The 'future of work' in minerals exploration – working under cover, searching for critical minerals, complying with ESG, or playing the 'Great Game'?

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ABSTRACT

For contemporary explorers both the nature and objectives of their work seems to become ever broader, beyond the traditional geological and technical aspects, complicated by sociopolitical and environmental factors, such as ESG investor requirements and Native Title negotiation, as well as the complexities of new technologies and innovations, such as geometallurgy, drones, artificial intelligence (AI), and 'big data'.

Whilst all explorers are cognisant of these issues, navigating them as an individual, team, or company is challenging. Strategically, the risk is being 'stuck in the middle' with no clear focus on ***for what it is that explorers should be looking*** and ***how they should be conducting exploration.***

The Centre for Exploration Targeting 'Future of Mining and Exploration' Scenarios (CET Scenarios) were established seven years ago to investigate these two issues. The workshops were run in Perth in 2016 and involved over 60 experts in mining, exploration, and other relevant fields. Since then, work has continued in understanding the implications of the scenarios and updating the scenarios in line with contemporary developments.

Ultimately, four sets of scenarios were developed – the 'Medieval', 'Novel', 'Star', and 'Dickensian' scenarios, which were framed by the interaction of economics, the environment, socio-politics, and geopolitics on our natural mineral resources. Based on these scenarios four conceptual, global search spaces were devised reflecting broad exploration opportunities open to miners and explorers:

1. **Under cover:** A well-established search space where mineral deposits have been hidden by deep non-economic cover, and which may also require expensive or new deep mining technologies.
2. **New minerals:** The focus of this conference, and a search space, which contains the many minor metals and minerals deemed 'critical' or 'strategic' and often associated with the energy transition.
3. **Socio-political:** This is the search space where if explorers can overcome, usually local, objections to mine development, they will be able to profitably discover and mine 'traditional' deposits using current technology.
4. **Geopolitical:** Another search space more obviously associated with this conference. The most common form is utilising government support to explore and develop more marginal mineral deposits, which are deemed strategic due to their domestic or 'friendly' location.

These search spaces are not only located in physically very different locations around the world but require vastly different skills and resources to overcome the barriers to entry. Expecting a single explorer, exploration team, or even a big mining company to master such a range of requirements is implausible. As such, in returning to the strategic question of ***for what*** and ***how to explore***, the message to explorers is not to pursue all these search spaces, but to focus on one (or two) in which the opportunity is aligned with the strengths of the explorer, team, or company, or in which such capabilities can be built.

This paper will begin outlining the nature of the mineral targets in the four different conceptual search spaces, their economic value, and the barriers to entry, and what the key skills and resources to unlock these search spaces will be.

AUTHOR'S NOTE

This work is intended to form the core of my pending PhD thesis discussion chapter. As such it is an ongoing piece of work. An earlier version of this work is to be presented as an abstract and poster at the AusIMM Critical Minerals Conference in Perth in November, 2023 (Sykes et al., 2023c, Sykes et al., 2023d). An 'early draft paper' is including below to give some idea of the direction of the ongoing work.

EARLY DRAFT PAPER

For contemporary mining and exploration geologists both the nature and objectives of their work seems to become ever broader and ever more complex (Sykes et al., 2018, Trench et al., 2018, Davies and Davies, 2018).

The nature of exploration and mining geology complexity

Complexity is added to the search for, development of, and exploitation of mineral deposits in the non-technical arena (Trench et al., 2014) by sociopolitical, geopolitical, and environmental factors, such as ESG investor requirements, environmental baseline studies, Native Title negotiation, and more recently geopolitical trade restrictions (Hale, 2022, Sharma, 2023), and decarbonisation efforts (Sykes et al., 2023a).

