Economic Geology: Lecture Notes

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4- Manganese formations

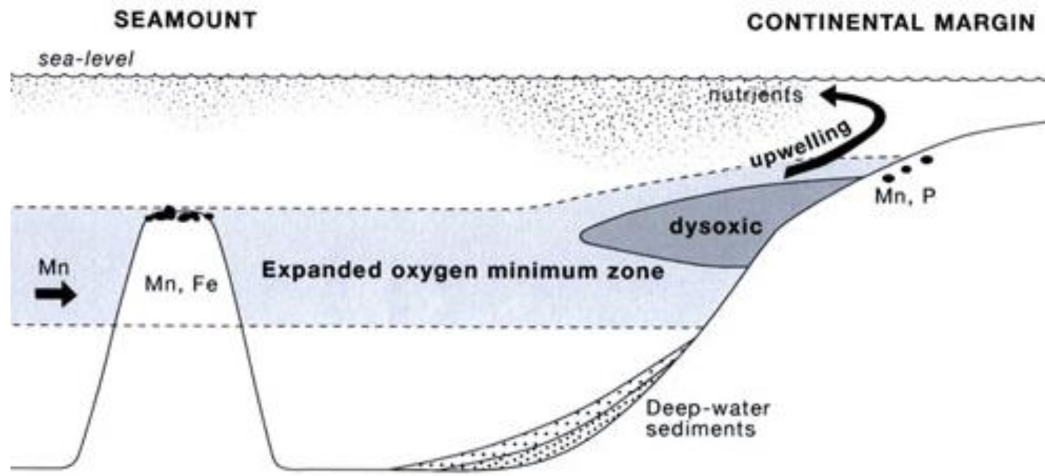
Marine manganese oxide strata (manganese formations, MnF) occur commonly interlayered with Superior type BIF. The Kalahari manganese field comprises about half of the world's manganese resources.

The concentration of Mn relative to Fe is believed to have been affected by earlier abstraction of iron from seawater and precipitation of BIF.

Consequently, the soluble manganese was relatively enriched and only when concentration of O2 continued to rise, Mn^{2+} was oxidized to Mn^{3+} and manganese rich beds were deposited. Manganese formations are only exploitable if enrichment processes acted on protore.

Oolitic manganese ore

Oolitic manganese ore occurs in seams within clastic marine sediments of epicontinental seas. The metal source for oolitic manganese deposits may have been continental weathering or ocean-floor hydrothermal venting.



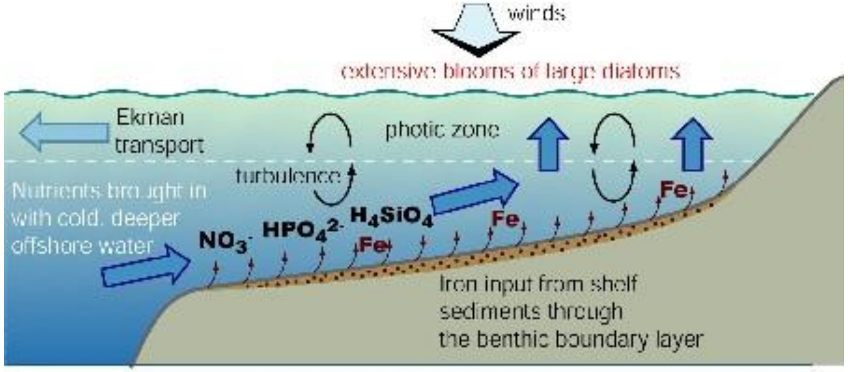
Mn is dissolved in the restricted sea either abiotically or by microbial anaerobic methane oxidation:

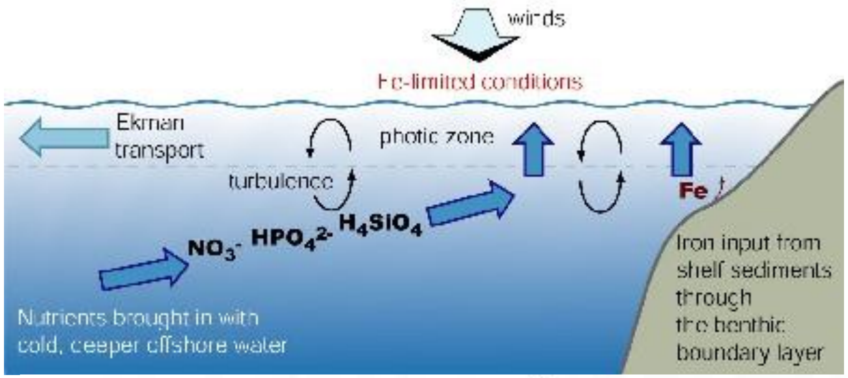
$$CH_4 + 4MnO_2 + 7H^+ \rightarrow HCO_3^- + 4Mn^{2+} + 5H_2O$$

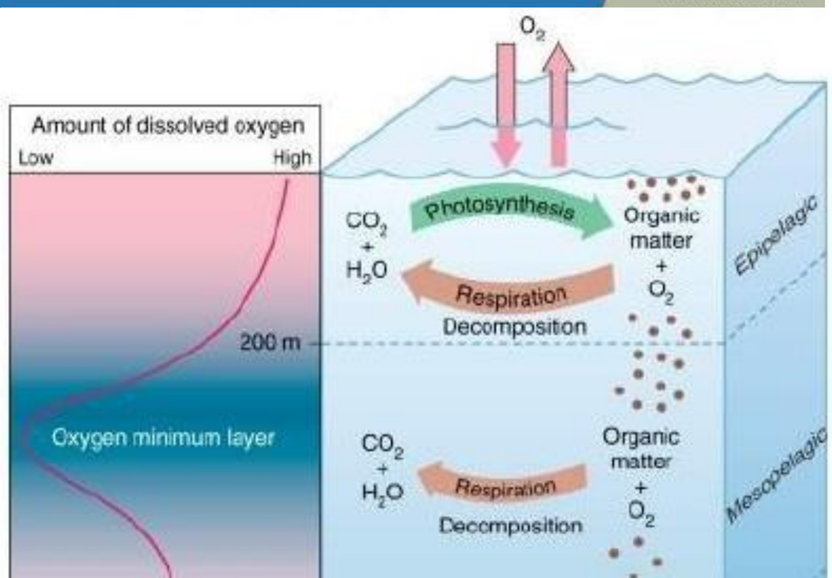
This process leads to enrichment of anoxic deep water with dissolved manganese (Mn2+). Interaction of the Mn-enriched deep water with oxygen-rich marginal zones induces precipitation of Mn oxides, especially during transgressive phases (Black Sea is example).

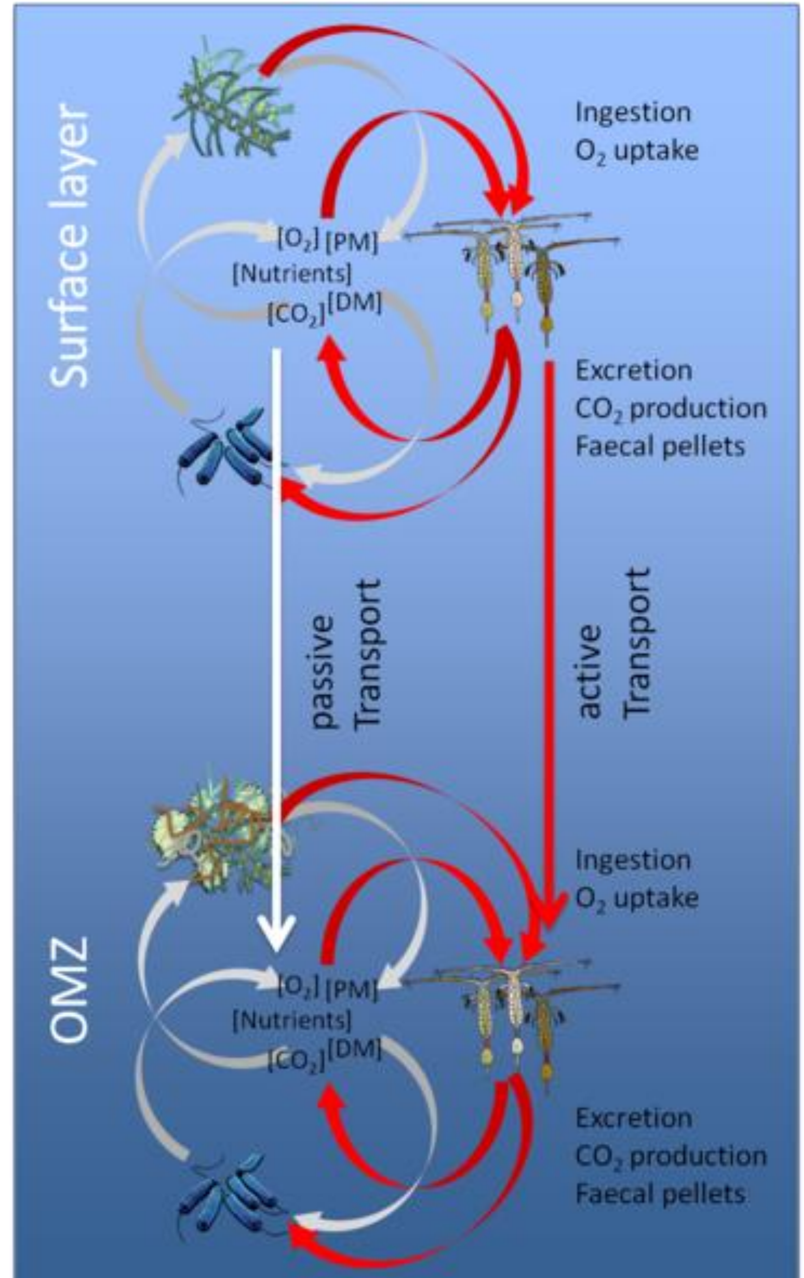
More extensive reducing conditions on the seafloor could cause mobilization of Mn-oxides from deep-water sediments into the mid-water column, and their transfer to shallow-water sediments where the upper boundary of the oxygen minimum zone intersects the seafloor. At this position, Mn2+ can be re-oxidized to insoluble Mn-oxide, which falls to the bottom and could be converted to Mn-carbonate during early diagenetic reaction with organic matter. Thus, major periods of oceanic upwelling are associated with Mn- anomalies.

