Lithospheric Electrical Characteristics of Eastern Jiangnan Orogen, South China

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Abstract: A large amount of mineral resources are distributed in the Southern China, which shows South China block has experienced a complicated geological evolution process. Three dimensional (3D) lithospheric electrical structure model of eastern Jiangnan orogen was established in this paper by 3D OCCAM inversion program. The 3D lithospheric electrical structure model has a good corresponding relationship with the subsurface geology and regional magnetic anomalies, and thus can provide more detailed information about underground geological structure. From the perspective of 3D electrical structure model in combination with regional geologic conditions and regional magnetic data, the eastern Jiangnan orogenic belt and adjacent regions are divided into 4 first-order tectonic units and 16 secondary tectonic units. The 4 first-order tectonic units include North China zone with low resistance, Dabie orogenic belt zone with high resistance, Yangtze zone with low resistance and high-resistivity, and Cathaysia massif zone with high resistance. The 3D model shows that layers and abnormal bodies with low resistivity in the crust and upper mantle in the Southern China are widely developed. The characteristics of 'U' shape high resistance root in the deep part of Dabie Mountains imply that the North China block and Yangtze block collided and subducted beneath the Dabie Mountains on the north and south sides, suggesting strong compression uplift tectonic settings. The overall performance of the Yangtze block is characterized by high resistance in the middle and low resistance around. Huaiyu terrane located in the east of Yangtze block is of low resistance characteristic, suggesting apparent obduction tectonic environment. Evidently the assaulted low resistance anomalous in the lower section occurred along the collage tectonic belt, and these low resistance anomalous could be related to the distribution and formation of a large amount of metal minerals above. The low resistance anomalous whose tendency for south east along Jiangshao fault indicate the Cathaysia massif obducted to Yangtze block. The establishment of 3D lithospheric electrical structure model of the eastern Jiangnan orogen is to explore the relationships between different tectonic units and analyse the formation and evolution of south China continent, which could have important reference value for forecasting and prospecting of potential minerals.

1 INTRODUCTION

Southern China is composed of Yangtze block and Cathaysia massif, which contains enrichment areas of mineral resources in the mainland of China. Stratigraphic sequence exposed in Southern China spans from the Proterozoic to Cenozoic. Basic, neutral and acidic igneous rocks are widely distributed, especially Mesozoic granule volcanic-intrusive rocks which are the most widely developed (Dong and Ma, 2011). Southern China contains abundant mineral resources, and various ores in huge reserves. There are many metallogenic belts distributed in the Southern China, such as the middle and lower reaches of the Yangtze river metallogenic belt and Qin-Hangzhou metallogenic belt. Its distinctive geological pattern, unique crustal growth and metallogenic regularity are rare in the worldwide, suggesting a deep geodynamic background and complicated tectonic evolution history of the South China block. Nowadays, the cause of abundant mineral deposits formation in this metallogenic belt has been still a hot issue and have attracted the attention of scholars of geologists.

Numerous geophysical prospecting works have been carried out by predecessors in the Southern China. After several generations of efforts, research results are abundant, while there are still many basic geological problems unsolved in the Southern China. One of the simplest reasons is lack of knowledge about deep geological information. Magnetotelluric

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(MT) sounding is one of the most important methods for deep exploration (Chen and Liu, 1984), due to its advantages in deep detecting, light equipment, stationing flexibly, and low-cost. MT sounding is widely used in the field of resource exploration and deep structure study of crust and mantle. In order to obtain deep structure information of the Southern China, we carried out a large area of regional magnetotelluric sounding work in the Southern China during 2008-2016, and also completed a measurement area of about 350 thousand square kilometers. 525 wide-band magnetotelluric sounding stations were acquired. At present, 1D and 2D inversion methods of magnetotelluric data have been developed, which have become the main means of the actual data processing and interpretation (Dong et al., 2012; Chen et al., 2011; Cai and Chen, 2010). The nonlinear conjugate gradients algorithm (NLCG) and the improved OCCAM method become the mainstream inversion methods (Rodi and Mackie, 2001; Rodi, 1976; Siripunvaraporn and Egbert, 2000). With the development of 3D forward calculation and the improvement of computer performance, 3D magnetotelluric inversion method is developing rapidly, and is gradually applied to actual data processing (Newman and Alumbaugh, 2000; Patro and Egbert, 2008; TANG et al., 2014; YANG et al., 2015; YANG et al., 2015; QIU et al., 2014).

