Helicopter AFMAG (ZTEM) Survey Results over the Ad Duwayhi intrusion related gold deposit (IRGD) in the Western Arabian Shield, KSA

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SUMMARY

ZTEM helicopter AFMAG electromagnetic and aeromagnetic surveys over the Ad Duwayhi IRGD gold deposit were designed to characterize the deposit signatures. Field data and 2D EM inversion results indicate the Ad Duwayhi intrusive centre features low magnetic susceptibilities and high resistivities that are consistent with the iron-depleted, quartz-sericite-carbonate alteration. Closer inspection of the ZTEM resistivity image suggests that the mineralized breccia zones represent weak resistivity lows within the larger resistive intrusion. The Ad Duwayhi gold porphyry lacks a visible low resistivity alteration halo that distinguishes IRGD's from porphyry copper deposits. The combined aeromagnetic low and ZTEM resistivity high signatures might allow discrimination of other buried IRGD gold deposits regionally.

Key words: Electromagnetic, ZTEM, AFMAG, aeromagnetic, gold, intrusive, IRGD.

INTRODUCTION

The Ad Duwayhi intrusive-related gold deposit (IRGD; Robert et al., 2007) is one of the newest discoveries by Ma'aden, the Saudi Arabian Mining Company (Doebrich et al., 2004). Mineral exploration in the last 40 years has included airborne geophysics, primarily regional magnetics and radiometrics (Figure 1). With the aim of accelerating exploration, Ma'aden has more recently been undertaking airborne geophysical surveys, including fixed-wing and helicopter electromagnetics. From December, 2011 to January 2012, as part of a larger survey campaign in the western Arabian Shield, helicopter electromagnetic survey tests were performed using the ZTEM (z-axis tipper electromagnetic; Lo and Zang, 2008) system, over the 31Mt Ad Duwayhi IRGD deposit, in order to determine its airborne geophysical signatures.

General Geology

Ad Duwayhi (Doebrich et al., 2004) is a Precambrian, shear-zone/vein-hosted IRGD deposit that is located approximately 450 km SW of Riyadh and 450 km E/NE of Jeddah, KSA (Figure 1). The deposit occurs within a late- to post-orogenic, Neoproterozoic age, northwest oriented granite body and a co-magmatic, square quartz-porphyry that is possibly a younger phase of the granite (Figure 2b). Older volcano-sedimentary sequences form topographic highs to the north, but the surrounding geology is covered by thick sand deposits. The Ad Duwayhi gold mineralization occurs as quartz veins, quartz vein breccia, stockworks and sheeted quartz veins, as well as banded tabular quartz veins (Figure 2c), with attendant quartz-sericite-carbonate alteration. It is characterized by low sulphide and base-metal content that typifies gold porphyries (Blevin, 2004). The Ad Duwayhi deposit is open at depth and to the southwest and features a total resource (measured + indicated + inferred) of 30.6 Mt at 2.43g/t Au (Ma'aden, 2011).

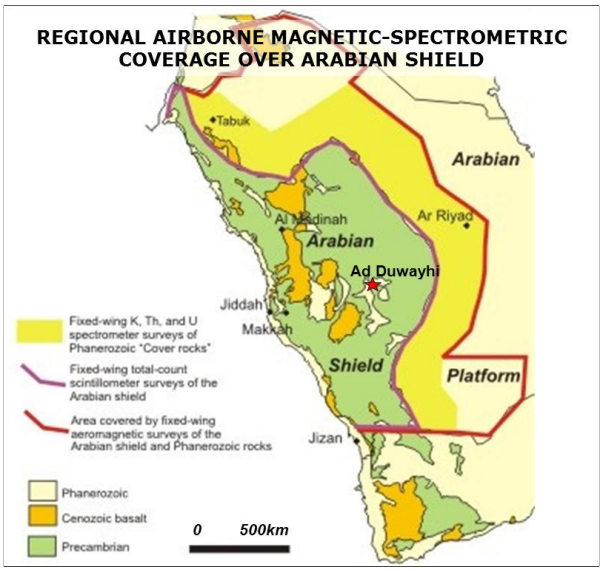

Figure 1. Regional airborne survey coverage of KSA in 2008, showing Precambrian Arabian Shield and Ad Duwayhi deposit location (after Saudi Geological Survey www.sga.com.ca).

