Lessons from the past: exploring for Abitibi greenstone-hosted gold deposits using geophysics

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SUMMARY

The Abitibi greenstone belt has been and continues to be a prolific gold producer. Historic production is in excess of 170 million ounces of gold and active exploration is ongoing. The geophysical responses at gold deposits are varied, making exploration using geophysics in isolation difficult. In this paper, we take a renewed look at the geophysical signatures over known Abitibi gold deposits and relate them to their mineralogy and geology. In the three case histories presented, airborne magnetic and electromagnetic responses reveal linear coincident or parallel responses that strike in the same direction as the main deformation zone. Conductive and susceptible sulfides were interpreted to cause the geophysical responses and gold mineralization was closely related to the sulfides.

INTRODUCTION

Gold mineralization is difficult to explore for using only geophysics as it does not have a characteristic set of geophysical responses. Instead, explorers tend to focus on structural settings, host geology, and regional attributes, such as the Abitibi greenstone belt in Ontario and Quebec, Canada (Figure 1). The Abitibi greenstone belt lies within the Archean Superior Craton and is a volcano-sedimentary belt that spans 700 by 200 km. The belt contains 14 mining districts consisting of more than 80 volcanic massive sulfide (VMS) deposits located in clusters and more than 50 gold deposits located along major deformation zones.

Greenstone-hosted gold deposits are typically structurally controlled and occur within old and deformed areas, such as the Archean Abitibi greenstone belt. Deposits are often spatially and genetically related to faults and shear zones which allowed the transport and deposition of minerals through hydrothermal fluids. Gold mineralization often occurs in quartz and quartz-carbonate veins or vein stockworks (Dubé and Gosselin, 2007). Common sulfides associated with this type of gold mineralization include pyrite, pyrrhotite, and chalcopyrite; within clastic sediment-hosted deposits, arsenopyrite is also common. Dubé and Gosselin (2007) provide a holistic overview of the geology of greenstone-hosted gold deposits.

In this paper, we take a renewed look at the geophysical signatures over Abitibi gold deposits and the associated mineralogy and geology by focusing on three case histories. Detour Lake and Casa Berardi were discovered over 30 years ago and the literature has provided good overviews of the historic geophysics that led to their discoveries. The third case history on the Destiny deposit is lesser known and has not been mined.

PHYSICAL PROPERTIES AND GEOPHYSICS

Historically, large-scale airborne horizontal-loop time-domain electromagnetics (EM) (e.g., INPUT) with accompanying magnetics were flown over a prospective area in the Abitibi greenstone belt. Conductors identified in airborne reconnaissance surveys were subsequently ranked for follow-up with ground geophysical methods and drilling. In general, the sulfide minerals and graphite, commonly associated with gold mineralization, tend to be good conductors (Telford et al., 1990), with the exception of sphalerite. However, the EM response of sulfides can vary a lot depending on the volume present in the rock. Pyrrhotite can be conductive at lower concentrations as it tends to form stringers easier than pyrite (Ward et al., 1966).

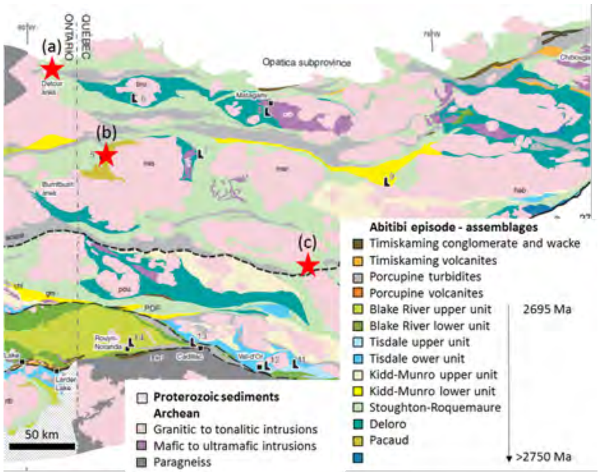

Figure 1: Regional geologic map of the Abitibi greenstone belt (figure adapted from Thurston et al. (2008)). Red stars show (a) Detour Lake mine, (b) Casa Berardi mine, and (c) Destiny deposit.

