

Why Australia has so much

URANIUM

Australia's vast resources of uranium amount to a staggering 40% of the world's total identified resources of uranium recoverable at low cost.

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Uranium mining in Australia began in 1954 at Rum Jungle in the Northern Territory and Radium Hill in South Australia. The first mining of uranium for electricity generation in nuclear reactors began in 1976, at Mary Kathleen in Queensland.

Australia is now the world's second largest producer. In 2004, Canada accounted for 29% of world production, followed by Australia with approximately 22%. Australia's output came from three mines: Ranger, which produced 5138 tonnes of U_3O_8 (11% of world production), Olympic Dam (4370 t, 9%) and Beverley (1084 t, 2%).

Exports have increased steadily to a record level of 9648 tonnes of U_3O_8 in 2004, valued at A\$411 million.

Australia's uranium sector is based on world-leading resources and high and increasing annual output. Our resources are generally amenable to low-cost production with minimal long-term environmental and social impacts.

Around 85 known uranium deposits, varying in size from small to very large, are scattered across the Australian continent (McKay & Miezitis 2001). After five decades of uranium mining, Australia still has the world's largest uranium resources recoverable at low-cost (less than US\$40/kg U, or US\$15/lb U_3O_8). In April 2005, these remaining low-cost resources amounted to 826 650 t U_3O_8 (= 701 000 t U), or roughly 40% of world resources in this category. Australia's total remaining identified resources in all cost categories amount to 1 347 900 t U_3O_8 .

Australia's initial in-ground resources of uranium (total resources before mining, without taking account of extraction and processing losses) amount to 2.4 million t U_3O_8 . The distribution of initial in-ground uranium resources among the main types of deposits is summarised in Figure 1.

Types of uranium deposits

Approximately 89% of Australia's initial in-ground resources occur in two main types of deposits:

Hematite breccia complex deposits—approximately 70% of resources occur in Proterozoic hematite granitic breccias at Olympic Dam in South Australia, the world's largest uranium deposit. Broadly similar hematite breccia mineralisation is being evaluated elsewhere in the same geological province at Prominent Hill (very low uranium grade) and at Mt Gee in the Mount Painter Inlier of the Curnamona Province. These are examples of 'iron oxide copper gold deposits' with higher uranium contents than most deposits of this type.

Unconformity-related deposits—about 19% of resources are associated with Proterozoic unconformities, mainly in the Alligator Rivers field in the Northern Territory (Ranger, Jabiluka, Koongarra).

Other significant resources occur in:

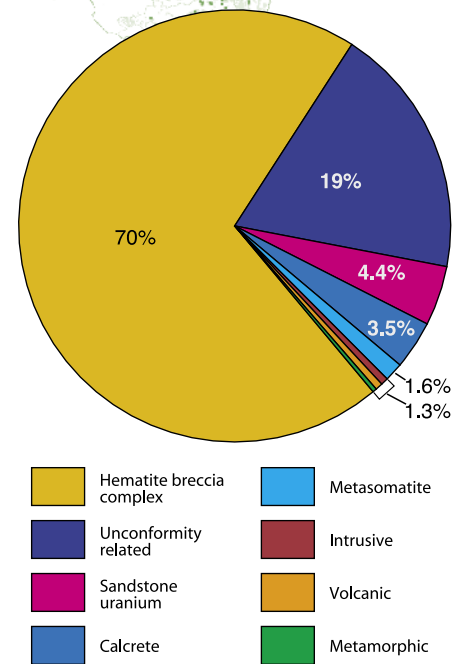
Sandstone uranium deposits—about 4.4% of resources, mainly in the Frome Embayment field, South Australia (Beverley, Honeymoon) and the Westmoreland area, Queensland.

Surficial (calcrete) deposits—about 3.5% of Australia's uranium resources, mostly in the Yeelirrie deposit in Western Australia.

