Intrabasinal sediments and tectonostratigraphy of the Lau Basin: Assessing linear vs diachronous models for the opening of the Lau back-arc

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Introduction

As sediment-hosted mineral deposits are often poorly preserved in the rock record (Reynolds, 2019), modern analogues can provide important insights on the extent and distribution of these deposits. Back-arc basins exhibit the conditions necessary for forming mineral deposits: a heat source to mobilize fluids and enrich them in minerals; a faulted and fractured permeable crust, to allow hydrothermal fluids to be transported to the surface; and sufficient sediment to host mineralization.

The Lau Basin in the southwestern Pacific Ocean is a type example of an active back-arc basin and fits all these criteria, making it a promising region to investigate present-day mineralization. Extension initiated at 6 Ma (Hawkins, 1995) and is accommodated by rifting and the formation of back-arc spreading centers. Small, primarily fault-controlled, sub-basins formed during both the rifting and spreading stages and contain a record of volcaniclastic and hemipelagic sedimentation. By identifying sedimentary characteristics such as composition, structure and sediment source, and relating them to the structure, composition and age of the underlying crust, the age and tectonic evolution of each sub-basin can be reconstructed. The tectonostratigraphic history of the sub-basins, along with their relationship to features like faults, hydrothermal vents and magmatic intrusions, provides insight into potential locations of sediment-hosted mineralization. The study area is the ~300 km long, east-west trending P03 seismic transect at 17°20'S (Figure 1). This is one of six seismic transects collected on the R/V Sonne SO267 cruise (Hannington et al, 2019). It was chosen for this study because it is the longest seismic line, extending from the center of the Lau Basin to the Tofua Arc.

