Intraplate Volcanism and Implications for Crustal Growth and Metal Endowment in Back-arc Basins: Evidence from the Niuafo'ou Volcanic Complex in the Northern Lau Basin

R. Dentelbeck[1], M. D. Hannington[1], A. T. Baxter[1], M. Ryan[1], and E. Bethell[1]

[1]Department of Earth and Environmental Sciences, University of Ottawa, Ottawa, Ontario

Introduction

High-temperature vents and some large sulfide occurrences have been found at spreading centers in back-arc basins including the Lau Basin in the SW Pacific (de Ronde et al., 2005). A significant proportion of volcanism that drives hydrothermal vents can be off-axis volcanism, away from back-arc spreading centers. For example, recent studies in the Lau Basin have shown that significant off-axis volcanism manifests as large magmatic centers such as the Niuafo'ou volcanic complex (Stewart et al., 2022). Hydrothermal vents and plumes have been discovered within the Niuafo'ou volcanic complex and in the surrounding region. As the majority of research on hydrothermal vents has been conducted on-axis, the amount of off-axis hydrothermal activity may be underrepresented and could contribute to significant additional sulfide accumulation in the basins. To quantify the amount of off-axis volcanism occurring in the NE Lau Basin, we used remote predictive mapping techniques to develop a detailed geological map of the Niuafo'ou volcanic complex and surrounding area covering 142 x 155 km.

Tectonic Setting

The Lau Basin is an intraoceanic back-arc basin in the western Pacific Ocean and is bounded by two major plates, the Australian Plate to the west and the Pacific Plate to the east (Zellmer & Taylor, 2001). Trench roll-back, coupled with upwelling high-temperature mantle, is proposed as the main driving force behind crustal extension in the basin (Hawkins, 1995).

Plate kinematics in the basin become increasingly complex moving from south to north. The northern Lau Basin is composed of three larger plates (Niuafo'ou, Futuna, and Tonga microplates) with numerous smaller microplates proposed (Conder and Wiens, 2011; Baxter et al., 2020; Stewart et al., 2021). Many of the plate boundary segments in the Lau Basin are not discrete linear features and are more diffuse, zones of deformation. Some segments, such as the northern boundary of the Niuafo'ou microplate, are obscured by significant outpourings of volcanism sourced from the Niuafo'ou volcanic complex. Although the Niuafo'ou volcanic complex occupies the proposed microplate boundary, the structural controls on volcanism and hydrothermal activity are not well understood. Recent geophysical and acoustic data collected in this region allow the construction of a new geological map, which sheds light on these processes and controls.

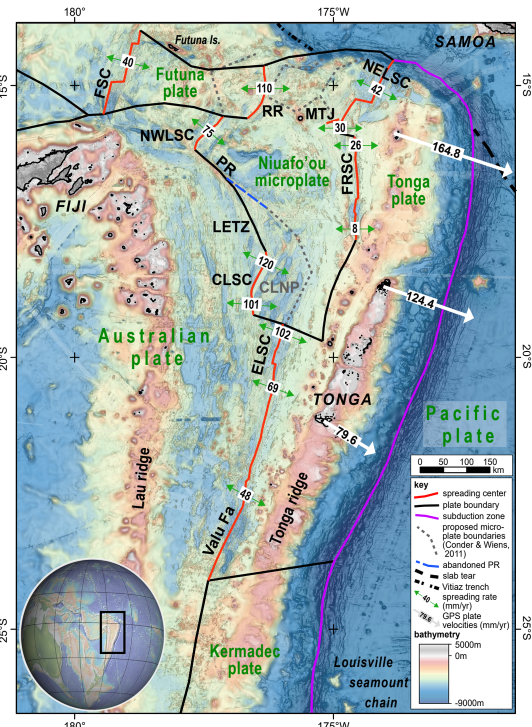


Figure 1: Adapted from Baxter et al. (2020) Regional bathymetric map of the Lau Basin displaying active spreading centers, and major microplate boundaries (Bird, 2003). FSC = Futuna Spreading Centre, NWLSC = Northwest Lau Spreading Center, RR = Rochanbeau Rifts, MTJ = Mangatolu Triple Junction-southern arm, NELSC = Northeast Lau Spreading Center, LETZ = Lau Extensional Transform Zone, FRSC = Fonualei Rift and Spreading Center, CLSC = Central Lau Spreading Center, ELSC = Eastern Lau Spreading Center.

