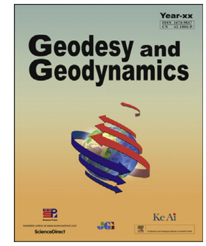
Ke Ai
ADVANCING RESEARCH
EVOLVING SCIENCE

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.keaipublishing.com/en/journals/geog;
http://www.jgg09.com/jweb_ddcl_en/EN/volumn/home.shtml



Mapping coalmine goaf using transient electromagnetic method and high density resistivity method in Ordos City, China

*Guiju Wu**, *Guangliang Yang*, *Hongbo Tan*

The Key Laboratory of Earthquake Geodesy, Institute of Seismology, China Earthquake Administration, Wuhan 430071, China

ARTICLE INFO

Article history:
Received 31 March 2016
Accepted 14 April 2016
Available online 30 July 2016

Keywords:
Transient electromagnetic method
High density resistivity method
Coalmine goaf areas
Geotechnical
Electrical

ABSTRACT

The research about subsurface characteristics by using transient electromagnetic method (TEM) and high density resistivity method (HDRM) were already conducted in Ordos. The objective of this research is to detect coalmine goaf areas based on rock resistivity. The data processing using wavelet transform, three point smoothing, RES2DINV and Maxwell processing software to obtain 2D resistivity structure. The results showed that the layers with maximum resistivity values (30–33 Ω m on Line 1, 30–31 Ω m on Line 2, 32–40 Ω m on Line 3) are founded at station 1–7, and 14–20 on Line 1,13–18 on Line 2, and 8–13 and 16–20 on Line 3 which is predicted as goaf layer, and the minimum resistivity values (20–26 Ω m of TEM, 45–75 Ω m of HDRM) at the other layers. This resistivity difference was caused by the geology and characteristics of the study area which is located close by the cleugh with rich coal, so the goaf area distinguishable with aquifer layer and coal seam. The results were also significant accidents and serious destruction of ecological environment.

How to cite this article: Wu G, et al., Mapping coalmine goaf using transient electromagnetic method and high density resistivity method in Ordos City, China, Geodesy and Geodynamics (2016), 7, 340–347, http://dx.doi.org/10.1016/j.geog.2016.04.014.

1. Introduction

From the beginning of the last century, the industrial development has had a negative impact on the exploitation of coalmine forming huge goaf areas. This problem has led to frequent accidents and serious destruction of ecological environment. Therefore, it is urgent to develop goaf detection and comprehensive work. Coalmine goaf detection is to find out the plane distribution and buried conditions underground, which can provide the basis for project safety assessment and disaster management. Recently, the mainly exploration

* *Corresponding author.*
E-mail address: wugjsky@126.com (G. Wu).
Peer review under responsibility of Institute of Seismology, China Earthquake Administration.

ELSEVIER | Production and Hosting by Elsevier on behalf of KeAi

http://dx.doi.org/10.1016/j.geog.2016.04.014

technologies in goaf are drilling detecting and geophysical detecting, although drilling detecting is the most intuitive and high precision, its project volume is massive, the rate of progress is slow and controlled range is small. So, the goaf detection method is generally given priority to with geophysical exploration, drilling technical method validation is complementary.

Measuring the electrical resistivity of the subsurface is the most powerful geophysical prospecting method in mineral exploration and the main method used for delineating coalmine goaf areas. Time-domain electromagnetic methods which are the subject of this paper, and in particular transient electromagnetic method (TEM) and high density resistivity method (HDRM), are increasingly used for grounded source exploration [1] and subsurface target mapping [2–5], all aspects of coalmine mapping [6–14]. Over the past decades, in particular, TEM and HDRM have been developed to provide early measurements for improved near-surface resolution and to increase the depth penetration.

Because of electrical interference of coal mine, topography affect, detection accuracy and detection depth, a single geophysical method may be problematic for geophysical prospecting. For example, using HDRM explores goaf areas, its effective depth is about 150 m, but if the depth of goaf area is over 150 m, HDRM is apparently ineffective; effective exploration depth of TEM is up to 200 m-500 m, even thousands of meters, but its shallow surface detection capability is weaker than HDRM. Therefore, in this paper, we integrated TEM and HDRM features to map the subsurface structure in Ordos. Fundamentally, the two geophysical methods complement each other. The inversion of data from the two methods is informative in spite of the fact that both methods measure the same physical property of earth. The combination of these two geophysical methods study goaf areas in coal mining areas is very important for the industrial development.

