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Three-dimensional constrained gravity inversion of Moho depth and crustal structural characteristics at Mozambique continental margin

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Abstract

Mozambique’s continental margin in East Africa was formed during the break-off stage of the east and west Gondwana lands. Studying the geological structure and division of continent-ocean boundary (COB) in Mozambique’s continental margin is considered of great significance to rebuild Gondwana land and understand its movement mode. Along these lines, in this work, the initial Moho was fit using the known Moho depth from reflection seismic profiles, and a 3D multi-point constrained gravity inversion was carried out. Thus, high-accuracy Moho depth and crustal thickness in the study area were acquired. According to the crustal structure distribution based on the inversion results, the continental crust at the narrowest position of the Mozambique Channel was detected. According to the analysis of the crustal thickness, the Mozambique ridge is generally oceanic crust and the COB of the whole Mozambique continental margin is divided.

Key words: 3D constrained gravity inversion, continent-ocean boundary, Mozambique continental margin, Moho depth

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1 Introduction

Continent-ocean boundary (COB) and continent-ocean transition zone (COT), as well as the formation of some special structures at the Mozambique continental margin, are considered important references to study the splitting and drift effect of Gondwana land. COB refers to the boundary between the continental crust and the oceanic crust (Basile, 2015). COB division is mainly determined by the properties of the crust. In the past, various geological and geophysical data of some regions in Mozambique, such as water depth, gravity and magnetism, refraction earthquake, and core sampling, have been collected (Salman and Abdula, 1995; König and Jokat, 2010; Leinweber et al., 2013; Vormann et al., 2020; Moulin et al., 2020; Vormann and Jokat, 2021). These works based on the geophysical measured data have explained small-scaled or local geologic structures and COB locations. However, the large-scale crustal structures in Mozambique’s continental margin have been scarcely examined in the literature. Hence, the calculation of the Moho depth and crustal thickness through gravity anomaly inversion has been proposed to study large-scale geologic structures and COB division in the study area. More specifically, Nguyen et al. carried out gravity inversion of the east Africa-Antarctica continental margin and acquired large-scaled Moho depth distribution. Moreover, Gondwana land before the fracture was rebuilt by combining the magnetic and relevant data (Nguyen et al., 2016). Hanyu et al. gained the Moho depth at the south Mozambique continental margin by performing gravity data combined inversion, and determined COB at the south continental margin by combining the magnetic data (Hanyu et al., 2017). On the one hand, the previously reported works in the literature lack regional Moho inversion of the whole Mozambique continental margin. On the other hand, the existing Moho depth information, which was detected from analyzing many deep seismic profiles and could provide constraints during gravity inversion of Moho, hasn’t been used well.

The Parker-Oldenburg inversion method has been improved according to Parker forward modeling formula (Parker, 1973) and it has been widely applied to potential field interface inversion. This method is often used in the gravity inversion of Moho (Greenhalgh and Kusznir, 2007; Chappell and Kusznir, 2008; Bai et al., 2015). However, only single-point Moho depth constraint during calculation can be provided, which is difficult for carrying out real fitting in Mozambique’s continental margin, which has great Moho relief. Wu Zhaocai et al. improved the inversion pro-

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cess of this method and developed an initial Moho interface by using several known control points of Moho depth. Hence, more reasonable inversion results of the Moho depth were derived (Wu et al., 2017). Under this perspective, in this work, such an improved multi-point constrained inversion method was applied. The uniform scaled Moho depth and the crustal thickness models in Mozambique continental margin and the surrounding regions were examined by using the Moho depth data from the published deep seismic profiles as the deep constraint of Moho. By combining with previously acquired seismic data in the study area, the large-scale crustal structure characteristics and COB positions in Mozambique's continental margin were systematically analyzed.

Nowadays, Mozambique has been placed in the middle of the Gondwana continent in many works in the literature on the reconstruction and dissociation process of the continent. The continental tectonic unit and COB formation were all influenced by the splitting activities of the Gondwana land (König and Jokat, 2010; Leinweber and Jokat, 2011; Nguyen et al., 2016; Mueller et al., 2016; Mueller and Jokat, 2019; Thompson et al., 2019). In the Early Jurassic period (~180 Ma), Gondwana land was split gradually along with eastern Africa and formed the east Gondwana land (Madagascar, Antarctica, India, and Australia) and west Gondwana land (South America and Africa) due to the Karoo mantle plume activities and violent magmatism (Leinweber and Jokat, 2012). In the Late Jurassic period, the volcanic action weakened and the east Gondwana land made a clockwise rotation in relation to the west Gondwana land. Meanwhile, the east Gondwana land exhibited progressive tensional fracture from north to south along with the Davie Fracture Zone (DFZ) and Mozambique Fracture Zone (MFZ), leading to the formation of Mozambique transform continental and passive continental margins composed of north section, middle section, and south section (Sinha et al., 2019; Vormann et al., 2020; Vormann and Jokat, 2021).

The north section (9°–16°S) of Mozambique's continental margin represents the transform continental margin controlled by DFZ (Mueller and Jokat, 2019; Sinha et al., 2019). There's the oldest NE–SW striking magnetic anomaly belt M41 (~167 Ma) in the eastern Somalia Basin (SB), indicating the initial splitting direction of Gondwana land (Gaina et al., 2013; Sinha et al., 2019; Vormann et al., 2020). Sinha et al. determined the COB of the north section of Mozambique's continental margin according to the extracted multi-channel seismic and gravity and magnetism data (Sinha et al., 2019). Additionally, the north section of Mozambique's continental margin also developed an about 1 200 km long sea ridge, which extended from south to north between 5°–20°S and was called Davie Ridge (DR). The terrain was divided into north and south sections due to changes at 13°S. According to the multi-channel seismic data, nDR denotes the depositional characteristics on the flat base (Mougenot et al., 1986; Franke et al., 2015). However, according to the works in the literature on deep seismic data on the south Davie Ridge (sDR), the local crustal velocity structure is consistent with the continental crust and it is actually a residual continental crust. As a result, COB shall be closer to Mozambique's coast (Vormann et al., 2020; Vormann and Jokat, 2021).