Airborne magnetic methods were often also used to derive geologic maps in areas of dominant glacial cover with poor bedrock exposure. Sulfide-bearing rocks can have a wide range of susceptibility, with pyrite-rich rocks having values as low as 10^{-4} SI, magnetite-rich zones showing values up to 10 SI, and pyrrhotite-rich rocks falling between these two end-members (Dentith and Mudge, 2014). This wide range in susceptibility for sulfide-rich rocks overlaps with many of the non-mineralized rock types seen in the Abitibi (e.g., gabbro, granodiorite, tonalite, metasediments, felsic volcanics, and banded iron formation) and thus airborne magnetics tends to not be used on its own to explore for sulfides and gold mineralization. Because these gold deposits are associated with hydrothermal fluids, alteration is commonly seen in and around veins and vein stockworks. This often causes a decrease in magnetite, resulting in low magnetic responses associated with gold deposits (Hodges and Amine, 2010).

Induced polarization (IP) can be a good ground-based geophysical method as it is generally more sensitive to lower concentrations of sulfides which produce little to no inductive EM response. The accompanying DC resistivity surveys can be

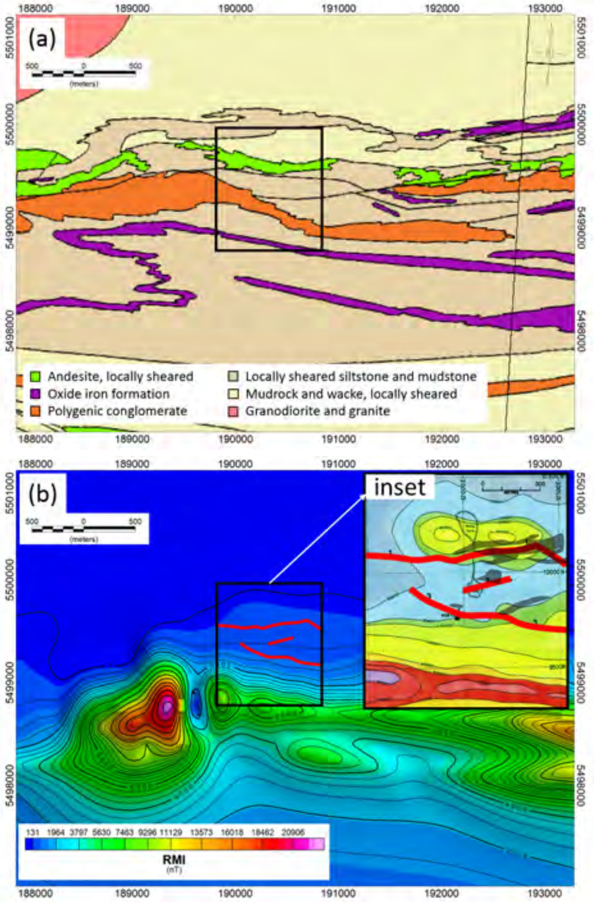

Figure 2: (a) Geology in the Casa Berardi area indicating east-west geologic structures (SIGÉOM geologic map). (b) Regional airborne total field magnetics, indicating a high response over iron-oxide formations. Inset shows ground magnetics with a lower amplitude high response associated with iron formation to the north of the mineralization (Dowsett and Krause, 1984). Red lines indicate three east-west trending conductors on the flanks of the magnetic high responses. Grey shows zones of gold mineralization. The drilling of the southern conductor resulted in the discover of the deposit.

useful to further delineate low resistivity areas where airborne data have indicated a conductor and to map zones of relatively higher resistivity associated with quartz veins.

Gravity appears to be commonly used in the search for VMS or magmatic nickel deposits but rarely for gold mineralization.

Two types of drilling are commonly used; bedrock diamond drilling to obtain core samples of targets being tested and overburden drilling obtain till samples which could provide a geochemical dispersion pattern from bedrock features.

CASA BERARDI MINE

The Golden Pond deposit, named thus for its proximity to two ponds, was discovered in 1981 along the Casa Berardi Deformation Zone in the northern part of the Abitibi greenstone belt (Figure 1). The deposit itself was called the Golden Pond deposit historically but is mined as the Casa Berardi Mine; both names here refer to the same deposit. Bate et al. (1987) interpreted that the deposit area is underlain by intermediate to mafic volcanics, with felsic volcanic flows and pyroclastics occurring as discrete, thin units. Sedimentary units trend east-west and contain graphite, argillite, and iron formation (Figure 2a). Granodioritic-monozonitic and tonalitic-dioritic intrusives are also found in the area. Younger diabase dikes cross-cut the older units and trend north to northeast. The geologic mapping of the area around the Golden Pond deposit is limited due to glacial overburden and appears to be heavily influenced by the interpretation of airborne geophysical data, primarily magnetics.

