URANIUM AND OTHER VALUABLE MATERIAL RECOVERY FROM POLYMETALLIC ORE BODIES AND WASTES

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Uranium From Polymetallic Ore Bodies

Primary Raw Material: if it is not grown (farmed, fished etc) – then it *must* be mined.

Uranium From Polymetallic Ore Bodies

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URANIUM FROM POLYMETALLIC ORE BODIES

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Uranium From Polymetallic Ore Bodies

The has now been given a new importance in the form of “comprehensive extraction”, “zero waste” etc because of three main interrelated drivers: socio-economics, environmental and, to a lesser degree, commercial

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For comprehensive extraction to be successful, all three have to be influencers

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URANIUM FROM POLYMETALLIC ORE BODIES

From the perspective of comprehensive extraction:

Environmental drivers - self evident from first principles

Socio-economic drivers – security of supply

Commercial – corporate/market driven

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Peak oil production espoused during the 1970's, concepts applied to metal commodities in the 1990's

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Peak oil production espoused during the 1970's, concepts applied to metal commodities in the 1990's

Fracking demonstrated that this concept was seriously flawed for even simple natural resource systems because of technology step changes

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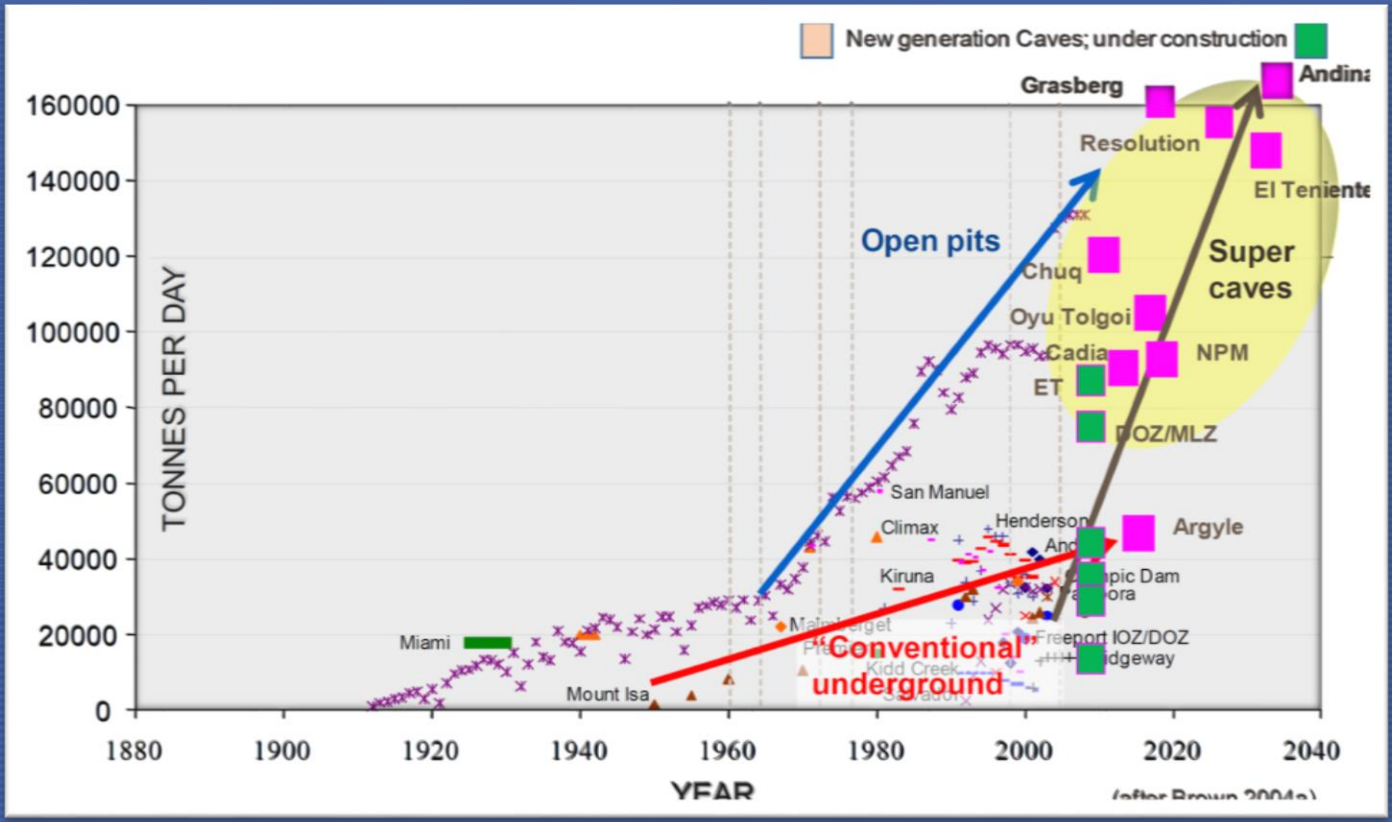
Nevertheless! Grades of metal ore deposits generally decline, depths of discovery increase, demand increases, and so to compensate, mining gets bigger.



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And so the wastes get bigger......

It has been estimated that, annually, the production of solid mine wastes now matches the amount of Earth materials moved by global geological processes(several thousand million tonnes per year)

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And so the *commercial* imperatives for more efficient extraction increase in order to

1) Improve project economics to satisfy demand
2) Reduce waste during mining

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Uranium From Polymetallic Ore Bodies

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Parallel drivers from an environmental perspective

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And so the *commercial* and imperatives for more efficient extraction increase in order to

1) Improve project economics to satisfy socio-economic demand
2) Reduce waste during and after mining

Parallel drivers from an environmental perspective

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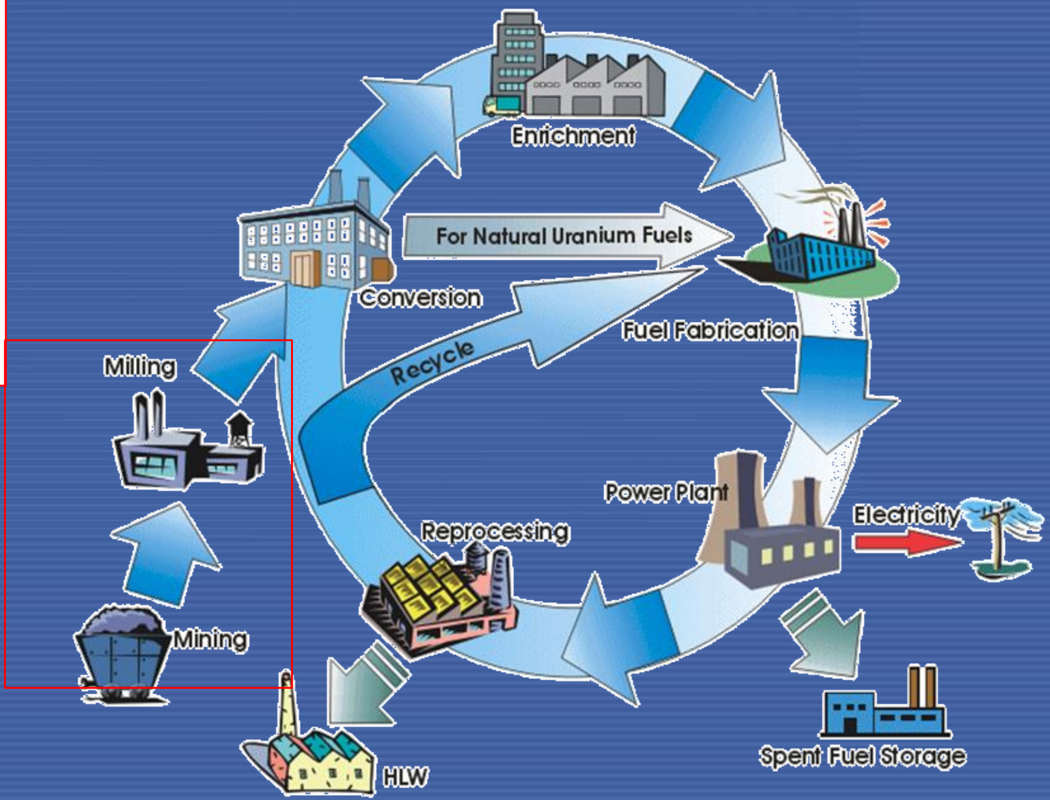
URANIUM FROM POLYMETALLIC ORE BODIES

The Nuclear Fuel Cycle



The Uranium Production Cycle (ISR, open cut, underground)

