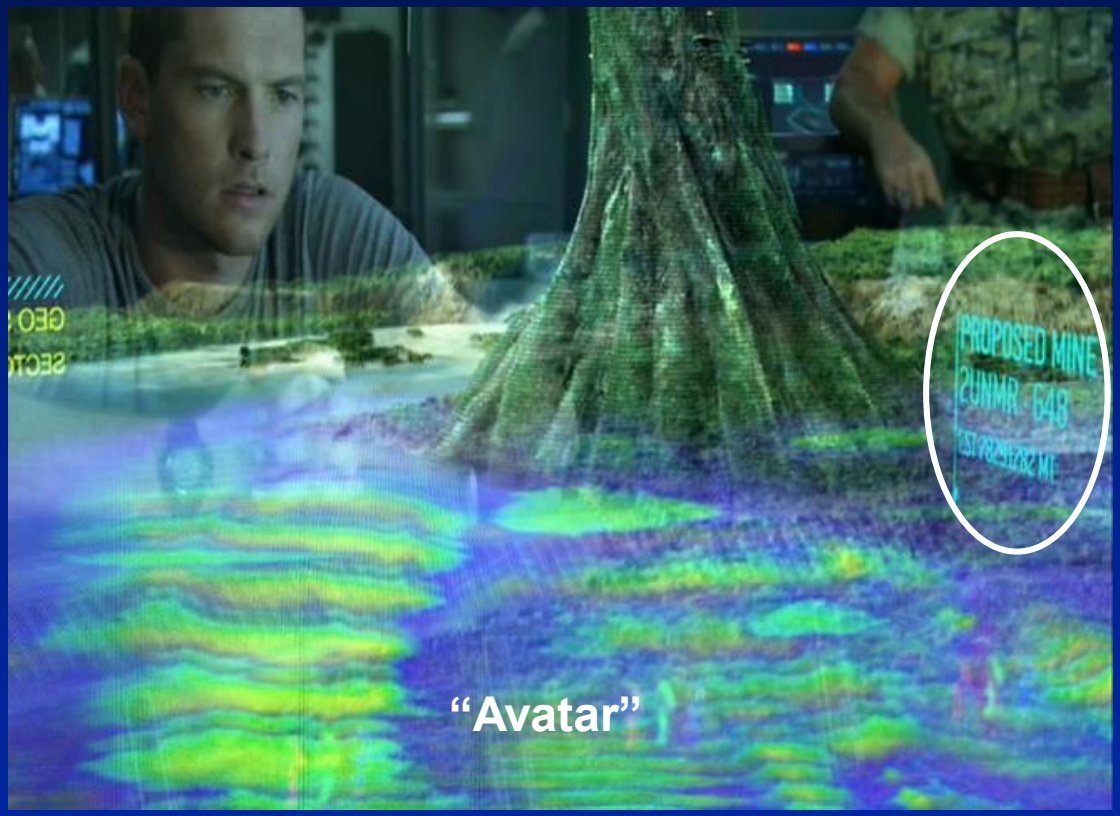
Landscape Analysis of Mineral Resources — *A View from Home Tree ("Avatar")*



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Multi-Resource Landscape Analysis

The Scope of this Talk

- **Mineral and energy resources are broad. I will only cover metallic mineral resources – *still a large topic.***
- **Coal has a host of specific issues beyond what I will discuss.**
- **Energy resources (hydrocarbon production, hydro, solar and wind facilities) while sharing some elements with mineral resources also have other issues.**

The similarities and differences in terms of landscape analysis can be teased out in discussion.

Mineral Resources — Spatial Considerations

Unlike some other resources (bio-resources, water, recreation), mineral resources have a fixed location – they cannot be moved within the landscape.

Mineral Resources — A Quick Primer

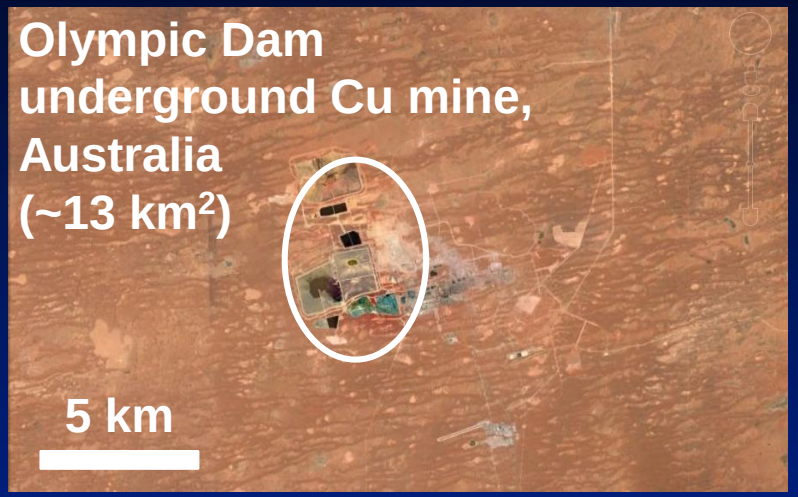
- Typical copper mines produce copper from rock that contains between 0.5 to 1.5% Cu (5000 ppm to 15,000 ppm Cu per metric tonne of rock).
- Typical gold mines produce gold from rock that contains 1 to 30 ppm Au per metric tonne of rock.

Thus, production of mineral resources generally requires physically digging up and processing very large quantities of rock or soil to produce small amounts of elements of interest.