SURVEY RESULTS & DISCUSSION

The ZTEM survey coverage at Ad Duwayhi consisted of in-line (Tzx) and cross-line (Tzy) tipper AFMAG (Ward, 1959; Labson et al.1985), at 80m avg. height, and aeromagnetic data, at avg. clearance of 97 m. A total 114 km of ZTEM were flown along 11 lines over a 20 km^2 area, averaging 10.4 km in length, and at a 200 m nominal line-spacing (Figure 2a). No tie lines were flown in the test survey.

Figure 3 presents the magnetic results obtained from the ZTEM survey, with the pole-reduced total magnetic intensity

(RTP) indicating generally weak magnetic susceptibilities in the vicinity of the Ad Duwayhi deposit that extend southward and might either reflect the mafic-poor granitoid intrusive host rocks or else due to magnetite depletion from the alteration. Conversely, the higher magnetic susceptibilities further north and northwest of Ad Duwayhi might either reflect the more mafic volcanic rich cover rocks, or else possibly contact-metamorphic effects or an alteration aureole in the surrounding bedrock. Large magnetic lows similar to the Ad Duwayhi response are also defined further to the east and west. The vertical gradient (Figure 3b) does not appear to highlight northeast trends that might reflect fault-controls for the Main Vein Zone; instead, the CVG appears to define a dominant north-south alignment to magnetic lineaments across the property, which agrees with regional trends, except across the immediate Ad Duwayhi area where the response is relatively flat.

Figure 4 presents the Total Phase Rotated (TPR) ZTEM tipper AFMAG results at the highest (360Hz) and lowest (30Hz) frequencies that correspond to progressively larger skin depths of investigation (DOI). The TPR images convert the tipper cross-over responses into peaks using phase-rotation (Lo and Zang, 2008; Legault et al., 2012). All indicate generally higher resistivities in the vicinity of the Ad Duwayhi deposit, which stands out as an anomaly, regionally; and might either reflect the lower porosities associated with the quartz-sericite-carbonate alteration or else the felsic mineralogy of the granitic host. The weakening response at lower frequencies might reflect limited depth extent to the deposit or to the granitoid intrusive or else reflects weaker resistivity contrasts at depth. However, Ad Duwayhi lacks any well-defined, low resistivity halo due to the surrounding pyrite-phyllic alteration that accompanies more typical ZTEM copper porphyry signatures (Paré and Legault, 2010). Yet there appears to be a weak NE-elongated trend to the Ad Duwayhi resistive TPR feature, particularly at highest frequencies; and, as with the magnetics, the Ad Duwayhi TPR anomaly is open to the south. A second resistivity high anomaly, approximately 1.5km west of Ad Duwayhi, that is narrower and more north-south trending, also correlates with a known gold occurrence and drilling.

ZTEM 2D Inversions

The ZTEM survey results have been interpreted using the Av2dtopo inversion code (Legault et al., 2012) that is based on 2D MT inversion code and was designed for the ZTEM airborne AFMAG system, as well as accounting for 2D topography and the air layer below the receiver. Figure 5 presents the resistivity-depth slices obtained from the ZTEM 2d inversion for a detailed 5.5 x 2km area directly over the deposit. The ZTEM inversions all used a 300 ohm-m half-space apriori model that was chosen based on airborne EM comparisons elsewhere in the region and other model testing