Upwelling of oxygen minimum zone (OMZ) OMZ water precipitates Mn and P.







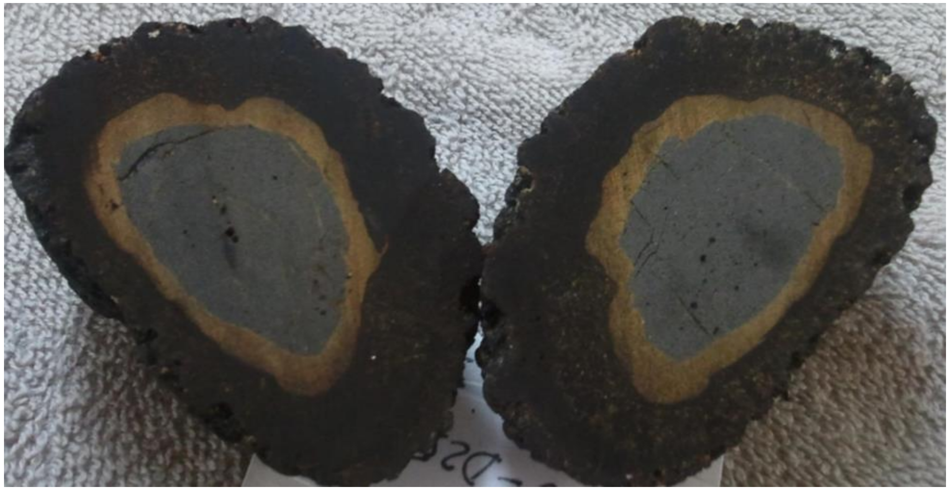


Manganese nodules

Manganese nodules occur over wide expanses of deep seafloor below the carbonate compensation depth (CCD). In shape and size, the Mn-nodules are compared to potatoes but, of course, smaller and larger specimens do occur.

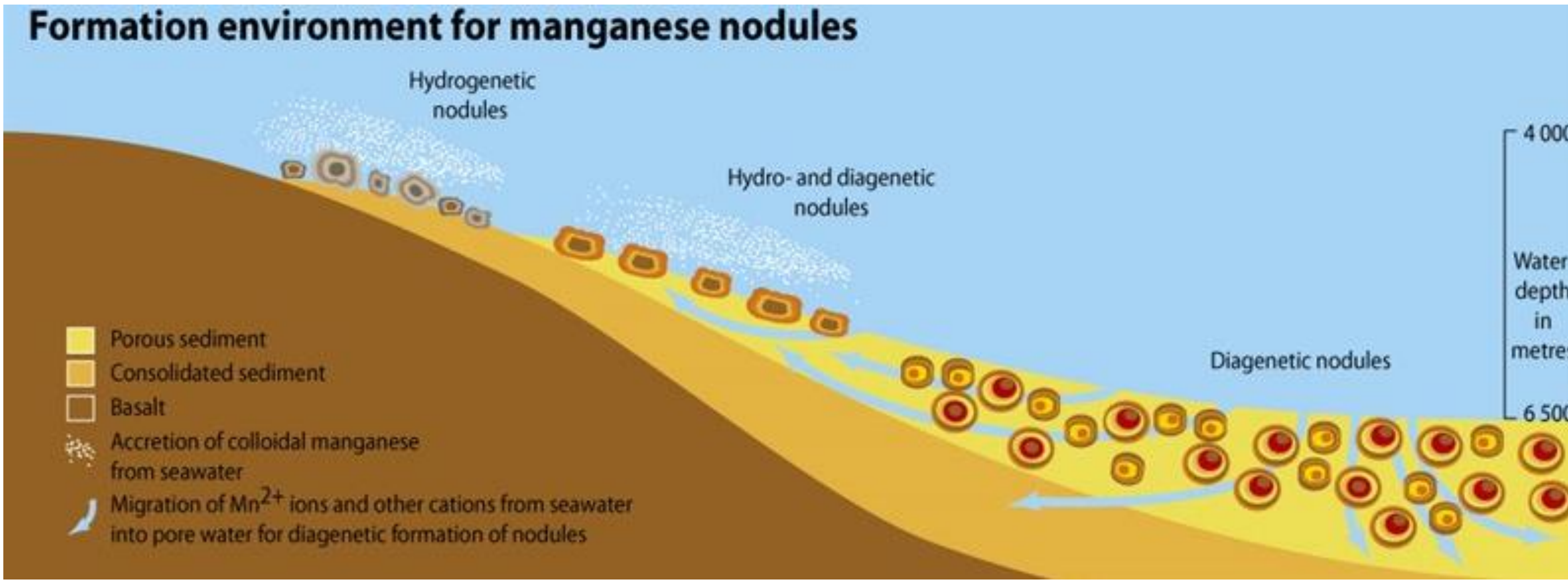
Economically prospective manganese nodule fields include the Clarion-Clipperton Zone in the Pacific. Nodules contain 29 wt.% Mn, 5% iron, 1.2% copper, 1.37% nickel, 1.2% cobalt and 15% SiO_2.

Mn-nodules have a botryoidal or smooth surface and consist of concentric shells of amorphous and crystalline manganese and iron oxi hydroxides. Formation of the nodules is partly by in-situ precipitation from pore fluids "diagenetic" and partly by attachment of colloidal particles or dissolved matter from seawater (hydrogenetic).



Mn-crust nodule that encloses a fresh basalt clast. Notice the distinct light-brown ring of alteration that forms a sharp contact between the edge of the basalt and the Mn-crust.

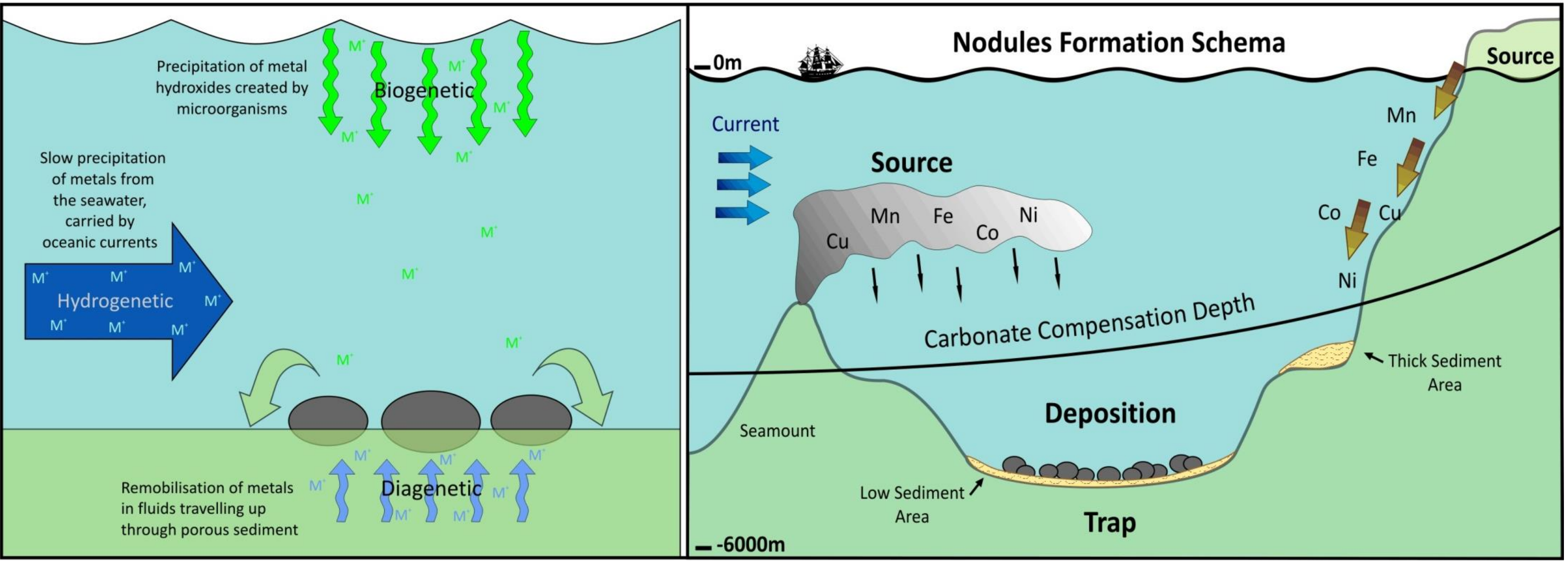
In both cases (diagenetic and hydrogenetic), microbial intervention may be essential. Manganese crusts grow mainly by hydrogenetic processes. Mn-nodules and crusts have remarkable contents of valuable metals. The source of these metals are most likely hydrothermal exhalations at mid-ocean ridges, submarine weathering of serpentinites, extraterrestrial dust and input from land to the oceans may contribute part of the endowment.