On the technical side, the processes of exploration, development, and mining are made more complex by the increasing depth (Schodde, 2014a, 2014b, 2017, Davies and Davies, 2018), decreasing grade, increasing waste and input-resource intensity (Mudd, 2007, 2010, Northey et al., 2013, 2014, Calvo et al., 2016), and less favourable metallurgy of orebodies over time (Olson Hoal and Frenzel, 2022). In turn, the technologies and innovations required to tackle this complexity, such as automation and robotics, artificial intelligence (AI), 'big data', block caving, data analytics, drones, electric mine vehicles, geometallurgy, portable analytics, remote operation, and the 'Internet of Things' (IoT), amongst many others (Schodde, 2019, Okada, 2022), whilst, admittedly, helping tackle these technical problems, do in themselves add further complexity to the work of geologists (Davies and Davies, 2018, Okada, 2022).

Whilst all geologists are cognisant of these multiplying technical and non-technical issues in the future of their work, navigating them as an individual, team, or company is challenging. Strategically, the risk is being ‘stuck in the middle’ (Porter, 1980, 1985) with no clear focus on for what it is that exploration geologists should be looking and how they should be conducting exploration; and both what sorts of mineral deposits, and how, mining geologists will be developing, operating, and closing mines in the future.

Tackling future complexity using scenarios

For the interpretation of the future of complex problems, like the ‘future of work’ problem for exploration and mining geologists outlined above, scenario planning is commonly used by private, public sector, and non-governmental organisations, including many large mining and energy companies (Ilbury and Sunter, 2001, Kahane, 2012, Wilkinson and Kupers, 2014, Ramírez and Wilkinson, 2016, Sykes et al., 2018).

One such example is The Centre for Exploration Targeting ‘Future of Mining and Exploration’ Scenarios (CET Scenarios). The overriding questions under investigation are those described above - ‘for what will we be exploring’ (i.e., the future of mining – and mining geology) and ‘how will we be exploring’ (i.e., the future of exploration – and exploration geology). The ‘CET Scenarios’ workshops were run in Perth in 2016 and involved over 60 experts in mining, exploration, and other relevant fields, with the aim of instigating further relevant research themes on the subjects arising in the scenarios workshops.

In line with this aim, work has continued in understanding the implications of the scenarios, conducting related research, communicating the ideas and receiving feedback, and updating the scenarios in line with contemporary developments. Several iterations of such related research has been published at a variety of AusIMM conferences, including previous Future Mining Conferences (Sykes et al., 2015), as well as those on mining geology (McCuaig et al., 2014, Sykes and Trench, 2014, Sykes et al., 2017), mine management (Sykes and Trench, 2016), complex orebodies (Sykes et al., 2018, Trench et al., 2018), critical minerals (Sykes et al., 2023b, Sykes et al., 2023c), for ‘new leaders’ (Sykes, 2014) and in New Zealand (Sykes et al., 2016b).

The ’CET Scenarios’ and the restrictions on exploration and mining

Ultimately, four sets of scenarios were developed – the ‘Medieval’ (Sykes and Trench, 2016), ‘Novel’ (Sykes et al., 2023b), ‘Star’ (Sykes et al., 2016b), and ‘Dickensian’ (Sykes et al., 2017) scenarios, which were framed by the interaction of economics, the environment, socio-politics, and geopolitics on our natural mineral resources. The key concept was that the remaining conceptual search space (Hronsky, 2009) for explorers – and thus the future of mining was defined by:

1. **Access restricted (search space):** Likely economic mineral deposits awaiting discovery in prospective terrains, but in which ‘access’ was restricted by one or more of a combination of technological, environmental, sociopolitical, and geopolitical factors (Sykes and Trench, 2014); or conversely,
2. **Economically restricted (search space):** Likely, marginally uneconomic mineral deposits awaiting discovery in terrains of lesser prospectivity, but in locations with supportive ‘access’ and thus more limited technological, environmental, sociopolitical, and geopolitical factors.

Examples of the first set (access restricted) would include mineral deposits ‘too deep’ to be either discovered or economically mined (i.e. technical restrictions); those in countries in which foreign investment is discouraged, such as China and Russia (‘geopolitical’ or ‘strategic’ restrictions); those in which there are objections from local communities and with Native Title complications (socio-political restrictions); and those in environmentally sensitive areas, such as National Parks, or which contribute greatly to climate change, such as coal deposits (environmental restrictions).

