TECTONIC ACTIVITY AND PLATE BOUNDARIES ALONG THE NORTHERN FLANK OF THE FIJI PLATFORM

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ABSTRACT

GLORIA imagery, Seabeam topography and shallow (< 60 km) seismic activity are used to infer the location and orientation of present day extensional and translational plate motions along the northern flank of the Fiji Platform. The multiplicity of regions of recent volcanic activity suggest that the loci of interplate motion have migrated rapidly since the switch from Vitiaz to New Hebridean subduction. At present the northern flank of the Fiji Platform is made up of two opposing sense strike-slip plate boundaries. The sinistral Fiji Transform Fault runs along the northwest flank of the platform and at least one or possibly two zones of dextral strike slip, including Peggy Ridge, run along the northeast flank. The present relationship of the latter to the Fiji Transform Fault in the west is not clear.

The Fiji Transform Fault exhibits east-west oriented sinistral strike slip motion which is offset by at least two extensional relay zones. These relay zones displace the Fiji Transform Fault to the north around the Fiji Platform.

On the northeastern side of Fiji, the principal plate boundary is Peggy Ridge, a currently active dextral strike-slip fault. West of Peggy Ridge, a series of conjugate dextral strike-slip faults oriented northwest-southeast lie along the northeast flank of the Fiji Platform adjacent to Cikobia Island. These faults are at the northern end of a belt of seismic activity which runs parallel to, but west of Peggy Ridge.

An assessment is made of the economic potential of the region and recommendations for further study are outlined.

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INTRODUCTION

The Fiji Transform Fault (FTF), often referred to as the Fiji Fracture Zone, lies along the northwestern flank of the Fiji Platform (Figure 1) and has a major role in the present day plate tectonic framework of the northern Melanesian Borderland (Auzende et al, 1988a) Sinistral motion along the FTF was first suggested by Isacks et al, (1969) based upon seismic activity, and was placed into a plate tectonic framework by Chase (1971). While the FTF has never been studied in detail it has been incorporated into almost all models of the present day geometry of Pacific/Indo-Australian plate interaction (e.g. Brocher and Holmes, 1985; Auzende et al, 1988a). The plate boundary, of which the FTF is a part, appears in most models as a simple zone of sinistral shear which links the eastward subduction beneath the New Hebrides Arc and the westward subduction beneath the Tongan Arc. Most models have shown the FTF as a single fault taking up this boundary motion from the North Fiji Basin (NFB) triple junction (Lafoy et al, 1990) to the northern Tonga Trench (Pelletier and Louat, 1989).

The northern flank of the Fiji Platform (Figure 2) was surveyed as part of a GLORIA study in offshore areas of five SOPAC member countries in order to examine the modern and relict seafloor fabrics which might indicate the history and present geometry of plate motion along this margin. Other survey areas are reported on separately.

The shift of subduction from the Vitiaz Trench to the New Hebrides Trench occurred between about five (Gill, 1987) and eight million years ago (Gill and Gorton, 1973). Models that both Falvey (1978) and Auzende et al, (1988a) proposed suggest that the necessary strike-slip motion between the Pacific and Indo-Australian plates was accommodated for at least the first seven million years along the Hunter Fracture Zone south of Fiji. Auzende et al, (1988a) suggested that the FTF has only been active for the last 0.7 Ma. If this were so, then assuming a strike-slip motion of about 10 cm per year (Minster and Jordan, 1978; Johnson and Sinton, 1990), the total translational displacement along the FTF system would be unlikely to exceed about 70 km.

Peggy Ridge, which lies northeast of the Fiji Platform (Figure 1), is believed to be either a dextral strike-slip fault along a 310'-oriented plane (Sclater et al, 1972; Parson et al, 1990), or a spreading axis (Chase, 1971). Parson et al, (1990) suggest that there is a component of extension across the fault, considering it a transtensional feature. The sinistral FTF and the dextral Peggy Ridge converge along the northern flank of the Fiji Platform which, until this study, had been poorly surveyed.

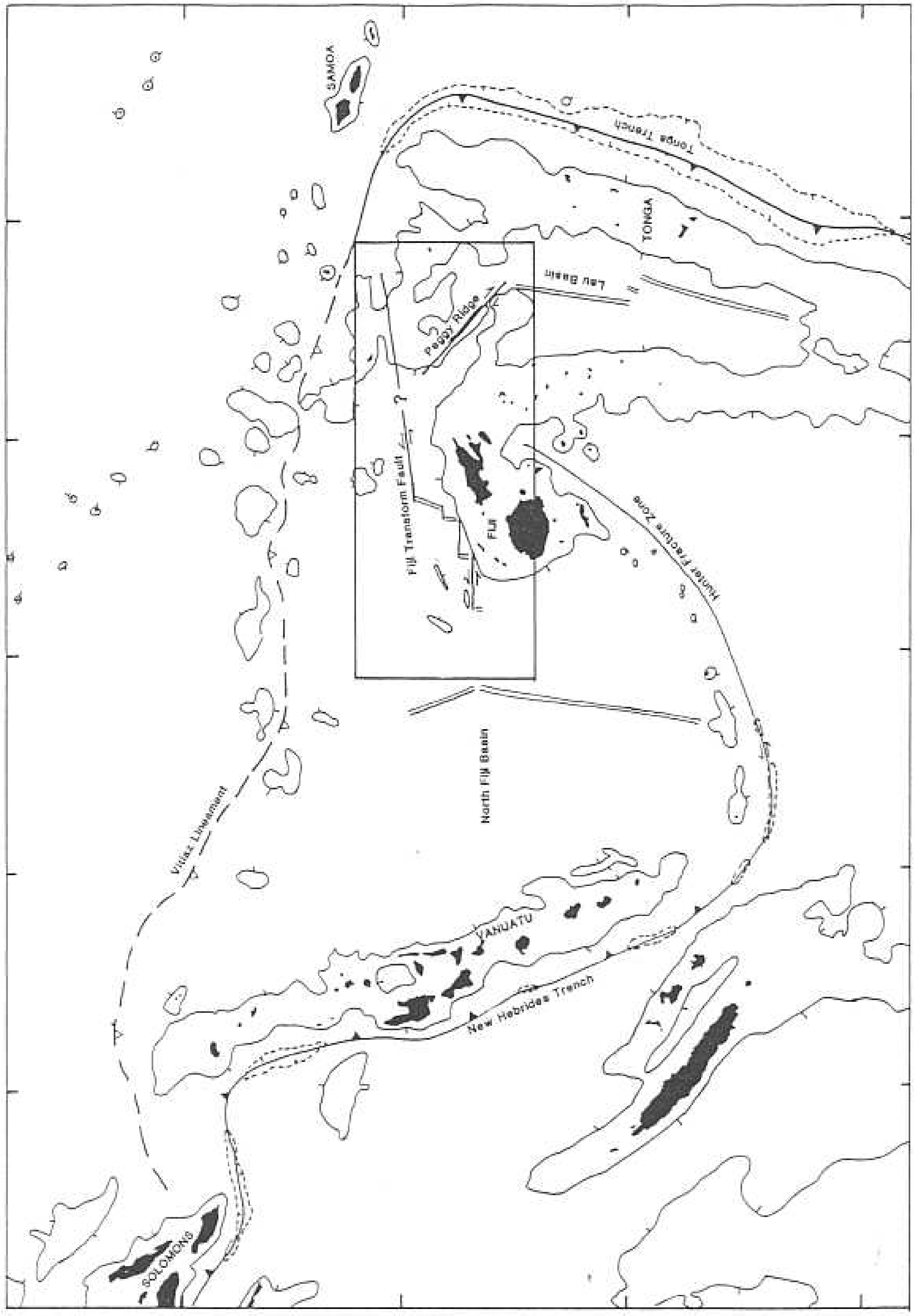

Figure 1. Regional topography and principal tectonic elements around Fiji. Thin line: 2000 m, dotted line: 6000 m. Bathymetry derived from ETOPO5. The box marks the study area of this report.

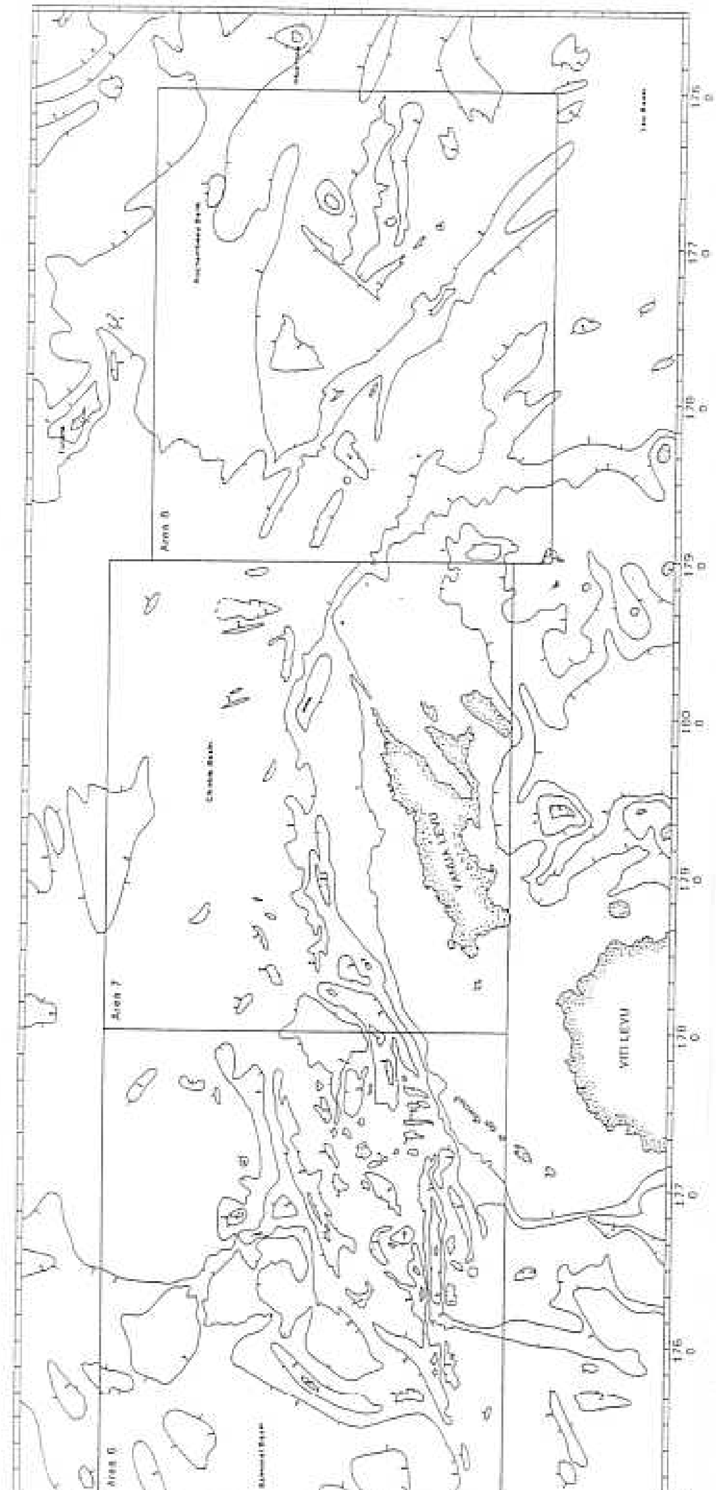

Figure 2. Bathymetry north of the Fiji Platform, contoured at 1000 m intervals. Bathymetry derived from data discussed in this report and extrapolated from Chase (1985). Areas 6, 7 and 8 refer to the three GLORIA mosaics used in this report.

During progressive plate geometry changes over the past 8 million years since the switch in subduction polarity, the Fiji Platform is believed to have undergone anticlockwise rotation (Malahoff et al, 1982). The palaeomagnetic data presented by Malahoff et al, (1982) indicate that the island of Viti Levu has undergone 90 degrees of rotation in the last 7 million years. Significantly, there is no indication that this sense of rotation has ceased at the present day, although if a least squares fit to the progression of rotation presented by Malahoff et al, (1982) is extrapolated, it indicates that the rotation may have slowed in recent times. In addition to the palaeomagnetic evidence for rotation, Auzende et al, (1988b) described a series of grabens located west of Viti Levu which they inferred is the result of dextral strike-slip motion from the anticlockwise rotation of Viti Levu.

DATA

GLORIA sidescan imagery (Somers et al, 1978), single channel seismic reflection and 3.5 kHz sub-bottom profiles, and Seabeam bathymetry was obtained in 1989 (Tiffin et al, 1989) along the northern flank of the Fiji Platform from the North Fiji Basin triple junction to Peggy Ridge in northwestern Lau Basin (Figures 3a, 4a and 5a). The GLORIA survey was designed to define seafloor tectonic fabrics indicative of plate motion geometry in a 50 km wide corridor immediately north of the Fiji Platform. This area was relatively unstudied, but high levels of seismicity have been recorded in the region, indicating active faulting.