Mineral Resources — A Quick Primer

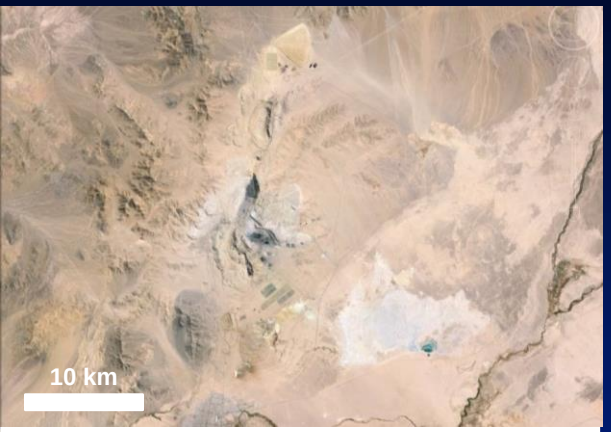
Mineral resources are NOT created equal.

- **Mineral deposits produced from underground mines — generally relatively small surface footprint.**



- **Mineral deposits produced from open pit operations — generally large scale surface disturbance.**

Mineral Resources — A Quick Primer



Mineral resources are NOT created equal. Different deposits have very different footprints (spatially & temporally).

Chuquicamata Cu mine, Chile (1910-present) – ~170 km² footprint; 105 year mine life to present.

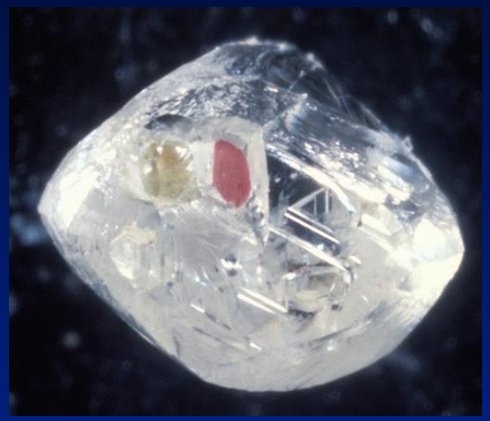
Bingham Canyon Cu-Au mine, Utah (1906-present) – ~50 km² footprint; 109 year mine life to present.

Flambeau Cu-Au mine, Wisconsin (1991-99) – < 2 km² footprint; 8 year mine life. *Site now hosts recreation and wildlife habitat.*

Mineral Resources — A Quick Primer

Mineral resources are NOT created equal

- **Some commodities have high value and are traded globally – they could be mined anywhere in the world (e.g., copper, diamonds, gold, phosphate, platinum, REEs, zinc).**

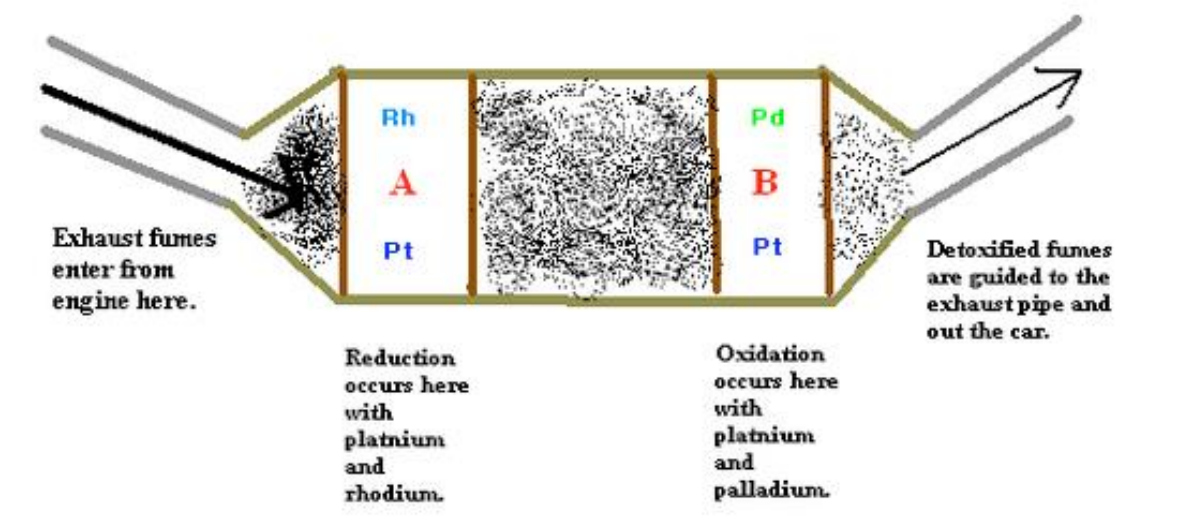


- **Other commodities have low intrinsic value and are only be mined near point of commodity usage (e.g., sand and gravel, limestone for cement).**