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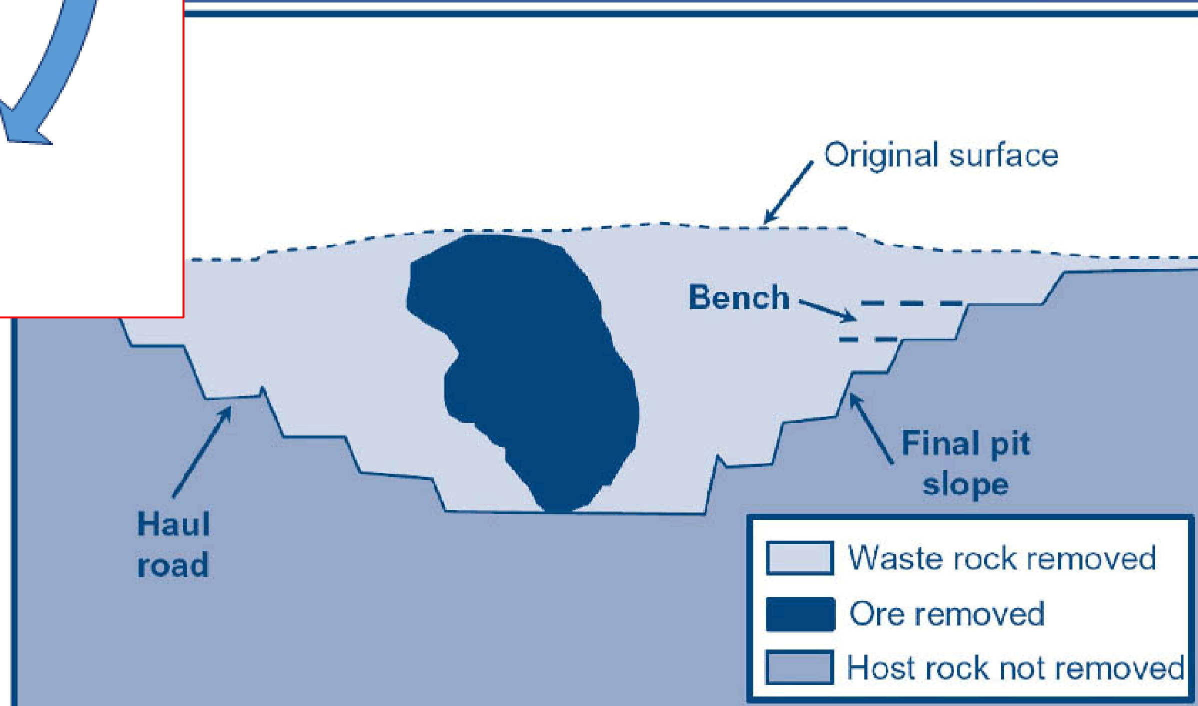
Strip ratios of non-ore waste rock: ore rock can commonly be 20:1 (open cut) to 1:1 (underground mining)



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Other types of mine wastes influencing the waste:metal

- Overburden
- Tailings
- Waste Slags
- Mine water
- Water treatment sludge
- Gaseous wastes

And because ore grades range from tens % to tens of ppm, the waste material to metal can be >> 1000:1

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Metal-containing ore bodies of all types form from geological processes that are not entirely exclusive to a particular metal and so:

- "Non-uranium" ore bodies will commonly have elevated uranium and
- "Uranium" ore bodies will commonly contain elevated quantities

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The world largest measured resource of uranium - ~ 2 Mt U – is found at Olympic Dam, South Australia. It is **not** a primary uranium deposit, it is a copper- gold deposit of sufficient size as to make the moderately elevated U (< 1000 ppm) commercially viable to extract. U is “co-product”

More-over there are several decades of global REE supply in tailings that have not been commercially viable to extract. REE is a “by-product”. This is not uncommon. At Mary Kathleen uranium mine site, 7 Mt of mill tailings carrying approximately 3 wt% total REE oxides. Critical metals!

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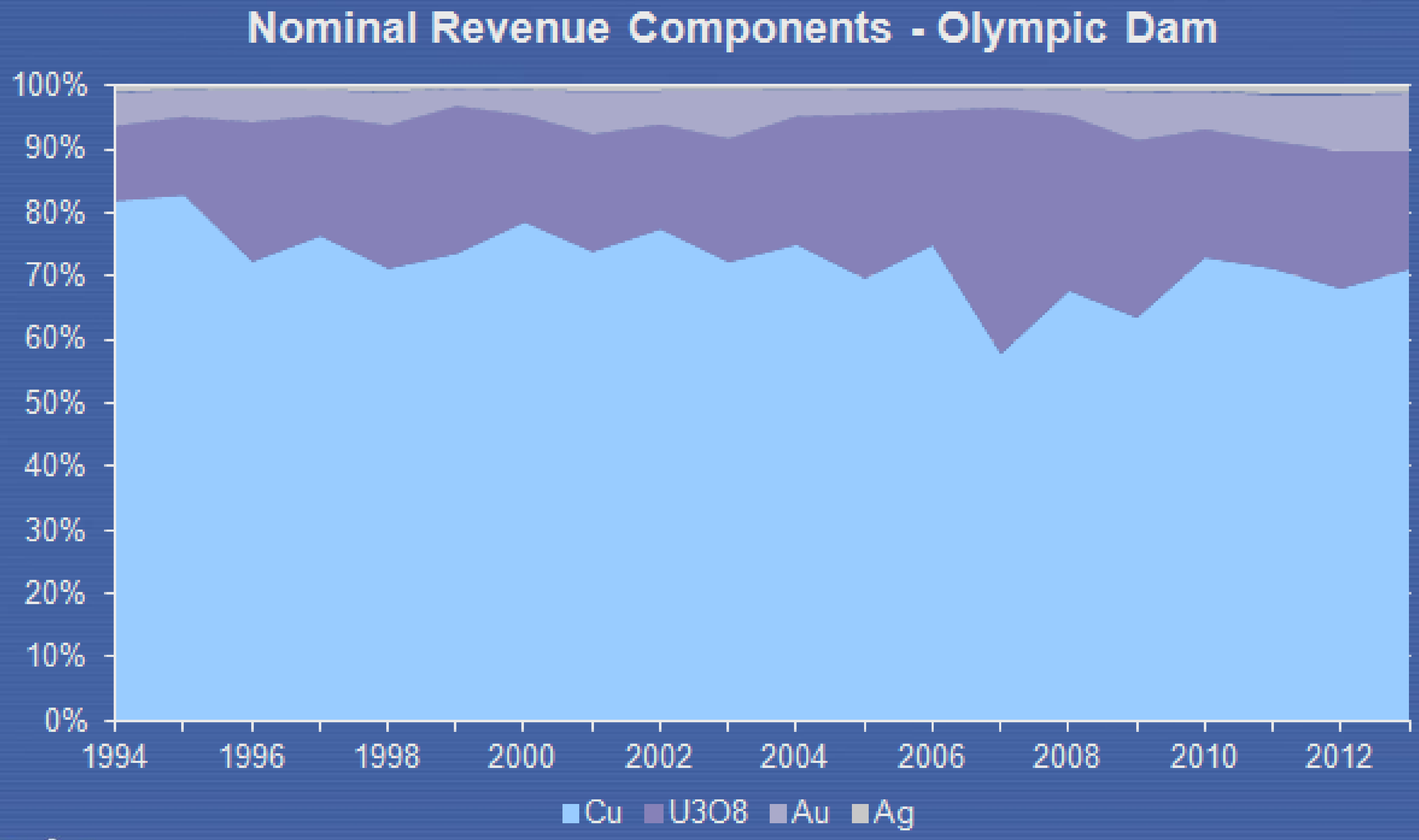

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As of 2015, Uranium produced in conjunction with other metals has accounted for over eleven percent of historical world uranium production (~2.5 MtU).

Gold, copper and uranium/vanadium deposits have provided the bulk of this production with 158,934 tU, 68,674 tU and 64,227 tU, respectively.

The speculative (largely publicly unestimated) resources, and/or unexploited resources in waste material where uranium extraction was of no initial interest are far greater…..

