## **Literature**

## **Tectonic environments of South American porphyry copper magmatism through time revealed by spatiotemporal data mining - Butterworth et al**

## <https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2016TC004289>

Cobalt—Styles of Deposits and the Search for Primary Deposits

<https://pubs.usgs.gov/of/2017/1155/ofr20171155.pdf>

In the United States, exploration for cobalt deposits may focus on magmatic nickel-copper deposits in the Archean and Proterozoic rocks of the Midwest and the east coast (Pennsylvania) and younger mafic rocks in southeastern and southern Alaska; also, possibly basement rocks in southeastern Missouri. Other potential exploration targets include—

• The Belt-Purcell basin of British Columbia (Canada), Idaho, Montana, and Washington for different styles of sedimentary rock-hosted cobalt deposits;

• Besshi-type VMS deposits, such as the Greens Creek (Alaska) deposit and the Ducktown (Tennessee) waste and tailings; and

• Known five-element vein districts in Arizona and New Mexico, as well as in the Yukon-Tanana terrane of Alaska; and hydrothermal deposits associated with ultramafic rocks along the west coast, in Alaska, and in the Appalachian Mountains.

NB most of these above are subduction-zone related → our hypothesis may have to be that we expect no correlation of the cobalt deposits to the subduction zone

* Apart from their occurrence in IOGC deposits which can occur associated with I-type granites, which are generally produced at subduction zones (see USGS pub above)
  + IOCG relatively common in south America along the Andes - see fig. 1 from candelaria paper below
  + Cobalt a low-concentration component of IOGC - would explain why all the deposits have a low concentration
  + HOWEVER see article below on IOGC formation - states that Candelaria formed in an anomalous extensional part of the Andes, also the local intrusions are anomalous in an Andean context: “This implies that special conditions, possibly detached slabs of metasomatized SCLM, may be required in convergent margin settings to generate world-class IOCG deposits.”
  + Also possible relationship to back-arc subduction systems in its presence in Besshi-type VMS

Age of Nazca subduction at least 230 Ma

Age of Mineralization of the Candelaria Fe Oxide Cu-Au Deposit and the Origin of the Chilean Iron Belt, Based on Re-Os Isotopes (also examines relationships/genetic links with magmatic activity) - concludes that fluids that formed IOCG deposits here have a temporal relationship with magmatic bodies, but cannot exclude nonmagmatic fluid origins

<https://watermark.silverchair.com/59.pdf?token=AQECAHi208BE49Ooan9kkhW_Ercy7Dm3ZL_9Cf3qfKAc485ysgAAAjcwggIzBgkqhkiG9w0BBwagggIkMIICIAIBADCCAhkGCSqGSIb3DQEHATAeBglghkgBZQMEAS4wEQQM7I8OR27BCqtHPpfyAgEQgIIB6pHjvStg3FoxPncN7J_cno9bqNJvennIbIEc0bli74z2JZ2yOxfHmKwdM4I7BMbbpTBtaomyChYKMvPzPHeNlGGTfP4ISTFIAPOptdcLFtPw49tQTF8babsVeEdIWO2T1hvnTQRyCLqBnLfwEFWa3Ob5CZodGch85rEQK5KWvDUunl1CPi0ZLJiMt1IwKIrFhNMEFCQrPTAMQYlkJ3AjBfdeZXfC1eZ_HC5FEoSQGEdUIxK4HEgAszlkp8Eor3RK622fHhoRS4yT97eM1Z_iPALXsq9vmank02k6Tj64ALC-9xvsmpZ9-vSqEYZKpMTm7oMr3WY9i6QwAIpjWE0-sW7tV167ULGld-e723rZcsAn-C3tvca3WDyj4miSr22dtIshT9EfufDE4qoEe2Cwkq8ssy-Jy4RXbL8zm8ZeCZtpaRpTDOZM0J11kM6G4T9Px1RL4-MI1TSjWwxktartr-jVbcgIk7ZqtuR9xVcIuS23TIDIBb_6brmkJv1JiQxd5yBO_VOBpbII9jOxcnnsu1FDt9Ts4mpiJASHigUzoDnaIiGkMUcOgREsTR9tvqtayCBbFWfH-JA1wyOsw4sQIMZzxJixRwJhQ1fa-sh7r0oIPNC479IJIGCXBLCfVwa11mucniOUjJf85KI>