The middle section (16°–21°S) of Mozambique's continental margin lies between DFZ and MFZ. According to the seismic data, there's a high velocity lower crust and seaward dipping reflectors (Leinweber et al., 2013; Mueller et al., 2016). Hence, the middle section of the Mozambique continental margin is regarded as a typical magma-rich continental margin, which is formed by the splitting of the Gondwana land toward the NW–SE direction (Mahanjane, 2012; Leinweber et al., 2013; Mueller et al., 2016). The south side of the middle section is the Mozambique Basin (MB) where the oldest NE–SW magnetic anomaly belt (M38n2n, 164.1 Ma) can be recognized (Mueller and Jokat, 2017). Combined with the velocity difference shown in deep seismic data, the COB at the middle section of Mozambique's continental margin can be determined (Mueller and Jokat, 2019). The special structural unit close to the coastal zone of Beira High (BH) is viewed as the residual continental land (Mueller et al., 2016).

The south section of the Mozambique continental margin (21°–36°S) is located next to the Mozambique Coastal Plain (MCP) and it is a transform continental margin formed by the joint control of the tension crack and strike-slip effect. As a result, the tectonic unit properties and origins, as well as COB and COT division at the continental margin of the south section are more complicated. In addition, the south section of Mozambique's continental margin is mainly developed with Northern Natal Valley (NNV) and Mozambique Ridge (MozR), which are separated by Ariel Graben (AG). Mueller and Jokat argued that NNV is an oceanic crust with a magnetic anomaly belt, and COB divided according to NNV leads to overlapping regions during the rebuilding of Gondwana land (Mueller and Jokat, 2019). According to research results on deep seismic data, the crustal velocity structure of NNV agrees with the continental crust and it is a continental crust undergoing magmatic floor invasion. Therefore, COB shall be divided at the seaward side of NNV (Moulin et al., 2020; Watremez et al., 2021). The crustal properties of MozR are still under investigation. According to the works on seismic data, the whole MozR is the abnormally thick oceanic crust formed by magma, which was erupted by the mantle plume (König and Jokat, 2010; Leinweber and Jokat, 2011; Gohl et al., 2011). However, from the analysis of the magnetic and gravity data, it was demonstrated that the north MozR (nMozR) is the thinned continental crust formed by stretching at the splitting of the Gondwana land, while the south MozR (sMozR) is the oceanic crust. Hence, COB shall be determined between nMozR and sMozR (Hanyu et al., 2017).

2 Data and methods

2.1 *Data source*

The study area is located at the east Mozambique continental margin (8°–36°S, 28°–52°E). The applied seafloor topographic data were collected from the 15″×15″ GEBCO_2020 global depth grid data published by the International Hydrographic Organization (IHO) in May, 2020 (Fig. 1a).

The gravity data were collected from the global gravity field model with a grid space of 1′×1′, which was constructed by combining CryoSat-2 and Jason-1 altitude measurement satellites (Fig. 1b) (Sandwell et al., 2014). Deposition thickness data were also collected from the total sedimentary thickness digital model of the global ocean and marginal sea (GlobSed), with a grid space of 5′×5′ (Fig. 1c). This model integrated the previously published models and the new summarized data, and 29.7% of total marine sediments were added compared to the previously published sediment models (Straume et al., 2019).

Meanwhile, the deep seismic exploration data (OBS) of the study area was applied (Leinweber et al., 2013; Mueller et al., 2016; Vormann et al., 2020; Vormann and Jokat, 2021) and 165 Moho depth points (Fig. 1, Table 1) were extracted as the known Moho depth control point for the constrained gravity inversion.