The remaining resources are mainly in metosomatite and volcanic (caldera-related) types of deposits.

Initial in-ground tonnage and grade relationships for Australian deposits are presented in Figure 2, based on Geoscience Australia's OZMIN 2005 database. This shows that:

- The hematite breccia mineralisation at Olympic Dam is characterised by a very large tonnage of low-grade uranium (~0.05% U_3O_8). Uranium is produced as a co-product with copper and gold. Other examples are much smaller.



▲ **Figure 1.** Distribution of Australia's initial in-ground uranium resources (t U_3O_8), by type of deposit. (Source of data: OZMIN 2005).

- Calcrete mineralisation is in medium to large tonnage deposits of low grade.
- Sandstone deposits are of relatively low tonnage but generally higher grades (> 0.1% U_3O_8) than the above types.
- Unconformity-related uranium deposits exhibit a wide range of ore tonnages and grades (generally between 0.1% and 1.8% U_3O_8). By way of comparison, in Canada's major uranium region—the Athabasca Basin—there are deposits of similar style and grade located just below the unconformity, but the McArthur River and Cigar Lake deposits, which straddle or extend just above the unconformity, are much higher grade (up to 26% U_3O_8) (Cuney 2005).

Exploration—past, present and future

As market prices for uranium fell from 1980 onwards, uranium exploration activity declined in Australia and overseas. By 2003, only five companies were actively exploring for uranium in Australia, and the 17 active projects were confined to areas adjacent to known deposits, mainly western Arnhem Land (NT), Frome Embayment and Gawler Craton–Stuart Shelf (SA).

Over the past two years, spot market uranium prices have trebled from around US\$10/lb U_3O_8 in early 2003 to US\$33/lb U_3O_8 in late 2005. Responding to these price rises, uranium exploration expenditure in Australia doubled from \$7 million in 2003 to \$14 million in 2004. Exploration has continued to increase dramatically during 2005, with about 70 companies exploring for uranium in more than 280 projects, but the current level of expenditure is a small fraction of peak levels of more than \$105 million (constant 2003 dollars) reached in 1980. The increase in expenditure that culminated in the 1980 peak was in large part due to the oil shocks of 1973 and 1979, strongly resembling the current situation of high crude oil prices and rising uranium exploration expenditure.

Early uranium discoveries relied extensively on airborne radiometric surveys. The 1960s and early 1970s saw extensive testing of surficial radiometric anomalies. This progressed to more sophisticated approaches, often based on conceptual geological modelling, which led to major discoveries at Jabiluka and Olympic Dam. In more recent exploration, airborne electromagnetic surveys have been used to locate palaeochannels in the vicinity of the Beverley and Honeymoon sandstone uranium deposits in South Australia, and to locate potentially mineralised graphitic rocks in the search for unconformity-style deposits.

Given the paucity of modern exploration, there is significant potential for additional uranium deposits to be found in Australia, including:

- unconformity-related deposits, including high-grade deposits at and immediately above the unconformity, particularly in Arnhem Land in the Northern Territory but also in the Granites–Tanami region (Northern Territory–Western Australia), the Paterson Province (Western Australia) and the Gawler Craton (South Australia)
- hematite breccia deposits, particularly in the Gawler Craton and Curnamona Province of South Australia, and the Georgetown and Mount Isa Inliers of Queensland
- sandstone-hosted deposits in sedimentary strata in various regions adjacent to uranium-enriched basement
- carbonatite-related rare earth–uranium deposits in Archaean cratons and Proterozoic orogens.

Despite the fact that there has only been one notable uranium discovery since 1980—the unconformity-related Kintyre deposit in 1985—Australia's low-cost resources have continued to increase through the delineation of additional resources at known deposits, particularly Olympic Dam.

Why so rich in uranium?

