-trending *P* axes clearly differ from those located further east and directly related to the subduction process. They coincide in latitude with thrust-type events on the plunging plate and with a lack of normal or strike-slip faulting events in the back-arc basin, suggesting a higher coupling in this part of the Tonga margin and the presence of an unusual compression belt below the active Tonga arc from 19°S to 23°S. This deformation being in line with the Louisville ridge which very rapidly sweeps the trench and recently underthrust the region of Tongatapu, we suspect that it is related to the subduction of the aseismic Louisville ridge.

A wide range of spreading rates (from 4 to 10 cm/yr), derived from many different identifications of magnetic anomalies, have been proposed for the Lau basin (see [6] and [19] and references herein). Taylor et al. [6] indicates that spreading rates deduced from magnetic anomalies over the last 0.7 Ma increase northward from 6.5 cm/yr in the East Lau Spreading Centre at 21°S to 9 cm/yr in the Central Lau Spreading Centre at 18°S. Spreading rates estimated by two GPS campaigns performed in 1990 and 1992 are substantially higher: 9.1 ± 0.5 cm/yr at 21°S and 13 ± 1 cm/yr at 18.5°S [9]. Although these geodetic rates obtained from only two epochs of measurements need to be confirmed, and provided that no off-axis active extension occurs, the discrepancy between the geodetically and the magnetically derived rates is large enough to infer that the opening rate has recently increased [6]. We suggest that this opening acceleration is related to the subduction of the Louisville ridge, which may successively produce, as it sweeps the Tonga margin, inhibition or reduction and then acceleration of back-arc spreading in its wake. Indeed the southward migration of the Louisville ridge–Tonga trench intersection mirrors approximately the southward propagation of the East Lau Spreading Centre.

3. The northern Lau basin and Tonga arc, and the Fiji fracture zone

In the northern Lau basin (Figs. 1 and 5), north of 18°S, opening occurs along two systems [20,21]: the North-West Lau Spreading Centre connected to the Central Lau Spreading Centre by the Peggy ridge transform fault, and the North-East Lau Spreading Centre along which a triple junction has been identified. Neither these structures nor their connections to the broad left-lateral Fiji fracture zone extending westward from the northern end of the Tonga trench are known in detail. However, from available marine bathymetric data, earthquake foci and focal mechanisms (Fig. 5) we infer the following present-day tectonics. The North-West Lau Spreading Centre, known up to 177°W, 100 km northeast of the Peggy ridge [6,20], likely extends further northeast as suggested by a NE-trending ridge lying from 177°W to 176°W. NW-trending seismic belts located northwest and northeast of the active volcanic island of Niuafo'ou suggest that a left-lateral and extensional transform zone connects the North-West Lau Spreading Centre to the triple junction on the North-East Lau Spreading Centre. Breaks in the topographic high bounding the southern flank of the E–W-trending northernmost part of the Tonga trench (near 174°W, 14.75°S and 175.5°W, 14°S and labelled B and A in Fig. 5) are located in the extension of the NE-trending North-East and North-West Lau Spreading Centres. These breaks may represent junctions between the trench and the two spreading systems. The N–S-trending southern part of the North-East Lau Spreading Centre ends at 18°S in the active Tonga arc where active rifting occurs [4,6,21] as indicated by a cluster of normal fault type events (Figs. 3 and 5). The bathymetric map suggests that the Peggy ridge transform fault continues northwest from the southwest end of the North-West Lau Spreading Centre to the northern end of the East Cikobia volcanic zone [20]. However, distribution of seismicity and focal mechanisms also suggests that the northern end of the East Cikobia volcanic zone may be directly connected to the northwestern tip of the Tonga trench (point A in Fig. 5) along one of the strike-slip faults of the Fiji fracture zone. Another branch of the fracture zone is located further north in the elongated depression just south of Futuna Island as indicated by a cluster of strike-slip and thrust-fault type events. Whatever the precise pattern of the current tectonics, it appears that the left-lateral motion occurring along the Fiji shear zone is largely accommodated by NW–SE to WNW–ESE extension along a series of spreading centres and pull-apart basins.

