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XI SIMPÓSIO BRASILEIRO DE EXPLORAÇÃO MINERAL
XI BRAZILIAN SYMPOSIUM ON MINERAL EXPLORATION

The formation of iron oxide – copper – gold (IOCG) and iron oxide – apatite (IOA) deposits: Insights from the chemistry of actinolite, apatite, magnetite and pyrite

Adam Simon

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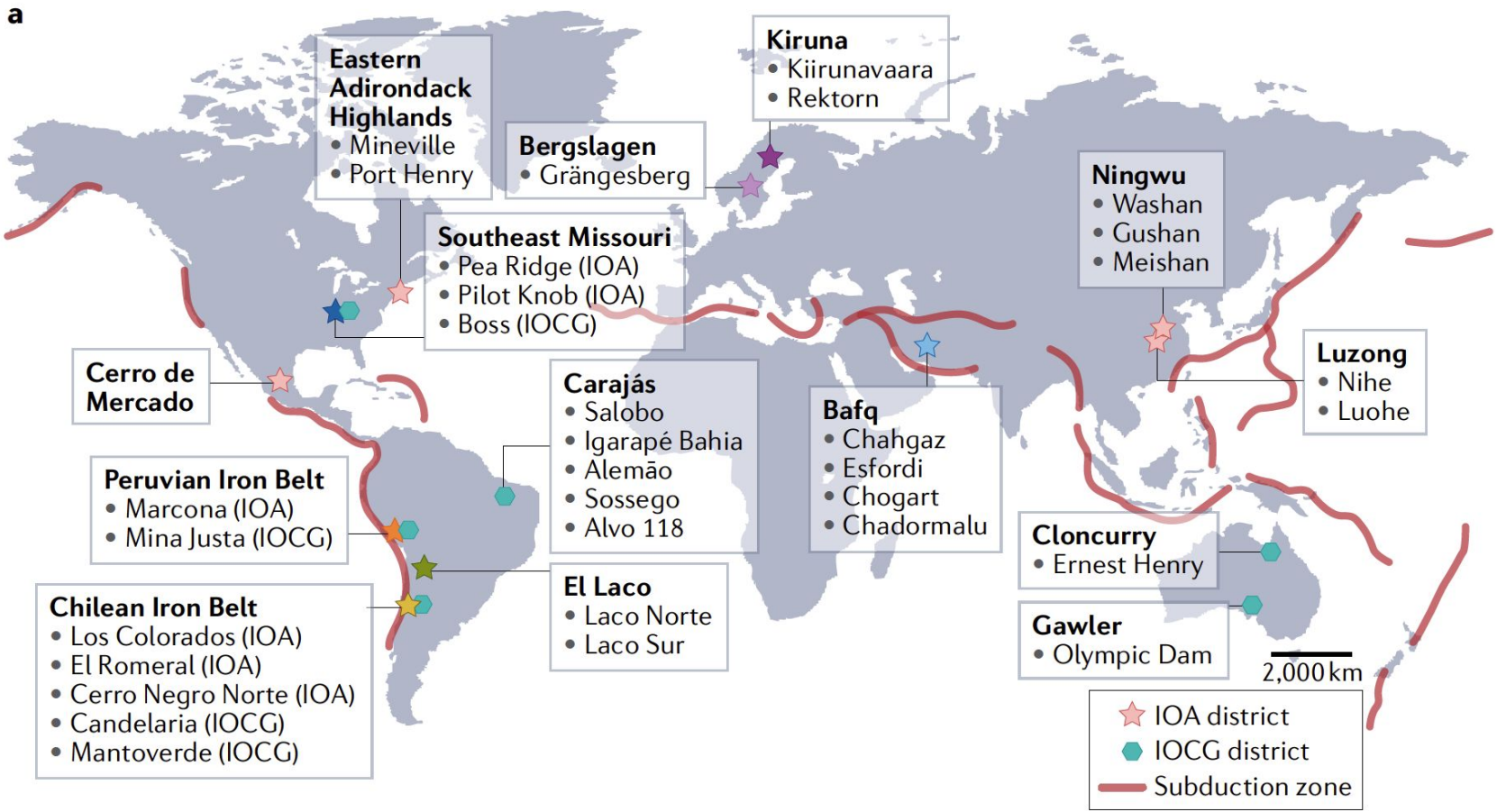
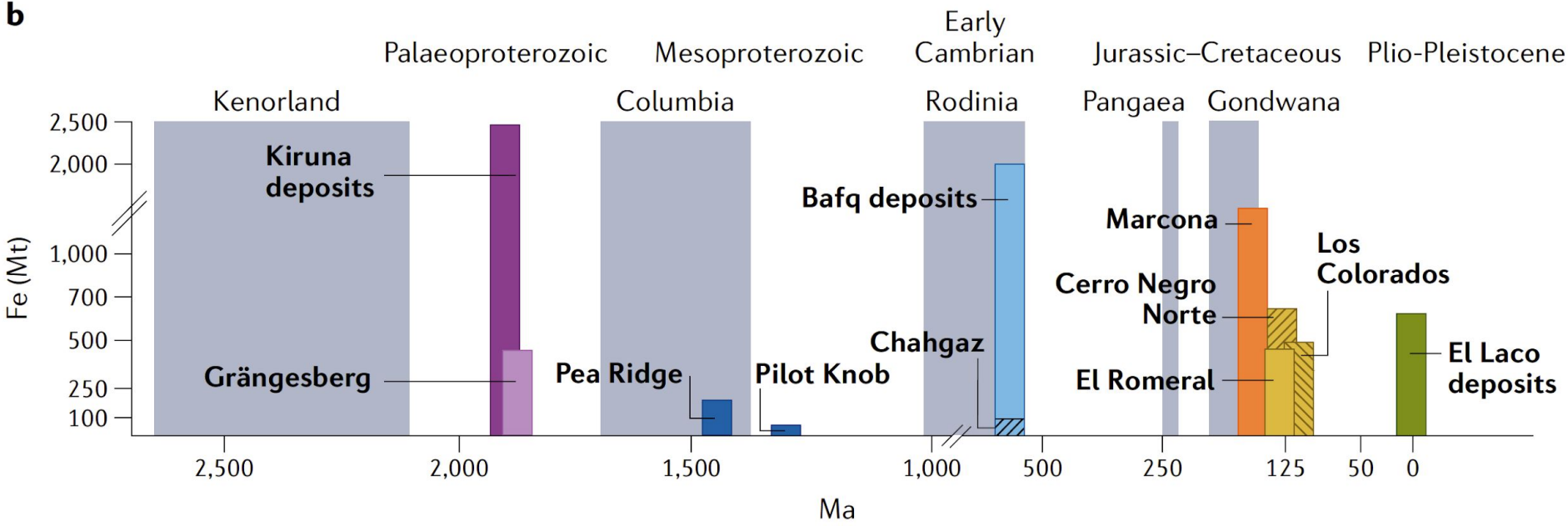
UNIVERSITY OF MICHIGAN

