Voisey's Bay, Ovoid Deposit and Discovery Hill dyke

Global Nickel Supply: Impacts On Electrification

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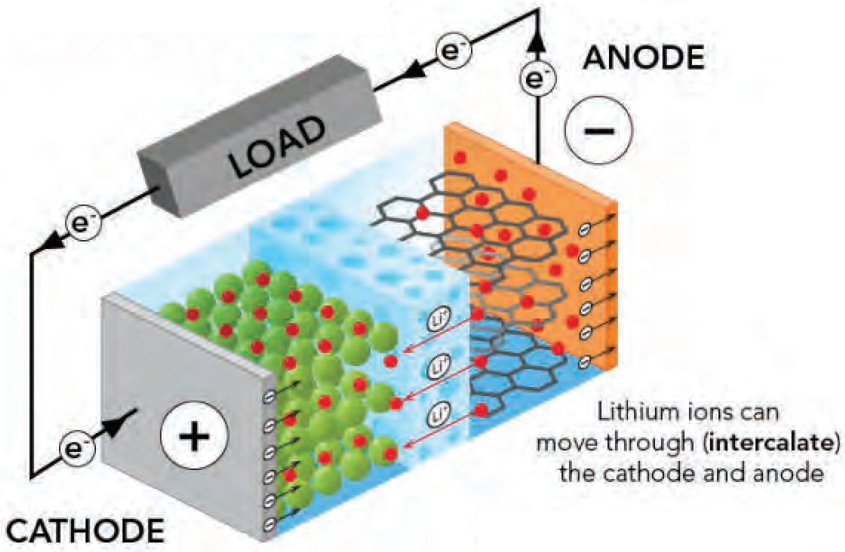
Electrification (May 2022 viewpoint)

Lithium-ion cells require cobalt and nickel. Adapted from G. Harper et al. (2019), Nature 575, 75–86 and Offer et al. (2020) Nature 582, 485–487



DISCHARGING

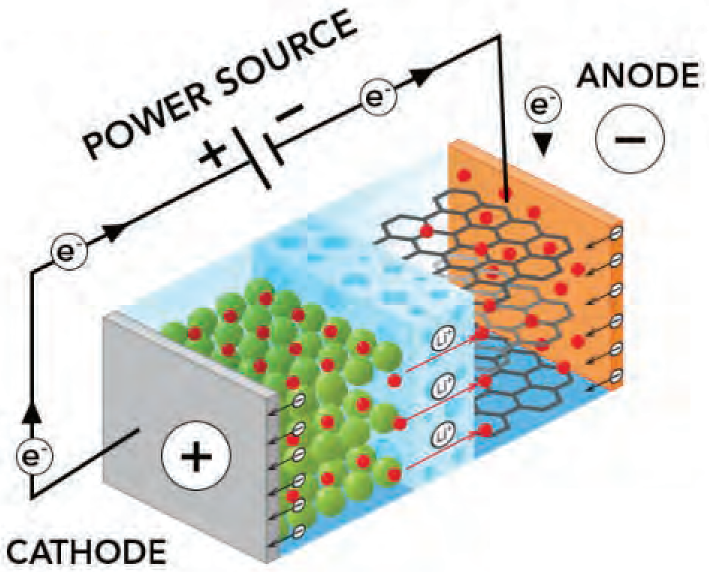
Positively charged lithium ions (Li+) move from the anode to the cathode through the electrolyte.

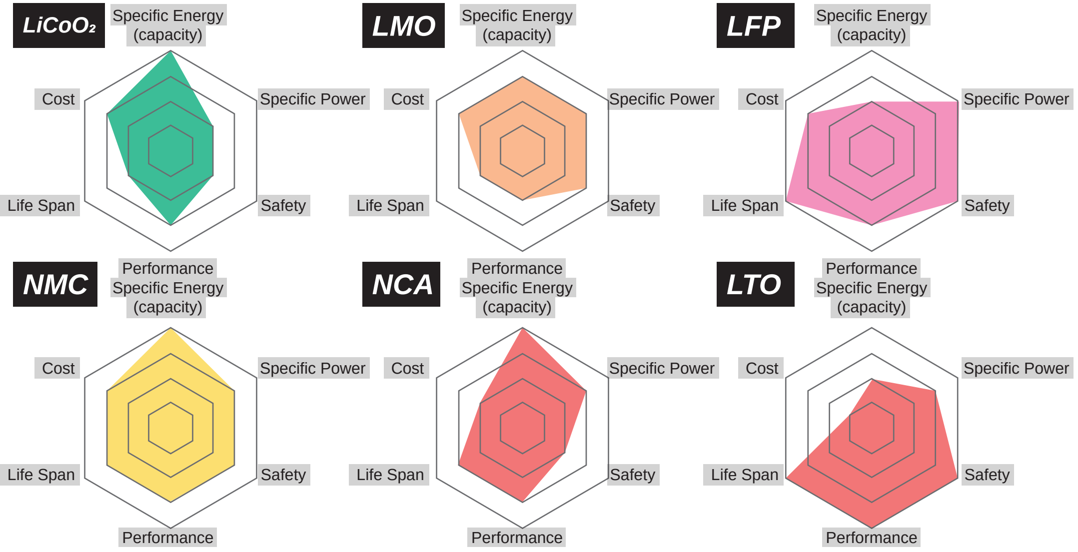
The electrons move from the anode to the cathode.

CHARGING

The lithium ions move back from the cathode to the anode.

The electrons move from the anode to the cathode.





Cobalt Oxide (LCO)
Lithium Manganese Oxide (LMO)
Lithium Iron Phosphate (LFP)
Lithium Nickel Manganese Cobalt Oxide (NMC)
Lithium Nickel Cobalt Aluminium Oxide (NCA)
Lithium Titanate (LTO)

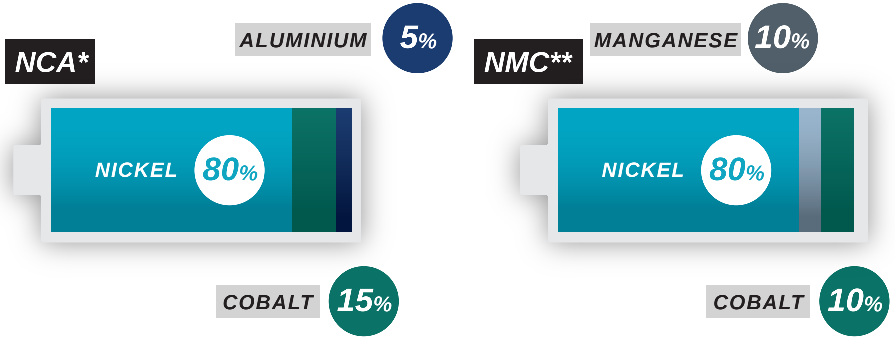
Battery trade-offs: https://www.evenergi.com/ev-basics-ev-batteries

Today's Battery Options

**NCA: Nickel Cobalt Aluminium*
***NMC: Nickel Manganese Cobalt*

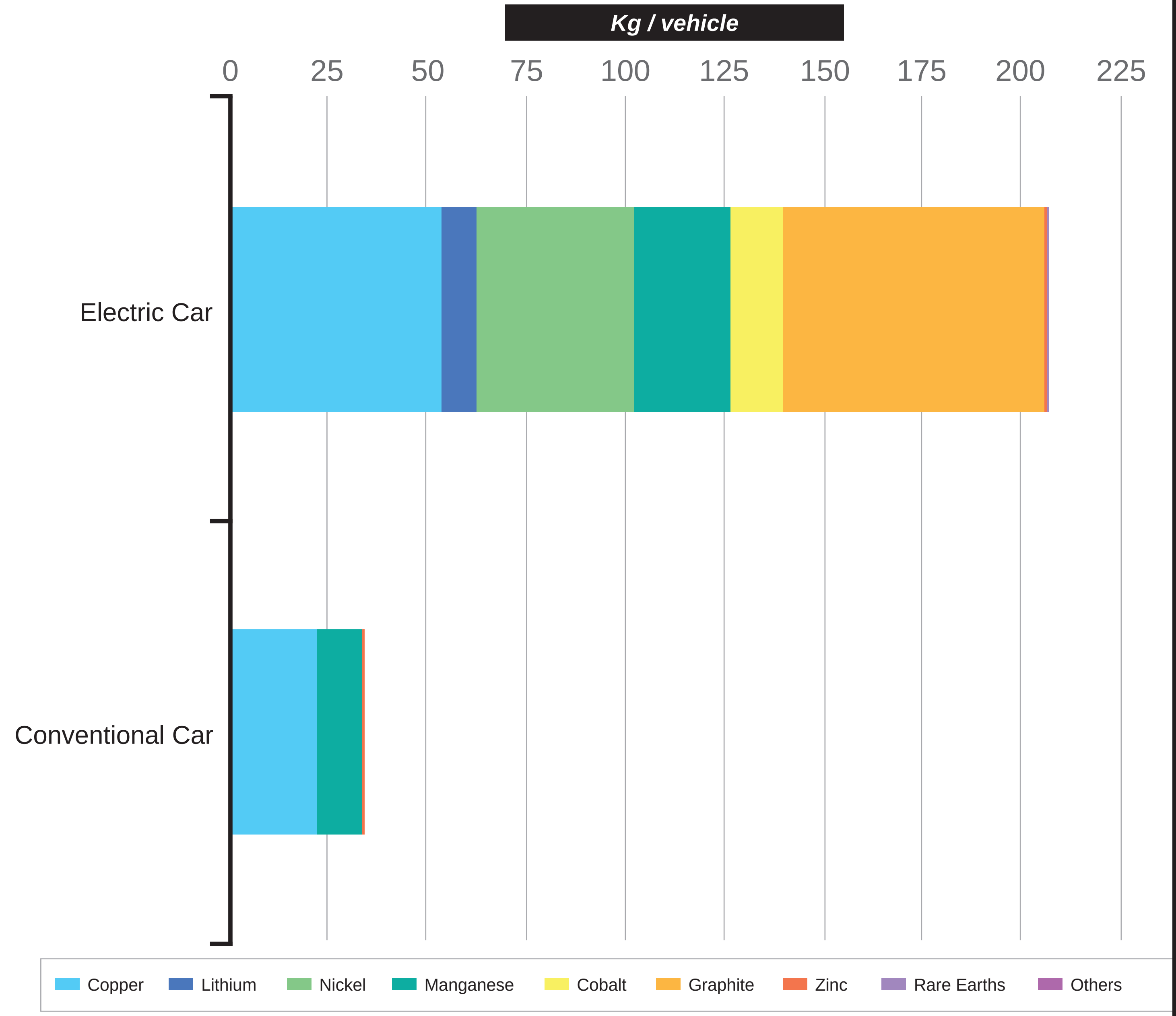
Lithium compounds are combined with other materials in order to create Li-ion batteries.

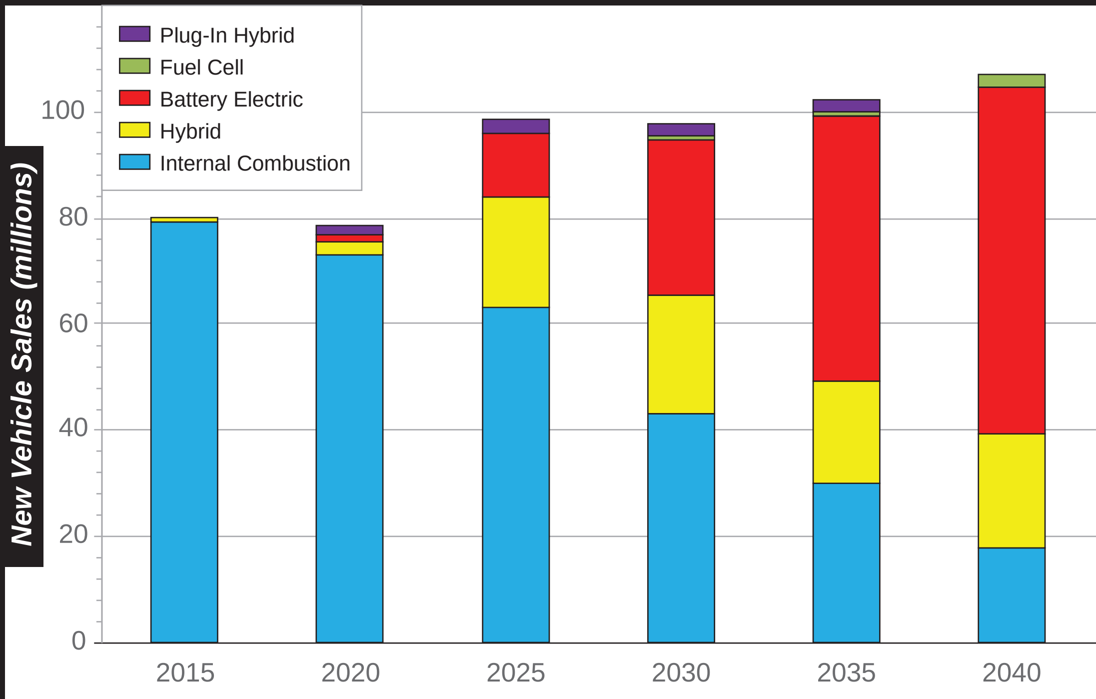
Two of the commonly used Li-ion battery chemistries contain nickel.