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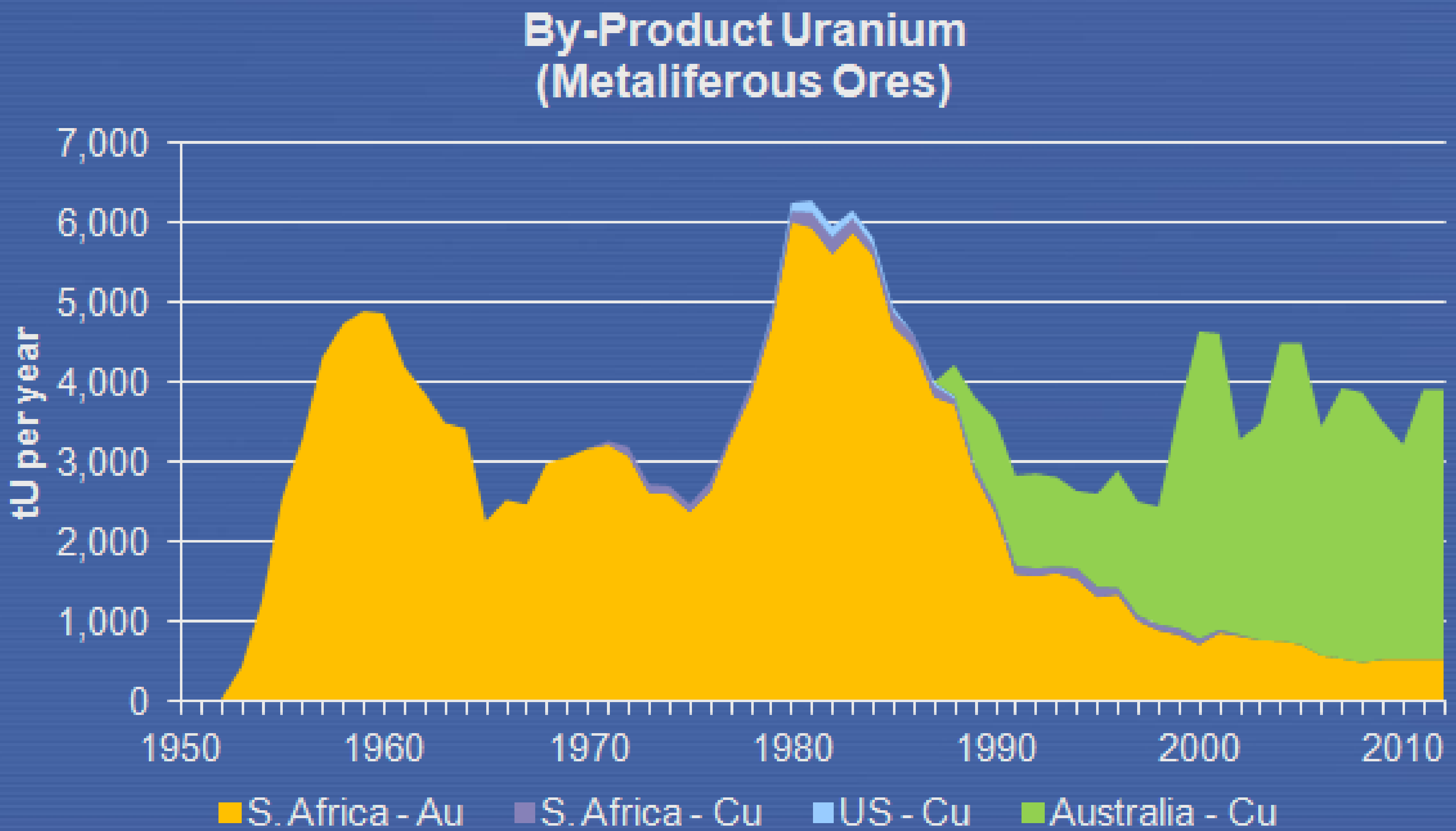

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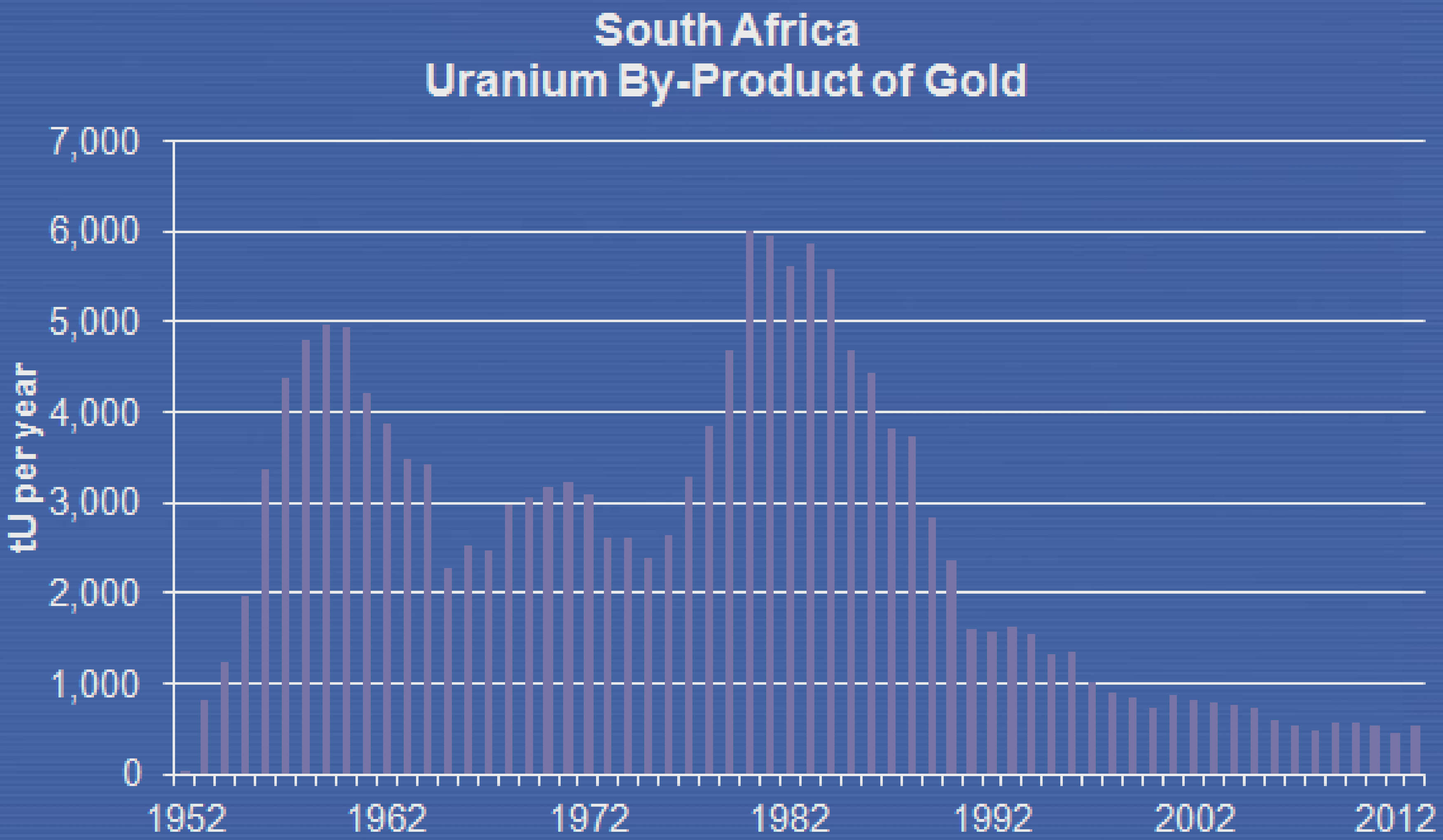

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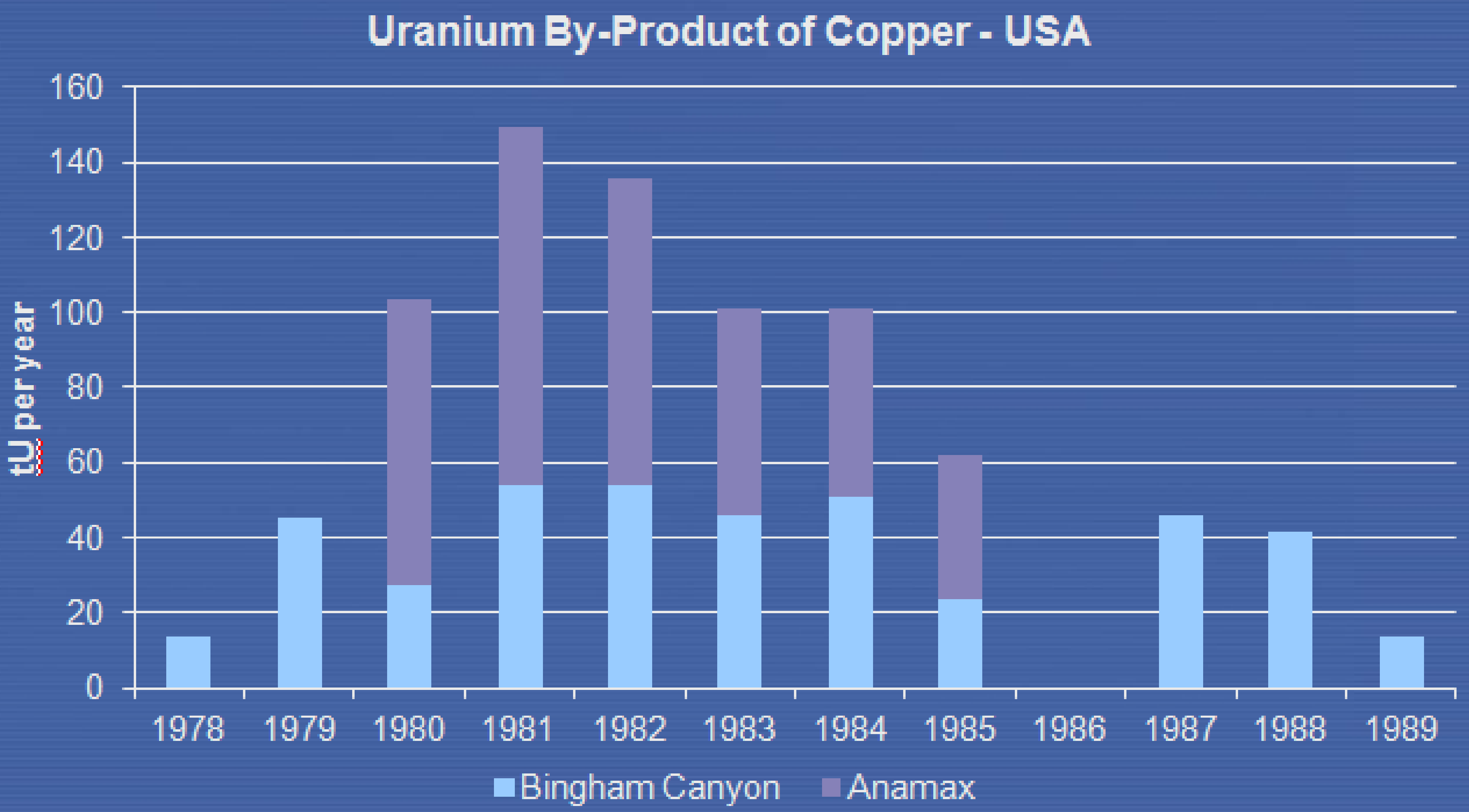

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In many "non-uranium" ore bodies, the naturally occurring radioactive material (NORM - uranium or thorium) is not sufficiently elevated enough to contribute *directly* to the revenue stream during extraction of other materials and so is concentrated in the waste material (TENORM).