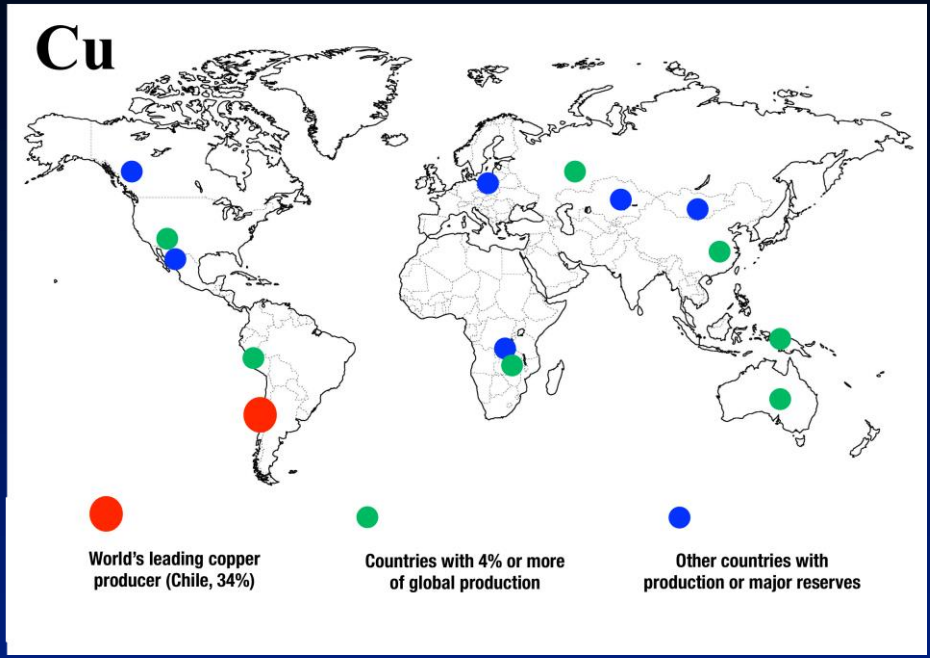
Mineral Resources — A Quick Primer

Mineral resources are NOT created equal.

- **Some commodities are very important to economic well being (importance of use).**
- **Commodity importance may vary with time — Prior to the 1970's platinum did not have many uses that were critical for the economy. When catalytic converters became a requirement for US autos due to air quality platinum became more critical to the US.**