Methodology

A geological map of the Niuafo'ou volcano was constructed using the lithostratigraphic legend presented in Stewart et al., (2022). The RPM-approach integrates multiple geophysical, acoustic, and ground-truthing datasets including seismic, magnetic, gravimetric, altimetric data, ship-based multibeam bathymetry data, and samples collected during marine expeditions to build the map. Multiple research cruises including the R/V Southern Surveyor (SS2008-07), the R/V Falkor (FK191120) , the R/V Roger Revelle (RR0916-2009), and the R/V Sonne (SO267-Archimedes I) collected ship-based multi-beam bathymetry data with a grid resolutions of 30 m, 50 m, 35 m, and, 50 m, respectively. Ship-based multi-beam bathymetry was used in conjunction with Global Multi-Resolution Topography (GMRT) to provide complete coverage of the seafloor for areas without any ship-based bathymetry data.

The map was developed using ESRI's ArcGIS Pro (version 3.0.2) software. The World Geodetic System (WGS) 1984 was used as the reference coordinate system with a Plate Carree projection.

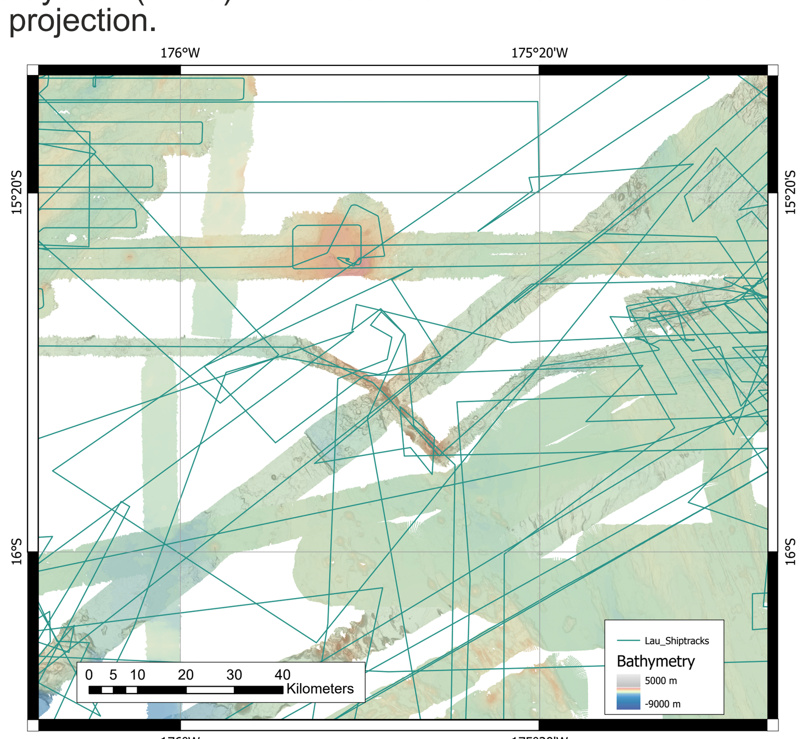
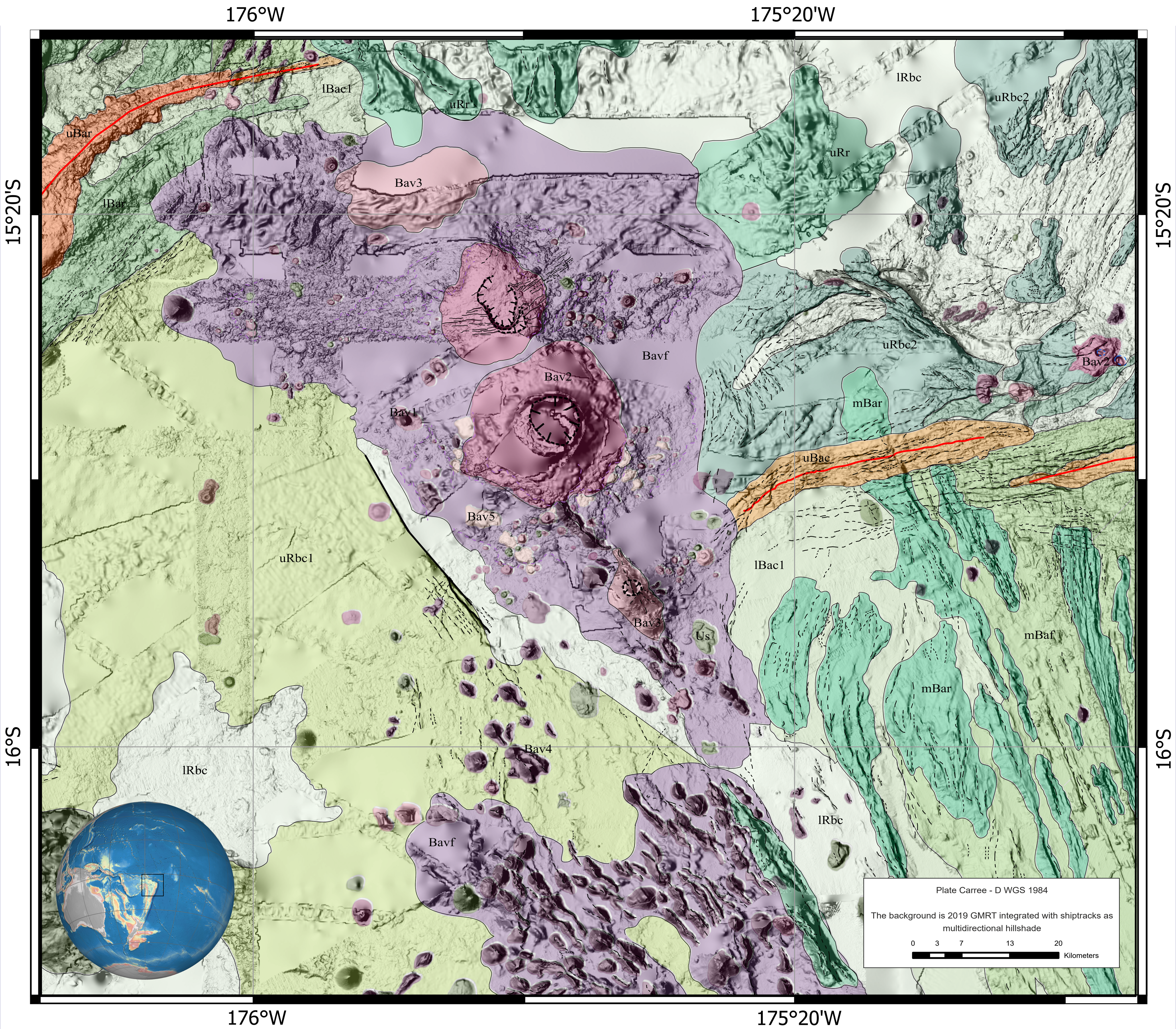


Figure 2: Available shipbpard MBES data used for mapping Niuafo'ou. Shipboard bathymetry available from the R/V Southern Surveyor (SS2008-07), the R/V Falkor (FK191120) , the R/V Roger Revelle (RR0916-2009), and the R/V Sonne (SO267-Archimedes I)