There are clear environmental drivers to remove uranium in primary processing as well as "re-mining" of waste, but what about socio-economic and commercial drivers?

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- Increase profit/robustness against individual metal prices
- Security of supply (where other sources do not exist)
- resource depletion/sustainability issues
- Reduce toxic waste legacy
- Offset remediation costs

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And all of these can change with time. A by-product can become a co-product and perhaps even the primary metal extracted. Or the reverse.

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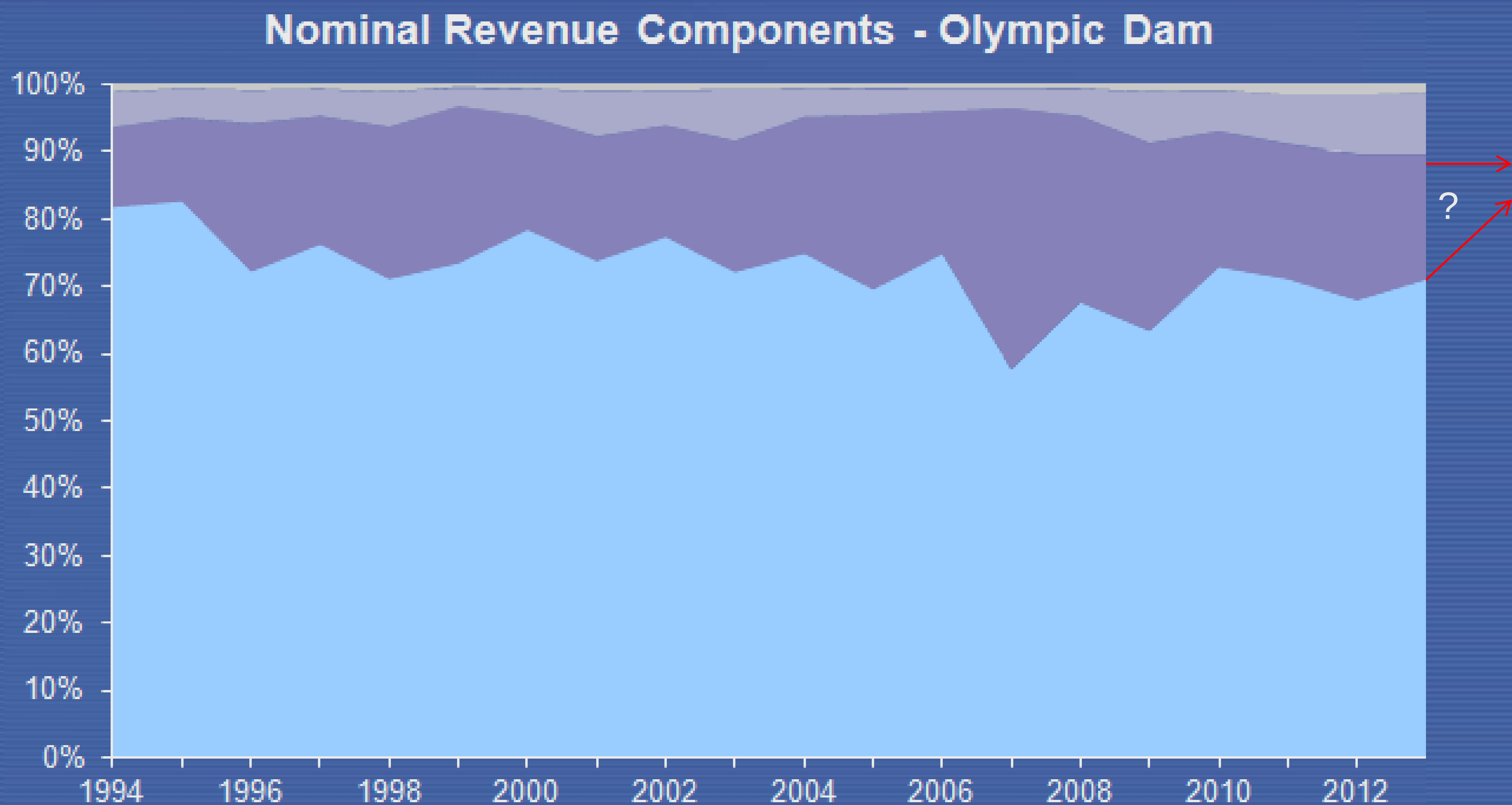

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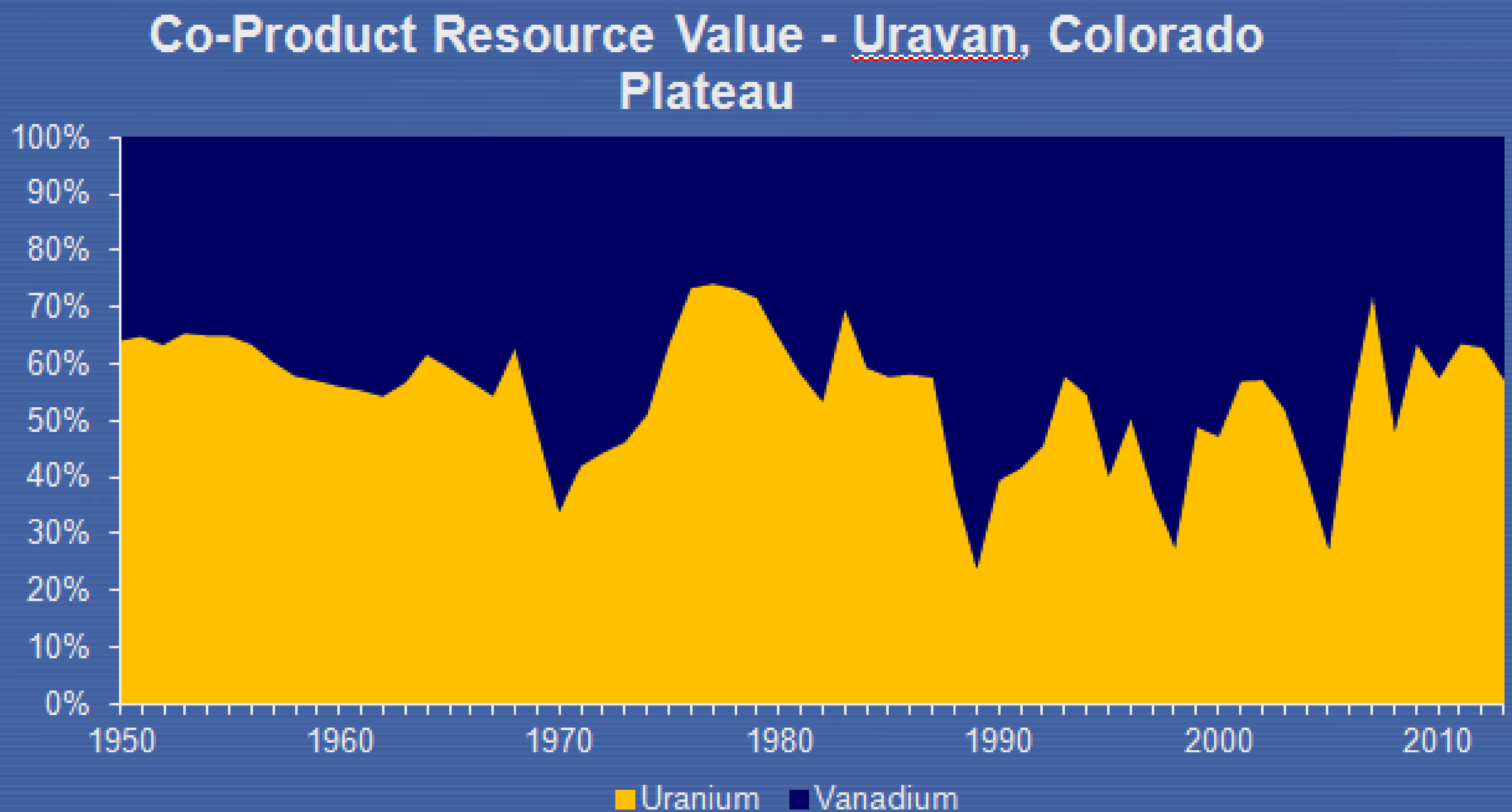