Mineral Resources — A Quick Primer

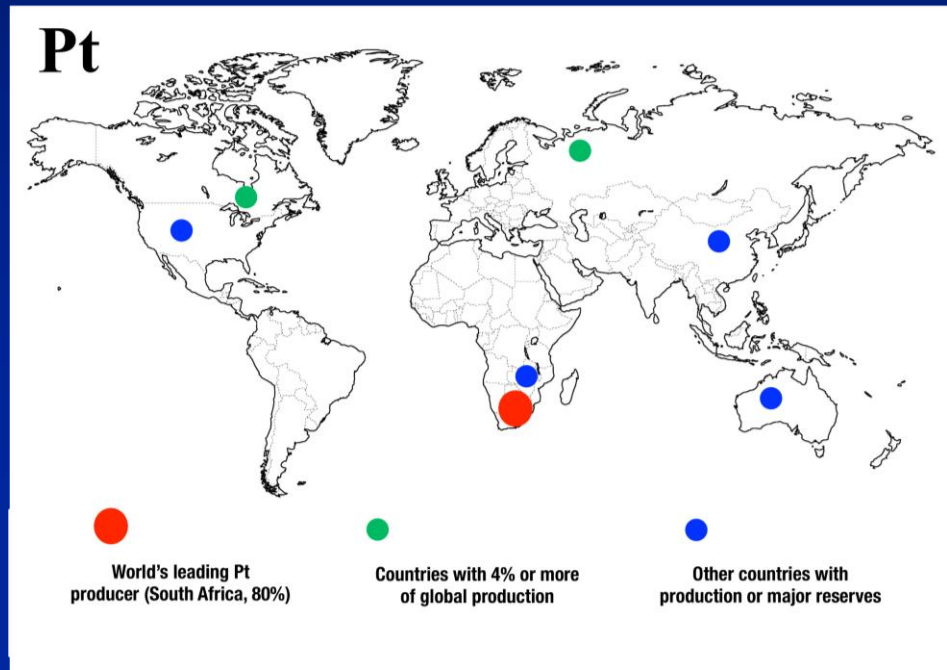


Mineral resources are NOT created equal

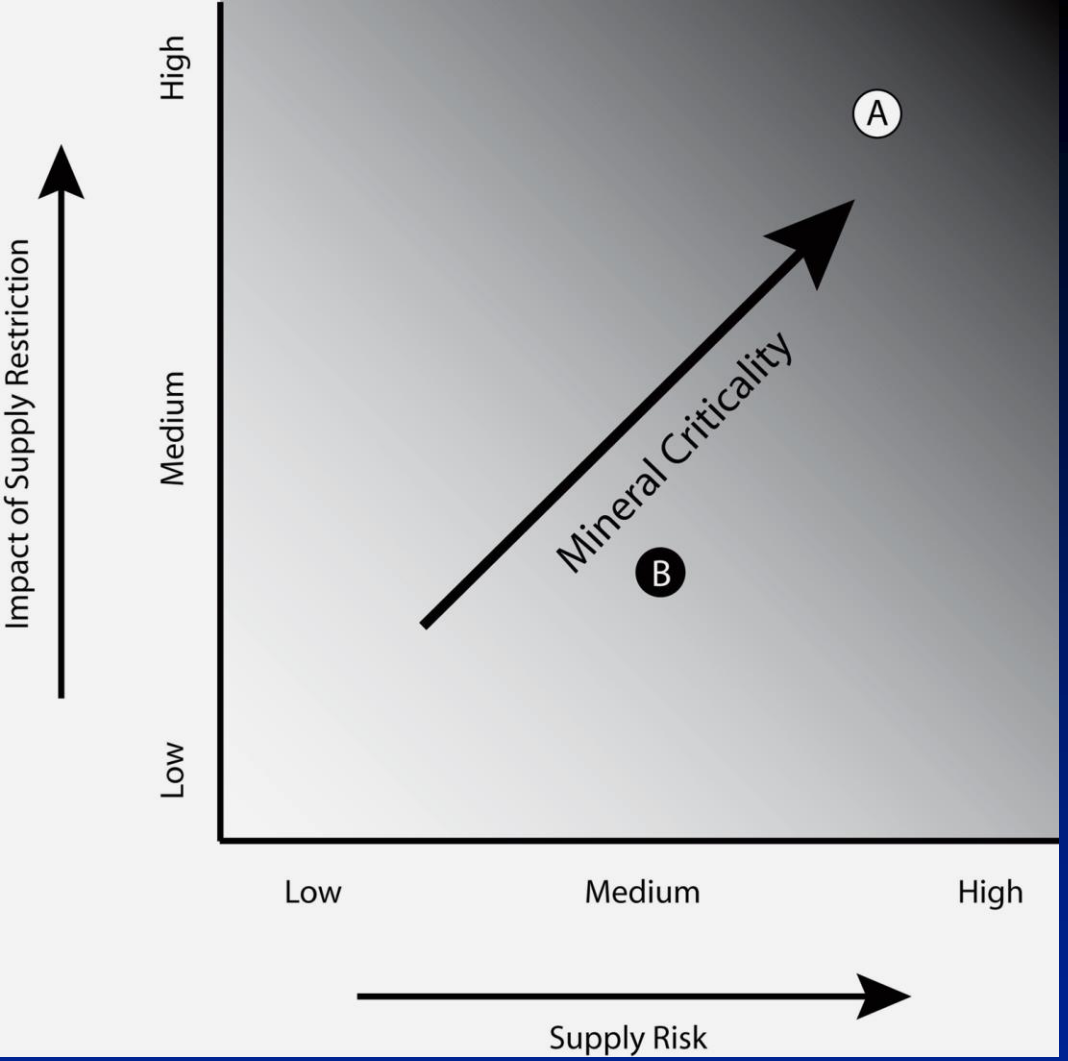
Some commodities (e.g., copper, gold, phosphate, zinc) are widely distributed — If a mineral resource is found in one area it may not need to be mined because other, economically equivalent deposits will be found in other areas.

Other commodities (e.g., diamonds, platinum, REEs) are found only in very specific locations and equivalent mineral resources are not expected to be found in other areas, thus there may be more incentive (societally) for development.

Thus different mineral resources have different supply risks.



Mineral Resource Criticality*



- Criticality is dynamic.
- Criticality is ‘more or less’, not ‘either/or’.

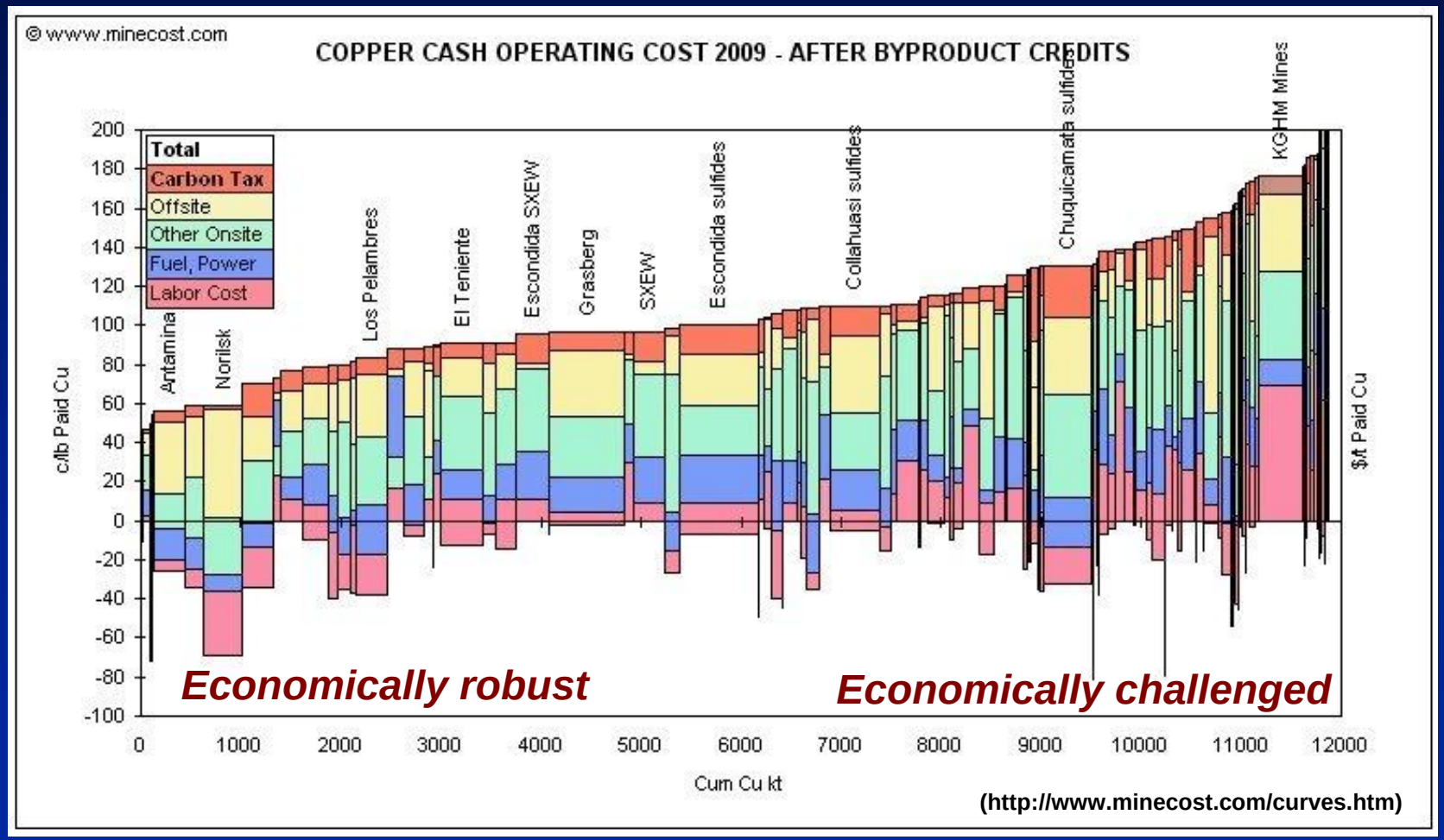
Degree of criticality is determined by: importance in use (vertical axis) and supply risk (horizontal axis).

