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OBLIQUE SPREADING IN THE SOUTHERN PART OF THE LAU BACK-ARC BASIN (SW PACIFIC)

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ABSTRACT

The Lau Basin is an actively spreading back-arc basin in the S.W. Pacific area. It is located at the convergent Pacific/Indo-Australian plate boundary, between the Tonga arc and the Lau Ridge. Geological and geophysical investigations were conducted during the R/V *Jean Charcot* SEAPSO 4 (January 1986) and PAPNOUM (April 1987) cruises, to study oceanic spreading and hydrothermal processes in the Lau back-arc basin. Multibeam bathymetric, magnetic, gravimetric and single-channel seismic reflection profiles were recorded in the southern part of the basin between 19°S and 23°S, and particularly on the Valu Fa Ridge. Geological sampling by dredging was also carried out. The Valu Fa Ridge, which is one of the most prominent features of the area, extends over a length of more than 200 km, from 22°40'S to 20°50'S. North of 21°30'S, a secondary volcanic chain, previously described as far as 20°30'S, can be traced northwards to 19°05'S in an en-echelon relay position behind the Tofua active volcanic arc. Altered basalts impregnated with sulfides, and methane anomalies in the water column indicate hydrothermal activity along Valu Fa Ridge.

The spreading axis of the Lau Basin seems to be represented in the central area by N-S ridges without sedimentary cover. The flow lines of basin opening are defined by N 60° transform faults which offset the axis and are oblique to the axis trend. The Valu Fa Ridge, which was first interpreted after its discovery in 1982 as a back-arc oceanic spreading center, is here interpreted as a part of the Valu Fa System - a mega-transtensional structure which is accommodating migration of the active Tofua volcanic front of the Tonga arc system westward within the back-arc domain. We infer that the Valu Fa System formed from differential kinematic motion due to a geometric incompatibility between oblique basin opening defined by flow lines, the direction of Pacific plate subduction, and the east to east-southeast clockwise migration of the Tonga arc.

INTRODUCTION

The Lau Basin is located at the convergent boundary of the Pacific and Indo-Australian plates. It is a N-S elongated back-arc basin developed over more than 1000 km between the Tonga active subduction-volcanic arc system to the east and the fossil Lau Ridge arc to the west (Figure 1). Its width increases from less than 100 km near 24°S to 300 km around 16°S. The general V shape of the basin and its relatively shallow depth (2250 m on average) suggests that it was created recently by rotation of the Tonga arc (Hawkins, 1974).

The magnetic anomaly pattern, the elevated heat flow values, the roughness of the basement, the thinness of the sedimentary cover and the freshness of the tholeiitic

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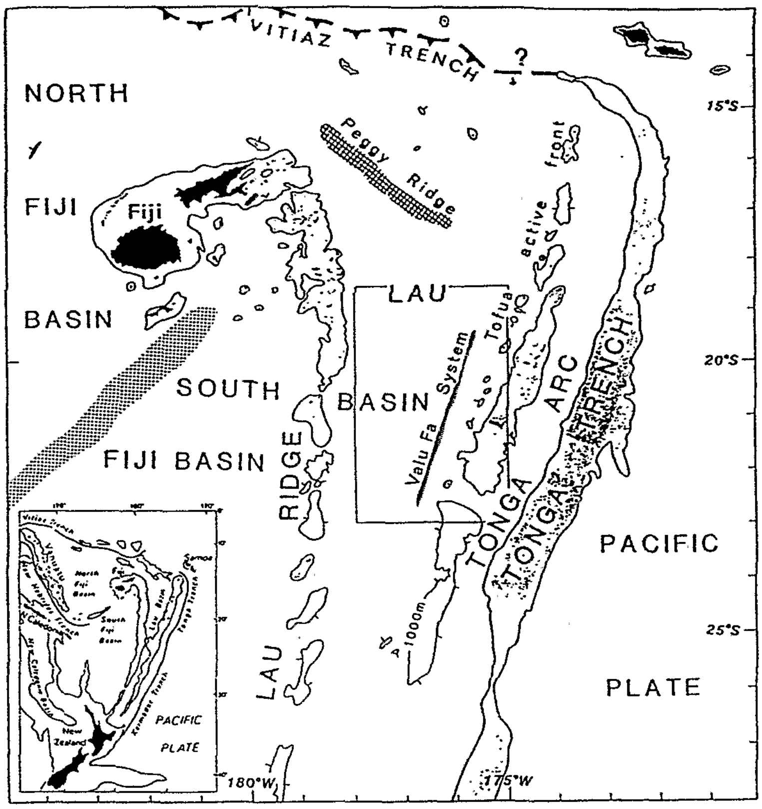

