3D VTEM inversion for delineating sub-vertical shear zones in the West African gold belt

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SUMMARY

Accurately delineating sub-vertical graphitic thrust faults and shear systems is one of the major strategies followed in West African gold exploration. Due to the dense vegetation and limited outcrops, airborne electromagnetic (AEM) surveys have been routinely flown for geological mapping. We present a case study for practical 3D inversion of VTEM data acquired in Ghana. The geology is very complex, and consists of carbonaceous shear zones containing multiple thrust faults. Certain types of gold mineralization are directly associated with the shear zones which manifest themselves as sub-vertical conductors. We compare results from 3D AEM inversion to those obtained from traditional AEM interpretation methods, including conductivity depth imaging, decay constant analysis, profile anomaly picking, Fraser filtering, and plate modelling. We show that even with no a priori information, 3D AEM inversion accurately delineates the sub-vertical conductors, and recovers the most accurate representation of the geology. Interpretations based on CDIs are shown to be unreliable.

Key words: 3D, inversion, AEM, VTEM, Ghana.

INTRODUCTION

The early Proterozoic Birimian greenstone belts of West Africa consist of steeply dipping metasedimentary and metavolcanic units. These can be traced for hundreds of kilometres along strike, trend north to northeast, are typically 20 to 60 km wide, and are separated by wider basins of mainly marine clastic sediments. Thin but laterally extensive chemical sediments, consisting of cherts, fine-grained manganese-rich and graphitic sediments, often mark the transitional zones. The margins commonly exhibit faulting on local and regional scales, and these structures are fundamentally important to the development of gold deposits for which the region is well-known (Griffis et al., 2002).

Within the Birimian greenstone belts, extensive fault networks are generally defined by zones of graphitic mylonite as well as quartz and carbonate veining (Allibone et al., 2002). These graphitic zones (e.g., Figure 1) manifest themselves as sub-vertical conductors. Delineating these steeply dipping conductors and their inferred thrust faults play a critical role in gold exploration, even though there is not a direct relation between graphite and gold mineralization. Due to the dense vegetation and limited outcrops, AEM surveys have been routinely flown in the region for geological mapping.

Figure 1. *Typical sub-vertical carbonaceous units associated with shear zones and possible mineralization in the Birimian greenstone belts of West Africa.*

AEM interpretation in this region is particularly challenging given the geological complexity. 1D methods such as conductivity depth imaging (CDI) or layered earth inversions (LEI) generally fail to recover geologically meaningful conductivity models. Plate models with or without conductive overburden have had very limited success. Sadly, the most reliable interpretations of AEM data to date have been based on purely qualitative means, such as anomaly picking or Fraser filtering. This is not unexpected as the sub-vertical conductors generate significant inline components which cannot be imaged or inverted using 1D methods. Also, the complexity of multiple conductors under overburden reduces the practicality of plate modelling.

Principles of 3D AEM inversion were formalized in Zhdanov (2009). Cox and Zhdanov (2007) and Cox et al. (2010) introduced 3D AEM inversion with a moving footprint. Wilson et al. (2011) demonstrated 3D inversion of first generation VTEM data from Golden Ridge prospect in the Lake Victoria gold fields of Tanzania. In the following section, we demonstrate a case study on how 3D AEM inversion of both inline and vertical components of recent generation VTEM data has been applied to AEM interpretation in the West African gold belt.

GEOLOGY

The project area discussed in this paper is located on the Manso Nkwanta-Asankrangwa gold belt, which is more or less in the central portion of the broad Kumasi Basin (Figure 2). It is almost entirely underlain by Birimian metasediments with localized volcaniclastic components. All investigations to date indicate that the gold is associated with broad quartz stockwork systems, most often hosted in thinly bedded metasediments, including numerous graphitic bands. A series of mainly NE-SW trending mineralized shear systems were proposed as the most promising target features by the project geologist (Griffis, R. J., pers. comm.), and mapping these was one of the main objectives of the subsequent AEM survey and interpretation. Delineation of individual thrust faults, and specifically identifying dilational jogs, bends and localized regions of decreased conductivity (possibly indicating silicification associated with gold mineralization) were additional requirements.