Examples of the second set (economically restricted) would include mineral deposits that have strong government support, despite questionable economics, because the minerals produced are deemed ‘critical’ for the domestic economy (‘geopolitical’ or ‘strategic’ support), or the mine itself, is deemed to be strategically important due to the provision of jobs, involvement in regional or rural development, or confers favour to a political party or interest group (sociopolitical support).

The 'CET Scenarios' and the 'search spaces' of the future

The remaining conceptual search space (Hronsky, 2009), in turn, can be divided into four partial types:

1. **Under cover:** A well-established search space where mineral deposits have been hidden by deep non-economic cover (Rowe, 2017, Gonzalez-Alvarez et al., 2020), and which may also require expensive or new deep exploration and mining technologies (Giles et al., 2014, Schodde, 2014a, 2014b, 2017, Trench et al., 2015, Rowe, 2017, Gonzalez-Alvarez et al., 2020, Okada, 2022). Physically this search space is mainly found in mature minerals terrain, from which it is easier (and thus less expensive) to undertake technologically risky exploration and mining (Merrow, 2011), and in which existing infrastructure also mitigates some of the risk of any new mining technologies that are required. Large-scale deep underground mining techniques, such as block caving are more likely to be associated with this search space, as may novel technologies, such as deep solution mining. Australia (Schodde, 2014a), North America (Okada, 2022), Chile (García et al., 2017, Hope et al., 2017, Wood and Trott, 2017), and Scandinavia serve as national or regional examples.
2. **New minerals:** An (always) emerging search space, which contains the many minor metals and minerals often deemed as 'critical' or 'strategic' and often, but not always, associated with the energy transition (Sykes et al., 2023a). Because, by definition, these minor metals and minerals have **not** been the subject of much previous exploration, they can be found all over the world. However, again, mature terrains and developed world locations are likely more favourable, but in this case, to mitigate the risk of entry into these 'minor' markets, which are often characterised by opaque pricing, oligopoly, vertical integration, and state interference (Maxwell, 2015, Sykes et al., 2016a, 2016c), and in which new exploration, mining, and processing technologies are required (Sykes et al., 2016a, 2016c, Trench et al., 2018), new marketing and financing arrangements need to be established (Trench et al., 2018), and often more downstream infrastructure is required (Stuckey and White, 1993, Trench et al., 2018). Fields such as geometallurgy (Olson Hoal and Frenzel, 2022) seem likely to be particularly important in this search space.
3. **Socio-political:** This is the search space where if explorers can overcome, usually local, objections to mine development (Sykes et al., 2016b, Sykes and Trench, 2016), they will be able to discover more traditional, economic mineral deposits, such as bulk surface deposits, or high grade shallow underground deposits, that from a technological perspective can be discovered and mined profitably with current technology. The challenges facing miners and mining geologists may be more 'traditional' and be focused on the miners themselves, such as worker productivity, employment conditions, health and safety, skills and training, etc. There is a tendency to assume that such socio-politically restricted search space is usually found in the developing world (Sykes et al., 2014), and from the perspective of geological prospectivity (Mejia and Aliakbari, 2023), this is true; however, there are still areas of the developed world, which also often have clearer legal frameworks (Mejia and Aliakbari, 2023), where such opportunities may lie.
4. **Geopolitical (or 'strategic'):** Another search space, which has become much more apparent in recent years (Sykes et al., 2017, 2023a, Gulley et al., 2018), though due to its restriction, rather than growth, at least, from a 'Western' or Australian perspective, due to the trade war with China (Gulley et al., 2018) and the military war between Russia and Ukraine (Faiola and Bennett, 2022, Hale, 2022), amongst other political ('cold') or military ('hot') conflicts.