Figure 1. Geodynamic setting of the Lau back-arc basin (S.W. Pacific). The box is the studied area. Bathymetry sim-plified from Kroenke and others (1983).

basalts sampled, all point to the Lau Basin being an active spreading basin (Chase, 1971; Sclater and others, 1972; Hawkins, 1974; Hawkins and Melchior, 1985). Auzende and others (1988) have recently suggested that the opening of the Lau Basin is closely related to the last phase of evolution of the North Fiji Basin.

The authors who have interpreted the magnetic pattern, Sclater and others (1972), Lawver and others (1976), Weissel (1977), Malahoff and others (1979, 1982), Cherkis (1980) and Davagnier (1986), all agree with the existence of magnetic lineations parallel to the major trend of the basin. However they disagree on the interpretation of these lineations, and the age they give for the opening of the basin varies from 5 to 2.5 Ma. The seismic reflection data show a very rough basement covered with a thin sedimentary layer except in some southern and central areas (Katz, 1976; Larue and others, 1982), confirming the young age of the basin.

Most of the dredged rock samples are fresh tholeiitic basalts with MORB affinities (Hawkins, 1974, 1976; Gill, 1976; Hawkins and Melchior, 1985). Some dacites and andesites, dredged in the northeastern and the southeastern part of the basin, correspond probably to island arc contamination of MORB type basalts (Jenner and others, 1987).

Recently, in part related to ODP site surveying, several cruises have been carried out in Lau Basin: in 1982 and 1984 the R/V *S.P. Lee* cruises (USA-New Zealand-Australia Tripartite Project), in 1986 the R/V *Thomas Washington* cruise (USA), in 1985 and 1986 the R/V *Sonne* cruises (Germany), in 1986 and 1987 the R/V *Jean Charcot* cruises (France) and in 1988 the R/V *Charles Darwin* cruises (Great Britain). These cruises were performed with all the modern tools of oceanology, especially with multibeam echo sounder, single and multichannel seismic reflection, long range side-scan sonar (GLORIA) and different means of rock and water sampling.

We present here essentially the data from the two R/V *Jean Charcot* cruises (Figure 2): SEAPSO 4 and PAPNOUM (IFREMER-ORSTOM, 1986 and 1987). We also used the results of two older cruises: AUSTRADEC (CEPM-ORSTOM, 1976) and EVA 3 (ORSTOM, 1977). The studied area is contained between 18°S and 23°S.

STRUCTURE

The interpretation of the seabeam data and of the single-channel seismic profiles allows us to present an isochrone map of the acoustic basement (Figure 3) and a structural sketch map (Figure 4) of the southern Lau Basin. These maps show two main structural features in this part of the basin.

The Valu Fa Tectonic System

The first one is the Valu Fa Ridge. It is a volcanic system discovered during the first USA-New Zealand-Australia Tripartite cruise aboard the R/V *S.P. Lee* in 1982. On two multichannel profiles carried out around 22°S, a deep seismic reflector was described 1.5 sec TWT below Valu Fa Ridge. It was suggested by Morton and Sleep (1985) that this reflector could be the top of a 2 to 3 km wide magma chamber. During the R/V *S.P. Lee* cruise in 1984 this magma chamber was found to be 80 km long beneath Valu Fa Ridge. Valu Fa Ridge was therefore interpreted by these authors as the southern extension of the spreading system of the Lau Basin. Nevertheless, although the Valu Fa Ridge appears to be a strong tectonic feature of this area it does not display any present day seismic activity (Pelletier and Louat, 1989).

