Three-dimensional Magnetotelluric Imaging of West Kunlun Tectonic Zone

Xiaolei WU[1], Bo YANG[1] and Gang WEN[1]
[1]School of Earth Sciences, Zhejiang University, Hangzhou, China, bo.yang@zju.edu.cn

SUMMARY

The West Kunlun Tectonic zone(WKTZ) is the collision front of the Asian plate and the Indian plate on the west side of the Tibetan Plateau. In this study, we used 295 MT stations to invert the three-dimensional electrical structure in this area, covering the southwest of the Tarim Basin to the WKTZ. The result model shows that there are three major conductive anomalies (C1, C2 and C3): C1 is the magma chamber of the Cenozoic volcano and has a connecting channel with the deeper C2; C2 is divided into two parts, shallow (<50km) and deep (50km 150km), the shallow C2 is inclined to the south, which corresponds well to the Jinsha suture, and the deep C2 is inclined to the north, mainly distributed in the lower crust-upper mantle scale. C3 is inclined to the north as a whole, and corresponds well to the Bangong-Nujiang suture. The resistivity data are sensitive to the margin of the crust slab, and there is a large-scale low-angle north-dipping low-resistance anomaly (deep C2) at the lower crust-upper mantle scale in the southern part of the West Kunlun Mountains, which is speculated to be the subducted Indian plate interface, so we presume that the subduction front of the Indian plate may have reached beneath the Kangxiwa fault (about 37°N).

Keywords: West Kunlun; Magnetotelluric Imaging; Electrical structure; Cenozoic volcano; Paleo sutures

INTRODUCTION

The West Kunlun Tectonic Zone (WKTZ), located at the southwestern margin of the Tarim Basin and the northwestern margin of the Tibetan Plateau, is a key region for understanding the collision between the Indian Plate and the Asian Plate (Fig. 1). To investigate the deep interactions between the Indian Plate and the Asian Plate, as well as the migration of melts and fluids associated with multiple stages of subduction and collision events in this region, we deployed a relatively dense MT array covering the East Pamir Plateau, Southwest Tarim Basin, and West Kunlun Mountain region. The MT data is sourced from multiple projects: (1) 62 wide-band (WB) MT sites from the SinoProbe Project, mostly located at the western corner of Tibet, collected during 2008-2010; (2) 153 WB MT sites located in the Tarim Basin, collected during 2009-2010 with support from the Chinese national oil company SinoPec; (3) approximately 80 LP sites located in the East Pamir and West Kunlun Mountains, collected during 2019-2023 with support from NSFC funds. The above data sources result in a dataset with a total of 295 MT stations, including 215 broad-band stations and 80 long-period stations, with frequencies ranging from 320 Hz to 20,000 seconds.

The site spacing is approximately 40 km for long-period MT sites and 20 km for wide-band MT sites. The data quality is very good for most sites. We employed the Modular Electromagnetic Data Inversion System (i.e., ModEM, Egbert and Kelbert, 2012) to invert the data. By setting the error floor to 5% of $|Z_{xy}|$ for Z_{xx} and Z_{xy}, 5% of $|Z_{yx}|$ for Z_{yx} and Z_{yy}, and a fixed value of 0.03 for $\mathbf{T}$, we achieved a normalized root-mean-square (nRMS) misfit of 2.08 after 148 iterations using the non-linear conjugate gradient scheme.

RESULTS AND DISCUSSION

Tectonic settings

The WKTZ can be divided into three parts from north to south (Fig. 1): the Northern Kunlun Terranes (NKT), the Southern Kunlun Terranes (SKT), and the Tianshuihai Terranes (TSHT). The major faults and sutures include the Kudi Suture (KDS), Jinsha Suture (JS), Bangong-Nujiang Suture (BNS), Kangxiwa Fault (KXF), Karakoram Fault (KKF), Altyn Tagh Fault (ATF), and Longmucuo Fault (LMF). The boundary between the NKT and SKT is the Kudi Suture, while the boundary between the SKT and TSHT is the Kangxiwa Fault.