# Iron Oxide Copper-Gold (IOCG) Deposits through Earth History: Implications for Origin, Lithospheric Setting, and Distinction from Other Epigenetic Iron Oxide Deposits

<https://pubs.geoscienceworld.org/segweb/economicgeology/article/105/3/641/128204/iron-oxide-copper-gold-iocg-deposits-through-earth>

# Cobalt mineralization in the Blackbird District, Lemhi County, Idaho (magmatic source! But the paper is from 1947)

<https://pubs.geoscienceworld.org/segweb/economicgeology/article/42/1/22/15952/cobalt-mineralization-in-the-blackbird-district>

Same area, more up to date paper (1990) - link to magmatic origin tenuous as the mineralisation is generally stratabound (indicates syngenetic origin)

<https://link.springer.com/article/10.1007/BF00190377>

# Petrography, Mineralogy, and Geochemistry of the Nkamouna Serpentinite: Implications for the Formation of the Cobalt-Manganese Laterite Deposit, Southeast Cameroon (sedimentary deposit)

<https://pubs-geoscienceworld-org.ezproxy1.library.usyd.edu.au/segweb/economicgeology/article/107/1/25/128328/petrography-mineralogy-and-geochemistry-of-the>

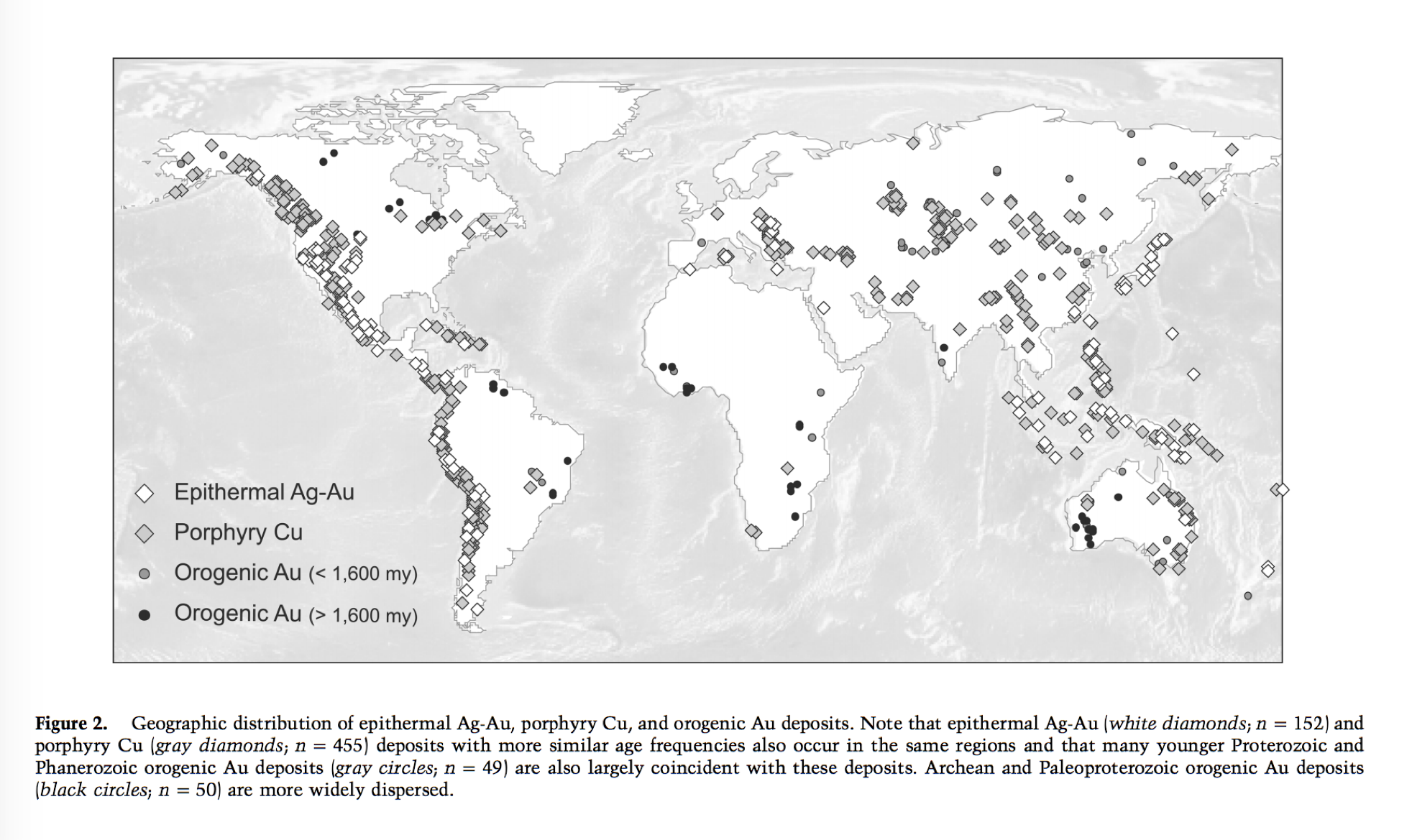
# Subduction and ore deposits

# [https://www.researchgate.net/publication/277976864\_Subduction\_and\_ore\_deposit](https://www.researchgate.net/publication/277976864_Subduction_and_ore_deposits)

# Cobalt stats and information

<https://www-jstor-org.ezproxy1.library.usyd.edu.au/stable/pdf/10.1086/521606.pdf?refreqid=excelsior%3A59fb5e0288d664594849ef4165cc5e81>

Tectonism and Exhumation in Convergent Margin Orogens: Insights from Ore Deposits



Porphyry Copper Deposits → are associated with subvolcanic, porphyritic intrusions of monzonitic to quartz dioritic composition. They are widespread at convergent margins worldwide… In these deposits, copper is found primarily as chalcopyrite and bornite along hairline fractures and larger