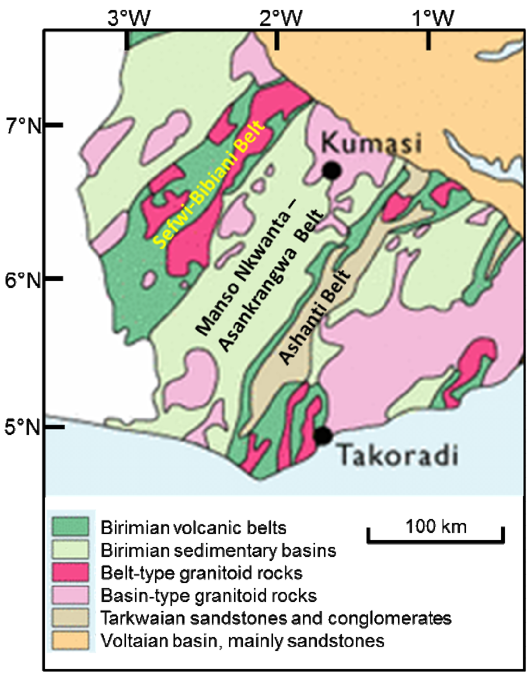

Figure 2. *Simplified geological map of south-western Ghana indicating the Manso Nkwanta-Asankrangwa greenstone belt (modified from Kesse, 1985)*

Figure 3. *Typical vegetation cover in south-western Ghana. The taller trees grow up to 30 m high.*

DATA AQCUISITION AND PROCESSING

The AEM survey was performed with the VTEM helicopter time-domain system at 200 m line intervals. Both inline and vertical components of dB/dt data and the whole waveform digitally integrated B field were acquired at a mean altitude of 64 m over densely vegetated terrain (Figure 3). A summary of the most important AEM system parameters is provided in Table 1. Standard VTEM data processing procedures by Geotech Airborne were applied to the data, including levelling, lag correction and spheric rejection.

Base frequency	25 Hz
Waveform	Polygonal, with incremental rise
Peak current	195 A
Peak dipole moment	411 400 NIA
Tx loop diameter (area)	26 m (540 m^2)
Tx turns	4
Mean Tx/Rx height	64 m
Rx Time gates	27 (0.083 – 7.8 ms)
Tx turn-off time	1.1 ms
Tx Pulse on-time	7.33 ms
Nominal survey speed (station spacing)	80 km/h (2.2 m)

Table 1. *VTEM system parameters.*

DELINEATING SUB-VERTICAL CONDUCTORS

A comprehensive interpretation was performed on the VTEM data using standard AEM interpretation workflows (Combrinck, M. and Botha, W., pers. comms.), including EMFlow CDI, decay constant analysis, semi-automated EM anomaly picking, and Fraser filtering of the inline component data. Only those results relevant to sub-vertical conductor delineation have been included in this paper. As shown in Figure 4, the 3.5 km broad north-east trending shear system was identified from all of the aforementioned interpretation products.

However, due to the sub-vertical nature of these conductors, their close proximity to each other, and the presence of conductive overburden up to 50 m thick, none of the aforementioned methods provided results that could confidently assign as potential drill targets. The maxima of the Fraser filtered inline component data proved the most useful for mapping the centre, top positions of conductors in plan view, and dips could be inferred from the EM anomaly picks. The limitations of such an interpretation were that the positions mapped from the inline component data assumed vertical dips only, and dips and depths–to-top inferred from the EM anomaly picks were accurate only for flat topography and no overburden effects. Hence, there remained ambiguity in the assignment of potential drill targets.