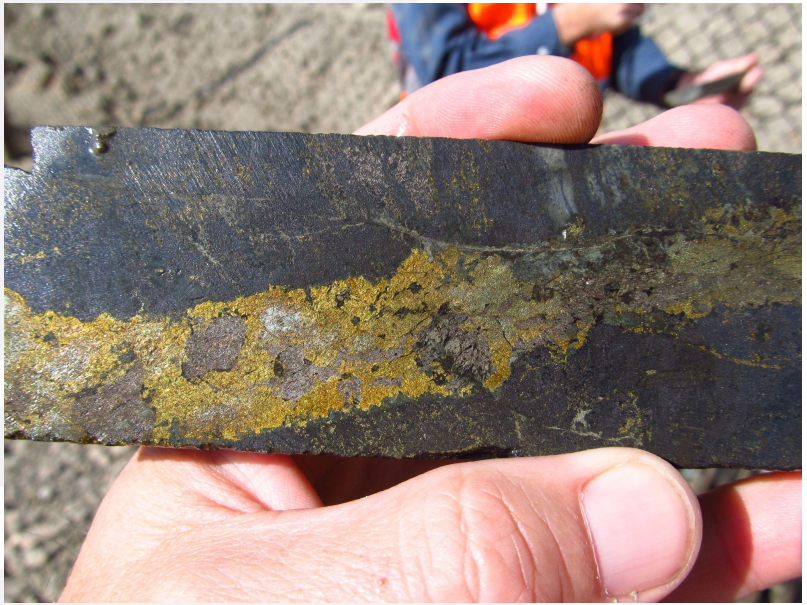


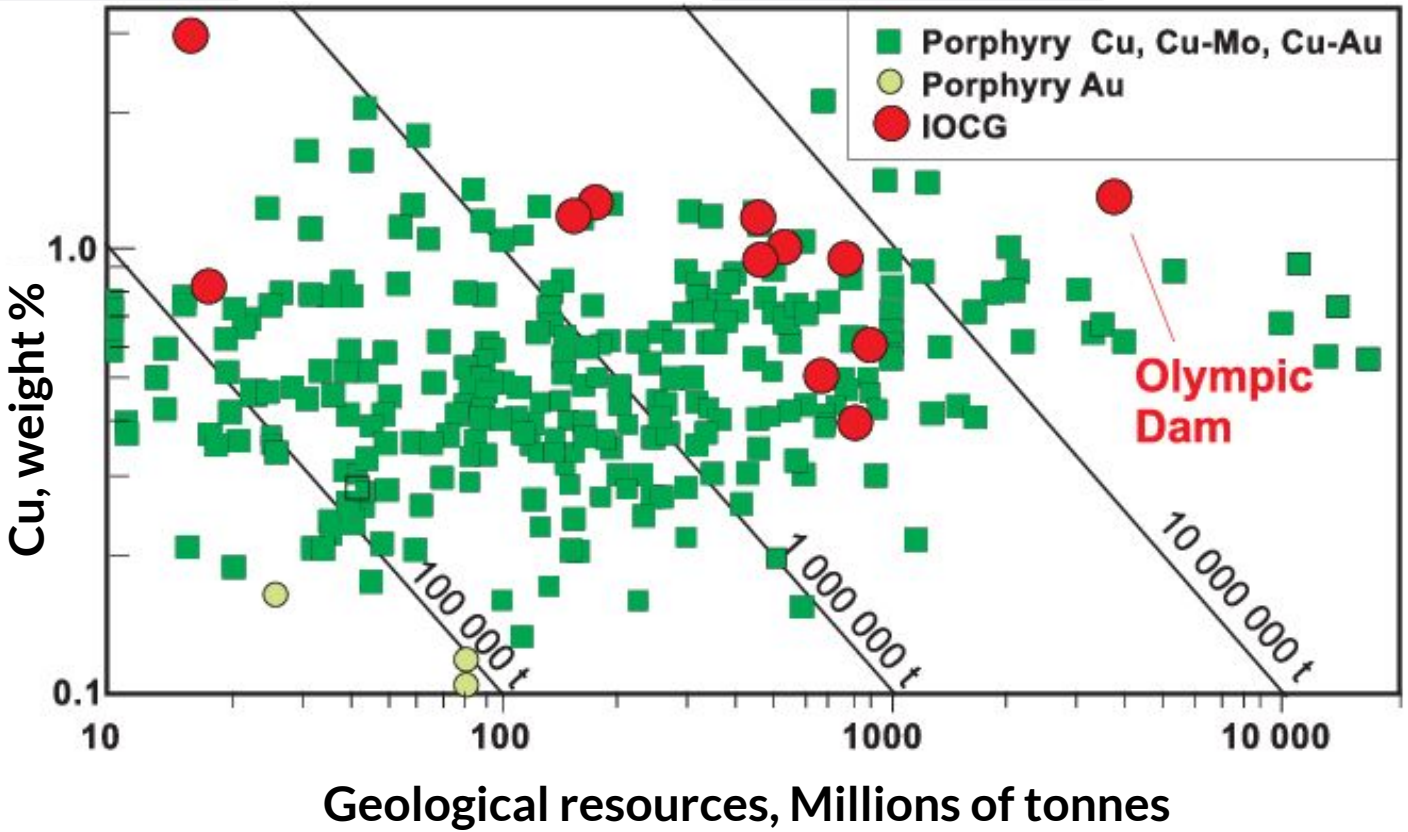
Source: Reich et al., 2022



Source: Reich et al., 2022

Element	Deposit type	Grade (median)	Crustal abundance	Clarke value
Cu	IOCG	0.5 %	0.027 %	~200
Fe	IOA	>40 – 50%	5 %	>8 - 10