The Valu Fa Ridge was mapped in detail for the first time between 21°51'S and 22°42'S by the R/V *Sonne* in 1985 (Stackelberg and others, 1985). The ridge, striking N 15°, is divided into several segments, and some volcanic cones are built on its flanks. The samples dredged on the ridge are andesites and andesitic basalt while those obtained from the volcanoes are basalts with tholeiitic affinities.

A second segment of Valu Fa Ridge, located between 21°15'S and 21°40'S (Figures 2, 3 and 4), was mapped during the SEAPSO 4 and PAPNOUM cruises (Foucher and others, 1988). Within the mapped area the ridge strikes N 15° and is about 7-10 km wide and 200-500 m high. A sharp transition in the axial morphology occurs near 21°26'S. The ridge crest has a dome shape and is at a quite constant depth of 1900 m south of the transition zone (between 21°26'S and 21°40'S). To the north, its topography is more subdued (2000-2100 m) and there is a 100 m deep axial valley. On a broader scale, bathymetric and geophysical data gathered during the SEAPSO 4 and PAPNOUM cruises indicate that Valu Fa Ridge extends northward to 20°50'S. North of 20°50'S, the ridge disappears under the sedimentary cover, and a secondary volcanic chain, traced from 21°30'S to 19°05'S in an *en* echelon position, occupies the axis of the sedimentary trough between the Valu Fa Ridge and the Tofua volcanic arc. The en echelon relay transition zone characterized by the presence of both ridges is 55 km long and 24 km wide.

So, the Valu Fa Ridge appears to be only a part of a large tectonic system, which is 450 km long and composed of several ridges in en echelon relay position. We call this tectonic system the Valu Fa System, which is composed of the Valu Fa Ridge and the secondary volcanic chain. Striking N 15°, it extends from 22°45'S to 19°05'S and is very linear and straight. Initial observations show that the Valu Fa System, firstly, is parallel to the Tofua active volcanic chain and also to the main trend of the Tonga arc in this area, and secondly, seems not to be cut by major transverse faults.

Fresh looking glassy andesites were dredged along the Valu Fa Ridge crest while tholeiitic basalts were sampled on a seamount of the secondary volcanic chain (Foucher and others, 1988). A methane anomaly (20 nl/l) found near the sea bottom at the axis of Valu Fa Ridge suggests hydrothermal activity.

The Axial Ridge System of the Lau Basin

The second major structural feature exhibited by Figures 3 and 4 is a system, striking grossly N-S, found in the axial part of the southern Lau Basin, west of the Valu Fa System. This new structural trend is characterized by a succession of N-S elongated horsts and grabens covered by a thin sedimentary layer.

The transverse seismic section in Figure 5, located near 21°S, illustrates the general structure of the southern Lau Basin observed on all the available seismic lines. On the western end of the profile, is a ridge characterized by an elevated topography and a total lack of sedimentary cover. This ridge, that we assume to be the main active spreading axis of the Southern Lau Basin, is located in the axial part of the basin and centered on 176°30'E. On the profile the ridge is marked by a symmetrical double high, due probably to the existence at this place of an overlapping spreading center.

This axial ridge without any sedimentary cover is well defined topographically. It can be followed easily from line to line and extends from 18°50'S to 21°40'S. It shows a striking topography (Figure 5) and includes several overlapping segments similar to those described on the East Pacific Rise (Macdonald and others, 1984). Numerous N 60°-trending faults crosscut the N-S oceanic crust structural trends, then dissect each axial ridge segment into offset portions. The N 60° faulting is concentrated in two main areas, around 20°15'S and 22°S.

This ridge also shows a magnetic symmetry and seems to correspond to the location of a spreading axis creating the N-S magnetic lineations identified by Weissel (1977) and Larue and others (1982) in this southern part of the Lau Basin.

