Forearc evolution in Complex Subduction Settings - Mesozoic and Cenozoic Examples from SE Asia.

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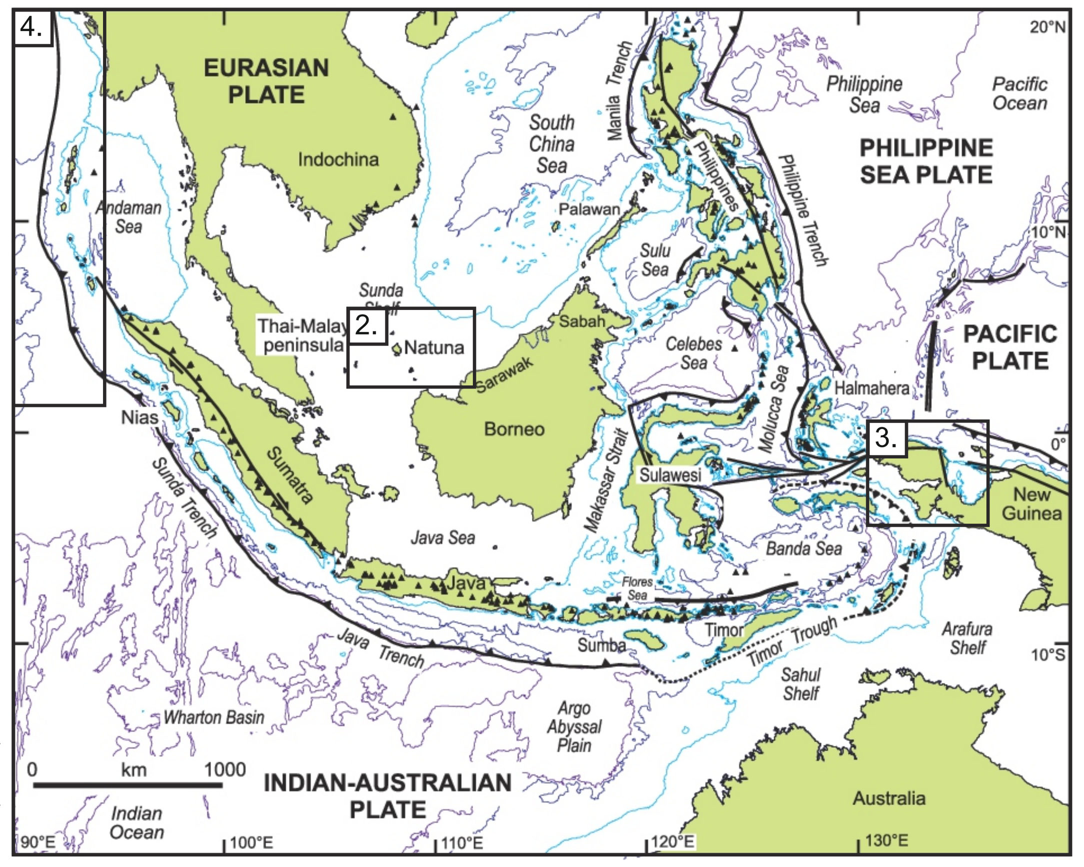
1. Overview of subduction settings in SE Asia:

Southeast Asia displays a full range of subduction settings and styles, including: steep, shallow, and oblique subduction, divergent double subduction, and subduction polarity reversal. Rapid uplift, collision, and sedimentation rates throughout the Cenozoic have made it possible to study these subduction zones and their eroded products in the field. Continued outcrop studies of fossil and modern subduction zones in SE Asia, combined with geochemisty, geochronology, and seismic tomography, provide an invaluable resource for deciphering ancient subduction zones that have since been overprinted by collision, burial, and metamorphsim.