GPS measurements indicate a rapid opening rate of 15.9 ± 1 cm/yr across the entire northern Lau basin and a fast convergence rate of 24 ± 1.1 cm/yr at the northern Tonga trench at 16°S [9]. It is worth noting that the difference between the two rates (8.1 cm/yr) is very close to the predicted Pacific–

Australian convergence rate (~8.5 cm/yr from NUVEL-1A). Magnetic data are insufficient to estimate the spreading rates on the North-West and North-East Lau Centres. A rate of 4.8 cm/yr, has been derived [6] from a positive magnetic lineation associated with the North-West Lau Centre. However, because it is averaged over 0.7 Ma, this rate may represent a minimum value and the actual rate is likely significantly higher. Indeed, crustal motion increases northward along the Central Lau Spreading Centre and reaches ~10 cm/yr [6] at its northern tip, which is connected to the North-West Lau Spreading Centre by the dextral Peggy ridge transform fault. Together with the total rate of ~16 cm/yr determined by GPS, such a high rate for the North-West Lau Spreading Centre (~8–10 cm/yr) would give in turn a present-day opening rate of ~6–8 cm/yr on the southern branch of the North-East Lau Spreading Centre. If the two spreading systems are connected by a left-lateral and extensional transform fault near Niuafo'ou Island, the spreading rate would be higher along the northeastern branch of the North-East Lau Spreading Centre.

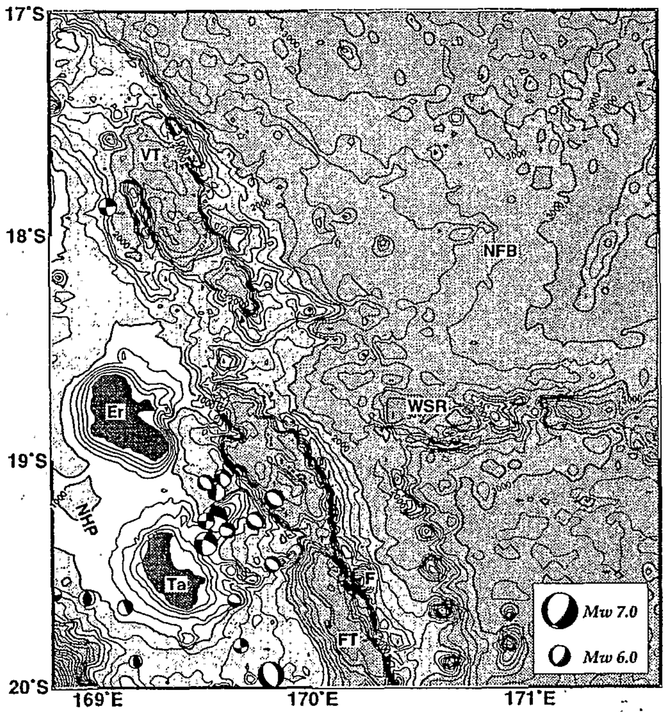

Fig. 6. Bathymetric map of junction area between the South New Hebrides Back-Arc Troughs (*VT* = Vate Trough, *FT* = Futuna Trough) and the West Spreading Ridge (*WSR*) of the North Fiji basin (*NFB*). Contour and grey scale intervals, and focal mechanism solutions as in Fig. 5. *NHP* = New Hebrides platform; *F, Ta, Er* = Futuna, Tanna and Erromango islands.