The bathymetric database consists of two transits of Seabeam data along the parallel paths of the GLORIA swaths as well as limited archived earlier Seabeam data between 177' and 178'E (von Stackelberg and Schloten, 1990), standard bathymetric data archived at SOPAC, and SeaMARC II bathymetry of the Yasawa Trough area (Jarvis, 1991). A series of new bathymetric charts of the region (Figures 3b, 4b and 5b) have been compiled on the basis of these data sets and seafloor fabric trends identified from GLORIA. Where new information has been incorporated, these charts supplant parts of earlier charts prepared by the Mineral Resources Department of Fiji for the northern Fiji area.

A 160 cubic inch airgun seismic system was deployed along the trackline of the GLORIA survey, along with a 3.5 kHz sub-bottom profiler. Due to the size of the bubble pulse, source ringing, and hyperbolae from rugged bottom, the airgun seismic reflection profiles do not define

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'Please see Pages 28 to 42 for Figures 3 to 10 sedimentary deposits less than about 200 m thick. The 3.5 kHz sub-bottom profiles give information on sediment cover less than about 30-40 m thick.

BATHYMETRIC FRAMEWORK

The northern part of the main Fiji Platform is considered here to be the major topographic high which includes the two large islands of Fiji, Viti Levu and Vanua Levu, the smaller islands such as the Yasawa Group, and a series of reef-crested highs to the east (Figure 2). The 1500 m contour is a useful indicator of the approximate extent of the northern Fiji Platform.

Two deep east-west oriented troughs are developed adjacent to the northwest side of the Fiji Platform (Figure 3b). The Yasawa Trough west of Yasawa Islands is a linear deep about 130 km long and about 12 km wide. It has a maximum depth of 5000 m. On its northern flank is an unnamed, east-west oriented, high ridge that rises to within 1000 m of the surface and extends for 60 km beyond the western limit of the adjacent Yasawa Trough. The Yadua Trough north of the Yasawa Islands is oriented east-west in its western part, but turns to the northeast at its eastern limit. Its maximum depth is 4000 m. North-south trending fabric (Figure 3b) is clearly seen on the GLORIA data in the offset between the troughs, extending from the eastern end of the Yasawa Trough in the south to the western end of the Yadua Trough in the north. This inter-trough area was surveyed in detail with Seabeam by the German research vessel Sonne (von Stackelberg and Schloten, 1990). These data also clearly delineate the north-south trending bathymetry.

Three other conspicuous bathymetric highs are located north of the Yasawa and Yadua troughs. Bligh Ridge (Figures 3b and 4b) lies immediately to the north and west of the Yadua Trough within the range of the GLORIA swath. West of Bligh Ridge and outside the GLORIA coverage is Braemar Ridge (Figure 3b), oriented at 075' and separated from Bligh Ridge by several basins with depths exceeding 3000 m. Braemar Ridge rises to within 1000 m of the surface and extends for over 180 km. North of, and parallel to Braemar Ridge, is the Grampian Trough, up to 3500 m deep. The third ridge, Balmoral Ridge (Figure 3b), lies in a NNE-SSW direction and extends north of the western end of the Yasawa Trough. The southern end of Balmoral Ridge, the southwestern end of Braemar Ridge and the western end of the ridge immediately north of the Yasawa Trough all converge at 16' 35'S 175' 45'E.

On the north side of the Fiji Platform north of Vanua Levu, Cikobia Ridge and Sau Sau Ridge (Figure 2) are separated from the main platform by an unnamed 50 km wide trough exceeding 1500 m in depth and with a maximum depth of 3600 m south of Sau Sau Ridge. Cikobia Island sits atop the 120'-trending Cikobia Ridge north of the eastern end of Vanua Levu. Sau Sau Ridge (Figure 4b) is an east-west oriented feature that extends from the western end of Cikobia Ridge to the northeastern tip of Yadua Trough north of the western end of Vanua Levu. North of Sau Sau Ridge, an extensive region of low topographic relief herein termed the Cikobia Basin has a mean depth of about 2500 m. The eastern edge of Cikobia Basin is bounded by a 3000 m deep trough which widens from south to north.

East of Vanua Levu, Peggy Ridge (Figure 5b) is one of the major tectonic and bathymetric features in northwestern Lau Basin. This elongate linear feature, striking 310', shoals to less than 1000 m and extends from the central Lau Basin to at least 15'N, 178'40'W. The topography between the northern end of Peggy Ridge and the eastern side of Cikobia Basin is complex. This terrain, herein termed the Qelelevu Basin, is bisected by a conspicuous volcanic edifice rising to within 1000 m of the surface, notable on both GLORIA and bathymetric data. Forming the southern flank of the Qelelevu Basin, the east-west oriented Qelelevu Ridge (Figure 5b) extends eastward from the above volcanic edifice to Peggy Ridge.

GLORIA IMAGERY

The seafloor signature observed in GLORIA sidescan imagery is predominantly an expression of seafloor roughness (Mitchell and Somers, 1989). GLORIA imagery is particularly well suited to delineating steep scarps and discriminating between those regions of the seafloor which are mantled by unconsolidated sediment and those which consist of exposed volcanic rocks. The three main acoustic facies distinguished on the GLORIA imagery are: a dark grey image resulting from low backscatter, interpreted as sedimentdraped seafloors; a lighter image from moderate backscatter, interpreted as consolidated basement outcrop, usually on ridges; and high backscatter resulting in a light image, interpreted as either steep scarps or extrusive neo-volcanics.

Four conspicuous regions of bright reflections discerned from the GLORIA data, are identified as zones of extrusive neo-volcanism :

(a) an area with N-S trends between the the offset Yasawa and Yadua Troughs (Figure 3c) called here the Yasawa-Yadua Volcanic Zone (YYVZ).

(b) a NE-SW trending seafloor fabric west and northwest of Sau Sau Ridge (Figure 4c) named herein the West Cikobia Basin Volcanic Zone (WCBVZ).

(c) a N-S trending bright zone northeast of Cikobia Island (Figure 4c) with NW-SE fabric on its western side, called here the East Cikobia Basin Volcanic Zone (ECBVZ).

(d) a NE-SW trending extremely broad sheet of volcanism which extends from Peggy Ridge to the northeast (Figure 5c), called here the Northwest Lau Basin Volcanic Zone (NWLBVZ).

A fifth smaller zone of recent extrusive volcanism is identified at the western end of the Yasawa Trough corresponding to the northern limit of a north-south aligned, 3000 m deep trough which joins the Yasawa Trough at this point (Figure 3b).

The northern end of the zone of most intense volcanism in the YYVZ is clearly truncated along the southern flank of the Yadua Trough. While the southern end is not seen on the GLORIA image, available Seabeam bathymetric data (von Stackelberg and Schloten, 1990) suggest that it terminates against the base of the slope of the Fiji Platform at the eastern end of the Yasawa Trough. The seafloor fabric on either side of the central axis, which probably represents the most recent volcanic activity, is parallel (Figure 6a) indicating symmetrical spreading is taking place.

To the north of the Yasawa and Yadua troughs, the GLORIA image of the seafloor is dominated by regions of moderate backscatter interpreted to be exposed basement along topographic highs. These highs are interspersed with regions of low backscatter that correspond to sedimented depressions between the highs (Figure 3c). The southernmost limits of the Balmoral and Braemar ridges are brightly imaged areas interpreted to mean that they consist of exposed basement rocks.

The WCBVZ northwest of Sau Sau Ridge (Figure 4c), has a central axis shaped in the GLORIA image like a NE pointing arrowhead with the central volcanic axis broadening to the south. The zone in some respects resembles a NE propagating oceanic spreading centre, but with some complicating features. The fabric on either side of the central axis is not what would be expected from a propagating system. The fabric immediately to the west strikes at about 045' but farther west rotates back to 000. The fabric to the east strikes at 020' and appears to truncate along the axis of volcanic activity, or further east, against the base of Sau Sau Ridge.

A Seabeam profile across the northern part (Figure 6b) reveals that the fabric on either side of the axis consists of inward facing ridges with a relief of about 200 m. At the axis, the relief is subdued over a width of 4 km without any apparent fabric, but with small conical volcanic mounds (Figure 6b).

The main axis of the ECBVZ appears to be a 3000 m deep fault-bounded trough (Figure 4b) that widens to the north at an angle of about 45 degrees. While the bathymetric control north of the GLORIA data is very sparse, the shadow zone on the GLORIA image suggests that the trough deepens in that direction. The bounding faults consist of a pair of conjugate inward-facing scarps, the crests of which slope gently away from the trough. Within the trough a 315'-striking ridge parallel to the western margin shoals to less than 2500 m.

On the west side of the main axis lies a second 315' striking belt of tectonic activity (Figure 4c). This region of reflective linear fabric, like the main region of volcanism, lies within a down-faulted but narrower trough. Both this trough and the ridge within the main trough appear to be part of the 315- striking fabric which extends almost across Cikobia Basin (Figure 4c). In the west the 315'-striking fabric meets and truncates the 020' aligned fabric from the eastern side of the WCBVZ at about 179' 30'E.

Only a very sparse fabric exists in the region immediately to the east of the ECBVZ. Farther east within Qelelevu Basin however, strong 315'-striking fabric reappears (Figures 4c and 5c).

The northern flank of Sau Sau Ridge is insonified by GLORIA and appears at the southern edge of the image. The ridge is strongly reflective and areas interpreted to be lava flows emanate from it near 179' 30'E. The flows appear to pool on the floor of Cikobia Basin. Discontinous depressions are notable along the flank of both Sau Sau Ridge and Cikobia Ridge. The GLORIA image suggests more east-west linearity in the northern flank of these ridges than is apparent from the currently known bathymetry, but the bathymetry in this area is not well controlled.

Although this area is now not very active seismically, it may represent an older trace of the FTF. An east-west fault trace is apparent on the flank of Cikobia Ridge. This fault trace is consistently offset dextrally by 315'-striking fault ridges that parallel the fabric on the west side of the ECBVZ. A Seabeam profile across the intersection of the two fault traces (Figure 6c) shows both traces are strongly expressed in the bathymetry. Traces of the east-west fault appear to extend discontinuously across Qelelevu Basin (where they are also offset dextrally) as far as Peggy Ridge where the trace is imaged as a bright reflector herein termed Qelelevu Fault (Figure 5c). Where the fault trace extends across the Qelelevu Basin, it is defined by a series of discontinuous topographic depressions.

Within Qelelevu Basin, north of Qelelevu Fault, lies a large volcanic edifice about 8 km in diameter which rises to within **1000** m of the surface. The edifice is strongly reflective along its northern flank, implying recent volcanic activity. The edifice shows no preferred structural alignment and it appears to overprint the 315' fabric developed in the surrounding Qelelevu Basin.

Peggy Ridge appears as a band of strong reflectivity trending 307' in the SE and 300' in the northwest, traceable from 177'W, where it passes southward out of the range of the GLORIA, to 179'W, where it disappears north of the GLORIA corridor. It appears to cut across all other fabrics in the region. Volcanic edifices are discernable along the crest of the ridge, and there is a faint ridge-aligned linear fabric within the highly reflective ridge axis.

The NWLBVZ (Figure 5c) is a 40 km broad band of brightly reflective image trending 045'E from Peggy Ridge, interpreted to be a zone of intense volcanism with distinct internal fabric striking 045'. It lies almost orthogonal to Peggy Ridge. The Seabeam bathymetry across the zone (Figure 6d) shows a markedly subdued relief, unlike the pronounced lineated relief of the WCBVZ and YYVZ (Figures 6a and 6b). The volcanic axis of the zone intersects Peggy Ridge adjacent to the Qelelevu fault trace. The brightness of the GLORIA signal does not noticeably change across the NWLBVZ, indicating the backscatter is similar and suggesting there is little difference in age across its width.

PETROLOGY

The only seafloor samples reported in this region were collected by the RV Sonne SO35 expedition (von Stackleberg et al, 1985). Samples recovered within the Yasawa-Yadua Volcanic Zone include an extensive collection of fresh basalts and metalliferous hydrothermal deposits. Johnson and Sinton (1990) have shown that the basaltic rocks of this suite can be assigned to three groups. Type 1 lavas closely resemble normal mid-ocean ridge basalt (MORB) but have slightly higher Ba and Rb than is common. Type 2 lavas are more enriched than Type 1 in K_2O, Al_2O_3, Rb, Ba, and Zr and are isotopically distinct. They resemble enriched back arc basin basalts (BABB) such as those found in the Marianas and Lau back arc basins (Sinton and Fryer, 1987; Hawkins and Melchoir, 1985). Type 3 lavas are even more enriched and are similar to ocean island basalts (OIB) such as those of Hawaii and Samoa. All three basalt types were emplaced simultaneously in recent times at the north-south spreading centre and, in some cases, more than one of the types can be identified within a single dredge. This has been taken to imply that the mantle beneath the FTF is heterogeneous on a relatively small scale (Johnson and Sinton, 1990).