In this paper, we introduce the process of how to construct 3D electrical structure model of eastern Jiangnan orogen by WSINV3DMT inversion program which is based on REBOCC 3D inversion algorithm. Based on the analyses of 3D electrical structure model, regional geology, regional gravity and magnetic data, we have preliminarily divided the tectonic units in the Southern China, and analyze the electrical characteristics and contact relationship of each structural unit. The 3D model provides important information for the formation and evolution of the mainland of Southern China and the favorable direction of subsequent prospecting.

2 REBOCC INVERSION THEORY

Data-space method is proposed by professor Weerachai Siripunvaraporn on the improvement of Occam inversion algorithm (Siripunvaraporn et al., 2004; Siripunvaraporn et al., 2005; Siripunvaraporn and Egbert, 2009). It is based on the calculation and storage format of the sensitivity function that transform from original model space (M╳M) to data space (N╳N) by derivation. The model roughness is defined which can make the model more flexible , and suppress the geoelectric structure irrationality. In OCCAM inversion, by solving the unqualified equation $U(m,\lambda)$ can achieve the goal:

$$U(m,\lambda)=(m-m_0)^{\mathrm{T}}C_m^{-1}(m-m_0)+\lambda^{-1}\{(d-F[m])^{\mathrm{T}}C_d^{-1}(d-F[m])-X_*^2\} \quad (1)$$

In order to get the required solution, the equation is usually not solved directly , but by using the penalty function as follows, because when λ fixed, $\partial \mathbf{U}/\partial \mathbf{m} = \partial \mathbf{W}/\partial \mathbf{m}$, $U(m,\lambda)$ and $W_\lambda(m)$ have the same value.

$$W_\lambda(m)=(m-m_0)^{\mathrm{T}}C_m^{-1}(m-m_0)+\lambda^{-1}\{(d-F[m])^{\mathrm{T}}C_d^{-1}(d-F[m])\} \quad (2)$$

λ^{-1} refers to Lagrange multiplier, and is used to control the smoothness of model fitting.

In general, the MT data is smooth and redundant, so in the data space, we do not need to use all sensitivity matrix as the base functions. The minimization of equation (2) in number k iteration can be expressed as a linear combination line of smooth sensitivity matrix $C_mJ_k^{\mathrm{T}}$:

$$m_{k+1}-m_0=C_mJ_k^{\mathrm{T}}\beta_{k+1} \quad (3)$$

β_{k+1} is unknown coefficient vector of basic functions $[C_mJ_k^{\mathrm{T}}]_j$,(j=1,…,N). put (3) into (2), it can be obtained:

$$W=\beta_{k+1}^{\mathrm{T}}\Gamma_k^n\beta_{k+1}+\lambda^{-1}\{(d_k-\Gamma_k^n\beta_{k+1})^{\mathrm{T}}C_d^{-1}(d_k-\Gamma_k^n\beta_{k+1})\} \quad (4)$$

$\Gamma_k^n=J_kC_mJ_k^{\mathrm{T}}$ is N╳N order "data subspace cross-product" matrix. Differentiating Beta of equation (4), make the result is zero, and rearranging, unknown expansion coefficient can be written as:

$$\boldsymbol{\beta}_{k+1}=(\boldsymbol{\lambda C_d}+\Gamma_k^n)^{-1}\boldsymbol{d_k} \quad (5)$$

By solving (5) over and over again, the optimal inversion results can be obtained according to the method of searching model space.