4. The southern North Fiji basin and New Hebrides arc, and the Loyalty ridge

Because relative motion between the Fiji platform and the Australian plate is small and not yet quantified [9], the Fiji platform can be considered as part of the Australian plate. Therefore, the convergence rate at the southern New Hebrides trench is equal to the opening rate in the southern North Fiji basin. The convergence rate determined from GPS at the southern New Hebrides trench is ~10 cm/yr near 18°S (from 9.5 ± 0.1 to 10.3 ± 0.9 cm/yr [10–12]) and ~12–13 cm/yr near 20°S (from 11.7 ± 0.8 to 12.7 ± 0.3 cm/yr [10,11,13]). Three extensional systems contribute to the total divergence rate in the southern North Fiji basin (Fig. 1). Although the main parts of these systems were fully mapped with multibeam equipment (see [7] for references), we still lack a clear picture of their southern ends and the connections between them. The East Spreading Ridge extends from its junction with the Fiji fracture zone to 19.5°S. Its magnetically derived spreading rate increases northward, from ~4 cm/yr at 18°S to ~5.5 cm/yr at 17°S [22,23]. Along the Central Spreading Ridge, south of the central North Fiji basin triple junction, the opening rate determined by magnetic anomalies increases from ~5 at 17°S to ~8 cm/yr at 20°30′S [23,24]. The southernmost segment of the Central Spreading Ridge is shifted 80 km east of the central segment (Fig. 6), and is opening at a the rate of ~5–6 cm/yr [23,25].

The third and western extensional system corresponds to the South New Hebrides Back-Arc Troughs. From gravity and bathymetry data, we infer that the northern and southern parts of these troughs, as well as the West Spreading Ridge (WSR), a newly identified structure extending inside the North Fiji basin, are connecting together in a kind of triple junction at 18°30′S and 169°45′E, northeast of Erromango Island (Figs. 1, 2 and 6). The directions of extension, inferred from bathymetric data (Fig. 6) and focal mechanism solutions (Fig. 4), are N–S on the eastern branch (West Spreading Ridge), NE–SW to ENE–WSW on the southern branch (Futuna Trough), and NNE–SSW to NE–SW on the northern