SEISMIC REFLECTION PROFILES

Seismic records reveal that sediment thicknesses on the seafloor between 175' 30'E and 177' 30'W rarely exceed 200 m. A thin sediment cover in parts of the central Cikobia Basin cannot be resolved on the single channel seismic profiles, and because the terrain is so rugged only hints of some pockets up to 15 m thick appear on the 3.5 kHz records. Seismically, there is little difference on the profiles between the basin area and the bare basalt on the crests of the ECBVZ and WCBVZ. Thicker sediments occur only to the west of Balmoral Ridge and east of Peggy Ridge.

The 3.5 kHz sub-bottom profiles exhibit predominantly hyberbolic echos of type IIIA and IIIB of Damuth (1980). Here, we interpret type IIIA echo character as basaltic lava exposed at the seafloor, and type IIIB as pelagic sediment draped over a rough basement terrain.

Type IIIA echo character is found in regions of high acoustic backscatter on GLORIA imagery. Such areas include the YYVZ, the WCBVZ, ECBVZ, Peggy Ridge and the NWLBVZ. Type IIIB echo character generally occurs in areas of low acoustic backscatter, probably corresponding to relatively thicker sedimented regions such as within the central Cikobia Basin, Qelelevu Basin east of the ECBVZ, and over much of the topography north of the Yasawa and Yadua troughs. In these regions some limited sub-bottom reflectors are visible on the profiles within the rough terrain.

Thick ponded sediments are only seen west of Balmoral Ridge, locally between Braemar and Bligh Ridges, and east of Peggy Ridge. Thick accumulations of sediment west of Balmoral

Ridge and east of Peggy Ridge are interpreted as indicating much older oceanic crust than in Cikobia and Qelelevu basins. Locally ponded sediments between Braemar and Balmoral ridges occur in 3000 + m deep basins and probably reflect higher sedimentation rates due to slumping of the surrounding highs, as was suggested by Cronan et al, (1981).

Of particular interest is a pair of basins at 16' 12'S, 177' 04'E and 16' 07'S, 177' 13'E. Seabeam and 3.5 kHz records indicate that these basins have both been infilled by slumped sediment to a level just below 3000 m. The ponded sediments have then been incised by 300 to 500 m deep troughs which lie on either side of the intervening high between the basins. This suggests that these depressions have recently been extensionally reactivated as pull-apart basins.

SEISMICITY

Various authors have presented epicental locations and motion studies of shallow earthquakes around the northern flank of the Fiji Islands (Isacks et al, 1969; Sykes et al, 1969; Johnson and Molnar, 1972; Eguchi, 1984; Hamburger and Everingham, 1986; Louat and Pelletier, 1989; Hamburger et al, 1990; Hamburger and Isacks, in press). The locations of all reported shallow epicentres in the ISC catalogue from 1963 to 1983 are presented in Figure 7. The principal epicentre clusters appear to be located:

- along the Yasawa/Yadua trough axes;
- around Qelelevu Island and extending to the southeast;
- along the axis of Peggy Ridge southeast of the Qelelevu Ridge intersection;
- diffusely around the Northwest Lau Basin Volcanic Zone;
- in a linear trend between Niaufo'oa Island and Rochambeau Bank, also trending southeast.

In addition, Hamburger and Everingham (1986) have shown that microseismicity is significant within the Fiji Platform itself, indicating that some deformation is being accommodated there. Specific loci of seismicity occur at the northeast end of Taveuni, where a strongly seismic zone lies close to the southeast trending belt of epicentres that trend southeast from Qelelevu Island. The zone is within the Fiji Platform and may be part of an unknown but crucial area where dextral southeast trending tectonics in the east meet the sinistral (?) northeast trending end of the Hunter Fracture Zone that swings northward after passing south of Fiji.

Aseismic zones include the seafloor to the north of the Yasawa and Yadua troughs (including Balmoral and Bligh ridges) and Cikobia Basin. Hamburger and Everingham (1986) point out that "the return period for major 'intraplate' earthquakes in this area may reach hundreds or even thousands of years. Thus a brief 'snapshot' of seismicity has a small likelihood of accurately representing the long term seismicity distribution". However, an earthquake of magnitude 6 was recorded in 1986, centred on Braemar Ridge.

Focal mechanism solutions have been derived for some epicentres and are presented in Figure 8. The principal motions described include:

- sinistral strike slip along the Yasawa Trough;
- sinistral ? strike slip along the Braemar Ridge;
- either east-west sinistral strike slip or north-south dextral strike slip adjacent to Qelelevu Island;
- sinistral strike slip to the northeast of the ECBVZ;
- dextral strike slip along Peggy Ridge.

The interpretation of strike-slip activity is often ambiguous and a pre-existing knowledge, or a preference of tectonic "grain", is required in order to choose one of two 'reasonable' strike-slip motions from focal mechanism data alone. Such preferences are commonly plotted (Eguchi, 1984) instead of the unbiased T-axis and/or P-axis plots. Thus a dextral strike-slip solution may also be taken as sinistral strike slip along an orthogonal plane if no other constraints are considered.

DISCUSSION

Sau Sau Ridge

Sau Sau Ridge and the parallel trough to the south suggest a strong tectonic lineament. Although only partially imaged by GLORIA in this survey, youthful looking volcanics suggest that the ridge may be still actively extruding. Minor seismic activity along the ridge, although much less frequent and more scattered (although this may be a function of the uncertainties of location) than along the FTF to the west, may support this observation.

Possibly Sau Sau Ridge and the traces of east-west oriented faults in Qelelevu Basin (including the Qelelevu fault trace) mark a former active path of the FTF along the northern edge of the Fiji Platform. Overprinting and offsetting of this fault fabric show that it is no longer active.

Balmoral, Braemar and Bligh Ridges

There have been few explanations for the presence of the Balmoral, Braemar and Bligh ridges which lie to the north of the modern FTF. Kroenke et al, (in press) attribute Balmoral Ridge to overthrusting at the western end of a now inactive fracture zone in Balmoral Basin to the north. Jarvis's (1991) model of the evolution of the WCBVZ also provides an explanation for the formation of both Balmoral and Braemar ridges. Like Bligh Ridge, he suggests that the other ridges were once attached to the Fiji Platform but have been rifted away through rift propagation into the arc lithosphere. This explanation implies that the three ridges originated as the product of island arc volcanism while still part of the Fiji Platform rather than being derived from backarc basin volcanism. It also implies that the sinistral FTF has been active for a good portion of the history of the North Fiji Basin. Thus, although some authors (e.g, Auzende et al, 1988a) argue that the FTF has only recently become active, Jarvis (1991) believes that the FTF has been active for a much longer time and has changed orientation from northeast to east-west through progressive, discrete jumps in its location.

An estimate of the age of Balmoral and Braemar ridges may be made using the model of Jarvis (1991) combined with the rate for rotation of Fiji given by Malahoff et al, (1982), assuming that the fault has jumped as result of rotation. Three other assumptions are necessary: (a) that the strike slip along the transform fault has always reflected the gross relative motion between the Pacific and Indo-Australian plates which itself has remained almost constant; (b) that the two ridges reflect the palaeo-orientation of the transform fault; and (c) that the two ridges have rotated along with the Fiji Platform.

Although the assumption (a) is questionable because spreading in the Lau and North Fiji Basins may have affected the movement on the FTF, the assumptions (b) and (c) appear to be reasonable. There is no evidence for asymmetric spreading between the ridges and the platform, suggesting that they have not rotated with respect to the platform.

Within the limitations of the above assumptions, the ages of the ridges can be estimated by comparing their mean strike with the strike of the present FTF and determining the age from the rate of platform rotation. The results give the age of Balmoral Ridge as 6 to 7 Ma, and that of Braemar Ridge as 2 to 3 Ma.

Focal mechanism solutions located along and to the south of Braemar Ridge (Hamburger and Isacks, in press), where there is relatively low seismic activity, indicate that there may still be some sinistral motion in this almost Inactive area. Seabeam and 3.5 kHz data provide evidence of extension in narrow pull-apart basins between Braemar and Bligh ridges, supporting the hypothesis of continued strike-slip activity in this region.

Yasawa and Yadua Troughs

The great relief and elongation of the Yasawa and Yadua troughs, and their intense seismic activity, strongly suggests that they represent an active plate boundary. Focal mechanism solutions clearly indicate that the Yasawa-Yadua trough/relay complex is undergoing sinistral strike-slip motions (Sykes et al, 1969). The northeastern end of the Yadua Trough, oriented as it is to the northeast, may represent a site of oblique extension rather than just translational motion.

The bathymetric expression of Yasawa Trough terminates westward near 176'E but focal mechanism solutions suggest sinistral strike-slip motion may continue even farther west. However, the GLORIA and seismic data clearly show relatively undisturbed and thick sediments west of 175' 30'E that continue west more than 100 km, as far as the eastern limb of the triple junction in central North Fiji Basin at 174' 30'E. There is no sign of sinistral strike-slip motion and very little sign of any tectonic activity in this region. Kroenke et al, (in press) postulate that the sinistral motion west of Yasawa Trough is taken up by north-south spreading which extends due south from the western terminus of Yasawa Trough. The GLORIA data clearly reveal recent volcanic activity at this point, lending strong support to this model.

Yasawa-Yadua Volcanic Zone (YYVZ)

Using data collected by the RV Sonne in 1985, Johnson and Sinton (1990) interpreted the north-south trending fabric across the YYVZ to be analogous to a transform relay zone. They also calculated from available pole of rotation data that the slip on the FTF is 9.5 +-0.7 cm/yr with azimuths between 265' and 273'. The GLORIA data confirm that the YYVZ is a relay zone similar to those described by Fornari et al, (1989). Fox and Gallo (1984) suggest that such relay zones are characteristic features of medium to fast slipping transform faults (i.e. rates between 6-18 cm/yr). If we assume the slip rate of 9.5 cm/yr applies also for the relay zone, then by measuring its offset width, we can estimated the age of the YYVZ. The GLORIA data show an offset of 25 km, with the FTF displaced northward relative to the western Yasawa Trough segment. This gives an age of about 260,000 years.

West Cikobia Basin Volcanic Zone (WCBVZ)

The axis of the WCBVZ is a slightly positive ridge, and the GLORIA image shows sub-parallel fabric extending from both sides. The brightness of the GLORIA image decays away from the axis, suggesting increasingly thick sediments, and inferring an aging basaltic seafloor. The WCBVZ thus has the primary attributes of a spreading ridge. The asymmetric fabrics and the truncation of fabric at the axis of volcanism suggest that in addition to extension, a component of rotation has occurred.

Jarvis (1991), using these GLORIA data, has interpreted the WCBVZ as an extensional relay similar in character to the YYVZ. Citing the observed orientation of spreading fabric as evidence for propagation, and noting the proximity of the southern end of the neovolcanic zone to the northern end of the Yadua Trough, he has proposed a model suggesting that the WCBVZ has propagated into the Fiji Platform, slicing off Bligh Ridge. While the fabric of YYVZ is ridge-parallel, indicating spreading orthogonal to the ridge axis, the fabric of the WCBVZ is highly arcuate and does not parallel the present neovolcanic axis. Older fabric also does not extend as far south as the neovolcanic zone. While recent volcanic activity is observed along the WCBVZ axis down to 15' 55'S, the older fabric terminates at 15' 30'S, suggesting a recent rotation and elongation of the spreading axis.

Figure 9 shows the proposed model of Jarvis (1991) for the development of this area. Jarvis also suggests that an active section of the FTF was originally located north and west of Bligh Ridge, which at that time was part of the Fiji Platform (Figure 9).

East Cikobia Basin Volcanic Zone (ECBVZ)

Unlike the YYVZ and the WCBVZ, the ECBVZ is a negative bathymetric feature and is notably asymmetric. The area of axial volcanism expands rapidly to the north suggesting interplate rotation, but there is no fabric within the axial volcanic zone. Outside of it, the fabric is entirely oriented at 315'. This suggests that rotation is probably not involved.

The 315'-oriented linear scarps seen prominently to the west of the axial zone pervasively extend from 179' 30'E to Peggy Ridge. They offset, and are thus younger than the east-west oriented fault traces that extend from the north flank of the Sau Sau Ridge to Peggy Ridge. The 315'-oriented fabric may represent a broad, diffuse zone of dextral strike-slip motion which extends around the northeast flank of the Fiji Platform. However, the northwestern part of Peggy Ridge itself appears to cut the 315'-trending fabric, suggesting it is an even younger tectonic feature of the region, and inferring a recent reshuffle of the plate boundaries. Therefore, another interpretation is that the ECBVZ is a zone of extension that has propogated southward and is now reaching into the northern Fiji Platform just north of the small island of Vetauua.

