MONASH University

Engineering

Mining & the Environment: *Sustainable or Responsible?*

Seminar – Acopian Centre for the Environment & Centre for Responsible Mining, American University of Armenia, Yerevan, 14 July 2016

Dr Gavin Mudd (Environmental Engineering)

www.nicholsoncartoons.com.au
Nicholson
9 Dec 1997
WHAT?! YOU WANT A FRIDGE AS WELL AS A RADIO?
A GREENHOUSE NIGHTMARE...

Georgius Agricola (1556) :

"… the strongest argument of the detractors is that the *fields are devastated by mining operations* … Also they argue that the *woods and groves are cut down*, for there is need of an endless amount of wood for timbers, machines, and the smelting of metals. And when the woods and groves are felled, then are exterminated the beasts and birds, very many of which furnish a pleasant and agreeable food for man. Further, when the ores are washed, *the water which has been used poisons the brooks and streams*, and either destroys the fish or drives them away. Therefore the inhabitants of these regions, on account of the devastation of their fields, woods, groves, brooks and rivers, find great difficulty in procuring the necessaries of life … Thus it is said, it is clear to all that *there is greater detriment from mining than the value of the metals which the mining produces*."

Source: Georgius Agricola, 1556, 'De Re Metallica'

Resources, Env. Impacts, Sustainability?

- **Background: ‘Peak Copper’ ‘Peak Cobalt’ ???**
- **Economic Mineral Resources**
  - *copper, nickel, cobalt, uranium, PGEs*
- **Global Copper & Uranium Mining**
- **Environmental ‘Costs’ of Cu: GJ, CO_2, H_2O**
- **Sustainability Reporting & Environmental Metrics**
- **Possible Insights & Even Wisdom (?)**

Peak Everything: Some Simple Ideas?

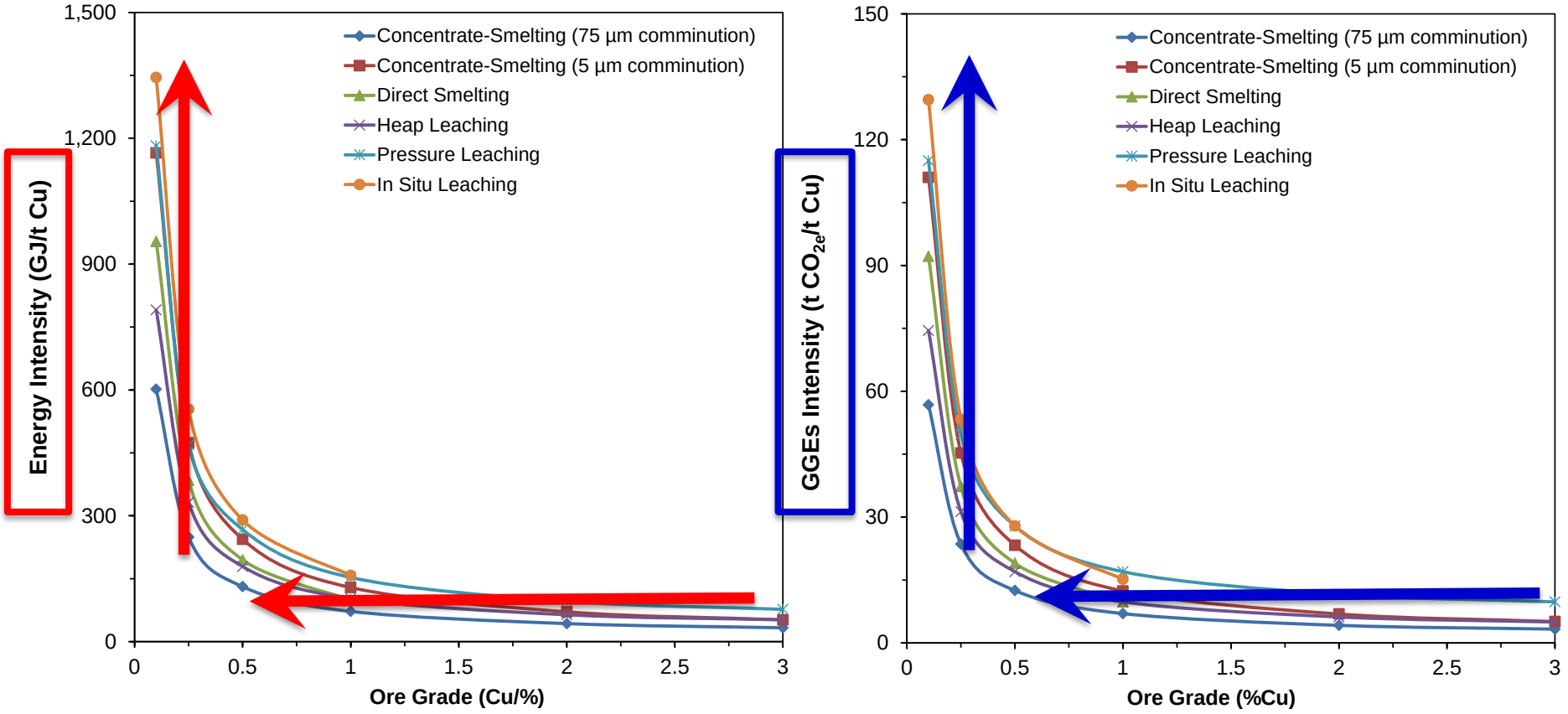
- **Mineral resources are used in everything we do and consume – food, shelter, transport, energy, etc …**
- **Minerals and metals production continues to grow – many substantially to meet societal demands**
- **But surely mineral resources are finite? Won't mining deplete these and we run out – ie. PEAK EVERYTHING?**
- **What about mine rehabilitation? climate change? renewable energy? mine wastes? water resources? lost land?**

How do we link resources & impacts to consumption?

Life Cycle Assessment: The Theory !!

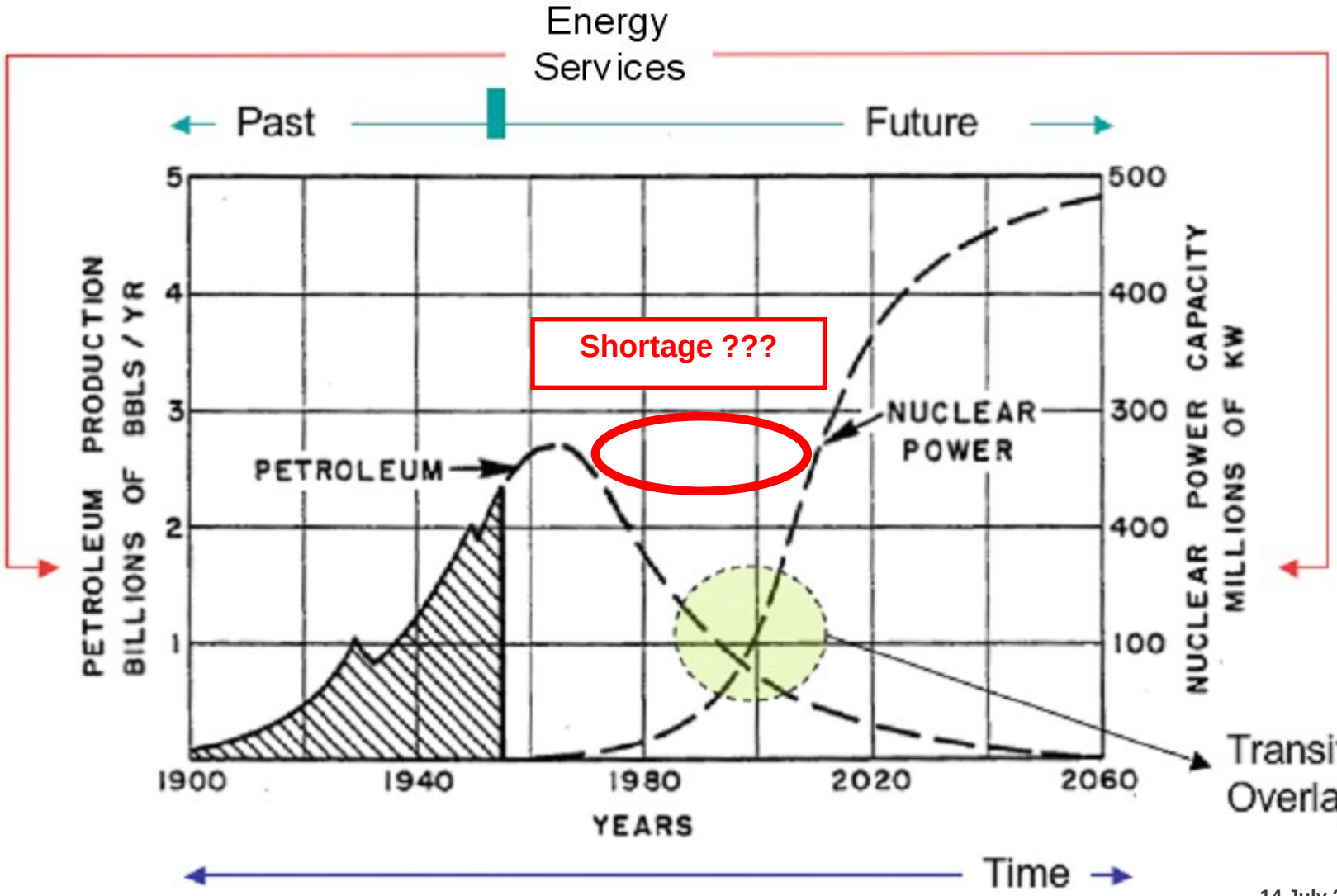
- In classic LCA, as ore grades decline, energy intensity and pollution issues increase for Cu (or Co, Ni, …)
- This is widely accepted – so over time, despite new technologies or efficiency gains, the mining industry keeps chasing its tail …
- But given the need to account for carbon risks (amongst many others), can we use LCA to model the future of global metal mining?

