The Balboa ZTEM Cu-Mo-Au porphyry discovery at Cobre Panama

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SUMMARY

This paper describes the ZTEM airborne EM and magnetic results over the porphyry copper-gold camp at Cobre Panama, with a focus on the discovery of the blind Balboa deposit in 2010, the first documented case attributed to the ZTEM system. Balboa is the westernmost of six porphyry copper-gold deposits that make up Cobre Panama and it escaped detection in 40 years of exploration that relied primarily on soil geochemistry, airborne magnetics and drilling. ZTEM was flown in summer 2010 to detect resistivity variations related to hidden porphyry systems in a region of dense jungle, difficult access and thick (20-30 m) conductive saprolite cover. The ZTEM survey detected all the known porphyry systems, including Balboa, based on anomalous conductive response. Our study presents the geophysical survey results at Cobre Panama and is supported by 2D-3D ZTEM and magnetic inversions that appear to validate the survey evidence. 2D synthetic modeling appears to confirm the detectability of the weakly conductive Balboa orebody below 30 m of saprolite cover.

Key words: ZTEM, airborne, electromagnetic, magnetic, inversion, porphyry, case-study.

INTRODUCTION

ZTEM (z-axis tipper electromagnetic; Lo and Zang, 2008; Legault et al., 2012) natural field helicopter EM has been widely used in porphyry copper exploration for nearly a decade in mapping resistivity contrasts that characterize porphyry copper deposit alteration systems (Ford et al., 2007; Hoschke, 2011). Indeed many ZTEM case-study examples over porphyry deposits have been published, including Lo and Zang (2008) in the Safford district of Arizona; Holtham and Oldenburg, (2010) at Bingham Canyon, Utah; Sattel et al. (2010) at Mt Milligan, BC, Izarra et al. (2011) at Copaquire, Chile, Witherly and Sattel (2012) at Babine Lake-Morrison, BC, Paré et al. (2012) at Pebble, Alaska, and, most recently, Hübert et al. (2016) at Newton, BC. However, in spite of its extensive use in porphyry exploration (Legault, 2012), there are few recorded ZTEM porphyry case-studies involving a blind discovery - exceptionally, the ZTEM discovery of the Balboa Cu-Mo-Au porphyry at Cobre Panama, in Panama is presented here.

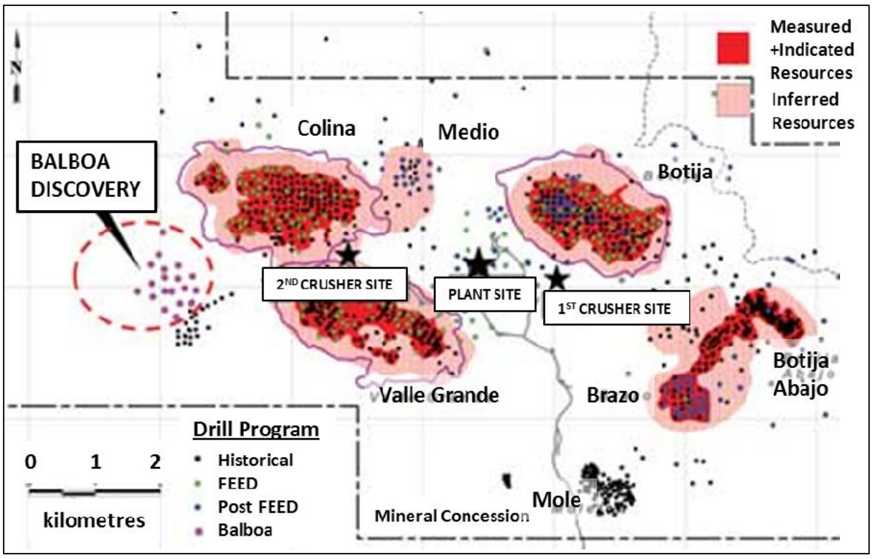

Figure 1: Porphyry copper-gold deposit outlines in mine plan at Cobre Panama, including Balboa discovery, showing drillhole locations (dots) and distribution of measured + indicated and inferred resources (after Fiscor, 2014).