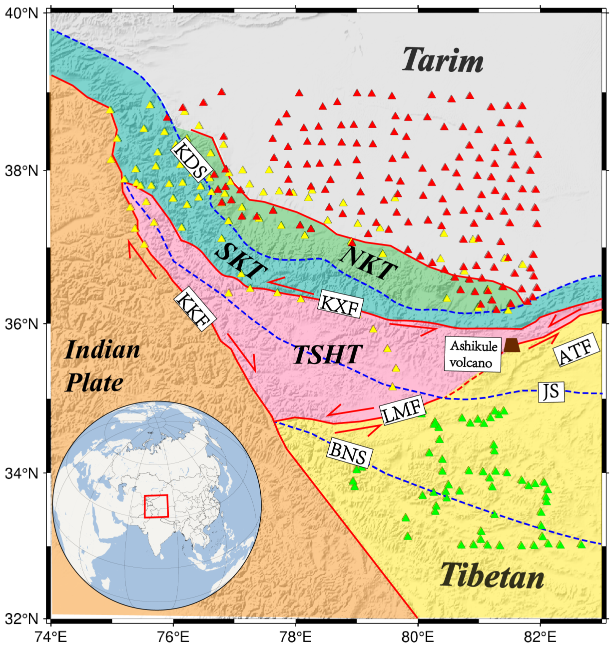

Figure 1: Tectonic Setting of the WKTZ, modified from (Zhang et al, 2023). In the map: green triangles indicate SinoProbe stations, yellow triangles indicate long-period stations, red triangles indicate broad-band stations. NKT: Northern Kunlun Terranes, SKT: Southern Kunlun Terranes, TSHT: Tianshuihai Terranes; KDS: Kudi Suture; JS: Jinsha Suture; BNS: Bangong-Nujiang Suture; KXF: Kangxiwa Fault, KKF: Karakoram Fault, ATF: Altyn Tagh Fault; LMF: Longmucuo Fault.

3D resistivity structure

The inversion result matches the geological structures at shallow depths very well (Figure 2a). In the eastern part of the study area, beneath the Ashikule Volcano, a conductive anomaly extends east-west within the 10 to 40 km depth range and is identified as the volcanic melt C1 (Figure 2b).

At the middle crust depths, two prominent conductive anomaly bands appear on the southern flank of the West Kunlun Mountains. These anomalies reach their maximum extent within the 50 to 60 km depth range (Figure 2c) and subsequently diminish from the extremities towards the center, with the deepest anomalies reaching approximately 140 km (Figure 2d). The conductive anomaly band beneath the Jinsha River Suture is labeled as C2, while the band beneath the Bangong-Nujiang Suture is designated as C3. Both C2 and C3 represent the most significant conductive anomalies within the West Kunlun tectonic belt, spanning a considerable depth, from the middle crust (30 km) to the lithospheric mantle (>100 km).

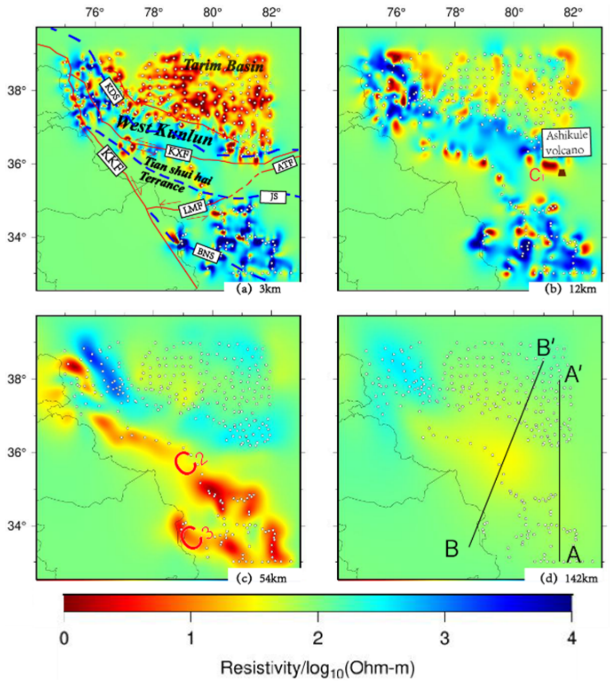

Figure 2: Depth Slices.(a-d) represent resistivity slices at depths of 3 km, 12 km, 54 km, and 142 km, respectively. (a) Tectonic setting of WKTZ. (b) The brown trapezoid represents Ashikule Volcano, the low-resistivity anomalies is C1. (c) The location of C2 and C3. (d)The location of profile AA' and profile BB'.

Cenozoic volcano

As Xu et al (2021) suggested, the magma primarily originates from the upwelling of mantle material through the analysis of the rock composition of the Ashikule Volcano's eruptive products. However, the inversion results indicate that the deepest magma chamber is at 40 km(Fig 4), which does not reach the depth of the mantle.

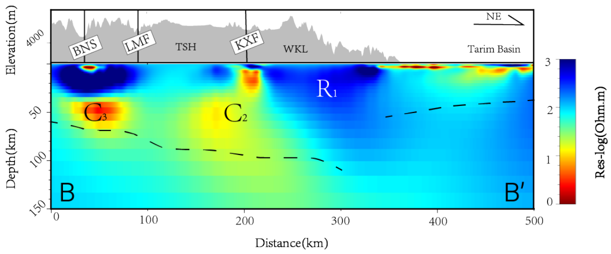

Figure 3: Prodile BB'.The black dashed line represents the reference Moho depth, modified from (Zhang et al, 2014; Kumar et al, 2022; Wittlinger et al, 2004).

Therefore, we speculated that the magma in this chamber is not the native magma of that depth but rather material that has upwelled from greater depths. The 3D model(Fig 4) display a channel between C1 and C2, which may be one of the pathways for magma migration.

