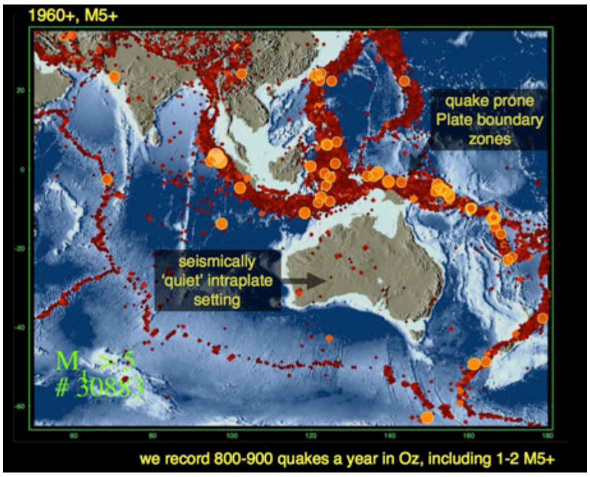
Preamble

In a forum like this it is important to begin by declaring ones bias. As a geologist, Uranium is a magical element and amongst the most important - along with Potassium and Thorium. The energy generated by its natural radioactive decay powers the movement of the tectonic plates, making mountains, opening ocean basins and forming volcanoes. Without Uranium our planet would be a whole lot different : it would be flat and featureless. In a word, BORING! But thankfully we wouldn't be here to observe it! Without the natural radioactive energy there would, almost certainly, be NO LIFE![1]

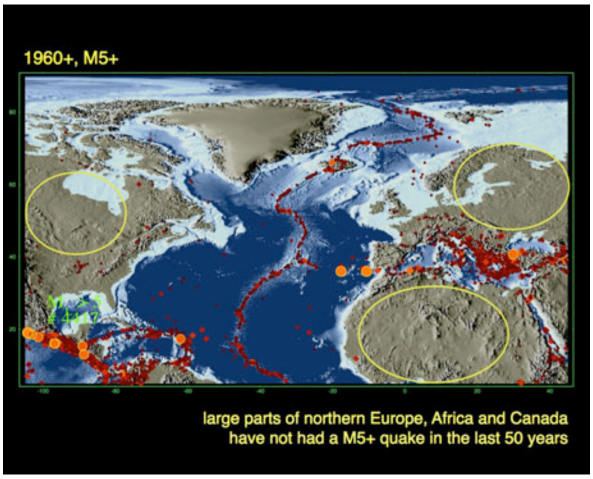
So there we are - with my bias declared - in this short session I want to address three questions relevant to Australia's nuclear energy futures from a geological perspective.

Question 1: How geologically stable is Australia?

[SLIDE 1] It is frequently asserted that Australia is the most stable of all continents, providing the best possible sites for long-term nuclear waste storage[2]. Tim Flannery (the Age, Saturday 5th August) cites the Officer Basin on the WA-SA border as the ideal. Several issues bear on this question including seismic activity and groundwater conditions. Here we address the seismic risk.



[SLIDE 2] As we know from the horrendous sequence of recent earthquake activity in Indonesia, AUSTRALIA is relatively STABLE. The Melbourne region for example is subject to about 1% of the seismic activity of Banda Aceh in Indonesia[3]. The question is how does AUSTRALIA compare to other relatively stable continental regions in INTRAPLATE settings, such as Northern Europe, Canada or Saharan Africa.



[SLIDE 3] The quantitative measure of seismic

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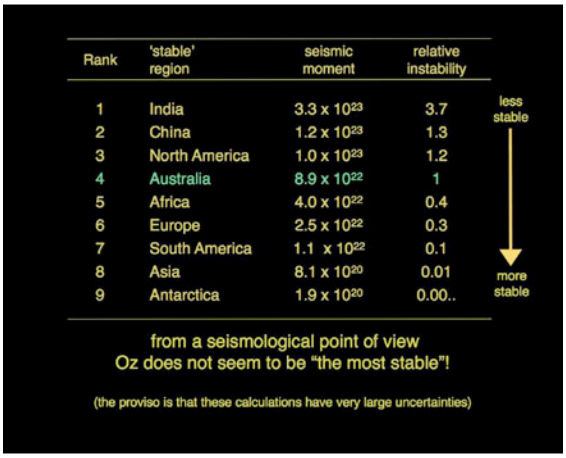
[1]the most primitive, ancestral lifeforms of our planet (so-called extremeophiles) seem to have evolved in extreme temperature environments protected from extinction by meteorite bombardment, freezing and other dangers associated with living of the ancient Earth.