The Balboa deposit is named after the explorer Vasco Nunez de Balboa who travelled across the Panama isthmus to discover the Pacific Ocean in 1513 (Burge, 2014). Balboa was discovered in 2010 at the Cobre Panama Cu-Mo-Au porphyry project, situated 20 km from the Caribbean coast and120 km west of Panama City. Balboa is the westernmost of a cluster of six tabular shallowly-dipping, calc-alkaline porphyry copper deposits at Cobre Panama (Figure 1) that are related to porphyritic intrusions on the southern margin of a granodiorite batholith. Modern exploration at Cobre Panama began in 1966, led primarily by soil geochemistry and drilling. Cobre Panama consists of a measured and indicated mineral resource of of 3,695 Mt at 0.37% Cu, 0.006% Mo, 1.3 g/t Ag and 0.07 g/t Au (Gray et al., 2015). By 2011, Balboa's indicated and inferred copper and gold resource had increased Cobre Panama's total by 19% and 29%, respectively (Engineering & Mining Journal News, 17-April-2012; www.e-mj.com), making it a significant exploration find. Balboa is located just 1 to 2 km from known deposits and measures more than 1,500 by 1,000 m in surface area, yet it escaped detection despite 40 years of exploration, in part due to leaching of copper during the surficial development of 20-30m of clay-rich saprolite in the project area. A property wide ZTEM survey in late 2010 was carried out and follow-up drilling of a ZTEM anomaly led to the blind discovery, lying just 60m below the surface, within 3 months of the ZTEM survey completion. Burge (2014) first presented the Balboa ZTEM discovery and it was subsequently described in Fiscor (2014).

Geology and Alteration

The Cobre Panama cluster of six copper-molybdenum-gold deposits is distributed over an area of ~10 x 5 km on the southern margin of the Petaquilla batholith (Figure 2). This granodioritic batholith yields U-Pb zircon ages from about 32 to 28 Ma (Hollings and Baker, 2013), with the younger end of the spread playing host to the copper mineralisation. Porphyry intrusions form a continuum from the batholithic composition to a feldspar-quartz-hornblende phase that contains slightly higher grade copper mineralisation. Contemporaneous, fine-grained, weakly magnetic andesite flow units cover much of the area and variably host mineralisation, and barren, post-mineral andesite dikes cut the mineralised porphyries. Since exhumation of the system, a tropical saprolite profile up to 30 m thick has developed. This profile is incised in the drainage valleys, which provide the only rare glimpses of outcrop. The transition from saprolite to fresh rock occurs quite rapidly over a few metres of saprock.