North of 18°S we have too little data to locate an active spreading axis. However, a N 20° ridge surveyed by the R/V *Sonne* (Stackelberg and others, 1985) could be the prolongation of the N-S spreading axis we described. Moreover, one hydrocast taken on the axial ridge (PAPATUA IV and V cruises, 1986) revealed large methane and manganese anomalies (H. Craig, pers. comm.) suggesting that this ridge like the Valu Fa one is the setting of active hydrothermalism.

The same N-S horsts and grabens are observed in the elongated basin located between the Valu Fa System and the Tofua arc as are observed west of the Valu Fa system. Similarly, Figures 3 and 4 also display N 60° transverse faults in this area. According to these observations, the Valu Fa System appears to obliquely cut the N-S structural trends of the central part of the Lau Basin, and to be a younger tectonic feature of the basin than the N-S structures.

In addition to the main structural features described above on the seismic profile of Figure 5, one should note:

- A relatively thick sedimentary layer (about 300 ms TWT, = 300 m) can be seen in the small basin located between the Tofua volcanic arc and the Valu Fa System. The basement in this area is affected by normal faulting and shows horst and graben topography.
- Valu Fa Ridge has very thin or no sedimentary cover. The ridge is here 10 km wide and appears as a 500 m high dome flanked by normal faults.
- A relatively thin sedimentary layer, which does not exceed 200 m can be seen in the large basin located west of Valu Fa Ridge. The horsts and grabens are very well expressed in the basement topography here.

DISCUSSION

Since its discovery Valu Fa Ridge has been interpreted as the main present day spreading axis of the southern Lau Basin (Morton and Sleep, 1985). Nevertheless, from the above structural analysis of the bathymetric and seismic data available for the southern Lau Basin, we wish to emphasize that the N-S axial topographic