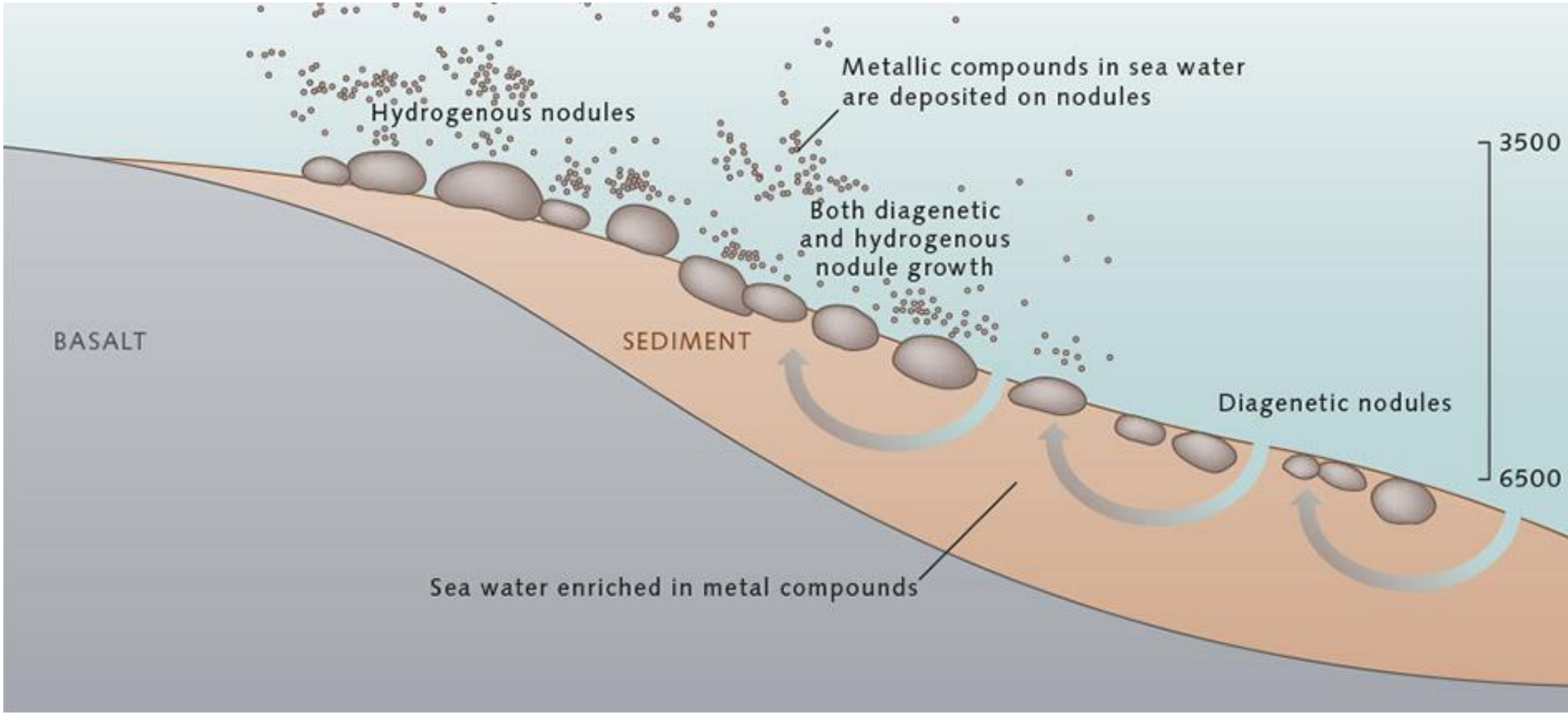


Formation environment for manganese nodules

Manganese nodules form on the deep seafloor as concretions formed by **concentric layering of iron and manganese hydroxides around a core.** They grow at a very slow rate, on the order of millimeters per million years. The nodules formed by **hydrogenetic processes** are most abundant, these are formed by slow precipitation of metals from seawater. Nodules are most abundant at depths between 4,000 m and 6,000 m in areas of low sedimentation rate. **Hydrogenous nodules** generally grow on siliceous and pelagic clay sediment.

Manganese nodules grow when metal compounds dissolved in the water column **(hydrogenous growth)** or in water contained in the sediments **(diagenetic growth)** are deposited around a nucleus. Most nodules are a product of both diagenetic and hydrogenous growth.




Metallic compounds in sea water
are deposited on nodules
Hydrogenous nodules
3500
Both diagenetic
and hydrogenous
nodule growth
BASALT
SEDIMENT
Diagenetic nodules
6500
Sea water enriched in metal compounds

5- Sediment-hosted, submarine-exhalative (SedEx) base metal deposits

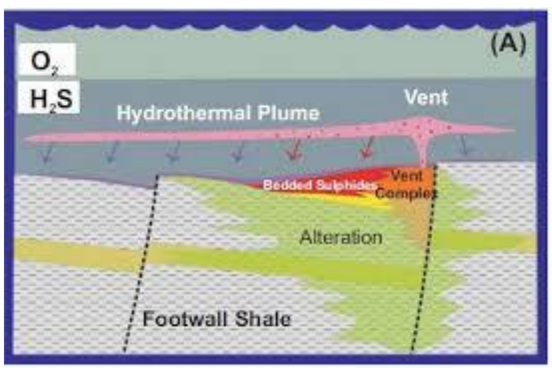
Hydrothermal-sedimentary sulphide ores occur in a continuum from:

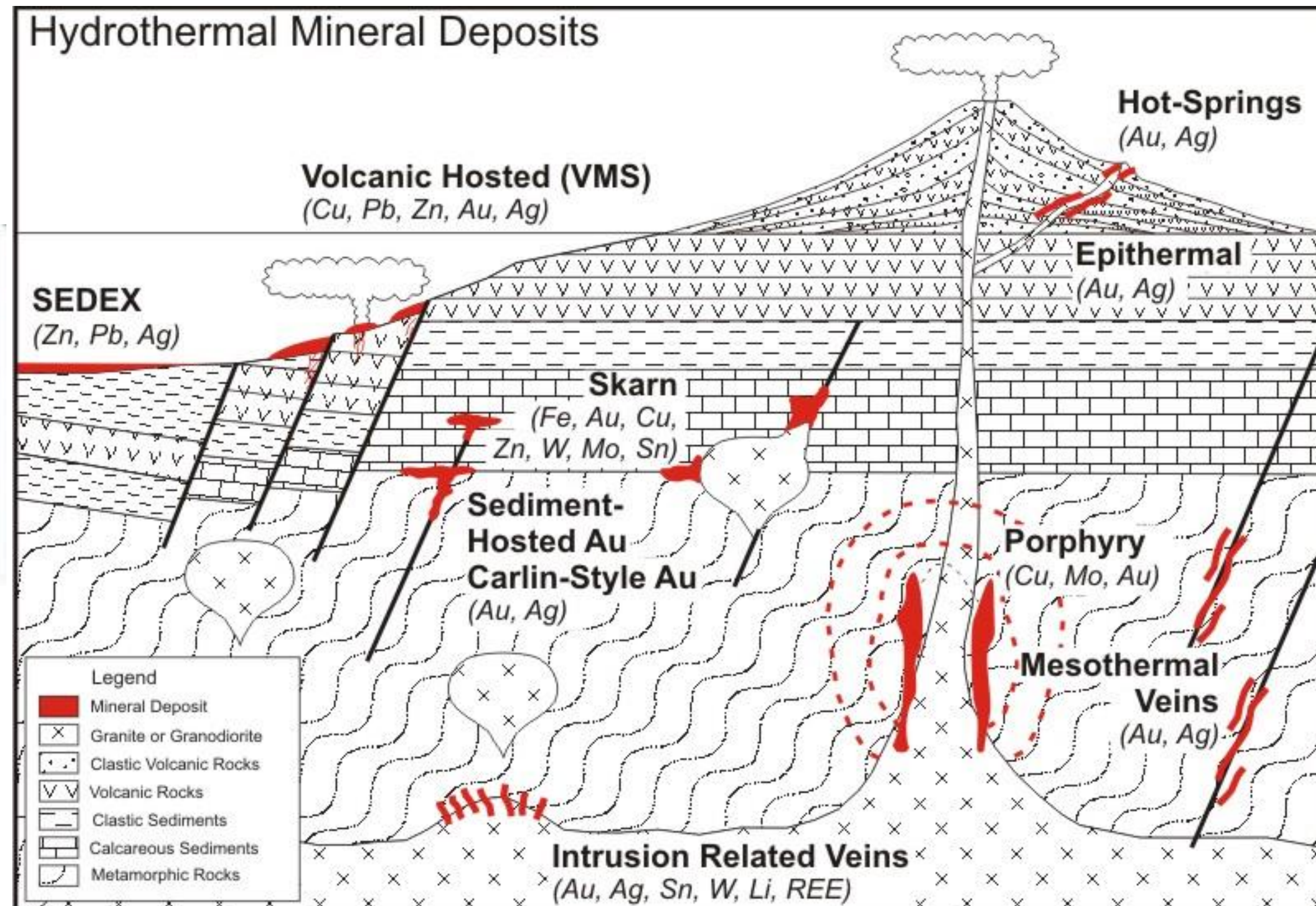
i) a proximal position to submarine volcanoes;

ii) more distal positions where only sparse ash layers in the sedimentary column point to synchronous volcanism; and

iii) to purely sedimentary settings.

