

Continent-ocean transition and sedimentary records in the southwestern South China Sea: Insights from seismic data evidence

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INTRODUCTION & AIM

The South China Sea (SCS), a classic West Pacific marginal basin (Fig.1), has achieved significant advances in understanding its tectonism and magmatism. IODP drilling revealed abundant altered basalts within the continent-ocean transition (COT) domain of the northern margin. However, seismic reflection profiles show no seaward-dipping reflectors (SDRs), indicating an intermediate-type passive margin between the two endmember models(Larsen et al., 2018; Mohn et al., 2022). However, the Southwest Sub-basin of the SCS (SW-SCS) remains controversial regarding its margin type and COT architecture due to: (1) limited spreading amount, (2) ambiguous magnetic lineations, (3) complex tectono-magmatic processes, (4) lack of direct basement samples, and (5) low-resolution geophysical data from early surveys.

Focusing on the magnetic anomaly termination zone representing the transition between oceanic crust and hyper-extended continental crust in the tip of the SW-SCS, we analyze the section A and B from the NH973-1 (Fig.2). The main objectives of this study are as followings: (1) Characterizing margin tectonics and stratigraphic architecture; (2) Deciphering magmatic emplacement history; (3) Reconstructing the process from continental thinning to lithospheric breakup and/or seafloor spreading. This work provides critical insights into the lithospheric final rifting of the SCS and their implications for Southeast Asian tectonic evolution.