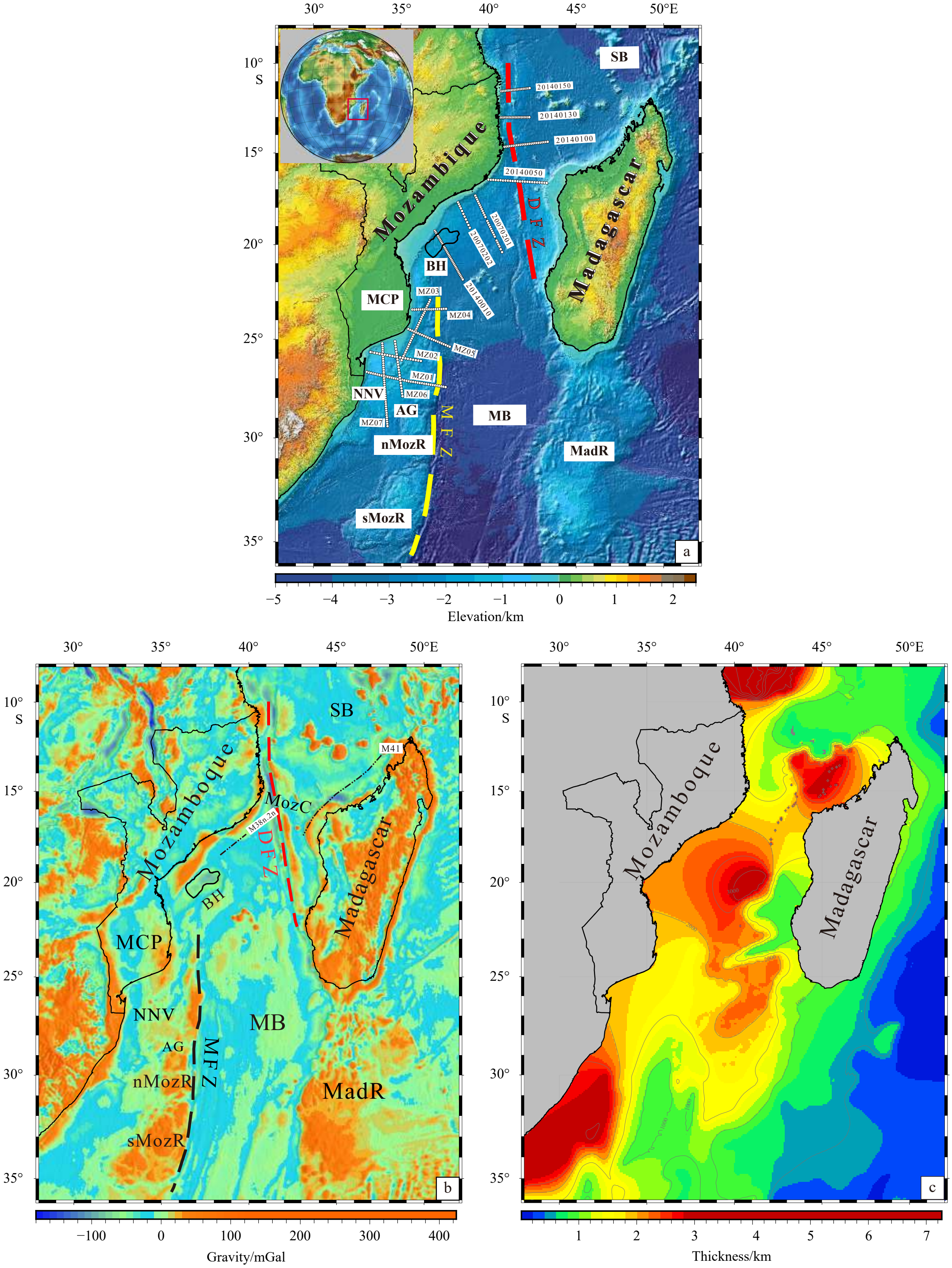

Fig. 1. Depiction of the topography and main geological structures of the study area, the white circle refers to the OBS station in the area (a); Free-air gravity anomalies in the study area, the dotted lines are magnetic anomaly strips (b); Sedimentary thickness in the study area (c). SB: Somalia Basin; DFZ: Davie Fracture Zone; MozC: Mozambique Channel; BH: Beira High; NNV: northern Natal Valley; MFZ: Mozambique Fracture Zone; nMozR: north Mozambique Ridge; sMozR: south Mozambique Ridge; MB: Mozambique Basin; MadR: Madagascar Range; AG: Ariel Graben; MCP: Mozambique Coastal Plain.

Table 1. OBS constraint points for inversion.

Name of measuring lines	Number of the used constraint points	Source
AWI-20140100	25	Vormann et al. (2020)
AWI-20140050	25	Vormann et al. (2020)
AWI-20140150	20	Vormann and Jokat (2021)
AWI-20140130	20	Vormann and Jokat (2021)
20070201	27	Leinweber et al. (2013)
20070202	11	Leinweber et al. (2013)
AWI-20140010	37	Mueller et al. (2016)
Total	165	

2.2 *Method*

The calculation process of Moho depth is schematically illustrated in Fig. 2. (1) According to free-air anomaly (FAA） and depth data , the FA2BOUG (Fullea et al., 2008) was applied to eliminate the gravity influence of seawater. (2) The gravity anomaly of the sedimentary formation was gained by performing Parker forward modeling (Parker, 1973). Next, it was deducted based on the calibration in the first step. Thus, the Bouguer gravity anomaly was derived after the calibration of sedimentary formation. (3) According to the gravity anomaly and known control points of Moho depth, which were gained in the second step, the Moho depth and crustal thickness were calculated by using the improved "multi-point constrained inversion method".

2.2.1 *Water depth and topographic correction*

The Fa2boug program (Fullea et al., 2008) was applied to calculate the gravity effect of seawater. This program is applicable to the published global gravity data and water depth data. According to the distance of the calculation point, the Fa2boug program divides the surrounding area of the calculation point into a short-distance region, a middle-distance region, and a long-distance region. Different calculation modes shall be also applied to different regions to eliminate the influence of seawater gravity within 167 km around the calculation point. This not only assured calculation accuracy, but also increased calculation efficiency.

2.2.2 *Gravity effect calculation of sedimentary layer*

After finishing bathymetric seawater, the gravity anomaly mainly includes the gravity effects of the sedimentary basement and Moho. Hence, the gravity effect of the sedimentary layer shall be calculated and eliminated to extract the gravity effect of Moho. When the gravity effect of the sedimentary layer is calculated, the sedimentary compaction model (Sclater and Christie, 1980) was used to determine the density variations of the sedimentary layer with depth. The calculation formula is as follows:

$$\rho\left(z\right)=\rho_{f}g\phi_{0}ge^{-z/d}+\rho_{g}(1-\phi_{0}ge^{-z/d}), \qquad (1)$$

where ρ_f is the fluid density, ρ_g stands for the solid density, ϕ_0 denotes the porosity, and d represents the depth attenuation parameter. These parameters were selected according to the fitting results of drilling data from the deep sea drilling program (DSDP) and previously reported works (Simpson et al., 1974; Nguyen et al., 2016; Wu et al., 2017). During the calculations, the sedimentary layer was divided into 50 layers vertically. The gravity impact of each layer was also calculated through Parker forward modeling, while the gravity effects of all layers were summed to get the gravity effect of the sedimentary layer (Fig. 3a). After eliminating the gravity impact of the sedimentary layer, the Bouguer gravity anomaly after sedimentary layer correction was acquired (Fig. 3b).

2.2.3 *Multi-point constrained Moho inversion*

The calculation steps of multi-point constrained Moho inversion were introduced as follows. (1) Linear regression was calculated according to the control point of the known Moho depth and Bouguer gravity anomaly with the gravity effect of the sedimentary layer being eliminated. Therefore, the initial Moho depth was acquired. (2) The difference between the gravity anomaly of the initial Moho surface and the Bouguer gravity anomaly was calculated, and used to invert the corrected value of the Moho surface depth. (3) The corrected value of the Moho surface depth was added to the initial Moho surface depth to obtain the new Moho surface, and the mean square error (MSE) with respect to the constraint point was calculated. (4) Steps (2) and (3) were repeated to calculate the MSE after iteration, thus reaching the minimum mean square error. Finally, the inversion results were gained. The comparison of Moho depth obtained by partial inversion with seismic profile data is shown in Fig. 4.

The survey line in the southern continental margin are basically located at NNV, where the depth of Moho is more than 10 km deeper than the northern Moho, and the crust thickness is also thicker. The survey line at NNV indicates that it is a stretched continental crust influenced by magmatism, and its crust density is much different from that in other regions. Since our inversion method requires a crustal density as an inversion parameter, if the survey line at the southern continental margin and the northern one are incorporated into the inversion process as constraints, no matter how crustal density parameter is selected, better inversion results cannot be obtained. In order to obtain a more accurate crustal thickness distribution of the Mozambique continental margin as a whole, we only select the survey line in the northern and middle continental margins, where crustal density is similar to the depth of the Moho surface, as control points to participate in the inversion (Table 1).