   There are two parts to this search space (as outlined earlier). The most common form is utilising government support to explore and develop more marginal mineral deposits, which are deemed 'strategic' or 'critical', and thus physically this search space is usually found in the developed 'Western' world. A local example of such a mine project is Iluka's Eneabba rare earth project in Western Australia, which received extra financial support from the

Australian government via its ‘Critical Minerals Facility’ to increase the capacity of the project, beyond what is required economically for the Eneabba tailings themselves, so that the processing facilities can be used more strategically to help develop other ‘stranded’ rare earths deposits in Western Australia, especially those owned by financially constrained junior companies (Iluka, 2023).

A less discussed, but nonetheless quietly applied approach to accessing otherwise restricted search space, involves anticipating and positioning for changes in the geopolitical favour to gain earlier access as a foreigner to a previously geopolitically closed country or region. A historic and contemporary example of this would be Iran, in which foreign ‘Western’ investment is currently discouraged by both Iranian and Western governments, but in which over which over the last one hundred years, both domestic Iranian and foreign ‘Western’ political sentiment has fluctuated several times (Frankopan, 2015). Japan represents another historical example of an ‘enemy’ turned ‘allied’ country to the ‘West’, which in this case has invested significantly in the Western minerals industry, especially in Australia (Kneeshaw et al., 2003, Lee, 2013). In the present day, countries such as Ukraine (Faiola and Bennett, 2022), Russia (Bortnikov et al., 2016, Hale, 2022), China (Sharma, 2023), and Myanmar (Gardiner et al., 2015, Gardiner and Sykes, 2016), will be of interest to geopolitically minded explorers looking for both new deposits and new sources of funds, as will traditionally neutral countries, with major mining and industrial sectors, such as India and Indonesia (The Economist, 2023), which may present an increasing source of competition to ‘Western’ and Australian miners, in this search space.

Case studies of the four conceptual search spaces

Four case studies of successful, relatively recent mineral discoveries and mine development have been compiled to help illustrate the nature of these four conceptual search spaces and the potential skills and capabilities required to successfully operate within these search spaces.

Under cover: Carrapeteena Cu-Au mine, South Australia, BHP

- Phase 1 is a sub-level caving mine, with a capacity of 65,000tpa Cu, and which began operating in 2019. Phase 2 is planned to be a larger block-caving operation (Sykes et al., 2023d).

- It is an Iron-Oxide-Cu-Au (IOCG) deposit, but at an average of 450m depth, entirely under cover. A consortium including a prospector, Teck Resources, and the South Australian government discovered the deposit in 2005. Extensive drilling was required for discovery – and resource development (Sykes et al., 2023d).

- It was developed by OZ Minerals, requiring numerous technical studies and concepts over a decade, as well as extensive UG development prior to feasibility. BHP bought OZ Minerals in 2022. Structural geology is critical for bulk underground mining and IOCG deposits are typically metallurgically complex. ‘Orexplore’ core scanning will be used at Carrapateena (Sykes et al., 2023d).

- Uranium in the South Australian IOCG deposits can be a marketing, environmental, and socio-political problem, though this does not appear to have been a major issue at the mine, thus far (Sykes et al., 2023d).

- The remote location can relieve environmental and socio-political pressures; however, conversely, there can be government pressure for local employment, beneficiation, etc., especially as a *quid pro quo* for earlier support. This doesn’t appear to have been a problem at Carrapateena yet (Sykes et al., 2023d).

New minerals: Sinclair Cs mine (closed), Western Australia, Pioneer Resources

- Sinclair Cs mine operated for around 1-year before mining its entire resource. It is located in the WA goldfields in an area of gold, nickel, and lithium mining. Mining was conventional open pit. Discovery to development was only two years (Sykes et al., 2023d).

