Electromagnetic response of MVT sulfide deposits on the Lennard Shelf, Canning Basin

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SUMMARY

The Canning Basin hosts Mississippi valley-type (MVT) lead-zinc sulfide occurrences, including the shallow (<500 m) Pillara, Kapok and Cadjebut deposits hosted in the Devonian reef complexes on the Lennard Shelf, as well as deeper examples within Ordovician carbonates along the Admiral Bay Fault Zone. The basin is covered by a regional airborne electromagnetic (AEM) survey with a nominal spacing of 20 km, funded by the Commonwealth Government's Exploring for the Future (EFTF) program. Some of the flight lines were slightly deviated to fly directly over the shallow MVT sulfide deposits on the Lennard Shelf. The resulting conductivity profiles help resolve the geometry of these mineralization occurrences and structural configurations.

Based on existing drillholes at the Kapok West deposits, sulfide mineralization correlates with a thick zone of high conductivity, which stands out from the background of more resistive carbonate platform in the Devonian reef complexes. The sulfide mineralization zone is interpreted to have been displaced by a set of antithetic north-dipping faults, which postdate the south-dipping Cadjebut Fault. Multiple phases of faulting might explain the topography of the Emanuel Range, and facilitated the movement of basinal brines leading to the MVT deposit in the brecciated zone.

Sulfide occurrences at Pillara are not as prominent as Kapok West, but they are still resolvable as a weakly conductive feature against the more resistive platform. The AEM data over the Pillara deposits show a more accurate depth-extent of the subsurface Devonian carbonates than gravity modelling. An east-southeast dipping fault interpreted in the AEM data is likely associated with a thin interval of moderate grade zinc mineralization as intersected by drillholes. The observations and interpretations illustrated above highlight the value of AEM data for predicting the structural geometry and exploration for sulfide deposits, particularly those hosted by resistive Devonian reef complexes on the Lennard Shelf.

Key words: AEM, MVT, Pb-Zn deposits, Devonian reef complexes, Lennard Shelf

INTRODUCTION

Many Mississippi valley-type (MVT) lead-zinc (Pb-Zn) deposits throughout the world are hosted in carbonate platform sequences and controlled by faults and fractures (Leach *et al*., 2010). Those deposits commonly lie at the flanks of basins or foreland thrust belts, and formed during the Devonian to Permian assembly of Pangea (Leach *et al.*, 2010). Similar deposits have also been discovered in the Devonian reef complexes on the Lennard Shelf of the Canning Basin. Compared with the deep sulfide deposits along the Admiral Bay Fault Zone in the southern part of the basin, the ones on the Lennard Shelf are relatively shallow and some economic deposits are within the depth investigation of airborne electromagnetic surveys (AEM).

Regional AEM surveys were rolled out across Western Australia over several years and cover a wide range of geological provinces. Some of the AEM lines were deviated from their nominal spacing of 20 km to fly over the Kapok West and Pillara deposits in the Lennard Shelf (Figs. 1 and 2). After inversion of the AEM data, those lines provide conductivity depth images that can help differentiate the sulfide deposits from the more resistive carbonate background and resolve the geometry of the mineralization.

SULFIDE DEPOSITS AND AEM RESPONSES

The MVT sulfide deposits on the Lennard Shelf are believed to be associated with basinal brines emanating from the Fitzroy Trough during the latest Devonian or earliest Carboniferous (Tompkins, 1994; Tompkins *et al.*, 1994; Hills, 2011). Wallace *et al.* (2002) and Middleton *et al.* (2019) interpreted that the mineralization have formed after the major fault movement during the Middle to Late Devonian, and have coincided with oil migration from the Fitzroy Trough to Lennard Shelf . The sulfate was probably derived from local Givetian evaporites within the cyclic Cadjebut Formation at the base of the Devonian succession (Wallace *et al.*, 2002). Sour gas accumulations then reacted with metalliferous brines from the Fitzroy Trough to produce the economic base-metal sulfide deposits on the Lennard Shelf (Wallace *et al.*, 2002). Some of these deposits have proven to be economic, such as Cadjebut, Goongewa, Pillara and Kapok in the southeastern Lennard Shelf, with the latter two deposits (Fig. 2) selected here for analysis of their structural features and variable responses on the conductivity depth images (CDI) profiles.