The ZTEM inversion depth-slices in Figure 5 show fairly consistent resistivities from shallowest to greater depths, below a thin layer of lower resistivities at surface. The ZTEM depth of investigation (DOI) estimates exceed 1.5km, based on the integrated conductance method of Spies (1989). In all the depth-slices, the Ad Duwayhi deposit is centred on a well-defined north-south to NE-trending resistivity high, which agrees with the previous TPR results and is consistent with both the felsic intrusive geology or else reduced porosities from the attendant porphyry alteration. However, within this larger resistivity high, the Main Vein Zone might also be interpreted to coincide with a weak NE-trending linear resistivity low, particularly visible at shallow depths (see Figures 5abc). This low may reflect the higher porosities within the thrust fault that hosts the Main Zone. West of Ad Duwayhi, the north-south resistivity high that coincides with the known gold occurrence becomes more visible below 200m, which likely reflects the thicker Quaternary cover, locally. Below 750m-1km, neither Ad Duwayhi nor the north-south resistive feature, further west, are easily distinguished in 2d inversions.

Figure 6 presents the ZTEM 2D inversion results, in section for L2440 (see Figure 5) and in 3D voxel-view, across Ad Duwayhi. As shown, both the Ad Duwayhi deposit and the known Au occurrence further west are both well centred on separate resistivity high features that appear to extend at least below 500m-750m depths. However, both the Main Vein Zone and the South Vein also appear to correspond, individually, to more localized weak, narrow, near-surface limited resistivity lows, which is consistent with their fractured and brecciated structural control. Also shown is the fact that Ad Duwayhi lies within a region of low magnetism, possibly reflecting iron-depletion alteration, whereas the known Au occurrence, further west, lies in a relative magnetic high, which differentiates each of these systems. Otherwise, Ad Duwayhi appears to be the only ZTEM resistivity high feature that is centred on a magnetic low in the survey area, which might therefore be a characteristic deposit signature. The 3D voxel in Figure 6b clearly highlights the resistivity highs associated with the known intrusive-hosted gold-mineralization, as well as the north-south resistivity lows that flank Ad Duwayhi porphyry, which might represent major structures or else more porous lithologies.

CONCLUSIONS

ZTEM and aeromagnetics have been able to characterize the regional geology and localized signatures associated with the Ad Duwayhi intrusive-related gold deposit. ZTEM defines the larger, low porosity felsic-rich/quartz-altered intrusive host as a resistivity high, whereas the more fractured/ porous vein systems that host the mineralization are defined as more localized, weak, linear resistivity lows. The ZTEM resistivity high signature over the Ad Duwayhi IRGD appears to lack a well-defined, surrounding resistivity low that normally characterizes the copper-porphyry response, due to the attendant pyritic-phyllic-propyllitic alteration halos. This distinguishes the two deposit type responses. In addition, the ZTEM has identified a flanking resistivity and magnetic high feature, lying 1.5km further west, that might represent a target of interest. The combined aeromagnetic and ZTEM signatures (high resistivity and low magnetic susceptibility) at Ad Duwayhi might be discriminating characteristics for similar IRGD gold deposits regionally.

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REFERENCES

Doebrich, J.L., Zahony, S.G., Leavitt, J.D., Portacio, J.S., Jr., Siddiqui, A.A., Wooden, J.L., Fleck, R.J., and Stein, H.J., 2004, Ad Duwayhi, Saudi Arabia: Geology and geochronology of a Neoproterozoic intrusion-related gold system in the Arabian Shield, Economic Geology, **99**, 713-741.

Blevin P.L., 2005, Intrusion Related Gold Deposits, Geoscience Australia, http://www.ga.gov.au /image_cache/ GA7241.pdf, 15 p.

Labson, V. F., Becker, A., Morrison, H.F., and Conti, U., 1985, Geophysical exploration with audio-frequency natural magnetic fields, Geophysics, **50**, 656–664.

Legault, J.M., Wilson, G., Gribenko, A., Zhdanov, M.S., Zhao, S., and Fisk, K., 2012, An overview of the ZTEM and AirMt systems – A case study from the Nebo-Babel Ni-Cu-PGE deposit, West Musgrave, Western Australia, In R.J.L. Lane (editor), Natural Fields EM Forum 2012: Abstracts from the ASEG Natural Fields EM Forum 2012: Published by Geoscience Australia, Geoscience Australia Record 2012/04, 101-121.