Cathode composition: https://nickelinstitute.org/media/8d926a9b562cbb4/2021-review-ni_energizing-batteries-v3.pdf

Electrification (May 2022 viewpoint)

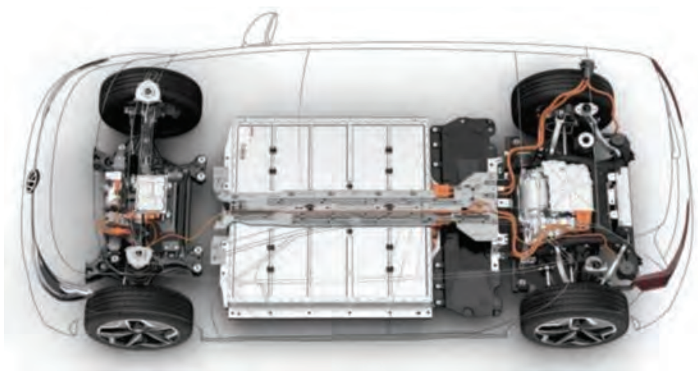




Vehicle sales: https://www.nature.com/articles/d41586-021-02222-1

Battery Balance:

voltage, energy density, safety, charging rate, life span, and cost

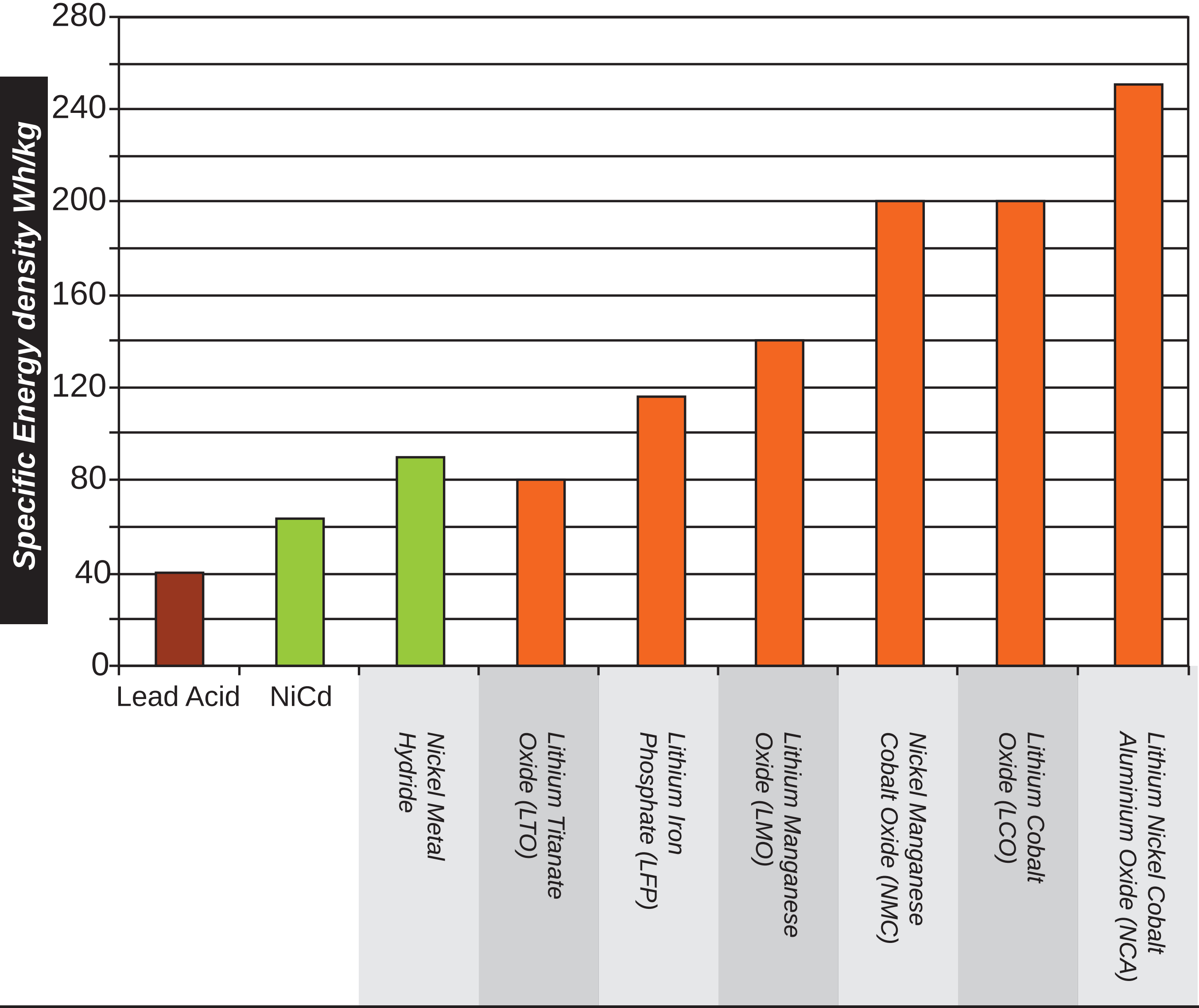


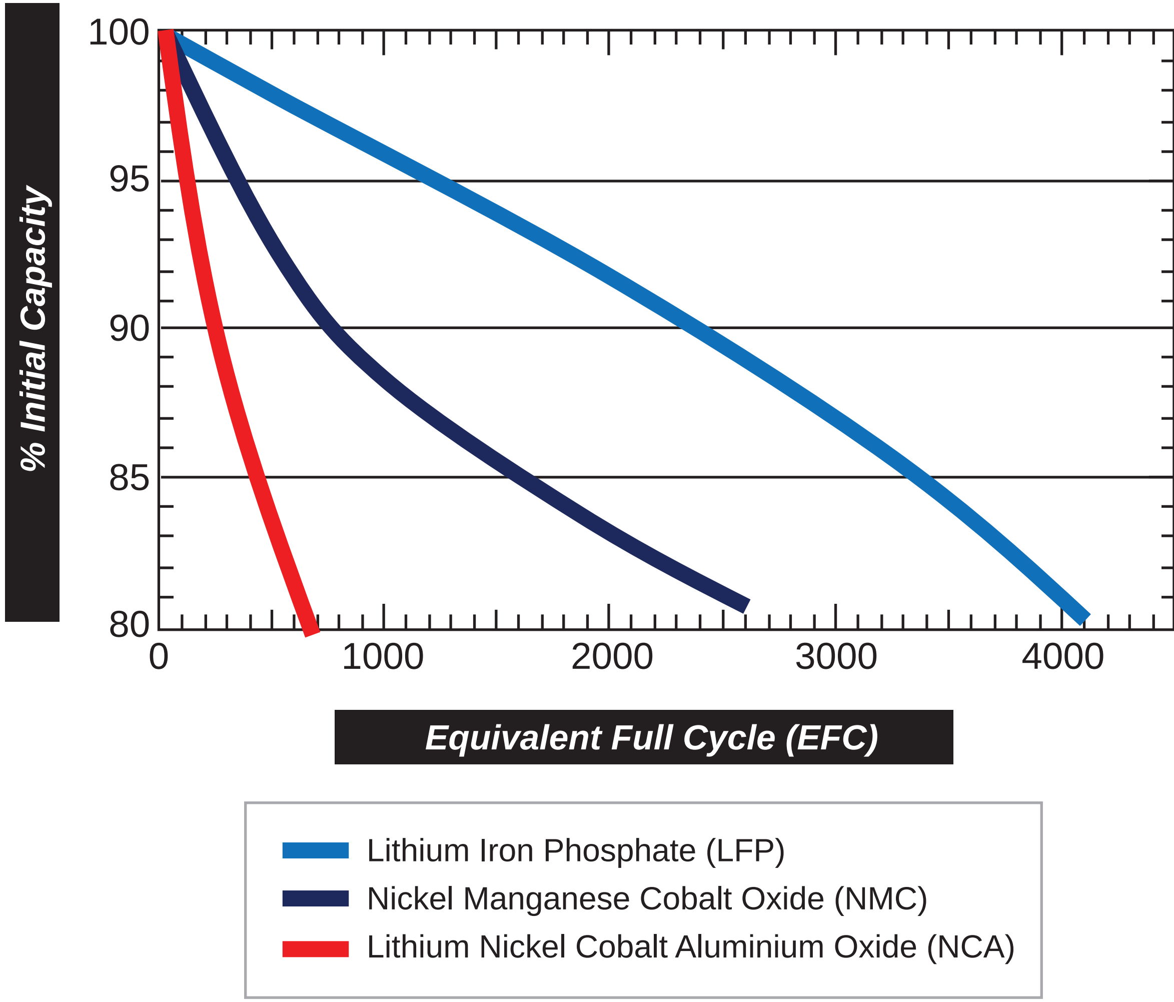
https://www.iea.org/data-and-statistics/charts/minerals-used-in-electric-cars-compared-to-conventional-cars

https://www.torquenews.com/1/lfp-batteries-pros-and-cons-elon-shifts-some-teslas-lfp

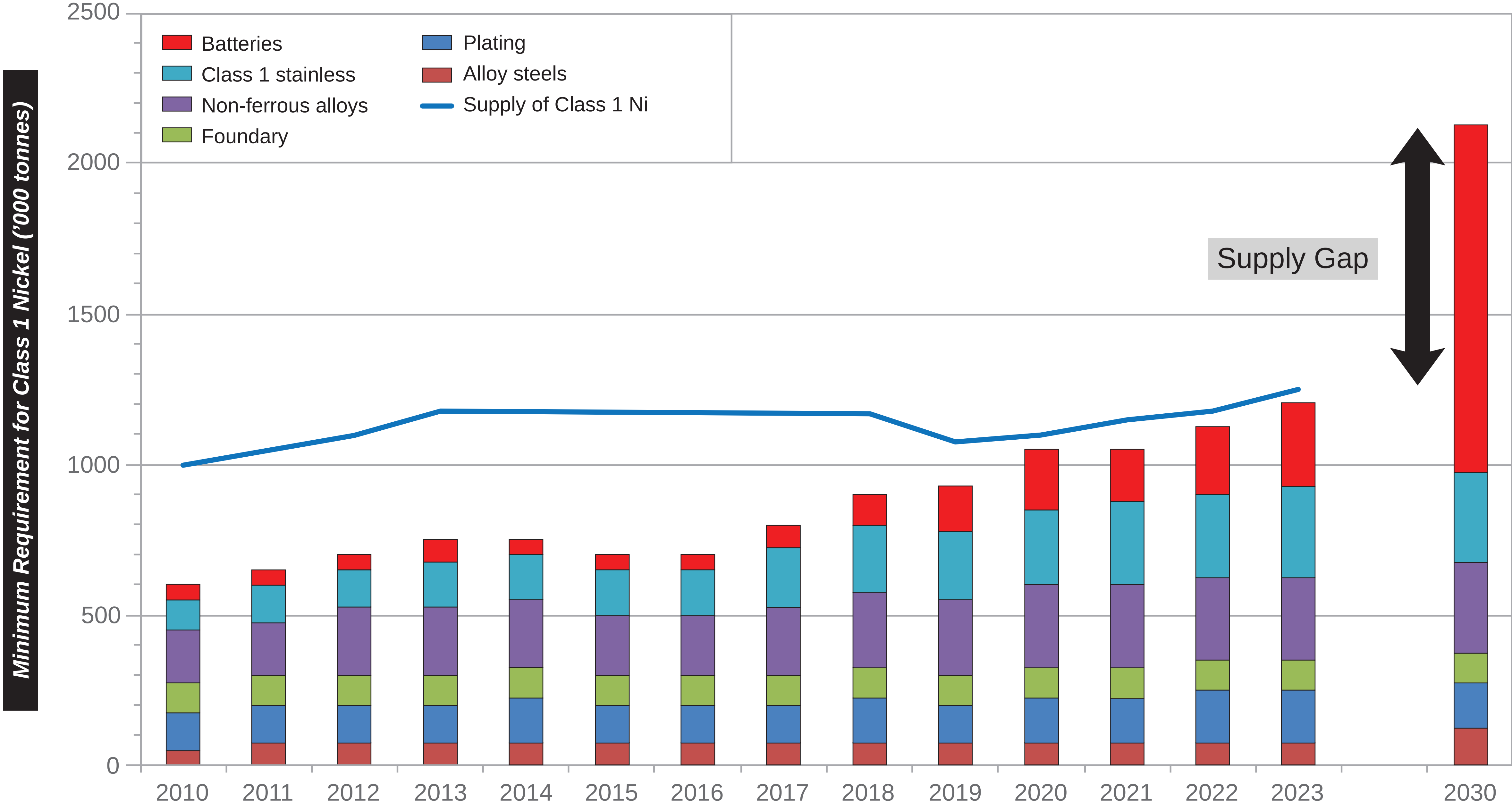
LFP Lithium Batteries Live Longer than NMC