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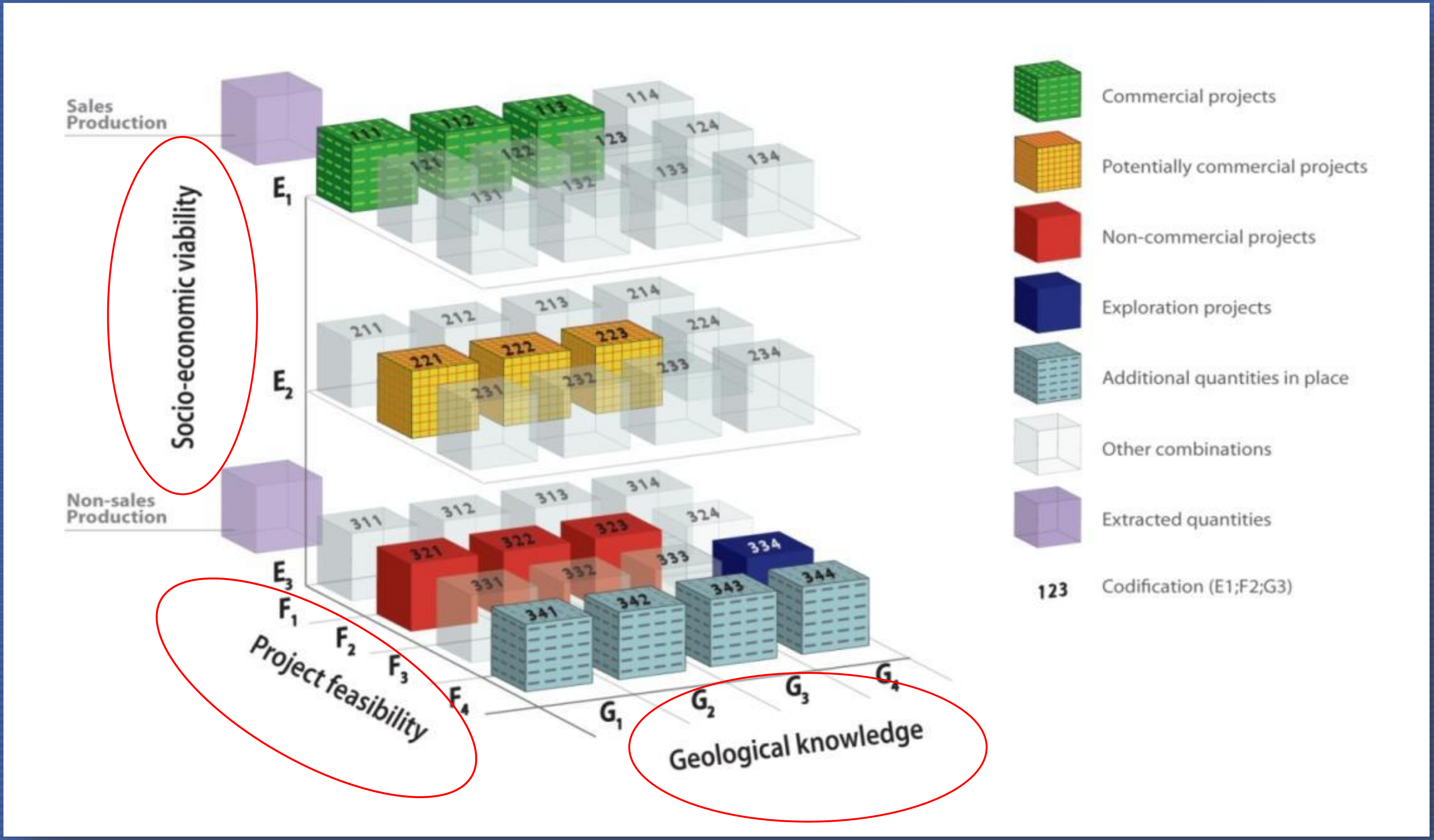
So how do we assess the potential for extraction of co-products from primary co-product and secondary (anthropogenic) by-product sources?

Uranium From Polymetallic Ore Bodies

The United Nations Framework Classification (UNFC) system provides an excellent opportunity, as it explicitly caters for all necessary aspects. This is the next step in UNFC



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https://www.unece.org/energywelcome/unfc-and-resource-classification.html

Uranium From Polymetallic Ore Bodies

So how do we assess the potential for extraction of co-products from primary co-product and secondary by-product sources?

Limitations:

• Primary co-product – we do not fully understand the relationship of metals to one another in ore bodies (a deposit is commonly evaluated empirically as “Commodity A”, with some “Commodity B”)
• Secondary by-product from waste – only minor direct information from original ore body, little or no direct grade data on waste

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We need to build an inventory....

(we already have them for metal as the primary products)

An example from uranium:

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UDEPO DEPOSIT CLASSIFICATION

1. Intrusive anatectic and intrusive plutonic* (granite monzonite = porpyhry copper, carbonatite, peralkiline complexes = REE)
2. Granite-related
3. Polymetallic hematite breccia complex* (IOCGU)
4. Volcanic-related
5. Metasomatite
6. Metamorphite
7. Proterozoic unconformity
8. Collapse breccia pipe
9. Sandstone*
10. Paleo quartz-pebble conglomerate*
11. Surficial
12. Coal-lignite
13. Carbonate
14. Phosphate
15. Black shales*

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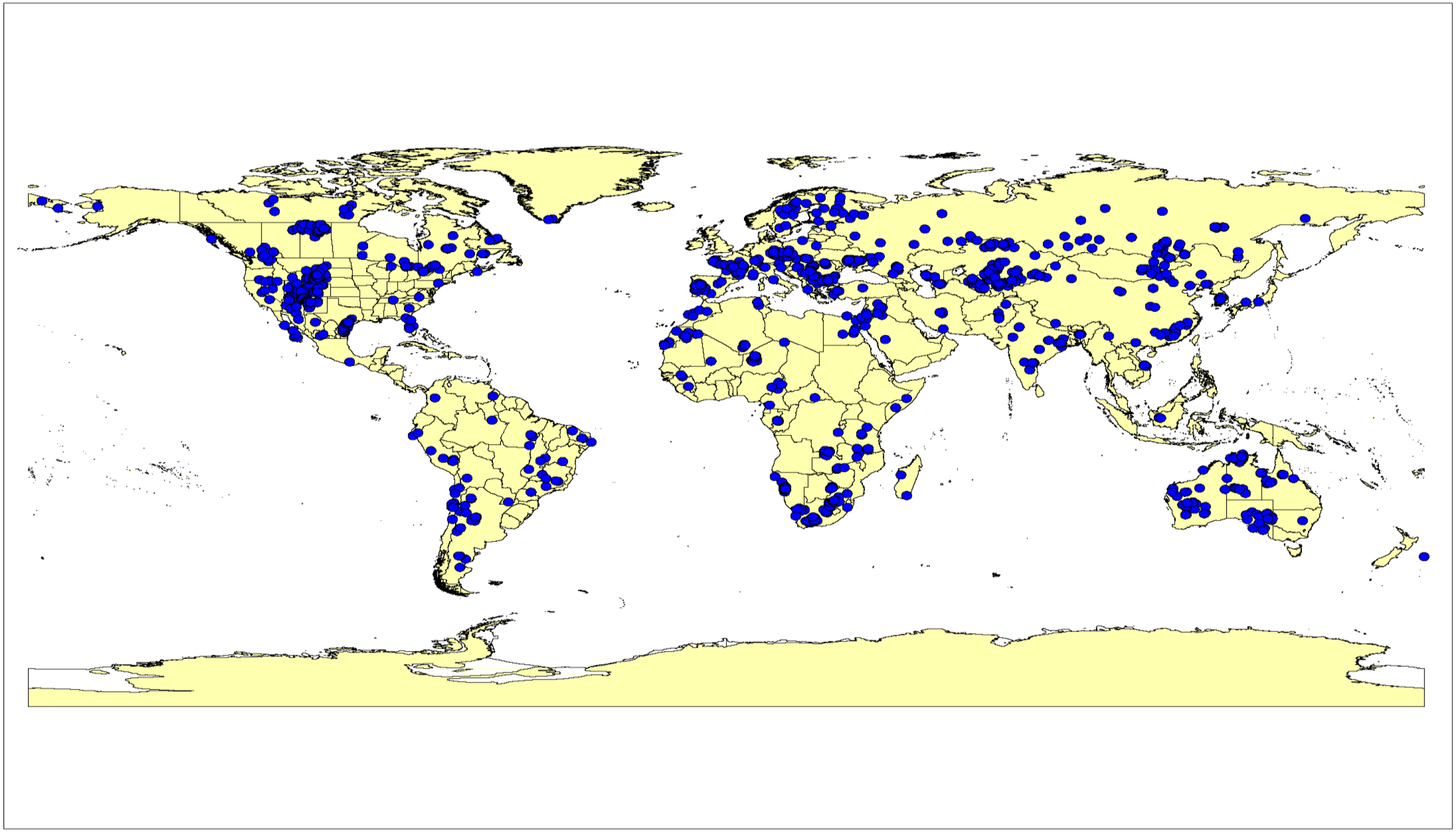
All UDEPO deposits (~2000, June 2016)



