GILLOT, E. Keynote Address: Progress in Seismic Imaging of Mineral Deposits. *Near Surface Geoscience Conference & Exhibition 2018* _ 9-12 September 2018, Porto, Portugal.

Keynote Address: Progress in Seismic Imaging of Mineral Deposits

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Abstract

Geophysical methods such as the surface seismic reflection method have been applied for many years and worldwide by the mining industry, the cost being a limiting factor for its expansion.
Recent development in wireless recording technology together with a dramatic increase in the productivity derived from the Middle East O&G industry such as blended vibroseis acquisitions made the seismic surveys more attractive and in accordance with budgets.
In parallel, the increased quality due to a higher vertical resolution of fault thought and ore body linked to a broadband spectrum acquisition make a huge difference even with the most recent surveys.

Despite its rich history of mining, current conditions in Europe present a number of social, political, legislative, cost, technical and physical challenges to exploration. In EU, the challenge is taken in serious with projects as INFACT (Innovative, Non-invasive and Fully Acceptable Exploration Technologies) within the H2020 agenda. It aims to overcome the obstacles by innovation and dialogue. It target innovative technologies that are more acceptable to society and benefit the exploration industry, unlocking potential in new or mature areas. Even if the first steps by airborne exploration improved a lot in the past decade through:

- Gravity Gradiometry (The Falcon® family), just to mention the helicopter solution ♦ bringing the finest gravity data that can be collected in the air when ground based techniques are unfeasible, either due to financial costs or accesses. It provides a cost and time advantage with comparable data quality. And ability to add significant value to seismic data.
- Fixed wings ♦ (Tempest) even if at moderate depth or helicopter EM,
- Gravity or magnetics

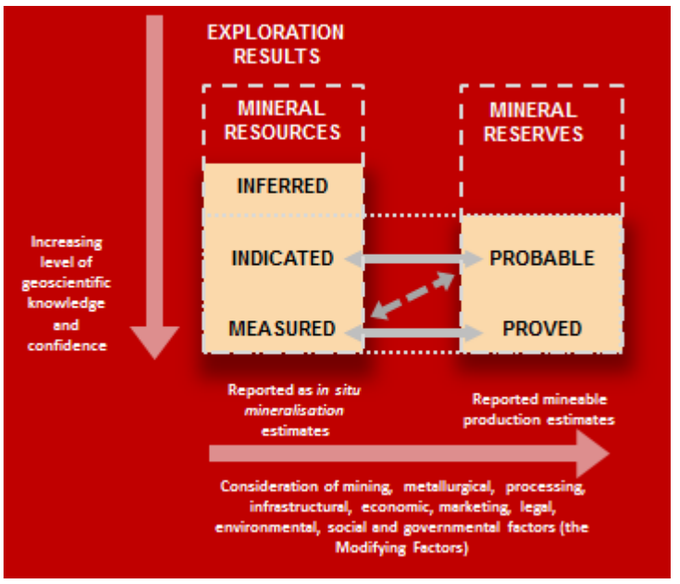
allowing now unrestricted imaging of most geological environments, at preliminary exploration stage (Exploration Target).

But it will never allow by itself a certification as measured "Mineral Resources" and therefore probable or proved "Mineral Reserves"[1] within whatever ♦ SAMREC (*South African Code for the Reporting of Exploration Results, Mineral Resources and Mineral Reserves*) or JORC systems that might be of use to investors.

The grade is needed and only obtained by drilling. At least some physical evidence of **assumed continuity** of the Mineralisation (for indicated) or better **confirmed continuity** of the Mineralisation (for measured) must be presented by the Competent Person[2].

[1] For example the "Mineral Resources" are classified (inferred > indicated > measured) could be converted into "Mineral Reserves" (probable > proved)

[2] Indicated level of confidence assume geological and grade or quality continuity between points of observation but Measured level need a confirmed geological and grade or quality continuity between points of observation.



Converting “Mineral Resources” into “Mineral Reserves” require consideration of the **Modifying Factors** (mining, processing, metallurgical, infrastructure, economic, marketing, legal, environmental, social and governmental factors) affecting extraction. It is common to include in Modifying Factors some allowance for geological losses affecting sometime 35% of the project resource.

Whatever at Resources or Reserves stage, the only way of confirming the continuity of the ore is a dense but often expensive network of cored drilling at ore depth or, better and cheaper a 3D seismic survey. Note that the 3D seismic dataset can be used to optimize the drilling campaign but will never replace it.

Seismic reflection has been applied for many years and in many places for mine exploration, mainly in stratiform or sedimentary context (coal, potash ♦ ♦).
Vertical structures, hard rocks with high velocities were for long creating quite a hopeless model for mine geoscientists to image their complex subsurface problems, not speaking of the price of such conventional seismic surveys.