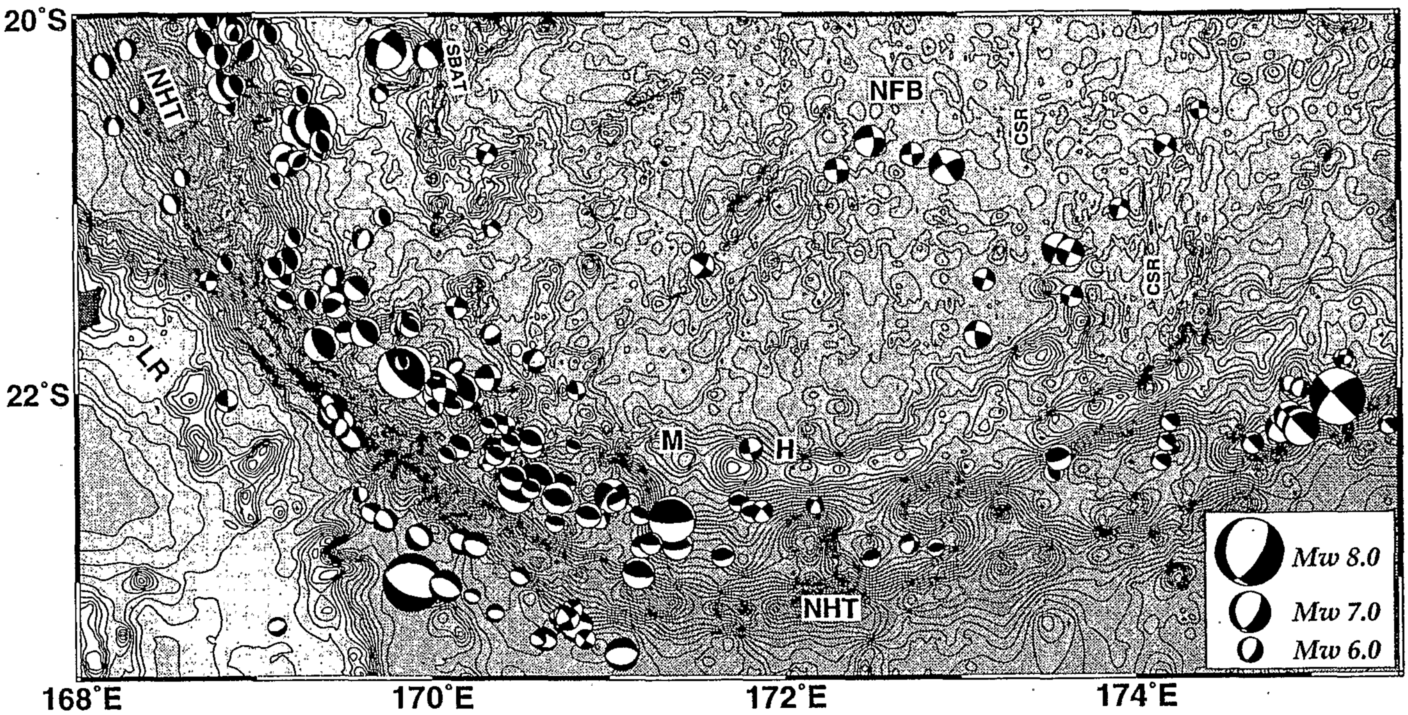

Fig. 7. Bathymetric map of the southernmost parts of the North Fiji basin and New Hebrides arc. Contour and grey scale intervals, and focal mechanism solutions as in Fig. 5. *NHT* = New Hebrides trench; *CSR* = Central Spreading Ridge of the North Fiji basin (*NFB*); *SBAT* = Southern New Hebrides Back-Arc Troughs; *LR* = Loyalty aseismic ridge. *M, H* = Matthew and Hunter islands.

branch (Vate Trough). Such directions of extension at the rear of the arc agree with the variation of the slip vectors azimuth and the counterclockwise deflection of slip vectors expected from Pacific–Australian motion at the New Hebrides trench (Fig. 3). The West Spreading Ridge centred on 18°45′S from 170°30′E to 171°30′E may be connected through a transform fault to an E–W ridge or rifting segment near 17°30′S 172°E, where normal fault earthquakes occur (Fig. 4). South of 20°S, the South New Hebrides Back-Arc Troughs migrate west toward the arc, change in direction to almost N–S, and end near 21°S in a volcanic area (Fig. 7). Taking into account that the total divergence rate in the southern North Fiji basin (~8–10 cm/yr according to magnetic anomalies) has to be in agreement with the convergence rate at the southern New Hebrides trench (~10–13 cm/yr from GPS measurements), the direction of convergence at the New Hebrides trench (~N66°E from seismicity and GPS data) implies that the extension at the South Back-Arc Troughs is fast (~5–6 cm/yr) and trends N–S to NE–SW, very obliquely to the arc. This conclusion assumes an E–W mean direction of opening on the Eastern and Central Spreading Ridges and no significant motion between the Australian plate and the Fiji platform. Better agreement with the actual direction of extension at the South Back-Arc Troughs (NE–SW to ENE–WSW), and a lower rate of back-arc extension (~3 cm/yr), result if some convergence and/or left-lateral strike-slip motion (~2–3 cm/yr) is considered to take place between the Australian plate and the Fiji platform along the Conway–Kandavu lineament, a structure currently assumed to be inactive.

