Geo-Marine Letters (1993) 13: 126–131

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Tectonic and structural features of the Pacific/Indo-Australian plate boundary in the North Fiji–Lau Basin regions, southwest Pacific

Received: 1 March 1993 / Revision received: 22 March 1993

Abstract The SOPAC GLORIA survey covered principally an east–west region of the southwest Pacific approximately along latitude 16°S between longitudes 167°E and 171°W. Although a main objective was to determine the potential for seabed resources, the survey covered parts of the boundary between the Pacific and Indo-Australian plates and therefore addresses fundamental tectonic processes in these areas. The boundary is complicated and in some regions is not completely known. It is made more complicated by being unstable in places, making its history unclear. This paper brings together the general results of the survey as discussed by other contributions in this special issue to provide an overall interpretation, particularly as it relates to the major plate boundary through the region.

Introduction

The South Pacific Applied Geoscience Commission's (SOPAC's) swath-mapping survey in 1989 was the first use by SOPAC of the GLORIA long-range swath-mapping system, and its third use in the South Pacific. Mainly nonscientific considerations made the use of the GLORIA equipment expedient at the time. However, it was found to be a very useful side-scan system for scientific purposes and the results justify its use. Pronounced tectonic fabric over most of the surveyed regions give an ideal target for side-scan signals, and GLORIA provided a rapid technique for study of large areas of the sea floor, many of which had not been investigated previously.

The geological complexity of the region is revealed very clearly by the imagery, and new geological interpretations, many presented for the first time in this special issue, have added significantly to our understanding of the tectonic framework, regional history, and geology. The results will guide future work by defining target areas where more thorough study is warranted, and by locating sites where sampling can answer regional as well as local problems. Locally certain detailed studies are needed, and those can now be planned, using the present knowledge as background and allowing that to guide high-precision approaches with more efficient use of ship time.

A major objective of the program was to investigate sea-floor mineral potential in areas of SOPAC member country Exclusive Economic Zones (EEZs) (Tiffin 1993). These areas received prime consideration, but data were also collected on the transits between areas. This allowed data to be obtained in areas where few earlier studies had been made and where other studies seemed unlikely in the near future, such as the backarc region of Vanuatu between the southern and northern backarc troughs, the western North Fiji Basin (NFB), and the area north of Western Samoa. Other areas were mapped because they were poorly understood parts of the regional tectonic framework. These included the northern Lau Basin and its termination at the westward-trending Tonga Trench. The survey tracklines and EEZs of the countries of the region are shown in Fig. 1 of Tiffin (1993).

Discussion of results

The major plate boundary between the Pacific Plate and the Indo-Australia Plate is complicated in the Southwest Pacific region by the presence of several microplates. Parts of the plate boundary were imaged during this survey. North and east of the Fiji Islands, the boundary elements imaged include the Tonga Trench over its western extension north of Lau Basin (informally named here the Tonga Transform Fault), the Northwest Lau Spreading Centre (NWLSC), the Peggy Ridge fault, and the Fiji Transform Fault. West of Fiji, the elements include the NFB triple junction and the South Pandora Ridge (SPR). The regional tectonic interpretation resulting from the survey is summarized in Fig. 1.

