

Deep resistivity structure in the central and northern parts of the Tibetan Plateau revealed by two-dimension magnetotelluric focused inversion

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SUMMARY

Tibetan plateau is a key area for understanding the rheology and tectonic evolution of continental plates, and exploring the dynamic processes of the continent, magnetotelluric (MT) plays an important role in researching geological structures at the scale of the lithosphere. In our study, we collect MT data in broadband period ranges ($T=0.003s$ to 3000) to reveal the lithospheric structures of Tibetan plateau. The inversion method is based on the focused 2D MT inversion with both transverse electric (TE) and transverse magnetic (TM) mode, we design a synthetic model experiment refer to the actual geological model of the Tibet Plateau to explain the importance of using both TE and TM mode and the controlling of the regularization parameter, through our designed inversion strategy we have successfully restored the true model which shows more accurate and stable in inversion result compared to the conventional inversion processing. We conducted our inversion strategy on a survey line running east-west through the central part of the Tibet Plateau at a distance of about 1300km, inversion result clearly shows a significant lateral variation in the thickness of the lithosphere related to the subduction and collision, continuous distribution of high conductivity layers in the middle and lower crust indicates that the presence of a large amount of partially molten and water rich fluids.

Keywords: Magnetotelluric, Tibetan plateau, Focused inversion, Lithosphere

INTRODUCTION

The Himalayan range is one of the largest and best documented continental collision belts (Peng et al., 2016), research on lateral variation of subduction-collision mode and asthenospheric mantle upwelling can provide significant constraints on the dynamic mode of the Tibet region. Magnetotelluric (MT) utilizes natural alternating electromagnetic fields as the field source, detecting the electrical structure within the Earth by observing the intensity of electric and magnetic fields at the surface, due to its high sensitivity to high electrical conductivity target and the ability to probe depths into the asthenosphere, MT finds widespread applications in resource exploration and lithospheric structure investigations (Queralt et al., 2007; Zhang et al., 2016; Chase et al., 2023).

Recent geophysical surveys have revealed the lithospheric heterogeneity under Tibetan plateau based on seismic tomography (Peng et al., 2016; Hou et al., 2023). Limited by the resolution of the three-dimension (3D) MT inversion, most of the MT research concentrate on crustal scale targets of Tibet plate (Bai et al., 2010; Zhang et al., 2019; Zhen et al., 2023). Due to the different sensitivity between two-dimension (2D) and 3D MT inversion, Although 2D MT inversion is restricted by the 2D

assumption, it still remains an important pre-interpretation process of MT research. Previous 2D MT research mostly use only transverse magnetic (TM) mode (Zhang et al., 2019; Zhen et al., 2023), the transverse electric (TE) mode is dominated by inductive effects in physics and is computed from currents flowing along strike, making it good at detecting conductors, TM mode is capable of detecting more moderate conductors and resistors since it is computed from currents flowing across strike and includes both inductive and galvanic effects (Chase et al., 2023), if we want to do the 2D MT research on the lithospheric scale resistivity structure, we need to integrate information from underground structures with different sensitivity brought by the both two modes.

Within the scope of this study, we use modified EMS (Song et al., 2022) as our regularization stabilizer in 2D MT inversion, we designed a synthetic model experiment based on the resistivity structure of the Tibet plate, demonstrating the importance of the combined TE and TM modes in revealing the structure at the lithospheric scale.

METHOD

Aiming at obtaining focus inversion result and excluding interference from complicated resistivity backgrounds, we use EMS stabilizer (eq. 1)

$$S_{EMS}(\mathbf{m}) = \sum_{i=1}^N (1 - e^{-\frac{(m_i - m_i^{apr})^2}{(m_i - m_i^{apr})^2 + \beta^2}}) \quad (1)$$

ε and β are the parameters that adjust the strength of the focusing effect, we replace the $m_i - m_i^{apr}$ with ∇m_i to reduce reliance on prior information of reference model.

SYNTHETIC TEST

In this section, we have designed a model to demonstrate that our method can more accurately reveal the lithospheric scale resistivity distribution (Figure 1).

