Geophysical Characteristics of Breakup Magmatism in the Southern South China Sea Margin

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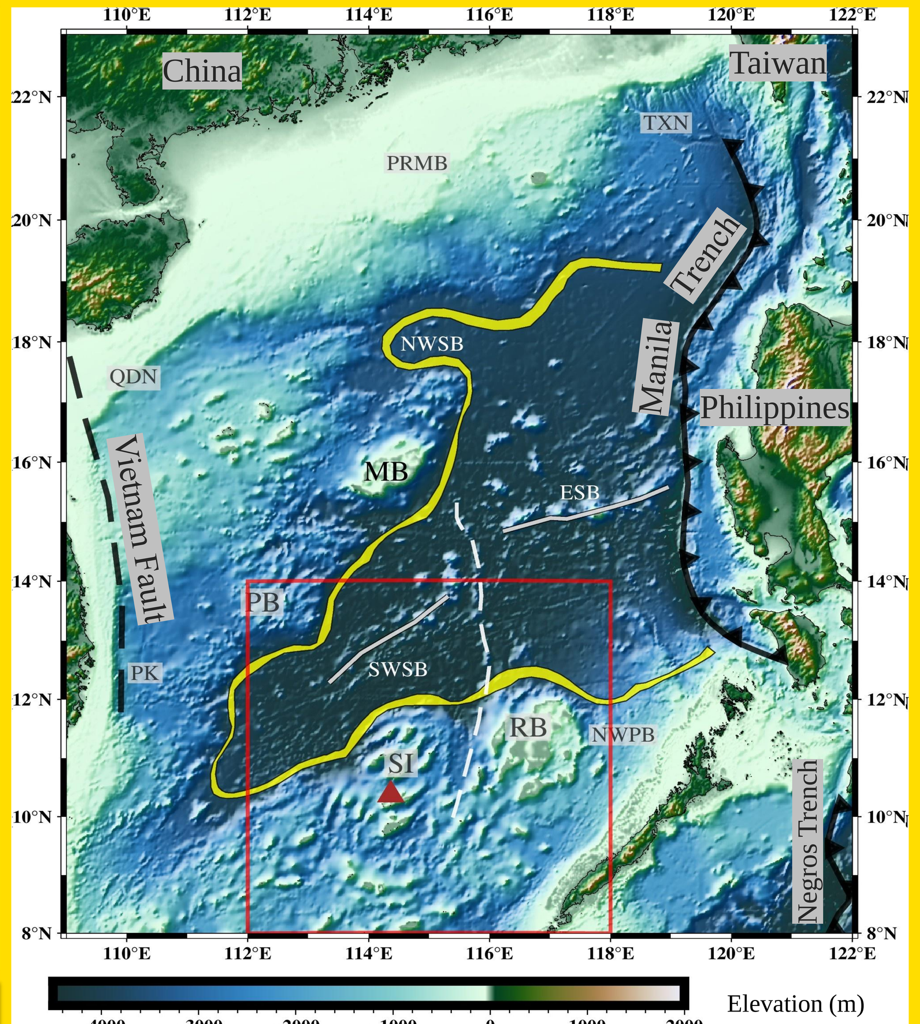
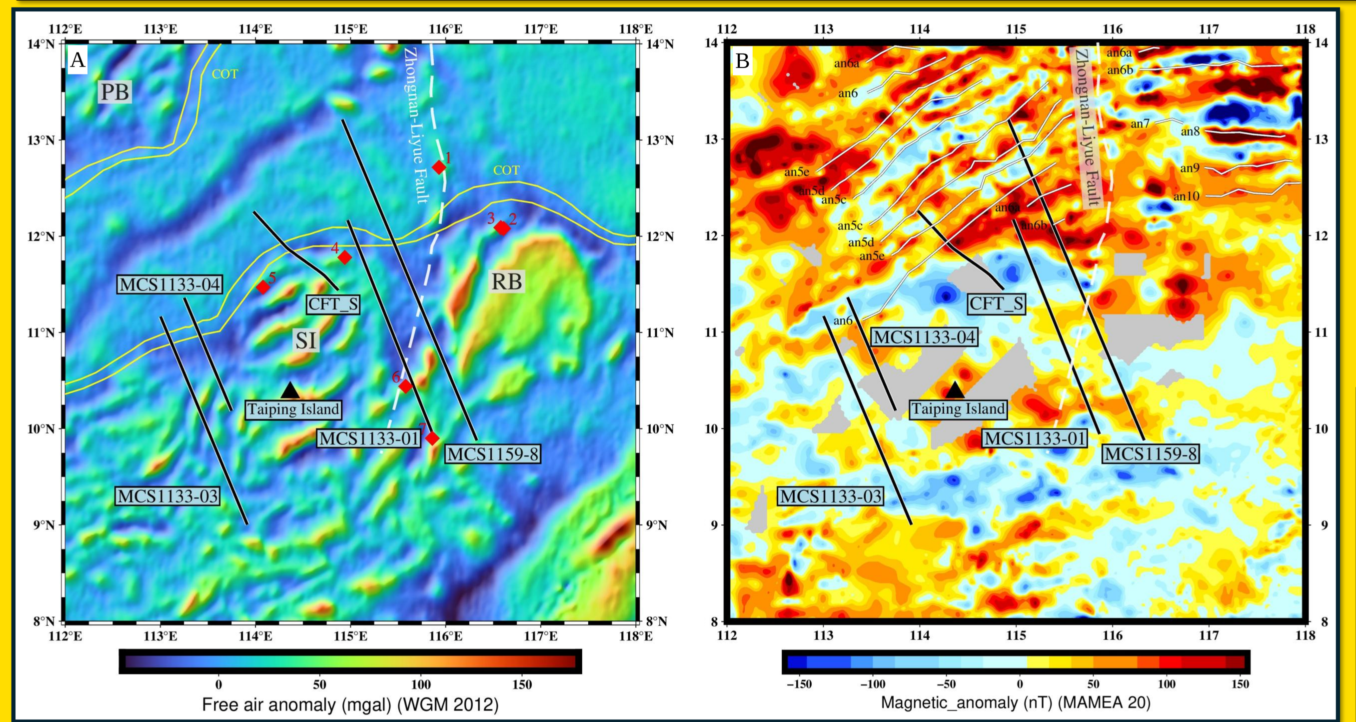
ABSTRACT The South China Sea Margin is a good natural laboratory featuring polyphase rifting processes that began in the late Eocene and ended late Miocene. The breakup first occurred in the East Sub-basin, and the expansion direction shifted from a north-south orientation to a northwest-southeast orientation around 23 Ma, with the propagation of new oceanic crust forming the Southwest Sub-basin. The involvement of magmatic activity is still not fully understood, nor is its influence during the breakup process of the Southwest Sub-basin. This study investigates the crustal structure and the magmatic activity by integrating multichannel seismic (MCS) profiles and shipborne gravity around Taiping Island (Spratly Islands). Gravity simulation results reveal the presence of a high-density igneous body in the continent-ocean transition (COT) east of Taiping Island (Spratly Islands). Areas with under-estimated gravity values in the model also imply that a high-density lower crust may exist. Therefore, this study suggests distinct magmatic intrusions within the South China Sea crust during the spreading of the southwest sub-basin. The formation of these high-density bodies may provide more insights to discover magmatism involving the ridge propagation process.