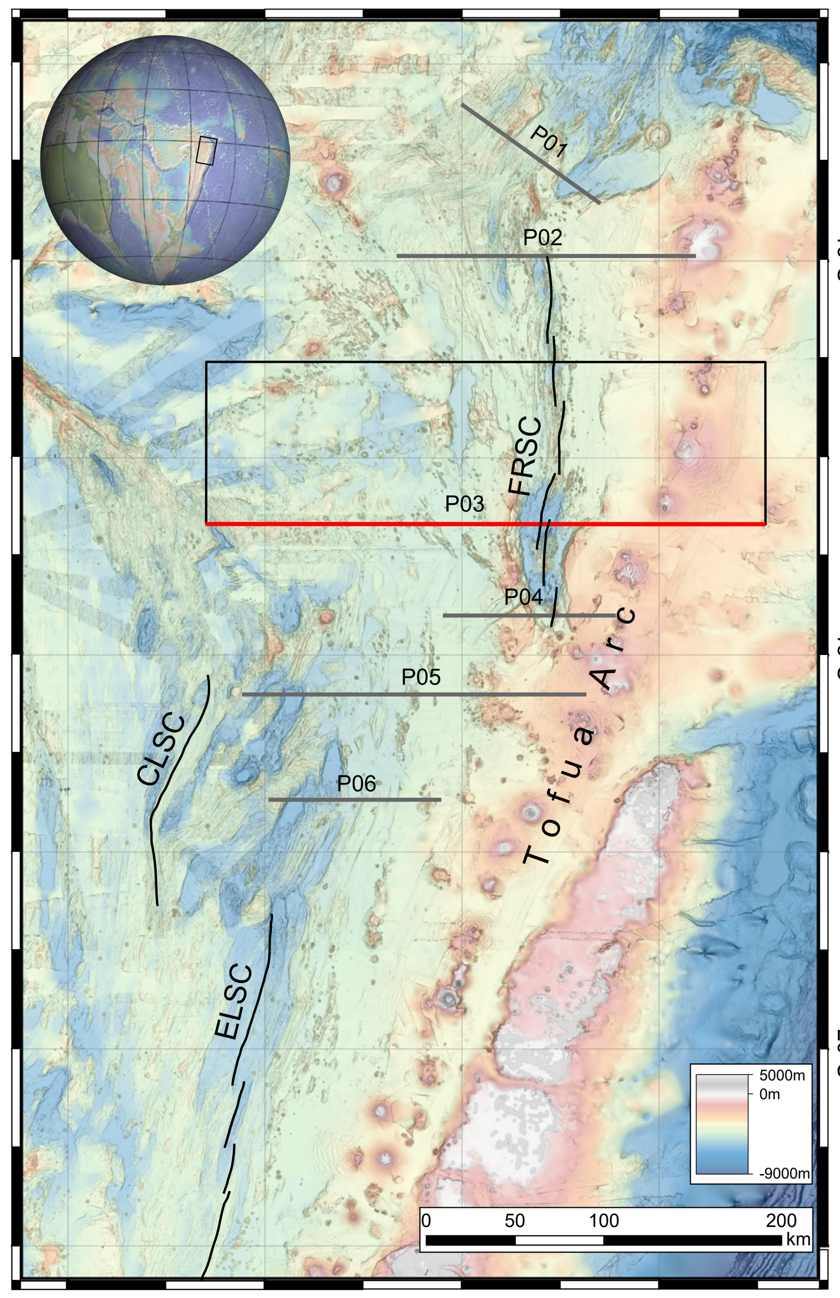

Figure 1 Bathymetric map of the Lau back-arc basin. The P03 seismic transect is shown as a red line, and the other five seismic transects are shown as grey lines. The area displayed in the 3D model of Figure 3 is outlined by the black box. Three main extensional zones are labeled: Eastern Lau Spreading Center (ELSC); Fonualei Rift and Spreading Center (FRSC); Central Lau Spreading Center (CLSC) (Zellmer and Taylor, 2001).

Methods

The three data sets used in this study are bathymetry, seismic reflection, and sub-bottom profiles collected with the 'ATLAS Parasound' system, referred to as 'parasound'. Together they are used to characterize the sub-basins and their sediment infill. The seismic data extends to mid-crustal level, while the parasound images the top 200 m of sediment, using a frequency of 0.5-6.0 kHz. We interrogated these datasets to create a database that categorizes the sub-basins, which was then used to identify likely areas for mineralization.

Opening order	Sub-basins	Width (km)			Sediment thickness (m)			Sediment type	Age (Ma)
		Min.	Max.	Avg.	Min.	Max.	Avg		
1	U-X	3	45	19	152	1216	665	NA	5.8
2	G-N	0.83	25.8	6.5	7.6	114	52.7	Primarily hemipelagic Minor volcaniclastic	< 3.55
3	A-F	0.8	2	1.5	15.2	38	27.6	Primarily volcaniclastic Minor hemipelagic	< 2.6
4	O & T	1.3	2.5	NA	60.8	76	NA	Primarily volcaniclastic Minor hemipelagic	> 0.78
5	P-S	0.9	2.9	1.65	19	91	56	Volcaniclastic and hemipelagic	< 0.78

Table 1 Summary table of the sub-basin characteristics. Minimum sediment thickness was calculated using two-way time from parasound data in sub-basins A-T, and using two-way time from the seismic data in sub-basins U-X. Sediment type was interpreted from the parasound data based on the acoustic character (Figure 4). The minimum age of sub-basin initiation was determined from magnetic data (Zellmer & Taylor, 2001; Cande and Kent, 1992), assemblage age (Stewart et al., in press) and basin initiation age (Hawkins et al., 1995).

Figure 3 This 3D bathymetric model covers the boxed area in the map of the Lau Basin (Figure 1). This is to provide regional context for the cross-section, which was interpreted from the seismic data from P03. Several features are marked on the cross-section: faults = black lines; sedimentary sub-basins = yellow; volcanic apron from the Tofua Arc = light yellow; volcanic ridges, cones, intrusions = red dashed lines. The identified sub-basins from this study are marked by their associated letters (A-X). Sedimentary basins are determined as such by first locating surface depressions in the seismic data, and then using the parasound data to determine if there is any sediment infill. Therefore, depressions in the seismic that do not correspond to a sub-basin do not have any sediment fill of note. The relative age is indicated by the colour bar at the bottom of the figure, and corresponds to the extensional model in Figure 2.