LABEL	UNIT NAME AND DESCRIPTION
	BACKARC VOLCNOES
Bav1	**Conical Volcano** Cone shaped edifice composed of lava flows and volcanoclasic material erupted onto backarc crust, commonly with a summit crater or caldera and/or cut by dike complexes (<1km diameter; width:height <=5)
Bav2	**Shield Volcano** Mound-shaped edifice composed of lava flows extruded onto backarc crust, commonly with a central caldera (<1 km diameter; width:height >5)
Bav3	**Dome Volcano** Dome-shaped edifice composed of lava flows extruded onto backarc crust or onto an axial volcanic ridge (<1 km diameter; length:width ~1)
Bav4	**Fissure Volcano** Elongate volcanic edifice composed mostly of lava flows extruded onto backarc crust, commonly with a central dike (<1 km length; length:width >3)
Bav5	**Flat-topped Pillow Mound** Flat-topped seafloor mounds formed mainly of pillow lava, commonly with a slope of 0 and forms a plateau.
Bavf	**Volcanic Field** A broad area of lava flows and volcanoclastic material surrounding a number of closley spaced volcanoes
	BACKARC RIFTS AND SPREADING CENTERS
Upper	
uBar	**Axial backarc volcanic ridge** Volcanic ridge narking the active spreading centre, commonly with discrete volcanic edifices (cones and domes), dike complexes, or calderas
uBac	**Axial backarc crust** Undivided backarc crust in the inner rift valley of an active spreading center
Middle	
mBar	**Proximal volcanic or tectonic ridge** Elongate volcanic edifice or coaslesced ridges in the outer rift valley or on the flank, adjacent to an active spreading center of axial volcanic ridge
mBac	**Proximal backarc crust** Undivided backarc crust in the outer rift valley, adjacent to an active spreading center or axial volcanic ridge (may include products of off-axis volcanism)

LABEL	UNIT NAME AND DESCRIPTION
	BACKARC RIFTS AND SPREADING CENTERS
Middle	
mBaf	**Backarc rift flank** Undivided backarc crust on the flank of the outer rift valley, including volcanic ridges, volcanoclastic material, and flows (may include products of off-axis volcanism)
Lower	
lBar	**Distal volcanic ridge** Elongate volcanic edifice or coalesced ridges on distal backarc crust (may include products of off-axis volcanism or earlier seafloor spreading from a distant ridge; commonly obscured by volcanoclastic cover)
lBac1	**Distal backarc crust** Undivided backarc crust beyond the outer rift valley and flank of an active spreading center (may include
	RELICT BACKARC
Upper	
uRr	**Relict ridge** Elongate volcanic edifice or coalesced ridges outside an identifiatble area of active spreading (may be product of intraplate volcanism, rifting of earlier backarc crust, or an unknown spreading center)
uRbc1	**Upper relict backarc** Undivided backarc crust outside an identifiable area of active spreading (may be a product of intraplate volcanism, rifting of earlier backarc crust, or an unknown spreading center)
Lower	
lRbc	**Lower relict backarc** Earliest exposed extrusive and instrusive rocks in the backarc and outside an identifiable area of active spreading
	OTHER BACKARC FORMATIONS
Us	**Seamount** Volcanic or tectonic edifice of undetermined origin
Ur	**Ridge** Elongate volcanic or tectonic feature of undetermined origin

SYMBOLS

Caldera wall · Crater rim · Spreading Center · Fault · Flow field boundary · Lineament

Figure 3: Geological Map of the Niuafo'ou Volcanic Complex, showing the identified formations. The legend used for this map was adapted from the geological legend of the Lau Basin by Stewart et al. (2022).

Magmatic Plumbing

The largest volcanic center in the area is the Niuafo'ou volcano, which may mark the Niuafo'ou microplate boundary. The shield-like geometry and large circular caldera are typical of shield volcanoes above small mantle hot spots. The four most prominent volcanoes mapped all have varying sizes and are aligned in a NW-SE orientation. They run parallel to spreading fabric of the Fonualei assemblage to the SW of Niuafo'ou. The rift valley of the FRSC is defined by a series of sub-basins (Stewart et al., 2022), some of which appear to extend as far north as Niuafo'ou. The large volume magmatism occurring in this region may be related to the thinner crust at the western margin of the broad Fonualei rift basin, which may be more readily penetrated by magma. Some of the volcanoes at this location may be relics of the earliest opening of the Fonualei Rift.