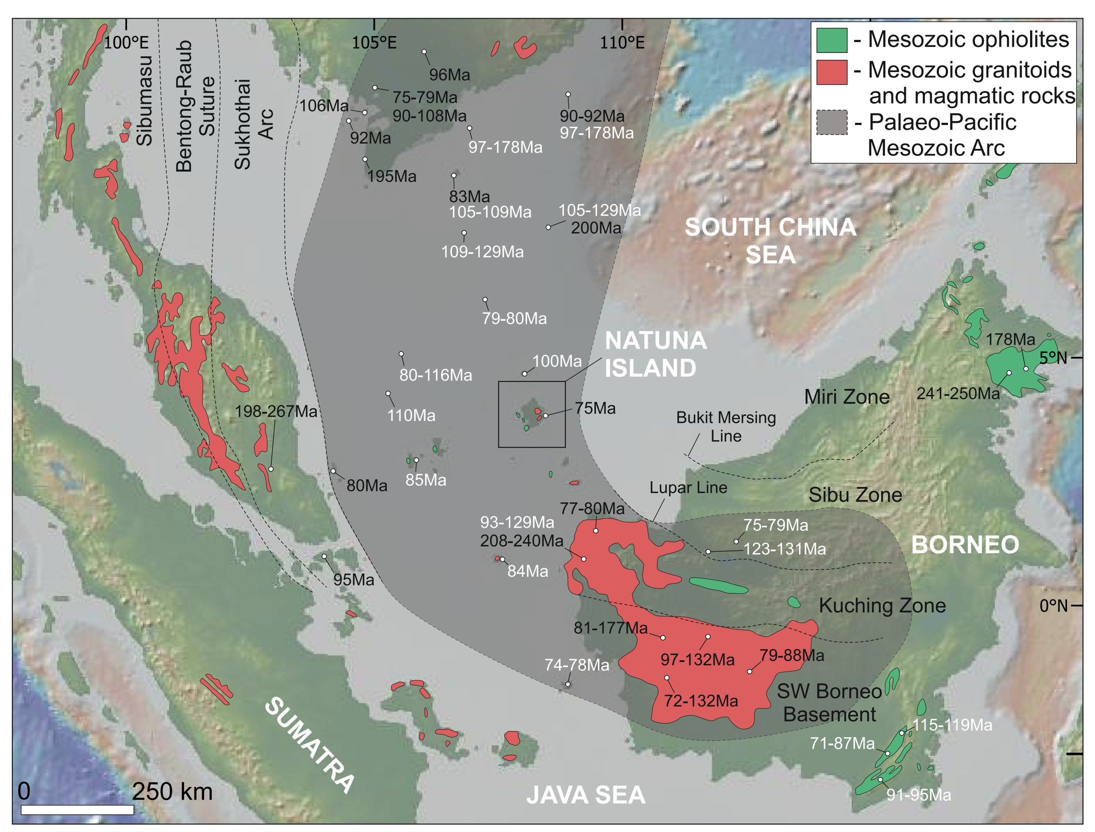
This poster summaries three ongoing projects from SEARG that focus on subduction zone dynamics in different settings and times throughout SE Asia. The first examines Palaeo-Pacific Plate subduction and Mesozoic magmatism on the island of Natuna. The second presents a new tectonic model for NW New Guinea towards improving our understanding of how arc-continent collisions progress in oblique suduction settings. The third reports sedimentary provenance data from the Nicobar Fan and shows the role that uplfited accretionary wedges play in supplying sediment to surrounding basins.

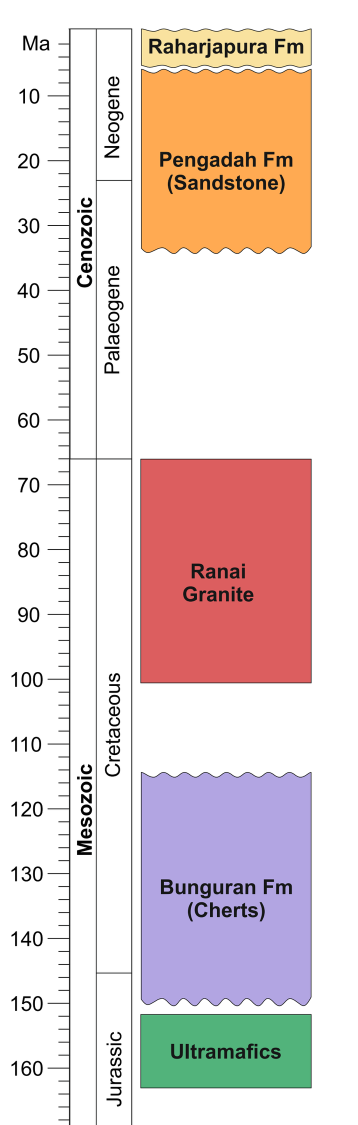
Right: Map of SE Asia showing the current tectonic configuration and structure. Inset boxes: 2. Magmatism through previously accreted crust - Natuna Island. 3. Forearc development in oblique systems - New Guinea. 4. Sedimentary provenance of accretionary wedges - Nicobar Fan (based on Hall, 2012).