Classic Energy vs %Cu



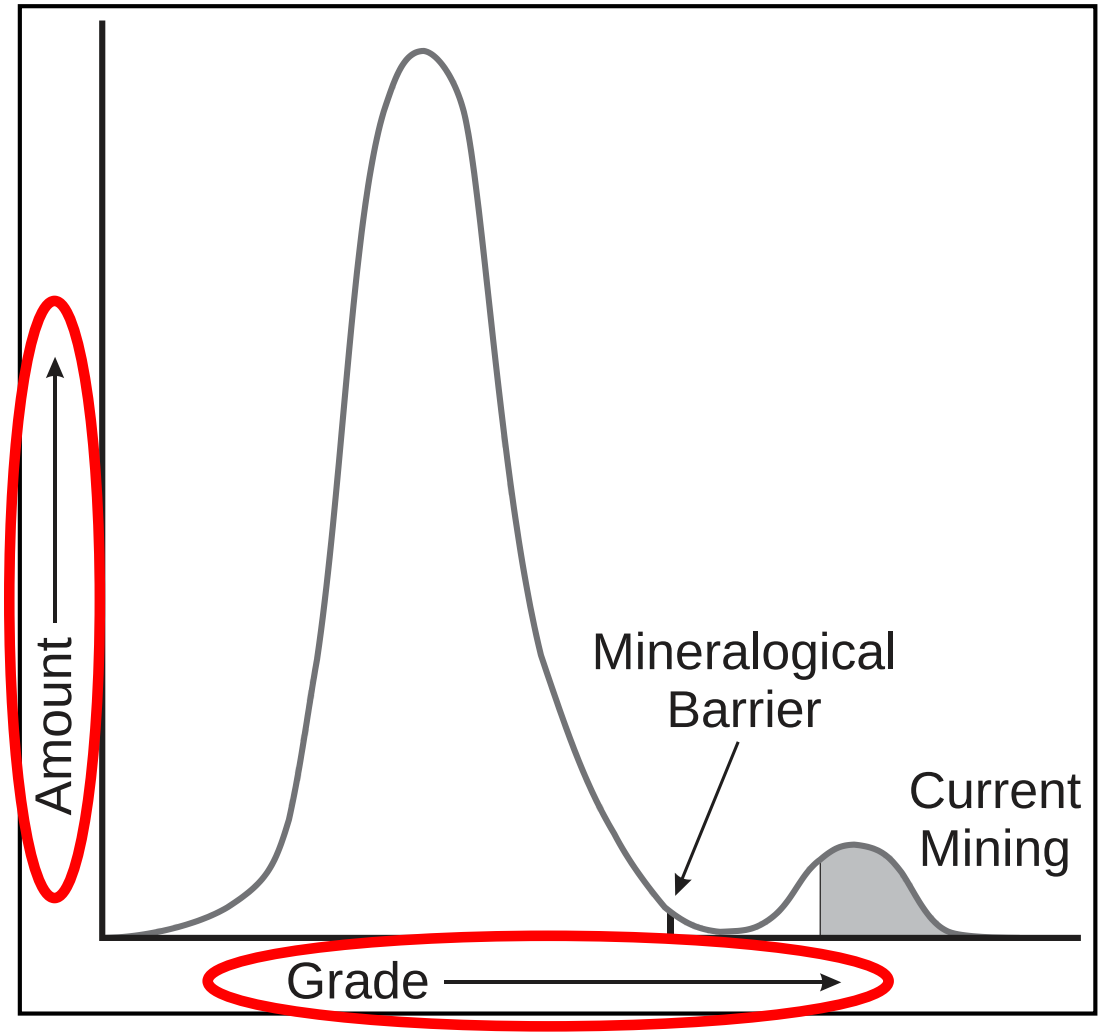
Norgate-Jahanshahi, 2010, Mins. Eng.

Hubbert's 1956 "Peak Oil" model …



Hubbert, 1956

Skinner's 1976 "Mineralogical Barrier" …



Economic Mineral Resources

- **To develop a more accurate data set for future Cu modelling, we did the 'math' …**
- **Heaps 'o companies report their mineral resources**
- **Add 1st + 2nd + 3rd + 4th + 5th + 6th + 7th … you get it ☺**
- **All deposits were classified by deposit type:**
  - ***Cu:*** *porphyry, VMS, IOCG, sediment-hosted …*
  - ***Ni:*** *magmatic, laterites, hydrothermal …*
  - ***U:*** *unconformity, sandstone, IOCG, …*
  - ***Co:*** *magmatic, laterites, hydrothermal …*
- **Surprise surprise – HEAPS of global Cu ! Ni ! U ! Co !**

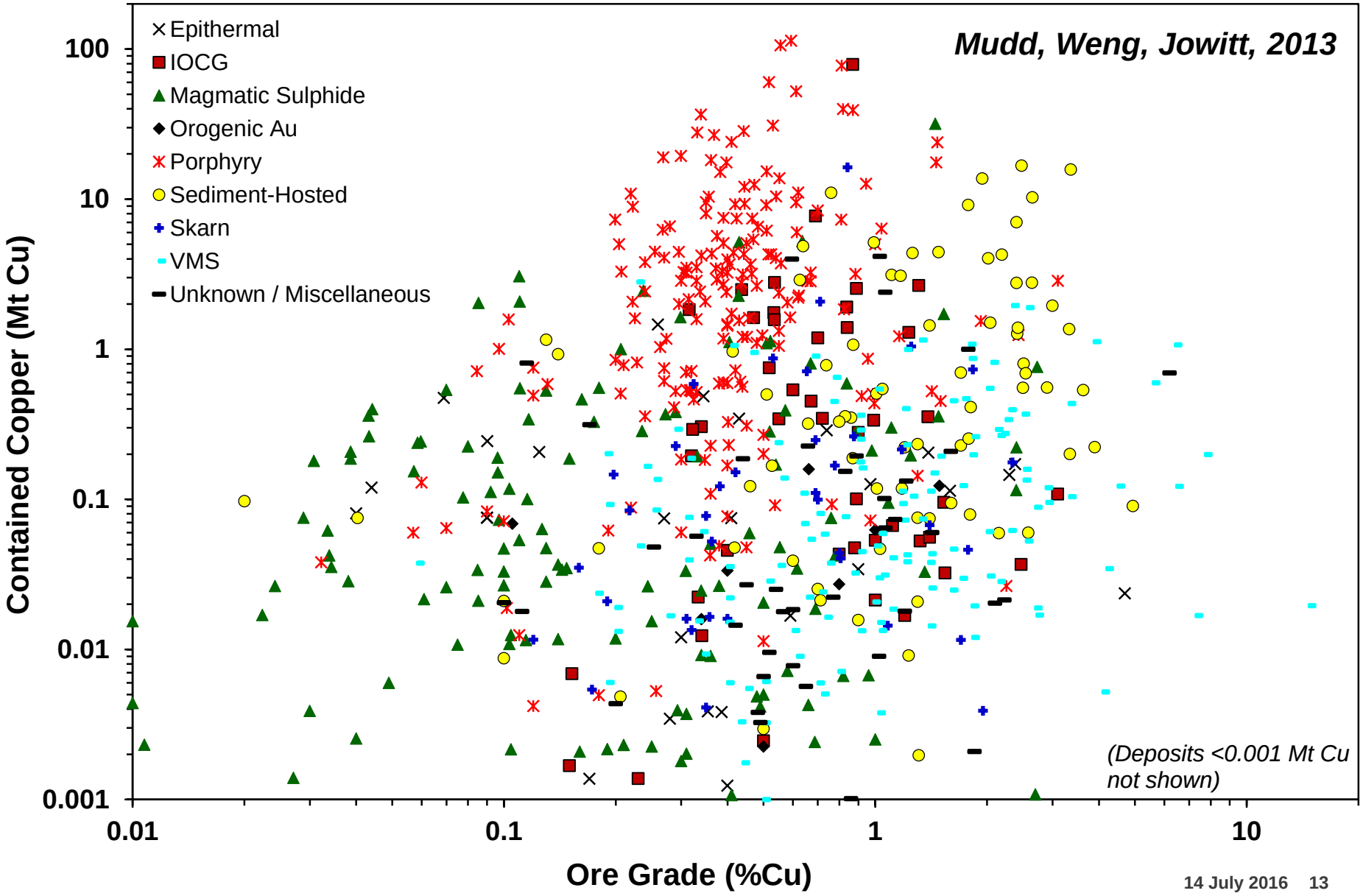
Country	**Tg Cu** *(Mt Cu)*	Reserves (2010)	Reserves (2011)	Reserves base (2008)	National estimate
Chile		150	190	360	
United States		35	35	70	70
Peru		90	90	120	
Australia		80	86	43	131.6
China		30	30	63	80.41
Mexico		38	38	40	
Indonesia		30	28	38	
Canada		8	7	20	7.29
Zambia		20	20	35	
Russia		30	30	30	
Kazakhstan		18	7	22	
Poland		26	26	48	
South Africa					13
India					11.42
Congo (Kinshasa)			20		
Other		80	80	110	
Total[1]		630	690	1,000	