3 DATA ACQUISITION AND 3D MODEL CONSTRUCTION

After MT curves editing and static shift correction, the field observation data can be used for inversion calculation. 3D inversion is the first choice for regional magnetotelluric data. A total of 525 wide-band magnetotelluric sounding stations were acquired in the Southern China. The distance between each adjacent station is about 20-30 kilometers. Because a large amount of computer memory is needed in 3D inversion calculation, the whole work area is decomposed into 6 sub blocks to carry out 3D inversion individually. A certain overlap area is retained between the two adjacent sub blocks so as to facilitate the post splicing work of each sub inversion result. Figure 1 shows the actual MT stations' distribution in the Southern China. Figure 2 shows the six sub blocks. 3D inversion is carried out according to the following steps and finally an accurate 3D electrical structure model is achieved. 21 frequency data are uniformly selected from the logarithmic range of 320Hz-5000S. In the horizontal direction, the center of the model within MT stations is divided by 10km uniform grid. In the vertical direction, to start with 50m thickness as the first layer, and then step down by 1.1 times gradually decline until reaching enough depth. 100 **Ω•m** homogeneous half space are selected as the initial model, and the mode of non diagonal impedance tensor (Z_{XY},Z_{YX}) is used for 3D inversion calculation. After 3D inversion calculation of each sub block is finished in turn, we can get the fusion electrical structure model of the whole work area using each sub block 3D result (Figure 3). The RMS error of the model is 2.75, the data fitting is relatively well, and the inversion results are credible.

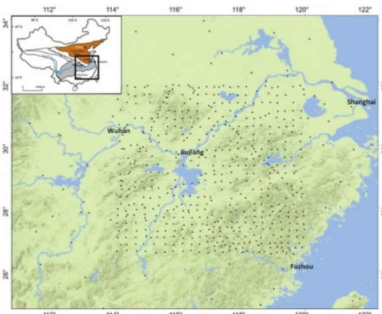

Figure 1: Map of study area and location of MT stations (The area of the work area is about 350 thousand square kilometres. A total of 525 wide-band magnetotelluric sounding stations were acquired.)

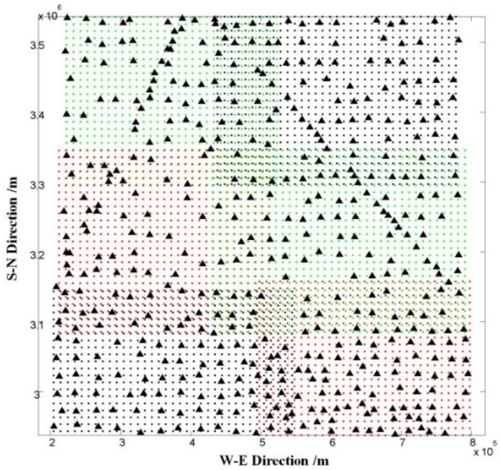

Figure 2: Actual MT stations and six sub blocks partition.

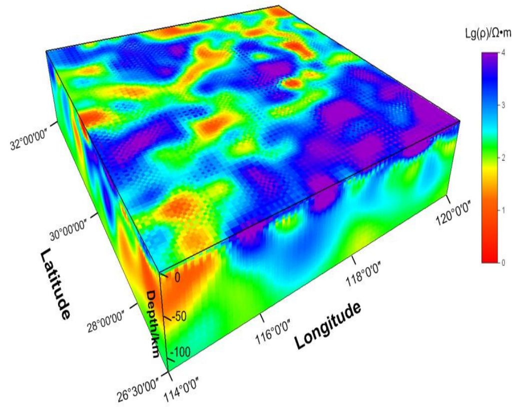

Figure 3: 3D lithosphere electrical structure model of eastern Jiangnan orogen.