Kapok West

The Kapok West deposit (Figs. 2 and 3) has generally high-grade sulfide mineralization at about 200 to 600 m below the surface to the south of the Emanuel Range on the Lennard Shelf. The mineralization coincides with zones of maximum dilation that were related to curvature in the fault plane of the NW-trending Cadjebut Fault, which is a splay from the Pinnacle Fault (Hills, 2011; mineralization intervals in drillholes KW10-052, 027 and CS10-080 marked in Figs. 2 and 3). The MVT lead-zinc sulfides at Kapok West are hosted in Givetian evaporitic dolomites of the Cadjebut Formation (Wallace *et al.*, 2002). These sulfides can be calibrated to a thick zone of high conductivity based on the mineral drillholes (Fig. 3). The CDI profile 1001001 shows that the conductive zone is repeatedly displaced by various faults at the site of Kapok West deposit. In contrast to the Cadjebut Fault which is mapped from surface geology (Crown and Towner, 1981; Playford *et al.*, 2009), the other faults are covered by Quaternary alluvial deposits, and were interpreted as south-dipping splays of the Kapok Fault, which is a dilational relay between the Pinnacles and Cadjebut Faults interpreted by Hills (2011).

The geometry of the Cadjebut and Kapok Faults is complex, and these faults likely dip in opposite directions at depth based on the conductivity profile. Within the complex system, the inferred north-dipping faults possibly postdate the south-dipping Cadjebut Fault, with strike-slip and reverse components. If this antithetic fault geometry and strike-slip movement is correct, it might explain the topography of the Emanuel Range and the brecciated zone hosting the MVT deposit. This brecciated zone was described as a dilational relay by Hills (2011) and as semi-massive open space fill by Wilson and Reynolds (2000), the result of multiple phases of faulting and fluid movement along the fault zone.

The CDI profiles 1001001–002 (Fig. 3) show that the moderately conductive body deepens towards the south with a lateral extension up to 300 m. The dip and southward extension are consistent with modelling results from drillholes at Kapok West (Hosken, 2010). However, the conductive sulfide shown on the section may alter the mineralization model due to its sample threshold (Hosken, 2010). The north-dipping interval has a broader extension with high conductivity under the Emanuel Range. However, it is unknown whether this northwards extension corresponds to the sulfide mineralization or the underlying Ordovician Emanuel Formation shale, which crops out 6 km northwest of the Kapok West deposit outside of the profile (Playford *et al.*, 2009; Fig. 3).

Pillara

A cluster of mineral exploration drillholes at the northern end of the Limestone Billy Hills to the northwest of Emanuel Range targeted the Pillara MVT deposit in the Devonian reef complex (Figs. 2 and 4). The deposit is hosted in a reef-fringed limestone platform and atolls flanked by marginal slope and basin deposits above a Precambrian granitic basement high (Gwatkin and Muccili, 2003). Subsequent mapping and drilling in the area suggested the presence of north northeast- and north-oriented faults, with initial movement controlling syn-depositional breccias of marine cements with later reactivation leading to mineralization that fills the re-brecciated open spaces (McCracken *et al.*, 2000; Gwatkin and Muccili, 2003). These north-northeast and north trending faults were interpreted as relay structures within a major transfer fault system that underwent sinistral strike-slip reactivation along the Lennard Shelf (Hutton, 2002; McCracken *et al.*, 2000; Gwatkin and Muccili, 2003).