Deposit type	Variable	Ore (Mt)	% Cu	g/t Au	% Ni	Cu (Mt)
Porphyry	Total	291,016.0	0.45	0.09		1,316.54
(200 projects)	Median	553.7	0.40	0.27		2.24
	Mean	1,455.1	0.48	0.40		6.58
	Std. Dev.	2,672.8	0.39	0.54		14.53
Sediment-hosted Cu	Total	10,873.9	1.52	0.01		165.45
(62 projects)	Median	42.1	1.54	0.27		0.62
	Mean	175.4	1.75	0.27		2.67
	Std. Dev.	297.2	1.05	0.26		4.48
Iron oxide copper-gold (IOCG)	Total	17,730.3	0.71	0.25		125.10
(51 projects)	Median	60.8	0.70	0.32		0.34
	Mean	347.7	0.84	0.81		2.45
	Std. Dev.	1,287.9	0.55	1.81		11.01
Magmatic sulfide	Total	26,542.6	0.29	0.13	0.24	76.21
(133 projects)	Median	30.3	0.20	0.14	0.31	0.05
	Mean	199.6	0.39	0.19	0.58	0.57
	Std. Dev.	439.8	0.51	0.33	0.66	2.84
Skarn	Total	4,901.0	0.70	0.04		34.45
(39 projects)	Median	18.2	0.64	0.60		0.10
	Mean	125.7	0.74	1.00		0.88
	Std. Dev.	387.8	0.56	1.85		2.96
Volcanogenic massive sulfide	Total	4,042.1	0.78	0.31		31.56
(144 projects)	Median	6.4	1.03	0.65		0.07
	Mean	28.1	1.51	1.02		0.22
	Std. Dev.	106.5	1.75	1.07		0.40
Other/miscellaneous	Total	2,701.1	0.59	0.28		15.97
(50 projects)	Median	6.0	0.63	1.52		0.03
	Mean	54.0	0.88	1.82		0.32
	Std. Dev.	147.2	0.93	1.44		0.86
Sediment-hosted Pb-Zn	Total	2,745.9	0.39	0.002		10.67
(21 projects)	Median	21.0	0.60	0.25		0.07
	Mean	130.8	0.70	0.36		0.51
	Std. Dev.	248.0	0.58	0.34		1.07
Epithermal	Total	2,717.0	0.18	0.20		4.91
(30 projects)	Median	13.9	0.32	0.89		0.08
	Mean	90.6	0.67	2.53		0.16
	Std. Dev.	166.1	0.98	5.18		0.28