Tectonostratigraphic sub-basin categorization

Along the P03 line, we identified 24 sub-basins (A-X) and grouped them into five categories (Figure 2) based on their morphology and the texture and interpreted age of the underlying crust. Table 1 summarizes each groups' key characteristics. Sub-basins A-F are found on the crust formed along the Eastern Lau Spreading Center (ELSC) (Figure 3). The rugged topography of the underlying crust with many volcanic cones and ridges results in narrow, small sub-basins. Sub-basins G-N to the east are also underlain by ELSC crust, but are significantly wider than those in the west, with much thicker sediment packages (Figure 4). They are well-developed and ridge-bound, with some cone intrusions. On either side of the Fonualei Rift and Spreading Center (FRSC; Figure 3) are sub-basins O & T, dipping away from the rift center. Sub-basins P-S are located in the FRSC, bounded by rotated basement blocks (Figure 5). Finally, sub-basins U-X are only visible in the seismic profile since they underlie the Tofua Arc. This data was used to create an extensional timeline of the Lau Basin, which is summarized in Figure 2.

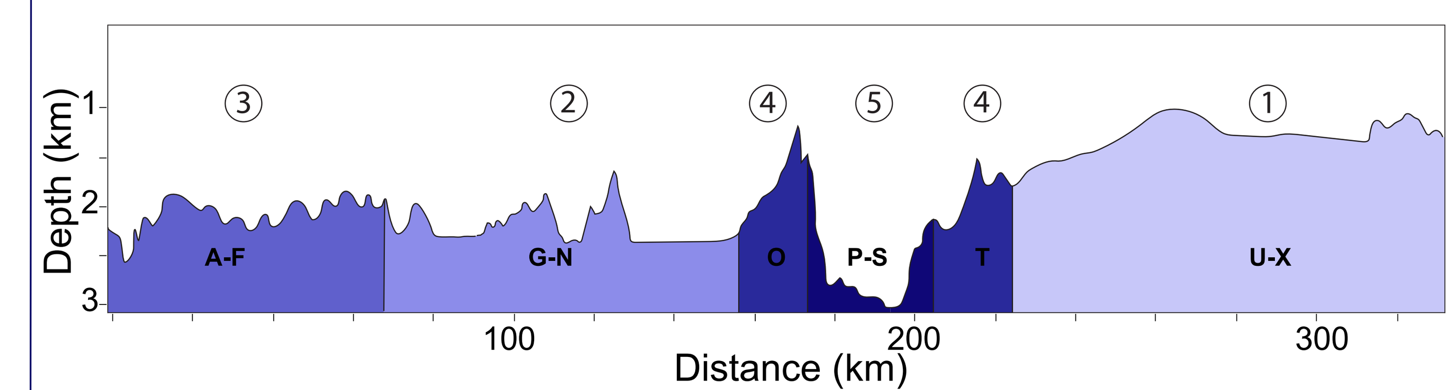

Figure 2 This bathymetric profile of the P03 seismic transect summarizes the sub-basin groupings and their extensional chronology. The numbers 1-5 indicate the opening order, with 1 being the oldest, and 5 being the youngest. The colours deepen from oldest to youngest, and they correspond to the colour bar at the base of the 3D model in Figure 3.

Back-arc basin sedimentation

To understand the provenance and composition of the basin sediments, we used the sediments recovered during marine drilling expedition, ODP Leg 135, as proxies. Clift et al (1995) suggested that the sediment in the Lau Basin is sourced locally because it is dominated by angular volcanic glass. To preserve this texture, the sediment underwent little to no transportation, implying that the volcanoes surrounding the sub-basins are the dominant sediment source. The angularity of the volcaniclastic sediment is important for this study because permeability increases with grain angularity (Tickell et al., 1938), meaning that the hydrothermal fluids could more easily permeate the sediment.

