Understanding Archean greenstone-hosted lode gold mineralization in Ontario Canada through helicopter TDEM data

Karl Kwan
Geotech Ltd.
Aurora, CAN
Karl.kwan@geotech.ca

Ian Johnson
Consultant
Toronto, CAN
ianjohnson@amtelecom.net

Jean M Legault*
Geotech Ltd.
Aurora, CAN
jean@geotech.ca

Kanita Khaled
Geotech Ltd.
Aurora, CAN
kanita@geotech.ca

Alexander Prikhodko
Geotech Ltd.
Aurora, CAN
alexander@geotech.ca

SUMMARY

We have analysed s large public-domain TDEM datasets acquired by Ministry of Northern Development and Mines – MNDM of Ontario Canada. Geophysical data set 1076 (6,500 out of the original 10,000 line-kms not affected by powerlines) located in an area east of Nestor Falls Ontario in the Western Wabigoon Terrane (WWT) for the purpose of understanding the potential deposition sites of possible gold mineralization. There are a large number of known mineral occurrences (mostly gold) in the Nestor Falls survey area. By analysing these two datasets, we try to determine the electromagnetic, magnetic and airborne inductively induced polarization (AIIP) signatures directly or indirectly related to the gold showings.

The results of the investigation indicate that some of the Archean lode gold showings are located at some distance away from the strongest conductors and others don't have any conductive signatures at all. The magnetic association is complex and the gold mineralization could be with or without magnetic signatures. Many Canadian Archean lode gold occur in resistive glaciated terrains, and sometimes show weak AIIP responses that can be seen in the Logrestau and Restau products. We believe that the EM, magnetic and the AIIP Logrestau or Restau signatures, if detected and interpreted properly, could potentially be used as proxies in the search for Archean greenstone-hosted lode disseminated gold mineralization in Ontario, and perhaps in other Archean terranes.

Key words: Airborne, electromagnetic, magnetic, AIIP, Cole-Cole.

INTRODUCTION

Greenstone belts are economically important repositories for syngenetic mineralization, e.g., VMS, uranium, komatiite-associated nickel deposits, and epigenetic orogenic lode gold deposits, which in Canada are almost exclusively in the volcanic rocks and successor basin units of Archean greenstone belts (Thurston, 2015 & Goldfarb et al. 2005). Archean lode gold is a very important part of global gold resources and the 3.1-2.6 Ga Superior province is second only to the Witwatersrand basin in terms of historic gold production. These greenstone-hosted lode disseminated gold deposits are structurally controlled and occur in any type of supracrustal rocks within a greenstone belt and cover stratigraphic positions from lower mafic-ultramafic volcanic piles to upper clastic sedimentary successions (Dubé & Gosselin, 2007).

The direct detection of Archean lode disseminated gold mineralization by geophysical methods is highly challenging and unfortunately rarely successful in exploration; detection is further complicated by the presence of minerals that have a geophysical response but are not of economic interest, for example, disseminated barren sulphides (Mir, Perrouty, Astic, Bérubé & Smith, 2019).

Hydrothermal sulphide-gold assemblages in the Archean gold deposits could be pyrrhotite-pyrite (reduced), magnetite/hematite-pyrite (oxidized) type (Neumayr et al., 2008). Results of a study of St. Ives gold camp (past production of 265 ton Au) in the southern part of Norseman-Wiluna greenstone belt within the Eastern Goldfields Province of the Yilgarn Craton of Western Australia by Neumayr et al. 2008 suggests that gold grades are highest where the redox state of the hydrothermal alteration assemblages switches from relatively reduced pyrrhotite-pyrite to relatively oxidized magnetite-pyrite and hematite-pyrite both in space and time. Gold deposition is inferred to have occurred where fluids of contrasting redox state mixed.

One of the main objectives of this paper is to provide a regional look at the EM/mag settings of known gold deposits in the areas covered by two recent OGS funded surveys over prominent Ontario greenstone belts. The belts have long histories of minerals exploration and base and precious metal discoveries. This look confirms that greenstone belts, well-marked by bands of elongated strong, near-vertical EM conductors with coincident magnetic axes, are the regional focus of most known base and precious metal deposits, It is understood that the EM conductors are primarily massive pyrrhotite, one component of chemical sediments. These formational conductors are of no exploration interest themselves. This regional relationship has been long understood and displayed after the Ontario Geological Survey first released the results from large scale high resolution AEM/mag surveys in the 1970s.