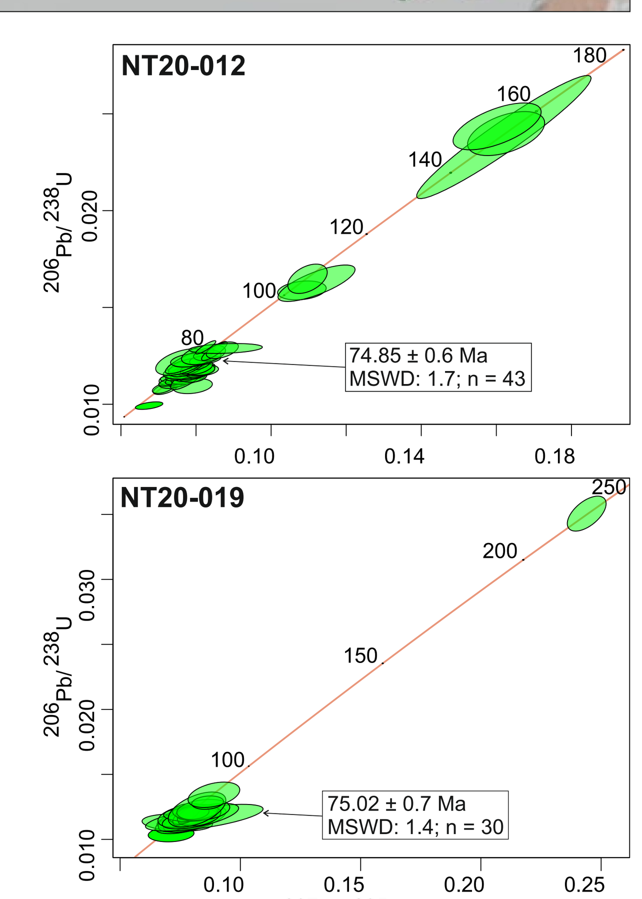
2. Magmatism through previously accreted crust - Natuna Island

Natuna Island lies within central Sundaland, a composite terrane of the Eurasian Plate formed of crustal fragments (derived from either Gondwana or Cathaysia) through a series of accretionary events since the Triassic (Hall, 2012). The geology of the Natuna is made up of a pre-Jurassic accretionary ophiolite complex, Jurassic–Cretaceous cherts of the Bunguran Formation, the Cretaceous Ranai Granite, the Oligo-Miocene siliciclastic Pengadah Formation, and the Plio-Pleistocene siliciclastic Raharjapura Formation (Hakim & Suryono, 1994). The Cretaceous granite and pre-Jurassic ophiolite form part of a large swathe of Mesozoic magmatism generated during the Yenshanian (Palaeo-Pacific Plate subduction) and Indosinian (Meso-Tethys subduction) orogenies (Metcalfe, 2013; Hennig-Brietfeld et al., 2021). Geochemical and U-Pb zircon geochronological studies are lacking from Natuna Island. This study aims to better understand the timing and style of magmatism along with the influence that pre-Jurassic ophiolitic crust has had on the Ranai Granite.