AEM profile 1002002 obliquely crosses the Pillara deposit, situated within the carbonate platform facies between exposed Precambrian basement to the south and shaly basin facies of the Devonian reef complex to the north (Fig. 4). Because the profile is oblique to geological features, the main structure shows as a low angle fault (Western Fault in Fig. 2, dipping to the east-southeast in McCracken *et al.*, 2000 and Gwatkin and Muccili, 2003) on the CDI section. The fault was intersected at a depth of 252 m below surface and is associated with a thin interval of moderate grade Zn mineralization in PD730 (Griggs, 2007). Sulfide deposits controlled by fault brecciation exhibit as a weakly conductive zone on the CDI section. PD645 intersected Devonian limestone at about 552 m under a thick cover sequence of Virgin Hills Formation, which was much deeper than originally modelled from gravity (Hutton, 2002). This thick cover is accurately imaged on the AEM profiles, which shows a conductive zone that deepens towards the north and is displaced by a steep fault (Fig. 4). The mineralization, which occurs at significant depth in PD645 (>570 m: Hutton, 2002), may continue across the steep fault located to the north to lie at about 200 m depth, or gradually shallow towards the south (thick intersection of mineralization from 150 to 250 m in PD635 in Hutton, 2002). Overall, the sulfide deposits at

Pillara are not shown as a prominent conductive layer as they are at Kapok West, but are only imaged as a weakly conductive feature. The difference in AEM signature between the two deposits possibly lies in the differing sulfide content or the obliqueness of the Western Fault to the AEM line direction, which potentially induces an anisotropy effect in the signals.

CONCLUSIONS

Based on intersections in mineral exploration drillholes, the MVT lead-zinc sulfides at Kapok West can be calibrated to a thick zone of high conductivity which is displaced by a set of antithetic faults. The brecciated zone acted as a dilational relay producing semi-massive open space, which was subsequently filled with mineralization after multiple phases of faulting and fluid movement along the fault zone. The Pillara sulfide deposits are also controlled by fault brecciation but are shown as a weakly conductive zone on the CDI profile. Its thickness of overlying strata was originally underestimated from gravity data (Hutton, 2002) but is accurately imaged on the AEM. Overall, the sulfide deposits at Pillara do not show as a prominent conductive layer as they do at Kapok West, with the difference possibly related to the sulfide concentration, or the oblique relationship between the AEM flight line and the direction of fault strike.