What I call conventional seismic is based on:

- a lot of geophones per trace derived from long history starting with low capacity 48 channels recorders.
- a lot of vibrators to mimic high energy level source as we were used with dynamite (x10kg at x10 meters).
- Rigid grid of acquisition.

and led to high costs of acquisition and a quality bottleneck.

Development of efficient and low cost wireless recorders together with a dramatic increase in the productivity derived from the Middle East O&G industry made the seismic surveys more attractive and in accordance with budgets. In Middle East all contractors record now some 20000 VP’s per day to compare with 1000 max in Europe.

To benefit of these advances, there are some changes to accept, and it’s quite revolutionary for some geophysicist.

The consequence of wireless surveys is to accept recording the seismic data in a “blind mode”. It is a compromise that has to be accepted. Waiting two weeks to see any data is quite amazing but attributes QC can be checked by AFD. The wireless equipment is also more reliable than old cable systems.

The idea is also to use lighter vibroseis sources, emit less energy but over more source points and in the same way go to denser single sensor receiver grids and with single 5Hz geophones. The consequence is to reach unequalled trace density per km² allowing the use of the best processing algorithms.

This increase trace density (meaning raypaths) can only be economically viable if joint to a dramatic increase of productivity. This is now possible using blended recording derived again from high count channels crews operating for O&G in Middle East. In conventional seismic, vibrators fleets work one after the other and better if distance separated. The slip sweep technique in mid-2000 allowed overlap in time between sweeps. Now there are no more constraints in time or distance separation and common productivity reach 2000 VP’s per day in Europe. The only limit is the amount of vibrators mobilized. So it is a balance between the size of the survey and the productivity.

In mining, there is no survey with a size compatible with the use of up to 32 vibrators as in Middle East or North

Africa. Six single vibes is the optimum compromise. The only remaining bottleneck is the capacity to roll receivers even in case of single phones because of the high cost of personnel in Europe and HSE exposure. This is overcome by putting emphasis on source side rather than receiver side.

Shallow depth target in open pit mine for example is also considered as a barrier due to high cost of dense shallow seismic acquisition. It is not the case as shown here in Eastern bushveld ♦.

If we add then a broadband vibroseis signal over at least 6-7 octaves, we get an increase penetration (starting as low as 1Hz), better resolution and definition. It's a game changer for quality ♦. The time we used wiggle seismic sections to pick horizons and convert them into depth is surpassed by attributes interpretation using the full volume of information.

In some specific cases with hard rock environment S waves can also be used ♦.

One geophysical technique is rarely sufficient to identify ore deposits. Each geophysical method used, whatever potential fields, EM or seismic, adds information ♦. Now we have proved being able to use a wireless seismic recorder to acquire EM data with unequalled measurement points density. Digital sensors used sometime for seismic acquisition would address the gravity. Wireless systems can be used as well overnight to record data for passive seismic imaging while acquiring active source seismic during the day. I see here a new range of opportunities for further developments.

Despite the rich history of mining, current conditions present a number of social, political, legislative, cost, technical and physical challenges to raw material exploration. In EU, the challenge is taken in serious and INFACT project (Innovative, Non-invasive and Fully Acceptable Exploration Technologies) within the H2020 agenda aim to overcome the obstacles t by innovation, dialogue and reform. It will improve innovative technologies that are more acceptable to society and invigorate and equip the exploration industry, unlocking unrealized potential in new and mature areas. Even if the first exploration steps by airborne exploration improved a lot in the past decade through:

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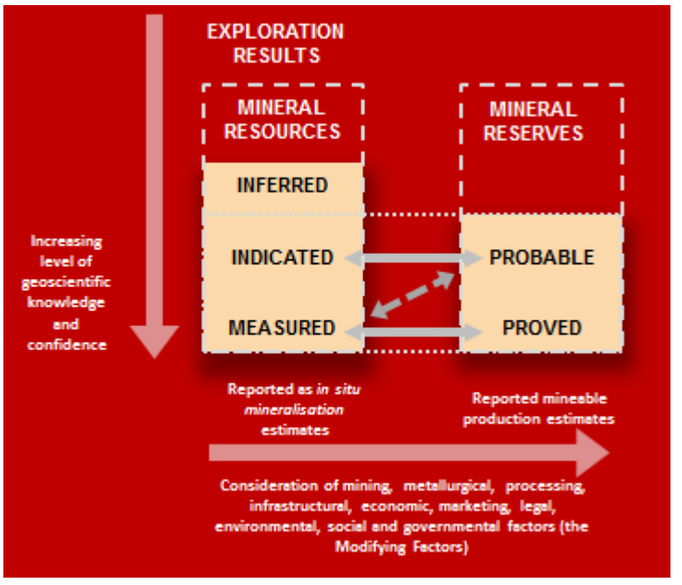

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