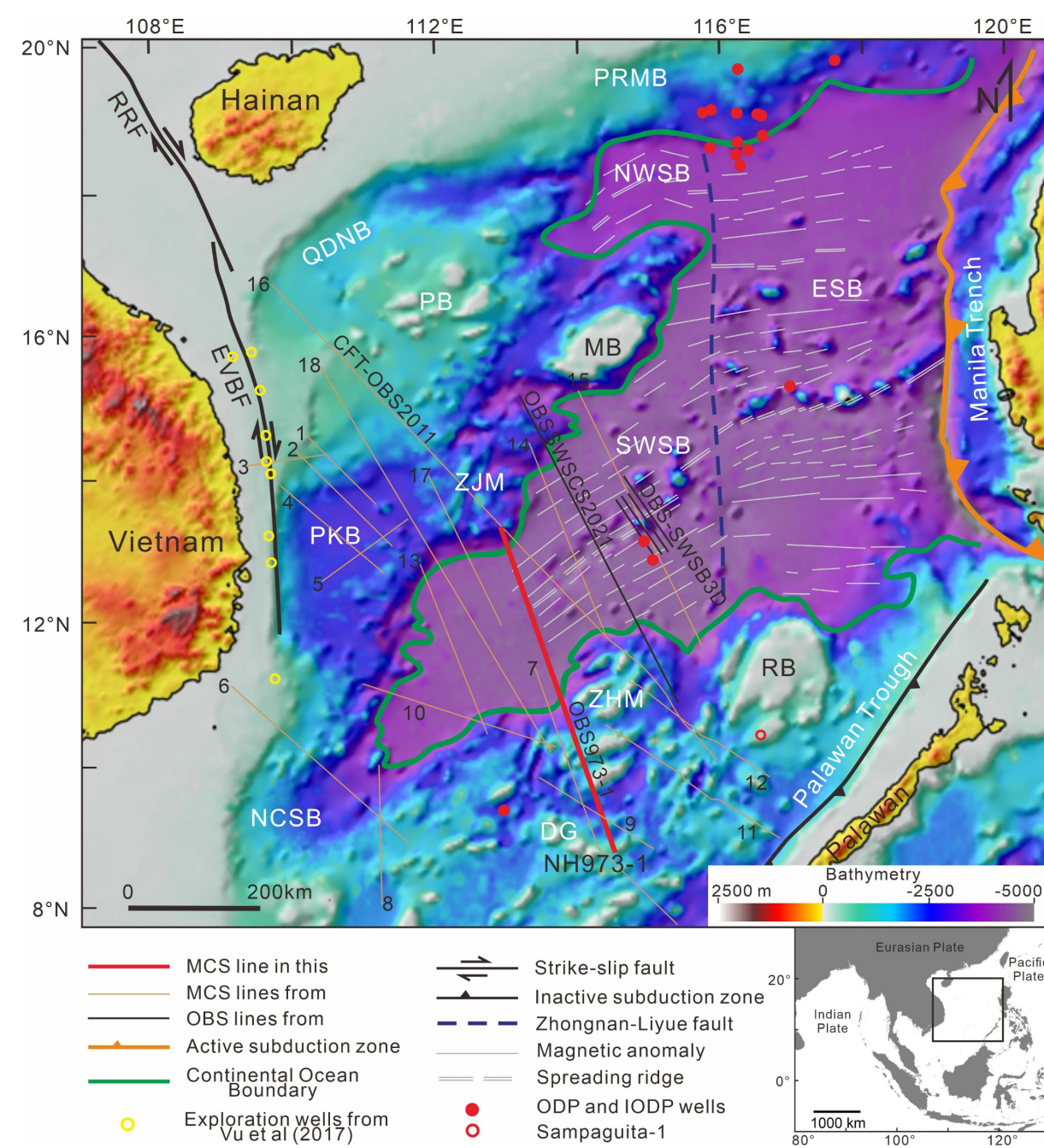


Fig.1. Study area and location of seismic line NH973-1.

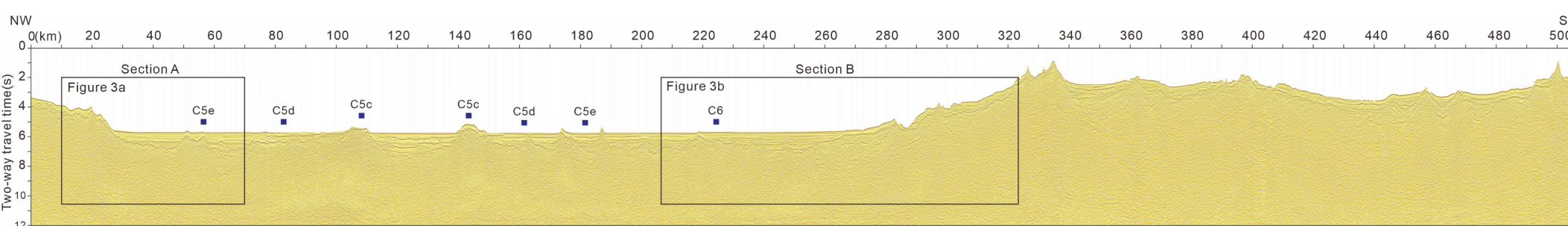


Fig.2. Uninterpreted regional seismic profile NH973-1 covering SW-SCS.

METHOD

Seismic interpretation: By identifying the characteristics of seismic facies—such as whether they are stratified, chaotic, or homogeneous—we distinguish the acoustic basement from the overlying Cenozoic sedimentary sequence and define three first-order interfaces: the seafloor, the top of basement (Tb), and the Moho. Based on the interrelationship between the Tb and the Moho, we describe the crustal architecture and divide the margin into four domains: necking, hyper-extension, COT, and oceanic crust domains. Next, we identify tectonic reflections within the sediments using onlap, downlap and truncation patterns combined with the stratigraphic correlations to adjacent basins and wells (e.g., the Phu Khanh Basin), which helps us further subdivide the sedimentary sequence into specific tectonic sequences. Finally, we recognize magmatic features, including intrusions and extrusions that occurred during rifting.

