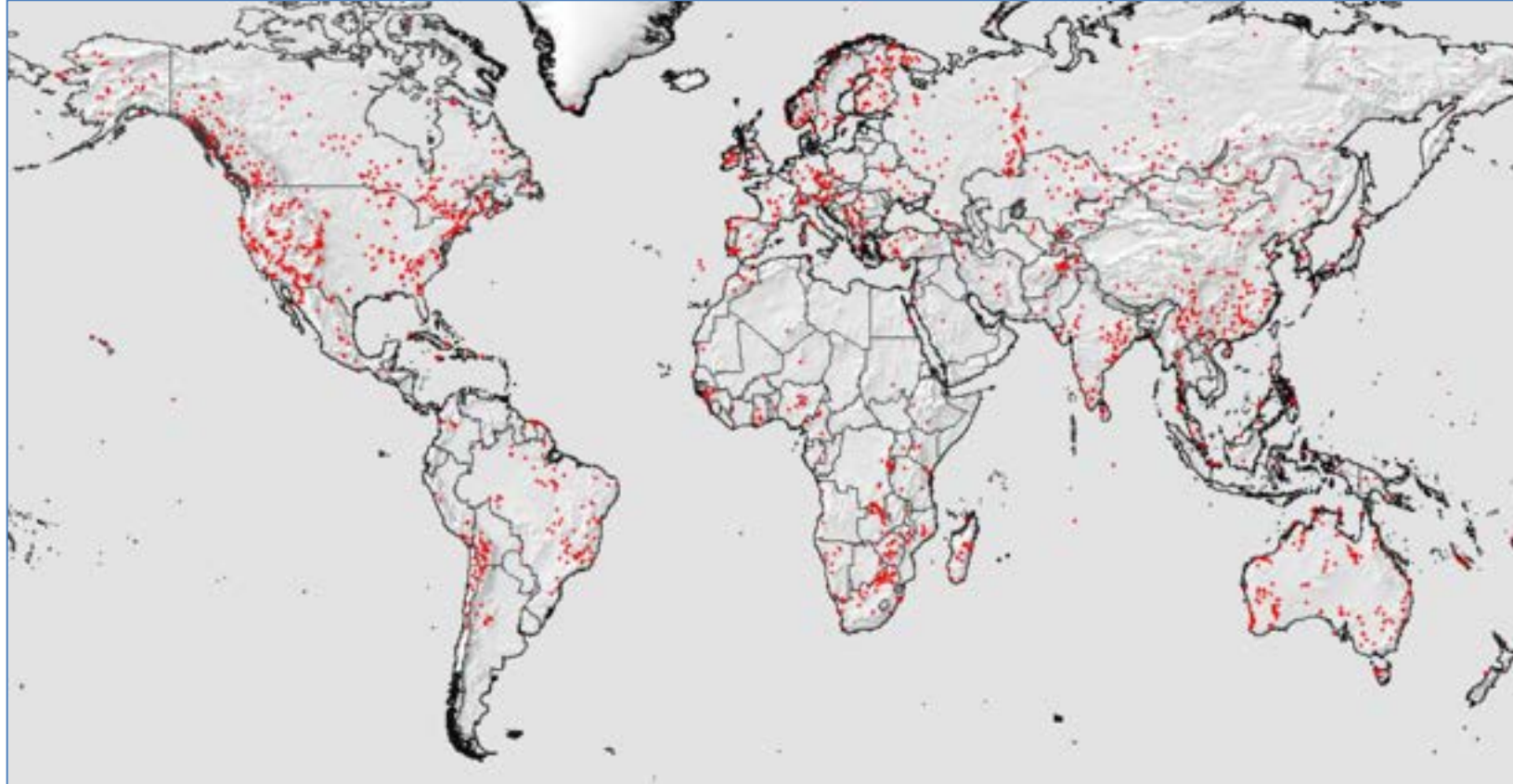
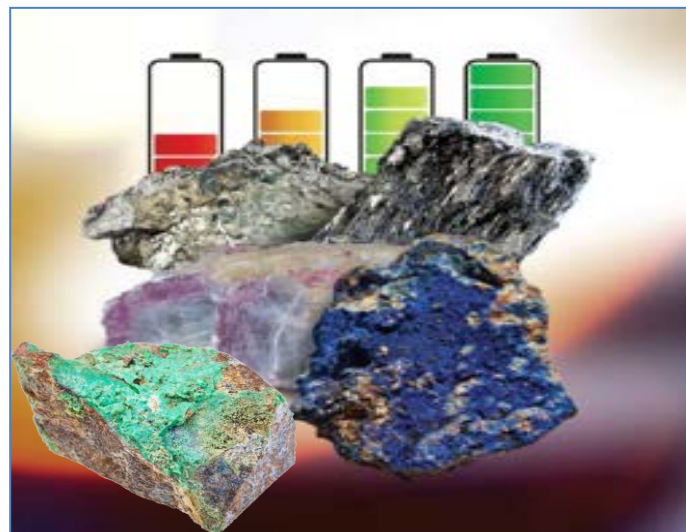


# Global Atlas 17: Critical Minerals



Modified after UNCTAD, Dallas Federal Reserve, Teslarati.com

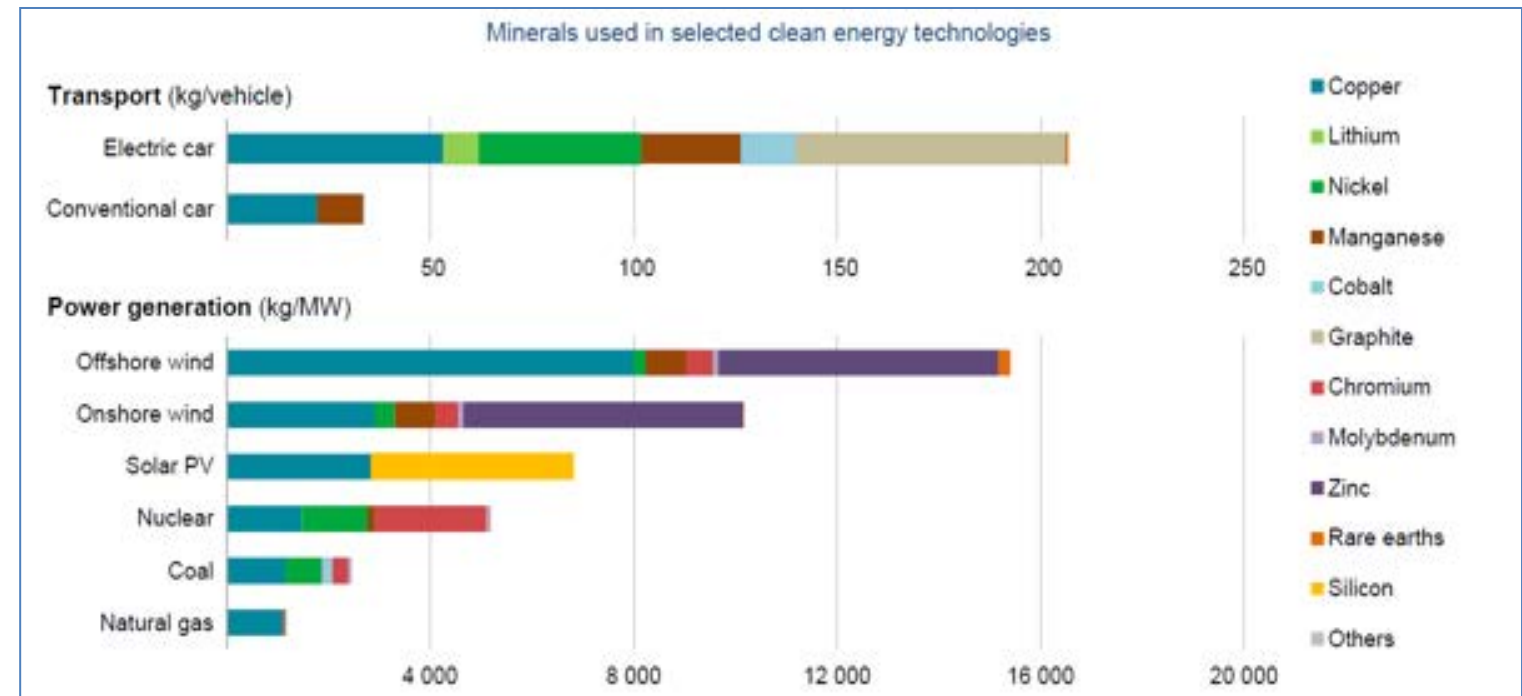


Global Atlas 17: Critical Minerals (musings from the desk of a retired geologist)  
Critical minerals are defined as metal and nonmetal elements and compounds considered vital to economic and national security yet whose supplies may be at risk because of geological scarcity, geopolitical issues, trade policies, or other factors related to extraction, refining, and transport.

This one is a very simple compilation of known distribution of critical mineral deposits around the world. I have incorporated the interesting “verbatim” responses from the Chat GPT AI engine regarding the various critical minerals to show how it can be a valuable teaching tool.



# Energy Transition Typical Mineral Requirements



Steel and Aluminum not included

Source: IEA May 2021

Clare n Crawford 2018, International Institute for Sustainable Development

# US Designated List Of Critical Minerals (2023)

List of REE Minerals

Atomic Number	Element	Symbol
21	Scandium**	Sc
39	Yttrium	Y
57	Lanthanum	La
58	Cerium	Ce
59	● Praseodymium	Pr
60	● Neodymium	Nd
61	Promethium*	Pm
62	Samarium	Sm
63	Europium	Eu
64	Gadolinium	Gd
65	● Terbium	Tb
66	● Dysprosium	Dy
67	Holmium	Ho
68	Erbium	Er
69	Thulium	Tm
70	Ytterbium	Yb
71	Lutetium	Lu



Thermofisher.com

# EU Designated List Of Critical Minerals (2023)

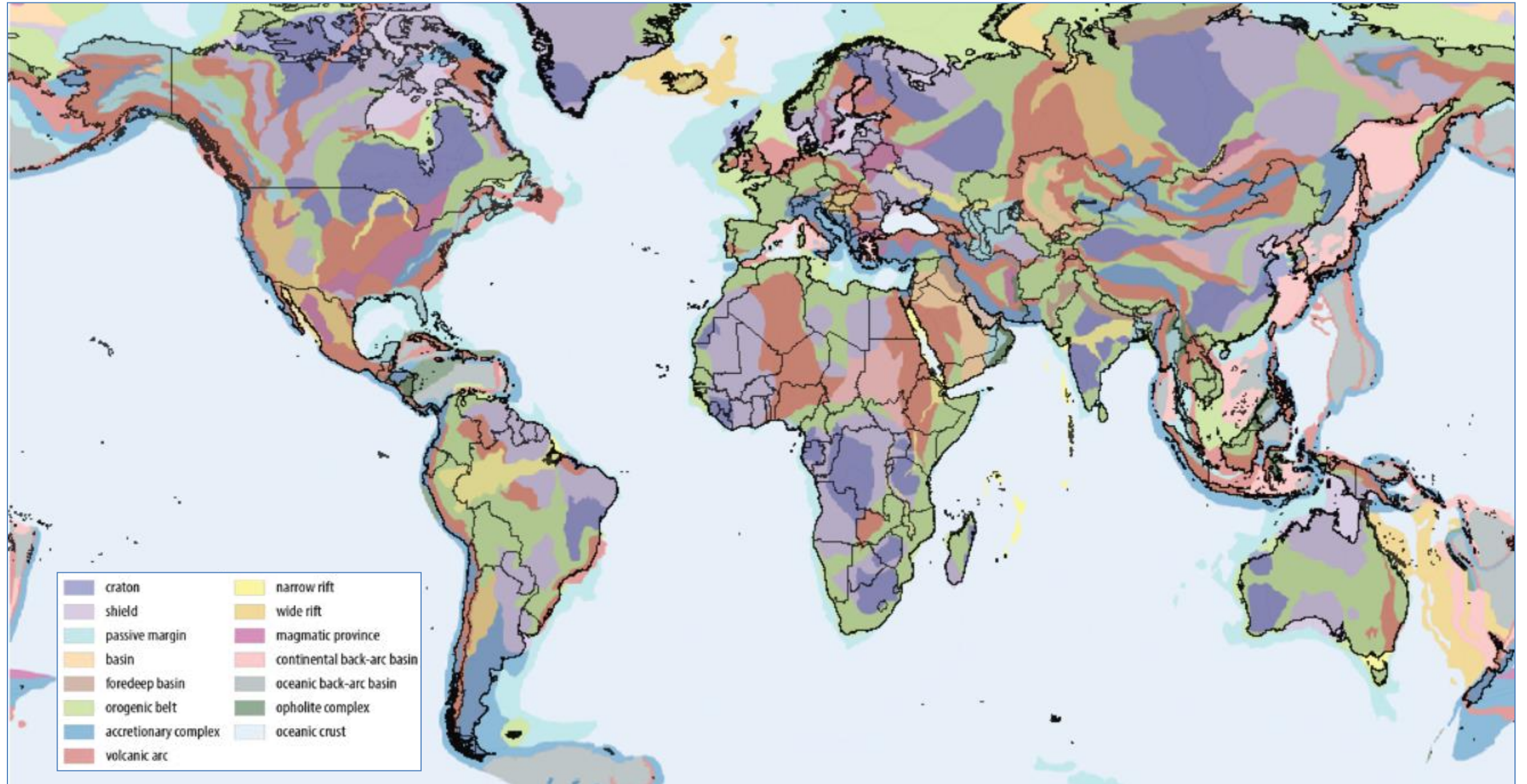
2023 Critical Raw Materials ( <i>new CRMs in italics</i> )			
aluminium/bauxite	coking coal	lithium	phosphorus
antimony	<i>feldspar</i>	LREE	scandium
<i>arsenic</i>	fluorspar	magnesium	silicon metal
baryte	gallium	<i>manganese</i>	strontium
beryllium	germanium	natural graphite	tantalum
bismuth	hafnium	niobium	titanium metal
boron/borate	<i>helium</i>	PGM	tungsten
cobalt	HREE	phosphate rock	vanadium
		<i>copper*</i>	<i>nickel*</i>

\* Copper and nickel do not meet the CRM thresholds, but are included as Strategic Raw Materials.

EU study on critical raw materials 2023



# Global Tectonic Framework

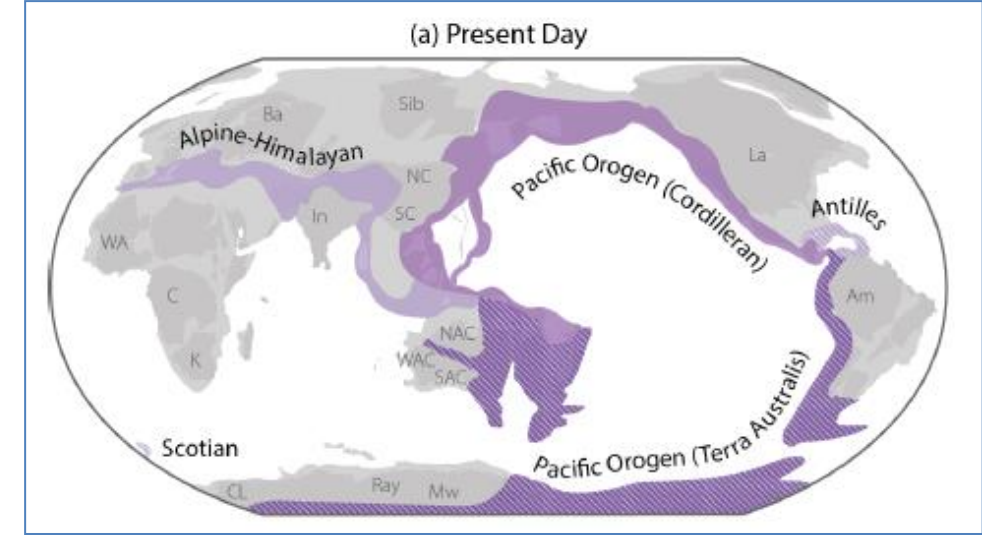
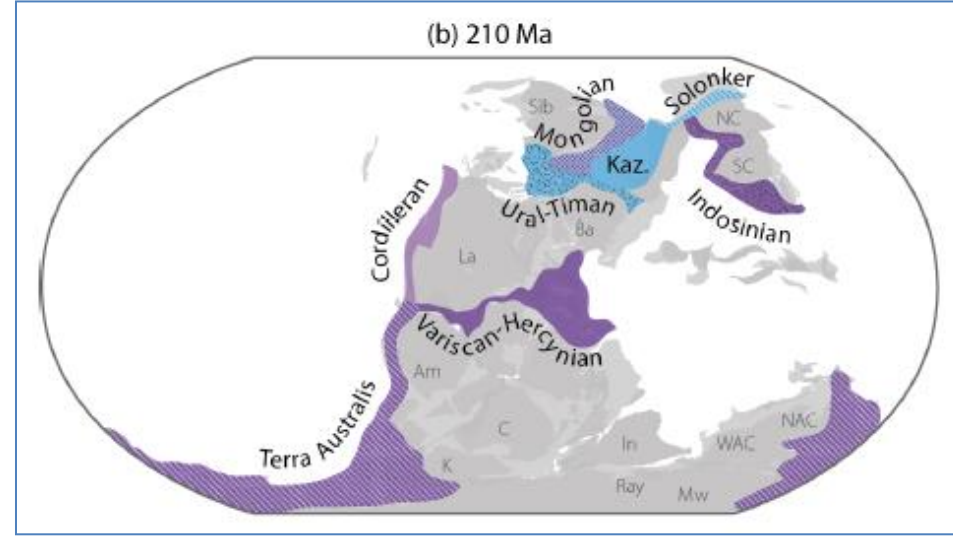
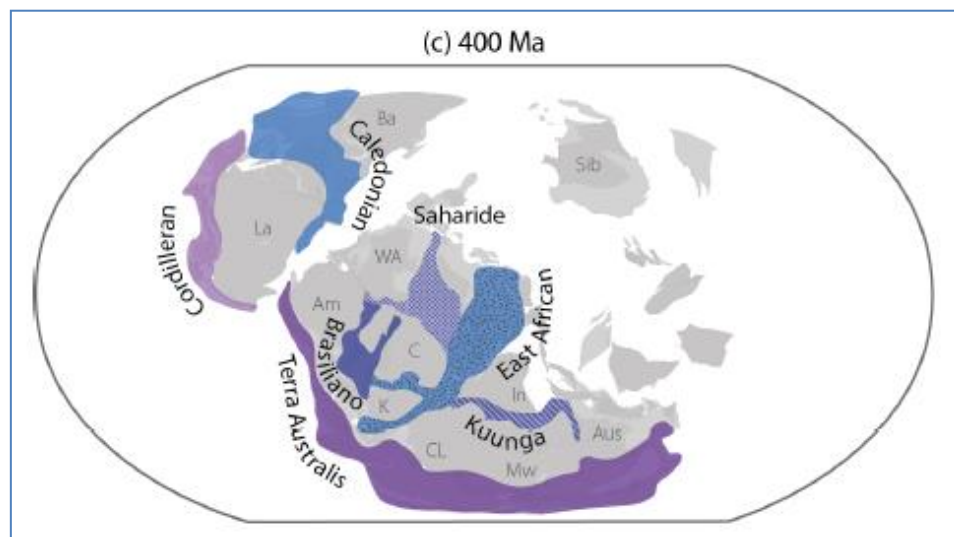
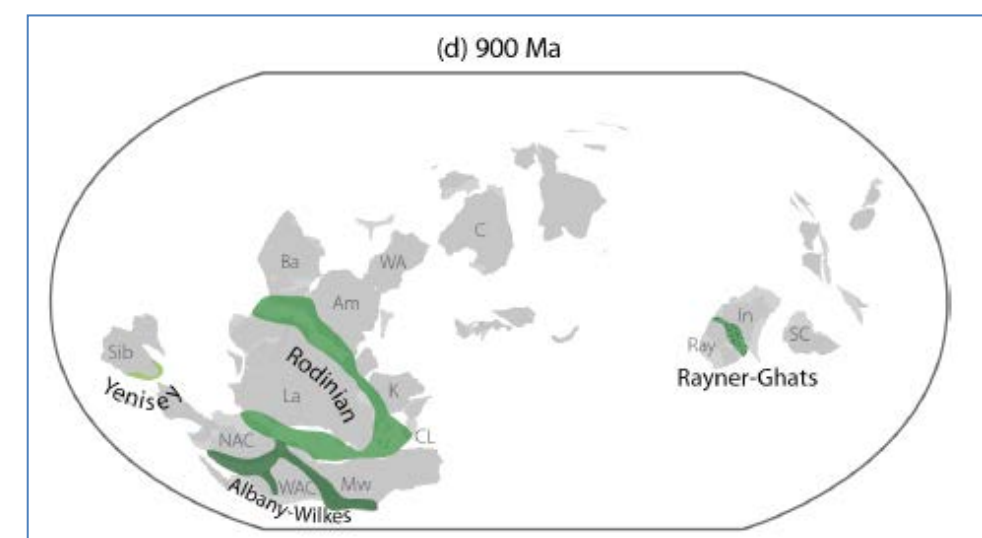
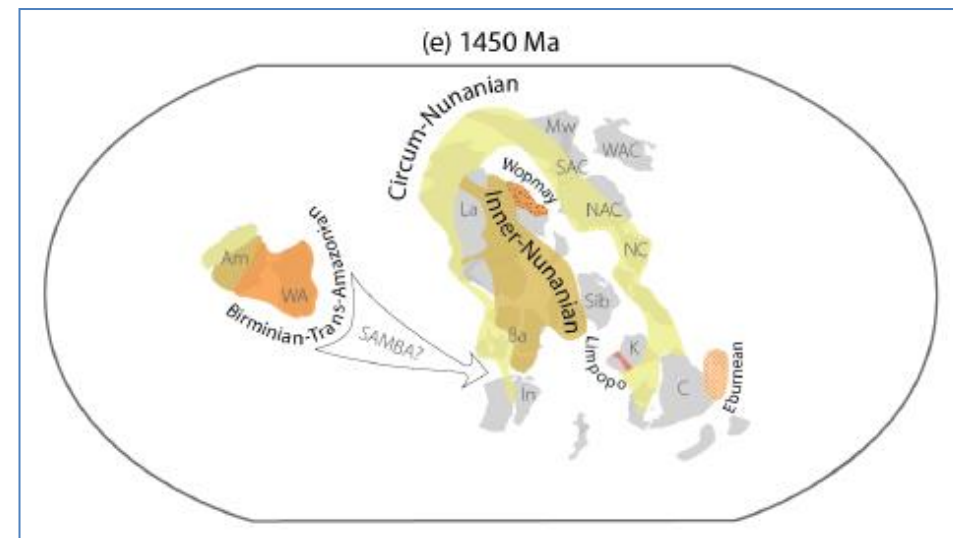
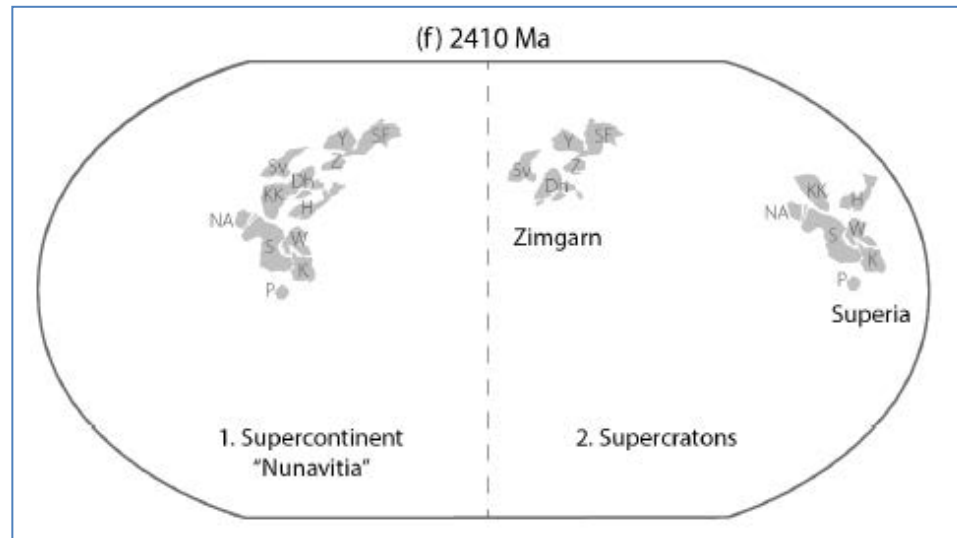


Hasterok et al 2022

Eddy Ong 2024  
Posted on LinkedIn



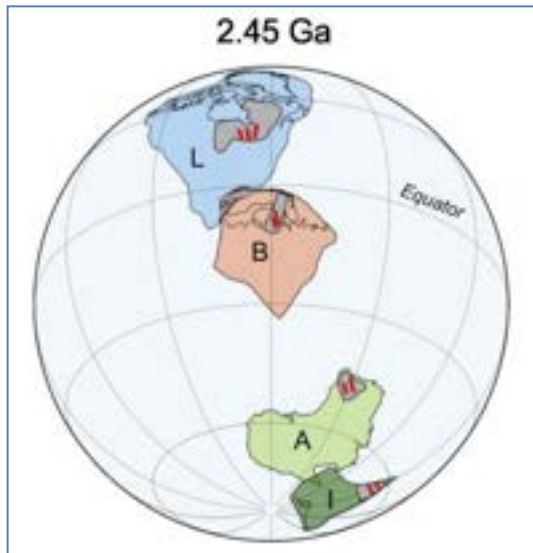
# Reconstruction (Proterozoic– Phanerozoic)



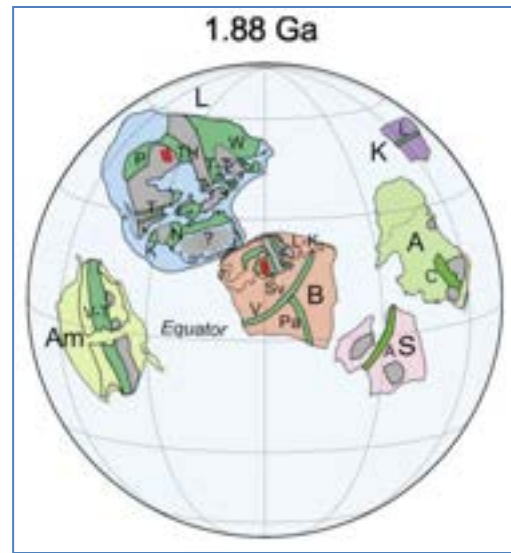
Hasterok et al 2022



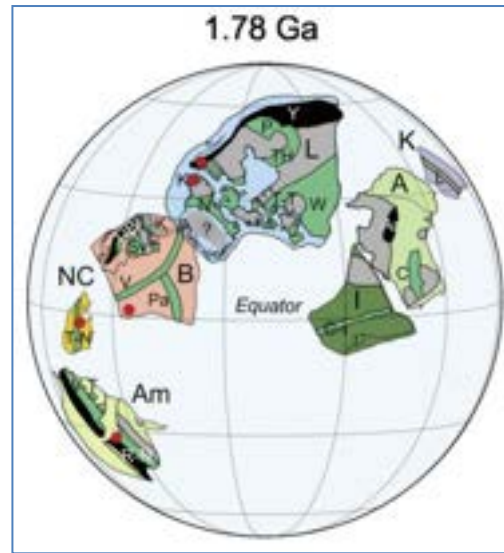
# Meso Proterozoic Reconstruction (2.45 – 1.04 Ga)



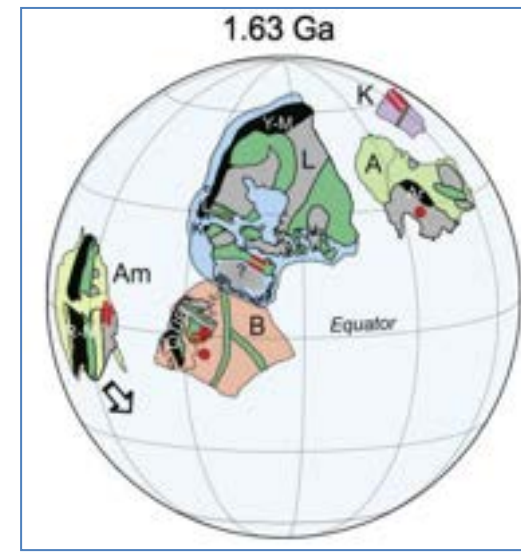
Laurentia (L), Baltica (B), Australia (A) and India (I)



Laurentia (L), Baltica (B), Amazonia (Am), Siberia (S), Australia (A) and Kalahari (K)

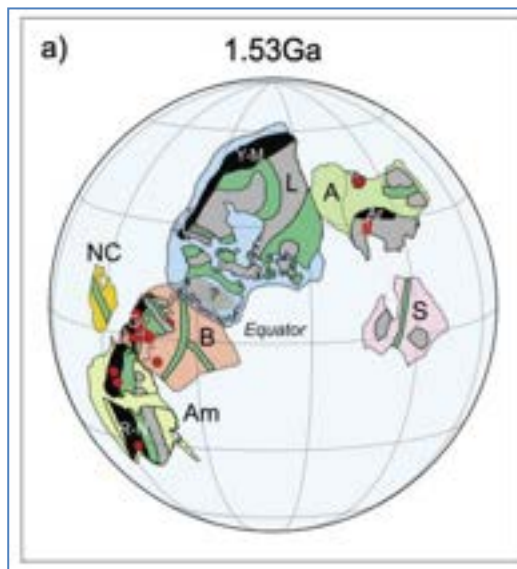


Laurentia (L), Baltica (B), North China (NC), Amazonia (Am), India (I), Australia (A) and Kalahari (K)

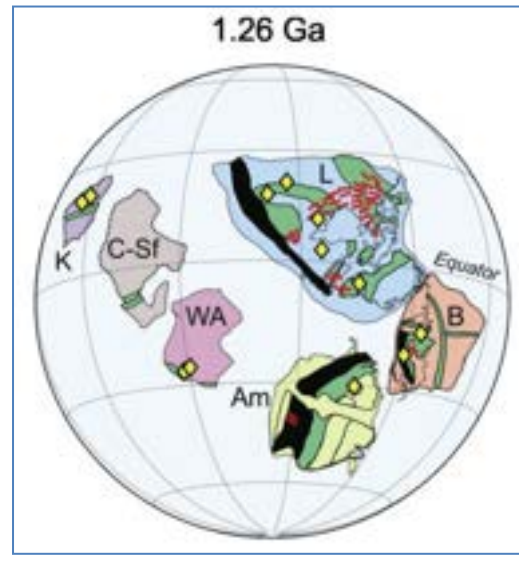
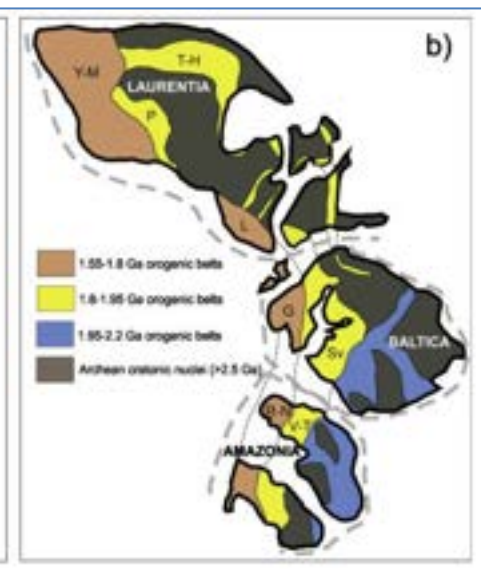


Laurentia (L), Baltica (B), Amazonia (Am), Australia (A) and Kalahari (K)

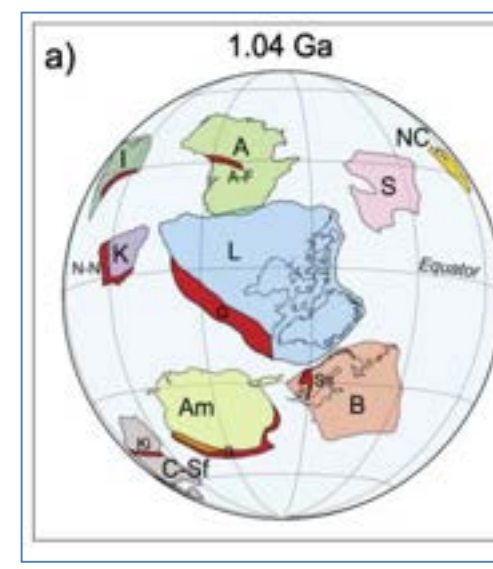
The ca. 2.45 Ga Dyke swarms are shown as red sticks.  
 The ca. 1.90 - 1.80 Ga orogenic belts (dark green)  
 The ca. 1.8–1.5 Ga orogenic belts (black)  
 The 1.78–1.70 Ga rapakivi granites (red circles)  
 The 1.63 Ga rapakivi intrusions and related dykes (red circles and sticks)  
 The ca. 1.55-1.50 Ga rapakivi intrusions and related dykes (red circles and sticks)  
 The ca. 1.26 Ga dyke swarms in Laurentia and Baltica (red sticks). Kimberlite occurrences of about this age are shown as yellow diamonds  
 The ca. 1.04 Ga Grenvillian age orogenic belts (red).  
 The orange belt in Amazonia marks the possible first collisional location after which the continent was rotated, the red belt was formed in a subsequent collision.



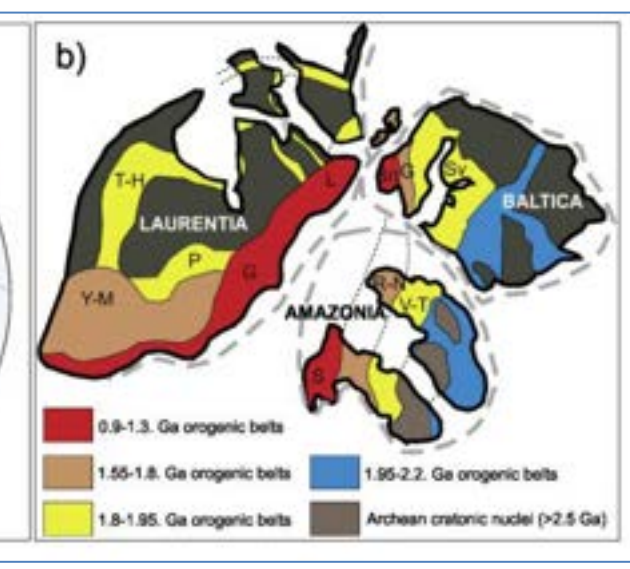
Laurentia (L), Baltica (B), Amazonia (Am), Siberia (S), Australia (A) and North China (NC)



Laurentia (L), Baltica (B), Amazonia (Am), West Africa (WA), Congo-São Francisco (C-Sf) and Kalahari (K)



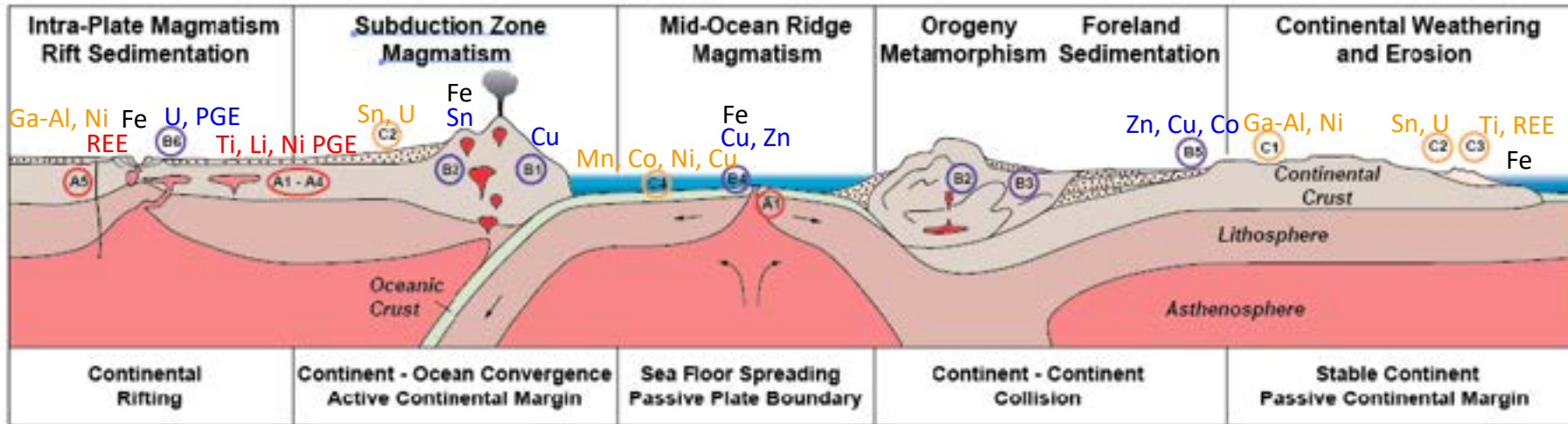
Laurentia (L), Baltica (B), Amazonia (Am), Congo/São Francisco (C-Sf), Kalahari (K), India (I), Australia (A), Siberia (S) and North China (NC)



**Pesonen et al 2012**



# Typical Fluids and Ore Formation in the Earth's Crust



## A: Magmatic Ore Deposits

- A1. Chromitites as (ultra-) mafic cumulates in layered intrusions and ophiolites
- A2. V-magnetite in mafic intrusions (V, Ti)
- A3. Pegmatites (Li, Cs, Be, Nb, Ta)
- A4. Ni- and PGE-sulfide deposits in mafic intrusions and flood basalts
- A5. Carbonatite (REE) and kimberlite (diamond) deposits

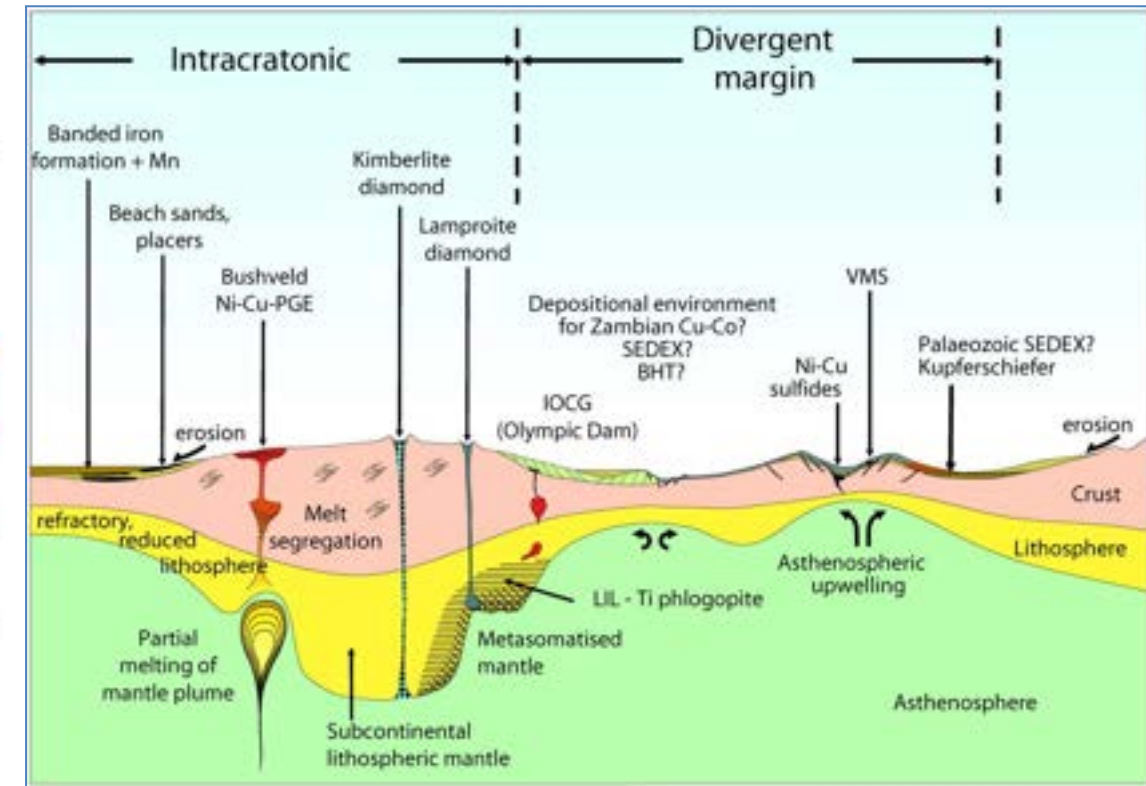
## B: Hydrothermal Ore Deposits

- B1. Porphyry Cu (Mo, Au) and epithermal Au, Ag (Hg,...) deposits
- B2. Sn-W veins and greisens in granites
- B3. Orogenic ('metamorphogenic') Au - Quartz vein deposits
- B4. Volcanogenic massive sulfides (Cu, Zn)
- B5. Sediment-hosted (MVT, 'sedex') Pb, Zn, Cd, Cu, Co deposits
- B6. Sandstone-hosted and unconformity-related U (V, F, Mo, Au, PGE) deposits

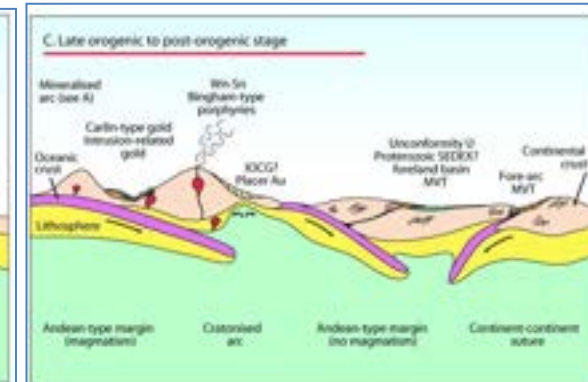
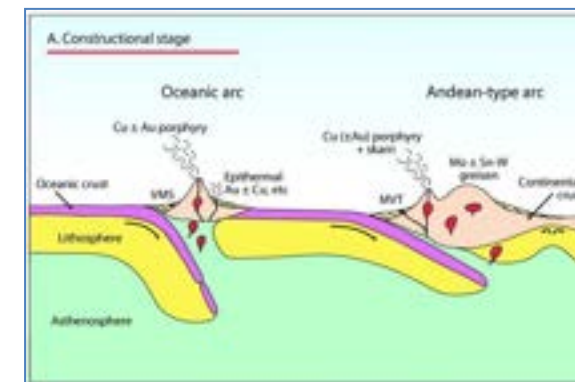
## C: Surface-Related Ore Deposits

- C1. Residual ore deposits: Bauxite (Al), Ni-laterite deposits
- C2. Alluvial placer deposits (Sn, Ta, Au, U)
- C3. Beach-sand placers (Ti, Zr, REE)
- C4. Manganese nodules and crusts on the ocean floor (Mn, Co, Ni, Cu...)

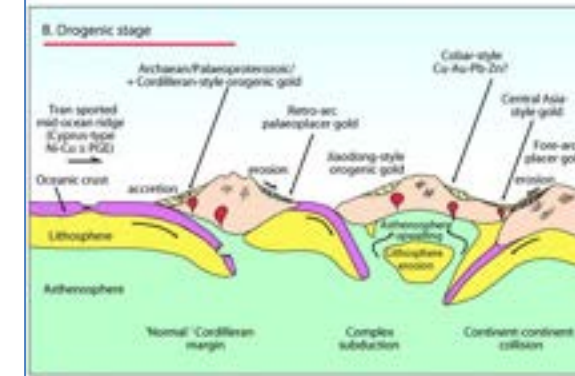
*Schematic illustration of the recurrent association of ore deposit types with global tectonic settings, including active and passive continental margins, oceanic spreading centres including back-arc basins, as well as land surfaces, sedimentary basins and hot spots in the interior of lithospheric plates (modified from Groves et al., 2005).*



Groves n Bierlein 2007

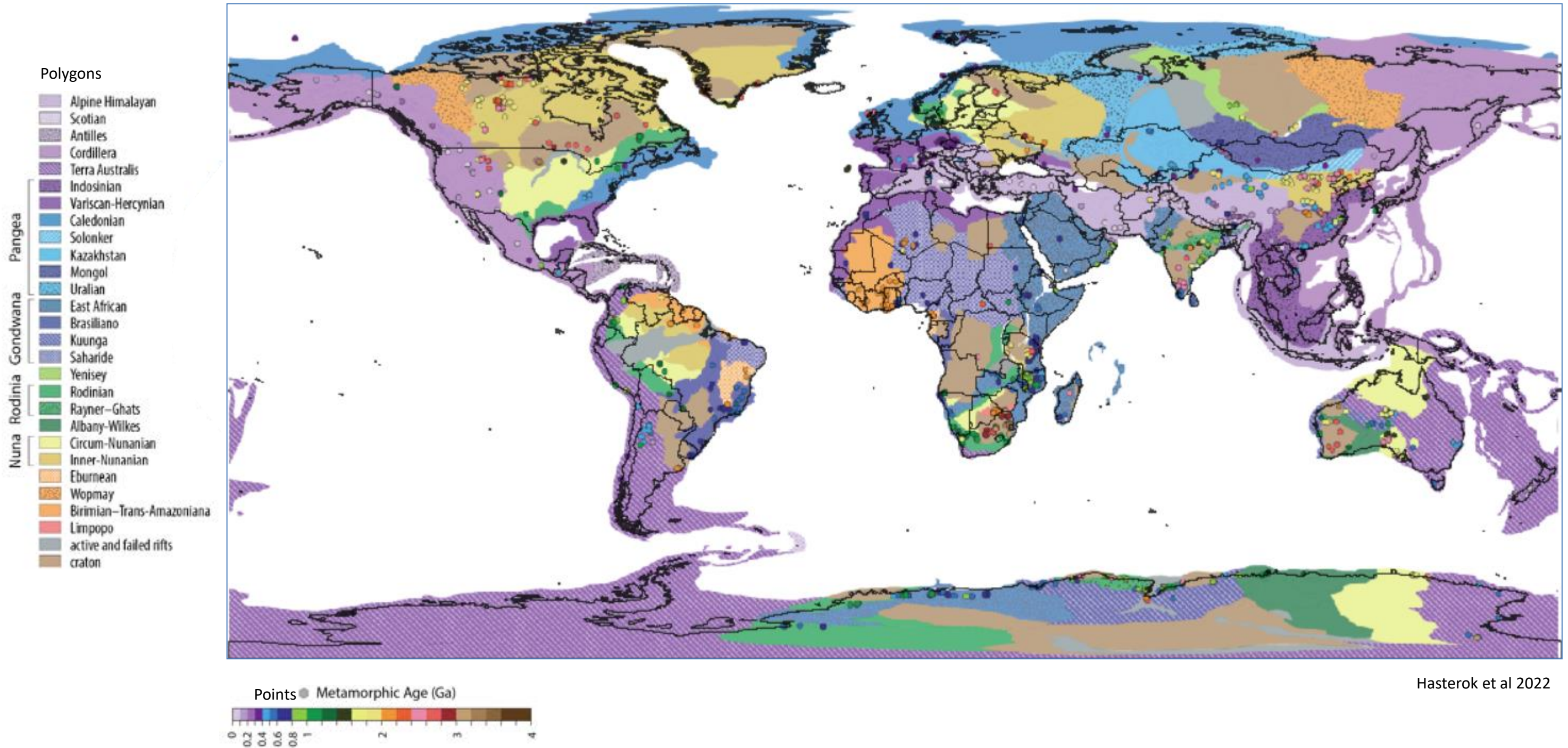


Groves n Bierlein 2007





# Age of Last Orogenic Event

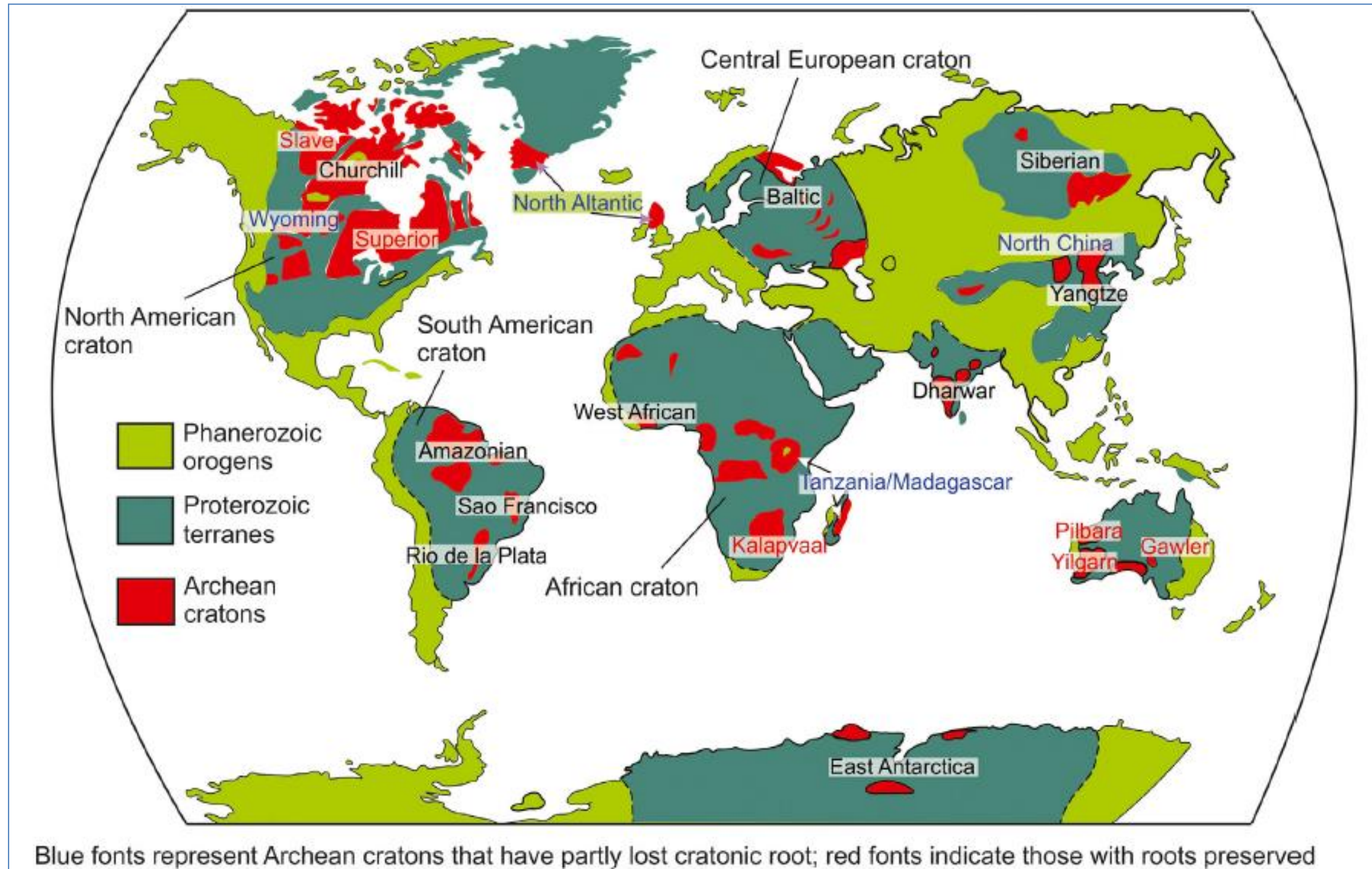


Hasterok et al 2022

Eddy Ong 2024  
Posted on LinkedIn

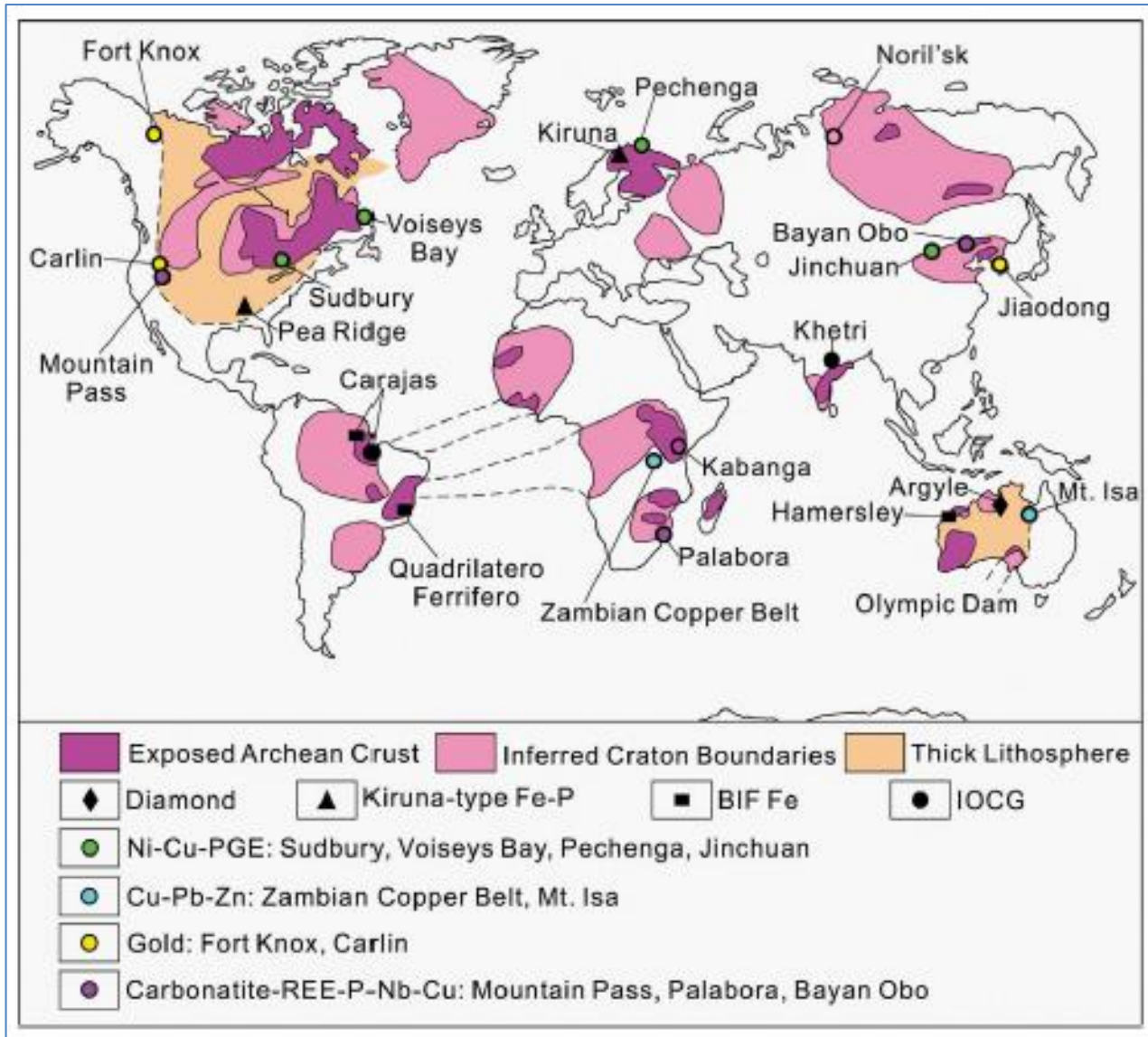


# Archean Cratons, Proterozoic terranes and Phanerozoic Orogens

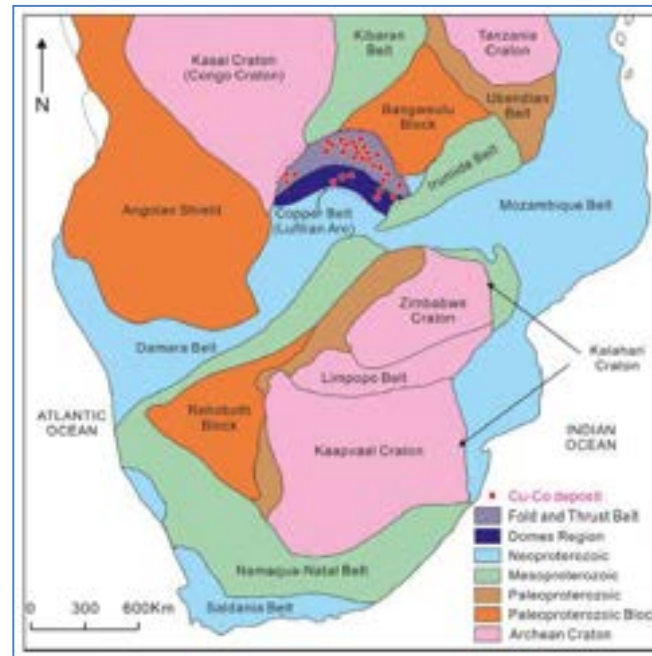
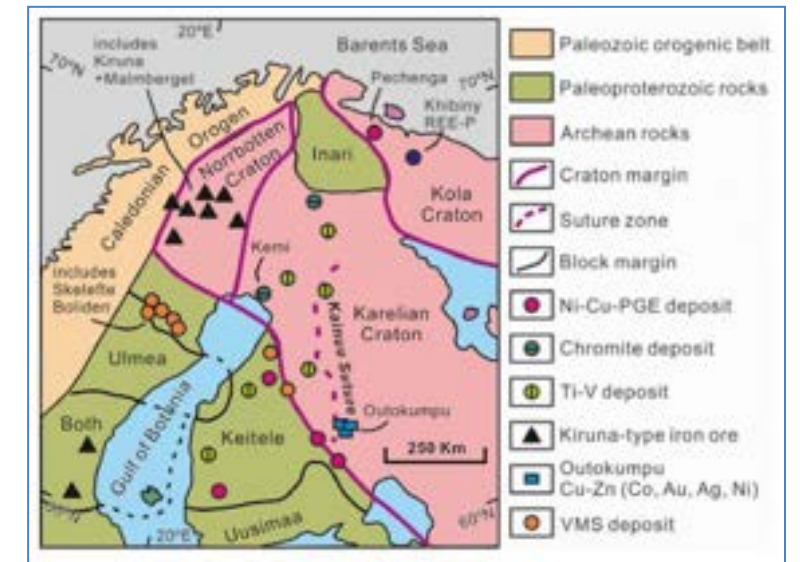
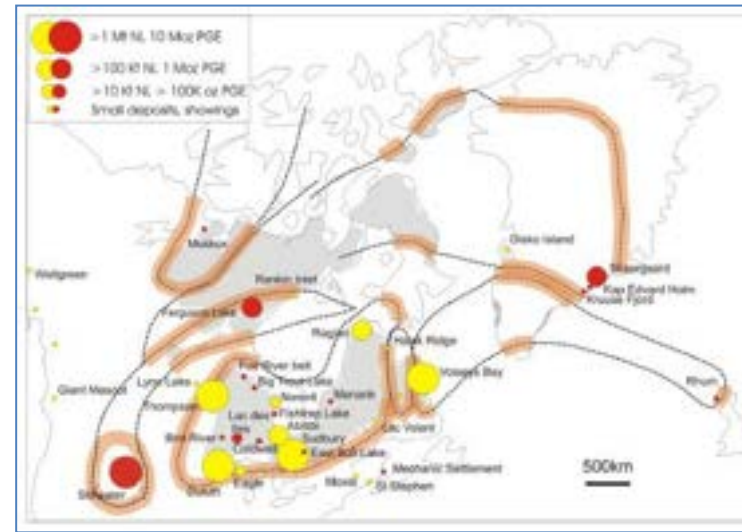




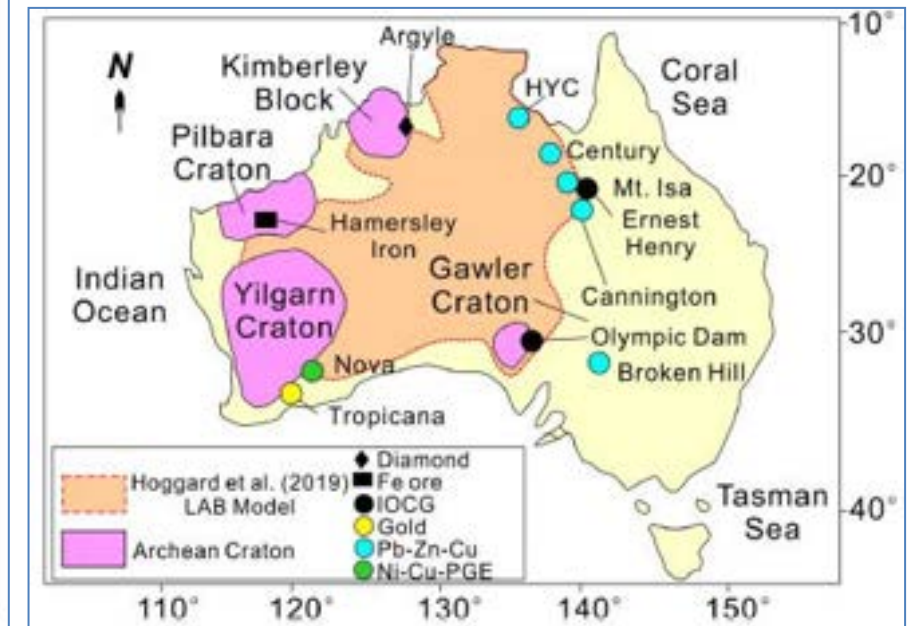
# Some Typical Mineralization near Archean Cratons



Groves n Santosh 2020



Groves n Santosh 2020



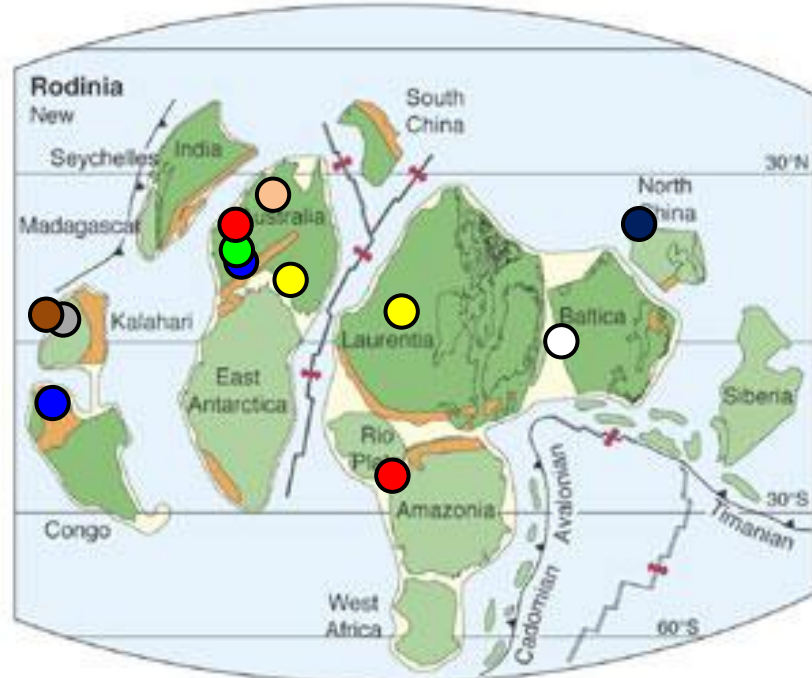
Groves n Santosh 2020



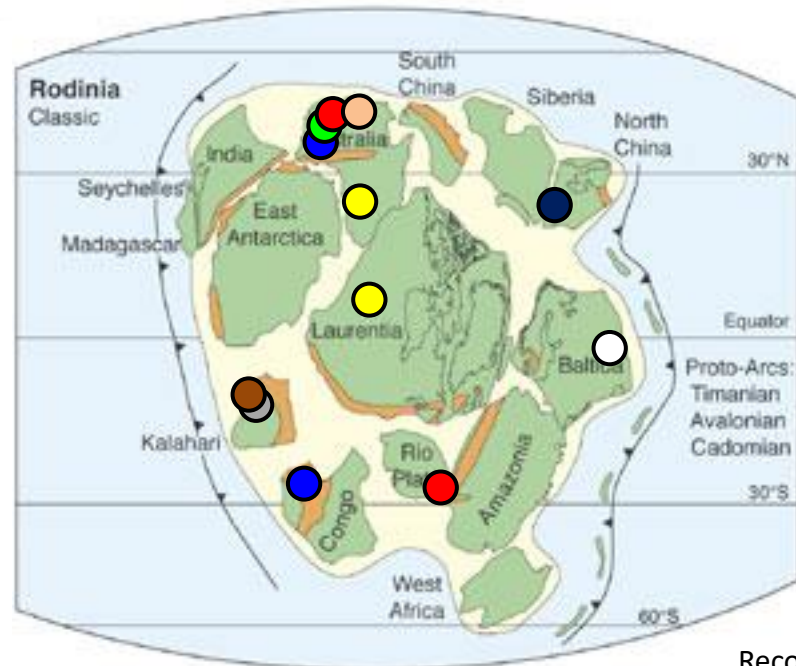
# Rodinia/ Pangaea Reconstruction and some Critical Minerals (CM)

## Proterozoic Rodinia (750 ma) ?

New

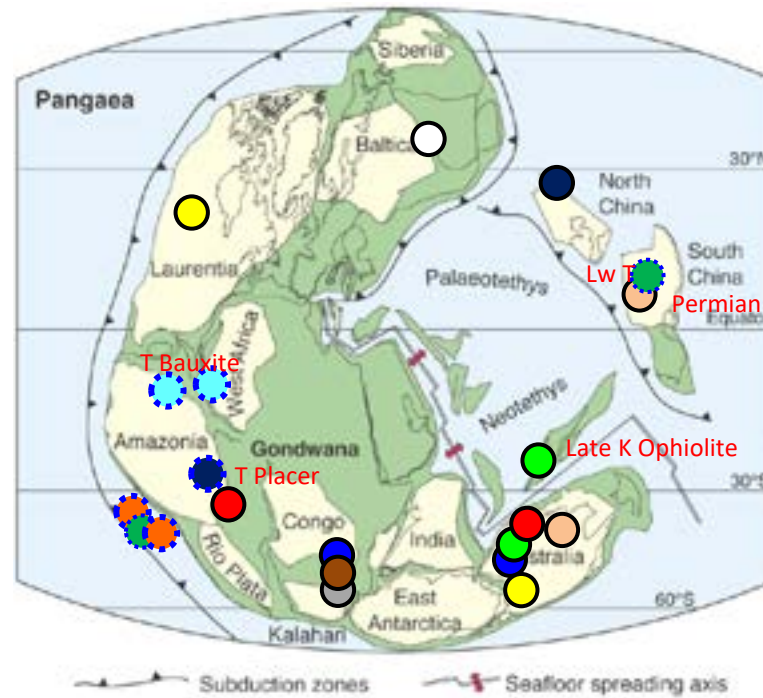


Classic



Reconstruction: Torsvik 2003

## Permo TR Pangaea



Reconstruction: Torsvik 2003

1300- to 1000-million-year-old mobile balls  
 Continents with paleomagnetic data (-750 million years ago)

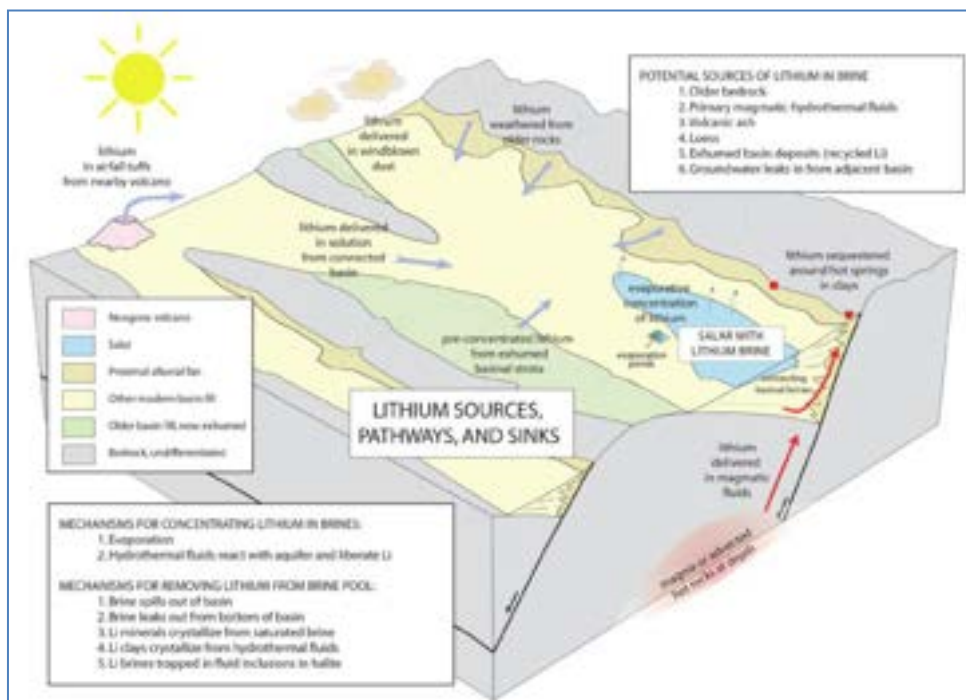
### Loc and Age of Some Large Critical Mineral Deposits

- Nickel (Arch-Proteroz)
- Cobalt (Late Proteroz-Cambrian)
- RRE (Middle Proterozoic)
- Platinum (Proteroz)
- Magnesium (Proteroz)
- Iron (Proteroz)
- Manganese (Proteroz)
- Titanium (Proteroz)
- Uranium (Proteroz)
  
- Cenozoic Deposits
- Lithium (Cenozoic Saline)
- Copper (Tertiary Porphyry)
- Ga-Al (Tertiary Bauxite)

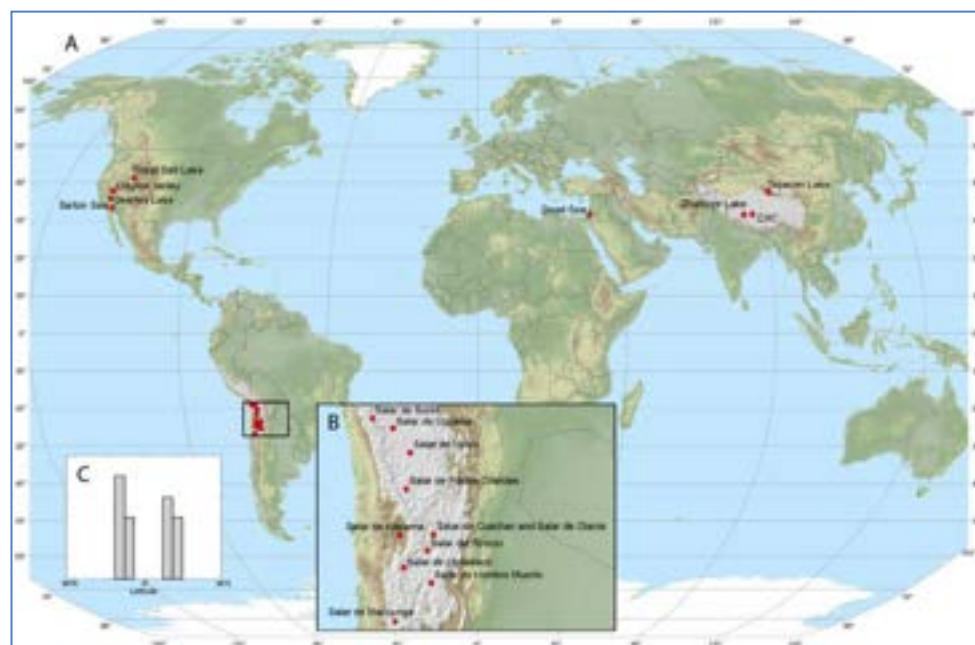


# Lithium

## Lithium Brines

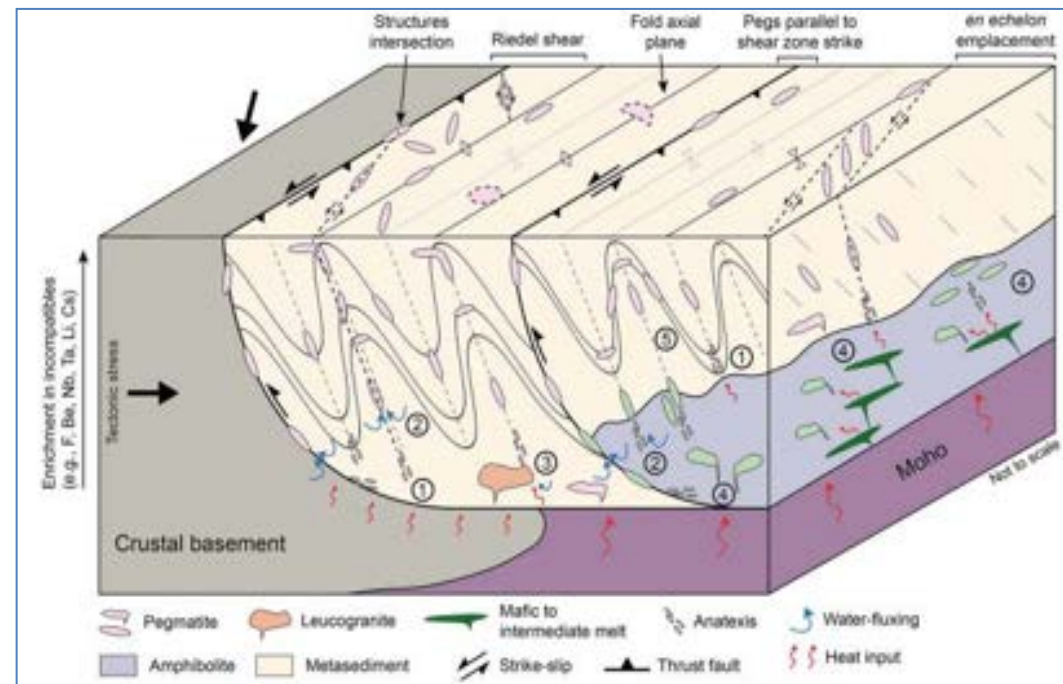


USGS 2013

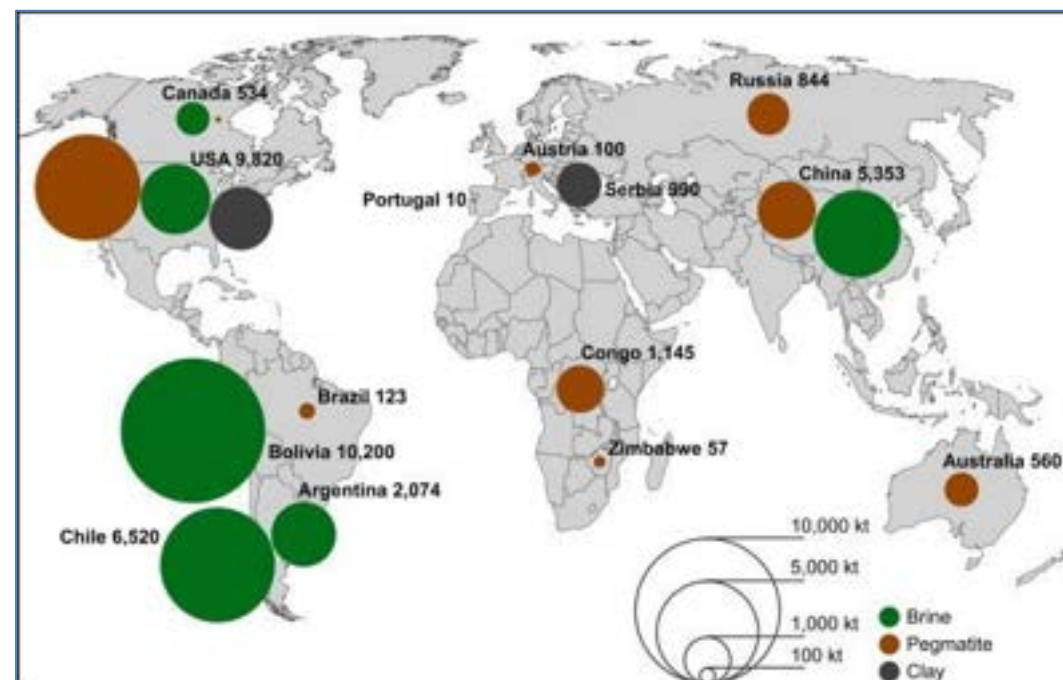


USGS 2013

## Lithium Pegmatites



Silva et al 2023



Weil n Ziemann 2014

Sources of potential extractable lithium can generally be divided into brines (salt flats, geothermal brines and oil field brines), minerals, clays and oceans.

Lithium brines in salt flats (dried salt lakes) occur in drainage basins with an evaporation rate exceeding precipitation. Such basins are predominantly situated at great heights in high mountain ranges and thus can be found in areas of Chile, Argentina, Bolivia, the USA, China and Tibet.

Geothermal brines containing lithium can be found in New Zealand, Iceland and the USA, which in the case of the latter also comprise oil field brines. The biggest lithium brine resources can be found in Bolivia, Chile and China.

Lithium-containing minerals such as spodumene, petalite, lepidolite, amblygonite and eucryptite are typically enclosed in pegmatites. These mineral occurrences are distributed over six continents. There are deposits in Australia, South America (Brazil), North America (Canada and the USA), Africa (Zimbabwe, Congo, Mali, Namibia), Europe (Austria, Finland, Germany, Ireland, Portugal, Spain) and Asia (Afghanistan, China, Russia). Lithium mineral deposits contain far fewer lithium reserves than do brine deposits. Thus, brines account for 66% of the world's lithium resources, while pegmatites only account for 26%. In 2010, huge lithium occurrences were discovered in Afghanistan, but exact numbers of its lithium content are not yet known.

Clay is a potential future source of lithium representing 8% of the resources. It takes the form of hectorites in certain states in the USA and jadarite in Serbia.

The lithium content in oceans is 0.18 ppm, making them a huge but only theoretically recoverable source of 44,800 million t of lithium since the extraction of lithium from seawater is not anticipated to be economical in the foreseeable future.

Weil n Ziemann 2014

Lithium deposits can be found in various geological settings, and their occurrence is associated with specific tectonic settings. Lithium is primarily sourced from three main types of deposits: pegmatites, brine deposits, and sedimentary rocks. Each of these deposit types is associated with different tectonic settings:

### **Pegmatite Deposits:**

**Tectonic Setting:** Pegmatite lithium deposits are often associated with Orogenic (mountain-building) and convergent tectonic settings. These settings involve the collision of tectonic plates, resulting in intense deformation and metamorphism.

**Formation:** Pegmatites are coarse-grained igneous rocks that form during the late stages of magma crystallization. They are enriched in lithium-bearing minerals due to the late-stage fractional crystallization process in magma chambers.

### **Brine Deposits:**

**Tectonic Setting:** Brine deposits are commonly associated with closed basins in tectonic settings that involve extensional or transtensional forces. Closed basins can form in both extensional rift environments and compressional settings.

**Formation:** Brine deposits are formed through the evaporation of saline water in closed basins, where lithium is concentrated as the water evaporates. This process is often associated with geothermal activity.

### **Sedimentary Deposits:**

**Tectonic Setting:** Lithium-rich sedimentary deposits are typically associated with continental rift settings and are formed in closed basin environments.

