A minerals systems approach to mapping Australia's endowment

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Mineral endowment is a key element in determining prospectivity. As part of an ongoing assessment of Australia's prospectivity, AGSO has compiled density plots of recorded mineral occurrences, which not only map Australia's historic mineral provinces but also highlight regions with anomalously high metal contents.

Most regions with a high abundance of recorded mineral occurrences contain one or more world-class deposits—although there are notable exceptions in the case of buried deposits. An abundance of occurrences can be due to the compounded effects of sequential or overlapping mineralising systems. It may also reflect an inefficient mineralising process or processes that resulted in dispersed low-grade mineralisation. Nevertheless, most of the known world-class deposits are in regions with a high density of mineral occurrences—suggesting surface prospecting probably played a key role in the discovery of many such deposits. Early results of AGSO's ongoing assessment of Australia's mineral potential indicate that substantial areas of potential remain (especially under cover).

The bulk of the world's metal resources are contained in larger than the median-size deposits, and most is concentrated in giant or world-class ones (namely the top 10% of deposits on a contained metal basis).[1] Moreover, most of the world's base and precious metal resources are contained in deposits of higher grade, occur in relatively few ore deposit types, and are concentrated in particular regions of the world. These observations lead to the conclusion that some parts of the Earth's crust are unusually endowed in certain metals and therefore more prospective than other areas.

World-class or giant deposits can profoundly affect metal supply and have a huge influence on net present value and cash flow (mine profitability). Such deposits therefore are a focus of global exploration today.

The minerals industry is undergoing radical change because of the combined influences of globalisation, low metal prices, investor demands for greater return on capital, competition for risk capital, the declining position of mining in equity markets, and the increased demands for community and environmental accountability (the 'triple bottom line'). In this environment, the industry will depend heavily on the discovery of major deposits with large, high-grade reserves to ensure low operating costs and long mine life. Other desired characteristics include a low environmental footprint and favourable ore mineralogy that allow ready extraction without environmental penalties.

The growth of the Australian minerals industry to its present position as a leading producer is built on a relatively small number of major (world-class) mines. These include historic giant deposits such as Kalgoorlie and Broken Hill that were found more than 100 years ago. Also included in Australia's list of major deposits and mineral districts—most of which were found in the last 40 years—are:

- Mount Isa copper and lead-zinc-silver deposits;
- bauxite deposits of Gove, Weipa, and the Darling Ranges;
- Bowen Basin coal seams;
- Hamersley iron province;
- Olympic Dam copper-uranium-gold deposit; and
- Yilgarn gold deposits.

This raises the question: 'What is Australia's mineral endowment and potential for further discoveries, especially for world-class resources?'.

Australia's mineral endowment

The distribution of known deposits and occurrences provides an insight into known mineralising systems. Figures 1 a–f are density maps of the distribution of significant mines and deposits (including both historic and undeveloped deposits). These figures show recorded occurrences of gold, copper, lead/zinc, iron, nickel and uranium mineralisation from AGSO's MINLOC database, which contains more than 74 000 mineral locations. The recorded mineral occurrences are presented as kernel density plots using a 100-kilometre radius and shown simply as low, medium and high concentrations.