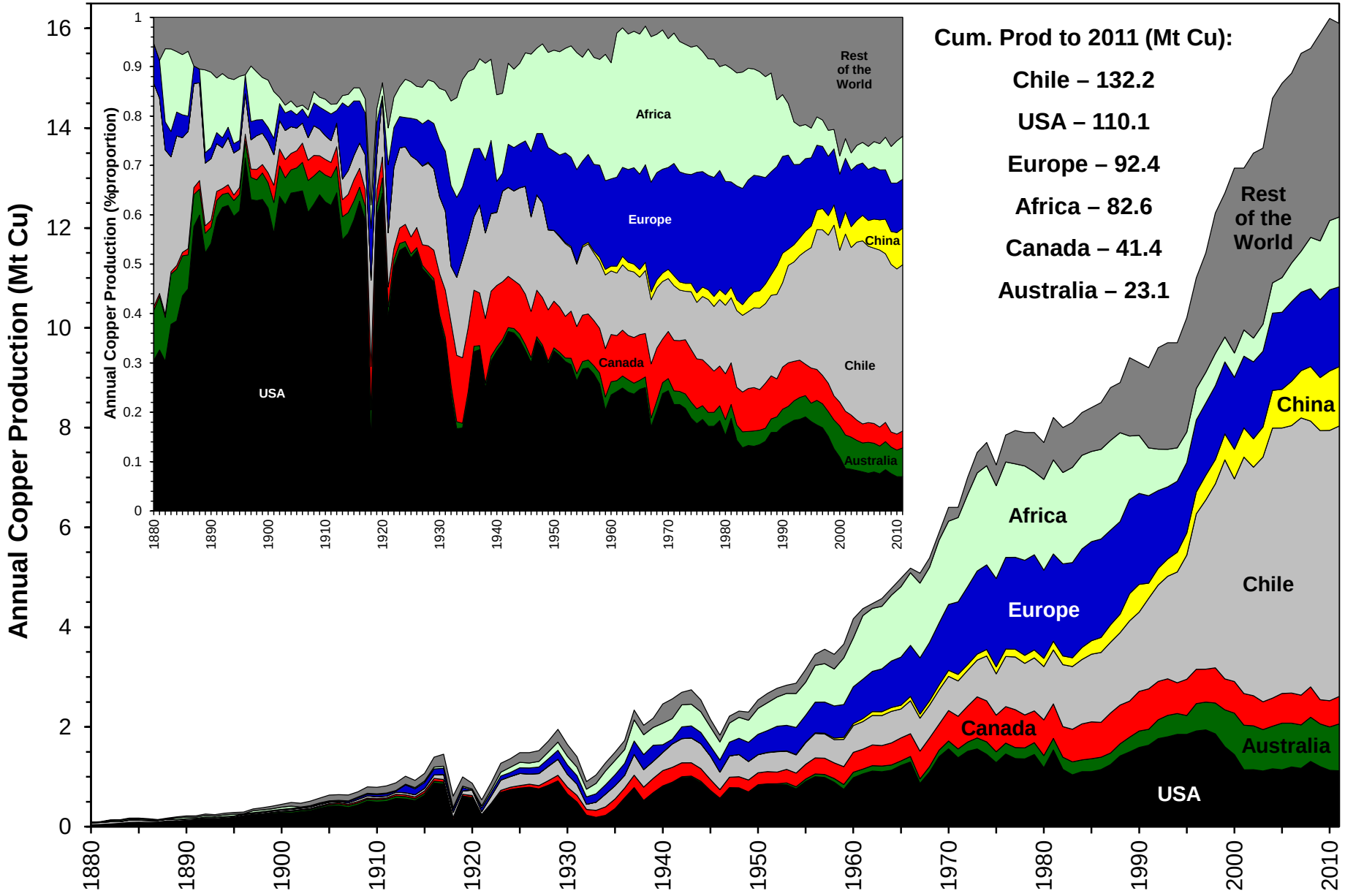
Total: 1,780.9 Tg Cu

Mudd, Weng, Jowitt, 2013

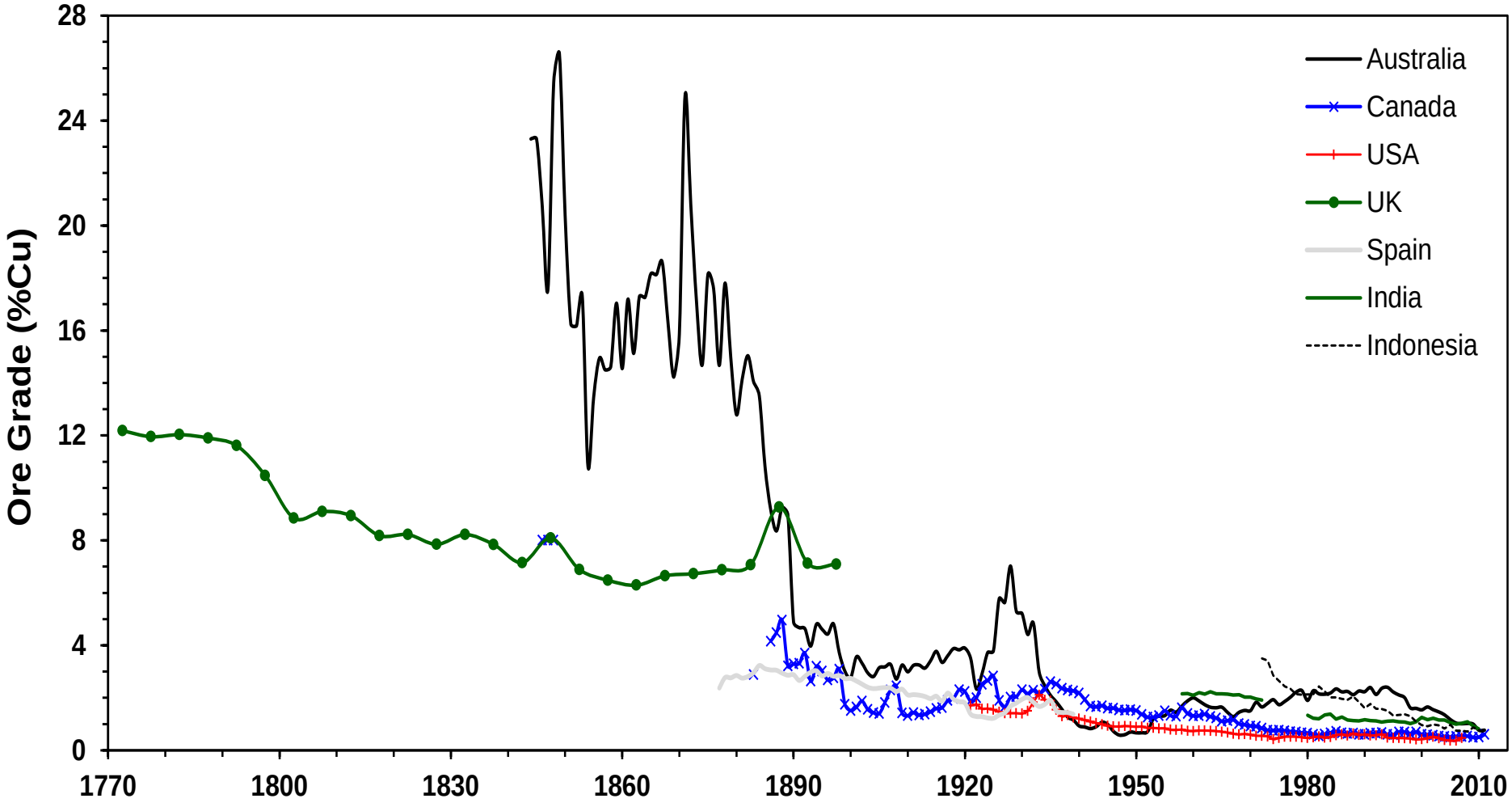
Copper Mineral Resources: %Cu v Mt Cu



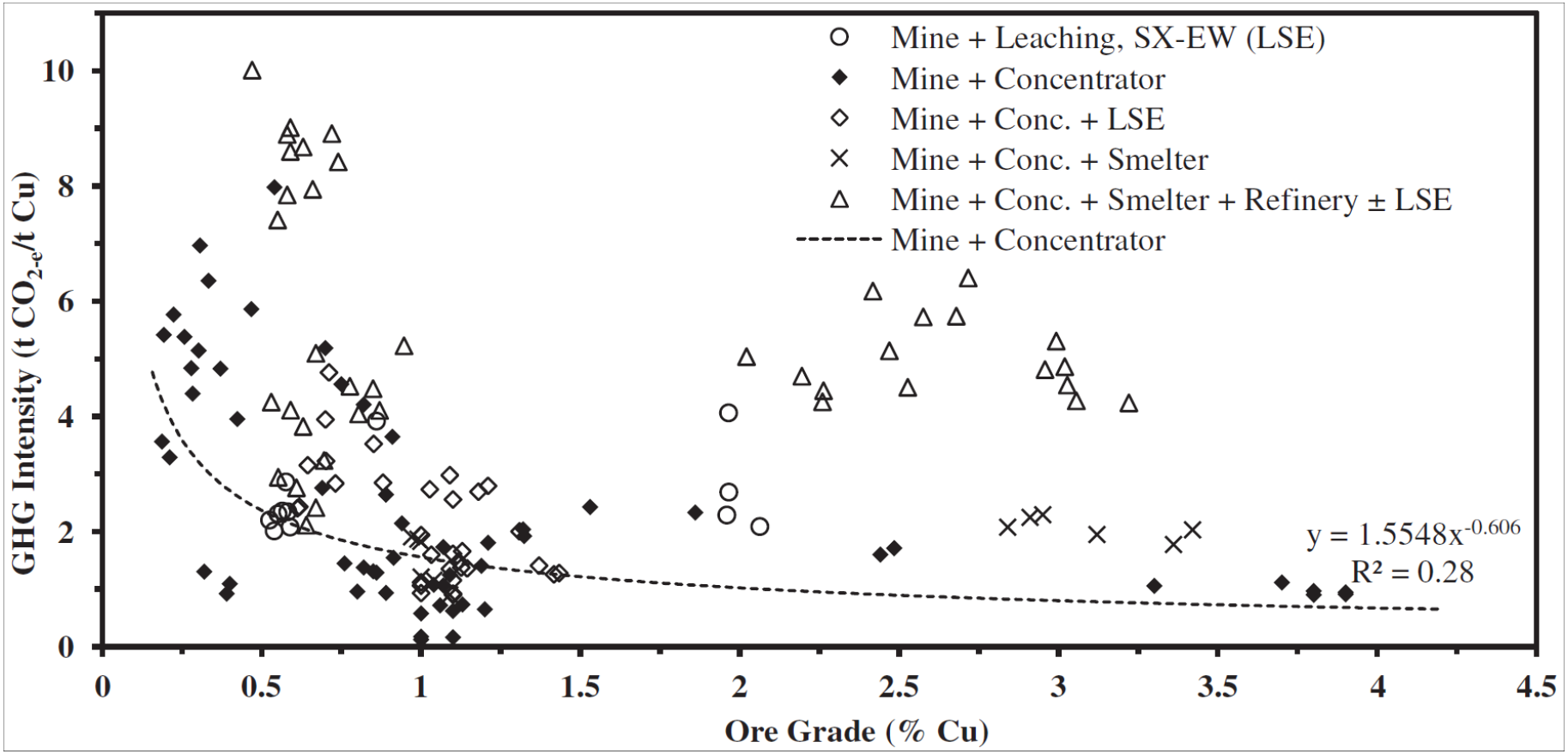
Historical Global Copper Production