veins in intrusive and/or immediately surrounding wall rocks...These ores formed from hydrothermal fluids of dominantly magmatic origin that ranged in temperature from at least 300 up to 600C and that deposited ore primarily in response to cooling of the fluid… most porphyry Cu deposits form at depths ranging from about 500 m to 5 km and averaging about 2 km.

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# <https://www.usgs.gov/centers/nmic/cobalt-statistics-and-information>

* Cobalt often a byproduct of copper and/or nickel mining (association with paper by butterworth)
* 60% produced in DRC

<https://www.cobaltinstitute.org/production-and-supply.html>



There are approximately 30 principal cobalt-bearing minerals and over 100 more which contain minor amounts of the metal or include cobalt as a substitute for other elements. Cobalt may substitute for transition metals in many minerals and chemical compounds and is commonly found in the place of iron and nickel as they share many similar chemical properties.

* Cobalt is only extracted ALONE from the Moroccan and some Canadian arsenide ores
* It is normally associated as a by-product of copper or nickel mining operations
* Around 58% of the world cobalt production comes from copper ores
* ~55% of the global supply originates from the Dominican Republic of the Congo
* Global reserves are distributed as follows:
  + Africa ~50%
  + Australasia ~24%
  + Americas ~10%
  + Rest of the world ~13%

Economic concentrations of cobalt can be found in four different geological settings, outlined in Table 2. Cobalt is almost always a by- or co-product of mining for other base metals, chiefly nickel and copper. Large quantities of cobalt also occur on the sea floor, contained within manganese nodules and cobalt-rich crusts, although they are not economically viable with current technology and economic conditions.