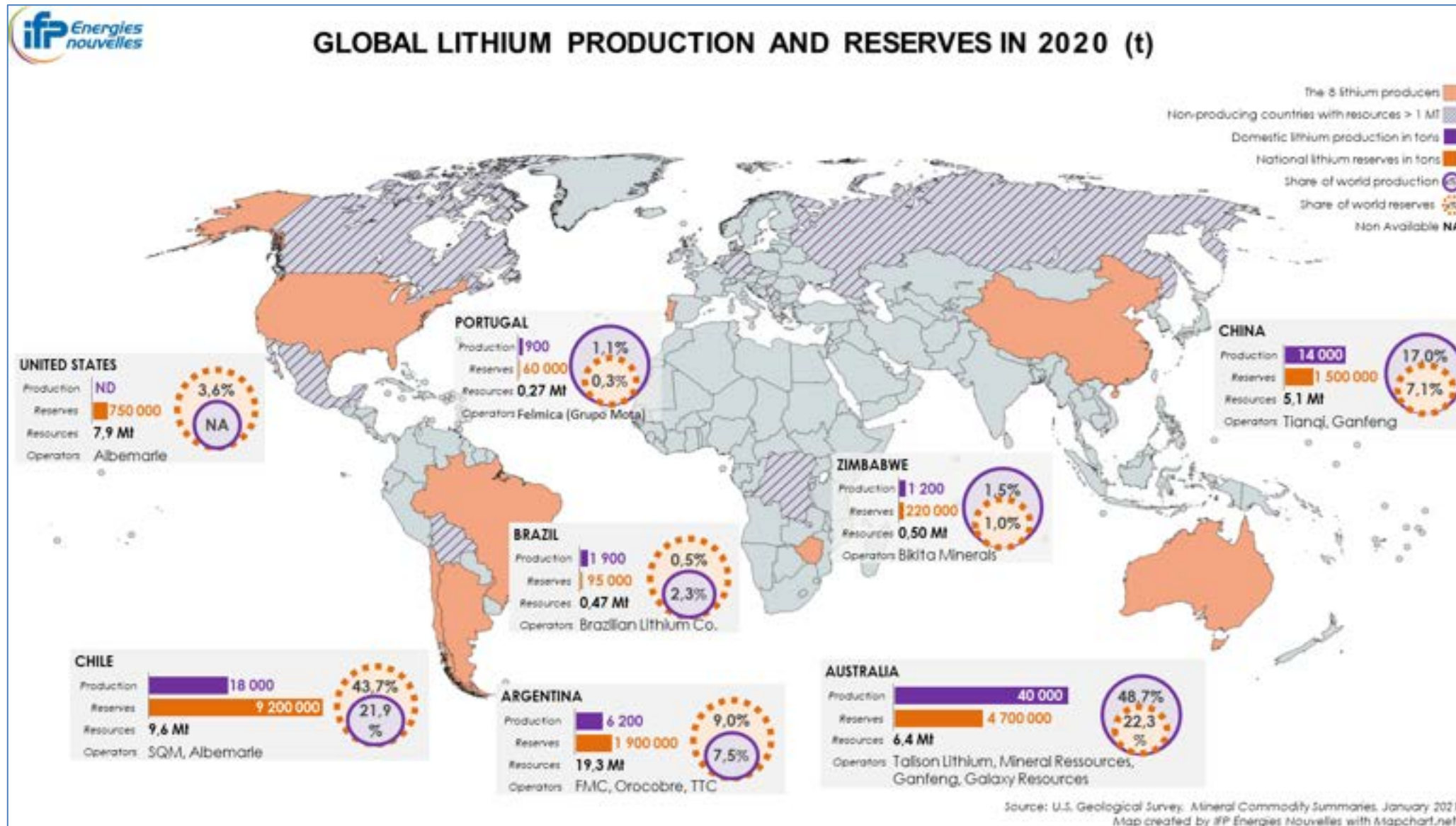
**Formation:** Sedimentary lithium deposits can form through the weathering and erosion of lithium-bearing rocks, followed by the transport and deposition of lithium minerals in closed basin environments. The lithium-rich sediments can later become consolidated into sedimentary rocks.

It's important to note that the tectonic setting alone may not provide a complete picture of lithium deposits. The specific geological and hydrothermal conditions within a given tectonic setting also play a crucial role in the formation and concentration of lithium deposits. Additionally, the economic viability of extracting lithium from these deposits depends on various factors, including the grade of the deposit, accessibility, and environmental considerations.



# Lithium

## Global Lithium Extraction and Reserves (t) 2020



Spodumene



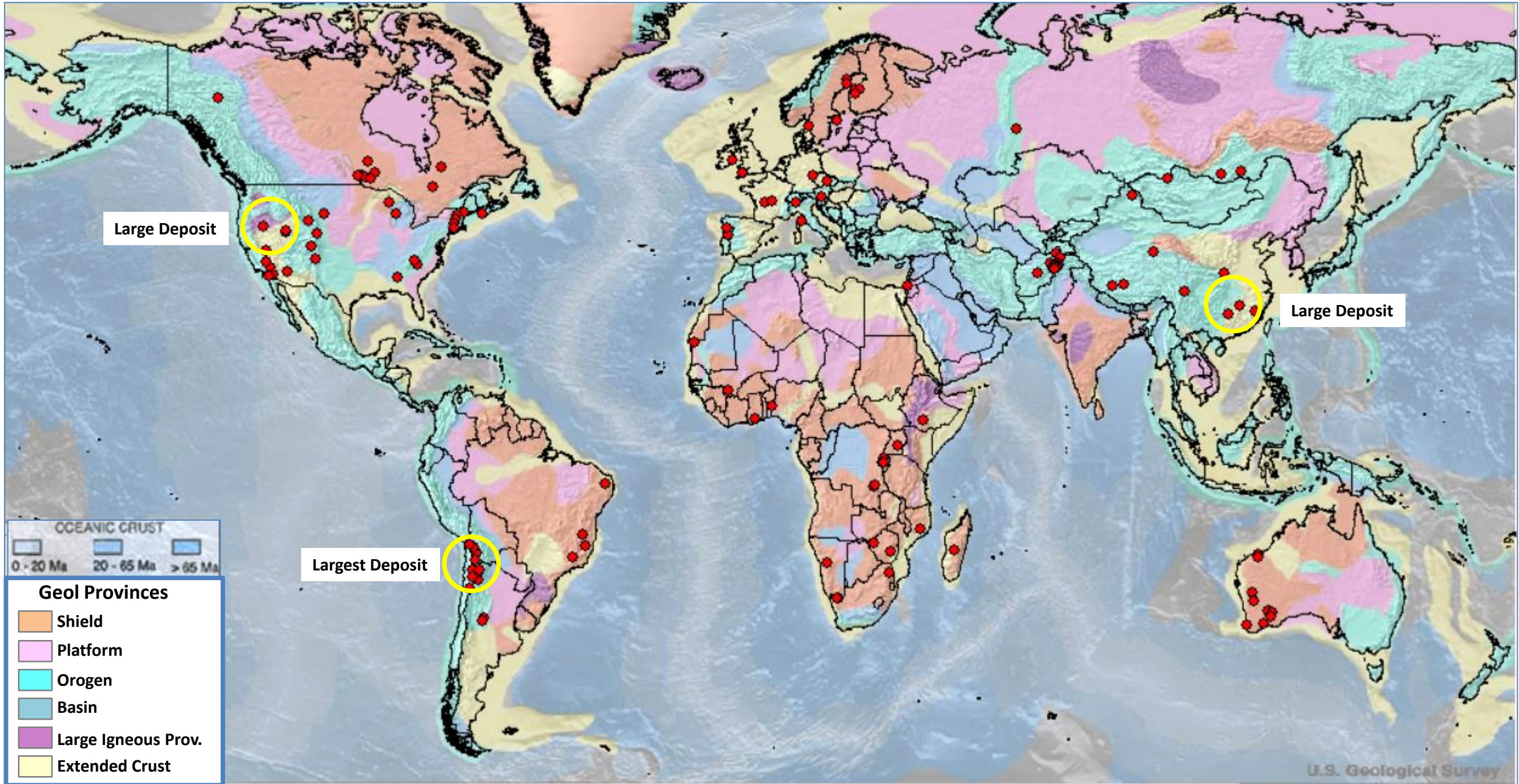
Greenbushes Mine Australia

ifpenergiesnouvelles.com  
 USGS Commodity Summary



# Lithium

## Province Type

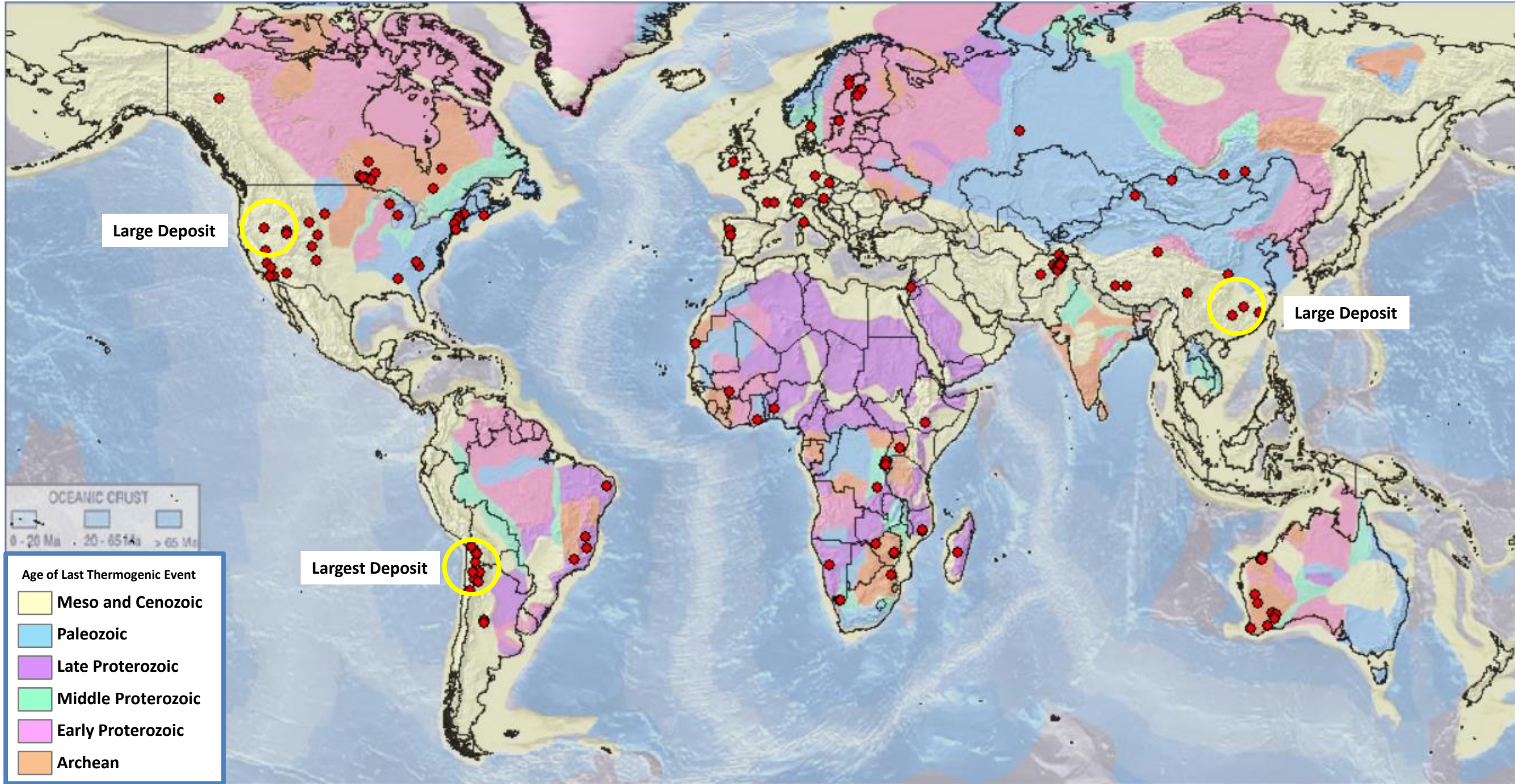


*Indicative Locations of deposits based on USGS data (may not be comprehensive)*



# Lithium

## Age of Last Thermogenic Event

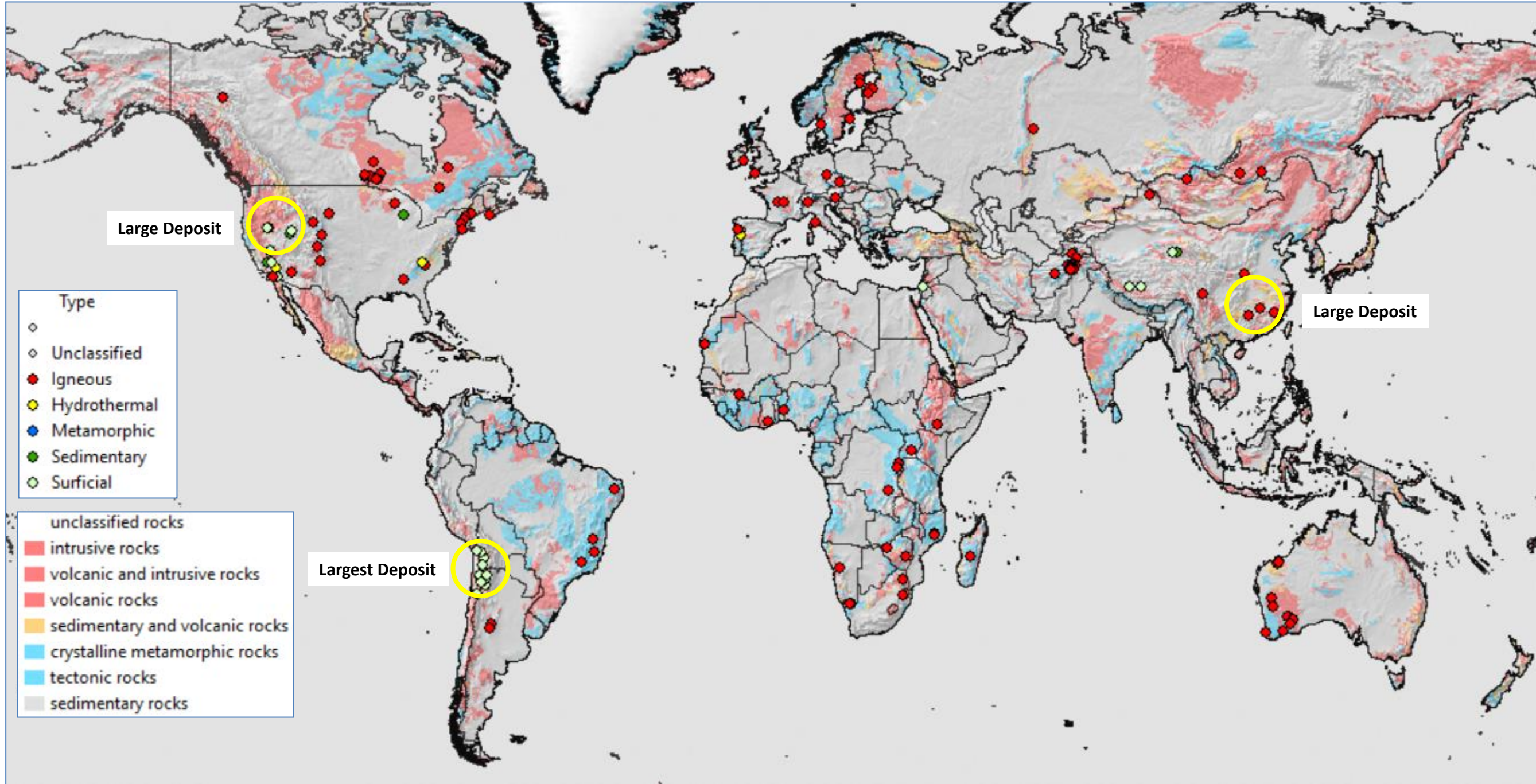


*Indicative Locations of deposits based on USGS data (may not be comprehensive)*



# Lithium

## Type of Deposit



Indicative Locations of deposits based on USGS data (may not be comprehensive)



# Lithium



1 Tanco, Canada	23 Salar de Pedernales, Chile	45 Zinnwald (and 4 others), Germany	67 Nuristan area, Afghanistan
2 Separation Rapids, Canada	24 Salar de Maricunga, Chile	46 Cinovec, Czech Republic	68 Zhabuye Salt Lake, China
3 James Bay, Canada	25 Salar de Olaroz, Argentina	47 Wolfsberg, Austria	69 Dangxiangcuo, China
4 Rose, Canada	26 Salar de Caucharí (2 projects), Argentina	48 Jadar, Serbia	70 West Taiji Nai'er, China
5 Whabouchi, Canada	27 Salar del Rincón (3 projects), Argentina	49 Polokhovskoe (and 2 others), Ukraine	71 East Taiji Nai'er, China
6 Val-d'Or, Canada	28 Salar de Pozuelos, Argentina	50 Mina do Barroso (and 3 others), Portugal	72 Qinghai Salt Lake, China
7 McDermitt, USA	29 Salar de Pastos Grandes, Argentina	51 Aljón, Portugal	73 Sichuan Aba, China
8 Kings Valley, USA	30 Salar de Ratones, Argentina	52 Valdeflórez/San José, Spain	74 Maerkang, China
9 Silver Peak, USA	31 Salar de Diablillos, Argentina	53 Alberta I, Spain	75 Jiajika, China
10 Bonnie Claire, USA	32 Salar del Hombre Muerto (3 projects), Argentina	54 Bougouni, Mali	76 Ningdu, China
11 Boron, USA	33 Mibra, Brazil	55 Goulamina, Mali	77 Finniss, Australia
12 Salton Sea, USA	34 Mina da Cachoeira, Brazil	56 Ewoyaa, Ghana	78 Pilgangoora, Australia
13 Clayton North, USA	35 Jequitinhonha, Brazil	57 Kenticha, Ethiopia	79 Wodgina, Australia
14 Magnolia, USA	36 Volta Grande, Brazil	58 Manono-Kitotolo, Democratic Republic of Congo	80 Kathleen Valley, Australia
15 Kings Mountain, USA	37 Länttä (and 5 others), Finland	59 Uis, Namibia	81 Mount Holland, Australia
16 Sonora, Mexico	38 Glenbuchat, United Kingdom	60 Karibib, Namibia	82 Greenbushes, Australia
17 Falchani, Peru	39 Aclare, Ireland	61 Orange River Area, South Africa	83 Mount Cattlin, Australia
18 Salar de Colpasa, Bolivia	40 United Downs, United Kingdom	62 Kamativi, Zimbabwe	84 Mount Marion, Australia
19 Salar de Uyuni, Bolivia	41 St Austell, United Kingdom	63 Zulu, Zimbabwe	85 Bald Hill, Australia
20 Salar de Pastos Grandes, Bolivia	42 Chédeville (and 4 others), France	64 Bikita, Zimbabwe	86 Buldania, Australia
21 Salar de Atacama (2 operators), Chile	43 Rittershoffen, France	65 Arcadia, Zimbabwe	87 Narraburra, Australia
22 Salar de Aguilera, Chile	44 Upper Rhine Valley, Germany	66 Parun area, Afghanistan	88 Ohaaki, New Zealand

How to cite: Shaw, R.A. (2021) Global lithium (Li) mines, deposits and occurrences (November 2021). British Geological Survey.

Shaw R.A. (2021)

Eddy Ong 2024  
Posted on LinkedIn



# World's Largest Deposits

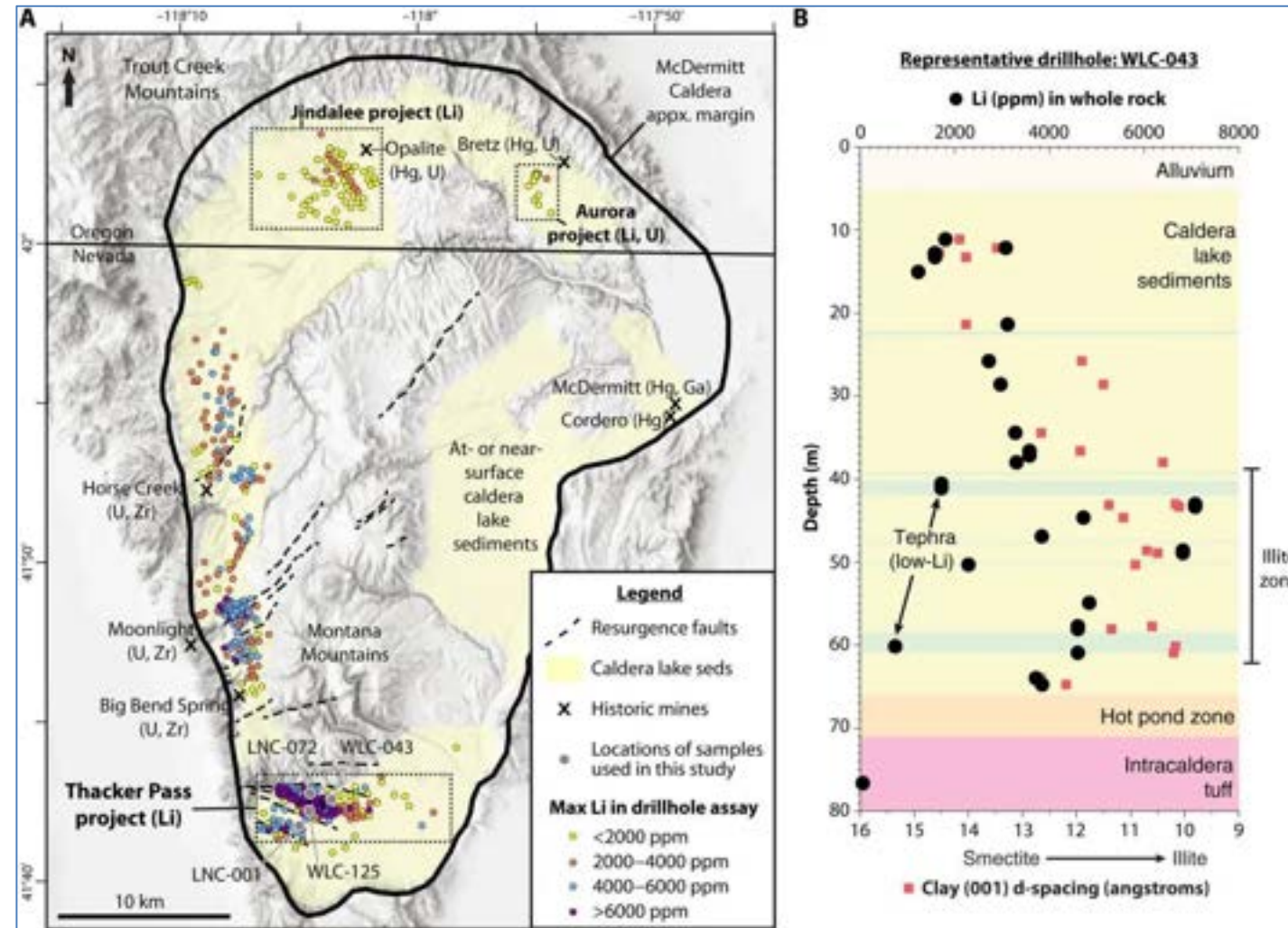
# Lithium

## Atacama Evaporative Brines, S America



Yale Environment 360

## Nevada McDermitt Caldera ? (undeveloped)

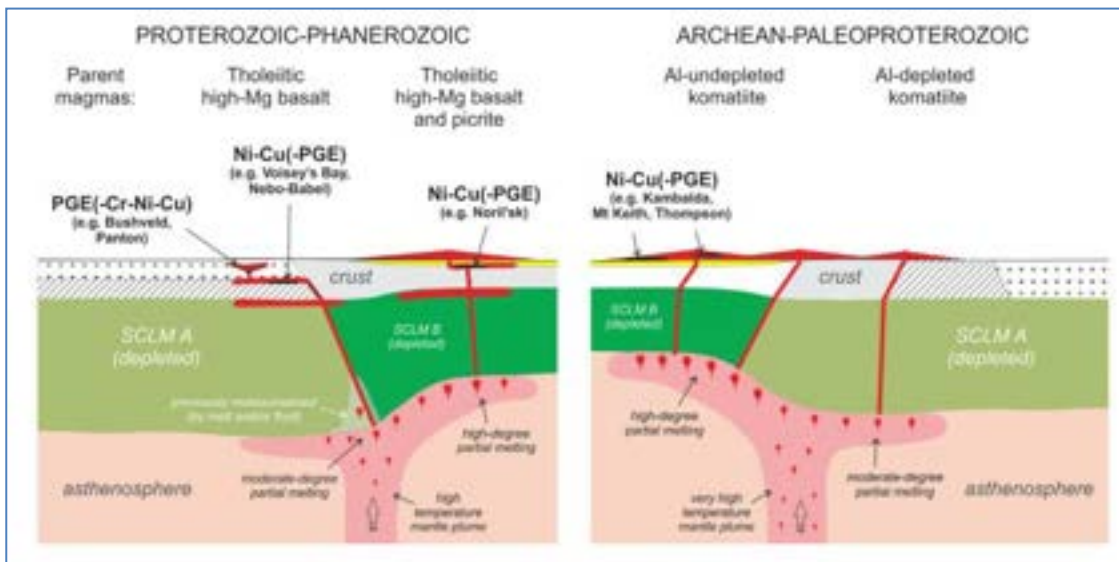


GeologyIn.com

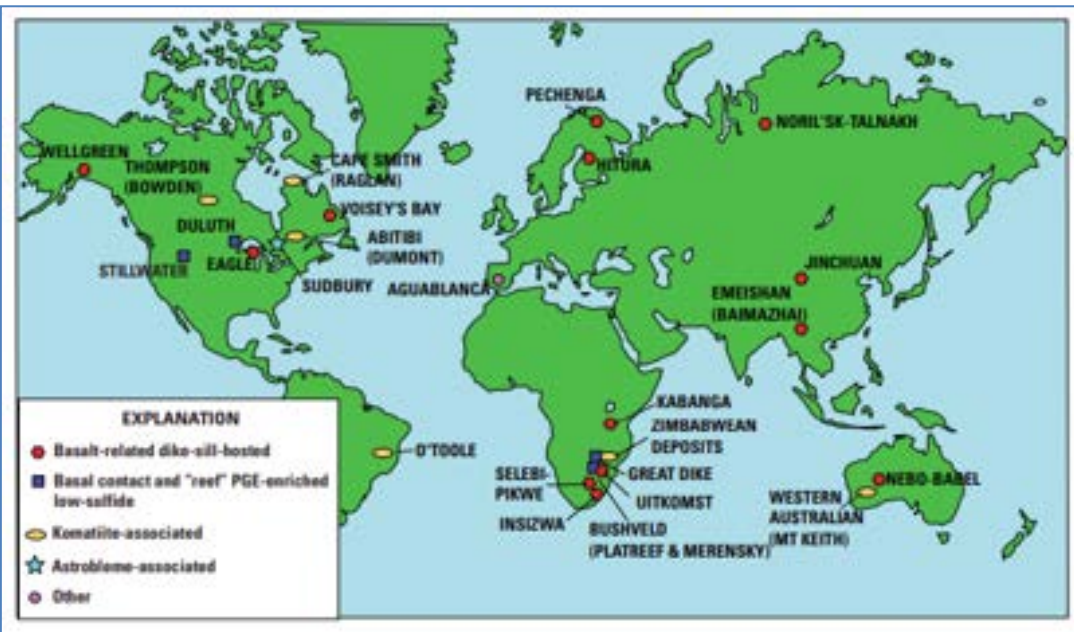


# Nickel

## Magmatic Nickel Sulphides

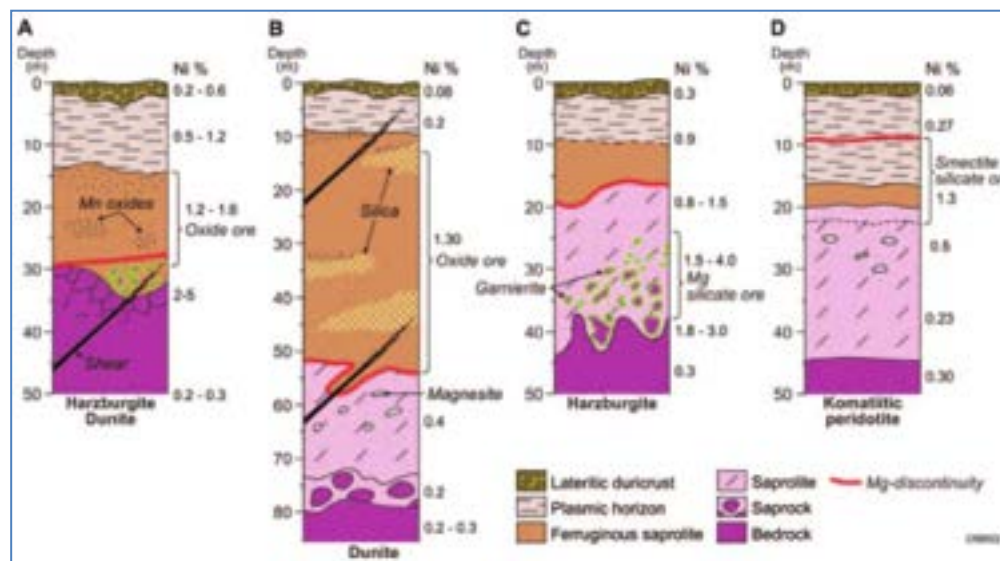


Geoscience Australia 2016

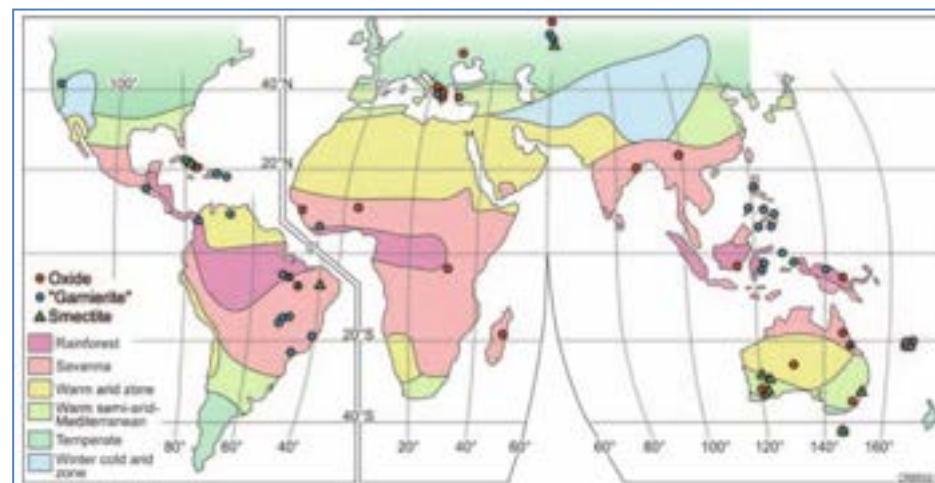


USGS 2010

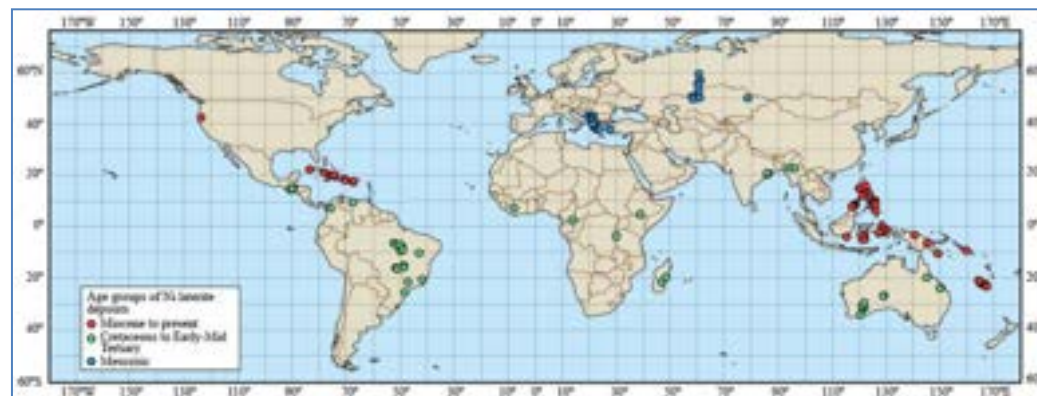
## Nickel Laterites



Butt n Cluzel 2013



Butt n Cluzel 2013



USGS 2011

Nickel laterite ores account for over 60% of global nickel supply. They are the product of intensive deep weathering of serpentinites under humid tropical conditions. Nickel is concentrated to over 1.0 wt% and is hosted in a variety of secondary oxides, hydrous Mg silicates and smectites. The formation, mineralogy and grade of the deposits are controlled by the interplay of lithology, tectonics, climate and geomorphology. Most deposits have a multi-phase development, evolving as their climatic and/or topographic environment change. The richest deposits (>3 wt% Ni) formed where oxide-rich regoliths were uplifted and Ni leached downwards to concentrate in neo-formed silicates in the saprolite. (Butt n Cluzel 2013)

Magmatic sulfide deposits containing nickel (Ni) and copper (Cu), with or without (±) platinum-group elements (PGE), account for approximately 40 percent of the world's nickel production.

Magmatic Ni-Cu ± PGE sulfide deposits are spatially and genetically related to bodies of mafic and/or ultramafic rocks. The sulfide deposits form when the mantle-derived mafic and/or ultramafic magmas become sulfide-saturated and segregate immiscible sulfide liquid, commonly following interaction with continental crustal rocks. Deposits of magmatic Ni-Cu sulfides occur with mafic and/or ultramafic bodies emplaced in diverse geologic settings. They range in age from Archean to Tertiary, but a large number of deposits are Archean and Paleoproterozoic. (USGS 2010)



# Working with ChatGPT

Nickel deposits are associated with various tectonic settings and geological environments. The most significant nickel deposits are often linked to specific types of ore-forming processes, and these processes can occur in diverse tectonic settings. Here are some common tectonic settings associated with nickel deposits:

## Magmatic Nickel Sulfide Deposits:

**Tectonic Setting:** Magmatic nickel sulfide deposits are often found in association with mafic and ultramafic intrusions. These intrusions are commonly associated with convergent and divergent tectonic plate boundaries.

**Formation:** Nickel sulfide deposits are formed through the crystallization of magmas rich in nickel and sulfur. These magmas originate from the mantle and intrude into the Earth's crust. Convergent boundaries can bring about subduction-related magmatic activity, while divergent boundaries can lead to the emplacement of mantle-derived magmas.

## Lateritic Nickel Deposits:

**Tectonic Setting:** Lateritic nickel deposits are associated with tropical and subtropical regions and are often found on the upper parts of ultramafic rocks. These ultramafic rocks can be part of ophiolite complexes, which are linked to both convergent and divergent tectonic settings.

**Formation:** Lateritic nickel deposits form through weathering processes that lead to the leaching of nickel from ultramafic rocks. The nickel is then transported and concentrated in the weathered regolith, forming lateritic nickel deposits.

## Nickel-Copper-PGE (Platinum Group Elements) Sulfide Deposits:

**Tectonic Setting:** Nickel-copper-PGE sulfide deposits are commonly associated with mafic and ultramafic intrusions in both convergent and divergent tectonic settings. They are often found in large igneous provinces associated with continental flood basalts.

**Formation:** These deposits form during the crystallization of magmas rich in nickel, copper, and PGEs. The sulfide minerals containing these metals separate from the magma and accumulate within specific zones of the intrusions.

## Hydrothermal Nickel Deposits:

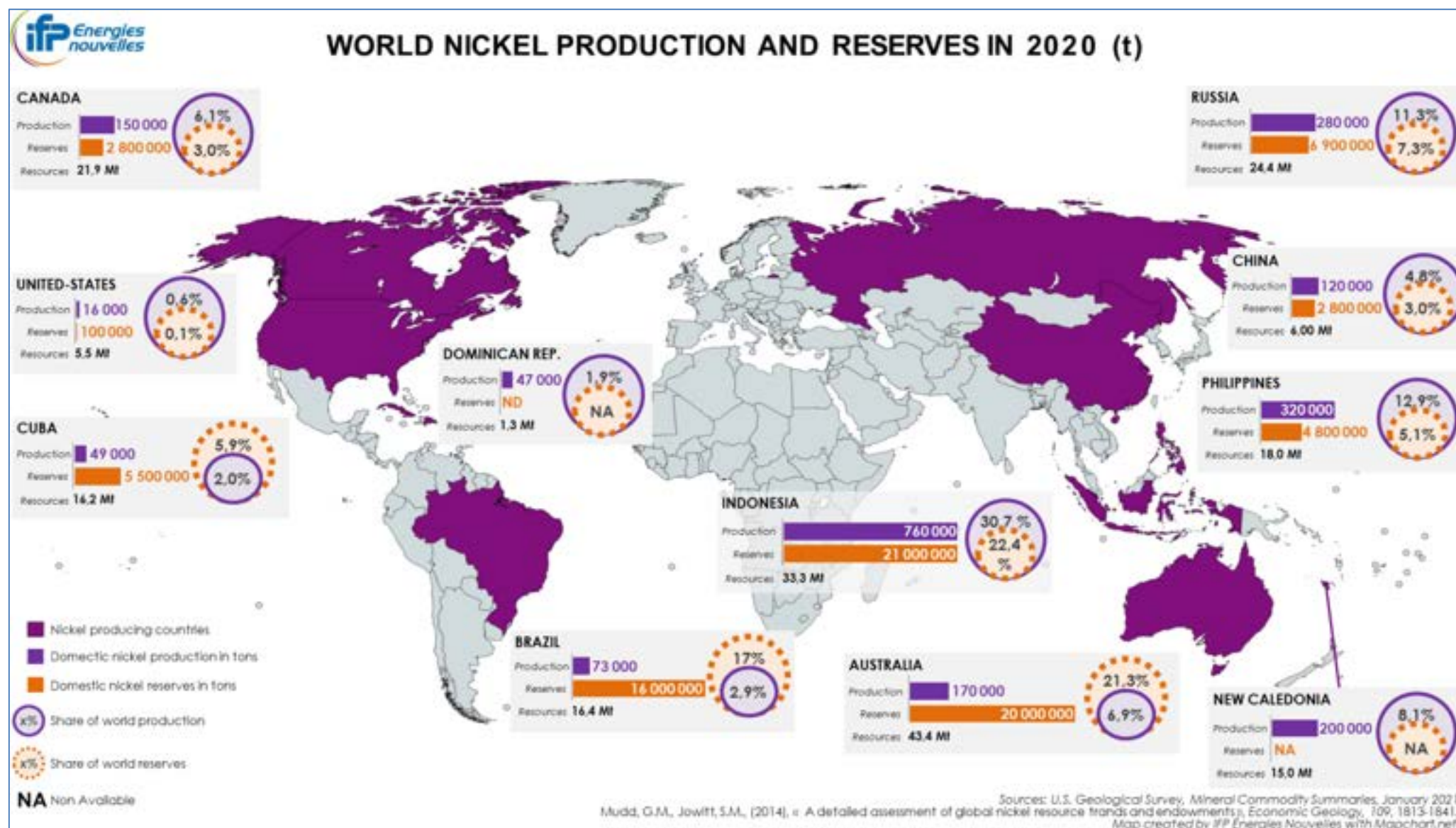
**Tectonic Setting:** Hydrothermal nickel deposits can occur in various tectonic settings, including mid-ocean ridges, back-arc basins, and continental rift environments.

**Formation:** Hydrothermal nickel deposits are associated with the circulation of hot fluids through the Earth's crust. These fluids leach nickel from the surrounding rocks and deposit it in fractures and porous zones.

It's important to note that nickel deposits can be found in different geological settings within a wide range of tectonic environments. The specific type of nickel deposit and its economic significance depend on the geological processes and conditions that prevailed during its formation.

# Nickel

## Global Nickel Extraction and Reserves (t) 2020



Pentlandite



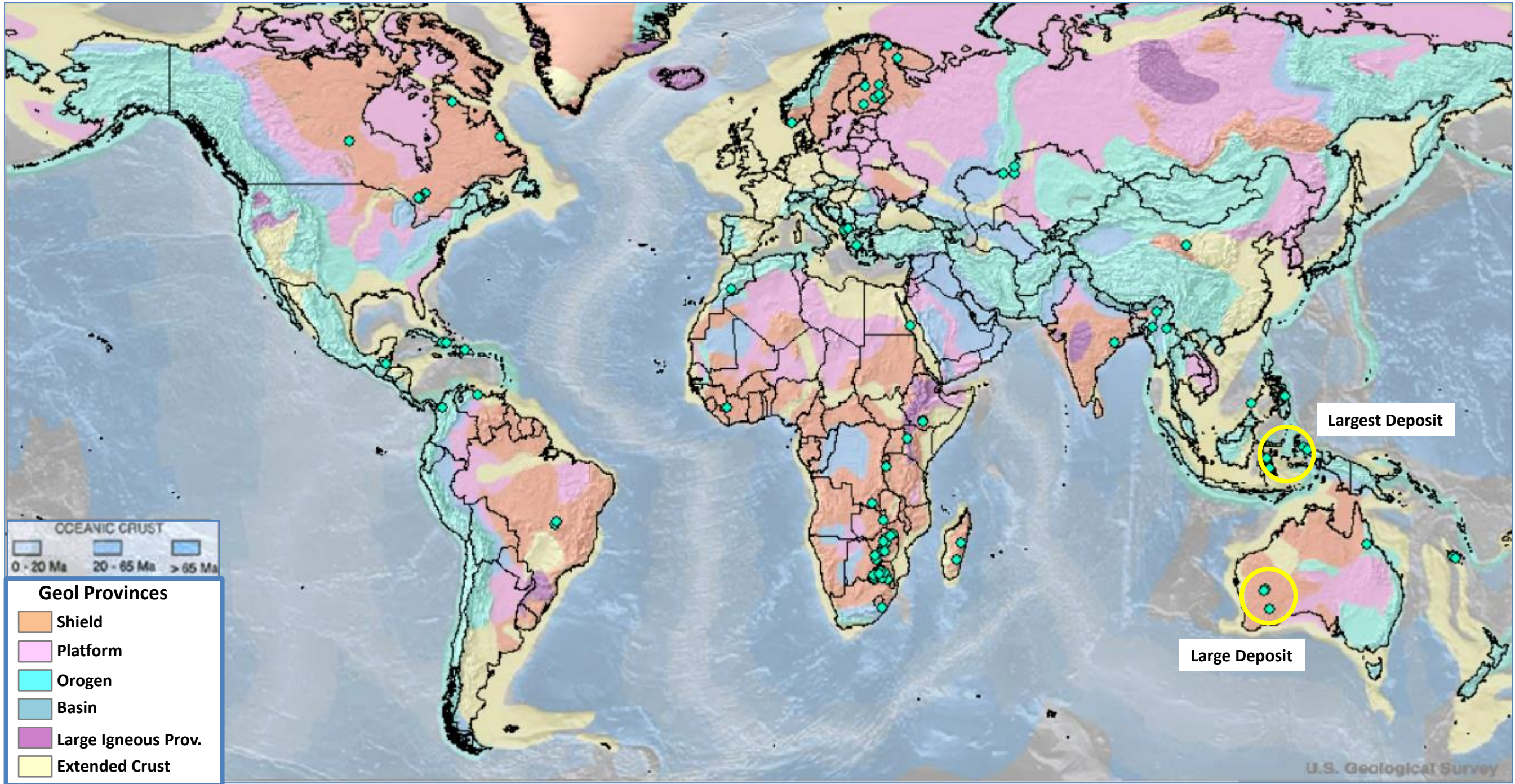
Norilsk Mine Russia

ifpenergiesnouvelles.com  
 USGS Commodity Summary



# Nickel

## Province Type

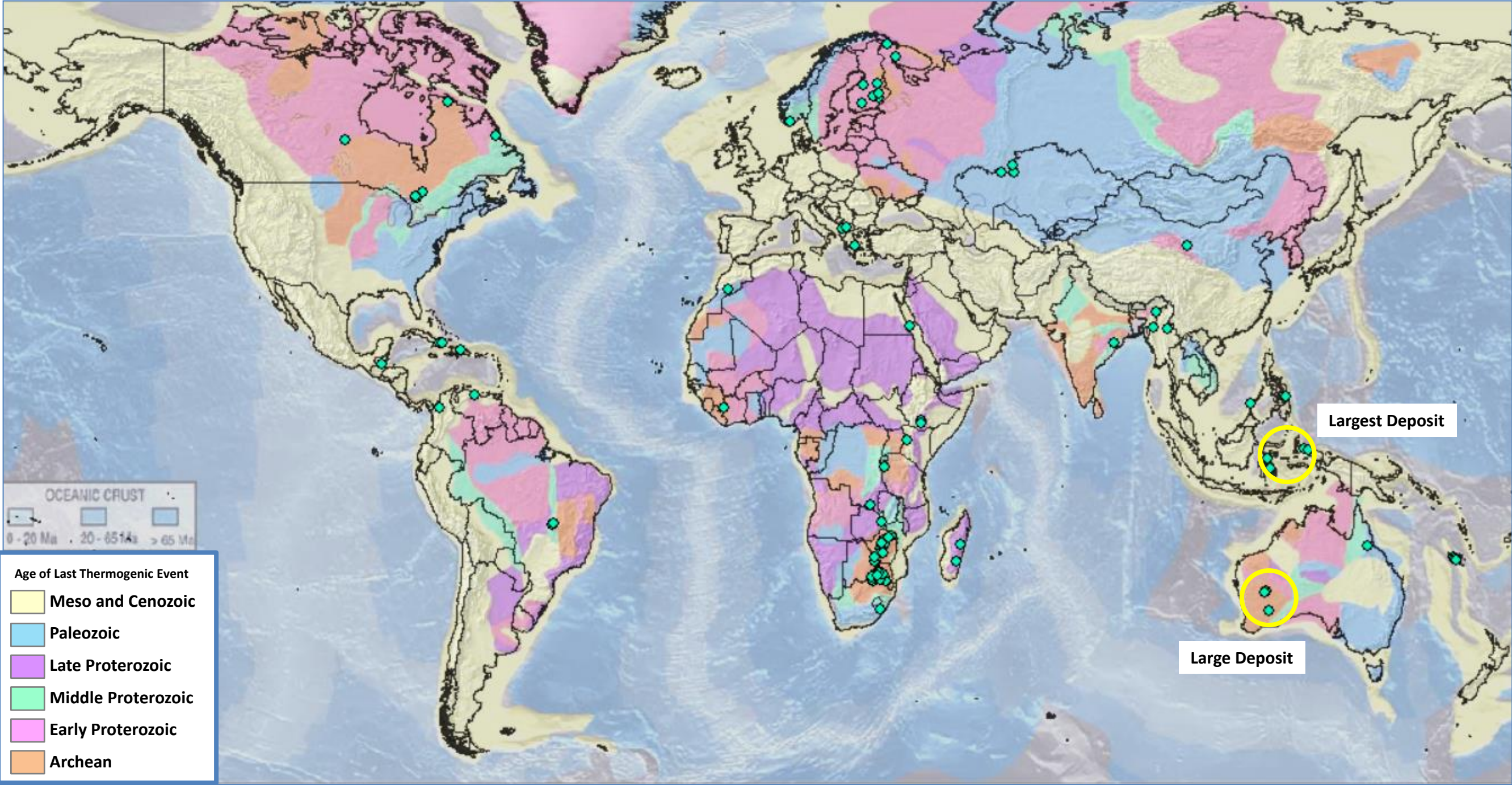


*Indicative Locations of deposits based on USGS data (may not be comprehensive)*



# Nickel

## Age of Last Thermogenic Event

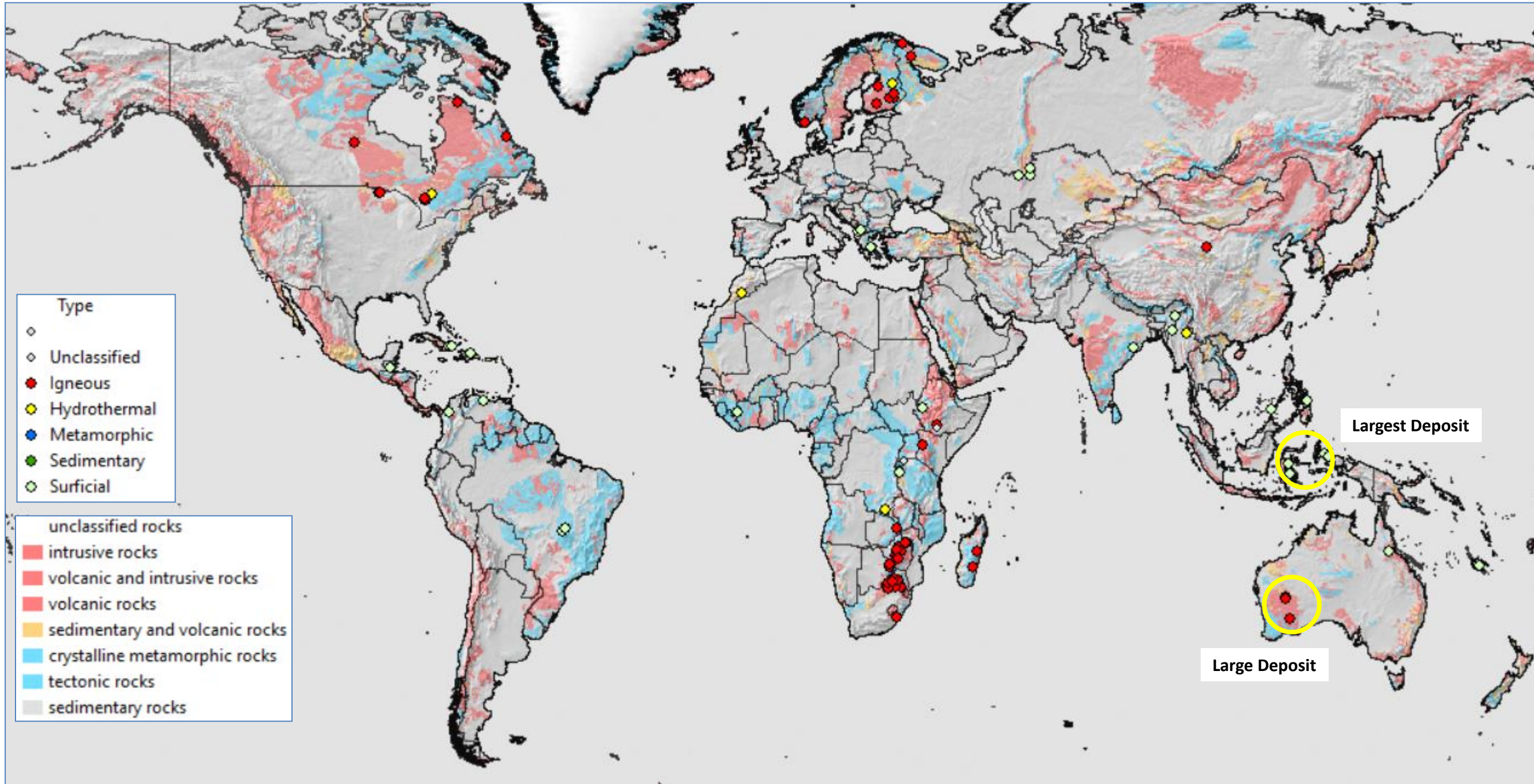


*Indicative Locations of deposits based on USGS data (may not be comprehensive)*



# Nickel

## Type of Deposit



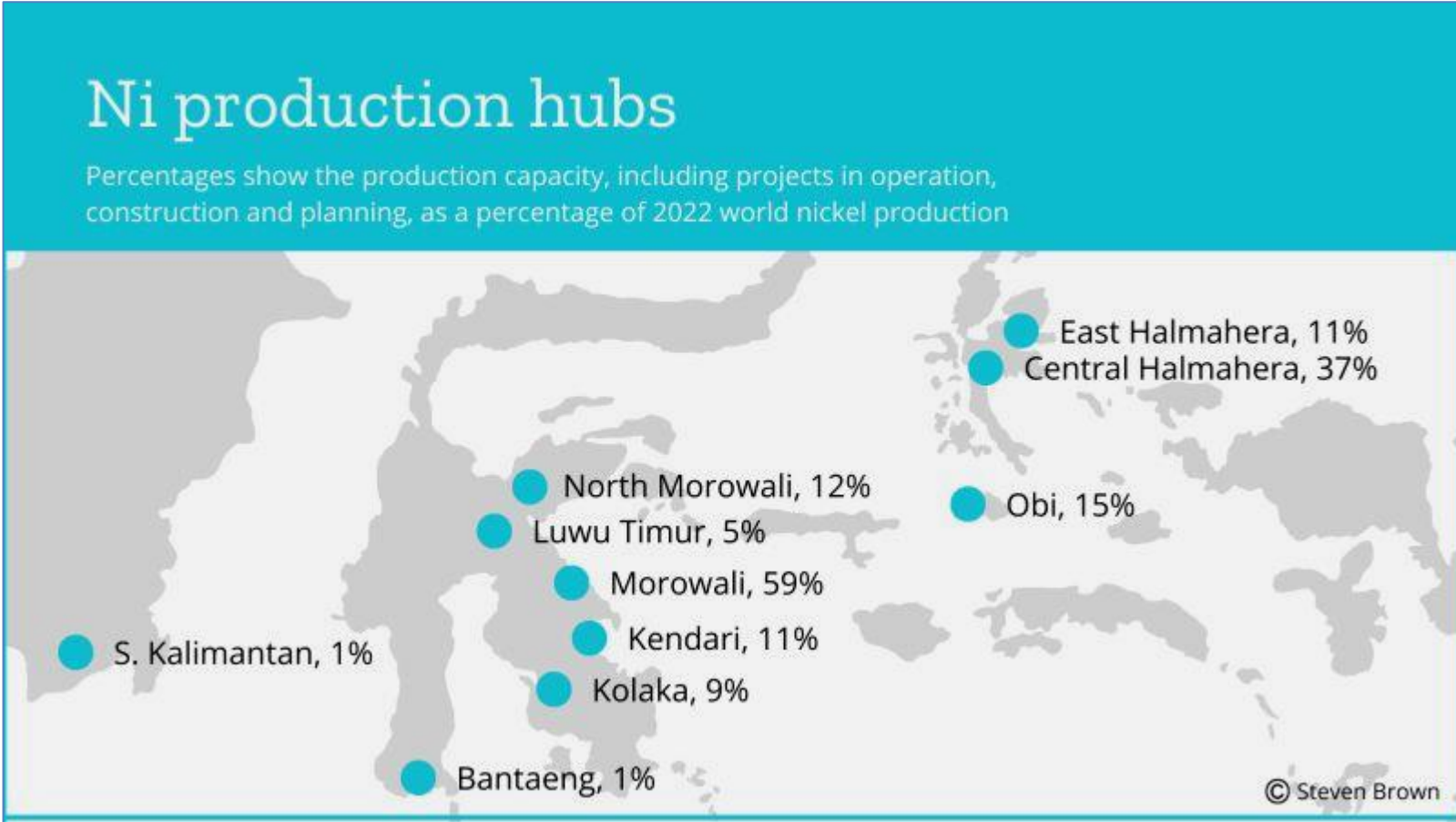
*Indicative Locations of deposits based on USGS data (may not be comprehensive)*



# World's Largest Deposits

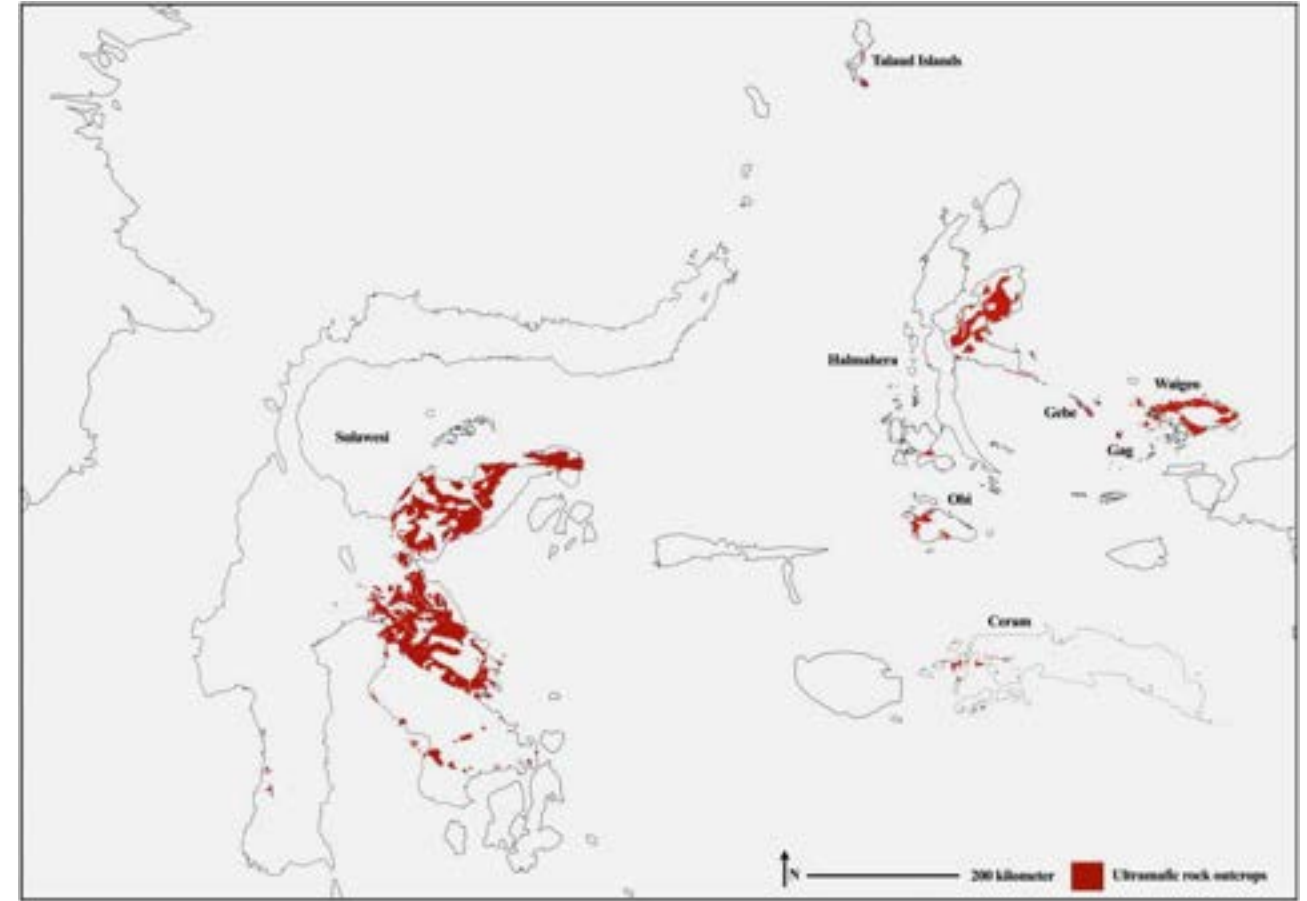
## Nickel

### Eastern Indonesia



Steven Brown LinkedIn Upload

### Ultra Mafic Nickel Laterites

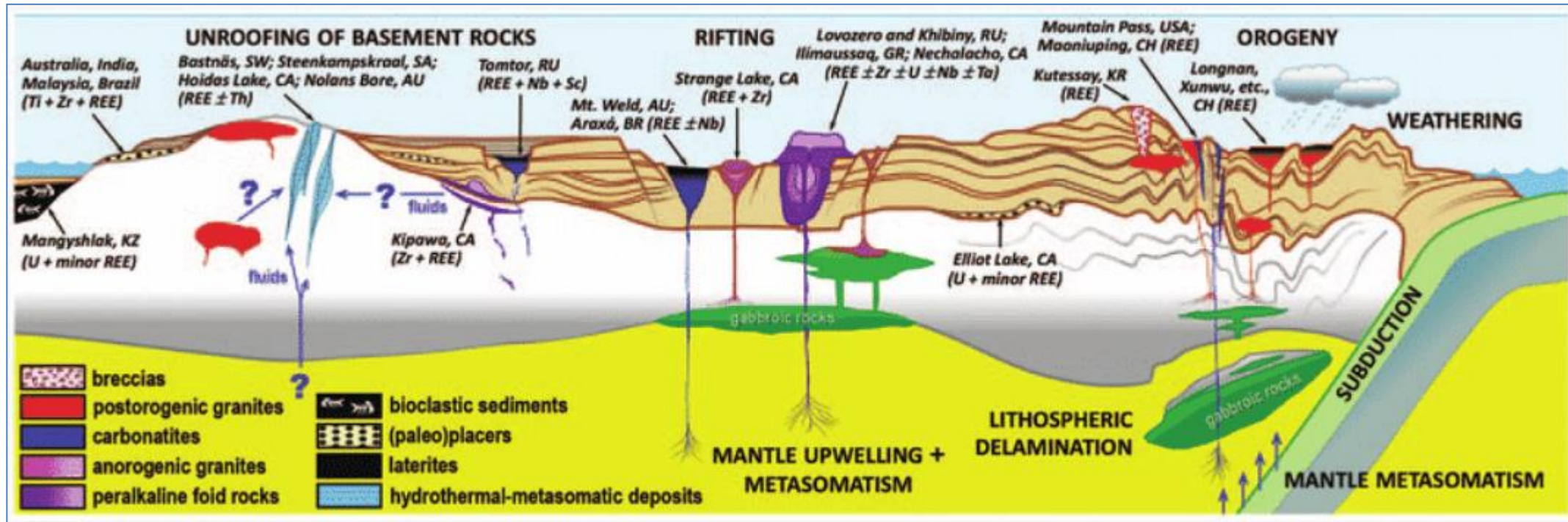


A van der Ent et al 2013



# REE

## REE deposit types



Chakhmouradian & Wall 2012

All of the known large REE deposits are Magmatic and are related to alkaline igneous activity (either carbonatites or agpaitic nepheline syenites). The total resource of these deposits are related to the scale of the primary igneous source, but the grade is a complex function of igneous source, magmatic crystallization, hydrothermal modification and supergene enrichment during weathering.

Sources conducive to the formation of large REE deposits are developed in subcontinental lithospheric mantle, enriched in trace elements either by plume activity, or by previous subduction. The reactivation of such enriched mantle domains in relatively restricted geographical areas may have played a role in the formation of some of the largest deposits (e.g. Bayan Obo).

Hydrothermal activity involving fluids from magmatic to meteoric sources may result in the redistribution of the REE and increases in grade, depending on primary mineralogy and the availability of ligands.

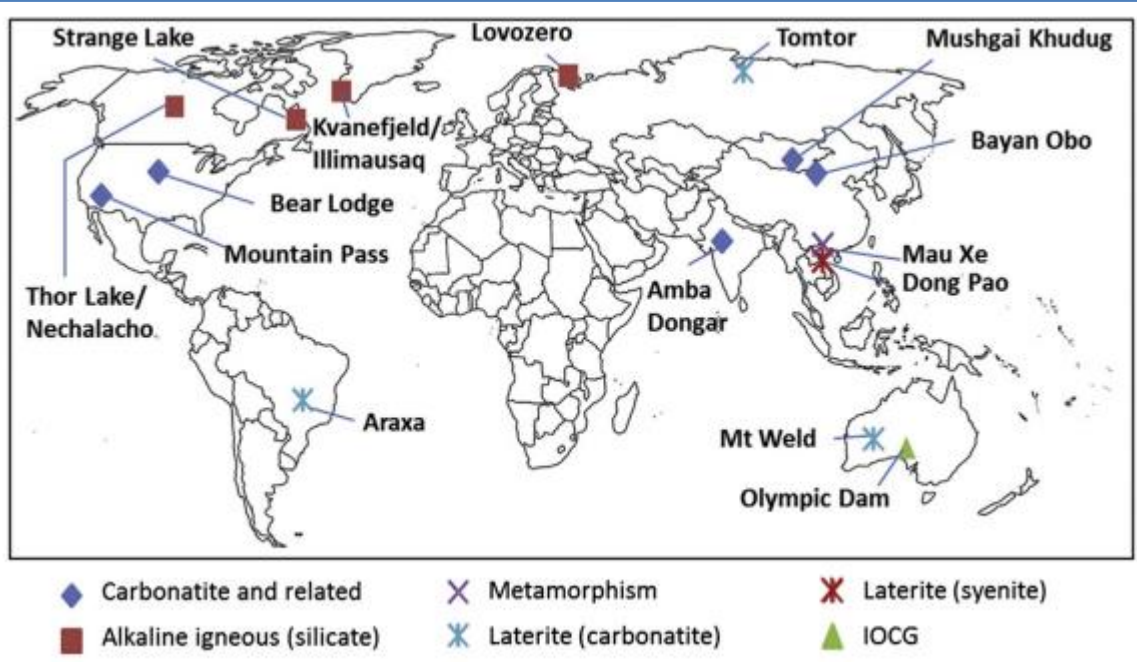
Weathering and supergene enrichment of carbonatite has played a role in the formation of the highest grade deposits at Mount Weld (Australia) and Tomtor (Russia).

(Smith et al 2015)

Relatively smaller quantities of REE are Sedimentary and are found in Residual/ placers, Phosphorite/ Phosphate, Ion adsorption clays and in some coals. (netl.doe.gov)

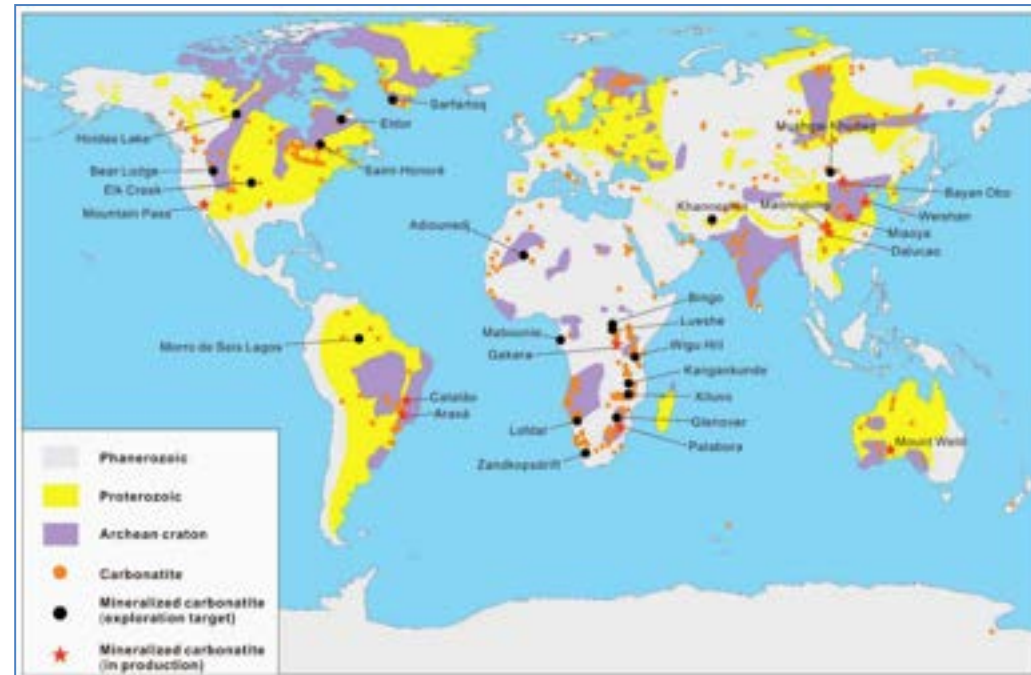
Eddy Ong 2024  
Posted on LinkedIn

## Major Types of REE



Smith et al 2015

## Carbonatite and Carbonatite related REE



Zhen-Yu Wang et al 2020



# Working with ChatGPT

Rare Earth Elements (REEs) are not associated with a specific tectonic setting in the same way that some metals like gold or copper may have well-defined associations. Instead, the distribution of REEs is more closely linked to specific geological processes and environments. REEs can be found in various geological settings, and their occurrence is often associated with specific types of rocks and mineral deposits. Here are some common geological settings where REEs are often found:

## **Carbonatite and Alkaline Intrusions:**

**Tectonic Setting:** Carbonatite and alkaline intrusions that host REE deposits can be found in both continental and oceanic settings.

**Formation:** These intrusions are often enriched in REEs due to complex geological processes, including the fractional crystallization of magma and the influence of incompatible elements. Carbonatites, in particular, are known for hosting significant REE deposits.

## **Ion Adsorption Clays:**

**Tectonic Setting:** Ion adsorption clay deposits, a significant source of light REEs, are commonly found in weathered tropical and subtropical environments.

**Formation:** The weathering of granitic rocks containing trace amounts of REEs results in the release and accumulation of REEs in the soil. This process is particularly prominent in regions with high rainfall and warm temperatures.

## **Bastnäsite and Monazite Deposits:**

**Tectonic Setting:** Bastnäsite and monazite deposits, which are common sources of REEs, can occur in a variety of geological settings, including igneous, metamorphic, and sedimentary environments.

**Formation:** These deposits often form through hydrothermal processes or as accessory minerals in igneous and metamorphic rocks. Additionally, monazite can be found in placer deposits derived from the weathering of such rocks.

## **Phosphate Deposits:**

**Tectonic Setting:** Phosphate deposits containing REEs are commonly associated with sedimentary basins.

**Formation:** The deposition of phosphorite in marine environments can concentrate REEs, especially in the mineral monazite, which often contains significant amounts of these elements.

## **Aluminum Phosphate Deposits:**

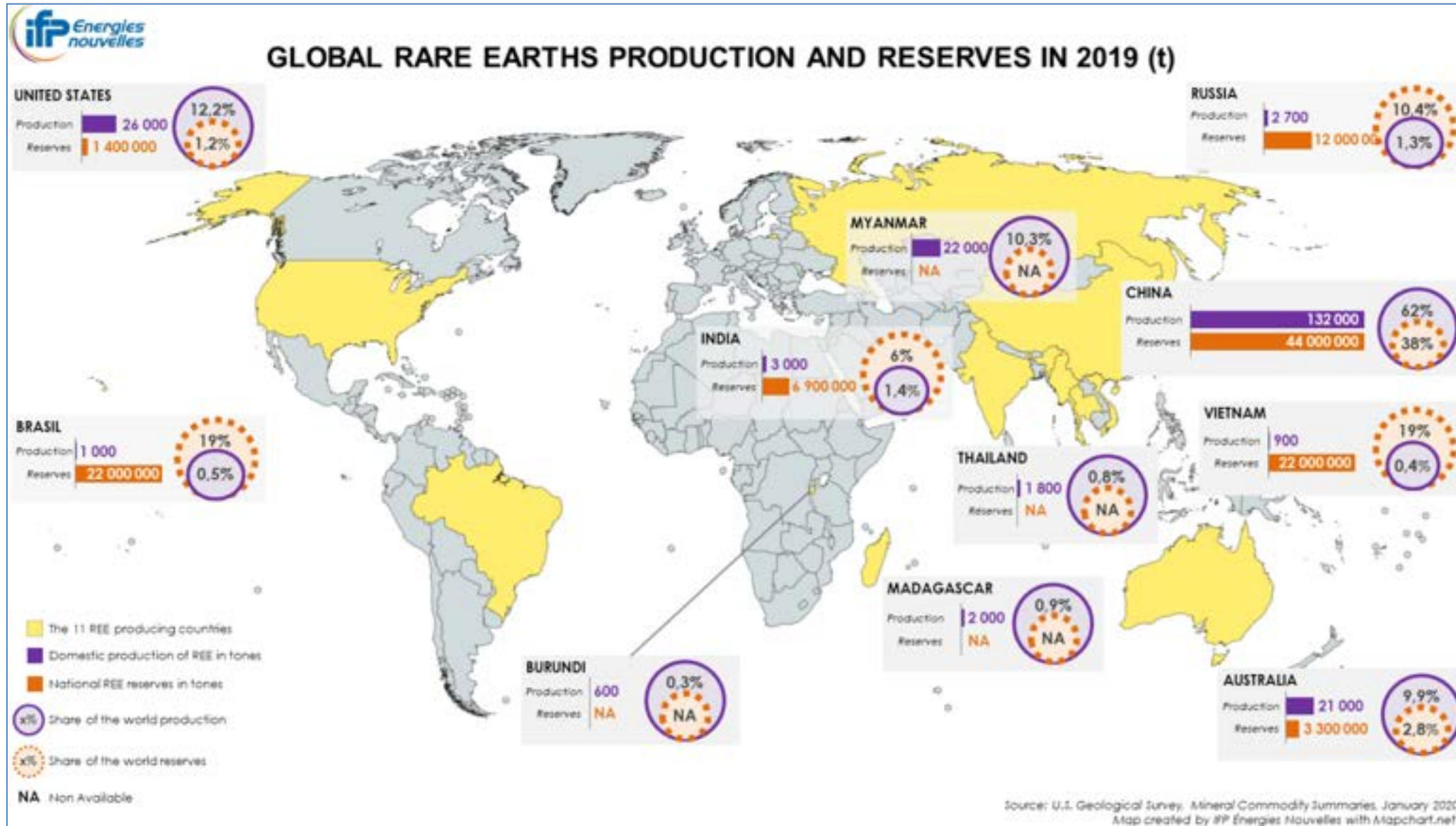
**Tectonic Setting:** Deposits rich in REEs associated with aluminum phosphates can be found in specific geological settings, including lateritic weathering environments.

**Formation:** The alteration and weathering of certain types of rocks, particularly those rich in apatite, can lead to the concentration of REEs in aluminum phosphate minerals.

It's important to note that the occurrence of REEs is diverse, and their distribution depends on a combination of geological, geochemical, and mineralogical factors. Economic concentrations of REEs are often found in deposits that have undergone specific geological processes favoring the enrichment of these elements.