Specific energy of lead-, nickel- and lithium-based systems. Li-Ni-Co-Al (NCA) is the clear winner



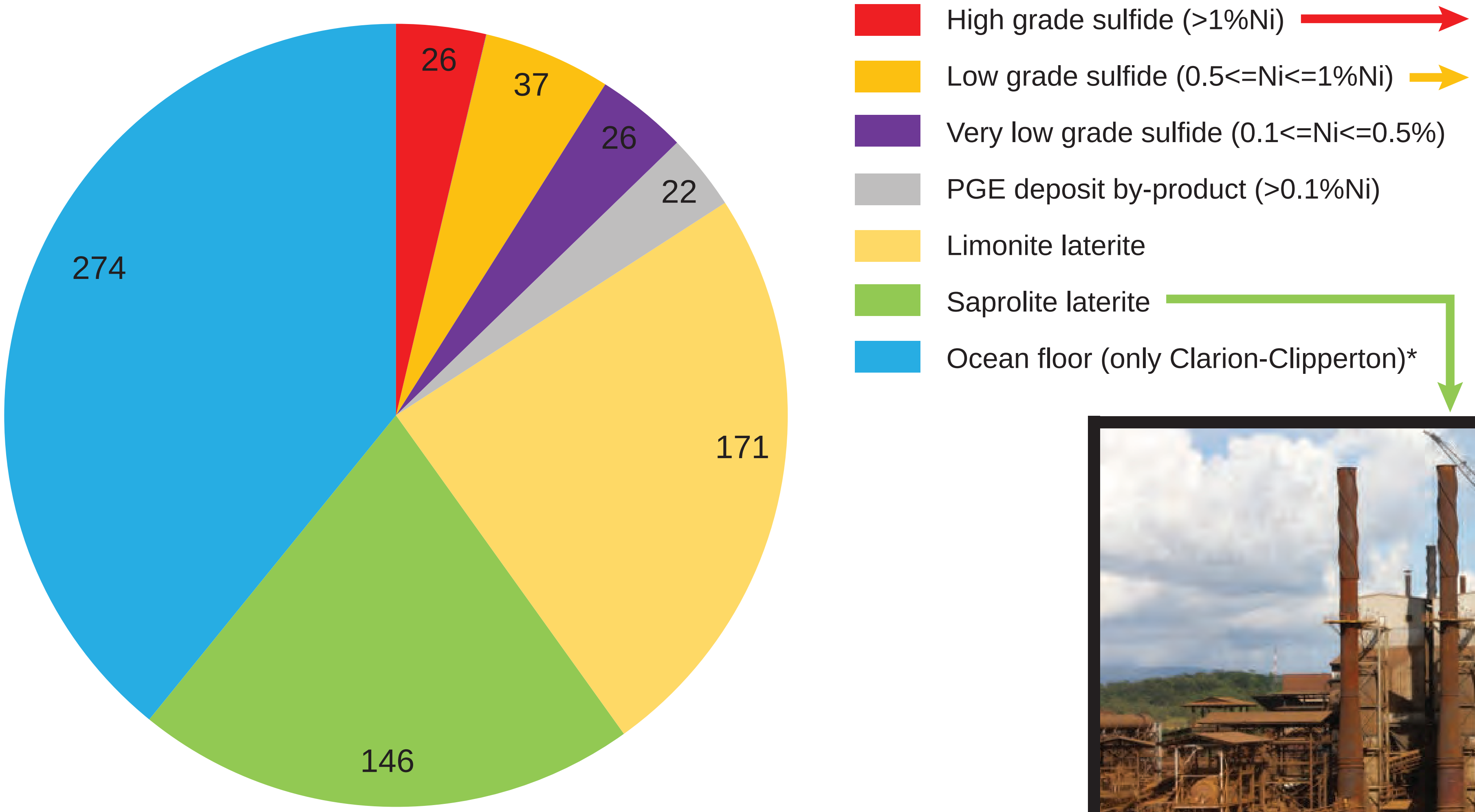


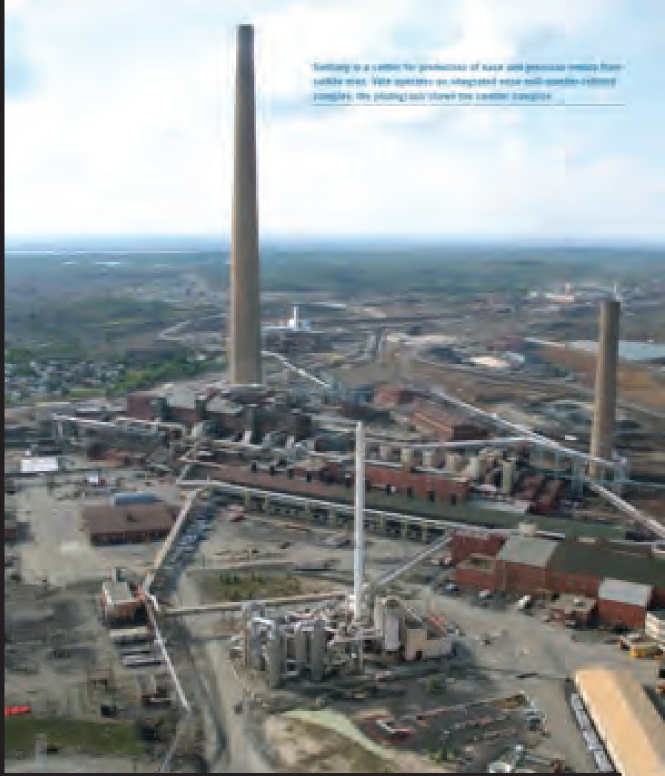
Dramatic decline in “spare” Class 1 nickel in medium and long term



Global Nickel Supply (Mmt Ni in-situ in MRMR)

- Most high purity nickel comes from high- and low-grade nickel sulfide
- High quality Ni is required for production of batteries



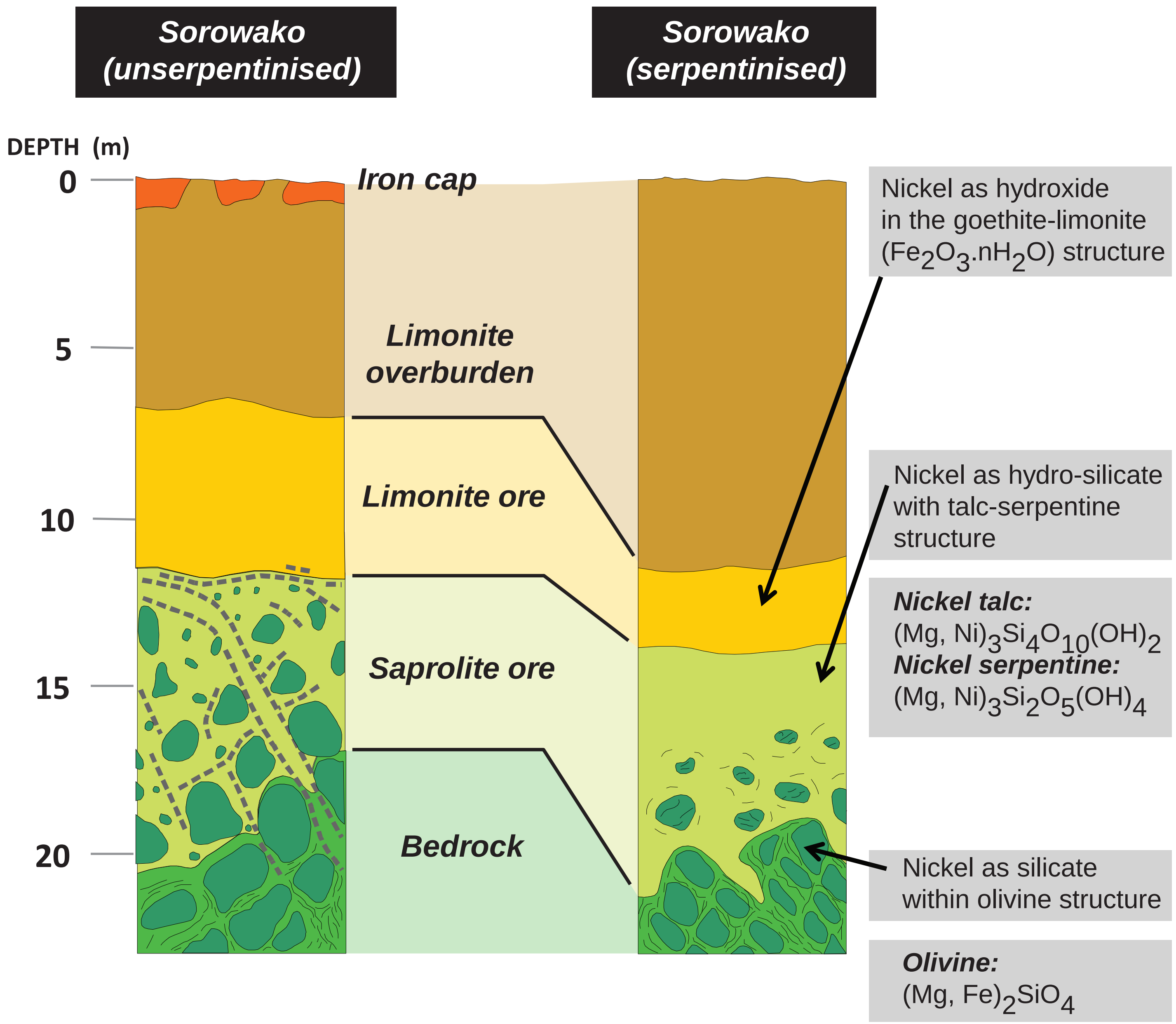


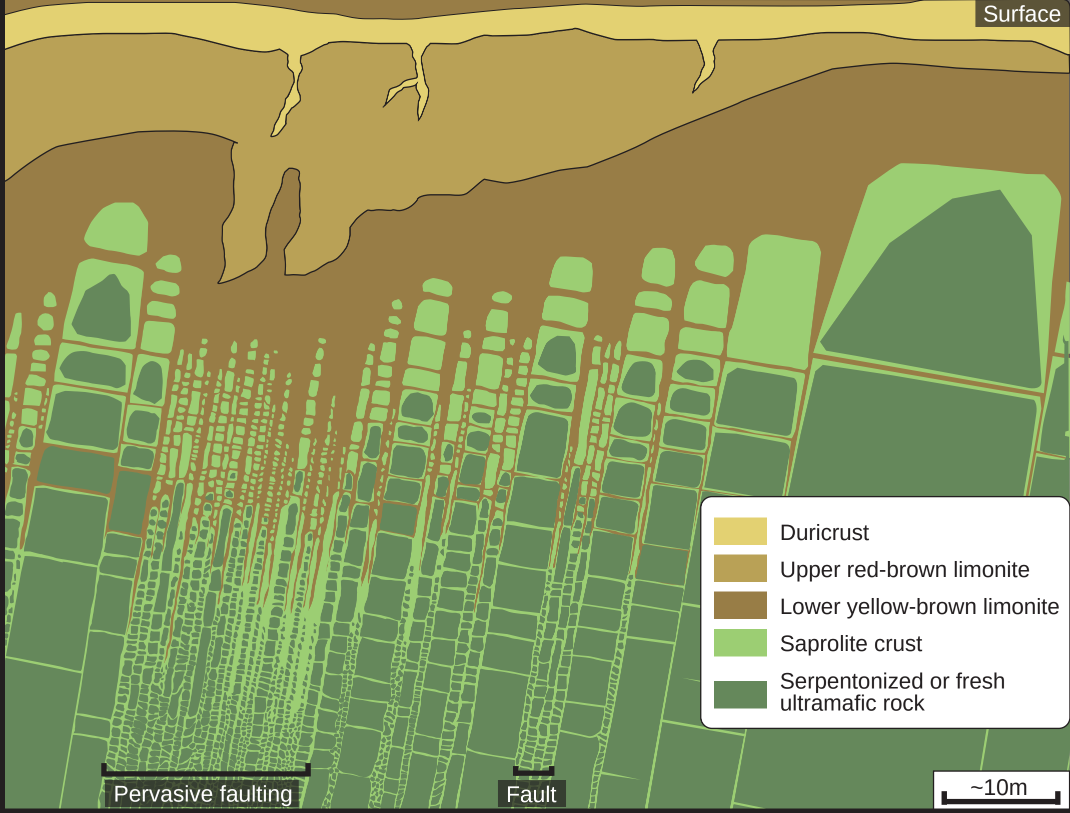
Vale Sudbury smelted complex, Sudbury, Ontario