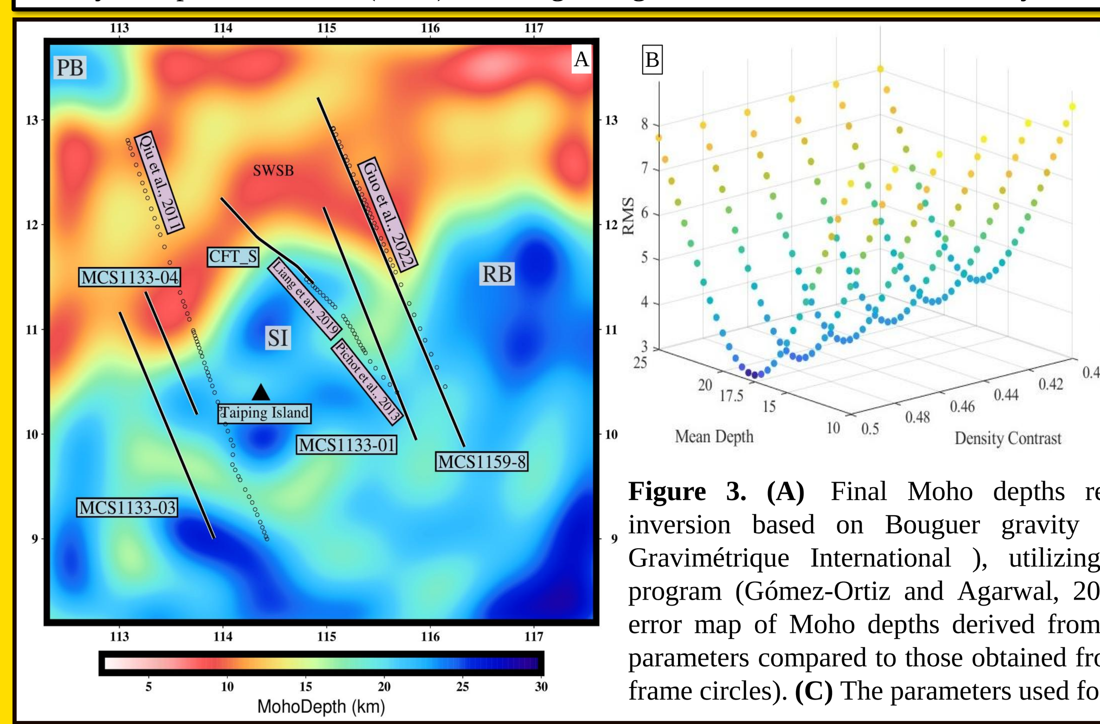


NWPB: NW Palawan Basin, **PK**: Phu Khanh Basin, **PRMB**: Pearl River Mouth Basin, **QDN**: Qiongdongnan Basin, **TXN**: Taixinan Basin, **ZJN**: Zhongjiannan Basin, **MB**: Macclesfield Bank (Zhongsha Islands), **SI**: Spratly (Nansha) Islands, **PB**: Penxi Bank, **RB**: Reed (Liyue) Bank. **ESB**: East Sub-Basin, **NWSB**: Northwest Sub-Basin, **SWSB**: Southwest Sub-Basin.

▶ **Figure 1.** Elevation with rifted basins. The bathymetric map has a non-linear color bar to assist in highlighting certain features. The white dashed lines is Zhongnan-Liyue Fault (Fang et al., 2023). The continent-ocean transition (COT) distribution is shown in the yellow band (Song et al., 2019). The gray solid lines indicate the mid-ocean ridge locations of the ESB and SWSB (Briais et al., 1993).



▲ **Figure 2. (A)** Free air anomaly map from WGM2012 (Bonvalot et al., 2012) in Spratly Islands (SI) in the southwestern SCS. The black solid lines represent the location of seismic profiles. The red diamonds represent the location of the dredge samples from seafloor in the Spratly Islands and the Reed Bank area including 1, Granite, 127 Ma; 2, Schist, 113 Ma; 3, Amphibolite, 146 Ma; 4, Tonalite, 158 Ma; 5, Monzogranite, 128 Ma; 6, Paragneiss, 115 Ma; 7, Gabbro, 176 Ma (Kudrass et al., 1985; Xiao et al., 2019; Yan et al., 2010) **(B)** Total Field Magnetic anomalies map. The magnetic map is compiled by Geological Survey of Japan and CCOP (2021), showing the ages of oceanic crust identified by Briais et al (1993).



C	Best Fitting Parameters
Mean Depth	17.5 km
Density Contrast	0.5 g/cm3
Number of iterations	5
RMS (OBS derived Moho Depth)	3.148

Figure 3. (A) Final Moho depths result derived from inversion based on Bouguer gravity anomalies (Bureau Gravimétrique International), utilizing a 3D MATLAB program (Gómez-Ortiz and Agarwal, 2005). **(B)** The RMS error map of Moho depths derived from different inversion parameters compared to those obtained from OBS data (black frame circles). **(C)** The parameters used for the Moho result.