Spitzer and Chouteau (2003) indicate that the gold mineralization at the Casa Berardi mine was developed in the volcanic-pyroclastic units near the contact with the sedimentary rocks and is found within quartz-dolomite-pyrite-arsenopyrite veins, quartz-vein stockwork, and disseminated sulfides. The mineralization is related spatially to the east-trending Casa Berardi Deformation Zone, which near the deposit, presents as a thin fault structure that contains a graphite- and pyrite-bearing argillite unit.

Airborne total field magnetic data over the deposit show an east-west trending high magnetic response, likely associated with the iron-oxide formation approximately 1 km south of the deposit. The deposit lies on the northern flank of this magnetic response but airborne data mask any smaller details. Dowsett and Krause (1984) presented ground magnetic data, shown with the airborne data in Figure 2b, and indicated a smaller amplitude magnetic high response to the north of the deposit. This aligns with the northern mapped iron formation.

Three EM conductors are presented with the ground magnetic data in Figure 2b and roughly trend east-west. The northernmost conductor lies on the southern flank of the northern magnetic high and aligns with a graphite-bearing fault separating the southern sediments from the northern andesite unit. The southernmost conductor lies on the northern flank of the southern magnetic high and is caused by graphite along the boundary between a conglomerate unit and the sediments. The middle conductor is likely associated with graphite within the sediments.

The gold mineralization is found within the graphite-bearing sediments and the sulfide-bearing andesite unit, which contains 5 to 10% pyrite and arsenopyrite. Historic IP data appeared to detect the sulfide zones which were associated with gold mineralization (Dowsett and Krause, 1984).

In summary, airborne magnetics and EM were able to identify a prospective area and help delineate the lithology. Ground magnetics, EM, and IP further aided to understand the controlling structures and deposit at the Casa Berardi Mine.

DETOUR LAKE MINE

The Detour Lake mine is situated in northeastern Ontario near the Quebec border (Figure 1). The deposit was discovered in 1974 after an airborne geophysical survey, ground geophysics, and eventual drilling of geophysical targets. The deposit lies

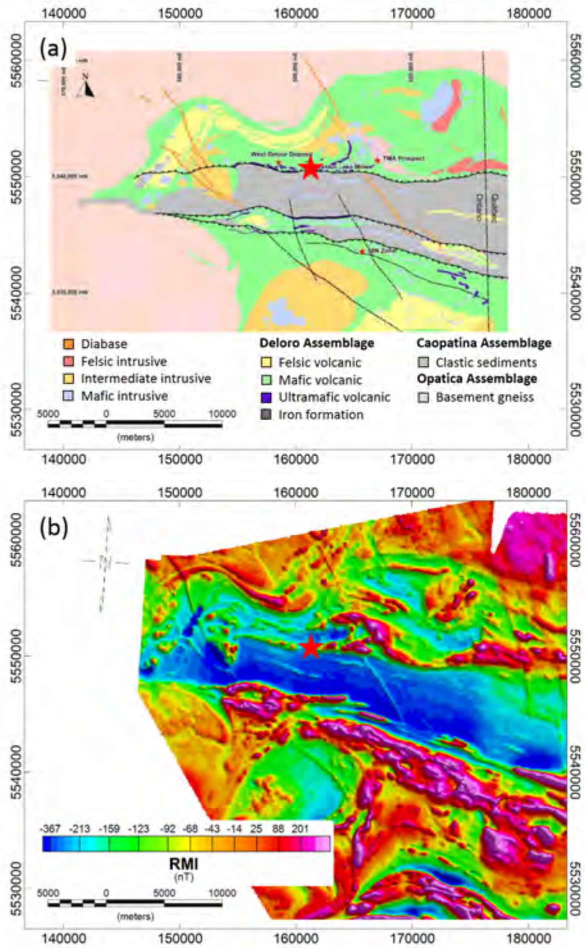

Figure 3: (a) Geology in the Detour Lake area indicating east-west structures, including the Deloro, Caopatina, and Opatica assemblages (figure adapted from Anwyll et al. (2017)). (b) Regional airborne magnetics (Ontario Geological Survey, 2009), with the red star indicating the deposit location.

just north of the Sunday Lake Deformation Zone in the Deloro Assemblage of mafic and intermediate metavolcanics, which strike east-west and have a near-vertical dip. The Deloro Assemblage is intruded by granodioritic and tonalitic intrusions (Anwyll et al., 2017), which likely influenced the structural evolution of the deformation zone. The Caopatina Assemblage, consisting of argillites, greywackes, quartz wackes, and mafic volcaniclastics, is “sandwiched” between the north and south parts of the Deloro Assemblage (Figure 3a). The southern contact is the east-west trending Massicotte Deformation Zone and Lower Detour Deformation Zone. The northern contact between the Deloro and Caopatina Assemblages is defined by the Sunday Lake Deformation Zone. Younger diabase dikes crosscut all formations and generally trend northwest-southeast.