- The caesium discovery was ‘fortuitously’ made whilst exploring for lithium. Otherwise, exploration was conventional (soil sampling of known pegmatites, handheld XRF, RC drilling, etc.,) – and done by a modestly-funded ‘junior explorer’ – Pioneer Resources. Some modest innovation in calibrating handheld XRF to work with lithium was nonetheless required. Geologists also had to familiarise themselves with geology and crystals that in themselves are not unusual but are certainly not amongst the core knowledge of most geologists (Sykes et al., 2023d).

- The challenges of processing pollucite into a caesium product were avoided in this case by selling ‘raw ore’. An additional, if modest, side business was created in selling ‘mineral samples’ (Sykes et al., 2023d).

- Caesium is rare and the market very small. Again, fortuitously, Pioneer Resources’ had unusual expertise in mineral markets and economics on the Board, which helped both in recognising the opportunity and navigating the marketing of such a niche product. Caesium is mainly used as ‘formate’ for oil and gas drilling. Interestingly, this market is a novel example of business model innovation, chemical leasing, and the ‘circular economy’ (Sykes et al., 2023d).

Socio-political: Quellaveco Cu mine, Peru, Anglo American

- Quelleveco Cu mine began operations in 2022 and is expected to produce 300,000tpa Cu, over a mine life 35-years. It cost US$5.5 billion to build and construction alone took 4-years (Sykes et al., 2023d).

- Anglo American acquired the project in 1992 meaning the discovery-to-operation timeline was more than 20-years. The project faced significant protests in the 2000s. Anglo American joined an experimental 'dialogue roundtable' in 2011-12, even though a similar effort had failed in 2008. The dialogue established rules around local groundwater use and required Anglo American to build two reservoirs, one for the mine, and one for local communities, as well as make a commitment to local employment. The dialogue process has since been adopted by the United Nations and World Bank for systemisation and implementation across the mining industry (Sykes et al., 2023d).

- The operation is a conventional open pit with sulphide flotation processing. The deposit is a classic porphyry copper of the sort seen throughout the Andes. Several large Cu mines were already present in the area. Nonetheless, as a newly built mine, it hosts the latest technologies in digitalisation, communications, and automation. Details on discovery are not readily available in the public domain, suggesting that exploration and discovery were not in themselves remarkable, beyond the not insignificant challenges of exploring in the high Andes (Sykes et al., 2023d).

Geopolitical: Jabal Sayid Cu mine, Saudi Arabia, Barrick & Ma'aden

- The mine began commercial production in 2016 and now typically produces around 65,000tpa Cu. It has a remaining mine life of around ten-years. Mining is a conventional underground operation with sulphide milling and flotation. It is a typical modest-sized Volcanic Massive Sulphide (VMS) deposit (Sykes et al., 2023d).

- The deposit was discovered by the French geological survey (BRGM) in 1965. At the time Saudi Arabia would have been a relatively frontier nation for minerals exploration. Despite hosting ancient civilisations, with attendant evidence of ancient mining activities thousands of years ago, Saudi Arabia has only developed a modern mining industry in recent decades. Saudi Arabia has long sought to diversify away from oil, with the establishment of Ma'aden in 1997 as part of the process (Sykes et al., 2023d).

- Jabal Sayid is now a 50:50 joint-venture between Barrick and state miner, Ma'aden. It has a long history of ownership including foreign and Saudi state interests, various foreign junior explorers, a variety of potential funders, and multiple design concepts, including integrating a smelter. The project has benefitted from government co-operation at several stages including the provision of historic exploration data, a partnership for water supply, and co-ownership with Ma'aden (Sykes et al., 2023d).

- The mine is located in an arid desert environment so efficient water use is critical. The mine has a partnership with the state water company and runs only on wastewater – for which some metallurgical innovation has been required (Sykes et al., 2023d).

The 'future of work' for exploration and mining geologists

The four broad conceptual search spaces outlined above are not only located in physically very different locations around the world, but require vastly different skills and resources to overcome the barriers to entry (Porter, 1979) - or to gain 'access'. For some foreign language skills are important, others data management and computer programming skills, others traditional field skills, others high-level academic geoscience knowledge, and so on. An analysis of the case studies has highlighted the following skills and capabilities profiles as potentially useful for operating each of the search spaces.

