Mineral System Science and Exploration Targeting Glossary of Terms

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Accretionary Orogens: These are long-lived (commonly 200Ma but up to > 500 Ma in the case of the Pacific margin) convergent margin settings with a complex history of alternating phases of extension and compression. They differ from simple collisional orogens such as the Himalayas or orogens that reflect a simple Wilson Cycle of continental extension-ocean formation-ocean subduction-continental collision. They are important because almost all significant Cu and Au metallogeny is associated with such orogens.

Advancing Accretionary Orogen: This is an accretionary orogen that is in a dynamic state where the upper and lower plates are converging with respect to each other, resulting in generally compressional geodynamics. The modern Andean margin is a good example.

Base Rate: This is the expected average background rate of the occurrence of some desired outcome; an example is the presence of an economic ore-deposit within an exploration target.

Business Interface: This term means the relationship between purely commercial corporate business objectives and the development of an exploration strategy which must include geoscientific issues.

Camp (also District): This term refers to a genetically-related, spatial cluster of ore deposits, typically of the dimensions of a few km to a few 10s of km. It is proposed that the geological meaning of a camp is a single, underlying fluid reservoir.

Chonolith: This is a term initially used by the Russians to refer to an unusual set of mafic intrusions with a characteristically irregular, pipe-like to tongue-like geometry and associated wall-rock metamorphic aureoles. These intrusions are important because they host Ni-Cu-PGE sulphides. They are thought to represent strongly focused magma conduit systems.

Complex Systems: These are non-equilibrium, energy-flow systems which spontaneously organize themselves so complex patterns emerge. This organisation is driven by the Second Law of Thermodynamics – the systems are maximizing their entropy production. These complex patterns are not predictable from studying individual components. They only exist as long as they are open to energy flow.

Constituent Processes: This is a hierarchical level in the framework proposed by McCuaig et al. (2010) for the practical application of the Mineral Systems approach to developing a targeting model. Constituent processes are those geological processes specific to the deposit type of interest; for example, in Komatiite NiS exploration - assimilation of sulphidic sedimentary rocks.

Critical Processes: These represent the highest hierarchical level in the framework proposed by McCuaig et al. (2010) for the practical application of the Mineral Systems approach to developing a targeting model. Critical Processes in this framework refer to very generic aspects of the mineral system such as “source, trap, transport”.

Detection: This the systematic collection of new exploration data (drilling, geochemical surveying, geophysical surveying) with the objective of directly detecting the presence of mineralisation. Detection activities are only effective in relatively focused target areas.

Distal Footprint: This term covers all aspects of the signature of the presence of a mineral deposit that extend beyond the obvious occurrence of mineralisation. It includes any concentric alteration zonation around a deposit, as well as spent fluid discharge volumes and large-scale fluid delivery systems.

Discharge Zone: This is the location where an ore-hosting fluid exit conduit discharges its fluids into a hydrological sink such as the hydrosphere or a permeable, extensive near-surface aquifer (or in the case of an orthomagmatic deposit, where a magma conduit discharges into a large sill-form magma chamber). These are important because some ore deposit types (e.g., MVT Pb-Zn deposits, VMS deposits) form in this setting.

Elephant Country Targeting Strategy: This targeting strategy focuses on provinces where giant deposits (“Elephants”) are already known. The main risk with this strategy is that no realistic opportunities remain in the province, or if they do, they are not realistically commercially available.

Emergent Property: This is a characteristic (or property) of a complex system that arises from the complex detailed interactions of the system, but that cannot be predicted from these interactions. Power-law size-frequency distributions, such as the Gutenberg-Richter relationship for earthquakes, are a good example. The highly organised behaviour of ant colonies is another good example.

Empirical Models: These are models for targeting ore deposits that are based on the empirically known attributes of the target orebody type. They are also known as Analogue Models because they are based on trying to find new deposits that are “analogues” to existing, well-documented deposits.

EMV: This is an abbreviation for Expected Monetary Value. The EMV provides an estimate of the value of a high-risk investment option such as a mineral exploration project. It is calculated using the formula: EMV = ($P_{success}$ x Pay-off if successful) - ($P_{failure}$ x cost of failure). In theory, the EMV is the average value that would be achieved if a large number of very similar high-risk investments were made. It is a risk-preference neutral measure of value, so it does not approximate well to market valuations.