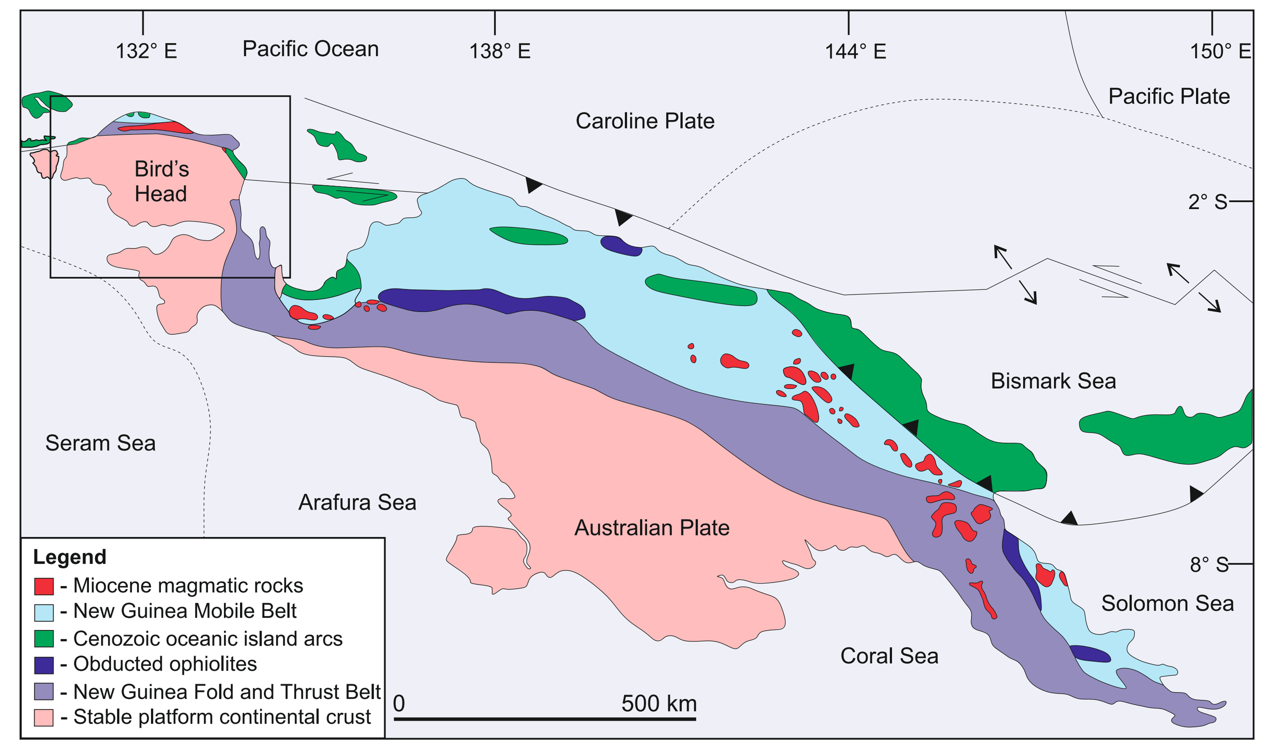


Left: Stratigraphy of Natuna Island. Hakim & Suryono, 1994. **Bottom middle:** Field photos from Natuna Island, **A** Bunguran Formation folded cherts, **B & C** Jurassic Ophiolite pillow basalts and gabbro, **D** Ranai Granite tors, **E** Different lithologies of the Ranai Granite. **Top right:** Map showing the location of Natuna Island and Mesozoic magmatic rocks in Sundaland. Additional age data from Hennig-Breitfeld et al., 2021. **Bottom right:** U-Pb zircon concordia plots for samples of the Ranai Granite.