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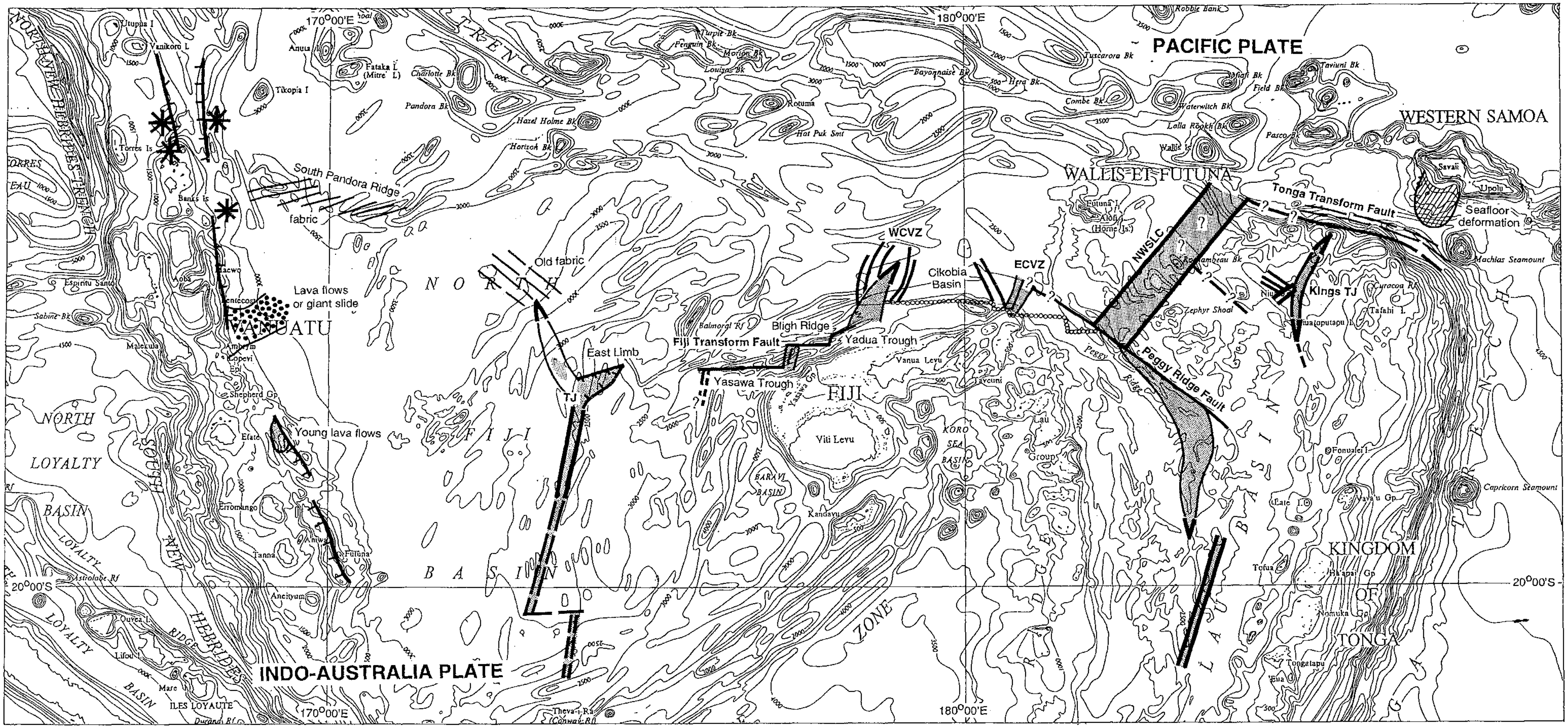

Fig. 1. The main tectonic and structural details of the survey areas are illustrated, including features of the boundary area. Stars in northern Vanuatu mark young volcanoes. Heavy double lines in Lau and North Fiji basins are spreading centers. Heavy single lines are faults; those with hachures are escarpments. Weighted points show direction of possible propogation of young spreading areas. NWSLC = Northwest Lau Spreading Centre; ECVZ = East Cikobia Volcanic Zone; WCVZ = West Cikobia Volcanic Zone; TJ = Triple Junction

The Pacific Plate around the Samoan Platform

Very striking details of the Pacific Plate north of the Tonga Trench are provided by the imagery. Long linear faults over the trench outer wall, described by Hill and Tiffin (1993), are aligned approximately with the trench axis. These faults reflect the stresses involved in bending the plate into the trench and are present even on the northern trench wall in an area where the relative plate motion is becoming strike-slip and subduction is no longer the major component.

South of the island of Savaii, strong deformation of a different and complex type is present on the sea floor as far south as the trench outer wall. If this deformation is the initial result of stresses associated with bending or subduction, it must have been also modified by other factors such as the nearby presence of a Samoan hot spot, or crustal weaknesses associated with volcanic structures on the Samoan Platform.