Cu Ore Grade Decline: Yes, Very Real …



Environmental Costs: Copper



Northey et al., 2013

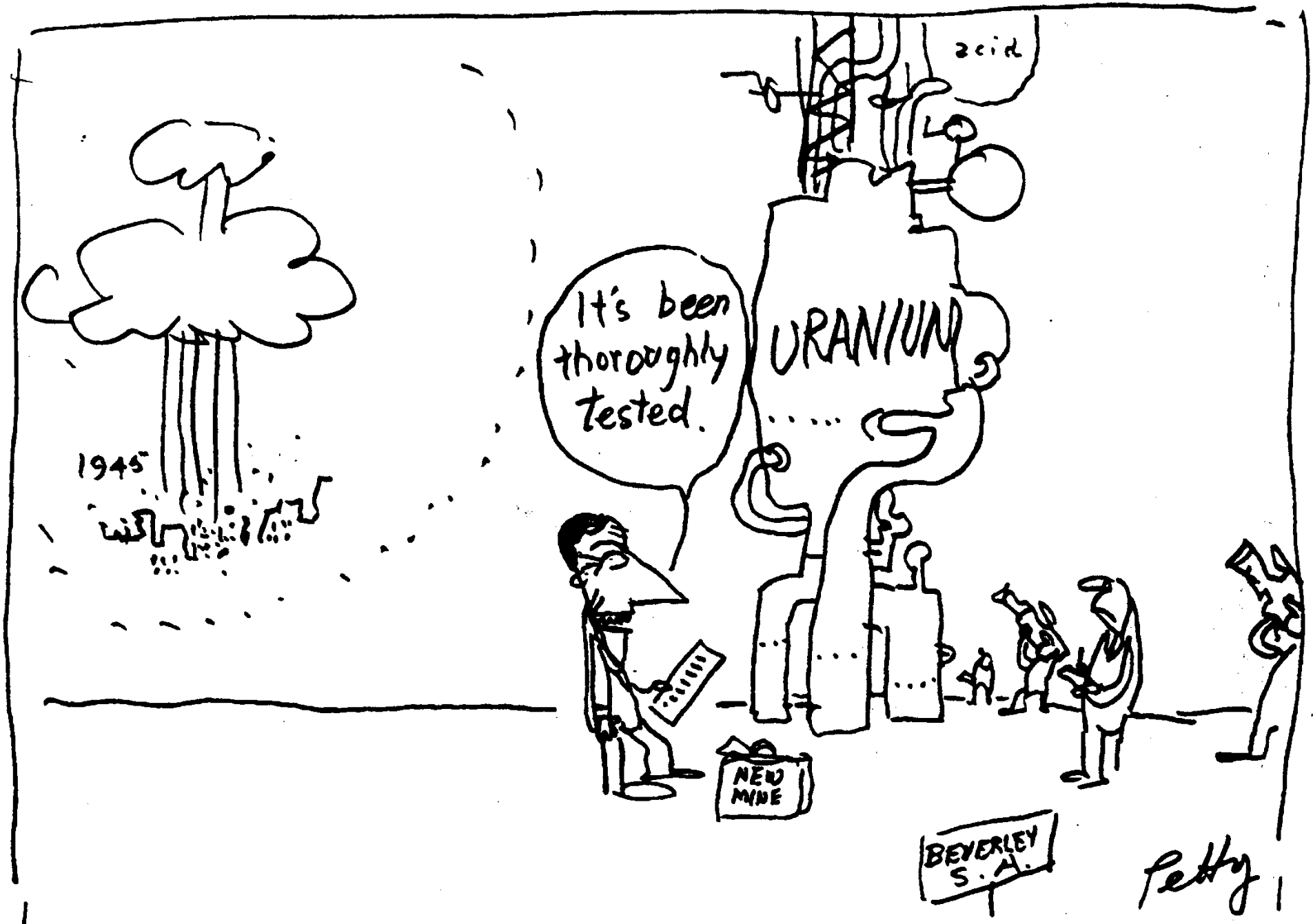
Now … get ready …

- For the most polluting mine site I have ever visited …

NO JOKE ☹

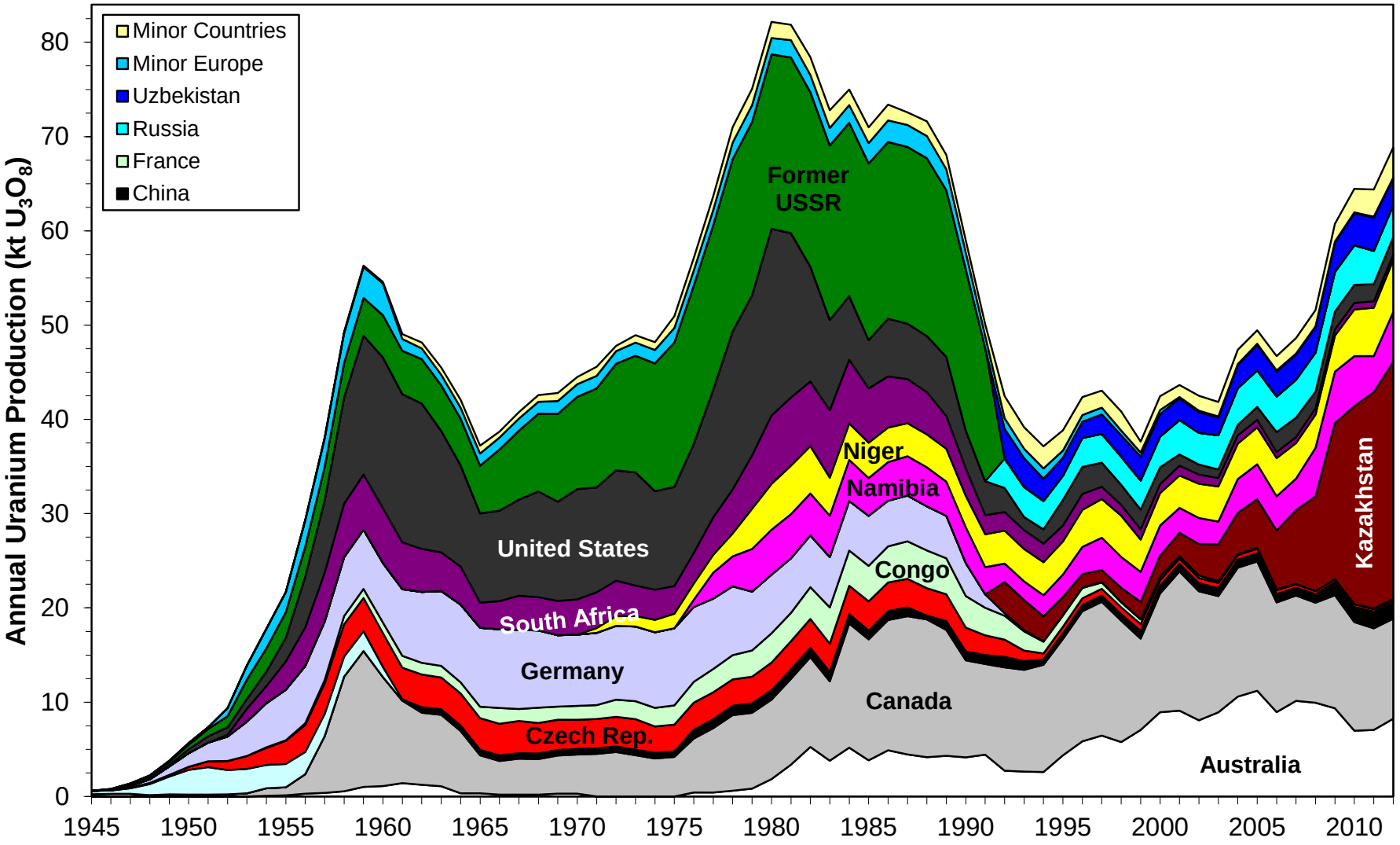
Redbank: Looks ok, hey?