# Global REE Extraction and Reserves (t) 2019



Carbonatite, Fenite



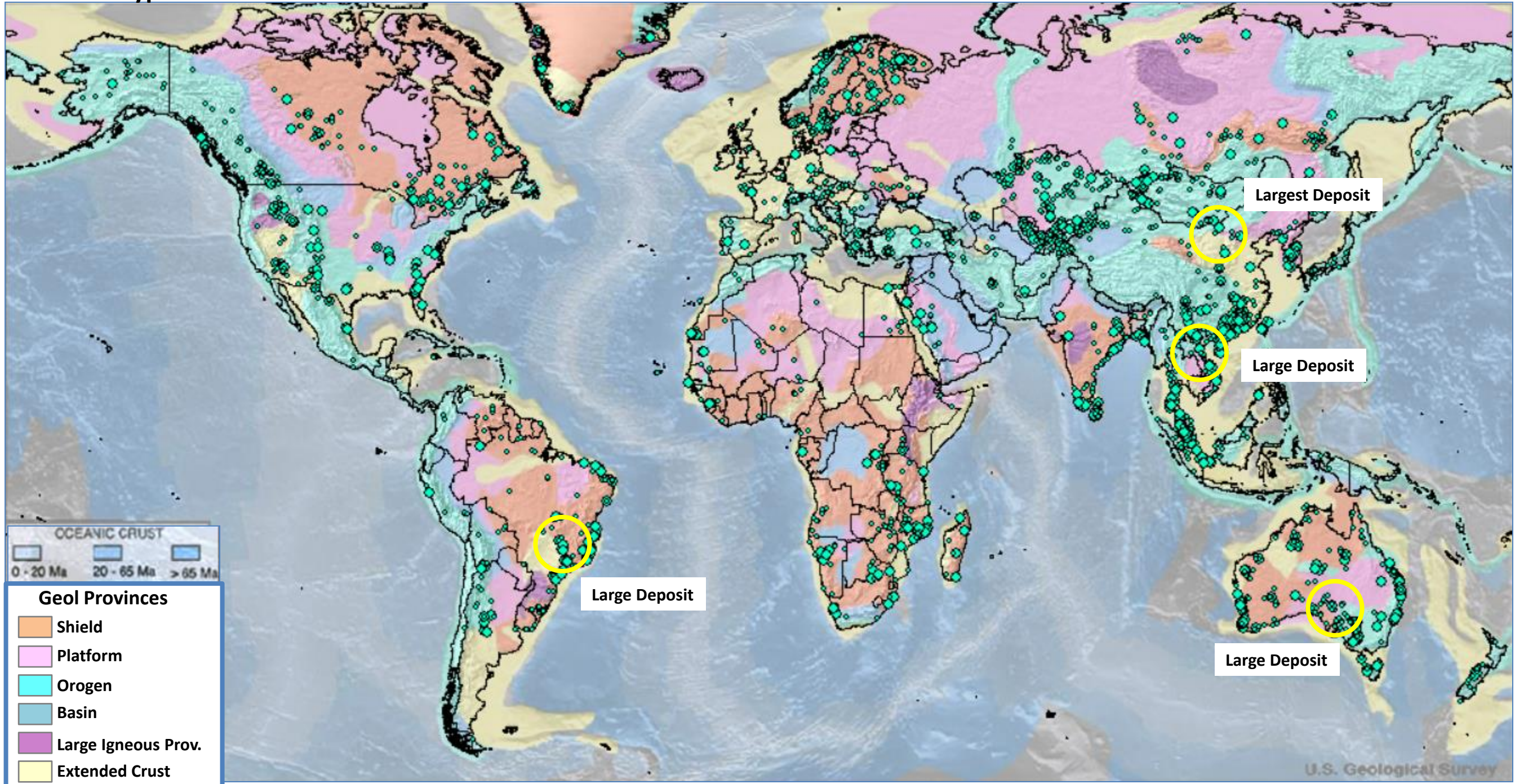
Bayan Obo Mine China

ifpenergiesnouvelles.com  
 USGS Commodity Summary



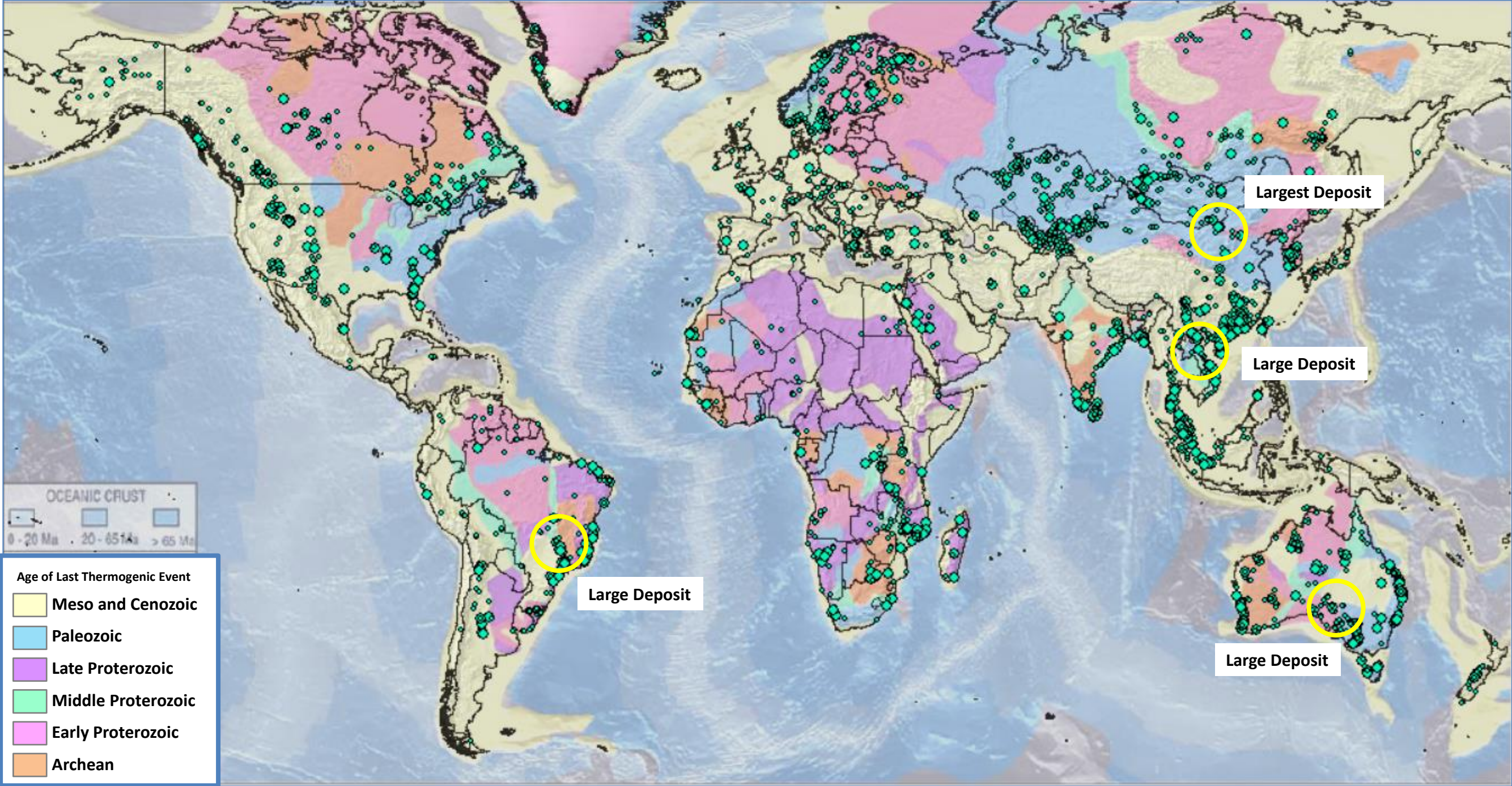
# REE

## Province Type





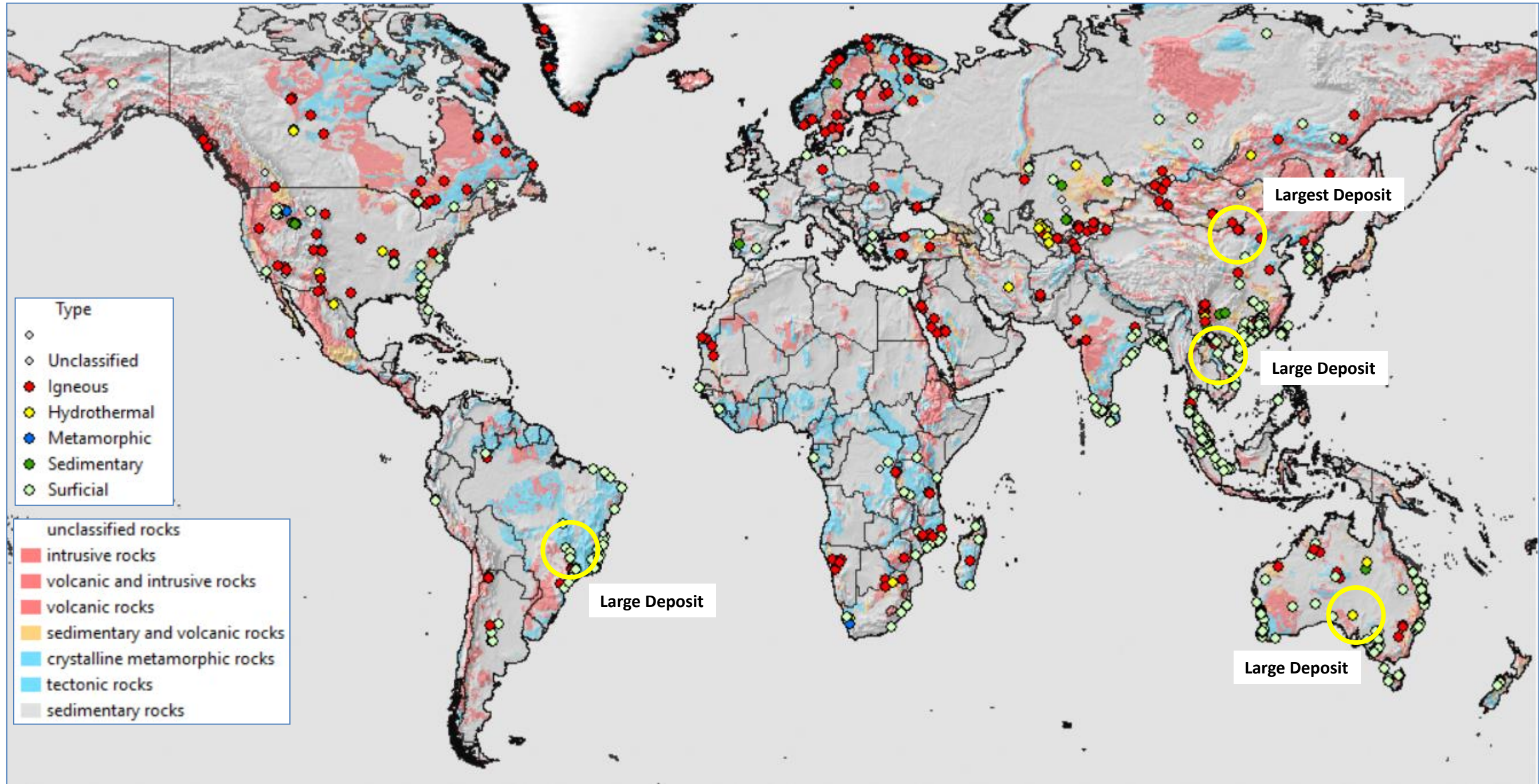
Age of Last Thermogenic Event



Indicative Locations of deposits based on USGS data (may not be comprehensive)



### Type of Deposit



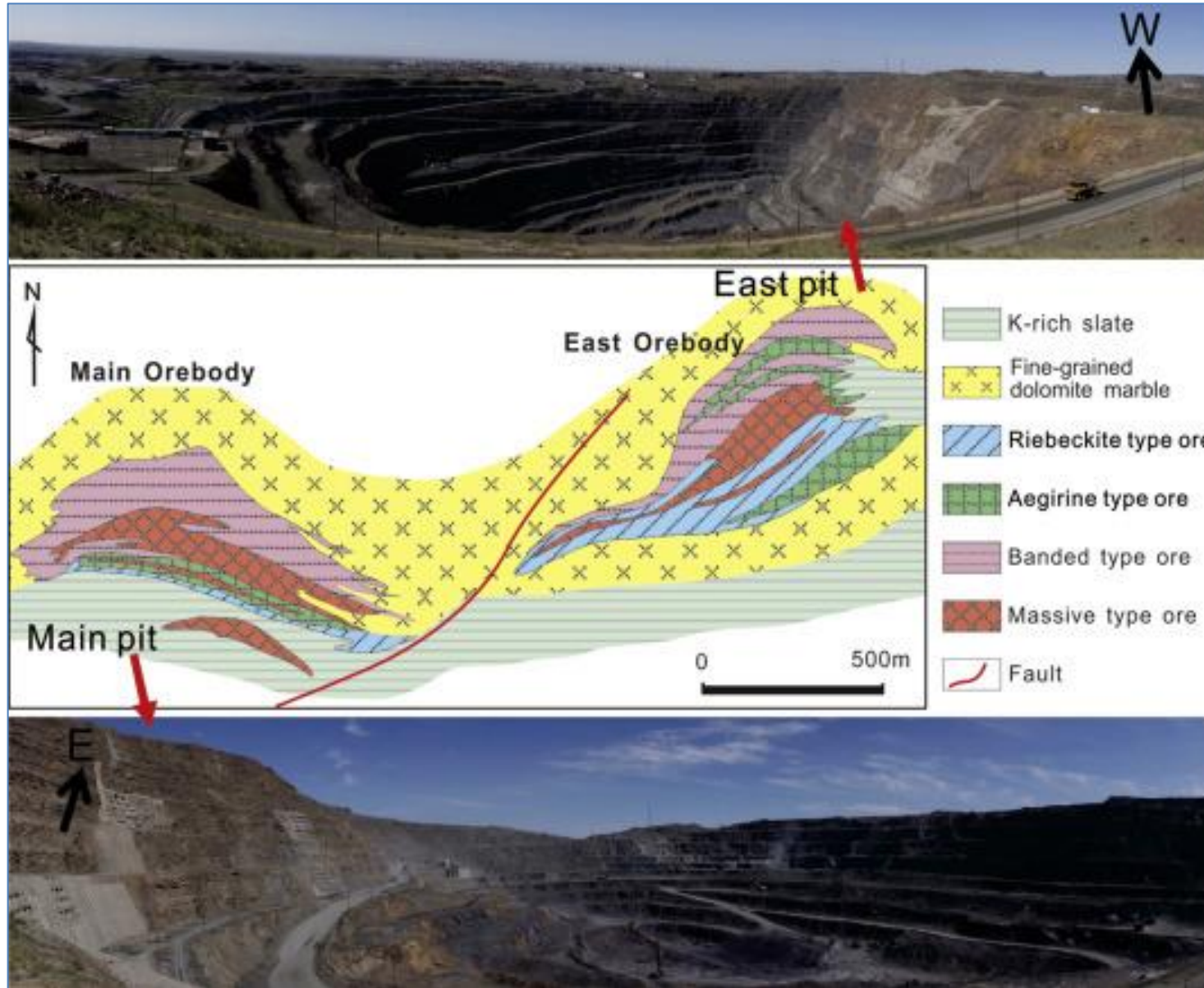
Indicative Locations of deposits based on USGS data (may not be comprehensive)



# World's Largest Deposits

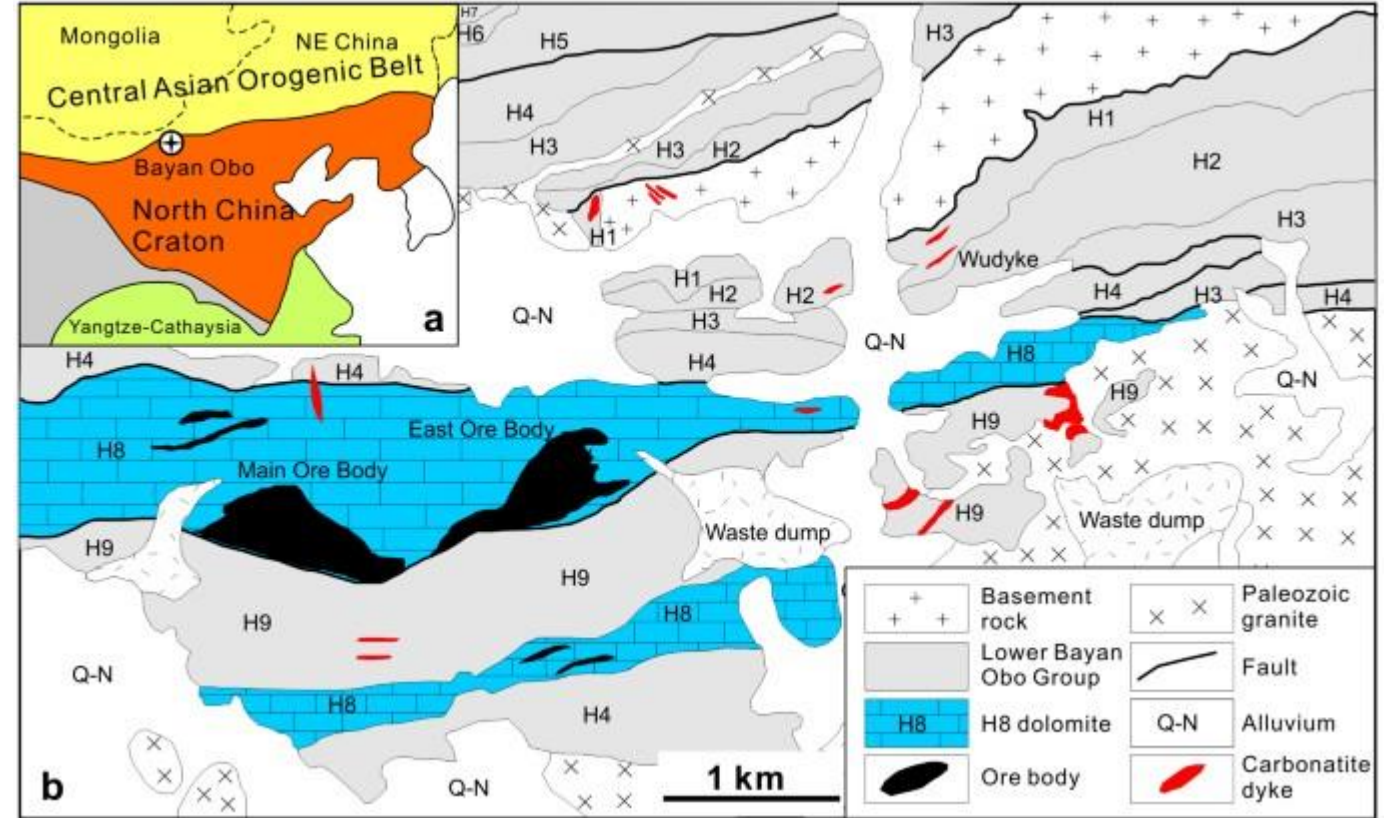
REE

## Bayan Obo REE- Nb- FE deposit, China



Hong- Rui Fan et al 2016

## Bayan Obo, China



Ming-Xing Ling et al 2013



# Cobalt

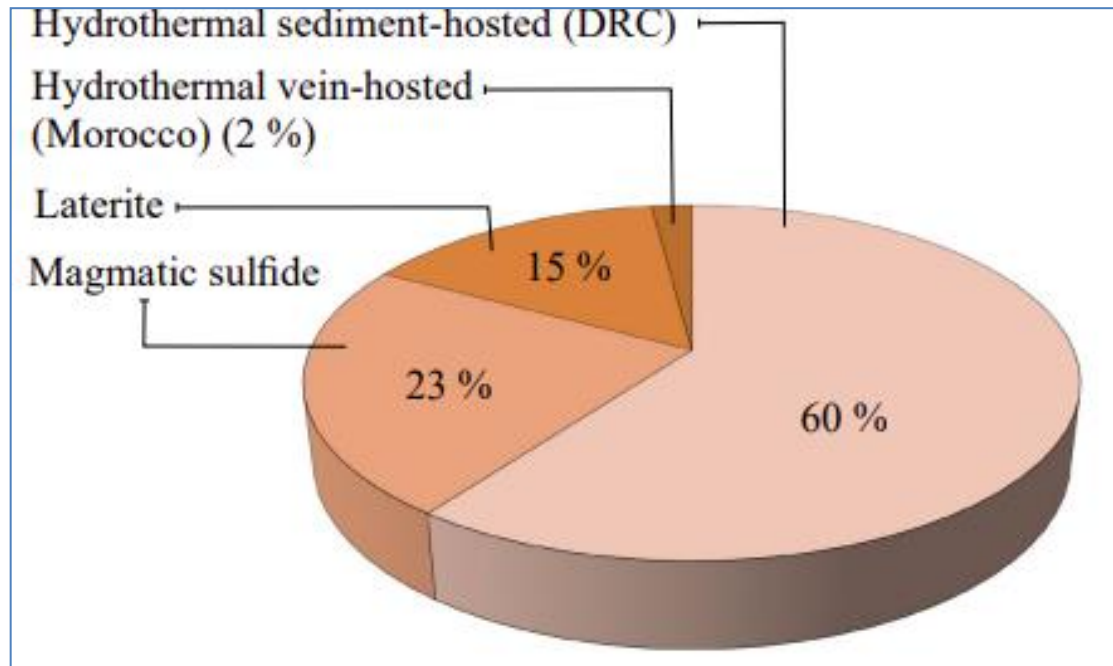
## Sedimentary hosted Deposits



## Magmatic Deposits

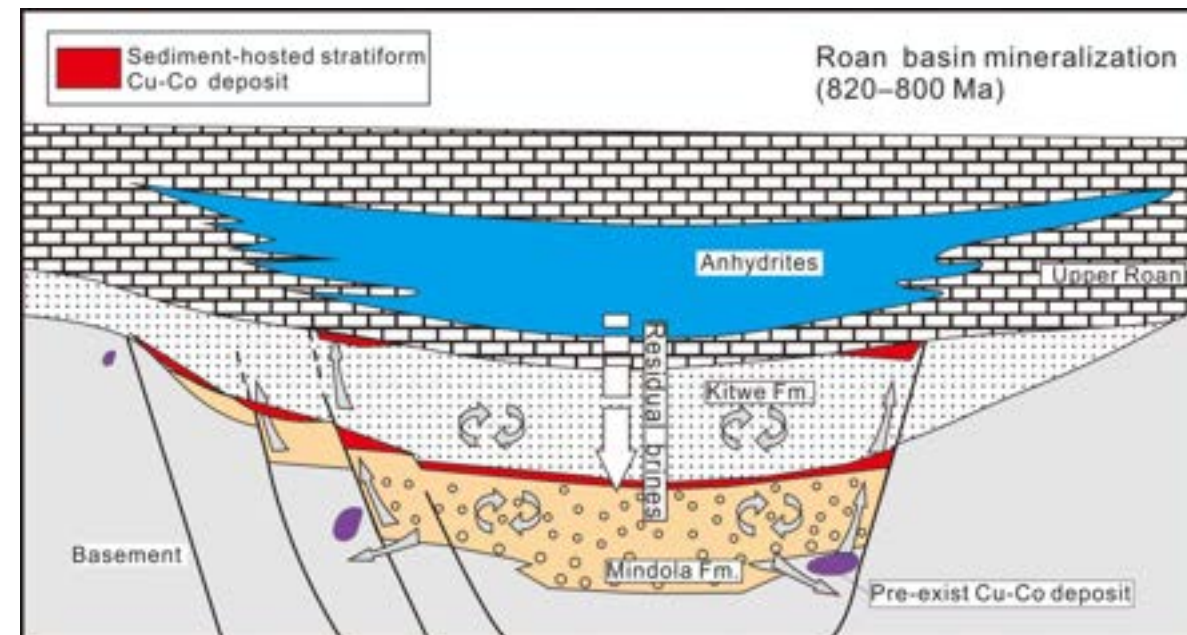


## Laterite Deposits



Williams-Jones n Vasyukova 2022, Slack (2017)

## Central African Cu-Co Sedimentary hosted Deposits



Chun- Fa Liu et al 2021

The principal deposit types that account for most of the world's cobalt mine production are stratiform sediment-hosted Cu-Co deposits, Ni-Co laterite deposits, and magmatic Ni-Cu(-Co-PGE) sulfide deposits. (USGS 2017)

Magmatic Cobalt rich deposits are typically associated with Olivine rich Mafic- Ultramafic rocks. Cobalt can subsequently be concentrated by aqueous fluids, either at ambient temperature in laterites developed over ultramafic rocks or hydrothermally in sediment-hosted copper deposits and in cobalt-rich vein deposits, where it crystallizes mainly as sulfide and arsenic-bearing minerals, respectively.

Approximately 60% of the world's cobalt resource is of hydrothermal origin and is contained in sediment-hosted copper deposits in the Democratic Republic of the Congo where Co is leached from mafic and ultramafic rocks by oxidized, chloride-rich hydrothermal fluids, derived from carbonaceous sediments that accumulated in intracratonic rift basins.

Over 50 % of the World's current supply of cobalt is also from the Democratic Republic of Congo (DRC), a country that has been in a state of civil war for at least 20 years.

Most of the remaining supply is as a by-product of the mining of Ni in magmatic sulfide (23 %) and laterite deposits (15 %) (Williams-Jones n Vasyukova 2022)

USGS 2017



# Working with ChatGPT

Cobalt deposits are associated with various geological settings, and the occurrence of economically viable deposits is linked to specific geological processes. Cobalt is often found as a byproduct of other metal ores, such as nickel and copper. Here are some common geological settings where cobalt deposits are typically found:

## **Magmatic Nickel-Copper-Cobalt Sulfide Deposits:**

**Tectonic Setting:** These deposits are often associated with mafic and ultramafic intrusions, and they can be found in both convergent and divergent tectonic settings.

**Formation:** Magmatic nickel-copper-cobalt sulfide deposits form during the crystallization of magma enriched in nickel, copper, and cobalt. The sulfide minerals containing these metals separate from the magma and accumulate within specific zones of the intrusions.

## **Lateritic Nickel-Cobalt Deposits:**

**Tectonic Setting:** Lateritic deposits, which can be a significant source of cobalt, are typically found in tropical and subtropical regions on the upper parts of ultramafic rocks.

**Formation:** These deposits form through weathering processes that result in the leaching of nickel, cobalt, and other metals from ultramafic rocks. The metals are then transported and concentrated in the weathered regolith, forming lateritic nickel-cobalt deposits.

## **Cobalt-Rich Ferromanganese Crusts and Nodules:**

**Tectonic Setting:** Cobalt-rich ferromanganese crusts and nodules are found on the seafloor in various oceanic settings.

**Formation:** These crusts and nodules form through the slow accumulation of ferromanganese and other minerals on the seafloor over long periods. They can contain significant concentrations of cobalt, among other metals.

## **Cobalt-Bearing Copper Deposits:**

**Tectonic Setting:** Cobalt can also be associated with copper deposits, particularly those formed in sedimentary or volcanic settings.

**Formation:** Cobalt may occur as a byproduct in copper deposits, and its presence is often associated with the same geological processes that lead to the formation of copper deposits, such as hydrothermal activity.

## **Vein and Replacement Deposits:**

**Tectonic Setting:** Cobalt can be found in some vein and replacement deposits associated with a variety of geological settings.

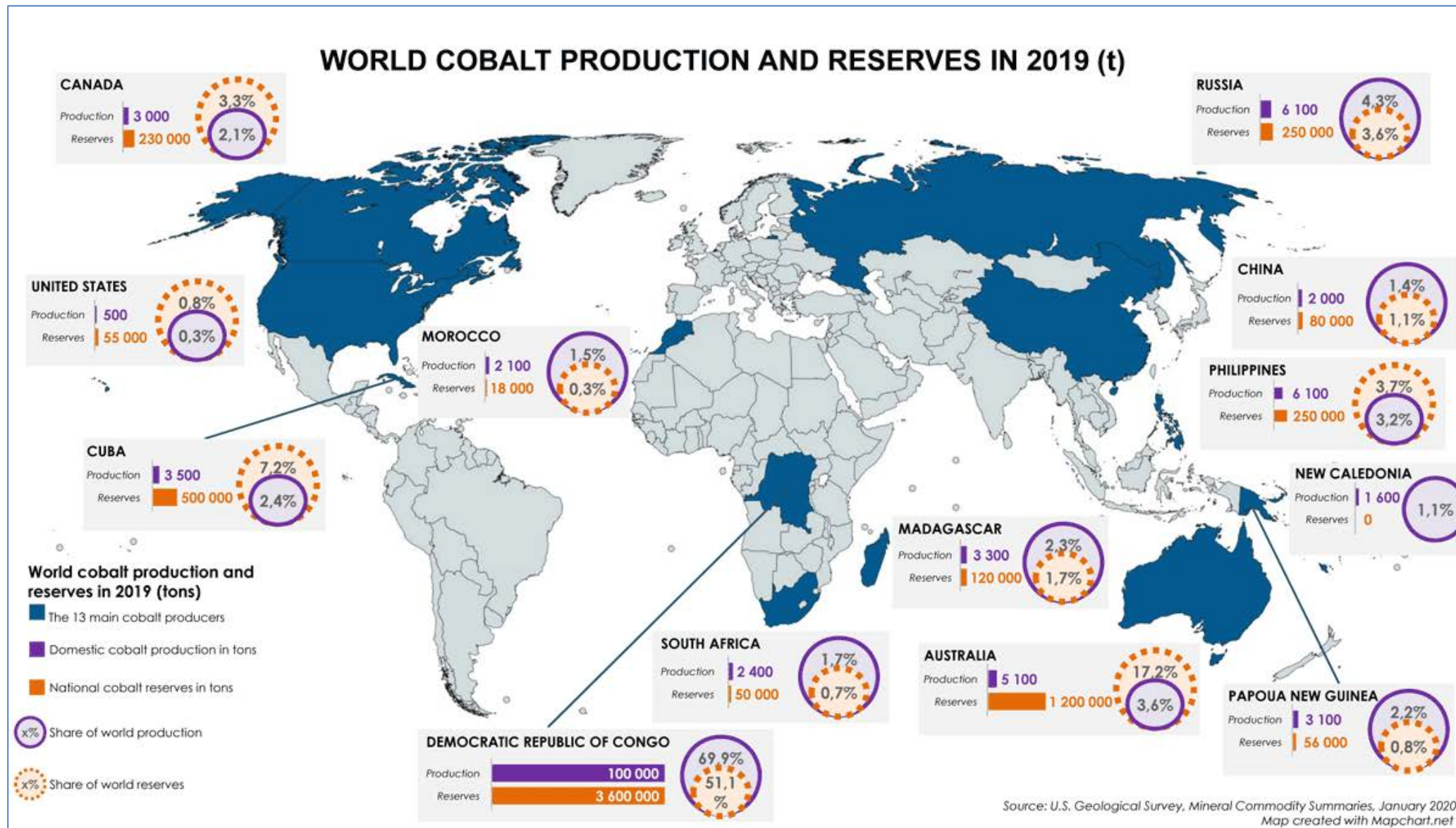
**Formation:** In certain geological environments, fluids rich in cobalt can migrate through fractures or replace existing minerals, forming vein or replacement deposits.

It's important to note that the geological settings of cobalt deposits can vary widely, and cobalt is often found in association with other metals. The economic viability of cobalt extraction depends on factors such as the grade of the deposit, accessibility, and market demand.



# Cobalt

## Global Cobalt Extraction and Reserves (t) 2019



Heterogenite



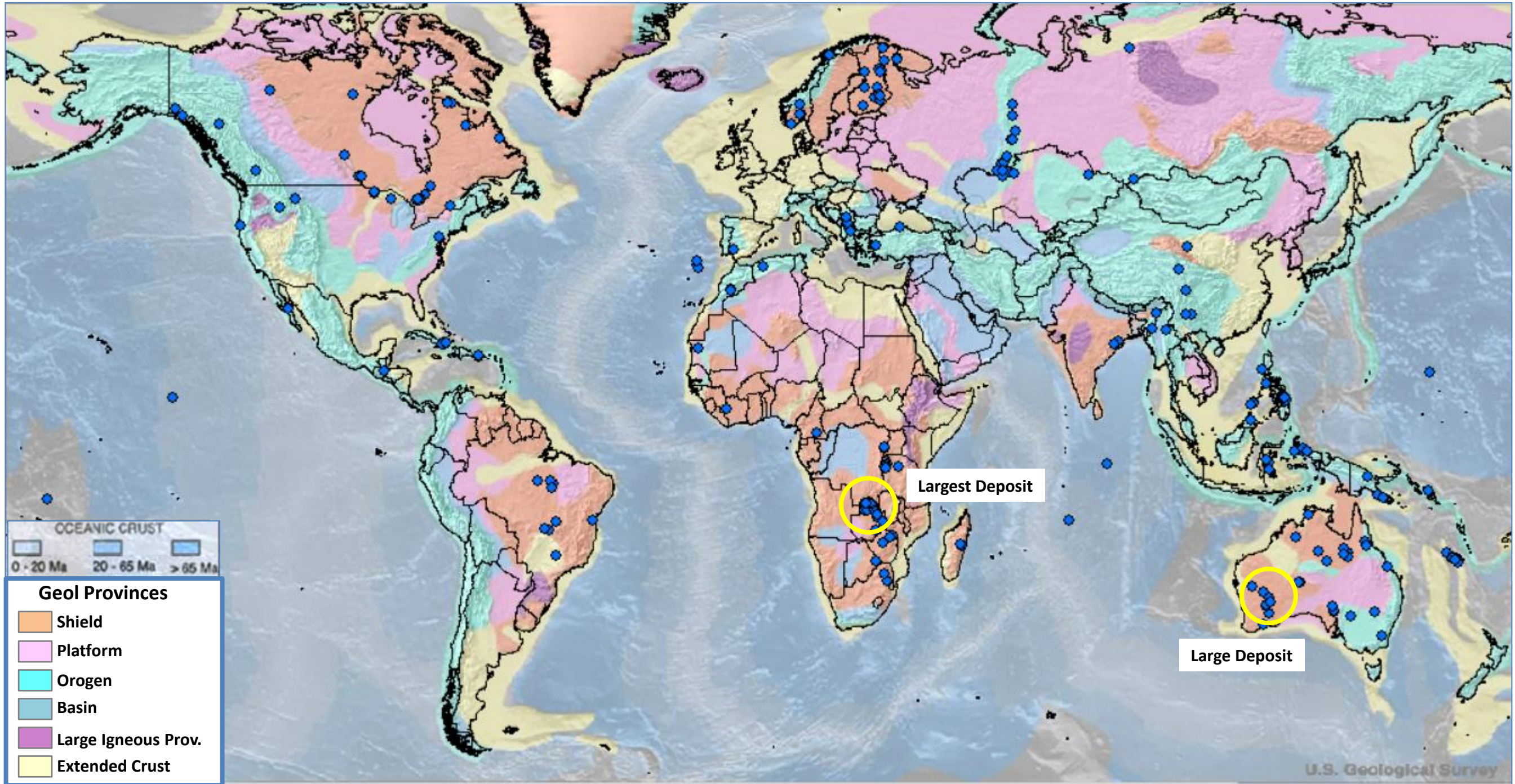
Mutanda Mine DRC

ifpenergiesnouvelles.com  
USGS Commodity Summary



# Cobalt

## Province Type

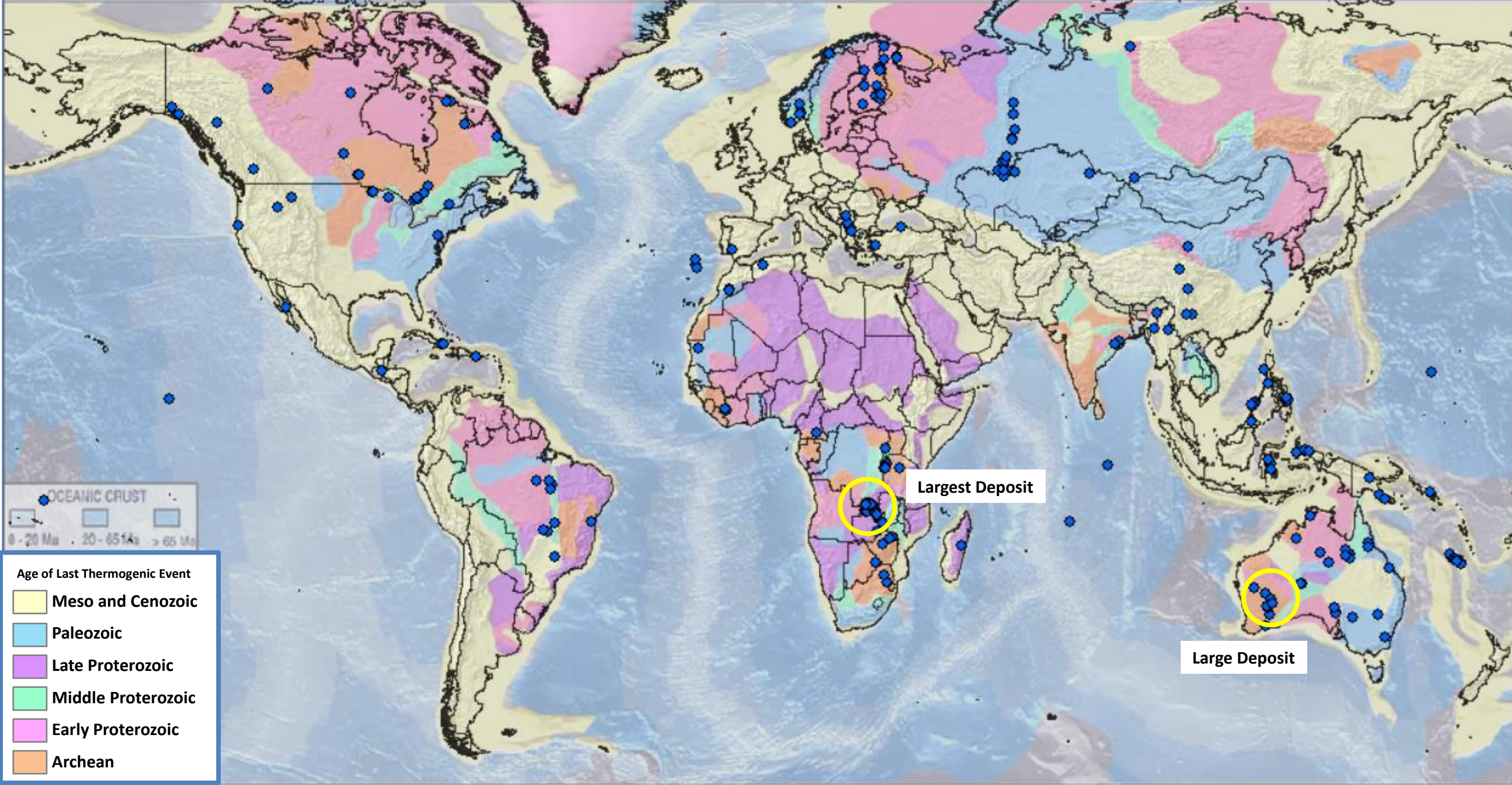


*Indicative Locations of deposits based on USGS data (may not be comprehensive)*



# Cobalt

## Age of Last Thermogenic Event

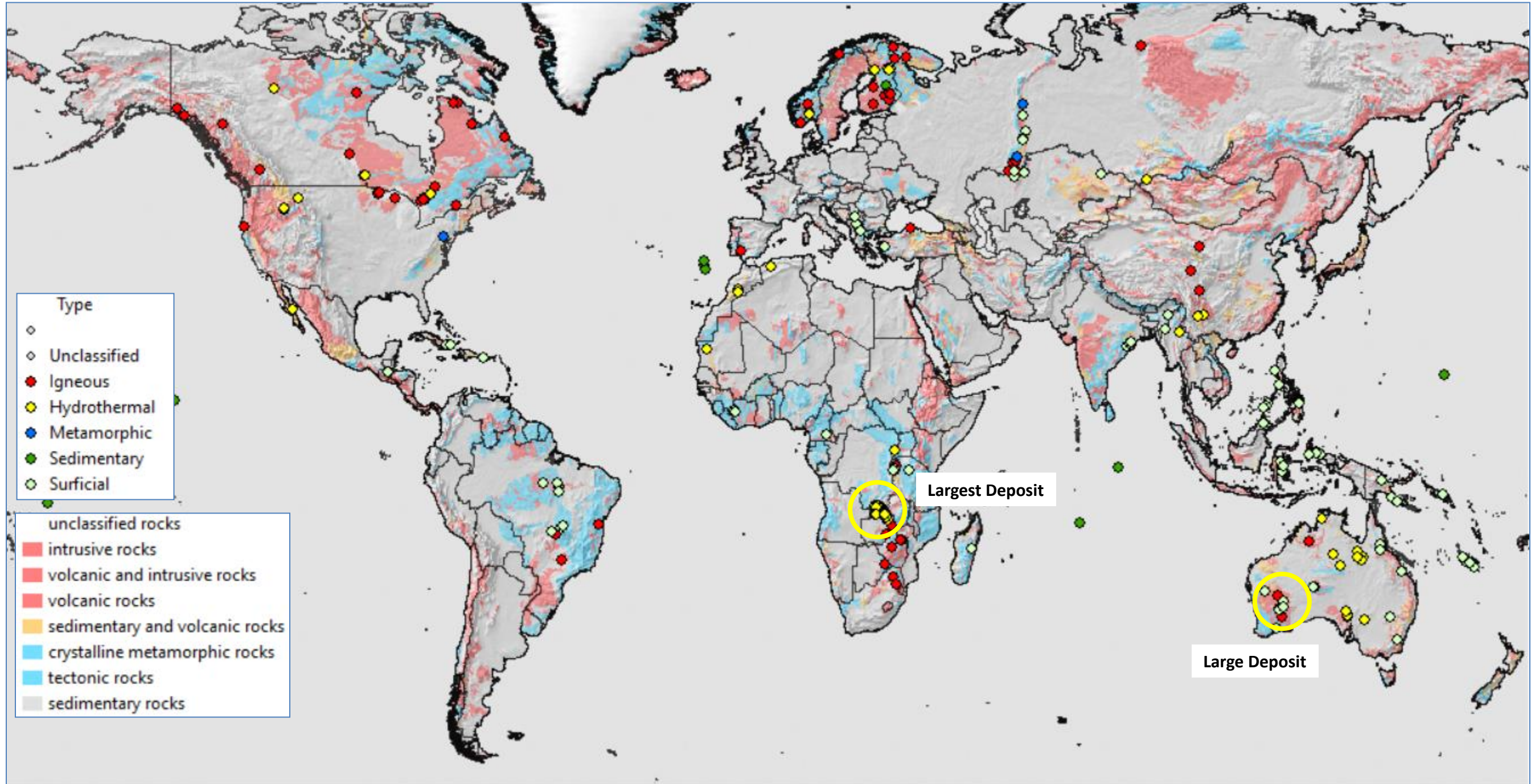


*Indicative Locations of deposits based on USGS data (may not be comprehensive)*



# Cobalt

## Type of Deposit



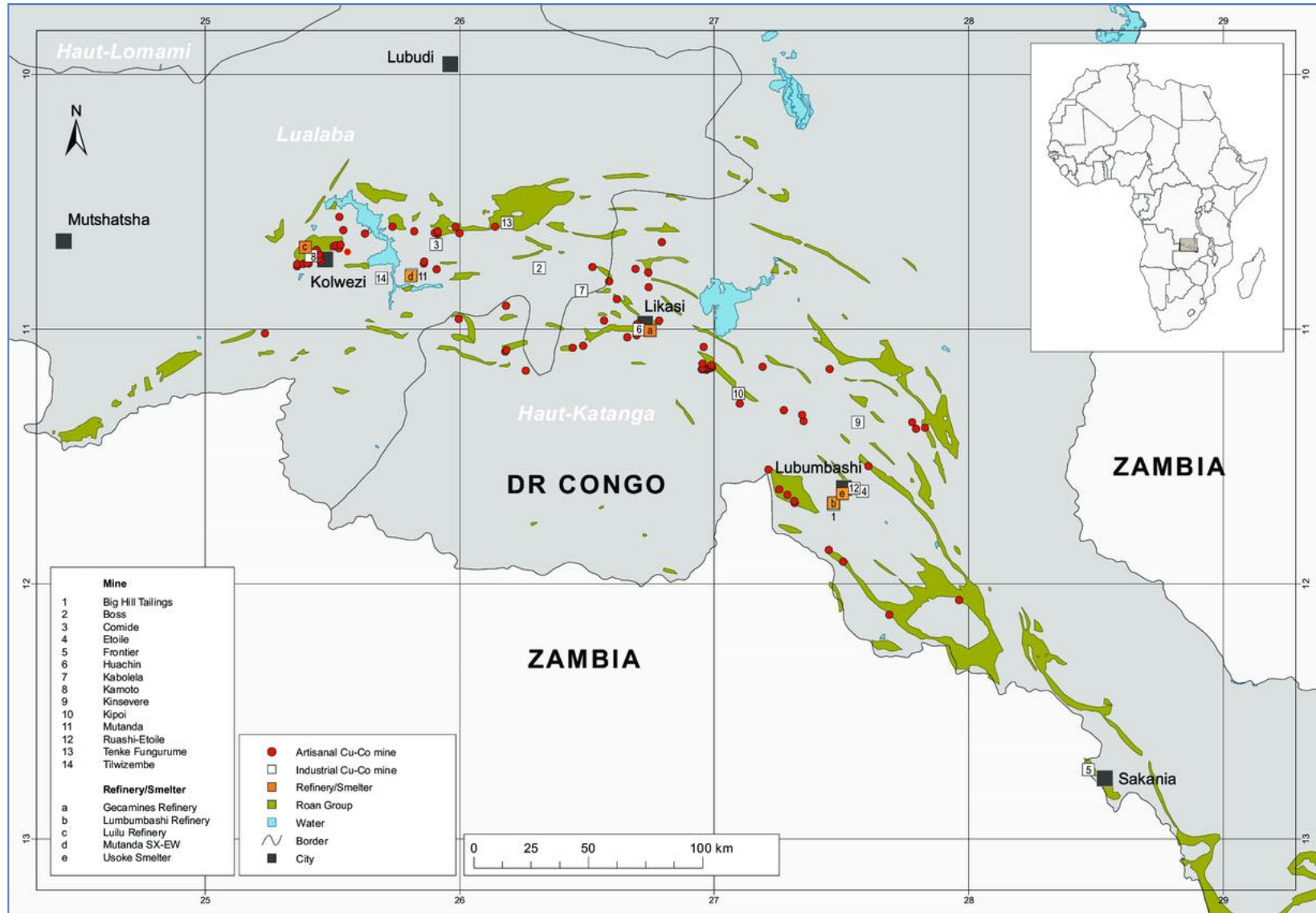
Indicative Locations of deposits based on USGS data (may not be comprehensive)



# World's Largest Deposits

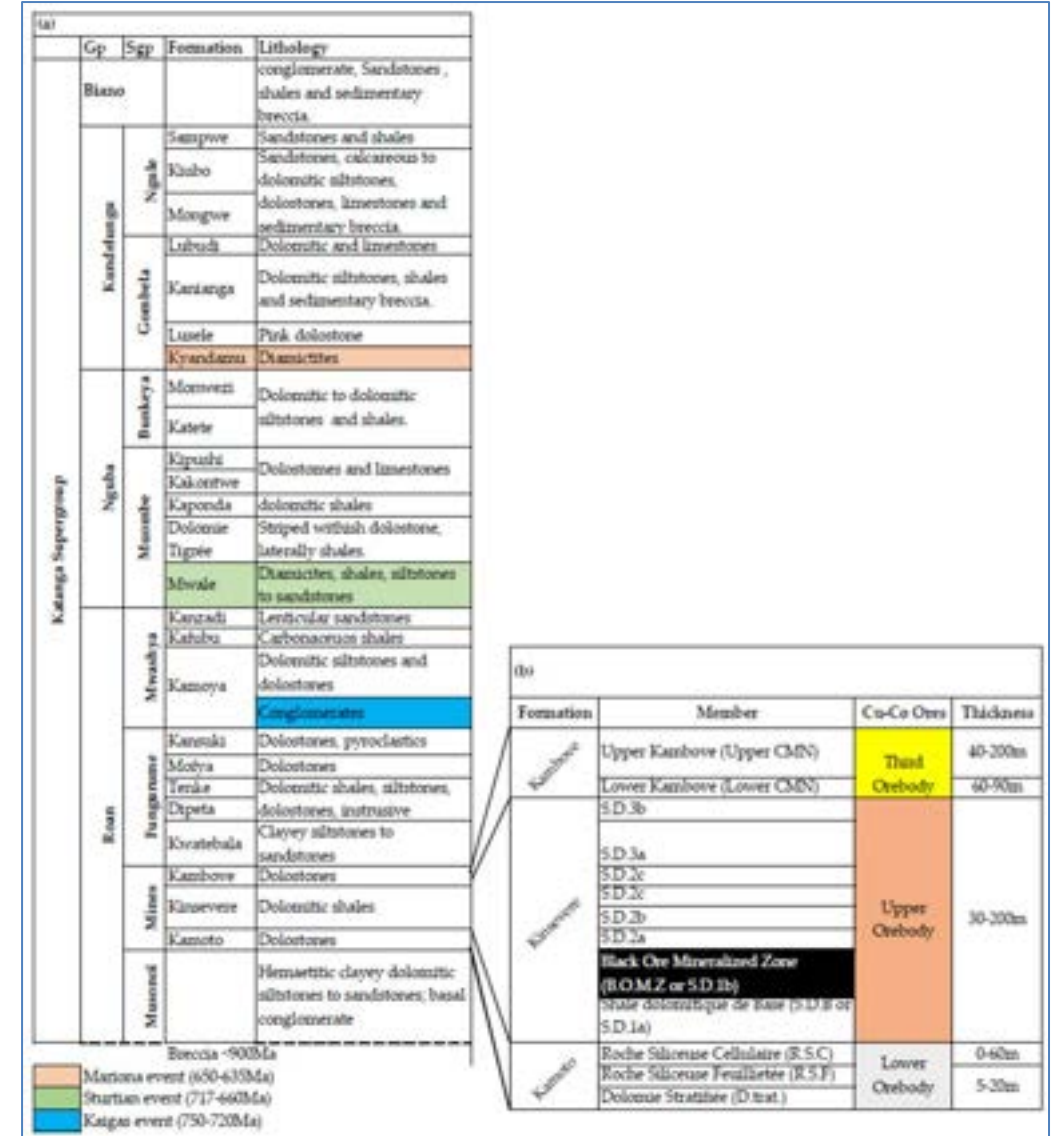
Cobalt

## DRC Cu-Co Belt, Central Africa



Siyamend Al Barazi et al 2017

## DRC Cu- Co Belt

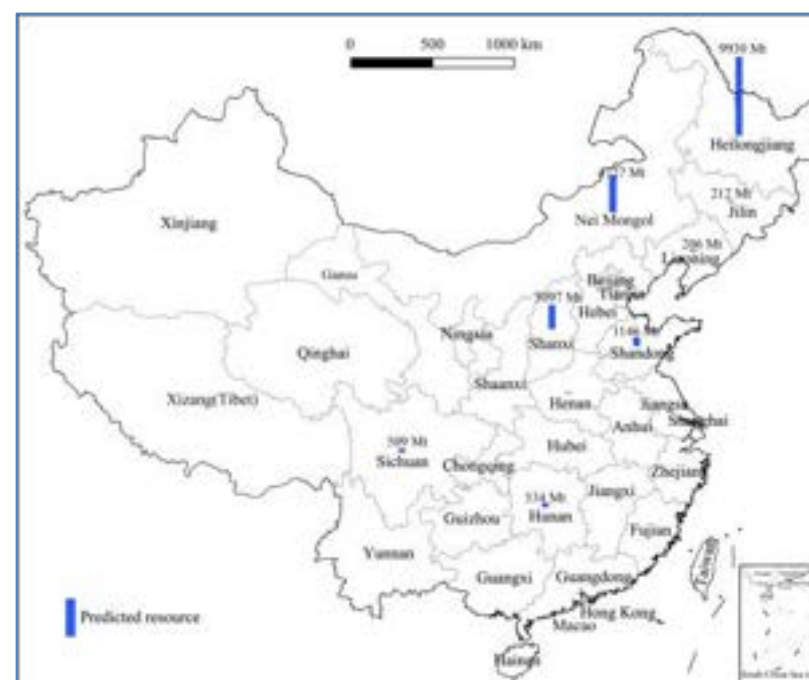
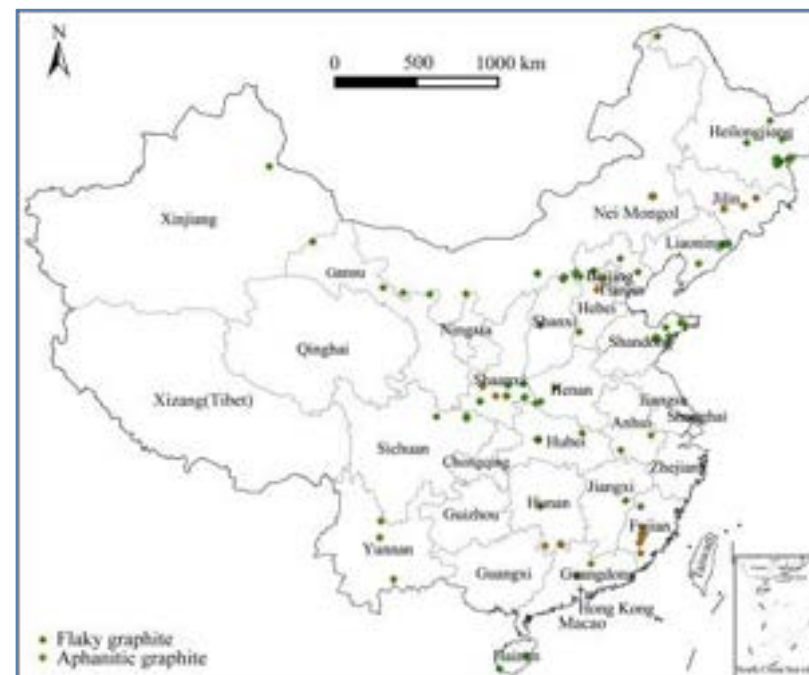
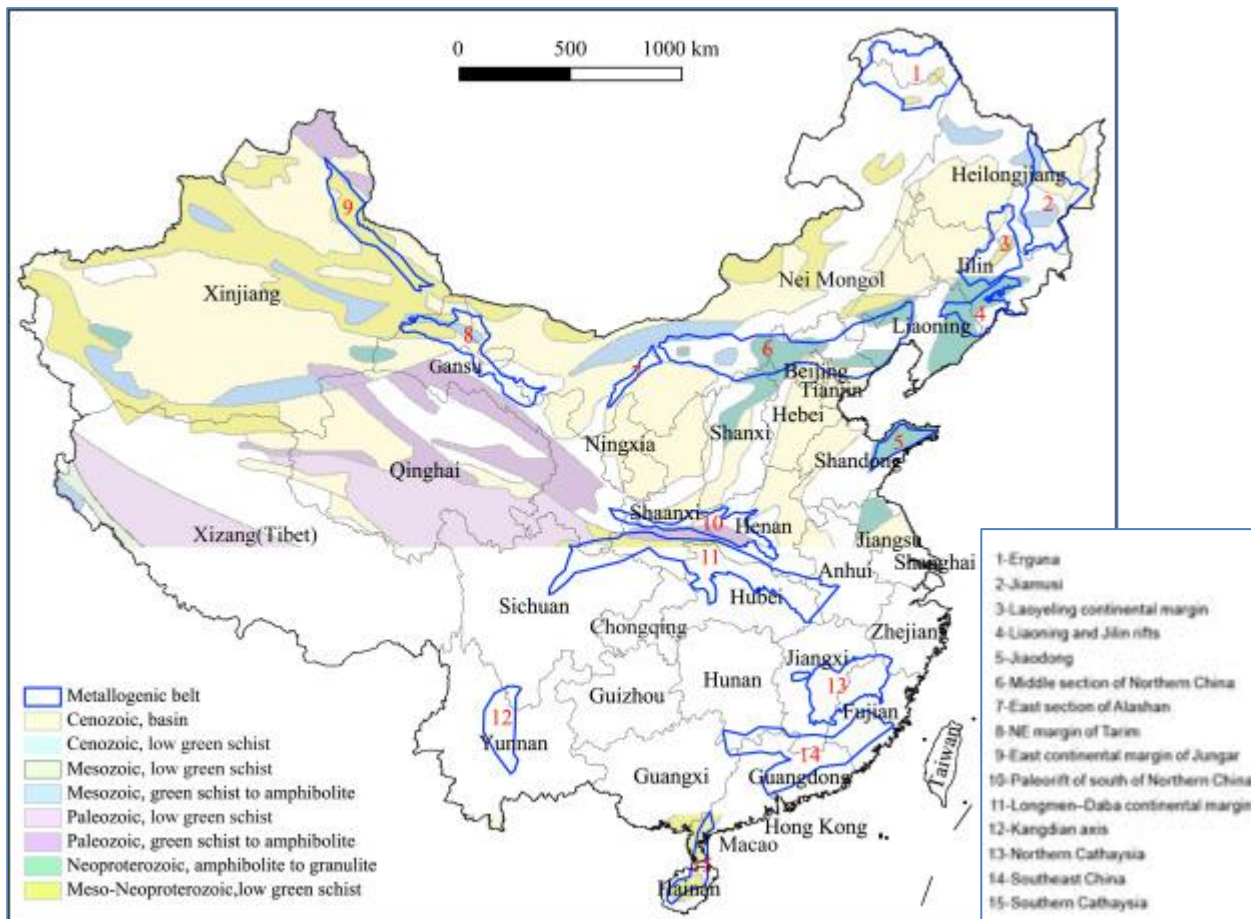


Pascal Mambwe et al 2022



# Graphite

## China Graphite deposits



Graphite ores are classified as “amorphous” (microcrystalline), and “crystalline” (“flake” or “lump or chip”) based on the ore’s crystallinity, grain-size, and morphology. All graphite deposits mined today formed from metamorphism of carbonaceous sedimentary rocks, and the ore type is determined by the geologic setting.

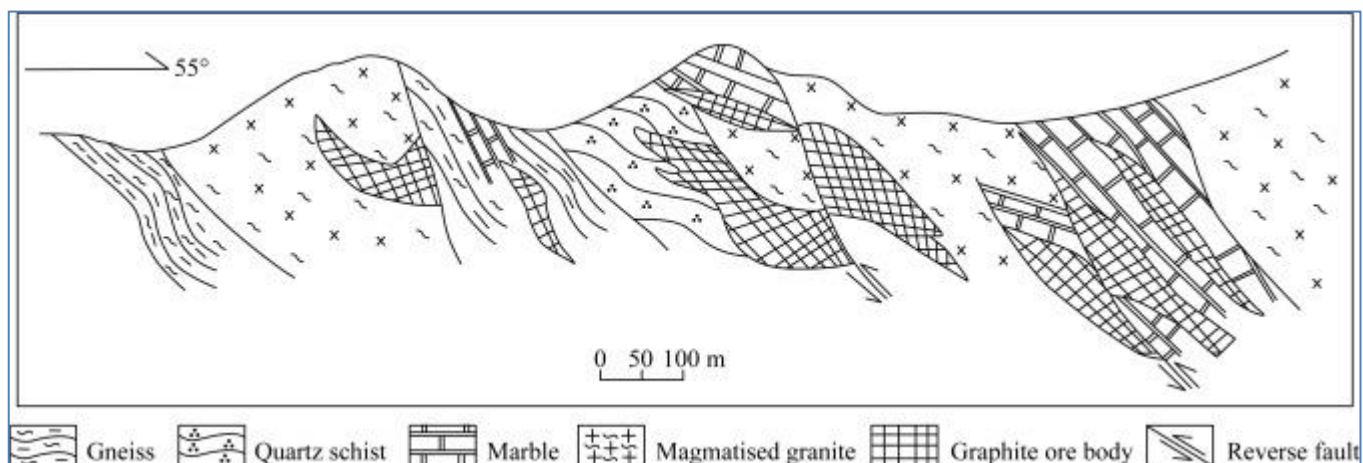
Thermally metamorphosed coal is the usual source of amorphous graphite. Disseminated crystalline flake graphite is mined from carbonaceous metamorphic rocks, and lump or chip graphite is mined from veins in high-grade metamorphic regions.

Because graphite is chemically inert and nontoxic, the main environmental concerns associated with graphite mining are inhalation of fine-grained dusts, including silicate and sulfide mineral particles, and hydrocarbon vapors produced during the mining and processing of ore.

Production of natural graphite is dominated by China, India, and Brazil, which export graphite worldwide. China provides approximately 67 percent of worldwide output of natural graphite, and, as the dominant exporter, has the ability to set world prices. China has significant graphite reserves, and China’s graphite production is expected to increase. (USGS 2017)

The principal types of natural graphite found in China are: (1) rare and most valuable lump graphite with a hydrothermal origin; (2) flake graphite formed as thin flakes in metamorphosed calcareous sedimentary rocks; and (3) amorphous, very fine-grained graphite that is the most common type formed during the metamorphism of anthracite coal seams. (Ning Cui et al 2017)

## Liumao Graphite Ore deposits from Area 2 (Li Sun et al 2018)



(Li Sun et al 2018)

(Li Sun et al 2018)



# Working with ChatGPT

Graphite deposits can be found in a variety of geological settings, and the formation of economically viable graphite deposits is influenced by specific geological processes. Graphite is typically associated with certain types of rocks and geological environments. Here are some common geological settings where graphite deposits are often found:

## **Metamorphic Environments:**

**Tectonic Setting:** Graphite is commonly associated with metamorphic rocks and is often found in metamorphic terrains.

**Formation:** Graphite forms through the metamorphism of organic-rich sediments, such as carbonaceous shale or coal. The heat and pressure associated with regional metamorphism can convert organic material into graphite. Metamorphic environments can include subduction zones, convergent plate boundaries, and areas with high-grade regional metamorphism.

## **Graphitic Schists and Gneisses:**

**Tectonic Setting:** Graphite deposits are frequently found in graphitic schists and gneisses within metamorphic terrains.

**Formation:** Graphite-rich rocks like schists and gneisses form during the metamorphism of sedimentary rocks containing organic material. The heat and pressure cause the carbonaceous material to transform into graphite.

## **Marble and Calc-Silicate Rocks:**

**Tectonic Setting:** Graphite can also occur in association with marble and calc-silicate rocks.

**Formation:** These rocks may contain graphite as a result of metamorphism and the breakdown of organic-rich sediments. The carbonaceous material can be introduced into carbonate rocks during metamorphic processes.

## **Hydrothermal Vein Deposits:**

**Tectonic Setting:** Hydrothermal vein deposits of graphite can form in various tectonic settings.

**Formation:** In some cases, graphite may be introduced by hydrothermal fluids. These fluids can transport carbon from one location to another, and under suitable conditions, graphite can precipitate in veins within host rocks.

## **Intrusive Igneous Rocks:**

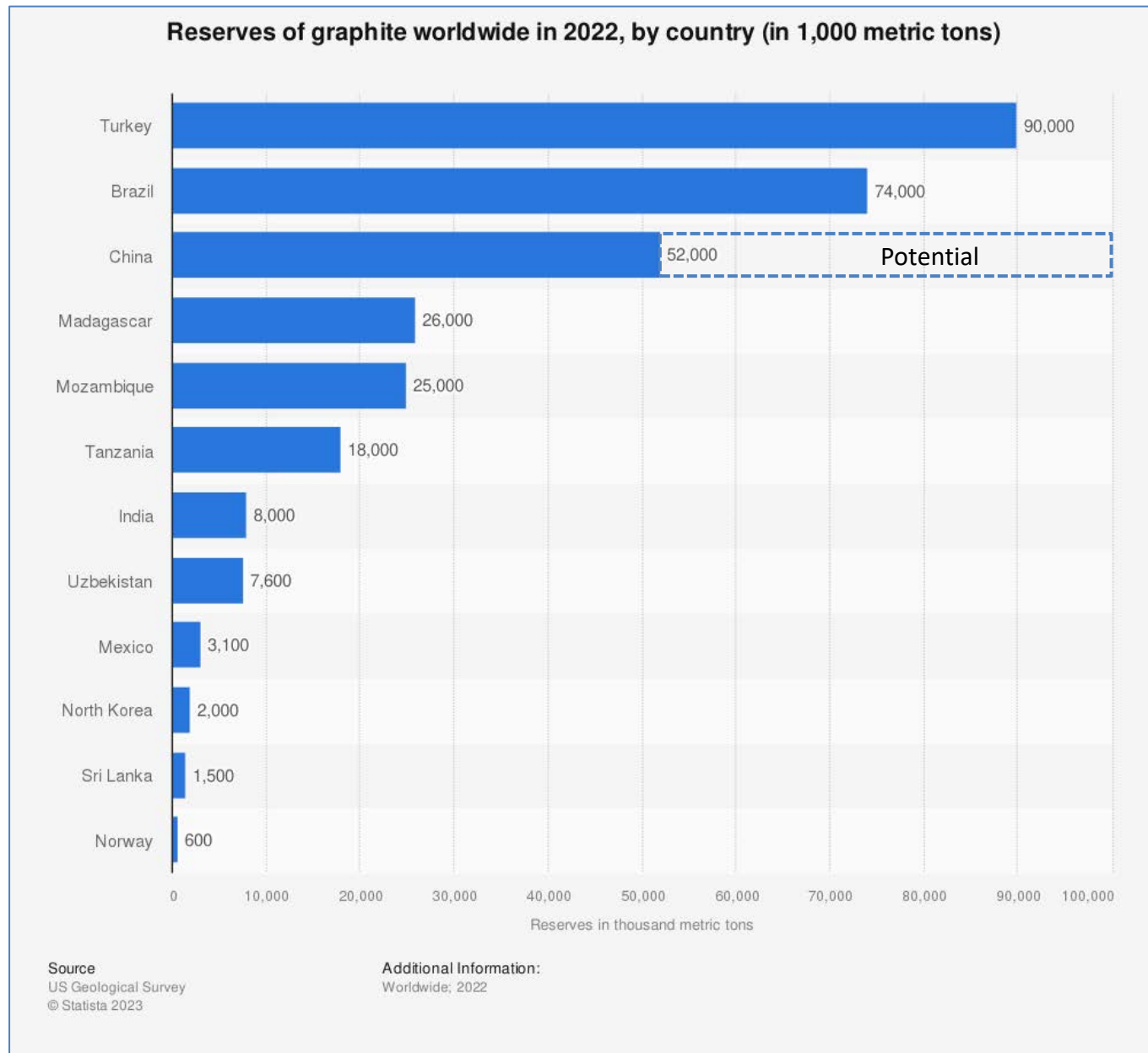
**Tectonic Setting:** Graphite can be associated with certain types of intrusive igneous rocks.

**Formation:** In some instances, graphite may be introduced during the emplacement of intrusive igneous rocks. The carbonaceous material may be assimilated from surrounding rocks or introduced by magmatic fluids.

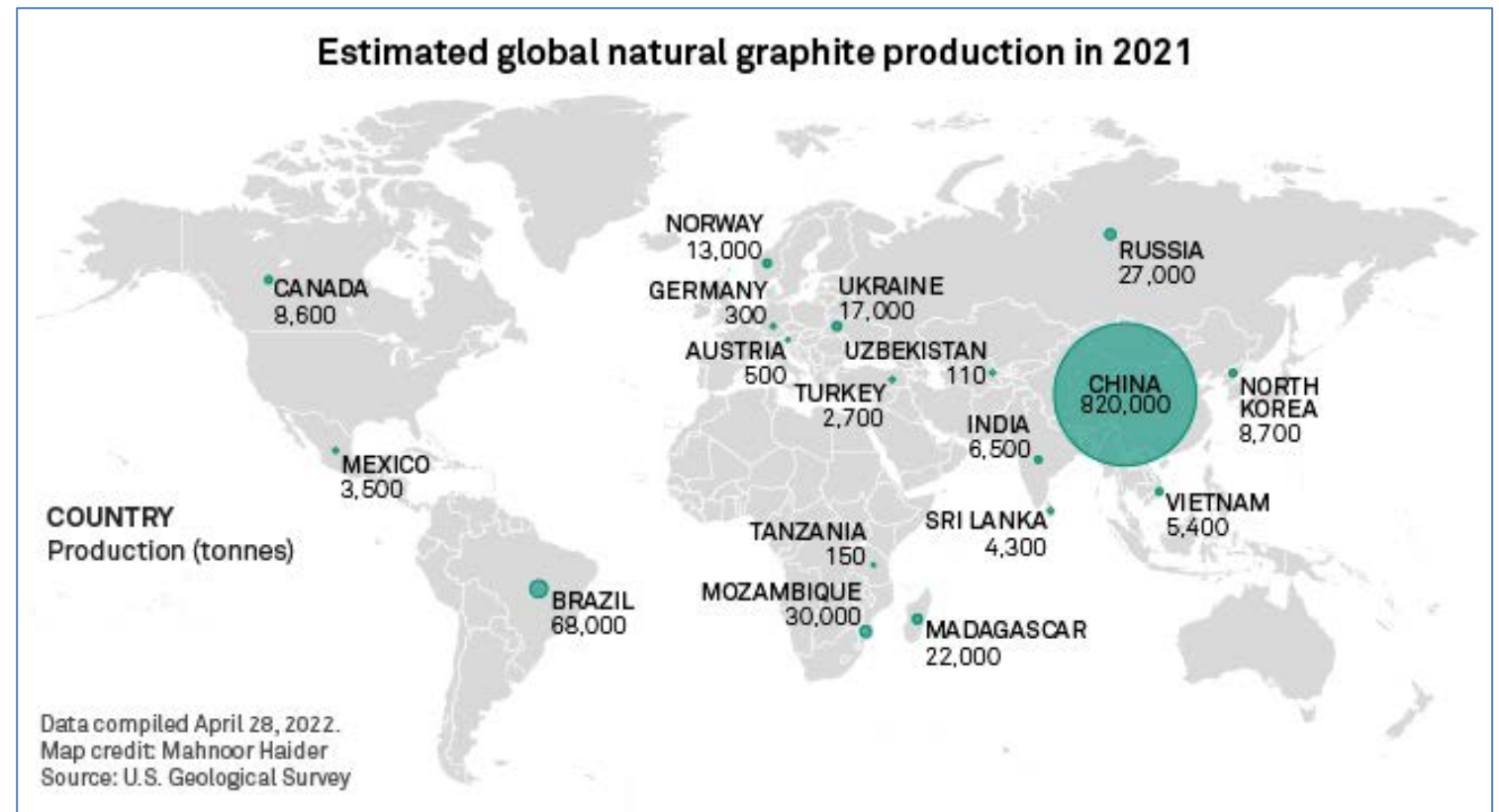
It's important to note that graphite deposits can vary in size, grade, and economic significance. The geological setting of graphite deposits is closely tied to the conditions under which carbonaceous material undergoes metamorphism or is otherwise concentrated. The exploration for graphite deposits involves understanding the geological history of the region and identifying the appropriate host rocks and conditions for graphite formation.



# Global Graphite Extraction and Reserves 2021



Statista.com



S&P Global



Graphite

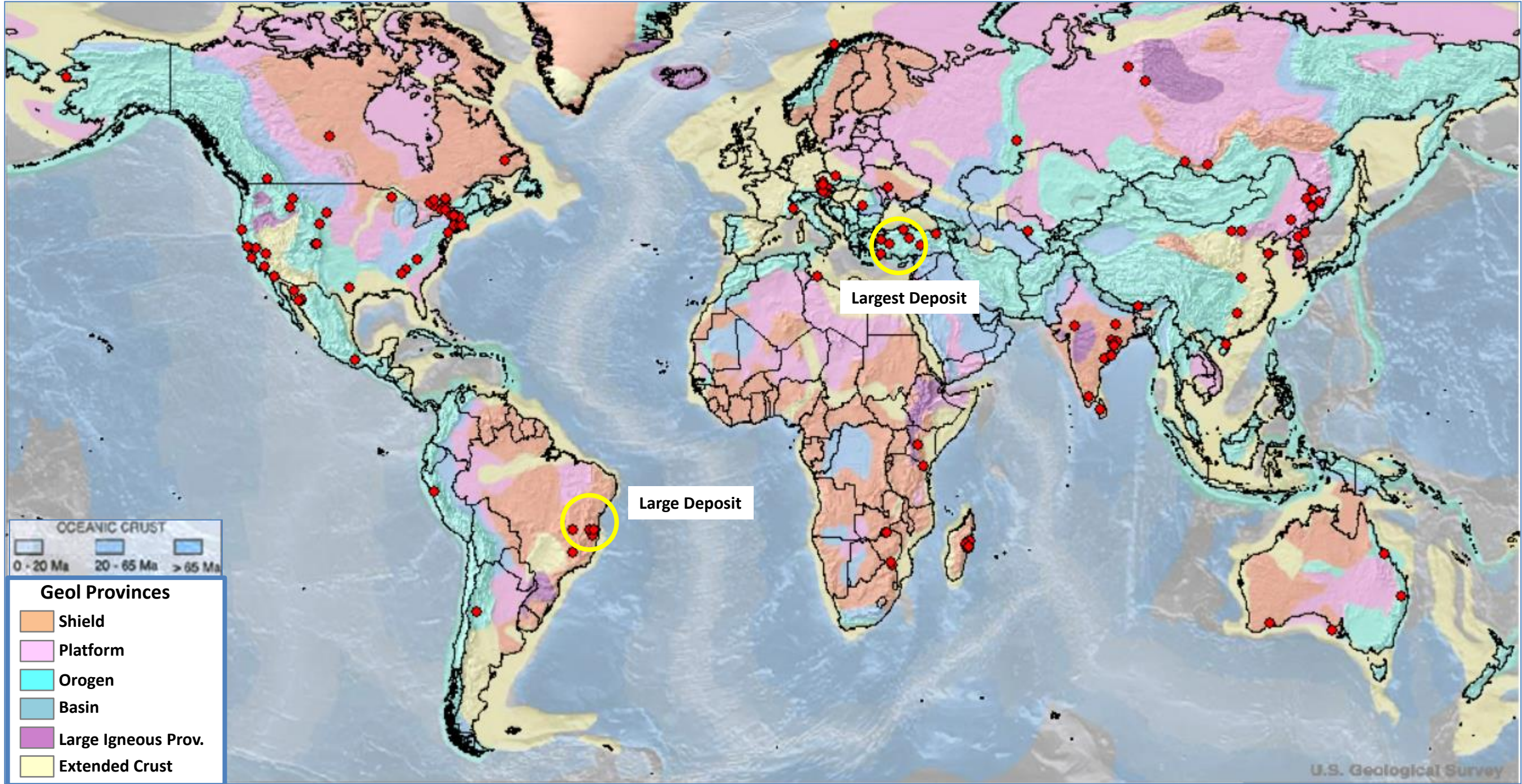


Balamba Mine Mozambique



# Graphite

## Province Type

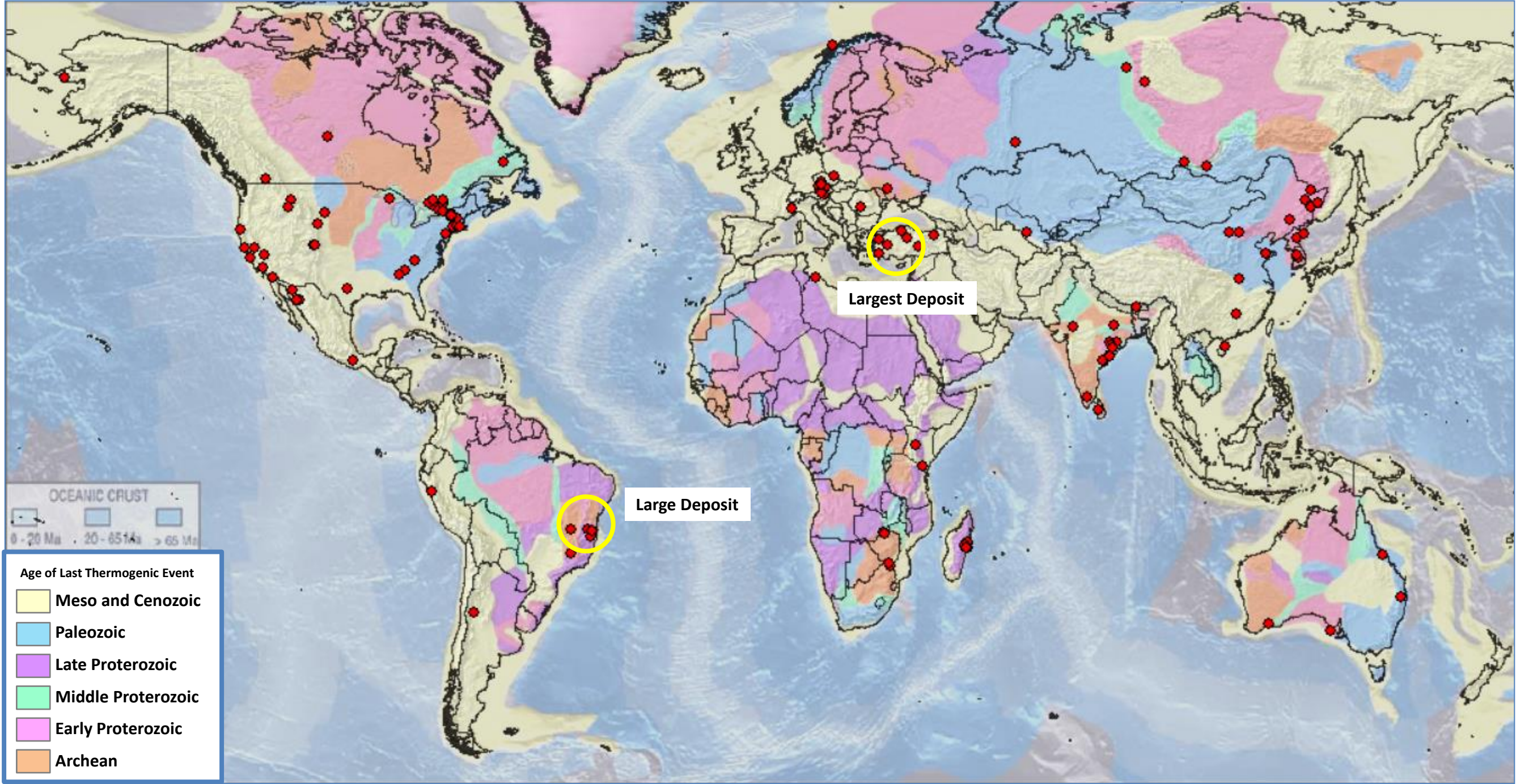


*Indicative Locations of deposits based on USGS data (may not be comprehensive)*



# Graphite

## Age of Last Thermogenic Event

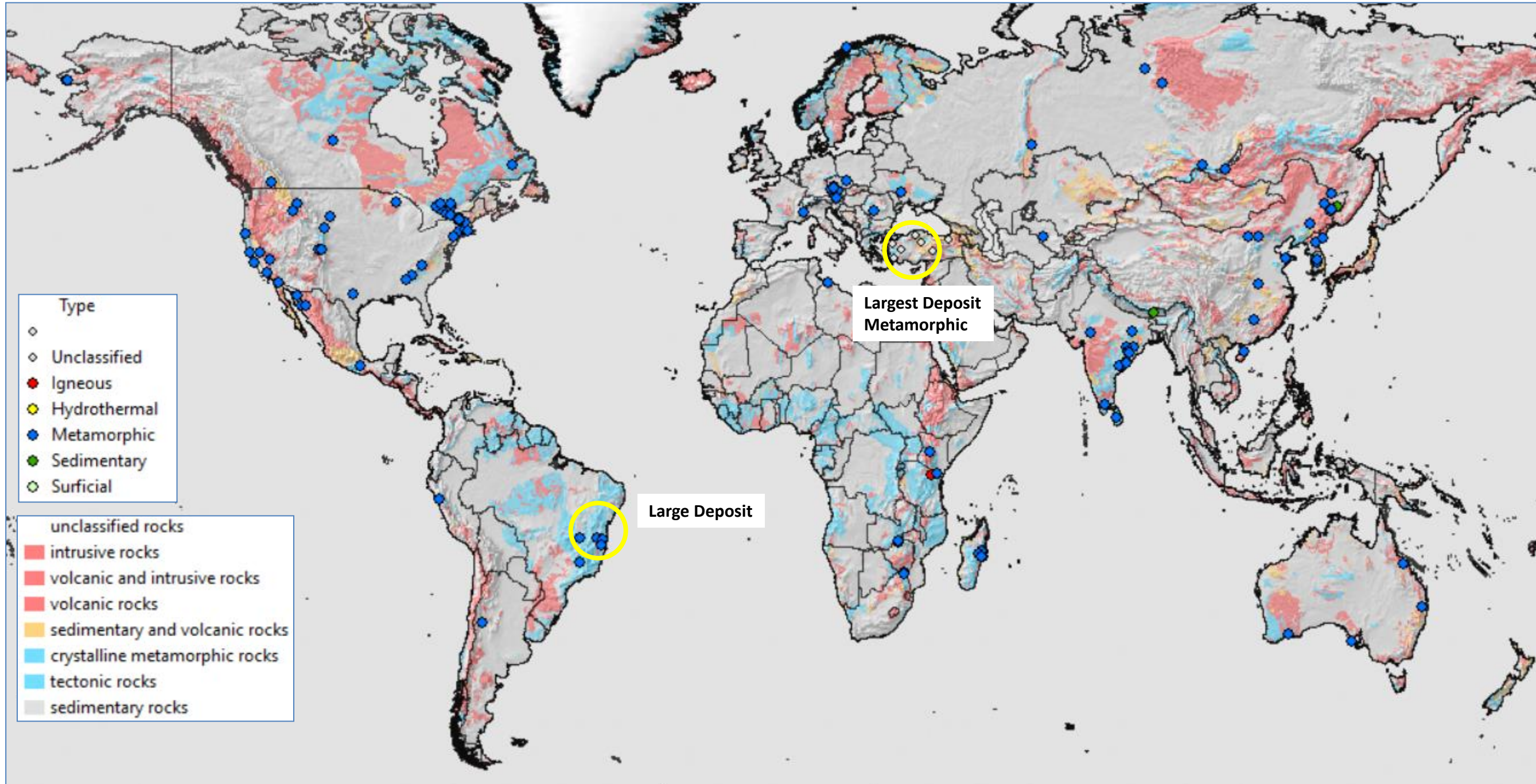


*Indicative Locations of deposits based on USGS data (may not be comprehensive)*



# Graphite

## Type of Deposit

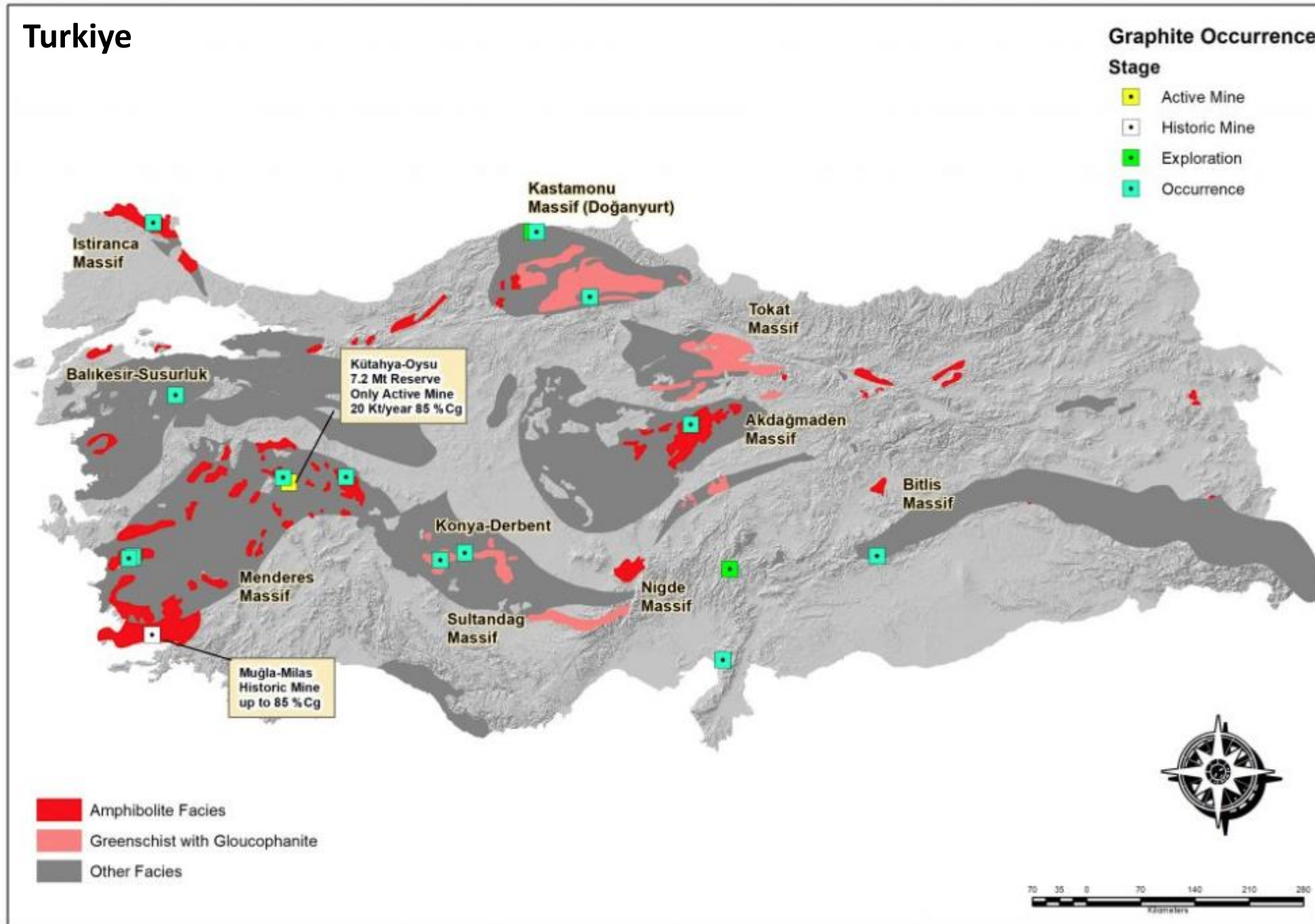


*Indicative Locations of deposits based on USGS data (may not be comprehensive)*



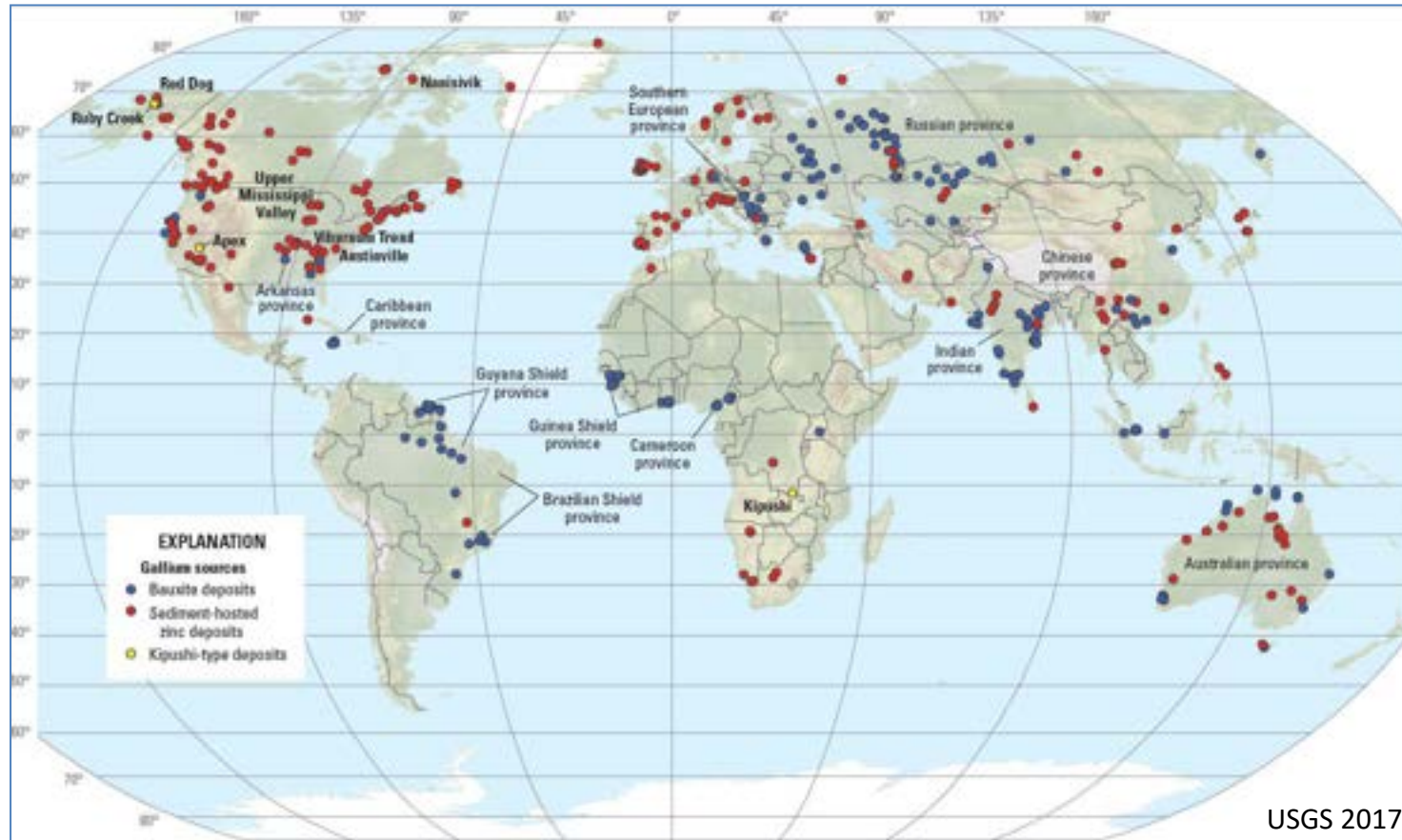
# World's Largest Deposits

## Graphite





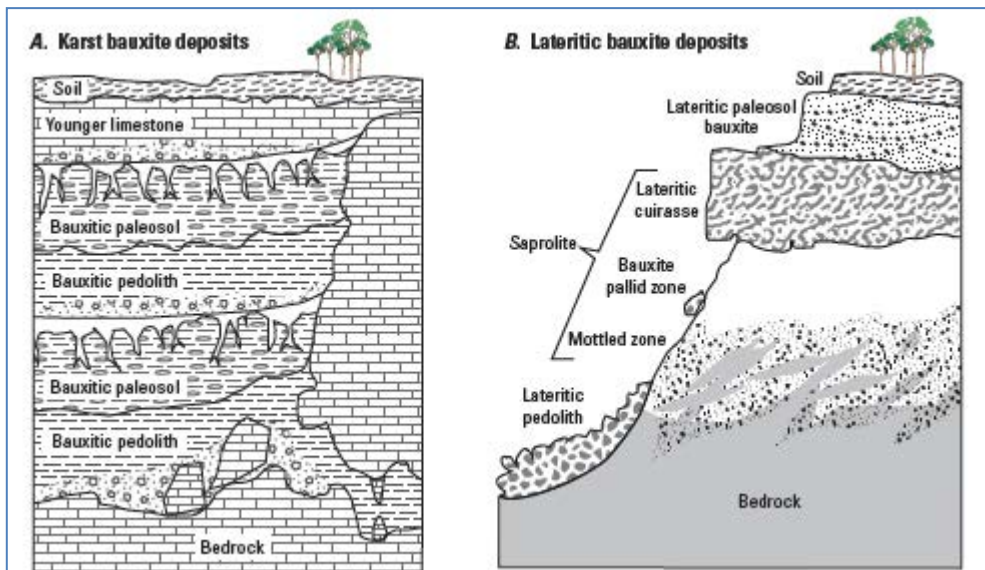
# Gallium



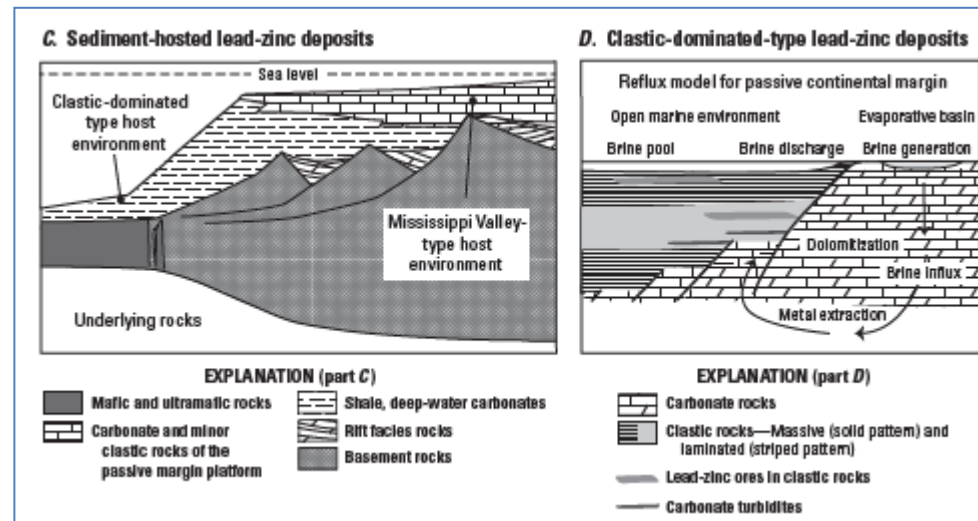
Gallium is dispersed in small amounts in many minerals and rocks where it substitutes for elements of similar size and charge, such as aluminum and zinc. For example, gallium is found in small amounts (about 50 parts per million) in such aluminum-bearing minerals as diaspore-boehmite and gibbsite, which form bauxite deposits, and in the zinc-sulfide mineral sphalerite, which is found in many mineral deposits.