Around Samoa, and in the northern Tonga Trench, there is evidence for extremely large blocks of several square kilometers in size that have slumped from steep slopes. If such slumps took place in modern times, they could constitute a hazard for nearby coasts by their capacity to generate large tsunamis. Tsunamis have been recorded on the coasts of Samoa in historical times. The removal of large amounts of material by slumping brings steep, often unstable, slopes closer to a coast.

Northern Lau Basin

The northern Lau Basin is an area of complex morphology that is difficult to map within the limitations of narrow-band standard echo-sounding methods, consequently its structural and tectonic frameworks have been equally difficult to understand prior to this survey. Although some swath bathymetry had been obtained earlier, it was not sufficiently extensive to reveal the widespread structural variability of the northern basin. The GLORIA survey has quickly revealed important information that would have taken considerably more ship time to map by other means.

The relative westward motion of the Pacific Plate with respect to the Indo-Australian Plate is accommodated by subduction in the Tonga Trench in the east and by strike-slip motion along the Tonga Transform Fault at the northern end of Lau Basin. The transform fault begins as a tear in the Pacific Plate under the northeastern corner of the basin and parallels the trench west-northwestward. Seismicity is distributed over the northern end of the basin within the crust and upper mantle. The Kings Triple Junction mapped in the northeastern area probably results from coupling between the crust and the tearing subducting plate in some manner not presently known (Parson and Tiffin 1993). Spreading activity with signs of hydrothermal mineralization in the northeastern basin had been found earlier (Nilsson et al. 1989; Hawkins and Helu 1986) and this survey has enhanced details of its extent and regional setting that were unknown previously.

Northwest Lau Spreading Centre

In the northwestern Lau Basin, the Northwest Lau Spreading Centre (NWLSC) was a major discovery of this survey. Although the survey covered only its southern part (Parson and Tiffin 1993; Hughes Clarke et al. 1993), it is unique in the region and must play a major role in the plate boundary system in an area where the boundary is unknown. It separates two quite different terrains. North of the imaged area, the NWLSC may continue to the Tonga Transform Fault, or it may terminate just north of Rochambeau Bank where a diffuse line of seismicity extends southeast toward Niuafo'ou Island. The northern area is not well investigated. In the south, it is fault bounded by the Peggy Ridge Fault. It should be investigated further as a potential source of mineralization as well as because of its role as a possible plate boundary. A former trace of the Fiji Transform Fault meets the Peggy Ridge Fault at its junction with the NWLSC.

Volcanics on the south side of the Peggy Ridge Fault adjacent to the NWLSC have a very different acoustic signature from that of the NWLSC. They comprise a massive seamount or volcanic pile, reaching from more than 2000 m to less than 1200 m deep and stretching over a distance of about 35 km along the fault before disappearing to the southeast outside of the imaged area. These volcanics may be the most western expression of the extensional system that is propagating southward from Peggy Ridge in central Lau Basin (Parson et al. 1990).

Peggy Ridge Fault

The Peggy Ridge Fault extends westward almost to the East Cikobia Volcanic Zone (ECVZ) (Hughes Clarke et al. 1993). Its relationship to the volcanic zone is not clear, as the fault trace passes north out of the imaged area before reaching it. However, it is likely that the fault reaches the ECVZ, where it may terminate. West of about longitude 180°, fault systems are sinistral, suggesting that the Peggy Ridge Fault is unlikely to be found further west. The fault must be one of the youngest structures in the region, as it crosscuts all other structures.

The ECVZ may have developed in response to the meeting of two dextral faults. The eastern side of the ECVZ is an abrupt boundary similar to the eastern side of the NWLSC. However, the western side is broken by SSE-striking elements of a fault system that enters the imaged area through Cikobia Basin northwest of Cikobia Island. Dextral offset of the north edge of the Fiji Platform proves the dextral motion of this fault system. If the dextral Peggy Ridge fault meets this dextral fault, the ECVZ could have resulted from the intersection.