Vale Sorowako smelter, Sulawezi, Indonesia

Code-compliant MRMR disclosed data assembled by PCL [Nov 2021] Source: USGS*

Soroako laterites: saprolites and limonites





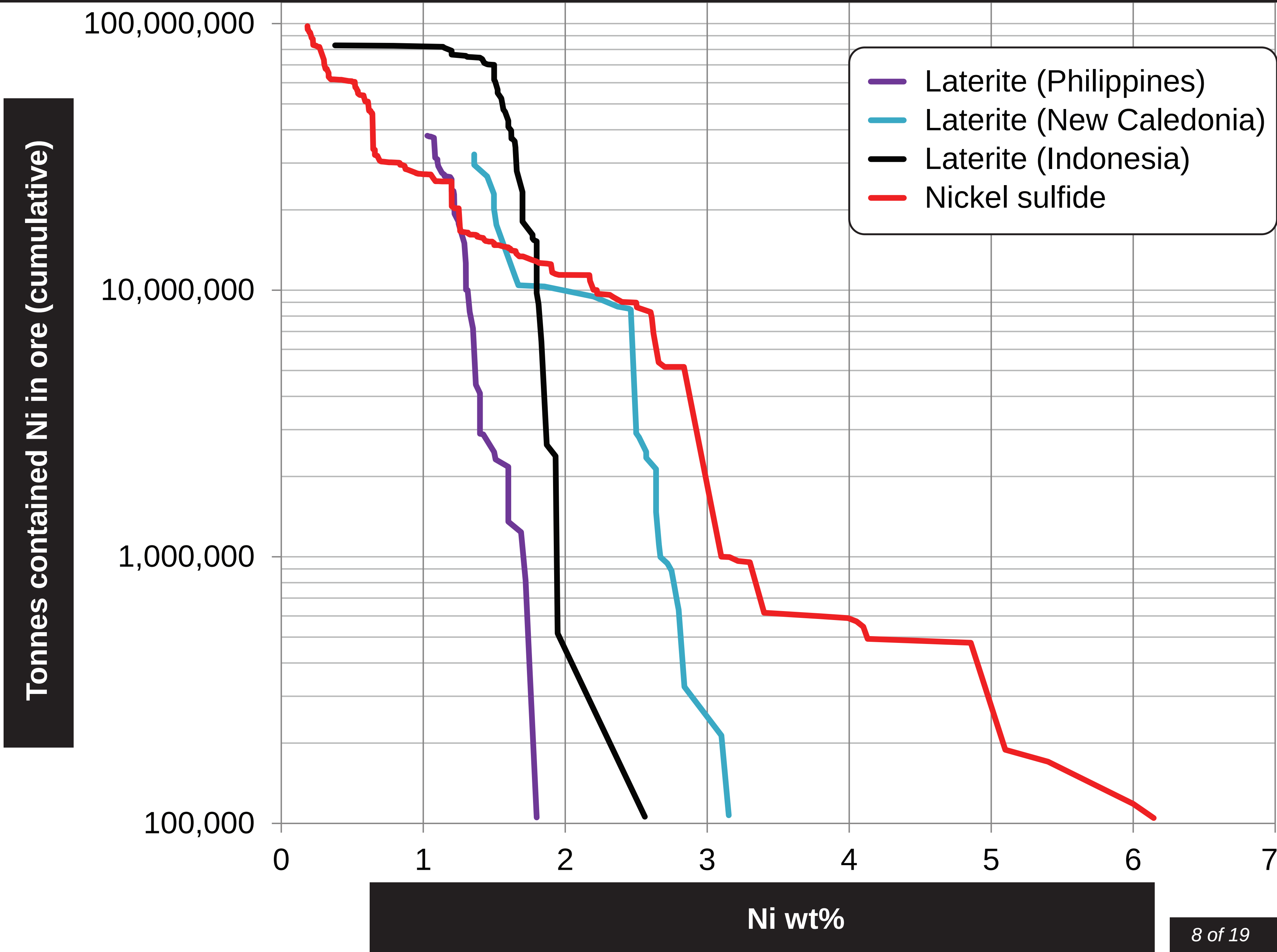
Global Nickel Supply from sulfides and laterites (Mmt Ni in-situ in MRMR; Lightfoot, 2016)

Sulfides:

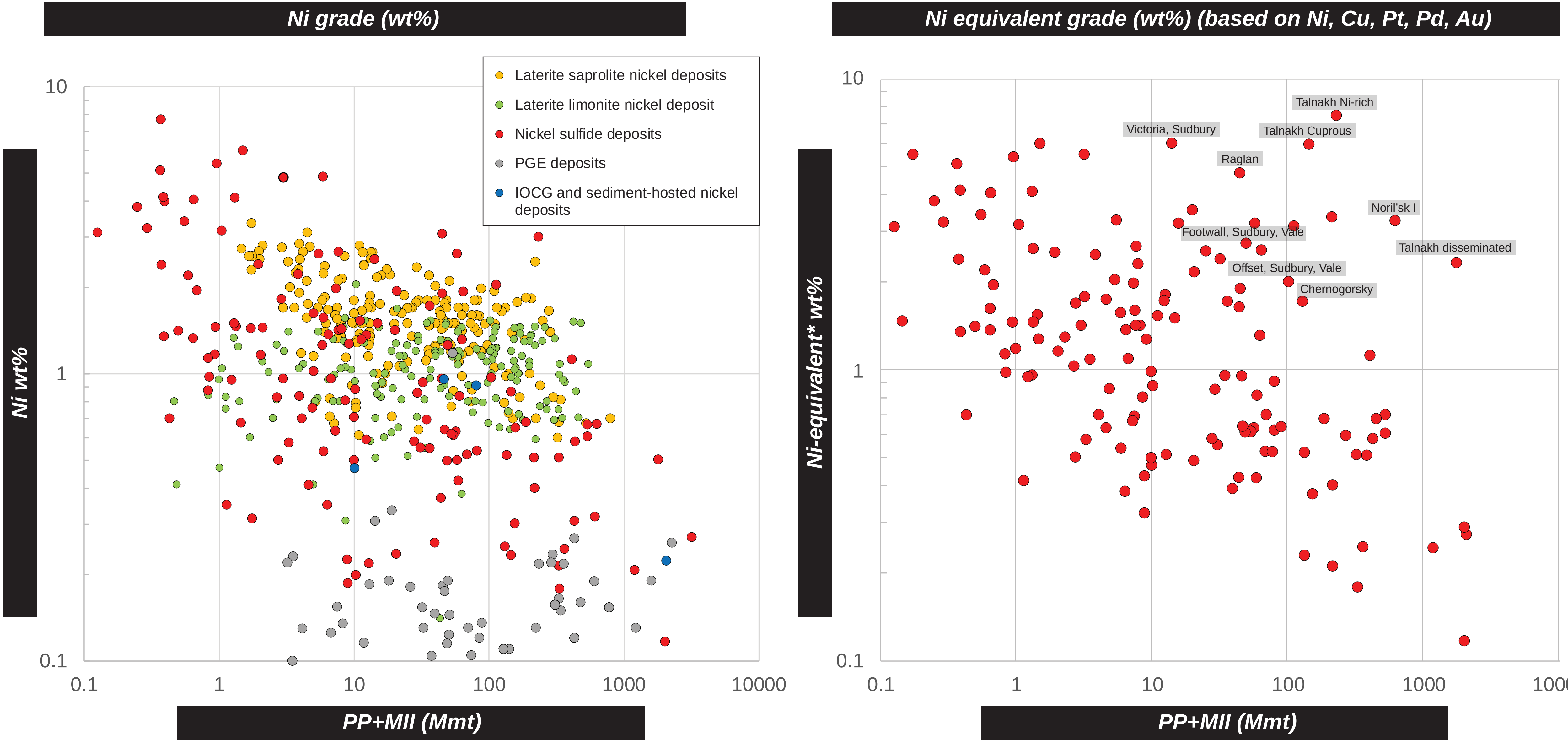
- By-product Co, but also Cu, Pt, Pd, Au, and Rh
- Higher Ni-equivalent value than laterites

Laterites:

- Highest grade ores in Indonesia



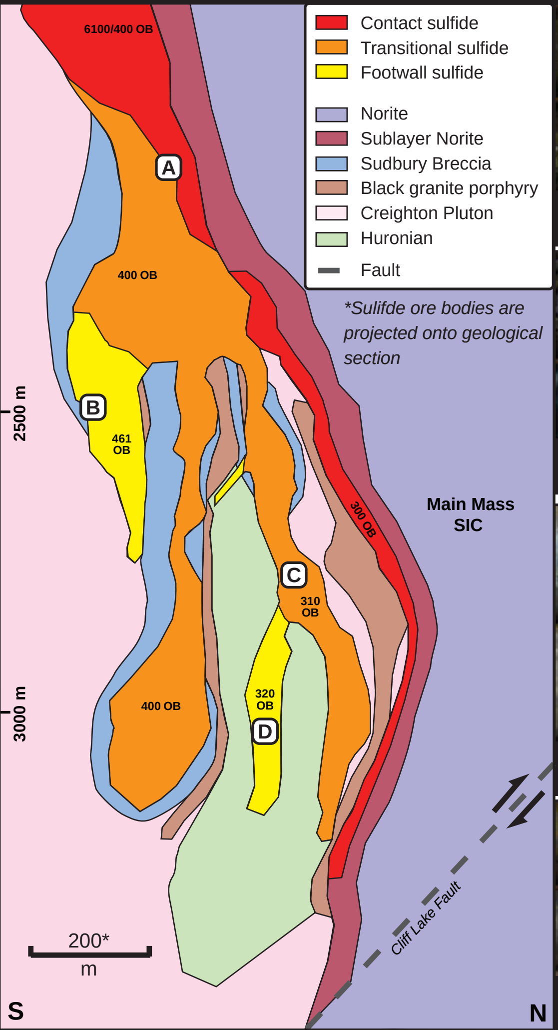
Global tonnage-grade plots for Ni and Ni-equivalent grade

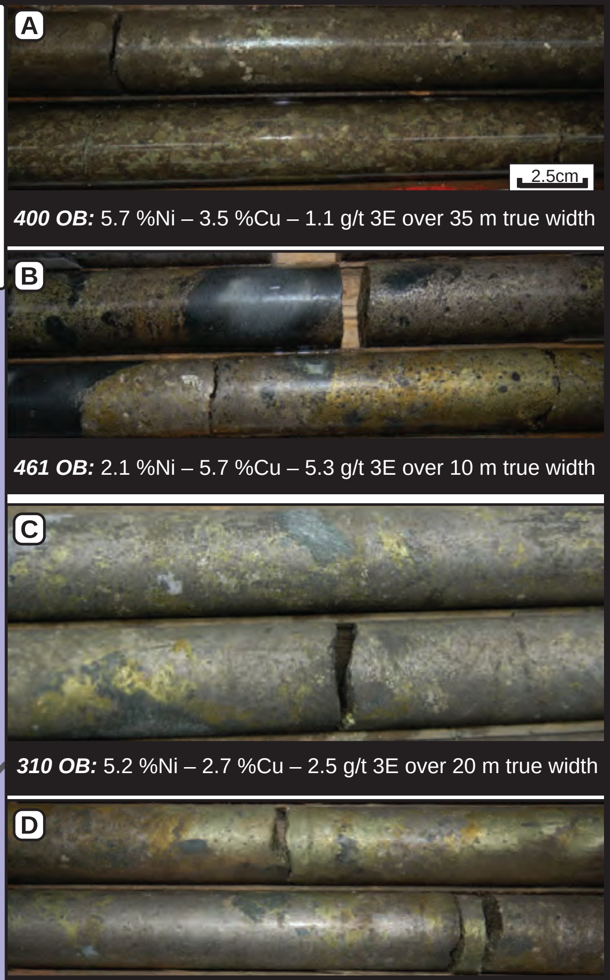


Sudbury

- History of discovery mostly in late 19th & early 20th centuries
- Long-life mines approaching exhaustion
- Depth of exploration and development requires high grades