* NRC Report: Minerals, Critical Minerals and the US Economy (2008)

Mineral Resources — A Quick Primer

Mineral resources are NOT created equal.

- **Some mines can produce the element(s) of interest at low cost while others are much higher cost.**



Mineral Resources & Landscape Analysis

Does a landscape have the potential for mineral resources and will developing them have an impact?

The answer to both these questions is almost always *YES* but this is not helpful.

How do we focus these questions?

Mineral Resources & Landscape Analysis

Two broad divisions of analysis should be considered:

- **Prospective Analysis — Evaluation of a landscape area for potential mineral resource development.**
- **Reactive Analysis — Evaluation of a known site-specific mineral resource.**

Mineral Resources & Landscape Analysis — Prospective & Reactive Analysis

For prospective analysis the question is: **Does a landscape have the potential for mineral resources?**

While for reactive analysis the question is:
How would development of a specific mineral resource impact the landscape?

The fundamental questions to be answered are very different (government must be involved in both, but in different ways).

Mineral Resources & Landscape Analysis — Reactive Analysis

- How would development of a specific mineral resource impact the landscape?
- Mineral resource development will always have an impact and generally a significant impact.
- Reactive analysis determines whether the impact could be compatible with other services provided by the landscape (ecosystem, water, recreation, energy, etc. services).

Mineral Resources & Landscape Analysis — Reactive Analysis

- Reactive analysis is based largely on an EIS/EIA of a site prepared by the private sector.
- Reactive analysis deals with existing law and is a regulatory matter.
- The answers will be given by regulatory land agencies and/or environmental agencies and must consider the broader landscape and all potential impacts over long time scales.

Mineral Resources & Landscape Analysis — Prospective Analysis

Prospective analysis is almost solely a government function — there is little scope for private sector involvement although the private sector may have a keen interest in the outcome.

There are a number of scientific as well as societal questions to be answered:

- **What areas are geologically favorable for mineral resources?**
- **What different types of mineral resources could be present?**
- **What is the likelihood of economically significant mineral resources (of different types)?**
- **What are the potential environmental impacts of these different types of deposits (both exploration for the deposits and production of deposits if found)?**

Mineral Resources & Landscape Analysis — Prospective Analysis

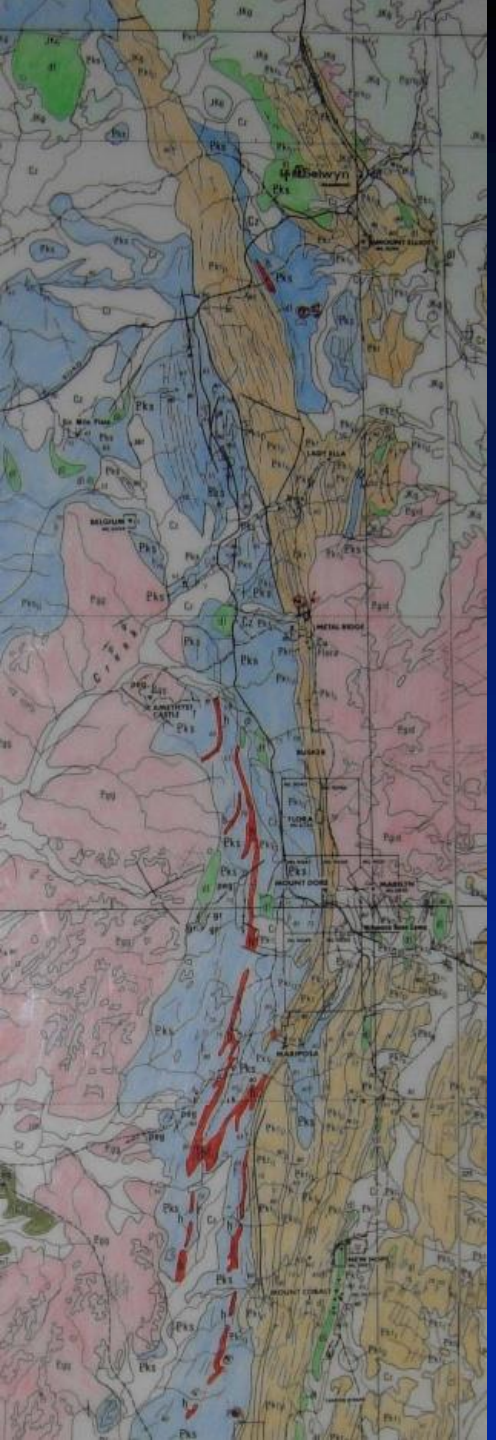
- Prospective analysis in a landscape context should include data on the potential environmental impacts during both **exploration** and **production**.
- Mineral exploration is rarely successful — even in landscapes that have significant mineral potential.
- Exploration can have impacts on the landscape through activities such as cutting of lines for geophysical surveys or construction of access roads for drilling.
- Such impacts can be minimized (almost eliminated) if sufficient funding is available (helicopter based surveys and drilling for instance) — is the mineral resource target one that has sufficient economic potential that the private sector may be willing to risk such a high investment?