Importance of the mineral

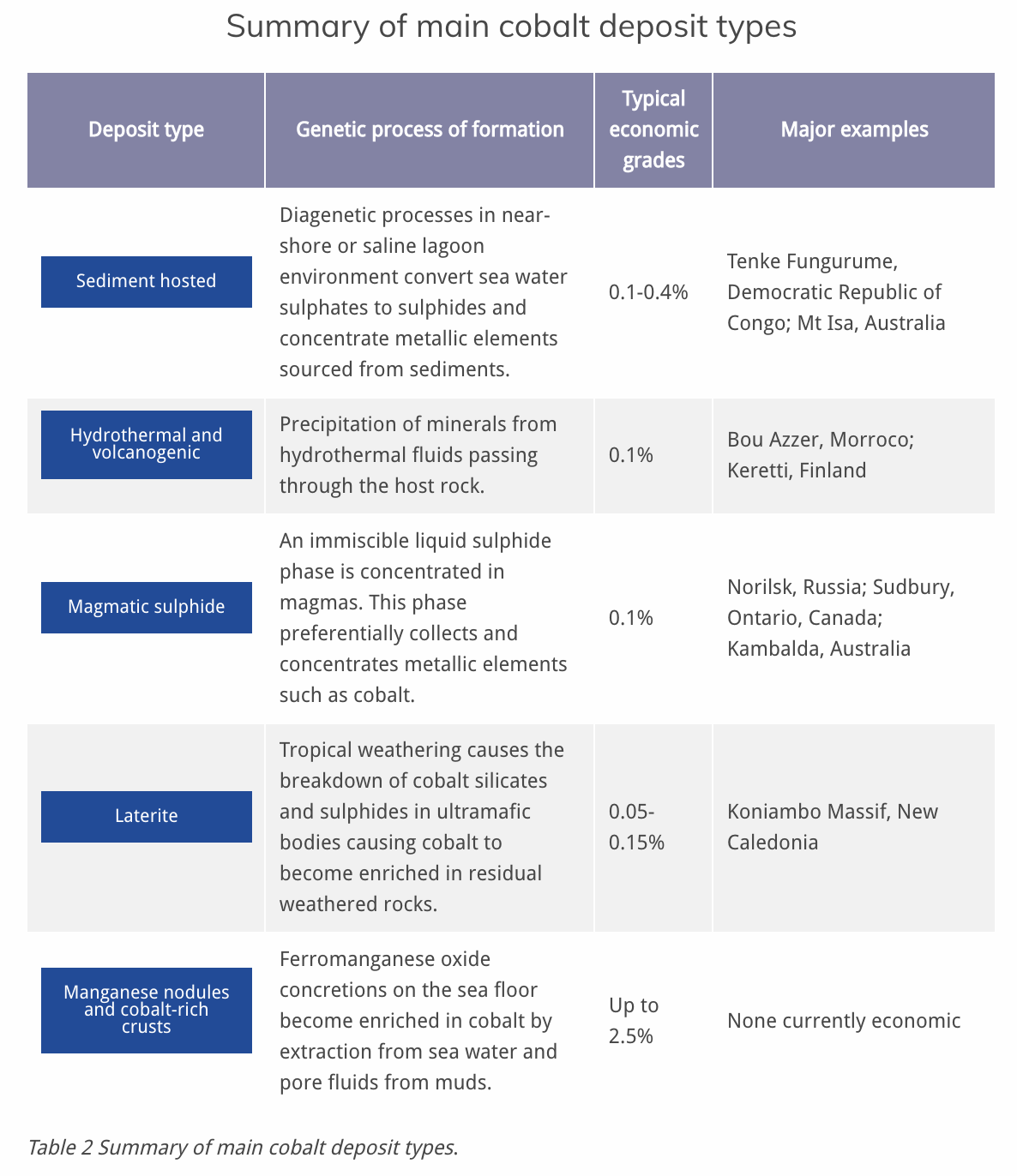
Cobalt is a critical raw material fundamental to industry and essential for enabling technological development and a low carbon future

Cobalt has many strategic and irreplaceable industrial uses whilst also being the central component of vitamin B12 which is fundamental to growth and vitality.