	Source energy (cubic inch)	Streamer channel	receiver length (m)	Shot Interval (m)	Record Length (sec)	Sample rate (ms)
MCS-1133	1050	108	1350	50	12	2
MCS-1159	825	108	1350	40	10	2
CFT- S	7000	480	6000	50	16	2

▲ **Table 1.** Parameters of multi-channel seismic acquisition

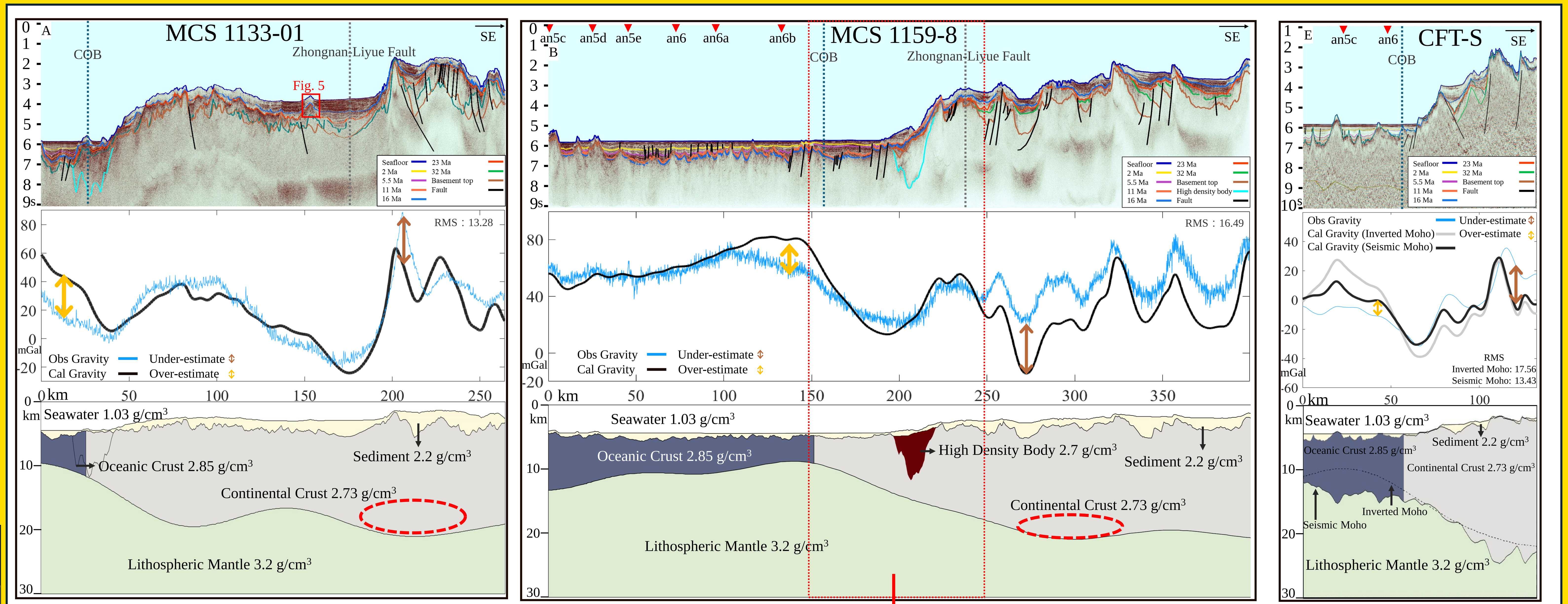
▶ **Figure 4.** The seismic profiles (upper part) and corresponding gravity models (lower part) of five surveys. The Time-Depth conversion of the sedimentary layers is based on an empirical formula derived from well logs in the Dangerous Ground area (Luo et al., 2021).