Under cover: Geoscience, engineering, geometallurgy, and technical innovation

- **Geology, exploration, and mining:** Conceptual geoscience due to lack of early-stage empirical evidence. Potentially new deposit types more likely to be found at depth, or more amenable to discovery at depth. Predictive exploration due to lack of early-stage empirical data. Multi-scale geophysics vital. Geochemistry & surface geological mapping less useful. 3D & 4D interpretative & predictive modelling may be useful. Exploration via drilling required for later stages. Mining at depth may require large-scale UG mining. Potential for novel mining techniques, such as solution, or targeted extraction, over the long term (Sykes et al., 2023d).

- **Processing:** New deposit and mine types may require new processing techniques. Economically marginal nature of deposits may require excellence and innovation in recovery to compensate (Sykes et al., 2023d).

- **Vertical integration, products, and markets:** Other technical challenges mean avoiding vertical integration is preferred; however, government pressure as *quid pro quo* for earlier support is not to be ruled out. Ideally, mineral products are to be kept 'as standard' due to technical challenges elsewhere. Nonetheless, new deposit types and ores may create some problems around marketing. Ideally selling into established markets so as not to add to technical challenges elsewhere (Sykes et al., 2023d).

- **Innovation and organisation:** Technical innovation-focused search space, potentially across geology, exploration, mining, and processing. Funding and patience required. Long-lead times for discovery and development, plus earlier and larger capex in exploration and development means strong, patient funding required. Ownership collaborations may mitigate risk. Government-support may be required (Sykes et al., 2023d).

- **Government:** Reliant on pre-competitive government geoscience data. Support for early-stage exploration and drilling may be required (Sykes et al., 2023d).

- **Environmental and socio-political:** Such challenges ideally to be kept to a minimum due to technical risk elsewhere. Remote location and / or non-historic mining location may help in this regard (Sykes et al., 2023d).

New minerals: Vertical integration, products and markets, and adaptive innovation

- **Geology, exploration, and mining:** Conventional geological knowledge, but a willingness to 're-learn' many different deposit types, crystals, alteration patterns, etc. Similarly, mainly conventional exploration techniques will be used, but they may need to be adapted to subtly different deposit types, elements, etc. An ability to see 'new' minerals opportunity in existing deposits, mines, closed mines, etc., and to utilise existing data sets, maps, etc., is important. Whilst conventional mining techniques may be applied, many niche minerals require alternate mining techniques, such as solution mining lithium *salars* (Sykes et al., 2023d).

- **Processing, vertical integration, products, and markets:** Minerals processing and metallurgy likely to be key, and expertise may be in limited supply. Geometallurgy has an obvious and important role. Vertical integration is likely for several reasons. Economically, it is usually required to enter small, nascent markets. Technically it may be required to produce the required 'products' for the market. Finally, there may be pressure from government for downstream integration for 'strategic' reasons. Knowledge of off-take dealmaking in unusual, data-poor, opaque markets, as well as how to develop a 'mineral product' for a client, rather than a 'mineral commodity' for a market is required. Understanding of market structure, oligopoly, game theory, etc., as well as to recognise and possibly adopt business and market model innovations may also be required (Sykes et al., 2023d).

- **Environmental and socio-political:** End-product links with ‘green’ and ‘ethical’ metals, etc., mean buyer and consumer expectations of ‘green and ethical’ behaviour by miners and explorers may be present. Reliant on government support and enthusiasm, and maybe even finance; however, political fortunes can rise and fall, adding instability to project development. Policy demands may also not align with corporate desires, e.g., vertical integration (Sykes et al., 2023d).

- **Innovation and organisation:** This search space probably requires the broadest range, if not the most radical, of innovations, covering the asset life cycle, value chain, and non-technical and technical innovations. The broad range of challenges faced mean diversity of technical and economic expertise is required in organisations (Sykes et al., 2023d).