[2] *"Australia has the geologically safest places in the world for the storage of waste"*, Bob Hawke ABC interview http://www.abc.net.au/news/newsitems/200509/s1468931.htm

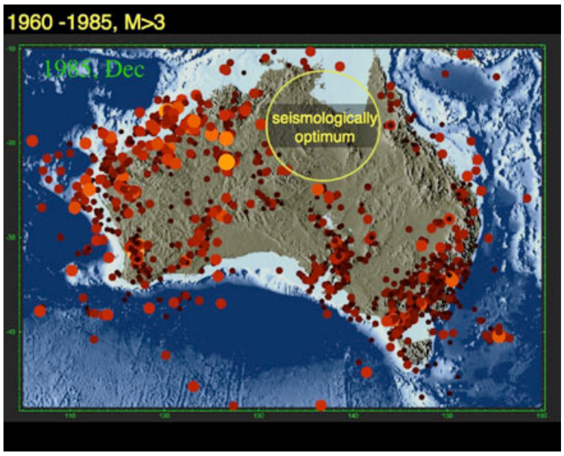
[3] While it seems obvious that wouldn't want to site any long term waste facility on an active plate tectonic boundary, it has been proposed that we put nuclear waste deep in the ocean trench where the ultimate fate of the material would be to be SUBDUCTED back into the interior of the Earth!

activity is termed the "SEISMIC MOMENT"[4]. Such measures indicate that Australia has a significantly higher level of activity than many other stable regions such as northern Europe or Saharan Africa. Of concern are the relative SEISMIC MOMENTS of the Indian sub-continent and China - two of our emerging "nuclear" customers - which have the highest seismic of any of the relatively stable regions of the globe[5].

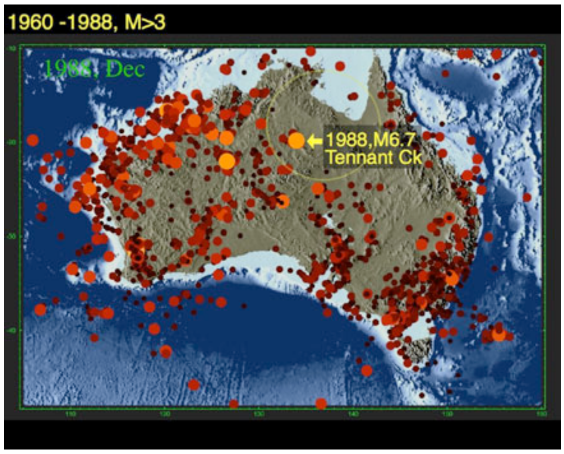


Rank	'stable' region	seismic moment	relative instability
1	India	3.3×10^{23}	3.7
2	China	1.2×10^{23}	1.3
3	North America	1.0×10^{23}	1.2
4	Australia	8.9×10^{22}	1
5	Africa	4.0×10^{22}	0.4
6	Europe	2.5×10^{22}	0.3
7	South America	1.1×10^{22}	0.1
8	Asia	8.1×10^{20}	0.01
9	Antarctica	1.9×10^{20}	0.00..

[SLIDE 4] Australia is subject to surprisingly LARGE magnitude quakes[6], with some of the largest quakes of recent times occurring in regions which we previously considered to be in the most stable parts of the continent. For example, had we been considering our options for waste storage 20 years ago in 1986 - TENNANT CREEK in the Northern Territory might well have been considered optimum from a seismological point of view.



[SLIDE 5] Two years later, the situation was very different, as a consequence of the 1988 M6.7 TENNANT CREEK quake. This quake ruptured a surface fault that displaced the surface up to 1 meter along a length of about 35 kms.



The rupture of such faults is likely to occur only every 10,000 years or so - and make the seismic risk very low, but definitely not negligible. At least in terms of the known earthquake activity the oft cited claim that AUSTRALIA is the geologically the MOST STABLE place on earth is not substantiated. Large parts of Africa, South America and Europe appear to be at least as stable if not

[4] Quantifying relative seismic moments in stable regions is difficult for a number for reasons, such as differences in the quality of seismic monitoring in different regions. This makes estimates of relative seismic moments very uncertain.

[5] This begs the question of whether we need to be engage India and China on the question of long-term waste storage as part of our provision of Uranium fuel.