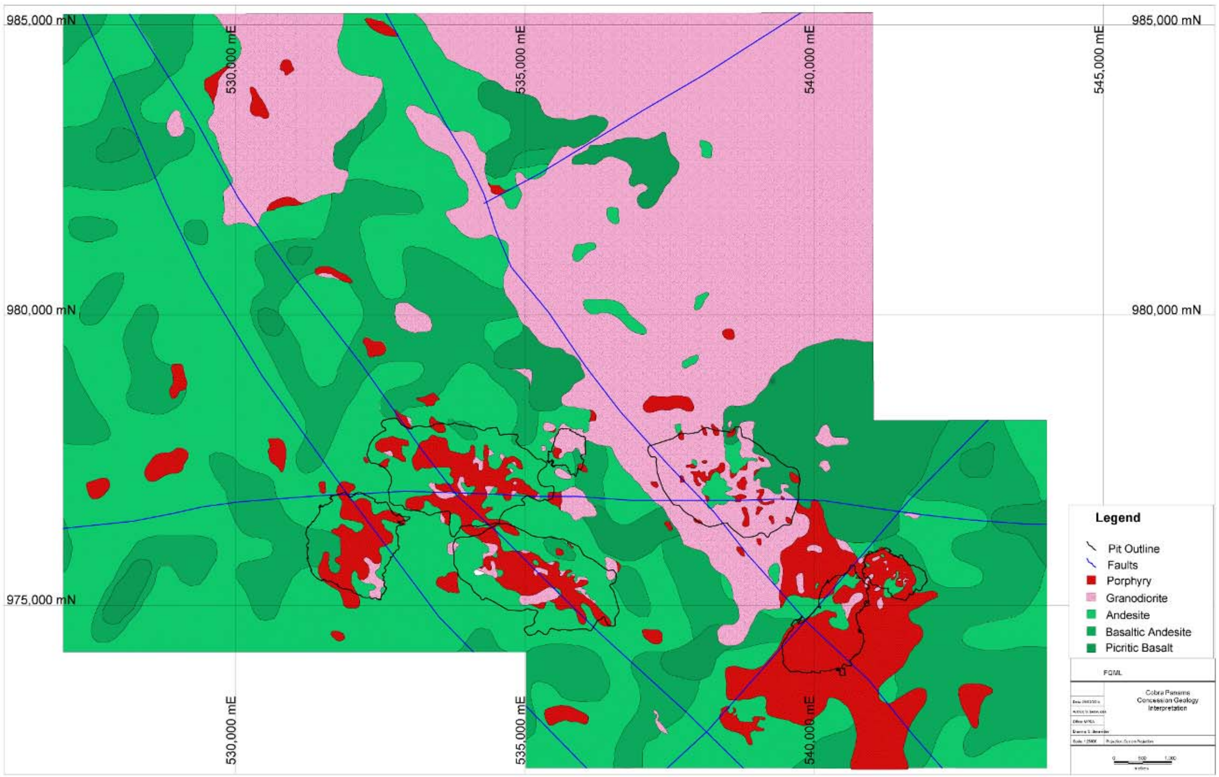

Figure 2: Mine lease geology at Cobre Panama from recent compilations and new mapping by First Quantum Minerals. The ultimate pit outlines include Balboa on the western end.

Alteration is mostly chlorite and chlorite-sericite. This overprints potassic alteration, but there are only rare patches of biotite and potassium feldspar alteration preserved. Quartz sulphide ± magnetite A and B veinlets provide widespread evidence of former potassic alteration. Disseminated chalcopyrite, pyrite and magnetite are abundant and often replace mafic phenocrysts with chlorite. Early mineral assemblages are overprinted by phyllic alteration that includes white and green sericite and ubiquitous pyrite with variable silicification or quartz veining. Magnetic lows may be associated with the mineralized zones where original magnetite is destroyed by the alteration. Acid weathering of the pyrite contributes to clay alteration and increases near-surface conductivity.

METHOD AND RESULTS

ZTEM System and Theory

Helicopter-borne geophysical surveys were carried out over the Cobre Panama Project from August 26th to September 8th, 2010, on behalf of Minera Panama SA and Inmet Mining Ltd., now owned by First Quantum Minerals since 2013. Principal geophysical sensors included a Z-Axis Tipper electromagnetic (ZTEM) system, and a caesium magnetometer (Figure 3). A total of 831 line-kilometres were flown along 300m spaced, north-south oriented flight lines, with nominal EM bird terrain clearance of 85 metres and a magnetic sensor clearance of 102 metres. The 246 km^2 survey block features moderate relief, with elevations ranging from 42 to 415 metres above sea level (Figure 3a). Flown early in the Cobre Panama mine development, the survey area had minimal culture, such as roads, trails and few buildings.