On the other hand, the interpretation of constrained seismic profiles makes inversion uncertain. Authors of these seismic modelings selected as constraints have a deep knowledge of the continental margin of Mozambique, and the interpreted seismic modelings are also widely recognized. At the same time, the sediment model also affects the inversion effect. The sediment model we used has also been widely used in gravity inversion by others. The inversion results obtained by using these data are relat-

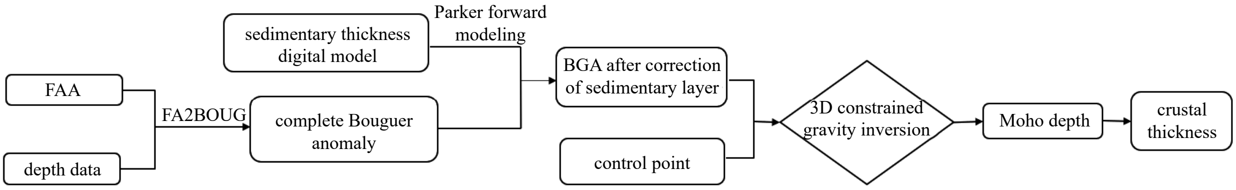

Fig. 2. Flowchart of inversion (FAA: free-air anomaly; BGA: Bouguer gravity anomaly).

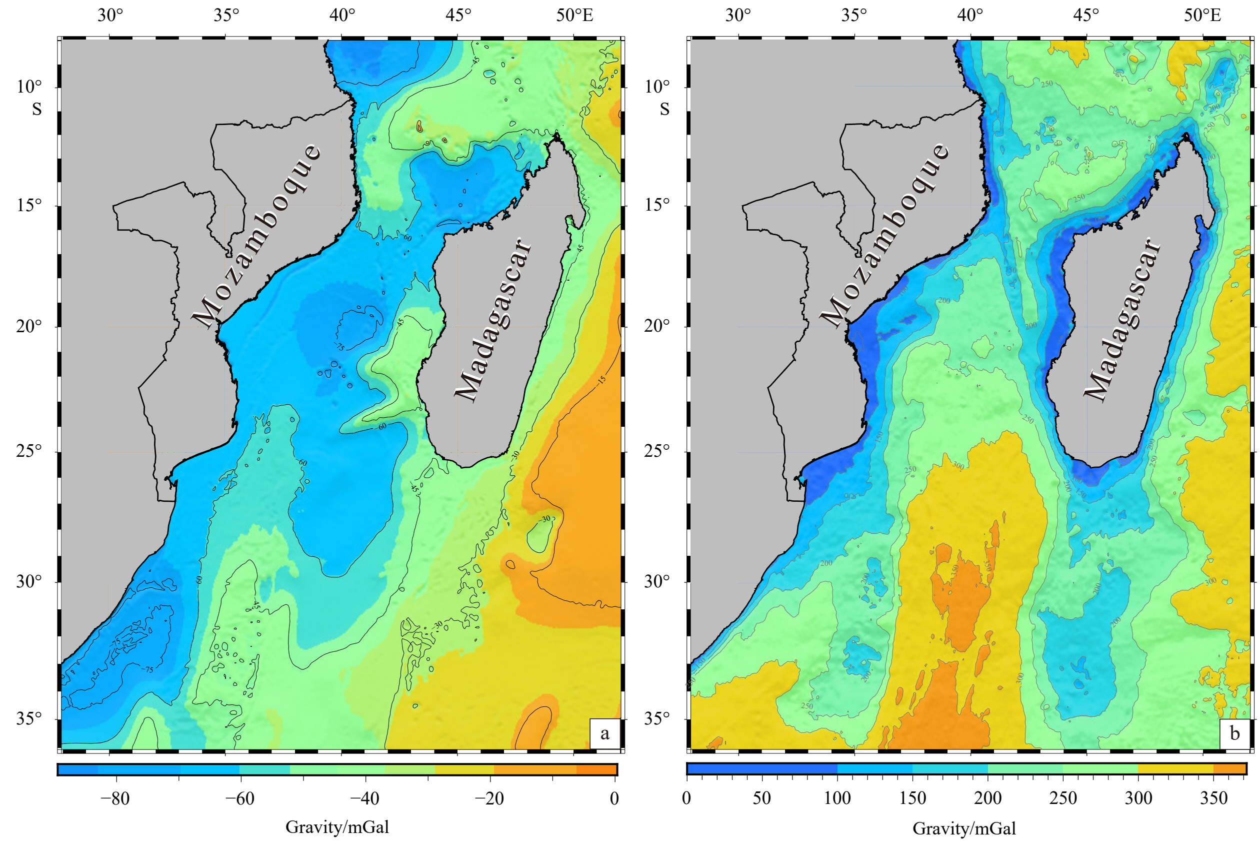

Fig. 3. Gravity effect of the sedimentary layer (a); Bouguer gravity anomaly after correction of sedimentary layer (b).

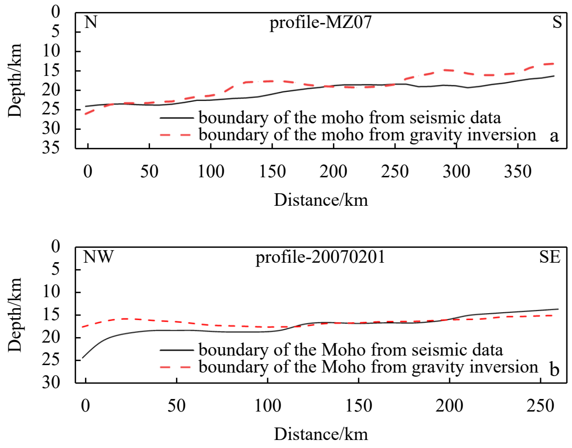

Fig. 4. Comparison of Moho depth gravity inversion results and deep seismic data interpretation results Measuring line MZ07 (a) Measuring line 20070201 (b). The positions of the measuring lines are shown in Fig. 1.

ively fitting to the actual situation (Fig. 4), and the mean square error is 2.3 km. It's going to support us to complete the relevant research. Finally, the Moho depth and crustal thickness results are shown in Figs 5 and 6.