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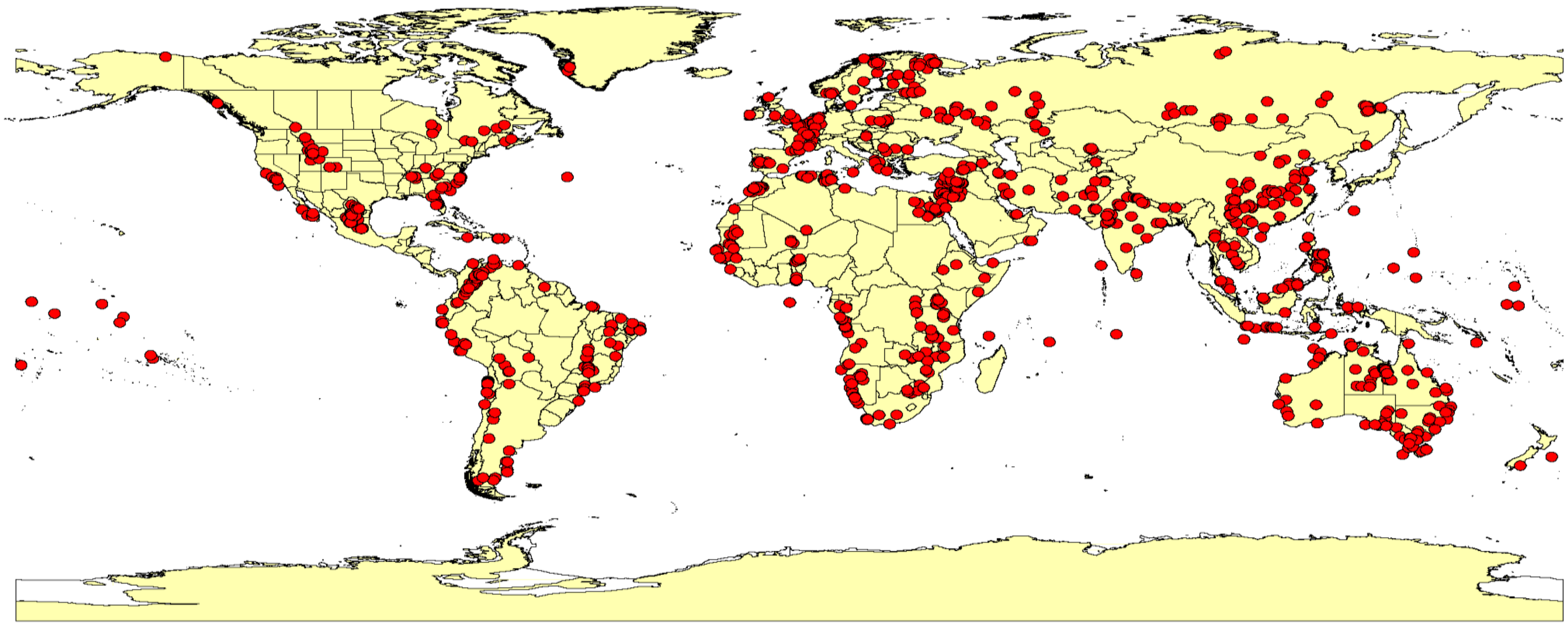
Phosphate deposits



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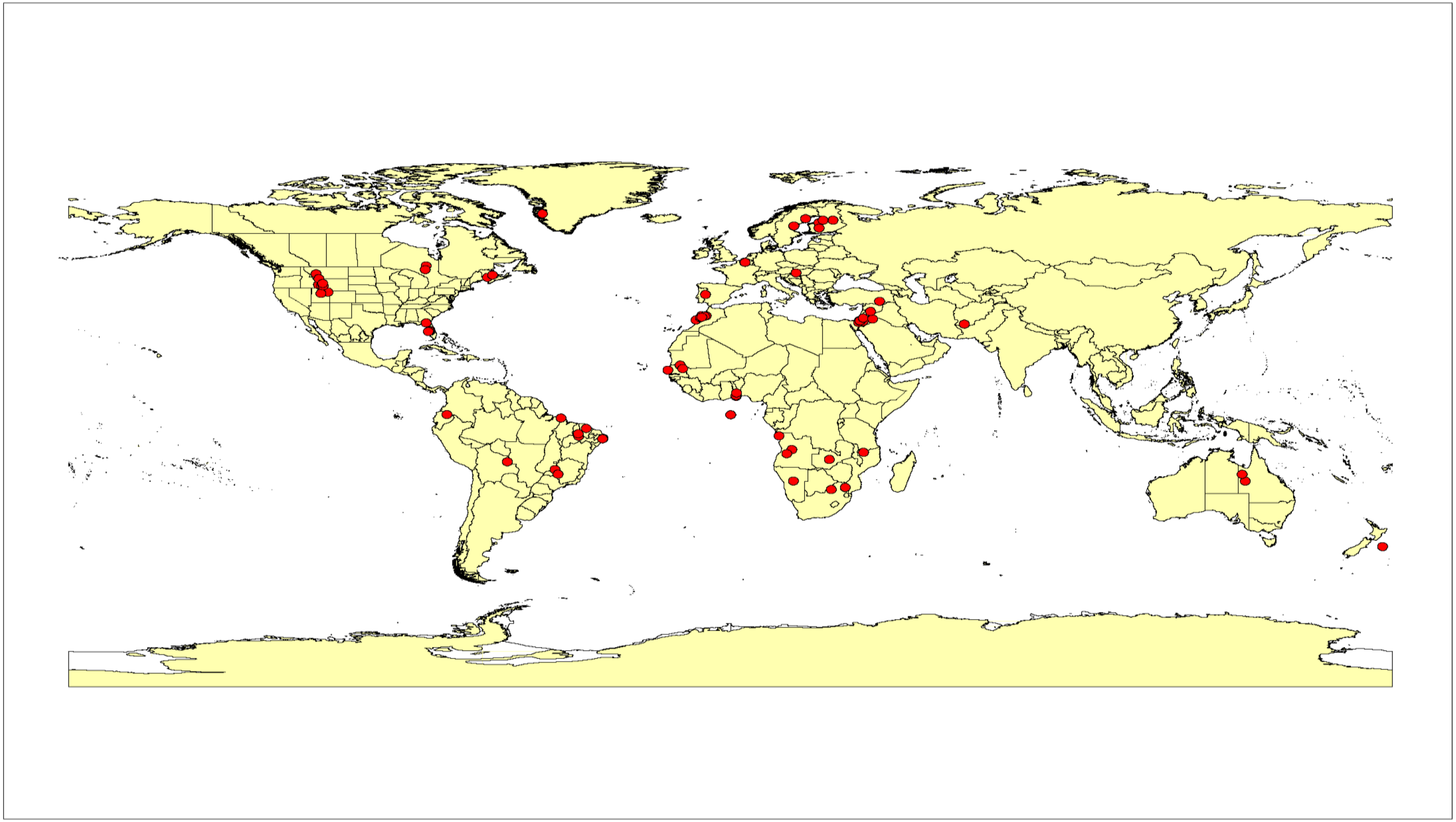
Phosphate deposits with identified U



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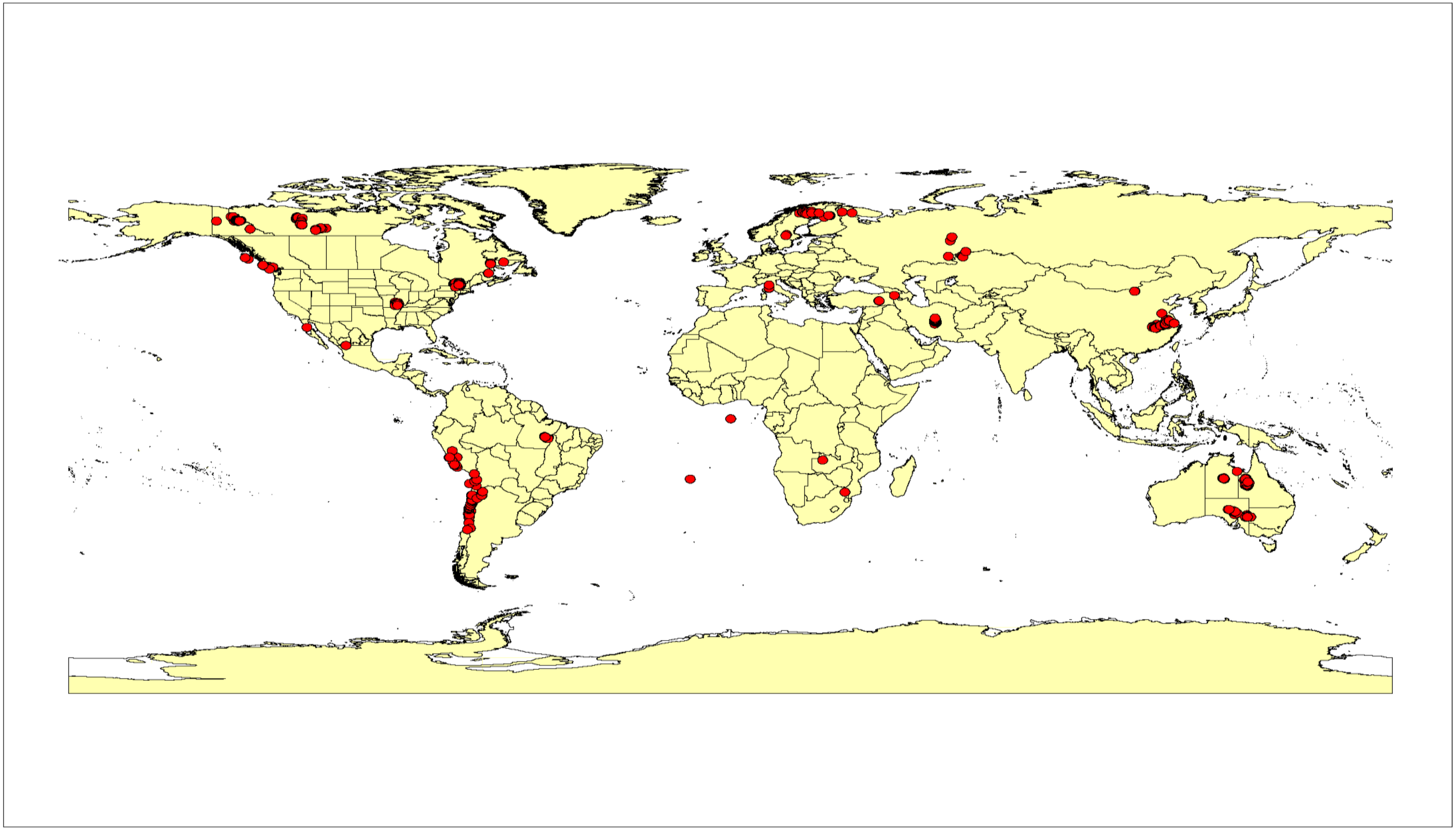
IOCGs (includes polymetallic iron oxide breccias = IOCGU)