West-facing section through Creighton Deep Deposits



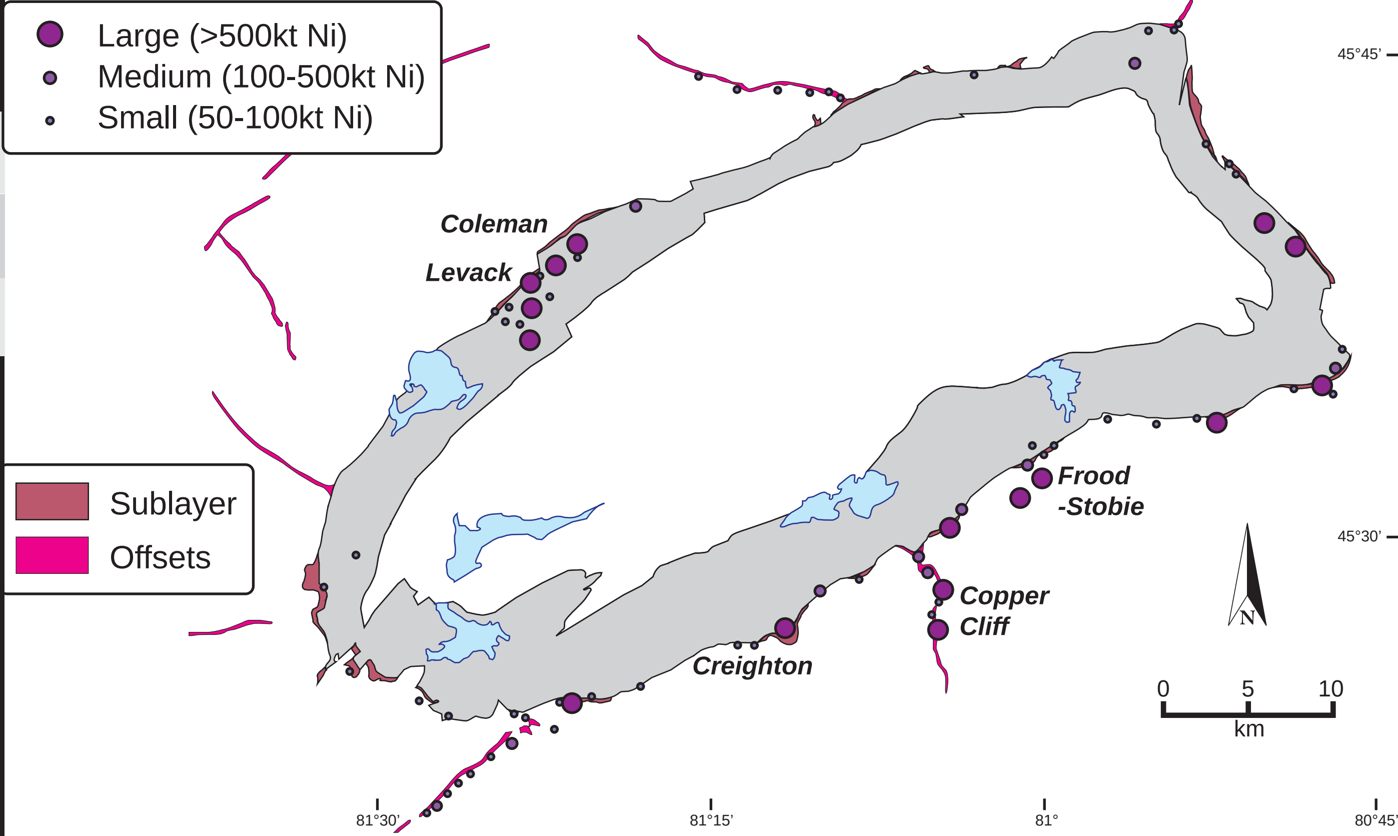


400 OB: 5.7 %Ni – 3.5 %Cu – 1.1 g/t 3E over 35 m true width

461 OB: 2.1 %Ni – 5.7 %Cu – 5.3 g/t 3E over 10 m true width

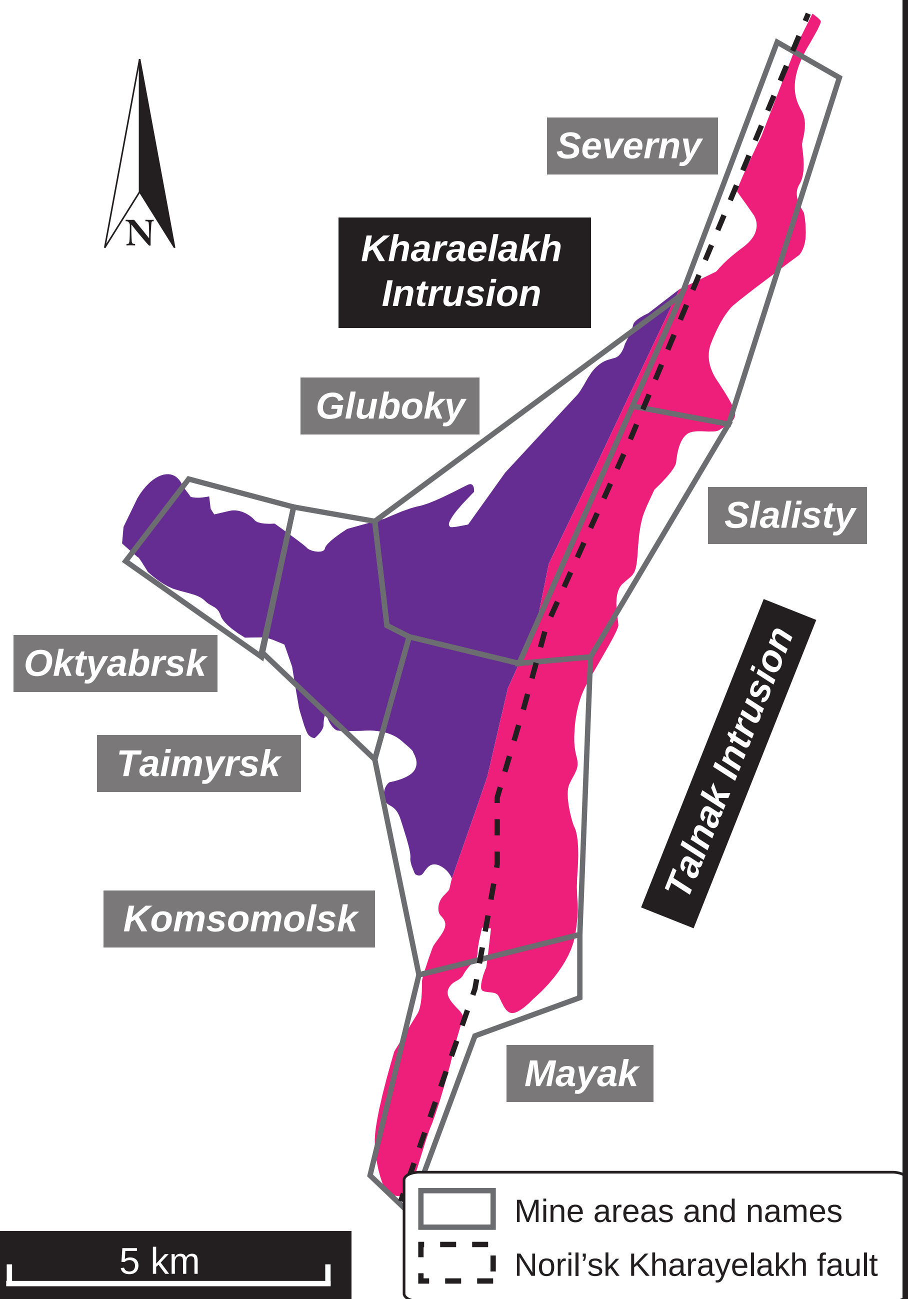
310 OB: 5.2 %Ni – 2.7 %Cu – 2.5 g/t 3E over 20 m true width

320 OB: 2.6 %Ni – 4.6 %Cu – 4.8 g/t 3E over 10 m true width



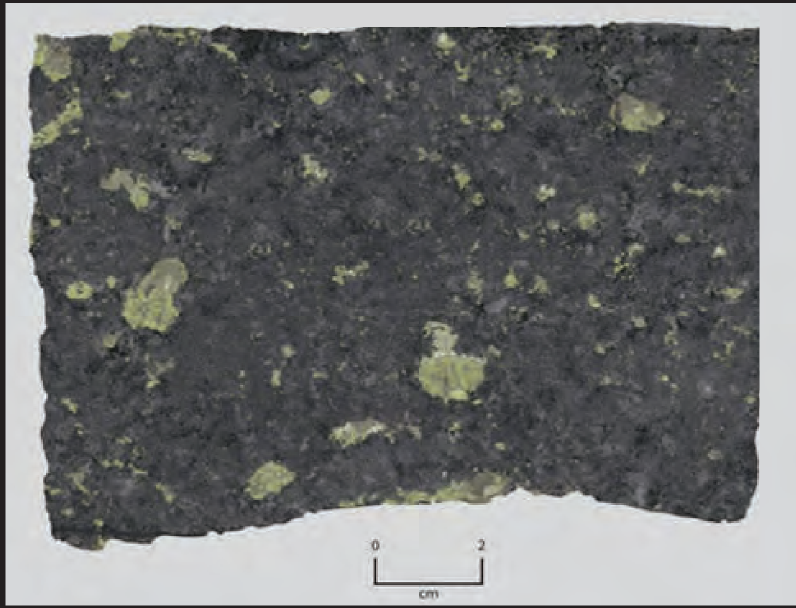
Lightfoot, 2016

Noril'sk-Talnakh

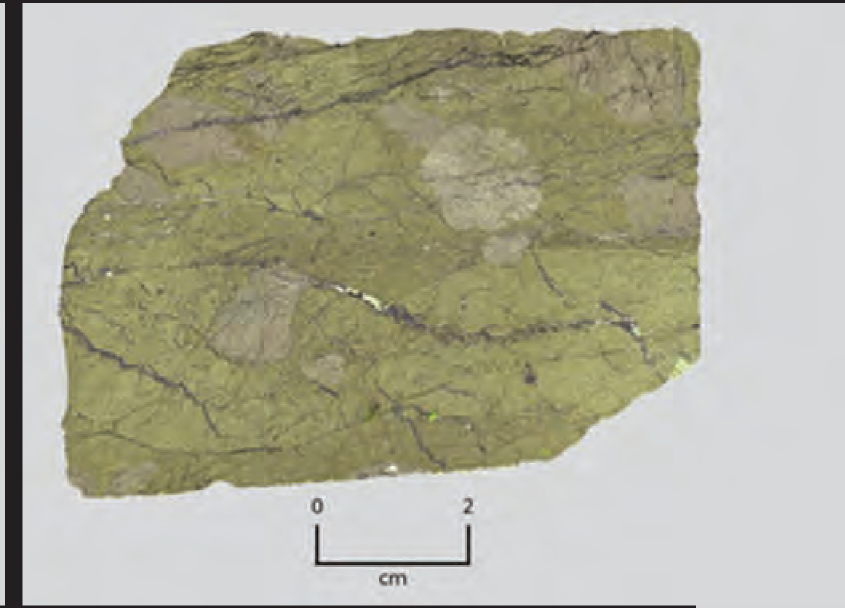


Noril'sk-Talnakh: *2020 production of 87.5 tonnes*
Other mines in Russia: 2020 production 3.5 tonnes
Most production comes from these 6 Oktyabrysk shafts