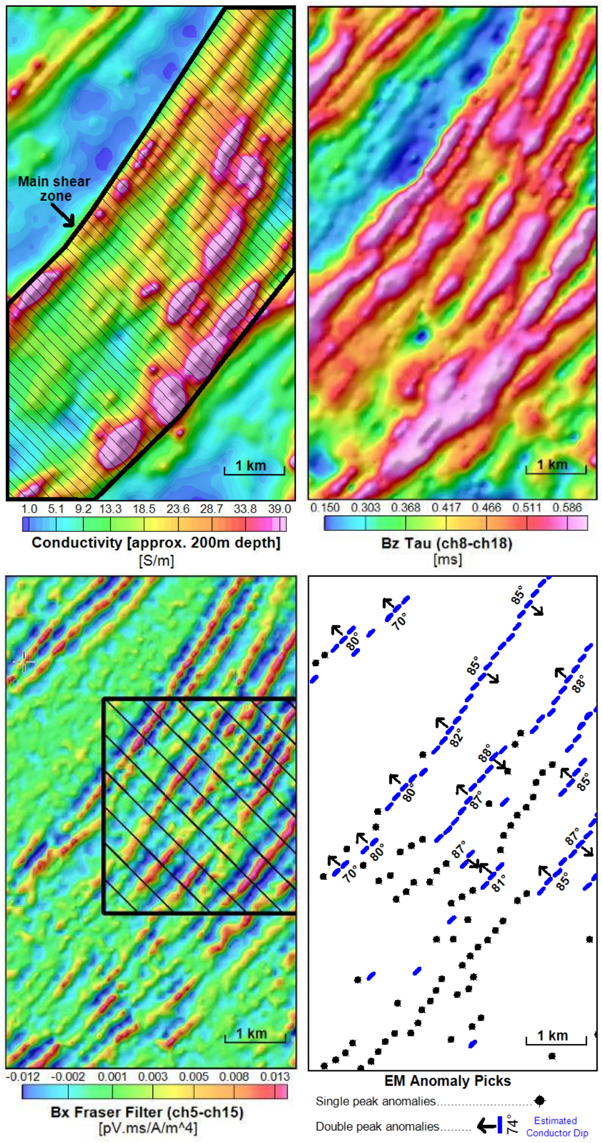

Figure 4. *EMFlow conductivities at depth 200 m (top left), decay constants (tau) calculated from B_z (top right), stacked Fraser filtered B_x data (bottom left) and EM anomaly pick symbols (bottom right). The hashed polygon (top left) indicates the interpreted extent of the main shear zone system that is comprised of multiple sub-vertical thrust faults and the hashed rectangle (bottom left) outlines the data used in the subsequent 3D inversion.*

Plate modelling did not fall within the scope of the original interpretation, but was subsequently applied to three discrete anomalies for additional comparison. EMIT's *Maxwell* plate modelling was used. Two parallel plates had to be used to simulate the VTEM response from each conductor. These results confirm the sub-vertical nature and locations of the conductors. However, accurate modelling required the use of multiple plates, as well as simulation of the conductive overburden that dramatically increased the runtime and lead to nonunique results.

TechnoImaging's large-scale 3D AEM inversion (Cox et al., 2010) was applied to a subset of the VTEM data (Figure 4) that contained the shear zone. The 3D earth model was discretised to 12.5 m across strike, 25 m along strike, and the vertical cell size increased with depth. Both inline and vertical B data were jointly inverted. The upper panel in Figure 5 shows a plan view of the 3D conductivity model at 200 m depth below the surface. Note how the conductors, recovered from the 3D VTEM inversion, closely match those positions and continuity inferred from the Fraser-filtered inline component contours (black). For comparison, the lower panel in Figure 5 shows a similar comparison of the Fraser-filtered inline component contours with EMFlow CDI-derived conductivities at the same 200 m depth. As expected, the CDI-derived conductivities are mapped adjacent to their true positions; an artefact typical of all 1D methods. Moreover, the conductivities derived from 3D inversion are representative of the actual rocks, whereas the CDIs underestimate the conductivity.