[6] Several magnitude 6.8 quakes occurred in the last 40 years. Palaeo-seimological studies here at Melbourne University suggest quakes with magnitudes as high as ~7.3 have occurred in the comparatively recent geological past. For example, about 50,000 years ago a large fault rupture some 70 kms long and with up to 8 m vertical displacement dammed the Murray River to form the Barmah Forest near Echuca.

more so[7].

Question 2: How much Uranium does Australia have?

The Australian continent has far more than its fair share of Uranium[8], making it seemingly inevitable that we will be involved in the nuclear fuel cycle if nuclear energy is to become a long-term replacement for fossil fuels. Our resource accounts for an estimated 30-40% of all known uranium resources globally[9], with most of our Uranium coming from the one deposit at OLYMPIC DAM is South Australia. This distribution of the Uranium resource has an eerie resemblance to oil in the Middle East, where Saudi Arabia contains ~20% of the global oil reserves and Iraq ~10%. In total, the Middle east accounts for ~60% of the current known oil reserves; a geological anomaly that continues to provide an extraordinary driver of international politics.

To answer why we have so much - and whether the known distribution is likely to be maintained we need a bit more detail. Measurements of the HEAT FLOWING from the interior of the Earth suggest that large parts of the Australian crust, mainly in South Australia and the Northern Territory, have about 2-3 times the normal concentration of Uranium. Normally Uranium occurs at levels as little as several parts per million. To make an economic deposit, this primary concentration of Uranium needs to be ENRICHED several hundred times by secondary processes. These naturally occurring enrichment processes[10] seem to have been particularly effective in the parts of Australia where higher than average abundances of Uranium have contributed to elevated temperatures in the shallow crust[11]. In this context, Australia might be expected to have a higher than average proportion of the Uranium resource, although not realistically to the 30-40% level of the present resource distribution.

With another Olympic Dam style discovery, it is conceivable that we could hold over 50% of the world's Uranium reserves. More realistically, our proportion of the resource will de-

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[7] Of course the geological factors that contribute safety are greater than seismological and one of those relates to ground water conditions. The problem with groundwater is that it is variable on the time-scales that are relevant to the life of the nuclear waste hazard. For example, the Australian hydrological regimes have changed enormously over the last 50,000 years, and understanding what they will be like over the next 50,000 years is a formidable challenge. Suffice it to be said that such of the debate about groundwater suitability implicitly relates it to the prevailing conditions - and do not easily translate to the life-time of the hazard itself.

[8] In fact, one reason why Australia might have a higher than average number of quakes given its intraplate tectonic setting, is that it is somewhat hotter than most continents because of the Uranium it contains and the heating from naturally occurring radioactivity may have caused a slight "softening" of our crust.

[9] This figure is constantly changing because almost all of our known reserves come from one extraordinary deposit - the OLYMPIC DAM deposit in SA. This deposit just keeps on getting bigger and bigger the more it is explored. While the Olympic Dam deposit is extraordinary there are indications that others may exist. For example, prospects such as PROMINENT HILL in South Australia have many similarities and may significantly increase Australia's proportion of the known reserve. Contra-wise, a discovery of an overseas "Olympic Dam" could dramatically reduce the Australian geopolitical Uranium inheritance.

[10] Not be confused with NUCLEAR ENRICHMENT of U235 needed for fueling reactors

[11] Probably because of powerful feedbacks between primary abundance of Uranium and the ability to achieve secondary enrichment to economic concentrations

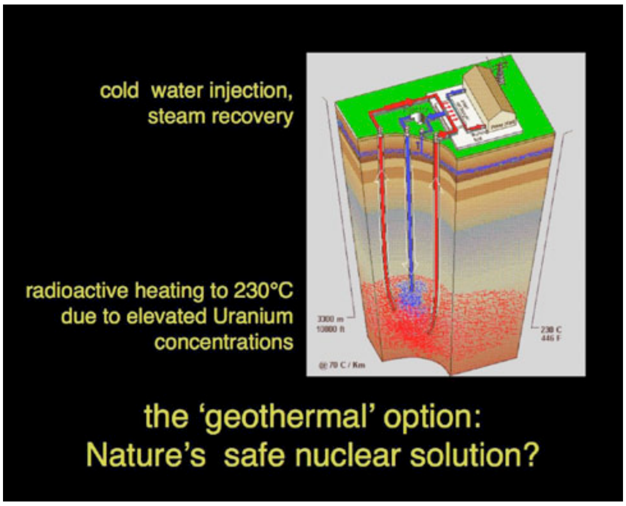
cline as exploration generates new discoveries, as it will inevitably, in other parts of the world. However, the heat flow measurements suggest we are likely to remain as the main resource holder into the long-term[12].