Lightfoot, 2016

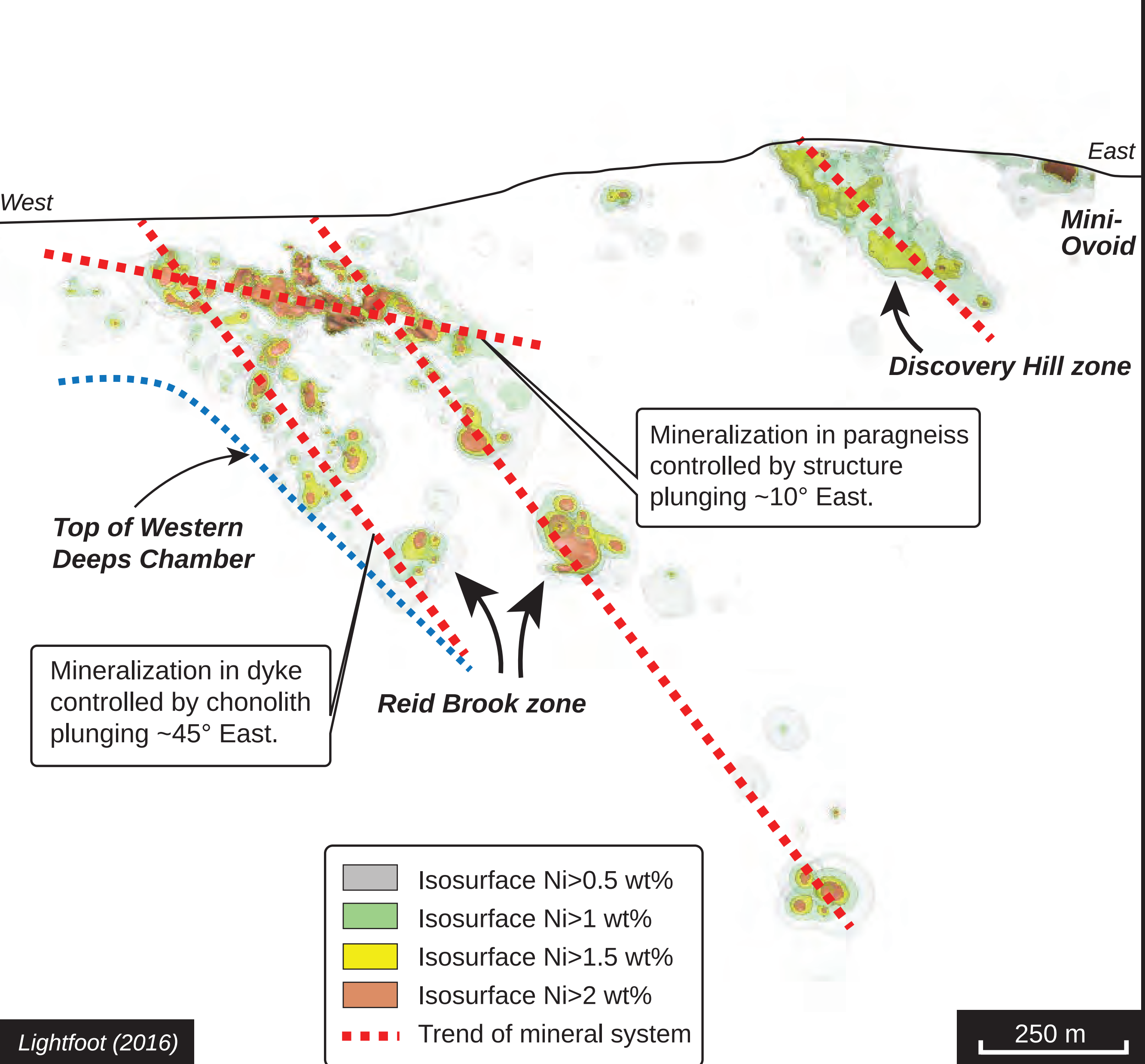


Disseminated style: 1,828$US/ tonne ISV
1.19%Ni, 1.96%Cu, 9ppm Pt, 13ppm Pd



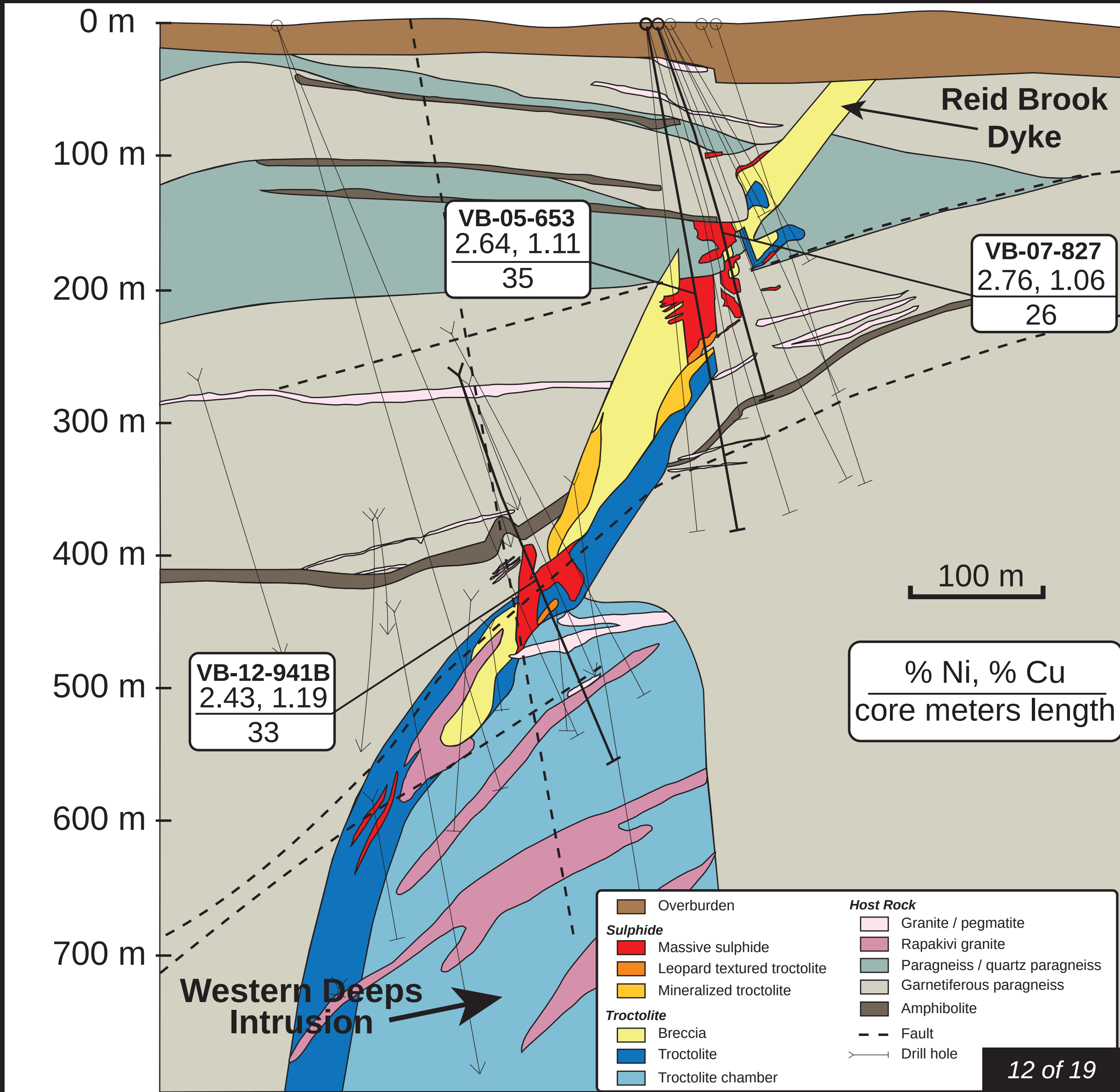
Ni-rich style: 25,987$US/tonne ISV
5.51%Ni, 29%Cu, 72ppm Pt, 334ppm Pd

Voisey's Bay: migration from open pit mining of Ovoid to underground development of the Reid Brook Zone



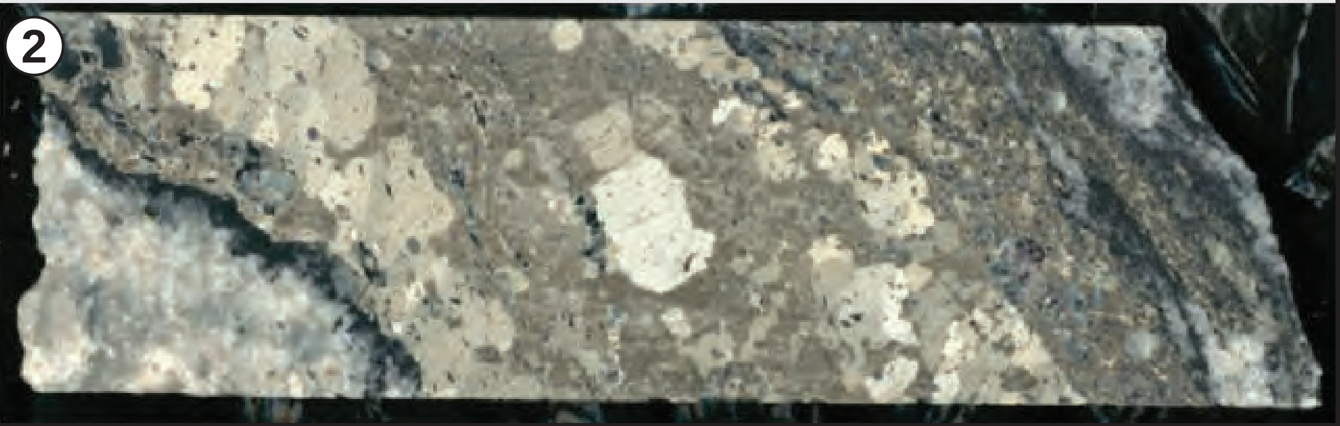
Lightfoot (2016)