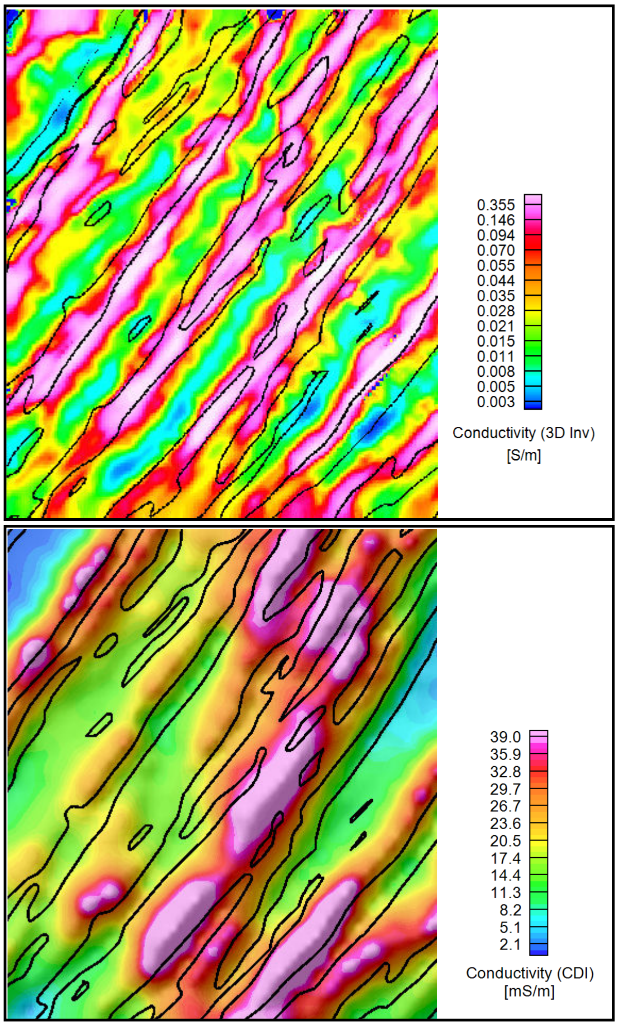

Figure 5. *(Upper panel) Horizontal cross section of conductivity at 200 m depth recovered from 3D inversion with contours of the Fraser filtered inline components superimposed. (lower panel) Horizontal cross section of conductivity at 200 m depth recovered from EMFlow CDI with contours of the Fraser filtered inline components superimposed.*

The lower panel in Figure 6 demonstrates how the 3D AEM inversion accurately delineated sub-vertical conductor geometries, and these correspond very well with those instances where the Maxwell plate models were able to be fit (Figure 6). For comparison, the upper panel of Figure 6 demonstrates how the EMFlow CDI-derived conductivities are displaced relative to the actual conductor location, depth and dip.

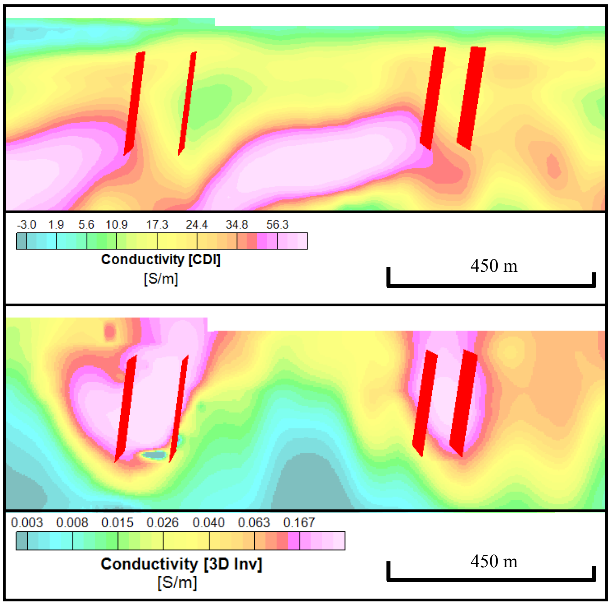

Figure 6. *A 1.2 km vertical cross section through two sub-vertical conductors extracted from (upper panel) the EMFlow CDI-derived conductivity model, and (lower panel) the 3D AEM inversion model. Maxwell plate models are superimposed in red. Note that two plates were required to simulate the VTEM responses for each conductor.*

In this case study, we have demonstrated that 3D AEM inversion can not only resolve subtle changes in dip and continuity along strike, but it also accurately recovers the depth. Several of the larger displacements in the conductor locations have been confidently interpreted as cross-cutting faults, and these match the expected geology. Smaller, as yet unverified variations in the conductor locations have the potential to allow identification of the extensional jogs, bends, and silicification zones associated with gold mineralization. In all, the 3D AEM inversion results have delivered a more complete geological picture than has historically been achieved using traditional AEM interpretation techniques.

CONCLUSIONS

Accurately delineating sub-vertical graphitic thrust faults and shear systems is one of the major strategies followed in West-African gold exploration. Due to the dense vegetation and limited outcrops, AEM surveys have been routinely flown for geological mapping. Although traditional methods of interpreting AEM surveys have been successful for locating conductive structures, they have been unable to recover the subtle geometries and properties of sub-vertical conductors so as to confidently assign the drill targets. In particular, interpretations based on CDIs are unreliable. We have demonstrated that 3D inversion can recover geologically meaningful results that capture the complexity typical of the West African gold belts. The 3D AEM inversion took just hours to produce a geologically meaningful result. This certainly suggests 3D AEM inversion is now indeed a practical consideration for mineral explorers and should be widely adopted. It is important to emphasise that data acquisition remains critical, as no interpretation method can extract more information than is inherently available in the data. For example, the inversion of inline component data is essential for recovering sub-vertical structures. Lower system noise and tighter line spacing also improves accuracy and model resolution. Last but not least, the ability to reliably describe the AEM system parameters should not be underestimated!

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