3 Inversion results and discussion

3.1 *Crustal structure characteristics in the north section (9°–16°S) of Mozambique continental margin*

The Moho depth in the north section of Mozambique's continental margin increased gradually from the west to east (Fig. 5a). The crustal thickness from ocean to continent decreased from about 20 km to 12 km (Fig. 5b). The Moho depth of SB ranges within 11–17 km and the crustal thickness is about 7–10 km (Fig. 5b). These results are basically consistent with local profile data interpretation in the deep seismic survey (Vormann et al., 2020; Vormann and Jokat, 2021).

At nDR, the crustal thickness in gravity inversion was more than 13 km (Fig. 5b) and the detected thickness according to deep seismic data was about 11 km (Vormann et al., 2020). In this region, the sedimentary thickness was great. Due to the influence of the strike-slip fault, the base structure was reconstructed (Vormann and Jokat, 2021), which might be the reason for the recorded differences in the crustal thickness. At sDR, the crustal thickness in gravity inversion was 14–19 km (Fig. 6a), which was close to the interpretation of the deep seismic data (13–19 km) (Vormann et al., 2020). According to the crustal thickness results of gravity inversion, the thick crustal area at sDR protruded and extended along with the SW direction (Fig. 7). The extension direction was consistent with the southern continental margin of Madagascar. Moreover, the south crust of Madagascar thinned quickly from continent to ocean, accompanied by serious changes in the crustal thickness. This might demonstrate that sDR and the south continental margin of Madagascar experience strike-slip tectonic activities along DFZ (Fig. 6a).

At the narrowest position of the Mozambique Channel (MozC), the mean crustal thickness was about 14 km and reached 20 km close to Madagascar, which was far higher than ordinary oceanic crust thickness. According to the deep seismic profile, the crust close to the Mozambique area has no oceanic crustal characteristics (Vormann et al., 2020). Moreover, accord-

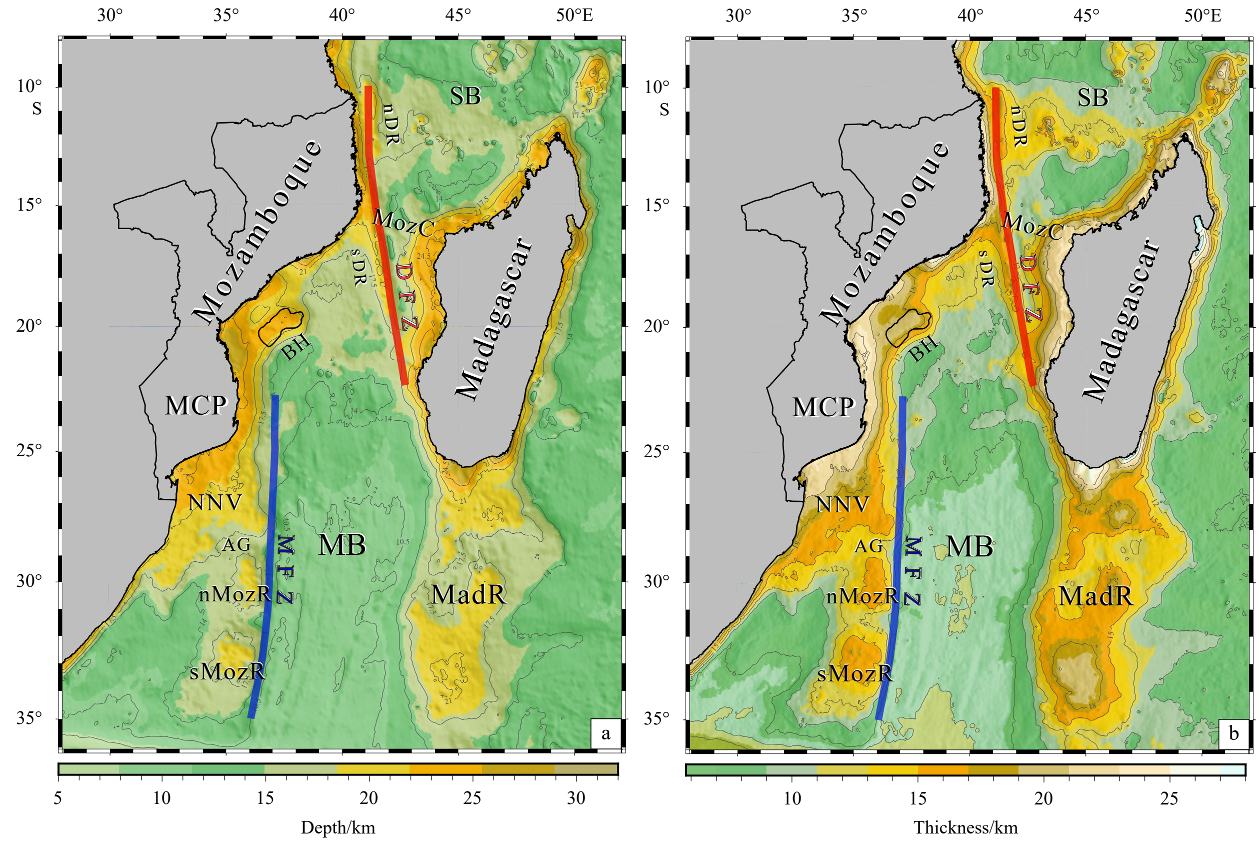

Fig. 5. Moho depth in the study area (a); crustal thickness in the study area (b). SB: Somalia Basin; DFZ: Davie Fracture Zone; MozC: Mozambique Channel; BH: Beira High; NNV: northern Natal Valley; MFZ: Mozambique Fracture Zone; nMozR: north Mozambique Ridge; sMozR: south Mozambique Ridge; MB: Mozambique Basin; MadR: Madagascar Range; AG: Ariel Graben; MCP: Mozambique Coastal Plain.

ing to the previously reported works in the literature, relatively large-scale magmatic activities at the Mozambique Channel did not take place (MozC) (Mueller and Jokat, 2017), and there's no condition for the formation of abnormally thick oceanic crust. Hence, it can be speculated that Madagascar and Mozambique were connected by the stretching continental crust at the narrowest position of the Mozambique Channel, without any oceanic crust (Fig. 7).