Only the cases ii) and iii) are referred to as sedimentary-exhalative or short, SedEX type ore deposits. The first are volcanogenic massive sulfides (VMS).

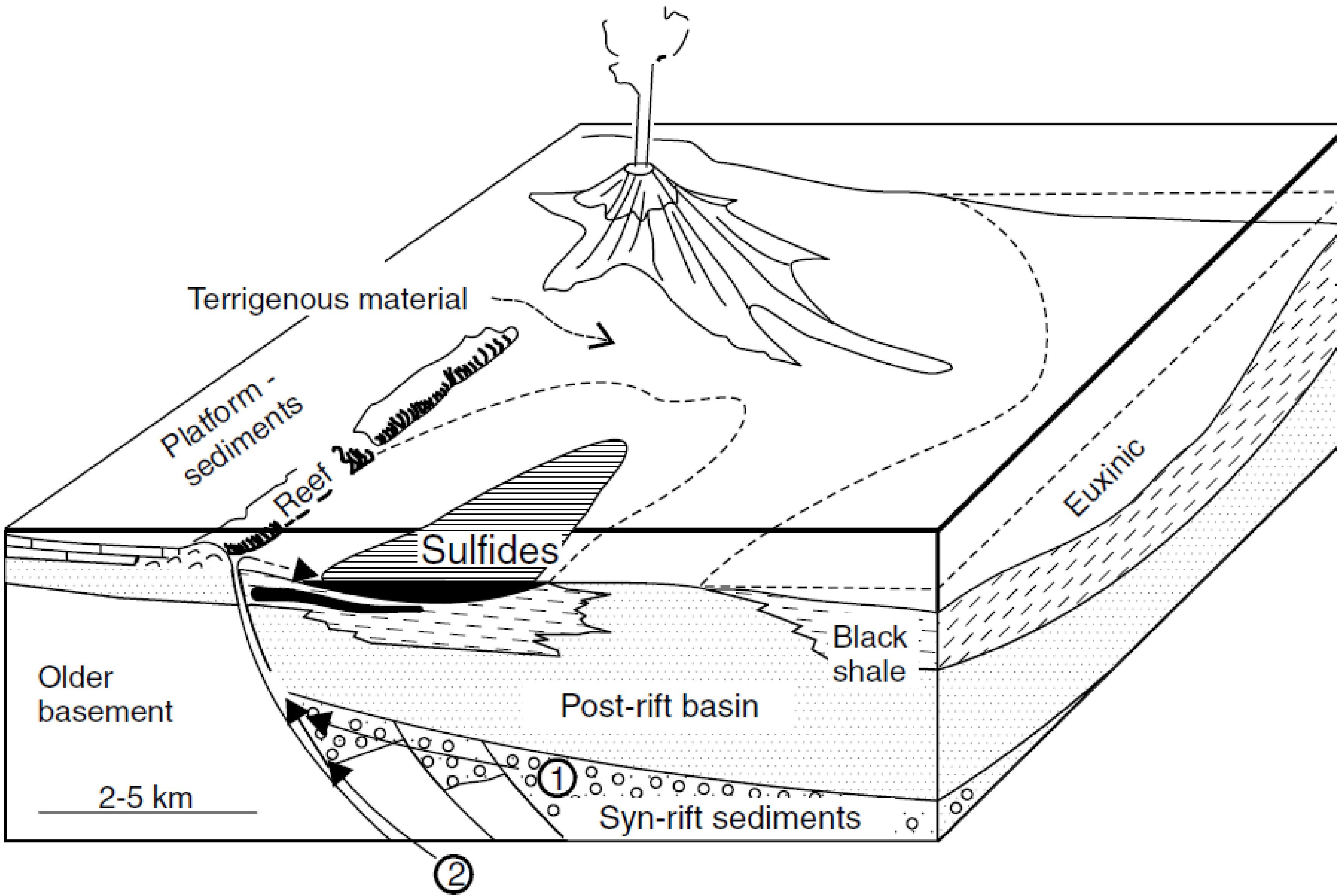




Submarine-exhalative (Sedex) base metal deposits

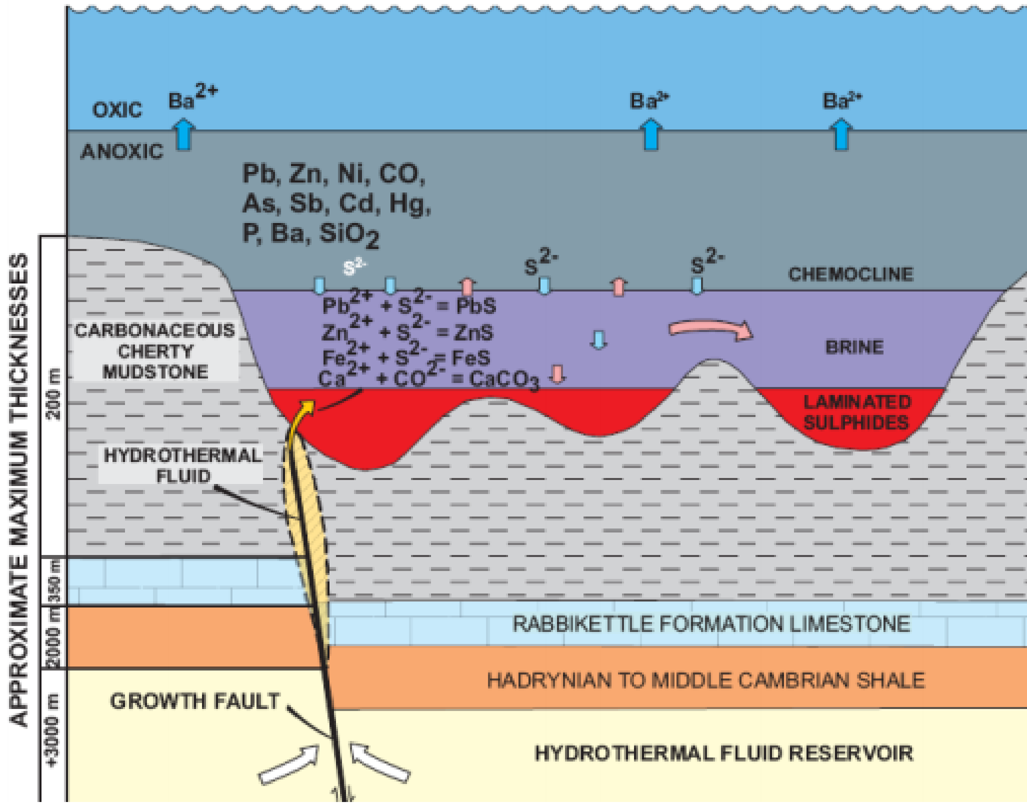
The term SedEx implies syngenetic origin of ore and host rocks. The characteristic setting of these deposits is submarine rifting within epicontinental seas. Ore bodies are typically related to faults, synsedimentary tectonic activity and the formation of local sub-basins. Extensional restricted basins associated with crustal thinning and distal volcanic centres may be part of the environment.