Redbank Cu, NT
WRD Seepage: pH 3.3

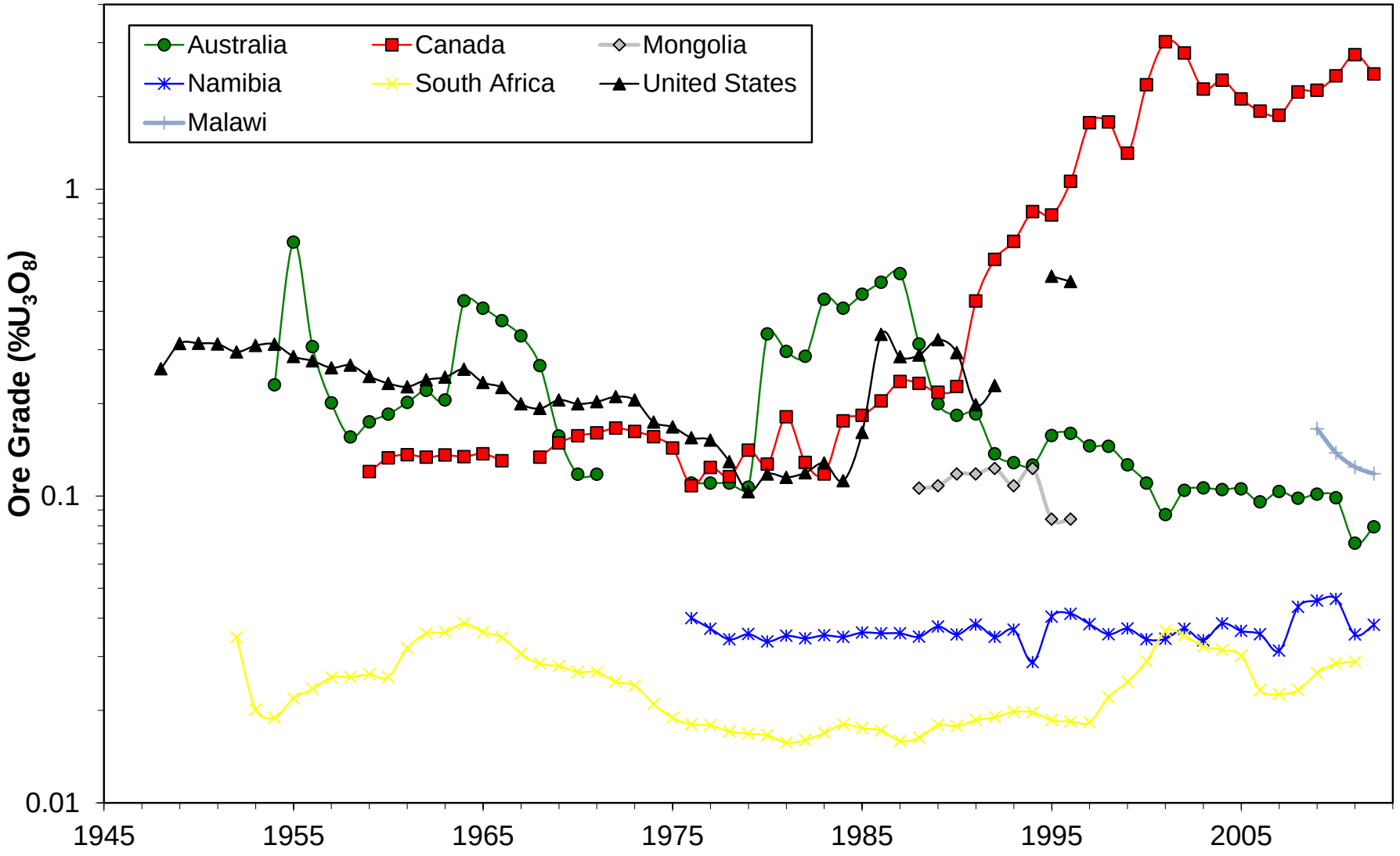


The Age 20/3/99

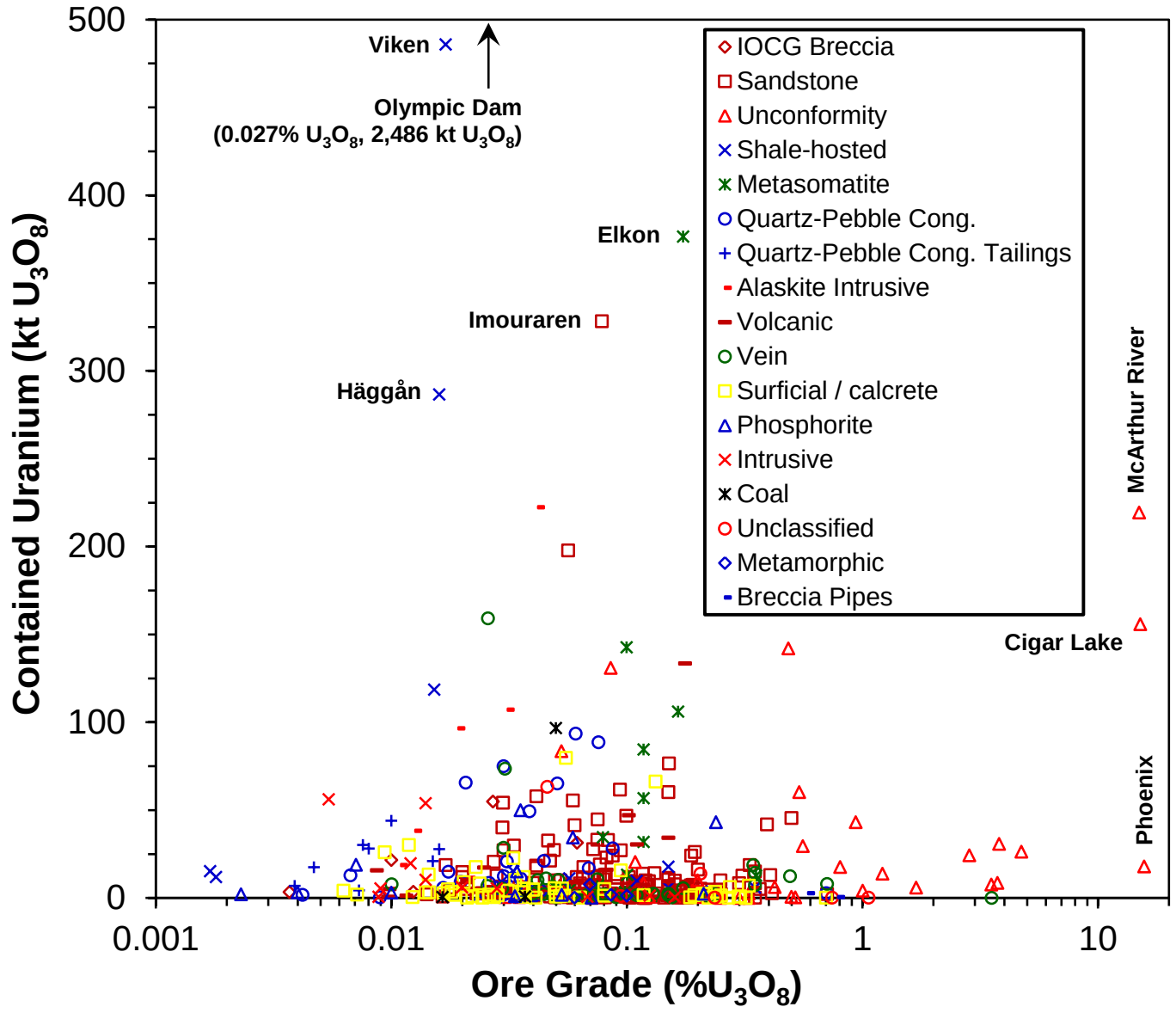
Historical Global Uranium Production



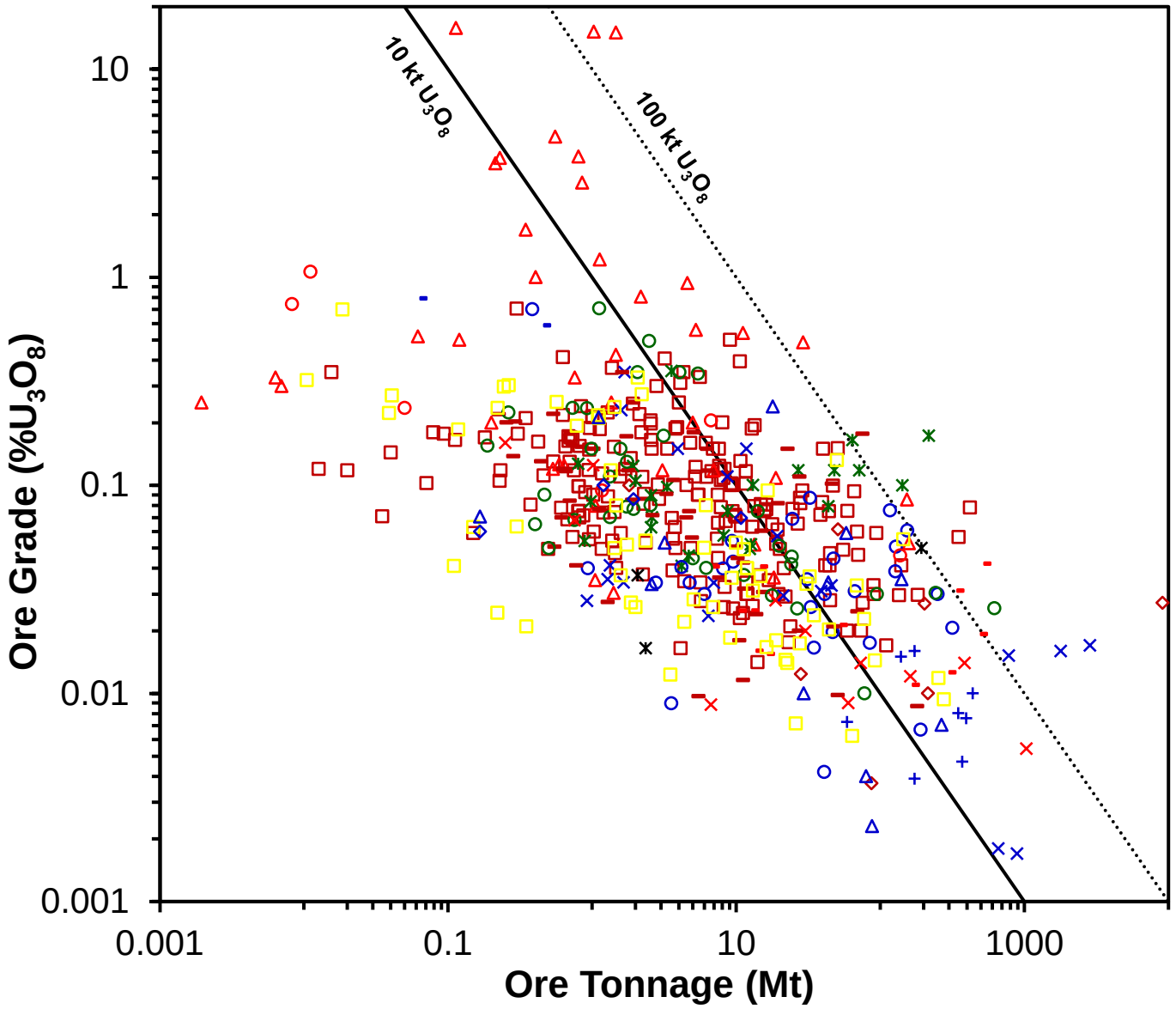
Historical U Ore Grades by Country



U Deposit Types by Grade-kt U_3O_8



U Deposit Types by Ore-kt U_3O_8

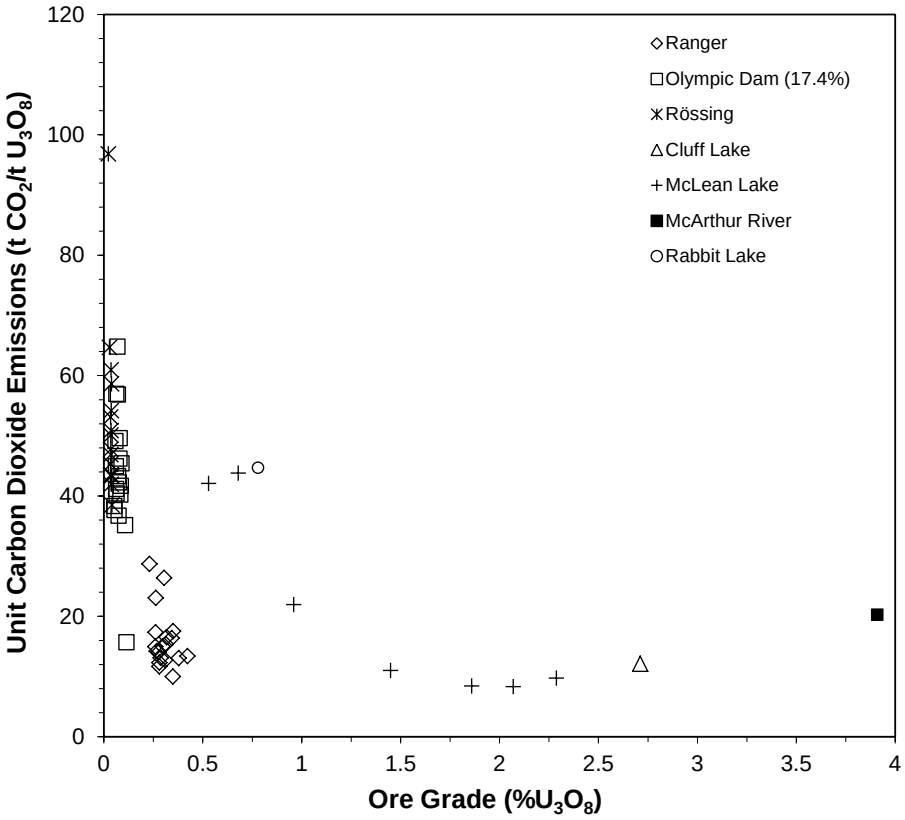


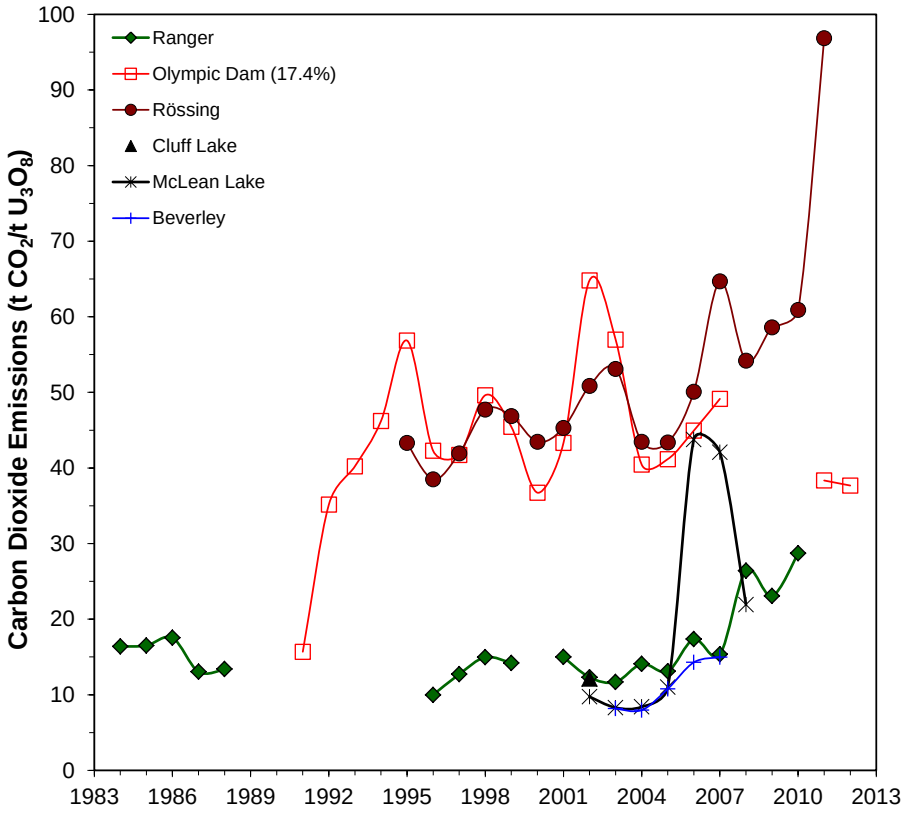
Uranium vs 'Sustainability' Metrics

Project	Mine Type	Electricity Source(s)	GGE intensity (t CO_2/MWh)	Ref's
McArthur River	underground	grid – coal[41%], gas[32%], hydro[21%], wind[5%], other[1%]	0.62	[1]
Cluff Lake	underground	on-site diesel	0.778	[2]
Rabbit Lake	underground	grid – coal[41%], gas[32%], hydro[21%], wind[5%], other[1%]	0.62	[1]
McLean Lake	open cut	grid – coal[41%], gas[32%], hydro[21%], wind[5%], other[1%]	0.62	[1]
Ranger	open cut	on-site diesel	0.778	[2]
Beverley	in-situ leach	on-site gas	0.443	[2]
Olympic Dam[17.4%,§]	underground	state grid – mostly coal, some gas, wind	0.79	[3]
Rössing	open cut	grid & imports – hydro[50%], coal[46%], diesel[2%], other[2%]	~0.47	[4]