Our study uses the TDEM and aeromagnetic data, as well as the Cole-Cole products from airborne inductive IP (AIIP) extracted from the airborne EM results, which are then compared to known mineral occurrences.

METHOD AND RESULTS

Nestor Falls Area – Western Wabigoon Terrain

The first large helicopter time-domain electromagnetic (TDEM) data for the investigation of geophysical signatures over Archean lode gold mineralization come from an area east of Nestor Falls, southwest Ontario. The TDEM survey was carried out by Geotech Ltd. on behalf of MNDM between January and March 2014 using the VTEM helicopter system (Witherly et al., 2004). The survey acquired 10,200 line-kms of magnetic and EM data at 200 m line spacing in NS direction with nominal terrain clearance of 45 m for EM bird. A large portion of the TDEM data not affected by powerlines, amount to 6,500 line-kms, are used for this study. The area covered by the data is populated with numerous waterbodies.

The TDEM survey is located in the Western Wabigoon Terrane (WWT) of the Superior province, Figure 1A. Few areas of exposed Archean crust have influences the understanding of Archean evolution as much as the WWT and adjacent portions of the Winnipeg River and Quetico Subprovinces. WWT hosts numerous past-producing gold deposits, mostly dating from the first half of the last century, but none were major producers (Beakhouse et al., 2011)..

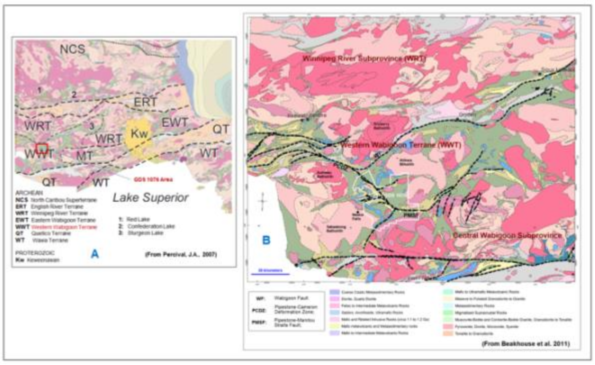

Figure 1: (A) Major tectonic terranes of SW Superior province; the GDS 1076 survey is located in the Western Wabigoon Terrane (WWT) (from Percival J.A. 2007); (B) Geological map of the Western Wabigoon Terrane (WWT) and major fault zones (WF, PCDZ and PMSF) in and around the Nestor Falls survey area (from Beakhouse et al. 2011).

The geological map of the WWT (from Beakhouse et al. 2011) is shown in Figure 1B. The descriptions of the WWT geology are based mainly on the work by Percival 2007 and references therein. The extracted texts are quoted here: “The WWT is dominated by mafic volcanic rocks with large tonalitic plutons. Volcanic rocks range in composition from tholeiitic to calc-alkaline, and are interpreted to represent ocean floor or plateau and arc environments, respectively. Volcanic rocks were deposited between ca. 2.745 and 2.72 Ga, with some rare older rocks and minor younger volcanic-sedimentary sequences. Plutonic rocks range from broadly synvolcanic batholiths composed to tonalite-diorite-gabbro (ca. 2.735-2.72 Ga), to younger granodiorite batholiths and plutons (ca. 2.71 Ga), monzodiorite plutons, and plutons and batholiths of monzogranite. Immature clastic metasedimentary sequences are preserved in narrow belts within volcanic sequences. They are younger than the volcanic rocks. At least two phases of deformation affected supracrustal rocks of WWT, from ca. 2709 Ga in the Lake of the Woods area, to ca. 2.70 GA in the Sioux Lookout-Savant area.”

The survey area is underlain mainly by greenstone belts surrounded by granitoid batholiths, i.e., Atikwa Batholith to the NE, Sabaskong Batholith to the SW, Aulneau Batholith to the west, and Dryberry Batholith to the north. Major tectonic faults in the area include the Wabigoon Fault (WF), Pipestone-Cameron Deformation Zone (PCDF) and the Pipestone-Manitou Straits Fault (PMSF).