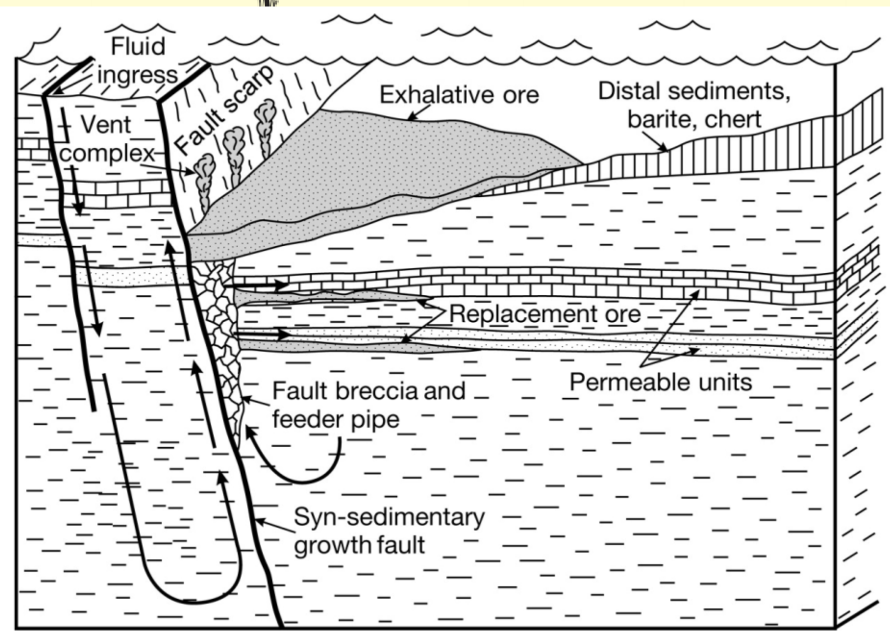
Schematic sketch of the geological setting of an exhalative-sedimentary (sedex) sulphide (-barite) ore deposit in a black shale basin. Note distal rift-related basaltic and felsic volcanic centres.



SedEX deposits are generally formed in fault-bounded sedimentary basins on continental crust (within-plate locations) rather than in volcanic piles on oceanic crust. To achieve SedEX deposits, the basin needs to accumulate several kilometres or tens of kilometres of oxygen lacking sediment, usually shales. SedEX are close to or enclosed in organic rich sdimentary rocks (e.g. black shales) indicating a state of partial (dysoxia) or severe oxygen depletion (hypoxia to anoxia) of bottom waters.

The correlation between the black shale and the depletion of oxygen could be interpreted in terms of the outpouring of profuse hydrothermal metalliferous fluids causing an euxinic marine sub-basin environment (i.e. anoxic, highly reduced and H2S stable).



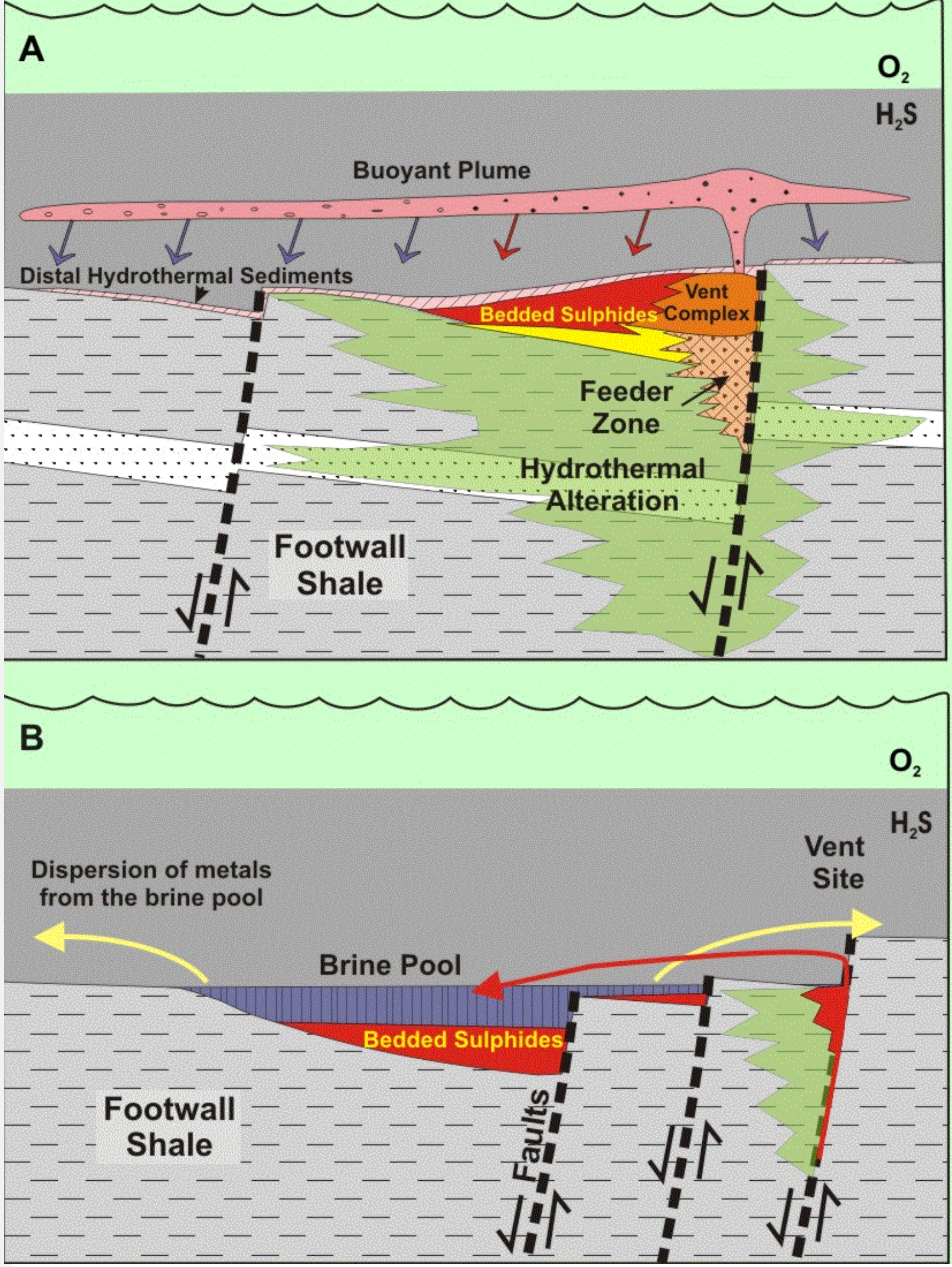


The sulphides in SedEX were deposited in a geologically very short time. However, the clastic sedimentation rate in the host basins was certainly not exceptionally low, but the sulphide deposition rate was very high.

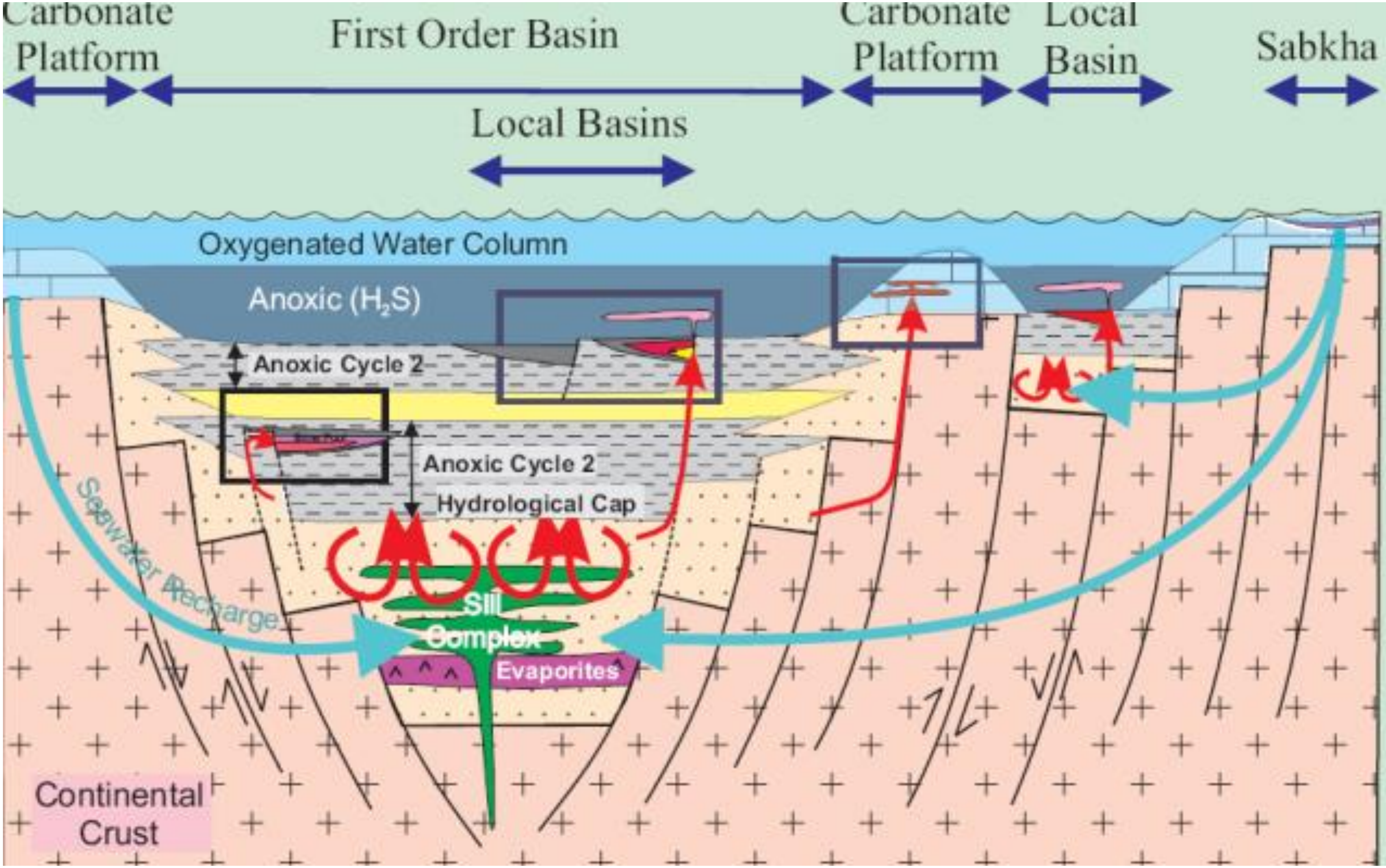
Fluids involved in SedEX ore formation include:

1. deeply convecting seawater and evaporitic brine;
2. occluded formation fluids;
3. diagenetic water of basinal sediments; and
4. fluids mobilized from a deep source (e.g. elevated heatflow from the mantle through fault planes).