At Tanzania-Mozambique Margin, Sinha et al. determined the COB positions according to multi-channel seismic data and gravity and magnetism data (Sinha et al., 2019), which were almost overlapping with the 13.5 km isopachous line of the crustal thickness from gravity inversion. Hence, the 13.5 km isopachous line of the crustal thickness was used to determine the COB positions (Fig. 6a) in the south section of Mozambique continental margin (11°–13°S) and COBs recognized by the existing deep seismic data at nDR were approximately consistent (Vormann et al., 2020; Vormann and Jokat, 2021). The determined COBs extended south along with Davie Fracture Zone (DFZ) until reaching the positions near the Mozambique Channel (MozC) (14.5°S/42°E). Because of the lack of deep seismic data in the Mozambique Channel Sinha et al. determined the COB crosses the Mozambique Channel. But according to the new works and evaluation of the crustal properties in MozC based on deep seismic data, it can be inferred that there is no oceanic crust (Vormann and Jokat, 2021) and the determined COB turned to SE direction and ran through the northern region of MozC. This was further northward than the COB determined by Sinha et al. (Sinha et al., 2019). The COB determined subsequently extended toward the northeast to the north section of the Madagascar margin along with the 13.5 km isopachous line of crustal thickness. According to the determined COB in this work, it overlapped with DFZ highly, indicating that the formation of COB at the north section of the margin was mainly controlled by DFZ. Moreover, the continental crust at MozC might be formed during the NW–SE striking splitting between the east and west Gondwana lands, and then it slipped southward to the present position with the east Gondwana land along with DFZ.

3.2 *Crustal structure characteristics in the middle section (16°–21°S) of Mozambique continental margin*

The Moho depth in the middle section (16°–21°S) of Mozambique's continental margin lifted up quickly, while crustal thickness thinned dramatically from continent to ocean. The crustal thickness of BH was about 20 km (Fig. 5b), which was consistent with the interpreted value of the deep seismic profile. Since abnormally thick sediments between the NW side of BH and the middle continental shelf of Mozambique exist, the velocity structure was complicated and it was difficult to determine the crustal properties according to the collected deep seismic data (Mueller et al., 2016). According to the gravity inversion results, the crustal thickness of BH changed slightly from the ocean to the continent. It was speculated that there is thinned continental crust between BH and the continental shelf of the middle Mozambique margin. On top of that, the crustal thickness gradient differences between the continental side and the seaside of BH might experience

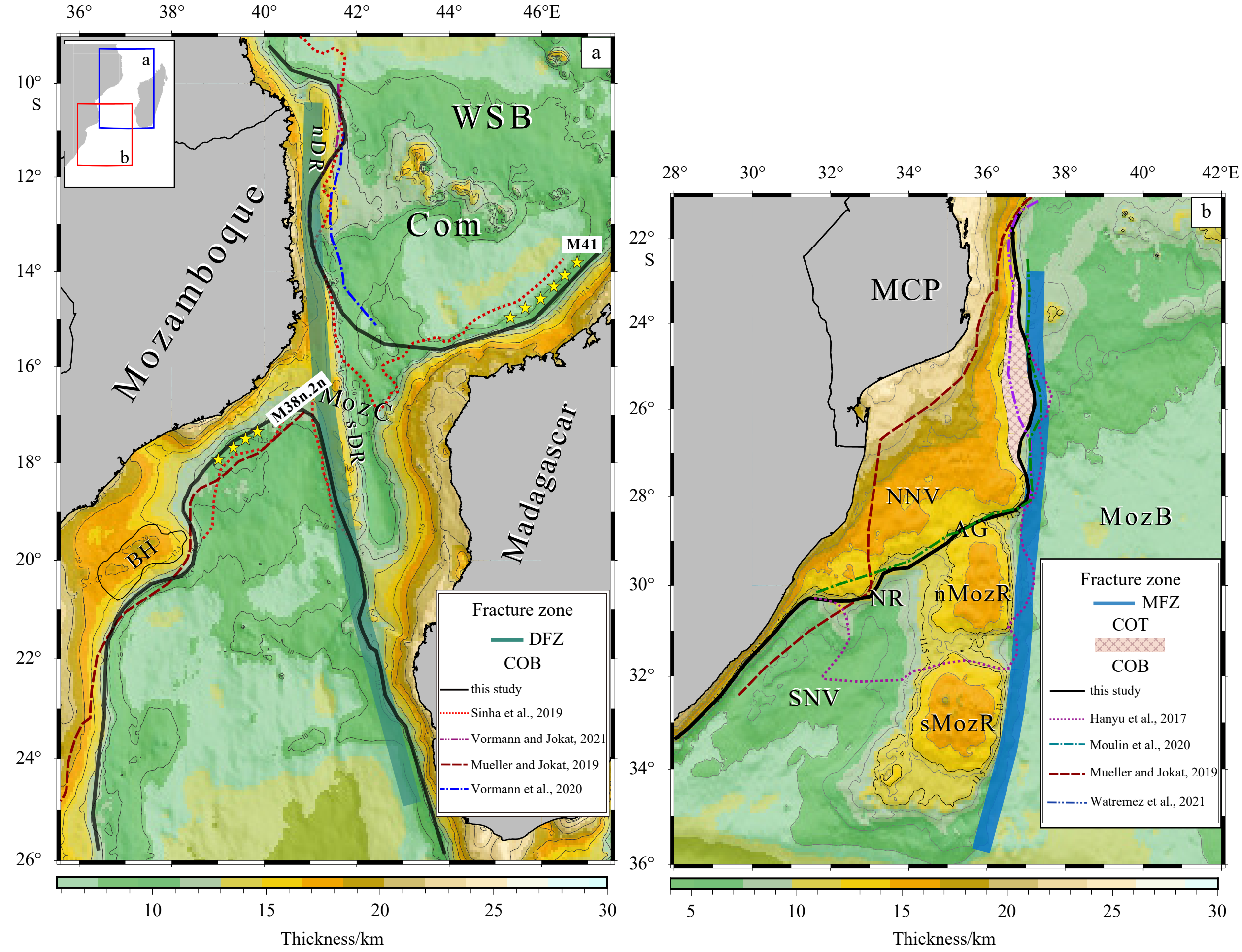

Fig. 6. COB distribution in Mozambique continental margin. a. North region; b. south region. The bottom map is crustal thickness. MozC: Mozambique Channel; BH: Beira High; nMozR: north Mozambique Ridge; sMozR: south Mozambique Ridge; AG: Ariel Graben; MCP: Mozambique Coastal Plain.