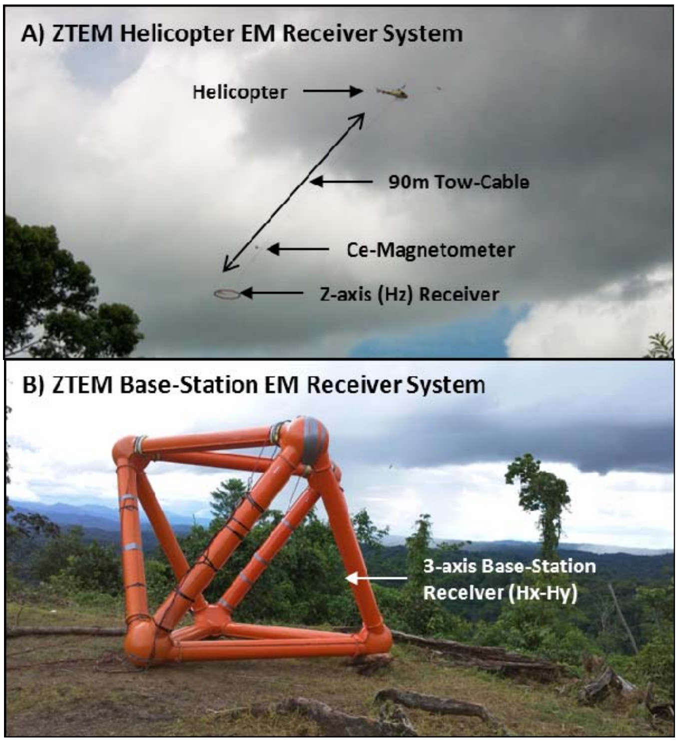

Figure 3: ZTEM EM system during survey at Cobre Panama project, showing: a) Mobile Z-axis receiver measuring H_Z, and b) Fixed base-station receiver, measuring H_X and H_Y (after Burge, 2014).

The ZTEM airborne AFMAG (Ward, 1959) electromagnetic system measures the anomalous vertical secondary magnetic fields that are created by the interaction between naturally occurring, plane wave audio frequency EM fields, caused by distant electrical sferic activity, and electrical heterogeneities in the earth.

In ZTEM surveys, a single vertical-dipole air-core receiver coil measuring H_Z (Figure 3a) is flown over the survey area in a grid pattern, similar to regional airborne EM surveys. Orthogonal, air-core horizontal axis coils (Figure 3b) are placed close to the survey site to measure the horizontal EM reference fields (H_X and H_Z). Data from the three coils are used to obtain the Tzx and Tzy Tipper (Labson et al., 1985) components at six frequencies in the 30 to 720 Hz band, according to the following equation by Holtham and Oldenburg (2008):

$$H_Z(r) = Tzx(r,r_0)\, H_X(r_0) + Tzy(r,r_0)\, H_Y(r_0) \qquad (1)$$

Where $H_Z(r)$ is the magnetic field measured at the mobile receiver (r) and $H_X(r_0)$ and $H_Y(r_0)$ are the magnetic fields at a fixed base station reference site (r_0).

The EM primary fields used in AFMAG have the unique characteristic of being uniform, planar and horizontal, and also propagate vertically into the earth, to great depth, up to several km, as determined by the magnetotelluric (MT) skin depth (δ_S) according to the following by Vozoff (1972):

$$\delta_S = 503 * \sqrt{(\rho / f)} \text{ metres} \qquad (2)$$

Where ρ is the bedrock resistivity (ohm-metres), f is the frequency of measurement (hertz).

ZTEM and Magnetic Survey Results

Figure 4 presents the ZTEM survey flight lines over the DEM (digital elevation model) and the aeromagnetic signature of the Cobre Panama region, as well as known porphyry deposit outlines and drill hole locations prior to the discovery of Balboa in 2010. The figure shows a correlation between relatively higher elevations and magnetic high anomalies over deposit area. The magnetic RTP (reduced-to-pole) image in Figure 4b shows a recognizable pattern of magnetic highs from volcanic andesites due to primary magnetite (Burge, 2014). However, all the known porphyry deposits are noticeably centred on magnetic lows, possibly representing demagnetized areas due to phyllic alteration (Burge, 2014). Exceptionally, Balboa coincides with a positive magnetic anomaly, which, along with the lack of geochemical anomaly due to thick leach-cap (G. Wells, pers. comm., 01-2016), masked it in previous exploration phases (Fiscor, 2014).