At the present time, gallium metal is derived mainly as a byproduct of the processing of bauxite ore for aluminum; lesser amounts of gallium metal are produced from the processing of sphalerite ore from three types of deposits (sediment-hosted, Mississippi Valley-type, and volcanogenic massive sulfide) for zinc. (USGS 2017)

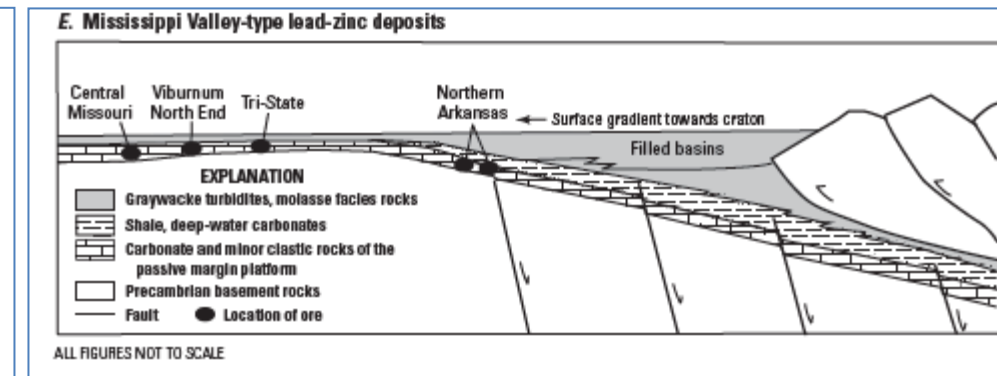
Although the main supply of this metal is as a by-product of the mining of bauxite, it is also known that Gallium can be concentrated by magmatic-hydrothermal processes in peralkaline igneous systems. (Timofeev n William-Jones 2015)



USGS 2017



USGS 2017



USGS 2017



Gallium is a relatively rare metal and is not commonly found in large, economically viable deposits like some other metals. It is often produced as a byproduct of aluminum and zinc ore processing. As such, the primary tectonic settings associated with gallium are those where aluminum and zinc deposits are formed. Here are some general associations:

### **Bauxite Deposits (Aluminum Ore):**

**Tectonic Setting:** Bauxite deposits, the main source of aluminum, are associated with tropical and subtropical weathering environments on stable continental platforms.

**Formation:** Gallium is often found in trace amounts within bauxite deposits, which form through the weathering of aluminum-rich rocks, usually under warm and humid conditions.

### **Sphalerite (Zinc Ore) Deposits:**

**Tectonic Setting:** Sphalerite deposits, which are a source of zinc and may contain gallium as a byproduct, can be found in various geological settings.

**Formation:** Gallium can be present in sphalerite ores, especially those associated with hydrothermal vein deposits. The gallium content in sphalerite can vary, and its economic significance depends on the specific deposit.

### **Rare-Earth Element Deposits:**

**Tectonic Setting:** Gallium can also be associated with rare-earth element (REE) deposits, as some REE minerals may contain gallium.

**Formation:** Certain rare-earth minerals, such as gallium-bearing sphalerite or gallium-rich minerals like gallite, can be found in association with REE deposits.

These deposits may occur in alkaline igneous rocks or carbonatite complexes.

### **Granitic Pegmatites:**

**Tectonic Setting:** Gallium can occur in granitic pegmatites, which are often associated with various tectonic settings.

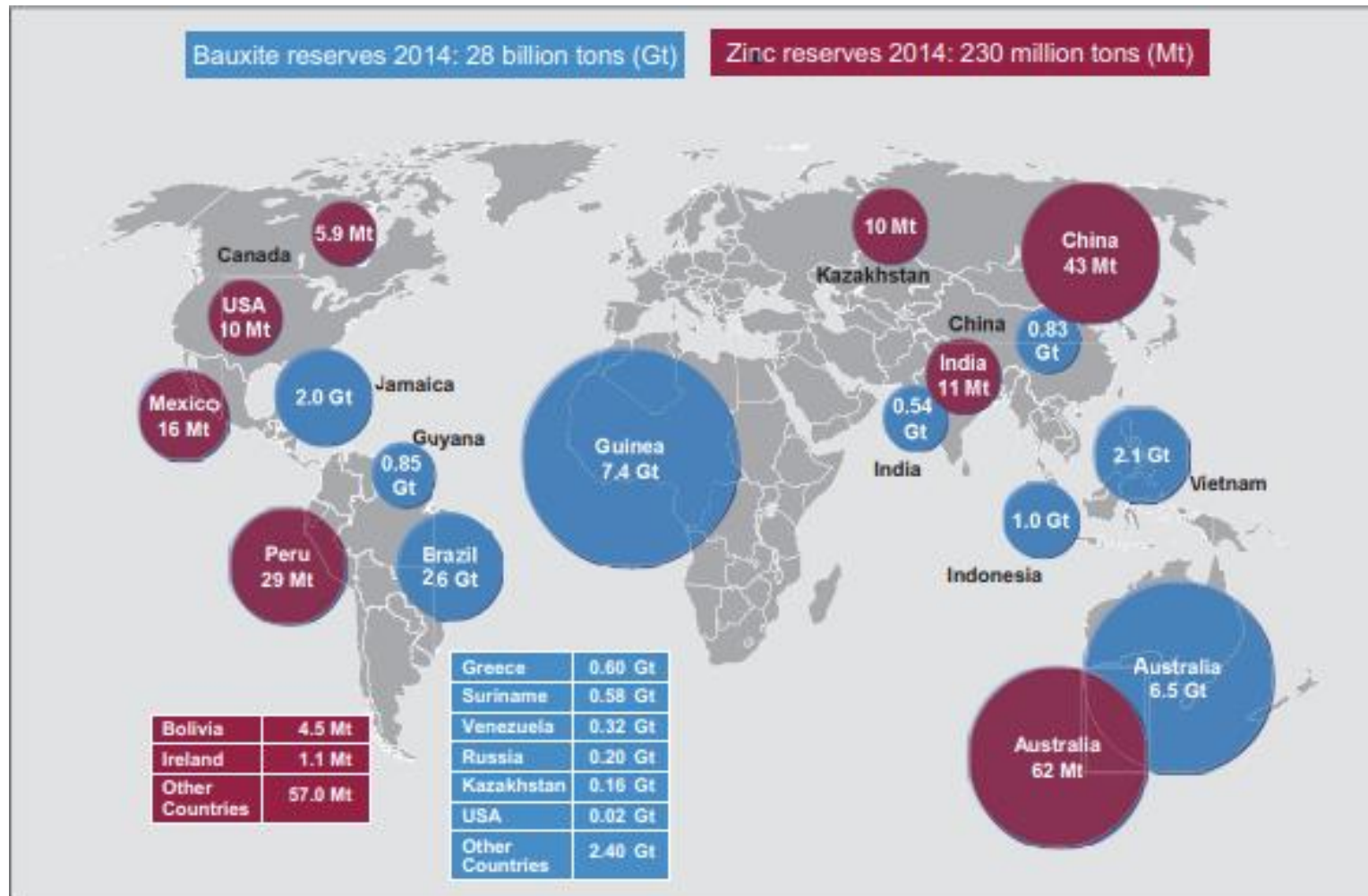
**Formation:** Gallium may be found in trace amounts within specific minerals in granitic pegmatites. However, the economic significance of gallium in pegmatites is generally low.

It's important to note that while gallium can be found in these various geological settings, its primary sources are often associated with the extraction of aluminum and zinc. Gallium is typically produced as a byproduct during the processing of bauxite for aluminum production and the refining of zinc ores. Due to its scarcity, gallium is not typically mined independently, and its production is closely tied to the demand for aluminum and zinc.



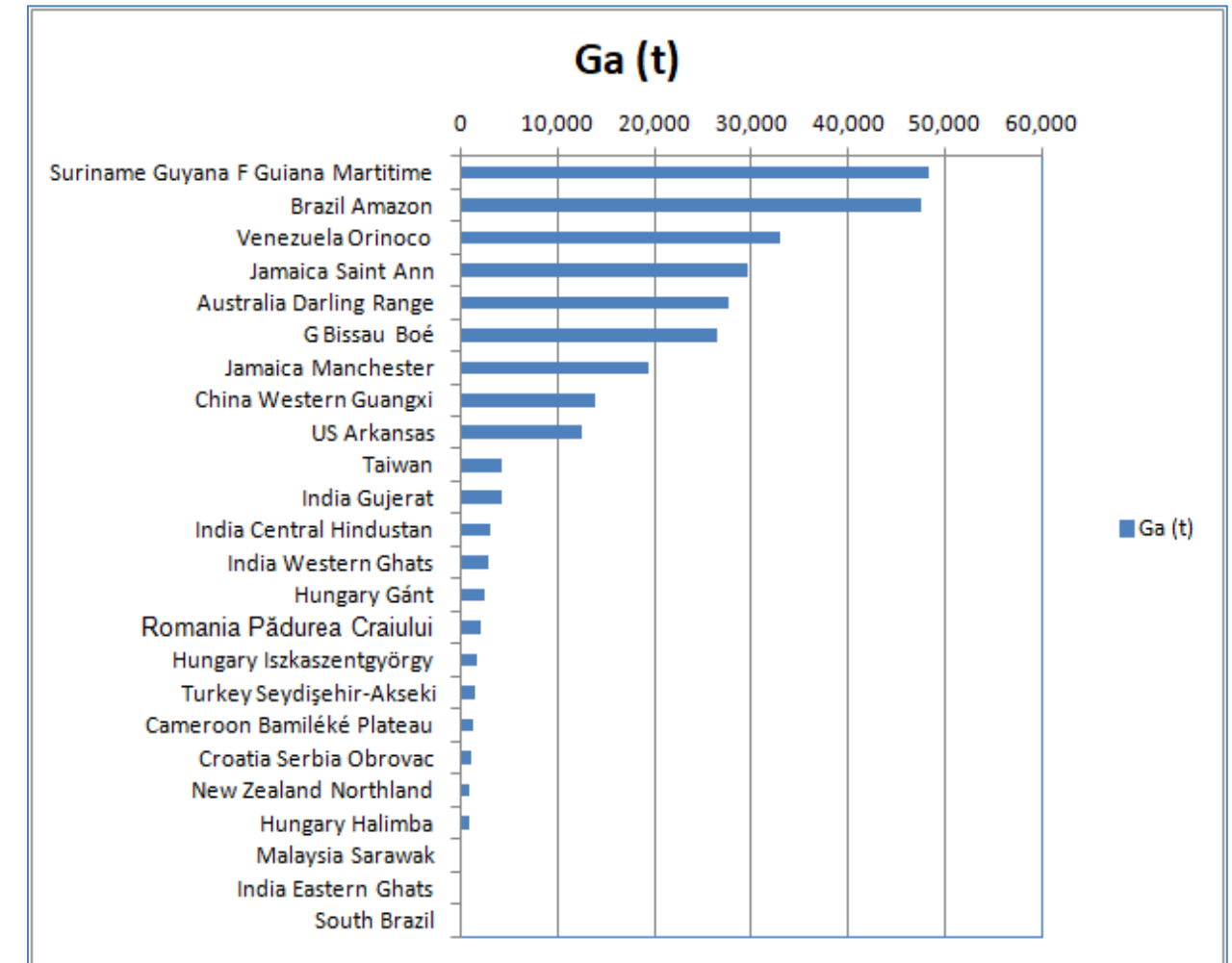
# Gallium

Most gallium is produced as a byproduct of processing bauxite, and the remainder is produced from zinc-processing residues (USGS 2022).



M Tanchum 2023 X post

## USGS Est Ga Reserves in Global Bauxite Deposits



USGS 2013

Gallium contained in world resources of bauxite is estimated to exceed 1 million tons, and a considerable quantity could be contained in world zinc resources. However, less than 10% of the gallium in bauxite and zinc resources is potentially recoverable. (USGS 2022)

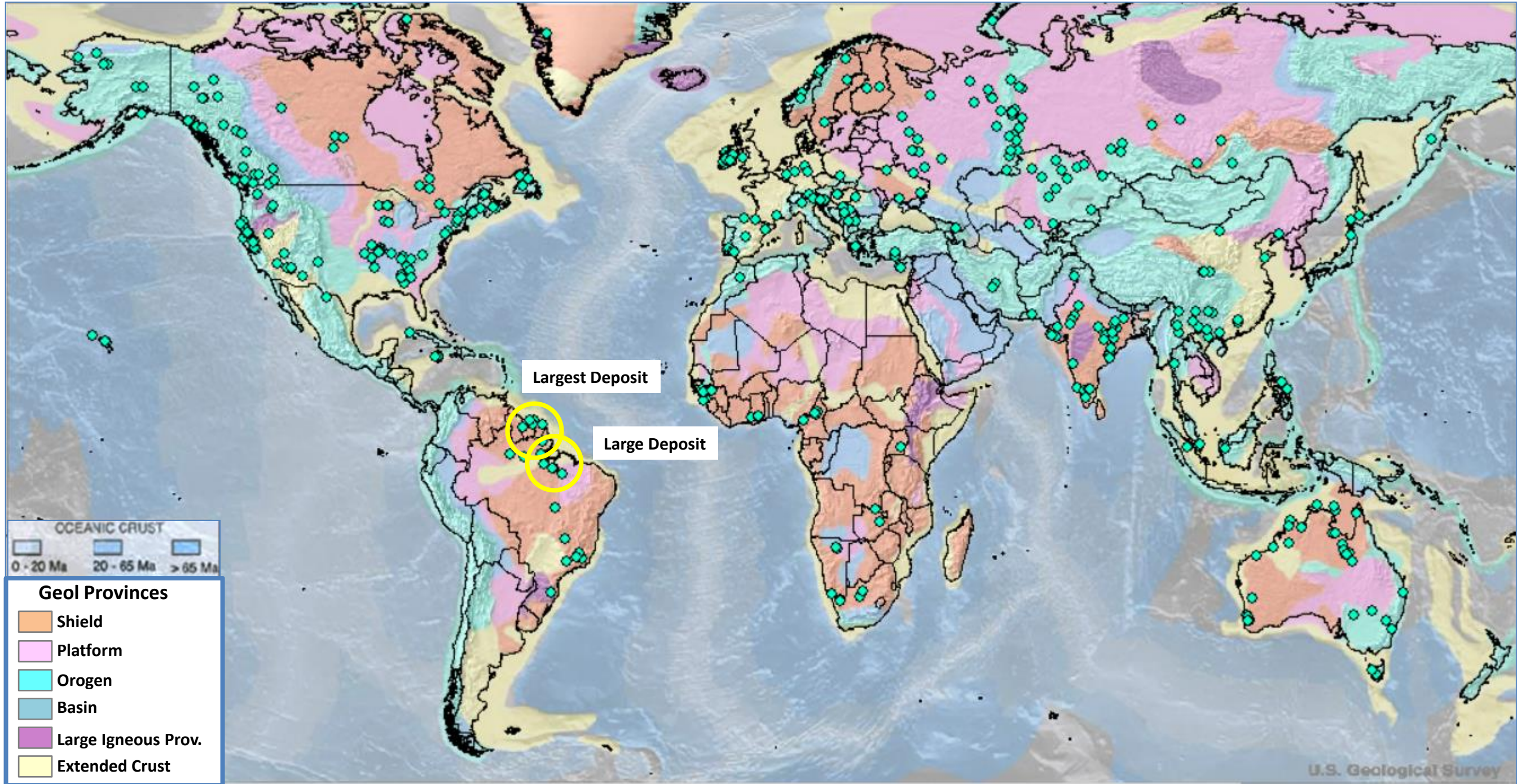
	Primary production kg		Reserves <sup>6</sup>
	2020	2021*	
United States	—	—	Quantitative estimates of reserves are not available.
China	317,000	420,000	
Japan	3,000	3,000	
Korea, Republic of	2,000	2,000	
Russia	5,000	5,000	
World total (rounded)	327,000	430,000	

USGS 2022



# Gallium

## Province Type

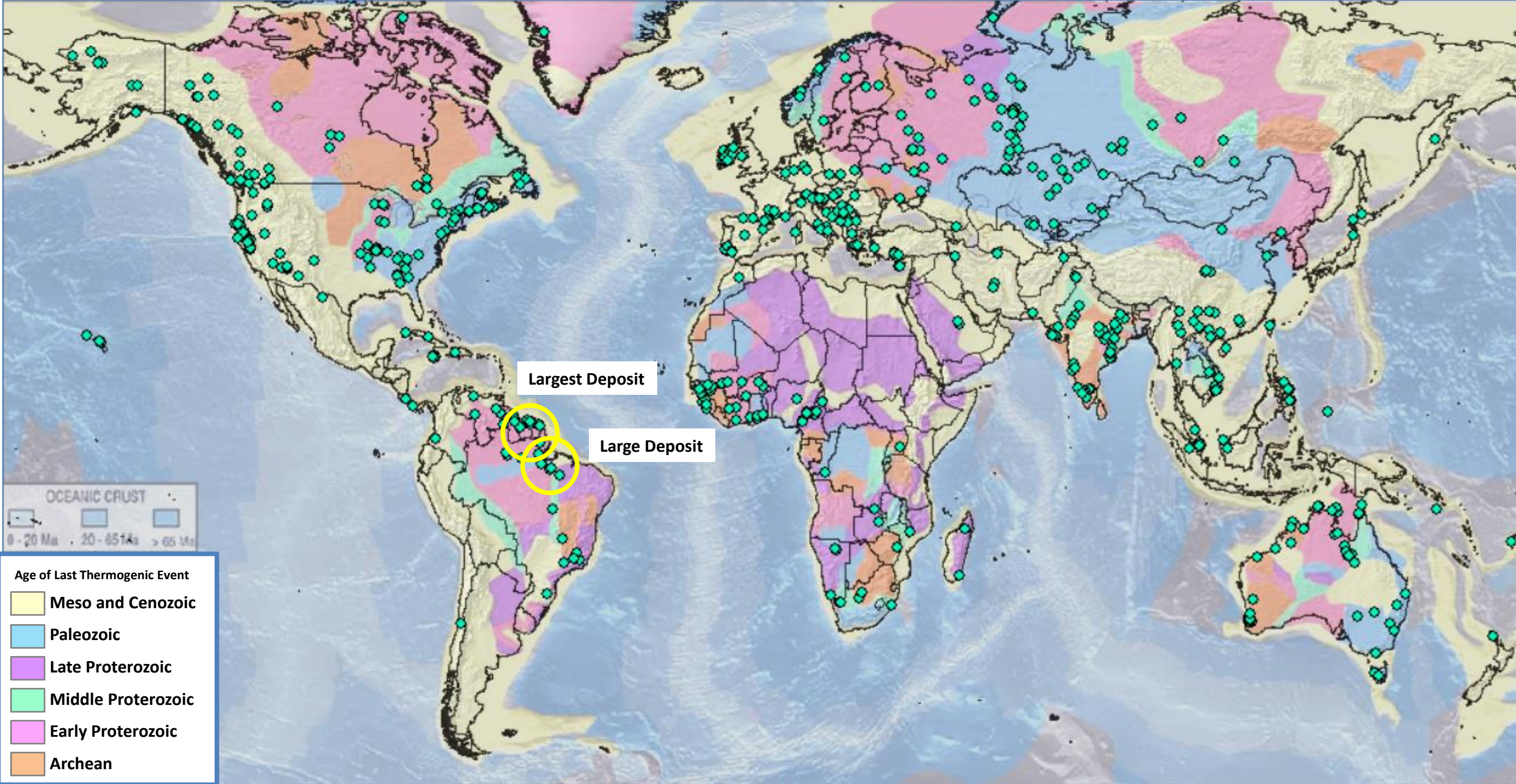


*Indicative Locations of deposits based on USGS data (may not be comprehensive)*



# Gallium

## Age of Last Thermogenic Event

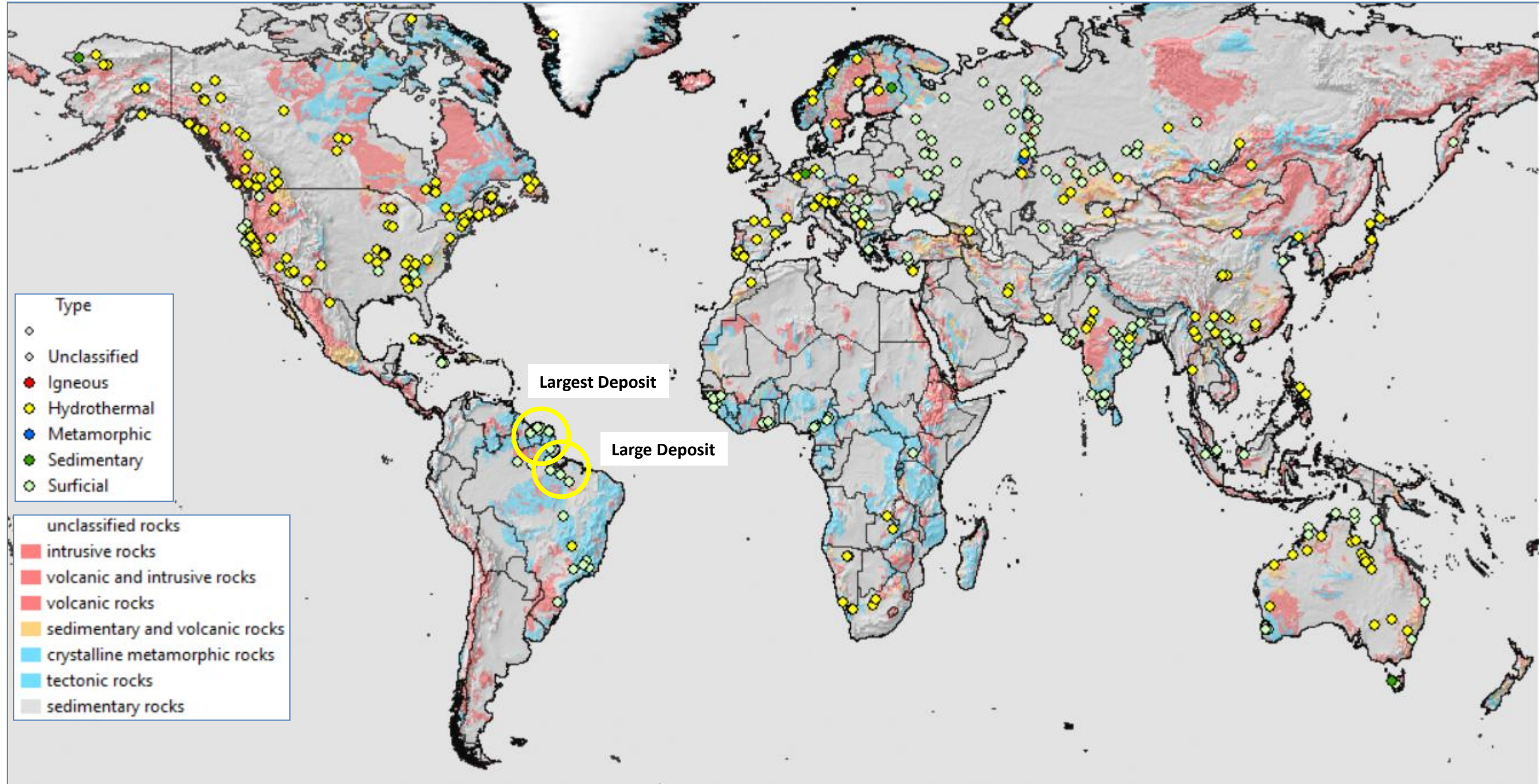


*Indicative Locations of deposits based on USGS data (may not be comprehensive)*



# Gallium

## Type of Deposit



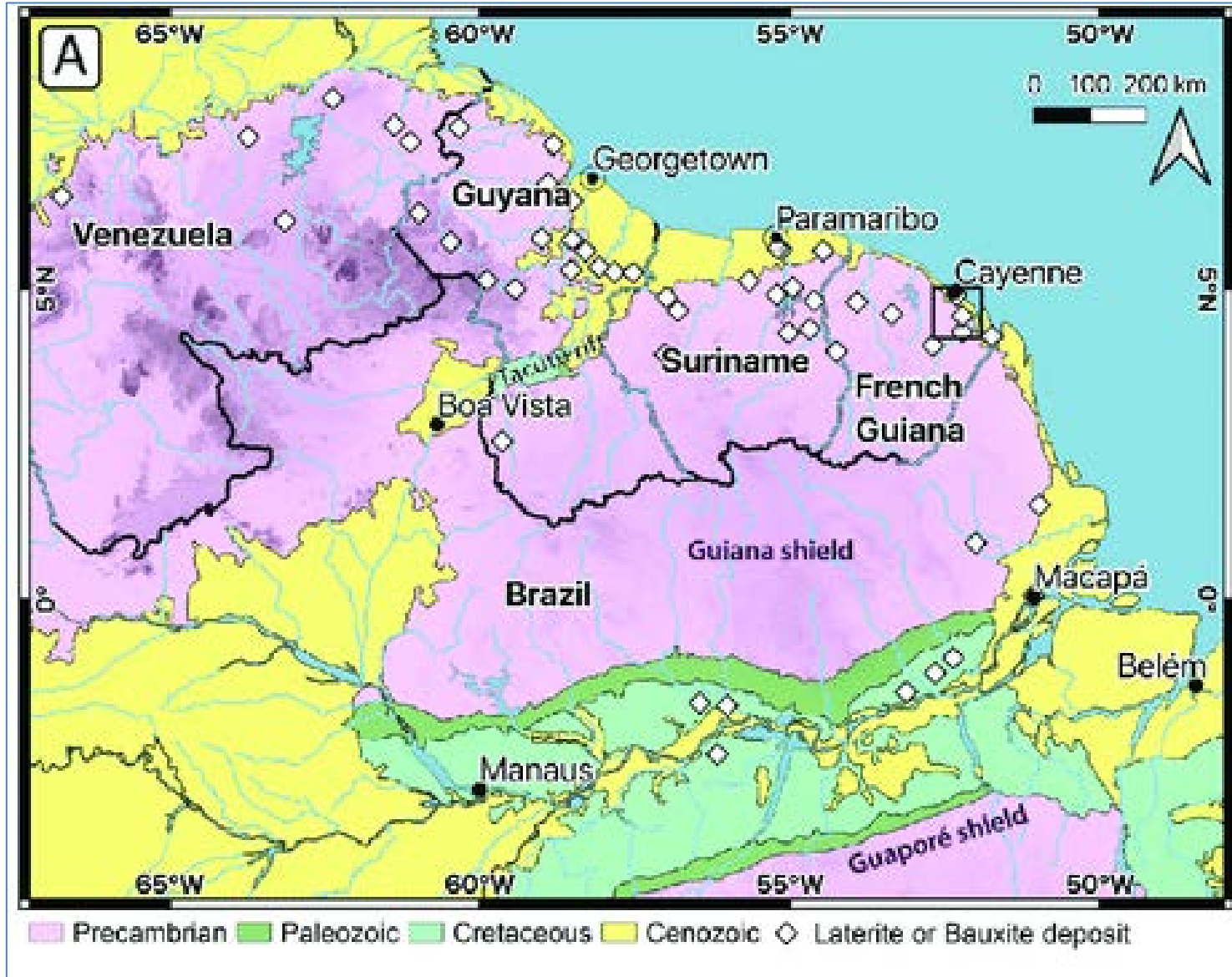
Indicative  
Locations of  
deposits based  
on USGS data  
(may not be  
comprehensive)



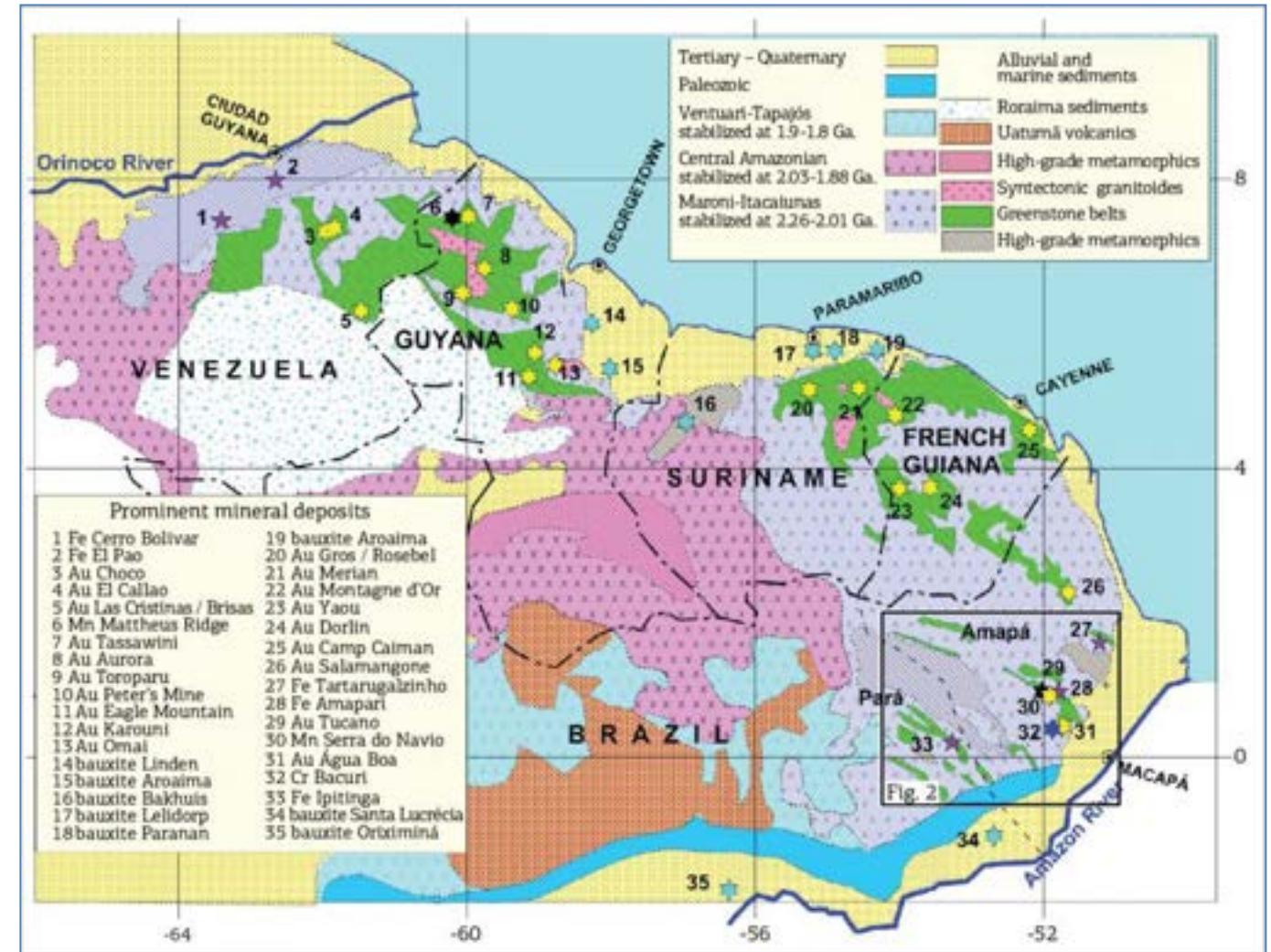
# World's Largest Deposits

## Gallium

### Bauxite associated Gallium



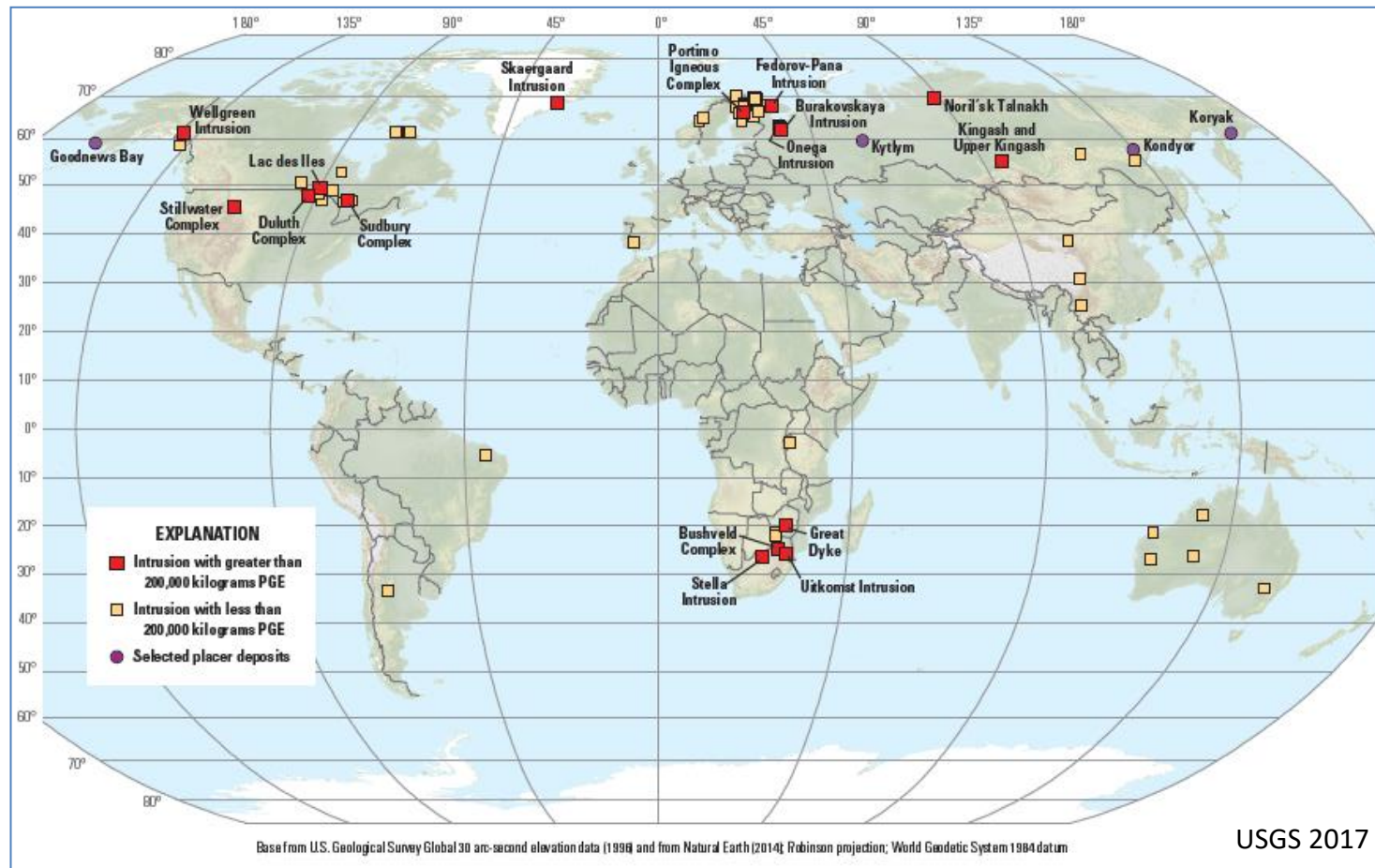
Heller et al 2022, Gomez et al 2019



Scarpelli n Horikava 2017



# Platinum Gp



Almost all the reported Platinum Group Elements production and identified resources are associated with deposits in three geologic features—the Bushveld Complex, which is a layered mafic to ultramafic intrusion in South Africa; the Great Dyke, which is a layered mafic to ultramafic intrusion in Zimbabwe; and sill-like intrusions associated with flood basalts in the Noril'sk-Talnakh area of Russia.

PGE enriched mineral deposit types: (a) magmatic—formed during the cooling and crystallization of magma, (b) hydrothermal—formed by the interaction of hot water and rock, (c) sedimentary—formed by the precipitation or settling of minerals directly from water in oceans or lakes, (d) residual—formed by the intense weathering of rocks under hot, humid conditions, and (e) placers—formed by the physical concentration of heavy particles of rocks or minerals by the action of moving water.

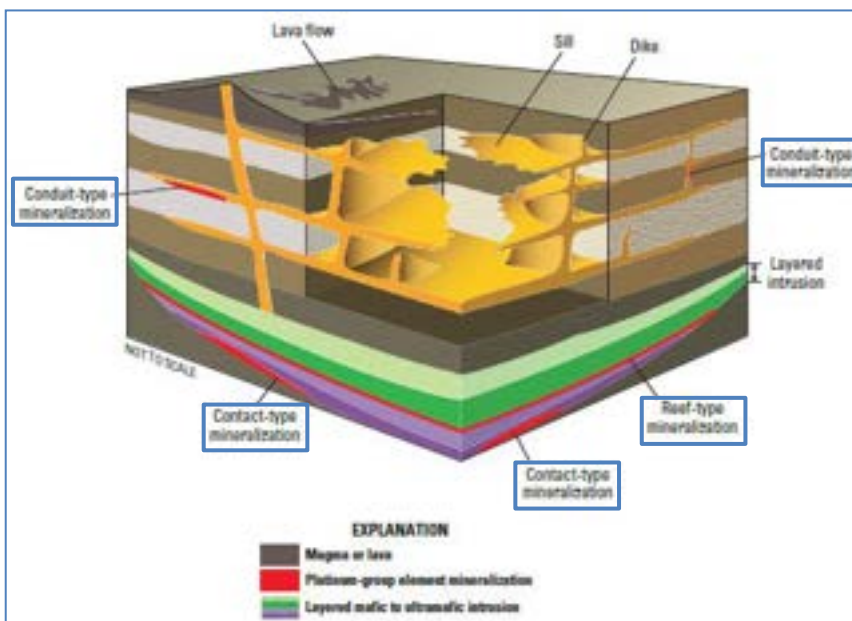
Magmatic deposits are the source of almost all the PGEs recovered by mining currently. Most magmatic copper-nickel-PGE deposits occur with continental flood basalts, aerially extensive mafic dike swarms, sill provinces, and large layered ultramafic-to-mafic intrusions, which are indicative of large igneous provinces (LIPs). Magmatic mined deposits associated with LIP-related igneous intrusions are divided into types based on such criteria as the lithology and form of associated igneous rocks, the depth of emplacement, the abundance of sulfide minerals, the relative proportion of metals, and the position of the ores within the intrusion. The 3 main types are conduit-type deposits, which occur in intrusions that are part of sill complexes and dike swarms, and reef-type (Sheet-like) and contact-type deposits, which occur in layered intrusions. The largest number of these deposits are found in intrusions of Archean and Paleoproterozoic age

The conduit-type deposits of the Noril'sk-Talnakh area of Russia are associated with an enormous outpouring of mafic magma that formed the Siberian Traps—the largest continental flood basalt province on Earth.

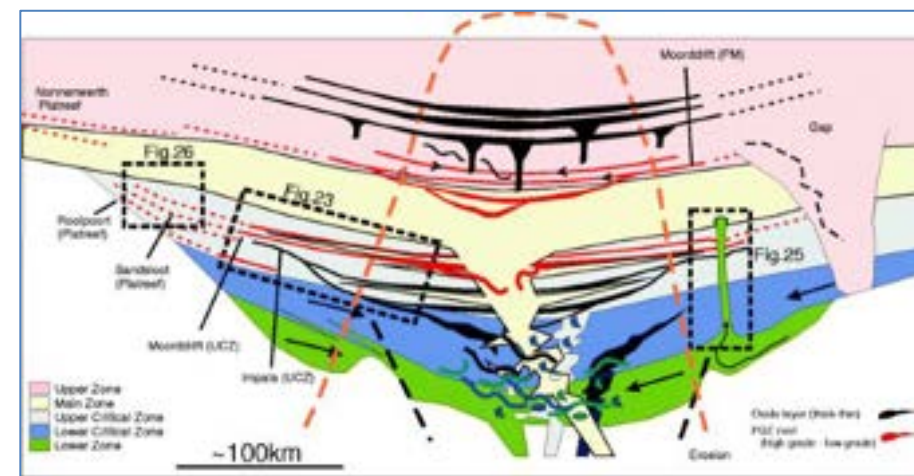
Reef-type PGE deposits are disseminated copper-, iron-, nickel-, and PGE-bearing minerals that are associated with one or more strata within a layered igneous intrusion; South Africa Merensky Reef and the UG2 Chromitite, Zimbabwe (the Main Sulphide Zone), and Montana (the J-M Reef)

Copper-nickel-PGE contact-type deposits consist of disseminated magmatic sulfide minerals found near the lower contact or margin of mafic to ultramafic layered intrusions; South Africa (the Platreef) and Minnesota (the Duluth Complex).

USGS 2017



## Bushveld Complex, S Africa





Platinum deposits are primarily associated with specific geological environments and tectonic settings. Platinum is a precious metal that is often found in association with other platinum group elements (PGEs) such as palladium, rhodium, iridium, ruthenium, and osmium. Here are some common tectonic settings where platinum deposits are typically found:

### **Bushveld Complex, South Africa:**

**Tectonic Setting:** The Bushveld Complex is a large layered intrusion in South Africa, and it is one of the most significant sources of platinum in the world.

**Formation:** The Bushveld Complex is an example of a layered mafic-ultramafic intrusion that formed during the early Proterozoic in a continental rift setting. The layers within the intrusion contain economically important concentrations of platinum group elements, including platinum, palladium, and rhodium.

### **Stillwater Complex, United States:**

**Tectonic Setting:** The Stillwater Complex in Montana, United States, is another major source of platinum group elements.

**Formation:** Similar to the Bushveld Complex, the Stillwater Complex is a layered intrusion that formed during the early Proterozoic in a continental rift setting. It contains layers with significant concentrations of platinum and other PGEs.

### **Merensky Reef and UG2 Chromitite Layer:**

**Tectonic Setting:** Platinum deposits are often associated with specific layers within mafic-ultramafic intrusions.

**Formation:** The Merensky Reef and the UG2 chromitite layer in the Bushveld Complex are examples of such layers. These layers, rich in platinum group elements, formed through various magmatic and fractional crystallization processes within the intrusions.

### **Alaskan-type Intrusions:**

**Tectonic Setting:** Some platinum deposits are associated with Alaskan-type intrusions, which are intrusions in convergent tectonic settings.

**Formation:** These intrusions are characterized by mafic-ultramafic rocks and are associated with subduction zones. They can contain economically significant concentrations of platinum group elements.

### **Ophiolite Complexes:**

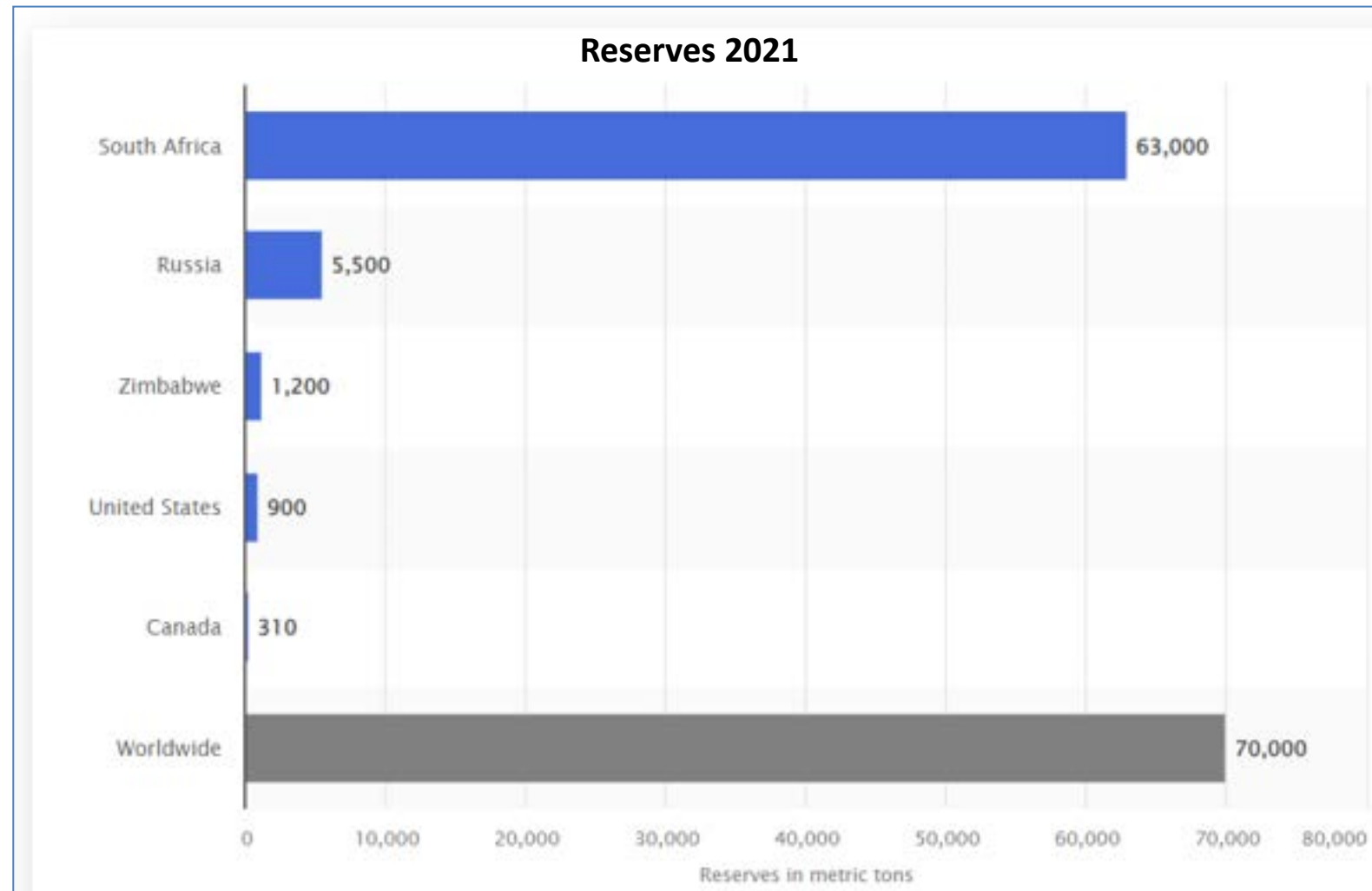
**Tectonic Setting:** Ophiolite complexes, which are fragments of oceanic lithosphere emplaced onto continental crust, can host platinum deposits.

**Formation:** Platinum mineralization in ophiolites is often associated with chromite deposits. These complexes may have formed in various tectonic settings, including mid-ocean ridges and subduction zones.

It's important to note that platinum deposits can occur in a variety of geological settings, and their formation is influenced by complex magmatic and tectonic processes. The economic viability of platinum mining depends on factors such as the grade of the deposit, accessibility, and market demand. Additionally, platinum is often found in association with other valuable metals, contributing to the overall economic significance of platinum group element deposits.



## Global Platinum Extraction and Reserves 2021

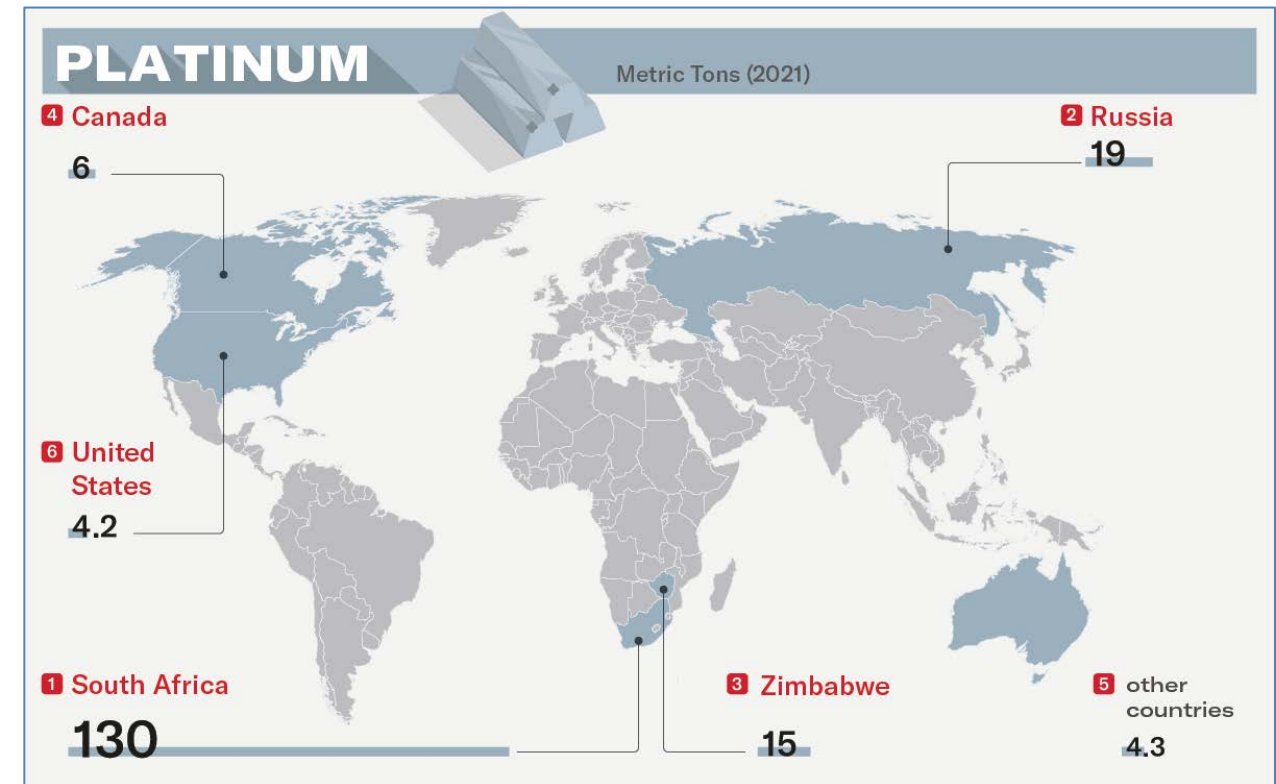


statistica.com

### Iridium forms part of the Platinum Group of Elements

In 2018 South Africa accounted for 87% of global iridium production, with a further 8% coming from Zimbabwe and 3% each from Russia and Canada, according to the US Geological Survey. 2019 worldwide Iridium production totaled 242,000 oz (6.8 tonnes)

## Production 2021



Madison Trust



Platinum Ore

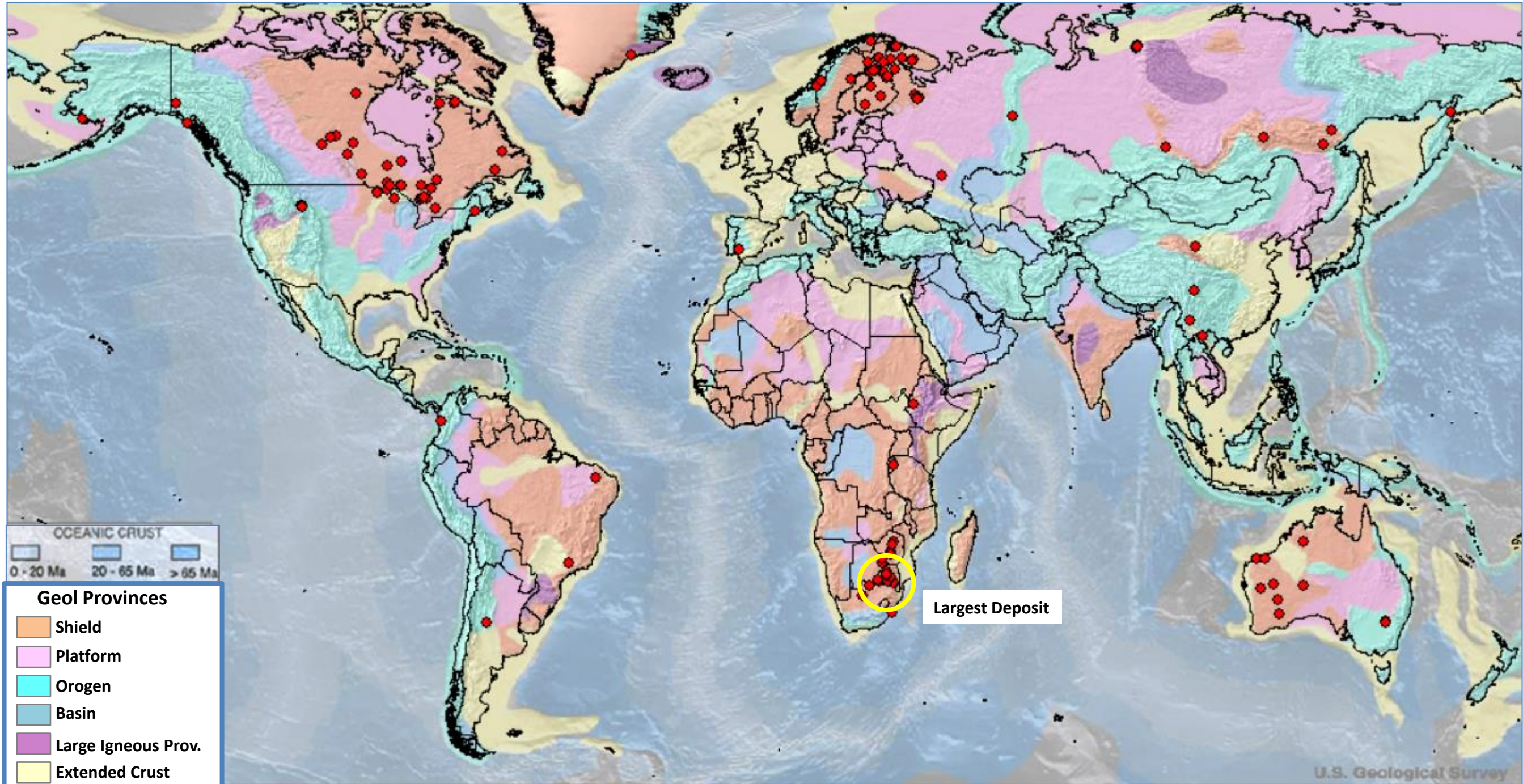


Mogolokwena Mine South Africa



# Platinum Gp

## Province Type

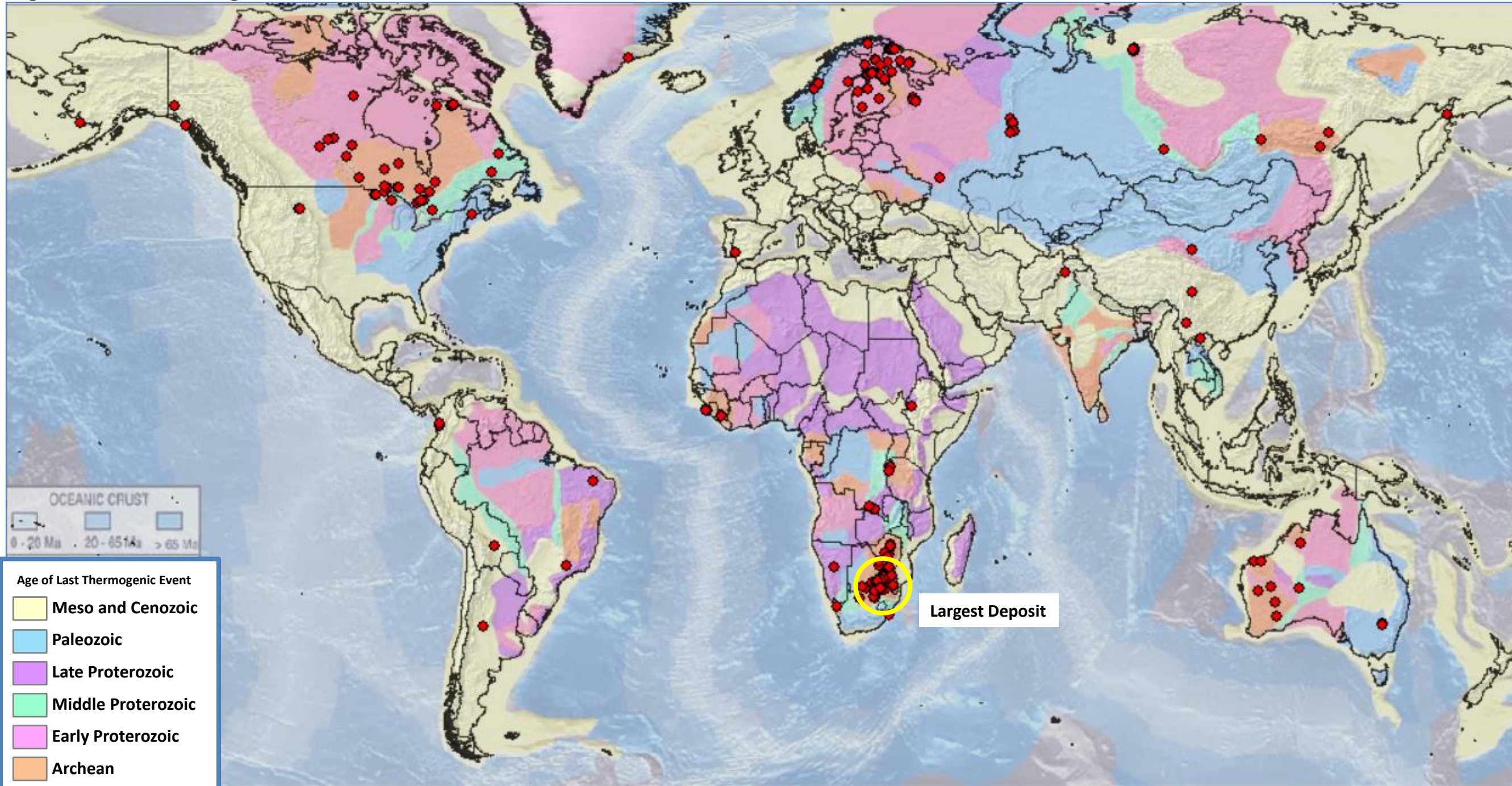


*Indicative  
Locations of  
deposits based  
on USGS data  
(may not be  
comprehensive)*



# Platinum Gp

## Age of Last Thermogenic Event

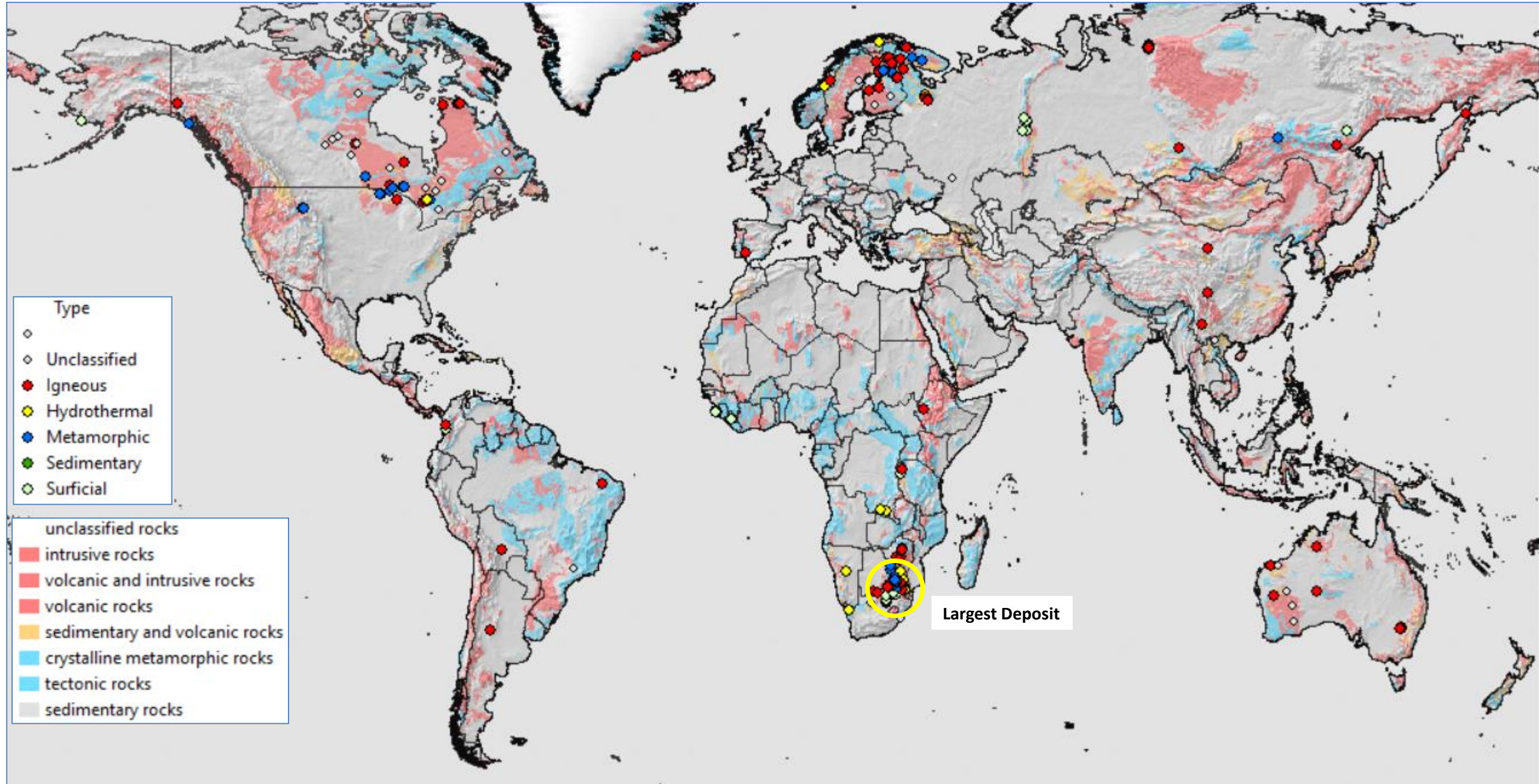


*Indicative  
Locations of  
deposits based  
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comprehensive)*



# Platinum Gp

## Type of Deposit



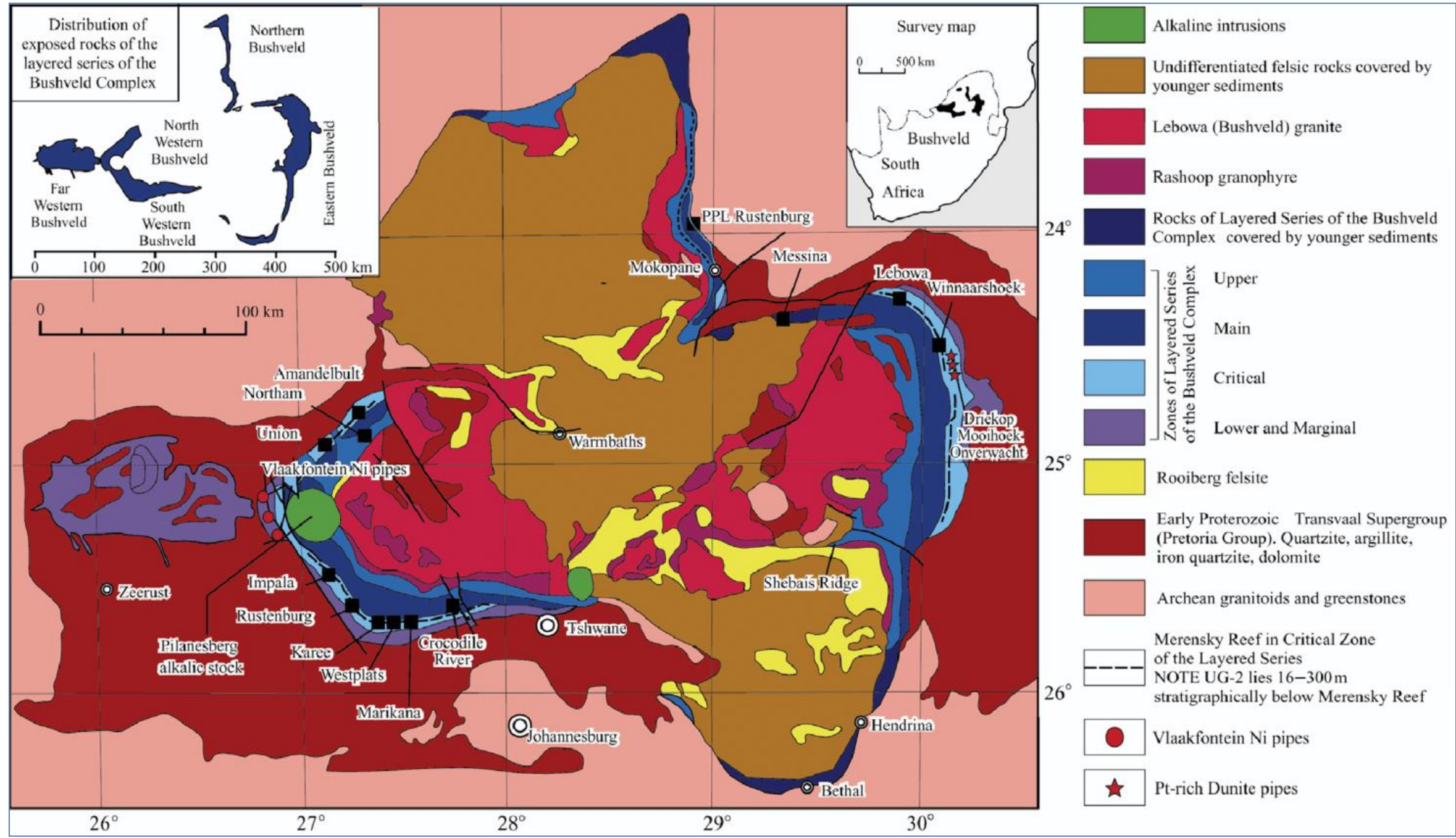
Indicative Locations of deposits based on USGS data (may not be comprehensive)



# World's Largest Deposits

## Bushveld Complex S Africa

Platinum Gp



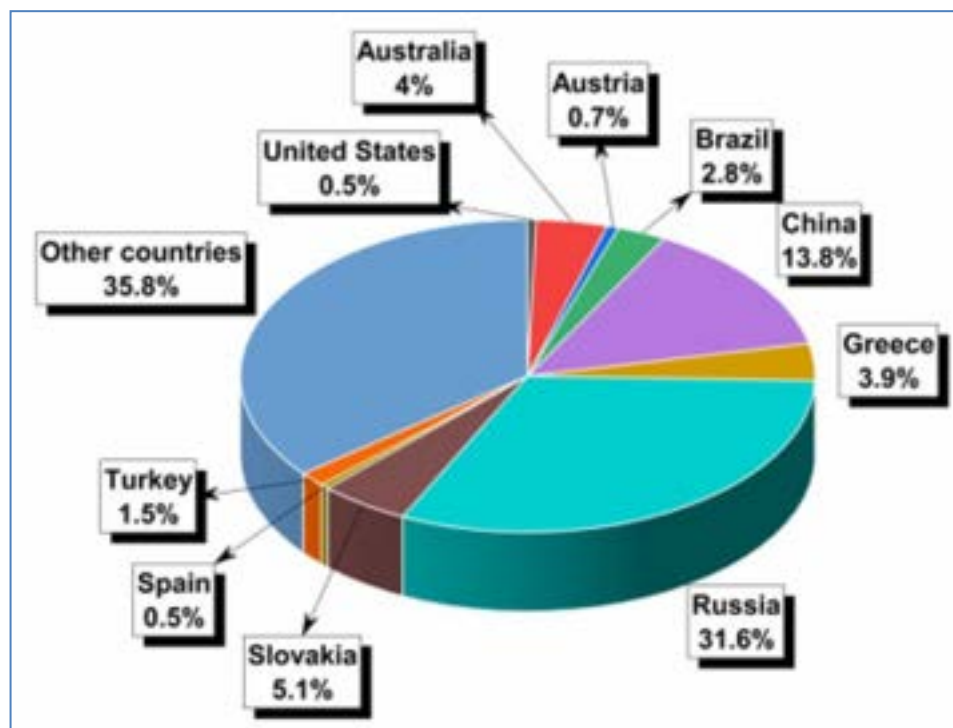
Naldrett et al 2008

Eddy Ong 2024  
Posted on LinkedIn



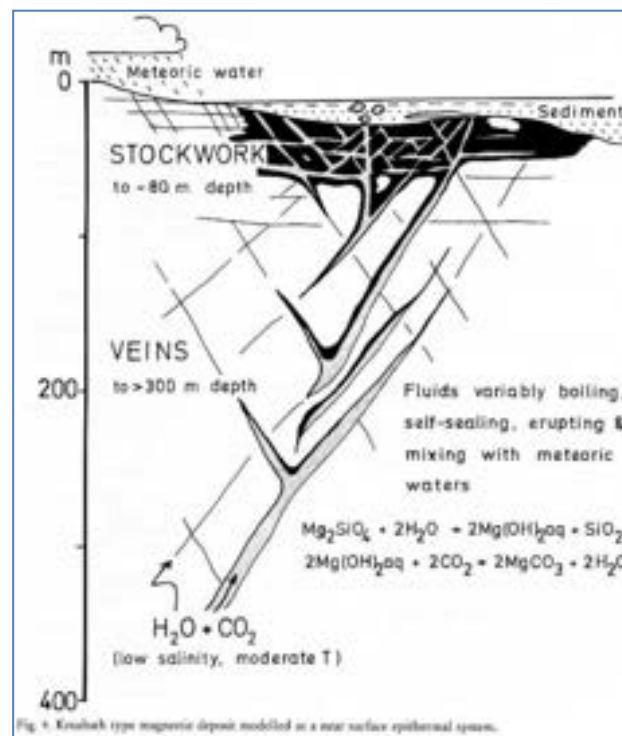
# Magnesium

## World Magnesite Reserves



Onyekwena et al 2023, Clean Tech and Environ Policy

## Kraubath Type



Walter Pohl 1990

Magnesite can be found as a sedimentary rock, a vein filling, an alteration element, and as a replacement mineral.

The world's largest reserves are found in deposits of the Veitsch type. These are strata-bound lensoid and nearly monomineralic ore bodies consisting of coarsely crystalline spar magnesite hosted by marine platform sediments. Formation is associated with subtidal evaporitic environments. Coarse crystals are a product of diagenesis.

Magnesite is also found as veins in ultramafic rocks, serpentinites, and other magnesium-rich rocks (Kraubath type). Magnesium-rich olivine (forsterite) favors production of magnesite from peridotite. Iron-rich olivine (fayalite) favors production of magnetite-magnesite-silica compositions.

Magnesite can be present within the regolith above ultramafic rocks as a secondary carbonate within soil and subsoil, where it is deposited as a consequence of dissolution of magnesium-bearing minerals by carbon dioxide in groundwaters.

Magnesite can also be formed by way of metasomatism in skarn deposits, in dolomitic limestones, associated with wollastonite, periclase, and talc.

Magnesite is known to precipitate in lakes in presence of bacteria either as hydrous Mg-carbonates or magnesite.

Walter Pohl 1990, Chemeurope.com  
Scheller et al 2021

## Vietsch Type

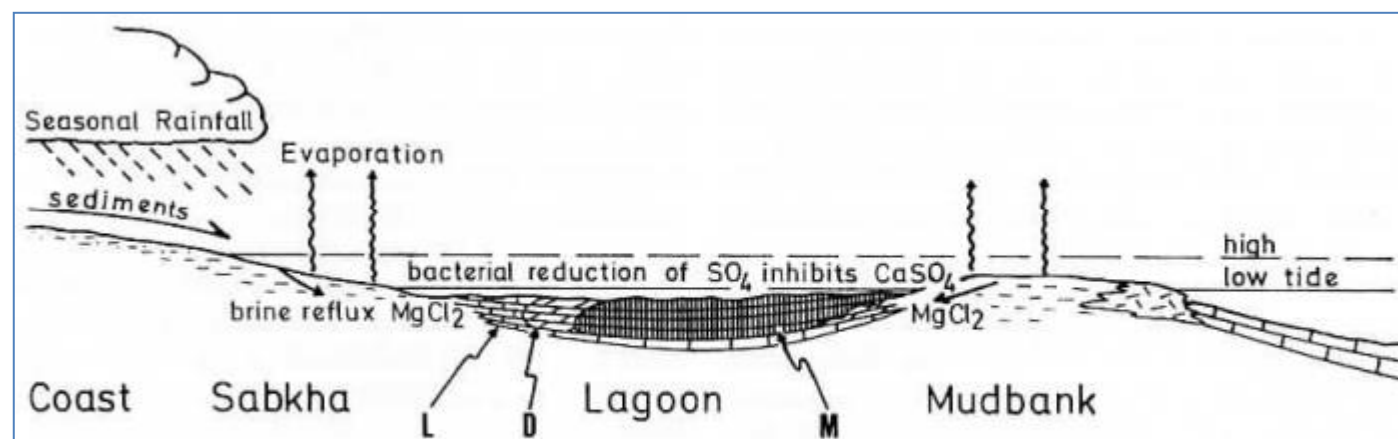
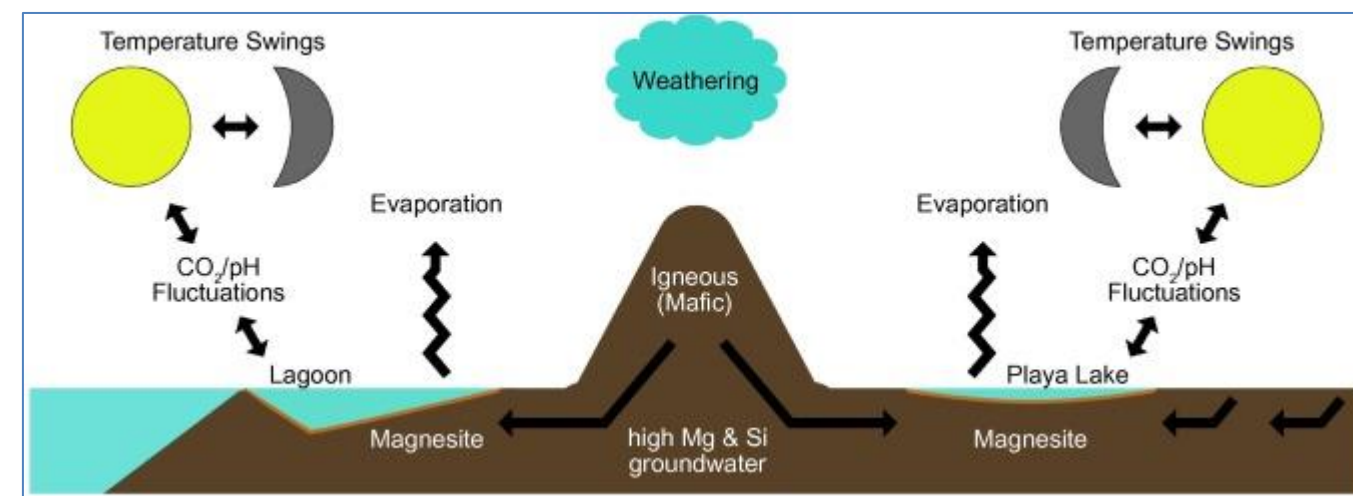


Fig. 2. Veitsch type magnesite deposit modelled as a close relative of shallow water marine chloride type evaporites. M - magnesite; D - dolomite; L - limestone.