Approximately 25 km north of the Niuafo'ou volcano is the Dugong submarine volcano. A 5 km-diameter caldera 1,155 m below sea level spans the summit of the volcano and is overprinted by multiple faults and surrounded by hundreds of small features assumed to be pillow volcanoes (Arculus, 2008). Dugong has a small hydrothermal plume near its base and fresh basaltic pillow fragments were recovered from a dredge of the area (Arculus, 2008). Dugong exhibits intense faulting around the caldera walls. The radial faulting pattern is anisotropic with the dykes clustering along the NE-SW axis. This orientation may suggest a regional stress field oriented perpendicular to the least compressive stress (NW-SE).

Structural Controls

Intense faulting is observed in the areas surrounding the Niuafo'ou volcanic complex in three main structural trends. The first trend is parallel to the Rochambeau Rifts to the NW of Niuafo'ou. The second trend follows the orientation of a large cluster of fissure volcanos to the south of Niuafo'ou and the western margin of the nearby Fonualei Rift and Spreading Center (FRSC). The third trend is more complex and contains faults that run subparallel to the southern arm of the Mangatolu Triple Junction (MTJ) intersected by faulting parallel to the western arm of the MTJ. These trends reflect extension at three different rift zones surrounding the Niuafo'ou complex (i.e., the Rochambeau Rifts in the northwest, the MTJ in the northeast, and the FRSC in the east). Some structure is also related to strike-slip faulting in response to microplate rotation in the northern Lau Basin (Baxter et al., 2020).

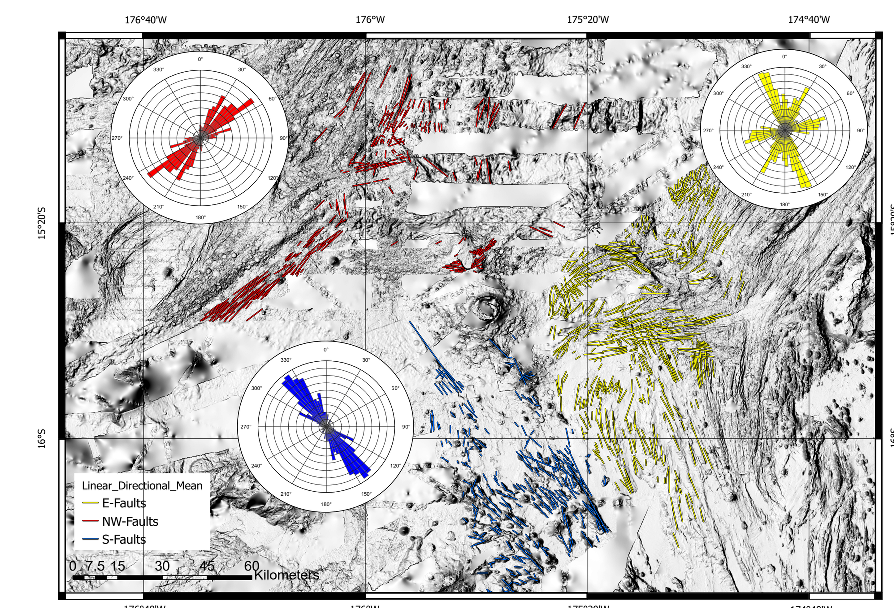


Figure 4: Detailed fault map with rose diagrams indicating the fault's strike direction for three areas within the mapped region. The faults are colour-coded by section. The faults shown in blue are oriented parallel to the western margin of the FRSC.

Conclusion

- Significant off-axis volcanism occurs away from spreading centers and is controlled by pre-existing structures in the underlying crust.
- Intersecting lineaments centered on the large Niuafo'ou volcanic complex suggest that it has formed during significant changes in rifting and microplate rotation.
- Hydrothermal activity in this part of the Lau Basin may be underrepresented because most of the search for vents has focused on the back-arc spreading centers.

Acknowledgements

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