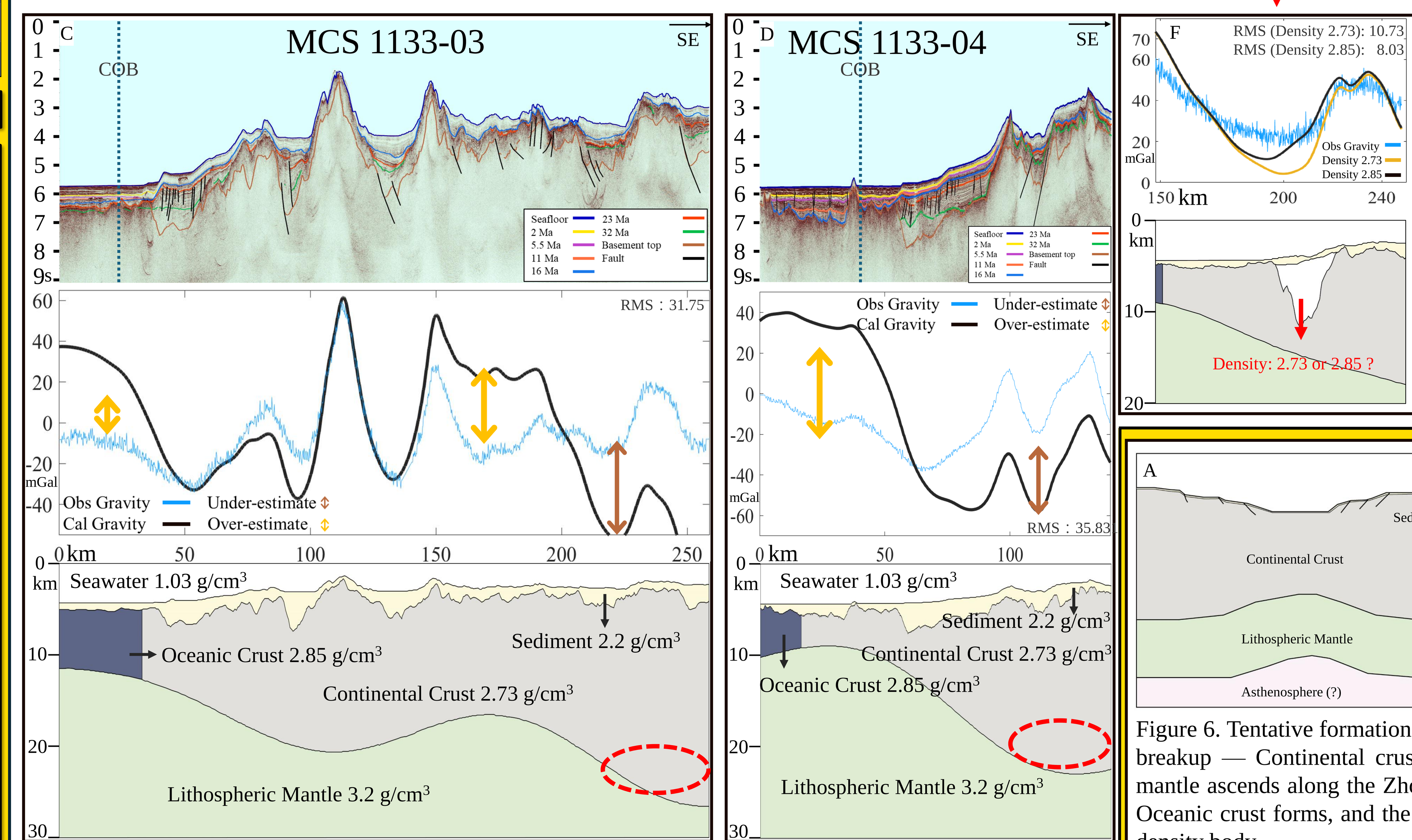
The simulated values and observed values generally show a similar trend. However, in the areas where the crustal thickness is higher, the simulated values are 20~50 mGal lower than the observed values. This may indicate a high-density body beneath the continental crust (red dotted ellipse). The simulated value is about 20~45 mGal higher than the observed value in four survey lines near the COT. This suggests that the density of the crust or the lithospheric mantle in this area should be lower than usual, possibly due to faults and fractures formed during the syn-rift phase or the result of water-rock interactions.

(E) Figure shows different gravity simulation results of seismic Moho (assume the velocity 6 km/s of crust) and inverted Moho. The RMS error of the gravity simulation based on the seismic Moho is slightly lower than that of the inverted Moho, indicating that the Moho depth derived from gravity simulation still contains errors or may vary due to heterogeneity in the regional crust.

(F) Figure shows the gravity simulation results of setting different densities for the high-density layer. The results show that the RMS error is lower for models with higher density, which is consistent with that of oceanic crust.