As we have seen with the Middle East with oil, in an ENERGY-DEPENDANT world the geopolitical ramifications of such a resource concentration provide a dimension to a nuclear-powered future that we may struggle to avoid, even if we wish to.

Question 3: What is the geothermal option?

I will finish by mentioning one of the potential up-sides to Australia's extraordinary enrichment of Uranium - the possibility of GEOTHERMAL ENERGY. Geothermal energy promises the prospect of an extraordinary large supply of SAFE "NUCLEAR" ENERGY, where there is no enrichment cycle and the waste is conveniently and naturally accommodated by the Earth[13,14].

[Slide 6] Natural radioactive decay generates sufficient heat to keep the inside of the Earth hot -thats why we get volcanoes. Typically the rate of increase of temperature with depth is around 20°C per kilometer. In the most Uranium-rich parts of Australia, temperature gradients are commonly twice this. In the hottest parts of Australia such as the Cooper basin where the geothermal explorer GEODYNAMICS has drilled to 4.2 kms in search of thermal reservoirs with temperatures of 250°C, geothermal gradients are up to ~60-70°C/km.



This possibility has spawned significant interest in geothermal energy - utilizing the long-term heat of the natural nuclear process accumulated over many millions of years[15].

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[12] We have much to learn about Uranium distributions in the Earths crust, and we are only just beginning to understand the links between primary concentration and secondary enrichment. My view is that we have barely scratched the surface with regard to the Australian Uranium resource potential.

[13] Although, not entirely without some problems as the radon generated by the natural radioactivity in the source rocks can leak to the surface where it may reach dangerous levels

[14] The type of geothermal energy we are seeking in Australia is very different to that in volcanic regions such as Iceland or New Zealand where groundwater heated by magma in the crust vents steam to the surface naturally.

[15] In terms of energy resources, the geothermal option sits between the NON-RENEWABLES and the RENEWABLES. The heat resource represents the accumulated radioactive energy over many millions of years, and the geothermal process seeks to tap this energy source on a period of several 10's of years. While the heat will ultimately be renewed by ongoing natural radioactivity, it does so at geological rates and so the resource will be depleted on human timescales. Extracting the heat has no significant environmental affect, because our atmospheric energy balance is so totally dominated by the incoming solar energy that it does not feel the much smaller flux of heat that comes from the deep earth. And of course, geothermal produces no greenhouse gas emissions.

In order to extract this heat we need to pump water into the hot rocks, and then recover it as steam, using a combination of injection and recovery wells. The resource that GEODYNAMICS is seeking to target is said to have the potential to provide energy equivalent of 50 million barrels of oil or more than 10 times Australia's total known oil reserves.

There are many challenges - from the identification of appropriate natural thermal reservoirs, to the engineering issues to with injecting water into the reservoir, circulating it through the reservoir in fashion that allows recovery, but does not concentrate the flow too much, cause chemical reactions that clog the system, or take to much energy to pump it, all at 3-4 kms depth in the crust.

We don't yet have a clear idea yet about just how this is going to work. At this stage we don't even know what the resources are. My own work with students has helped show that South Australia in particular contains some excellent prospects. If it can be made to work there, then I am confident that the possibilities elsewhere will be greatly expanded. However at the moment the risks are huge, especially for the small start-up companies brave enough to venture in this field, and the industry here in Australia is currently at a knife's edge.[16]

CONCLUDING REMARKS

In this short comment I have only just touched on some of the well known and not so well known issues to do with our NUCLEAR inheritance from a geological perspective. To reiterate:

[1] while Australia is amongst the most stable regions tectonically, it DOES NOT appear to be the MOST STABLE as is often asserted in discussions of long-term waste storage here.

[2] Our Uranium resource is extraordinarily large for geological reasons that are not entirely apparent, adding an important geopolitical dimension to the NUCLEAR issue.

[3] Finally, this very enrichment of Uranium may have created the potential for generating an inherently much safer 'nuclear' option in the form of geothermal energy.

[16] the federal government announcement on Monday, 14th August of ~$135 million to Geoscience Australia to help secure Australia's energy future will hopefully go a long way to helping this sector overcome the many hurdles on the immediate horizon.