The eastern boundary of the ECBVZ is almost orthogonal to the northern extension of Peggy Ridge. It is on the wrong side of the ridge to act as a relay zone. The eastern boundary is a steep, 1200 m high fault scarp that separates an area of sediments on the east that appears to be older than much of the area north of Fiji, from young-looking volcanics in a 3000 m deep trough marking the axis of the ECBVZ. Although there is no associated fabric outside of the axial area to the east, the axial area appears to cut the 315' trends to the west. Some of these older faults close to the propagator may have been reactivated during the more recent activity and now appear to have young volcanics associated with them.

The ISC data (Figure 7) clearly indicate a second trend of epicentres which lie along the northeast flank of the Fiji Platform parallel to but west of the epicentral trend at Peggy Ridge. The northern part of this second epicentral belt includes the strike-slip solutions north of Qelelevu Island presented by Eguchi (1984). Although Eguchi preferred an east-west sinistral strike-slip motion for these focal mechanisms, on the basis of the cross-cutting seafloor fabrics, a 315'-oriented dextral strike- slip motion would be equally acceptable, and indeed, in our opinion, preferable.

Peggy Ridge

The southeastern end of Peggy Ridge has been studied by GLORIA (Parson et al, 1990) and interpreted to be a leaky transtensional ridge exhibiting dextral motion. The northwestern part of Peggy Ridge imaged in this survey is much narrower than in the southeast, suggesting that translational rather than extensional tectonics dominate here. The high positive relief, young volcanism and cross-cutting nature of Peggy Ridge confirm it as a currently active leaky fault. The northwestern end of the fault trends slightly more to the west than the southeastern part.

Focal mechanism solutions along Peggy Ridge south of the Qelelevu Ridge intersection indicate that the ridge is undergoing dextral strike slip (Eguchi, 1984). A focal mechanism solution for the northern end of Peggy Ridge (Eguchi, 1984) may also be interpreted as dextral strike slip. The density of seismic epicentres, however, notably declines along the ridge north of the intersection with the NWLBVZ. We suggest that fast spreading across NWLBVZ is currently taking up most of the strike-slip motion along Peggy Ridge and is thus effectively acting as an extensional relay. This has resulted in less seismicity along the northwestern section of Peggy Ridge.

Northwest Lau Basin Volcanic Zone (NWLBZ)

On the basis of the broad neovolcanic zone and subdued relief, the NWLBVZ is interpreted as a fast spreading axis. The lack of partially buried fabric across the width of the zone implies that spreading was initiated only recently. If a characteristic spreading rate for fast spreading centres is used (e.g. 20 cm/yr), then the age of the NWLBVZ can be estimated at about 200,000 years. East of the zone, the GLORIA image suggests the presence of thick sediments indicating that the crust to the east was formed by another process.

SUMMARY

New GLORIA imagery reveals complex tectonic terrains north of the Fiji Platform. From these data, together with bathymetry, recent seismicity, and geometry of recent volcanic activity, two opposing translational plate motions appear to predominate. Sinistral motion along the FTF in the west clearly approaches close to the Fiji Platform along 16' 45'S, but is successively offset to the north around Fiji by at least two extensional relay zones. In contrast, on the northeast flank of the Fiji Platform, there appear to be at least two parallel belts of dextral strike-slip motion. The easternmost is at Peggy Ridge, a welldefined bathymetric high with recent extrusive volcanic activity. The western belt is much more diffuse along the northeastern edge of the platform margin, and is expressed by a series of conjugate faults without significant bathymetric or volcanic signature, but clearly seen on the GLORIA data. The FTF and these twin dextral fault zones meet just north of the region covered in this GLORIA survey.

The orientation of Sau Sau Ridge, the east-west Qelelevu fault trace, and the trough to the south, all suggest that at some time in the past the FTF may have extended along this latitude. The low level of seismicity along Sau Sau Ridge, the overprinting of the east-west oriented fault traces with crosscutting fabric, and the fact that Peggy Ridge truncates the Qelelevu fault trace, all indicate that this region is no longer active as a sinistral transform fault.

More than one focus may be responsible for the sinistral strike-slip motion through the region northeast of Fiji. Given the youth of this transform zone and the history of rapidly changing backarc tectonism and plate geometry (Parson et al, 1990; Auzende et al, 1988b), some motion could equally well be accommodated through a combination of left-stepping relays through Yasawa and Yadua Troughs, minor sinistral motion along Braemar Ridge, and continued activity along the Sau Sau fault trace. The poor definition of the FTF east of the Fiji Platform probably reflects the complexity of the area caused by changing boundary conditions over the past five million years since the opening of Lau Basin, and is also exacerbated by a lack of good bathymetric and other data.

Indirect methods have provided an estimate of the age of the major tectonic elements. The West Cikobia Basin Volcanic Zone and the Yadua and Yasawa troughs are younger than Braemar Ridge. Auzende et al, (1988a) have postulated a major plate reorganisation at 0.7 Ma and the Yasawa-Yadua Volcanic Zone and Northwest Lau Basin Volcanic Zone both postdate this (0.2 - 0.3 Ma). The time of initiation of Peggy Ridge, the East Cikobia Basin Volcanic Zone,

Sau Sau Ridge and the Qelelevu Fault trace all remain unconstrained. However, a tentative relative chronology may be established. Since the 315'-trending fabric of the ECBVZ offsets the Qelelevu Fault trace, it must be younger than that fault. As Peggy Ridge appears to cut the 315' trends in the northern Qelelevu Basin, it is therefore younger than the ECBVZ. In fact, the northwestern end of Peggy Ridge appears to be a young feature in the area, compared to the surrounding seafloors, and may even be younger than the more mature southeastern end. The eastern boundary of the ECBVZ which is nearly orthogonal to Peggy Ridge may be a transfer zone between the western end of Peggy Ridge and the area of seismicity near Qelelevu Island. The NWLBVZ must have appeared at the same time, or later, than Peggy Ridge.

A reconstruction would have early sinistral strike-slip activity along the Sau Sau-Cikobia Ridge axis, replaced later by a diffuse zone of dextral strike-slip across the northeast flank of the Fiji Platform. This in turn was replaced, or focussed into the modern Peggy Ridge. Part of the dextral motion along the northwestern segment of Peggy Ridge has been recently offset dextrally across the NWLBVZ. Our interpretation of the present tectonic framework as indicated by the present data is shown in Figure 10.

ECONOMIC POTENTIAL

Hydrothermal Mineralisation

The four principal volcanic zones (YYVZ, WCBVZ, ECBVZ and NWLBVZ) are all potential sites for modern hydrothermal sulphide accumulations and the German research vessel Sonne did in fact recover hydrothermal material from the YYVZ in 1985 (Johnson and Sinton, 1990). However, water depths of 2000 m or greater cover these areas and make it unlikely that they would become economically viable within the forseeable future. The shallowest region of apparent volcanism appears to be the crest of Peggy Ridge which locally rises to within 1000m of the surface. No hydrothermal deposits have yet been found there.

Cronan et al, (1981) noted enhanced manganese and iron concentrations (up to 11 % Fe and 2 % Mn on a carbonate free basis) in surficial sediment cores recovered from Braemar Ridge and Bligh Ridge immediately to the north of the present survey. While the reported concentrations exceed those of normal pelagic sediments in the Southwest Pacific, Cronan et al, (1981) concluded that there was no evidence for local hydrothermal activity. Rather they attributed the enhanced levels to local terrigenous influx from the Fiji Islands through aeolian transport mechanisms.

Hydrocarbons

The lack of significant sediment accumulations greater than 200 m thick in this region rule out any likelihood of hydrocarbon deposits within the area surveyed.

Manganese Nodules

Cronan (1984) has defined three main criteria which appear to govern the location of potentially economic manganese nodules: elevated biological productivity; depths near or below the calcium carbonate compensation depth (CCD); and low sedimentation rates. The area covered in this survey lies south of the main equatorial belt of high surface biological productivity and depths only locally exceed 2500 m, well above the CCD. While sedimentation rates are unknown in the region under consideration, cores in the nearby North Fiji Basin show sedimentation rates there are between 3 and 14 m/Ma (Brocher et al, 1985). Such sedimentation rates are marginal or too high to expect preservation of manganese nodules of economic significance (Cronan, 1984). These factors all rule out the presence of economic manganese nodule resources in the study area.

RECOMMENDATIONS FOR FUTURE WORK

While the GLORIA imagery has illuminated several previously unknown structural elements, especially to the north of the Fiji Platform, and amplified upon many known ones, there remain several unanswered problems. In order to gain a better geometric picture of the region it is necessary to expand the sidescan coverage, especially in three regions:

(1) North of Cikobia Basin and along Rochambeau Bank. This would establish the limits of the active FTF trace northward beyond the GLORIA coverage. It would also help to define the link between the FTF, the Northwest Lau Basin Volcanic Zone, Peggy Ridge and the Tonga Trench.

(2) South of Sau Sau Ridge and Cikobia Island and around the flanks of the Qelelevu Island margin. This would clarity the nature of the Sau Sau Ridge fault trace and whether it is still active, and would also define the extent of dextral strike-slip motion along the northeastern flank of the Fiji Platform.

(3) In the Taveuni-Rabi area east of Vanua Levu. This would resolve the tectonics of this part of the Fiji Platform where there is a high level of seismicity, and determine the relationship of this seismicity to that of the region just north of the platform.

In addition, three other important objectives should be:

- to examine the petrology and date the activity of the various recent volcanic elements through dredging.
- to undertake marine magnetic surveys across the sites of recent volcanic activity in order to define their spreading history.
- to test the various areas of volcanic activity for associated hydrothermal sedimentation, especially the NWLBVZ.

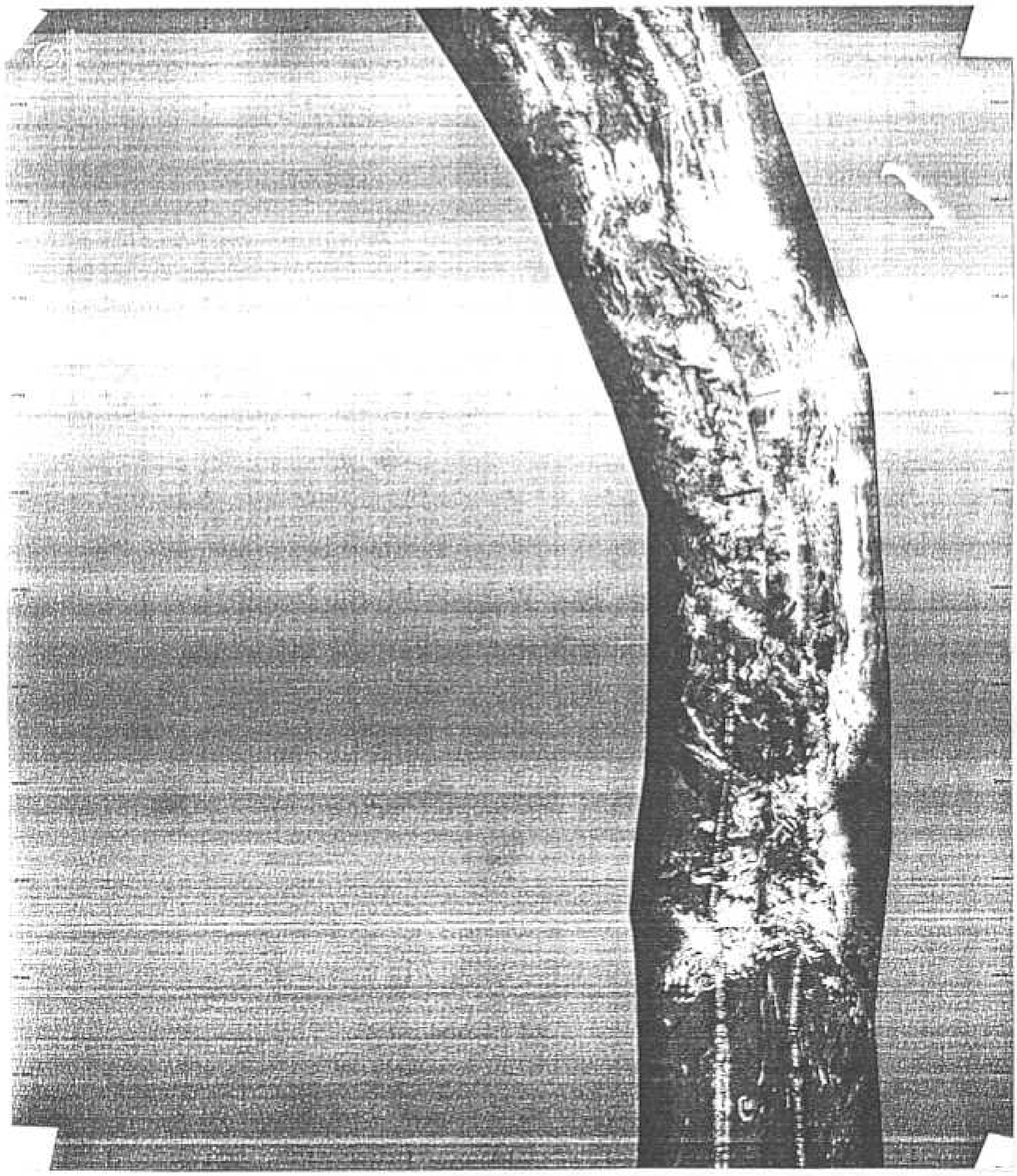

Figure 3a. GLORIA mosaic of Mosaic Area 6.