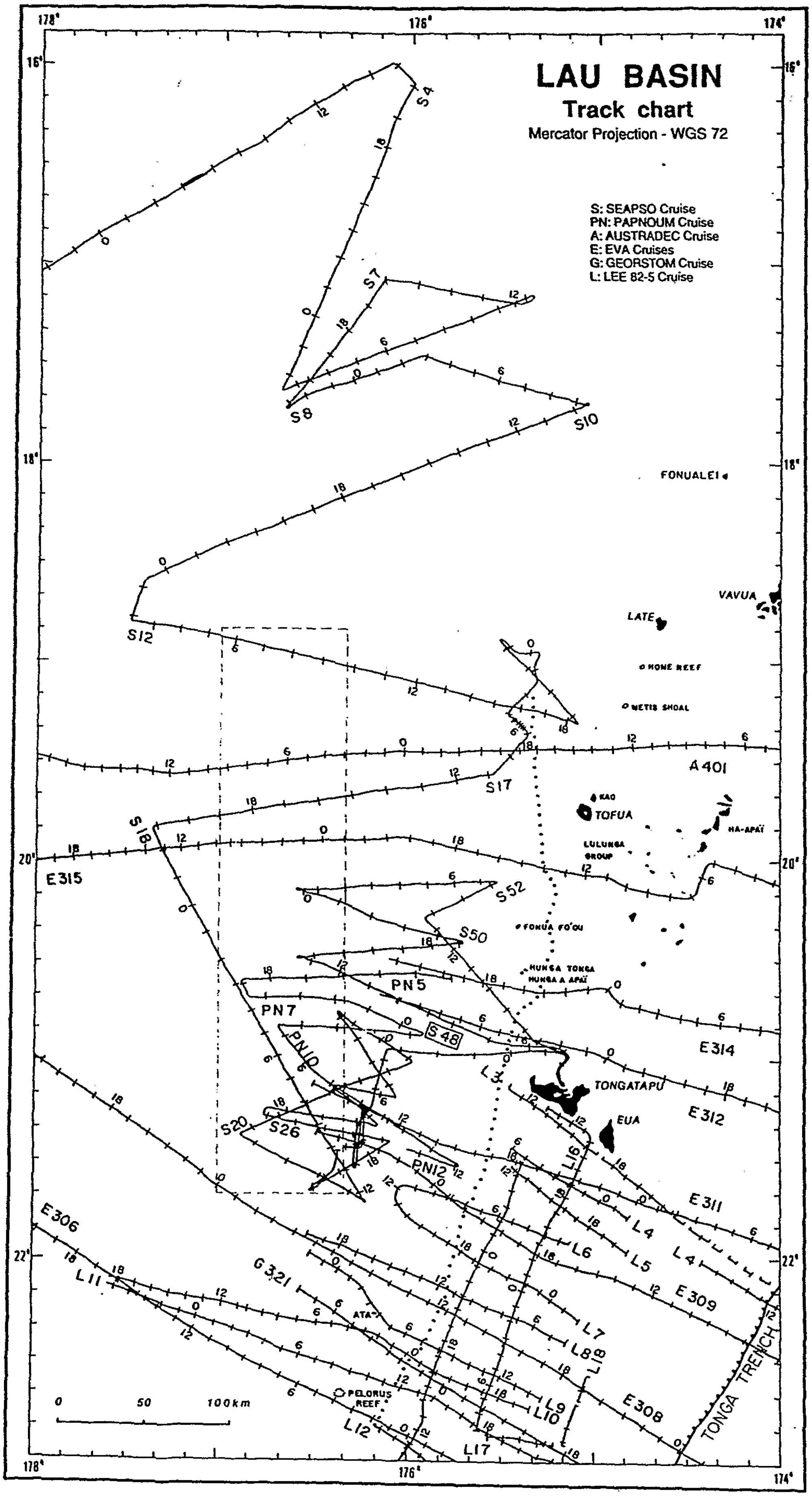

Figure 2. Location map of the cruises in the Lau Basin used for this work. SEAPSO 4 (S) and PAPNOUM (PN) tracks have Seabeam, seismic reflection and magnetic data. AUSTRADEC (A) and EVA (E) tracks have mainly seismic refle-ction data. Ship tracks of GEORSTOM (G) and LEE 82 (L) cruises are also given. The dashed rectangle indicates on each map the area where the spreading ridge of Lau Basin is located. The dotted line shows the eastern limit of the isochron map of Figure 4.