2. Geological setting

The research area is located in Ordos shown in Fig. 1, the terrain is erosion hilly topography and complicated, it is high in north-west and low in south-east. Most of the area is covered by aeolian sand, and gully aspect. The region is semi-arid, semi-desert plateau continental climate, the temperature is different between day and night. Rain is little all the year round, annual precipitation is 194.7–531.6 mm and concentrates in July, August and September, annual evaporation is 2297.4–2833.7 mm. Terrain cutting is severe, and about 50% area is covered by Quaternary aeolian sand and loess, other is bedrock outcropping. The results of drilling reveal that the stratum from old to new is T_3y (Upper Triassic Yanchang formation), $J_{1\text{-}2}y$ (Middle and Lower Jurassic Yan'an formation), J_2z (Middle Jurassic Zhiluo formation), N_2 (Neogene system), Q (Quaternary). T_3y is coal-bearing strata and sedimentary basement, it is not exposed on the earth's surface in this region; $J_{1\text{-}2}y$ is the main coal-bearing strata and exposes in the surrounding valleys, the lithology consists of a set of sandstone, mudstone, sandy clay and coal seam; the main lithology of J_2z is medium grained sandstone and argillaceous or clay cementation, it is relatively loose, its lateral thickness is rather changeable; N_2 is sporadic occurrence; and Q is widely scattered. There is no fault, big fold structure and magmatic rock intrusion in the research area. And the geological structure is simple.

3. Measuring method theory

3.1. *Transient electromagnetic method*

TEM systems consist of a transmitter instrument, transmitting coil or transmitting wire, receiver coil or antenna, and receiver instrument. Depending on subsurface resistivity, current induced, receiver sensitivity and transmitter–receiver geometry, TEM measurement allows geophysical exploration from a few meters below the surface to several hundred meters of depth (showing in Fig. 2). The method using transmitting coil sends a pulsed magnetic field, and receives induced electromotive force of the secondary eddy-current magnetic field with receiver coil during the intermittent pulse magnetic field, which is to understand the electrical characteristics of underground media. The secondary induced field decay is associated with subsurface conductivity, if the electrical conductivity is better, the secondary field is decreased more slowly, otherwise, the electrical conductivity is worse, the secondary field is decreased more quickly.

The data from field of TEM is induced electromotive force with time. In order to getting resistivity distribution, the induced electromotive force should be converted to apparent resistivity with the following formula,

$$\rho = \frac{\mu_0}{4\pi t}\left(\frac{2\mu_0 S_T S_R}{5t(V(t)/I)}\right)^{2/3}$$

where, $\mu_0 = 4\pi \times 10^{-7}$, S_T is the area of the sending circle, S_R is the area of receiver circle, t is the time of measuring time, $V(t)/I$ is the normalized induced electromotive force what is transient value. Therefore we can detect subsurface distribution characteristics of geological bodies from studying the transient variation with time.

3.2. *High density resistivity method*

HDRM in working is the same as the conventional resistivity method in principle, the difference is that HDRM in observing is set higher density measured points, the electric poles layout on certain interval measuring points. And in measuring, a number of electrodes are used and they can combine freely between electrodes, which can extract more geoelectric information, the working system diagram is shown in Fig. 3. Actually, HDRM is a many kinds of arrangement of conventional resistivity method, and combines with data automatic processing. Using the following formula we can get the resistivity on each measuring point.

$$\rho_s = (\Delta V/I) \times K$$

where the K is array coefficient,

$$K = \frac{2\pi}{\frac{1}{AM} - \frac{1}{AN} - \frac{1}{BM} + \frac{1}{BN}}$$

Advantages of using HDRM are: (1) several layouts of the electrodes could be designed and all arrangement detecting electrodes could be finished at one time without any changing