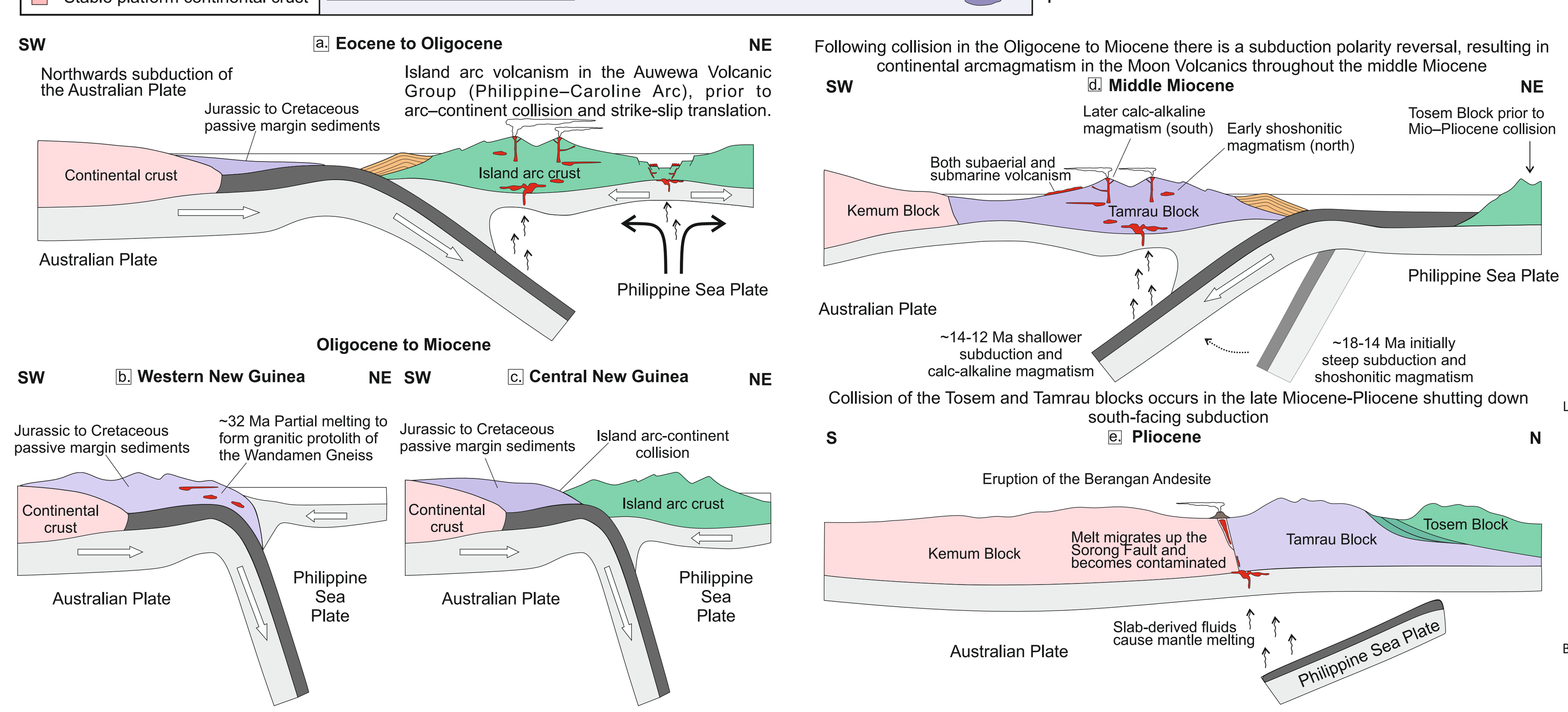


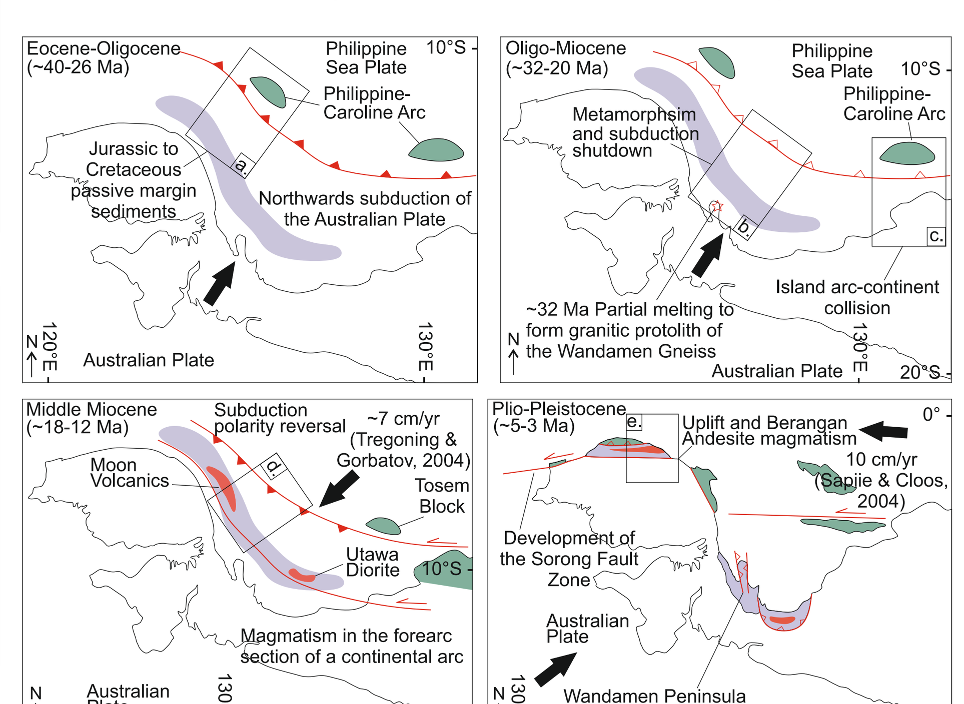
3. Forearc development in oblique systems - New Guinea

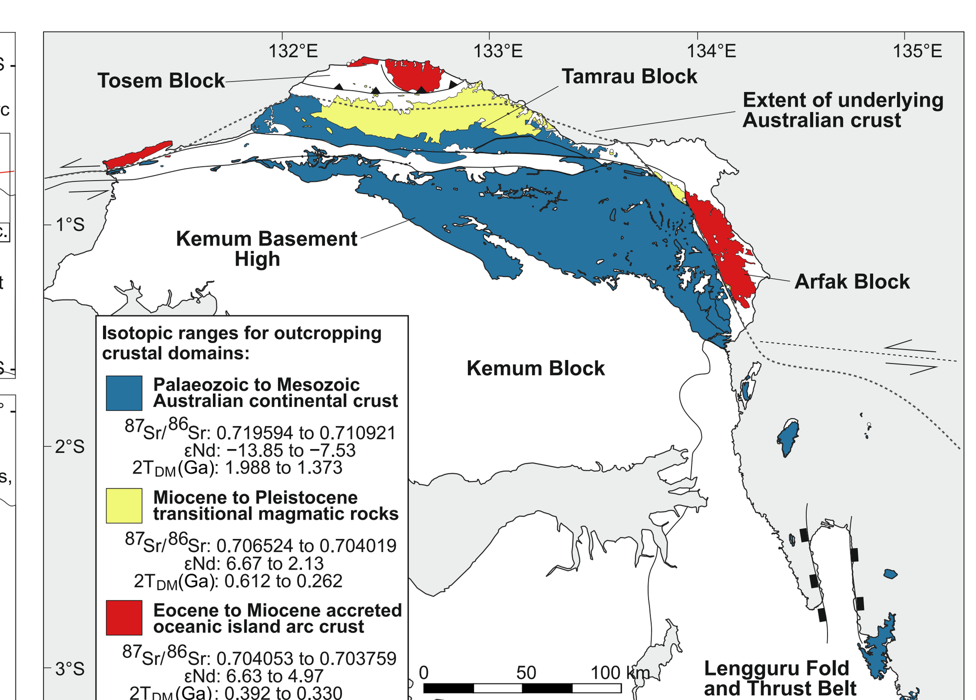
The Cenozoic geological evolution of New Guinea is complex; the island has experienced multiple periods of island arc accretion, continental arc magmatism, and orogenesis. Rocks recording the effects of these processes can be correlated along much of central and eastern New Guinea through the New Guinea fold and thrust belt, the New Guinea mobile belt, and the Maramuni arc (Baldwin et al., 2012; Davies, 2012). However, due to a comparative lack of detailed geological study these terranes have not previously been correlated into New Guinea's westernmost peninsula (the Bird's Head). Recent field, geochronology, and geochemistry studies of Cenozoic volcanic rocks in the Bird's Head have revealed a complex history of arc-continent collision, short-lived subduction and subduction polarity reversal, and strike-slip movement (Webb et al., 2020; 2021). The complexity of this part of New Guinea is in part due to the obliquity of the subducting margin, with the Philippine Sea Plate butting against a promontory of thick Australian continental crust throughout much of the Cenozoic. Volcanic rocks in the Bird's Head reveal three distinct stages of Cenozoic magmatism: **1.** Eocene to Oligocene island arc volcanism during northwards subduction of the Australian Plate, terminated during initial Oligo-Miocene arc-continent collision; **2.** Middle Miocene continental arc magmatism through previously accreted sediments, following a flip in subduction polarity (resulting in southwards subduction of the Philippine Sea Plate); **3.** Plio-Pleistocene eruption of crustally-contaminated mantle-derived melts in strike-slip settings following terminal arc-continent collision. Finally, isotopic fingerprinting of these distinct phases of magmatism has been used to map their relationship to specific New Guinea terranes furthering our understanding of the island as a whole.