Fiji Transform Fault

The active section of the Fiji Transform Fault (FTF), which is the major plate boundary north of Fiji, is most clearly defined between longitudes of about 176°E and 179°E. Here it follows the east-trending Yasawa and Yadua Troughs, stepping northward around the Fiji Platform by way of offsets through north–south extensional relay zones. The fault trace through the central part of the Yadua Trough is not as sharply defined as elsewhere. In this area, the trough trends northeast rather than east, perhaps because the fault is breaking Bligh Ridge away from the Fiji Platform (Jarvis et al. 1993a) and has not pulled it far enough away to allow a fault trace to be clearly distinguished everywhere in the separation zone. In this area, the fault zone resembles a jagged tear.

Inactive traces of the FTF are found across the northern edge of the Fiji Platform as far east as Peggy Ridge. The old fault traces are all offset southward by later dextral faults, with the result that this eastern part of the fault is now dead. The northern edge of the Fiji Platform between longitudes 179°00'E and 179°30'W may be the site of one such old trace, now broken by short offsets along younger SSE-trending faults that cross the Cikobia Basin. The active fault therefore must follow the West Cikobia Volcanic Zone northward out of the survey area, where it may deflect eastward along an unknown northern fault, as Hughes Clarke et al. (1993) suggest. However, seismicity does not clearly define fault activity north of the WCVZ, and no other data are available to determine its location precisely.

Much of the area north of Fiji beyond this survey is not well known. The trace of the FTF beyond the WCVZ is unknown. It is also uncertain how the Peggy Ridge Fault fits into this model. The faults have opposing movements: Peggy Ridge Fault is dextral, the FTF is sinistral. Eventually the plate boundary must meet the Tonga Trench. The most probable location for that is at or near its western extension at the Tonga Transform Fault.

West of Fiji, the FTF does not connect directly to the eastern arm of the NFB triple junction, as is usually thought. The area between the eastern limb of the triple junction and the Yasawa Trough, where the fault trace is clearly visible, is sediment covered and structurally almost undisturbed. In fact, weak seismicity does continue at least partly toward the triple junction from the western Yasawa Trough, but no major fault activity is apparent in the GLORIA data. The fault may step southward near longitude 176°E as suggested by Jarvis et al. (1993b). North-trending topography south of the western Yasawa Trough is evident in Seabeam data as far south as latitude 17°50'S, suggesting a possible southward step, but seismicity does not confirm it. It is not yet apparent how, or where, the fault meets the triple junction in the NFB.

The age of the FTF trace in its present location is not well constrained. Changes in fault location and possible propagation of extensional offsets into the Fiji Platform may have been responsible for rifting and moving away other parts of the northern Fiji Platform now located at Braemar and Balmoral ridges, as well as Bligh Ridge (Hughes Clarke et al. 1993, Jarvis et al. 1993a). This hypothesis remains to be tested.

North Fiji Basin

The northern and eastern arms of the triple junction were imaged in the GLORIA survey. The association of the eastern arm with the Fiji Transform Fault is not known. The eastern arm is a large rift graben bounded on the north and south side by high fault scarps. The arm extends only about 75 km eastward from the triple junction and terminates very rapidly by the closure of the southern boundary scarp with the northern one. The floor of the graben consists of basalt with a thin veneer of sediment, as noted in submersible dives. Hydrothermal deposits have been found at the triple junction (Auzende et al. 1990), but not in the eastern arm.

The northern arm is composed of an en-echelon series of three small grabens. Except for an area near the triple junction, recent volcanism is not extensive in the northern arm, and it is considered to be an immature part of the NFB spreading system. Older NW-trending fabric of the NFB meets the northern arm in the northern part of the imaged area. This latter fabric continues to the South Pandora Ridge.

South Pandora Ridge

The North Fiji Basin is thought to have formed originally by clockwise rotation of the New Hebrides Volcanic Arc away from the old Vitiaz Arc, with the northwest NFB opening in a scissors-type action. One GLORIA swath across the North Fiji Basin area is insufficient to resolve the role of the western South Pandora Ridge (also called Hazel Holme Fracture Zone) within the tectonic framework of the region, but it shows that a wide area of extremely rugged terrain makes up the SPR. It also suggests that the SPR is neither an ordinary transform fault nor a well-defined extensional feature. In the western part of the SPR, there is no evidence of strike slip movement along slip planes or of young volcanic activity.