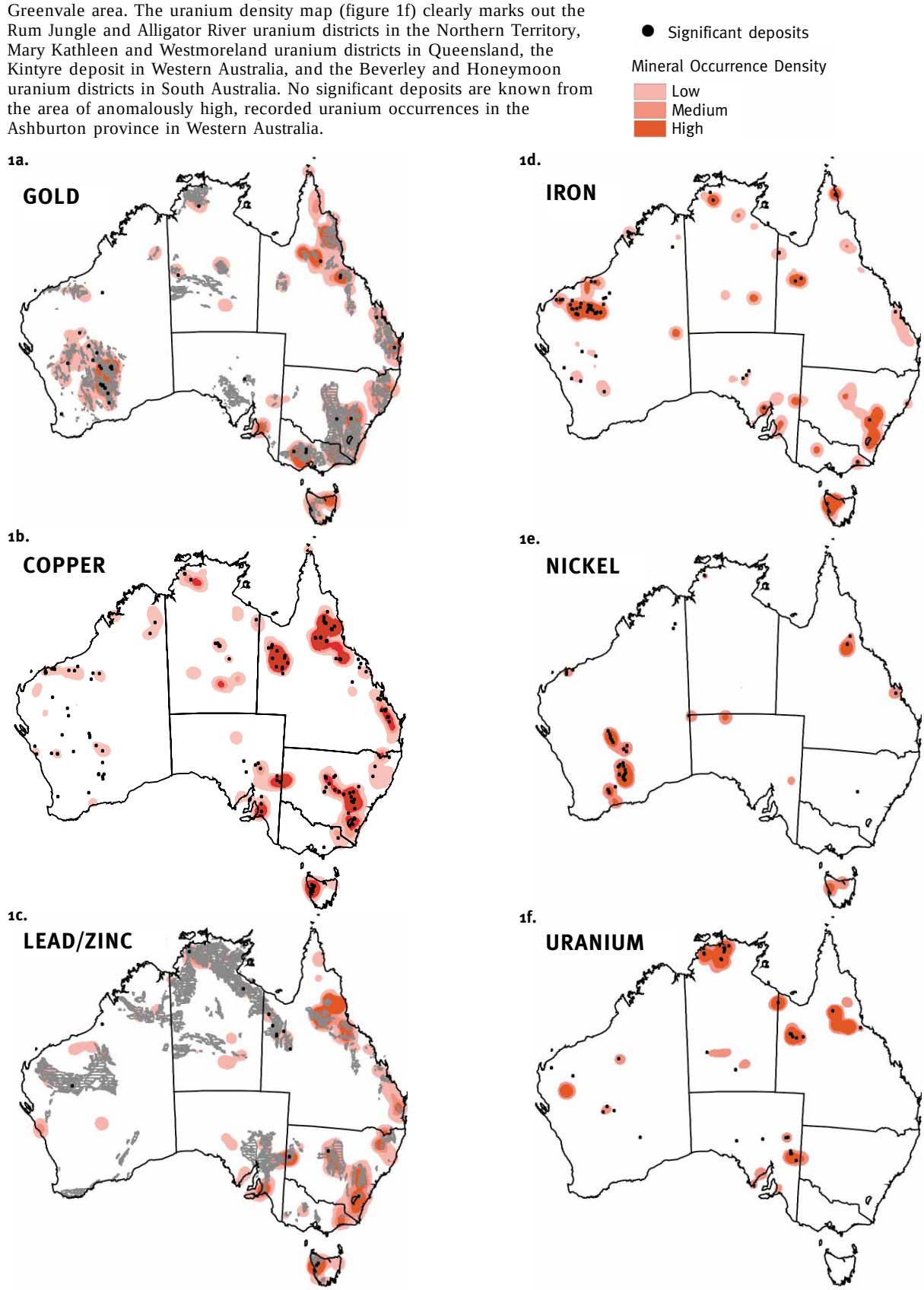
The plots show that gold and copper are the most widely recorded metals in Australia. Recorded gold occurrences (figure 1a) are concentrated in the Archaean Yilgarn craton and in the various elements of the Tasman Fold Belt. This includes northern Tasmania, the historic major lode gold deposits of the Ballarat–Bendigo field of Victoria, the porphyry-epithermal and lode gold of Lachlan Orogen in New South Wales, and the breccia-hosted, lode gold and epithermal deposits of central Queensland.

