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3D High-Precision Tunnel Gravity Exploration Method for Concealed High-Density Ore-Bodies: A Case Study on the Zhaotong Maoping Carbonate-Hosted Zn-Pb-(Ag-Ge) Deposit in Northeastern Yunnan, China

Han Run-Sheng, Li Wen-Yao, Wang Feng, Liu Fei, Qiu Wen-Long, Lei Li

Abstract**—**Accurately positioning detection of concealed deposits or ore-bodies is one of the difficult problems in mineral exploration field. Theory calculation and exploration practices for tunnel gravity indicate that 3D high-precision Tunnel Gravity Exploration Method (TGEM) can find concealed high-density three-dimensional ore-bodies in the depth. The ore-finding breakthroughs at the depth of the Zhaotong Maoping carbonate-hosted Zn–Pb–(Ag–Ge) deposit in Northeastern Yunnan have proved that the exploration method in combination with MEAHFZ method is effective to detect concealed high-density ore-bodies. TGEM may overcome anomalous ambiguity of other geophysical methods for 3D positioning of concealed ore-bodies.

Keywords**—**3D tunnel gravity exploration method, concealed high-density ore-bodies, Zn–Pb–(Ag–Ge) deposit, Zaotong Maoping, Northeastern Yunnan.

I. Introduction

THE positioning exploration of concealed deposits (ore-bodies) is the scientific frontiers of modern metallogenic prognostics and main difficult problems in resources exploration field. Geophysical exploration methods are usually applied to detect concealed ore-bodies in the half space domain, such as electric, magnetic and electromagnetic methods, etc. [1]-[3]. However, these geophysical exploration methods are difficult to obtain practical effect due to strong ambiguity and electromagnetic interference in concealed deposit (ore-bodies) exploration. Gravity exploration method is mainly applied to detect in the half-space domain of 1:100000-1:1000000 regional scales on the earth's surface. As exampled in the Zhaotong Maoping large-sized Zn-Pb-(Ag-Ge) deposit in northeastern Yunnan, the study discusses 3D high-precision TGEM to solve the 3D positioning difficulties caused from electromagnetic interference and anomalous ambiguity of the other geophysical methods in order to explore concealed high-density ore-bodies.

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II. Method Principle

High-density ore-bodies refer to one of obviously higher-density ores than of wall-rocks. When the average density of ores is significantly higher than of ore-hosted rocks, the geophysical precondition can satisfy 3D TGEM application. 3D high-precision TGEM is an effective geophysical technique. The method principle is on account of the measurement of tunnel gravity and gravity gradient, corrections of observation data, study on gravity anomalies, and gravity anomaly gradients of X, Y, Z directions. Based on the theory calculation and exploration practices, 3D TGEM method can find concealed high-density ore-bodies.

III. Method Procedures

A. Tunnel Gravity Measurement

Tunnel gravity measurement includes anomalous observation, the horizontal anomaly gradient, and the vertical anomaly gradient. According to observation data, the gravity anomalies (Δg) of measuring points, the horizontal gradient of gravity anomalies (V_{XZ} and V_{YZ}) in X and Y directions and the vertical gradient of gravity anomalies (V_{ZZ}) in Z direction can be obtained, then ore-bearing positive anomalies or negative anomalies are delineated.

B. Corrections of Observation Data

The corrections of observation data contain the kinds of corrections of tide, zero drift, terrain, Bouguer anomaly, tunnel and goaf, etc.

C. Targeting Exploration of Ore-Bodies

For the ground geophysical prospecting, geophysical anomalies indicate field source ore-bodies in the half 3D. However, for tunnel geophysical prospecting, field source ore-body should be distributed in any positions of 360 degrees in anomalous areas. Therefore, it is very difficult to determine the specific positions of ore-bodies (namely front, behind, left, right, up, down or inside of anomalous areas) around the tunnel. The research shows that TGEM may solve the uncertain location problems of ore-bodies based on the spatial variation rules of gravity anomaly (Δg), the vertical gradient (Vzz), and horizontal gradient of gravity anomaly (Vxz or Vyz) for the ore-bodies. It shows that, in any levels of the upper and the bottom of ore-bodies, the curve of zero vertical gradient of gravity anomaly (Vzz) is an ellipse. Within the ellipse Vzz is positive, while outside the ellipse Vzz is negative. In order to facilitate describing the spatial location, in the upper part of ore-body, ore-body is speculated to be distributed in the upper when Vzz is positive, and ore-body is speculated to be located in the outside upper when Vzz is negative. At the bottom of ore-body, ore-body is inferred to locate in the bottom when Vzz is positive, and ore-body may be distributed in the outside bottom while Vzz is negative.