Walter Pohl 1990



Hobbs n Xu 2020



## Working with ChatGPT

Magnesium is not typically found in large, economically significant deposits like some other metals. Instead, magnesium is more commonly distributed in minerals and rocks, and its extraction is often tied to the mining and processing of magnesium-containing minerals. Here are some general associations with geological settings where magnesium is commonly found:

### **Magnesite Deposits:**

**Tectonic Setting:** Magnesite deposits, the primary source of magnesium, are associated with a variety of tectonic settings.

**Formation:** Magnesite (magnesium carbonate) can form through the alteration of ultramafic rocks, particularly serpentine minerals. These rocks are commonly associated with mantle peridotites and ophiolite complexes, which can be found in various tectonic settings, including mid-ocean ridges and subduction zones.

### **Dolomite Deposits:**

**Tectonic Setting:** Dolomite, a mineral containing magnesium, can be found in sedimentary settings.

**Formation:** Dolomite forms through the chemical replacement of calcium in limestone by magnesium. It is often associated with marine environments, where magnesium-rich seawater interacts with calcium-rich sediments.

### **Serpentinite:**

**Tectonic Setting:** Serpentinite, a rock rich in magnesium, is commonly associated with certain tectonic settings.

**Formation:** Serpentinite forms through the hydration and alteration of ultramafic rocks in settings such as subduction zones or where mantle rocks are exposed at the Earth's surface.

### **Brucite Deposits:**

**Tectonic Setting:** Brucite, another magnesium mineral, can be found in various geological settings.

**Formation:** Brucite can form through the alteration of ultramafic rocks and is often associated with hydrothermal processes.

### **Evaporite Deposits:**

**Tectonic Setting:** Some magnesium compounds, such as magnesium chloride, can be found in evaporite deposits.

**Formation:** Evaporite deposits form in arid climates where the evaporation of seawater or saline lakes concentrates dissolved minerals, including magnesium salts.

### **Igneous and Metamorphic Rocks:**

**Tectonic Setting:** Magnesium is a common constituent of various igneous and metamorphic rocks.

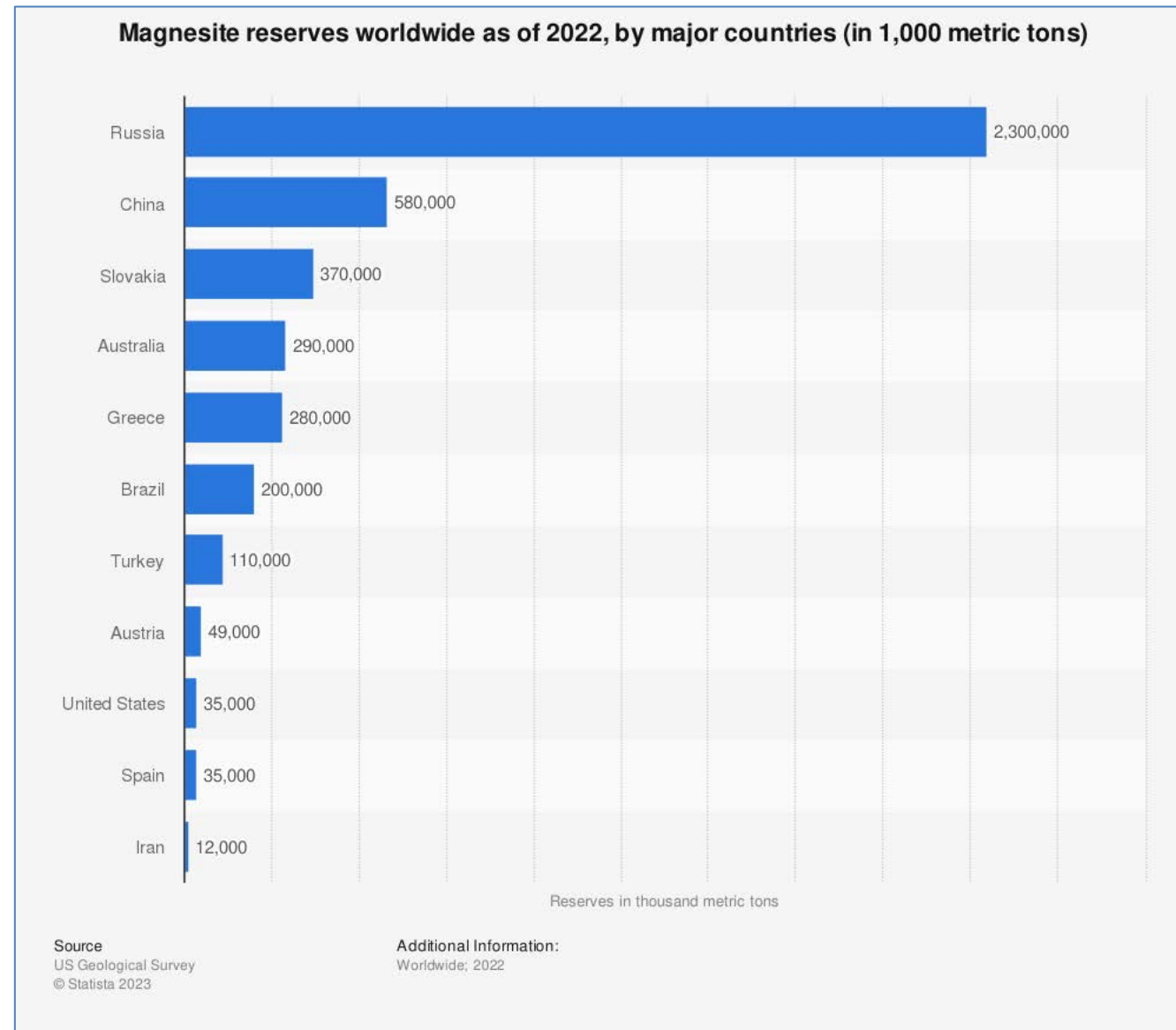
**Formation:** In igneous rocks, magnesium is often found in minerals such as olivine and pyroxene. In metamorphic rocks, it may be present in minerals formed during the alteration of pre-existing rocks.

While magnesium itself is not typically mined independently, the extraction of magnesium compounds is essential for various industrial applications. Magnesium production often involves processing minerals like magnesite or brucite. The geological settings mentioned above highlight where these magnesium-containing minerals are commonly found.

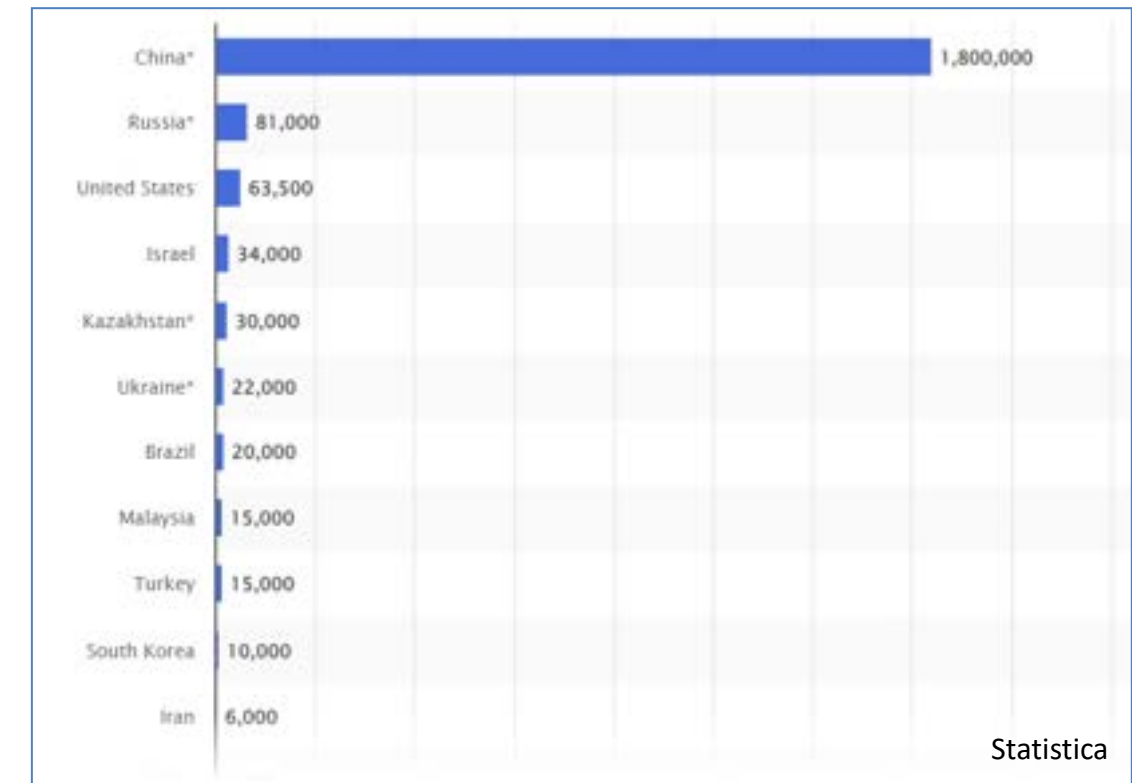


## Global Magnesite Extraction and Reserves 2022

### Reserves 2022



### Production Capacity mt 2021

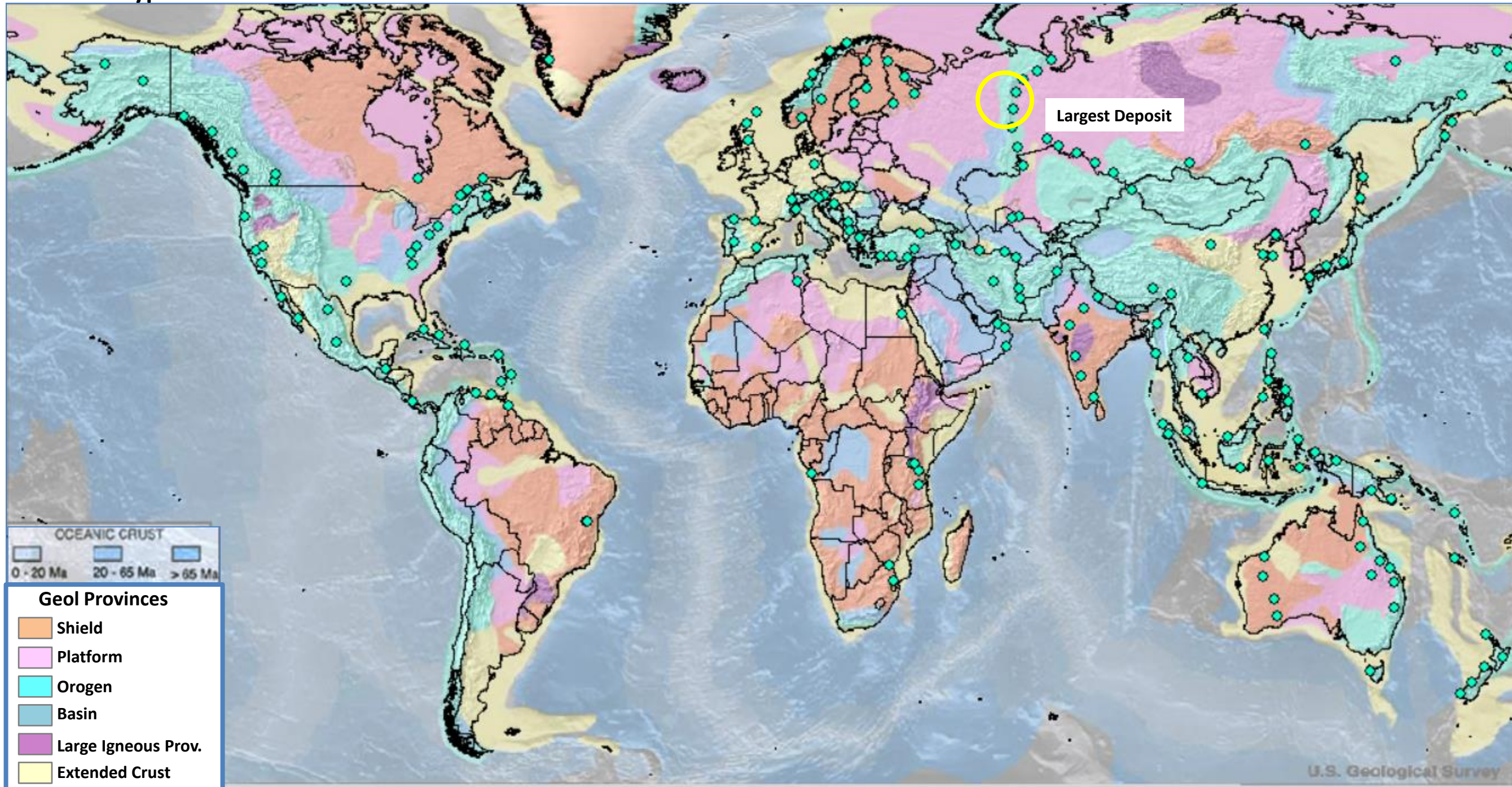


Yerakini Mine Greece



# Magnesium

## Province Type

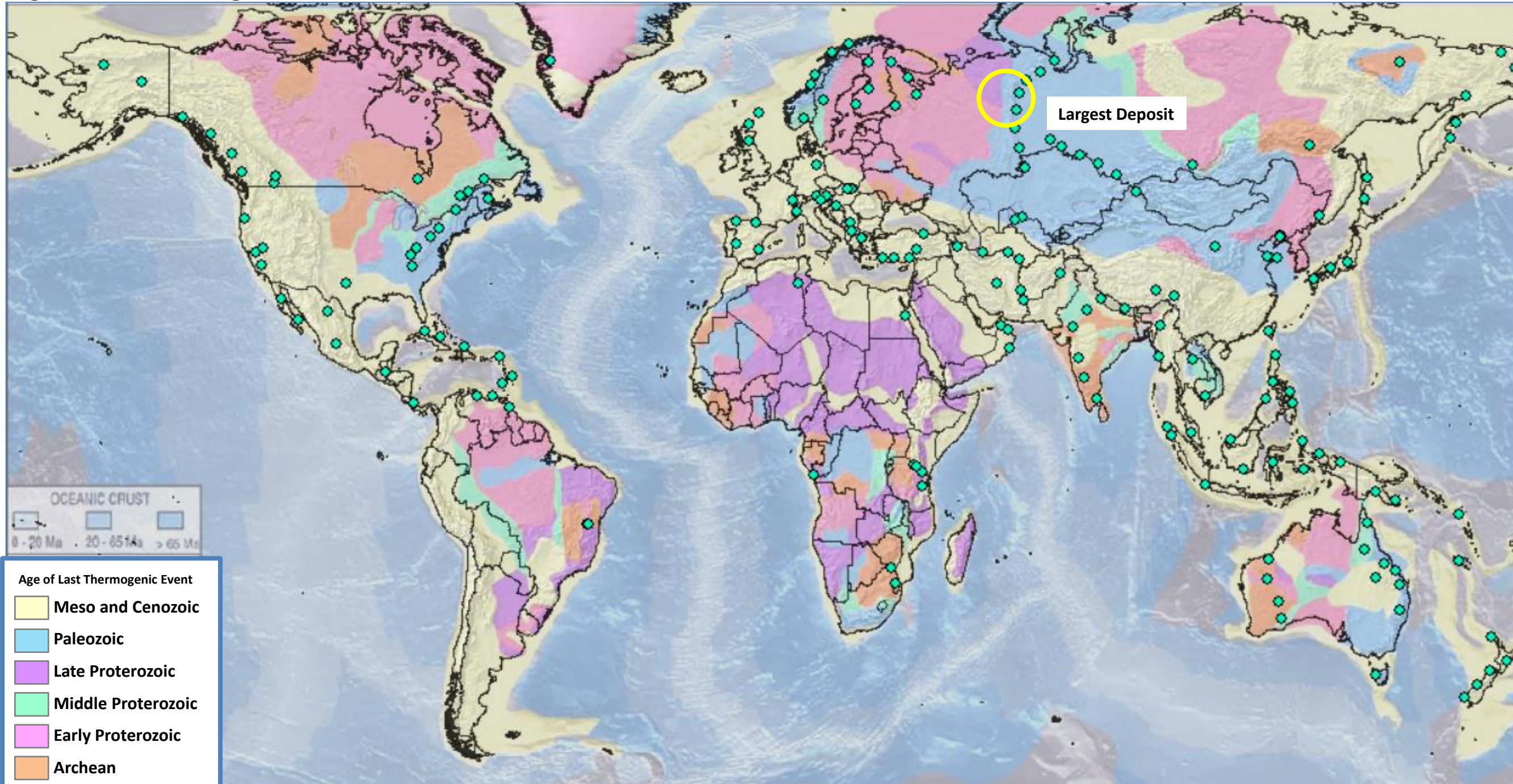


*Indicative  
Locations of  
deposits based  
on USGS data  
(may not be  
comprehensive)*



# Magnesium

## Age of Last Thermogenic Event

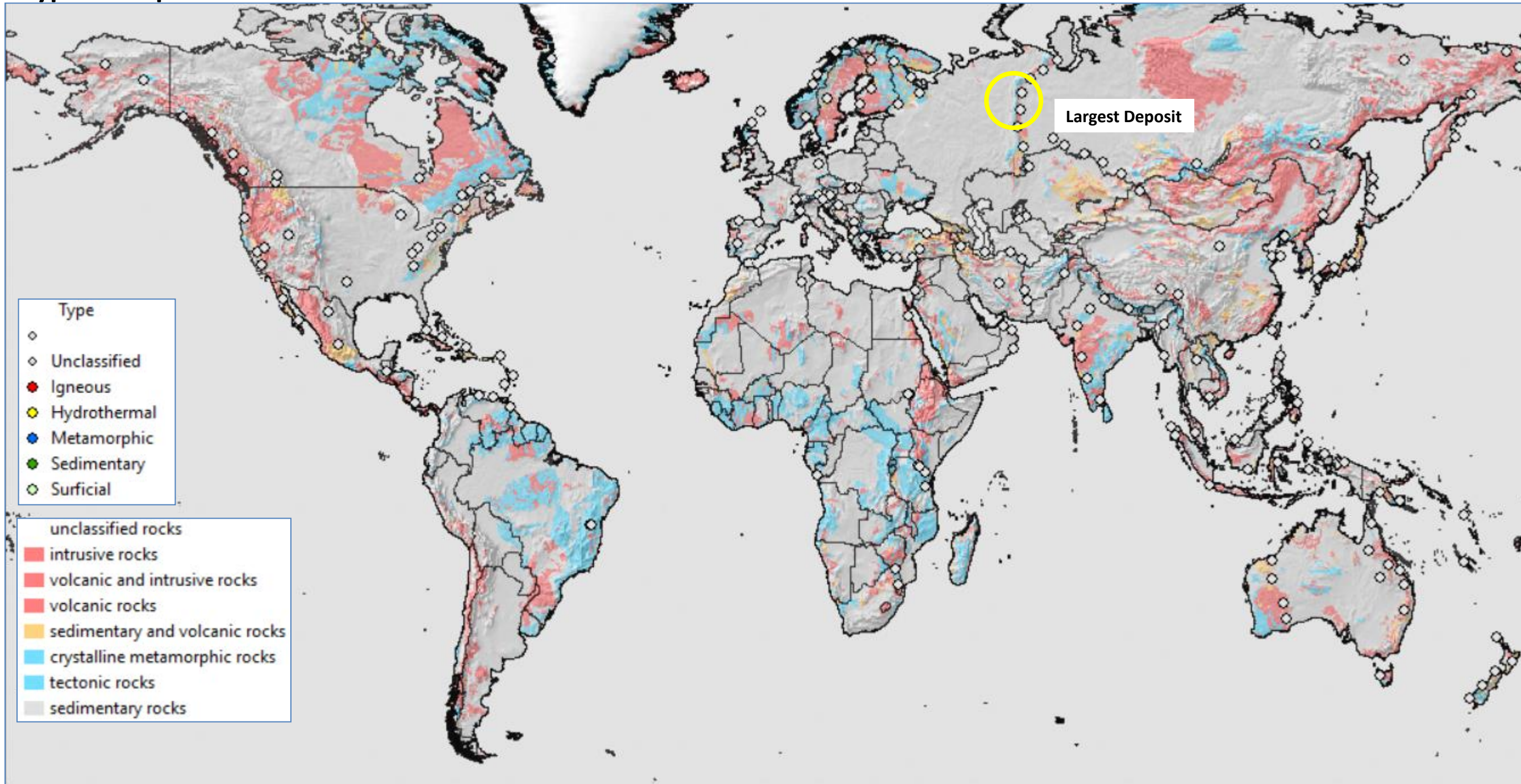


*Indicative Locations of deposits based on USGS data (may not be comprehensive)*



# Magnesium

## Type of Deposit Unclassified



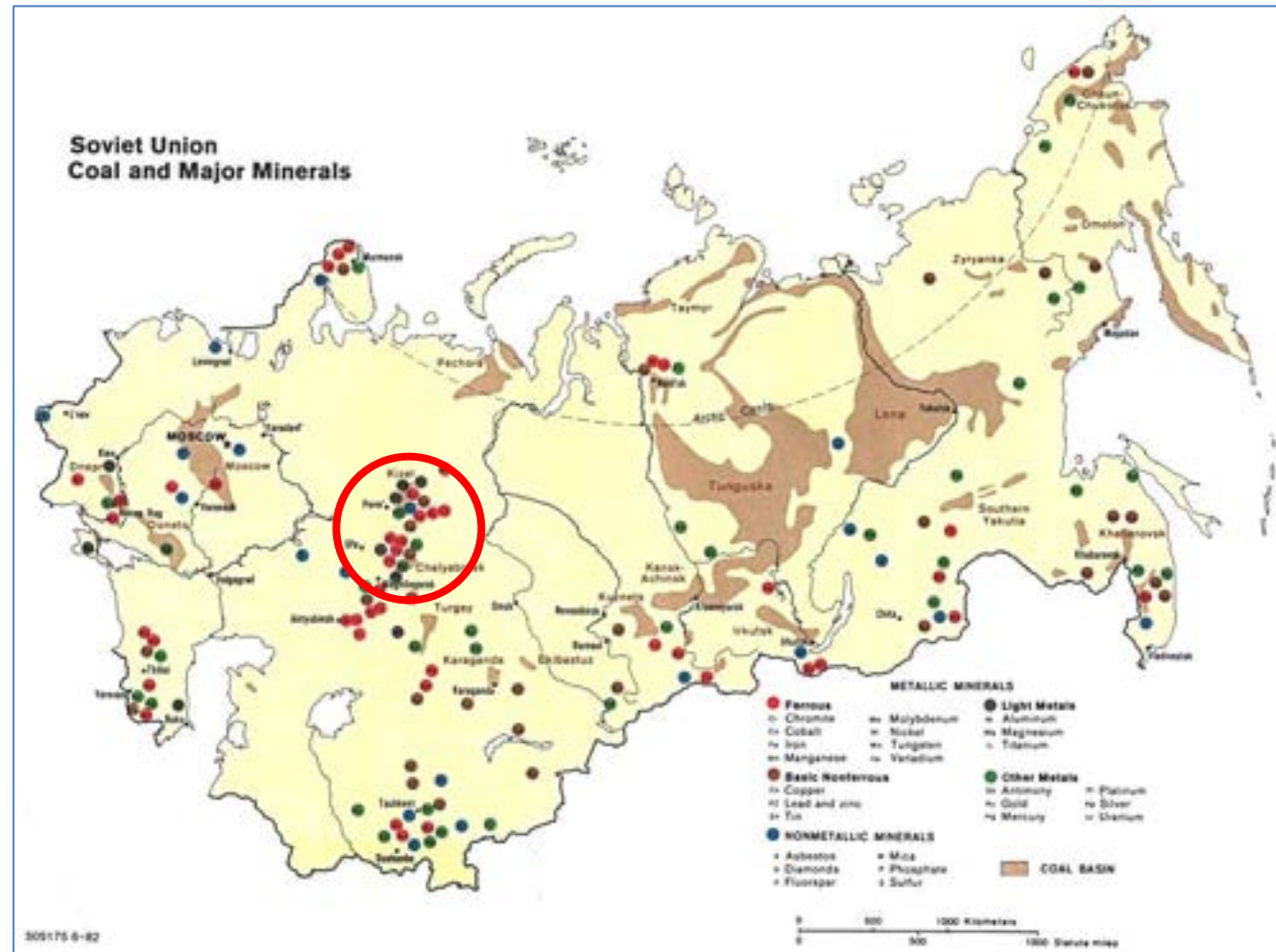
*Indicative Locations of deposits based on USGS data (may not be comprehensive)*



# World's Largest Deposits

# Magnesium

## Major Russian Magnesium Deposits



[Russiacon.weebly.com/natural-resources](http://Russiacon.weebly.com/natural-resources)

## Lacustrine strata-bound magnesite deposits in the Alpine–Himalayan orogenic system

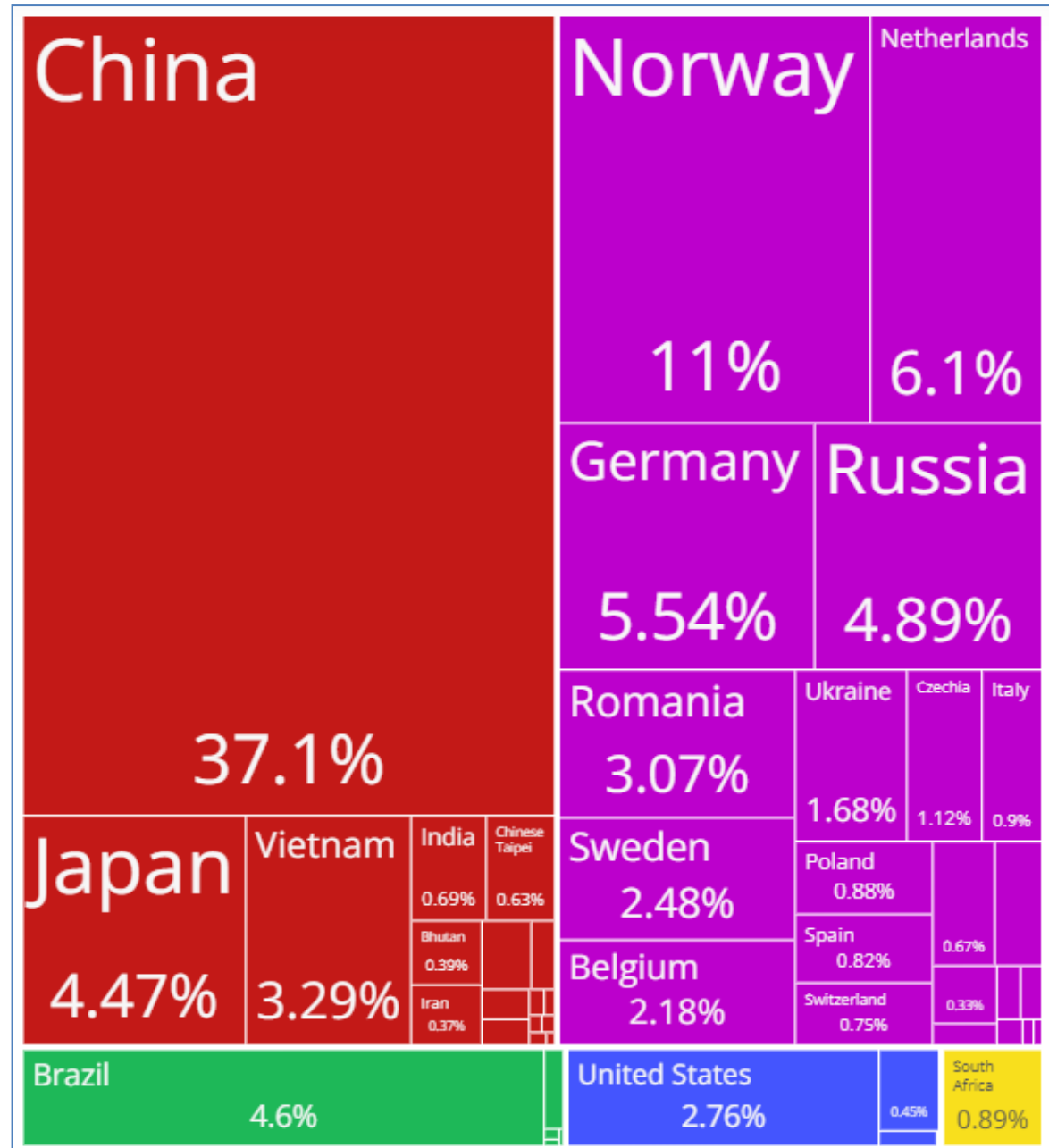


Xuhui Yu et al 2024



## Major Silicon Carbide Production 2021

Production 2021 (\$1.02 B)



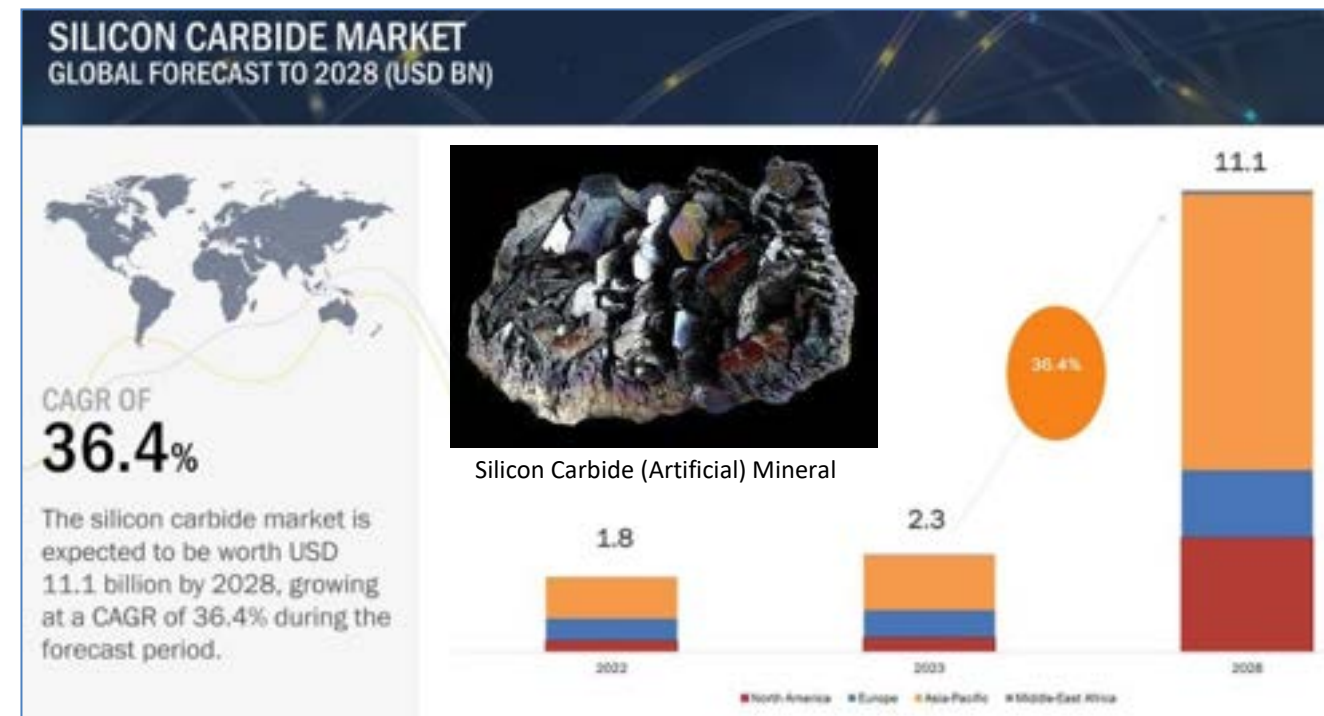
OEC.world

Silicon carbide (SiC) or carborundum is a synthetic material manufactured through the fusion of high-grade silica sand and finely ground carbon (petroleum coke) in an electric furnace at high temperature (1600–2500°C).

Silicon carbide is a semiconductor containing silicon and carbon. Grains of silicon carbide can be molded together to form very hard ceramics that are used in applications requiring high endurance.

Silicon carbide is widely used in manufacturing semiconductors due to its properties, like the ability to work at high temperature or high voltage, or both, and reduced form factor.

(Source: <https://www.mordorintelligence.com/industry-reports/silicon-carbide-market>)



Marketsandmarkets.com



# Working with ChatGPT

Silicon is a chemical element widely distributed in nature, primarily occurring in the form of silicon dioxide (SiO<sub>2</sub>), which is commonly known as silica. Silica is a major component of various minerals, rocks, and sediments. The tectonic setting of silicon deposits is broad, as silicon is pervasive in Earth's crust. Here are some common geological settings where silicon deposits are found:

## Quartz Veins and Pegmatites:

**Tectonic Setting:** Quartz veins and pegmatites, which are common sources of silicon, can occur in a variety of tectonic settings.

**Formation:** Quartz, a mineral composed of silicon dioxide, often forms in hydrothermal veins and pegmatites. These settings can be associated with various geological processes, including igneous intrusions and hydrothermal activity.

## Granitic and Silicic Volcanic Rocks:

**Tectonic Setting:** Granite and silicic volcanic rocks, which often contain high amounts of silica, can be associated with various tectonic settings, including convergent and continental settings.

**Formation:** Granite is an intrusive igneous rock rich in quartz, while silicic volcanic rocks, such as rhyolite, are extrusive rocks with high silica content. Both types of rocks can be found in diverse geological environments.

## Sandstone and Sedimentary Deposits:

**Tectonic Setting:** Sandstone deposits, which often contain silica grains, are commonly found in sedimentary environments.

**Formation:** Sandstone is formed through the accumulation and lithification of sand-sized grains, including silica. The tectonic setting can vary, as sandstone can be deposited in continental, marine, or transitional environments.

## Silica-Rich Metamorphic Rocks:

**Tectonic Setting:** Certain metamorphic rocks, such as quartzite, which is composed almost entirely of quartz, can be found in various tectonic settings.

**Formation:** Quartzite forms through the metamorphism of quartz-rich sandstone or chert, and the tectonic setting can range from regional metamorphism in convergent boundaries to contact metamorphism associated with igneous intrusions.

## Diatomite Deposits:

**Tectonic Setting:** Diatomite, a sedimentary deposit consisting of the fossilized remains of diatoms (algae with silica skeletons), can be found in various tectonic settings.

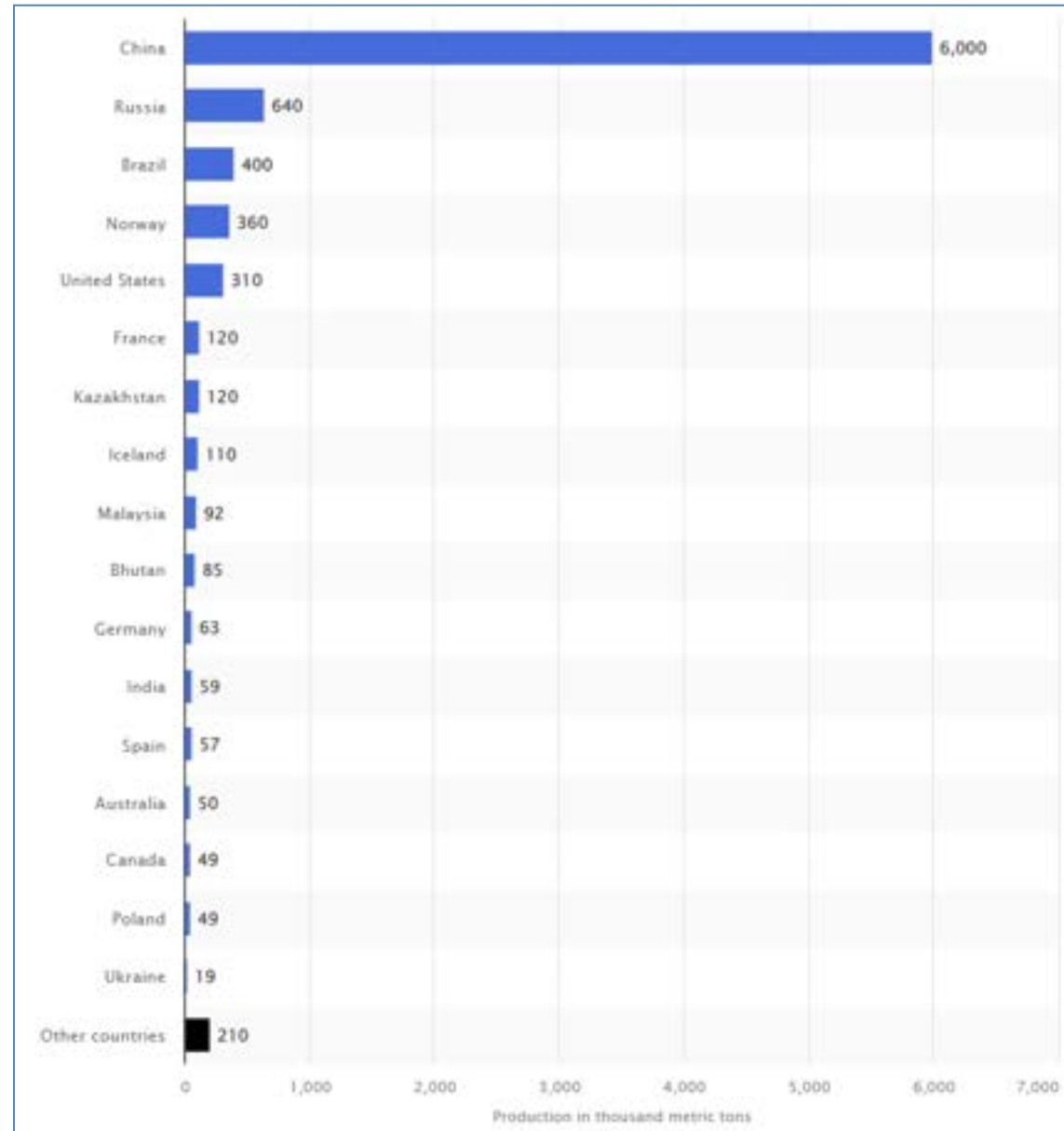
**Formation:** Diatomite deposits can accumulate in lake beds, coastal areas, or marine environments, and their formation is not strictly tied to a specific tectonic setting.

Silicon is a major component of Earth's crust and is found in a wide range of geological settings. It is important to note that the extraction of silicon is primarily achieved through processing silica-rich minerals, such as quartz, which can be sourced from various geological environments. The tectonic setting of silicon deposits is, therefore, diverse and depends on the specific geological processes leading to the formation of silica-containing materials.

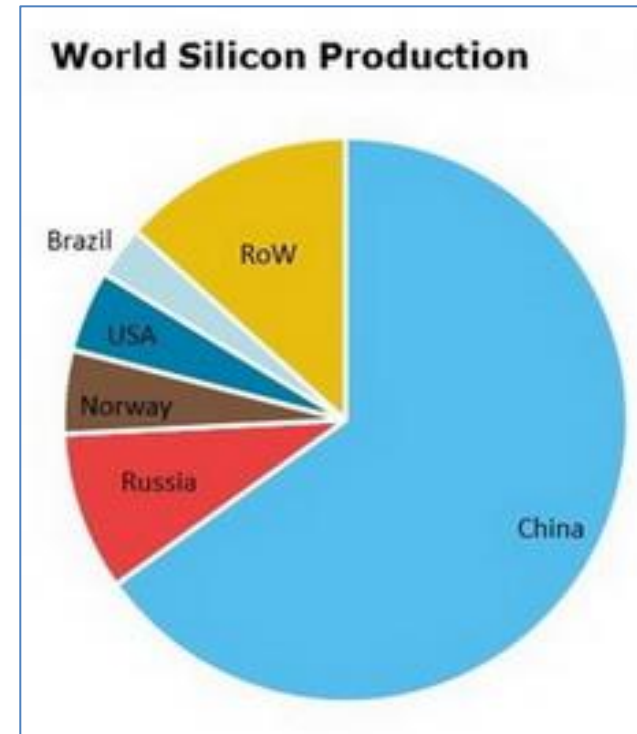


## Major Silicon Production 2022

Production 2022 (1000 metric tons)



Statista



World and US domestic resources for making silicon metal and alloys are abundant and, in most producing countries, adequate to supply world requirements for many decades. **The source of the silicon is silica in various natural forms, such as quartzite. No Reserves est of Silicon available as there is more than ample amounts available in the form of Silica (Quartz). It is the second most abundant material available in the earth's crust next to oxygen.**

Excluding the United States, ferrosilicon accounted for almost 70% of world silicon production on a silicon-content basis in 2021. The leading countries for ferrosilicon production were, in descending order and on a silicon-content basis, China, Russia, and Norway. For silicon metal, the leading producers were China, Brazil, and Norway. China accounted for approximately 70% of total global estimated production of silicon materials in 2021. (USGS Commodity Summary)



Silicon dioxide (Quartz)

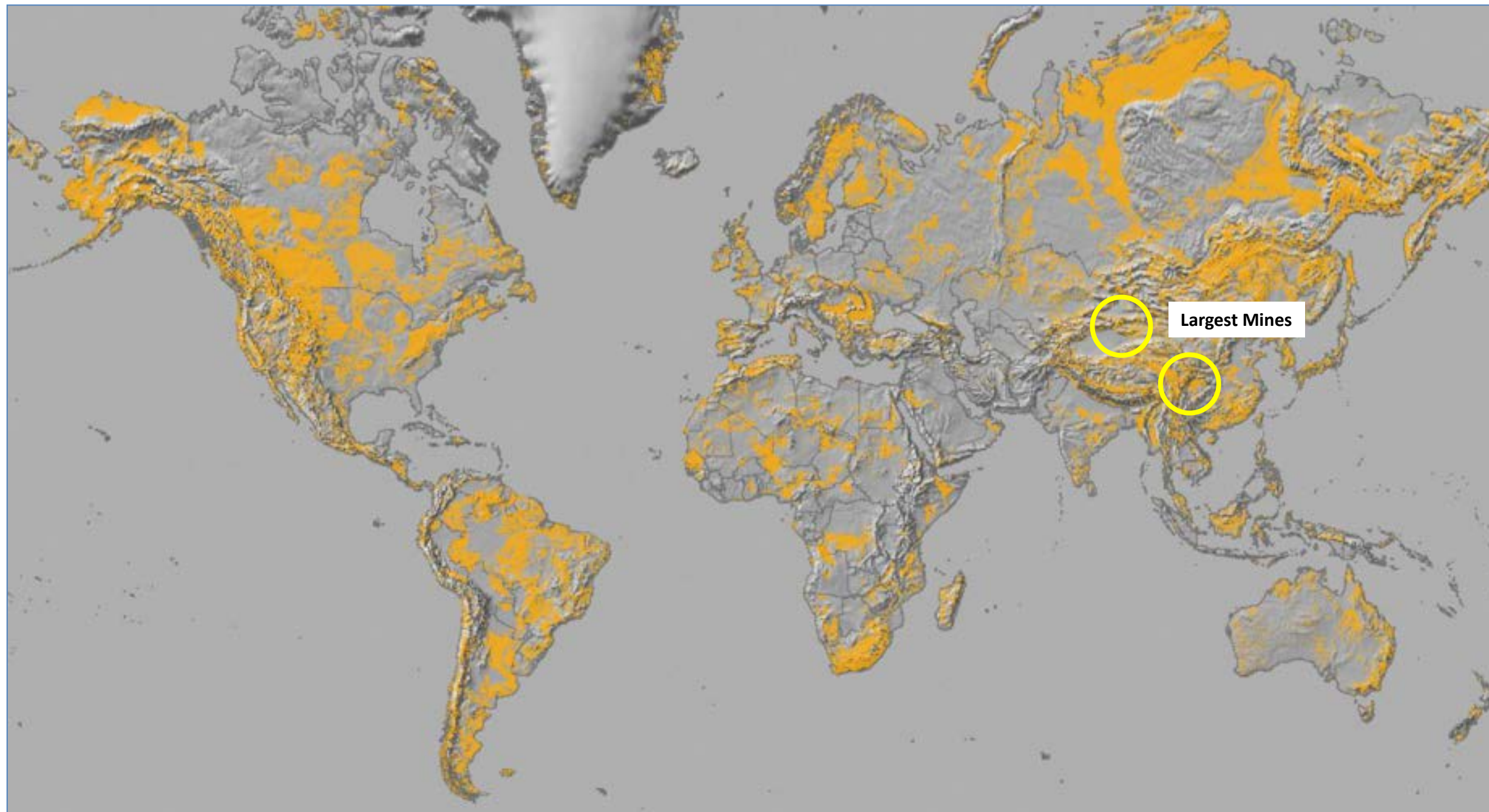


Silicon Mine, China



# Silicon

## Surface Lithology showing quartz rich rocks

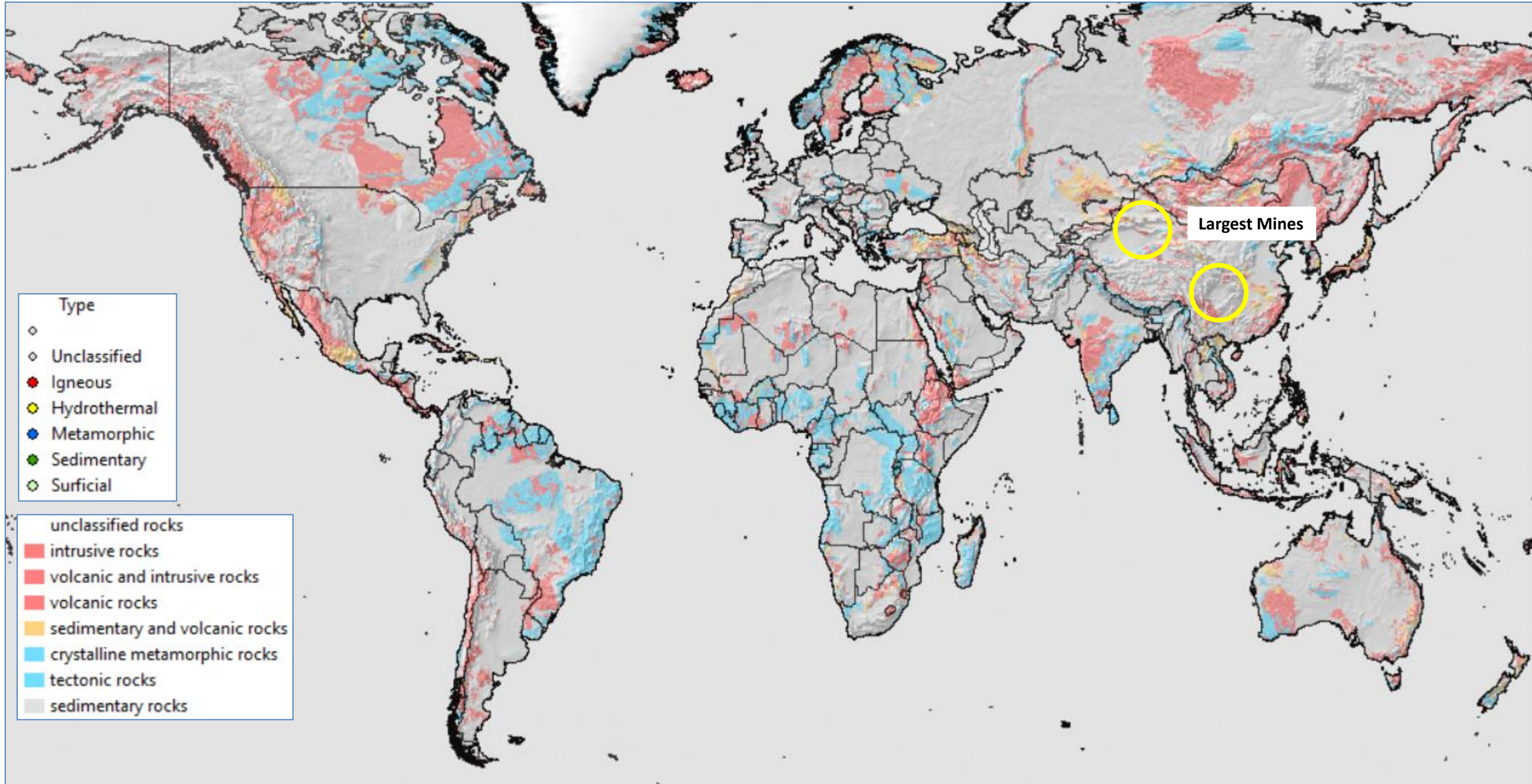


Hartmann n Moosdorf, 2012

Eddy Ong 2024  
Posted on LinkedIn



# Silicon

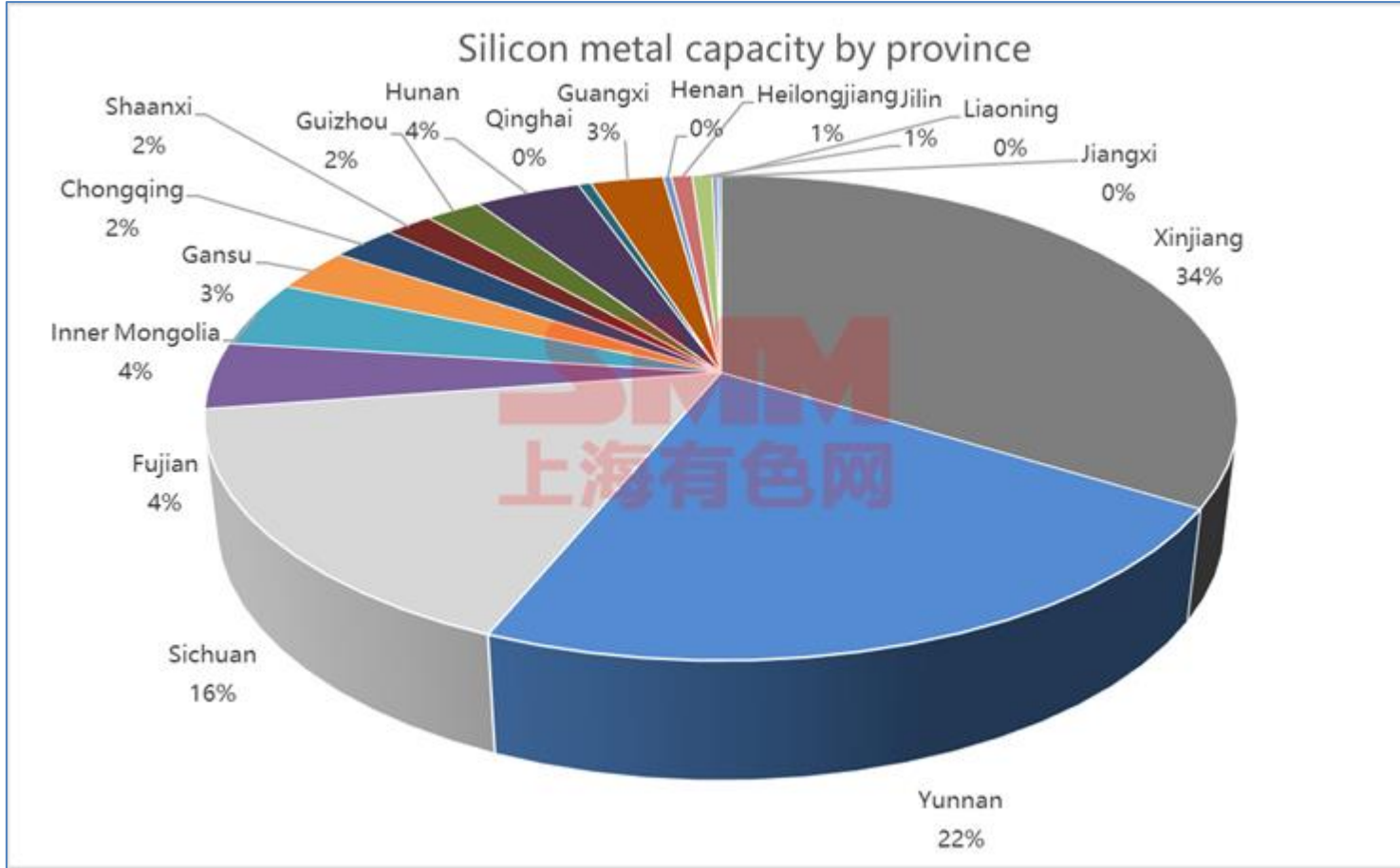




# World's Largest Deposits

Silicon

## China is the Largest Producer

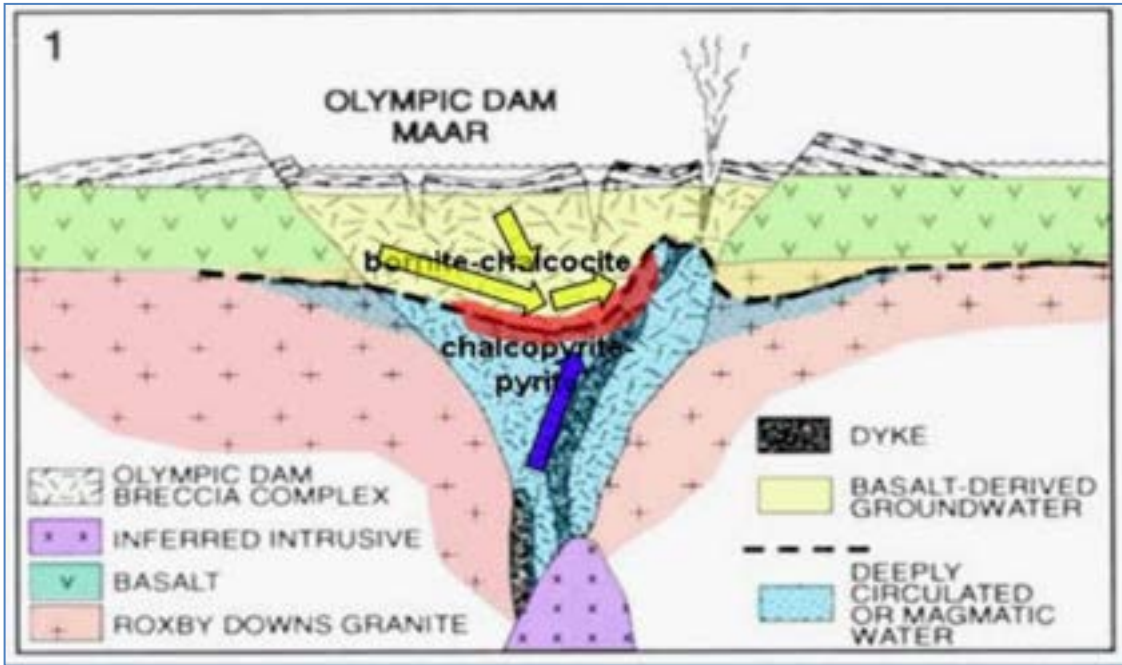


SMM 2022



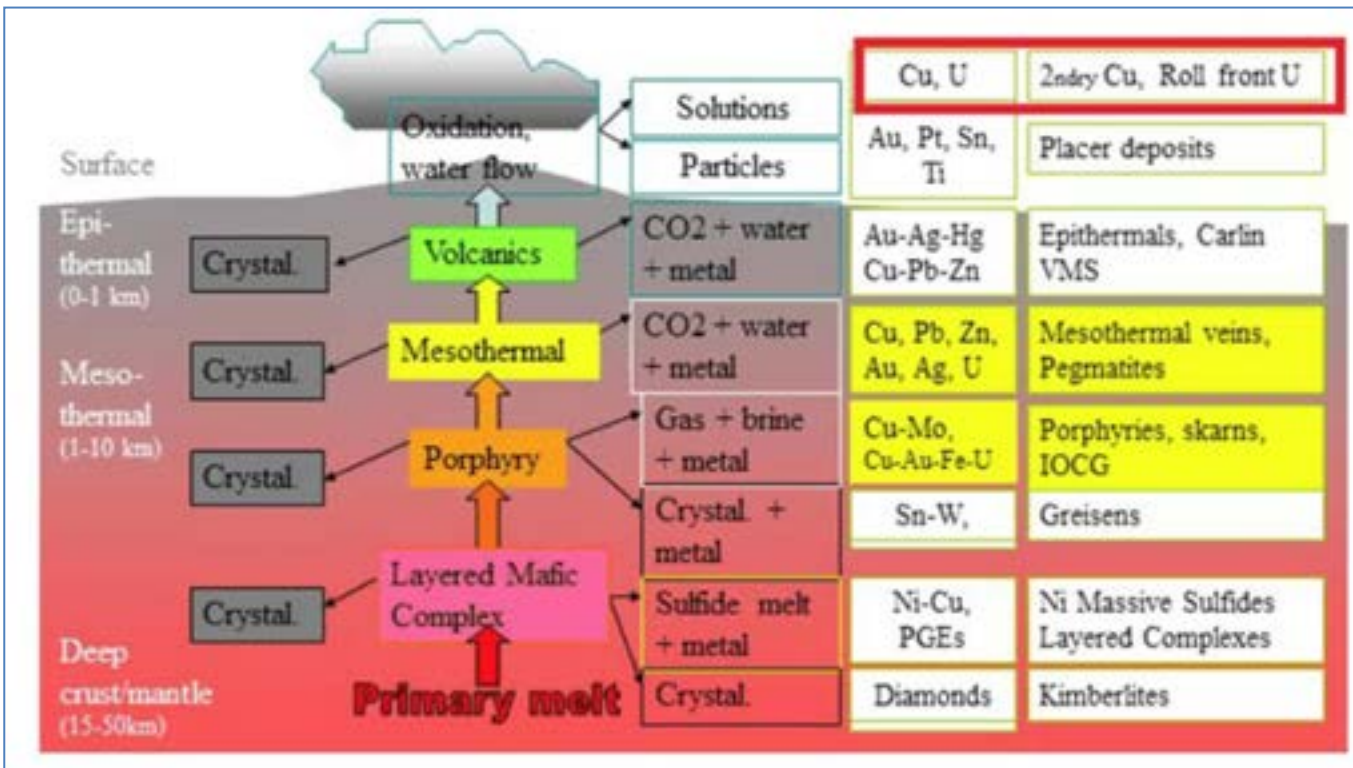
WoodMac 2023





Haynes 1995, Michaud 2018, Metallurgist

Secondary Uranium Deposits



Michaud 2018, Metallurgist

There are at least 14 different deposit types but only six of these are really economically significant in global terms. These can be broadly grouped into two; primary deposits where the uranium is introduced with the original magma and secondary deposits where the uranium is dissolved by groundwater and then re-deposited on solution. They are associated with:

**Primary** (U introduced with magma)

- IOGC (Iron Oxide, Copper, Gold)
- Intrusive related (veins, pegmatites)

The IOGC genetic model calls for a mixing of cool, shallow saline oxidizing groundwater from within the basaltic volcanics with hot deep more reduced magmatic water. The uranium is postulated to have been brought in with a shallow saline water and precipitated in the mixing zone due to reduction. Precipitation in reducing conditions is a common theme in uranium deposits. (Olympic Dam Australia)

Intrusive related uranium deposits provide one of the clearest examples of magmatic concentration of metals with the uranium being concentrated in the last remnants of the magma crystallized, however the grades are still some of the lowest in the uranium deposits. (Rossing Namibia)

**Secondary** (U dissolved by ground water and redeposited)

- Unconformity related
- Sandstone hosted
- Surficial (calcrete)
- Quartz pebble conglomerate

Secondary uranium deposits are classified as secondary because they result from groundwater leaching uranium from a primary source rock; the uranium is then transported in solution and re-deposited often resulting in a major grade increase.

Unconformity related deposits are some of the most important uranium deposits economically as they have the highest grade. Uranium rich fluids precipitated out at significant redox boundary at unconformities (Cigar Lake W Canadian Shield).

In Sandstone hosted deposits as the name implies the uranium is deposited in sandy sediments usually interbedded with shale or mudstone. Contact with plant debris or sulfides that act as reductants cause precipitation. (Powder River, Niger, Kazakhstan)

Surficial Uranium Tertiary- Recent deposits are formed at the surface due to evaporation of uranium bearing groundwater. Calcrete or Caliche is the most common host. (Langer Heinrich Namibia)

Detrital uranium occurs in some Archaean-early Palaeoproterozoic quartz-pebble conglomerates that unconformably overlie granitic and metamorphic basement. Quartz-pebble conglomerate uranium deposits occur in conglomerates deposited in the range 3070-2300 million years ago. Fluvial transport of detrital uraninite was possible at the time because of the prevailing anoxic atmosphere.

Michaud 2018, Metallurgist , World Nuclear Association



# Working with ChatGPT

Uranium deposits are associated with various geological settings, and the type of deposit can be influenced by the tectonic environment in which they form. Uranium is often found in a variety of geological settings, and its occurrence is linked to specific types of rocks and mineralization processes. Here are some common tectonic settings where uranium deposits are typically found:

## **Sedimentary Environments:**

**Tectonic Setting:** Uranium deposits are often associated with sedimentary basins, both in continental and marine settings.

**Formation:** In sedimentary basins, uranium can be concentrated through various processes, such as the precipitation of uraninite (a uranium mineral) in reducing environments or the accumulation of uranium-rich detrital sediments.

## **Sandstone-Hosted Deposits:**

**Tectonic Setting:** Sandstone-hosted uranium deposits are commonly found in sedimentary basins, often associated with red beds and other sedimentary rocks.

**Formation:** Uranium in sandstone-hosted deposits is often sourced from the leaching of uranium-bearing rocks in the surrounding area. The uranium can then be transported and precipitated within the pore spaces of the sandstone.

## **Roll-Front Deposits:**

**Tectonic Setting:** Roll-front uranium deposits are a type of sandstone-hosted deposit and are often associated with continental settings.

**Formation:** These deposits form where oxidized groundwater containing uranium encounters reduced conditions in a sandstone aquifer. Uranium precipitates at the "roll-front" where these two water types meet.

## **Vein and Hydrothermal Deposits:**

**Tectonic Setting:** Uranium can also be found in vein deposits associated with hydrothermal activity.

**Formation:** Hydrothermal uranium deposits may form when uranium-bearing fluids migrate through fractures in rocks and deposit uranium minerals in veins. These deposits can occur in a variety of tectonic settings.

## **Metamorphic Environments:**

**Tectonic Setting:** Uranium may be mobilized and concentrated in metamorphic terrains.

**Formation:** During regional metamorphism, uranium can be mobilized from pre-existing rocks and concentrated in specific zones, forming uranium deposits.

## **Granitic Intrusions:**

**Tectonic Setting:** Uranium can be associated with certain granitic intrusions.

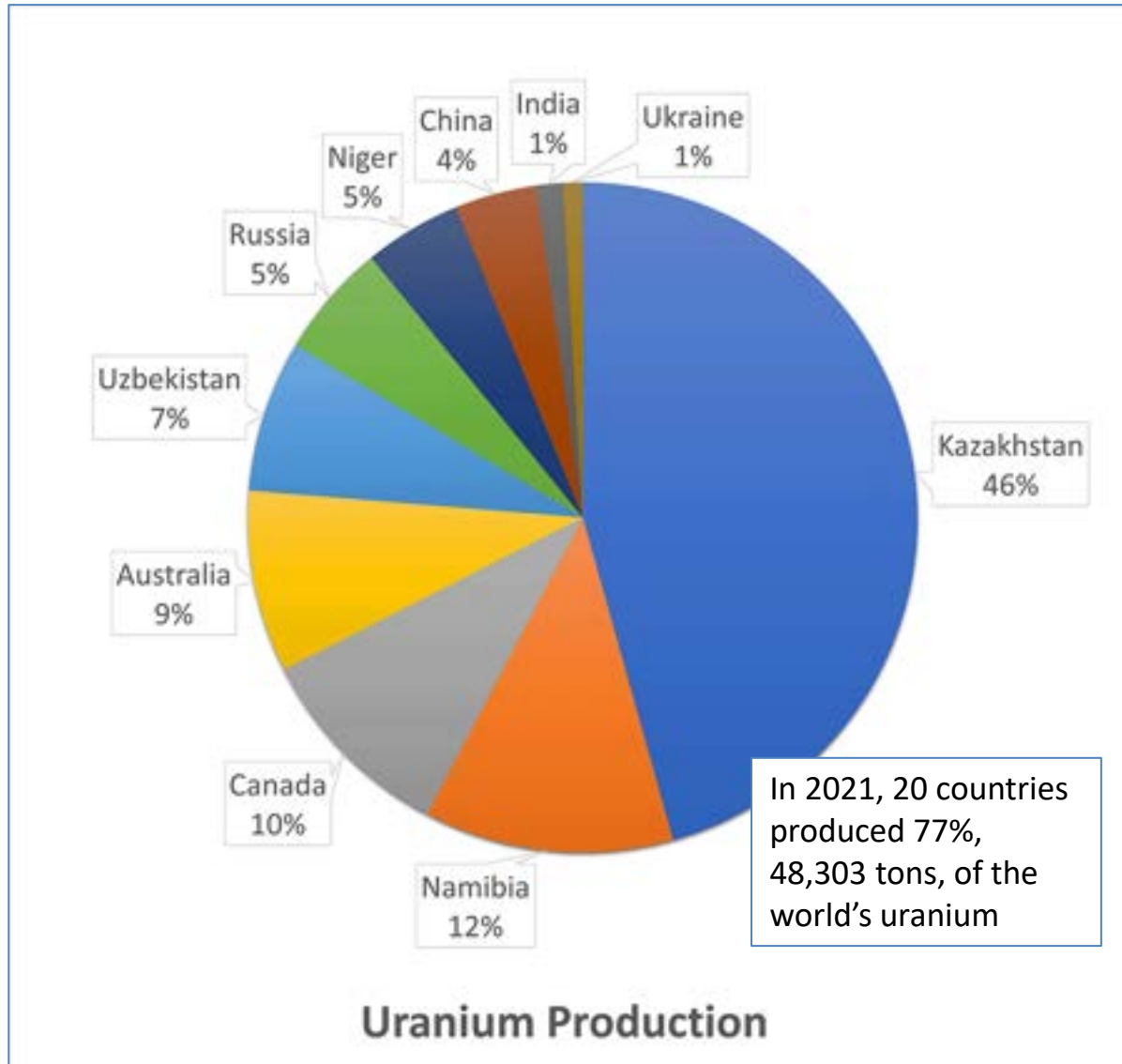
**Formation:** Uranium deposits may form through the concentration of uranium in hydrothermal fluids associated with the emplacement of granitic intrusions.

It's important to note that the occurrence of uranium is diverse, and the geological settings of uranium deposits can vary widely. The economic viability of uranium extraction depends on factors such as the grade of the deposit, accessibility, and market demand. Additionally, the exploration and mining of uranium are subject to regulatory and environmental considerations due to the radioactivity associated with uranium and its decay products.



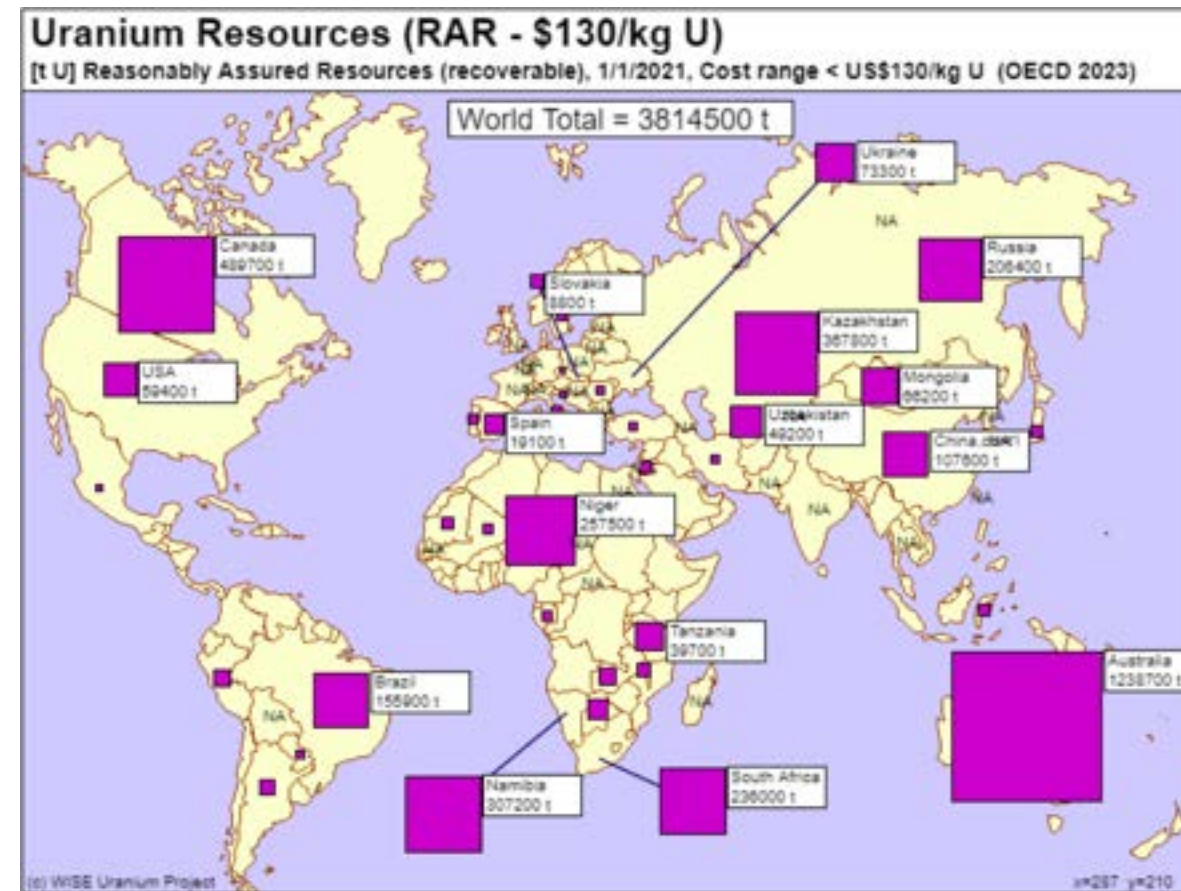
# Global Uranium Extraction and Reserves 2021

Production of Uranium world wide by country in tonnes



Worldpopulationreview.com

Reserves of Uranium worldwide in 2021, by country (in metric tons)



Wise-uranium.org

USGS Commodity Summary



Uranium Ore

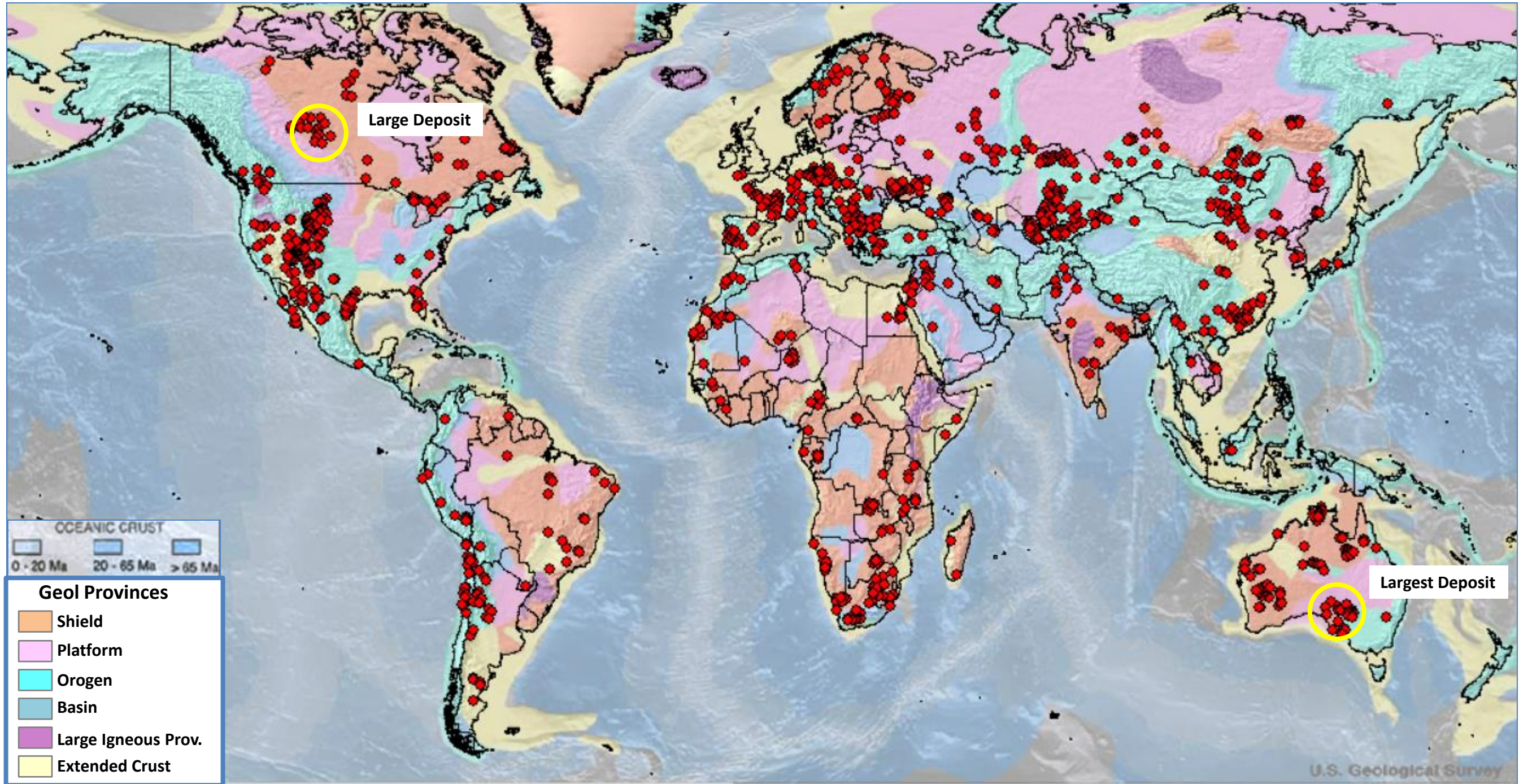


Uranium Mine Kazakhstan



# Uranium

## Province Type

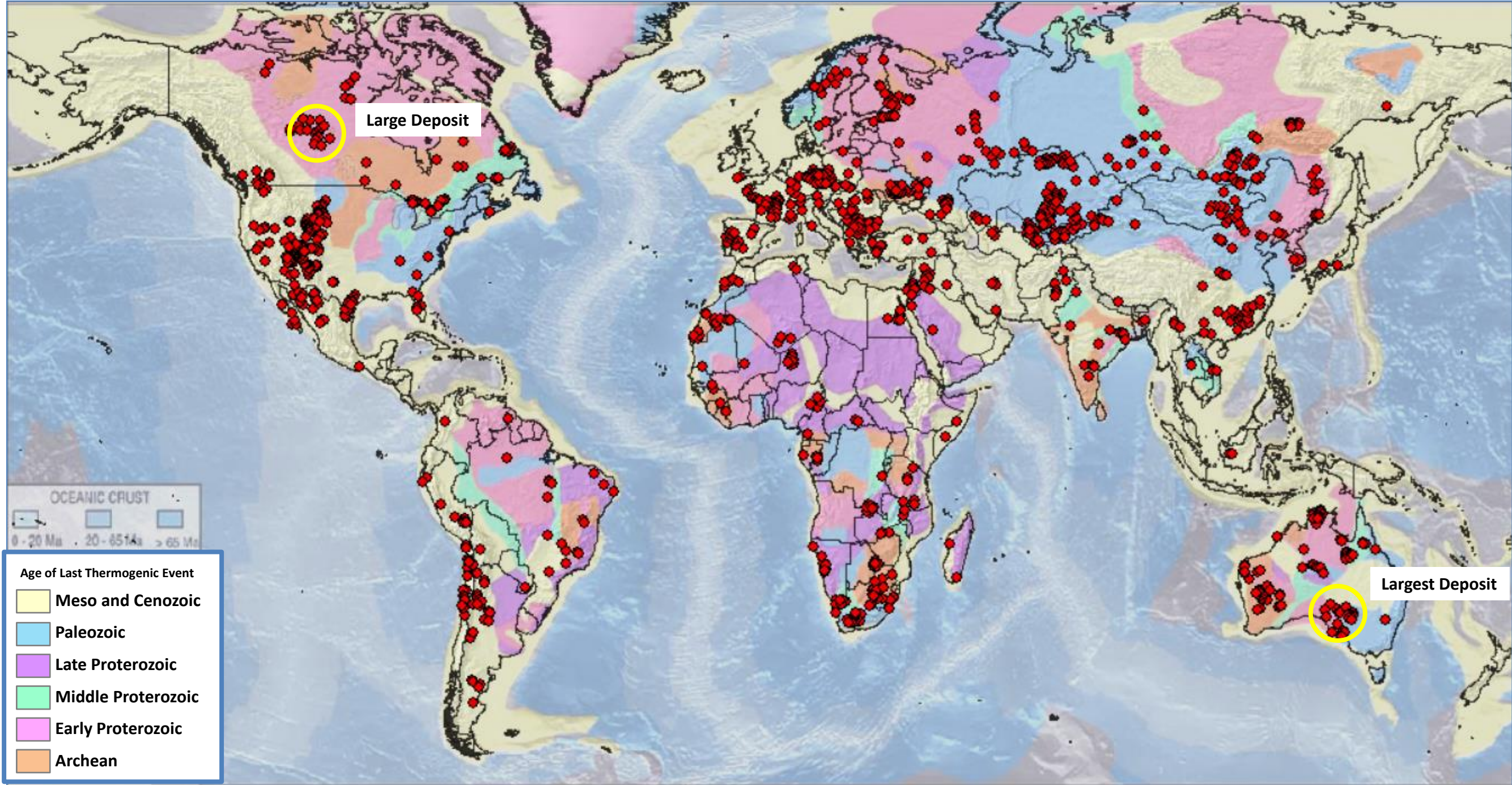


*Indicative Locations of deposits based on USGS data (may not be comprehensive)*



# Uranium

## Age of Last Thermogenic Event

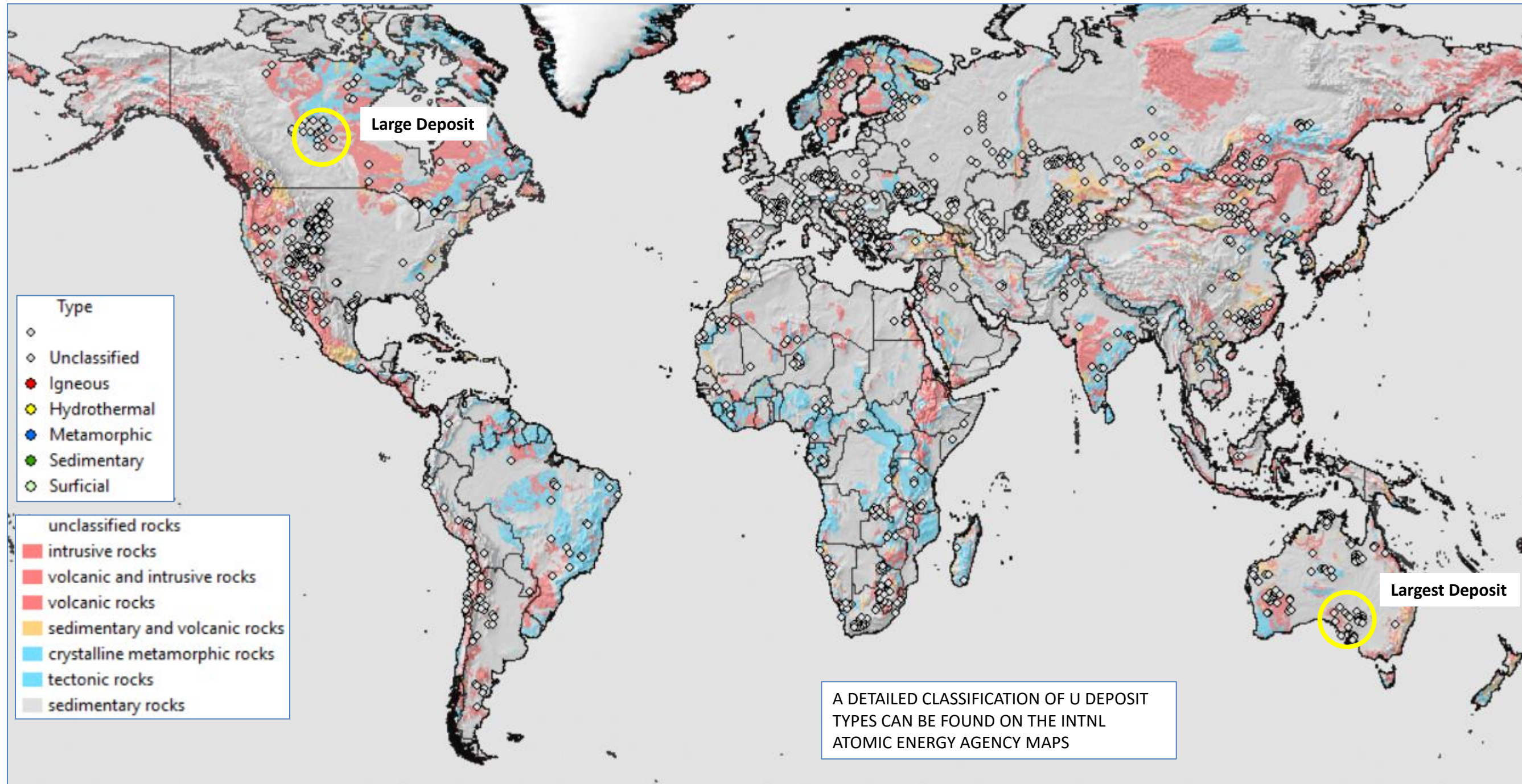


*Indicative Locations of deposits based on USGS data (may not be comprehensive)*



# Uranium

## Type of Deposit Unclassified



Indicative Locations of deposits based on USGS data (may not be comprehensive)