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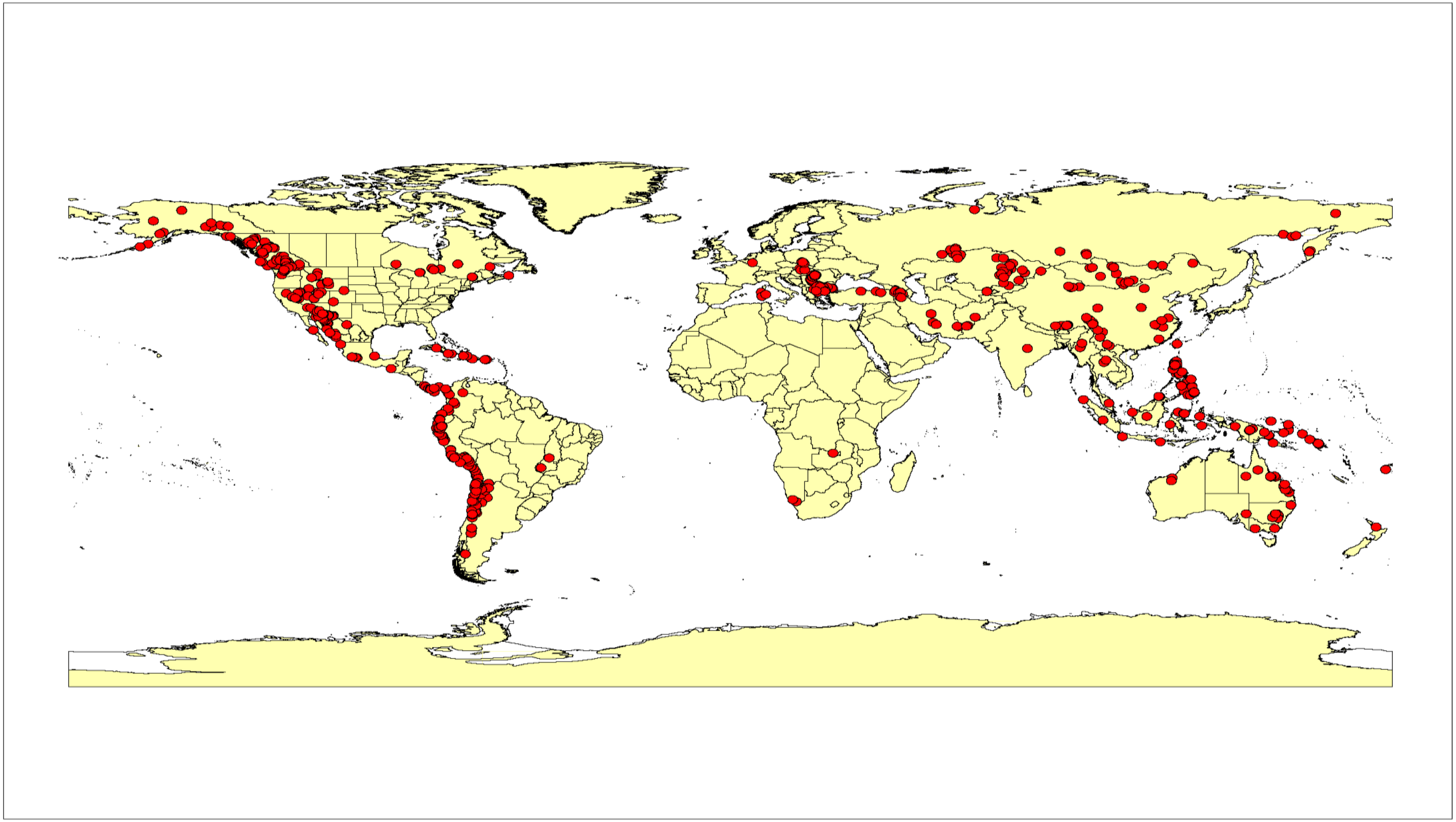
Porphyries



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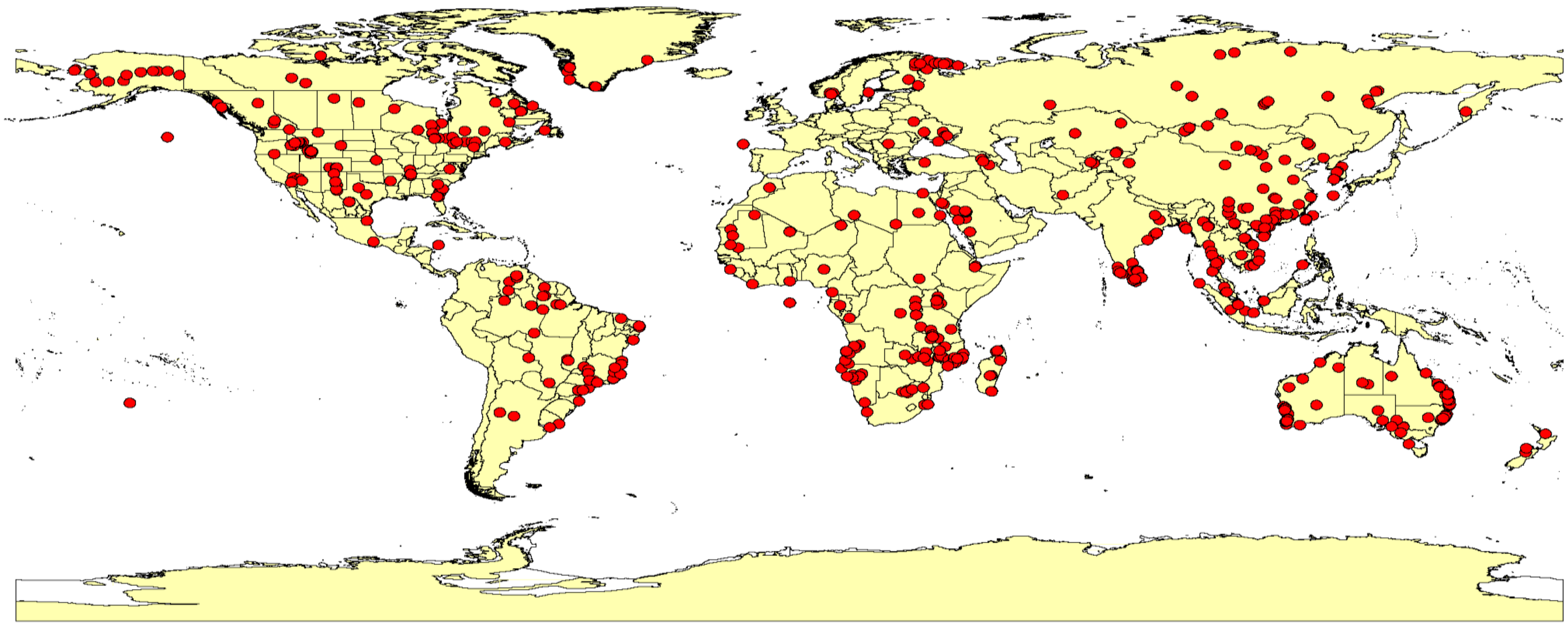
REE deposits