Time-depth conversion: As line NH973-1 is in the time domain, we performed time-depth conversion using two key constraints: co-located OBS973-1 and intersecting OBSCFT2011 at the Zhongjian Massif for determining the approximate velocities of the crust (Fig. 1). The average seismic velocities are ~5.6 km/s for the upper crust and ~6.7 km/s for the lower crust. The time-depth conversion procedure comprises four key steps: (1) identifying the seafloor, tectonic interfaces within sediment, the Tb, the Conrad (boundary between the upper and lower crust), the Moho, and faults on the time-domain Line NH973-1; (2) deploying pseudo-wells along profile to track interface depth variations and locate fault displacement points; (3) calculating sediment interface depths using the time-depth conversion equation: $Z = 0.000152626t^2 + 0.714658t$ (where t = the two-way travel time in ms starting from seafloor); (4) calculating the depths of the the Conrad and Moho interfaces using velocity models from OBS973-1 and OBSCFT2011; (5) generating depth-converted section with calibrated interface depths and kinematically restored fault geometries.

RESULTS & DISCUSSION

We identified two critical geometric points on each conjugate margin: the continental crust breakup point marking continental crustal breakup, and the continental lithosphere breakup point marking lithospheric breakup. These points demarcate three first-order rift domains from continent to ocean: thinned continental crust, COT and oceanic crust domains (Fig. 3).