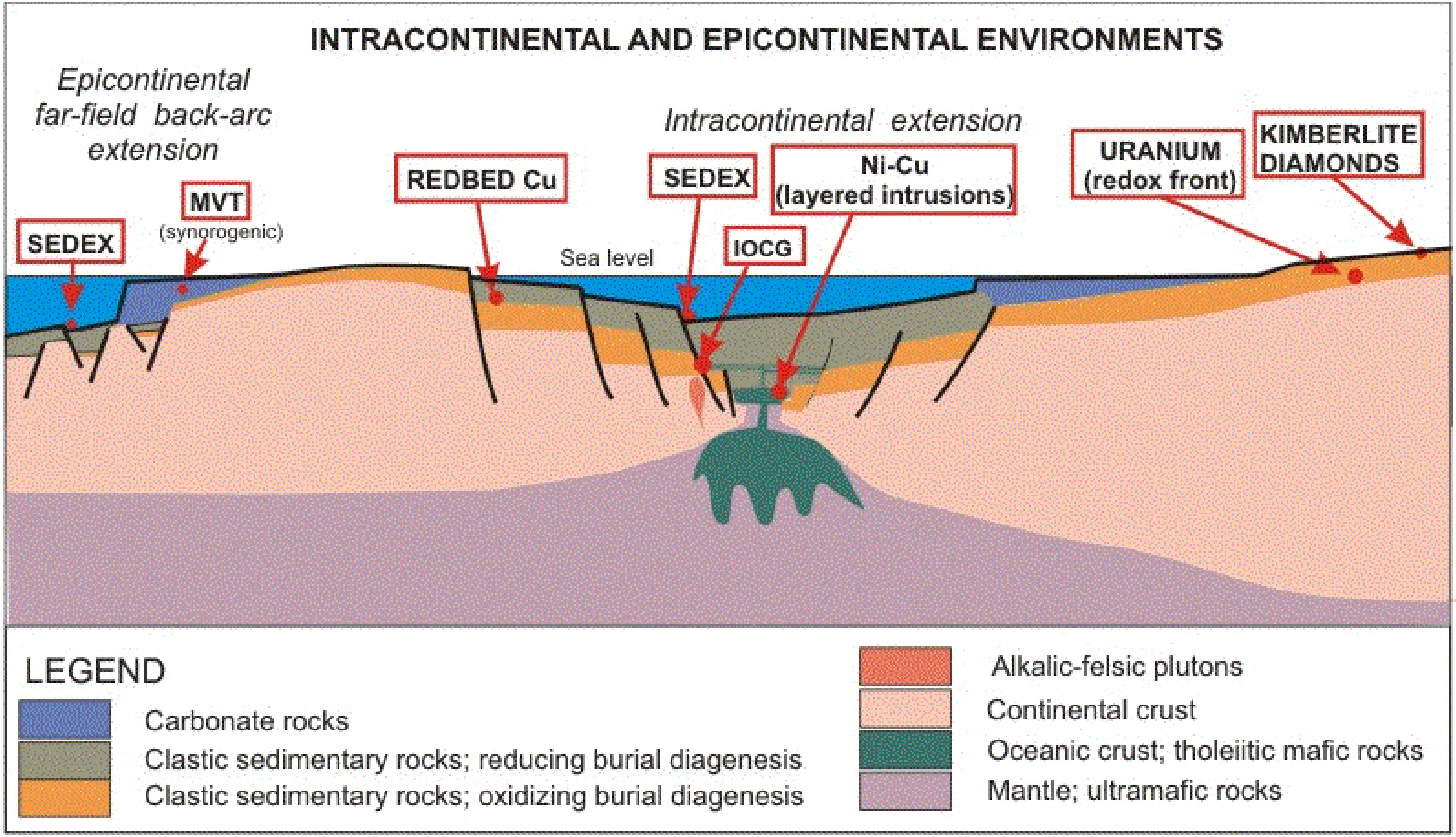
The heat derived from the hydrothermal solutions together with the heat from the sediment burial leach the metals; lead, zinc and silver from the sediments and concentrate them with those in the hydrothermal solutions forming the SedEX (e.g., Broken Hill, Australia).



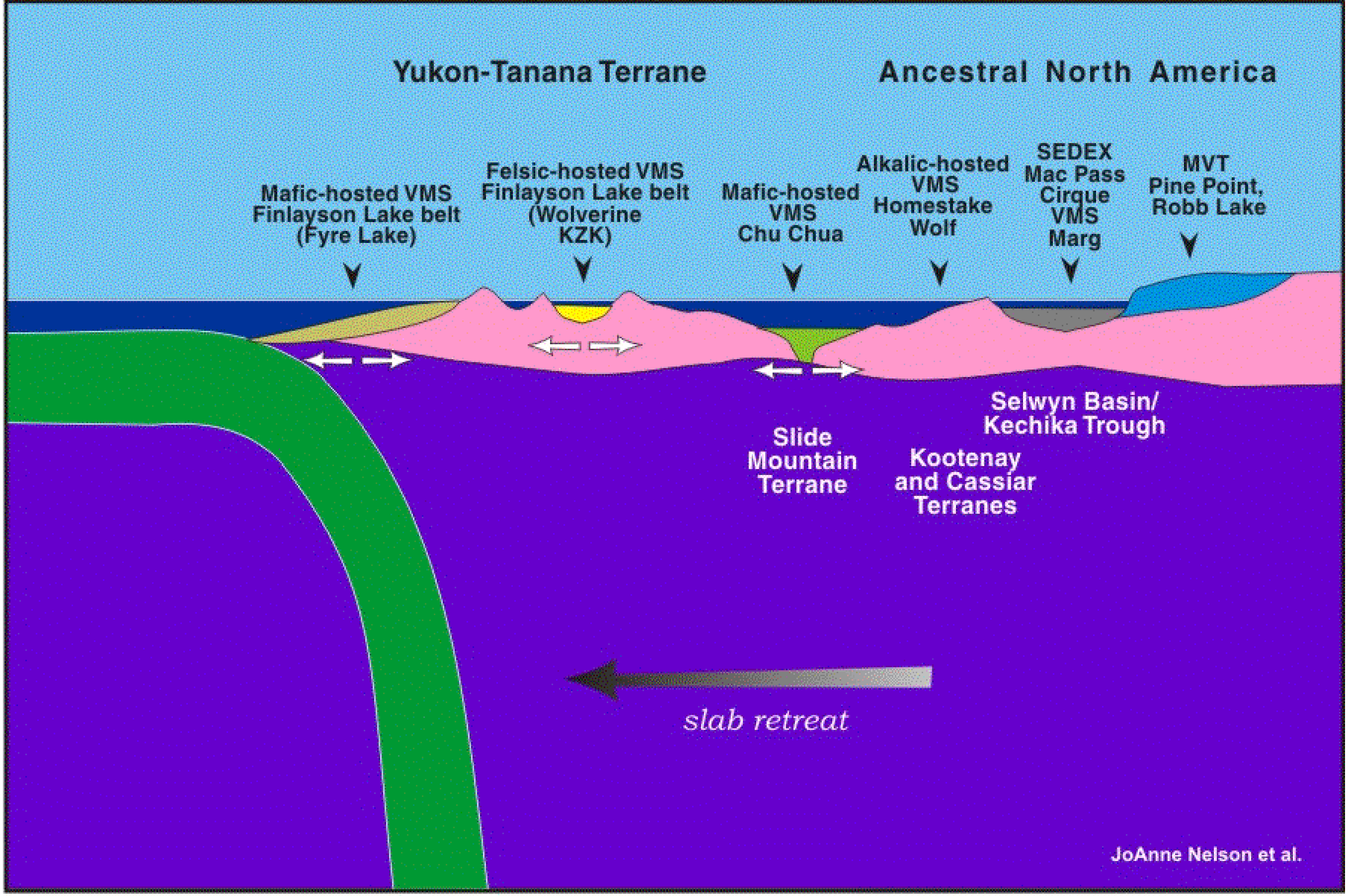
Genetic models for SedEX deposits. A. Vent-proximal deposits formed from buoyant hydrothermal plume.



Model of the sedimentary basin architecture of productive basins hosting SEDEX deposits.