Project	Ore Grade	Electricity	Total Diesel & Electrical Energy		CO_2 Emissions[‡]	
	%U_3O_8	kWh/t ore	MJ/t ore	GJ/t U_3O_8	kg CO_2/t ore	t CO_2/t U_3O_8
McArthur River	3.91	1,083 (1)	6,027 (2)	153 (2)	782 (2)	19.9 (2)
Cluff Lake	2.71	*no data*	5,187 (1)	194 (1)	325 (1)	12.1 (1)
Rabbit Lake	0.78	438 (1)	2,513 (2)	355 (2)	337 (2)	47.5 (2)
McLean Lake	0.53-2.29	249±17 (7)	4,848±868 (7)	415±293 (7)	198±43 (7)	20.7±16 (7)
Ranger	0.231-0.423	*no data*	594±152 (20)	224±64 (20)	44±13 (20)	16.7±5.5 (20)
Beverley (ISL)	~0.18	-	-	216±63 (5)	-	11.2±3.3 (5)
Olympic Dam[17.4%,§]	0.053-0.114	17.1±1.4 (6)	118±24 (21)	250±53 (21)	22.8±3.3 (18)	43.5±10 (19)
Rössing	~0.03-0.04[#]	19.5±0.8 (5)	124±26 (17)	422±140 (17)	15±2.2 (17)	52.0±13.6 (17
Production Weighted Average		~92 (20)	1,017 (70)	274 (75)	102 (68)	31.5 (73)

Uranium vs Greenhouse (CO_2)





Mudd, 2014

N
W
E
S
Image © 2006 DigitalGlobe
© 2005 Google
Pointer 12°59'41.36" S 131°00'26.45" E elev 252 ft
Streaming 100%
Eye alt 11474 ft

Rum Jungle, NT

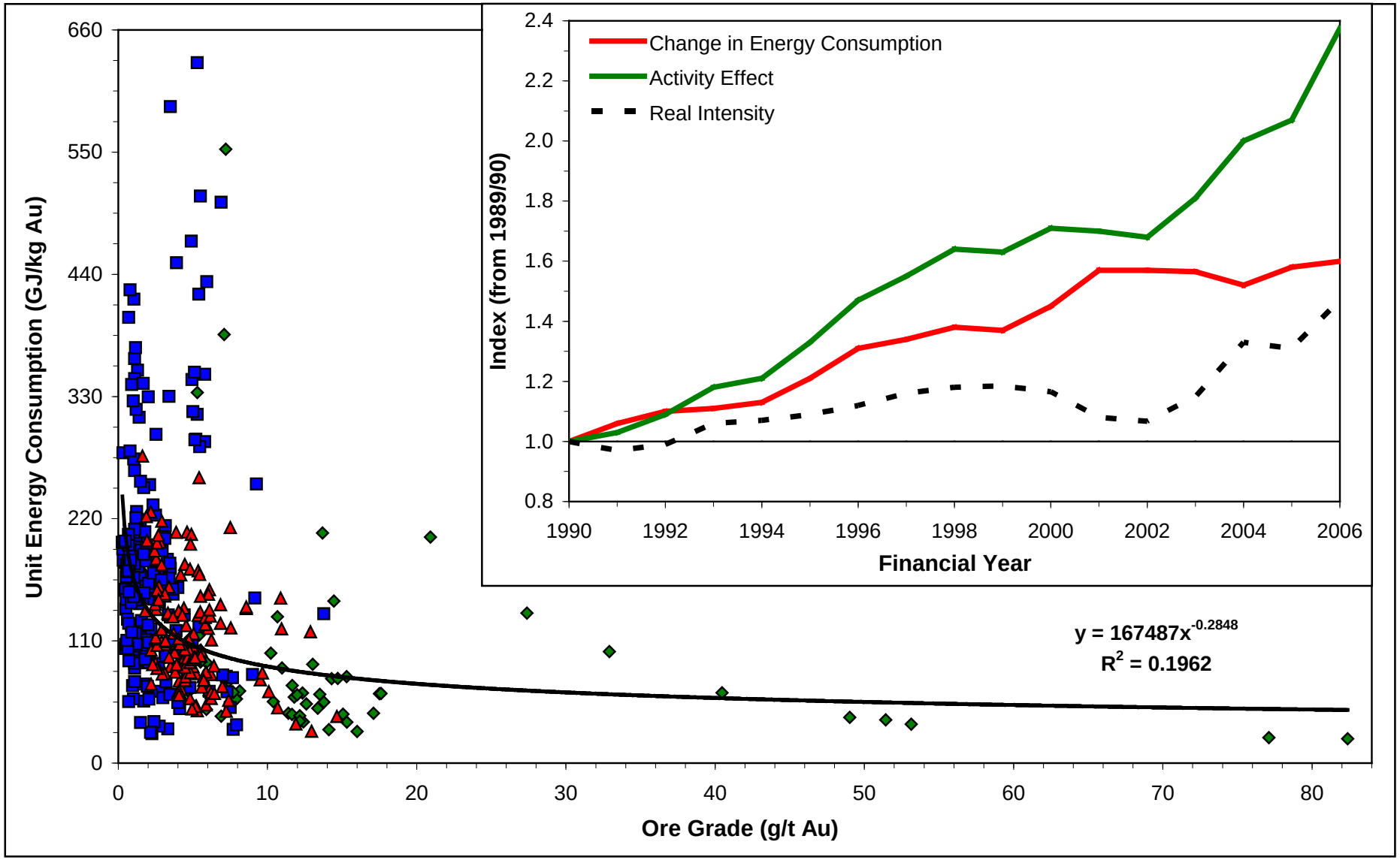
West Rand, South Africa

Straz pod Ralskem, Czech Rep.