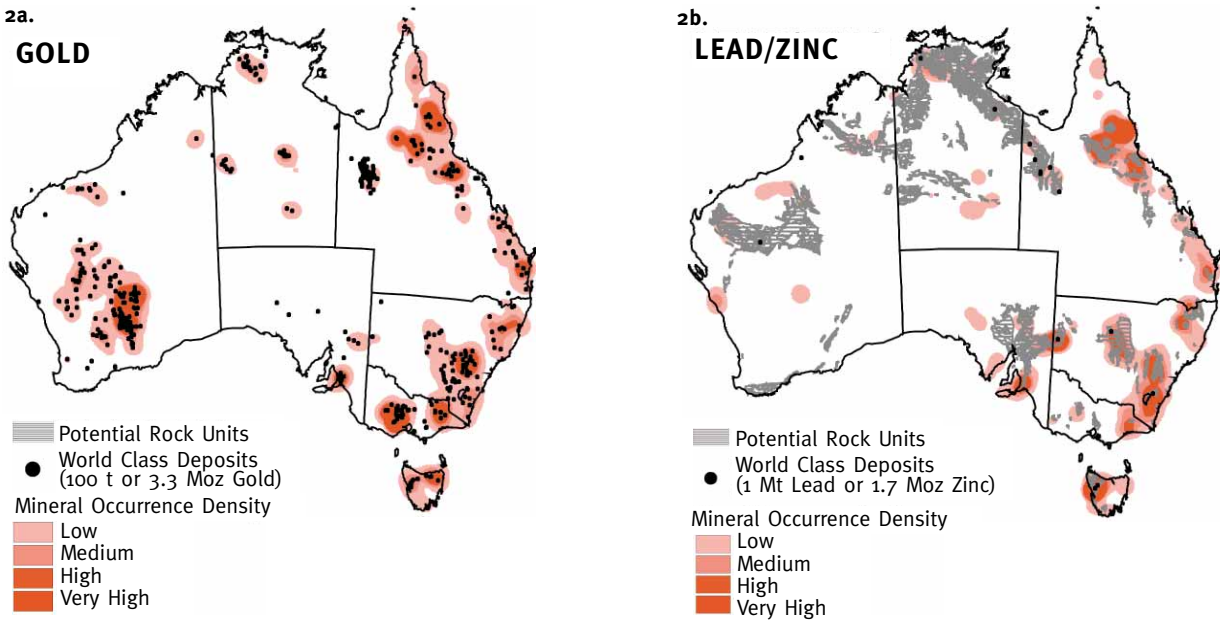
Copper deposits and recorded occurrences (figure 1b) are concentrated in the Mt Isa province, the Kanmantoo province, the western Curnamona craton, and widely distributed in the Tasman Fold Belt. These occurrences highlight the volcanic associated massive sulphide (VAMS) district of western Tasmania, the VAMS and porphyry deposits of the Lachlan Orogen, and the base metal provinces of central and north Queensland.

Figure 1c broadly maps Australia's lead-zinc provinces, especially the major VAMS districts of Tasmania and New South Wales, the Elura and Broken Hill deposits, as well as occurrence-rich regions of North Queensland (mostly in the Kennedy province). Other lead-zinc mineralised districts, such as the Lennard Shelf (the 7th largest zinc producing province in the world) and the Pine Creek province, are also identified. The world-class Carpentaria–Mt Isa zinc belt in northern Australia, however, is not especially prominent. This belt hosts more zinc than any other comparable province in the world with seven world-class, Proterozoic sediment-hosted base-metals deposits: McArthur River, Century, Dugald River, Hilton, Mt Isa, Lady Loretta (all with 2 Mt or more contained zinc), and Cannington (5 Mt contained lead, 1.9 Mt contained zinc).

Australia's iron ore provinces and occurrences of banded iron formations, iron-rich skarns and gossans are shown in figure 1d. In the case of nickel (figure 1e), the density occurrence map marks out the nickel districts of the Eastern Goldfields (Kambalda, Mount Keith–Agnew), the Forrestania belt, the west Pilbara, and the lateritic deposits in eastern Australia, notably the Greenvale area. The uranium density map (figure 1f) clearly marks out the Rum Jungle and Alligator River uranium districts in the Northern Territory, Mary Kathleen and Westmoreland uranium districts in Queensland, the Kintyre deposit in Western Australia, and the Beverley and Honeymoon uranium districts in South Australia. No significant deposits are known from the area of anomalously high, recorded uranium occurrences in the Ashburton province in Western Australia.

