An Overview of Mineral Exploration and Deposit Modelling

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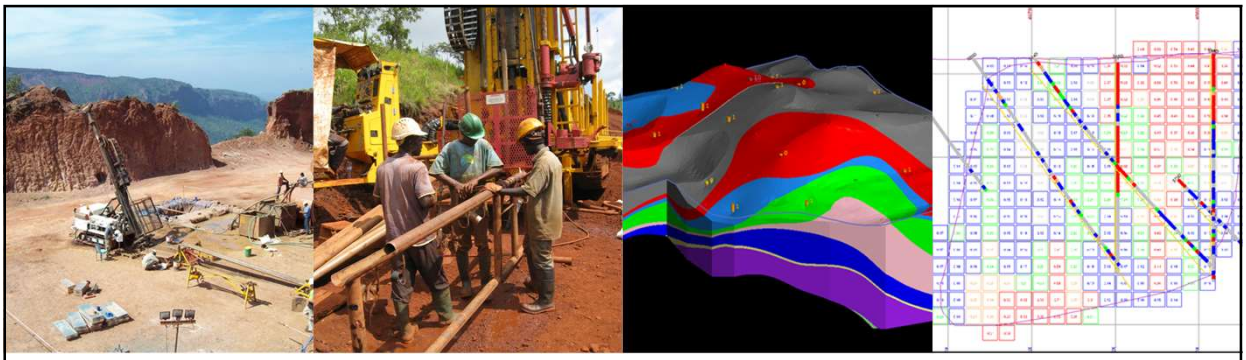

An Overview of Mineral Exploration and Deposit Modelling

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For: The Undergraduate 1st Year and 2nd Year Students of IIT, Kanpur

Date: 23rd November 2020

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Fundamentals of Mineral Exploration

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Civilization and Minerals

- Minerals and metals are essential components for the growth of human civilization and society.
- The use of mineral can be dated back to pre-historic age.
  - Copper age – 6000 BC
- Industrial Revolution in Europe started in 1800s and caused exponential demand of minerals
- Are these minerals abundant in the earth's crust and readily available for extraction?

Steel

Aluminium Foil

Cement

Jewellery

Hematite
Fe_2O_3

Bauxite
$Al_2O_3.2H_2O$

Limestone
CaO3

Native Gold
Au

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What is a Mineral Deposit?

When a useful element is sufficiently concentrated in an accessible part of the Earth's crust so that it can be profitably extracted it is called a Mineral Deposit.

	Average crustal abundance	Typical exploitable grade	Approximate concentration factor
Al	8.2%	30%	×4
Fe	5.6%	50%	×9
Cu	55 ppm	1%	×180
Ni	75 ppm	1%	×130
Zn	70 ppm	5%	×700
Sn	2 ppm	0.5%	×2500
Au	4 ppb	5 g t^{-1}	×1250
Pt	5 ppb	5 g t^{-1}	×1000

Source: Robb 2003

There must be some geological processes that enable enrichment of these elements.

- Igneous Processes
- Hydrothermal Processed
- Sedimentary Processes
- Surficial Processes

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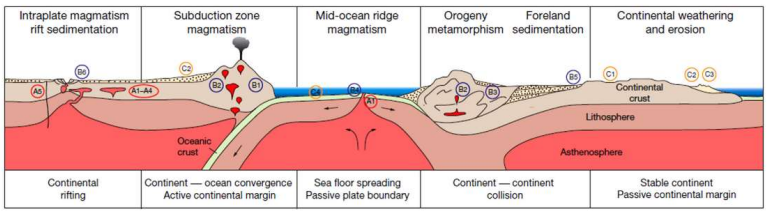
Where to Find Mineral Deposits?

If you want to find elephants, go to elephant the country.



A: Magmatic ore deposits

A1. Chromitites as (ultra-)mafic cumulates in layered intrusions and ophiolites

A2. V-magnetite in mafic intrusions (V, Ti)

A3. Pegmatites (Li, Cs, Be, Nb, Ta)

A4. Ni- und PGE-sulfide deposits in mafic intrusions und flood basalts

A5. Carbonatite (REE) and kimberlite (diamond) deposits

B: Hydrothermal ore deposits

B1. Porphyry Cu (Mo, Au) and epithermal Au, Ag (Hg,...) deposits

B2. Sn-W veins and greisens in granites

B3. Orogenic ("metamorphogenic") Au-quartz vein deposits

B4. Volcanogenic massive sulfides (Cu, Zn)

B5. Sediment-hosted (MVT, 'sedex') Pb, Zn, Cd, Cu, Co deposits

B6. Sandstone-hosted and unconformity-related U (V, F, Mo, Au, PGE) deposits

C: Surface-related ore deposits

C1. Residual ore deposits: bauxite (Al), Ni-laterite deposits

C2. Alluvial placer deposits (Sn, Ta, Au; U)

C3. Beach-sand placers (Ti, Zr, REE)

C4. Manganese nodules and crusts on the ocean floor (Mn, Co, Ni, Cu...)