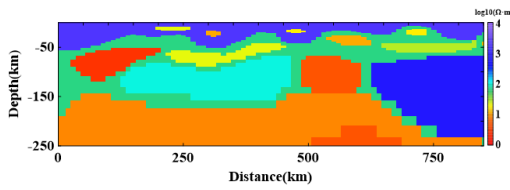


Figure 1. True model

The observation stations are evenly distributed on the surface, $\Delta_{receiver} = 10\text{km}$, the data we used for the inversions both TE and TM mode with 80 frequencies over a range of $320 \sim 3.4 \times 10^4$ Hz, the apparent resistivity and phase data both added with 5% gaussian random noise (Figure 2).

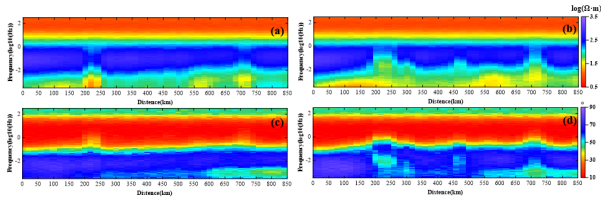


Figure 2. Synthetic MT response (add 5% Gaussian noise). (a) TM mode apparent resistivity. (b) TE mode apparent resistivity. (c) TM mode phase. (d) TE mode phase.

Firstly, we use OCCAM2DMT (Constable *et al.*, 1987; deGroot-Hedlin & Constable, 1990) to invert TE and TM mode separately, the initial models are both set to $10 \Omega \cdot \text{m}$, the inversion results show in Figure 3. The RMS misfits are 1.002 and 1.005 respectively.

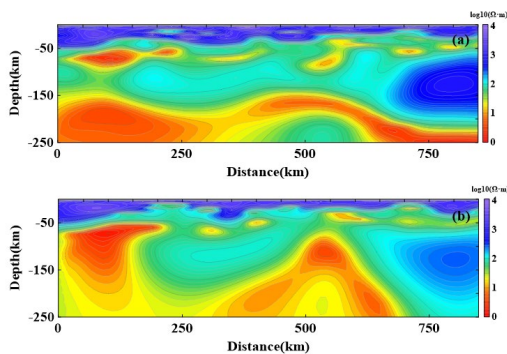


Figure 3. Results of separate TE and TM mode inversion. (a) OCCAM inverted result only uses TM mode. (b) OCCAM inverted result only uses TE mode.

TE mode can reveal the high conductivity targets better, the upwelled asthenosphere at distance of around 550km is well revealed by TE mode, on the contrary, this feature is not present on TM, but TM mode exhibits stronger ability to reveal high resistivity targets. In this case, we need to use both modes. The combined TE and TM mode inverted result (Figure 4) shows better revealing of the synthetic model with the RMS misfit 1.004 after 25 times of iterations.

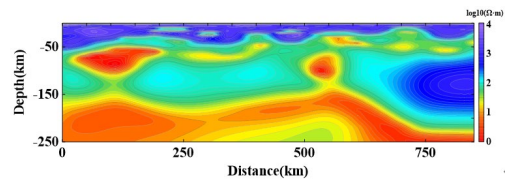


Figure 6 Results of combined TE and TM mode OCCAM inversion.

Although the fitting of the data is still at the noise level, the unstable changes in regularization factors and the ambiguity of iteration termination conditions have caused the inversion results to deform and distort, deviating from the true model. In order to better control the inversion process, we use the adaptive regularization and the misfit error reduction rate as the termination condition, the detailed strategy is as follows:

- The modified EMS stabilizer focusing factor β is set to 0.5, and the adjustable coefficient ε is set to 1.
- Regularization factor is set to 5 in the logarithmic case with a base of 10, we first use the golden-section search at the beginning of the inversion, if the misfit error reduction rate lower than 5%, we abandon the golden-section search and record the regularization factor value at this iteration as the initial regularization factor value of adaptive regularization.
- In the adaptive regularization process, if the current regularization factor can reduce the rate of data fitting error by more than 1%, we accept the results of this iteration, else we cutup the step-size until the rate of data fitting error larger than 1%, if the step size is reduced 10 times and still cannot meet the condition, we decay the regularization factor with the Attenuation coefficient in 0.95, and repeat the previous process.
- The inversion process will be terminated if the regularization factor decays more than 3 times in one iteration or the regularization factor is lower than 1.