Entropy: This is a thermodynamic concept and is basically low-grade, diffuse heat that cannot be harnessed to do anything useful. All natural systems want to maximise their entropy (if they are closed systems) or maximise their entropy production (if they are open systems). This is an important concept in targeting because it implies that all major ore systems should also have significant associated thermal anomaly haloes.

Explorability: This means the practical ability to explore an exploration target systematically. In some cases, conceptually high-quality exploration targets cannot be economically explored because factors such as excessive cover depth mean that the target has low Explorability.

Exploration Search Space: This is the set of parameters that constrain economically effective exploration. These relate to factors such as cover depth, geographical area and deposit type. In many cases, the concept of the Search Space relates directly to a specific new (ie previously unexplored) rock volume but in other cases it relates to looking at previously explored rock volumes for new target types.

False-Positive: This term means a positive response obtained by an exploration technology or targeting concept that does not correlate with the presence of an ore-deposit.

False-Positive Rate: This is the proportionate number of times that a positive response obtained by an exploration technology or targeting concept does not correlate with the presence of an ore-deposit. False-positive rates are characteristically high for most common exploration technologies.

Fertility: This term refers to the tendency for any particular geological region or geological time period to be significantly better endowed in mineral deposits (in terms of both their number and size) than geological environments that are otherwise comparable. Fertility in this context (related to ore deposits) is a different concept to fertility in a petrological sense; the latter relates to the re-enrichment of previously depleted mantle lithosphere by relatively incompatible components such as Ca, Al, Na, K and H_2O.

First Mover Targeting Strategy: This is a targeting strategy that focuses on identifying, and then being first to explore, potentially prospective geological environments that have not been previously targeted for the commodity of interest.

Fluid Delivery Pathway: This is a large-scale permeability architecture that has delivered potential ore-forming fluids from a large, diffuse source region to the reservoirs which are inferred to underlie major ore deposits. This architecture is defined by fracture permeability associated with Master Conduit structures (in almost all cases) and also (in some cases) by permeable stratigraphic horizons. These fluid delivery pathways may leave a distinctive alteration signature, e.g., the formation of "red-beds" in clastic sequences or dolomitisation in carbonate rocks.

Fluid Exit Conduit: This is an extremely high-permeability rock-volume that forms (for a short period of time) above an over-pressured fluid reservoir when it ruptures and therefore intensely focuses fluid and/or magma flow. They tend to be broadly pipe-like to ribbon-like in geometry. Porphyry stocks and NiS hosting chonoliths are good examples. They are very important because they are the primary geological element that hosts ore deposits.

Fluid Flow Barrier: This is a physical barrier to the continuous ascent of potentially ore-forming fluids/magmas that results in the formation of an over-pressured reservoir (until it is breached, drained and the over-pressuring process begins again). These barriers may be a physical seal (i.e., an impermeable lithology) but may also be caused by an interflow of tectonic stress conditions and crustal depth. These barriers are the reason why fluid flow systems self-organise. In the terminology used by physicists to refer to SOC systems, they are referred to as Threshold Barriers.

Fluid Reservoir: This is an over-pressured rock volume that forms beneath a fluid flow barrier. These reservoirs periodically rupture to produce ore-forming fluid exit conduits. Fluid reservoirs probably provide the geological meaning to the concept of a Camp or District (of deposits); all the deposits in a single camp may be sourced from the same underlying fluid reservoir.

Fluid Sink: This the ultimate discharge and dispersal site for the fluids that have organised to form an ore-deposit. Fluid Sinks are likely to be either the hydrosphere (eg bottom of the ocean, as is the case for VMS deposits) or a permeable stratigraphic horizon (eg carbonate reefs such as is the case for MVT deposits). In the case of orthomagmatic systems, they may also represent large sill-form magma chambers.

Fractal: This describes geometry that is self-similar (i.e., it looks the same at different scales).

Fundamental (Lithospheric) Architecture: This is the arrangement of the basic structural building blocks that constitute our continents. These domains tend to be of a scale of a few hundred km in diameter. They are likely to have formed early in the earth's history, probably by the end of the Mesoarchean. Although their boundaries are inherently prone to reactivation in later orogenic events, they do not necessarily all become important tectonic boundaries in every cycle. However, even if they are not such boundaries, they are still favourable sites for the development of Master Conduits.