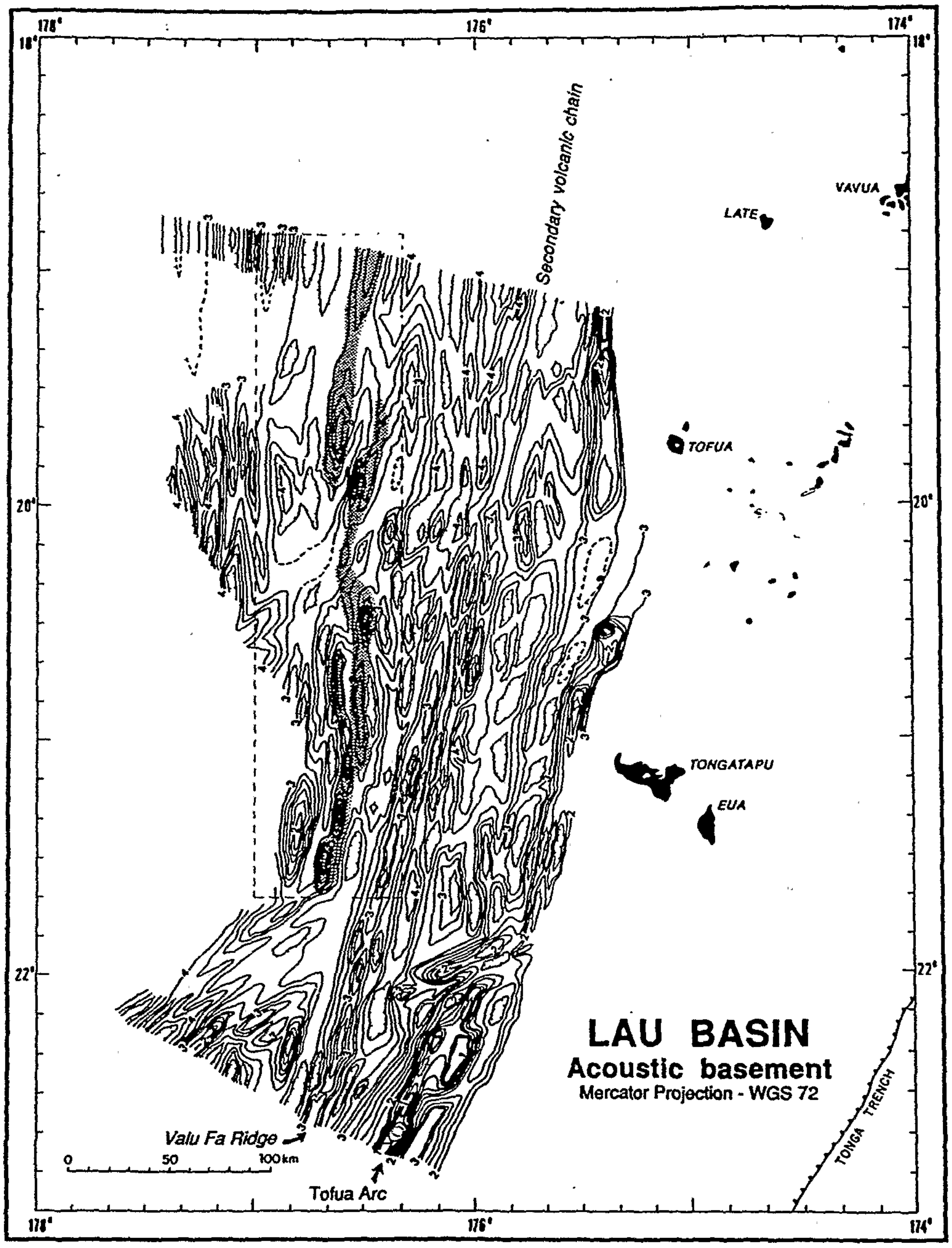

Figure 3. Isochron map of the acoustic basement in the southern part of the Lau Basin; the isochron values are in seconds TWT and the interval is 0.2 seconds. The dashed rectangle indicates the area where the spreading ridge of Lau Basin is located.

ridge located near 176°30'W can be interpreted as the main active spreading axis of the southern Lau Basin.

As a matter of fact, this ridge is continuous from 22°30'S to 18°S, except for small scale interruptions (overlapping spreading center, offsets, echelons, etc.), and is a symmetry axis for the morpho-structural lineations occupying the axial part of the Lau Basin.

On the other hand, as we have seen before, the arc, the N-S spreading axis, and the back-arc domains of the southern Lau Basin are affected by N 60° transform faulting (Figure 4). We assume that these faults define the flow lines of the opening motion of the basin (Figure 6). If this is case, the pole of opening of the basin must be located at the end of the radius trending about N 150°, joining the pole to the circle adjusted to the N 60° directions. However, the relative motion of the Tonga-Kermadec arc system with respect to the Lau-Coleville Ridge is of a sphenochasm type with a rotation pole located south of New Zealand, near 60°S-180° (Minster and others, 1974).

If so, the pole of opening determined from the N 60° structures cannot coincide with the pole of rotation of the Tonga-Kermadec arc (i.e. the rotation pole between the Pacific and Indo-Australian plates), whose radius is parallel to the subduction trench. There is a geometric incompatibility between the N 60° spreading motion in the back-arc basin and the eastward sphenochasmic rotation of the arc, unless the two motions are decoupled through dextral strike-slip faulting. In order to absorb the relative motion which, with time, becomes too large between the two systems, we suggest that this inferred strike-slip movement could have focused during the recent past (possibly for the last million of years) along the Valu Fa System which is character-

Figure 4. Structural map of the southern part of the Lau Basin. 1: normal faults manifested by scarps; 2: interpreted strike slip and transform faults; 3: ridge crests; 4: lows; 5: axial spreading area of the Lau Basin. The dashed heavy lines are inferred faults. The dashed rectangle indicates the area where the spreading ridge of Lau Basin is located.

ized by a great linearity and appears to be a more recent feature crosscutting an earlier N-S grain of the oceanic back-arc crust and its N 60° fractures. The apparent right lateral offset of N 60° faults observed on either side of the Valu Fa System supports this interpretation. At the beginning and during the first stages of oceanic opening of the Lau Basin, the geometric incompatibility would not have been so important and we can speculate that the right-lateral strike-slip movement was diffused within the arc and back-arc domains. Nevertheless, the horst and graben structure and the uplift of the Valu Fa System are not satisfactorily explained by strike-slip movement alone.