Reid Brook Zone: 53700E Section – Looking West

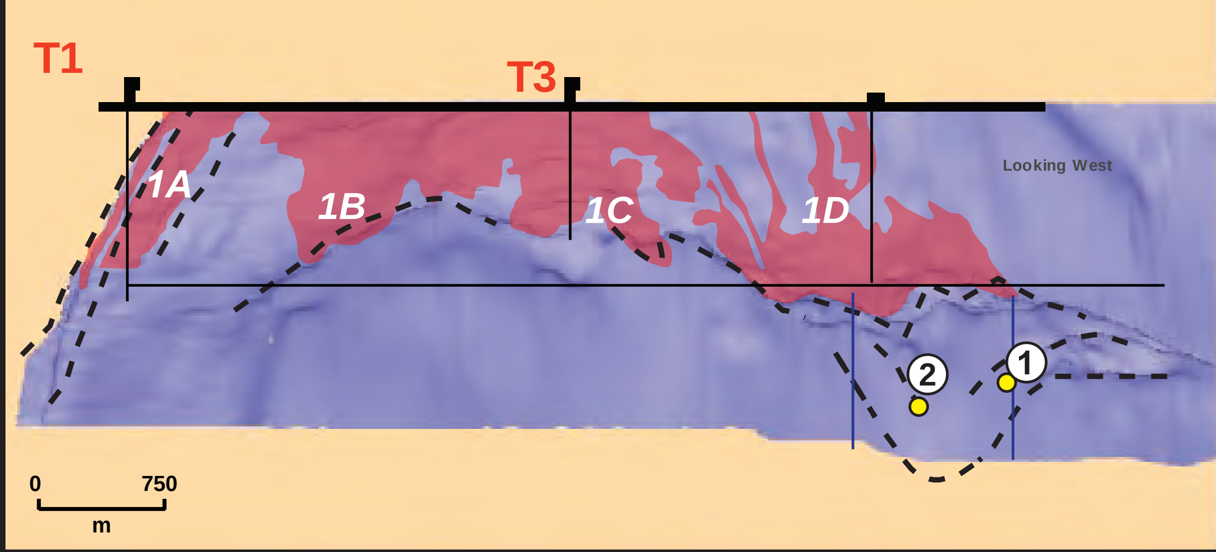


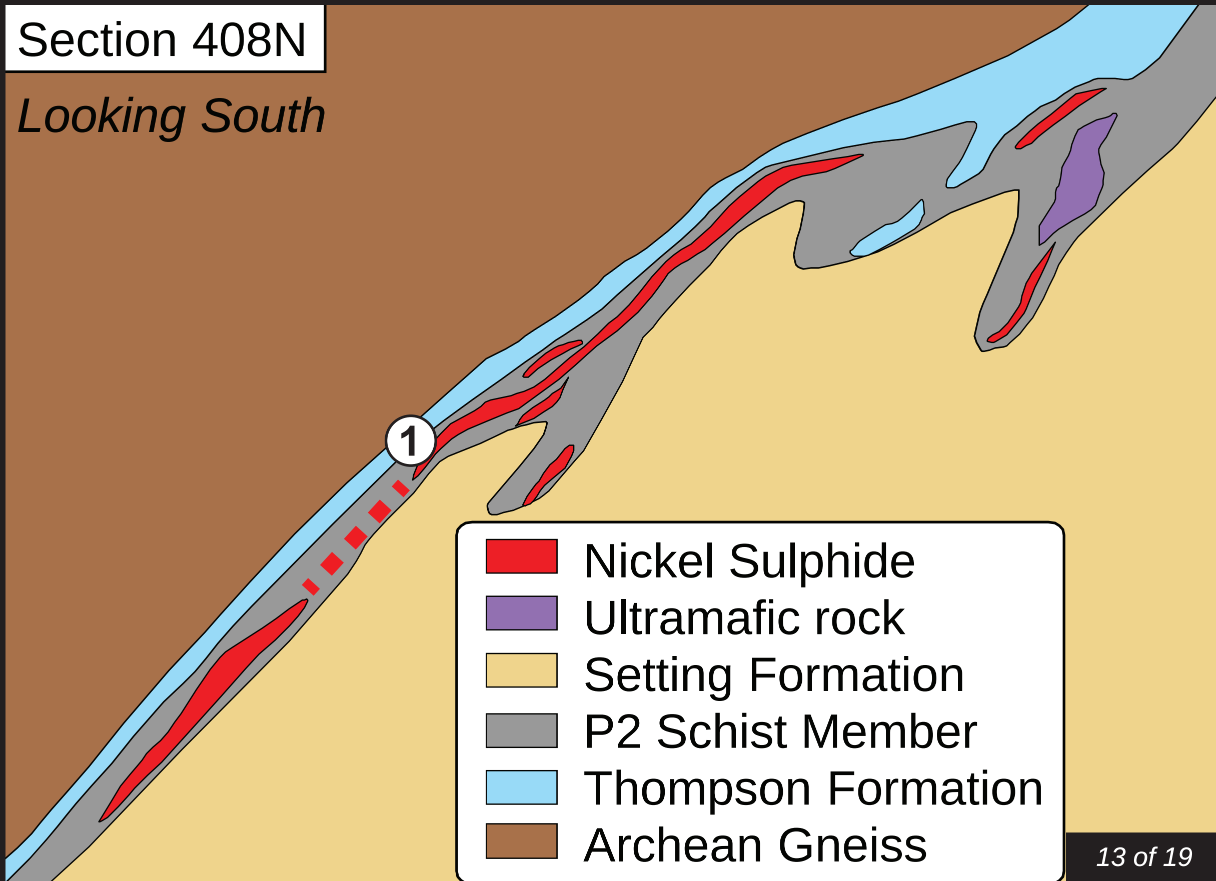
Thompson Deposit

BH 1301450 4.75% Ni, 1.28 g/t TPM / 31.0m true thickness

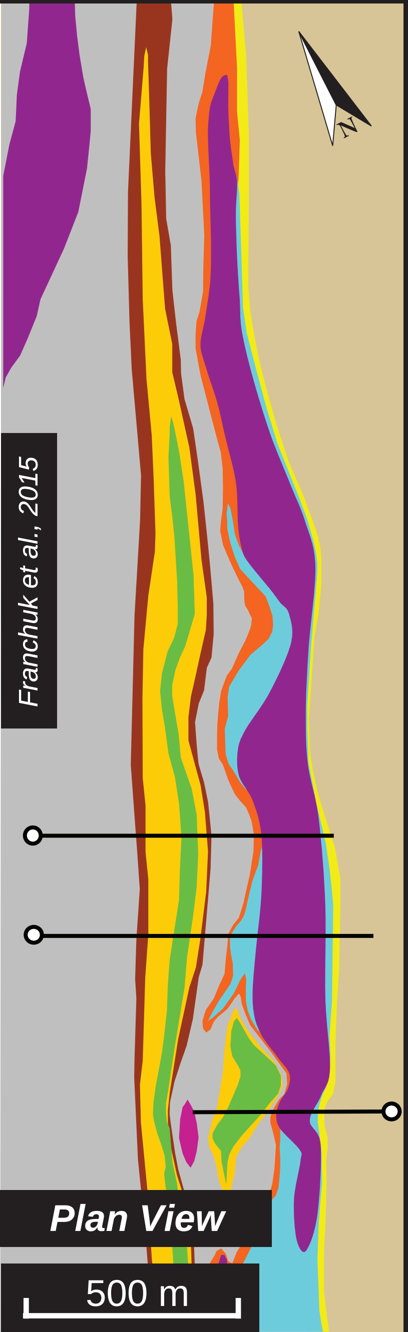


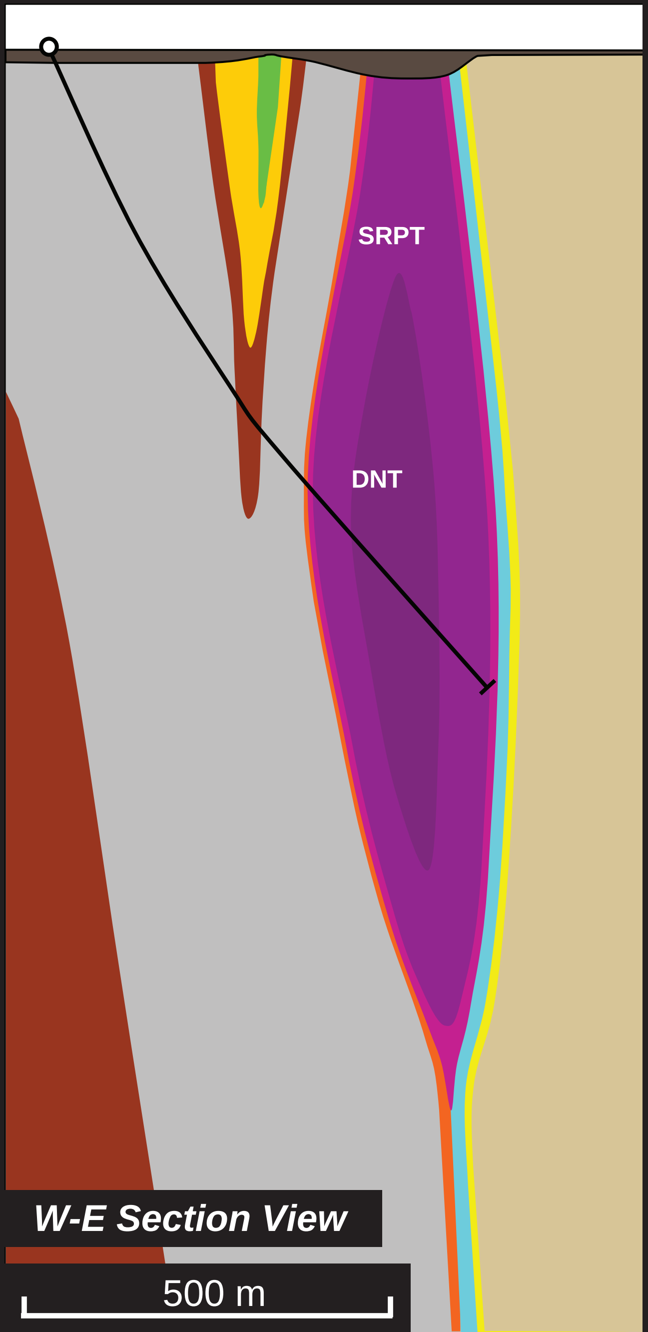
BH 1140690 2.04% Ni, 0.505 g/t TPM / 17.1m true width

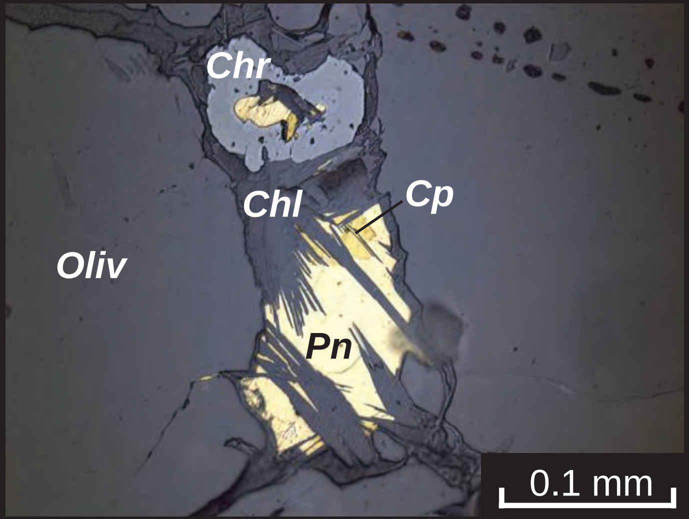


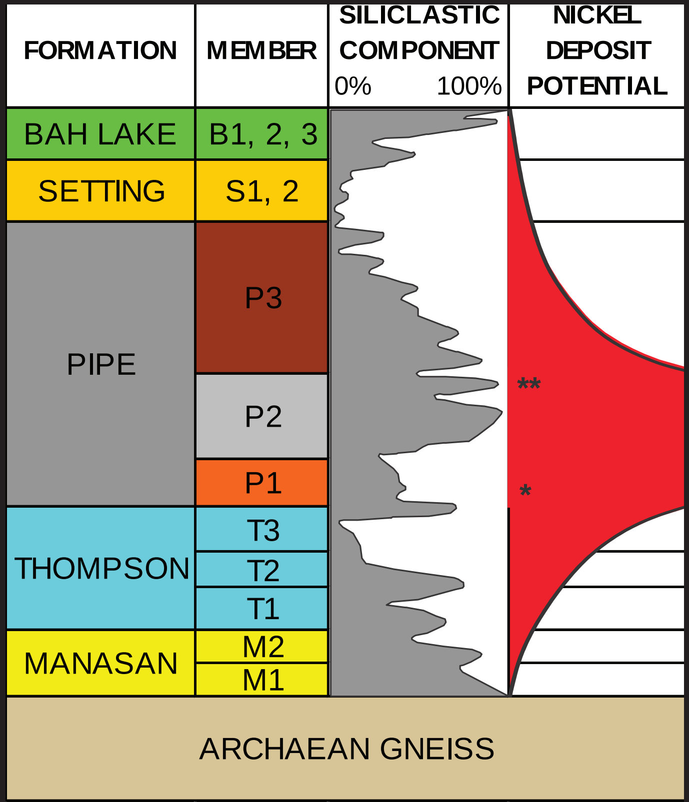


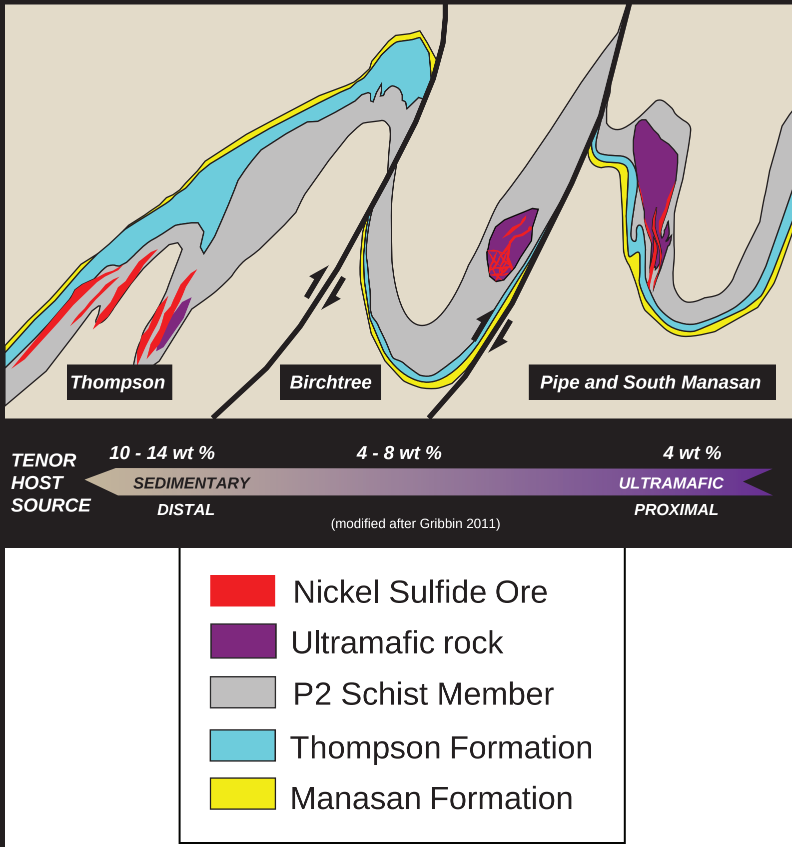
South Manasan Deposit: low-grade Ni sulfide with PGE





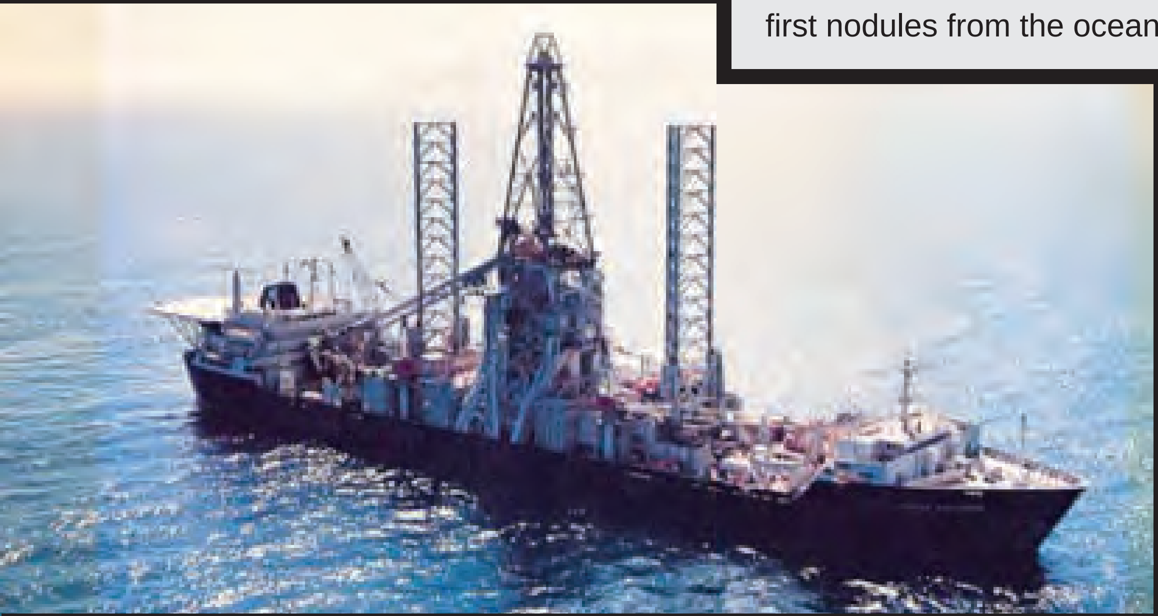




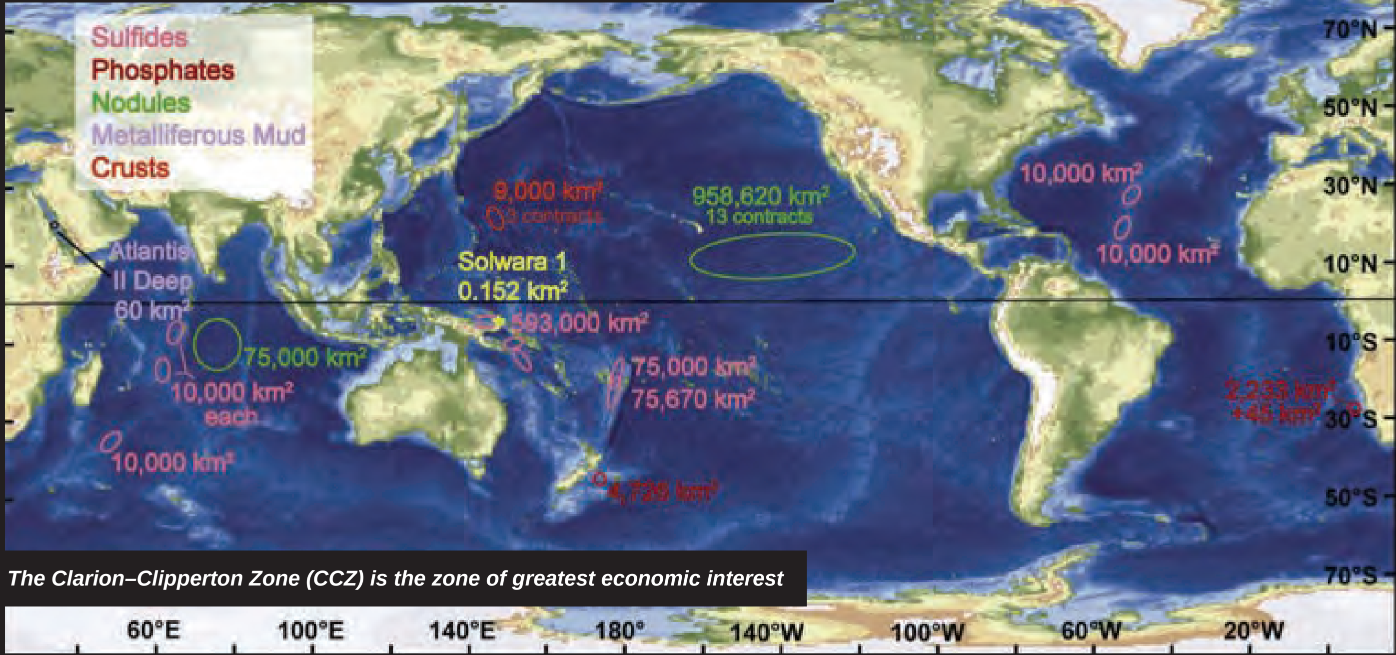


Deep sea nodules

GSF Explorer, formerly USNS Hughes Glomar, was a deep-sea drill platform built for Project Azorian, the secret 1974 effort by the CIA's Special Activities Division to recover the Soviet submarine K-129. It went on to dredge some of the first nodules from the ocean floor.