Top left: Overview map of the island of New Guinea showing the regional tectonic structure and the main tectono-stratigraphic terranes. Inset box shows the location of the below figures. Map based on Baldwin et al., 2012; Davies et al., 2012; Webb et al., 2020 **Middle:** Cross-sectional tectonic reconstructions of the Bird's Head region from the Eocene to Pliocene. Reconstructions are based on new fieldwork, geohcronology, and geochemistry that highlight the timing and style of subudction, arc-continent collision, and magmatism. From Webb et al., 2020. **Bottom left:** Map view tectonic reconstructions of the Bird's Head from the Eocene to Pliocene with plate movements and velocities showing the effects of arc-continent collision in an oblique margin. Inset boxes correlate to equivalent time slices in the middle figures. From Webb et al., 2020. **Bottom right:** Map showing isotopic ranges for different terranes of the Bird's Head. These include highly evolved Proterozoic Australian continental crust, moderately evolved Cenozoic magmatic rocks that intruded through thinned continental crust, and primitive island arc volcanics.

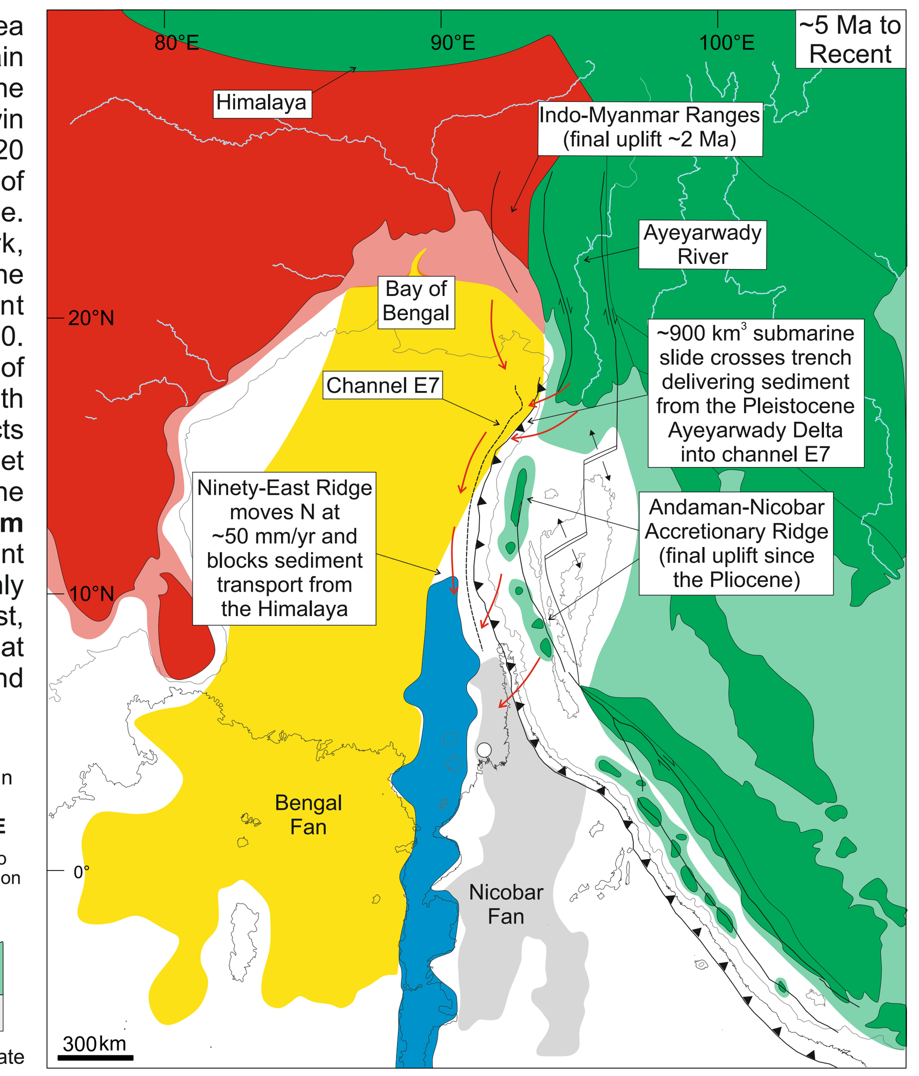


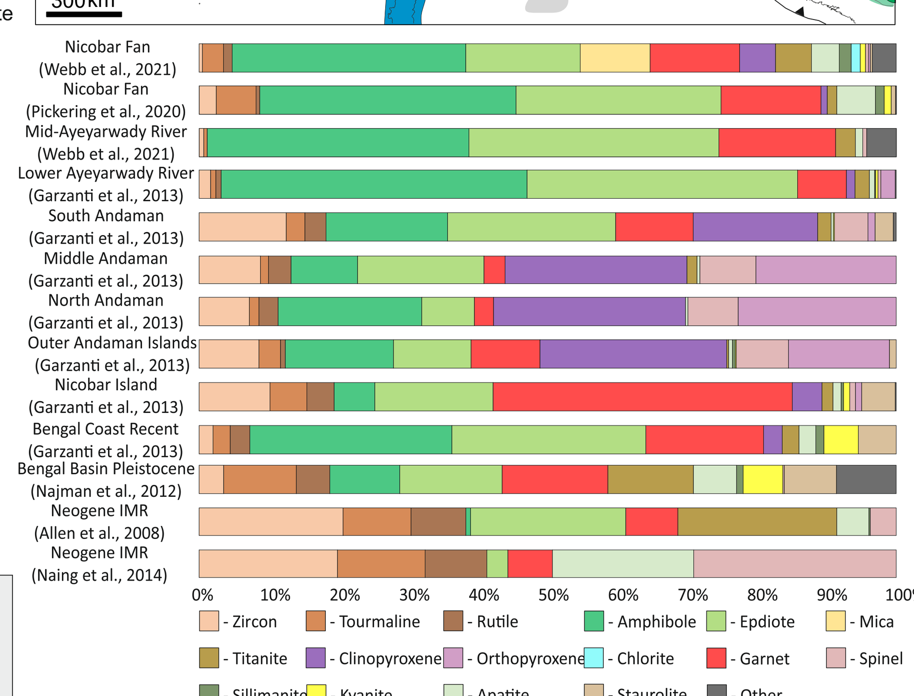


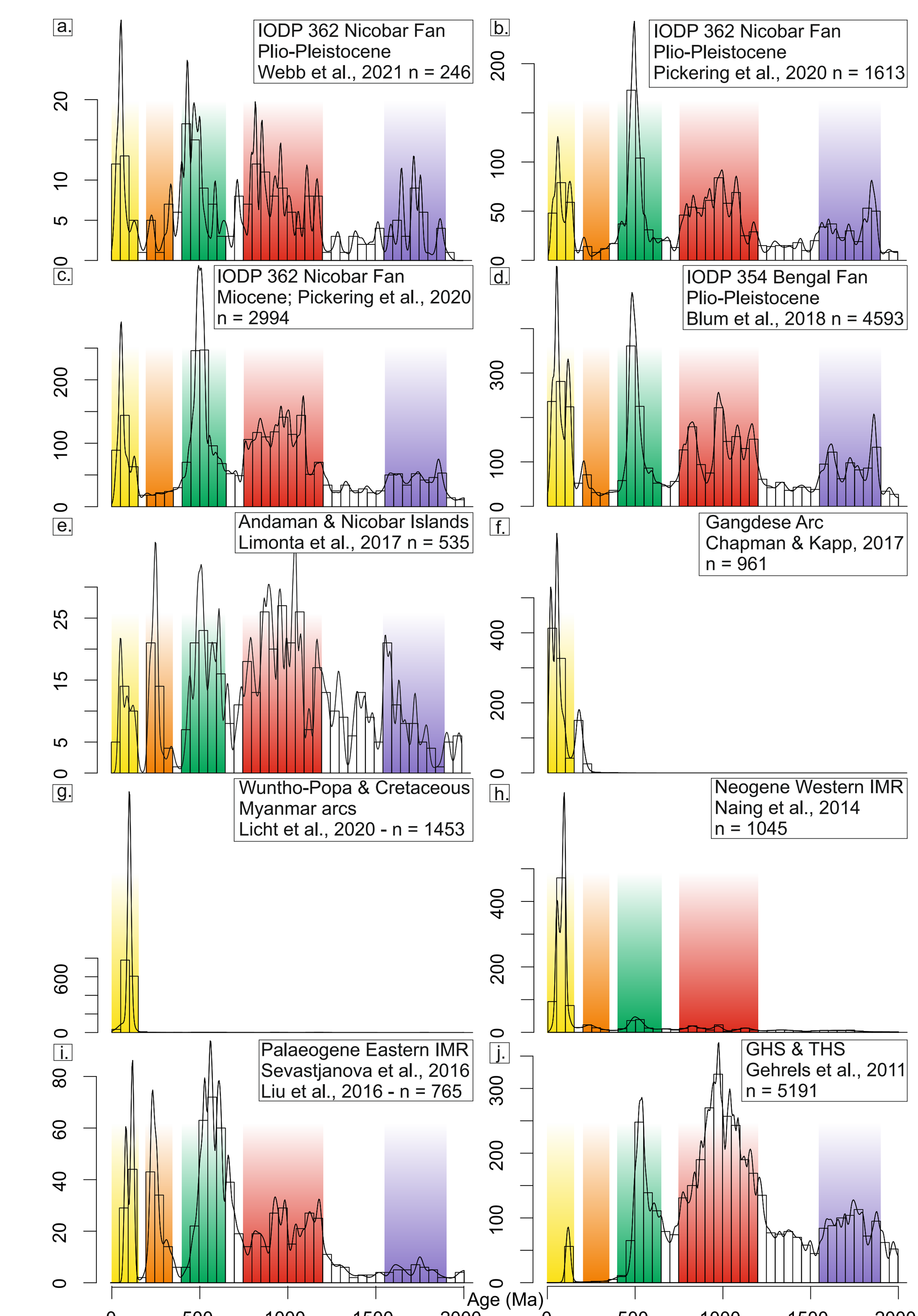


4. Sedimentary provenance of accretionary wedges - Nicobar Fan

High sedimentation rates, rapid uplift, and extensive subduction systems mean that accretionary wedges have played an important role in the geologic history of SE Asia. Our recent study on the Nicobar Fan showcases the role large accretionary wedge systems have in providing sediment fill to these basins and how sedimentary provenance can be used to track this. The Bengal-Nicobar Fan System is among the largest submarine fans on Earth and previous studies have shown that the fan has acted as a major sink for eroded Himalayan sediment throughout the Cenozoic (Blum et al., 2018; Pickering et al., 2020), however, additional sources do exist. To test this, we compared U-Pb detrital zircon ages and heavy mineral compositions of Plio-Pleistocene sediments from the Nicobar Fan with potential sources to determine sedimentary depositional pathways. The data shows that whilst a large proportion of the detrital zircon ages correlate with magmatic and metamorphic sources in the Himalaya, the heavy mineral compositions indicate a greater complexity in source regions. Heavy mineral data from the Ayeyarwady River in Myanmar can be correlated with those from the