The Loyalty aseismic ridge enters the southern end of the New Hebrides trench at 21°–22°S (Fig. 1). There, a significant variation of slip vectors azimuth from thrust-type earthquakes (Fig. 3) and a cluster of intra-arc strike-slip fault-type events at 22°S and 170–171°E (Figs. 4 and 7) suggest that the New Hebrides arc is fragmented by an E–W-trending left-lateral strike-slip shear zone [5,26]. GPS measurements of convergence confirm the presence of such a sinistral shear zone. Indeed the GPS convergence rate and azimuth are ~12–13 cm/yr and N246° at Tanna [10,11,13], while they are 5.7 ± 0.3 cm/yr and N203° at Matthew [13], which requires ~9–10 cm/yr of left-lateral motion along a E–W strike-slip fault zone. The precise location and geometry of such a shear zone are however still unknown. Strike-slip fault type events distributed along 22°S from 170°E to 172°E, and E- to ENE-trending prominent scarps at the rear of the Matthew–Hunter arc from 171°E to 174°E (Fig. 7) together suggest that the fault zone runs near 22°S from the trench to the southern end of the southernmost segment of Central Spreading Ridge. Besides, book-shelf tectonics and NW–SE extension may also occur along a broad shear zone across the arc and the southern North Fiji basin. Such a deformation is indicated by NE-trending ridges and troughs near 21°S 172°E (Figs. 2 and 6). The presence of NW–SE extension is also supported by a few earthquakes with normal fault component near 22°S 170.5°E. Whatever the precise process, it appears that the subduction of the Loyalty ridge is responsible for the inhibition of the westward component of the convergence motion south of the ridge–trench intersection, the fragmentation of the overthrusting plate and the rapid (~9–10 cm/yr) eastward displacement of the Matthew–Hunter platelet relative to the southern New Hebrides arc.

5. The central North Fiji basin and New Hebrides arc, and the D'Entrecasteaux ridge and West Torres plateau

The D'Entrecasteaux aseismic ridge enters the central part of the New Hebrides trench (Figs. 1 and 2). Its subduction is considered to be responsible for the anomalous morphology of the central New Hebrides arc [27]. There, in contrast to the rest of the arc, the direction of slip vectors matches the direction of Pacific–Australian motion as predicted by the NUVEL-1A model (Fig. 3). In addition, a zone of crustal shortening extends along the eastern margin of the central New Hebrides arc from 13°30′S to 16°30′S, in front of the subducting D'Entrecasteaux aseismic ridge and West Torres plateau [5]. Seismic activity is even higher along the eastern margin than along the western margin. GPS measurements indicate that the central New Hebrides arc (15°S to 16.5°S) slowly converges relative to the Australian plate (~4–5 cm/yr) and moves eastward relative to the southern New Hebrides arc along a dextral strike-slip zone [10–12]. Bathymetry, seismicity and GPS data suggest that a transverse-arc shear zone extends from the trench west of Vate Island to south of Epi Island at the junction area between the South New Hebrides Back-Arc Troughs and the central New Hebrides back-arc compressional zone (Fig. 1). From the mean GPS convergence rate of 4.2 cm/yr in the central New Hebrides, and assuming a total convergence rate of ~8.5–13.2 cm/yr and ~0.7 cm/yr of convergence taken as elastic strain accumulation, Taylor et al. [11] proposed that the relative eastward displacement of the central New Hebrides and back-arc shortening occur at a rate of ~3.6–8.3 cm/yr. It is interesting to note that the convergence rate of 13.2 cm/yr, inferred from drilling results on the D'Entrecasteaux ridge [28], equals the sum of the NUVEL-1A Pacific–Australian convergence rate at the central New Hebrides (8.5 cm/yr) and the spreading rate of ~4.7–5 cm/yr [23,29] derived from magnetic anomalies at the N160°-trending ridge north of the central North Fiji basin triple junction. However we propose that the present-day crustal shortening rate at the central New Hebrides back-arc is not likely to exceed ~5.5 cm/yr, because kinematic and geologic considerations suggest that the mean magnetically derived spreading rate at the N160° ridge is significantly higher than the present-day opening rate. The left-lateral strike-slip motion rate on the Fiji fracture zone northwest of the Fiji platform is ~8.5 cm/yr (the Pacific–Australian motion north of Fiji) and likely even higher if E–W spreading in the northeast North Fiji basin is taken into account (Fig. 1). This value implies a minimum residual strike-slip motion of approximately ~3 cm/yr along the complex boundary west of the 176°E triple junction, given a ~5.5 cm/yr opening rate at the East Spreading Ridge [23]. A maximum spreading rate of ~2 cm/yr on the N160° ridge is thus obtained, given a ~5 cm/yr opening rate on the Central Spreading Ridge south of the 16°50′S triple junction [23]. This gives in turn a maximum shortening rate of ~5.5 cm/yr at the rear of the central New Hebrides arc. A slow spreading at the N160° ridge is also suggested by its morphology (wide and deep axial graben [29]) and by the lack of R–R–R triple junction in the fully mapped area [30] between the N160°-trending ridge and the E–W trending Northern Spreading Ridge (Fig. 1). It should be pointed out that the development of the Fiji fracture zone and of the central North Fiji basin triple junction are contemporary with the d'Entrecasteaux ridge–New Hebrides arc interaction. The fracture zone and triple junction are also located at the same latitude as the southern end of the central New Hebrides back-arc compressive belt. The subduction/collision of the D'Entrecasteaux aseismic ridge reduces locally the convergence rate across the trench and produces arc fragmentation, eastward motion of the central segment relative to adjacent arc segments and underthrusting of the North Fiji basin crust below the central arc segment [5,10,11,27,28]. We propose moreover that the effects of the subduction/collision of the ridge are felt further in the back-arc basin in the form of a reorganisation of the pattern of accretion and a reduction of the spreading rate in the central part of the North Fiji basin.