Lo, B., and Zang, M., 2008, Numerical modeling of Z-TEM (airborne AFMAG) responses to guide exploration strategies, SEG, Expanded Abstracts, **27**, 1098-1101.

Ma'aden, 2011, Ma'aden Saudi Arabian Mining Company, Annual Report, 123 p.

Paré, P., and Legault, J.M. , 2010, Ground IP-resistivity and airborne SPECTREM and helicopter ZTEM survey results over Pebble copper-moly-gold porphyry deposit, Alaska, SEG, Expanded Abstracts, **29**, 1734-1738.

Robert, F., Brommecker, R., Bourne, B. T., Dobak, P. J., McEwan, C. .J., Rowe, R. R., Zhou, X., 2007, Models and exploration methods for major gold deposit types: In B. Milkereit (editor), Proceedings of Exploration 07: Fifth Decennial International Conference on Mineral Exploration, 691-711.

Spies, B., 1989, Depth of investigation in electromagnetic sounding methods, Geophysics, **54**, 872-888.

Ward, S. H., 1959, AFMAG - Airborne and Ground: Geophysics, **24**, 761-787.

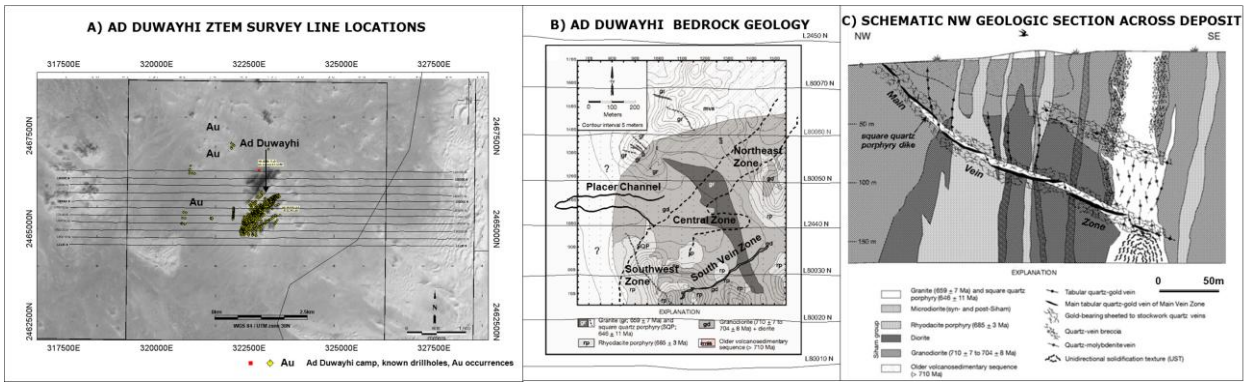

Figure 2. Ad Duwayhi geology: a) Google image with ZTEM lines locations, deposit drillholes & other gold occurrences (courtesy Ma'aden Gold); b) Bedrock geology and deposit outlines, with ZTEM lines (modified after Doebrich et al., 2004), and c) Schematic NW-SE geologic section through the Main and South Vein zones (after Doebrich et al., 2004).