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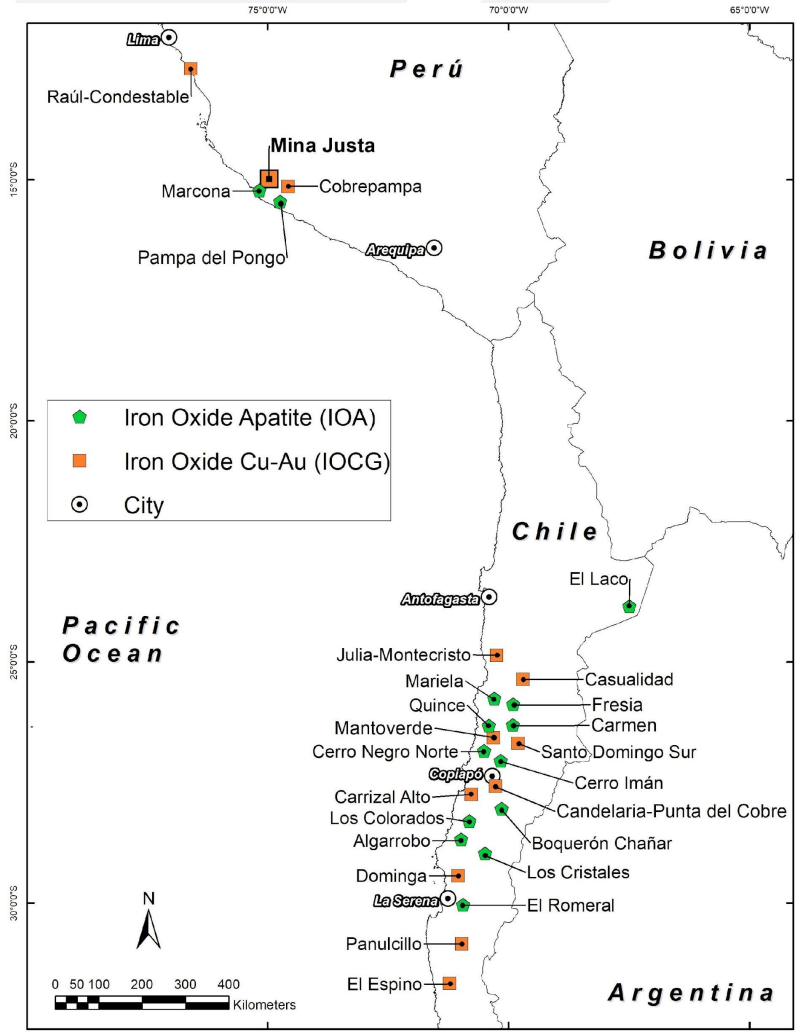