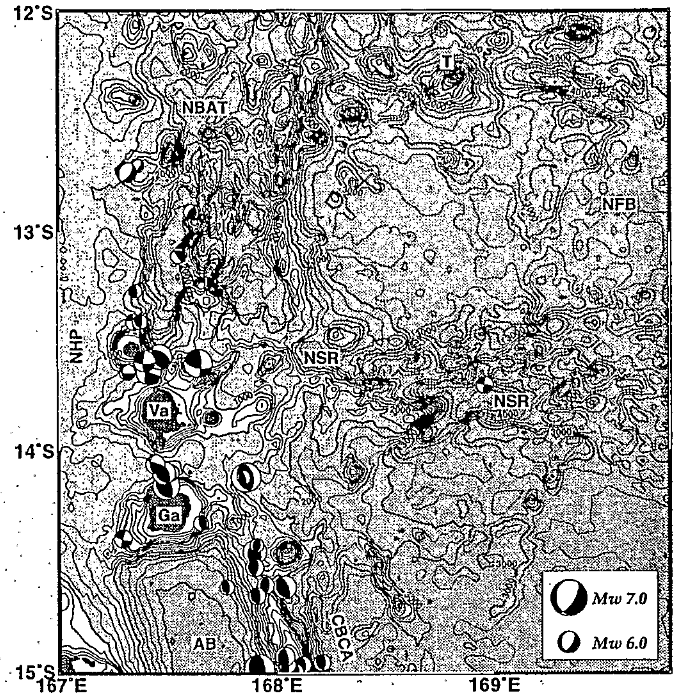

Fig. 8. Bathymetric map of the junction area between the North New Hebrides Back-Arc Troughs (*NBAT*), the central New Hebrides back-arc compressional belt (*CBAC*) and the North Spreading Ridge (*NSR*) of the North Fiji basin (*NFB*). Contour and grey scale intervals, and focal mechanism solutions as in Fig. 5. *AB* = Aoba basin; *NHP* = New Hebrides platform; *T, Va, Ga* = Tikopia, Vanua Lava and Gaua islands.