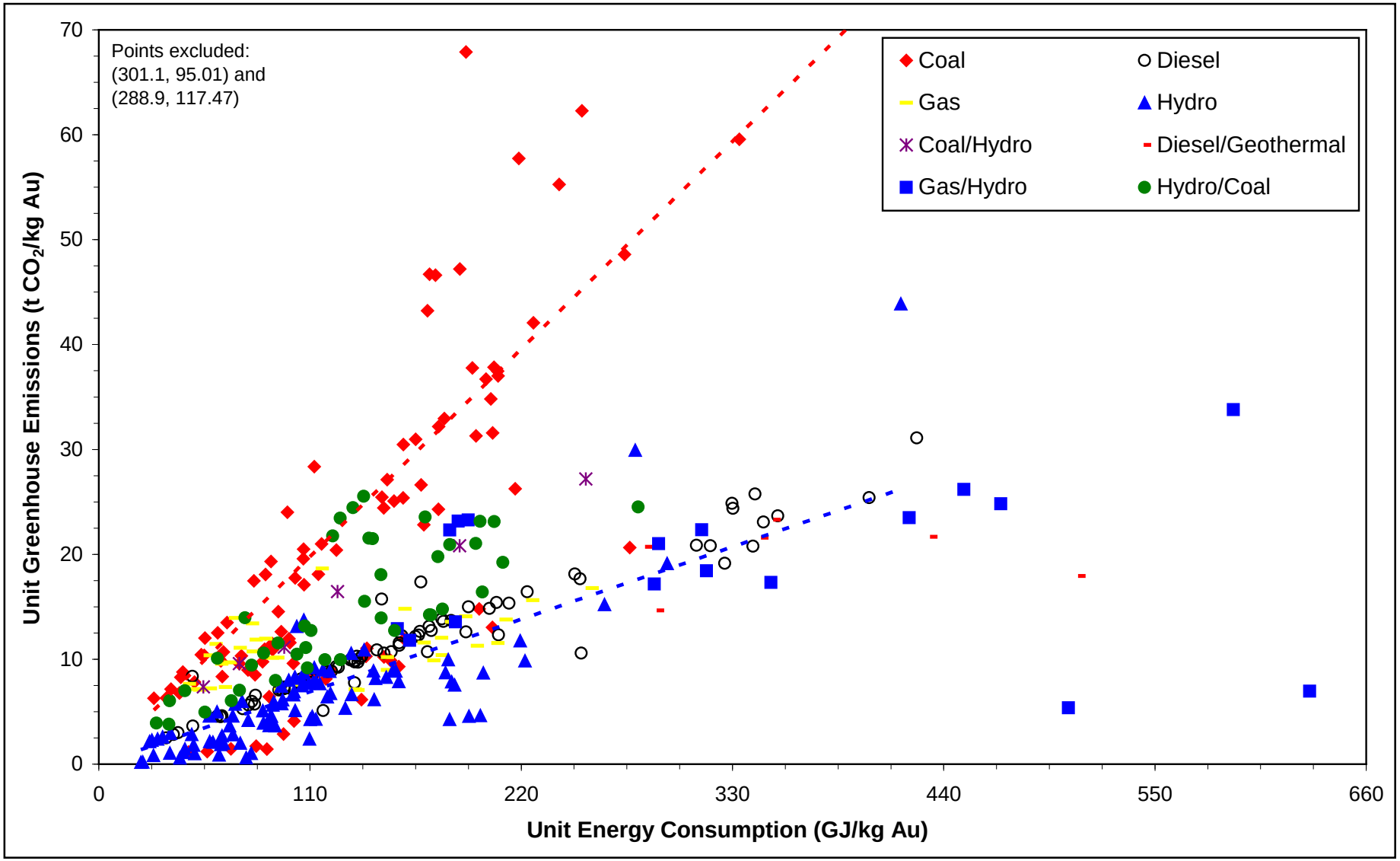
Sustainability Metrics

- Sustainability report data provides rich grounds to investigate the environmental ‘metrics’ of mineral/metal production
- Useful to assess metrics such as:
  - **energy intensity (MJ/t ore, GJ/t metal)**
  - **water intensity (m^3/t ore, m^3/t metal)**
  - **carbon intensity (t CO_2/t ore, t CO_2/t metal)**
  - **plotted versus ore throughput (MJ/t ore v Mt/year)**
  - **plotted versus ore grade (eg. GJ/t metal v g/t, %)**

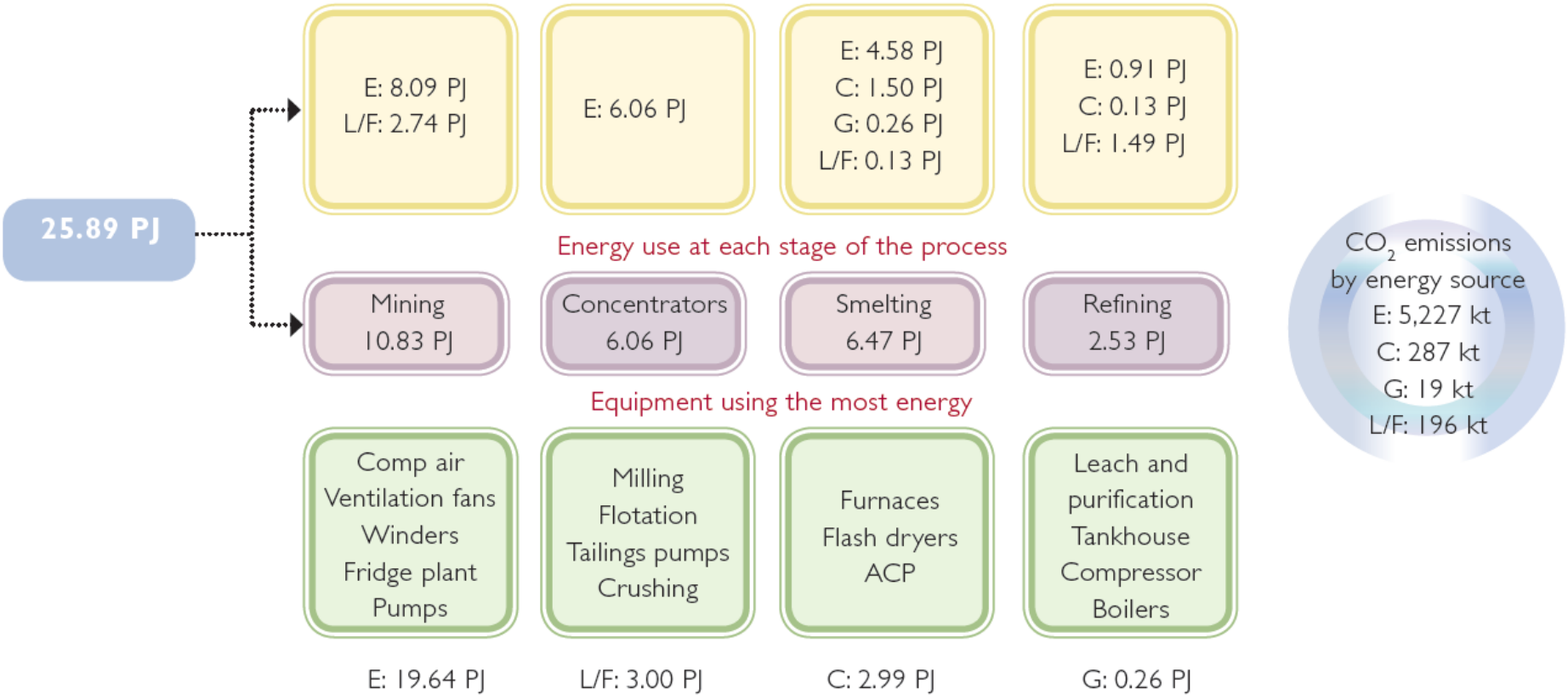
Sustainability Metrics: Energy



Sustainability Metrics: Energy vs Carbon



Example: GRI v Energy



Source: Anglo Platinum, 2007 Sust. Report.

Future Thinking: eg. Boliden

- A major future trend will have to be efficient recycling technology & systems
- Eg's include computers & 'eWaste', Pt in cars, Li batteries, urban infrastructure …

RECYCLING ELECTRONIC SCRAP PAYS

1 TONNE OF MOBILE TELEPHONES YIELDS:

50–150 kg copper
500–700 g silver
150–400 g gold

1 TONNE OF ORE YIELDS:

3,7 kg copper
4,2 g silver
0,2 g gold

Boliden, 2007, Sustainability Report.

Key Findings: The Future of Cu? U?

- There is still heaps o' copper & uranium about …
- Economic Cu-U resources are already sufficient for this century – even with demand growth
  - *some projects remain untouched due to social and/or environmental objections (eg. Windy Craggy, etc …)*
- Global mining industry now reports on sustainability performance annually – with data showing key trends and issues
- Overall, we will not 'run out' of resources – but the environmental & social impacts are growing

Acknowledgements

Much of this research (Cu!) has been undertaken as part of the Mineral Futures Research Cluster, a collaborative program between the Australian CSIRO (Commonwealth Scientific Industrial Research Organisation; The University of Queensland; The University of Technology, Sydney including Monash University; Curtin University of Technology; CQUniversity; and The Australian National University. The authors gratefully acknowledge the contribution each partner and the CSIRO Flagship Collaboration Fund.