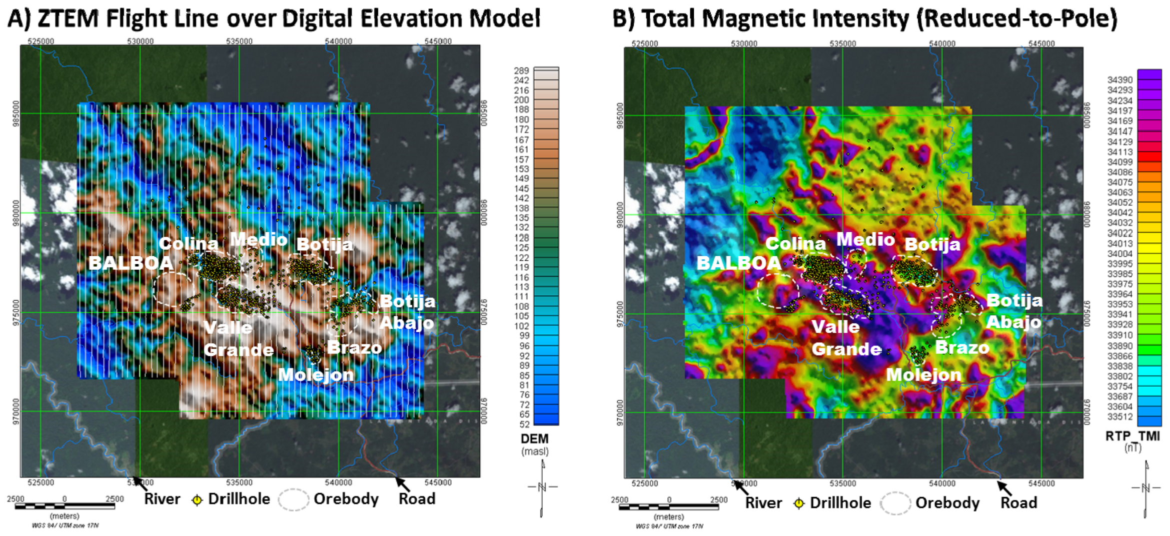

Figure 4: ZTEM survey results over Cobre Panama deposit area: a) Digital Elevation Model (DEM), and b) Total magnetic intensity (reduced to pole), showing porphyry deposit locations and drill-hole coverage prior to Balboa discovery (after Burge, 2014).

Figure 5 presents the ZTEM tipper data, displayed as the Total Phase Rotation (TPR; Izarra et al., 2011; Legault et al., 2012), at both high and low frequencies, giving a sense of relative depth of investigation, according to Equation 2. In spite of possible topographic artefacts (Sattel and Witherly, 2012), the differences in the two TPR signatures are noticeable and, as noted by Burge (2014), the higher frequency (shallow depth) ZTEM results (Figure 5a) appear to map elevated conductivity closely associated with all the known porphyry orebodies; whereas the anomalies that persist at low frequencies (Figure 5b) also coincide with known deep sulphides zones at Botija and Brazo-Botija Abajo, as well as the untested anomaly Balboa northwest of Cuatra Crestas prospect (Burge, 2014). The low frequency ZTEM image in Figure 5b also displays a large/long wavelength negative tipper response in the Cobre Panama deposit region that suggests anomalously higher resistivities at depth.

ZTEM and Magnetic Inversion Results

The ZTEM data have been converted to equivalent resistivity-depth distributions using from 2D and 3D ZTEM inversions using the Geotech Av2dtopo code (Legault et al., 2012) and UBC MT3dinv code (Holtham and Oldenburg, 2008), respectively. Both inversions accounted for topography and used a 500 ohm-m half-space apriori start model. Figure 6a presents the 2D resistivity depth slice at 0m and Figure 6b presents the 3D inversion result at -500m depth as an overlay on the 2D depth slice, for comparison. The images in Figure 6ab resemble quite closely the high and low frequency TPR images shown in Figure 5ab; in particular the shallow conductivity anomalies observed over all the known porphyries, as well as higher conductivities associated with the higher grade deposits, including Balboa, that are highlighted in the deeper inversion images and were predicted by the known geology. Below 500-1000m, the ZTEM 2D and 3D inversion results also indicate increasing resistivities extending to depth, as shown in Figure 6b.