GIS: This is an acronym for Geographical Information System: a computerised methodology for assembling diverse data sets in a common spatial framework. This assembly of data sets may then be used at two levels: a) qualitative comparison and synthesis of the various data layers, and b) mathematical analysis of the relationships between various data elements with the goal of generating prospectivity maps.

Heuristic: This is a mental short-cut or "rule of thumb" that we use to speed up mental processing, but that can mislead us in many contexts in mineral exploration because human beings have not evolved to deal well with situations of high risk and uncertainty.

High Unit Value Deposit: This is a mineral deposit with a high monetary value per tonne of ore. The economics of such deposits are relatively insensitive to the depth of the deposit. Therefore, they are good targets in areas of deeper cover.

Inverted Rift: This term refers to a former rift zone that has been closed (inverted) by compressional deformation, commonly becoming a localised region of uplift and stronger deformation. These zones are important because they are hosts to several major deposit types including VMS and Orogenic Au deposits. These zones have characteristic geological patterns that enable their recognition within broader orogens.

Lineament: This is a linear pattern of structural elements and discontinuities in plan that cannot be correlated easily with any discrete mapped structure at the current erosional level, but that in most cases probably represent the manifestations of a master structure at depth. O'Driscoll-type lineaments are a particular type of lineament that probably has a somewhat different genesis.

Lithosphere: This is the rigid outer layer of the earth. It is comprised of a relatively thin upper layer with a felsic to intermediate composition (the Crust) and a much thicker lower layer of depleted upper mantle with a peridotite composition (sub-continental lithospheric mantle).

Lithospheric Architecture: This is the large-scale structure of the continental lithosphere, comprising a mosaic of discrete domains. Domain boundaries are particularly significant sites for localisation of later tectonic activity and mineralisation.

Lithosphere Enrichment: This refers to a process whereby the upper mantle lithosphere beneath continents becomes locally enriched in incompatible elements, most significantly those of economic importance such as gold. This enrichment seems to be a critical factor in regional-scale variations in fertility for some commodities, most notably gold.

Mappable Targeting Criteria: These criteria comprise the lowest hierarchical level in the framework proposed by McCuaig et al. (2010) for the practical application of the Mineral Systems approach to developing a targeting model. Mappable targeting criteria are those actual patterns or elements that can be identified in our typical exploration data sets (e.g., magnetics) that we interpret to reflect aspects of our mineral-system based targeting model.

Master Conduit: This term refers to a fundamental, steep dipping trans-lithospheric structural zone that organises mineralisation-related fluid flow through the lithosphere. Most large ore-deposits are closely associated with such structures, but their signature may be cryptic in commonly-available near-surface geological data sets.

Mineral System: This is the *entire* physico-chemical system that results in the formation of an ore deposit. These are very large scale systems, commonly continental-scale.

Mineral System Science: This is the science of understanding mineral systems and defining their key process components at all scales. It also has the goal of mapping these components to physical rock volumes and defining the key generic unifying process elements that govern ore-forming systems.

Ocean-Continent Transition: This is the transitional zone present in many extensional continental margins between clearly oceanic and clearly rifted continental lithosphere. It is now recognised that this zone is commonly characterised by the total removal of continental crust, but exhumed continental lithospheric mantle. The existence of this transition zone during extensional tectonics has significant implications for the basement structure of accretionary orogens when they are inverted by compressional tectonics; it means that younger crust will commonly end up overlying an older basement of continental lithosphere.

O'Driscoll-type Lineament: This is an enigmatic type of empirically observed regional-scale lineament that can be tracked across large continental areas, including across tectonic boundaries known to be the loci of significant differential tectonic motion. These structures are best seen in diffuse, low-resolution data-sets. They cannot represent any discrete fundamental structures at depth and instead must represent long-lived patterns of organisation that last longer than the elements that form them at any one time. These structures are important because they show an empirical correlation with the very largest ore deposits.

Opportunity Cost: This is an economic concept that relates to the potential value that is foregone (associated with alternative opportunities) when we make a decision to commit to a particular investment opportunity.