# World's Largest Deposits

## Athabasca Basin, Canada

### Unconformity deposits

- Highest grade, most significant economically (33% of world prod.)
- Occur mainly in Athabasca Basin (N Sask) but also Thelon Basin (Nunavut) and McArthur Basin (NT Australia)

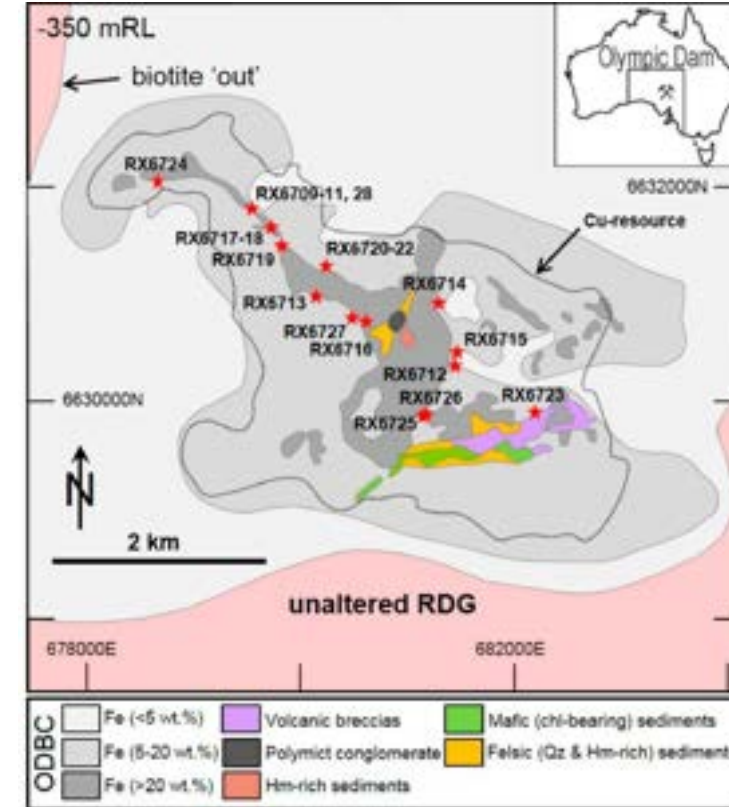
#### Examples:

- Key Lake
- Wheeler River
- McArthur River
- Cigar Lake
- Roughrider
- Patterson Lake S

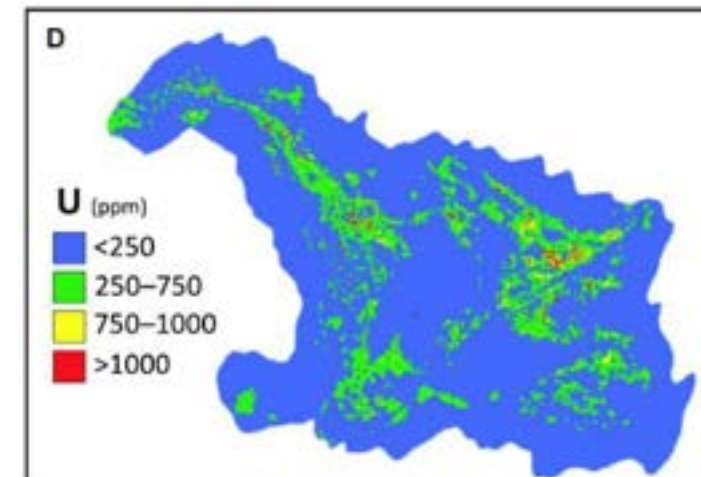


911metallurgist

## Olympic Dam Australia



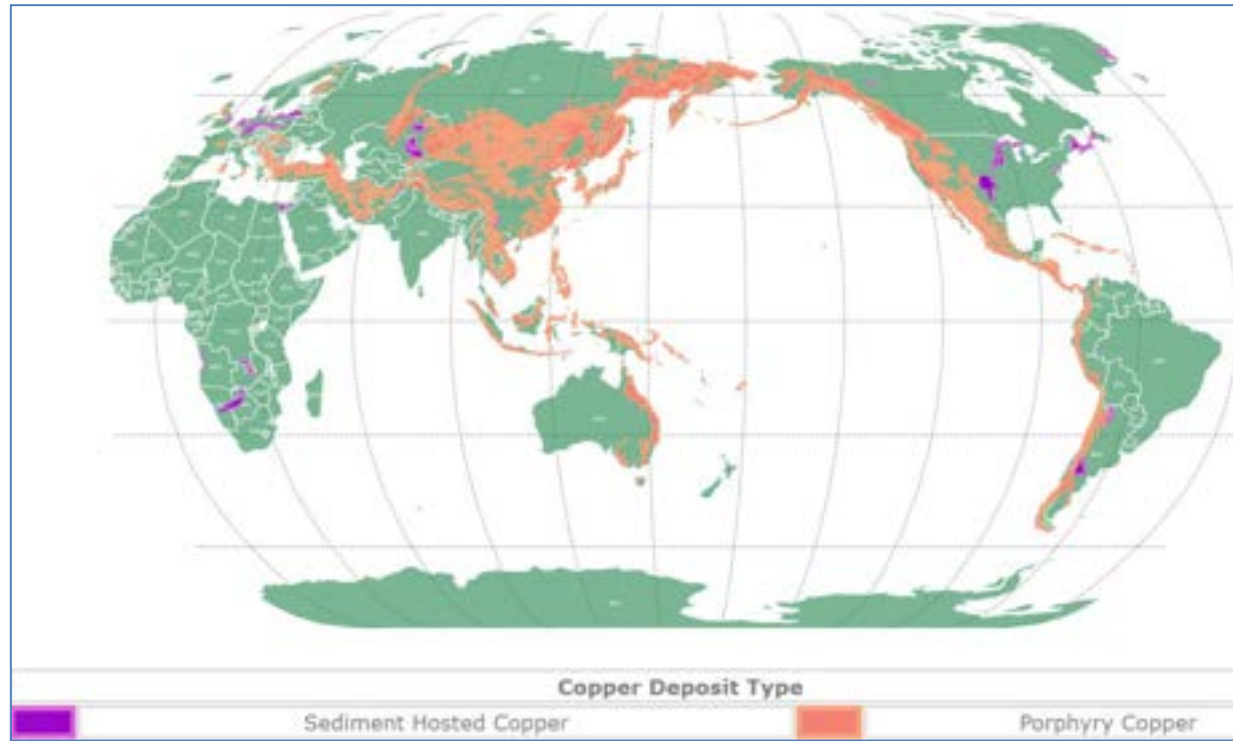
Schmandt et al 2017



Ehrig et al 2021

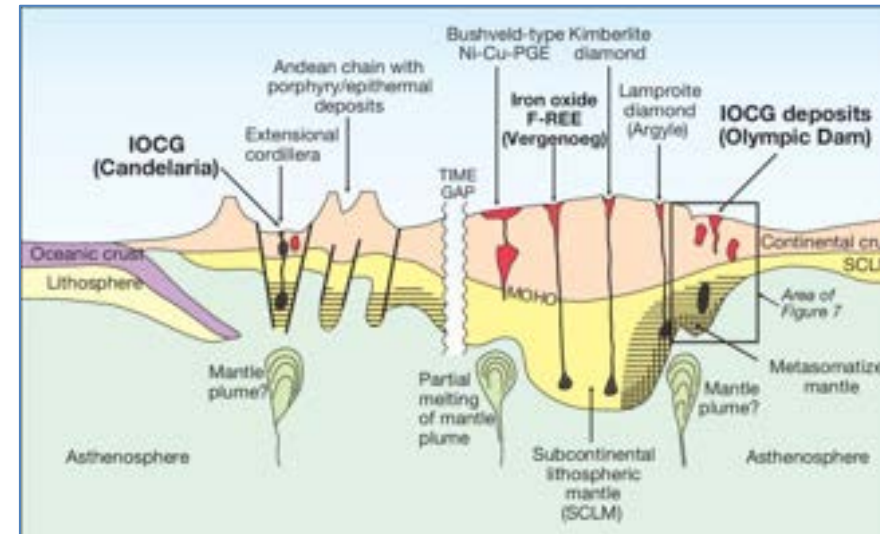


# Copper

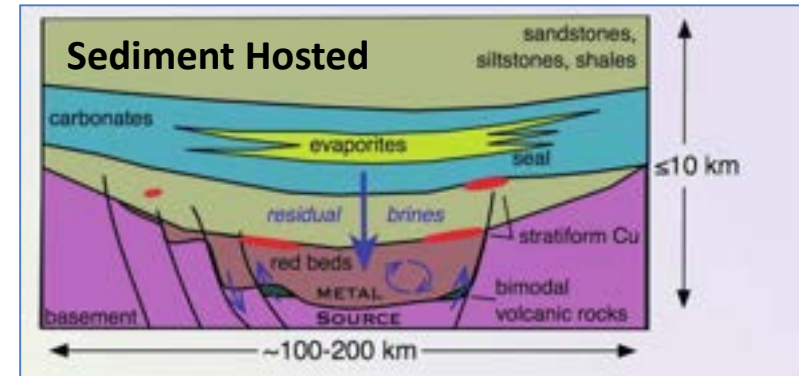


USGS 2016, databayou.com

## IOCG

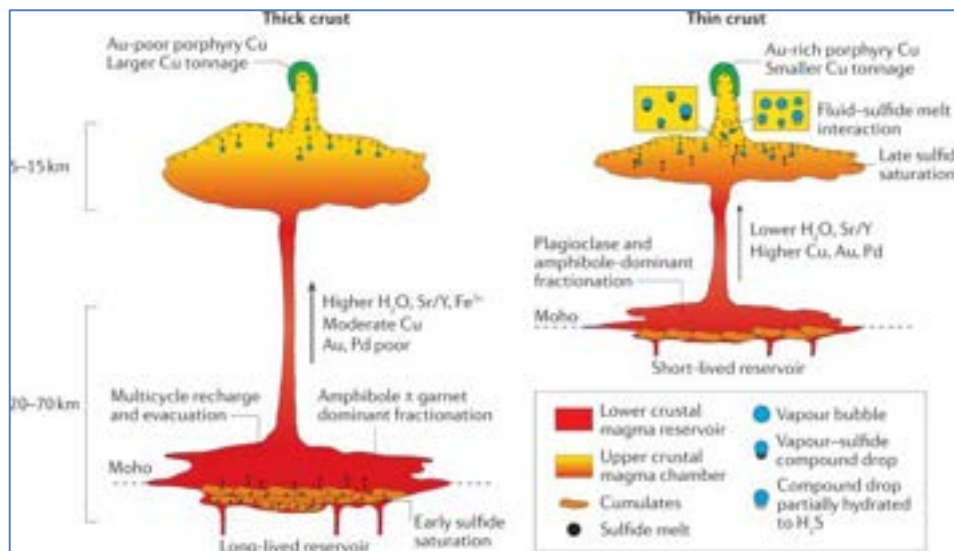


Groves et al. (1987) and Groves and Bierlein (2007)



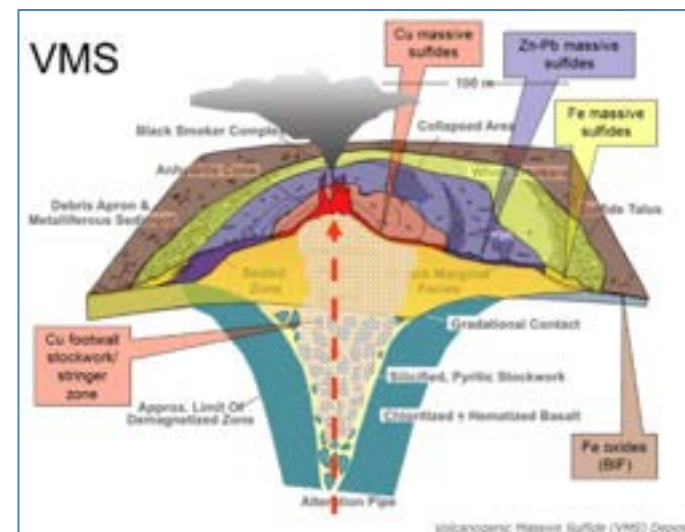
Hitzman et al., 2010

## Porphyry



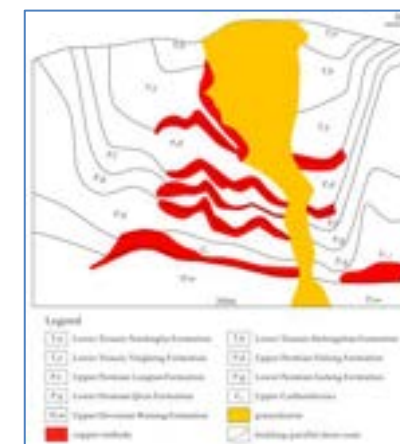
Jung-Woo Park et al., 2021

## Volcanogenic Massive Sulphide



geologyscience.com

## Skarn



Tao Sun et al., 2018

Copper mineralization can occur in a variety of geological settings, but the most common ones include:

**Porphyry copper deposits:** These are the world's largest and most important sources of copper and are associated with large, intrusive igneous rocks. Porphyry copper deposits form in the shallow crust (within 1-6 km depth) when hot, metal-rich fluids rise from cooling magma chambers and encounter cooler rock, causing copper and other metals to precipitate in the surrounding rock. **IOCGs** can be loosely classed as type of Porphyry deposit.

**Sediment-hosted copper deposits:** These deposits occur within sedimentary rocks that were deposited in marine or lacustrine environments. The copper is usually associated with shale, sandstone, and carbonate rocks, and the deposits can be stratiform (parallel to the bedding) or structurally controlled.

**Volcanogenic massive sulfide (VMS) deposits:** These are typically small to medium-sized deposits that form at or near the seafloor in volcanic or sedimentary rocks. They are characterized by high grades of copper, zinc, lead, and other metals, and are often associated with hydrothermal vents on the seafloor.

**Copper skarns:** These are hydrothermal deposits that occur in carbonate rocks, typically near intrusions of granitic or dioritic rocks. Skarn deposits are usually characterized by high grades of copper, as well as significant amounts of other metals such as gold, silver, and molybdenum.

**Copper oxide deposits:** These deposits are usually found near the surface and are formed by weathering and oxidation of copper sulfide minerals. They typically occur in arid or semi-arid regions, where copper minerals are leached from the rocks by acidic groundwater and accumulate in the form of copper oxide minerals.



# Working with ChatGPT

Copper deposits are associated with various geological settings, and the type of deposit can be influenced by the tectonic environment in which they form. Copper is commonly found in different types of ore deposits, each associated with specific geological processes and tectonic settings. Here are some common tectonic settings where copper deposits are typically found:

## **Porphyry Copper Deposits:**

**Tectonic Setting:** Porphyry copper deposits are often associated with convergent plate boundaries, where tectonic plates are colliding or subducting.

**Formation:** Porphyry copper deposits form in magmatic-hydrothermal systems associated with large granitic intrusions. Subduction zones are common tectonic settings for these deposits.

## **Volcanogenic Massive Sulfide (VMS) Deposits:**

**Tectonic Setting:** VMS deposits, including copper-rich ones, are commonly associated with submarine volcanic activity in convergent or divergent tectonic settings.

**Formation:** VMS deposits form on the seafloor through the deposition of minerals from hydrothermal fluids emanating from submarine volcanic vents.

## **Stratabound Sediment-Hosted Deposits:**

**Tectonic Setting:** Sediment-hosted copper deposits can form in a variety of tectonic settings, including continental rifts and passive continental margins.

**Formation:** These deposits are associated with the diagenetic and sedimentary processes that lead to the concentration of copper in specific layers of sedimentary rocks.

## **Intrusion-Related Copper Deposits:**

**Tectonic Setting:** Intrusion-related copper deposits are associated with various tectonic settings, including convergent and continental rift environments.

**Formation:** These deposits form through the emplacement of intrusive igneous rocks and associated hydrothermal systems. The copper mineralization is often related to the intrusion and alteration of host rocks.

## **Skarn Deposits:**

**Tectonic Setting:** Skarn deposits, which can contain copper, are often associated with contact metamorphism in various tectonic settings.

**Formation:** Skarns form at the contact between intrusive igneous rocks and carbonate-rich sedimentary rocks. Copper mineralization occurs as a result of hydrothermal activity associated with the metamorphic processes.

## **Orogenic Gold-Copper Deposits:**

**Tectonic Setting:** Orogenic gold-copper deposits can form in collisional orogenic belts where tectonic plates converge.

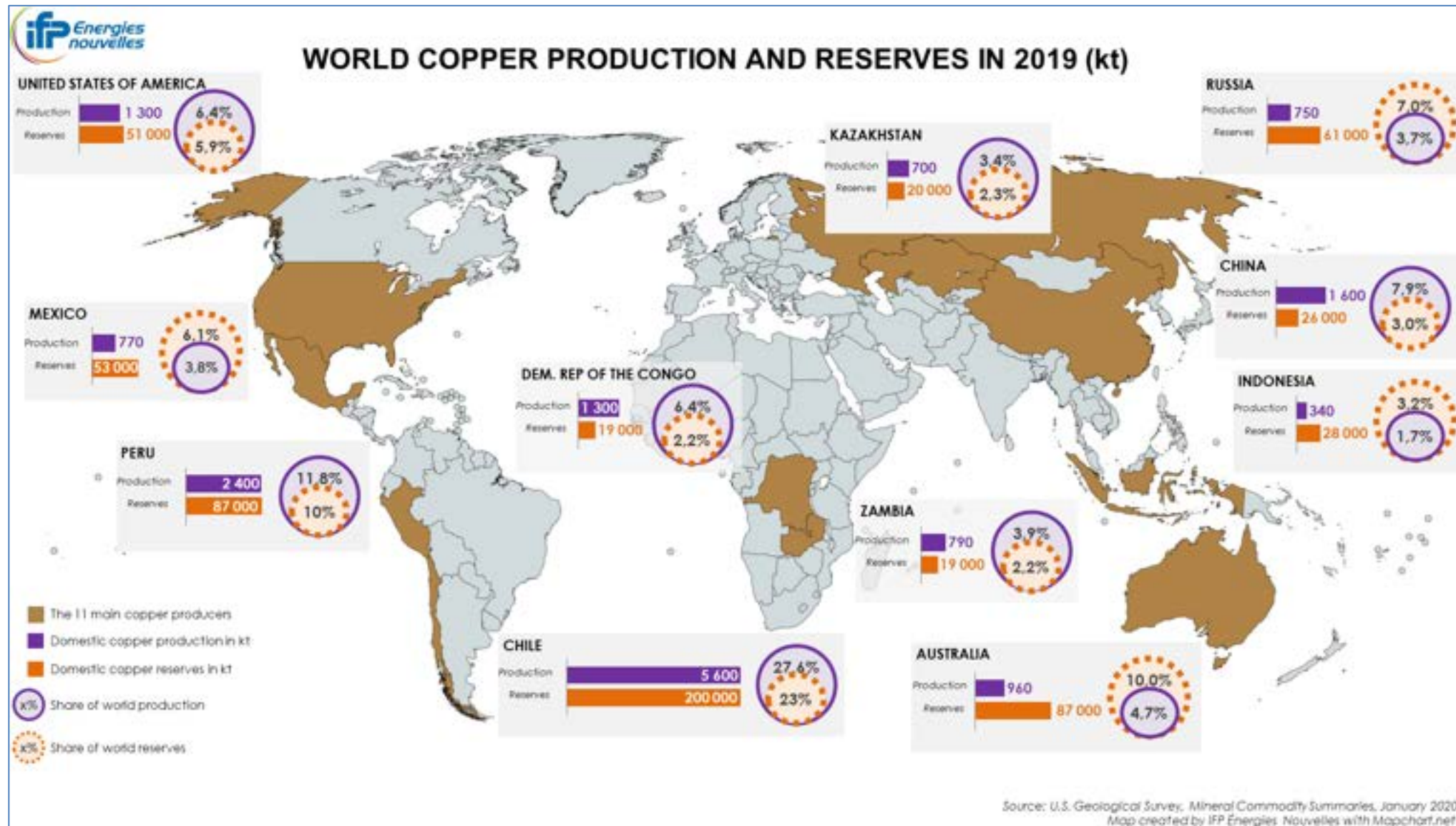
**Formation:** These deposits are often associated with large-scale crustal deformation and mountain-building processes. Copper mineralization may occur in association with gold deposits.

It's important to note that copper deposits can have complex geological histories, and multiple tectonic processes may contribute to their formation. Economic copper deposits often result from the interplay of magmatic, hydrothermal, and sedimentary processes in specific tectonic settings. The exploration and mining of copper are influenced by factors such as ore grade, accessibility, and market demand.



# Copper

## Global Copper Extraction and Reserves (t) 2019



Chalcopyrite



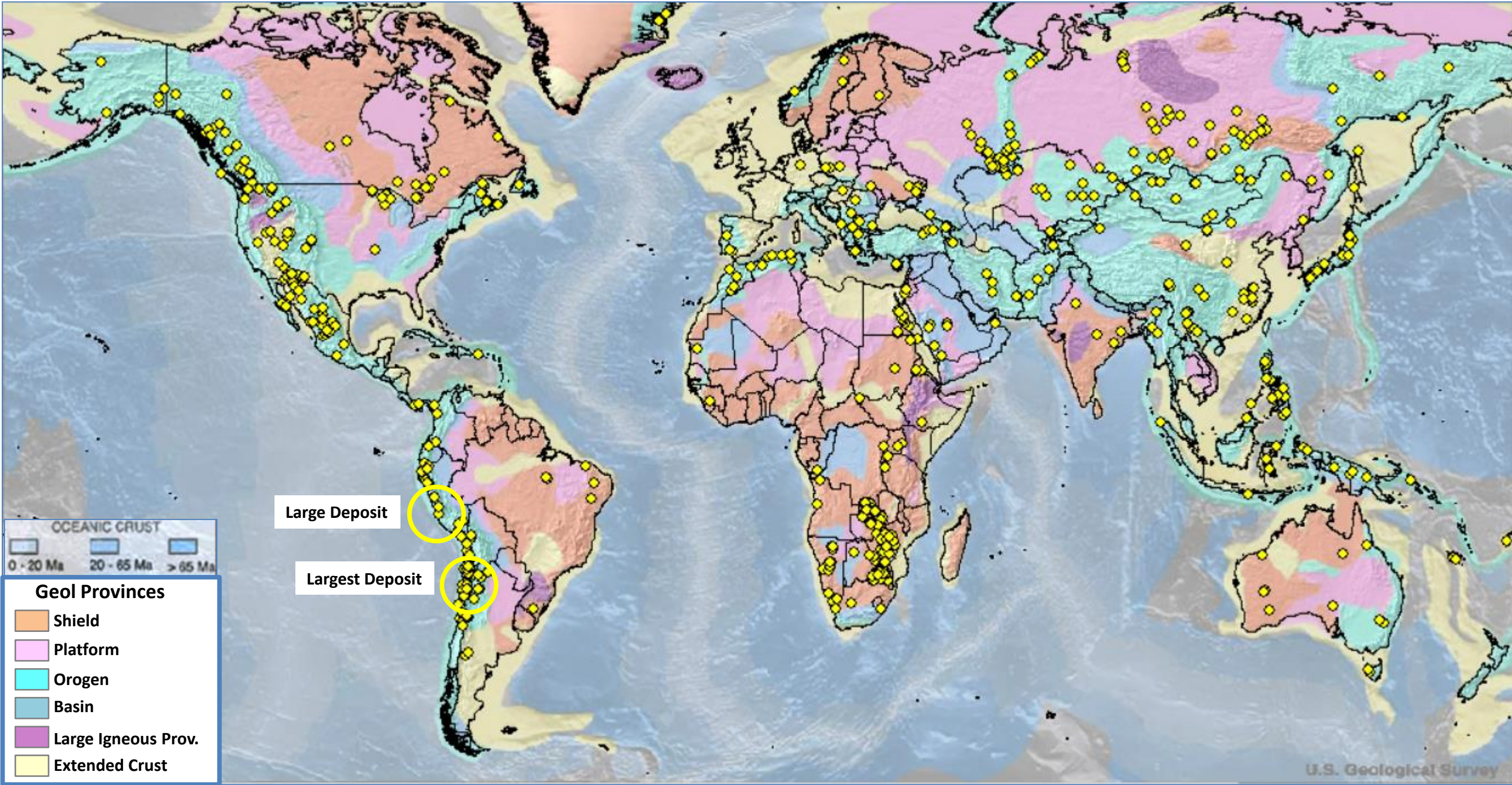
Escondida Mine Chile

ifpenergiesnouvelles.com  
USGS Commodity Summary



# Copper

## Province Type

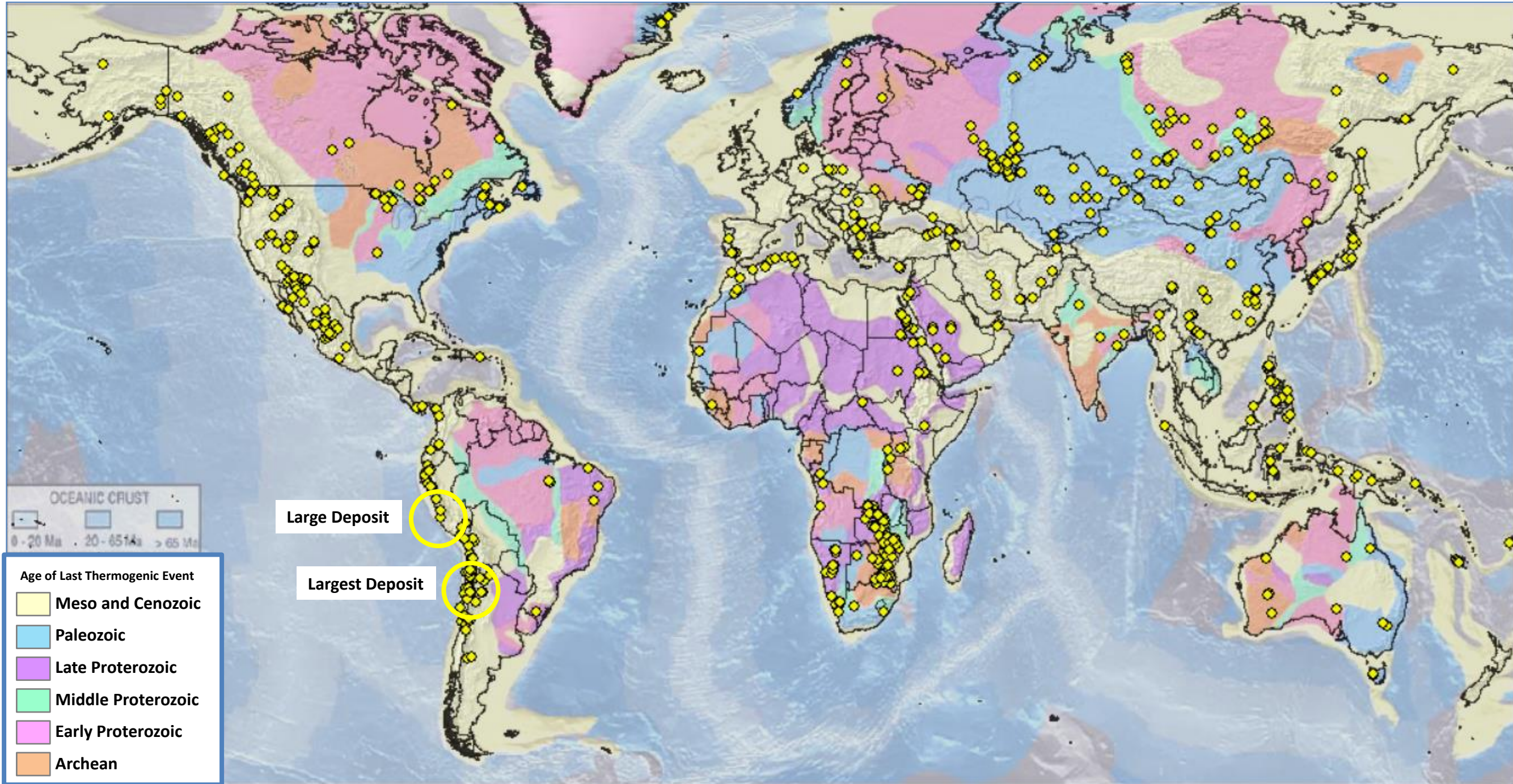


*Indicative Locations of deposits based on USGS data (may not be comprehensive)*



# Copper

## Age of Last Thermogenic Event

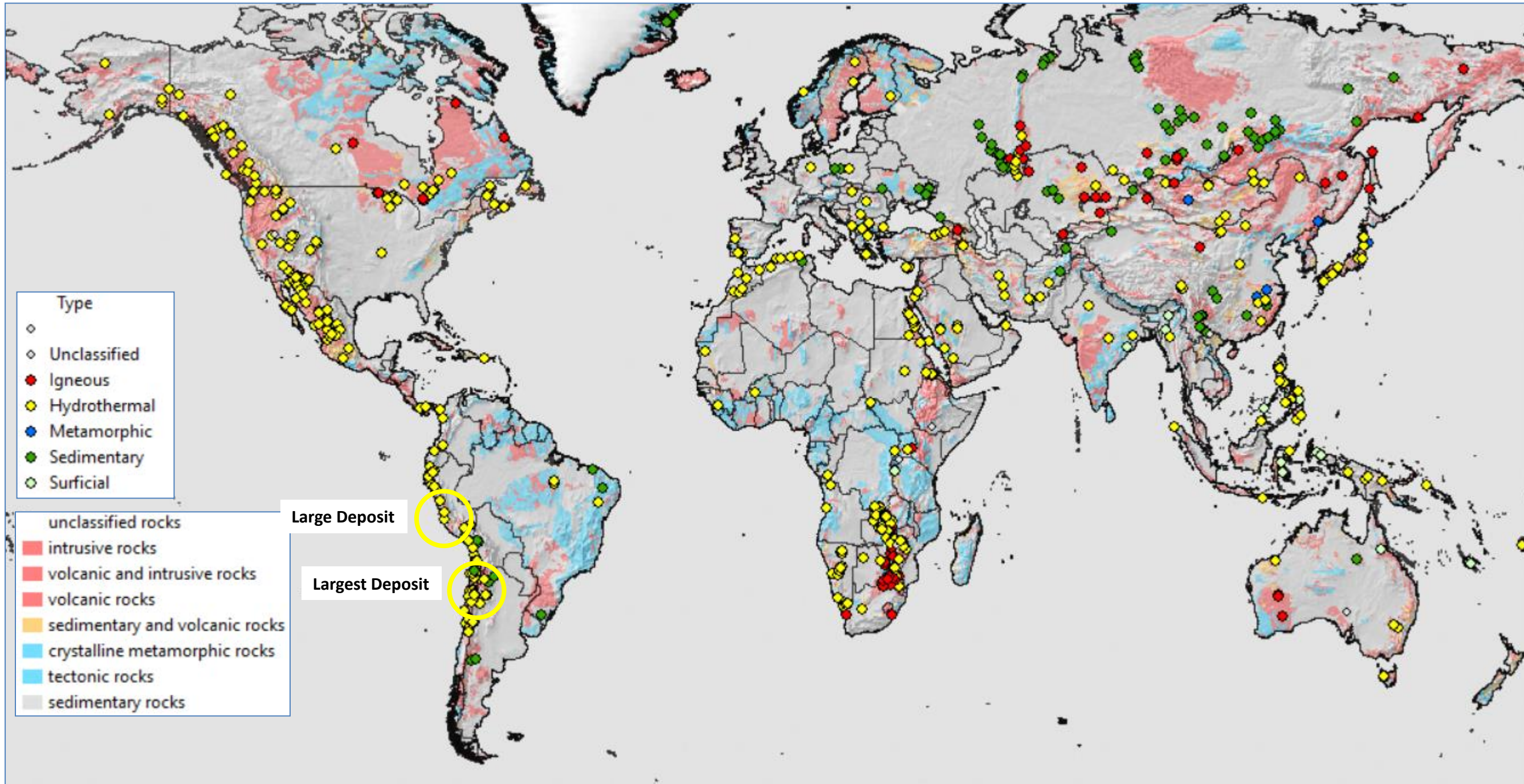


*Indicative Locations of deposits based on USGS data (may not be comprehensive)*



# Copper

## Type of Deposit



Indicative Locations of deposits based on USGS data (may not be comprehensive)



# World's Largest Deposits

## Escondida Porphyry Cu Deposit

Copper

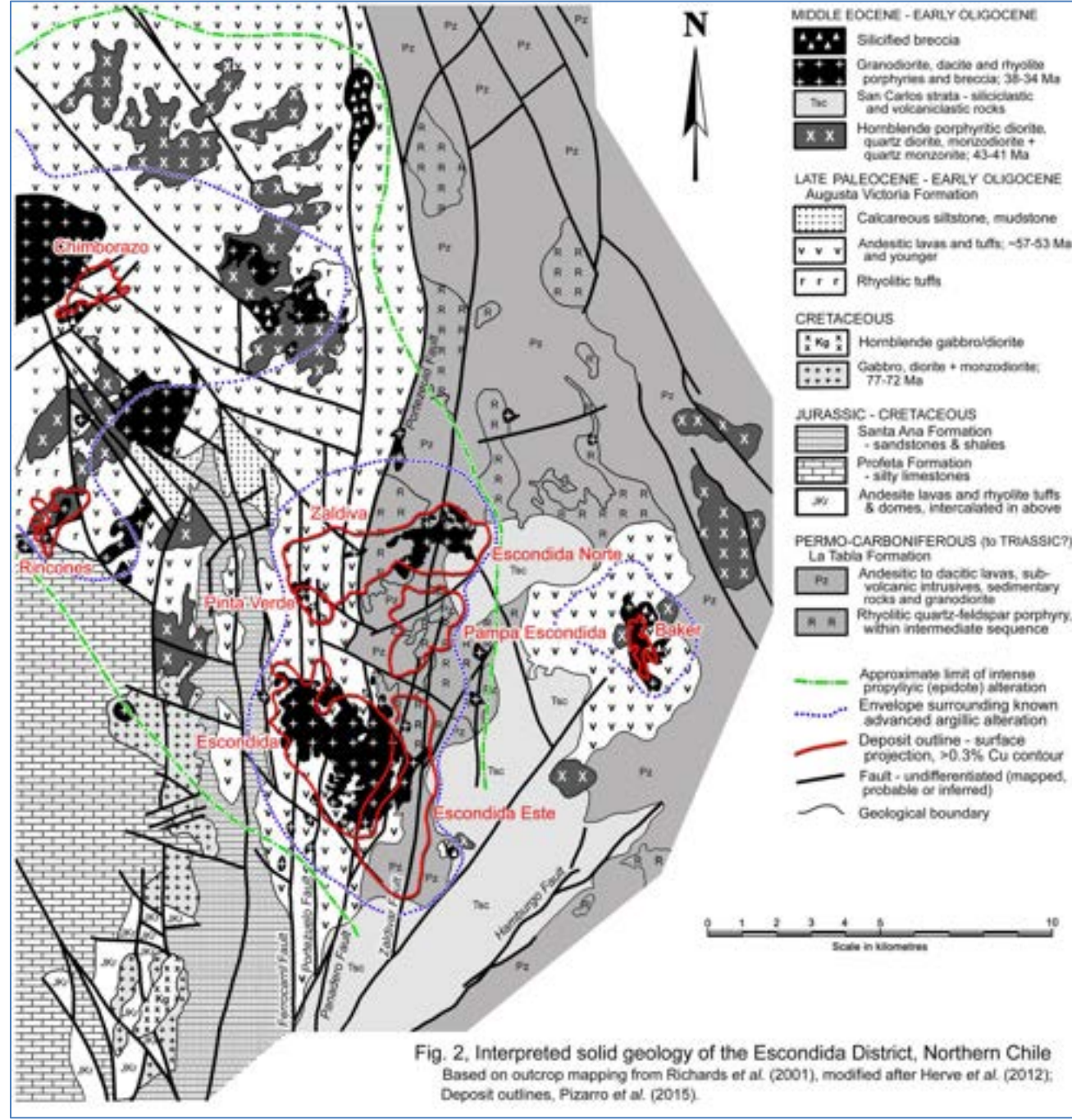
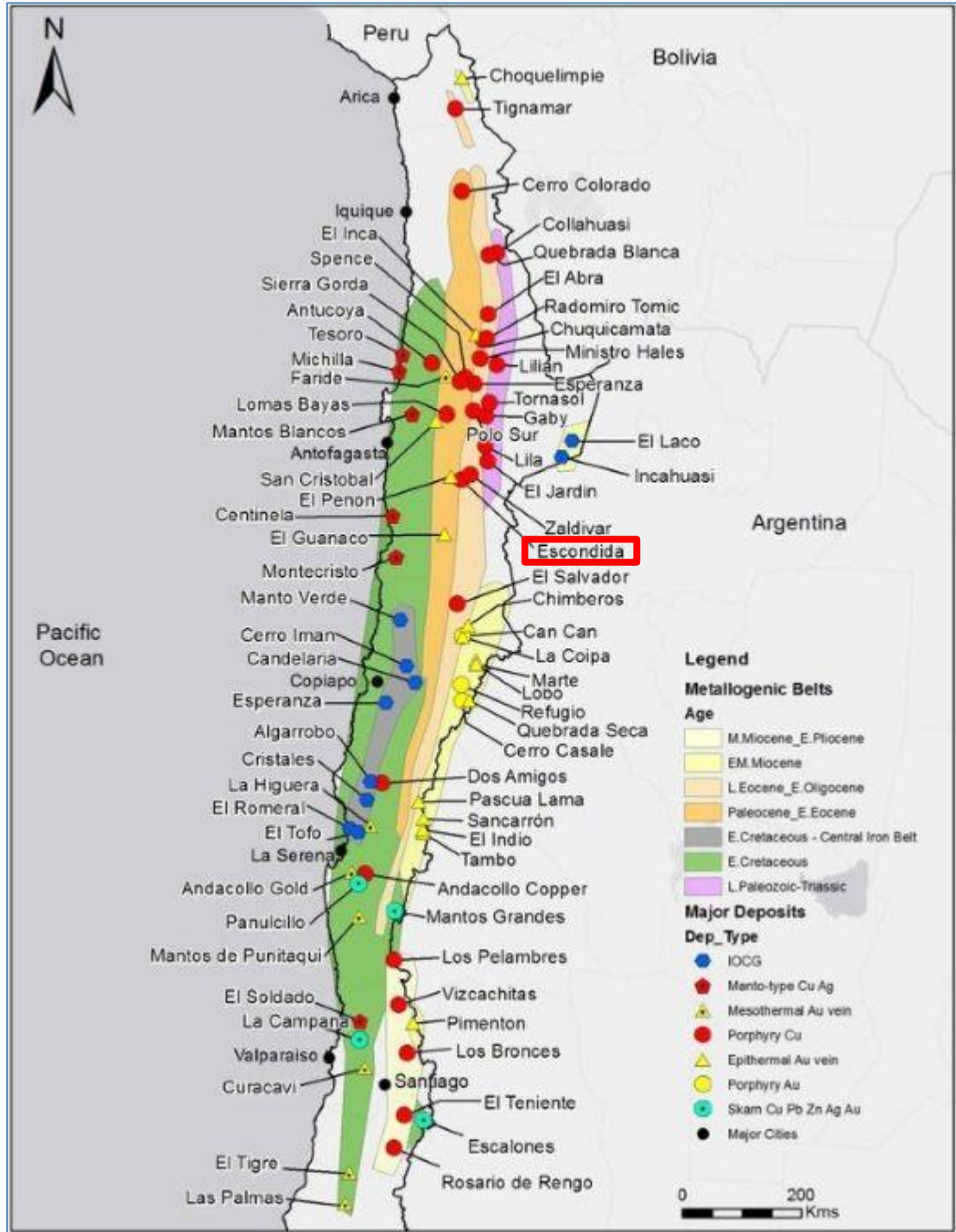
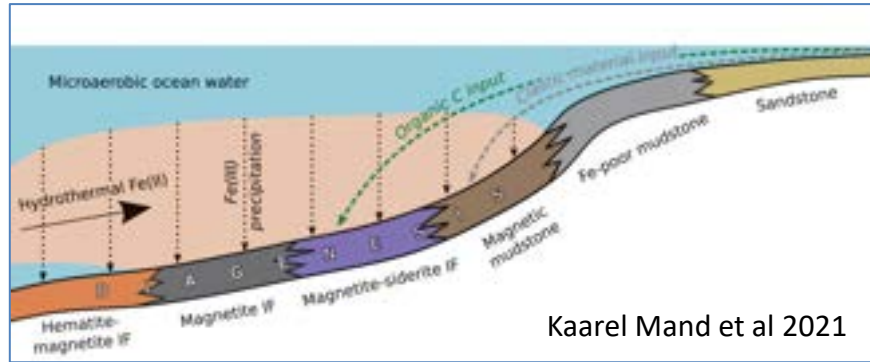


Fig. 2. Interpreted solid geology of the Escondida District, Northern Chile. Based on outcrop mapping from Richards et al. (2001), modified after Herve et al. (2012); Deposit outlines, Pizarro et al. (2015).



## Sedimentary Banded Iron Fm

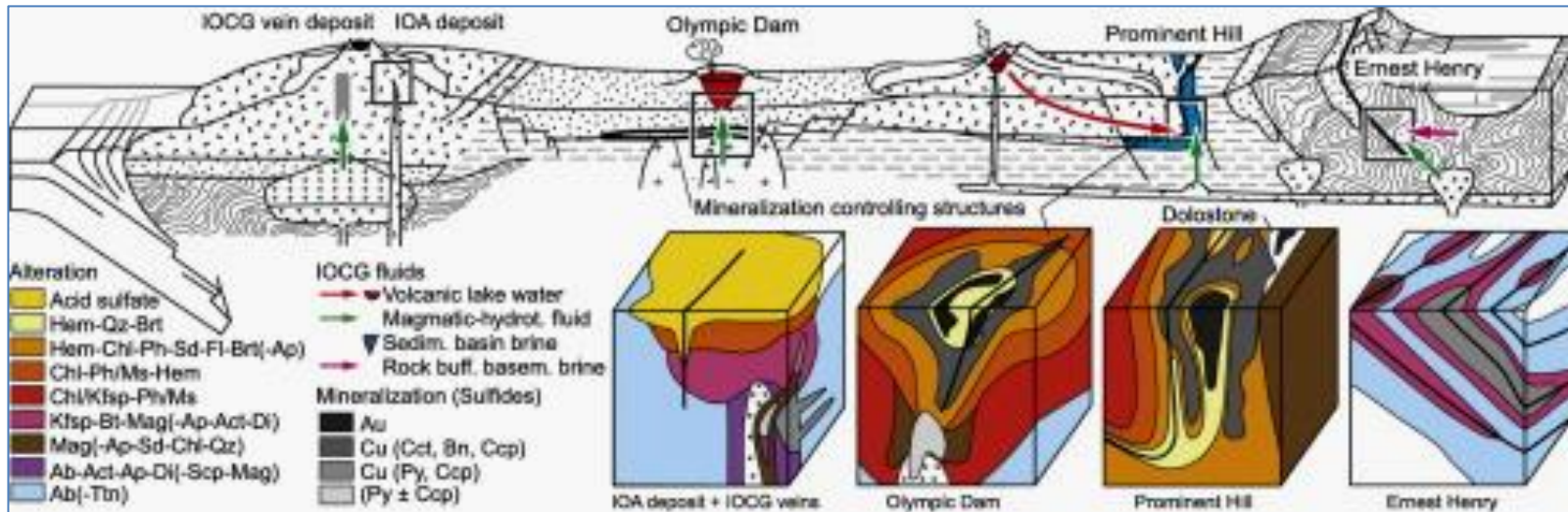


Kaarel Mand et al 2021



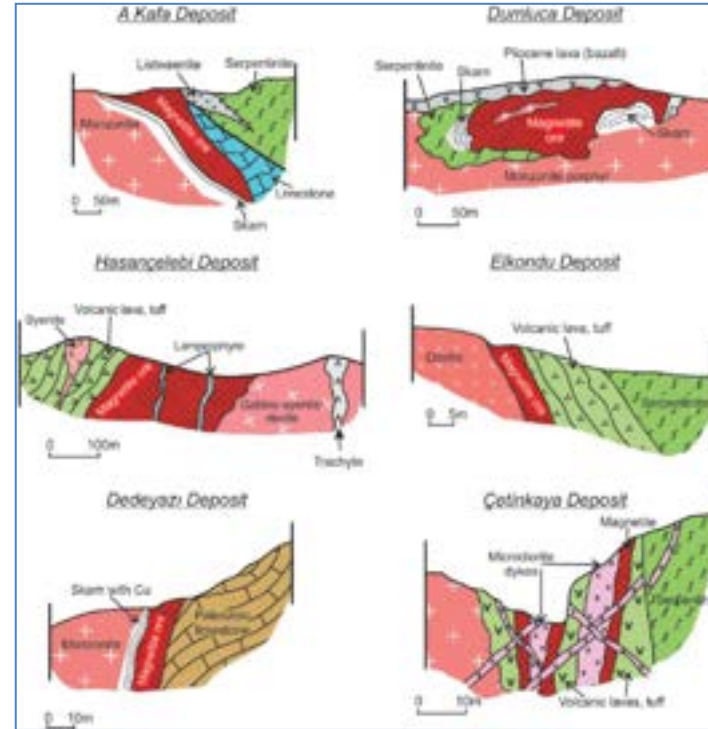
Malistani 2020

## Igneous Iron Ore type



Schlegel et al 2020

## Skarn Iron Ore type



Ozturk et al 2016

# Iron Ore

Iron ore deposits can occur in a variety of geological settings, including sedimentary, igneous, and metamorphic rocks. The most common type of iron ore deposit is the banded iron formation (BIF), which is a sedimentary rock that consists of alternating layers of iron-rich minerals (such as hematite or magnetite) and chert or other silica-rich minerals. Iron ore can also occur in igneous rocks as titanomagnetite and vanadiferous magnetite deposits, as well as in metamorphic rocks as metamorphosed iron formations or skarn deposits.

**Sedimentary rocks:** Banded iron formations (BIFs) are the most significant sedimentary rocks hosting iron ore deposits. BIFs are found in a variety of geological settings, including lake, marine, and fluvial environments. Some of the largest iron ore deposits in the world, such as those in the Pilbara region of Western Australia, are hosted in BIFs. They are generally of Proterozoic age.

**Igneous rocks:** Iron ore deposits can also occur in igneous rocks, particularly in association with mafic and ultramafic intrusions. These deposits are commonly referred to as titanomagnetite deposits due to the presence of titanium and magnetite minerals. Examples of titanomagnetite deposits include the Kiruna deposit in Sweden and the Bushveld Complex in South Africa.

**Metamorphic rocks:** Iron ore can also be found in metamorphic rocks that have undergone high-pressure and high-temperature conditions. These iron ore deposits are typically associated with skarns, which are contact metamorphic rocks that form at the contact between intrusions and carbonate-rich rocks. Skarn deposits are relatively small compared to BIFs and titanomagnetite deposits, but they can be economically important sources of iron ore.

**Secondary:** Goethite and limonite are iron oxide minerals that are commonly associated with weathering of iron-rich rocks and can form deposits known as laterites. Laterite deposits are typically found in tropical and subtropical regions where intense weathering has occurred. They are characterized by their high moisture content and low iron content, and are typically considered lower-grade iron ore deposits.

geologyscience.com



# Working with ChatGPT

Iron deposits are associated with various geological settings, and the type of deposit is influenced by the tectonic environment in which they form. Iron is a common element in the Earth's crust, and iron deposits can be found in a variety of geological settings. Here are some common tectonic settings where iron deposits are typically found:

## **Banded Iron Formations (BIFs):**

**Tectonic Setting:** BIFs are often associated with stable, continental cratons, which are ancient and relatively stable portions of continental crust.

**Formation:** BIFs are sedimentary rock sequences that contain alternating layers of iron-rich minerals (such as hematite or magnetite) and chert (silica-rich rocks). They formed during periods of Earth's history when the atmosphere and oceans contained high levels of dissolved iron, allowing the precipitation of iron-rich sediments.

## **Iron Oxide-Copper-Gold (IOCG) Deposits:**

**Tectonic Setting:** IOCG deposits can form in various tectonic settings, including continental rifts, convergent plate boundaries, and intraplate settings.

**Formation:** These deposits are characterized by the presence of iron oxide minerals along with copper and gold. They form through a combination of magmatic, hydrothermal, and structural processes associated with a variety of tectonic settings.

## **Metamorphic Iron Deposits:**

**Tectonic Setting:** Metamorphic iron deposits can form in a variety of tectonic settings where regional metamorphism occurs.

**Formation:** Iron-rich minerals in sedimentary rocks can undergo metamorphism, leading to the concentration of iron in metamorphic rocks such as banded iron formation, magnetite-rich schists, or hematite-rich metasediments.

## **Hydrothermal Iron Deposits:**

**Tectonic Setting:** Hydrothermal iron deposits can form in association with volcanic and hydrothermal activity in various tectonic settings.

**Formation:** Iron-rich minerals can be precipitated from hydrothermal fluids, forming veins or replacement deposits in a variety of geological environments.

## **Sedimentary Iron Deposits:**

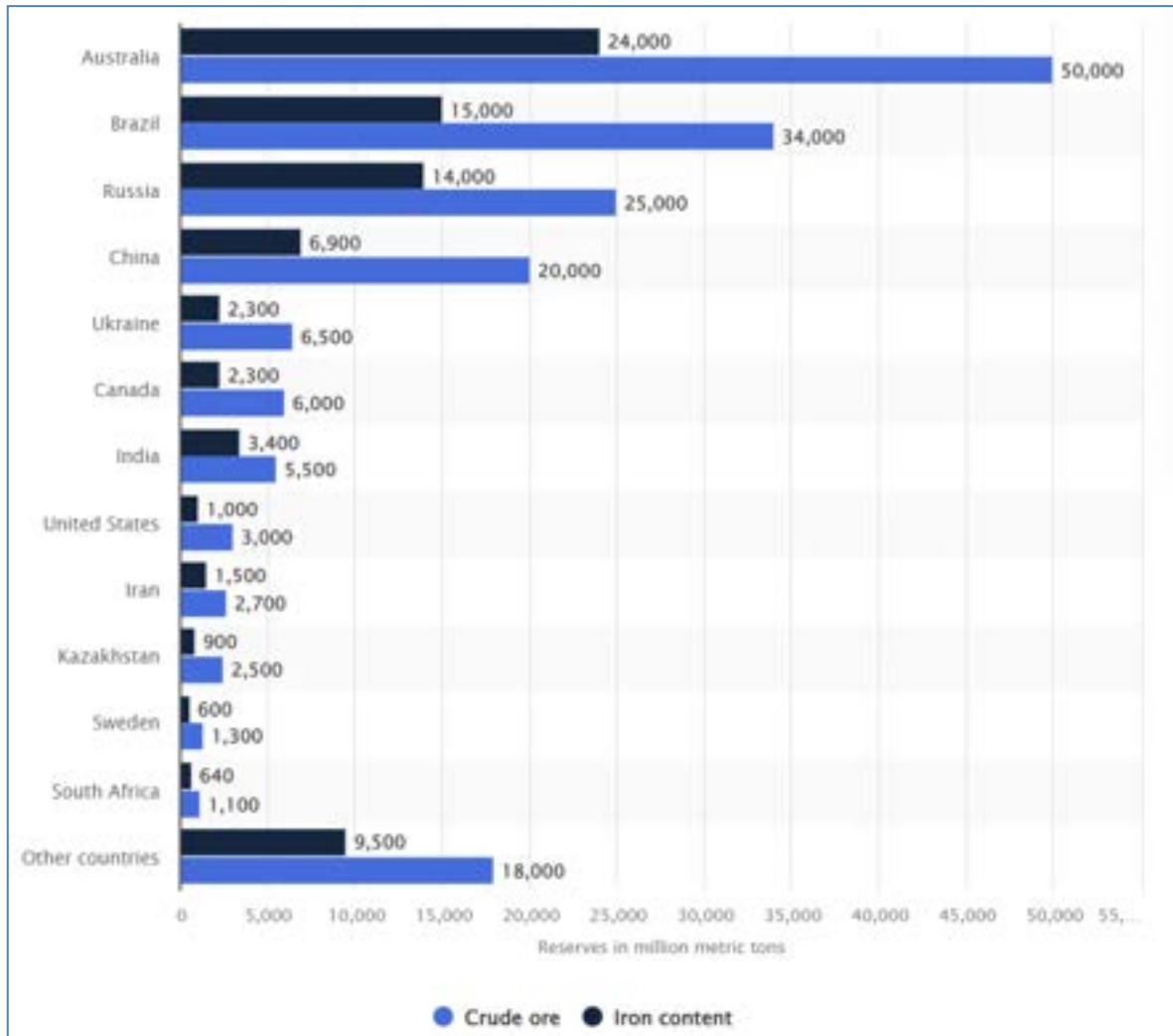
**Tectonic Setting:** Sedimentary iron deposits can form in various tectonic settings, including continental rifts, passive continental margins, and active tectonic margins.

**Formation:** These deposits result from the concentration of iron in sedimentary rocks through processes such as weathering, erosion, transportation, and deposition.

The economic significance of iron deposits is often related to their size, grade, and accessibility. Large-scale iron mining typically targets high-grade deposits that are economically viable for extraction. The exploration and exploitation of iron deposits are influenced by a combination of geological, economic, and environmental factors.



# Global Iron Ore Extraction and Reserves 2020



World Iron Ore Reserves 2020: Garside Dec 2021

USGS Commodity Summary



Iron ore production for 2018 (million mt). Source: RMG Consulting 2020



Hematite

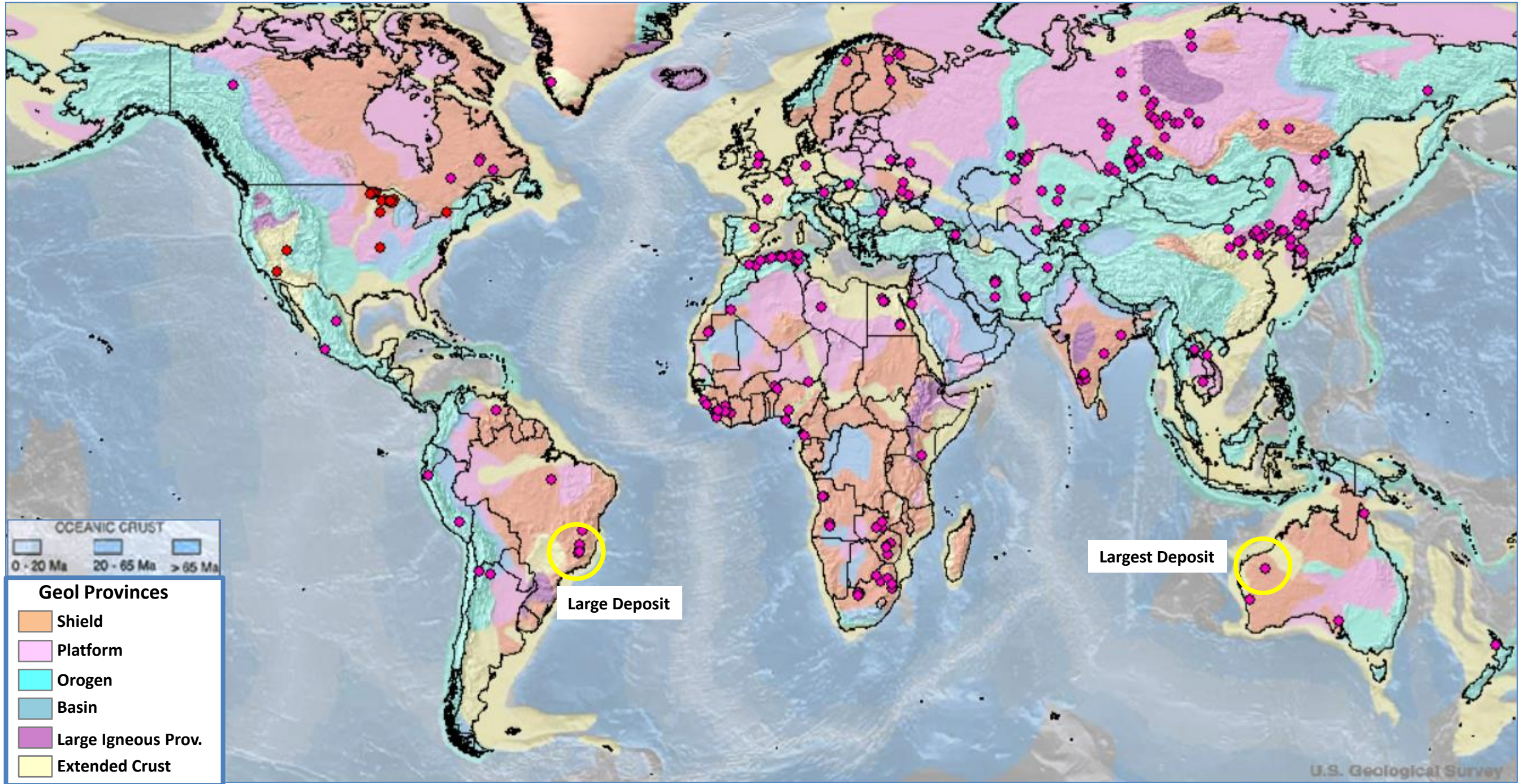


Carajas Mine Brazil



# Iron Ore

## Province Type

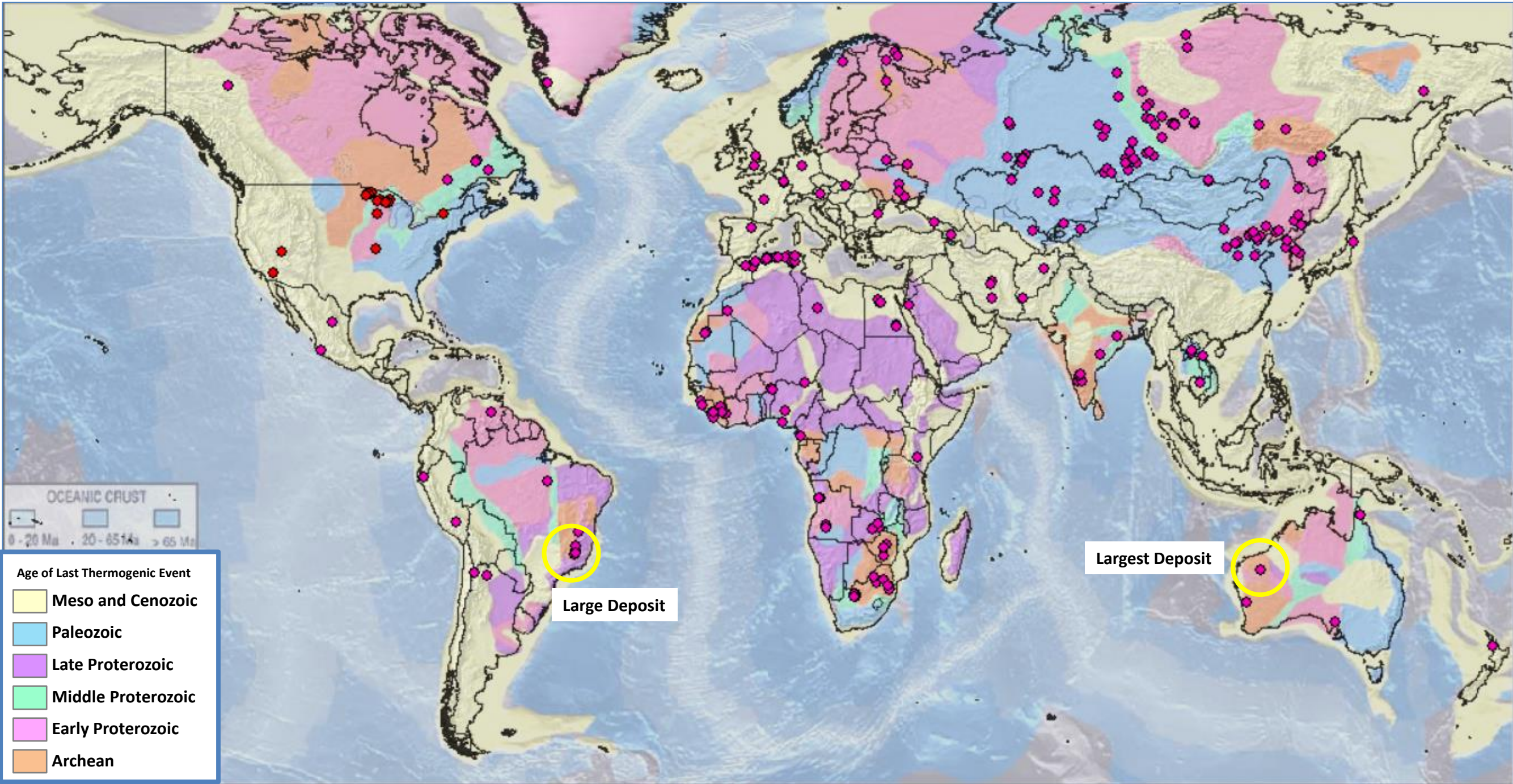


*Indicative Locations of deposits based on USGS data (may not be comprehensive)*



# Iron Ore

## Age of Last Thermogenic Event

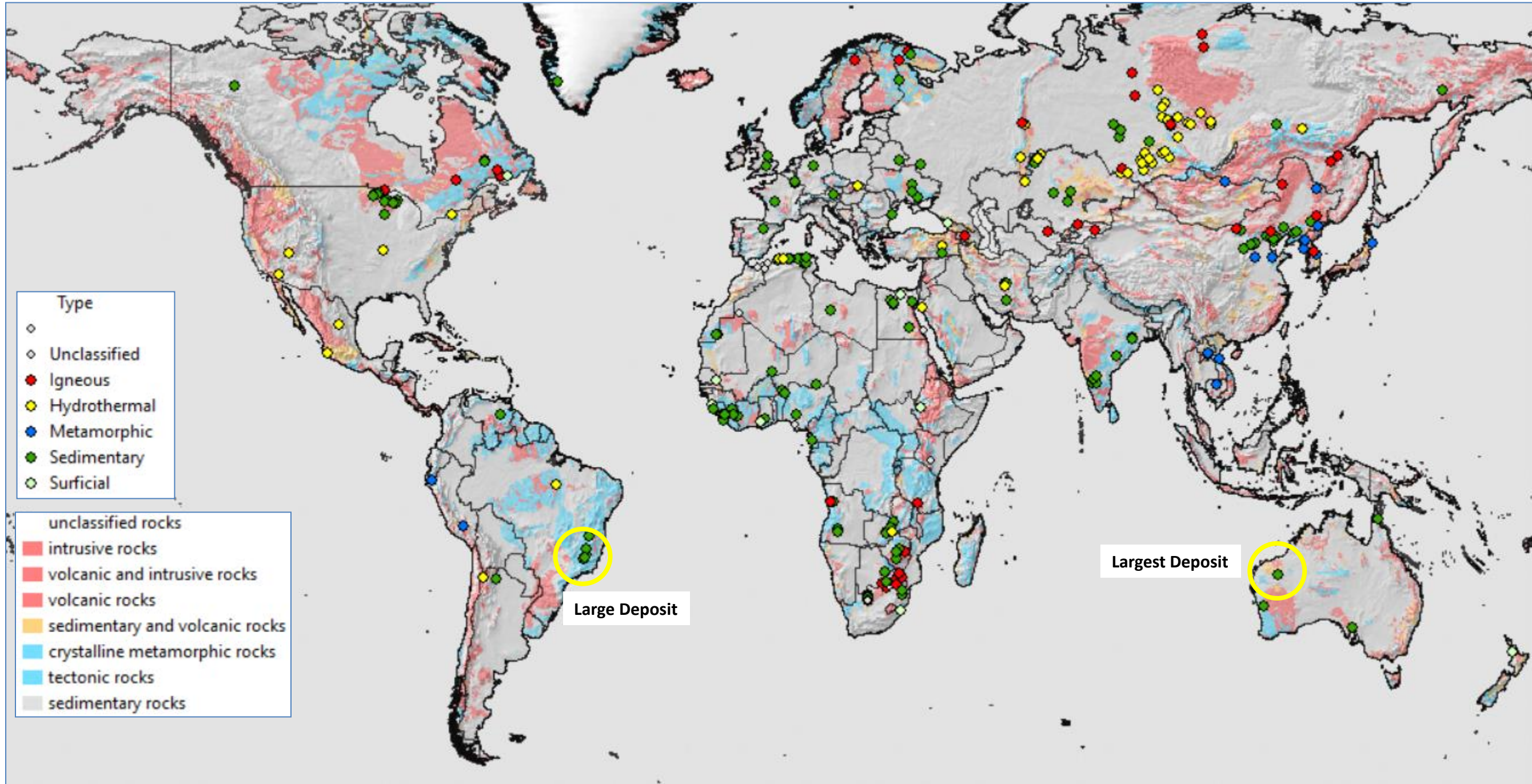


*Indicative Locations of deposits based on USGS data (may not be comprehensive)*



# Iron Ore

## Type of Deposit

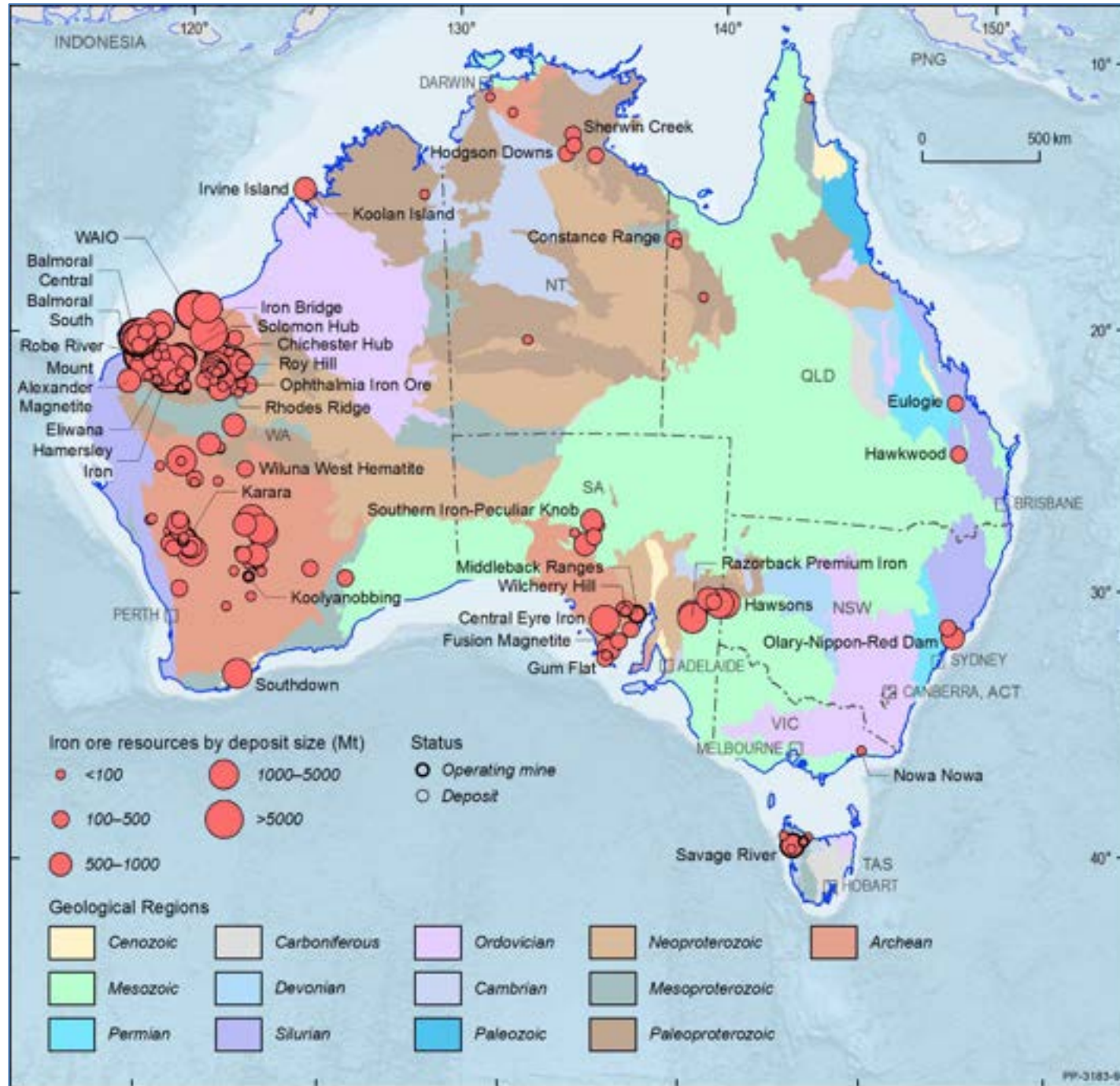


*Indicative Locations of deposits based on USGS data (may not be comprehensive)*

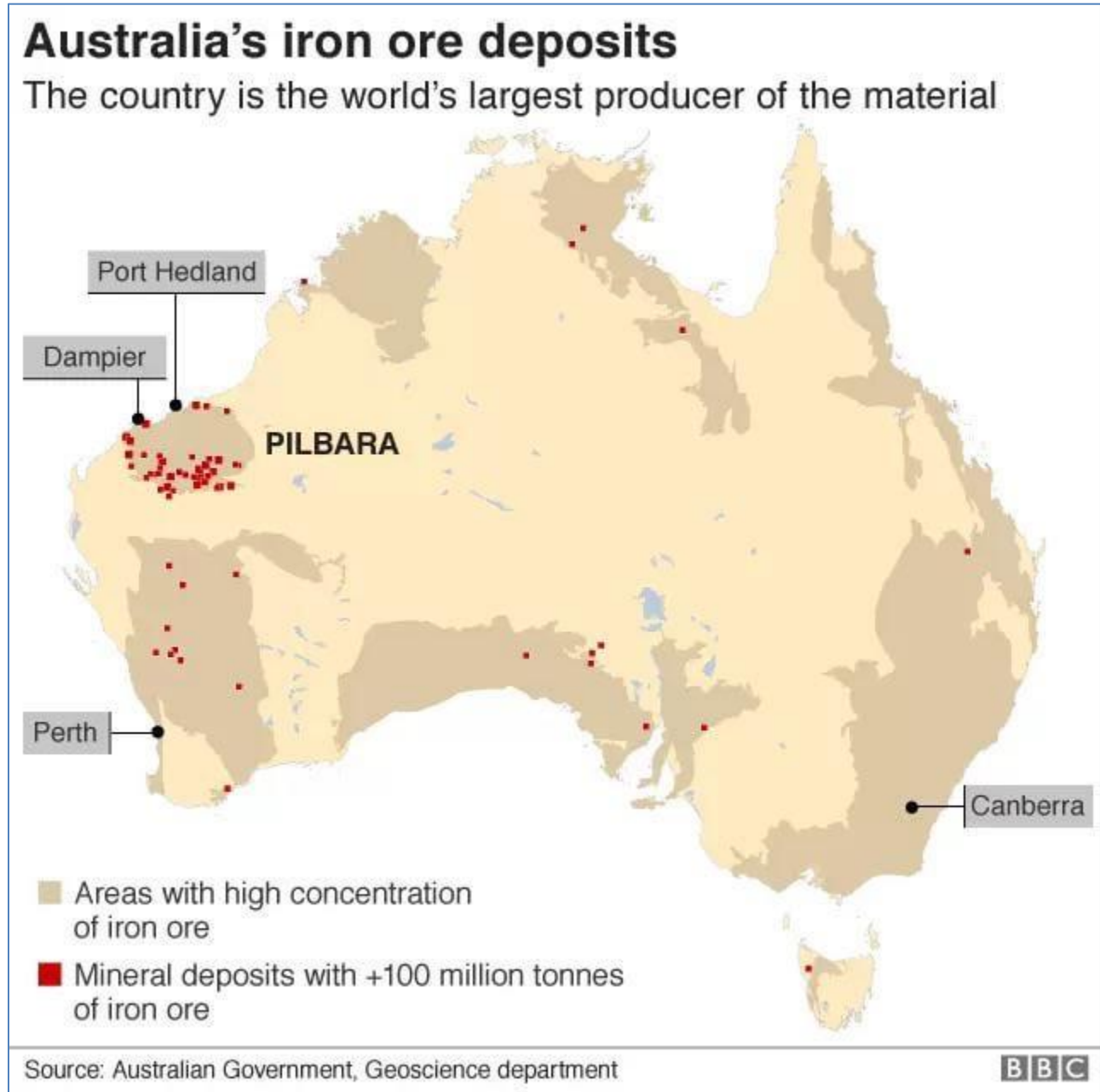


# World's Largest Deposits

## Iron Ore

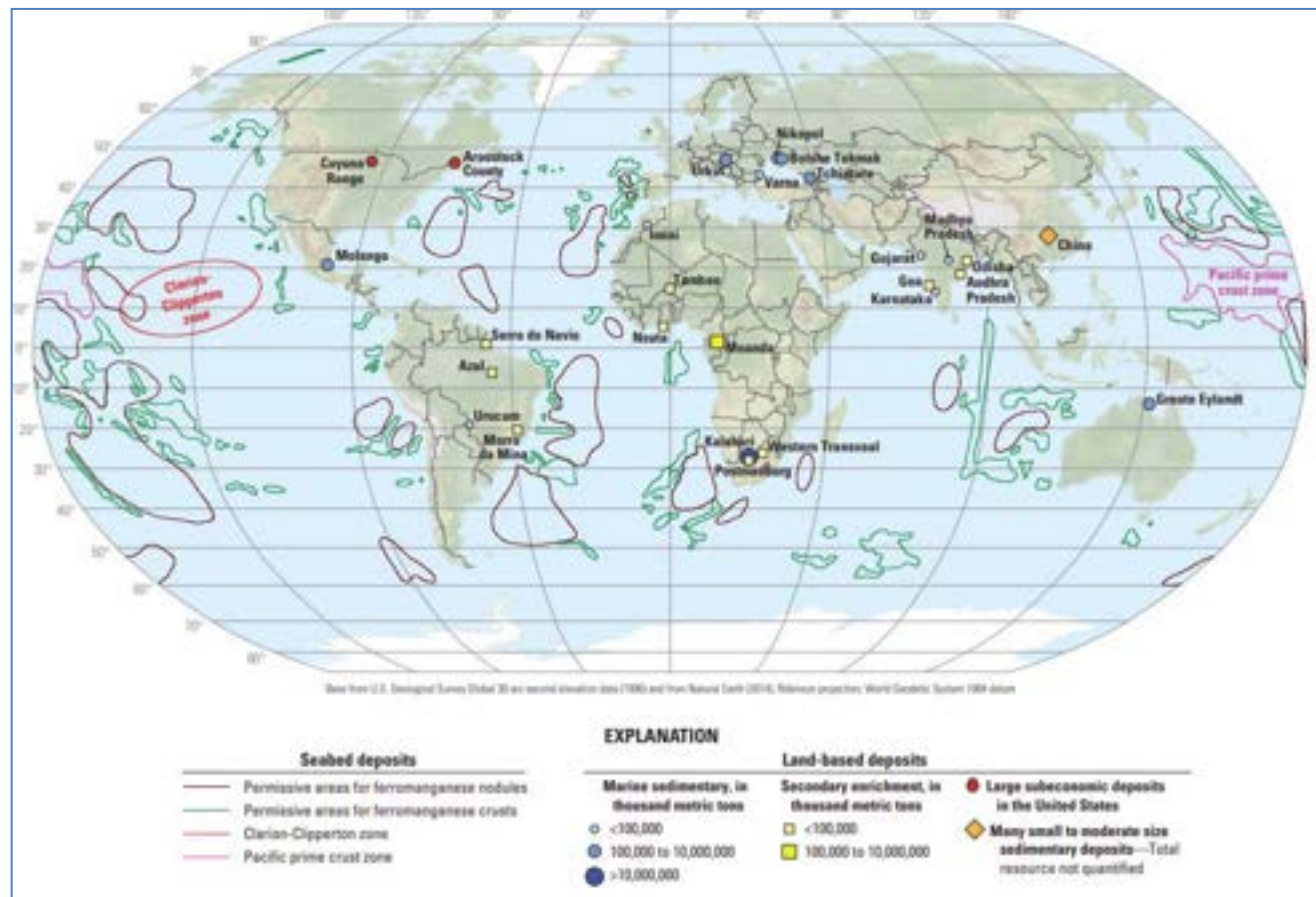


Geoscience Australia





# Manganese



USGS 2017

## Manganese Deposits in Marine Sedimentary Rocks

The vast majority of land-based manganese resources occur as extensive layers of manganese-rich sedimentary rocks, some of which formed as long as 2.5 billion years ago. Two types of sedimentary manganese deposits can be distinguished based on the nature of rocks with which they are interlayered and, by inference, the character of ocean water from which they were precipitated:

### (a) manganiferous sediments that occur independent of iron concentrations

The larger of such deposits include Molango in Mexico, Groote Eylandt in Australia, the deposits of the Black Sea region, and many deposits in China. These relatively low-iron deposits are thought to have formed in shallow marine settings adjacent to stratified oceans that contained a low oxygen deepwater mass.

### (b) manganiferous sediments interlayered with ferruginous strata.

These are in banded iron formations that are found widely in Precambrian sequences in many parts of the world. These include the vast manganese deposits of the Kalahari district in South Africa and the Urucum mining district in Brazil, and many deposits in India. The hallmark of such deposits is the interlayering of iron- and manganese-rich layers, which indicate that the deposit formed from an ocean in which both iron and manganese were enriched, but that the two metals were differentiated from each other at the site of deposition, perhaps by subtle changes in the oxidation state or acidity of the ocean water.