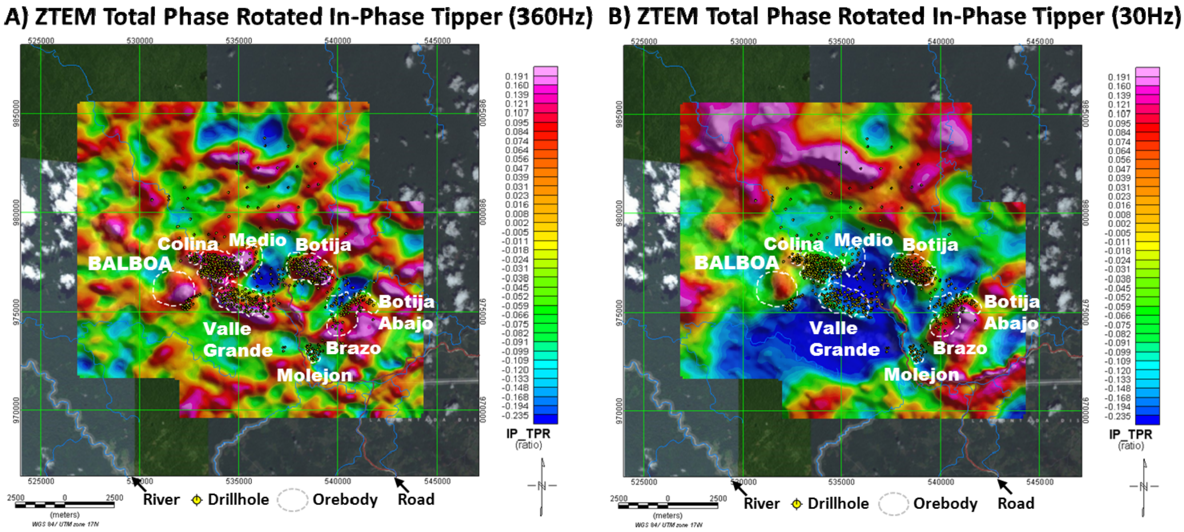

Figure 5: ZTEM survey results over Cobre Panama deposit area: a) Total phase rotated (TPR) In-phase tipper at 360Hz, and b) In-phase TPR at 30Hz, highlighting EM anomalies that extend to lower frequencies over the Botija, Brazo and Botija Abajo porphyry deposits, as well as the Balboa discovery.

Figure 7a presents the Balboa deposit cross-section (after Burge, 2014), showing the 0.4% copper ore shell and the sulphide shells that define the porphyry deposit, which dips northward, and the surrounding porphyry system alteration halos. Figure 7b shows the corresponding ZTEM resistivity cross-section, obtained by 3D inversion, directly over Balboa. As shown, the ZTEM conductive anomaly correlates directly with the higher grade zone, both spatially and at depth, based on the 3D inversion results. The Balboa anomaly also appears to extend further northward, subcropping below the western edge of the Colina deposit, suggesting that the two porphyry systems are potentially joined at depth. Figure 7c presents the corresponding 3D magnetic susceptibility section for L1170, using the Geosoft MVI 3D inversion code (Ellis et al., 2012), which accounts for magnetic remanence. The section shows that Balboa occurs in a relative magnetic susceptibility low, reflecting magnetite depletion due to hydrothermal alteration.