After Heinrich 2014

There must be a series of activities that enable understanding of the geometry, shape, continuity, variability, mineralogy, and other factors that has impact on the extractability of these elements.

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What is Mineral Exploration?

Mineral exploration is the search for materials in the earth's crust that appear in high enough concentrations and amounts to be extracted and processed for profit.

It also aims to discover deposits of minerals and rocks that can be used to meet the resource needs of society.

It is also carried out to replace the ore deposit being mined currently and or increase the company's ore reserve.

Photo Courtesy – SRK Consulting

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Type of Discoveries

Greenfield Discoveries

- The term comes from the building industry – where undeveloped land is described as Greenfield.
- Findings from a broad base grassroots exploration programme well away from known orebodies or known mineralised belts.
- Pioneering discoveries in new locales.
- Example – Broken Hill (Australia) 1883

Brownfield Discoveries

- The term comes from the building industry - where previously developed land is described as Brownfield.
- Discovery is made by enhancing the reserve in strike and dip continuity of known orebody or in the vicinity of an existing mine.
- Economics of development are improved by existing infrastructures.
- Example - Rampura-Agucha (India) 1977

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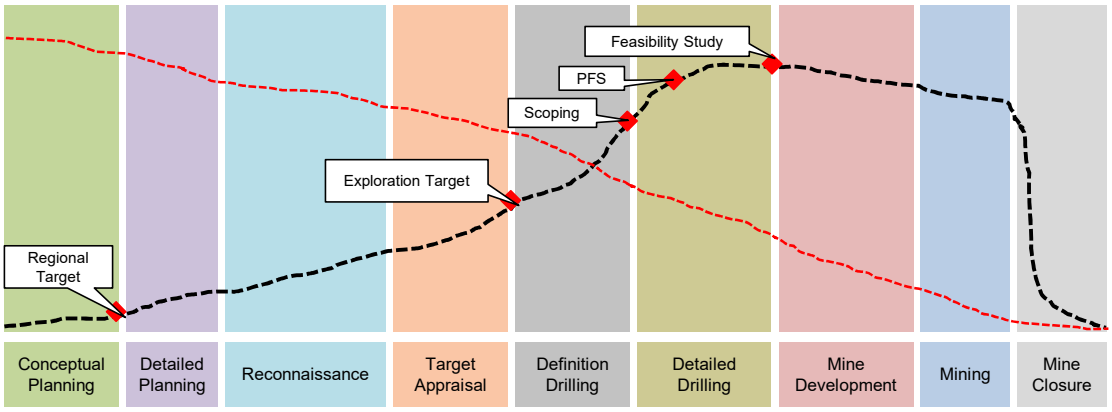
Stages of Exploration



Modified from Eimon 1988 and Moon 2013 ---------- Risk ---------- Expenditure

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Mineral Exploration Tools

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Exploration Tools

- Surface Indication and Ancient Mining
- Geological Mapping
- Exploration Geophysics
- Exploration Geochemistry
- Drilling, Logging, Sampling and Assay

Photo Courtesy – SRK Consulting

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Surface Signatures

- **Favourable Geological Formation**
  Ultramafic Rocks in Sukinda Valley (India) for Chromite Exploration
- **Weathering**
  Presence of gossans above Rajpura-Dariba zinc-lead-silver deposit (India)
- **Ancient Mining and Smelting**
  Zawar Mine, zinc-lead-silver deposit (India)
- **Shear Zone**
  Copper sulfide veins in Surda Copper Deposit (India)
- **Lineament**
  Aravalli Mountain, India (India)

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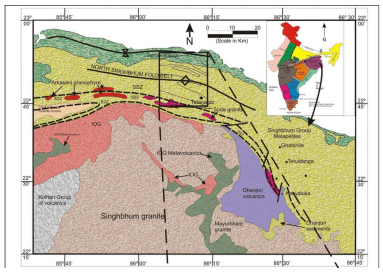
Geological Mapping

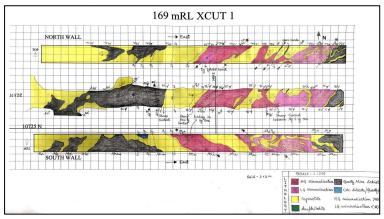
A geological map is a record of geological facts such as occurrence of rocks in space and their contacts, weathering effects such as leaching or gossan, and structure in their correct space relations.