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Figures

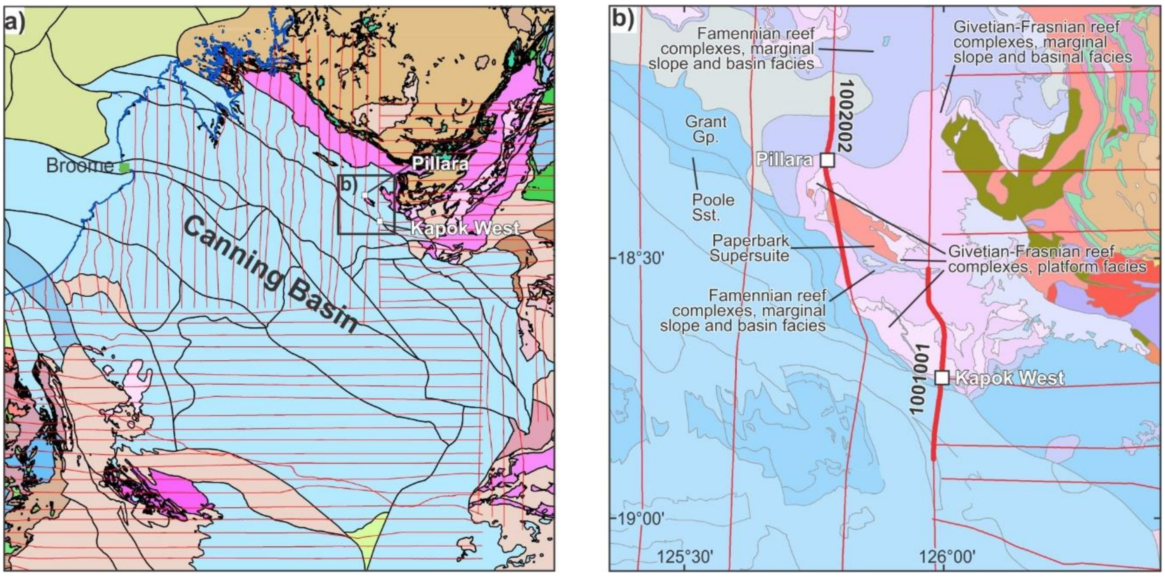

Figure 1. Geological maps and AEM lines: a) tectonic map of the Canning Basin showing the location of Pillara and Kapok West deposits (GSWA, 2017); b) interpreted bedrock geology in the south-eastern part of the Lennard Shelf (GSWA, 2020)

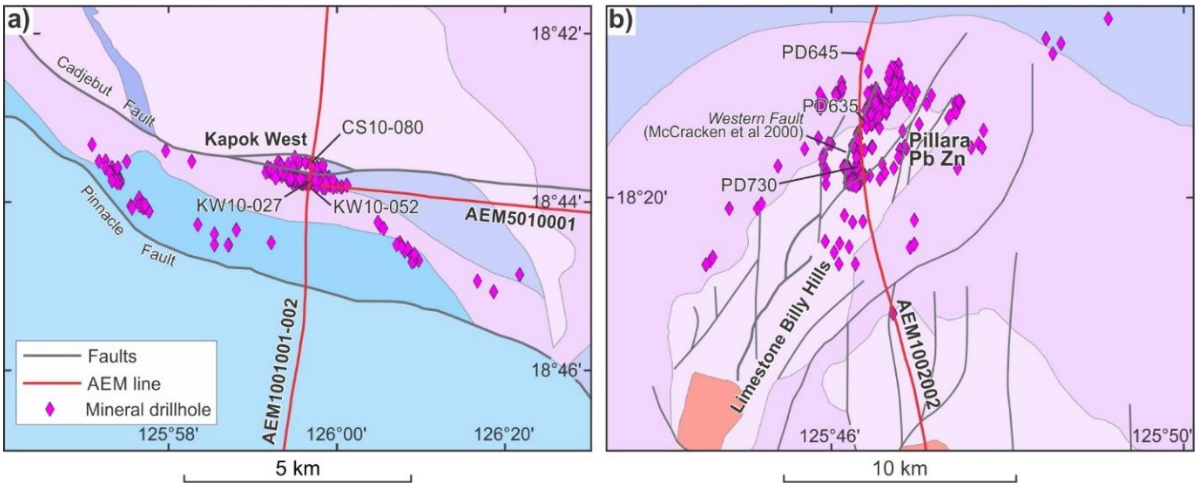

Figure 2. Maps of interpreted bedrock geology and mineral drillholes: a) Kapok West and b) Pillara deposits, modified after GSWA (2020a), McCracken *et al.* (2000) and Playford *et al.* (2009).

