The evolution of the use of geophysics in the search for blind VHMS deposits in the Abitibi greenstone belt, Québec Canada
Ken Witherly, Condor Consulting, Inc.; Michel Allard, Xstrata Zinc Canada

Summary

Geophysical technologies have contributed significantly to numerous discoveries of VHMS deposits in the Abitibi greenstone belt since the 1950s when airborne EM technologies were first commercialized. Since the mid-1980s however, the discovery rate has dropped drastically even with major improvements to geophysical technology and much better understanding of the geological processes involved in deposit formation and the geochemical signatures associated with deposits. While the Abitibi belt is still perceived as being prospective, the search space for new deposits has to be expanded. At the deposit scale, this means developing an effective means to discriminate deposits of interest inside formational conductive zones. At the regional scale, to develop new greenfields areas, new data sets such as high resolution gravity need to be acquired and assessed along with traditionally acquired EM and magnetics.

Introduction

The Abitibi greenstone belt is a subprovince of the Superior Archean Craton and has been a world class resource of base metal and gold deposits with 67 significant (>0.2Mt) volcanic-hosted massive sulphide (VHMS) deposits indentified since the discovery of the Horne mine in 1923. The Abitibi deposits tend to cluster and form distinct mining districts such as at Noranda (Gibson and Galley, 2007) and Matagami (Figure 1).

Figure 1: Location of main VHMS mines and mining districts in Abitibi greenstone belt

Given the distinctive geophysical responses associated with most VHMS deposits, geophysical techniques have played a significant contribution in the discovery of 45 of these deposits (Figure 2) and of about 75% of the 50 undercover (non-outcropping) deposits (Figure 3).

Figure 2: Geophysically assisted discoveries over time.

Over the last two decades in spite of a significant advancement in the understanding of VHMS deposits and the terrains they form in, as well as improvements in geophysical methodologies and geochemical techniques to explore undercover, the discovery rate of new deposits has dropped off significantly. The exception being camp-focused programs where modest but consistent success driven by the application of new techniques seems to be sustainable (Allard 2009). What has been missing is lack of new camps being indentified or the discovery of major (>20 Mt) deposits. Given the discovery of new terrains such as the Abitibi on a global basis is becoming harder, it is worth trying to assess geologically whether the Abitibi has significant new assets to reveal and if so, what as far as an exploration process is either missing or underemphasized in current methodologies? As with most serious assessments, an examination of the past success and missteps (failures?) is a good starting point.
Evolution of geophysics in the Abitibi

Historical evolution

Following Boldy (1979) who divided the exploration life cycle of the Noranda mining district (a major sub-component in the Abitibi) into three periods, we are proposing a similar chronological assessment of VHMS exploration in the entire Abitibi.

Pre 1955-aka The Stone Age. Geophysics was in its infancy and most of discoveries were made by prospecting; the majority of deposits were found initially were outcropping but with some success drilling away from these deposits in an incremental step-off fashion.

“We didn’t need to be a good fisherman at that time, there was a lot of fish in the lakes.”

Period 1955-1985-aka The Golden Age. This is considered the period whereby the systematic use of geophysical techniques started and achieved its greatest success. While the distinctive geophysical character of VHMS was recognized in the 1930s-40s; the ores were of high electrical conductance and often magnetic, it was not until geophysical surveying could be applied from aircraft that the exploration for VHMS literally “took off”. The term ‘saturation exploration’ was defined in this time to describe the systematic application of airborne and then ground geophysics followed by drilling. Mattagami Lake Mines discovered in 1956 (Mackay and Paterson, 1959) is a good example of such a discovery. Out of this huge amount of effort, statistics such as 1:1000 targets tested would prove to be economically “interesting”.

Over the years following as technology improved and AEM surveys were systemically applied to areas deemed favorable, often being re-flown as technology improved under the assumption that new technology could detect deposits that had been missed by earlier surveys.

In the sixties and seventies, AEM contributed to the discoveries of 20 deposits in the Abitibi including Joutel, Kidd Creek and Selbaie. The methodology was simple and was defined at one stage as ‘saturation prospecting’ to describe the flying of large areas (in effect prospecting from the air), followed up by ground geophysics and drilling. The target model, conductors hosted in a bimodal synvolcanic setting was also relatively simple. It described mainly the immediate surroundings of the deposits without reference to the regional tectonic setting.