IV. Application Example

A. Deposit Geology

The Zhaotong Maoping Zn–Pb–(Ag–Ge) deposit is one of the typical poly-metallic deposits in northeastern Yunnan. It is located in the junction of the near SN-trending Xiaojiang deep fault, the Qujing-Zhaotong concealed fault and the NW-trending Ziyun-Yadu fault. The ore district structures can be divided into the NE-trending Maoping fault and the Fangmaba fault as well as the NW-trending Luoze River fault. These faults are arranged in imbricated shape on the profile, forming a typical thrust-fold structure which controls Maoping, Fangmaba and Luoze River Zn-Pb deposits (Fig. 1). The NE-trending compressional-shear Maoping fault and the Maomaoshan reversal anticline jointly controlled the Maoping large-sized lead-zinc deposits [4].

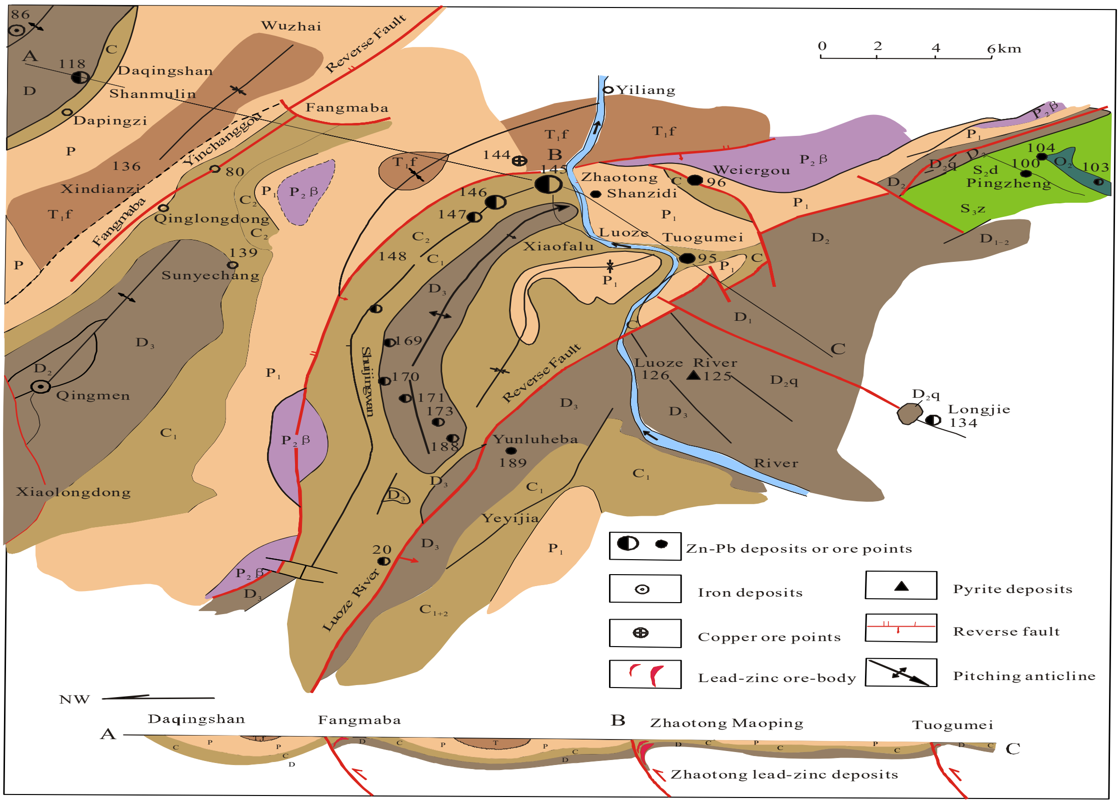

Fig. 1 Simplified geological map of the Zhaotong Maoping Zn–Pb–(Ag–Ge) ore district [9]

The deposit is mainly composed of I, II and III ore-bodies groups, and ore-bodies extend with NE-SW-trending strike and dipping towards NE-trending or SW-trending within 60~90°. Ore-bodies are mainly distributed in the forms of lens, net veins, and reticulum at the plunging end of the reversal anticline and NE-trending steep dipping interlayer faults in NW inverted limb. These ore-bodies have obvious end-to-end alignment and inflation/contraction on the plane and profile. The boundary between ore-bodies and ore-hosted rocks is obvious. The ore-bodies occur in 35~144 m length, 0.6~60.0 m thickness, and deepening is more than 1200 m.