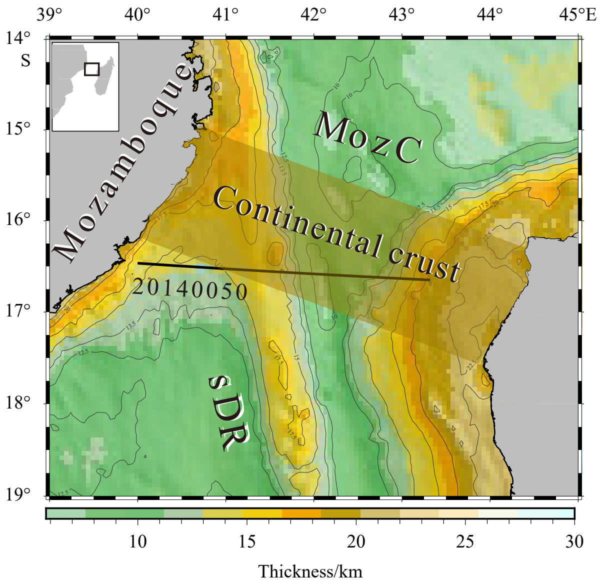

Fig. 7. Crustal thickness map of the Mozambique Channel. The brown translucent area is part of the continental crust. MozC: Mozambique Channel; MB: Mozambique Basin.

twice tensional fractures with different degrees.

In the middle section of the Mozambique continental margin, the COB positions revealed by previously reported works in the literature (Mueller and Jokat, 2019; Sinha et al., 2019; Mueller et al., 2016) were also approximately consistent with the 13.5 km isopachous line of the crustal thickness and the 18 km isobath of Moho depth (Fig. 6a). In deep seismic data or gravity data and magnetic data, the positions of COB are shown in the Fig. 8. The COB in this work was divided into east and west parts at the boundary of MozB. The COB at the west of MozB was formed during NW–SE splitting between the east and west Gondwana land and it extended southwestward along with the 13.5 km isopachous line from 17°S, by passing the broken BH in the middle section. As far as the COB on the east of MozB is concerned, it extended southwestward to the south Madagascar margin along with sDR and DFZ from 17°S. This COB was mainly controlled by the N–S strike-slip action of the east and west Gondwana lands along with DFZ. Hence, the determined COB was basically overlapping with DFZ (Fig. 6a).

3.3 *Crustal structure characteristics of the south section (21°–36°S) of Mozambique continental margin*

The south section of Mozambique's continental margin was the Mozambique coastal plain (MCP), where the crustal thickness thinned quickly from continent to ocean. Particularly, it de-

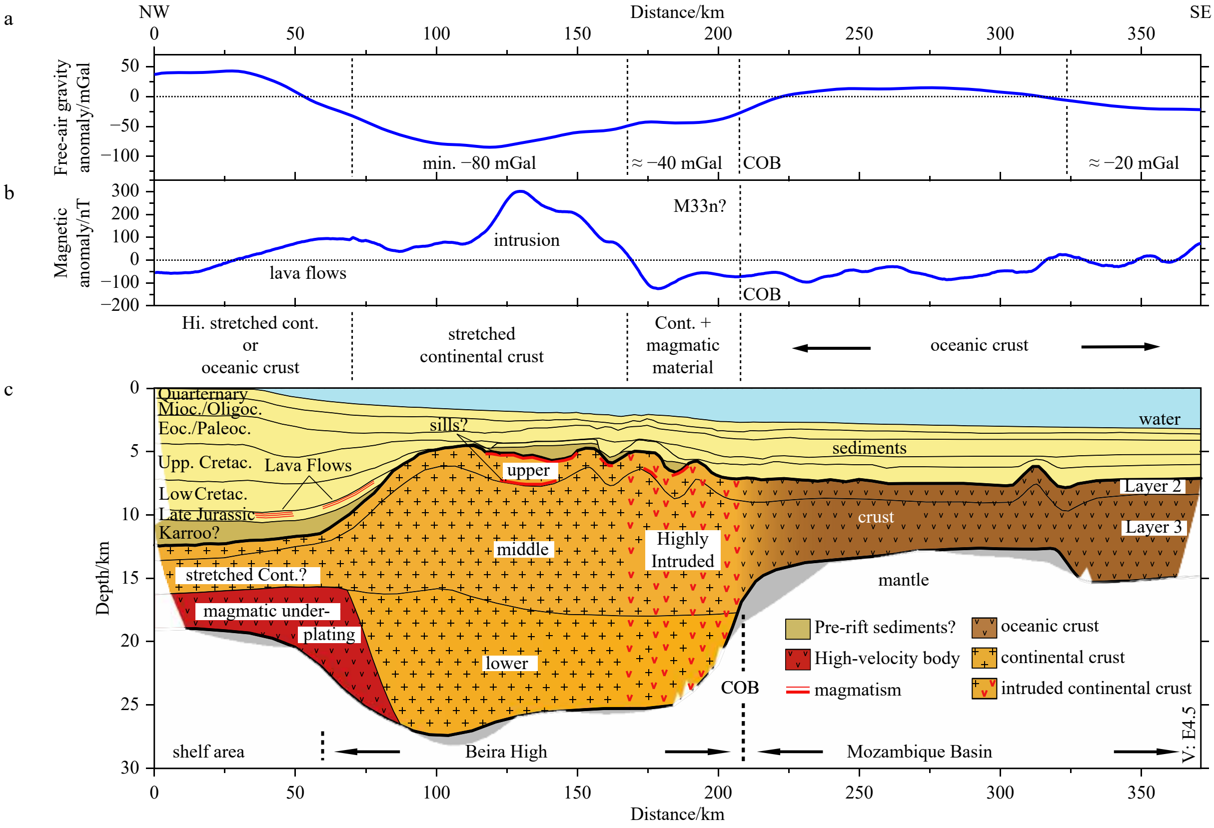

Fig. 8. Geological interpretation of profile AWI-20140010. The free-air gravity anomaly (a). The magnetic anomaly along the profile are shown (b). Geological interpretation of the profile (c) (Mueller et al., 2016).

creased from 24 km to 14 km within the scope of 100 km (Fig. 5b). This result is in direct line with the crustal changes interpreted by OBS data. Moreover, the seismic velocity structure was similar to BH and was speculated that it was the extended continental crust within 100 km of the eastern margin of MCP (Watremez et al., 2021; Evain et al., 2021). The crustal thickness from the east of MCP to the north of MB was 8–14 km, which was higher than the common oceanic crust. However, the local velocity structure exhibited obvious oceanic crustal characteristics and the anomaly thickness might be caused by the violent magmatic activities in the late stage (Watremez et al., 2021).