Spatial and temporal relationships between uranium deposits and unmineralised uranium-enriched rocks from across the continent have been studied in an attempt to explain why Australia has such a high proportion of the world's known uranium resources. This study was based on Geoscience Australia's extensive OZCHEM database (www.ga.gov.au/gda/index.jsp).

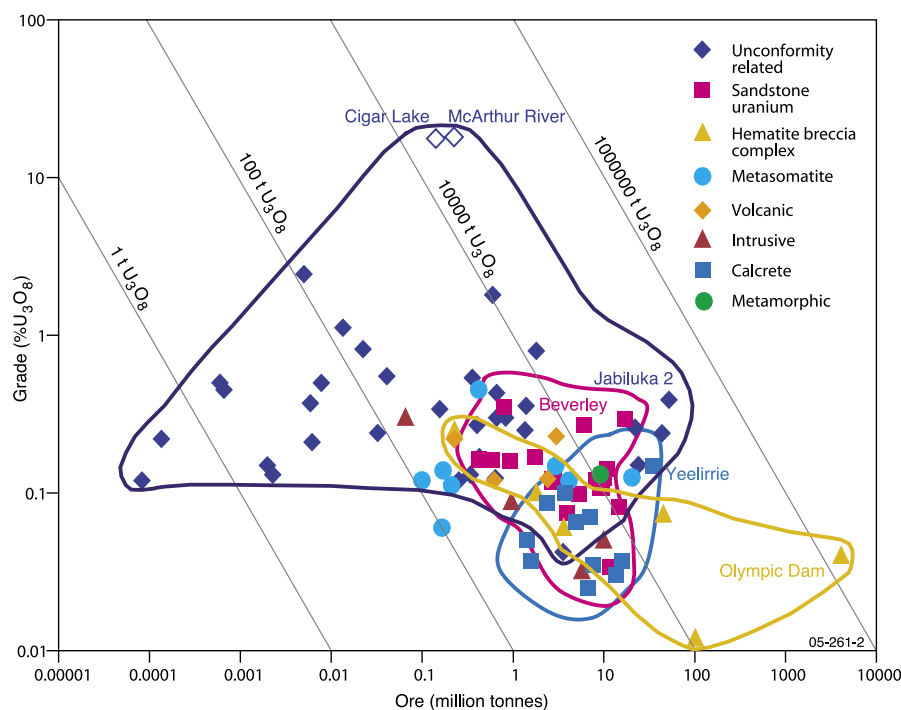
Of approximately 22 000 rocks in the OZCHEM database analysed for uranium, over 2700 have 10 ppm U or more (at least four times crustal average and more than twice the average for felsic igneous rocks). These uranium-enriched samples are mainly granitic and felsic volcanic rocks, but include a small proportion of associated gneisses and sedimentary samples. Their distribution is indicated in Figure 3. It is a significant observation that all known uranium deposits exhibit clear spatial relationships with uranium-enriched bedrocks. This observation holds true at regional to local scales.

Figure 4 shows the ages of uranium mineralisation in relation to the ages of the uranium-enriched granitoid intrusives and associated felsic volcanics, which were clearly emplaced during major magmatic events during:

- the late Archaean (2.69–2.65 Ga) (Champion & Sheraton 1996)
- the Palaeo-Mesoproterozoic. (~1.9–1.5 Ga)
- in eastern Australia, the Silurian to the Permian (0.43–0.25 Ga).

Of these intervals, the Proterozoic produced the greatest volumes of uraniumiferous igneous rocks. These are widespread in South Australia, the Northern Territory and parts of Western Australia and Queensland in regions of high geothermal gradients (Howard & Sass 1964, Etheridge et al 1987). The uranium-enriched felsic igneous rocks are mainly highly fractionated and/or have alkaline affinities. Most felsic igneous rocks contain uranium in accessory minerals such as zircon and monazite, but the uranium-enriched examples appear to be characterised by significant proportions of uraninite, which is relatively readily leached under low-temperature oxidising conditions.