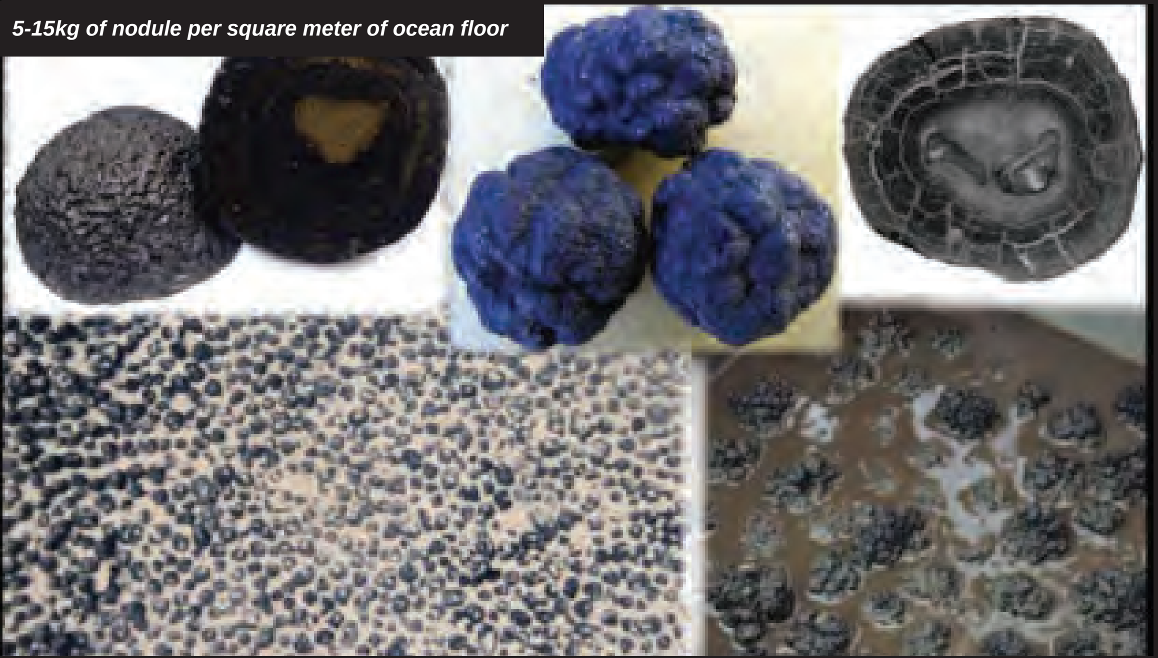


Map of current deep-ocean mining contracts



The Clarion–Clipperton Zone (CCZ) is the zone of greatest economic interest

5-15kg of nodule per square meter of ocean floor



Entity	Deposit Type
States and companies with deep-ocean minerals contracts.	
China	Nodules, sulfides, crusts
France	Nodules, sulfides
Germany	Nodules, sulfides
India	Nodules
Japan	Nodules, crusts
Korea	Nodules, sulfides
Russia	Nodules, sulfides, crusts
Inter-ocean metals (Bulgaria, Cuba, Czech, Poland, Russia, Slovak)	Nodules
Companies	
Diamond Fields International Ltd.with Manfa International	Metalliferous mud
G-TEC Sea Minerals NV	Nodules
Nauru Ocean Resources	Nodules
Tonga Offshore Mining (owned by Nautilus Minerals)	Nodules
UK Seabed Resources Ltd.(owned by Lackheed Martin UK Holdings Ltd)	Nodules
Marawa (Kiribati)	Nodules
Nautilus Minerals	Sulfides
Neptune Minerals	Sulfides

USGS source: Hein et al., 20-21 DOI: 10.1016/j.oregeorev.2012.12.001

Deep sea nodules

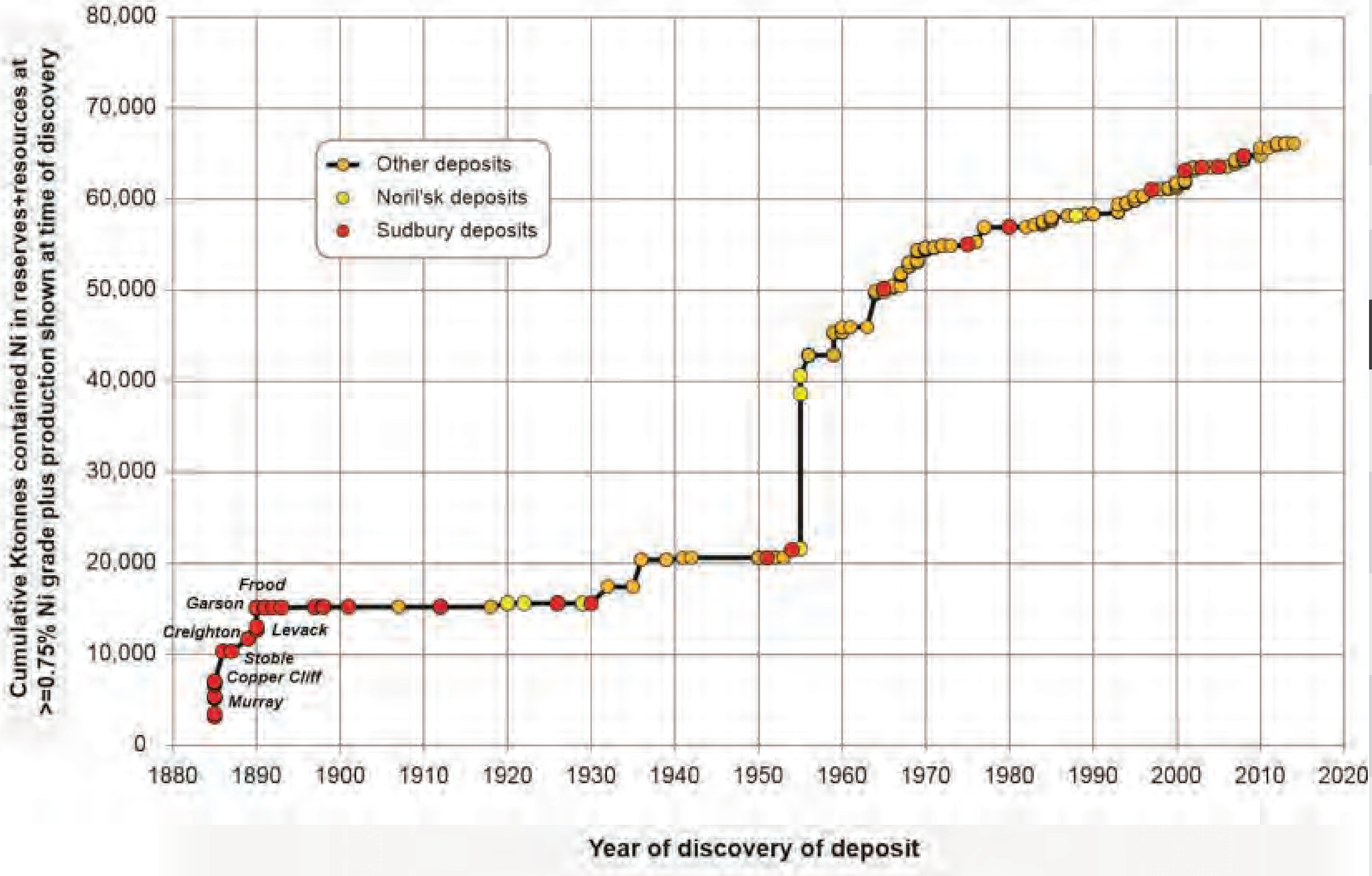
Compelling resource base, but…mining the deep seabed is fraught with challenges

Element	Atlantic Ocean	Indian Ocean	North Pacific Prime Zone	South Pacific	CCZ nodules	Peru Basin nodules
As (ppm)	308	207	389	287	67	65
Au (ppb)	6	21	55	33	4.5	
Bi (ppm)	19	30	42	22	8.8	3.3
Cd (ppm)	4.1	3.5	3.6	4.1	16	19
Co (ppm)	3608	3291	6655	6167	2098	475
Cu (ppm)	861	1105	982	1082	10714	5988
Hg (ppb)	86	38	9.3	32	18	16
Li (ppm)	33	8.3	3.3	3.5	131	311
Mo (ppm)	409	392	463	418	590	547
Ni (ppm)	2581	2563	4216	4643	13002	13008
Pb (ppm)	1238	1371	1636	1057	338	121
Sb (ppm)	51	40	41	35	41	61
Sn (ppm)	8.3	9.7	13	11	5.3	0.9
Th (ppm)	52	56	12	15	15	6.9
U (ppm)	11	10	12	12	4.2	4.4
V (ppm)	849	634	642	660	445	431
Zn (ppm)	614	531	669	698	1366	1845
TREE+Y (ppm)	2402	2541	2454	1634	813	403
Ir (ppb)	5	7	12	2	2	
Os (ppb)	2	4	2	3		
Pd (ppb)	6	15	4	7	8	
Pt (ppb)	567	211	477	465	128	40
Rh (ppb)	37	20	24	33	9	
Ru (ppb)	18	20	18	13	12	

Contained metal tonnages (million tonnes)	Clarion-Clipperton Zone Nodules (Million metric tonnes)	Crust Zone (Million metric tonnes)	Global Terrestrial Resource (USGS; Million metric tonnes)	Global Terrestrial Reserves (Million metric tonnes
As	1.40	2.90	1.60	1.00
Bi	0.18	0.32	0.70	0.30
Co	44	50	13	8
Cu	226	7.4	1,000	690
Li	2.8	0.02	14	13
Mn	5,992	1,714	5,200	630
Mo	12	3.5	19	10
Nb	0.46	0.40	3.00	3.00
Ni	274	32	150	80
PGM	0.003	0.004	0.08	0.07
Te	0.08	0.45	0.05	0.02
Th	0.32	0.09	1.20	1.20
Th	4.20	1.20	0.001	0.0004
Ti	67	88	899	414
TREE as oxide	15	16	150	110
V	9	4.8	38	14
W	1.30	0.67	6.30	3.10
Y	2.00	1.70	0.50	0.50

USGS source: Hein et al., 20-21 DOI: 10.1016/j.oregeorev.2012.12.001

Plot of year of initial discovery of deposit versus cumulative contained Ni in reserves + resources with >0.75%Ni grade



Discovery driving force:

- Major mining companies: tiny fraction of income goes back into grassroots exploration
- Juniors: market pressures and funding uncertainty
- Non-conventional nickel: low grade, NPI, nodules
- China SOE discovery: highly effective in past ~15 years

Implications to professional geoscientists:

- Data curation: encourage best practices in data curation (Geological Survey)
- Ensure that companies can't sit on undeveloped treasures: fair rule sets (Government)
- Data utilization: inefficient utilization of exploration data (ML and AI approaches)
- Mentor and train young geoscientists in applied exploration geosciences (Academia)
- Industry: organize PGeo rule sets across Canada, remove uncertainties, engage communities and First Nations

Thank you to those who influenced my research on ore deposits and career as an exploration geoscientist

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Ashok Rao
Ed Ripley
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FORWARD-LOOKING STATEMENTS

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E&L mineral zone, Nickel Mountain (2019)

All of the scientific and technical information contained herein has been reviewed and/or prepared by Dr. Peter C. Lightfoot, P.Geo, a “Qualified Person” within the meaning of National Instrument 43-101: Standards of Disclosure for Minerals Projects.