First, the horst and graben structure points to some approximately E-W component of stress. A possible interpretation of this extensional deformation would be in terms of an E-W to ENE-WSW regional extensional stress field induced in the vicinity of the Tonga arc by the subduction process itself. This extensional stress field could be also accentuated by velocity differences due to the obliquity between the directions of Pacific plate subduction and Lau Basin opening.

Secondly, this extensional deformation must have been sufficiently large to allow for the formation of a shallow magma chamber of considerable width under the ridge (Morton and Sleep, 1985). We postulate that thermal expansion associated with this extension and magmatism has induced the uplift of the whole Valu Fa System.

The parallelism between the Valu Fa System, the Tofua volcanic arc and the Tonga structural arc also suggests that these features are closely related, a relationship supported by the andesites and dacites dredged on Valu Fa Ridge. The Valu Fa System, interpreted here as a transtensional system lying just behind the arc, could have provided a zone of weakness favoring the rise of deep magma material and accommodating the most recent relative westward drift of Tofua arc volcanic activity into the Lau Basin.

CONCLUSION

To sum up, the axial topographic ridge, near 176°30'W, in the southern Lau Basin, has several characteristics making it the main spreading center active in this part of the basin. The Valu Fa System, on the other hand, can be interpreted as a right-lateral transtensional faulting boundary where the relative motion of the Tonga arc with respect to the axial back-arc basin has been absorbed in the recent past by a mainly right-lateral strike-slip movement. This new interpretation allows us to explain most of the observations on the whole southern Lau Basin and on the Valu Fa System, such as the lack of transform structures crossing the Valu Fa ridge, the mainly arc type volcanism, the shallow magma chamber and the asymmetry of the sediment thickness on either side of the ridge.

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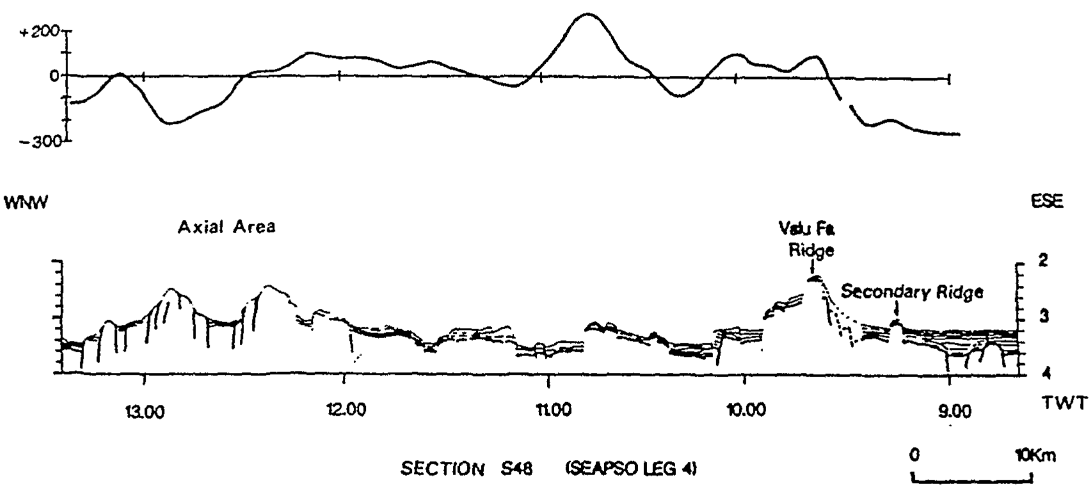

Figure 5. Interpreted single channel seismic section S48, from SEAPSO 4 cruise on board R/V Jean Charcot (See Figure 2 for location of the line).