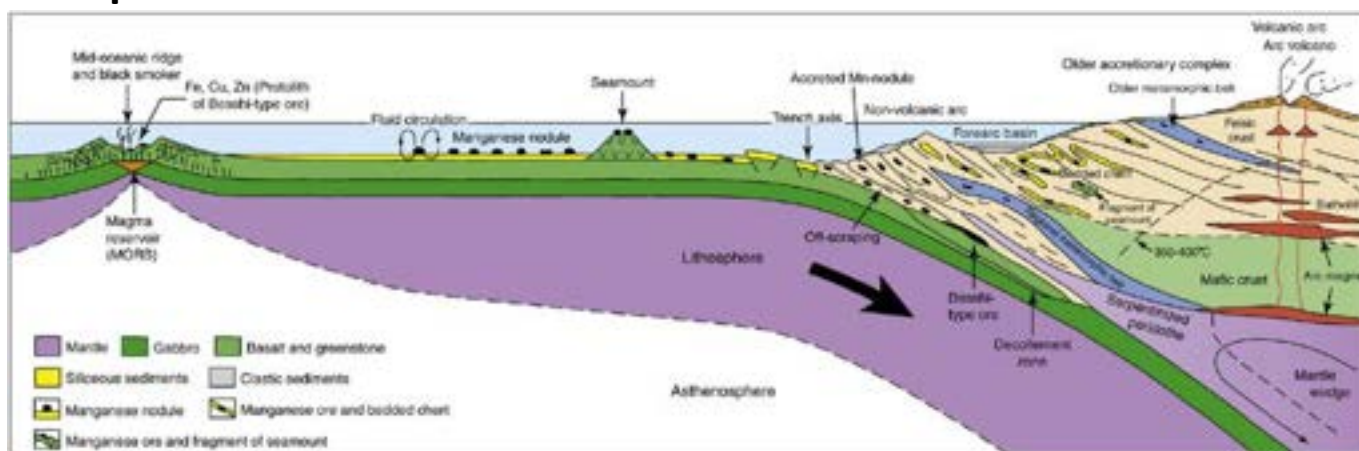
## Secondary Enrichment (Supergene) Deposits

Nonmanganese components are leached out which result in residual enrichment of the manganese. Significant occurrences of these types of deposits are the Moanda deposit in Gabon, the Azul and the Serra do Navio deposits in Brazil, and numerous deposits in India. By their nature, the resources of these deposits are smaller than are those of the major sedimentary-type deposits, but the deposits are still substantial in terms of both their resources and current production

## Seabed Deposits

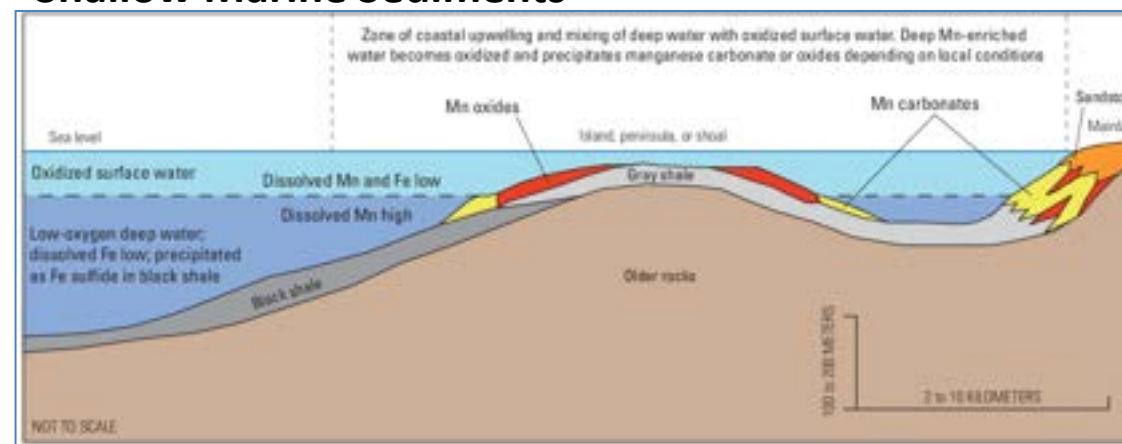
The world's ocean floors include tens of millions of square kilometers (km<sup>2</sup>) covered with manganese-rich deposits of ferromanganese nodules and crusts. No manganese or other metals have been produced from any of these deposits in spite of several decades of research and exploration.

## Deep Marine Sediments



Nakagawa et al 2009

## Shallow Marine Sediments



USGS 2017

USGS 2017



Manganese deposits can be found in various geological settings, and their occurrence is influenced by specific geological processes. Manganese is often associated with specific types of rocks and mineralization environments. Here are some common tectonic settings where manganese deposits are typically found:

### **Sedimentary Manganese Deposits:**

**Tectonic Setting:** Sedimentary manganese deposits are often associated with continental shelves and margins, particularly in marine basins.

**Formation:** These deposits form through the precipitation of manganese oxides and hydroxides from seawater. The manganese minerals accumulate on the seafloor over long periods, forming layers of sedimentary manganese ore.

### **Epithermal Manganese Deposits:**

**Tectonic Setting:** Epithermal manganese deposits can form in various tectonic settings, including continental rifts and island arc environments.

**Formation:** These deposits are associated with hydrothermal processes that involve the circulation of hot fluids through fractures in the Earth's crust. The fluids leach manganese from the surrounding rocks and deposit it in veins and replacement zones.

### **Metamorphic Manganese Deposits:**

**Tectonic Setting:** Metamorphic manganese deposits can form in regions undergoing regional metamorphism.

**Formation:** Manganese can be mobilized and concentrated during metamorphic processes, resulting in the formation of manganese-rich rocks. This can occur in settings such as regional metamorphism associated with mountain-building events.

### **Oxide and Hydroxide Manganese Deposits:**

**Tectonic Setting:** Oxide and hydroxide manganese deposits can be found in various tectonic settings, including continental platforms and oceanic ridges.

**Formation:** Manganese oxides and hydroxides may form through weathering processes, particularly in regions with well-drained soils. These weathered materials can accumulate and concentrate manganese.

### **Manganese Nodule Fields:**

**Tectonic Setting:** Manganese nodule fields are commonly found on the deep ocean floor.

**Formation:** Manganese nodules are small, rounded accretions that form over long periods on the seabed. They consist of concentric layers of manganese and iron oxides, and their formation is associated with slow precipitation of metals from seawater.

### **Manganese Carbonate Deposits:**

**Tectonic Setting:** Manganese carbonate deposits can form in various marine environments.

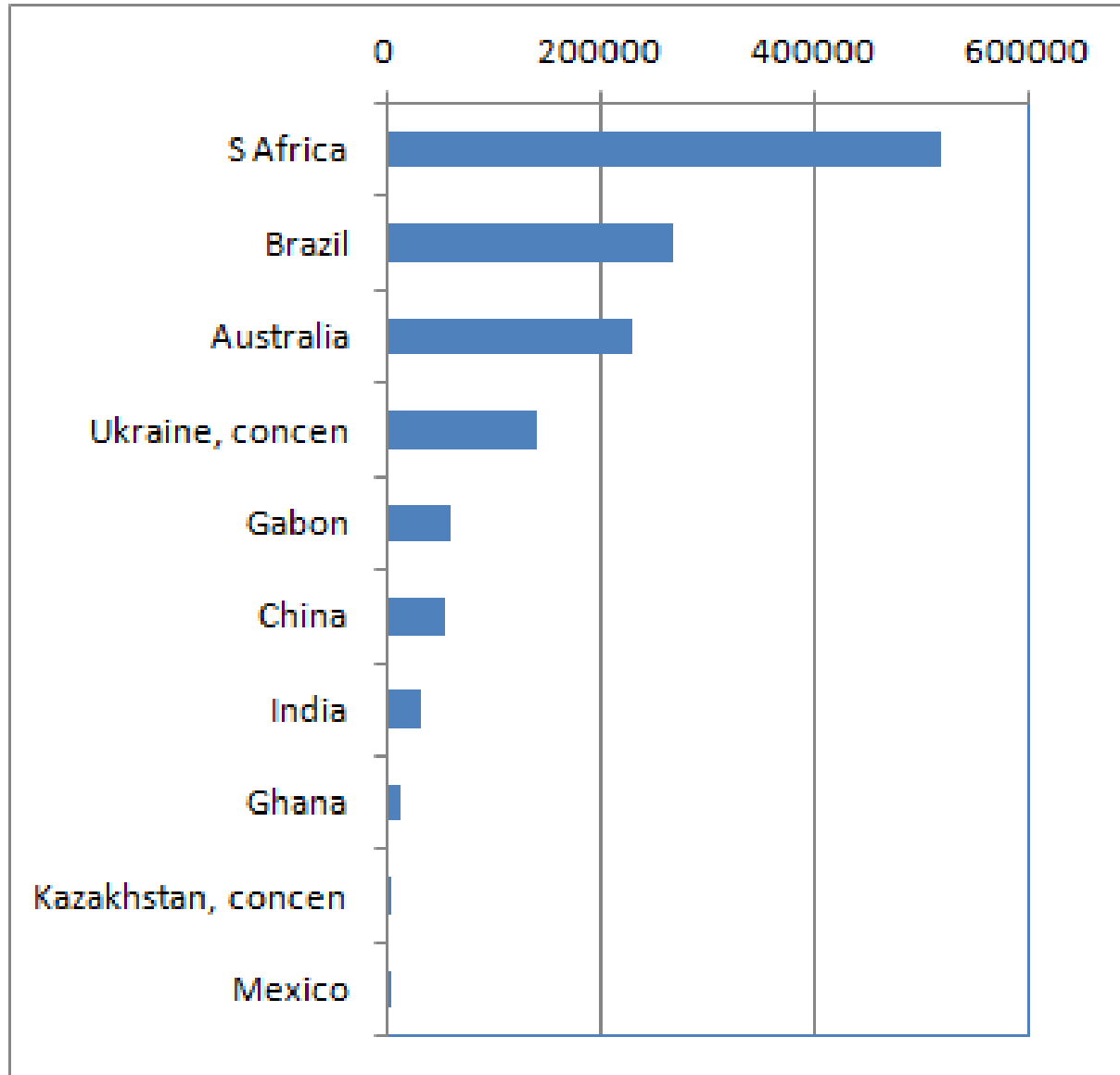
**Formation:** These deposits are associated with the precipitation of manganese carbonates from seawater, often in association with biogenic processes involving microbial or organic activity.

The economic significance of manganese deposits depends on factors such as the concentration of manganese, accessibility, and market demand. Manganese is a critical element used in the production of steel, batteries, and various industrial applications. The exploration and mining of manganese deposits involve understanding the geological processes that led to their formation and identifying economically viable occurrences.



## Global Manganese Extraction and Reserves 2020

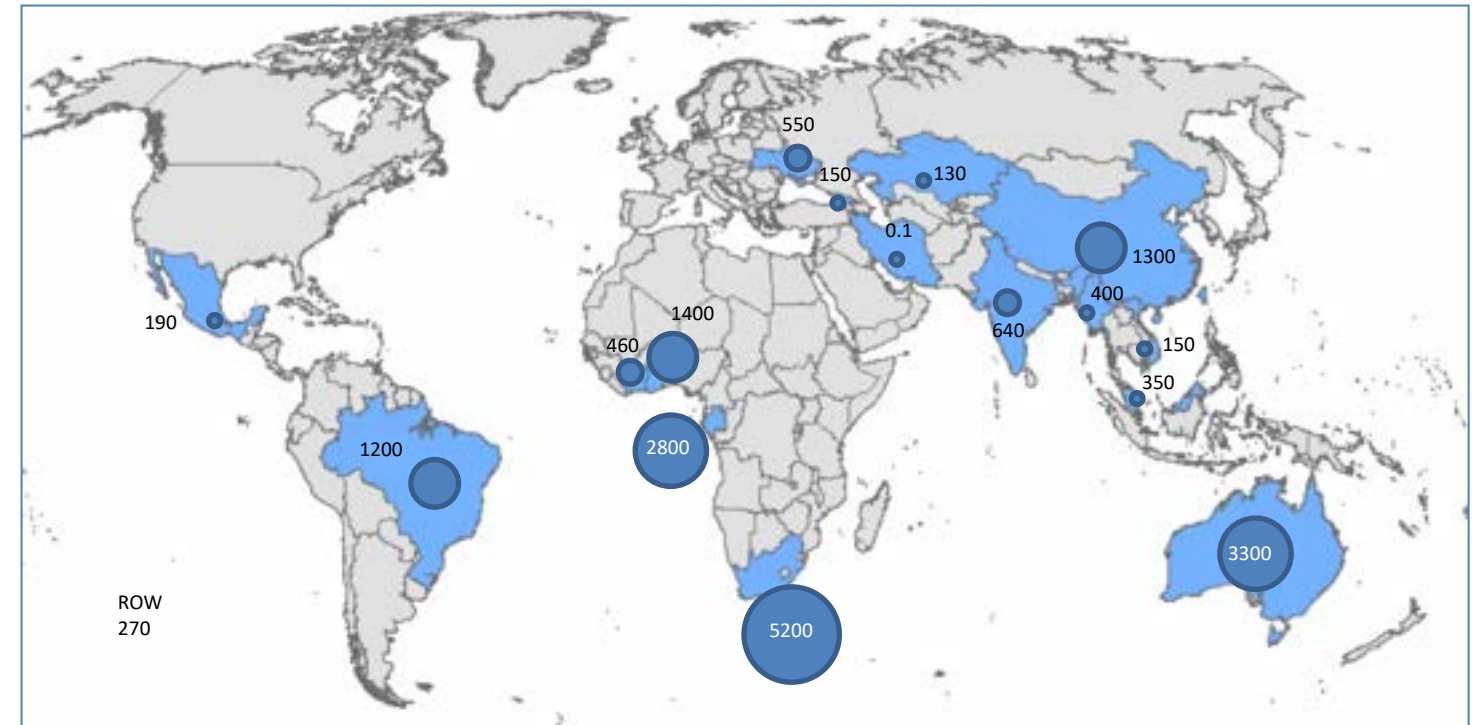
Reserves of Manganese world wide by country in 1000 tonnes



Statistica.com

USGS Commodity Summary

Production volume of manganese worldwide in 2020, by country (in 1000 metric tons)



Pyrolusite

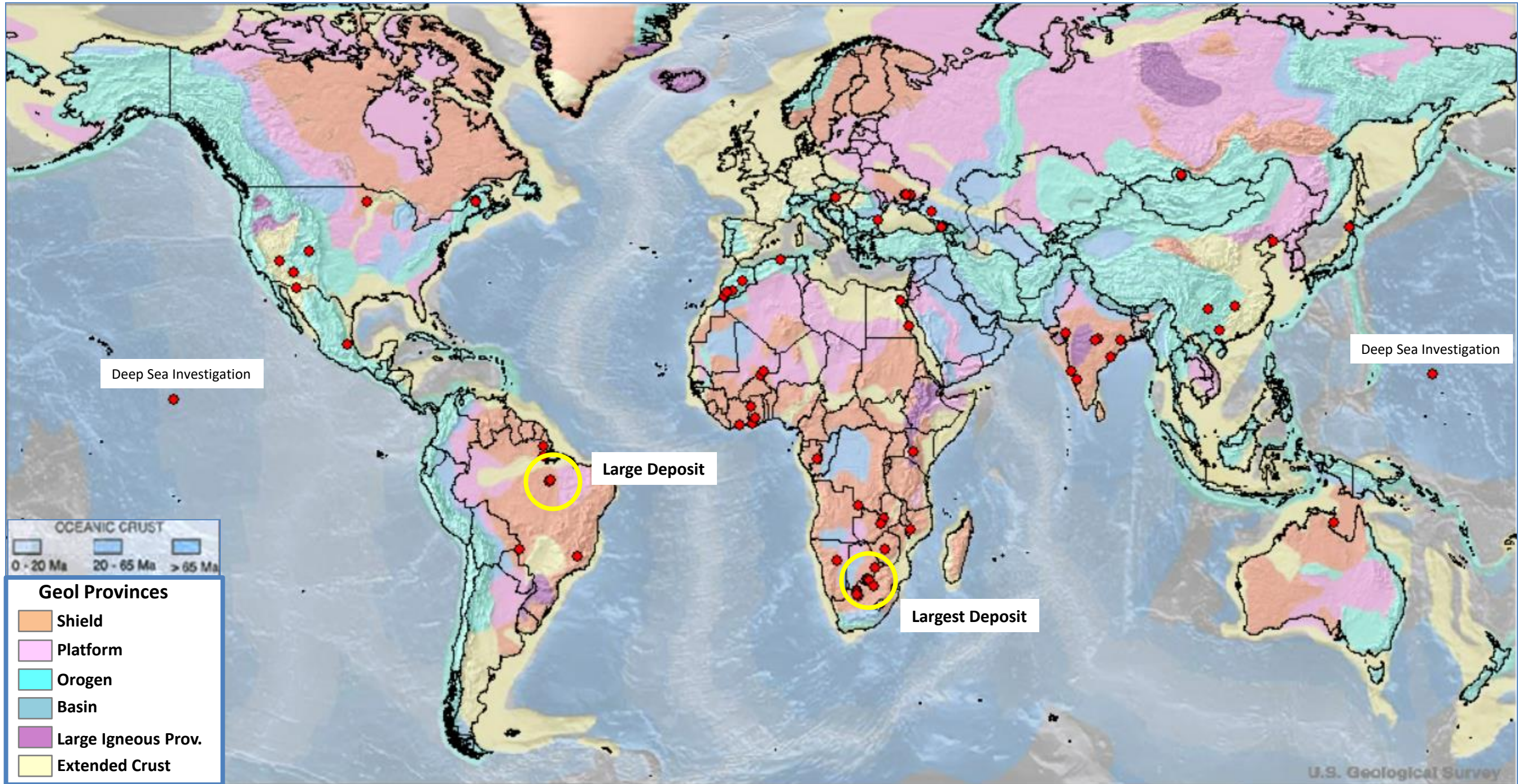


Mamatwan Mine S Africa



# Manganese

## Province Type

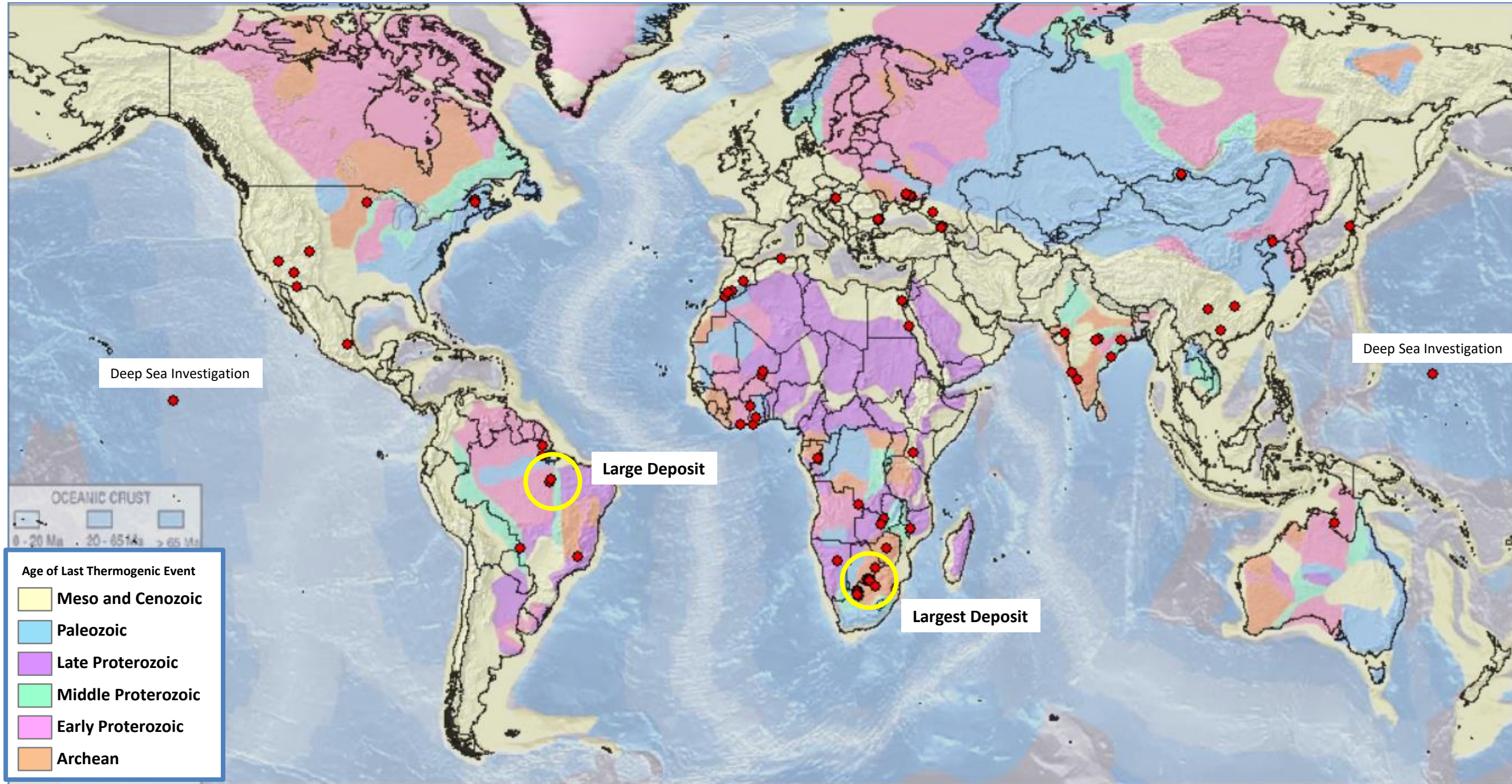


*Indicative Locations of deposits based on USGS data (may not be comprehensive)*



# Manganese

## Age of Last Thermogenic Event



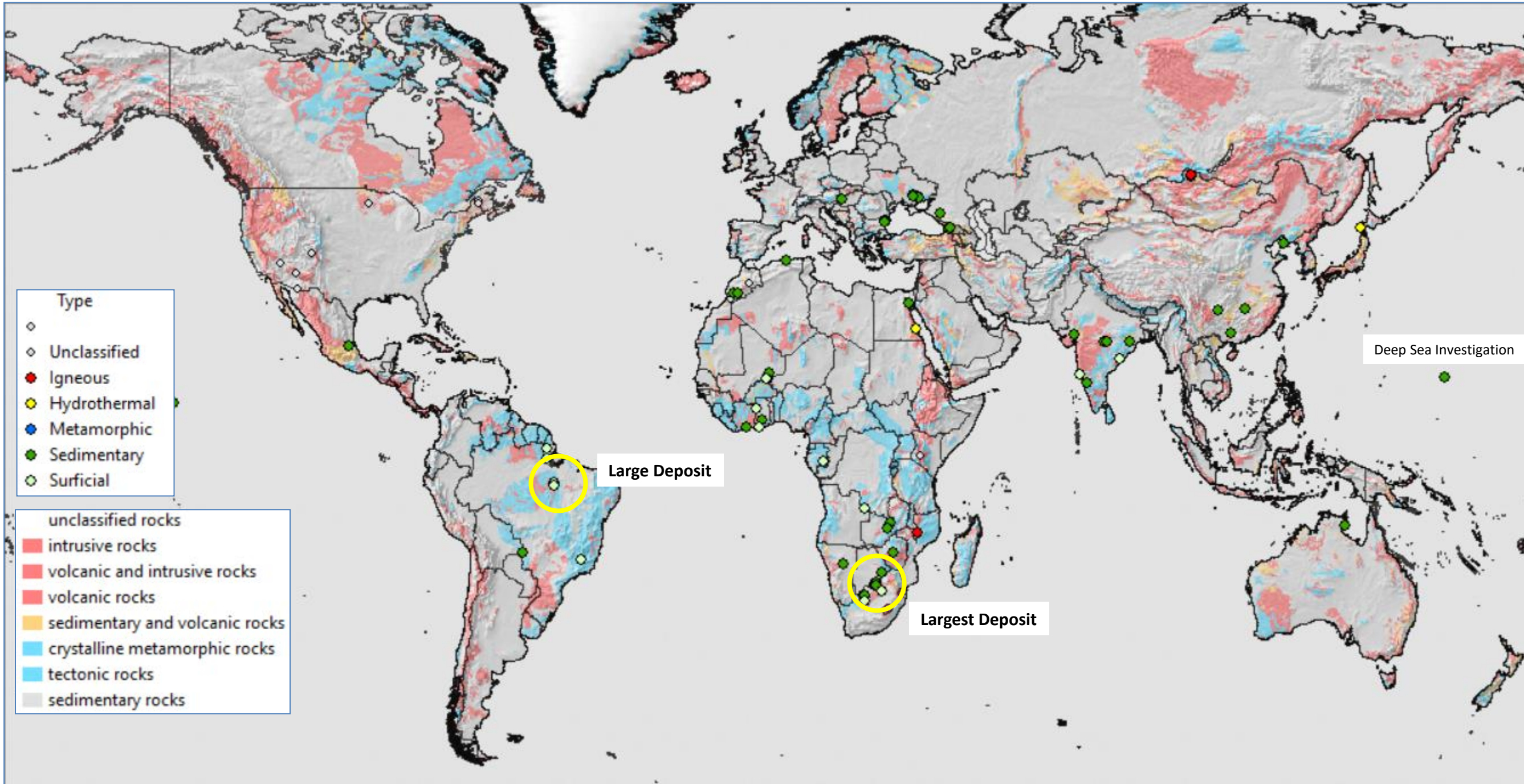
USGS data, USGS Age of Last Thermogenic Event

Eddy Ong 2024  
Posted on LinkedIn



# Manganese

## Type of Deposit



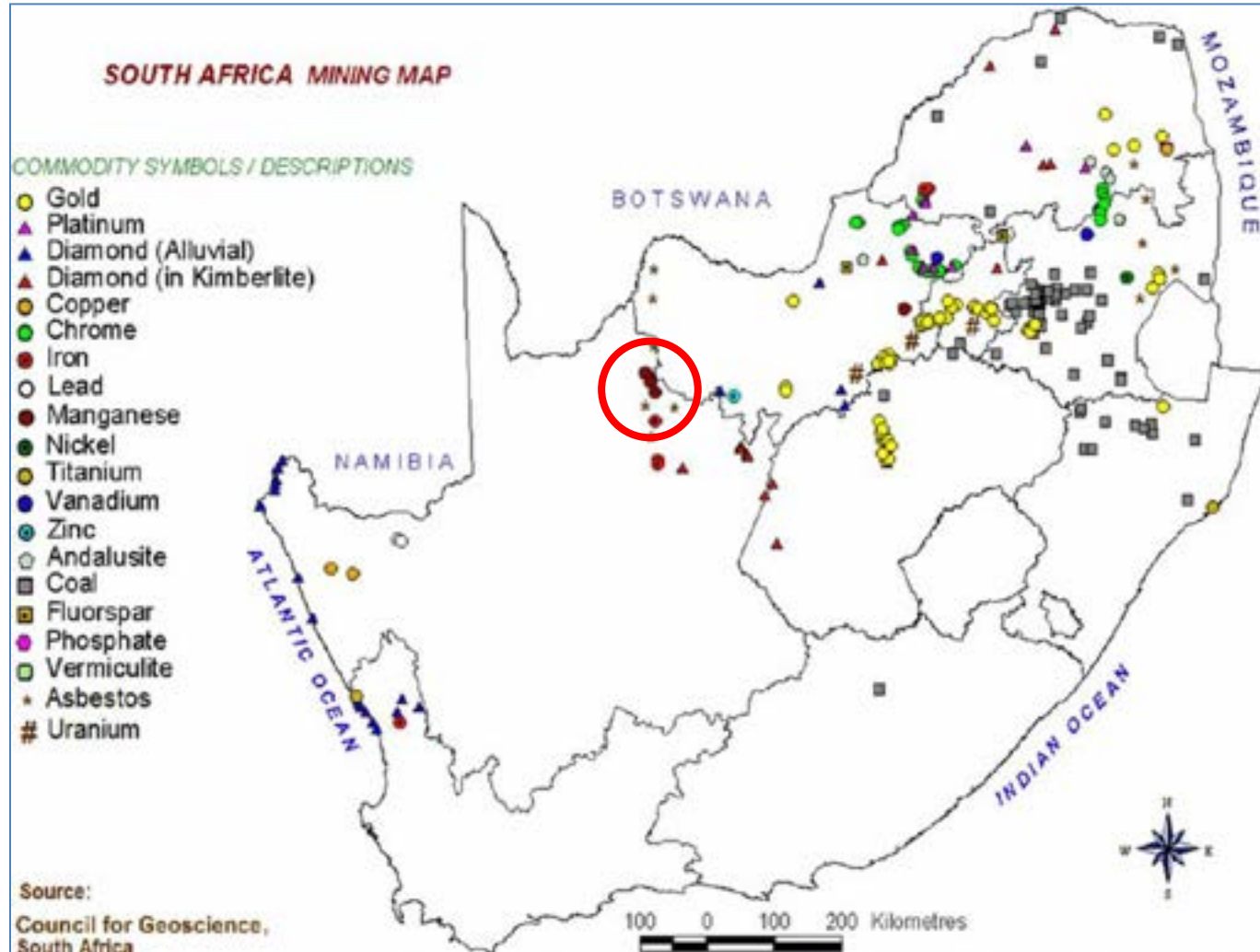
Indicative Locations of deposits based on USGS data (may not be comprehensive)



# World's Largest Deposits

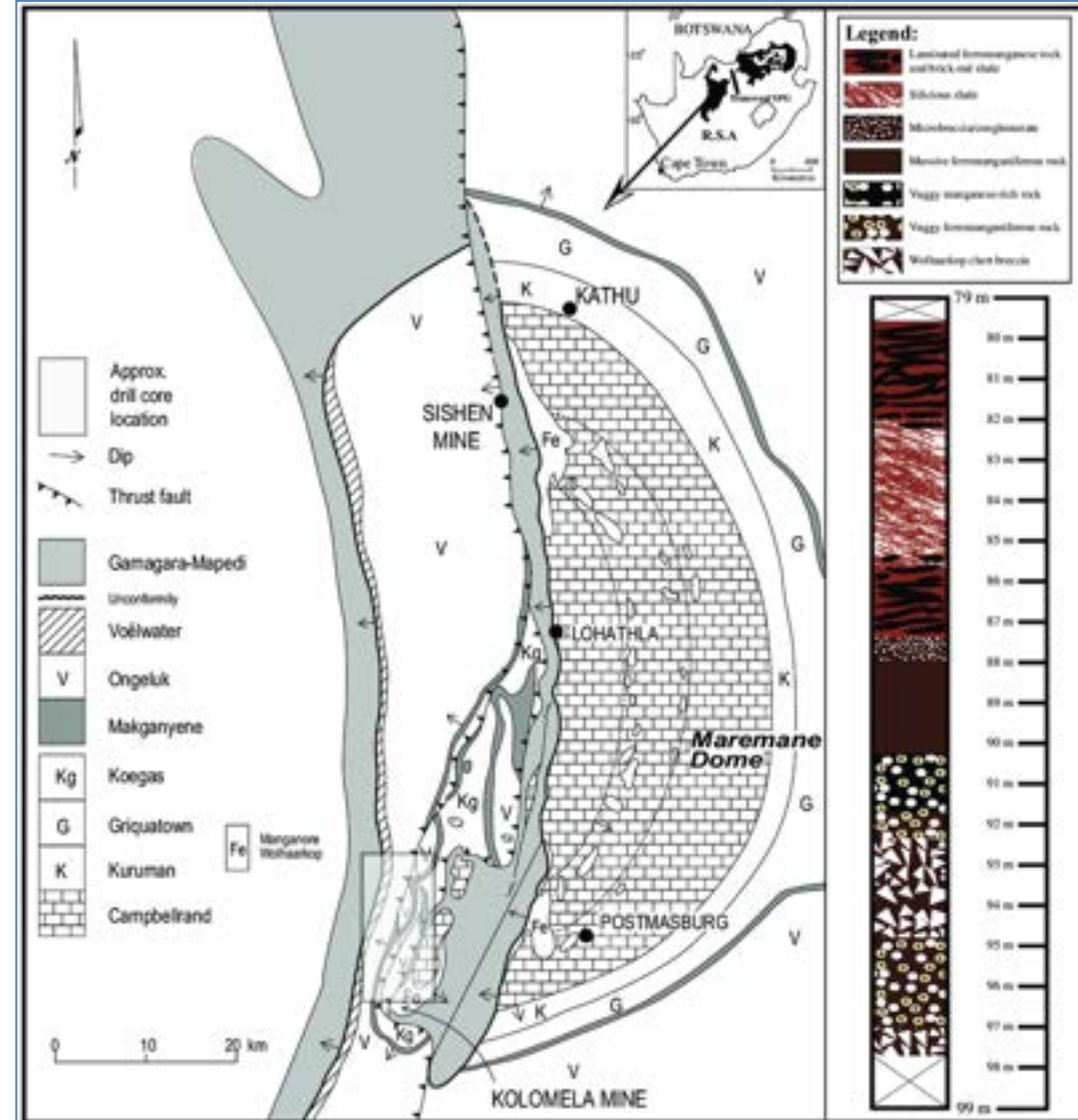
# Manganese

## South Africa



Utembe et al 2015

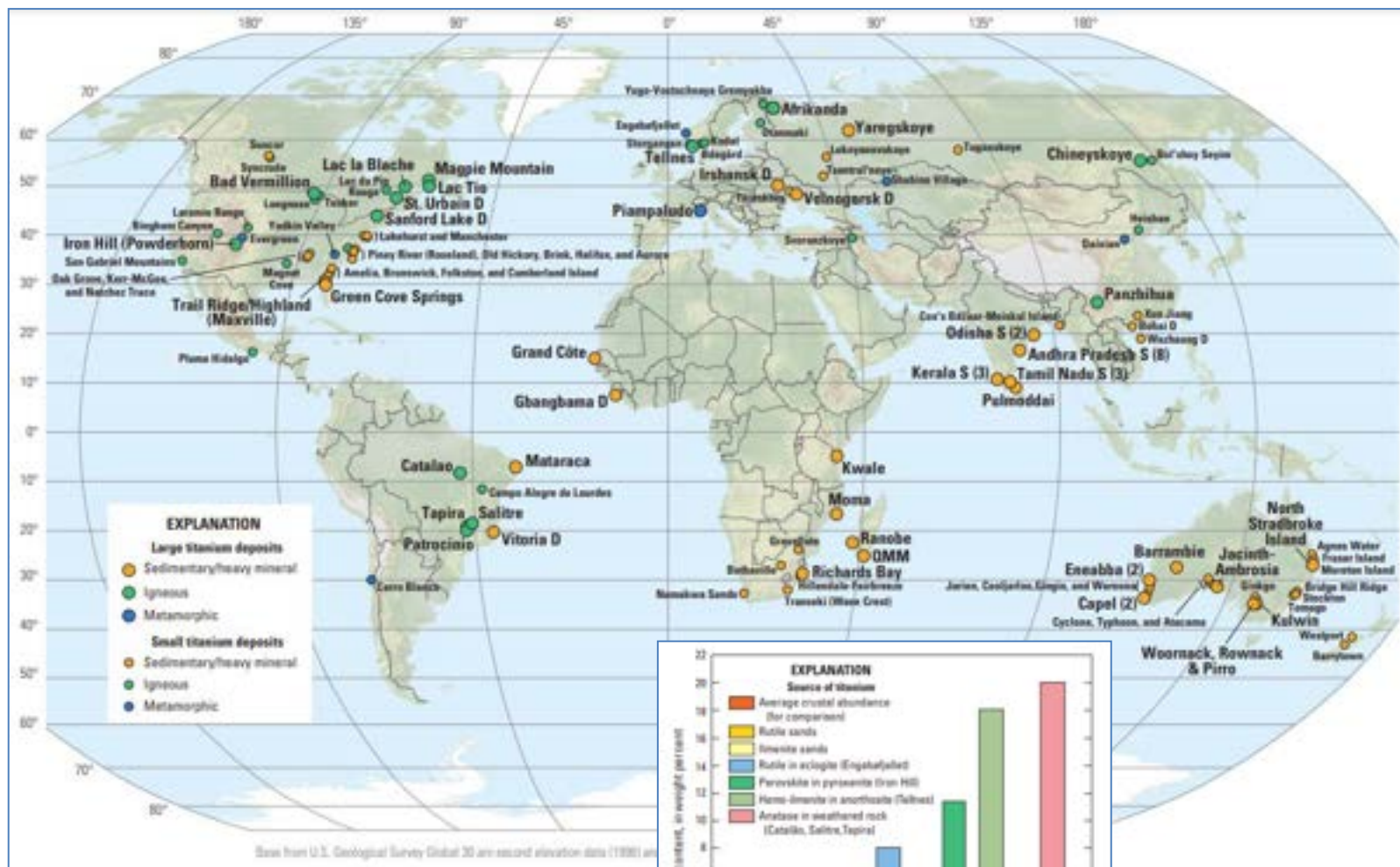
## Postmasburg Manganese Field



Costin et al 2015



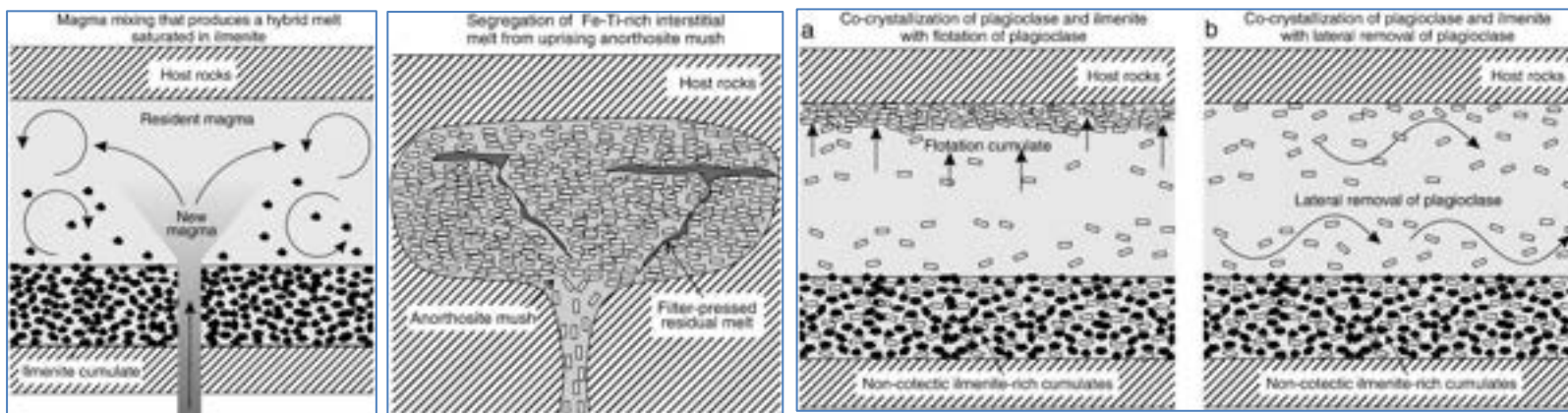
# Titanium



USGS 2017

USGS 2017

## Some invoked magmatic processes



Charlier et al 2015

Titanium-bearing minerals occur in diverse geologic settings, but many of the known deposits are currently subeconomic for titanium because of complications related to the mineralogy or because of the presence of trace contaminants that can compromise the pigment production process.

Ilmenite and rutile are currently the principal titanium bearing ore minerals, although other minerals, including anatase, perovskite, and titanomagnetite, could have economic importance in the future.

Ilmenite is currently being mined from two large magmatic deposits hosted in rocks of Proterozoic-age anorthosite plutonic suites.

Most rutile and nearly one-half of the ilmenite produced are from heavy mineral alluvial, fluvial, and eolian deposits.

Deposit class	Deposit type <sup>1</sup>	Typical mineralogy	Level of economic importance	Example deposits
<b>Magmatic (igneous and igneous related)</b>				
1-1	Massif anorthosite	Hemo-ilmenite	1	Lac Tio, Quebec; Tellnes, Norway
1-2	Anorthosite-gabbro	Ilmenite, titanomagnetite	2	Sanford Lake district, N.Y.
1-3	Layered mafic intrusion	Ilmenite, titanomagnetite	2	Maggie, Quebec; Panzihua, China
1-4	Troctolite/ultramafic	Ilmenite, titanomagnetite	3	Longnose, Minn.
1-5	Albititic/metasomatized	Rutile	3	Kragero, Norway; Roseland, Va. (in part)
1-6	Alkalic/metasomatized	Perovskite, brookite, rutile	3	Iron Hill, Colo.; Magnet Cove, Ark.
1-7	Weathered alkalic rocks	Anatase	2	Catalão, Salitre, and Tapira, Brazil
1-8	Weathered anorthositic rocks	Ilmenite, rutile	4	Roseland, Va. (in part)
<b>Metamorphic</b>				
M-1	Eclogite-hosted	Rutile	2	Engelbøfjellet, Norway; Piampaludo, Italy
M-2	Amphibolite-hosted	Rutile	3	Daixian, China
M-3	Greenschist-hosted	Rutile	5	Dinning, Md.
M-4	Contact metasomatized anorthosite	Ilmenite, rutile	4	Roseland, Va. (in part)
M-5	Metasomatized aluminum-rich schist	Rutile	5	Evergreen, Colo.
<b>Hydrothermal (igneous and [or] metamorphic)</b>				
I/M	Hydrothermal porphyry ore deposits	Rutile	3	Bingham, Utah; El Teniente, Chile
<b>Sedimentary-related</b>				
S-1	Fluvial	Rutile, ilmenite	1	Mogbwemo and Sherbo River, Sierra Leone
S-2	Beach (strandline) and (or) coastal dune	Ilmenite, altered ilmenite, rutile, leucocene	1	North Stradbroke Island, eastern Australia; Richards Bay, South Africa; Trail Ridge, Fla. (in part)
S-3	Lithified paleo-placers (fluvial and [or] beach)	Ilmenite, altered ilmenite, rutile, leucocene	2	Bothaville, South Africa
S-4	Weathered sedimentary deposits	Altered ilmenite, leucocene	1	Trail Ridge, Fla. (in part)

USGS 2017



# Working with ChatGPT

Titanium deposits are associated with a variety of geological settings, and the occurrence of economically viable deposits is influenced by specific geological processes. Titanium is generally found in the minerals ilmenite, rutile, and leucosene. Here are some common tectonic settings where titanium deposits are typically found:

## **Igneous Intrusions (Ilmenite-Rich Deposits):**

**Tectonic Setting:** Ilmenite-rich deposits are often associated with mafic to ultramafic igneous intrusions.

**Formation:** Ilmenite, a titanium-iron oxide mineral, can crystallize from magmas enriched in titanium. These intrusions may occur in a variety of tectonic settings, including convergent plate boundaries and intraplate settings.

## **Placer Deposits:**

**Tectonic Setting:** Placer deposits containing titanium minerals can be found in various geological settings, including coastal and alluvial environments.

**Formation:** Weathering and erosion of titanium-bearing rocks can release titanium minerals, which are then transported by rivers and concentrated in placer deposits in coastal areas or riverbeds.

## **Metamorphic Rocks (Rutile-Rich Deposits):**

**Tectonic Setting:** Rutile-rich deposits can be associated with high-grade metamorphic rocks.

**Formation:** Rutile, a titanium dioxide mineral, can form during the metamorphism of sediments or rocks rich in titanium. These metamorphic rocks may be found in regions experiencing high-grade regional metamorphism.

## **Titanium-Rich Beach Sands:**

**Tectonic Setting:** Coastal environments, particularly in tropical and subtropical regions, can host titanium-rich beach sands.

**Formation:** Titanium minerals, such as ilmenite and rutile, are resistant to weathering and can be concentrated in beach sands through the erosion and transportation of source rocks.

## **Carbonatite Complexes:**

**Tectonic Setting:** Titanium-bearing minerals, including ilmenite, can be found in carbonatite complexes.

**Formation:** Carbonatite magmas enriched in titanium can lead to the formation of deposits with titanium minerals. Carbonatite complexes can occur in various tectonic settings, including continental rifts and intraplate regions.

## **Lateritic Weathering Environments:**

**Tectonic Setting:** Titanium may also be present in lateritic weathering environments.

**Formation:** The weathering of titanium-bearing rocks, often under tropical or subtropical conditions, can lead to the development of lateritic profiles where titanium minerals, such as leucosene, are concentrated.

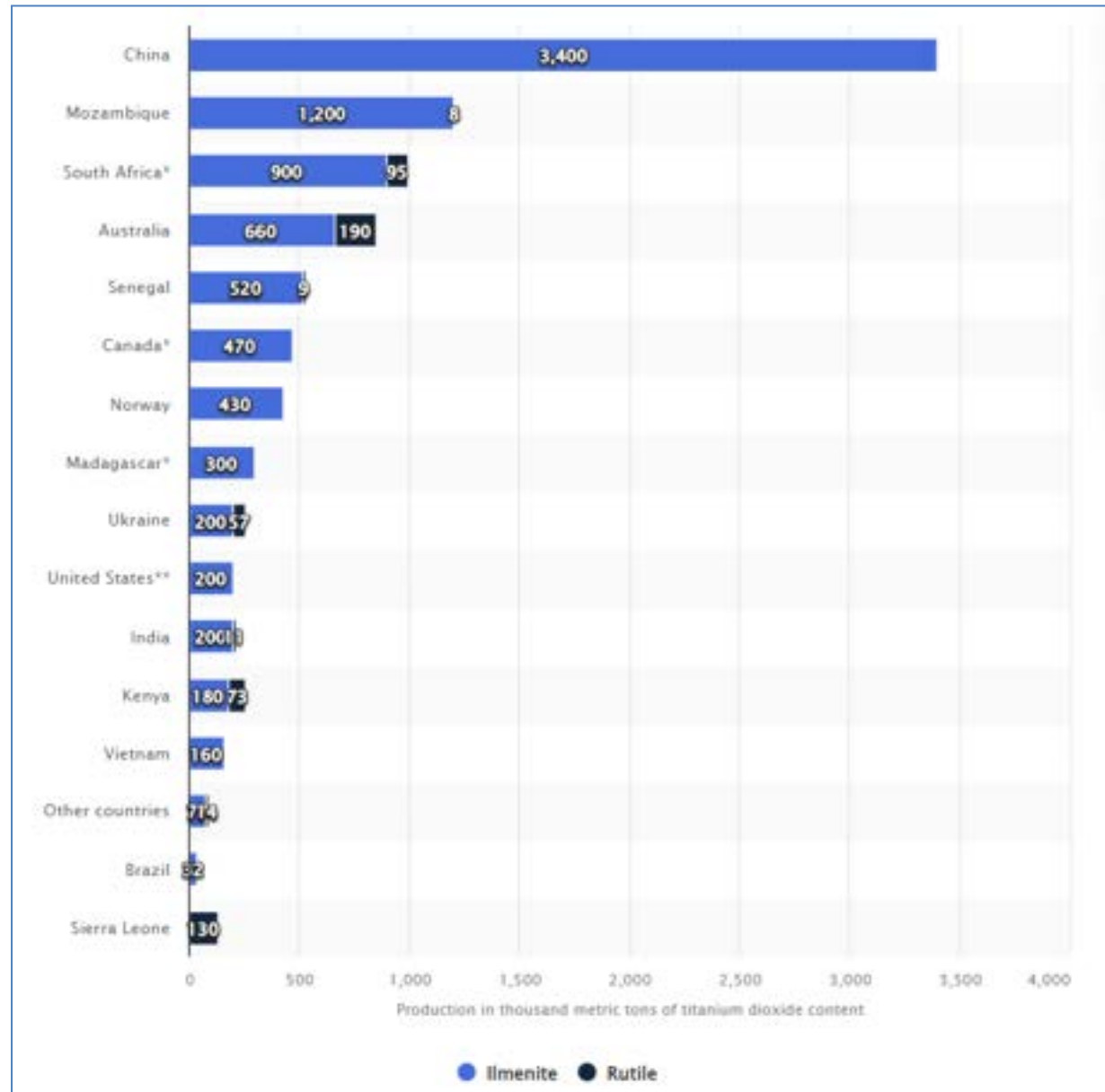
It's important to note that the occurrence of titanium deposits is diverse, and their economic significance depends on factors such as the concentration of titanium minerals, the accessibility of the deposit, and market demand for titanium. Titanium is a valuable metal used in various industries, including aerospace, pigment production, and medical applications. The exploration and extraction of titanium deposits involve understanding the geological processes that led to their formation and identifying economically viable occurrences.



# Titanium

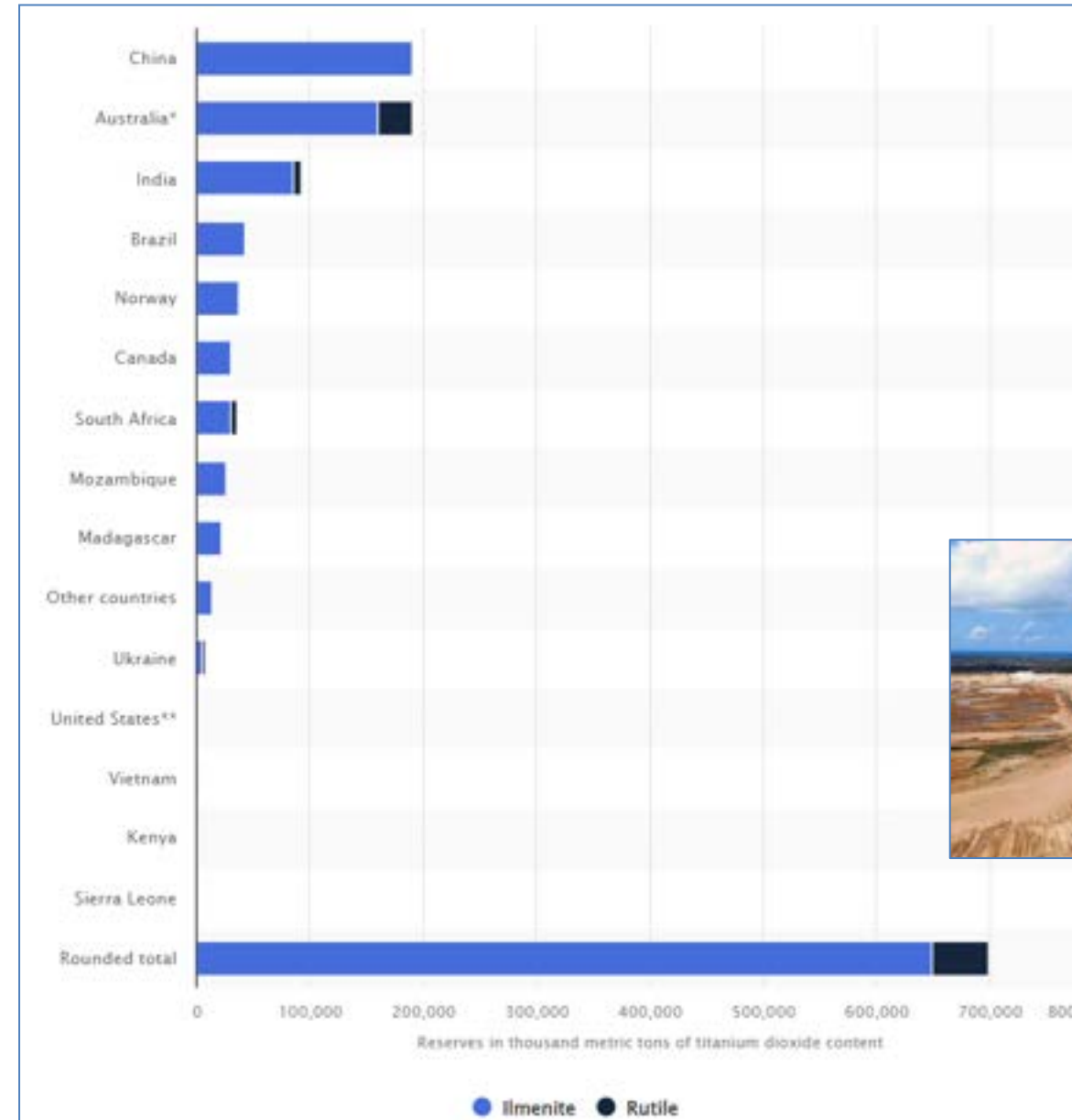
## Global Titanium Extraction and Reserves 2022

Production of Titanium world wide by country in 1000 tonnes



Statista.com  
USGS Commodity Summary

Reserves of Titanium worldwide in 2022, by country (in 1000 metric tons)



Statista.com



ilmenite

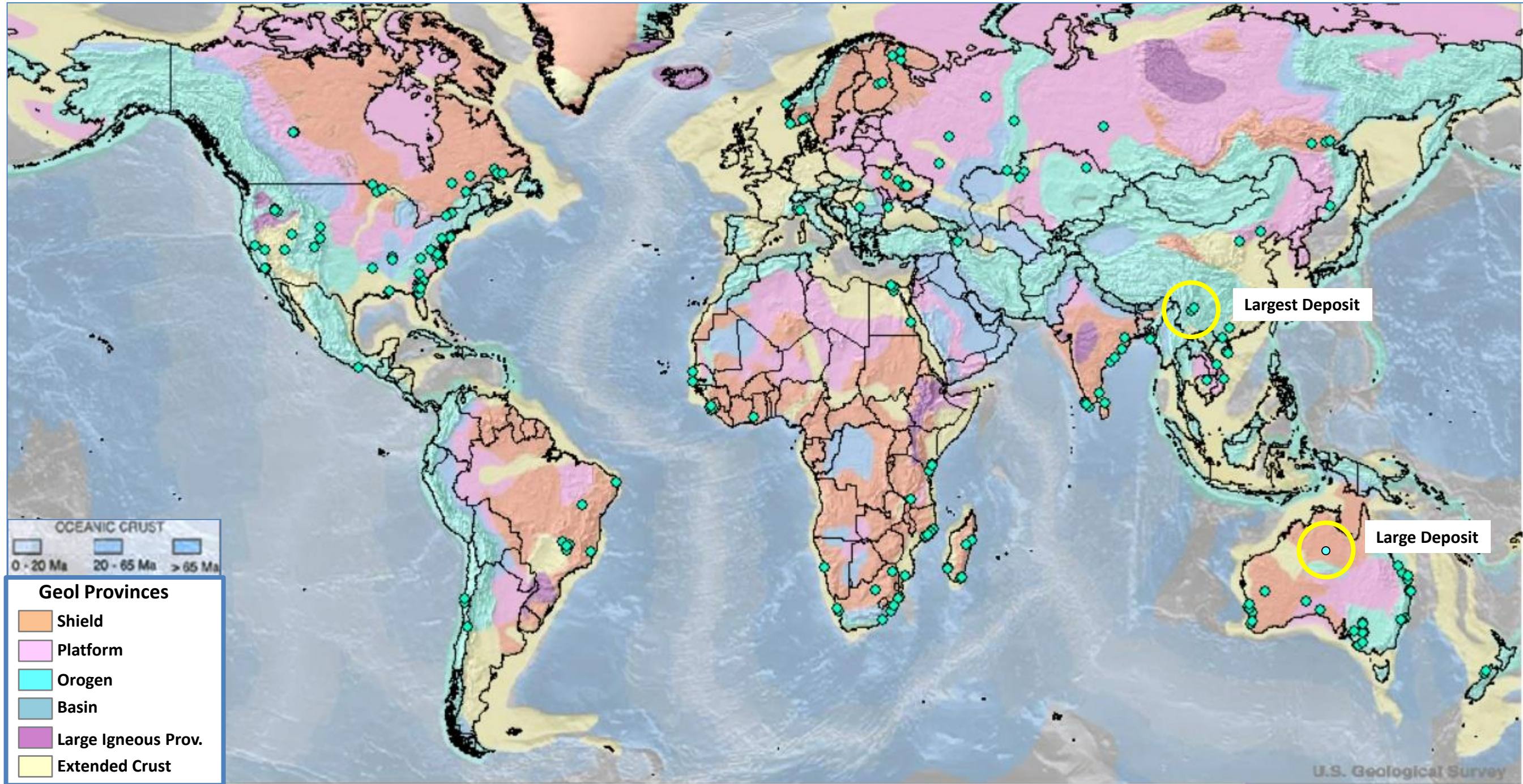


Moma Mine Mozambique



# Titanium

## Province Type

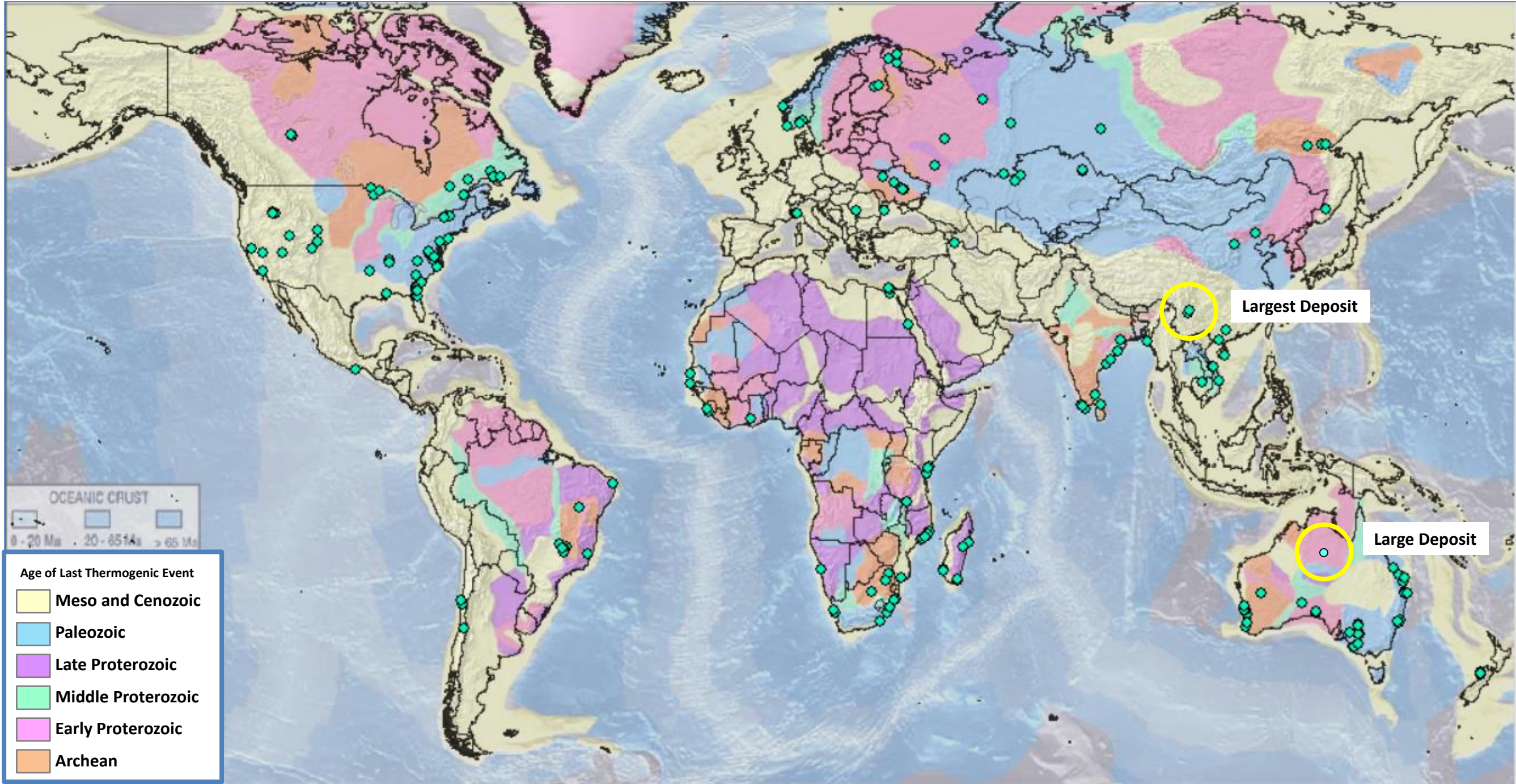


*Indicative Locations of deposits based on USGS data (may not be comprehensive)*



# Titanium

## Age of Last Thermogenic Event

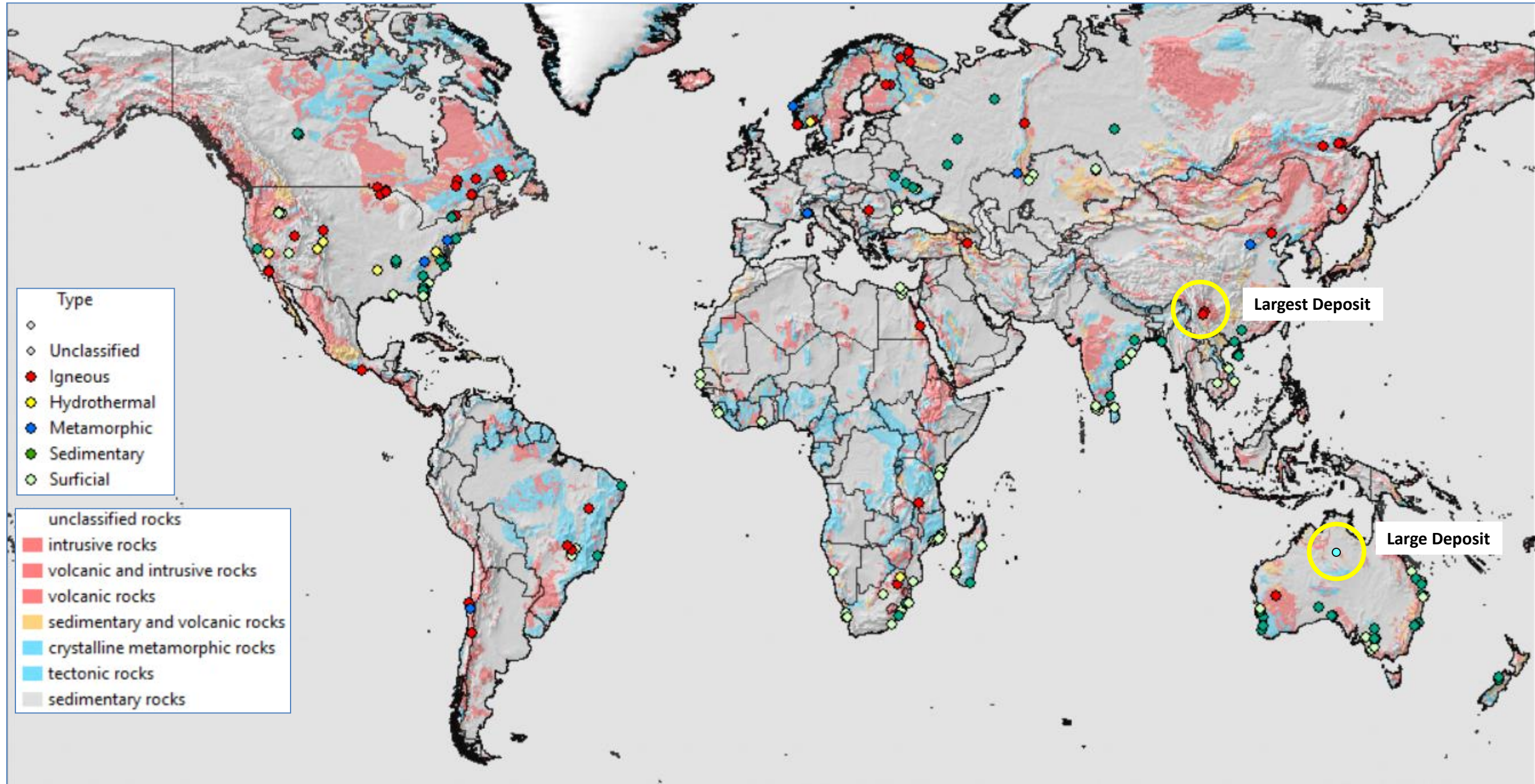


*Indicative Locations of deposits based on USGS data (may not be comprehensive)*



# Titanium

## Type of Deposit



*Indicative Locations of deposits based on USGS data (may not be comprehensive)*

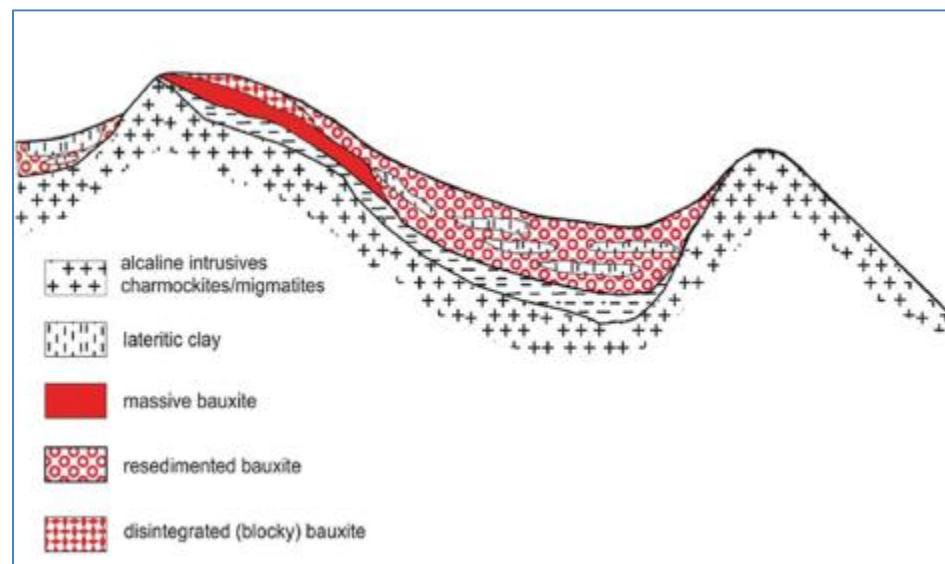






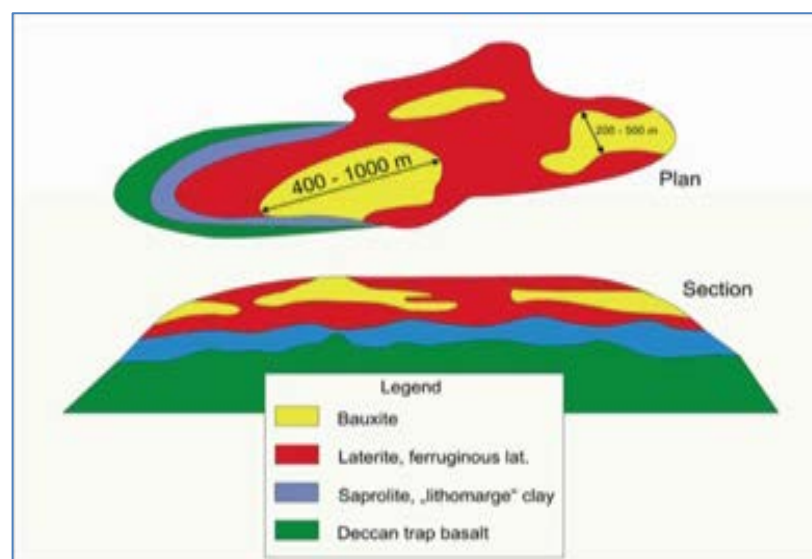
# Aluminum

## Bauxite and Laterite



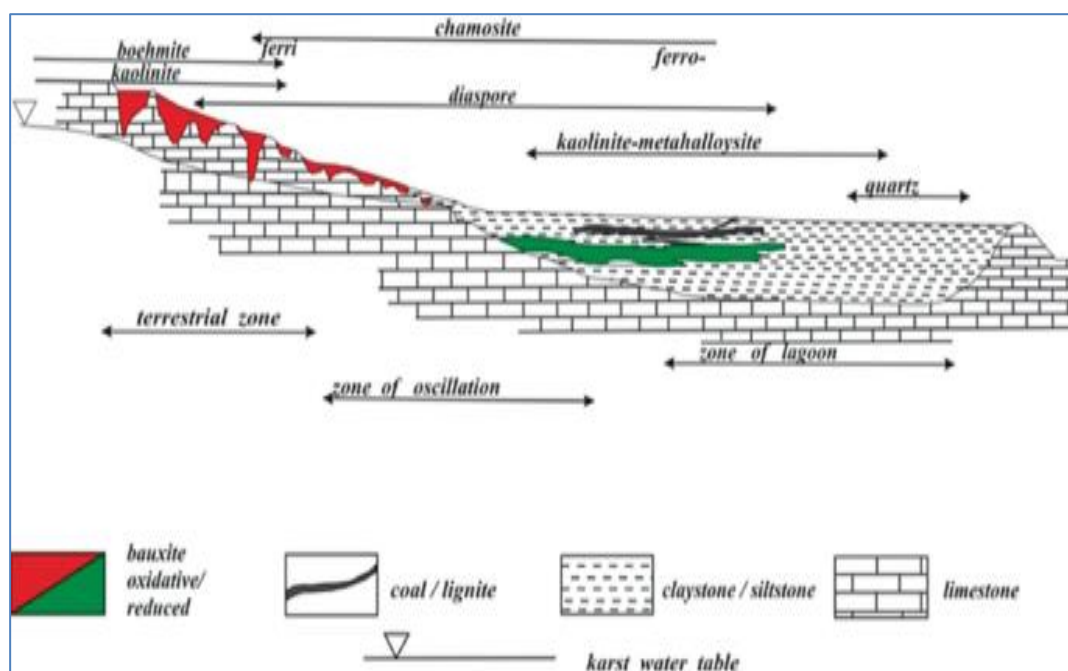
Komlossy et al 2022

## Bauxite and Laterite



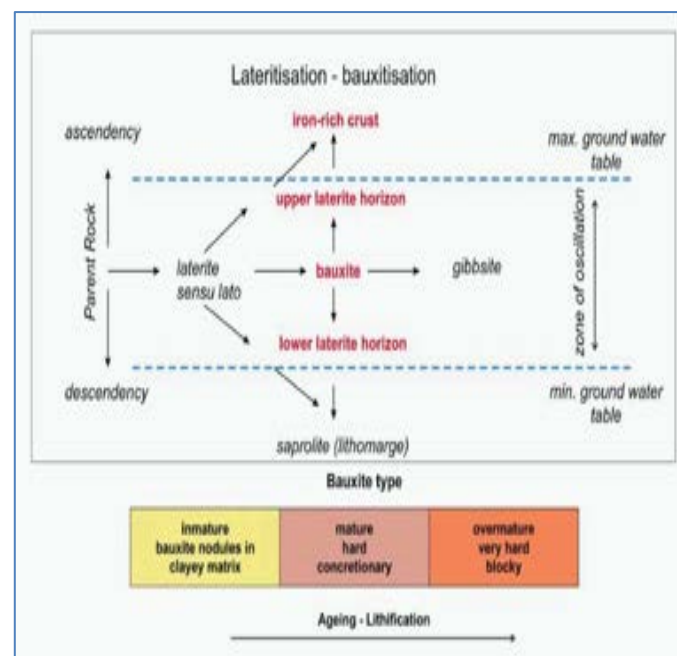
Komlossy et al 2022

## Bauxite



Komlossy et al 2022

## Process



Komlossy et al 2022

Aluminum ore deposits can be broadly classified into three main types based on their geological characteristics: bauxite deposits, lateritic deposits, and primary deposits.

**Bauxite deposits:** Bauxite is the most important type of aluminum ore, and bauxite deposits are the primary source of aluminum worldwide. Bauxite deposits are typically formed by weathering and erosion of aluminum-rich rocks, such as feldspars and mica, in tropical and subtropical regions with high rainfall and warm temperatures. Bauxite deposits are usually found as shallow, flat-lying deposits, often occurring in extensive plateaus or hills. Bauxite deposits are typically composed of a mixture of aluminum hydroxide minerals, such as gibbsite, boehmite, and diaspore, along with other minerals, such as hematite, goethite, and quartz.

**Lateritic deposits:** Lateritic deposits are another type of aluminum ore deposit that forms through weathering and leaching of aluminum-rich rocks, but they occur in regions with lower rainfall and less intense weathering compared to bauxite deposits. Lateritic deposits are typically found in tropical and subtropical regions, but they can also occur in other environments, such as arid and semi-arid regions. Lateritic deposits are characterized by a thick weathering profile, consisting of a layer of bauxitic or ferruginous (iron-rich) clay, called laterite, overlying a layer of unaltered rock. Lateritic deposits can contain aluminum hydroxide minerals, such as gibbsite and boehmite, along with other minerals, such as hematite, goethite, and kaolinite.

**Primary deposits:** Primary aluminum ore deposits are those that contain aluminum minerals in their original form, without significant weathering or alteration. Primary deposits are typically associated with igneous and metamorphic rocks, and they can occur in various geological settings, such as volcanic rocks, pegmatites, and metamorphic rocks. Primary deposits are relatively rare and less economically important as a source of aluminum compared to bauxite and lateritic deposits.

The characteristics of aluminum ore deposits can vary depending on their type and geological setting. Bauxite deposits are typically shallow, flat-lying, and extensive, with a mixture of aluminum hydroxide minerals and other minerals. Lateritic deposits are characterized by a thick weathering profile and contain laterite, a clay-rich layer, overlying unaltered rock. Primary deposits can occur in various geological settings and may contain different types of aluminum minerals.



Aluminum is not typically found in the Earth's crust in the form of metallic deposits like some other metals such as gold or copper. Instead, aluminum is commonly found in minerals, with bauxite being the primary ore for aluminum extraction. Bauxite deposits are associated with specific geological settings. Here are some common factors and settings associated with aluminum ore deposits:

### **Lateritic Bauxite Deposits:**

**Tectonic Setting:** Lateritic bauxite deposits are often associated with tropical and subtropical climates.

**Formation:** Lateritic bauxite deposits form through the weathering of aluminum-rich rocks, such as granite or basalt. The weathering process involves the leaching of silica and other minerals, leaving behind a residue of aluminum-rich minerals, including gibbsite and boehmite.

### **Lateritic Weathering Environments:**

**Tectonic Setting:** Lateritic weathering environments, often associated with warm and humid climates, can favor the concentration of aluminum.

**Formation:** Lateritic weathering involves the breakdown of primary aluminum minerals through chemical weathering. This process leads to the formation of lateritic profiles with residual concentrations of aluminum minerals.

### **Residual Soil Deposits:**

**Tectonic Setting:** Residual soil deposits containing aluminum can be found in a variety of tectonic settings, especially in areas with specific weathering conditions.

**Formation:** Residual soils can accumulate aluminum minerals through the weathering of underlying rocks. The degree of weathering and the composition of the parent material influence the concentration of aluminum.

### **Bauxite Formation in Karst Landscapes:**

**Tectonic Setting:** Bauxite deposits can also form in karst landscapes, which are characterized by soluble rocks such as limestone.

**Formation:** Aluminum can be concentrated in bauxite deposits in karst areas through the leaching and weathering of underlying rocks. Karst features may facilitate the accumulation of bauxite.

### **Lateritic Bauxite in High Relief Areas:**

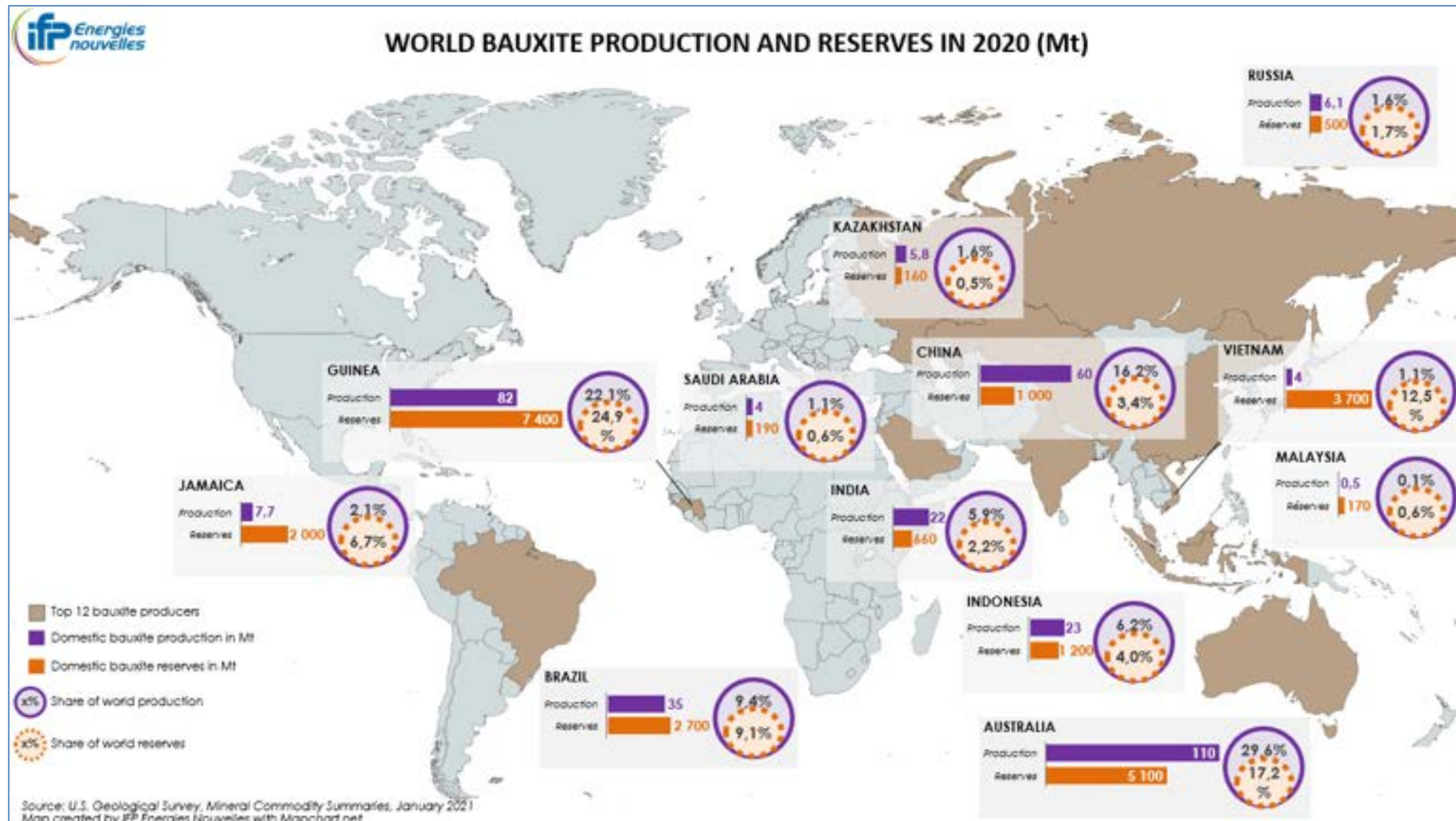
**Tectonic Setting:** Lateritic bauxite deposits are sometimes associated with high relief areas where erosion has exposed aluminum-rich rocks.

**Formation:** The weathering of exposed rocks in high relief areas can lead to the concentration of aluminum minerals, forming lateritic bauxite deposits.

It's important to note that aluminum is highly abundant in the Earth's crust, but it is commonly found as part of various minerals rather than as metallic deposits. Bauxite is the primary commercial source of aluminum, and the exploration and extraction of aluminum involve identifying economically viable bauxite deposits. The tectonic setting alone may not be the sole determinant; rather, weathering and geological processes play a crucial role in the formation of aluminum ore deposits.