4 3D ELECTRICAL CHARACTERISTICS OF EASTERN JIANGNAN OROGEN

4.1 Plane Electrical Characteristics and Structural Units Division

The value of plane vertical conductance is calculated by layer thickness and the corresponding resistance. It is usually expressed in symbol S, $S=H/\rho$, representing local rock conduction ability of a certain thickness. The Southern China has experienced a complex geological evolution history that its geological structure is complicated. For the theoretical of different geophysical exploration methods are different, the methods of dividing structural units may be different as well. Figure 4a displays plane vertical conductance within 50 km thickness of South China which is calculated using 3D electrical structure model. In accordance with electrical characteristic differences, and additionally combining with plane resistance characteristics at the depth of 10 km (Figure4b), regional geology on surface (Figure 4c) and satellite magnetic anomaly (Figure 4d), the working area is divided into 4 first-order tectonic units and 16 secondary tectonic units. The 4 first-order tectonic units include low resistance North China zone, high resistance Dabie orogenic belt zone, low resistance and high resistivity interval Yangtze zone and high resistance Cathaysia massif zone. As can be seen from Figure 4, the electrical characteristics of each structural unit have a good spatial correspondence with the regional geology and the satellite magnetic anomaly.

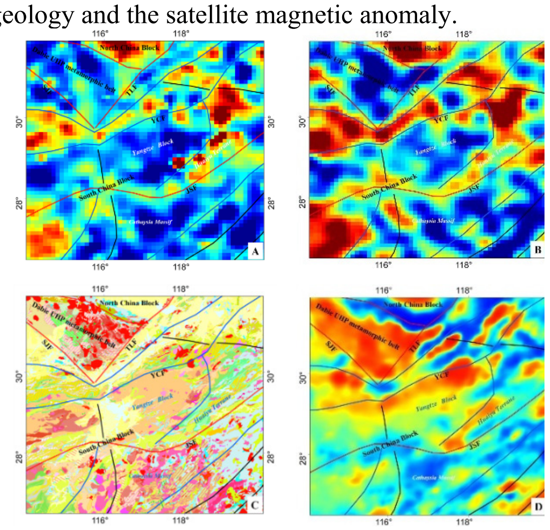

Figure 4: Structural units division of eastern Jiangnan orogen. (a) plane vertical conductance within 50 km depth; (b) plane resistance characteristics within 10 km depth; (c) regional geological map on earth surface; (d) satellite magnetic anomaly. TLF:Tancheng-Lujiang fault, XGF:Xiangfan-Guangji fault, YCF:Yangxing-Changzhou fault, JSF:Jiangshan-Shaoxing fault.

4.2 Vertical Electrical Characteristics and the Relationship between Different Structural Units

As can be seen from the plane vertical conductance map (Figure 4a), the North China block is of low resistance characteristic, while the Dabie orogenic belt and the Cathaysia massif are characterized by high resistance. The Yangtze block is featured by middle high resistance and low resistance around. Different structural units in both horizontal and vertical directions clearly show different electrical characteristics.

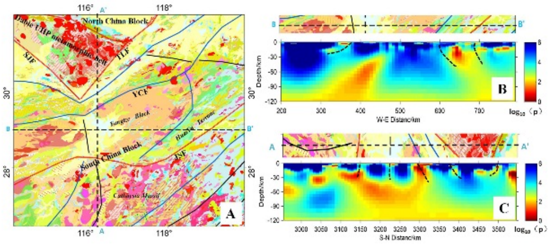

Figure 5: Vertical electrical characteristics of two profiles. (a) the position of two profiles AA' and BB'. (b) electrical characteristics of the West-East line BB'. (c) electrical characteristics of the South-North line AA'.