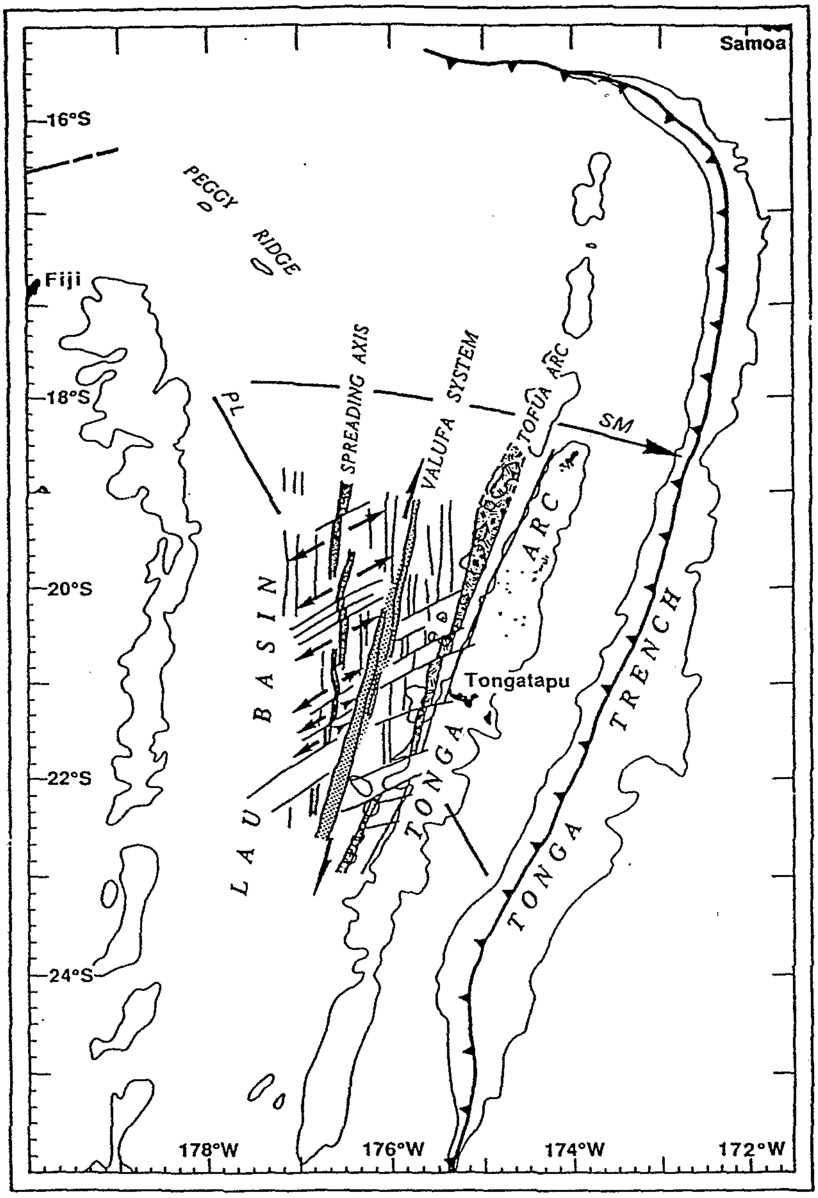

Figure 6. Interpretative tectonic sketch of the southern part of the Lau Basin. The whole Valu Fa System appears as a transtensional structure recording a N15-20° dextral strike-slip movement, roughly parallel with the Tonga arc. This particular tectonic stress is a consequence of an incompatibility between the oblique opening of the Lau Basin and the sphenochasmic rotation of the Tonga arc (SM). Thus, the Valu Fa System is considered as a zone of weakness allowing the formation of an underlying magma chamber and volcanism along the ridge. This could be interpreted as a new jump of the active volcanic front of the Tonga arc towards the Lau Basin. PL is the planar projection of the Eulerian rotation axis according to the flow lines of the Lau Basin.

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