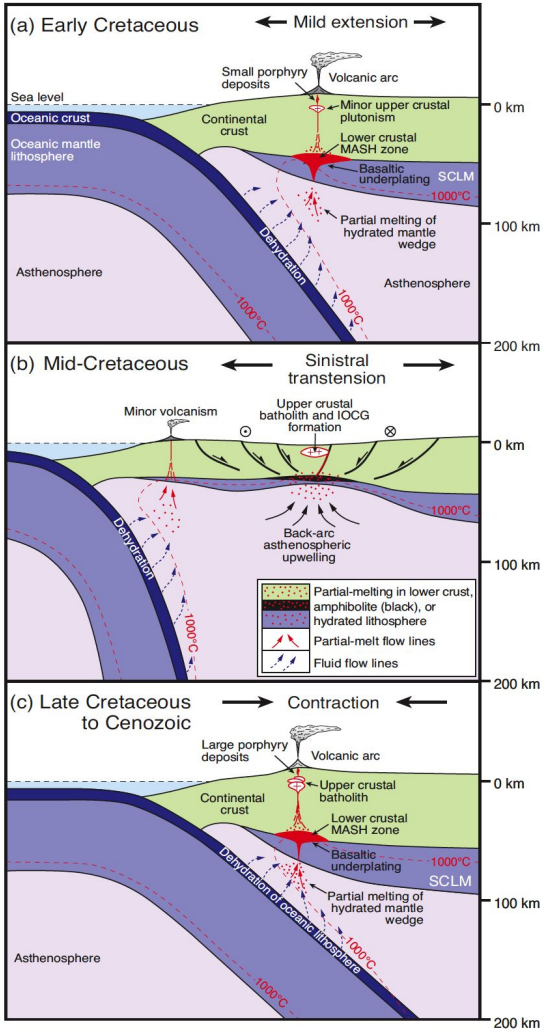

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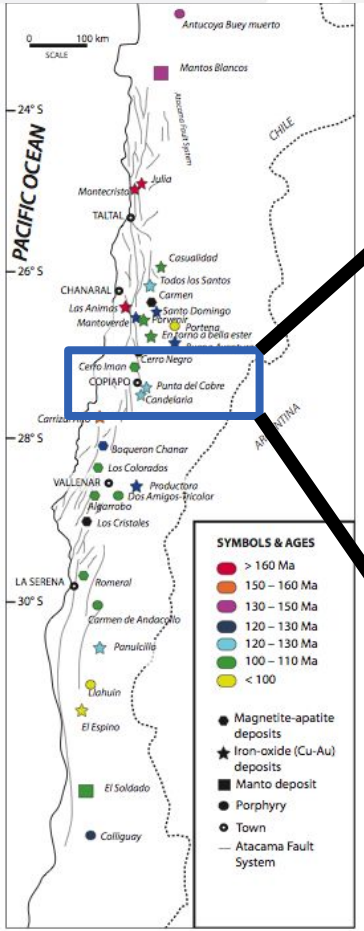
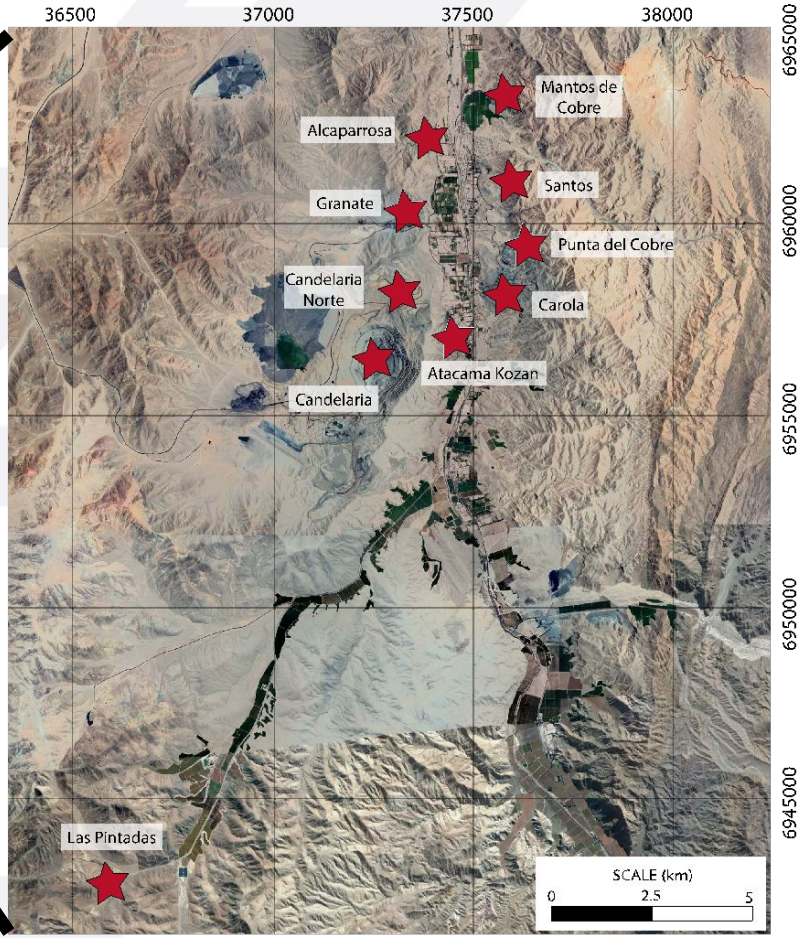
Punta del Cobre district