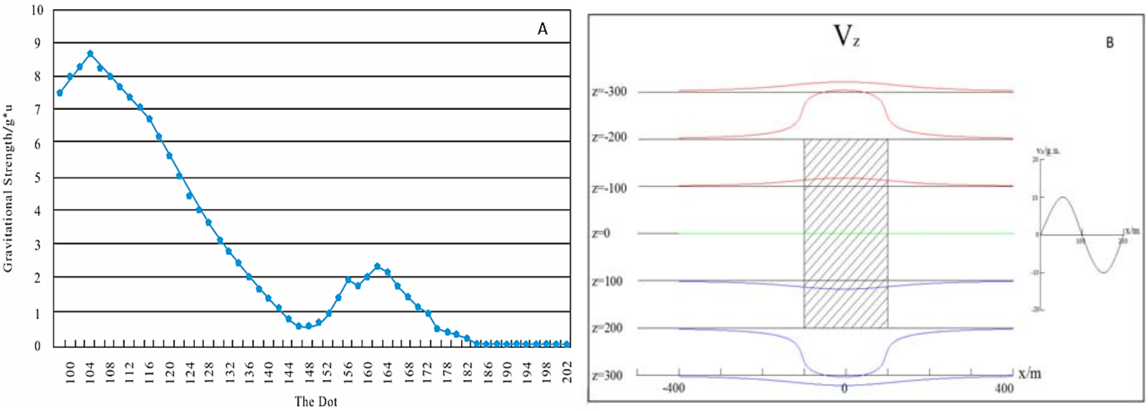

Fig. 2 The tunnel gravity measurement of three dimensional unusual Significance: A. The gravitational strength of the dot. B. The sketch of the tunnel gravity measurement of three dimensional unusual significance