Socio-political: Environmental, social licence, dialogue, and social innovation

- **Geology, exploration, mining, and processing:** Conventional geology, exploration, mining, and processing techniques. However, there is likely to be a requirement to involve local stakeholders from the early exploration stage and potentially train and hire locals (Sykes et al., 2023d).

- **Vertical integration, products, and markets:** There is likely to be substantial pressure for vertical integration to help provide more benefits for local communities. Notwithstanding this, conventional products for established mineral markets are preferable to mitigate risks elsewhere (Sykes et al., 2023d).

- **Environmental and socio-political:** Social and environmental capabilities for geoscientists may be extensive – such projects may employ as many ‘environmental’ as ‘economic’ geoscientists. Foreign and especially local and indigenous languages are particularly desirable. Experience and training in negotiation, dialogue, etc., is likely required. An ability to see potential local impacts from exploration and mining is critical (Sykes et al., 2023d).

- **Organisational:** Sophisticated, adaptive organisation is required that can balance local interaction with global sustainability standards, whilst also fulfilling technical and economic needs. The ability to work with a wide range of formal and informal groups, including governments, NGOs, MLOs, and local communities – including many in conflict with you and other stakeholders is a must (Sykes et al., 2023d).

- **Innovation:** ‘Non-technical’ innovation may be required, for example, in developing processes for engaging with local stakeholders. Typically, these are not strengths of a ‘technically-orientated’ mining industry. Technical adaptiveness may also be required to help provide operations that aligned with the desires of stakeholders, e.g., where to position and how to use shared infrastructure (Sykes et al., 2023d).

- **Government:** Whilst formal government relations remain important, conflict with or isolation from formal authorities means that informal, local relations will likely be more important, and ultimately, that solutions to environmental and social problems may be developed locally, from the bottom up, rather than top down from government or NGOs, etc., (in contrast to the geopolitical search space discussed below) (Sykes et al., 2023d).

Geopolitical: Government relations, negotiation, organisational flexibility

- **Geology, exploration, mining, and processing:** Conventional geology, exploration, mining, and processing techniques, but likely focused on geology that has major economic potential (copper, iron ore, etc.,) to compensate for the higher geopolitical risks (Sykes et al., 2023d).

- **Innovation:** Again, ideally, the requirements for technical innovation should be minimised, notwithstanding that some innovation may always be required to adapt to local conditions (Sykes et al., 2023d).