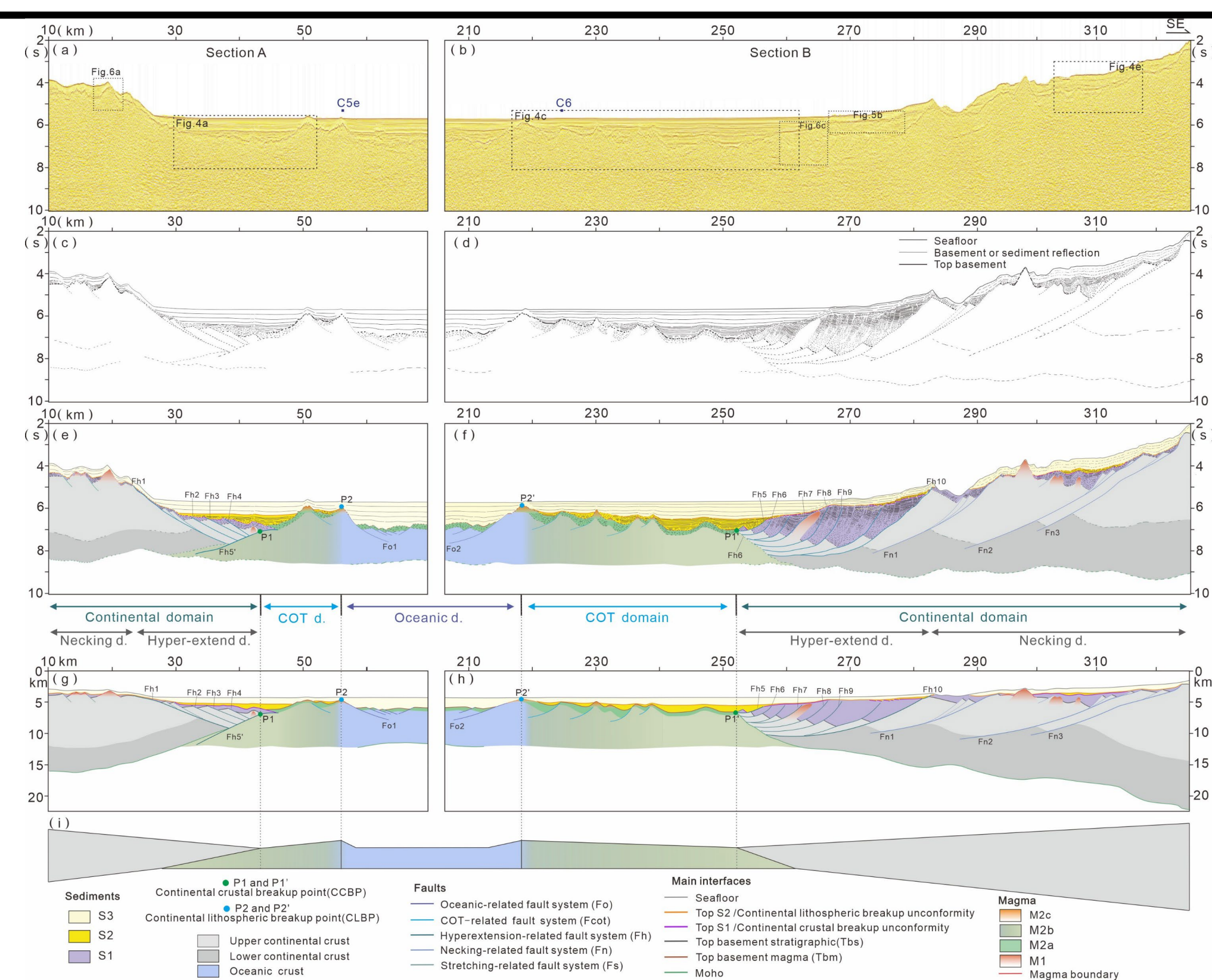


Fig.3. The tectono-stratigraphic and magmatic interpretation of Section A and section B

Within the thinned continental crust domains, the Tb and Moho converge oceanward, intersecting at the CCBP where crustal thickness tapers from 12/20 km to 0 km. The thinned continental crust domains preserve complete S1-S3 sequences. Magmatism is limited to sporadic dikes, sills and volcanoes that were synchronous with the deposition of S1. Faults can penetrate into the lower crust or sole into the Moho.

The COT domain is characterized by significantly reduced tectonism. The M2a lava flows display distinct wedge-shaped thickening toward faults, indicating that the magmatic emplacement was syn-tectonic. The Tb, defined by the top interface of M2, overlies these normal faults. The COT domain contains S2 and S3, but lacks sequence S1

In the oceanic crust domain, Tbm maintains an overall sub-horizontal geometry and parallel to the reappeared Moho, yielding a crustal thickness of ~1.8 s TWT (~6 km), which consistent with slow-spreading oceanic crust. The oceanic crust domain contains only S3.

Based on the observation of tectono-stratigraphy and magma, we classified the evolution of the SW-SCS into three first-order stages: continental crust breakup (comprising stretching, necking, and hyperextension phases), ocean-continent transition and seafloor spreading (Fig.4).

The crustal breakup stage is dominated by tectonic thinning that evolved from distributed high-angle normal faulting under a pure-shear regime to localized low-angle detachment faulting under a simple-shear regime. The continent-ocean transition stage features waning tectonic activity and magmatic accretion as the primary driver for lithospheric breakup. The seafloor spreading stage involves slow-rate spreading that transitioned from symmetric to asymmetric.