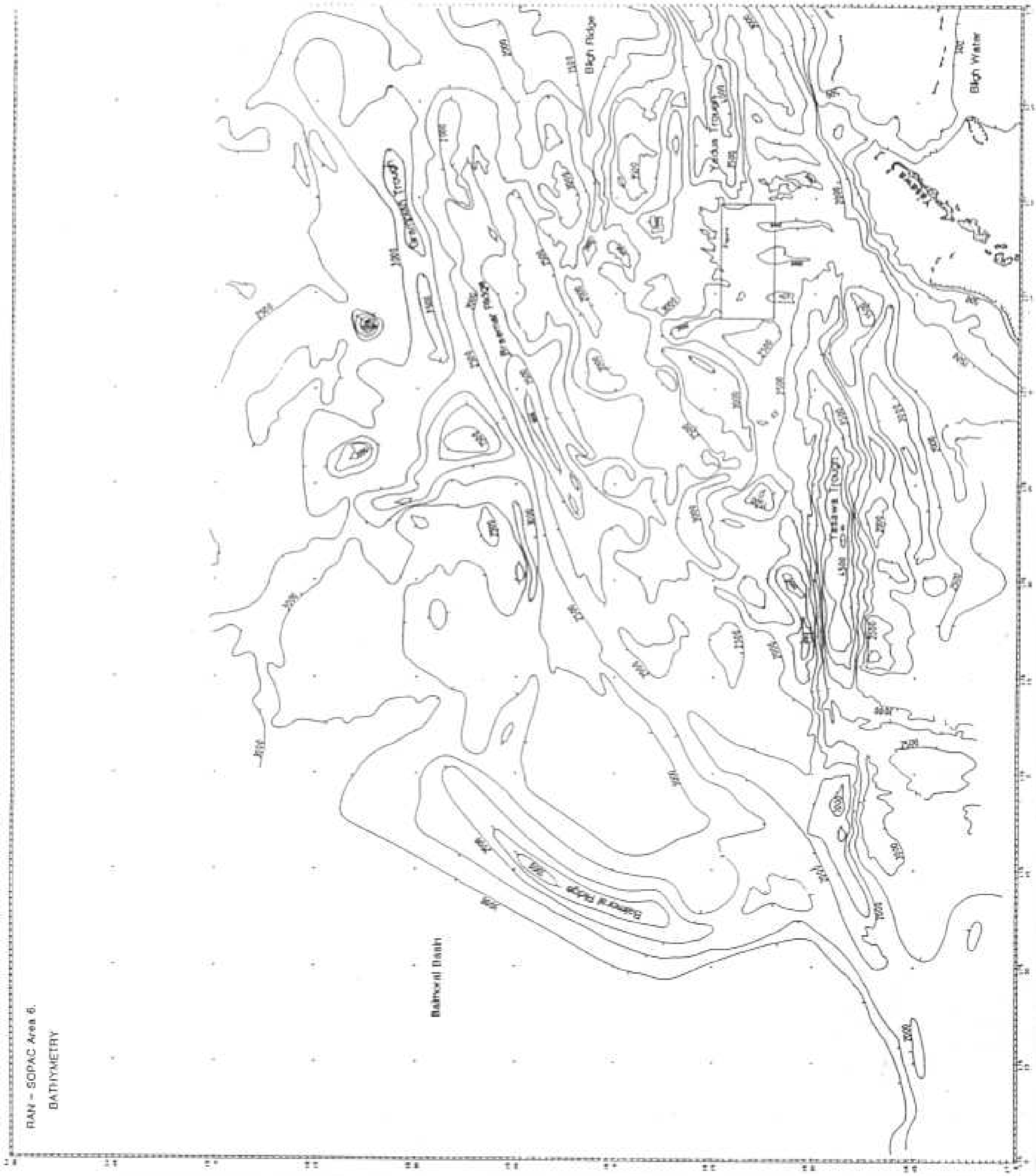

Figure 3b. Bathymetry of Mosaic Area 6, same scale as Figure 3a.

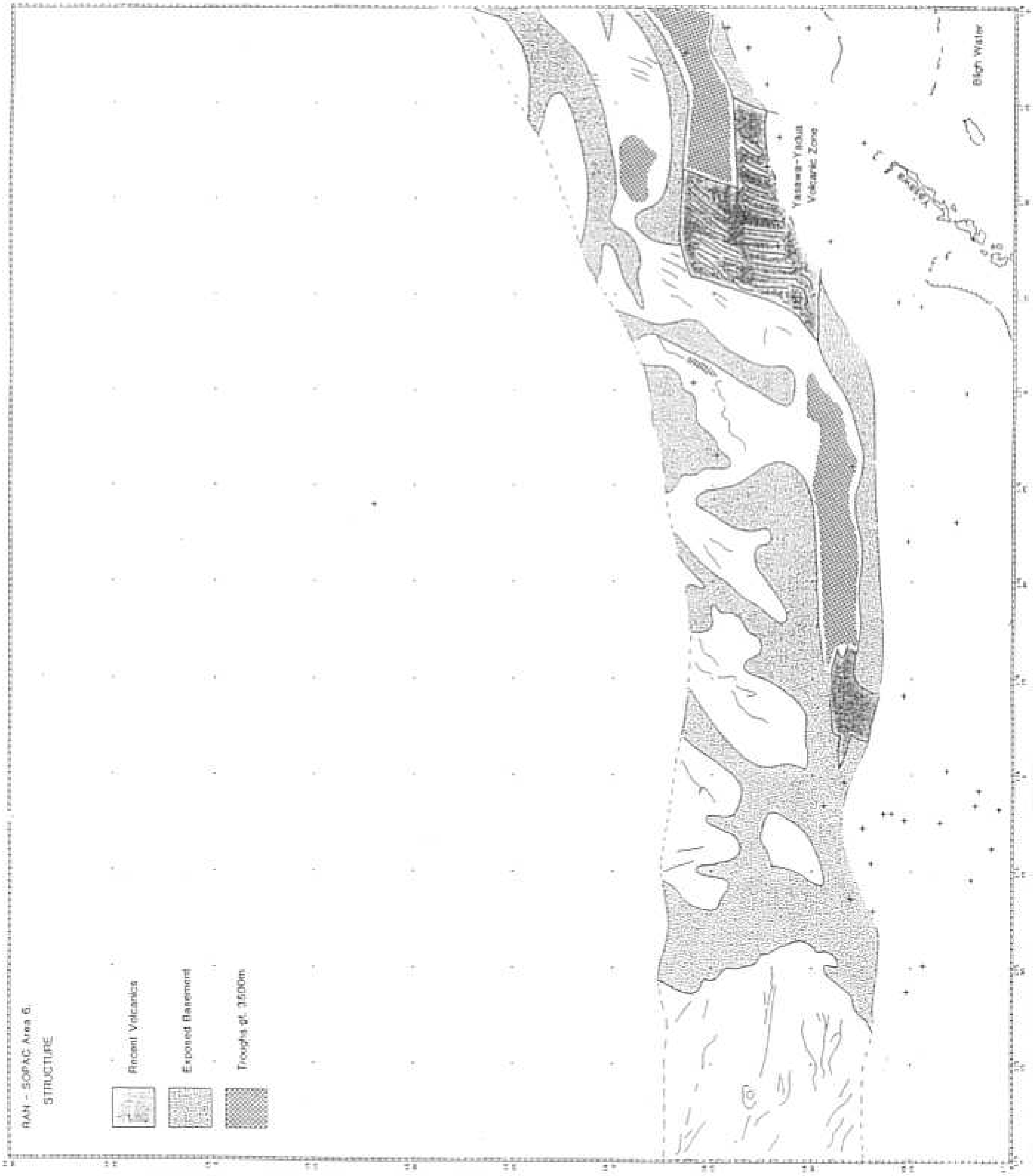

Figure 3c. Interpreted Structure of Mosaic Area 6.

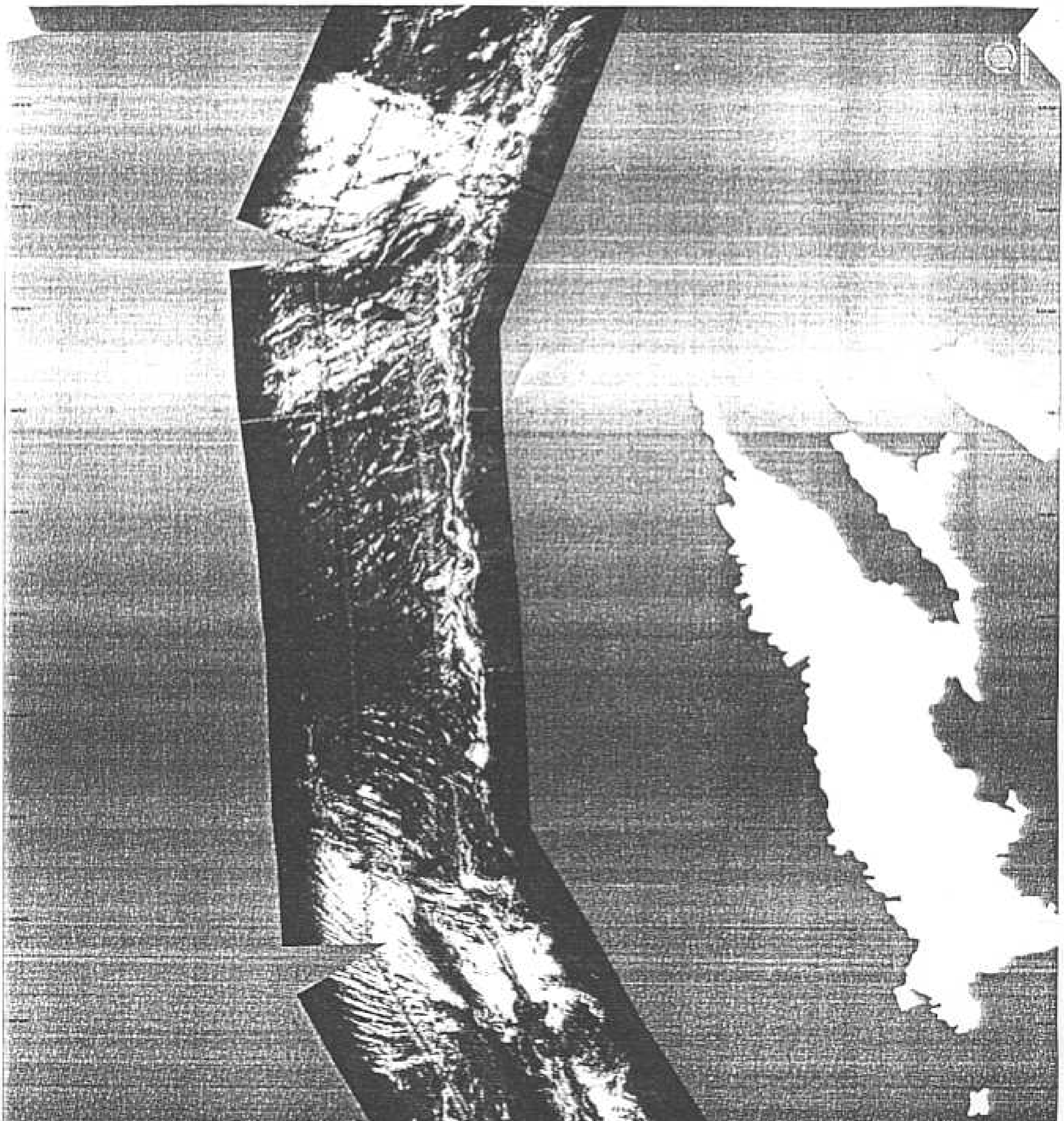

Figure 4a. GLORIA mosaic of Mosaic Area 7.