Research results





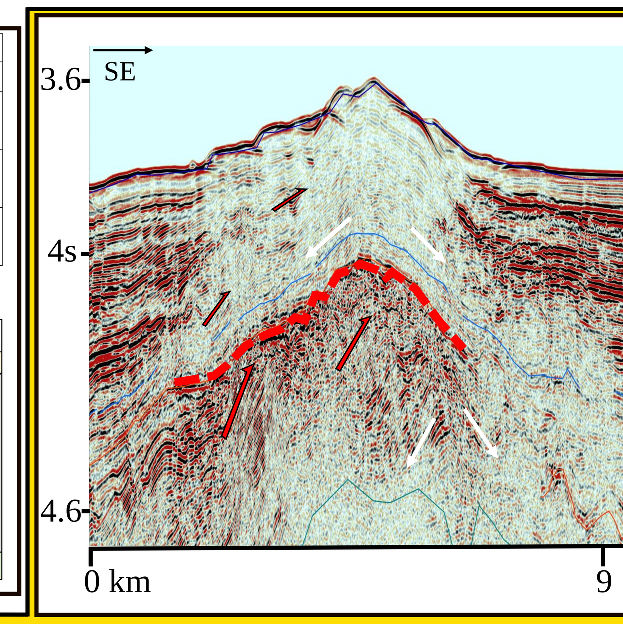


Figure 5. This figure shows a magnified area within the red box of MCS1133-01. The strata in the image exhibit various dip angle variations, with adjacent regions showing opposing dips (white arrows), while thick syn-rift strata located at the high relief area. Strata are truncated by an unconformity surface (red dashed line, 23Ma), suggesting the possible presence of multi-phase uplift events.

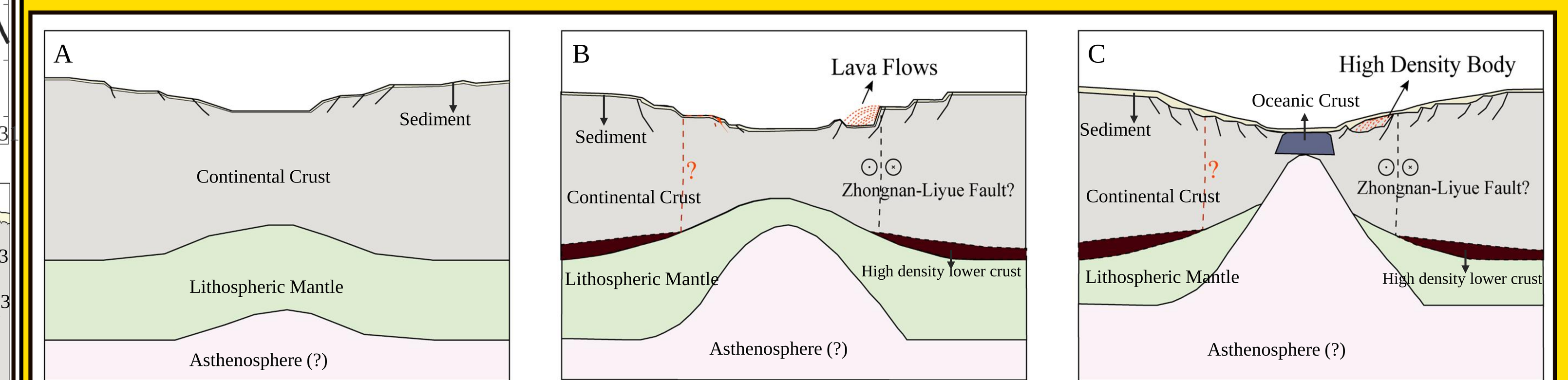


Figure 6. Tentative formation of the high-density body: (A) Rift-onset — No magmatism has occurred yet. (B) Pre-breakup — Continental crust undergoes thinning, and localized magmatism in the lower crust or lithospheric mantle ascends along the Zhongnan-Liyue Fault, erupting to form basaltic lava flows. (C) Sea floor spreading — Oceanic crust forms, and the subsidence of the continental crust leads to an increase in the dip angle of the high-density body.

Conclusion

• This study utilizes multichannel seismic and ship-borne gravity data to establish 2D crustal architectures.
• A shallow high-density body is identified near the COT on the east side of Taiping Island.
• The overestimation and underestimation of simulation values suggest the heterogeneity of crustal density.
• The continental margin of southwestern sub-basin of the South China Sea may have experienced localized uplift during breakup.

Reference