Option Value: This term refers to the potential additional future value of a mineral deposit that may not be formally recognised at the time of its discovery or purchase. This value is usually associated with expanding the production rate in the future through expansions of the resource base, either through near-mine exploration success or technological innovation. This may also be referred to as Long-term Option Value, and doing so recognises that often this option value is either not realised for considerable periods of time or may continue to be realised over a long period of time.

Paleo-latitude: This is the geographical latitude at which a mineral system was located during the time of its active formation. This concept is most important in relation to sediment hosted base-metal deposits which show a strong association with Paleo-latitudes between 40^{o} N and 40^{o} S, which is thought to represent the interval where evaporites may have formed.

Pericontinental Rift: This is a rift that has formed at the margin of a continental or micro-continental block during continental extension, usually though the reactivation of an older basement structure. The linear, localised nature of a peri-continental rift distinguishes it from the general processes of extension that occur at continental margins.

Permissive Principle: This is a philosophical principle that is relevant to targeting. Simply stated, the principle is that, if there is no negative evidence for the presence of a particular favourable targeting element (i.e., because of the lack of available data), the element should be assumed to be present until proven otherwise.

Potential Master Conduit: This is a regional-scale structure that is inferred (from a synthesis of a variety of geological and geophysical datasets) to represent a long-lived, steep-dipping, translithospheric discontinuity. When tectonically active, such structures provide the first-order organisation of mineralisation-related crustal fluid flow. However, depending on the tectonic history, not all Potential Master Conduits will be active during every metallogenic event that affects their region.

Potential Master Conduit Network: This term refers to the interpreted network of Potential Master Conduit structures that are inferred from a synthesis of a variety of geological and geophysical datasets. This is the essential and most important ingredient in any targeting exercise.

Power Law: This is a mathematical relationship represented by $\mathbf{y=ax^{k}}$. Power Laws are common in natural processes and reflect the signature of a system optimising the process

of removing a gradient to energy flow. A famous power-law relationship in geology is the Gutenberg-Richter Law that relates the size and frequency of earthquakes. Importantly, mineral deposit size-frequency distributions show characteristic power law relationships. Fractal spatial distributions often manifest as Power Law size frequency distributions. Zipf's Law is a particular type of Power Law.

Prediction: In the exploration business predictions are made about locations with the potential to host ore deposits, usually on the basis of data that is already in existence. Prediction operates best at the larger, more regional scales and gives way to Detection in relative effectiveness at smaller scales.

Primary Fluid Source Region: This is the original source for the fluids that form a mineral system. The two most important fluid sources are magmas (and magma source regions) and the hydrosphere (rain on highlands, coastal lagoons etc).

Probabilistic Targeting: This is a process that seeks to generate targets that are quantified by estimating the probability of success of an ore discovery. This process is generally associated with more complex targeting models. Although widely applied in the petroleum industry, it has not yet been used very much in mineral exploration.

Process Models: These are the targeting models that are based on the fundamental processes involved in the formation of an ore deposit. These are sometimes also referred to as conceptual models. The Mineral System approach is a specific type of process model that focuses on the entire system scale.

Prospectivity Maps: These are maps of a region of interest that show estimated prospectivity of discovery generated by some type of automated GIS-based methodology.

Proxy: This refers to a particular element of pattern that may be recognised in available data sets but that is inferred to represent the occurrence of a more conceptual targeting ingredient. For example, gravity gradients may be considered a proxy for the occurrence of a Potential Master Conduit Structure.

Quantitative Risk Analysis: This is a process that seeks to provide numerical estimates of the likely economic value of exploration targets. It is closely related to probabilistic targeting which is a necessary input to allow Quantitative Risk Analysis. Although widely applied in the petroleum industry, it has not yet been used very much in mineral exploration.

Representativeness: This term refers to the degree to which a particular Proxy is likely to actually represent the desired targeting ingredient. For example, a strong gradient in

Magnetotelluric data is likely to be a more representative proxy for deep crustal structure than is a lineament in magnetic data.

Resolution: This is the spatial detail used by a particular data set to map the earth's surface or rock volume.