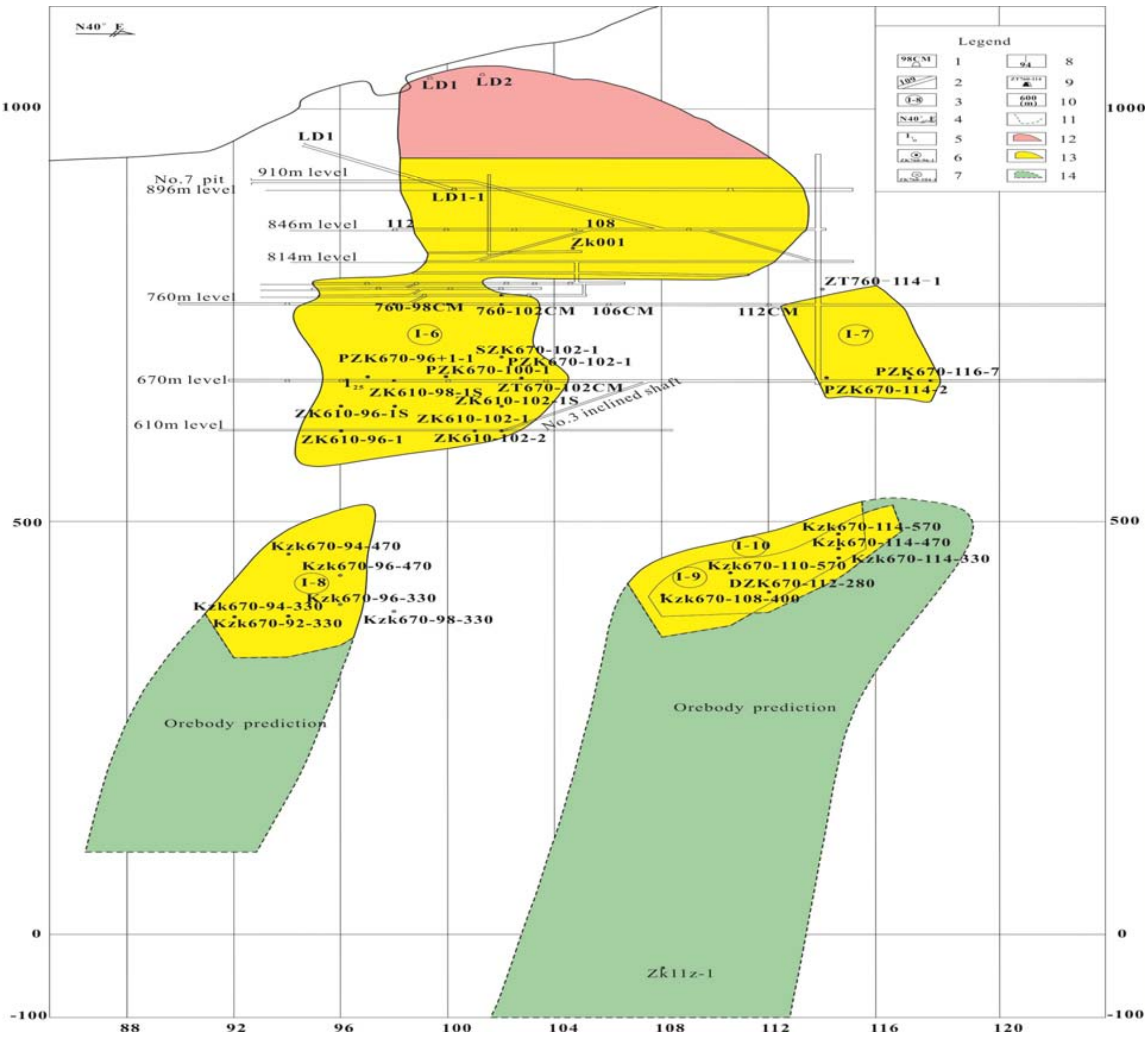

Fig. 3 Projection profile of concealed ore-bodies found newly at No. 1mineralized belt in the Maoping Zn-Pb-(Ag–Ge) deposit
1. Transverse drift; 2. Inclined; 3. Ore-body number; 4. Azimuth; 5. Station; 6. Ore drilling; 7. Not ore drilling; 8. Exploration line; 9. Sampling number; 10. Elevation; 11. Boundary resources (above (333) grade); 12. Oxidized ore-bodies; 13. Sulfide ore-bodies; 14. Predicted ore-body positioning. Especially, it is suitable for accurate positioning for concealed ore-bodies on 1:500 ~ 1:10000 scales

The deposit represents typical geological features which are different from general known typical MVT-type Pb–Zn deposits [5], [6].

1) The deposit is identified as a high Zn & Pb grade (normally ≥25％, locally>50％) deposit.
2) Zn–Pb ores have high contents of germanium, cadmium, indium and argentine. The reserves of Zn, Pb and Ag, Ge and Cd exceed large-scale deposit.
3) The deposit has a close genetic relationship with thrust-fold structures, and the ore-bodies are controlled by the left-hand compressional-shear faults. The trending length of ore-bodies is less than deep extent.
4) Ore-hosted rocks are HTD dolomite or dolomitic limestone.
5) The deposit from the hanging-wall to the foot-wall has the mineral assemblage from pyrite–barite–ferrondomite–marmatite to sphalerite–galena to pyrite–dolomite–calcite.
6) The features of un-mixing LCO_2-bearing-fluid inclusion within six kinds of fluid inclusions indicate that CO_2 fluid shows general ebullition ore-controlling structures. The homogenizational temperatures and salinities of fluid inclusions for sphalerite and calcite are 180–218 °C, 9～11 wt.％NaCleq and 260～350 °C, 4.1～9.5 wt.％NaCleq. The ore-forming hydrothermal solution is considered to be mainly derived from deep fluid source and metamorphic basement indicated by C-H-O-S-Pb isotope geochemistry. The deposit belongs to Carbonate-Hosted Huize--type (HZT) Zn–Pb–(Ag–Ge) Deposit [5], [7].

In the deposit, the average density of ore-hosted rocks (dolomitic limestone or dolomite) (94 pieces) is 2.62 ~ 2.69 g/cm^3. The average density of ores in three ore-bodies groups (46 items) is 3.85~3.99 g/cm^3. Obviously, the density of ores is 1.20 g/cm^3, which is higher than of ore-hosted rocks, then physical precondition to apply TGEM can be satisfied [8].

B. Method Application

Based on ore-forming geological condition and the application of MEAHFZ method [7], five anomalies (Δg-2, Δg-7, Δg-14, Δg-16 and Δg-17) have obtained by accurate measurement for the tunnel gravity at 720 m, 760 m, 814 m, 910 m levels in the ore district. They are in accordance with the known ore-bodies. Seven ore-anomalies in the depth (Δg-2, Δg-3, Δg-6,Δg-7, Δg-10, Δg-13, and Δg-18) have been discovered. For example, positive gravity anomalies have been found in 760 m level and above (Fig. 2). According to the principle of 3D gravity exploration, if the residual density of the ore-body is more than 0, and its occurrence is approximately upright, and gravity anomaly is positive when the observation plane is in the upper of ore-body. Gravity anomaly is 0 when the observation plane is in the ore-body center. Gravity anomaly is negative when the observation plane is under the ore-body center. Verified by the ZK11z-1 drill engineering, a rich and thick ore-body has been discovered in -36 m elevation (Fig. 2). By a series of engineering exploration, I-8, I-9, and I-10 ore-bodies have been successively found and it is shown that the ore-body extends deeper. Zn-Pb metal resources have newly increased more than 3Mt (Fig. 3).

V. Conclusion

1) 3D TGEM is applicable in obviously higher gravity anomalies by density distinction between ores and ore-hosted rocks than the detecting precision of gravity meter. It may effectively explore the concealed ore-bodies in the depth. So, the method is beneficial in popular applications.
2) This method has advantages unaffected by electromagnetic interference, high detection precision and a little affection by the terrain, and overcomes the anomalous ambiguity of the other geophysical methods for concealed ore-bodies

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