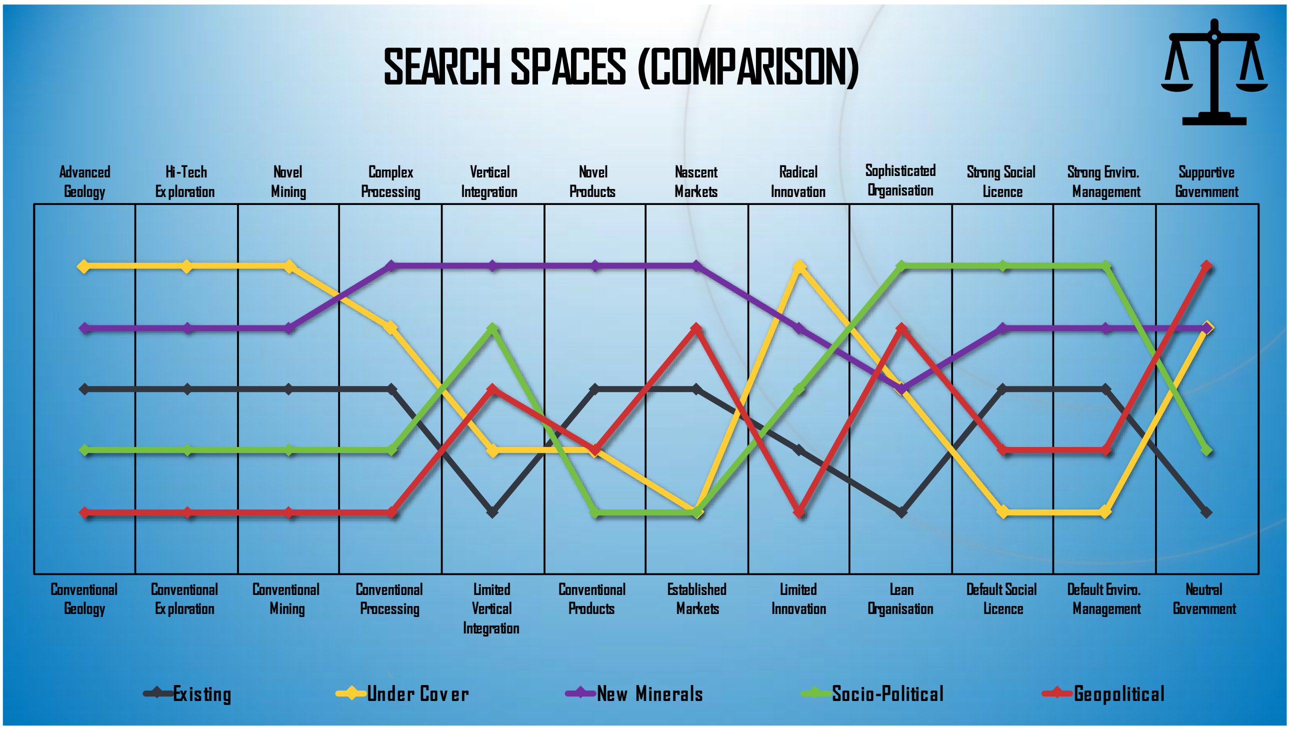
- **Vertical integration, products, and markets:** There may be pressure for vertical integration to help provide more benefits for local communities. Conventional products (e.g., copper concentrates) for established mineral markets, so as not to add marketing problems to the major geopolitical risk. Nonetheless, dependent on the geopolitical isolation or alignment there may be some limits on market opportunities, constraints imposed by governments, or the requirement to operate it unusual, niche, and regionalised markets (Sykes et al., 2023d).

- **Government:** Relative to other geoscience professionals the 'geopolitical' capabilities may be extensive, potentially including roles such as 'government exploration liaison' – and all project geologists likely will have some level of these capabilities to mitigate problems. Foreign languages, cultural understanding, in-country networks, etc., are particularly desirable. Experience and training in negotiation, diplomacy, dialogue, etc., is likely required. An ability to see the link between exploration and mining activities and local and state political incentives – and that these also change – is critical. It is likely collaborations and partnerships, including shared ownership, will be required with state organisations. Preferred funders, suppliers, off-takers may have to be used. Avoiding corruption will be a primary challenge (Sykes et al., 2023d).

- **Environmental and socio-political:** Ideally, extensive environmental and socio-political problems should be avoided, so as not to add to the geopolitical risk. Nonetheless, working with government does not mean that permissive permitting will be forthcoming. The solutions to environmental and socio-political problems will likely come via collaboration with government though (Sykes et al., 2023d).

Strategic decisions around the 'future of work'

The 'strategy canvas' (Kim and Mauborgne, 2004) below communicates our initial thoughts on the required skills and resources for each of the four search spaces, outlined above, though some nuance is still required to appreciate what is required at an individual, team, and organisational level.



Nonetheless, expecting a single explorer, exploration team, or even a big mining company to master such a range of requirements, as above, is implausible. As such, in returning to the strategic question of for what and how to explore in the future, the message, drawing from core principles of strategic management (Porter, 1980, 1985, Treacy and Wiersama, 1993, Kim and Mauborgne, 2004), is for miners and explorers to not try and pursue all these search spaces, but to focus on one (or two) in which the opportunity is aligned with the strengths of the miners, explorers, teams, and company (Porter, 1980, 1985), or, at least, in which such capabilities can be built – and importantly, in which the exploration and mining 'silos' are aligned over the long-term (Sykes and Trench, 2014).

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