In order to study the contact relationship between various structural units, two electrical profiles are selected in the work area (Figure 5). From profile C (A-A') in Figure 5, the high resistance with a U-shaped structure in the deep is performed in the Dabie mountain, the deepest place can reach about 80 km depth, indicating obvious high resistance "root" characteristic. There is a high conductivity layer in the depth of about 30 km through deep high resistance zone under the Dabie mountain. The exploration results of the low resistivity layer are in agreement with previous results. The fractures located on both sides of Dabie mountain are steep, and enclosed to the high conductivity layer in the deeper. The Yangtze block is characterized by high resistance in the middle and low resistivity around, and there is a large low resistance anomaly under the middle high impedance body. Low resistance belt along the Yangtze River which is located in the north of Yangtze massif shows apparent high conductivity characteristic. The low resistivity zone is linked to low resistance anomalous in deep mantle. The Jiangshao fault located in the southern margin of the Yangtze block is characterized by a narrow range of low resistance zones under which there is an local upward protruding structure. It can be seen from the profile (B-B') in Figure 5 that the middle part of the Yangtze block and Cathaysia massif are characterized by a wide range of high resistance. It is probably the base structure formed in the Neoproterozoic Era, and its anomaly range and depth of high resistivity are much larger than those of the Dabie Mountains. HuaiYu terrane located in the east of Yangtze block is of high conductivity characteristic. The shallow low-resistance anomalous connected with low resistance fluid in deep mantle through a narrow passage. Tendency of low resistance anomalies overall represents to southeast. The above two profiles clearly demonstrate the electrical characteristics of each structural unit and the contact relationship between each other. The 3D electrical structure model is of great value to study the formation and evolution of the Southern China continent and the ore controlling factors of deep deposit.

5 GEOLOGICAL SIGNIFICANCE REVEALED BY THE 3D ELECTRICAL MODEL

Generally the 3D electrical structure model contains abundant underground information. The characteristics of ‘U’ shape high resistance root in the deep part of Dabie Mountains indicates that the northside of North China block and the southside of Yangtze block collided and subducted beneath the high resistance bodies of the Dabie Mountains, which made the Dabie mountains shows an obvious compression uplift structure pattern. During the Permian - Triassic period, the tectonic environment in the Southern China area expanded, the low resistivity layer was formed at the 30km depth below the Dabie Mountain. Low resistance belt along the Yangtze River located in front-end Dabie orogenic belt shows significant high conductivity characteristics. The low resistance abnormal body is related with deep low resistance anomalous in upper mantle, which could form the migration channel for deep soft fluid. The low resistance channel may have closed relationship with the distribution of abundant of metal mineral resources above. Huaiyu terrane located in the east of Yangtze block is of high conductivity characteristic, suggesting obvious collage of tectonic patterns, with which the two low resistance layers in crust exist. The double low resistivity layer may indicate the existence of a double crustal structure. Double crust structure has formed its unique form of mineral resources system. Jiangshao fault shows an evident low resistivity characteristic, and the low resistivity zone tends to the Southeast. Its formation may be related to the cracking events during Early Neoproterozoic-Paleozoic era. At that same time, a lot of low resistance layers were widely developed in crust during the cracking period.

6 CONCLUSIONS

This paper introduces the process of how to construct 3D electrical structure model of eastern Jiangnan orogen by WSINV3DMT inversion program which based on REBOCC 3D inversion algorithm. Based on the 3D electrical structure model and other related geophysical data, the 3D electrical structure characteristics and geological significance of Jiangnan orogenic belt are analyzed and the following conclusions are obtained:

Using regional magnetotelluric data, the 3D electrical structure model of eastern Jiangnan orogen is established for the first time. Combined with regional geology, regional gravity and magnetic data, the eastern JiangNan orogen can be divided into 4 first-order structural units and 16 secondary structural units.

The characteristic of ‘U’ shape high resistance root in the deep part of Dabie Mountains indicates the North China block and Yangtze block collided and subducted beneath the Dabie Mountains on the north and south sides individually, suggesting strong compression uplift tectonic settings.

Huaiyu terrane located in the eastern of Yangtze block shows low resistivity, implying apparent obduction tectonic environment. There are obvious assaulting low resistance anomalous in the lower section along the collage tectonic belt, and these low resistance anomalous could be related to the distribution and formation of a large number of metal minerals above.

Jiangshao fault shows an obvious low resistivitythat the low resistivity zone tends to the Southeast, which means Cathaysia massif collided over the Yangtze block.

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