TDEM Data and Mineralization

The reduced-to-pole (RTP) total field magnetic data from the TDEM survey and known base metal and gold mineral occurrences in the survey area are shown in Figure 2. There are 82 Au occurrences (defined as Au > 0.5 g/t), seven prospects (Au>0.5 g/t with mineralized section over 1 m) and developed prospects with reserves (Au>6 g/t over 100,000 t) in the survey area. There are also 14 base metal occurrences, mainly of Ni-Cu-Zn variety. The mineralization showings are located either in or close to the faults.

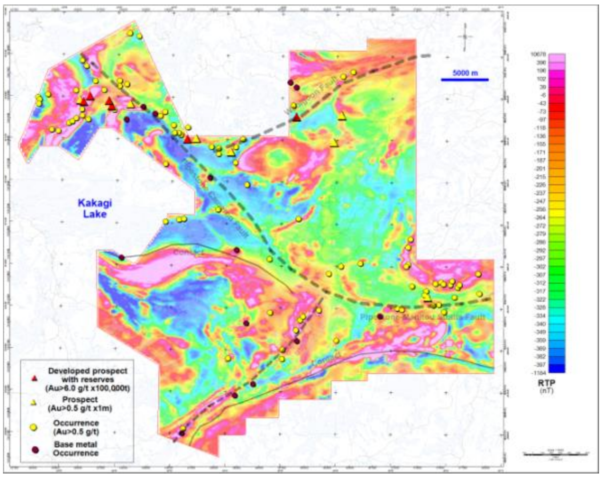

Figure 2: Reduced To the magnetic Pole (RTP) data and known mineral occurrences (from MNDM) in the TDEM survey area.

The EM induction time-constant TAU data of the TDEM survey are shown in Figure 3. The syngenetic base metal mineralization occurrences are normally associated with the strong conductors, while most of the Au showings, while regionally associated with the greenstone belts, are some distance away for the strong conductors.

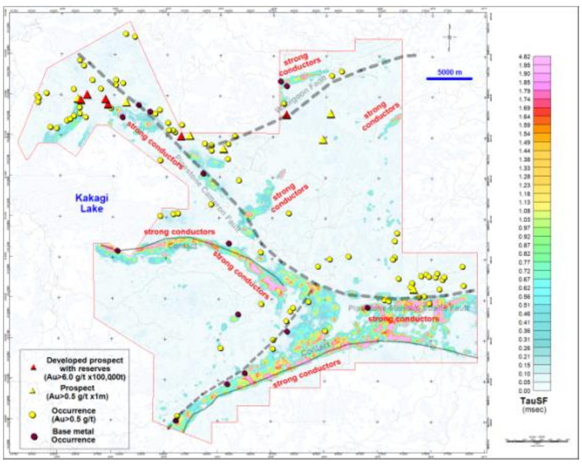

Figure 3: EM induction time-constant data and known mineral occurrences (from MNDM) in the TDEM survey area.

AIIP results

AIIP mapping (Kwan et al. 2018) of the Nestor Falls EM data is carried out. The mapping generates AIIP apparent resistivity, chargeability and Cole-Cole time-constant. The derived AIIP apparent resistivity and Cole-Cole time-constant data of Nestor Falls are shown in Figure 4. Similar to EM induction time-constant TAU data, the AIIP apparent resistivity highs coincide with the greenstone belts and major fault zones. The AIIP Cole-Cole time-constants highs are distributed mainly in the NW and NE parts of the survey area, and some are located in the waterbodies, possibly associated with clay.