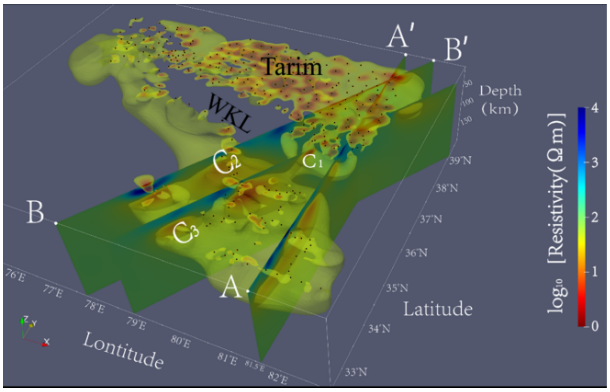

Figure 4: 3D model in Paraview. The yellow-green surface represents the 50$\Omega \cdot m$ iso-surface, and the area enclosed within it is characterized by a conductive anomaly.

Conductive sutures

Based on the distribution of conductros, we can infer the approximate subduction direction of the paleo sutures. The conductor cutting through the Solonkhe suture provides evidence for the southward subduction of the Paleo-Asian oceanic lithosphere (Ye et al, 2019), while the northward and southward dipping conductor beneath the Bangong-Nujiang suture indicate the bidirectional subduction of the Neo-Tethy ocean lithosphere (Sheng et al, 2019).

In the WKTZ, the Bangong-Nujiang suture(BNS) records the northward subduction of the Neo-tethys, and the Jinsha suture (JS) records the southward subduction of the Paleo-Tethys.

CONCLUDING REMARKS

Incorporating the distribution of conductive anomalies from the three-dimensional resistivity model, we inferred that the Indian plate lithosphere and the Asian plate lithosphere collided and converged in front of the Western Kunlun Mountains. Prior to the collision, a significant amount of melt was generated at the leading edge. A portion of this melt migrated along the plate interface, becoming part of the fluid, while another fraction followed magmatic conduits into the volcanic magma chambers.

In conclusion, in the WKTZ, conductive anomalies at the mid-to-upper crustal scale (shallower than 50 km) are predominantly controlled by paleo sutures and saline fluids, while at the lower crust to upper mantle scale(<150Km), they are influenced by melts at the collision front (Fig 5). Furthermore, based on the distribution of deep conductors, we infer that the subduction front of the Indian Plate has reached beneath the Kangxiwa Fault (about 37°N).

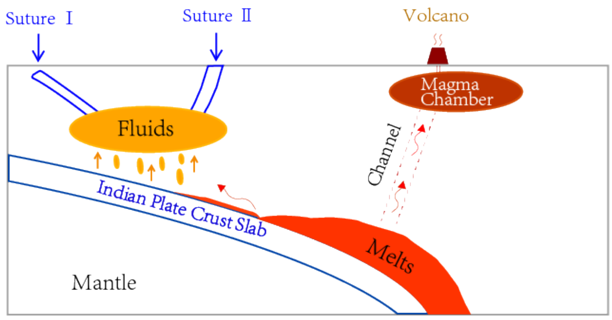

Figure 5: Conceptual model

ACKNOWLEDGMENTS

This study is funded by NSFC grants (41774079, 41830212) and the Academician Projects of Inner Mongolia Geological Survey Fund Management Center (2017-YS02, 2020-YS02).

REFERENCES

Egbert GD, Kelbert A (2012) Computational recipes for electromagnetic inverse problems. Geophysical Journal International 189:251–267

Kumar V, Rai SS, Hawkins R, Bodin T (2022) Seismic Imaging of Crust Beneath the Western Tibet Pamir and Western Himalaya Using Ambient Noise and Earthquake Data. Journal of Geophysical Research: Solid Earth 127(6)

Sheng Y, Jin S, Wei W, Ye G, Dong H, Zhang L, Liang H, Lu Z (2019) Lithospheric electrical structure in the central Tibetan Plateau and its tectonic significance. Journal of Asian Earth Sciences 184:103996

Wittlinger G, Vergne J, Tapponnier P, Farra V, Poupinet G, Jiang M, Su H, Herquel G, Paul A (2004) Teleseismic imaging of subducting lithosphere and Moho offsets beneath western Tibet. Earth and Planetary Science Letters 221(1-4):117–130

Xu J, Zhao B, Yu H, Wei F, Chen Z (2021) Volcanic geology and petrochemistry of Ashikule volcanic field in western Kunlun Mountains of the Tibetan plateau. Geological Society, London, Special Publications 510(1):133–146, DOI 10.1144/SP510-2020-133, URL https://www.lyellcollection.org/doi/10.1144/SP510-2020-133

Ye G, Unsworth M, Wei W, Jin S, Liu Z (2019) The Lithospheric Structure of the Solonker Suture Zone and Adjacent Areas: Crustal Anisotropy Revealed by a High-Resolution Magnetotelluric Study. Journal of Geophysical Research: Solid Earth 124(2):1142–1163

Zhang Z, Wang Y, Houseman GA, Xu T, Wu Z, Yuan X, Chen Y, Tian X, Bai Z, Teng J (2014) The Moho beneath western Tibet: Shear zones and eclogitization in the lower crust. Earth and Planetary Science Letters 408:370–377

Zhang Z, Sun J, Zhang B, Ren Z (2023) Cenozoic source-to-sink relations between the West Kunlun Mountains and SW Tarim Basin: Evidence from an integrated provenance analysis. Palaeogeography, Palaeoclimatology, Palaeoecology 632:111858