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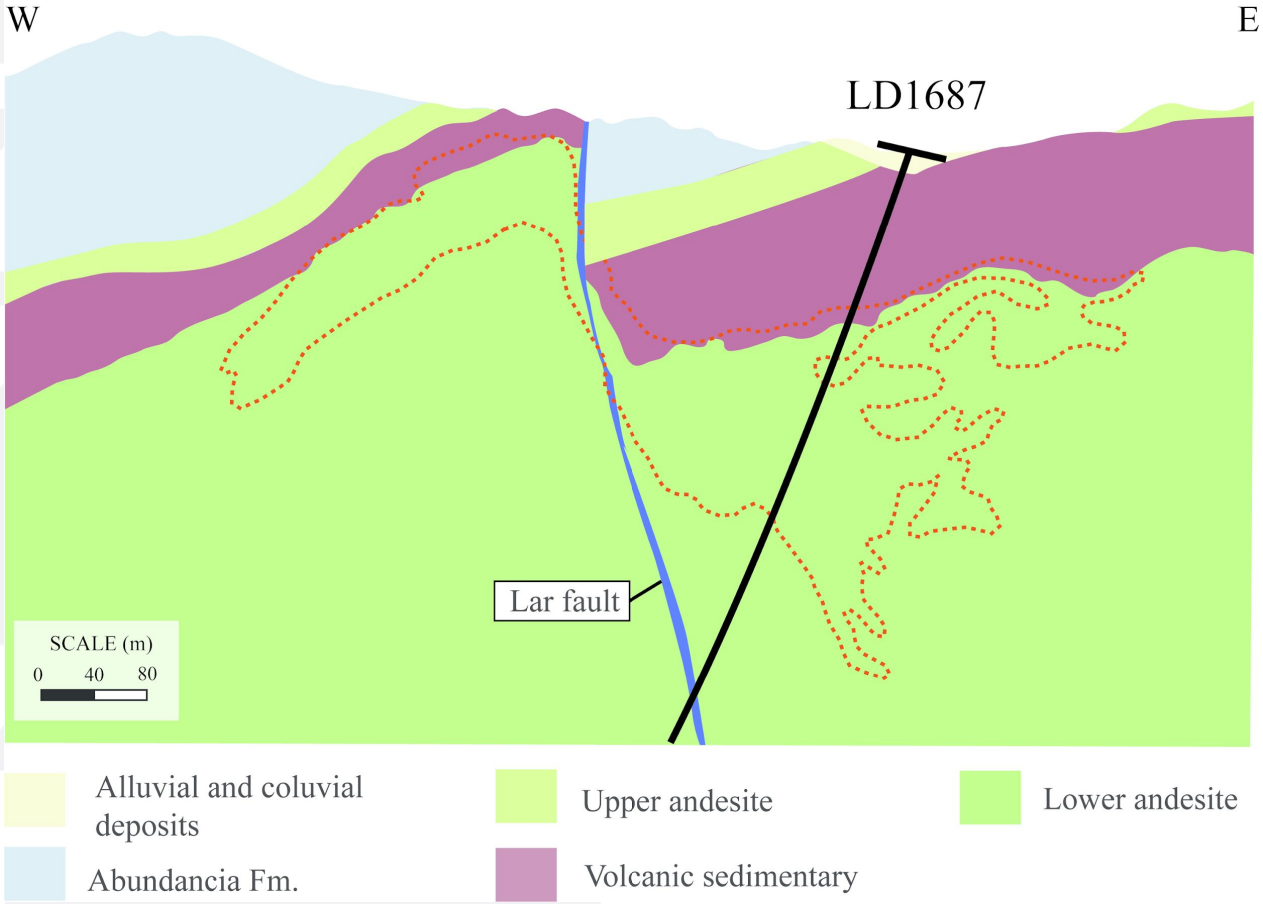
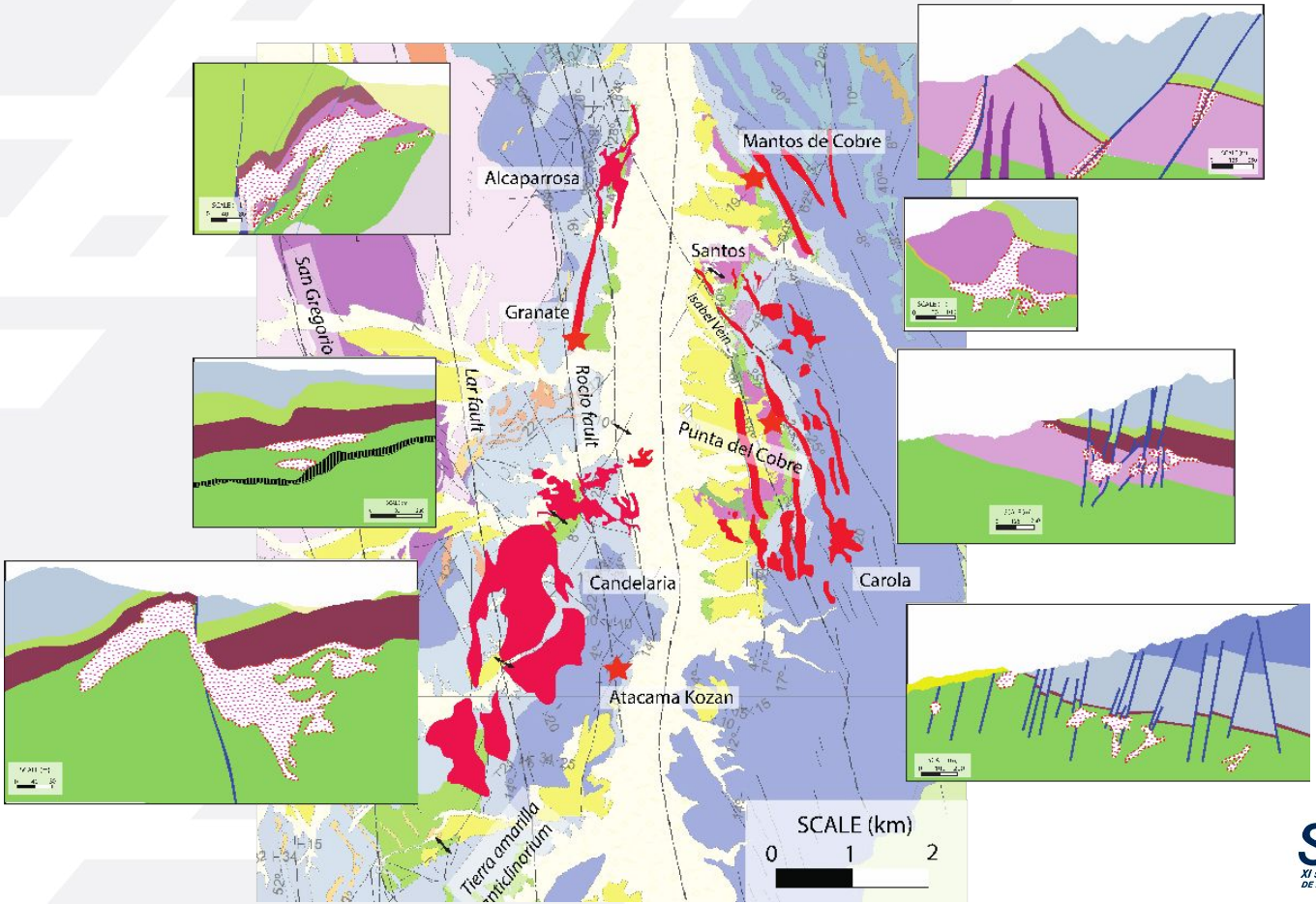
Candelaria IOCG deposit