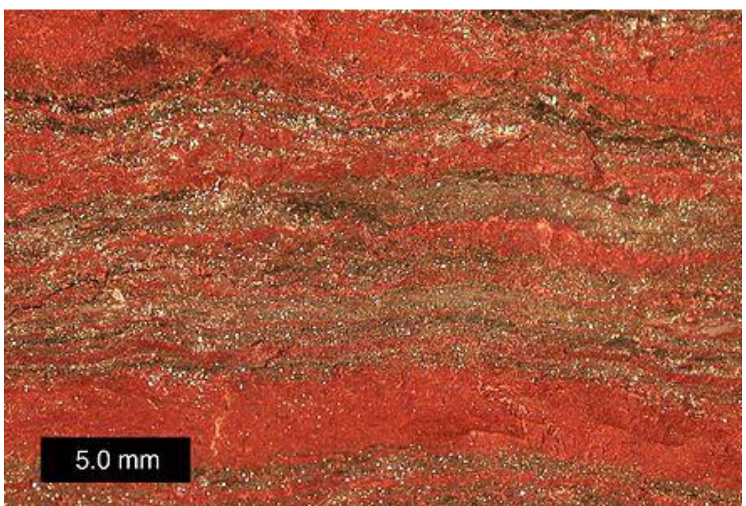


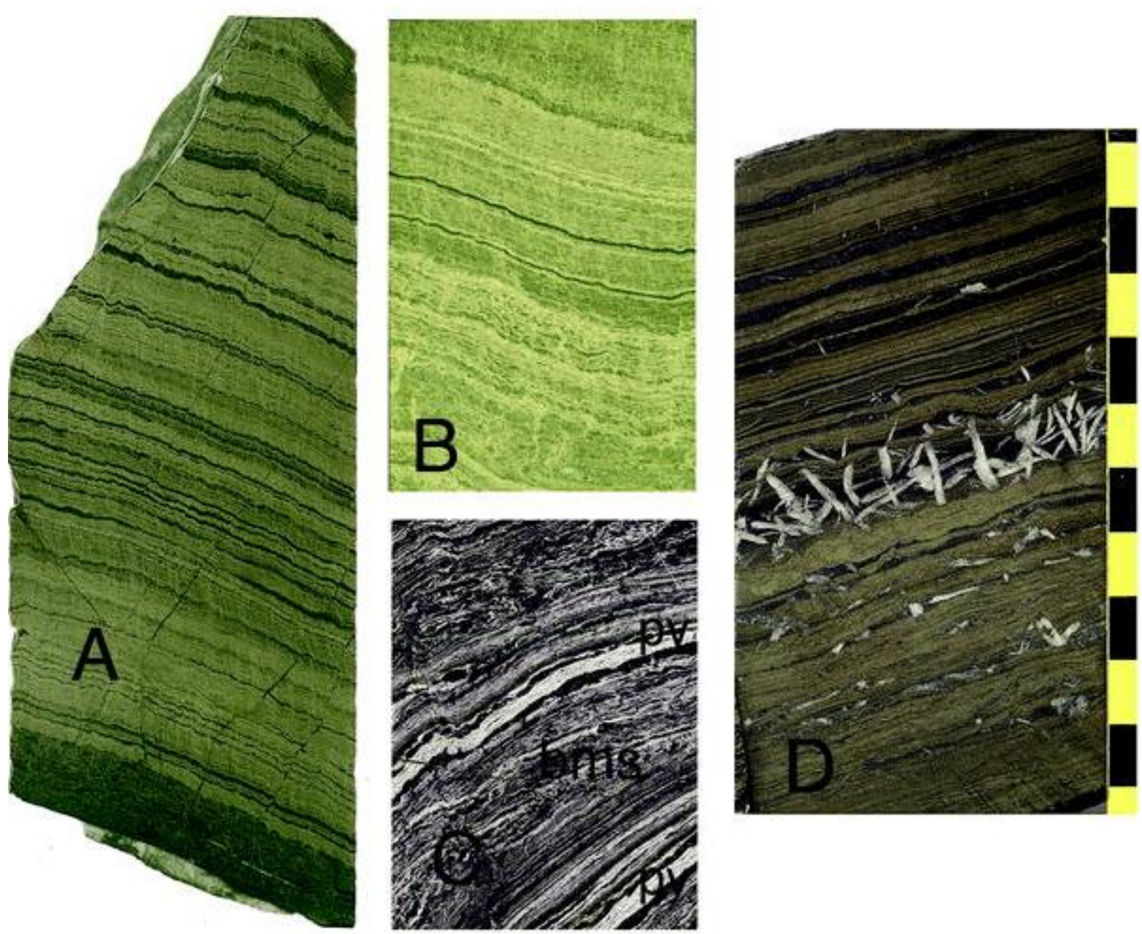
Schematic illustration of the major geological characteristics of mineral deposit types that typically occur in ore-forming environments within the interior regions of continents.



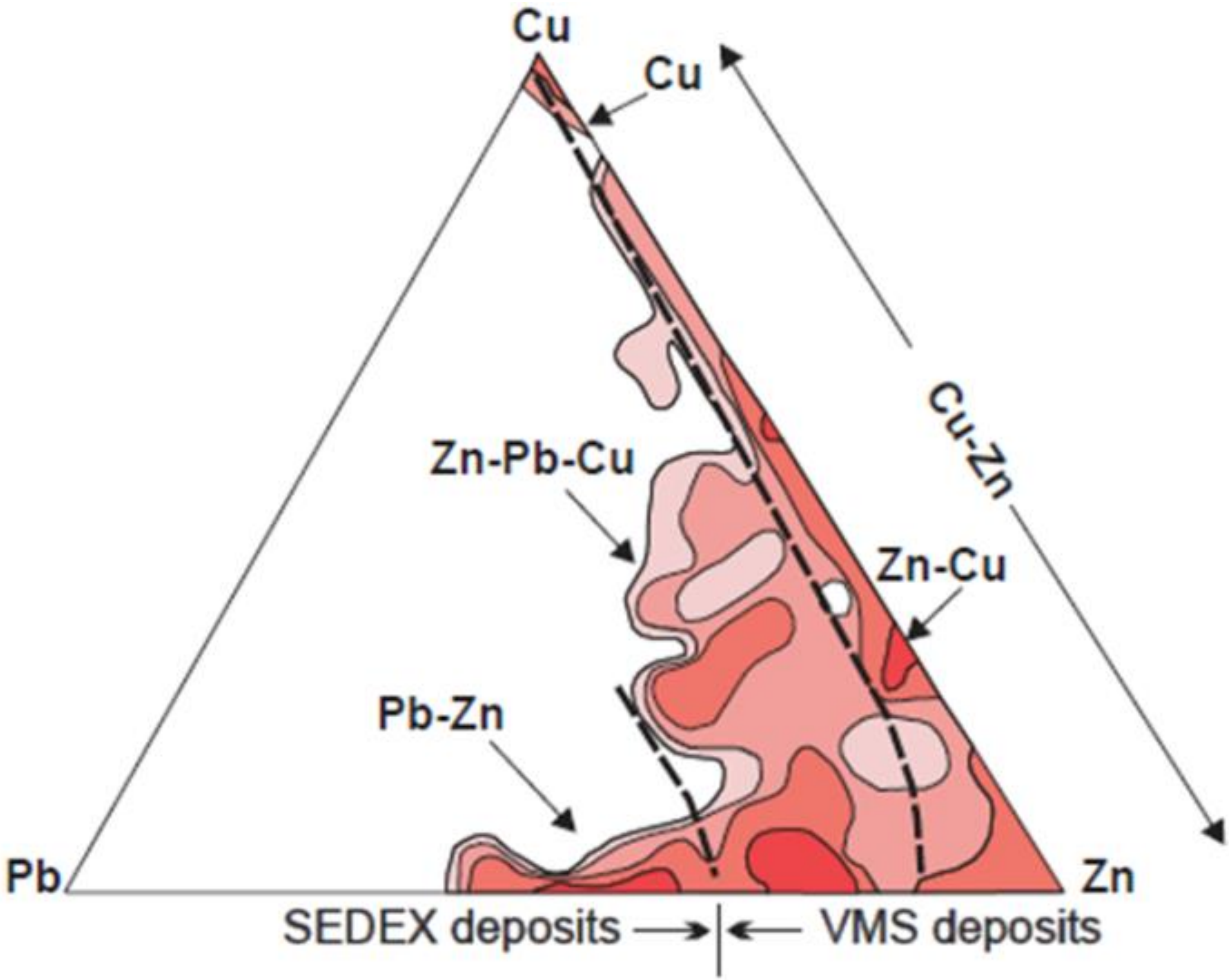
Tectonic model for the Devono-Mississipian margin of western North America, showing a complex history of ocean plate subduction and slab rollback, back-arc rifting and the formation of SEDEX and MVT deposits in the northern Canadian Cordillera

Sedex ore bodies are stratiform and stratabound, and consist of massive, laminated or banded sulphides with varying admixture of clastic matter, barite and other exhalites (SiO_2, haematite, etc.). In appearance they are very similar to volcanic-hydrothermal exhalative (VMS) orebodies; the decisive difference is the sedimentary as opposed to the volcanic genetic setting. VMS are principally controlled by volcanic point heat sources, however, Sedex ore is commonly localized by extensional faults (e.g. basinal growth faults).