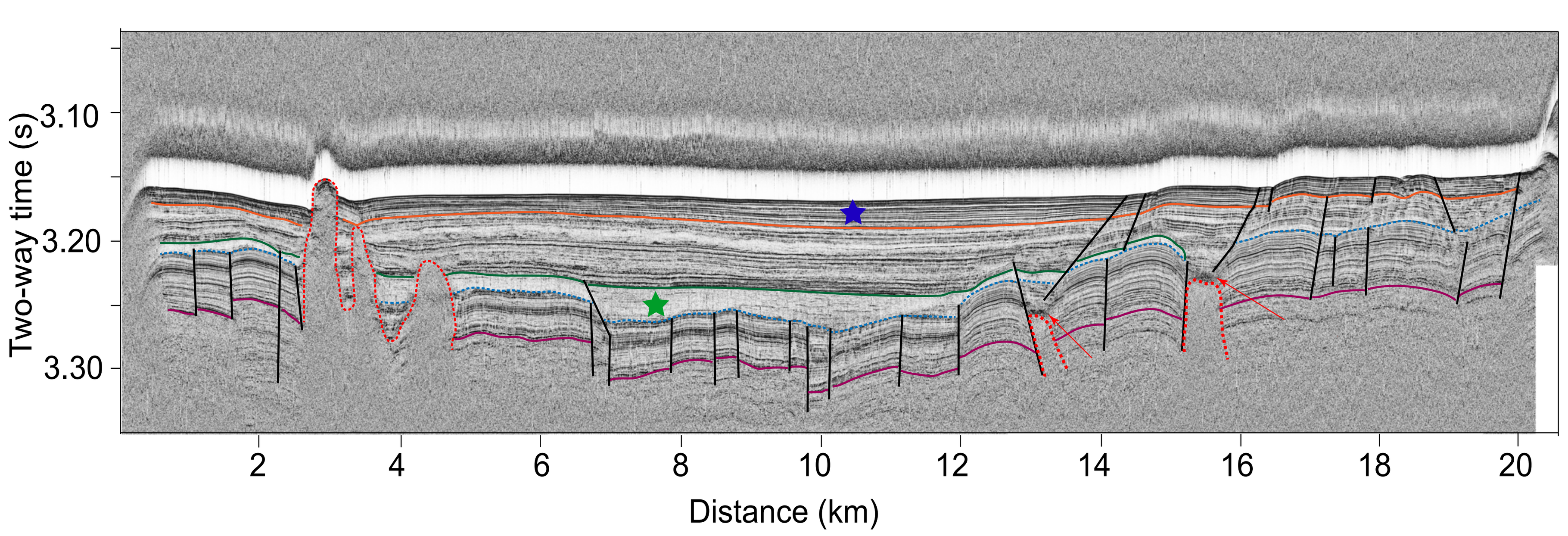

Figure 4 Parasound section of sub-basin N. Coloured lines separate sedimentary packages. The angular unconformity between the older and younger sediment packages is marked by the dotted blue line, where the older sediments are deformed and faulted and the younger sediments are continuous with few faults. Red arrows point to the two anomalies that are interpreted to be ore deposits. The emplacement of the anomalies is the same in both cases: above magmatic intrusions (outlined by a dotted red line) and in between two intersecting faults. Sediment type can be interpreted from the acoustic signature. The light grey, thick bed marked by the green star is interpreted as volcaniclastic, and the dark-grey, thinly bedded sediment is interpreted to be hemipelagic material, marked by the blue star.

Mineralization potential

One of the main goals of this study is to find sites where mineralization may be occurring in the sub-basins. To do so, we targeted faulted regions near magmatic sources to identify anomalous signals in the parasound data. Normal faults are the dominant fault type in the Lau Basin and can act as pathways to the surface for hydrothermal fluids. An area that appears promising for mineralization is the FRSC. It contains numerous normal faults, and the spreading center provides the necessary heat to mobilize fluids. Additionally, the FRSC sediment is mainly volcaniclastic and therefore permeable. A dark anomaly is visible in the parasound of sub-basin S (Figure 5). It appears to be contained in several strata and has diffuse boundaries. Another promising area is sub-basin N (Figure 4). The older sediment has been deformed and faulted and is separated by an unconformity from the less deformed, younger sediment. The angular discontinuity in the sediments hosted in sub-basin N is indicative of block rotation during re-activated faulting. Such reactivation of large, long-lived structures is a primary control mechanism on the development of mineral deposits (Hanley and Adams, 1992). In the parasound of sub-basin N, there are two anomalies similar to the one found in sub-basin S. Sub-basins S and N are potential targets to further investigate the nature of this anomaly to determine if it is an actively-forming sediment-hosted mineral deposit.