Surface Geological Map

Underground Geological Map

- Regional Scale (1:50,000 – 1:25,000)
- District Scale (1:50,000 – 1:25,000)
- Deposit Scale (1:5000-1:500)





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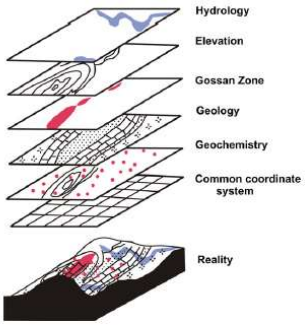
Remote Sensing

Remote sensing is the process of detecting and monitoring the physical characteristics of an area by measuring its reflected and emitted radiation at a distance (typically from satellite or aircraft). Special cameras collect remotely sensed images, which help researchers "sense" things about the Earth.

Application in Mineral Exploration

- Recognizing hydrothermally altered rocks by their spectral signature
- The mapping and analysis of the geology, faults and fractures of an ore deposit

Integration of multilayer data and overlay for multidisciplinary interpretation



Reference – Halder 2013

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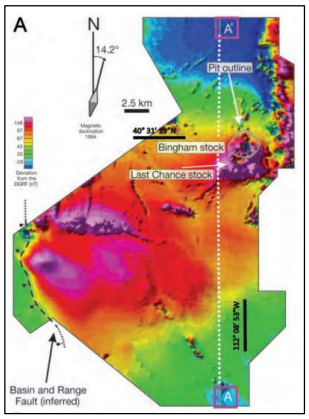
Exploration Geophyics

Exploration Geophyics involves acquisition and interpretation of the physical properties of rocks to determine the subsurface geology.

Method	Application	Examples
Gravimetric	Ground, marine	Heavy minerals deposits, iron ores
Magnetic	Ground, marine, airborne, drill-hole logging	Iron ores, magnetite, pyrrhotite, black sands, kimberlites, chromite ores,
Electrical: Resistivity	Ground, marine, drill-hole logging	Sulfide deposits, massive sulfides, base metals
Radioactive	Ground, airborne, drill-hole logging	Radioactive minerals: uranium, thorium, potassium; coal
Seismic	Ground, marine	Coal, uranium, heavy minerals, buried placer deposits

Integration of geological and geophysical data is the key to the right interpretation.

Aeromagnetic Map over Bingham Porphyry Copper System



Steinberger et al. (2013)

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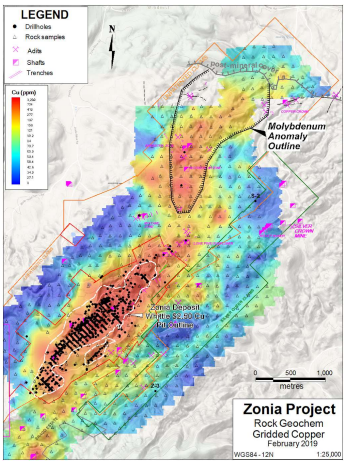
Exploration Geochemistry

fundamentally deals with the enrichment or depletion of certain chemical elements in the vicinity of mineral deposits other than barren regions.

Each deposits, there are central zone or core where valuable elements/minerals are concentrated. The zone surrounding the core deposit is known as halo or anomaly. The analysis of pathfinder elements show the path of mineralization discoveries.

Geochemistry is a important component of mineral exploration as major all deposits are low grade with high tonnage. Discovery is highly dependent on geochemical analysis.



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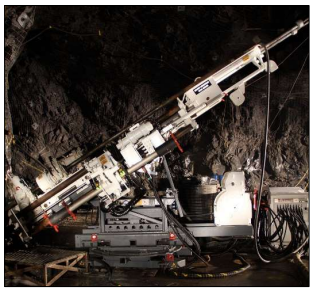
Drilling

Drilling is used for obtaining detailed information about rock types, mineral content, rock fabric, and the relationship between the rock layers close to the surface and at depth.

- Rotary
- Percussive
- Auger
- Reverse Circulation
- Diamond Core



Typically low quality and used for reconnaissance exploration.

Typically high quality and used for definition drilling.

Drilling is the most expensive activity in mineral exploration and therefore warrants careful planning after integrating all surface exploration data

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Geological Logs

Geological Log is a written and/or graphic record of the geologic data obtained from drillhole core and/or cuttings.

- Recovery
- Geotechnical
- Lithology
- Alteration
- Mineralisation
- Structural

Obtaining core is expensive so it is sensible to retain it for future examination.