◀ **Figure 2.** Logarithmic plot of U_3O_8 grade (weight %) versus initial mineral resources (Mt) for Australian uranium deposits. Two major unconformity-related uranium deposits in Canada are also plotted (as open symbols). The diagonal lines show tonnes of contained U_3O_8 .



These observations support the conclusion that the large number of uranium deposits and prospects across Australia reflects the extensive emplacement of uranium-enriched felsic rocks in three main periods of igneous activity. While some uranium deposits appear to have formed during these widespread thermal events, most formed from uranium-enriched source rocks by subsequent low-temperature processes.

In the case of Olympic Dam, mineralisation is of similar age to felsic igneous activity. Together with the close spatial association, this supports the view that the uranium was concentrated during hydrothermal activity resulting from this igneous-thermal event (Oreskes & Einaudi 1990, Reeve et al 1990, Reynolds 2000). Olympic Dam's combination of huge tonnage and recoverable uranium grades make it unique among known iron oxide Cu–Au deposits, leading to speculation about its genesis. A number of coincident factors may have been involved:

- high palaeogeothermal gradients
- vast volumes of generally uranium-enriched granitic rocks emplaced at shallow crustal level, and intruding coeval felsic volcanics
- generation of a maar volcanic setting
- overprinting of relatively reduced (magnetite-stable) alteration by hematite-stable oxidised and uranium-bearing fluids, with precipitation of uranium resulting from reduction by mixing with ascending fluids or by reactions with pre-existing sulphide-bearing magnetite alteration.

Some small intrusive and volcanic-style uranium deposits also have temporal association with felsic host rocks, including the intrusive-style Crocker Well deposit in Mesoproterozoic granitoids in South Australia and the Ben Lomond volcanic-style deposit in Carboniferous rhyolitic tuffs in northeastern Queensland (McKay & Miezitis 2001).

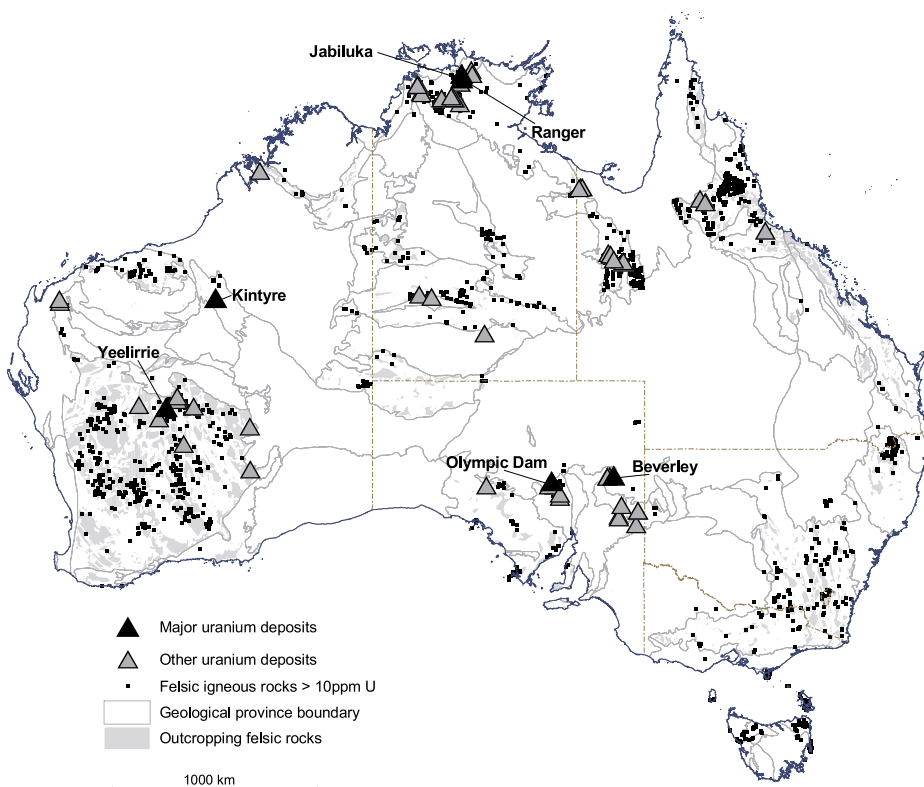
More generally, the uranium mineralisation is considerably younger than the spatially related igneous rocks. This is the case for the calcrete, sandstone and unconformity-related deposits, which appear to have formed as a result of uranium mobilisation from older uranium-enriched source rocks under low-temperature oxidising conditions, and precipitation by redox reactions. The high-grade deposits are likely to reflect relatively more efficient oxidation–reduction systems.