6. The northern North Fiji basin and New Hebrides arc

In the northern part of the North Fiji basin, accretion occurs along an E–W-trending, 1200-km-long slow spreading ridge known from west to east as the Hazel Holme [32], South Pandora [30,31] and Tripartite ridges [30,31]. Here, we call the whole structure the Northern Spreading Ridge. From a bathymetric and magnetic survey, Lagabrielle et al. [30] proposed that the central part of the ridge is opening at the very slow rate of ~1.6 cm/yr and that the eastern part possibly propagates eastward. However, the presence of a NE-trending trough, of which the signature is visible on the gravity map at 14–14°30′S and 179–179°30′E (Fig. 2), and of a NNE-trending neovolcanic zone, mapped from 16°S 178°40′E to 15°15′S 179°E north of the Fiji platform (the West Cikobia volcanic zone [20]), suggests that the North Spreading Ridge possibly ends eastward in a R–R–R triple junction (Fig. 1). The western end of the North Spreading Ridge intersects the New Hebrides arc at 13°30′S and 168°E (Fig. 8) in the junction area between the central New Hebrides back-arc compressive belt and the North New Hebrides Back-Arc Troughs [33]. Active or recent deformation may also occur (or has occurred) at the Tikopia trough [32], which extends east of Tikopia Island from 169°45′E to 169°E, parallel to the Northern Spreading Ridge. In line with the Tikopia trough and island, a large volcanic edifice near 12°15′S divides the North New Hebrides Back-Arc Troughs in two parts, suggesting a link between the structures of the North Fiji basin and those of the back-arc troughs.

The North New Hebrides Back-Arc Troughs domain widens and deepens northward [32]. Moreover normal fault type events with ENE–WSW *T* axes cluster at the deepest trough near 11°S and 167°E (Figs. 4 and 9), suggesting very active back-arc extension in the north. We propose that this extensional boundary crosscuts the New Hebrides arc at 10°30′S and is connected westward to the trench near 11°S and 164°15′E by a series of dextral transform faults and extensional relay zones (Figs. 1 and 9). Around 10°30′S, from 166°E to 167°E and between the Reef and Ndende Islands (Santa Cruz Group), the E- to ENE-trending Santa Cruz trough [32], together with strike-slip earthquakes at Ndende, suggest a right-lateral strike-slip fault zone at the northern termination