The South Pandora Ridge is enigmatic in that current models suggest that it should be a major plate boundary, but since it does not seem to have the characteristics of either a transform fault or an extensional rift system, it may be a transitional feature. Many active tectonic elements in the NFB are inferred to have a recent origin of less than 0.75–1 Ma, and movement along the SPR may be related to a reorganization of movement in the NFB. It could be a temporary relay (Johnson et al. 1993) with motion following individual horsts and grabens rather than following a well-defined trace as on the Fiji Transform Fault. The northern NFB is not a well studied area and further investigations are needed to properly interpret the role of the South Pandora Ridge in this tectonic setting.

New Hebrides Backarc

The backarc basins of the New Hebrides Arc may not have formed by a process of backarc extension, as earlier thought (Charvis and Pelletier 1989). With the possible exception of Vate Trough, which may have young volcanics on its floor, the absence of neovolcanism in the troughs suggests that they are not incipient backarc basins related to subduction in the New Hebrides Trench (Johnson et al. 1993). It also reduces their potential for sea-floor minerals.

The basins may be structurally related to tectonism in the NFB.

Steep escarpments are common along the backarc, not only westward-facing scarps on the eastern side of the backarc basins, but eastward-facing scarps also occur along the arc platform in the central area between the north and south basins. This central escarpment along the east side of Maewo and Pentecost islands is suggested to have been caused by collision of the subducting D'Entrecasteaux Ridge with the arc at the New Hebrides Trench (Greene et al. 1988; Price et al. 1993), which has thrust the arc eastward along slide planes. If so, these escarpments would be edges of thrust sheets above the fault planes.

A distinctly brighter, but locally patchy, backscatter pattern in sediments off southern Pentecost and Ambrym islands may be due to lava flows, either from fissures or off the nearby islands, or it may be due to giant slides from volcanically active nearby islands (Price et al. 1993). If the latter, these could represent geological hazards of a dangerous proportion due to their extremely large size and tsunami generating capacity, should they occur again.

Mineralization

Mineralization in the region is most likely to be found in the northwestern Lau Basin at the NWLSC, around the Kings Triple Junction in the northeastern Lau Basin near where sulfides have already been recovered, and in the extensional basins along the FTF. The prospects of mineralization in the backarc areas of Vanuatu are small, and the likelihood of finding minerals along the western South Pandora Ridge is also small. Sulfides have already been located in the North Fiji Basin near the triple junction and in several places along its mature southern arm (Auzende et al. 1990), but they are less likely to be located along the immature northern arm where rifting is not accompanied by extensive volcanism. The eastern arm may have some potential, especially near the triple junction.

Conclusions

By simple mechanics there must be a complete system of tectonic boundaries between the Indo-Australian Plate, where it subducts into the New Hebrides Trench, and the Pacific Plate, where it subducts into the Tonga Trench. The boundaries are not simple, and indeed several small microplates have been found over the boundary zone. Not all of the boundaries have been found or even inferred, and this paper has attempted to summarize what we know in an attempt to point out the areas where little is known and where other boundaries are likely to be located. It is in the boundary areas where most complex structures are found and where mineralization is most likely to occur, as is evident by the number of areas along boundary zones elsewhere where minerals have already been identified. More work is needed in most of these areas, but it is especially important in terms of the plate boundaries to determine answers to the following questions:

1. Where does the Fiji Transform Fault go northeast of the Fiji Islands?
2. What structures lay there?
3. What mineralization may be found in the small relay basins of the FTF?
4. What is the full extent of the NWLSC?
5. What mineralization may be found there?

In the North Fiji Basin, we need to know the relationship of the South Pandora Ridge within the tectonic framework of that area and the other plate boundaries that may be present in the northern part of the basin. We do not know what happens to the Fiji Transform Fault just west of Fiji. We hope that by highlighting these areas, it will stimulate further interest in them and bring about more scientific studies using new technologies in the region.

Acknowledgments The author thanks all those who took part in the project and helped bring about its successful completion. The European Economic Community supported the project; ship time was provided by the Royal Australian Navy.

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