## Global Bauxite Extraction and Reserves (t) 2020



Bauxite Laterite



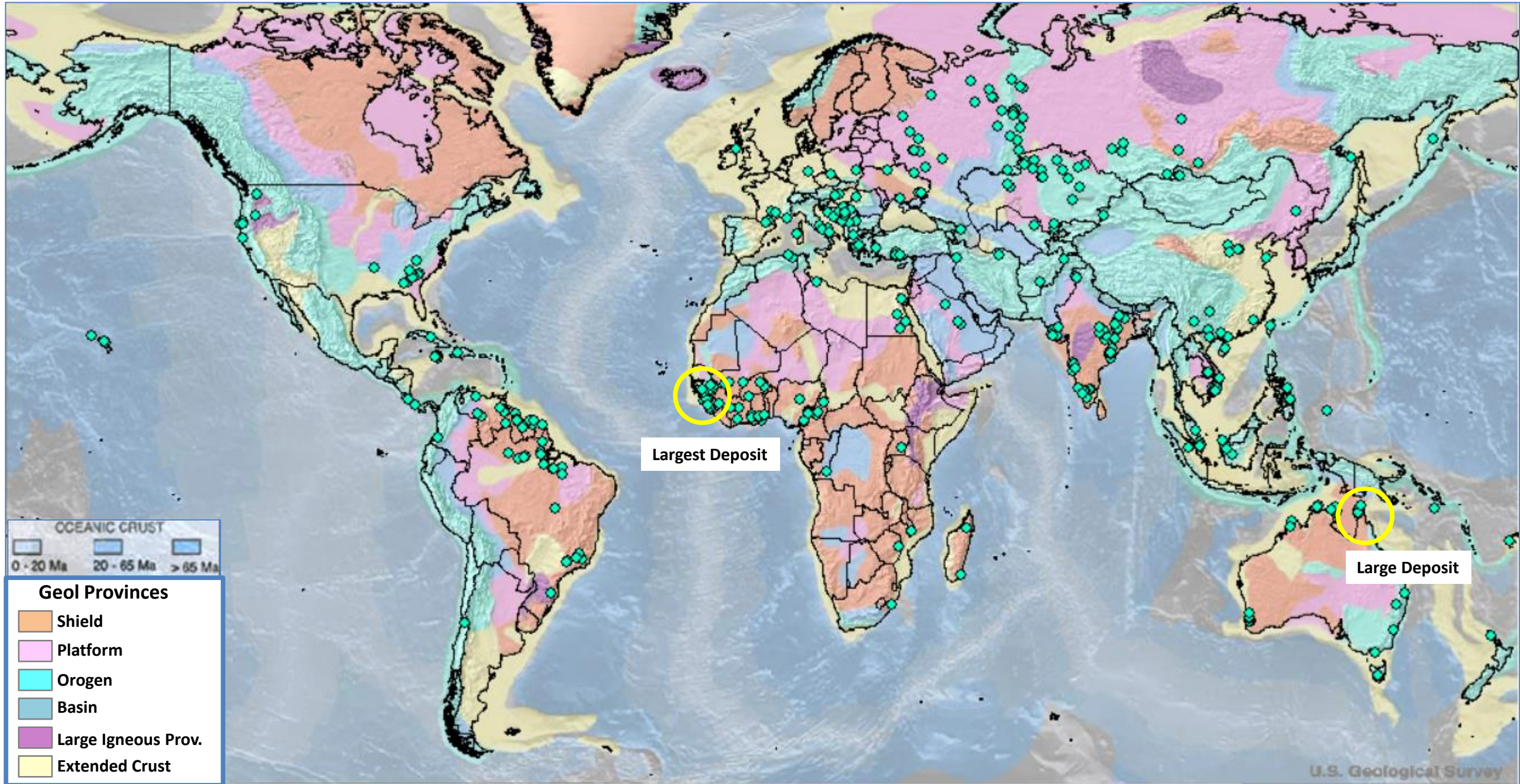
Huntly Mine Australia

ifpenergiesnouvelles.com  
USGS Commodity Summary



# Aluminum

## Province Type

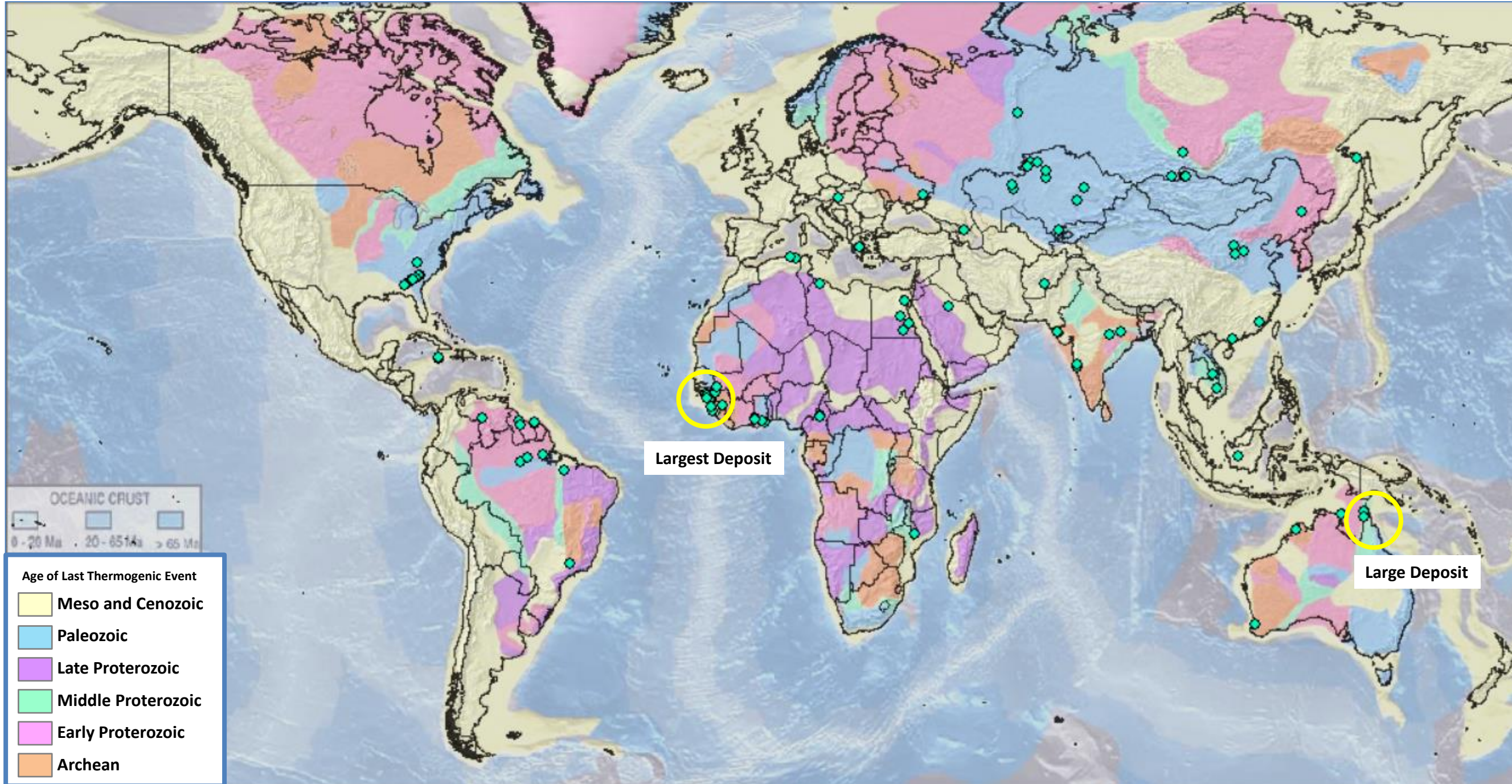


*Indicative Locations of deposits based on USGS data (may not be comprehensive)*



# Aluminum

## Age of Last Thermogenic Event

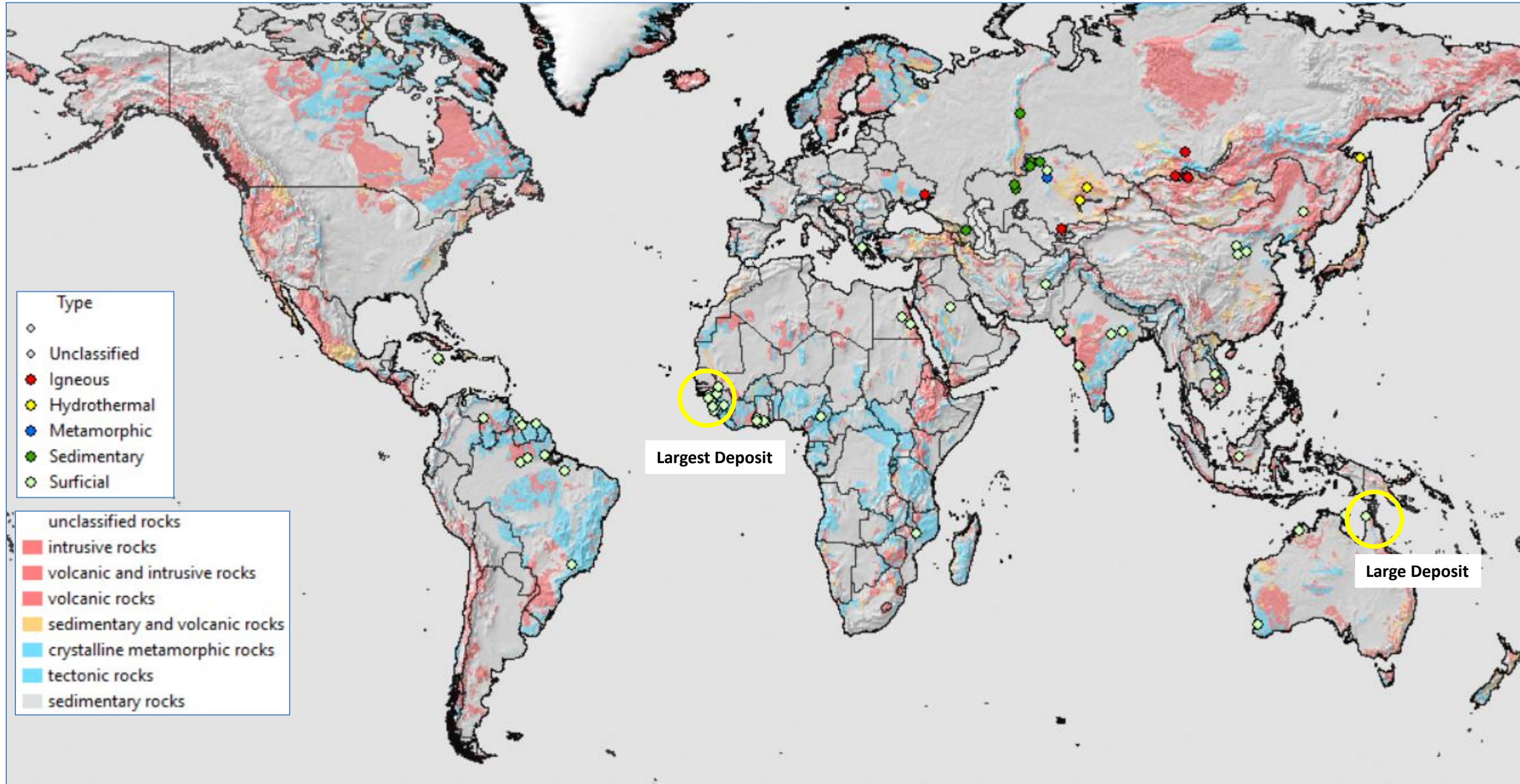


*Indicative  
Locations of  
deposits based  
on USGS data  
(may not be  
comprehensive)*



# Aluminum

## Type of Deposit



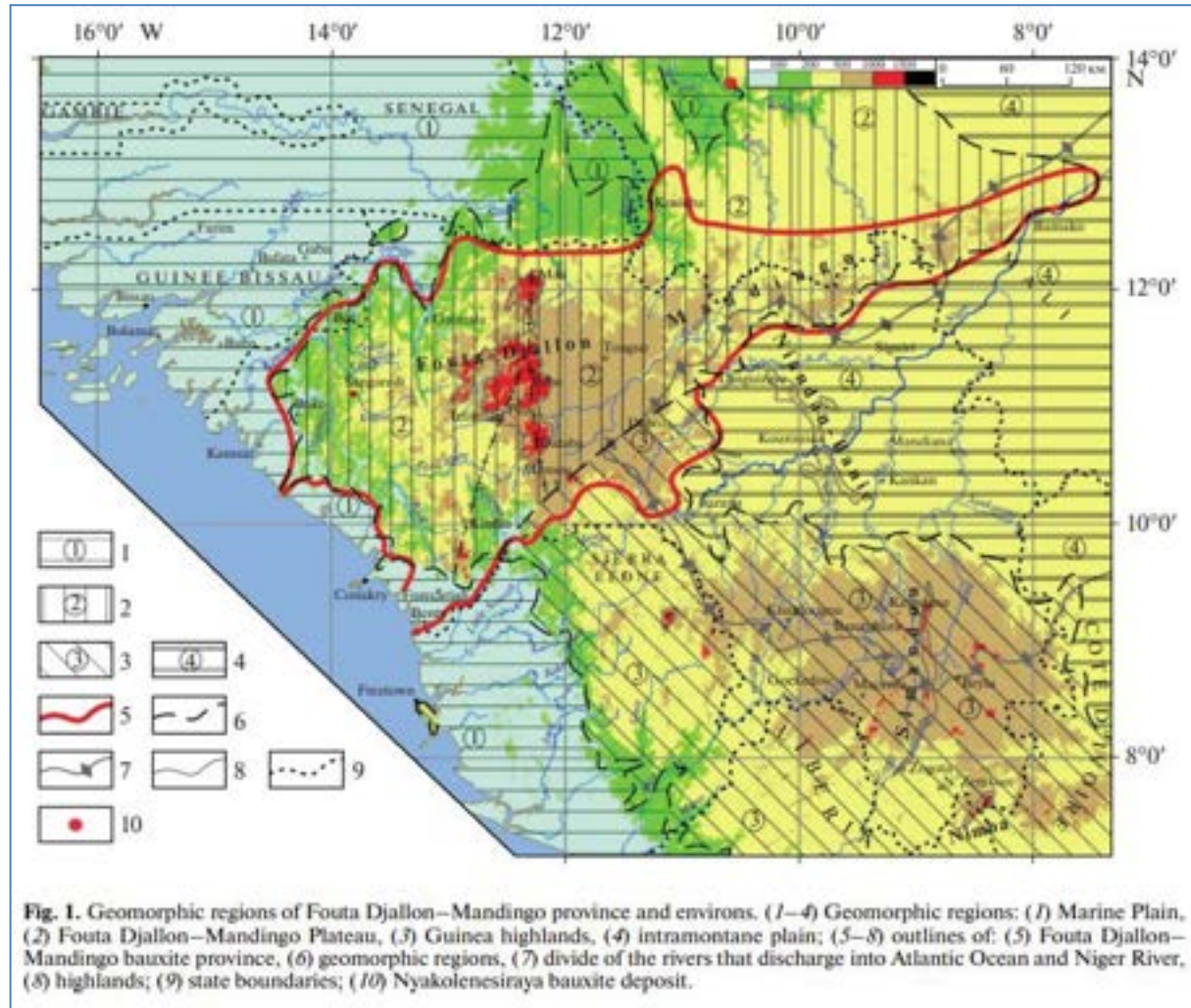
Indicative Locations of deposits based on USGS data (may not be comprehensive)



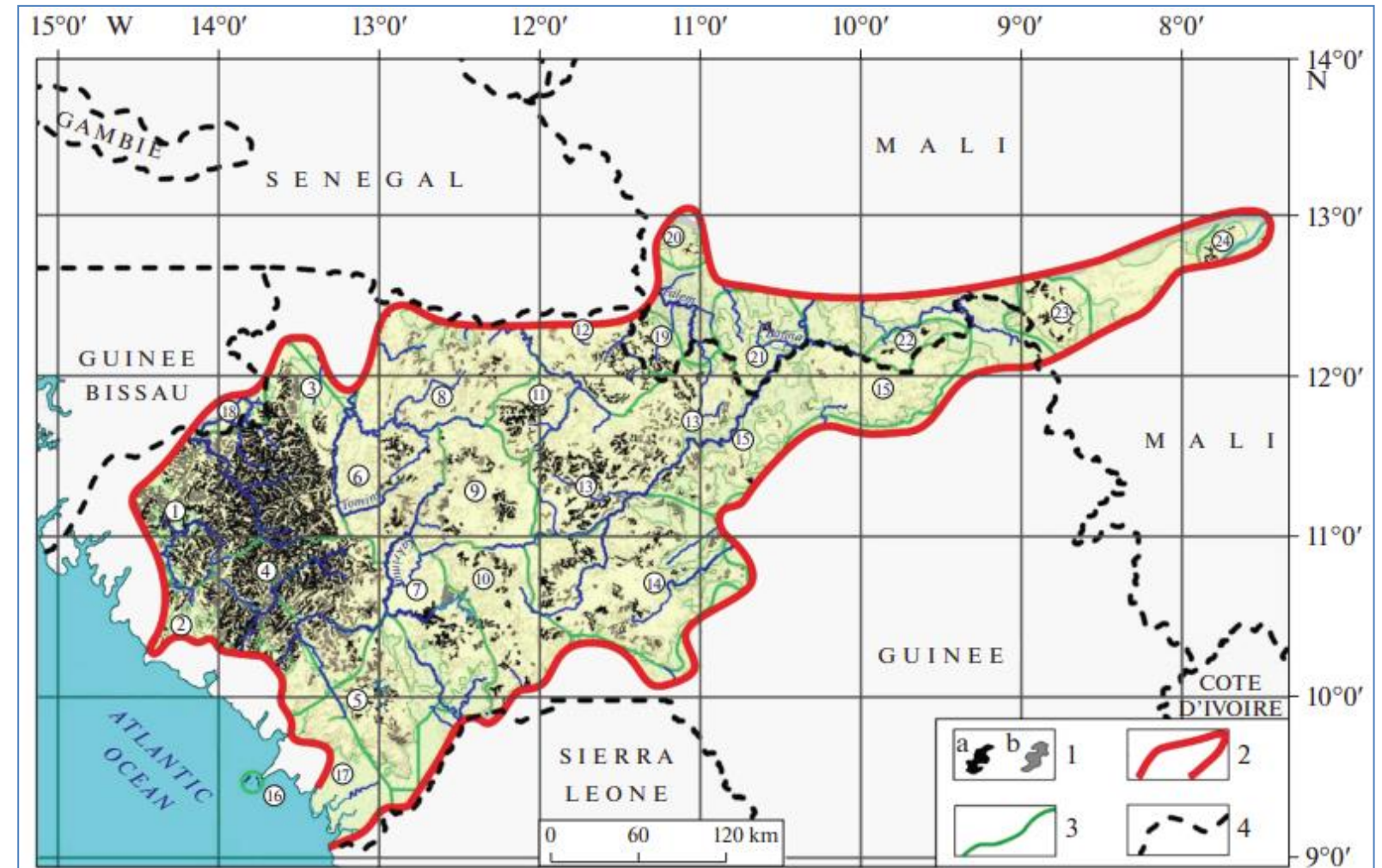
# World's Largest Deposits

# Aluminum

## Fouta Djallon–Mandingo Bauxite province, Guinea



Mamedov et al 2019



Mamedov et al 2019



# Fluorine

In igneous systems, fluorine is one of a number of elements that are largely incompatible, in that they do not readily go into the common silicate minerals that crystallize from the melt. As a result, they become concentrated in the residual magma during differentiation.

Because of fluorine's incompatibility, it may also occur in high concentrations in volcanic gases as well as in sublimates formed from the gases. Rocks altered by such gases similarly contain substantial amounts of fluorine.

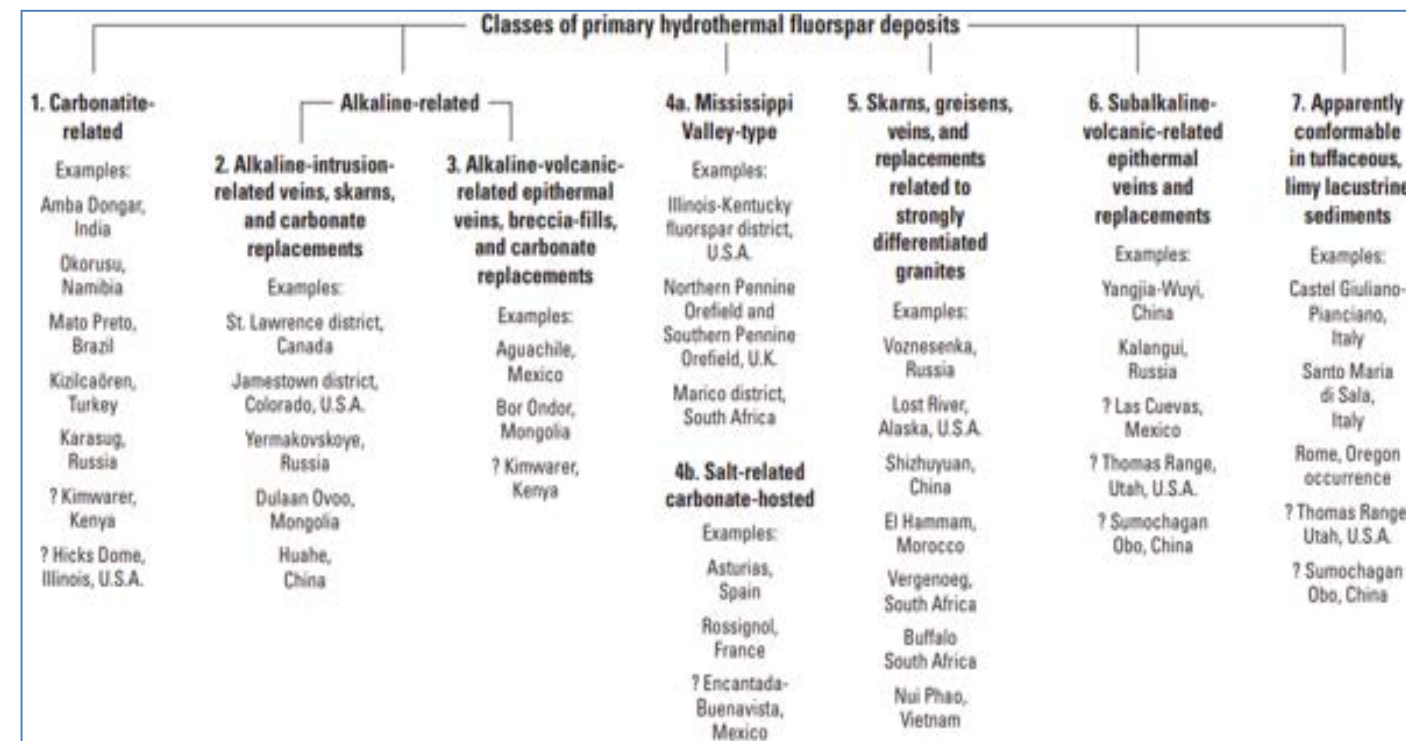
In sedimentary rocks, fluorine's highest syngenetic concentrations (concentrations formed at the time of sedimentation) are found in phosphorites because of the element's substitution for hydroxyl ions in apatite, which is the principal phosphorous-bearing mineral in phosphorites.

Fluorspar is the commercial name for fluorite (isometric  $\text{CaF}_2$ ), which is the only fluorine mineral that is mined on a large scale. Most deposits mined for fluorine are hydrothermal (that is, the fluorine minerals have precipitated from hot water). Fluoride, like many other dissolved components, is found at high concentrations in brines of various origins. Magmatic brines and brines from deep within sedimentary basins are potential mineralizing fluids for various types of hydrothermal fluorspar deposits.

USGS 2017



USGS 2017



USGS 2017



Fluorine is not typically found as a mineral deposit itself, but rather it is often associated with certain minerals that contain fluorine. Fluorine can be present in various geological settings, and its occurrence is commonly associated with the hydrothermal alteration of rocks and the presence of specific mineral assemblages. Here are some common tectonic settings and geological environments where fluorine can be associated:

### **Granitic Pegmatites:**

**Tectonic Setting:** Fluorine-bearing minerals can be found in granitic pegmatites.

**Formation:** Pegmatites are coarse-grained igneous rocks, and certain minerals within pegmatites, such as fluorite (calcium fluoride), can contain significant amounts of fluorine. Pegmatites are often associated with intrusions in various tectonic settings.

### **Hydrothermal Vein Deposits:**

**Tectonic Setting:** Fluorine-bearing minerals, including fluorite and fluorspar, can be found in hydrothermal vein deposits.

**Formation:** Hydrothermal fluids can transport fluorine from surrounding rocks and deposit fluorite in veins. These veins may be associated with a variety of tectonic settings, including areas of active or past hydrothermal activity.

### **Skarn Deposits:**

**Tectonic Setting:** Fluorine-bearing minerals can be associated with skarn deposits, which form at the contact between intruding magmas and carbonate rocks.

**Formation:** Skarns result from the alteration of carbonate rocks by the intrusion of igneous rocks. Fluorine-bearing minerals such as fluorite can be present in the altered zones.

### **Carbonatite Complexes:**

**Tectonic Setting:** Fluorine can be associated with carbonatite complexes, which are igneous intrusions composed predominantly of carbonate minerals.

**Formation:** Carbonatite magmas may contain fluorine, and minerals like fluorite can crystallize from these magmas. Carbonatite complexes can occur in various tectonic settings.

### **Sedimentary Environments:**

**Tectonic Setting:** Fluorine can be present in sedimentary rocks, often associated with certain mineral types.

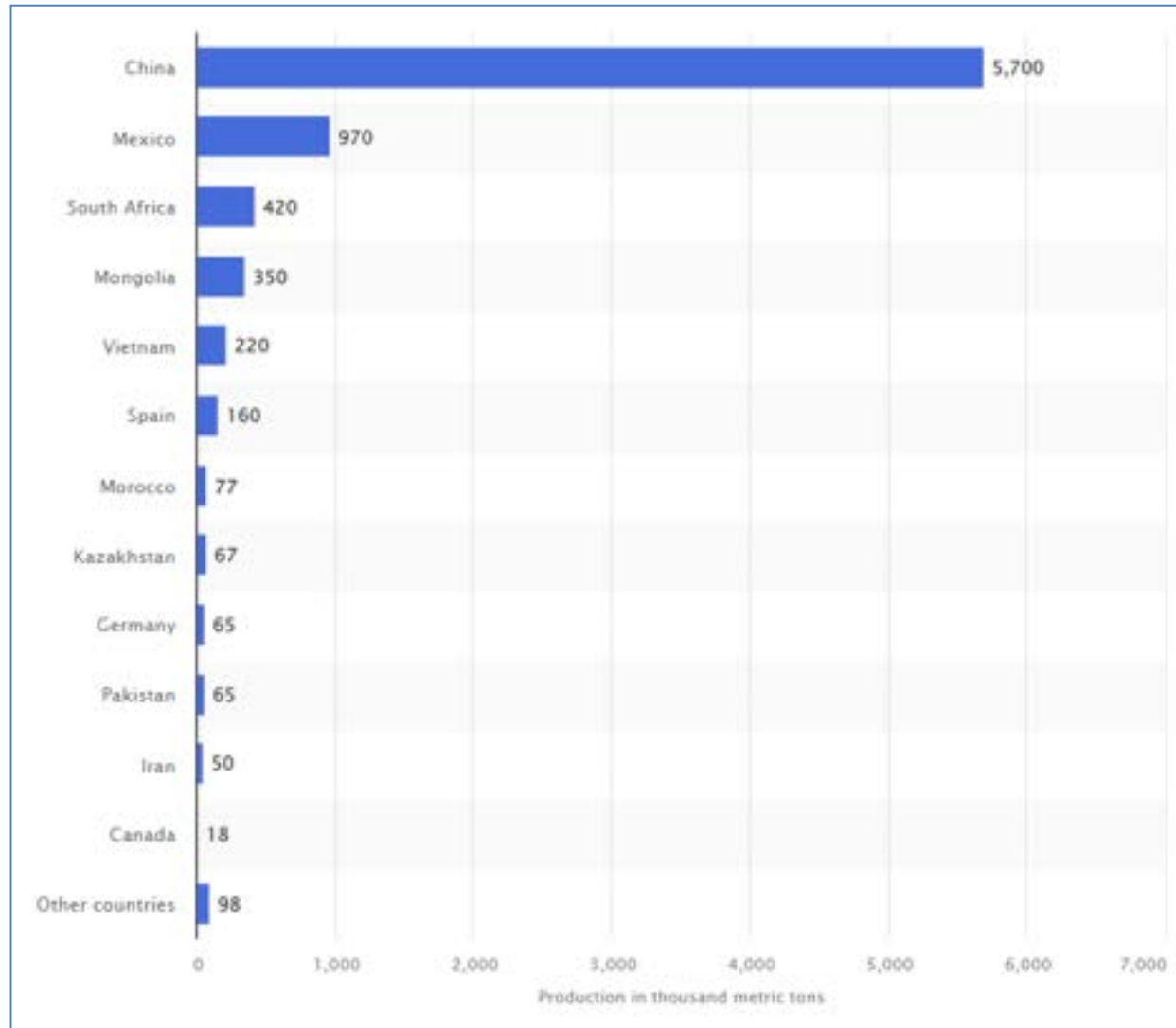
**Formation:** Fluorine may be concentrated in sedimentary rocks through various processes, including the deposition of fluorine-bearing minerals from hydrothermal fluids or the accumulation of fluorine-rich organic matter.

It's important to note that while fluorine is widespread in the Earth's crust, economically significant fluorine deposits are relatively rare. Fluorine is often associated with minerals such as fluorite, fluorspar, and apatite. The exploration for fluorine deposits involves understanding the geological history of the region, identifying the appropriate host rocks and mineral assemblages, and assessing the economic viability of extraction.



## Global Fluorspar Extraction and Reserves 2022

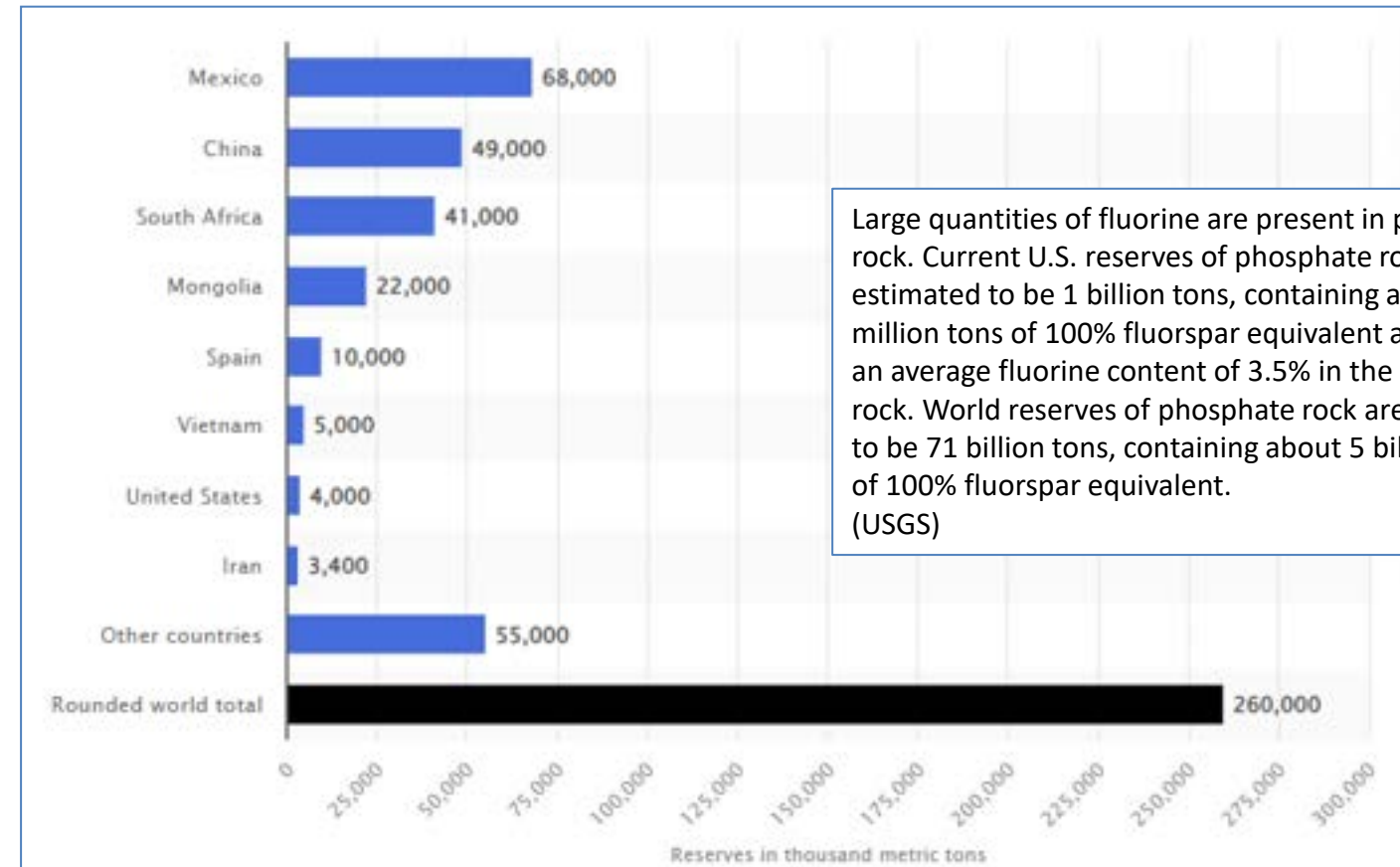
Production of Fluorspar world wide by country in 1000 tonnes



Statista.org

USGS Commodity Summary

Reserves of Fluorspar worldwide in 2022, by country (in 1000 metric tons)



Large quantities of fluorine are present in phosphate rock. Current U.S. reserves of phosphate rock are estimated to be 1 billion tons, containing about 72 million tons of 100% fluorspar equivalent assuming an average fluorine content of 3.5% in the phosphate rock. World reserves of phosphate rock are estimated to be 71 billion tons, containing about 5 billion tons of 100% fluorspar equivalent. (USGS)

Statista.org



Fluorspar Ore

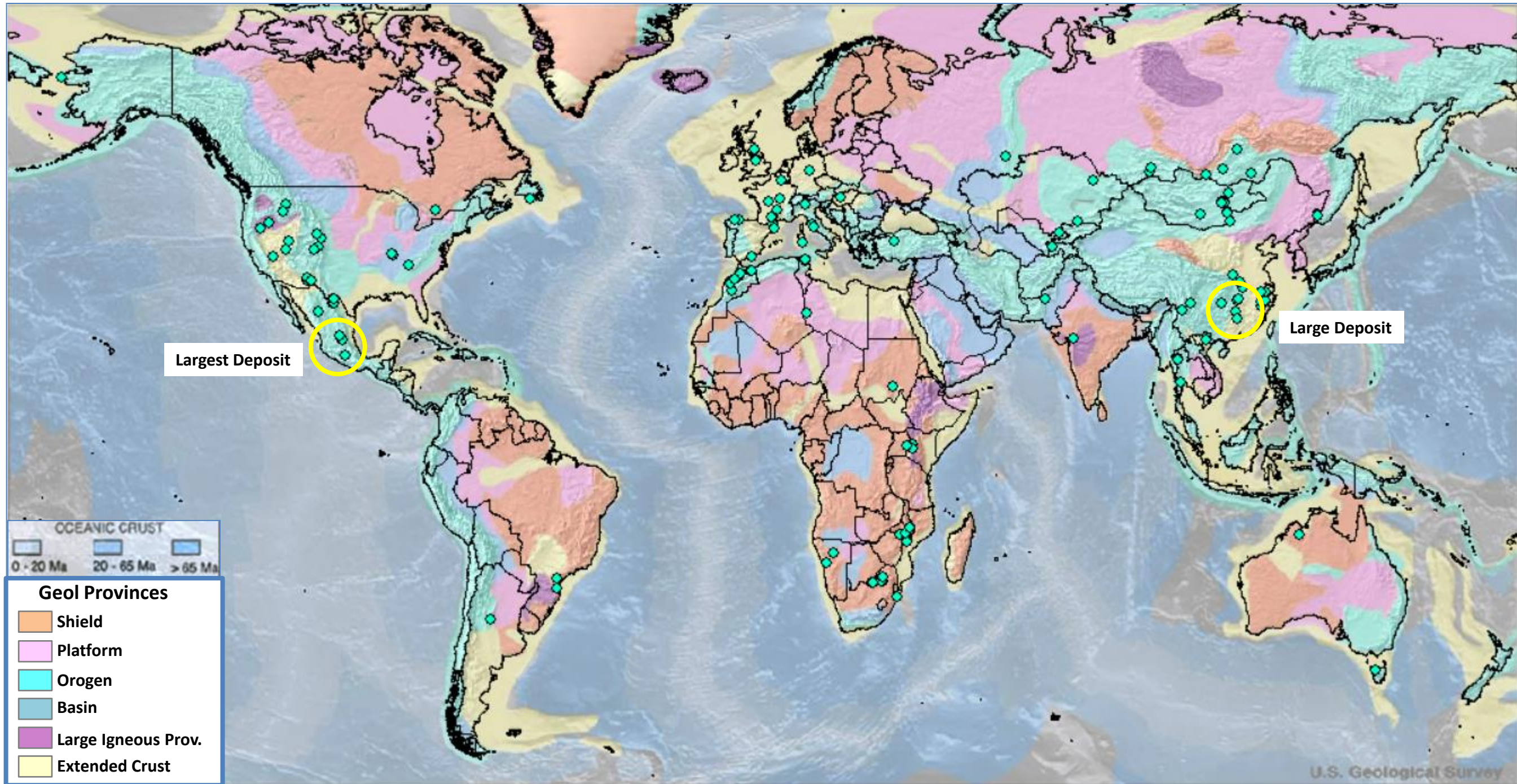


Nokeng Mine S Africa



# Fluorine

## Province Type

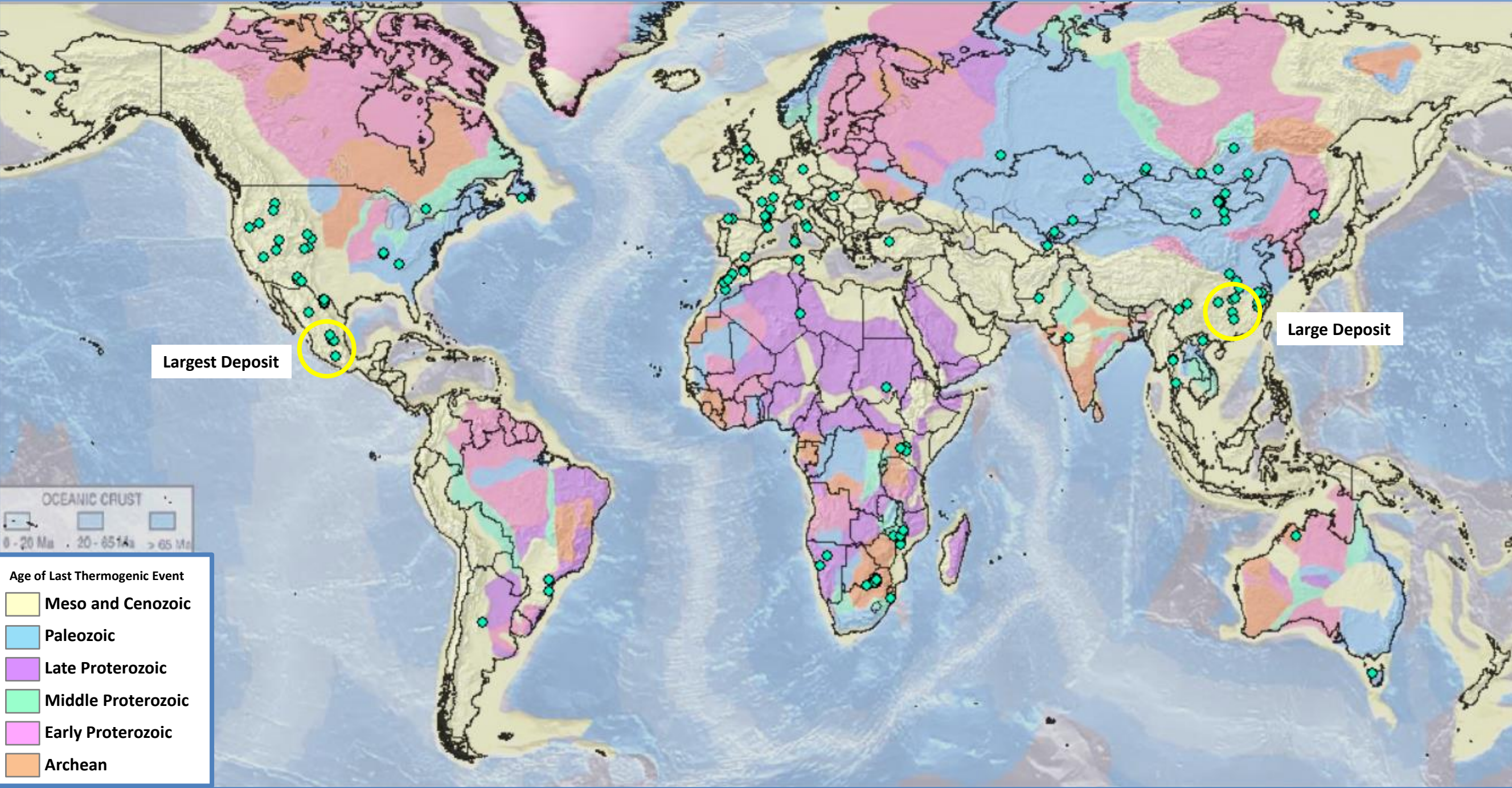


*Indicative Locations of deposits based on USGS data (may not be comprehensive)*



# Fluorine

## Age of Last Thermogenic Event

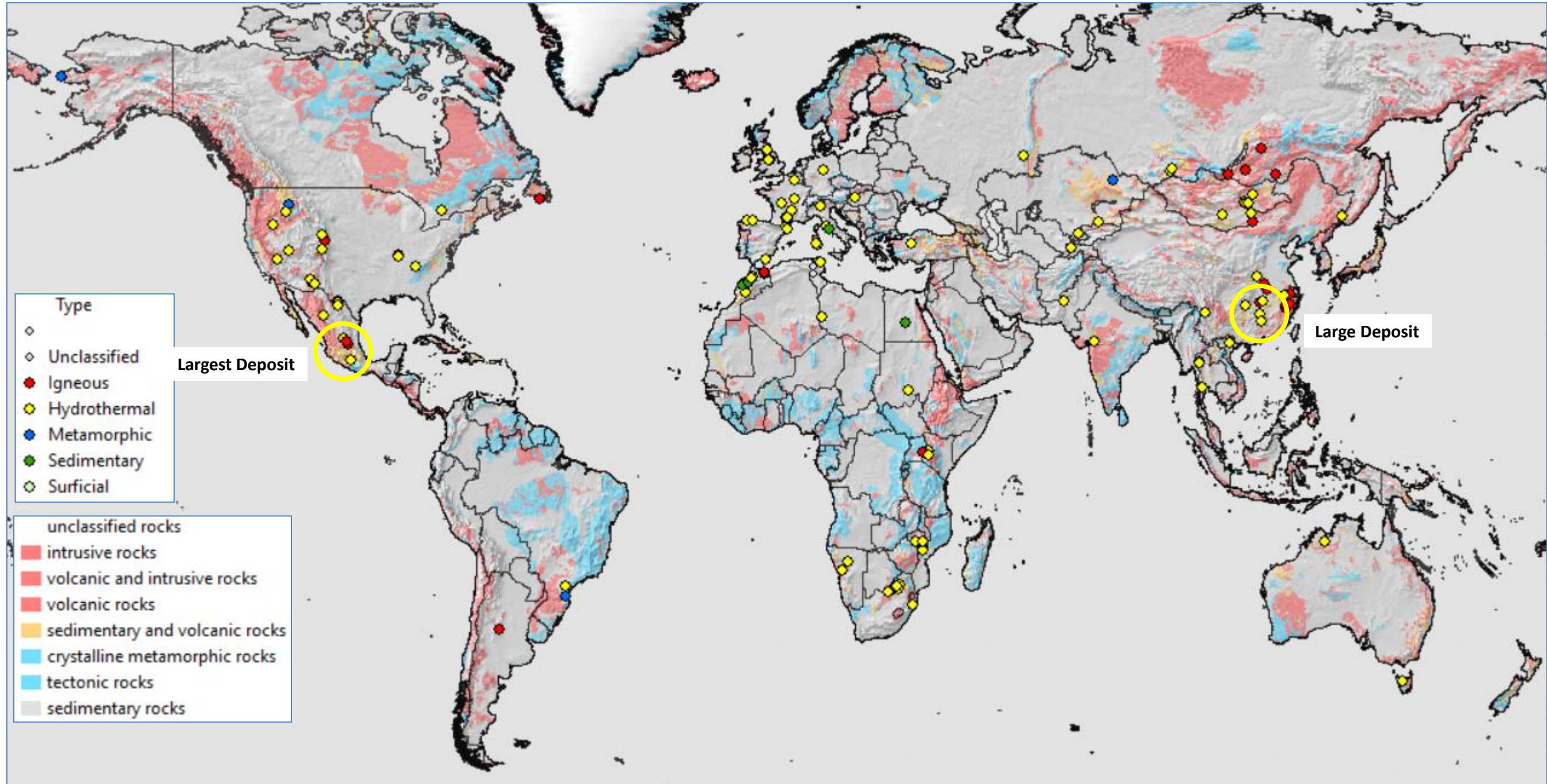


*Indicative Locations of deposits based on USGS data (may not be comprehensive)*



# Fluorine

## Type of Deposit



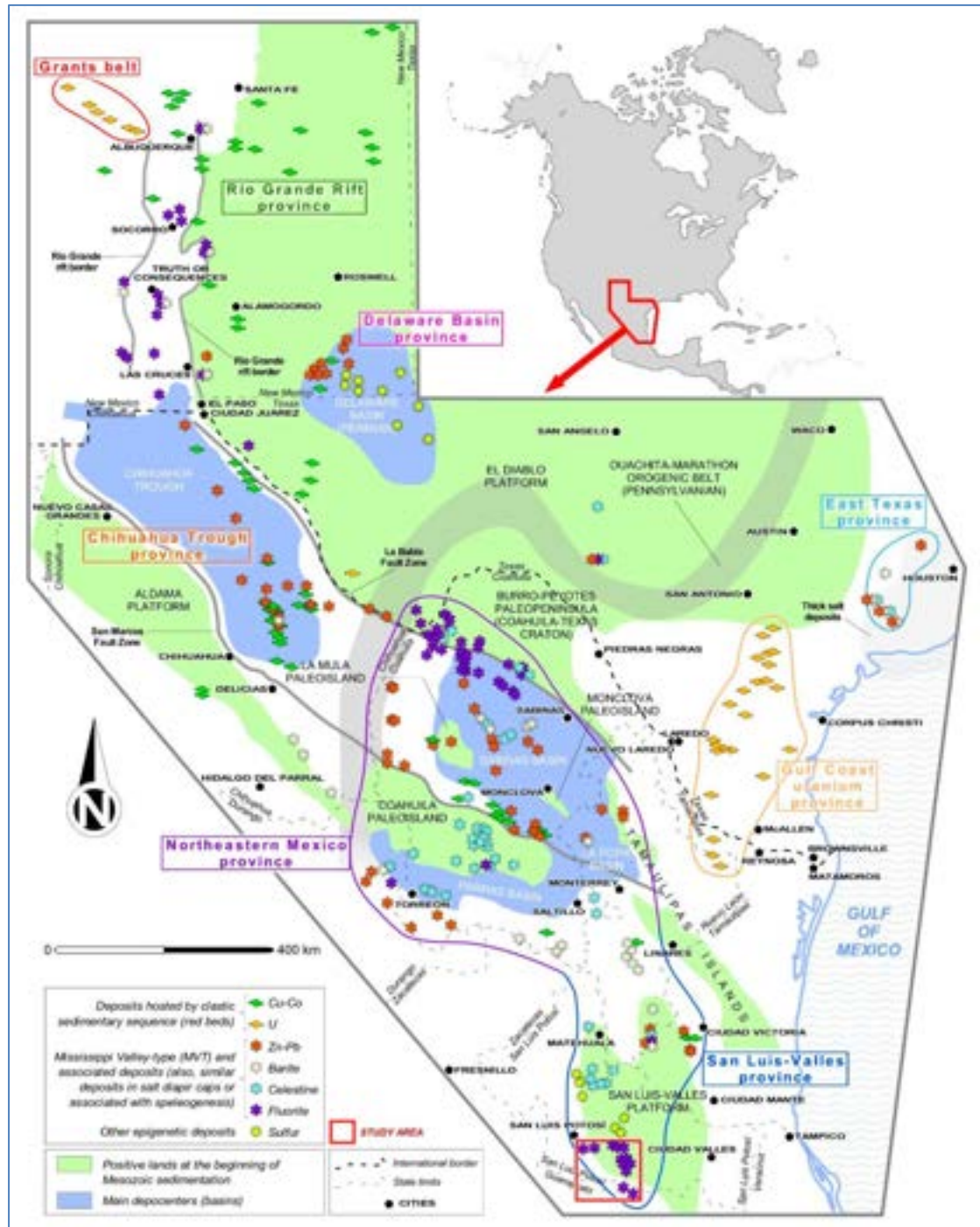
Indicative Locations of deposits based on USGS data (may not be comprehensive)



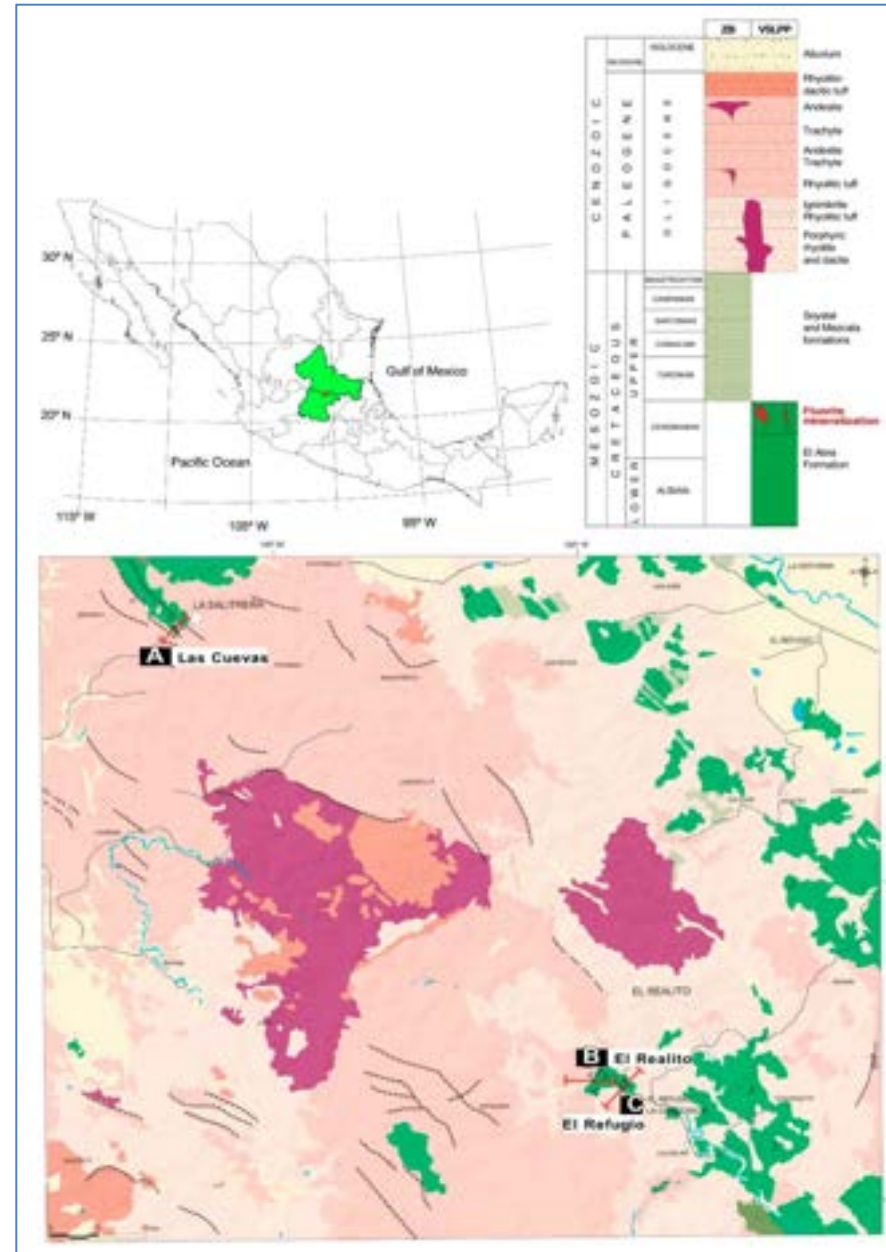
# World's Largest Deposits

## Central Mexico

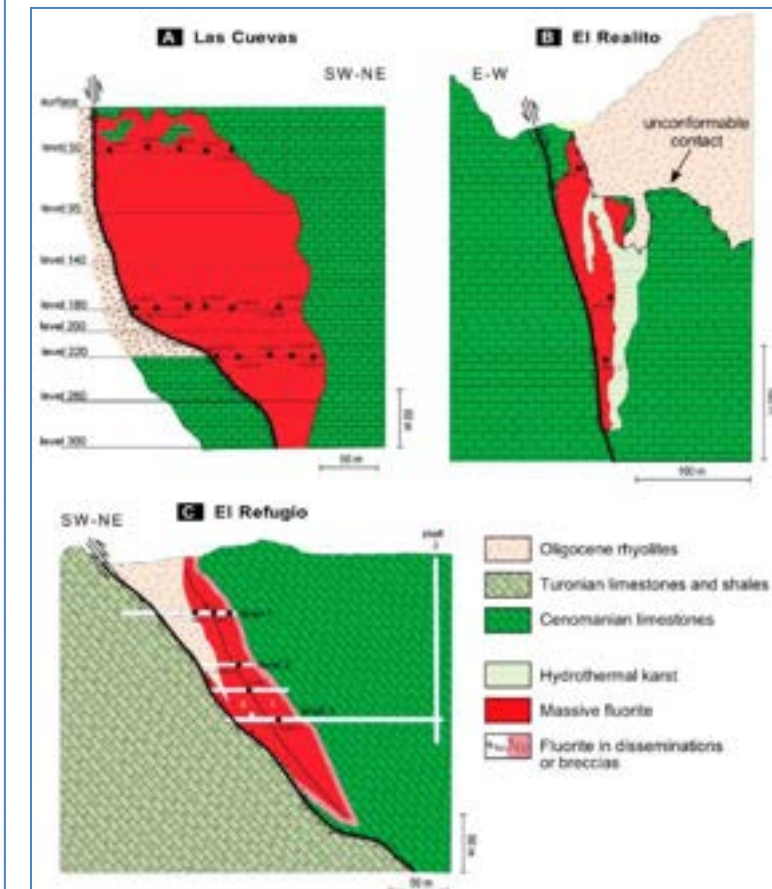
Fluorine



E Gonzalez- Partida et al 2019



E Gonzalez- Partida et al 2019



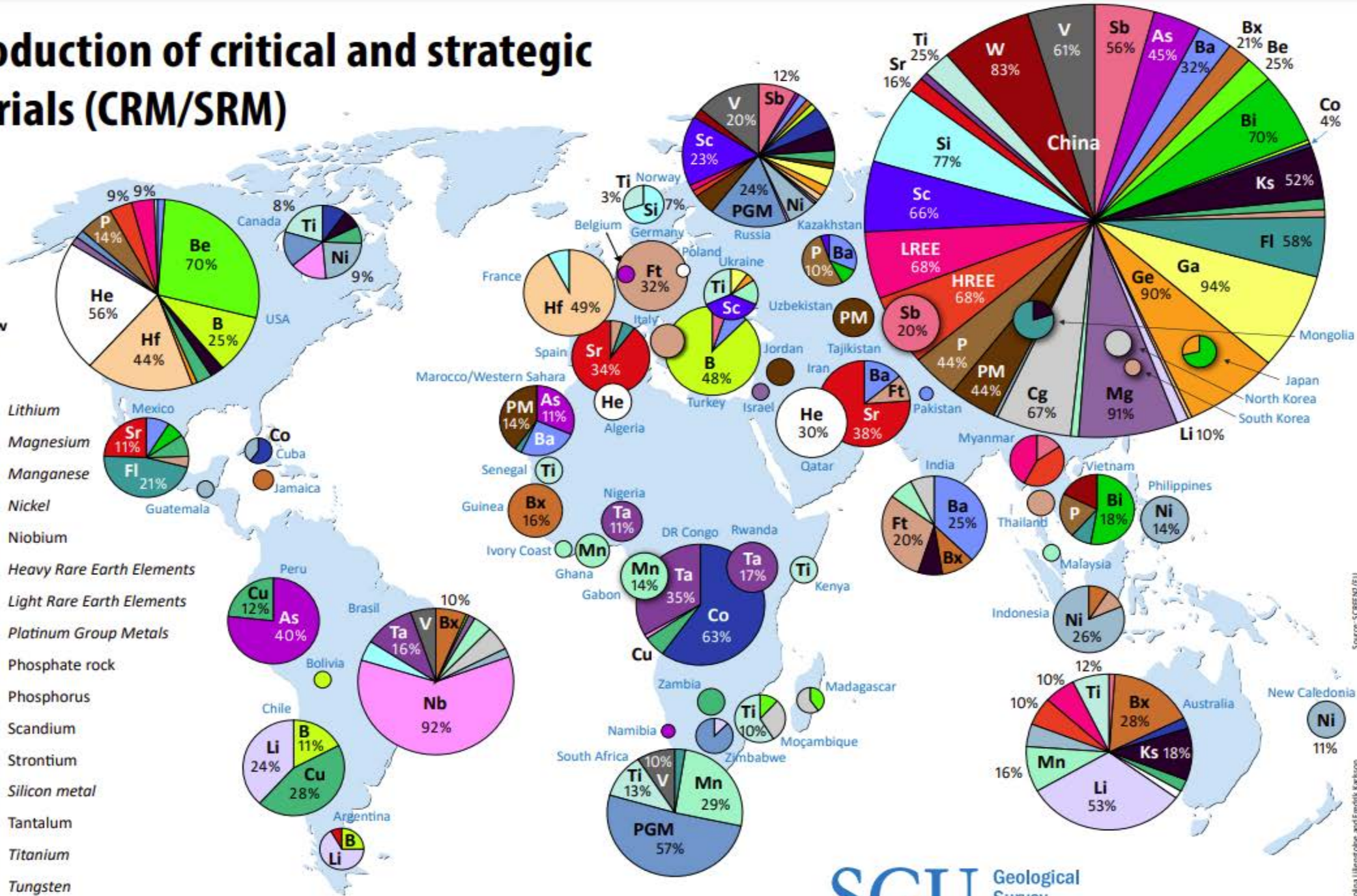
E Gonzalez- Partida et al 2019



# Global production of critical and strategic raw materials (CRM/SRM)

Critical and strategic raw materials included in the EU list

- |                            |                                       |
|----------------------------|---------------------------------------|
| <b>Sb</b> Antimony         | <b>Li</b> Lithium                     |
| <b>As</b> Arsenic          | <b>Mg</b> Magnesium                   |
| <b>Bx</b> Bauxite          | <b>Mn</b> Manganese                   |
| <b>Ba</b> Baryte           | <b>Ni</b> Nickel                      |
| <b>Be</b> Beryllium        | <b>Nb</b> Niobium                     |
| <b>Bi</b> Bismuth          | <b>HREE</b> Heavy Rare Earth Elements |
| <b>B</b> Borate            | <b>LREE</b> Light Rare Earth Elements |
| <b>Cg</b> Natural graphite | <b>PGM</b> Platinum Group Metals      |
| <b>Co</b> Cobalt           | <b>PM</b> Phosphate rock              |
| <b>Fl</b> Flourspar        | <b>P</b> Phosphorus                   |
| <b>Ft</b> Feldspar         | <b>Sc</b> Scandium                    |
| <b>Ga</b> Gallium          | <b>Sr</b> Strontium                   |
| <b>Ge</b> Germanium        | <b>Si</b> Silicon metal               |
| <b>Hf</b> Hafnium          | <b>Ta</b> Tantalum                    |
| <b>He</b> Helium           | <b>Ti</b> Titanium                    |
| <b>Ks</b> Coking coal      | <b>W</b> Tungsten                     |
| <b>Cu</b> Copper           | <b>V</b> Vanadium                     |
- italic= strategic*



## EU Critical Minerals

aluminium/bauxite	antimony	arsenic
baryte	beryllium	bor/borate
flourspar	phosphate rock	phosphorus
<b>feldspar</b>	gallium	germanium
natural graphite	hafnium	helium
rare earth elements: HREE and LREE	silicon metal	cobalt
coking coal	copper*	lithium
<b>magnesium</b>	<b>manganese</b>	nickel*
niobium	platinum group metals: PGM	scandium
strontium	tantalum	titanium
vanadium	bismuth	tungsten

\*=Strategic but not critical raw material

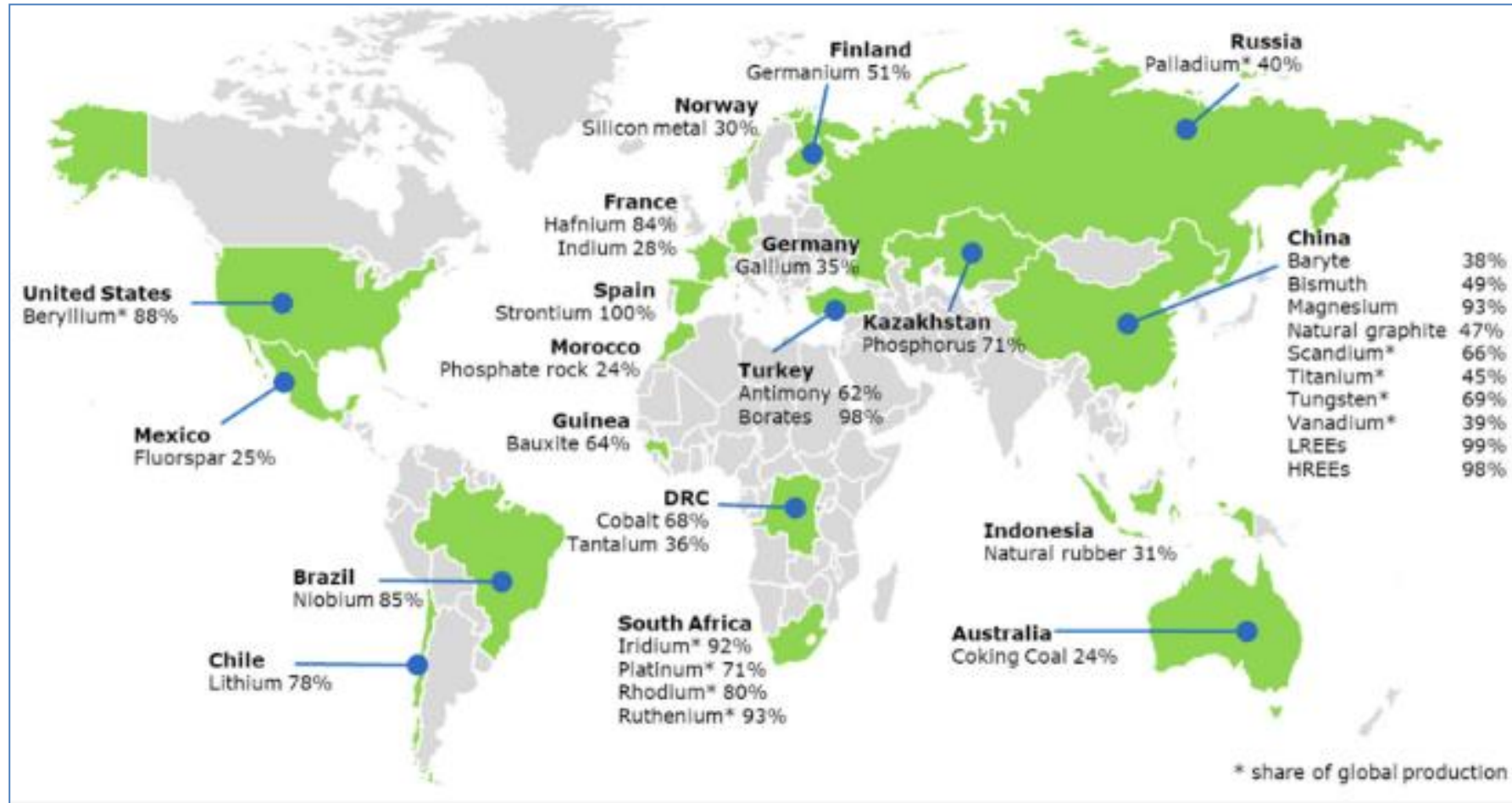
Geol Survey Sweden

SGU Geological Survey of Sweden

SGU 2023. Carolina Liljenstolpe and Fredrik Karlsson



# Major Supplier of Critical Mineral Countries to EU



Czerwinski 2022

## EU Critical Minerals

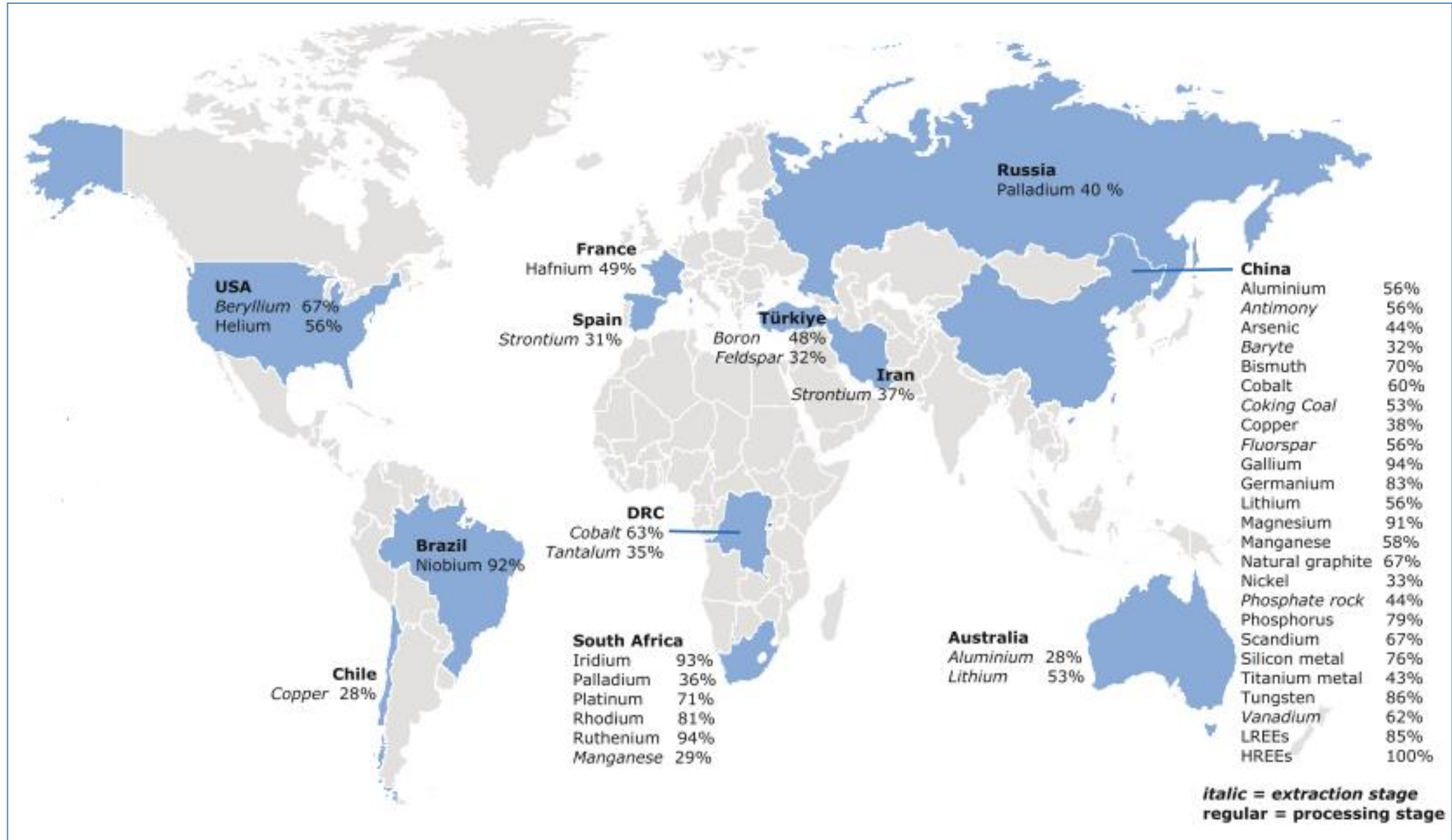
aluminium/bauxite	antimony	arsenic
baryte	beryllium	bor/borate
flourapat	phosphate rock	phosphorus
<b>feldspar</b>	gallium	germanium
natural graphite	hafnium	<b>helium</b>
rare earth elements: HREE and LREE	silicon metal	cobalt
coking coal	copper*	lithium
magnesium	<b>manganese</b>	nickel*
niobium	platinum group metals: PGM	scandium
strontium	tantalum	titanium
vanadium	bismuth	tungsten

\*=Strategic but not critical raw material

Geol Survey Sweden



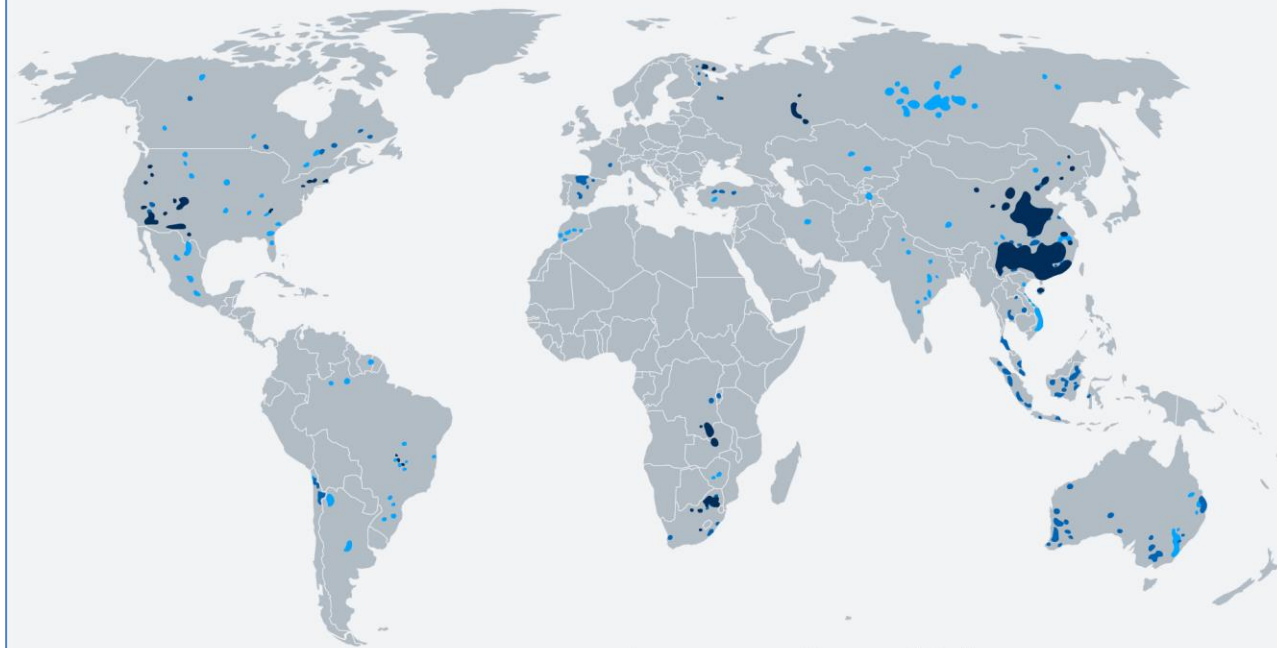
# Major Supplier of Critical Mineral Countries to EU



EU study on critical raw materials 2023



## The most important mining areas of critical raw materials



Relevance of mining areas  low medium high



Source: EU Commission, US Geological Survey  
Methodology: [github.com/dw-data/crm](https://github.com/dw-data/crm)

Penke 2021 DW.com

## China dominates the critical raw materials market



*Suppliers' market share of critical raw materials*

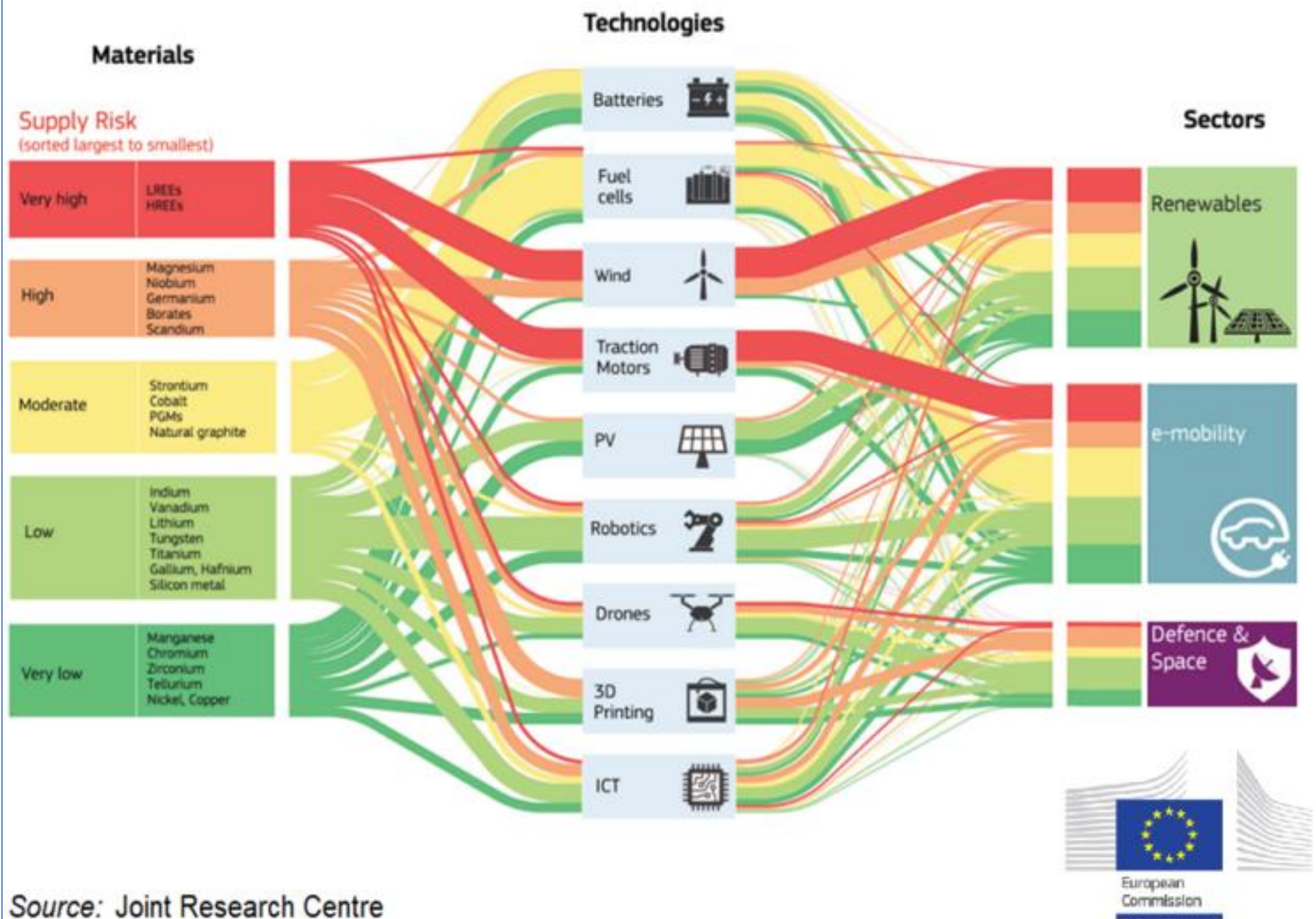


Source: EU Commission | Methodology: [github.com/dw-data/crm](https://github.com/dw-data/crm)

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# Critical raw materials and their supply risk



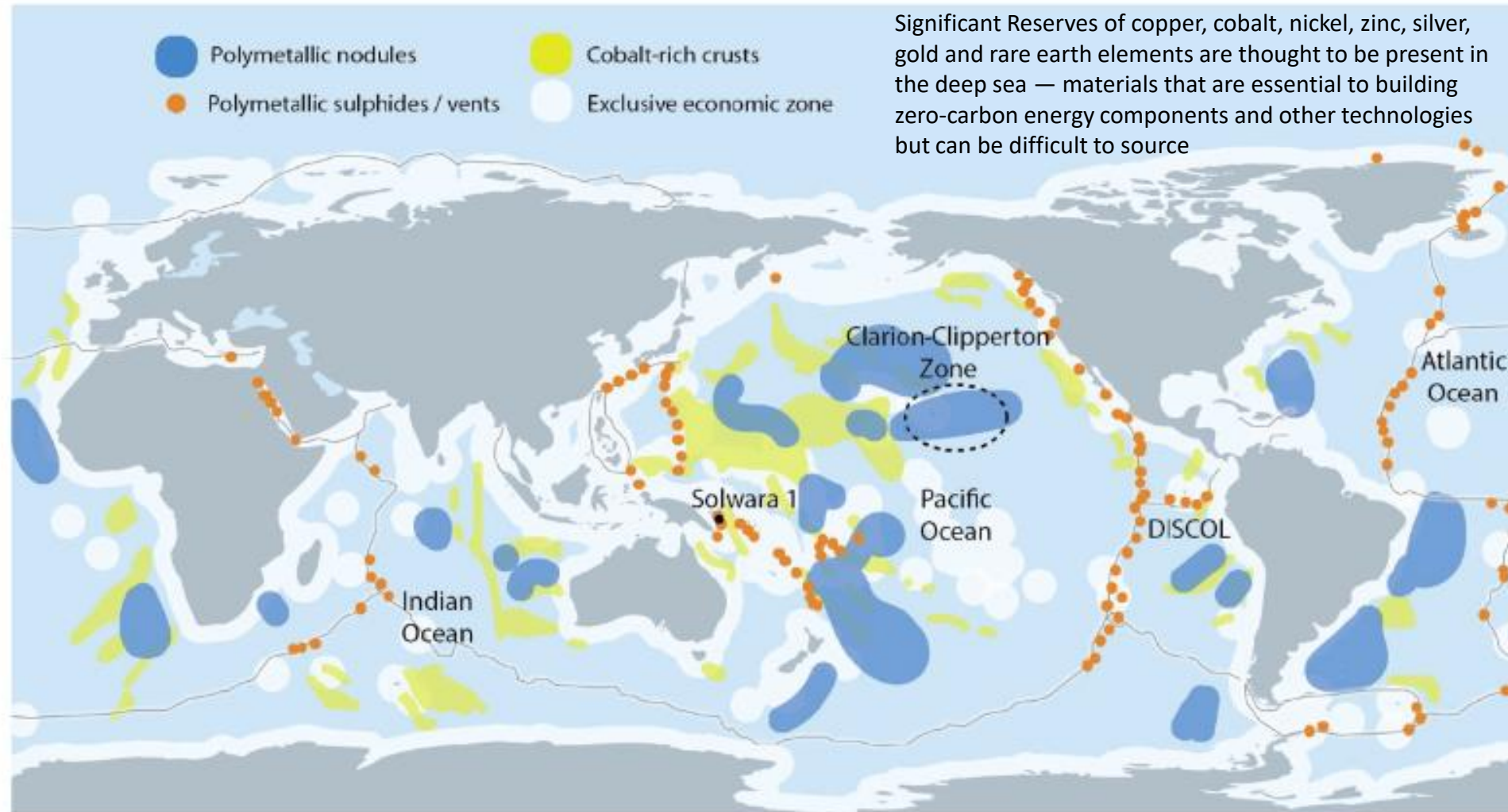
Source: Joint Research Centre

Eddy Ong 2024  
Posted on LinkedIn



# Status of Deep Sea Mining

## Distribution of critical mineral resources in the deep sea



Note: The white area around Antarctica is not an exclusive economic zone but rather governed by an international commission.

Source: Miller et al. 2018; Hein et al. 2013.

23.07.13

In January 2024, Norway initiated a process to open its own waters for exploration of deep-sea mineral resources, likely starting in the early 2030s. Other countries may follow suit, though in practice, many will be constrained by a lack of available funding and technical ability.

There is also a great diversity of opinion on seabed mining among nation states. Some, such as Norway and Nauru, are leading the charge for exploration and extraction; others, such as Germany and Canada, as well as the European Parliament, have called for national and regional moratoria.

In addition, the bulk of the most attractive mineral deposits are found not in countries' EEZs but on vast seafloor abyssal plains in international waters. One area of particular interest is the Clarion-Clipperton Zone in the Pacific Ocean.

This mineral-rich region already hosts exploration contracts for 17 deep-sea mining contractors, with their combined exploration areas covering approximately 1 million square kilometers (about the same area as Ethiopia). The contracts were awarded by the ISA (International Seabed Authority) which has 168 country signatories and the EU.

While exploratory mining to test equipment has occurred at a small scale, deep-sea mining has not yet been undertaken commercially. But some national governments and mining companies plan to begin as soon as possible, which could be within the next few years. What happens next will largely hinge on the ISA and how it decides to regulate deep-sea mining.