In particular:

- There is a clear spatial relationship of the Cainozoic calcrete-type uranium deposits in the western part of the continent, including the large Yeelirrie deposit, with the uranium-rich Archaean felsic rocks in the northern part of the Yilgarn Craton. The probable source rocks are approximately 2.6 billion years older than the uranium deposits.

- Sandstone uranium deposits are the most widely distributed type of uranium deposit in Australia and range in age from Neoproterozoic for the Westmoreland group of deposits in Queensland (Ahmad & Wygralak 1990) to Cainozoic for those of Honeymoon and Beverley in the Frome Embayment, South Australia. The Mulga Rock sandstone deposit in Western Australia was sourced from uranium in the Archaean basement to the west (Fulwood & Barwick 1990). Those in the Frome Embayment are derived from the adjacent exceptionally uranium-rich Proterozoic felsic rocks and perhaps from pre-existing uranium mineralisation (Curtis et al 1990).
- Unconformity-related uranium deposits, which formed in the late Palaeoproterozoic to late Neoproterozoic, are variably younger than the spatially associated Palaeoproterozoic to late Archaean felsic igneous rocks. In uranium fields such as in the Alligator Rivers – Arnhem Land region, available geochronological data provides evidence for several ages of mineralisation. This implies several episodes of transport and deposition of uranium, presumably triggered by tectonic activity, and resetting of ages through overprinting events.

It is interesting that no significant uraniferous deposits have been found in Late Archaean–Palaeoproterozoic conglomerates in Australia, which do not have the high proportions of quartz pebbles that are characteristic of the major gold–uranium bearing conglomerates of the Witwatersrand in South Africa, and to a lesser extent the uranium-bearing Elliott Lake conglomerates at Canada. This probably reflects the absence of major and relatively rapid uplift and erosion of fertile Archaean crustal blocks in Australia.



◀ **Figure 3.** Australian uranium deposits in relation to occurrences of felsic igneous rocks known to have at least 10 ppm uranium.