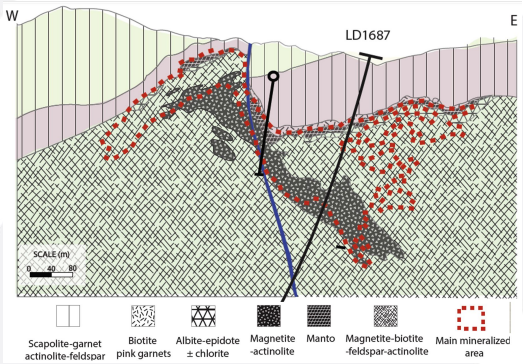
Source: del Real

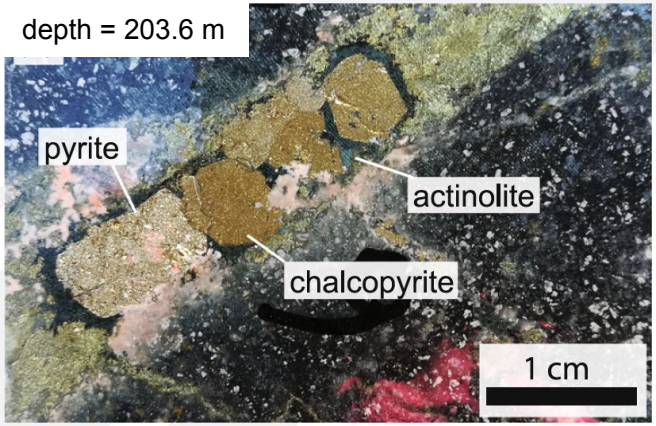
Punta del Cobre district

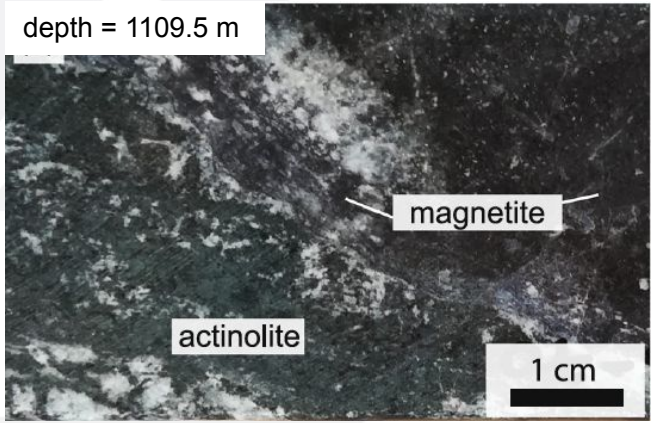


Source: del Real

Candelaria IOCG deposit







…transitions to chalcopyrite-magnetite-biotite –K-feldspar ± pyrite ± actinolite mineralization/alteration dated at ca. 115 Ma that represents the main Cu mineralization stage in the area.

Pervasive magnetite-actinolite (sulfide-free) alteration assemblages at deeper levels along with regional-scale Na ± Ca-rich hydrothermal alteration

Source: del Real

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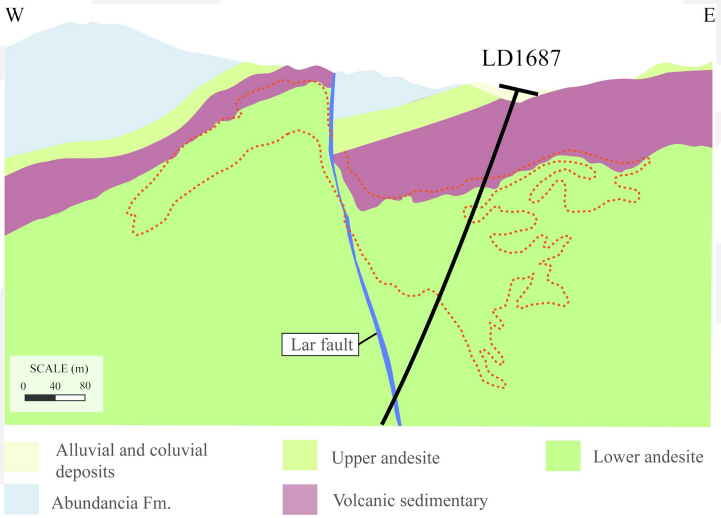
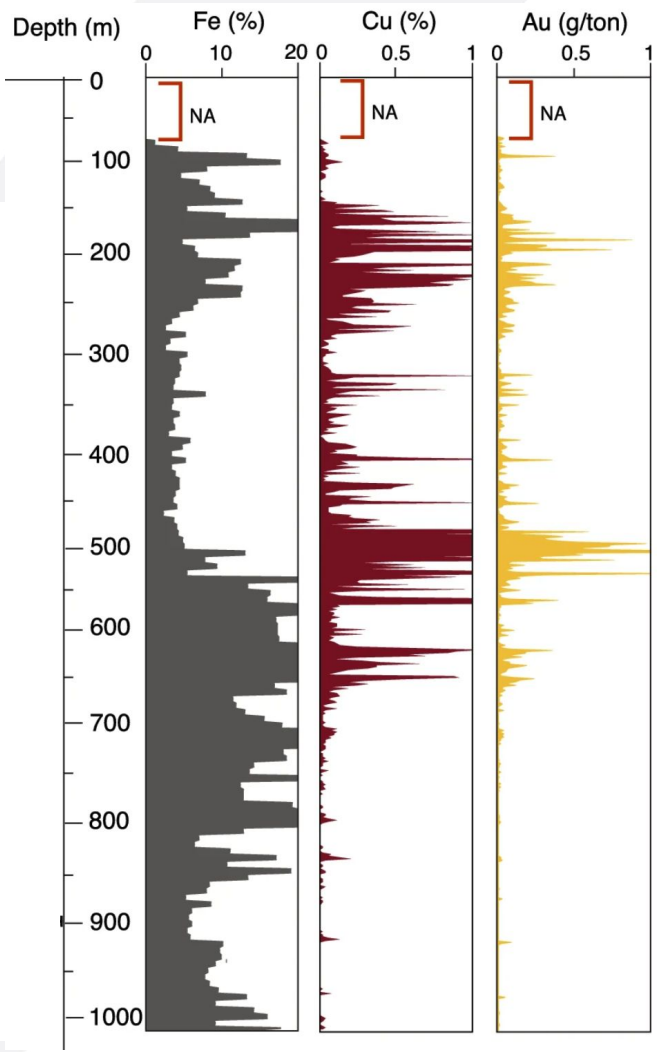
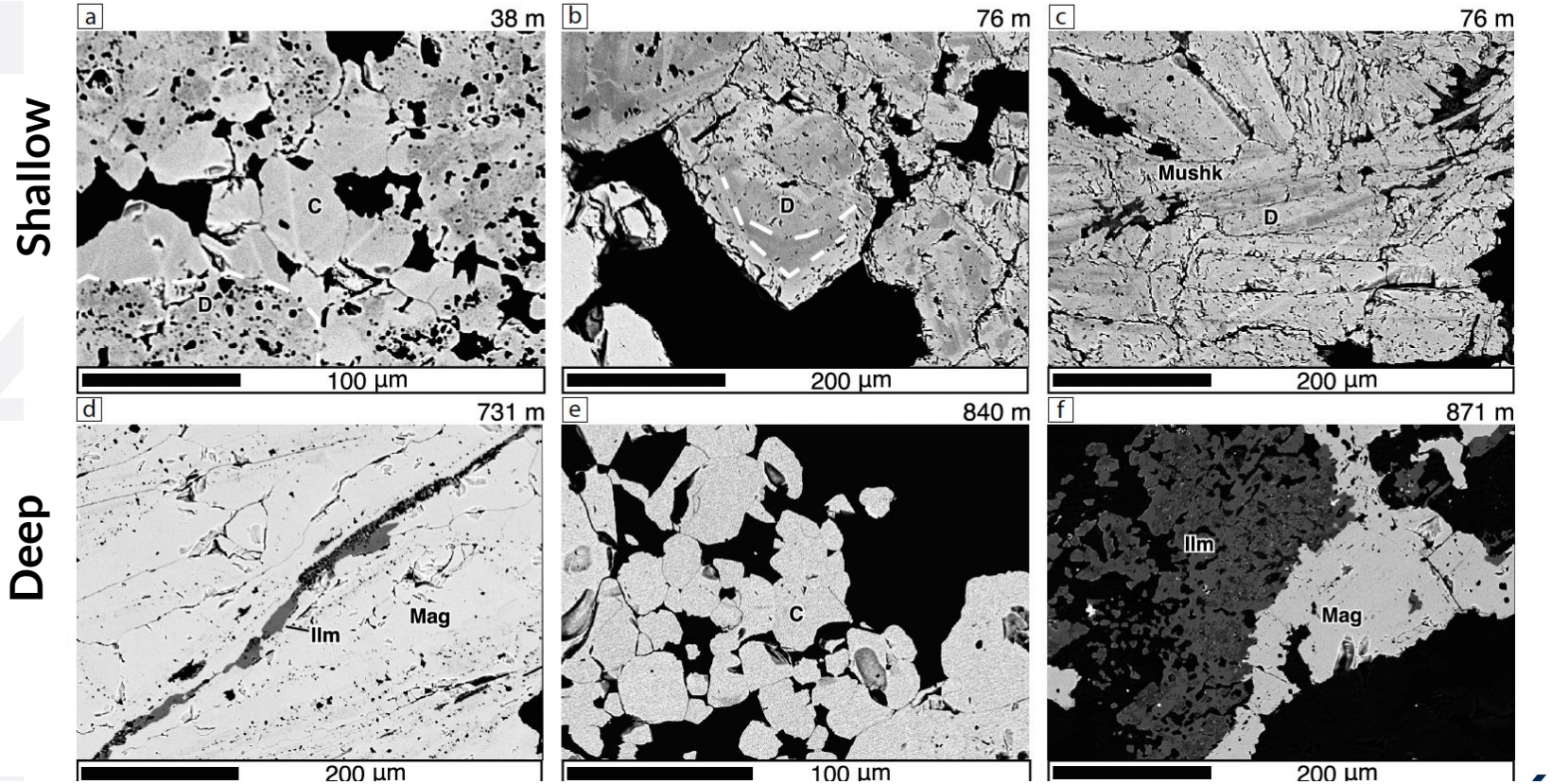
Candelaria metal grades