Gold mineralization is spatially related to the Sunday Lake Deformation Zone. The Deloro Assemblage rocks that contact the Sunday Lake Deformation Zone are within the Lower Detour Lake Formation, consisting of ultramafic komatiitic and tholeiitic volcanic rocks, and are highly deformed and altered into biotite and talc-chlorite schist (Anwyll et al., 2017). The formation also hosts a gold-mineralized stratigraphic marker, referred to as the Chert Marker Horizon. Gold mineralization is associated with pyrite, pyrrhotite, and chalcopyrite and found in deformed quartz veins, fractures, and breccias (Anwyll et al., 2017; Crone, 1984).

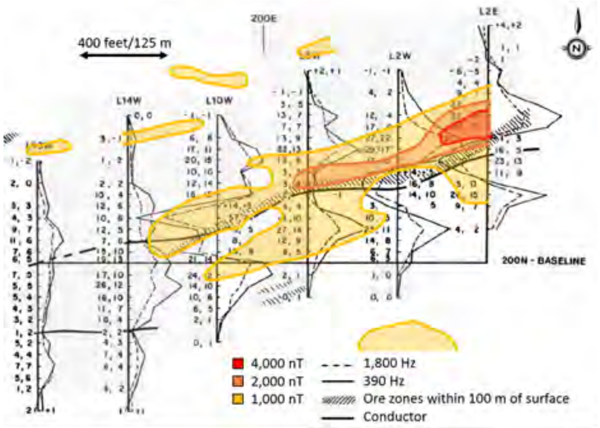

Figure 4: Horizontal Shootback EM survey along north-south lines with ground magnetics plotted overtop in color. The data indicate a narrow conductor with coincident magnetic high over a gold mineralized zone at the Detour Lake deposit (figure adapted from Crone (1984)).

Regional airborne magnetic data show a distinct low magnetic response over the Caopatina Assemblage, with relatively higher responses to the north and south (Ontario Geological Survey, 2009) (Figure 3b). The Detour Lake deposit lies along a linear high magnetic feature that trends east-west, along the northern edge of the magnetic low correlated with the clastic sediments. In 1974, several conductors were identified in the area by an airborne EM Mk VI INPUT survey flown to explore for base metals. One anomaly, designated Anomaly #38, consisted of a 3 km long conductor with a northward steep dip and a coincident 900 nT magnetic anomaly.

Ground magnetic and Shootback EM surveys were conducted to further understand Anomaly #38. The Shootback EM system is a frequency-domain system that was employed in hilly areas where it could be difficult to align the transmitter and receiver coils, resulting in measuring false dip angles (Telford et al., 1990). To overcome this, at each station, the receiver and transmitter are switched to make reciprocal measurements. The response clearly detects the conductor (Figure 4). Crone (1984) states that smaller nearby conductors are caused by small zones with sulfides but that most were devoid of gold mineralization.

Ground magnetic data show the coincident magnetic anomaly (Figure 4), which is attributed to pyrrhotite within the Chert Marker Horizon. Crone (1984) reports that a DC resistivity and IP survey overlapping the ground EM and magnetic surveys indicated a coincident high chargeability anomaly with a low resistivity anomaly over the mineralized area.

In summary, the success of geophysics in the discovery of the

Detour Lake deposit is attributed to the amount of sulfides associated with the gold mineralization, causing coincident magnetic, EM, and IP responses. However, other sulfide zones in the area had similar geophysical responses but showed no gold mineralization, indicating the challenges associated with exploring for gold.