Nicobar Fan (notably high % amphibole, apatite, and garnet with reduced ultra-stable minerals). The Ayeyarwady River sediments themselves are derived from Triassic accretionary wedge and ophiolitic material from the Indo-Myanmar Ranges (McNeil et al., 2021), which have experienced extensive uplift since the Oligocene along with other accretionary wedge material along the Sunda Arc (including the Andaman-Nicobar Accretionary Ridge; Allen et al., 2008). Ultimately this study displays that whilst the Nicobar Fan remains a dominant sink for Himalayan sediment, it can also be used to track the erosion of accretionary wedge material in the eastern Indian Ocean.







Top left: Tectonic setting and sediment routing pathways for the area surrounding the Nicobar Fan from ~5 Ma to Recent. Red arrows show sediment routing pathways from the Himalaya, the IMR, the Ayeyarwady River, and Andaman-Nicobar Ridge, based on U-Pb zircon and heavy mineral data. Based on Hall, 2012, Pickering et al., 2020a, Webb et al., 2021 **Bottom left:** Heavy mineral plots comparing heavy mineral components from the Nicobar Fan and possible source regions. Citations in figure. **Right:** Histograms with KDEs showing comparisons between U-Pb zircon data from the Nicobar Fan and possible source regions. Citations in figure.

5. Conclusions & Future Work:

- The selection of studies presented here show that Southeast Asia is a natural laboratory for studying both modern and Cenozoic subduction systems (including their forearcs). Fieldwork forms a vital component of these studies.
- Further geochemical and geochronological data will be collected to support the Natuna Island study. These data will be used to better understand the Palaeo-Pacific Mesozoic arc linking Borneo to Vietnam and the role that previously accretioned crust plays in the evolution of Mesozoic magamtism.
- Isotopic mapping from the New Guinea study will be expanded throughout SE Asia to determine its potential for mapping the nature of the underlying crust in poorly exposed regions and its application for mineral exploration.
- The Nicobar Fan study will compliment future work on how far south Himalayan provenance signatures extend along the Sunda Arc. Sedimentary provenance data will be collected from forearc islands offshore Sumatra in the southern section of the arc to track changes in sediment composition and uplift rates compared with samples in the north

6. CV & Pubs!

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