Retreating Accretionary Orogen: The typical dynamic state of a long-lived convergent margin orogen, characterised by subduction zone roll-back and extensional tectonics (e.g., back-arc rifting) in the upper plate. This phase of orogenic history is generally not metallogenically prospective except, sometimes, for VMS base metal deposits within rifting arc lithosphere, or for Au and Cu-Au deposits within the continental retroarc following the end of a flat-slab episode.

Risk: This word is used in many different contexts in English, even just within the exploration and mining industry. In this context, Risk is taken to mean our best estimate of the likelihood of failure of an exploration opportunity (target or project) and is therefore the inverse of Probability of Success. Risk should not be confused with Uncertainty.

SCLM: This is an acronym for Sub-continental Lithospheric Mantle. This is the upper rigid part of the mantle that does not participate in mantle convection and is strongly linked to the overlying crust. It is typically relatively geochemically depleted (with a depleted Ilherzolite to Harzburgite composition) and the majority of it was probably formed in the Archean. It may also be referred to as non-convecting upper mantle or continental lithospheric mantle.

Secular Patterns: These are changes in the geological environment of all types (atmosphere, hydrosphere, biosphere, mantle convection pattern, super-continent cycles) that show systematic patterns of variation throughout earth history. These patterns provide a first order control on the temporal and spatial patterns of distribution of many ore deposit types.

Self-Organised Critical System: In this context, the term is used in the sense of Bak et al. (1987). SOC systems are complex dynamic systems characterised by slow, continuous energy input and rapid, discontinuous, but highly organized, energy output. Ore formation is proposed to be related to these output events.

Sherman-Kent Scale: This scale was designed to translate verbal, qualitative estimates of likelihood into quantitative estimates of probability. For example, "highly likely" translates to Probability of 0.75-0.90. This scale has been designed to assist in quantitatively capturing expert opinion.

Size-Frequency Distribution: This refers to the relationship between the size of a particular entity and the frequency of its occurrence; in this context, it is primarily applied to mineral deposits. Deposit size-frequency distributions typically show Power-Law characteristics.

Syn-Cycle (Lithospheric) Architecture: This term refers to the arrangement of lithospheric domains that have behaved as coherent structural entities during a particular orogenic cycle of interest. Syn-cycle domains may comprise one or more fundamental lithospheric domains. There has been a general tendency for the size of syn-cycle lithospheric domains to increase throughout geological time, with each major super-continental cycle being associated with, on average, larger domains. This presumably reflects the secular cooling of the earth.

Targeting Elements: This is an intermediate hierarchical level in the framework proposed by McCuaig et al. (2010) for the practical application of the Mineral Systems approach to developing a targeting model. This level refers to the particular geological features, which are considered to be proxies for key constituent processes, and whose expression we seek in our available datasets (i.e. mappable targeting criteria). For example, the presence of sulphide-rich sediments might be a targeting element that is a proxy for the presence of an inverted rift zone (a constituent process).

Targeting Science: This is a body of practical knowledge and concepts that is concerned with the applied process of mineral exploration targeting. Targeting science deals with the outputs of mineral system science, as well as the interface with economic objectives, the constraints imposed by previous exploration activity and the development of the most effective targeting methodologies (including with reference to available exploration technologies).

Translithospheric Fault: This is a fault or fracture that is interpreted to transect the entire lithosphere, including the upper mantle section. Generally these are expressed in the crust as discontinuities manifest in regional-scale geophysical, geological, topographic, or spectral data, and they may sometimes correspond with mapped faults or fracture sets.

Uncertainty: This refers to the lack of precise knowledge regarding key input parameters into the targeting process. This must not be confused with risk - a highly uncertain project is not necessarily higher risk than a low uncertainty project**.**

World-Class Deposit: This term refers to that small proportion of mineral deposits that comprise the majority of the industry's production and wealth generation. These are large, high-margin deposits that can maintain profitability throughout the entire business cycle.

Zipf's Law: This is a particular application of the Power-Law concept that focuses on the rank order of elements in a size-frequency distribution. In this context, it has been applied to mineral-deposit size-frequency data in order to help estimate the residual endowment of a mineral province. In this situation, the general formula for Zipf's Law is $\mathbf{y=cr^{-k}}$ where:

y = the size of element of rank **r**
c = a scaling factor equal to the size of the largest deposit
k = a constant, considered to approximate 1