Figures 1 a–f. Kernel density plots of recorded mineral occurrences and major deposits (from AGSO's database) for gold, copper, lead/zinc iron, nickel, and uranium.





Figures 2a–b. Maps showing the distribution of world-class gold and lead/zinc deposits in relation to kernel density plots of recorded mineral occurrences and prospective rock sequences from AGSO's national GIS.

World-class deposits and mineral potential

Most regions with an anomalously high distribution of recorded mineral occurrences contain one or more world-class deposits of that metal(s) as shown, for example, in figure 2a: gold and figure 2b: lead/zinc. Clearly the most endowed region in terms of gold is the Yilgarn craton—notably the Eastern Goldfields, which hosts some 16 world-class deposits. World-class gold deposits are associated with many other concentrations of recorded gold occurrences, including Ballarat, Bendigo, Cadia, Cowal, Gympie, Kidston, Mt Leyshon and Charters Towers. A number of major deposits—such as Telfer, Boddington and Olympic Dam—however are not associated with a high density of recorded occurrences.

World-class deposits are not always found in regions with the highest density of recorded mineral occurrences. For example: no world-class lead or zinc deposits are currently associated with the high density of recorded occurrences in the Georgetown–Mt Garnet region (although a number of small deposits are known). Australia's major lead-zinc province is not highlighted as a province, even though there are concentrations centred about the McArthur River, Century, and Mt Isa–Hilton deposits, and a region north of the Roper River. Cannington is a blind deposit under 10–60 metres of cover.

A lack of major deposits associated with high-density occurrences in some districts, and a paucity of occurrences associated with world-class deposits in other mineral districts, may be due to several factors. Firstly, there are inherent weaknesses in the database, which is influenced by such factors as the nature of the outcrop, amount of cover, and exploration accessibility including that of early prospectors. Secondly, in some provinces high-density occurrences may reflect the influence of multiple, overlapping or sequential weak mineralising events, none of which may have resulted in major deposits. A third possibility is that high-density occurrences may indicate dispersion of mineralising fluids through 'leaky' or inefficient mineralising systems (source, transport and trap). The more focused or efficient mineralising events, therefore, may have resulted in less minor mineralisation (fewer occurrences), but significant deposits.

In a number of mineral districts[2] and petroleum basins[3] there is a parabolic fractal relationship between size and rank of deposits when plotted on a log-log basis. This relationship is widely used to predict the ultimate size of oil and gas fields in a basin. The relationship is less certain in the case of mineral deposits. For example: a log-normal distribution has been demonstrated in some gold provinces but, taken as a group, giant gold deposits (>100 tonnes) do not form part of a single population.[2] Rather, the well-endowed belts contain anomalously large gold deposits.[2] This is examined further in figure 3, which shows a cumulative frequency plot of gold deposits in the Eastern Goldfields, Murchison and Southern Cross terranes of the Yilgarn craton. Gold deposits from the Murchison and Eastern Goldfields terranes show a similar distribution, except for the super-giant Kalgoorlie deposit. Deposits in the Southern Cross terranes, in contrast, define a different curve (figure 3). This implies differences in the scale or efficiency (e.g., focusing or timing of fluid flow and fluid trap) of the gold mineralising systems. The Murchison terranes are more like those of the Eastern Goldfields than the Southern Cross terranes. Broken Hill is a mineral province that shows an even greater 'gap' between a giant and minor deposits. The giant Broken Hill silver-lead-zinc deposit (>150 Mt, pre-erosion possibly ~300 Mt) is distinct from a 'tail' of small deposits, suggesting that the mineralising system was highly efficient in focusing and concentrating the mineralisation.

