

## Critical Minerals – Rare Earth Elements, Lithium and Copper – Ore Deposit Types and Global Distribution

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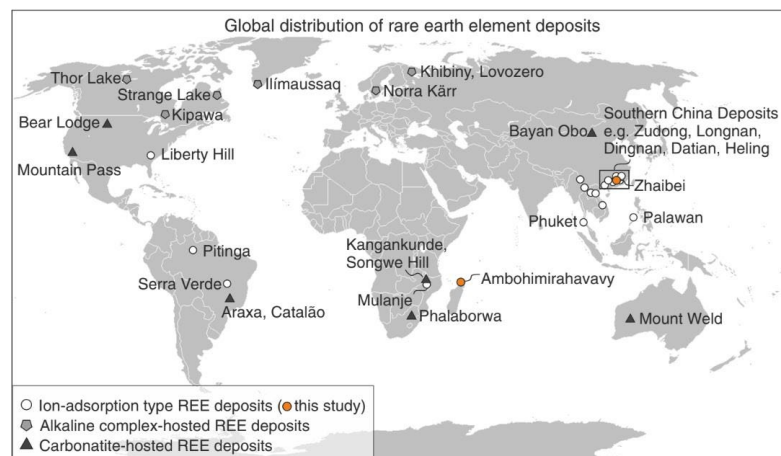
Specific critical minerals, considered energy minerals, are key to progressing a diversification of energy supply to include renewable sources.

### Rare Earth Elements (REE)

REE consist of 15 lanthanides (plus Yttrium (Y) and Scandium (Sc)). All but promethium are non-radioactive. The remaining REE, 14 actinides, are radioactive and mostly man-made. Lanthanides are less reactive with less complex magnetic properties. There are 8 Light (LRE) and 7 Heavy (HRE) lanthanides. Critical rare earths (CRE) include Nd, Pr (LRE) and Dy, Tb (HRE); reported as oxides CREO & T (total) REO. Critical applications, in minute amounts, are in digital tech due to essential magnetic and luminescent properties.

REE deposits occur in intrusive igneous rocks (alkaline complexes – 0.2-1.4 wt.% TREO, carbonatites – 3-5 wt.% TREO), regolith clays (ion-adsorption clays) – 0.1 wt.% REO (HRE) and monazite-xenotime beach sand placers (70 wt.% monazite).

REE deposits occur globally. **Carbonatite-hosted** in western USA, Brazil, Malawi, S. Africa, western Australia and Mongolia; **alkaline complex-hosted** in Canada, Greenland, Russia and Sweden; **ion-adsorption clay** in eastern USA, northern and east-central Brazil, Malawi, southeast China and Myanmar and **beach placers**, mainly in coastal India (not shown), as of 2020.



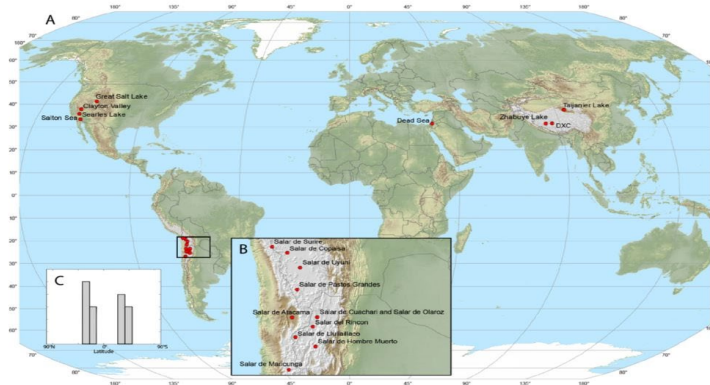
Borst A.N. et al., 2020 NATURE COMMUNICATIONS (2020) 11:4386

### Lithium (Li)

Lithium is essential in the manufacture of heat-resistant glass, ceramics, grease lubricants, flux additives for iron, steel and aluminum manufacture, metal batteries and lithium-ion batteries; these uses consume more than 75% of all lithium produced. Lithium is found as six ore deposit types: **shallow closed-basin brines** (58%), **pegmatites and related granitoids** (26%), **lithium-enriched claystone** (7%), **deep oilfield brines** (3%), **geothermal brines** (3%), and **lithium-**

**enriched zeolites** (3%) (Bradley and Jaskula, 2014, U.S. Geological Survey Fact Sheet 2014–3035).

Shallow closed-basin brines, the principal ore deposit type, occur in three regions of the world with distinct tectonic settings: 1) western USA Basin and Range extensional province, 2) S. America, altiplano of Argentina, Chile and Bolivia (Lithium Triangle) on the Andean convergent margin 3) Tibetan Plateau, Himalayan-Tibetan collisional orogen.



Global Distribution of **Shallow Closed-Basin Li Brine Systems**; Bradley, D. et al., 2013, USGS Open File Report 2013-1006.

## Copper

Copper (Cu) is an essential element in an industrialized society with innumerable uses. In 2022, it was estimated that 60 new large copper mines would be required to match demand for the metal (Australia Office of Chief Economist) whereas exploration, development, mine operation and closure (Mining Life Cycle) can take several decades. It is estimated that to reach copper net-zero by 2050 will **require twice the amount of copper (1.4 billion tonnes) produced over the course of human history (700 million tonnes)** (R. Friedland, 2022, Indaba Conference, S. Africa). This will not occur. Automobile production is a principal user of copper – ICE 30 kg, EV – 120 kg (USGS, 2020, Mineral Commodities Summaries).

The 8 principal copper-bearing minerals, with weight percent copper, are: **Sulphide** – chalcocite (80), digenite (78.1), covellite (66.5), bornite (63), chalcopyrite (34.5); **Oxide** – cuprite (88.8); **Carbonate** – malachite (57.5), azurite (55.3).

Economic copper deposits occur globally as 6 different types (Hitzman, M., Kirkham, R., Broughton, D., Thorson J., and Selley, D., 2005, Economic Geology 100th Anniversary Volume, Society of Economic Geology, pg. 609-642): 1) **porphyry copper** – granitic intrusion; generally lower grade (0.44%) and very high tonnage (10's of millions to > 1 billion tonnes); 2) **sediment-hosted stratiform copper** – intra-continental basin; higher grade (1-2%); high tonnage (<10 million tonnes to billion tonnes); *main source of copper*; 3) **iron oxide copper-gold (IOCG)** – origin still debated; 0.2-5%; 10 - >4,000 Mt; 4) **volcanic redbed copper** – rift basin / volcanic arc; 0.77-12.8%; 0.85-220 Mt; 5) **Mount Isa-type copper** - metamorphic; 3.3%; 6.1 Mt; 6) **Kipushi-type copper** – carbonate replacement; 4.8%; 3.8 Mt.