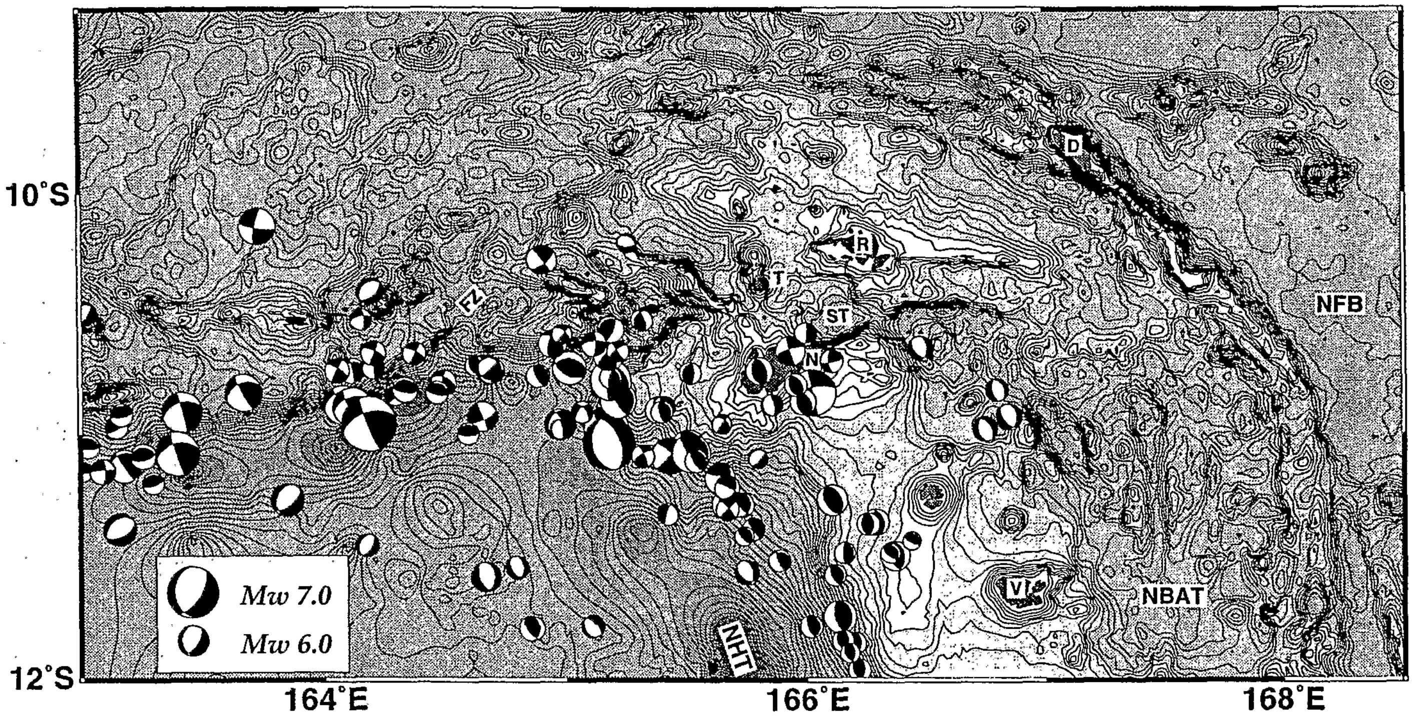

Fig. 9. Bathymetric map of the northern parts of the North Fiji basin and New Hebrides arc. Contour and grey scale intervals, and focal mechanism solutions as in Fig. 5. *NHT* = New Hebrides trench; *NBAT* = North New Hebrides Back-Arc Troughs; *NFB* = North Fiji basin; *ST* = Santa Cruz Trough; *FZ* = fracture zone; *D, V, N, R, T* = Duff, Vanikoro, Ndende, Reef and Tinakula islands.

of the back-arc troughs. NNE–SSW extension in the region 10°–10°30′S and 165°E–166°E is evidenced by a normal fault earthquake and WNW-trending ridges and troughs, on which the Tinakula volcano sits (the only active aerial volcano in this part of the arc). NE-trending scarps and strike-slip earthquakes indicate that a NE–SW right-lateral transform fault extends from 9°50′S 165°15′E to 10°50′S 164°15′E, and connects the northwestern end of the Tinakula extensional zone to the trench. In this arrangement the northern part of the New Hebrides platform is pushed westward. West of this transform fault zone and north of the trench, from 163°E to 165°E, bathymetry and seismicity data also suggest the occurrence of E–W to ENE–WSW sinistral motion associated with NW–SE extension (Fig. 9). The direction of extension in the North New Hebrides Back-Arc Troughs and the large deflection of earthquake slip vectors from predicted Pacific–Australian motion (Fig. 3) imply a high rate of extension in the back-arc (~6–8 cm/yr) at 11–12°S and a rapid convergence at the trench (~15–17 cm/yr).

7. Conclusion

Bathymetric data collected in the last decade improve our knowledge of the tectonics of the back-arc region between the Tonga and New Hebrides arcs, and indicate, together with earthquake distribution and focal mechanisms, a deformation distributed on numerous spreading ridges, instead of a diffuse and shear-dominated system as previously proposed [3]. However, in the tectonic map proposed here, several plate boundary segments end without connection and motion rates rapidly vary along plate boundaries, suggesting close Euler poles, rotations and intra-microplate deformation. Additional bathymetric data are required in some areas to confirm the inferred structures and to understand better the tectonic puzzle of this area, especially the southern North Fiji basin, the northernmost Lau basin and the region north of the Fiji platform.

The large variations in consumption rate along the Tonga and New Hebrides trenches, and in divergence rate as well as tectonic style within the Lau and North Fiji back-arc basins, are closely related to the subduction of aseismic ridges. Indeed slower convergence, across-arc strike-slip faulting, back-arc thrusting and slow or absent back-arc spreading occur where subducting aseismic ridges enter the trench (i.e., the Louisville, Loyalty and D'Entrecasteaux ridges). Rapid convergence at trenches correlates with fast divergence in back-arc basins. Parallel spreading ridges co-exist in the regions of maximum divergence (northern Lau basin and southern North Fiji basin). Even though back-arc tectonics is driven by general subduction processes, these relationships suggest that the specific subduction of aseismic ridge may play a significant role in the geometry (reorganisation) and the rate (reduction, acceleration) of the spreading in the back-arc basins.

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