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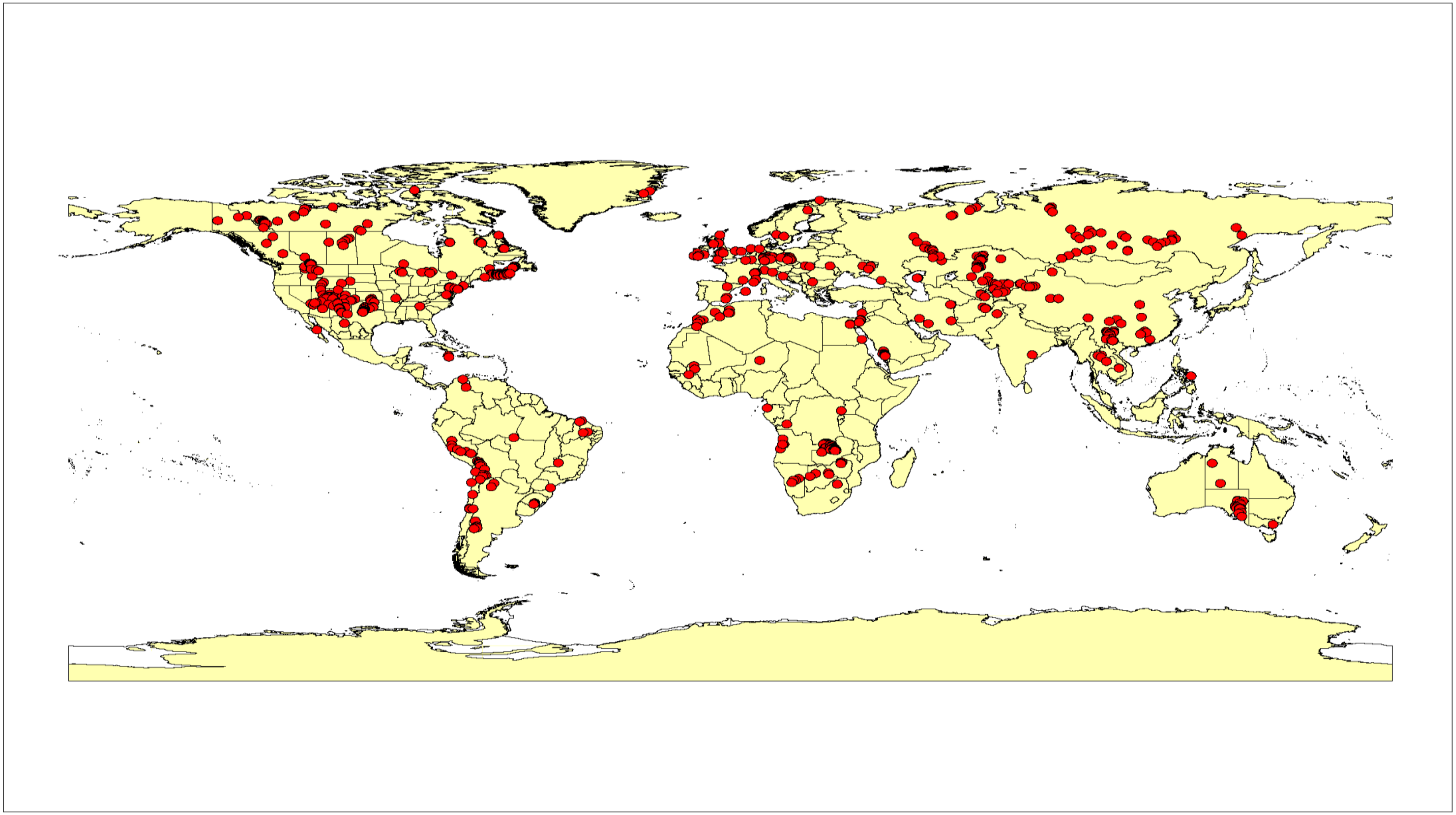
Sediment Cu(+/- Au) deposits (commonly with U in mine waste)



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Deposit type-subtype-class	*Resources UDEPO*	*Grade (ppm)*	*UDEPO deposits*	*World deposits*
Porphyry copper	225.000 t	10-40	7	691
Peralcaline complexes	460.000 t	70-750	14	125
Carbonatites	210.000 t	30-450	12	848
IOCG	2.5 Mt	30-250	16	> 100
Coal-lignite	7.2 Mt	50-400	13	1600
Black shales	20.7 Mt	10-200	26	Several hundreds
Phosphates	14 Mt	50-200	45	1635
			133	**5-6000***

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Unconventional deposit subtypes, including some with co/byproduction

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So conservatively rather than 5000-6000 additional deposits already discovered there are likely to be 500-1500 i.e. Maybe 5-10 times more uranium resources in already discovered polymetallic deposits

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So what about Uranium and other metals in mine wastes?

There is even less information. Mainly indirect (ie derived from original resource estimations, minus production and remaining ore – a poor proxy for many reasons). In the case of uranium mining most focus is on physical (radio-activity levels) not chemistry (grades)

However significant progress is being made by several EC funded projects – but in Europe only (ProSum, INTRAW. MINEA, Minerals4EU etc).

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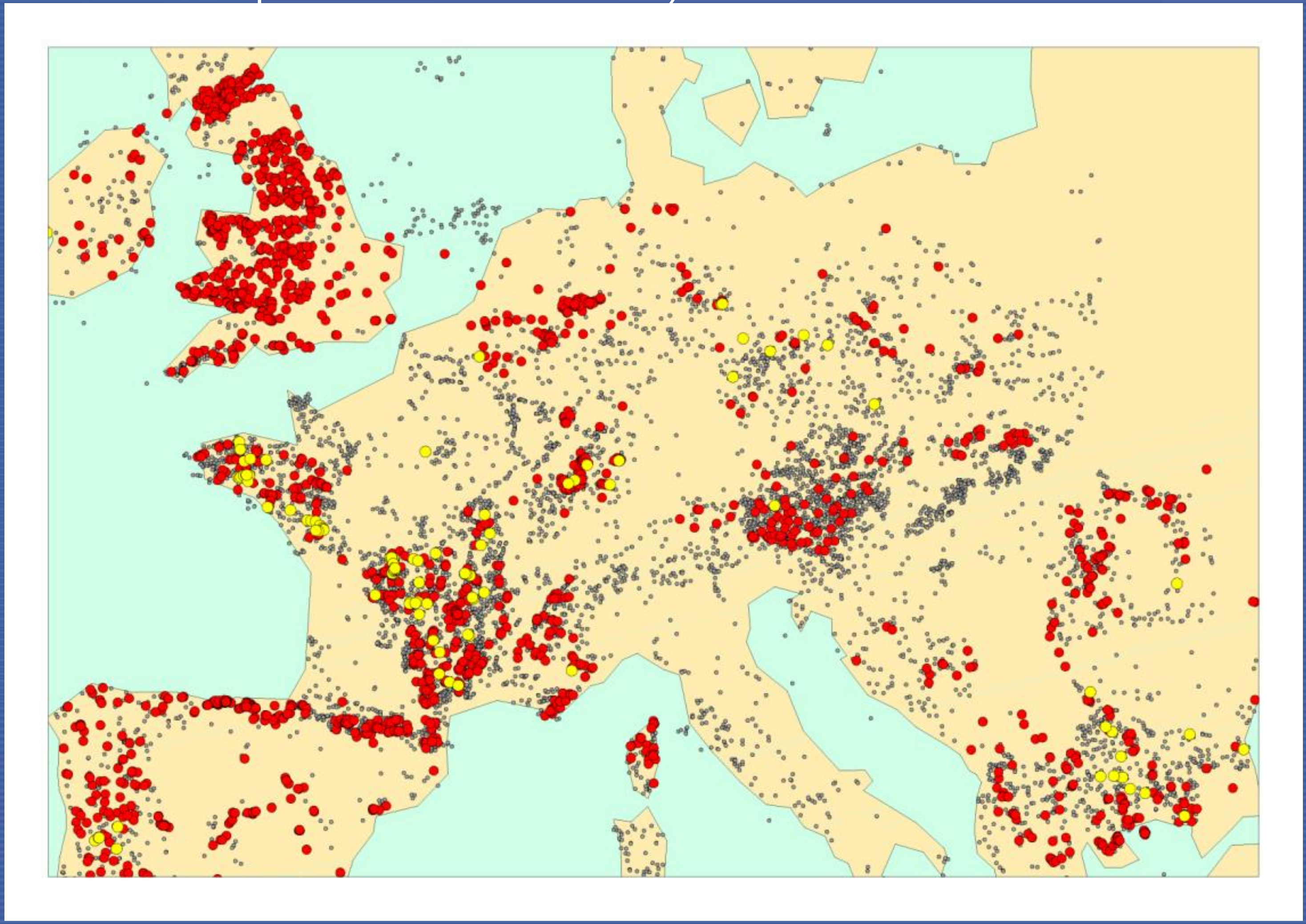
Mine and mine waste in Europe
(data courtesy of Minerals4EU http://www.minerals4eu.eu/)

Grey – mines

Red – mine waste sites

Yellow – uranium in mine waste sites



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Conclusions

- There are likely largely unmeasured co-product uranium resources up to an order of magnitude greater than is currently identified
- A similar situation could be expected for other metals
- There are billions of tons of mining waste globally in millions of KM^3 that could potentially contain millions of tons of metal extraction of which could ease supply and environmental issues
- UNFC is a appropriate vehicle for assessing and classifying these co and by-product resources when enough geological information is available

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