* Cobalt Institute

Cobalt (Co) is a metal used in numerous diverse commercial, industrial, and military applications, many of which are strategic and critical. On a global basis, the leading use of cobalt is in rechargeable battery electrodes. Superalloys, which are used to make parts for gas turbine engines, are another major use for cobalt.

* USGS (United States Geological Survey)



Hydrothermal and Volcanogenic → sub zones

This deposit type groups together a wide range of deposit styles and mineral assemblages. The key process is precipitation from hydrothermal fluids passing through the host rock often sourced from, or powered by, volcanic activity. Ores can be found where minerals have been remobilised along fault planes, in veins, fissures and cracks, or as metasomatic replacement of host rocks.

<https://www.cobaltinstitute.org/hydrothermal-and-volcanogenic.html> → major examples of hydrothermal and volcanogenic cobalt deposits including Australia, Canada, China, USA, Finland, etc. With detailed case studies of formation in Morocco and Sweden (potential comparative case study)

<https://prd-wret.s3-us-west-2.amazonaws.com/assets/palladium/production/s3fs-public/atoms/files/mcs-2019-cobal_0.pdf>

Identified world terrestrial cobalt resources are about 25 million tons. The vast majority of these resources are in sediment-hosted stratiform copper deposits in Congo (Kinshasa) and Zambia; nickel-bearing laterite deposits in Australia and nearby island countries and Cuba; and magmatic nickel-copper sulfide deposits hosted in mafic and ultramafic rocks in Australia, Canada, Russia, and the United States. More than 120 million tons of cobalt resources have been identified in manganese nodules and crusts on the floor of the Atlantic, Indian, and Pacific Oceans.

<https://www.usgs.gov/centers/nmic/cobalt-statistics-and-information> → annual reports of cobalt (mainly just for the US though)

Only place in South America where cobalt is mined is within Brazil.

* Votorantim Metais S.A. (co.) - lateritic nickel-cobalt ore mined from Niquelandia, Goias State
* Mirabela Nickel Ltd. (co.) - cobalt in nickel sulfide concentrate from its Santa Rita open pit mine and concentrator in Bahia State
* <https://s3-us-west-2.amazonaws.com/prd-wret/assets/palladium/production/mineral-pubs/cobalt/myb1-2015-cobal.pdf>
* Shedd 2015

<https://pubs.usgs.gov/of/2010/1179/pdf/ofr2010-1179.pdf>

Magmatic sulfide-rich Ni-Cu±PGE deposits hosted in picritic and tholeiitic dikes and sills present some unique and challenging targets for geophysical exploration… as a result, geophysical methods can be very useful in detecting and characterizing such deposits.

The Ni-Cu±PGE sulfide deposits, as well as their host intrusions, are small, commonly only tens or hundreds of meters in length, and thus represent the proverbial “needle in a haystack” for any regional-scale exploration program.

The aeromagnetic survey method is the most effective tool for reconnaissance-scale exploration of dike- and sill-hosted Ni-Cu±PGE sulfide deposits.

magmatic sulfide-rich Ni-Cu±PGE deposits related to picritic or tholeiitic basalt dike-sill complexes… Magmatic sulfide deposits form when mantle-derived, sulfur undersaturated picritic or tholeiitic basalt magmas become sulfide saturated, commonly following interaction with crustal rocks. Sulfur saturation results in the formation of an immiscible sulfide liquid; the sulfide liquid tends to segregate into physical depressions or other areas in the lower parts of dike- and (or) sill-like intrusions because of changes in magma flow dynamics. Economic deposits develop almost exclusively within dynamic magmatic systems that experience repeated surges of magma. Such dynamic systems promote the interaction of a sulfide liquid with a sufficiently large amount of silicate magma to concentrate chalcophile elements to economic levels. The principal sulfide minerals generally consist of intergrown pyrrhotite, pentlandite, and chalcopyrite. Cobalt (Co) is found in pentlandite