Core Photography provides excellent platform for digital archiving and future reference for fresh geological appraisal

Photo Courtesy – SRK Consulting

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Sampling

Sampling is a scientific, selective process applied to a large mass or group (a population, as defined by the investigator) in order to reduce its bulk for interpretation purposes.

This is achieved by identifying a component part (a sample) which reflects the characteristics of the parent population within acceptable limits of accuracy, precision, and cost effectiveness.

In the minerals industry the average grade of a tonnage of mineralized rock (the population) is estimated by taking samples which are either a few kilograms or tonnes in weight. These samples are reduced to a few grams (the assay portion) which are analyzed for elements of interest.

Photo Courtesy – SRK Consulting

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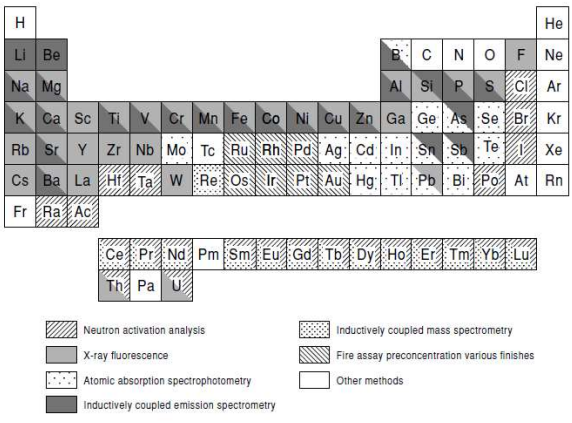
Assay

Assay is a process for the determination of concentration of certain element in ore.

Method	Multielement	Precision	Sample Type
Calorimetry	No	Poor	Solution
AAS	No	Good	Solution
XRF	Yes	Good	Solid
ICP-ES	Yes	Good	Solution
ICP-MS	Yes	Good	Solution

The choice of analytical method should aim at optimizing the main target element through an understanding of mineralogy.



After Moon 2013

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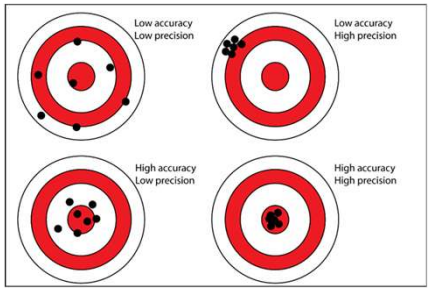
Quality Assurance and Quality Control

Quality Control (QC) – measures that are included in each assay run to ensure that the analytical test has been successfully competed

Quality Assurance (QA) – the overall program / procedures in place to ensure that the final results reported by the laboratory are correct including reporting.

Potential Error Sources	Control Measures
Sampling Errors	Field Duplicate
Contamination	Blank
Sample ID Errors	Blank
Accuracy of Assay Results	Standard/CRM
Precision of Assay Results	Pulp Duplicate
Laboratory Performances	Check Samples in Umpire Laboratory



Identify the potential sources

Analyse, Improve and Control

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Deposit Modelling

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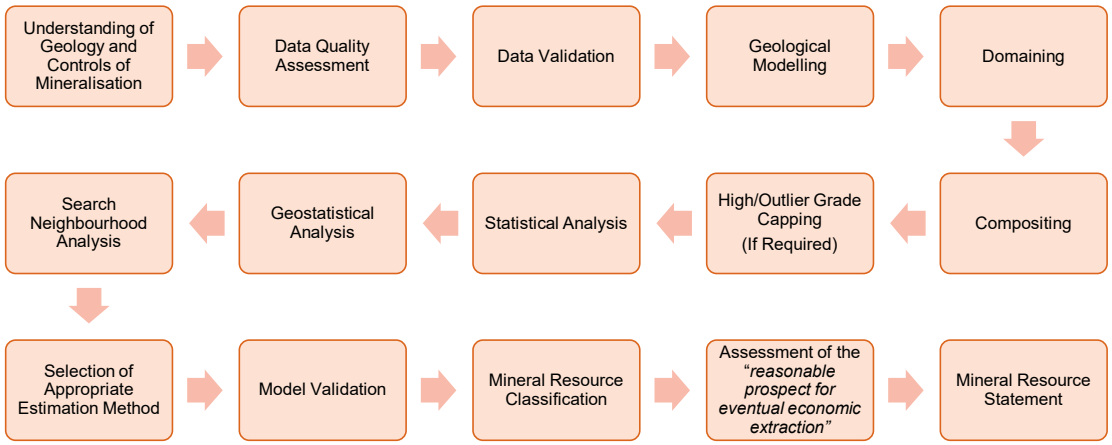
Workflow of Deposit Modelling