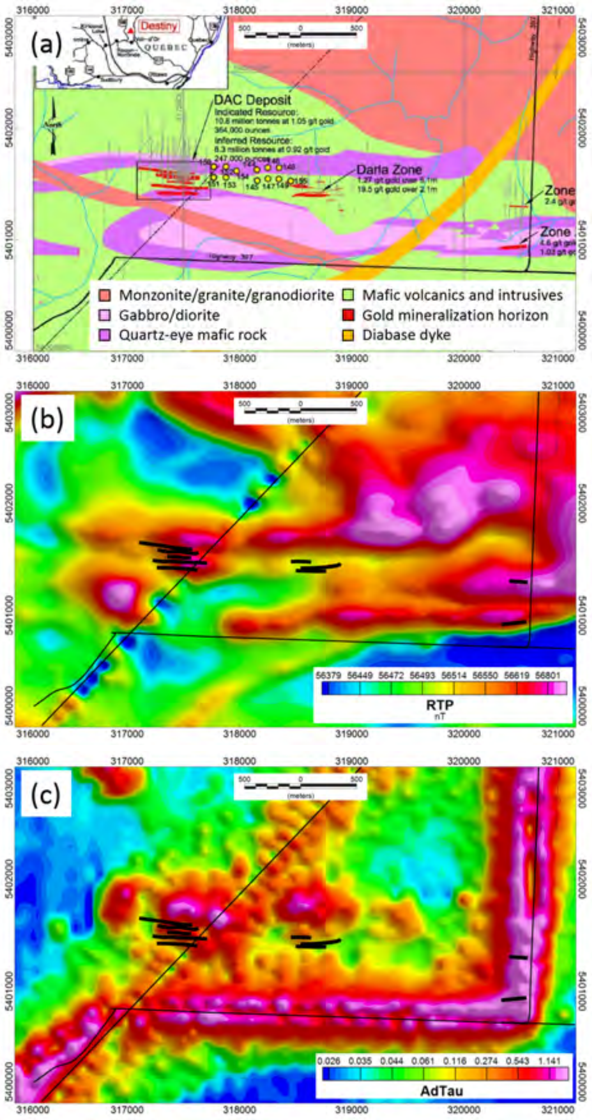

Figure 5: (a) Geology in the Destiny area (figure adapted from McCracken (2017)). (b) Airborne magnetic data indicating high response over the gabbro and quartz-eye mafic sills. (c) The AdTau showing a linear high conductivity associated with the deposit geology. The EM data are severely impacted by nearby power lines.

DESTINY DEPOSIT

The case histories of Casa Berardi and Detour Lake provide some background information for the geophysical signatures from important gold deposits which have been developed into mines These patterns can be used to explore in greenfield environments elsewhere in the Abitibi using modern airborne exploration tools. The Destiny area (including the DAC deposit, Darla Zone, Zone 21, and Zone 20) is one such example with recent geophysical data but relatively no historical information. The deposits at Destiny lie to the north of the Chicobi Deformation Zone (Figure 1).

The area is underlain by the Lower Amos Formation, consisting of metavolcanic rocks, including tholeiitic basalts which are intruded by ultramafic and gabbro sills (McCracken, 2017) (Figure 5a). All rocks are cut by north-northeast and northeast trending faults except for younger diabase dikes emplaced along northeast faults (Koziol, 2004). The Destiny area is covered by glacial overburden, like at the other deposits, and is approximately 10-20 m thick. Drilling indicated that gold mineralization is found within quartz veins and associated with sheared and altered rocks (Koziol, 2004). Two mineralization phases were recognized by Koziol (2004): the first was accompanied by alteration where the altered zones contain up to 20% disseminated and vein pyrite and pyrrhotite, with minor sphalerite. The second mineralization contains higher gold grades in quartz veins and stockwork that crosscut the first event and is associated with disseminated to stringer pyrite and lesser amounts of pyrrhotite, sphalerite, galena, and chalcopyrite.

In 2008, a VTEM survey was flown over the Destiny area (Venter and Bournas, 2008). The reduced-to-pole magnetic total field data show high magnetic responses aligning with the gabbro and quartz-eye mafic sills, attributed to magnetite content of up to 10% (Koziol, 2004) (Figure 5b). The DAC deposit actually lies within two parallel linear magnetic features. Figure 5c shows the calculated AdTau from the VTEM dB_z/dt data (Sattel and Witherly, 2008). Nearby power lines highly affected the EM data, likely obscuring responses associated with the two easternmost mineralized zones (Zones 20 and 21). A linear east-west conductor aligns with the mapped quartz-eye mafic rock north of the DAC deposit and the Darla Zone. The linear conductor is slightly offset but parallel to the magnetic linear anomalies. The magnetic and EM anomalies observed at Destiny are interpreted to be caused by sulfides within the gabbro and quartz-eye mafic sills, with gold mineralization associated with the sulfides.

CONCLUSION

In this paper, we re-examined the geophysical signatures associated with three gold deposits in the Abitibi greenstone belt: Casa Berardi, Detour Lake, and Destiny. Two of the deposits have been developed into significant mines while the third deposit is subject of on-going exploration. Each deposit had both linear airborne magnetic and EM responses, which were coincident or parallel to each other. Additionally, the responses all trend east-west and roughly parallel to the main strike direction of the nearby deformation zones. In all three case histories, the gold deposits were only confirmed after drilling the geophysical anomalies. In all cases, the geophysical responses were interpreted to be caused by sulfides and/or graphite. Drilling was required to determine if (1) sulfides are present, and (2) if the sulfides are associated with gold.

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