Exploration: How Do We Know Where Mineral Resources Are?

- Unless a deposit sticks out of the ground we won't know where it is located.

- Even those mineral deposits that do subcrop must be evaluated with significant drilling (high cost, commonly several millions of dollars, usually over multiple years).

- Deposit location and delineation is not a function of government (in the U.S.) but of the private sector.



What is Government's Role in Prospective Analysis at the Landscape Scale?

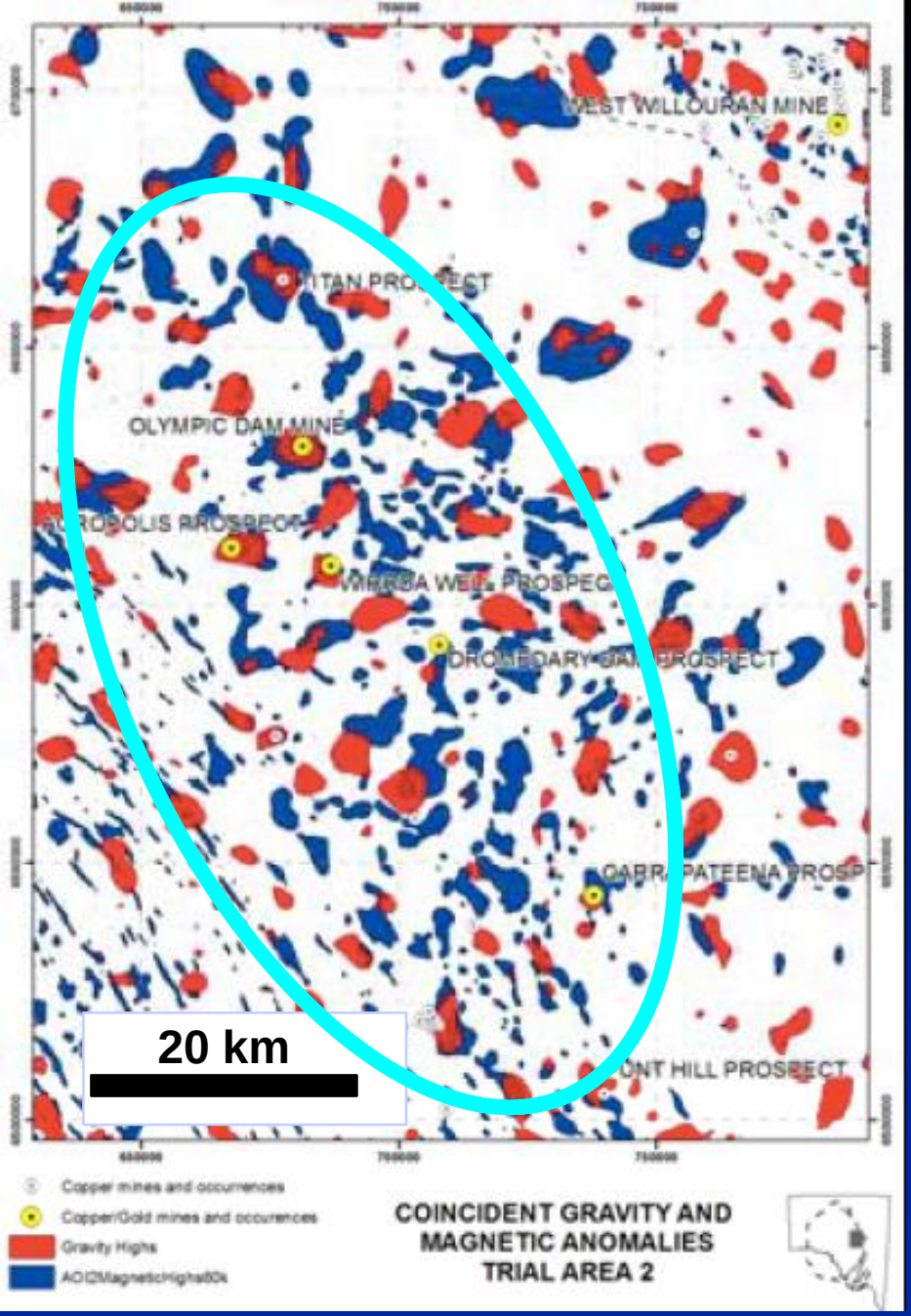
Delineate areas that could be permissive for mineral deposits:

- **Through geological mapping (USGS), regional geophysical surveys (Australia, Canada, minor USGS), geochemical surveys (less commonly done by government).**

- **By land classification of areas where a mineral resource development project might be allowed to move forward and areas where other land use considerations preclude mineral development.**

Both these are important government functions.