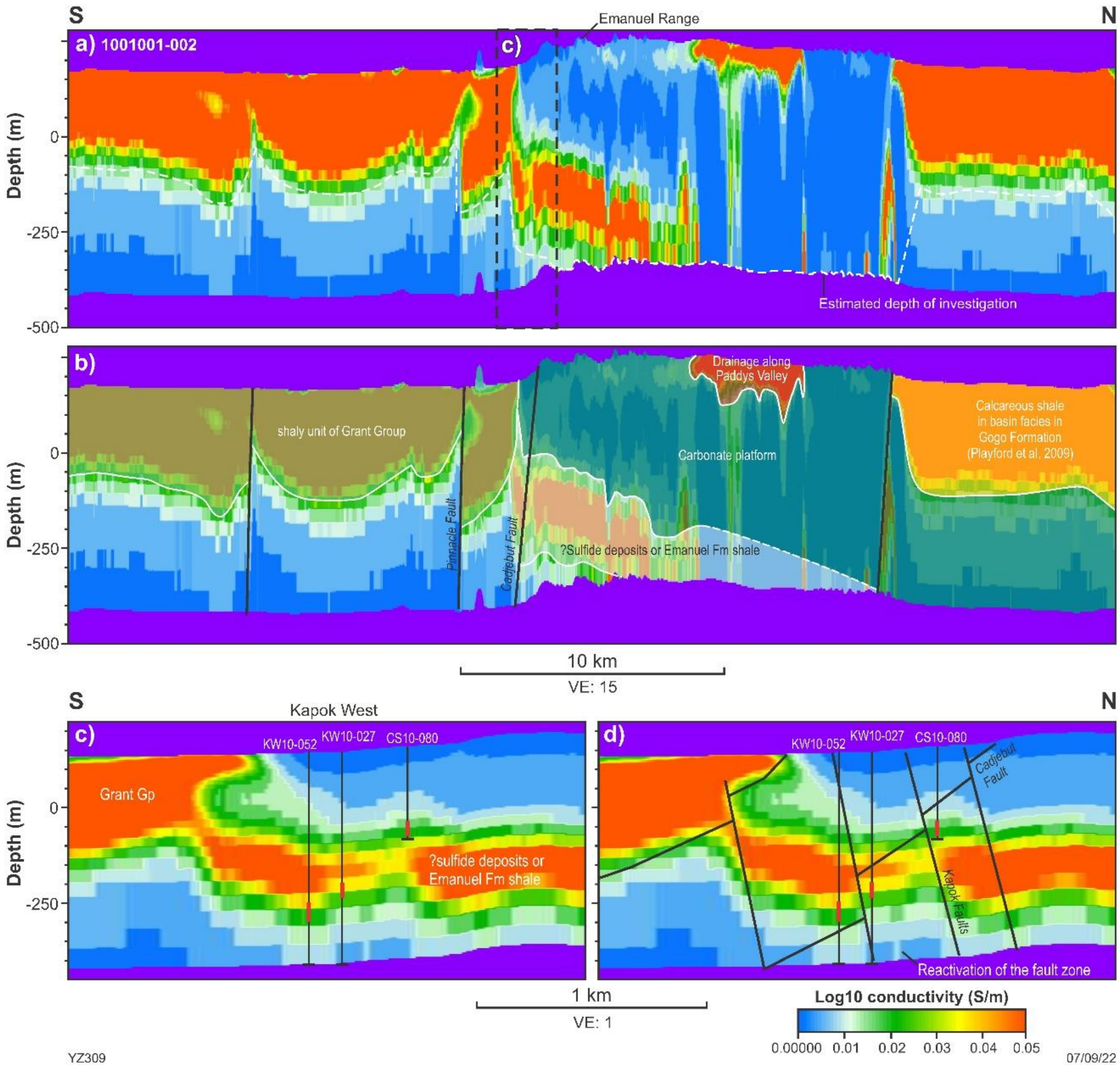

Figure 3. MVT lead-zinc sulfide mineralization at Kapok West on AEM profiles: a) uninterpreted CDI 1001001; b) interpreted CDI 1001001; c) enlarged CDI section across the deposit; d) interpretation of the enlarged CDI section. The mineralization hosted in the Givetian evaporitic dolomites can be calibrated to a thick zone of high conductivity in the dilational relay due to fault movement