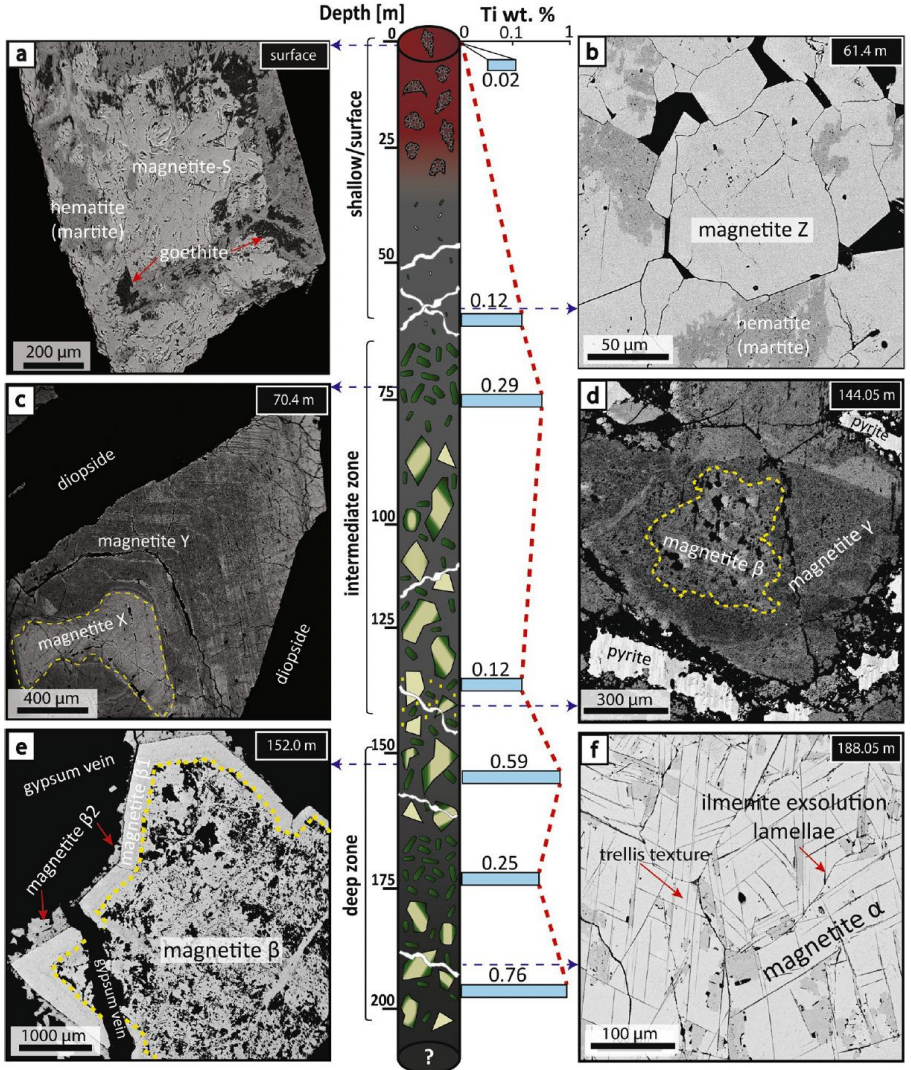
Source: del Real et al. (2023)