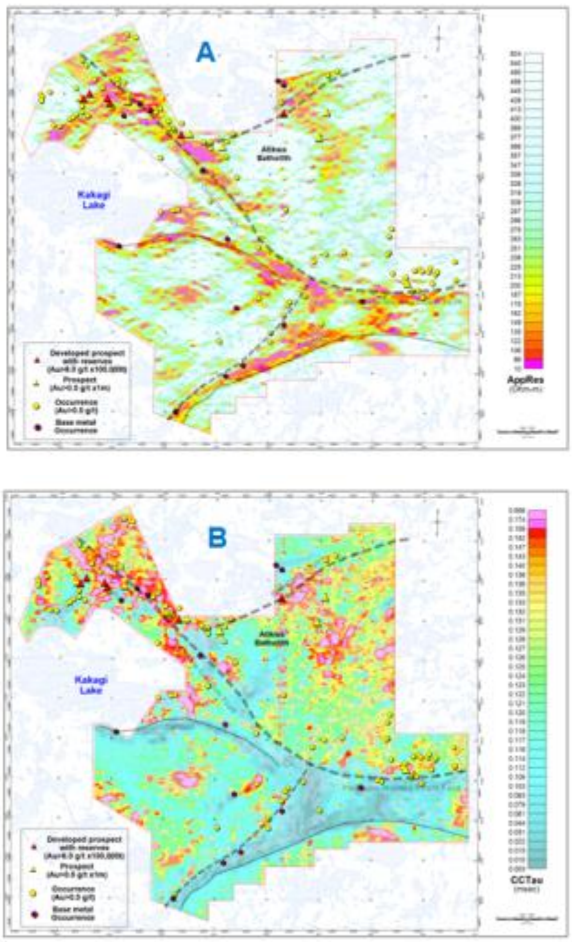

Figure 4: (A) AIIP apparent resistivity and (B) AIIP Cole-Cole time-constant data, Nestor Falls.

The AIIP product log(apparent_resistivity)*Cole-Cole_time-constant called Logrestau can highlight areas of weak to moderate conductivity with moderate to strong Cole-Cole time-constants. There are some weak, but still visible responses in Logrestau product. The high Logrestau zones, G-1 to G-5, are highlighted and shown in Figure 5, over the Logrestau (Fig. 5A) and the topographic base (Fig. 5B). The zones G-1 to G-4 are located in the NW of the TDEM data area, and G-5 is located in the SE corner. A large number of known gold showings are located either within or close to these zones

The key observation drawn from this case is that the known gold deposits and showings are located some distance away from the strongest conductors possibly associated with pyrrhotite and/or massive sulphides.

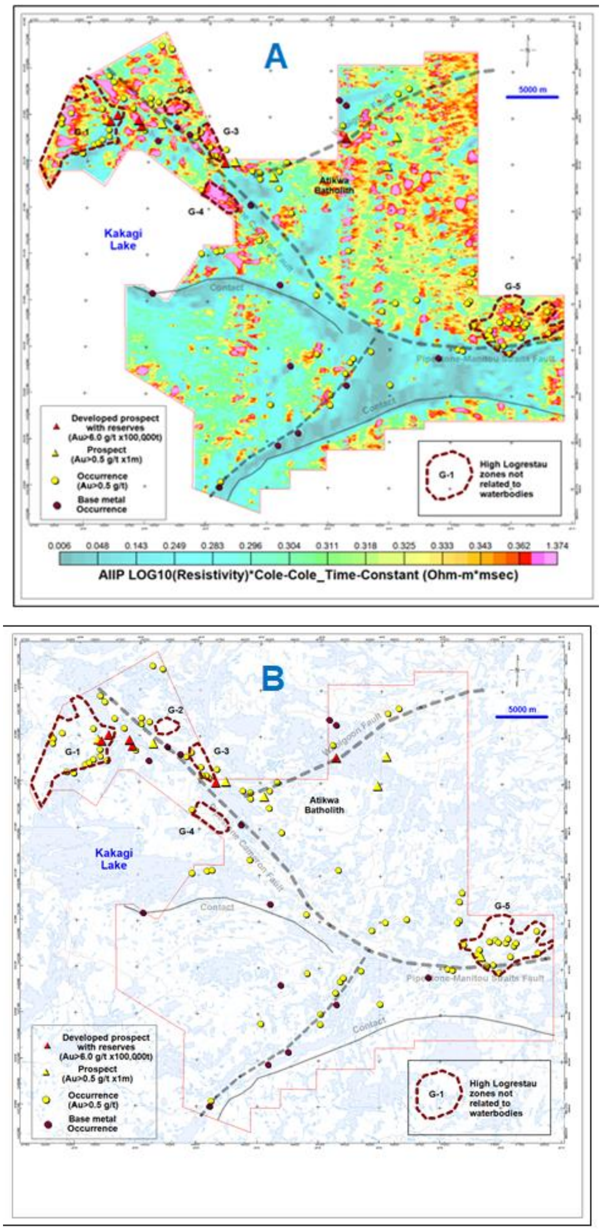

Figure 5: ((A) High Logrestau zones; (B) High Logrestau zones over the topographic base of drainages, Nestor Falls region.