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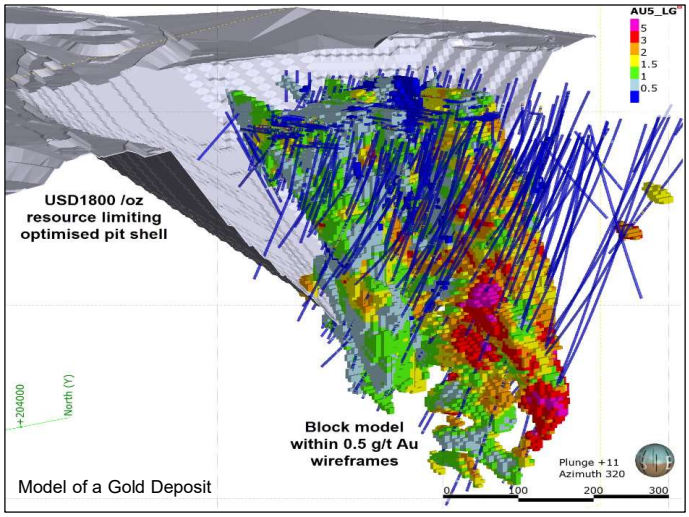
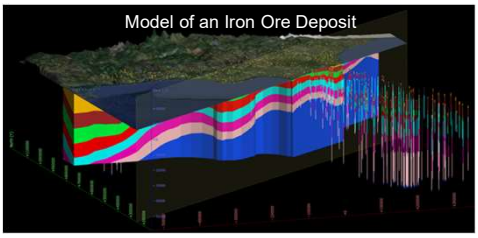
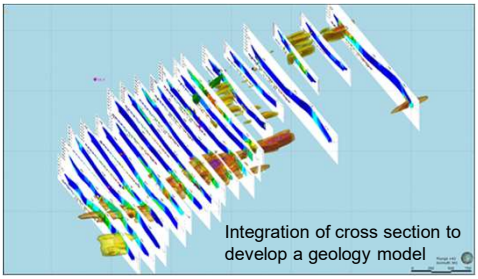
Example of Deposit Modelling







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Reporting

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Stakeholders of Geological Reports

- Geologists/ Engineers – Further Exploration Planning/Engineering Decisions
- Company Management – For better visibility of future business cases and opportunities
- Banks/Investors – Investment Decisions/Valuation
- Government – Maintaining National Inventory/Regulation/Policy Decision

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Guiding Principles

Globally efforts are being made for harmonization of terminologies

CRIRSCO Type Public Reporting Codes for Stock Exchange Listing and Fund Raising
JORC 2012 – Australasia
NI 43-101 – Canada
SAMREC – South Africa

United Nation's Framework Classification System

Other Rule Based Codes
GKZ System (Former Soviet Union)
Indian Standard Practice for Coal

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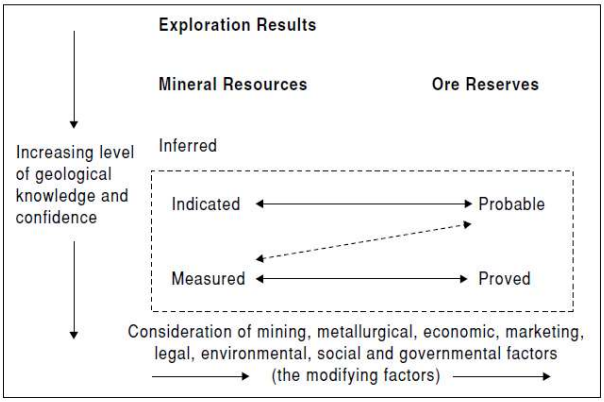
Reporting Principles



Reports should be based on the principles of Transparency, Materiality and Competency

Exploration Results must be presented with sufficient caution – reflecting the uncertainties

Resource and Reserve must not be added together

Mineral Resource Classification and Reporting requires sufficient relevant experience and detailed understanding on the style of mineralization, nature of deposit and activities undertaken.

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Concluding Remarks

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Concluding Remarks

- Mineral Exploration is a time consuming and financially risky activity.
- It involves a series of geological tasks, involving geology, geophysics, geochemistry and several other applied sciences.
- Deposit Modelling can be complicated. A thorough understanding of the geology and data generation processes are essential to undertake deposit modelling.
- Mineral Resource Classification and Reporting requires sufficient relevant experience and detailed understanding on the style of mineralization, nature of deposit and activities undertaken.

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Thank you for your attention

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