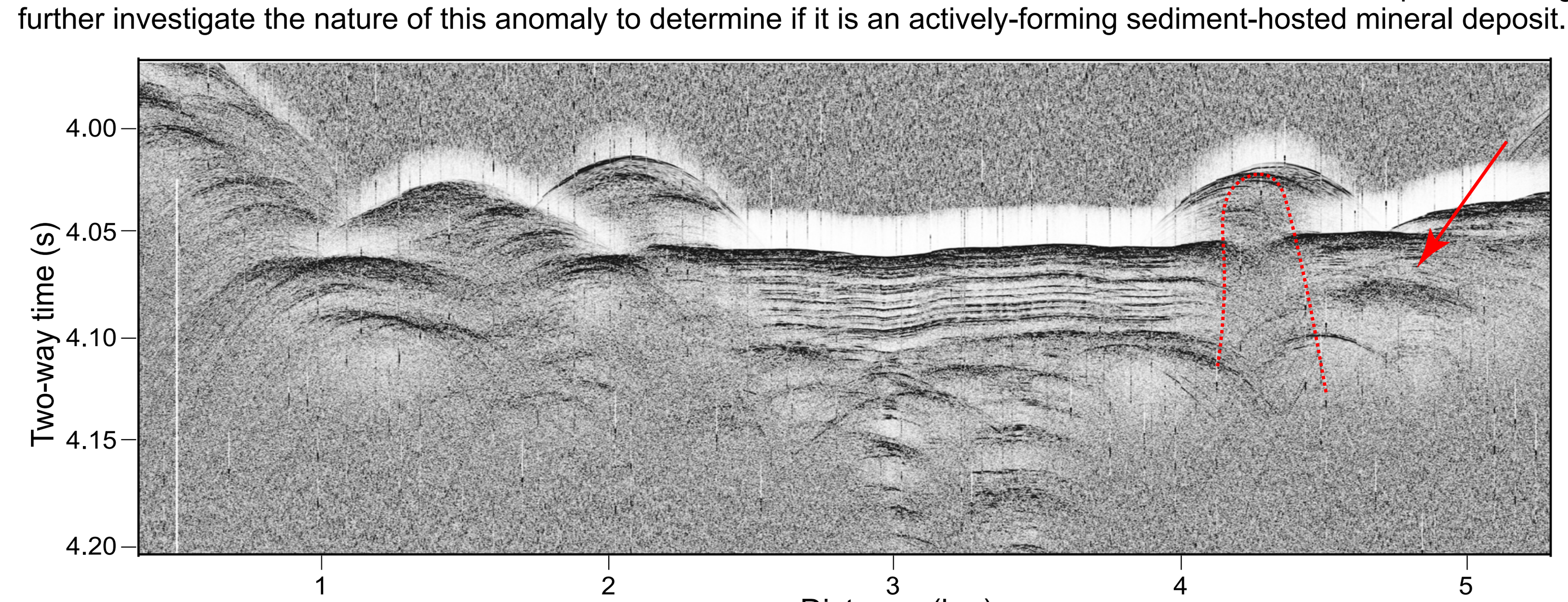

Figure 5 Parasound section of sub-basin S. The red arrow points to the anomaly interpreted to be a mineral deposit. The red dotted line outlines a volcanic intrusion. The sediment type is interbedded volcaniclastic and hemipelagic material. Parabolic echoes in the west of the section are caused by rugged topography at the outer boundary of the sub-basin.

Conclusions

- By relating the sedimentary sub-basins to the crustal evolution of the Lau Basin, we have identified five groups associated with different tectonic settings and ordered them from oldest to youngest.
- The FRSC and the eastern ELSC are likely locations for sediment-hosted mineral deposits and we have identified a potential acoustic signature of mineralization.
- The correlation of these sub-basins with others in the Lau Basin will produce a complete extensional model and will reveal other areas that are likely hosts for mineral deposits.
- The understanding of mineral deposits in a modern back-arc will provide important insights for exploration in ancient back-arc settings preserved in the rock record.

Acknowledgements

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