An Example of Government information Aiding Mineral Development: Gawler Craton, South Australia



- 2010 — Government derived geophysical (magnetic and gravity) surveys have lead to development of numerous geophysical targets.
- How many of these anomalies represent ore deposits?
- This is for the private sector to determine.
- However, this government derived geophysical map shows where most likely mineral potential is — critical for prospective analysis.

Prospective Analysis — Government Products Needed

What areas are geologically favorable for mineral resources and what different types of mineral resources could be present?

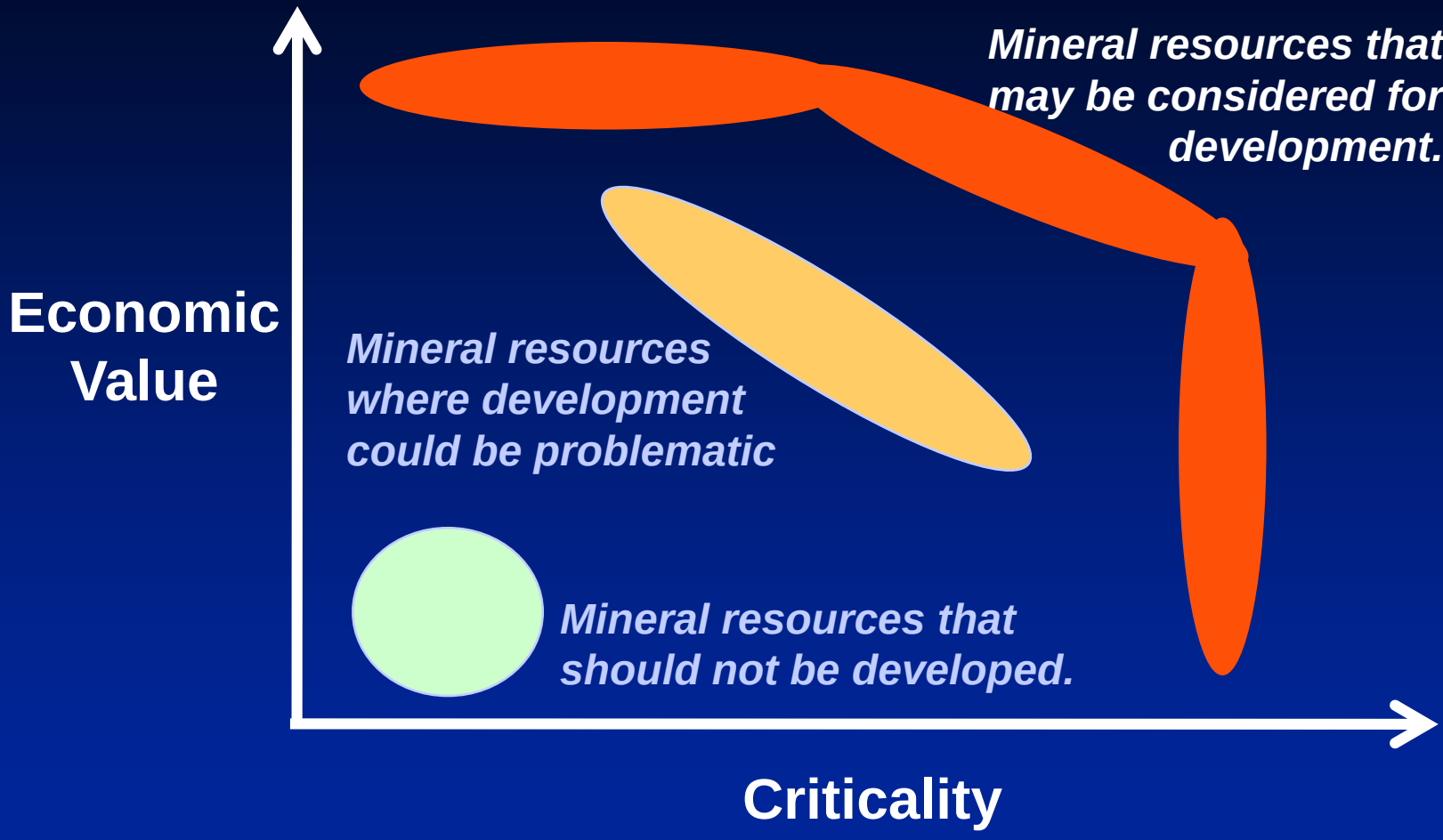
- **Ore deposit models**
- **Geological maps**
- **Geophysical data**

What is the likelihood of economically significant mineral resources (of different types) and what are the potential environmental impacts of these different types of deposits?

- **Ore deposit models**
- **Environmental ore deposit models**
- **Landscape data (for environmental analysis)**

In addition, the government also needs data on commodity criticality.

Value : Criticality Index of Mineral Resources



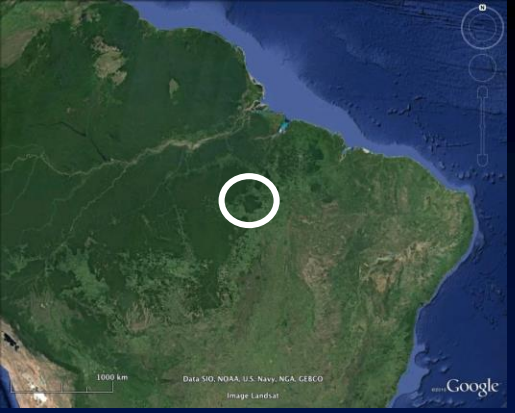
Such an index needs to be prepared for each type of mineral resource that may be present in a landscape.

