# Development of the emerging electromagnetic methods for deep earth exploration

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**Abstract:** Three emerging techniques for surface electromagnetic (EM) exploration with high detection accuracy and large depth of investigation, namely, WEM (wireless electromagnetic method), MTEM (multi-channel transient electromagnetic method) and SOTEM (short-offset grounded-wire TEM), are introduced. In detail, we proposed a newly developed sky-wave theory in which EM wave can propagate in full space of ionosphere-atmosphere-lithosphere. Correspondingly, we developed the WEM recording system to measure the sky-wave to obtain the structures down to ~10 km depth. We then introduced MTEM as a highly effective method for mineral exploration with target depth of 3km. Using self-developed MTEM system, we presented the results obtained from mineral exploration study carried out in China. Lastly, we proposed the SOTEM method for a greater detection depth (1.5km) than traditional loop source TEM (500m) with a small offset and high resolution. **Keywords:** Deep Earth Exploration; WEM; MTEM; SOTEM

#### Introduction

Due to fast development in emerging economies, the shallow (<~1km depth) mineral resources in the Earth are being rapidly consumed. It is necessary to detect the deeper mineral resources down to ~10 km depth. The magnetotellurics (MT) method, which uses natural EM signals as an energy source, has been applied well to studies of crustal and upper mantle resistivity (Simpson and Bahr, 2005). However, it is very inefficiency to improve the signal-to-noise ratio and resolutions of the resistivity images in the upper crust via long-term fix spot observation for a few weeks or months.

The controlled source audio frequency magnetotelluric method (CSAMT), which uses artificial EM signal as a source, has been applied to geophysical and engineering explorations (Chave,1982). However, the effective detectable range of the CSAMT is approximately 5 to 10 km (areal distance) from the source, hence, the resolution should be improved (Di et al., 2010).

In or der to meet the requirement of deep resource explorations of up to  $\sim 10$  km depth at present, the paper is organized into three different sections that are related to the three new EM methods for Deep Earth Exploration: First WEM sounding was introduced, then MTEM was discussed and lastly, SOTEM.

# WEM exploration technology



**Figure1.** Illustration of EM propagation in the earth media. (a) The propagation of sky-waves in radio communications, (b) Sky-waves for underground investigations.

The traditional theory of sky-waves in WEM, which are excited by a ~100 km length grounded wire, which indicates that sky-waves propagate from the atmosphere upward into the ionosphere, and then reflects back to the Earth's surface (Fig.1a). We proposed a new method to develop the sky-waves theory in which the sky-waves can propagate in full-space of Ionosphere-Atmosphere-Lithosphere (Fig.1b). First, we developed a new sky-wave model in which sky-waves can propagate in full space of ionosphere-atmosphere-lithosphere. With the new model, we discovered that sky-wave can propagate with lower attenuation to larger distances than would be predicted by the traditional model. This result suggests that the sky-wave may be suitable for exploration of the upper crust over large area.



Figure 2. Photos of the data acquisition station.

We have developed a signal recording system to measure the sky-wave reflected back towards the earth surface from the lithosphere (Fig.2) (Di et al 2013). A case study is presented. Fig. 3 shows the obtained resistivity structure down to 10km depth, in Sichuan Provinces, west of China. It is obvious that the resistivity is discontinuous, which indicates that the geological structure of the study area is complex, as shown by previous seismic exploration result and known geological structures there.



Figure 3. The comparison of survey results between obtained resistivity and former velocity structures.

# **MTEM detection systems**

MTEM were originally proposed by Ziolkowski and Wright (2001). As shown in Fig.4a, all receivers are arranged in a stationary array, while the transmitter was moved along the survey line to measure the response at different offsets. Fig.4b shows the array configuration, where R1-R16 represents the location

of the receivers, S1-S5 represent the source positions; and the dashed line under R6 represents the multifold offset coverage sounding points.

We developed a distributed MTEM acquisition system (Fig.5a), the transmitter emits a PRBS source waveform and the receivers simultaneously recording the signal. Pictures of the developed MTEM system are shown in Figs. 5a and 5b. The largest order of the PRBS was 16, the max transmitting voltage was 1000V and the current was 50A, the max number of receiver channel was 200 (Di et al 2016).



**Figure 4.** The configuration for the MTEM.(a) Inline array configuration, (b) Schematic of the multifold offset coverage.



Figure 5. MTEM system used in the field survey. (a) Transmitter, (b) receivers.

The acquisition and processing of MTEM data along a 4.8 km profile over the Cao-si-yao molybdenum ore deposit was conducted (Fig.6a), a good earth impulse response curve was still obtained at a long offset. The peak times of the collected data were extracted and used to calculate the subsurface apparent resistivity value. The obtained 2D inversion result showed a resistive structure (Fig.6b) that was consistent with known geological information about the ore body (Fig. 6c) (Di et al 2017).



Figure 6. MTEM Field survey. (a) Survey line layout, (b) apparent resistivity section, (c) geological interpretation result.

#### **SOTEM exploration Method**

The loop source TEM is one of the mostly used in applications. But its detection depth is relatively small. We proposed a new type of technique, SOTEM, which earnests the advantages of the near-source survey for deeper stratum detection. (Xue et al., 2013) (Fig.7). The instrument used could either be a V8or a GDP32.1D Occam inversion scheme was introduced to invert the field data (Li et al., 2016).

The survey area was about 30km north of Houqiu ore deposit which was one of the biggest banded iron formation mine in China. The survey area was covered by Quaternary sediments .We designed two SOTEM survey lines across the main magnetic anomaly zone (Fig.8a, green lines). The length of transmitter dipole used was 1000 m, the base frequency of current was 1 Hz, the current strength was 16 A, and the source-receiver offset was 500 m. Fig.8b showed sudden isoline drop between the depths of 600 m and 1300 m around site 800, which was confirmed by drilling as ore bodies.



Figure 7. Diagrammatic sketch of the SOTEM setup.



Figure 8. SOTEM survey achievement. (a) SOTEM survey lines, (b) 1D inversion result of SOTEM data for Line 1 and well log section.

# Conclusion

As the shallow oil and mineral resources are being exhausted, the exploration of deep resources become the focus for breakthrough of the future. The conventional EM methods (such as MT, CASMT, and etc.) cannot obtain high-resolution image of subsurface structure at present. We proposed that the WEM (for 10km depth), MTEM (for 3km depth) and SOTEM (for 1.5km depth) methods could be applied in exploration of deep seated resources within the upper crust and realize high signal-noise ratio data. The research of the new methods has received increasingly great attention with excellent results achieved.

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