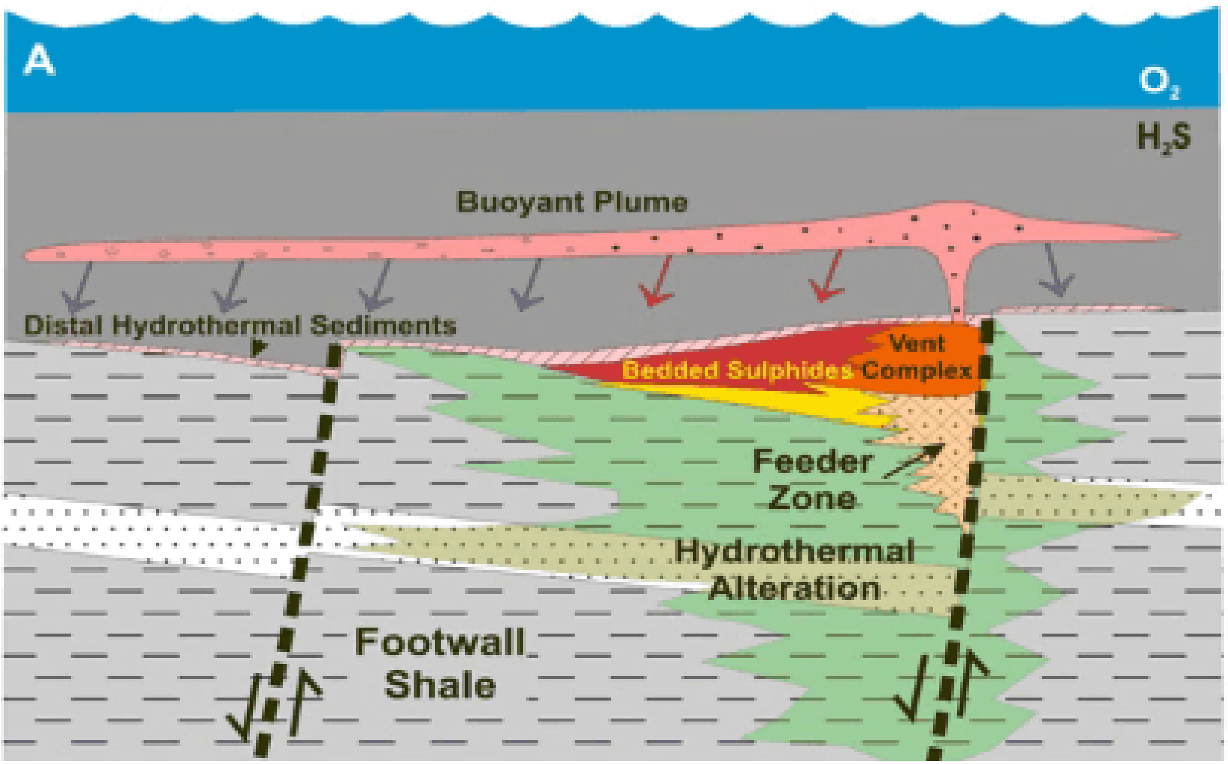


Single ore beds are either monomineralic or mixtures of galena, sphalerite, pyrite and pyrrhotite, rarely including more than traces of arsenopyrite and copper sulphides. SedEx compete with porphyry deposits for the role of the largest base metal accumulations on Earth.

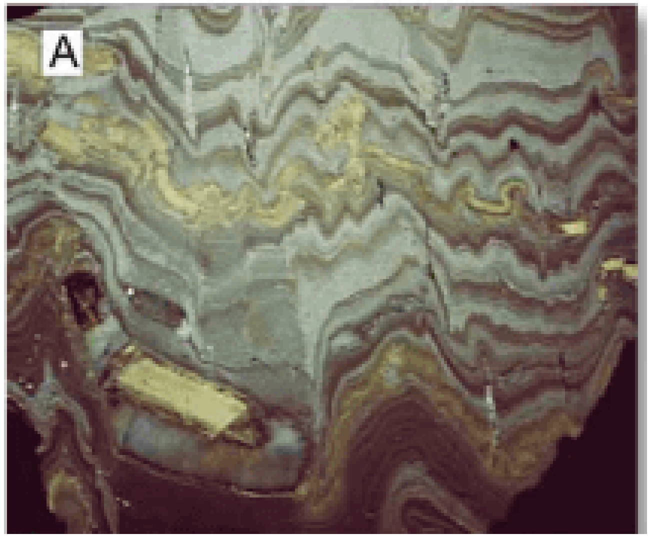


SedEx – Similarities to VMS

- Deposited on the **seafloor** at the same time as the host rocks
- Massive sulfide lenses with underlying feeder zones
- Often form in **clusters** or **stacked lenses**
- Metal transported as chloride complexes in brines.

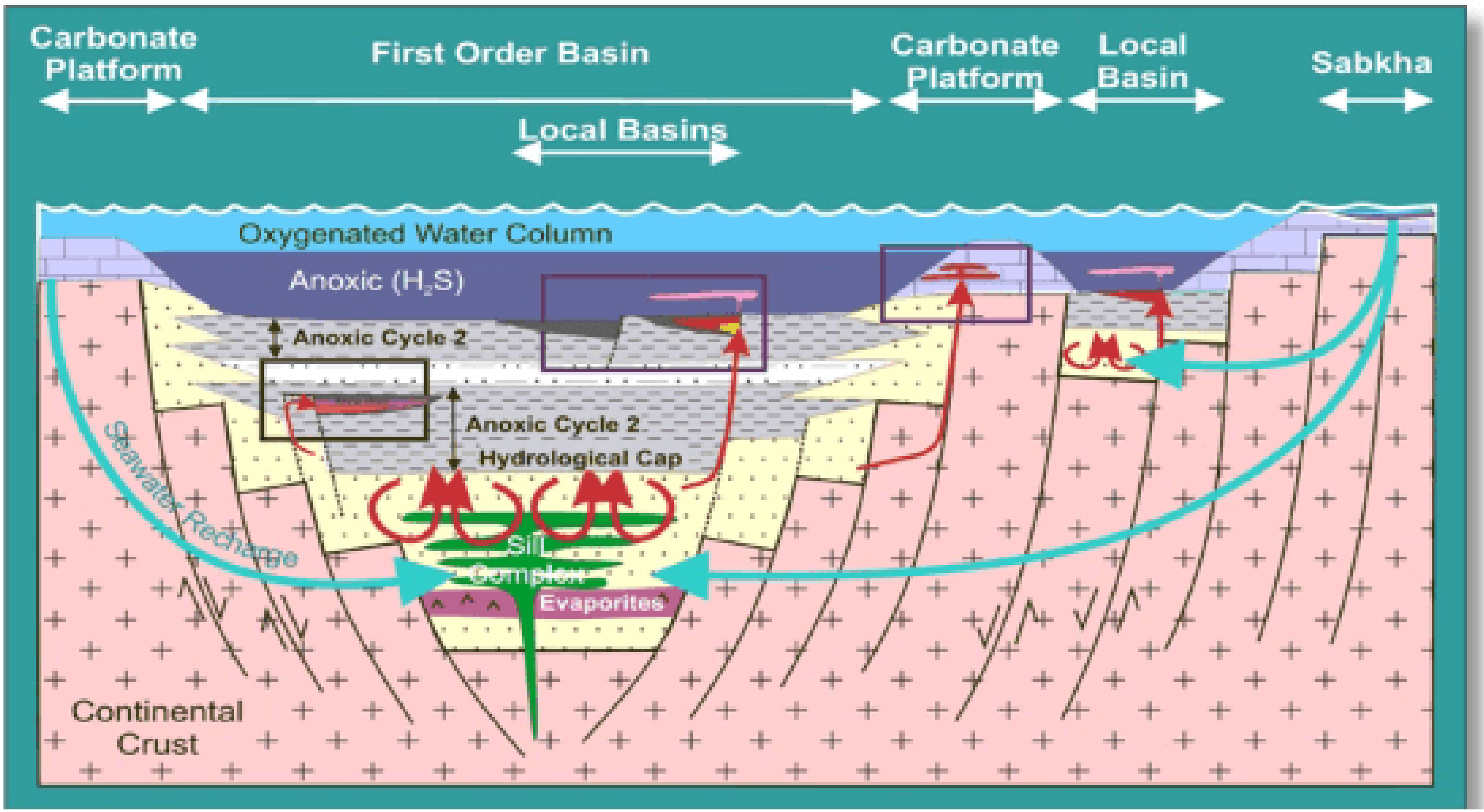


- Often deformed



SedEx – Differences from VMS

Form in fault-bounded **sedimentary** basins on **continental crust**, not oceanic crust. **Host rocks** are usually shales - volcanics are rare
Metals derived ~100% from host sediments/basement, not intrusives
Insignificant Cu and Au; more Pb and Ag; Zn in both.



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