The relationship of mineral occurrence, mineral resource and mineral potential is being further explored by using a mineral systems approach and resource data such as grade and tonnage curves. AGSO is undertaking an assessment of

Australia's mineral potential to support resource exploration and as an important input to land-use planning and infrastructure development.[4] The assessment is using a GIS-based mineral systems approach, which attempts to identify all geological processes that control the generation and preservation of mineral deposits.[5] Emphasis is placed on *source(s)* of heat (energy), metals and fluids, *transport* mechanisms for the migration of fluids, and *trap*—including the mechanical and physico-chemical conditions that result in precipitation of metals from fluids, as well as post-depositional modification and preservation of the mineralisation. The approach is based on determining the likely presence or absence of elements critical to formation of some 21 different ore deposit types known to host world-class deposits in Australia or in similar rocks elsewhere in the world, based on widely adopted models.[6] Assessment of potential is based on examination of the time–event plots for each province. This includes basement geology, magmatic history, and basin evolution including sediment type, orogenic/metamorphic events, and metallogenic events.

The rock sequences prospective for gold and lead-zinc deposits based on this approach are shown in figures 2a and 2b. These figures show that the areas prospective for these metals extend beyond the known mineralised districts defined by the distribution of occurrences and deposits. Many of these areas are buried or poorly exposed, suggesting that considerable potential lies under cover.

Mineral occurrences, deposits and potential

From a preliminary examination of mineral occurrences, deposits and potential, the authors conclude that:

1. The density maps of recorded mineral occurrences highlight regions of crust with anomalously high metal contents and outline most of Australia's historic mineral provinces.
2. Most of the known world-class deposits, with important exceptions, occur in regions with a high density of recorded mineral occurrences. This suggest that most past discoveries, with the exception of blind deposits like Olympic Dam and Cannington, were strongly driven by surface prospecting.

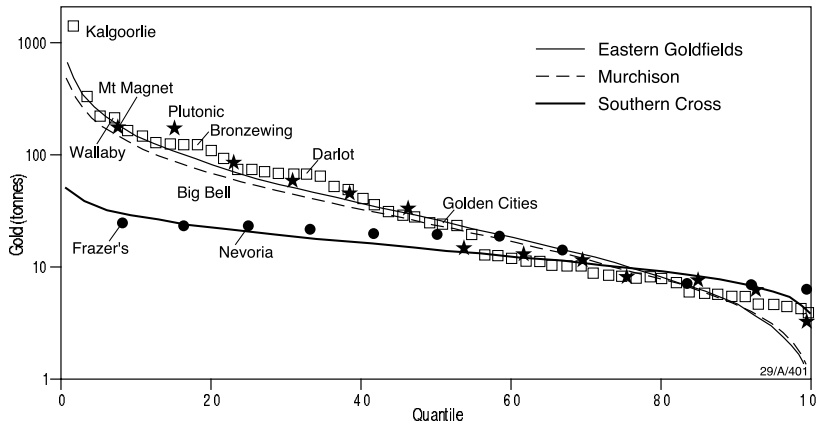


Figure 3. Cumulative frequency plots of gold deposit size (tonnes of contained gold) for the Eastern Goldfields, Murchison and Southern Cross terranes.

3. Most regions with a high density of recorded mineral occurrences contain one or more world-class deposits, but some have no known major deposit(s). It is not clear whether major deposits remain to be found in these areas. Some high concentrations appear to result primarily from the cumulative effects of low levels of occurrences associated with overlapping but distinct mineralising systems. These may also represent systems where the mineralised fluids were widely dispersed rather than focused to form economic deposits.
4. Early results of an assessment of mineral potential indicate that substantial areas of potential remain. The areas are likely to be in extensions of known provinces under cover, in poorly outcropping provinces, and especially in under-explored greenfields provinces under cover. Successful exploration of many of these areas will require a new approach that integrates new geophysical imaging tools (such as gravity gradiometry or seismic) with new conceptual approaches based on a better knowledge of the controls on mineralising processes.

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The maps of recorded mineral occurrences, deposits and potential can be down loaded free from www.agso.gov.au/minerals/promotion/promote.html.

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