We obtain the modified EMS inversion result with combined TE and TM mode (Figure 7a) with the RMS misfit 1.03 after 17 times of iterations. Through our robust inversion strategy, true model can be revealed more accurately and avoid the inversion process go to extreme through the control of the regularization factor (Figure 7b).

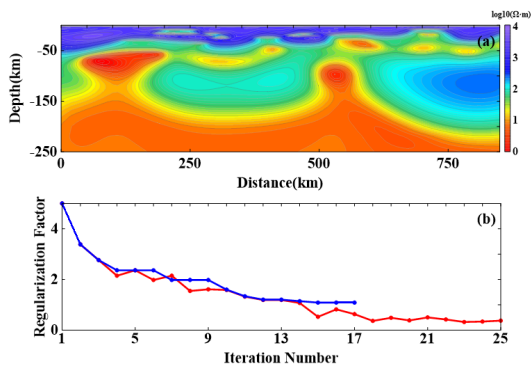


Figure 7 Combined TE and TM mode modified EMS inversion. (a) inversion result. (b) Changes in regularization factors during iteration, blue solid line represents the EMS inversion, red solid line represents the OCCAM inversion.

FIELD DATA PROCESSING

Synthetic model test has proved that our inversion strategy has ability to reveal the Tibet plate electrical structure. We choose a set of MT measurement points with an east-west strike direction near 32° N for 2D inversion (Figure 8), electrical structure can be considered as 2D structure since most of the phase tensor skew angles among the data from different frequencies are lower than 3°, both TE and TM mode with 80 frequencies over a range of 320~3.4×10⁻⁴ Hz within 108 sites are used.

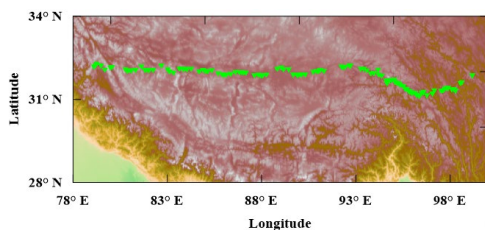


Figure 8 Measurement points (marked as green triangle) location map

All the inversion parameters and iteration termination conditions are set as demonstrated in previous section, error floor is set to 7.5%. The inversion result shows in Figure 9, RMS misfit decreases from 11.7 to 3.09 within 20 iterations.

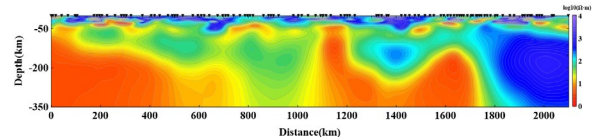


Figure 9. Field data inversion result

From the inversion results, we can see that there are multiple continuous high conductivity layers near 20-50km depth of the profile, the high crustal conductivities of the Tibetan plateau are more likely to come from interconnected fluids, including partially molten or water rich fluids (Wei et al., 2001), there are several upwelling channels of the mantle material can be observed around 100-200km depth, which might be the origin of the high conductivity layers. The thickened lithosphere of the Tibetan plateau has Experienced multiple periods of detachment during different geological, with detached lithospheric blocks sinking into the mantle transition zone and lower mantle (Ding et al., 2022), the detachment of the lithosphere leads to surface uplift and upwelling of the asthenosphere, the variation of the lithosphere thickness in distance can be clearly characterized from the inversion result Figure 9. The heating of the lithosphere causes magmatic activity and partial melting of the middle and lower crust, forming crustal channel of high conductivity flows.

CONCLUSIONS

Throughout the synthetic test and the filed data process, we can draw such conclusions:

- Both TE and TM mode are important in revealing the lithospheric scale resistivity structure since they have different sensitivity with different targets.
- The control of the regularization factor is significant since the contribution of data at this scale will be lower, we should choose an appropriate strategy to make the inversion process more stable.
- 2D approximation still plays an important role in the pre-process of 3D MT. Through the 2D inversion result, we can clearly observe the east-west variation of the lithosphere and upwelled asthenosphere caused by multiple periods of detachment in the Tibetan plateau indicate origin of the high crustal conductivities.

Although 2D inversion may obtain higher resolution results compared to 3D inversion, but it still strictly restricted by the 3D structure effects. In the future, we will continue to perform 2D inversion on the survey lines in the region, and use the 2D inversion results of the region as the initial model for 3D inversion.

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