Period 1985-present: aka The New Age. In the last 25 years, the rate of grassroots VHMS discoveries in the Abitibi belt has fallen to almost zero despite what are considered significant advances in geological modeling, better understanding of geochemical alteration signatures, the development of higher powered and sophisticated geophysical instruments and the essentially the emergence of PC-based computer processing and more recently high end visualization.

We didn’t need to be a good fisherman at that time, there was a lot of fish in the lakes.”

The last grass root discovery was the Gonzague Langlois deposit in 1989 (Lacroix et al 1993) by SEREM. Airborne EM is attributed to only one VHMS discovery in this time period. Ground and borehole geophysics has resulted in significantly more deposits being located. In almost all instances these are relatively small deposits in historic mining areas. With the declining success in the VHMS base metals search, many junior explorers have re-focused to gold exploration with a good degree of success in some cases.

Based on historical trend and on regional VHMS models, we will present some ideas that could explain the decline and we will try to envision some possible future “solutions”.

“We didn’t need to be a good fisherman at that time, there was a lot of fish in the lakes.”

Quo Vadis VHMS Exploration?

Many hypotheses have been proposed to explain the relative decrease in new VHMS discoveries. The root arguments as to the cause of this were based on the following perceptions:

- All the big deposits have been found. The undiscovered ones are typically too small, too deep and therefore uneconomic.
- Since the Abitibi has been intensively explored in the past, the chance of finding is decreasing; this results in less exploration effort which in turn leads to fewer discoveries and so on.
- Intrinsic limits of detection technologies and geological knowledge.

The practical reality is that without major new discoveries either in existing camps or in new greenfields areas, the exploration industry losses incentive to engage in what it regards as high risk/low reward exploration. Bullet point 2 above is basically this message.

A modern initiative: A major initiative to ‘break open’ the Abitibi started in 2001 following the discovery of Perséverance orebody in the Matagami camp using the MEGATEM technology. Xstrata Zinc (then Noranda Inc.) re-evaluated the potential of the Abitibi belt and felt that an Abitibi-wide VHMS exploration program was warranted. Collaborating with Xstrata were their JV partners; Virginia Gold Mines, Novicourt Mines and Eastmain Resources. The rationale behind this decision was:

- Relatively few deposits have been found at a depth below 50 m (Figure 2)
- Limited drilling has been below 100 m (Figure 4)
- In-house tests had demonstrated that the MEGATEM system could detect typical VHMS at least to a depth of 250 m. (Gingerich and Allard 2001)
Evolving role of geophysics in the Abitibi

- Typical VHMS deposit has a high in-situ value (Figure 5). A stand alone 20 Mt deposit shows an in-situ value of 350$US/t (at current prices) is deemed as an attractive target (Figure 5).
- Exploration risk could be shared with the government and junior companies.

The program was primary based on collecting and interpreting MEGATEM data. Priorities were based on the following criteria:
- Coincident MAG-EM anomalies
- Isolated anomalies (avoid formational)
- On Xstrata properties or open ground
- Untested by previous drilling
- Located in favorable geology environment

The large geological-geochemical database collected over the years was used to query AEM results using intelligent GIS algorithms to support area and target selection using the well established geological model.

On the Québec side, 349 AEM anomalies were followed up and 203 were drilled tested for a total 267 DDHs. While discoveries can occur well after the initial generative work, at this stage no new deposits have been attributed to the MEGATEM initiative.

**Targets and statistics:** Figure 7 shows a cumulative frequency plot for VHMS deposits (drawn from a global data base) and their sizes. The ‘target’ model for the Xstrata Abitibi search at 20Mt is also marked.

This plot shows very clearly that the majority of VHMS deposits are far smaller than the target of choice and unless there is an effective means to rank targets with some gradation as to size before testing, a large number of targets will have to be tested prior to finding the target of choice.

This graph also does not convey the distraction of ‘false positives’: those targets that appear like VHMS targets but are in fact not in the right geological setting. Barren sulfides, graphite are the most typical sources of such ‘false positives’. The traditional means to try and remove these from the list of targets for follow-up is to invoke that “no formational” targets will be selected. This rule was stated explicitly in the Xstrata criteria for follow-up listed earlier. The problem with this filter is that legitimate VHMS deposits have been found in what can be termed formational settings but we lack the cost effective technology (short of drilling) to screen this style of target. This conundrum has vexed explorers for decades and was captured once by an explorer under the enthusiastic mantra of “Stop screening and start drilling” (Gaucher 1975). Thirty five years later this is still a problem.