Mineral Resources & Landscape Analysis — Focusing the Prospective Analysis

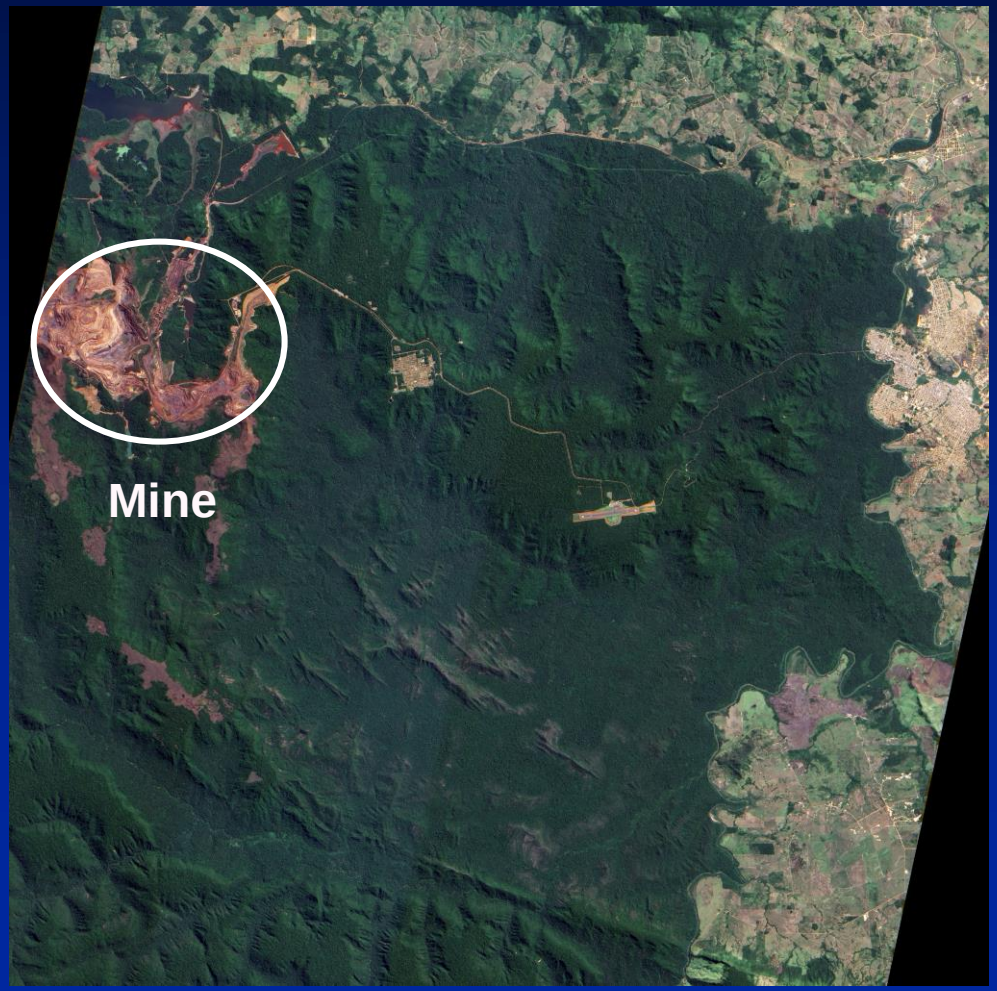
The correct question should be, does a landscape have the potential for **societally beneficial** mineral resources?

Societally beneficial aspects may include:

- Commodity criticality (e.g. REE, Pt) — note that criticality changes through time,
- Economically robust mineral resource — ability to provide sufficient economic impact to overcome or pay for some adverse impacts,
- Mineral resource development that could lead to other societal benefits (infrastructure development, etc.).



Mineral Resources & Landscape Analysis — An Example of (Unintended) Societal Benefits of Prospective Analysis



- The Brazilian government set aside a large mineral concession in the Amazon rain forest for mineral development (Carajas) in the 1970's.
- The area is now a major refuge for the Amazon ecosystem due to protection from deforestation by agriculture.

Mineral Resources & Landscape Analysis — Potential Gaps for Governmental Prospective Analyses

In order to undertake comprehensive prospective analyses government needs to ensure it has data on:

- Commodity criticality (constantly updated),
- Ore Deposit Models to allow for prospectivity analysis (maps with probabilty),
- Environmental Ore Deposit Models to allow for environmental impact analysis (also maps),
- Economic Ore Deposit Models to consider economic robustness of different ore deposit types.

Mineral Resources & Landscape Analysis

Unlike some other resources (bio-resources, water, recreation), mineral resources have a fixed location – they cannot be moved within the landscape.

The conflict in the popular movie "Avatar" was due to the location of the Unobtanium deposit beneath Home Tree.

The deposit was site specific – to a particular planet and a particular site.

The stark choice presented in “Avatar” is the reactive analysis reality for mineral resource analysis and land managers.

However, with informed prospective landscape analysis of mineral resource potential the true cost-benefit of the sustainable natural resource management would have been known.

Viewers might have had a different “take away” message of the movie if Unobtanium was critical to human survival and it was so rare and so spatially restricted that Home Tree was the only source. Wars have been (and probably will be) fought over mineral resources. But with better landscape analysis society can at least make informed decisions.