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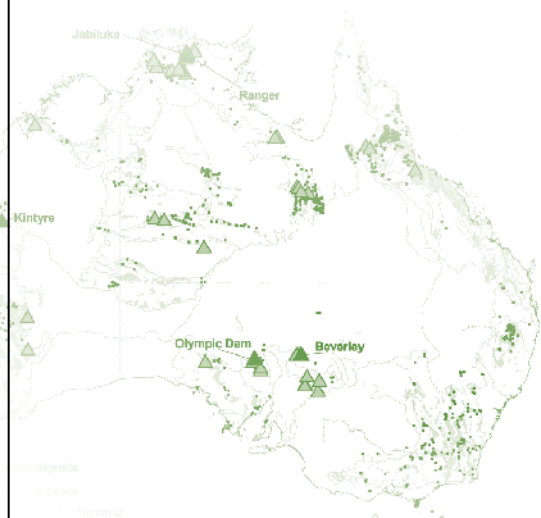
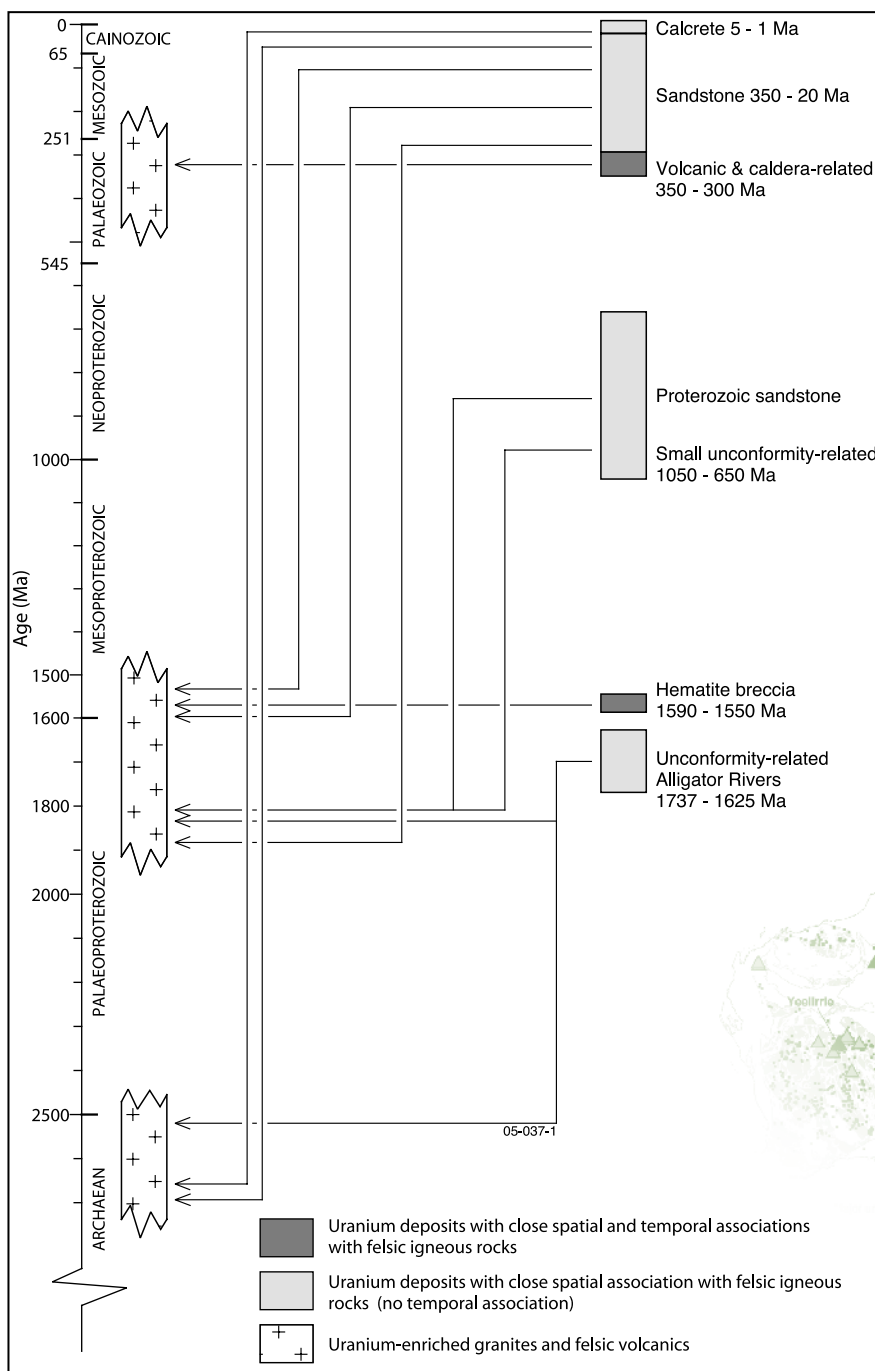


Figure 4. Ages of uranium deposits and uranium-enriched felsic igneous rocks. Lines link each deposit type to the age of its probable source rocks.