At NNV, Hanyu et al. reported that the crustal thickness in gravity inversion was 11–14 km (Fig. 5b) (Hanyu et al., 2017). According to the gravity inversion results in this work, the local crustal thickness was about 15 km. The crustal thickness of NNV interpreted by OBS data reached 30 km, whereas NNV was a continental crust with magmatic invasion. The local crustal density presented complicated changes due to magmatic effects, thus resulting in errors in the gravity inversion results (Moulin et al., 2020; Watremez et al., 2021).

At present, the majority of the works in the literature argue that sMozR was oceanic crust influenced by volcanic-based activities (König and Jokat, 2010; Gohl et al., 2011; Hanyu et al., 2017; Fischer et al., 2017; Matsinhe et al., 2021). However, there's still controversy over the crustal properties of nMozR. By thoroughly analyzing the three-component magnetic data, Hanyu et al. didn't discover oceanic crustal characteristics, while the authors pointed out that nMozR was the extended continental crust (Hanyu et al., 2017). Other reports have concluded that the nMozR is an oceanic crust based on seismic and magnetic data showing that the velocity structure of the crust here is very different from the continental crust (König and Jokat, 2010; Leinweber and Jokat, 2011; Gohl et al., 2011). According to the acquired inversion results (Fig. 5b), the crustal thickness of sMozR was generally about 11–14 km, reaching 15 km locally. The Moho depth was 16 –18 km and the crustal thicknesses of nMozR and sMozR were basically consistent with Moho depth. As a result, it can be concluded that nMozR was also the abnormally thick oceanic crust formed upon the strong influence of the magmatic activities during the splitting of Gondwana lands, same with sMozR.

In the south section of Mozambique continental margin (21°–36°S), the 11.5 km isopachous line of the crustal thickness and the 15.5 km isobath of Moho depth from the inversion results were close to the COB, which was determined in previously reported works (Mueller and Jokat, 2019; Moulin et al., 2020; Watremez et al., 2021). In deep seismic data, the positions of COB and COT are shown in the Fig. 9. On this basis, COB at the south section was plotted (Fig. 6b). The COB from 22°S to 28°S extended southward along with MFZ. However, different from the COB determined by Hanyu et al. (Hanyu et al., 2017) at 28°S, it was assumed that the MozR was the oceanic crust. Thereby, the plotted COB turned to SW and it separated NNV (thinned continental crust) and (MozR) (oceanic crust) through AG. Subsequently, the delineated COB extended along with an 11.5 km isopachous line of crustal thickness to near the southern Mozambique coastline. By combining with COT at south margin and COT positions interpreted by local seismic data, the 13 km isopachous line of the crustal thickness and the 17 km isobath of Moho depth were used as the inner boundary base lines in the whole COT at the south margin. Similarly, they turned to SW at AG. In this way, there's an

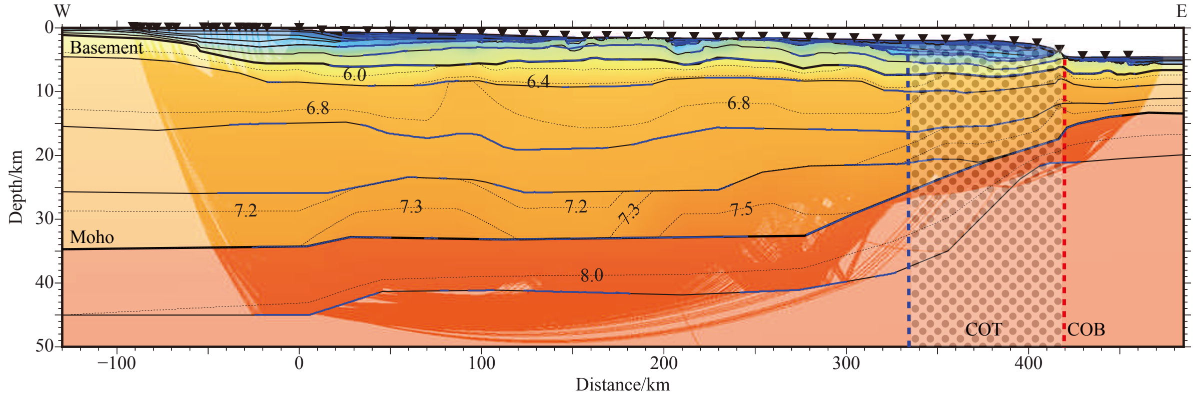

Fig. 9. P-wave velocity models of profile MZ1 (km/s) (Moulin et al., 2020).

about 70 km wide COT at 36.5°W and it extended from 23°S. Moreover, it narrowed from the north to south until reaching 27.3°S (Fig. 6b). According to the determined COB and COT, it can be concluded that the formation of COT and COB at the south margin was controlled by splitting and strike-slip of the east and west Gondwana lands. In the Early Jurassic period, both the east and west Gondwana lands had NW–SE splitting and the COT at the south margin was also formed during this period. Subsequently, the east and west Gondwana lands developed N–S strike-slip along with MFZ in the late Jurassic period. Accordingly, COT narrowed gradually from north to south, while COB was distributed along with MFZ.

4 Conclusions

The seismic constrained gravity inversion of Moho can get regional Moho distribution and crustal thickness distribution matching with seismic detection results. This result provides effective information to study local geologic structures. According to the extracted inversion results, a large-scaled crustal structure at Mozambique continental margin was studied and COB was determined. Meanwhile, according to the distribution characteristics of crust and Moho structures at the Mozambique continental margin, the narrowest part of the Mozambique Channel is considered to be continental crust. It connects Madagascar with Mozambique. Also, the sDR and the south continental margin of Madagascar experience strike-slip tectonic activities along DFZ. More geological survey data is needed to provide constraints on the location of the sDR at the time of reconstruction in Gondwana. In the south section of the Mozambique continental margin, the crustal structure distribution supports the fact that nMozR and sMozR are both abnormally thick oceanic crusts formed by the influence of violent magmatic activities during the splitting of east and west Gondwana land. Moreover, COB is located in the north part of MozR.

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