Although it seems likely to relate to hydrothermal alteration, the source of conductivity for Balboa and the other porphyry orebodies has not been determined with certainty, since the sulphide ore is disseminated and non-supergene enriched. Subsequent to the Balboa discovery, a helicopter time-domain EM (HTEM) survey was flown to determine the overburden characteristics for mine-development purposes. The HTEM survey resolved the 10-30m conductive saprolite layer but did not appear to detect the conductive anomalies related to the deeper porphyry bodies. Since ZTEM is relatively insensitive to horizontal layering (Sattel and Witherly, 2012), the 2D-3D inversions do not appear to define the conductive blanket either (see Figure 7b). A synthetic 2D model (Figure 8a) that replicates the Balboa deposit, from the 3D inversion result in Figure 7b, was tested using a 30m thick, 30 ohm-m surficial layer, based on the HTEM evidence. As shown in Figure 8b, in spite of the presence of the conductive blanket, a dipping conductive anomaly, extending to 750m depth and very similar to the Balboa response, is defined in the 2D ZTEM inversion result, which would appear to confirm its detectability using passive airborne electromagnetics.

CONCLUSIONS

The Balboa discovery is a geophysical success story, where a significant porphyry copper deposit was discovered beneath cover at Cobre Panama after many exploration and drilling campaigns, as a result of conventional soil sampling failing to clearly identify

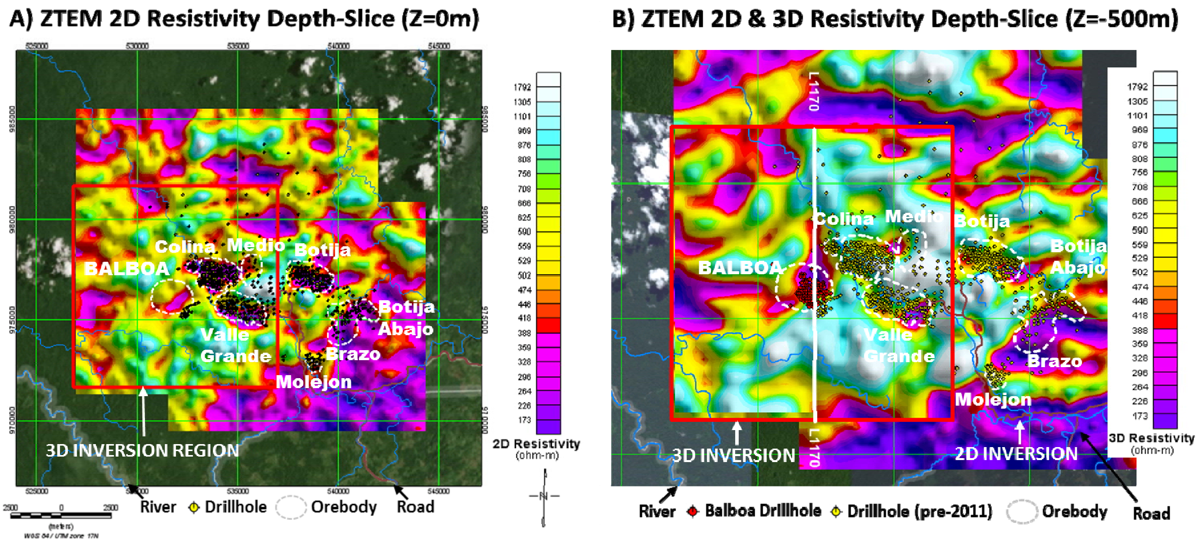

Figure 6: ZTEM 2D-3D inversion results over Cobre Panama deposit area: a) 2D resistivity depth slice at 0m depth, showing 3D inversion region (red polygon) and b) Close-up of 2D & 3D resistivity (red polygon) at -500m depth, showing Balboa (red symbols) and pre-2011 (yellow) drillholes, and location of L1170 profile presented in Figure 7bc.