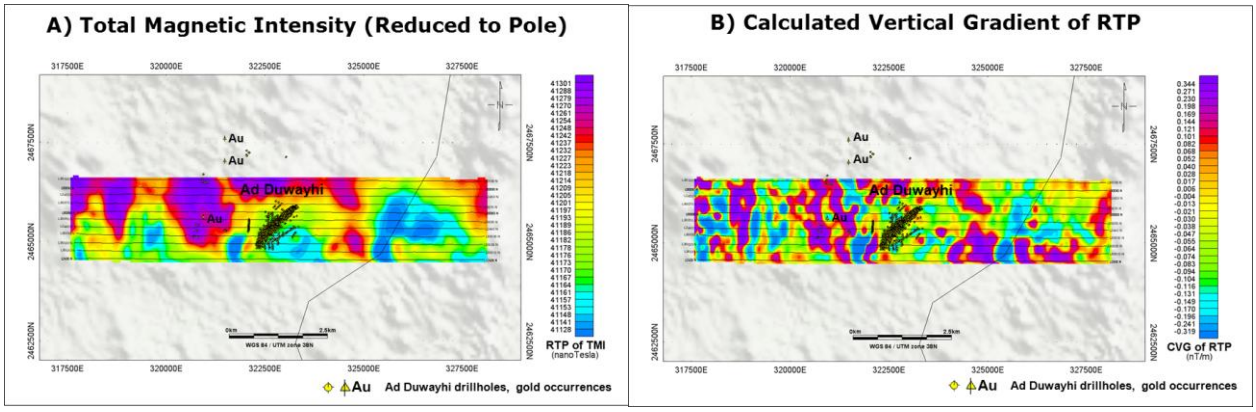

Figure 3. a) Total magnetic intensity (TMI) after reduction to pole (RTP), and b) Calculated Vertical Gradient (CVG) of magnetic RTP, with Ad Duwayhi drillholes and other gold occurrences.

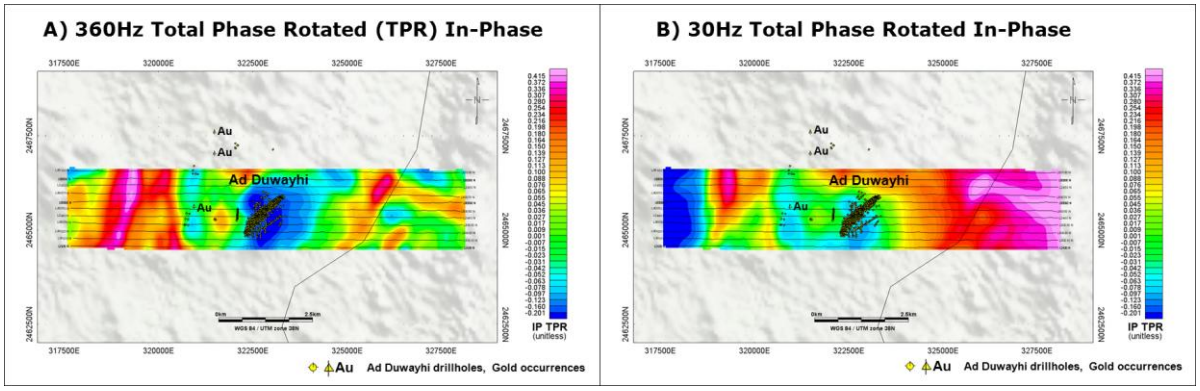

Figure 4. a) ZTEM Total Phase Rotation (TPR) for In-phase (IP) tipper at 360Hz (shallowest depth of investigation (DOI)), and b) 30Hz IP TPR (greatest DOI), with Ad Duwayhi drillholes and other gold occurrences.