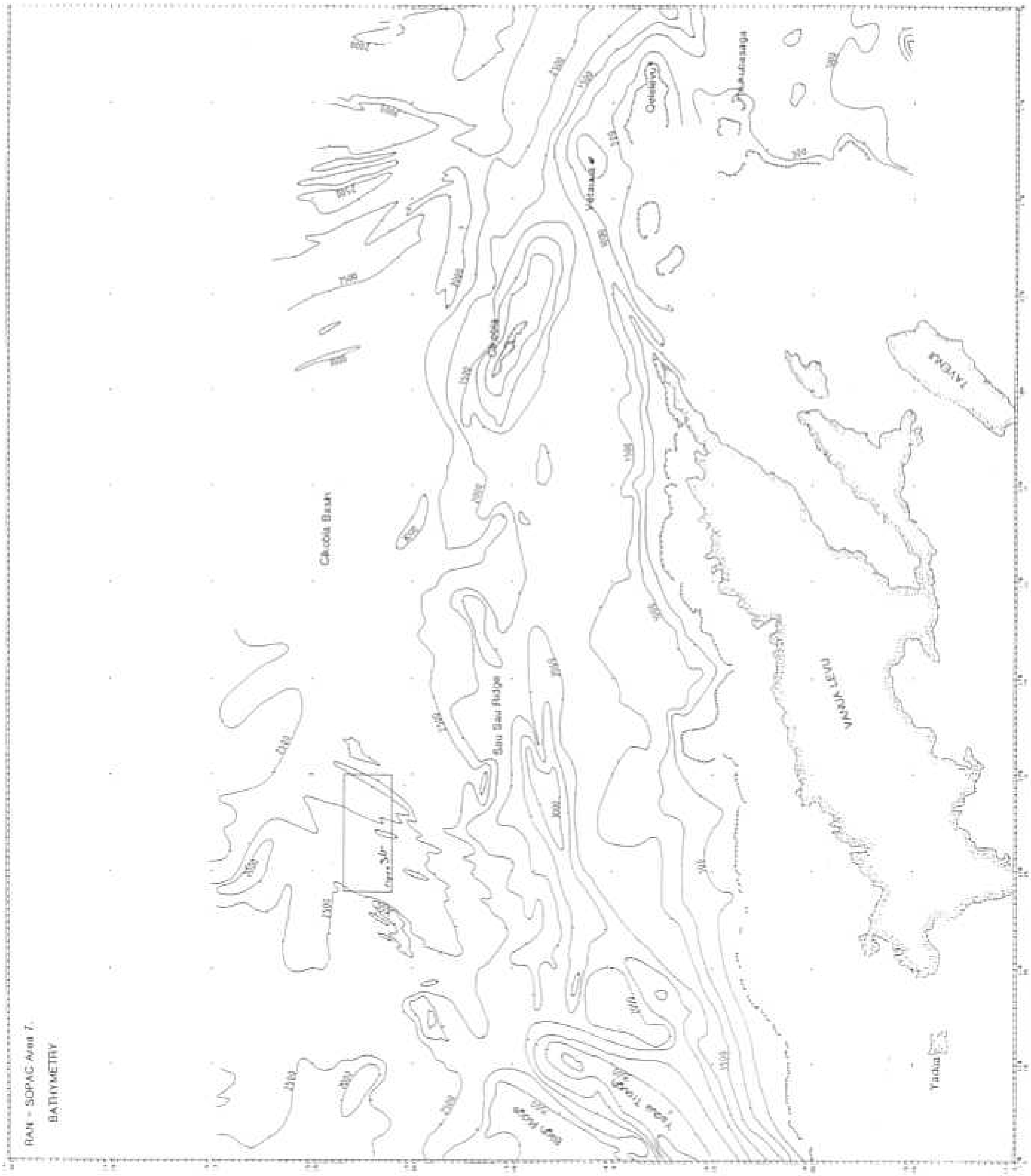

Figure 4b. Bathymetry of Mosaic Area 7, same scale as Figure 4a.

Figure 4c. Interpreted Structure of Mosaic Area 7.

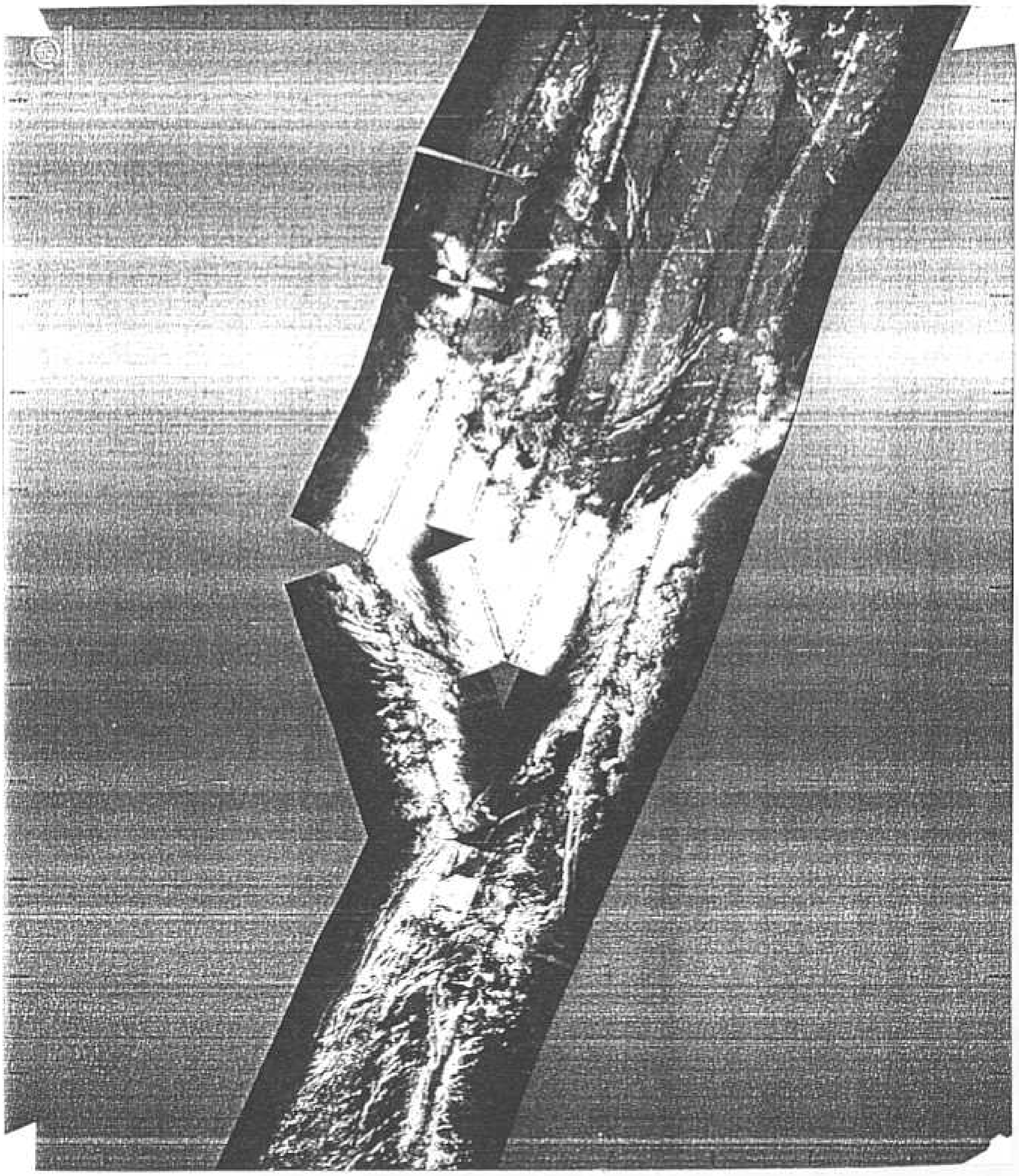

Figure 5a. GLORIA mosaic of Mosaic Area 8.

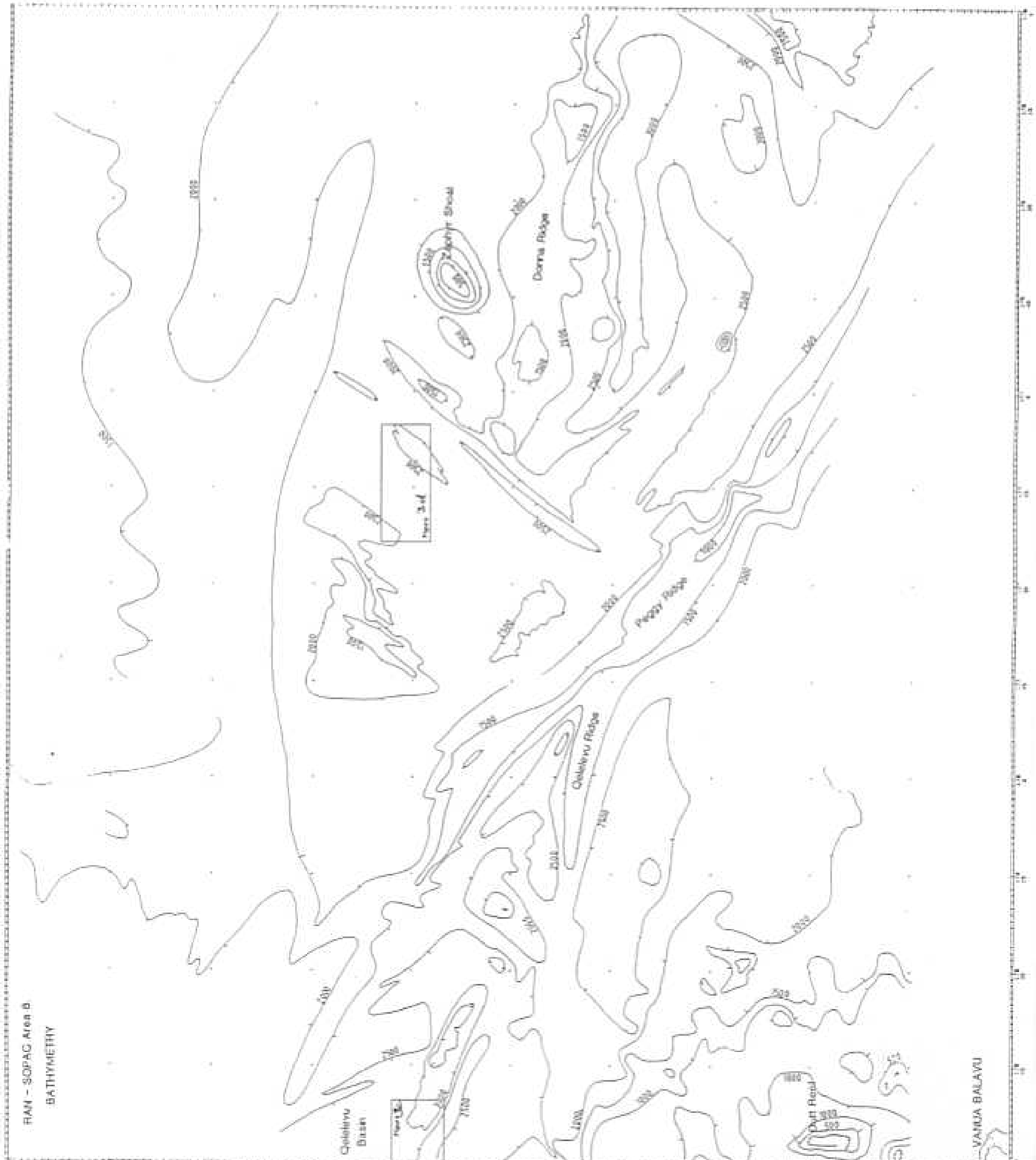

Figure 5b. Bathymetry of Mosaic Area 8, same scale as Figure 5a.