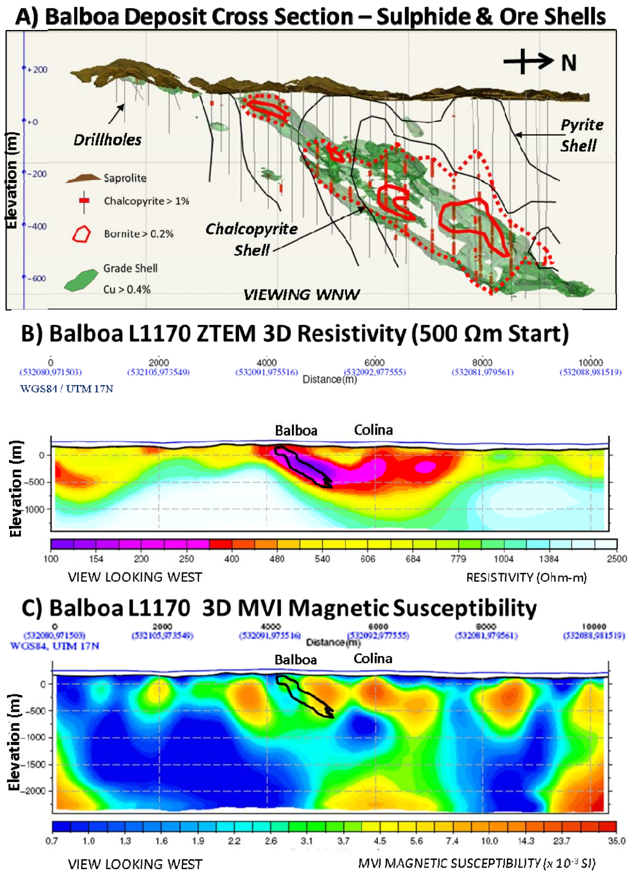

Figure 7: a) Balboa deposit cross-section, showing >0.4% Cu grade shell (green) and drill-holes (after Burge, 2014); b) 3D ZTEM inversion for L1070 over Balboa, and c) 3D MVI magnetic susceptibility inversion for L1070, both showing outline of ore grade shells (after Burge, 2014).

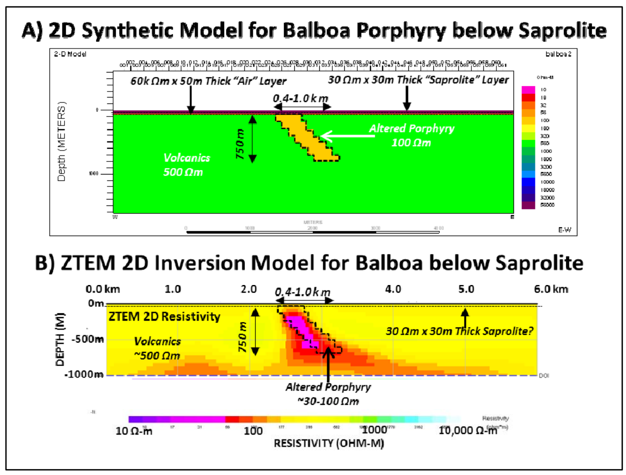

Figure 8: ZTEM 2D synthetic modeling: a) 2D resistivity model for a porphyry body, resembling Balboa, buried below 30m of conductive saprolite (30 Ω-m), and b) 2D inversion of synthetic ZTEM data from model in Figure 8a.

Balboa and aeromagnetics providing an unexpected signature. The ZTEM appears to map all the porphyry deposits in the tropical environment at Cobre Panama, including Balboa, making it the first documented case of a porphyry copper discovery using ZTEM airborne EM. Our 2D-3D inversion analyses appear to confirm the bedrock source of conductivity that extend from surface to >500-750m depths. The exact source of conductivity is undetermined, with mainly disseminated mineralization and a lack of visible supergene enrichment, although it is assumed to be related to clay-phyllic alteration. Subsequent HTEM surveys also do not appear to detect any of the porphyry bodies below the conductive saprolitic weathering blanket. However, 2D synthetic modeling of the Balboa deposit that incorporates the saprolite appears to confirm its detectability using passive ZTEM airborne EM.

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