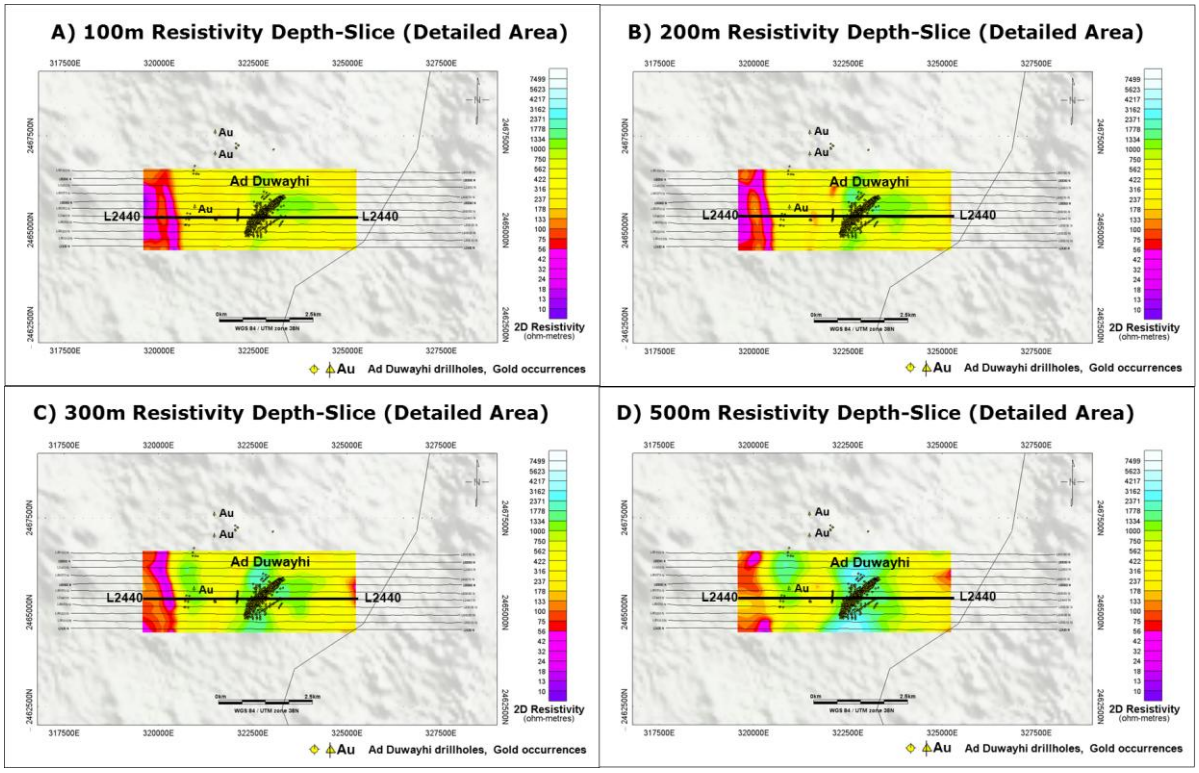

Figure 5. a) ZTEM resistivity depth-slice at 100m from 2D inversion, b) at 200m, c) at 300m, and d) at 500m, with Ad Duwayhi drillholes, other gold occurrences and also L2440 that is highlighted in Figure. 6a.

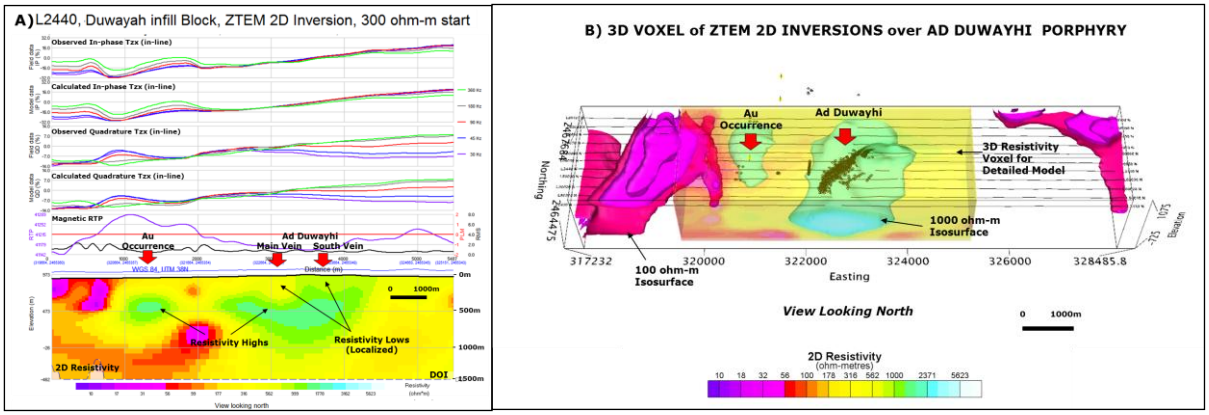

Figure 6. ZTEM Inversion Modeling at Ad Duwayhi: a) L2440 cross-section showing ZTEM Tzx (in-line) observed vs. calculated profiles and 2D resistivity section, and b) 3D voxel view of ZTEM 2D resistivity, with drillholes and flight lines.