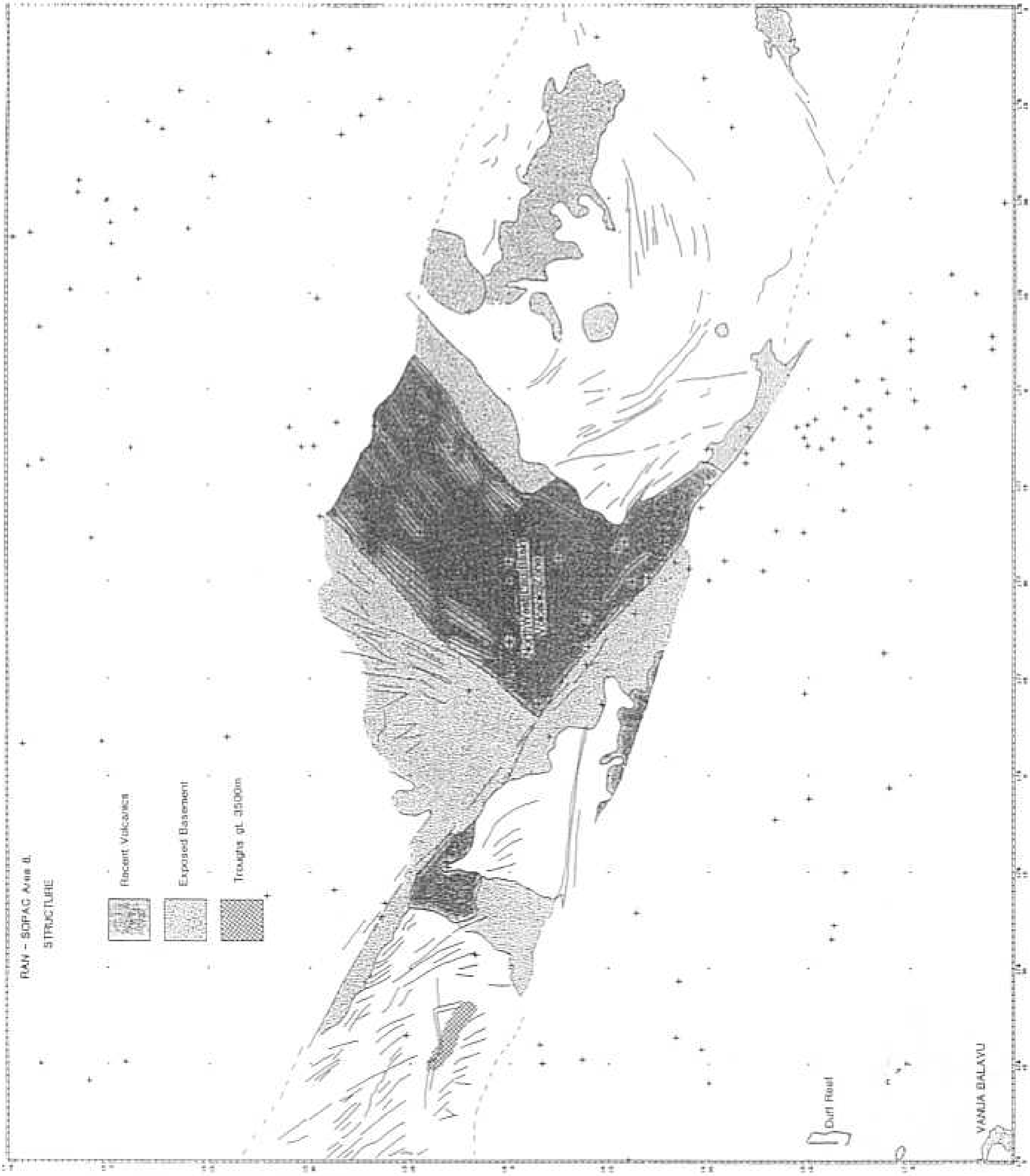

Figure 5c. Interpreted Structure of Mosaic Area 8.

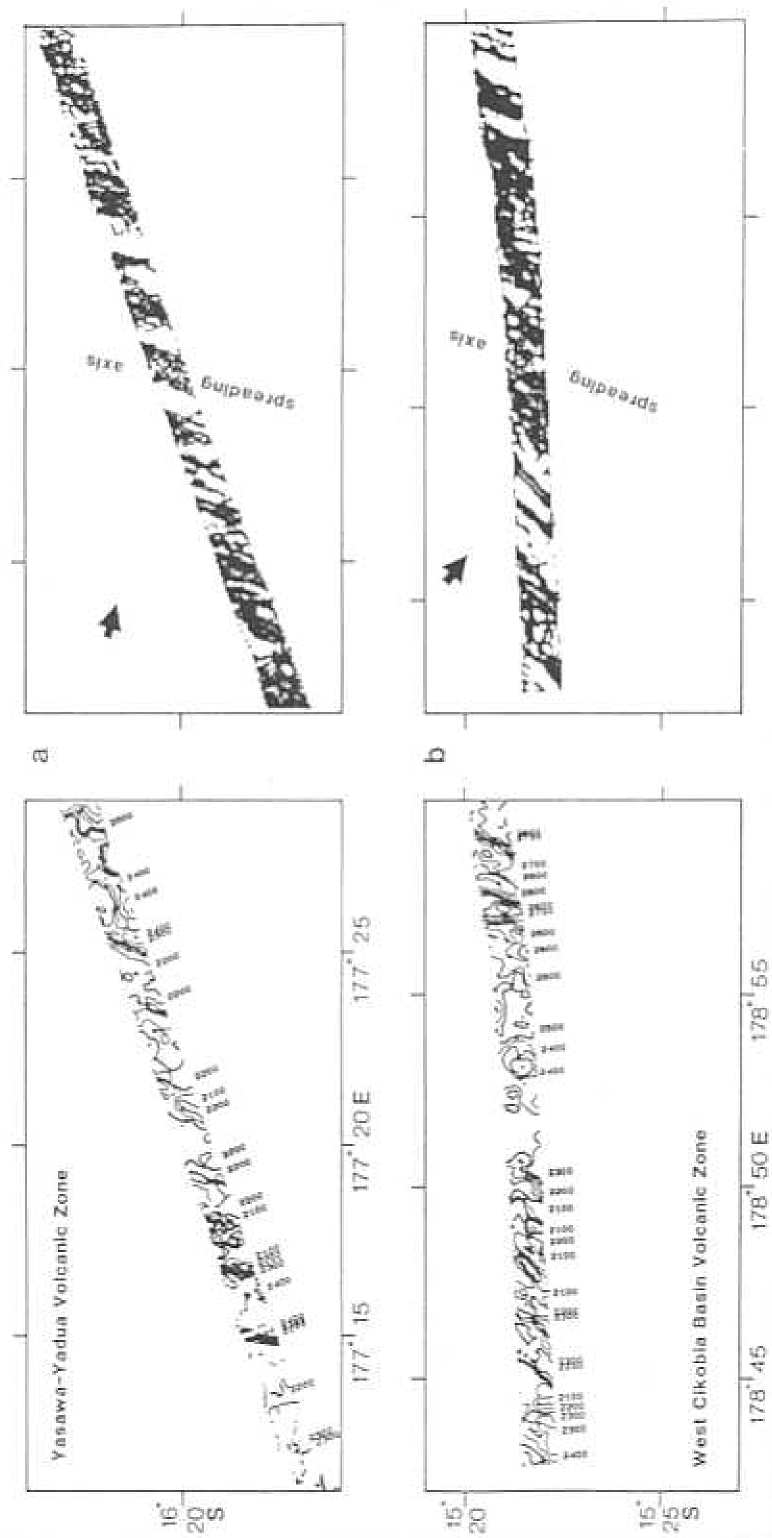

Figure 6. Contoured and artificially illuminated Seabeam data. Arrow indicates direction of artificial illumination.

a: Yasawa-Yadua Volcanic Zone axis.

b: West Cikobia Basin Volcanic Zone axis.

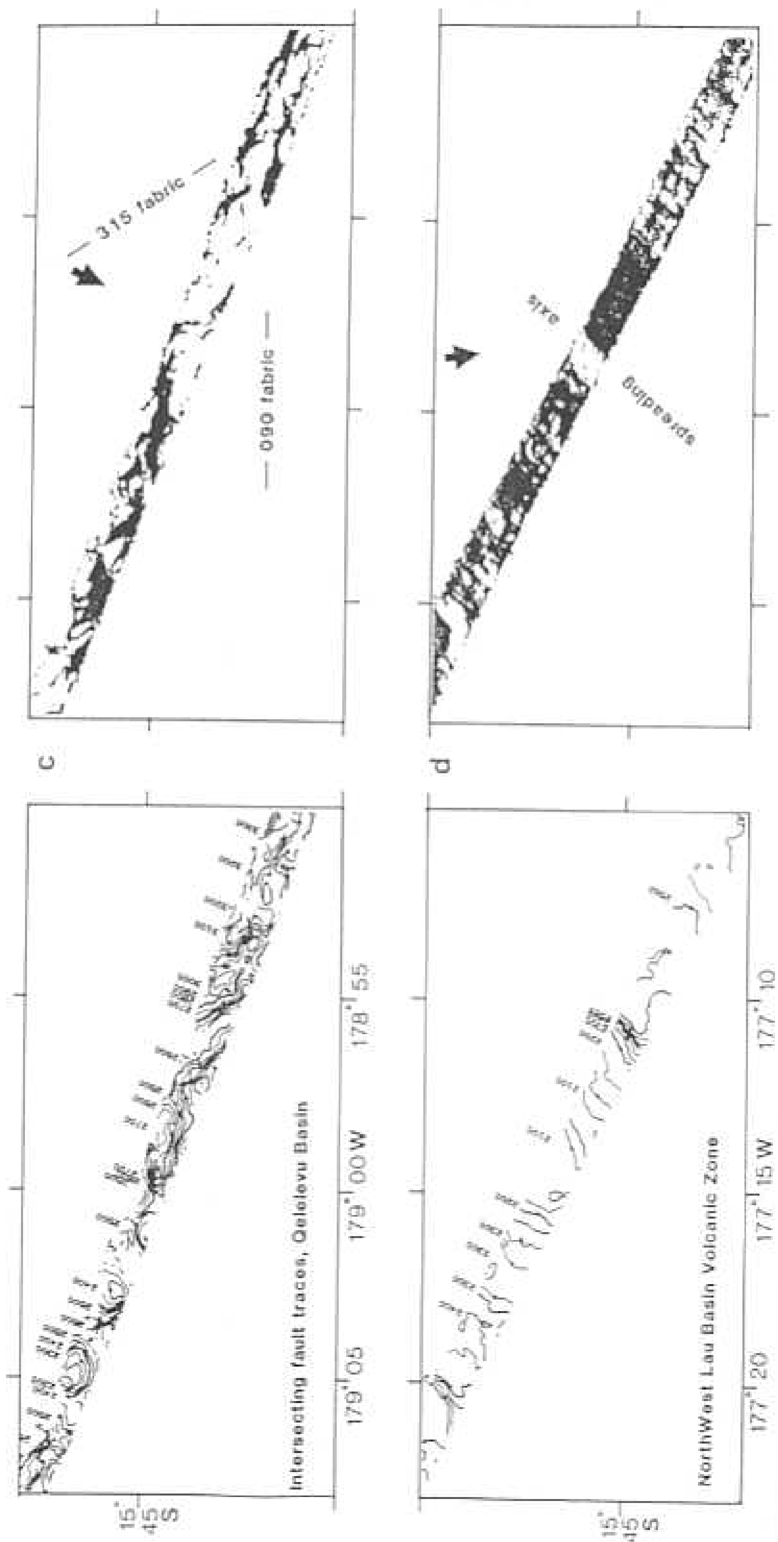

Figure 6. Contoured and artificially illuminated Seabeam data. Arrow indicates direction of artificial illumination.

c: Intersecting fault traces, Qelelevu Basin.

d: Northwest Lau Basin Volcanic Zone axis.

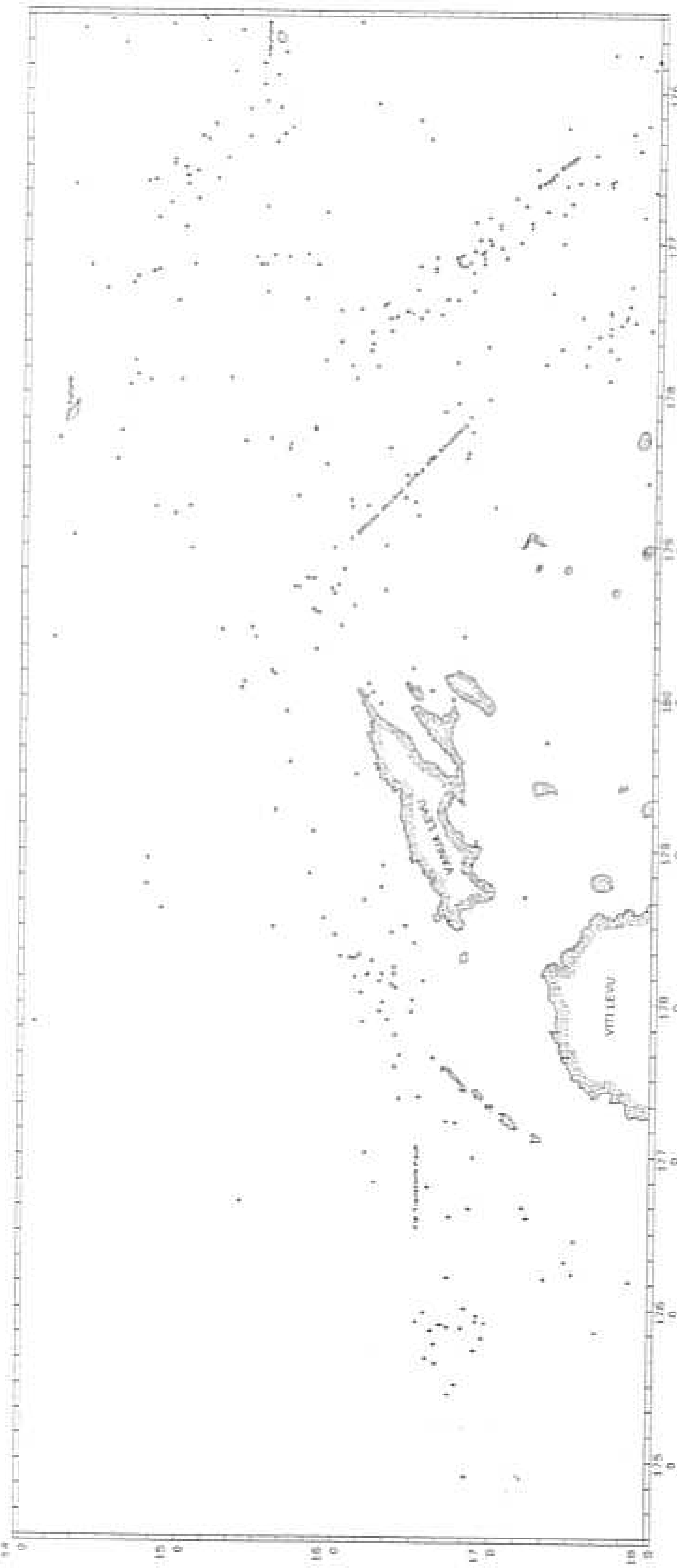

Figure 7. Earthquake epicentre locations from the ISC catalogue. All data are from 1963-1983, with magnitude greater than 4.0, depth shallower than 60 km, and with more than 10 reporting stations.