1 Xstrata and Virginia Gold Mines donated 82 000 lkm of MegaTEM to the Québec government thereby allowing other groups to access and use these outcomes.
Evolving role of geophysics in the Abitibi

Search Space: A term that has been adopted into the exploration vernacular is ‘search space’. In the present sense it means the area where economic opportunities exist given the present state of exploration methodologies, extractive and processing technologies. To expand the search space means to increase the opportunities for economic development. In our case, we’d like to better understand what the economic opportunities are at depth in the Abitibi and also, can we develop means to assess areas with formational conductors which currently are excluded from the search space due to the lack of adequate discrimination technologies. Some suggestions as to how to address these issues are presented below.

Geological Model: While the geophysical technology can be benchmarked over time, it is often much harder to define advances in geological models as it pertains to enhanced exploration effectiveness. There is a natural accrual of knowledge about deposit models and terrains with time and VHMS deposits and the Abitibi are no exception. The major synthesis indentified by the authors is the 2007 review by Galley et al. While lacking some of the nuances available in modern studies, earlier efforts to capture geological models sometimes seem more focused on the direct application to exploration; Figure 8 is such an example which is taken for Boldy (1981). In this figure he shows the VHMS at the deposit scale (on top) and the semi-regional or “caldera” (camp) setting. The presence of felsic rocks as both flows and intrusives is considered a critical element of the geological setting, concurrently associated with mafic flows.

Figure 9 is drawn from another set of authors (Piercey and Galley 2009) and provides a stylized model of the crust showing the ‘heat engine’ which drives the spreading and hydrothermal solutions which then form the VHMS deposits.

At Scale 1, we need to confront how to deal with formational settings as there is an enormous amount of ‘real estate’ at shallow depths which could be opened for rapid and inexpensive assessment assuming a practical means were available to bias drilling to dense metallic conductors. Figure 12 shows a geology image and geophysical layers for the Reid-Mahaffy Test Site west of Kidd Creek (Dransfield 2009). The geology would be largely determined from drilling and some interpretation from the magnetics, so the unique pre-drilling layers for assessment are the magnetic and EM results. With a high density, broad coverage gravity layer now available, there...
Evolving role of geophysics in the Abitibi

Future of geophysics applied to VHMS exploration

Now and into the future, near mine exploration will remain quite effective as discussed by Allard 2009. Incremental advances in technology can be expected and in the right geological circumstances, significant discoveries could be made such as the Lalor Deposit (Gilmore et al 2009).

On a broader scale, the efficacy of geophysical techniques to search at depth (2-3 km) will remain challenging. As a colleague recently stated to one of the authors “we can see deep but things are fuzzy”; the expectation is this will remain the case for the foreseeable future. More integrated modeling of multiple data sets is expected to help define areas of interest but specific targeting (i.e. where to drill) will likely require some new definitions of geoscience infrastructure such as systematic seismic-MT transects and deep drilling for geological control and to feed-back into modeling.

Economically the shortest returns could be realized if the means could be developed to target effectively in the areas classified now as ‘formational conductors’.

While geophysics was counted on almost exclusively for decades to drive VHMS exploration, going forward better integration of all relevant techniques is required. This requires a degree of geoscience sophistication and collaboration that pose’s challenges for many smaller exploration-focused companies (aka juniors).

Acknowledgements

The one author (MA) wishes that thank his employer Xstrata Zinc Canada for permission to use information developed during the course of Xstrata’s exploration programs in the Abitibi.
Evolving role of geophysics in the Abitibi

References


Allard, M., 2009 Successful applications of geophysics in the search for blind VMS deposits in the Abitibi; presented at KEGS PDAC workshop, Toronto March 2009


Mackay, D. G., Paterson, N. R., 1959, Geophysical discoveries in the Mattagami, Québec, CIMM annual general meeting, Montreal, 1959, Transcript CIMM bulletin September 1960, p.703-709-


Piercey, S. And Galley, A.G., 2009 An Overview of Volcanogenic Sulfide (VMS) Deposits; presentation at UBC MDRU March 2009