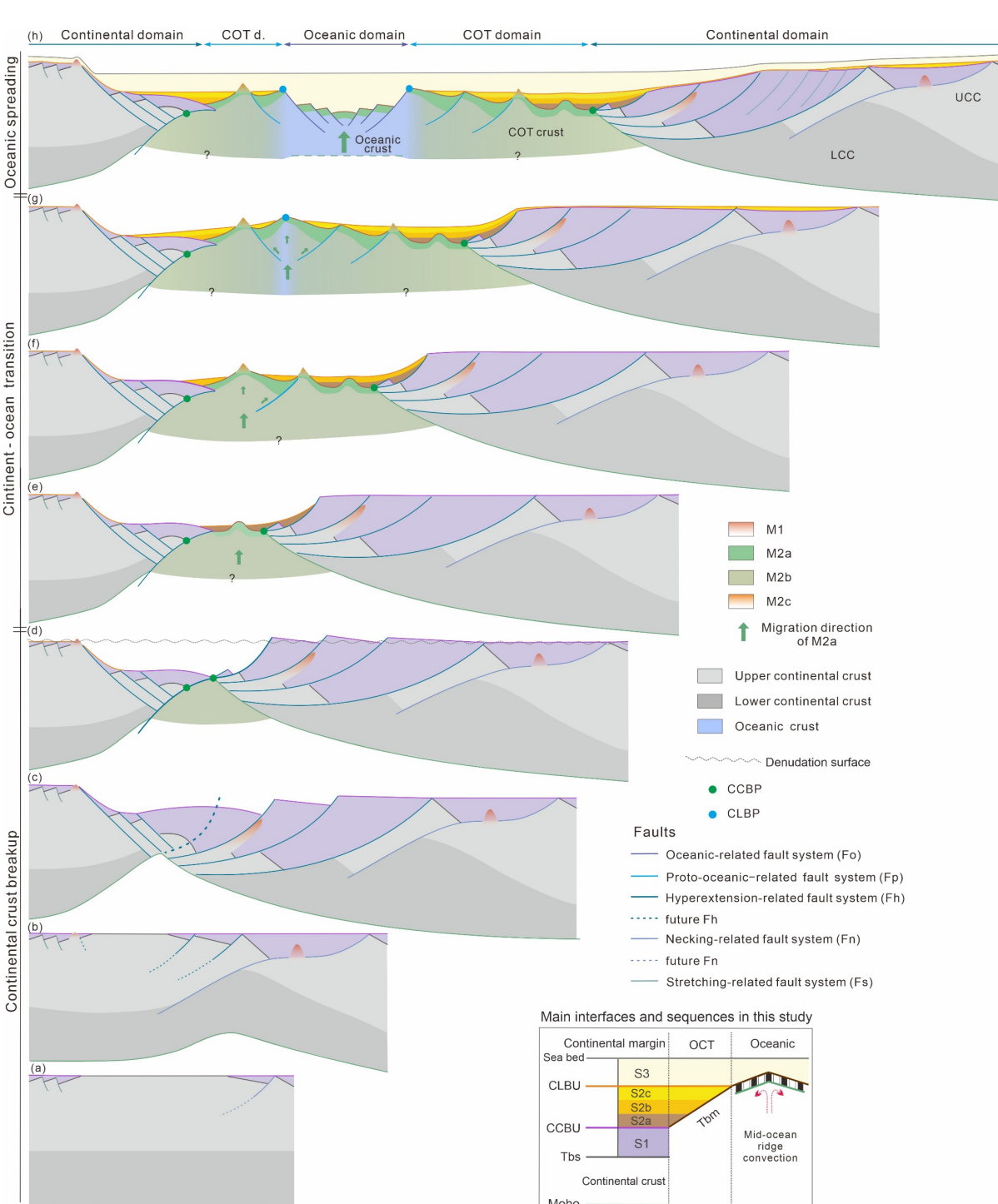


Fig.4 Conceptual model showing continental thinning-breakup and subsequent seafloor spreading in the SW-SCS

CONCLUSION

Based on detailed interpretation along 2D seismic profile NH973-1, this study systematically characterizes the crustal architecture and tectonic-stratigraphic- magmatic records of SW-SCS, investigates the lithospheric extension-breakup processes, and proposes an evolutionary model

FUTURE WORK / REFERENCES

Larsen, H.C., Mohn, G., Nirrengarten, M., Sun, Z., Stock, J., Jian, Z., Klaus, A., Alvarez-Zarikian, C.A., Boaga, J., Bowden, S.A., et al., 2018. Rapid transition from continental breakup to igneous oceanic crust in the south china sea. *Nat. Geosci.* 11 (10), 782-789.

Mohn, G., Ringenbach, J.C., Nirrengarten, M., Lei, C., McCarthy, A., Tugend, J., 2022. Mode of continental breakup of marginal seas. *Geology* 50 (10), 1208-1213.