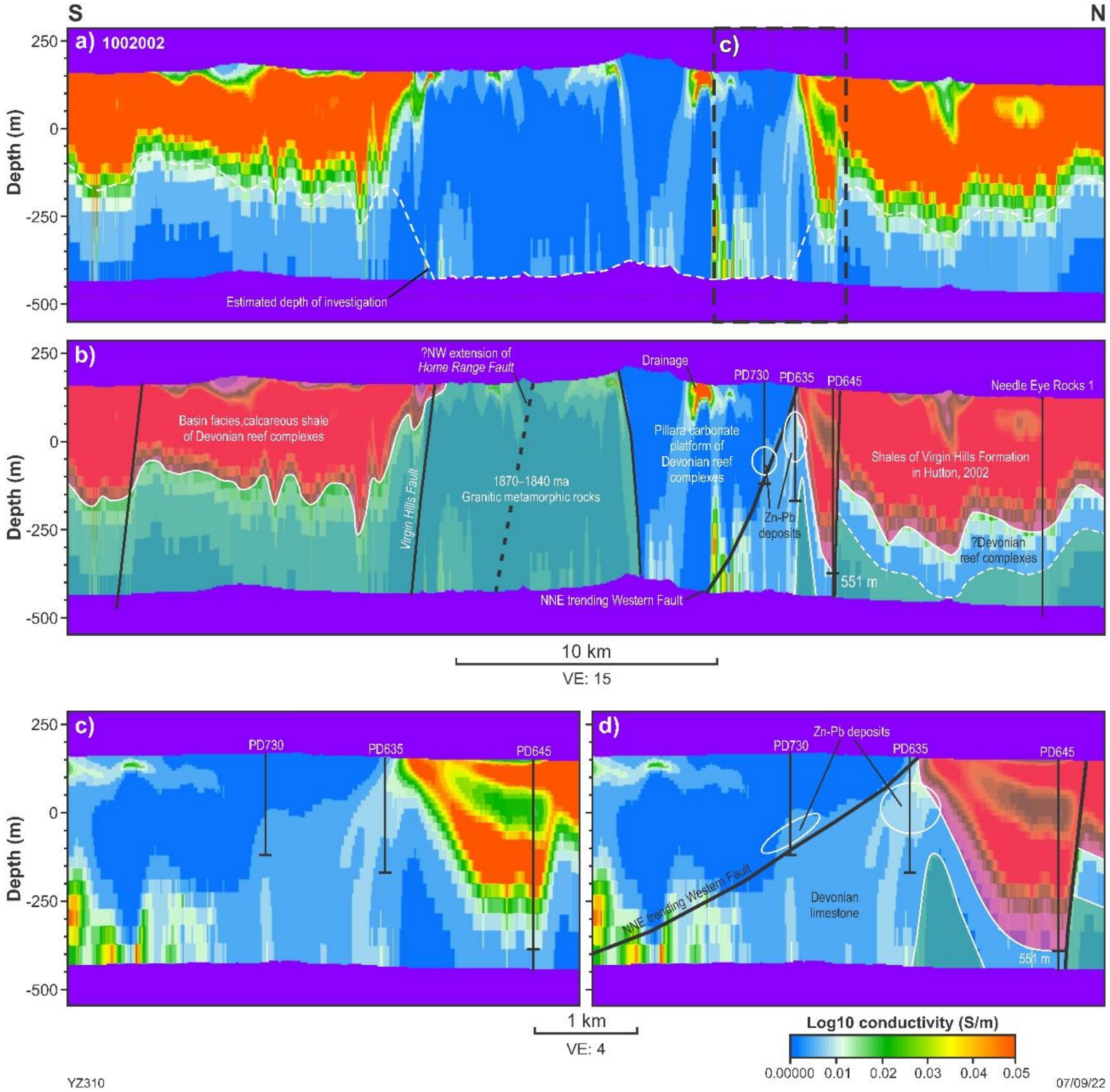

Figure 4. MVT lead-zinc sulfide mineralization at Pillara on AEM profiles: a) uninterpreted CDI 1002002; b) interpreted CDI 1002002; c) enlarged CDI section across the deposit; d) interpretation of the enlarged CDI section. The sulfide deposits controlled by the fault brecciation exhibit as a weakly conductive zone on the CDI section

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