CONCLUSIONS

We have analysed a large TDEM datasets acquired in 2014 by MNDM over an area in the Western Wabigoon terrane of the Superior province. We notice that the known gold mineralization showings tend to occur in locations away from the strongest conductors dominated by syngenetic or epigenetic sulphide minerals such as pyrrhotite and chalcopyrite, and we believe that the hypothesis of Neumayr et al. (2008) to be valid for Archean lode gold mineralization. The AIIP Logrestau or Restau products could help an interpreter to identify potential gold exploration targets in resistive zones located at shallow depths (<100 m). Hence, it is our belief that, if detected and interpreted properly, these parameters could potentially be used as proxies in the search for Archean greenstone-hosted lode disseminated gold mineralization in Ontario, and perhaps in other Archean terranes in the world.

ACKNOWLEDGMENTS

The authors are grateful to Geotech Ltd. for permission to publish the results of the study. We like to acknowledge the contributions made by MNDM to encourage greenfield/grassroots mineral exploration by acquiring and subsequently releasing the Geophysical Data Sets 1076. We also thank Richard S. Smith for very helpful review, discussion and encouragement for this study.

REFERENCES

Beakhouse, G.P., Webb, J.L., Rainsford, D.R.B., Stone, D. and Josey, S.D. 2011, Western Wabigoon GIS synthesis–2011: Ontario Geological Survey, Miscellaneous Release–Data 280. (Download website: http://www.geology ontario. mndm. gov.on.ca/mndmaccess/ mndm_dir.asp? type=pub&id =MRD280)

Dubé, B., and Gosselin, P., 2007, Greenstone-hosted quartz-carbonate vein deposits, in Goodfellow, W.D., ed., Mineral Deposits of Canada: A Synthesis of Major Deposit-Types, District Metallogeny, the Evolution of Geological Provinces, and Exploration Methods: Geological Association of Canada, Mineral Deposits Division, Special Publication No. 5, 49-73.

Goldfarb, R.J., Baker, T., Dube, B., Groves, D.I., Hart, C.J.R., and Gosselin, P., 2005, Distribution, character, and genesis of gold deposits in metamorphic terranes: in Hedenquist, J.W., Thompson, J.F.H., Goldfarb, R.J., and Richards, J.P., eds, Economic Geology 100th Anniversary Volume, 407–450.

Goldfarb, R.J., Groves, D.I. and Gardoll, S., 2001, Orogenic gold and geologic times: A global synthesis, Ore Geology Reviews, 18, 1-75.

Kwan, Karl, Legault, Jean M., Johnson, Ian, Prikhodko, Alexander and Plastow, Geoffrey, 2018, Interpretation of Cole-Cole parameters derived from helicopter TDEM data – Case studies: Extended Abstract, SEG Anaheim 2018 International Exposition and 88th Annual Meeting.

Mir, R., Perrouty, S., Thibaut, A., Bérubé, C.L. and Smith, R.S., 2019, Structural complexity inferred from anisotropic resistivity: example from airborne EM and compilation of historical Resistivity/IP data from the gold-rich Canadian Malartic District, Québec, Canada: Geophysics (in press), 1-52, https://doi.org/10.1190/geo2018-0444.1.

Neumayr, P., Walshe, J., Hegemann, S., Petersen, K., Roache, A., Frikken, P., Horn, L. and Halley, S., 2008, Oxidized and reduced mineral assemblages in greenstone belt rocks of the St. Ives gold camp, Western Australia: vectors to high-grade ore bodies in Archean gold deposits?: Miner Deposita, 43, 363-371.

Percival, J.A., 2007, Geology and Metallogeny of the Superior Province, Canada: in Goodfellow, W., ed., Mineral Deposits of Canada: A Synthesis of Major Deposit Types, District Metallogeny, the Evolution of Geological Provinces and Exploration Methods: Geological Association of Canada, Mineral Deposits Division, Special Publication 5, 903–928.

Thurston, P.C., 2015, Greenstone belts and granite-greenstone terranes: Constraints on the nature of the Archean world: Geoscience Canada, 42, 437-484; http://www.dx.doi.org/10.12789/geocanj.2015.42.081;.

Witherly, K., R. Irvine, and E. B. Morrison, 2004, The Geotech VTEM time domain electromagnetic system: 74th Annual International Meeting, SEG, Expanded Abstracts, 1217–1221.