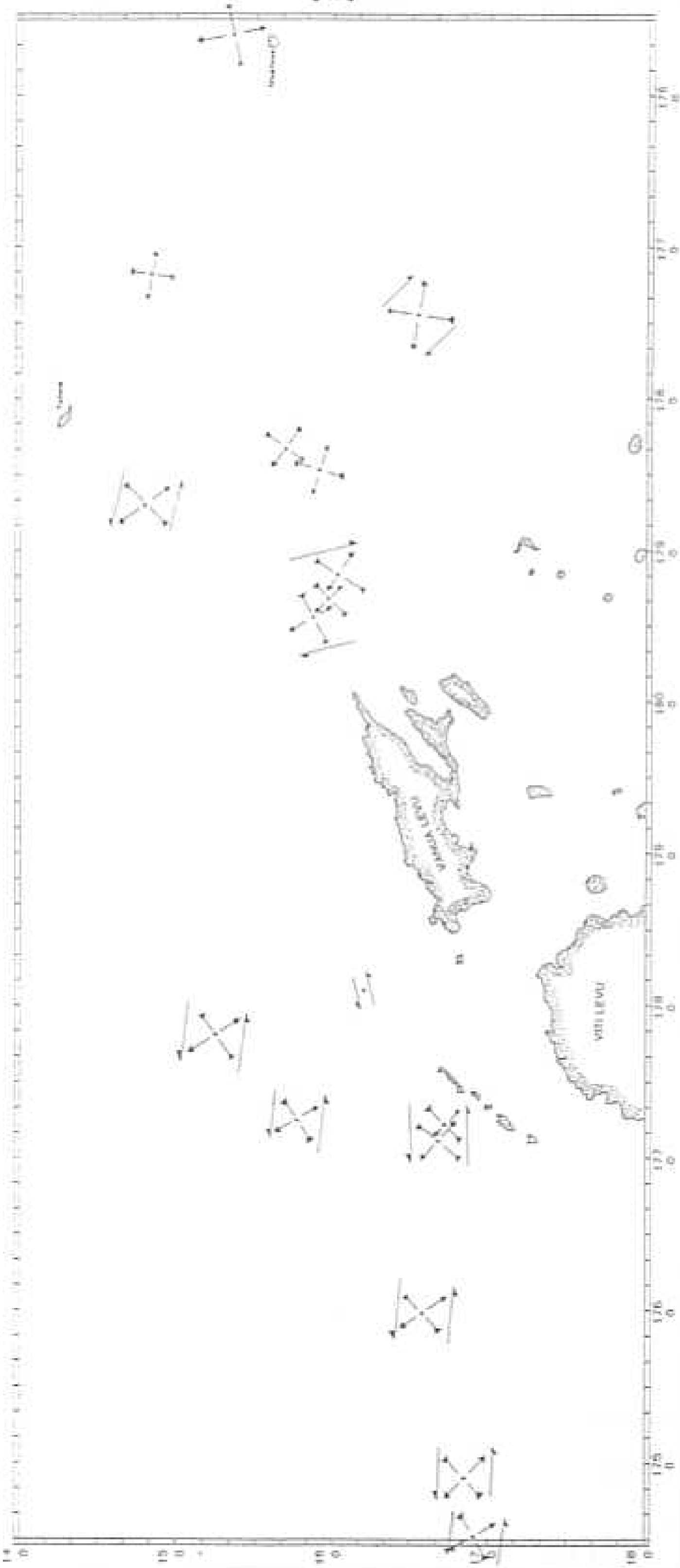

Figure 8. Focal mechanism solutions for shallow earthquakes. Data sources: Sykes et al, (1969), Isacks et al, (1969), Johnson and Molnar (1972), Eguchi (1984) and Hamburger and Isacks (in press). Filled arrows indicate the orientation of P- and T-axes and one sided arrows indicate the preferred sense of strike slip.

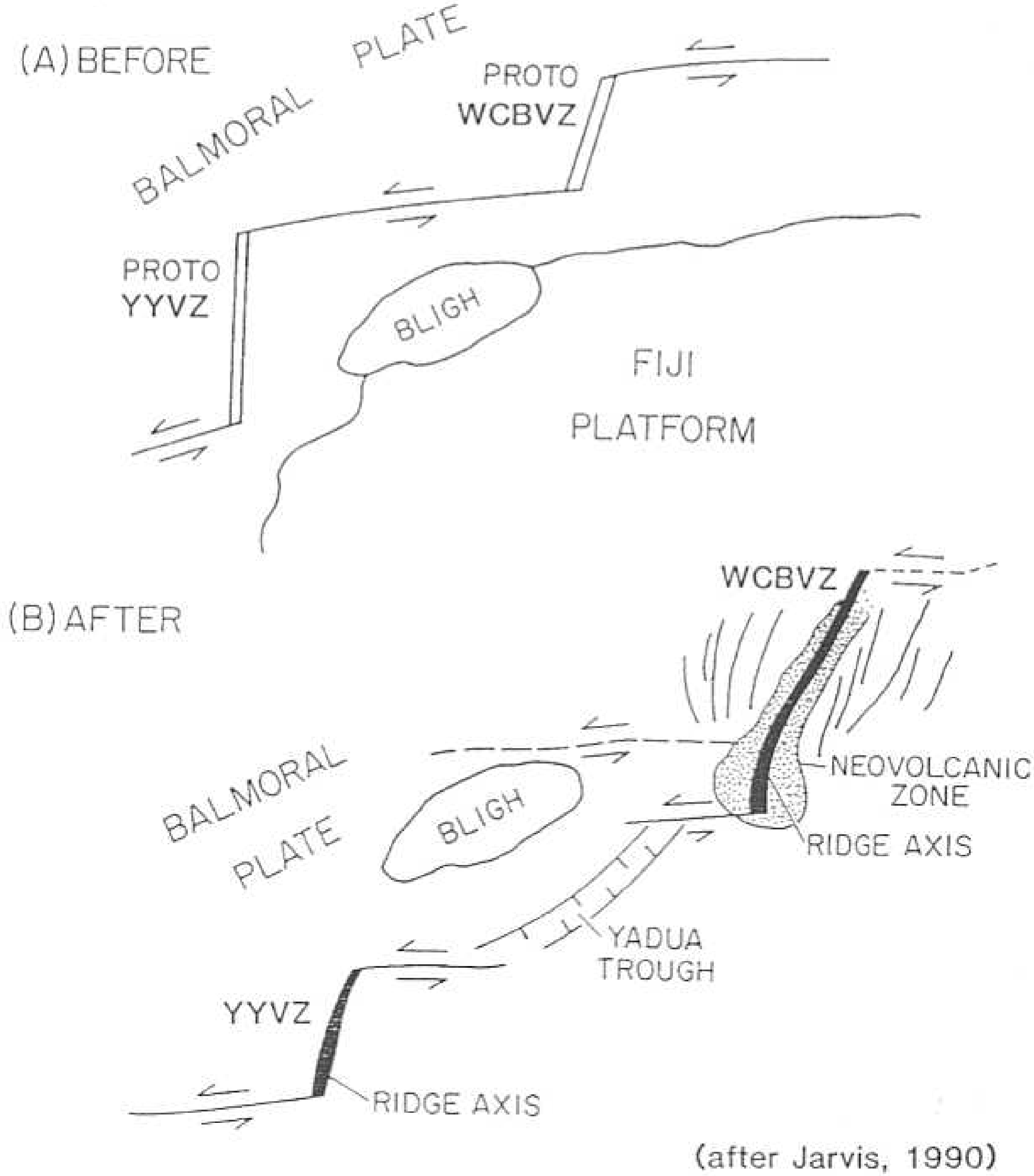

Figure 9. Interpretation of the evolution of the Yadua Trough, Bligh Ridge and West Cikobia Basin Volcanic Zone (after Jarvis, 1991).

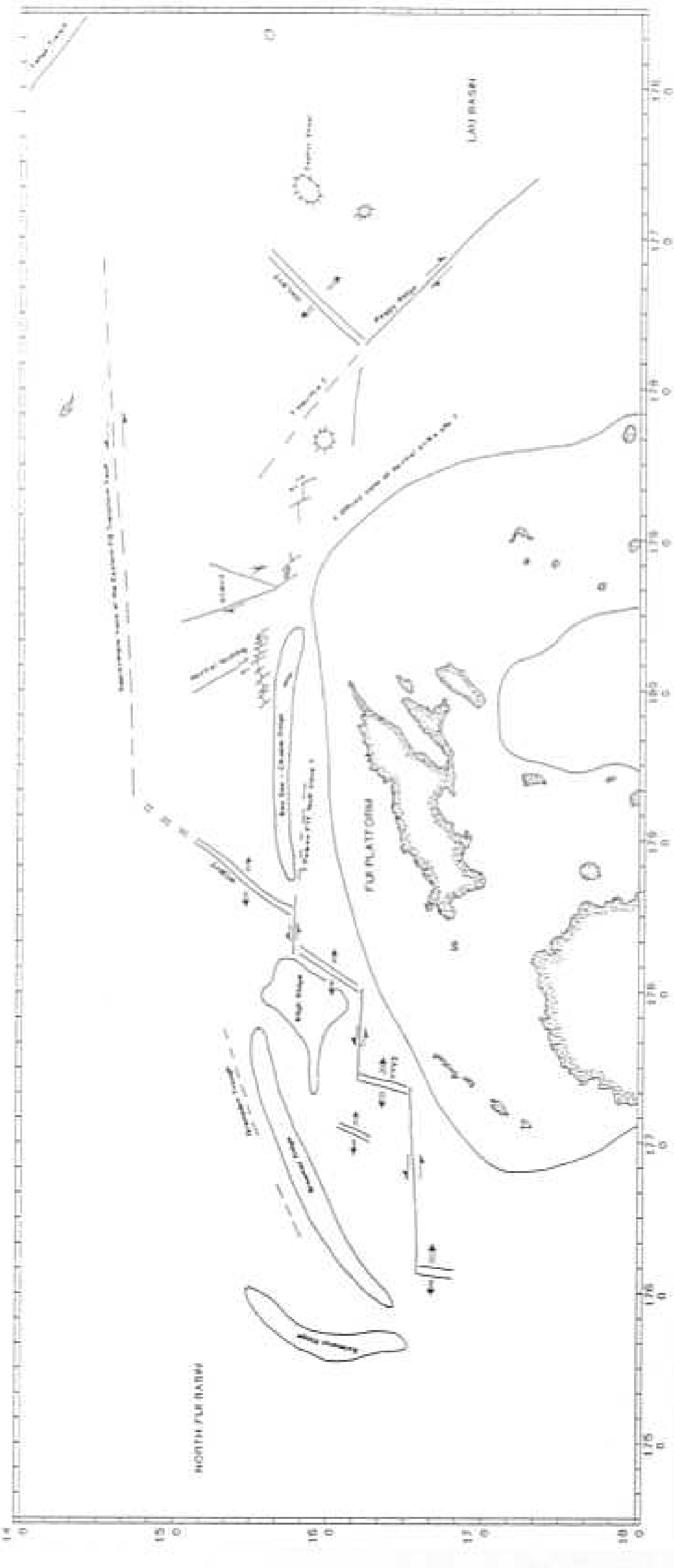

Figure 10. Tectonic boundaries along the northern flank of the Fiji Platform as interpreted from the data in this report.

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