Magnetite, Candelaria



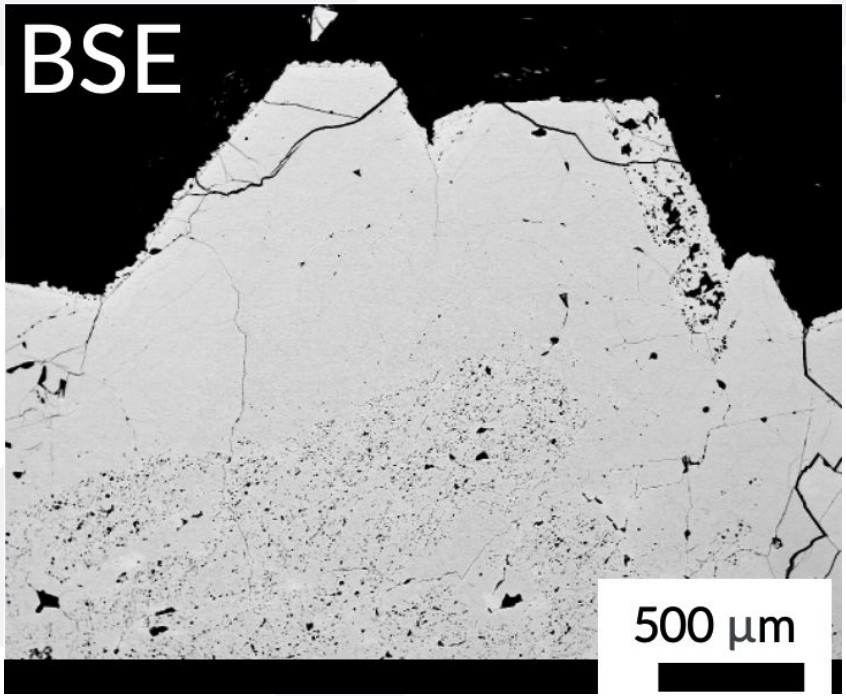
Source: Rodriguez-Mustafa

Magnetite, El Laco

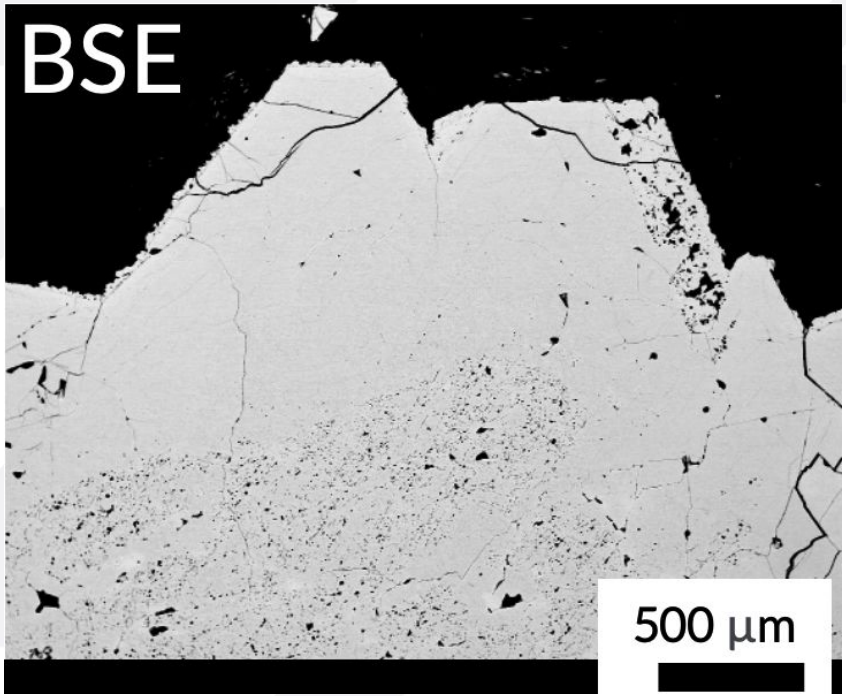


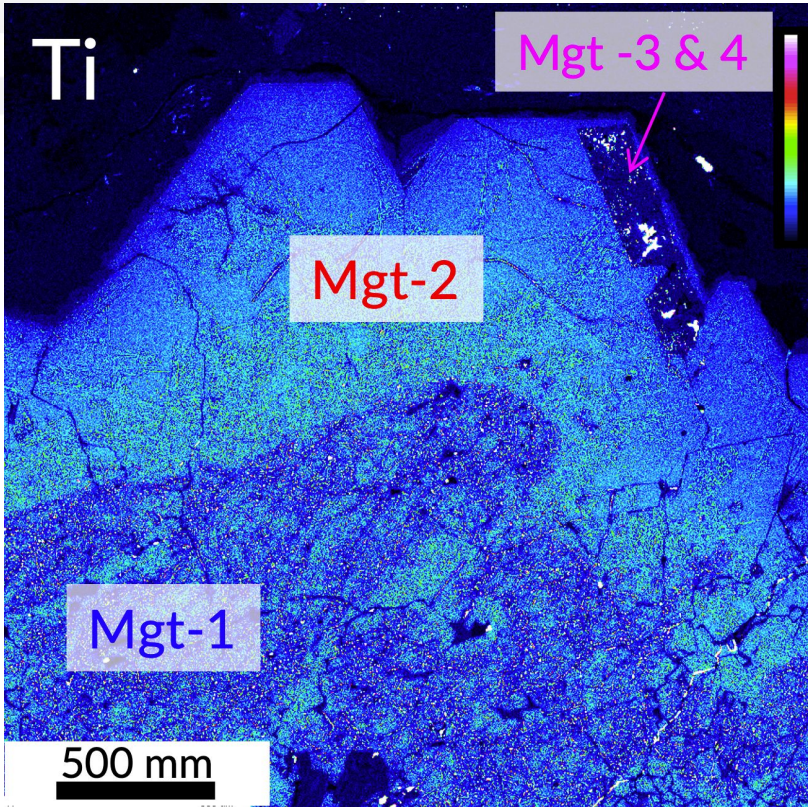
Source: Ovalle et al., 2018

Magnetite, Los Colorados



Magnetite, Los Colorados





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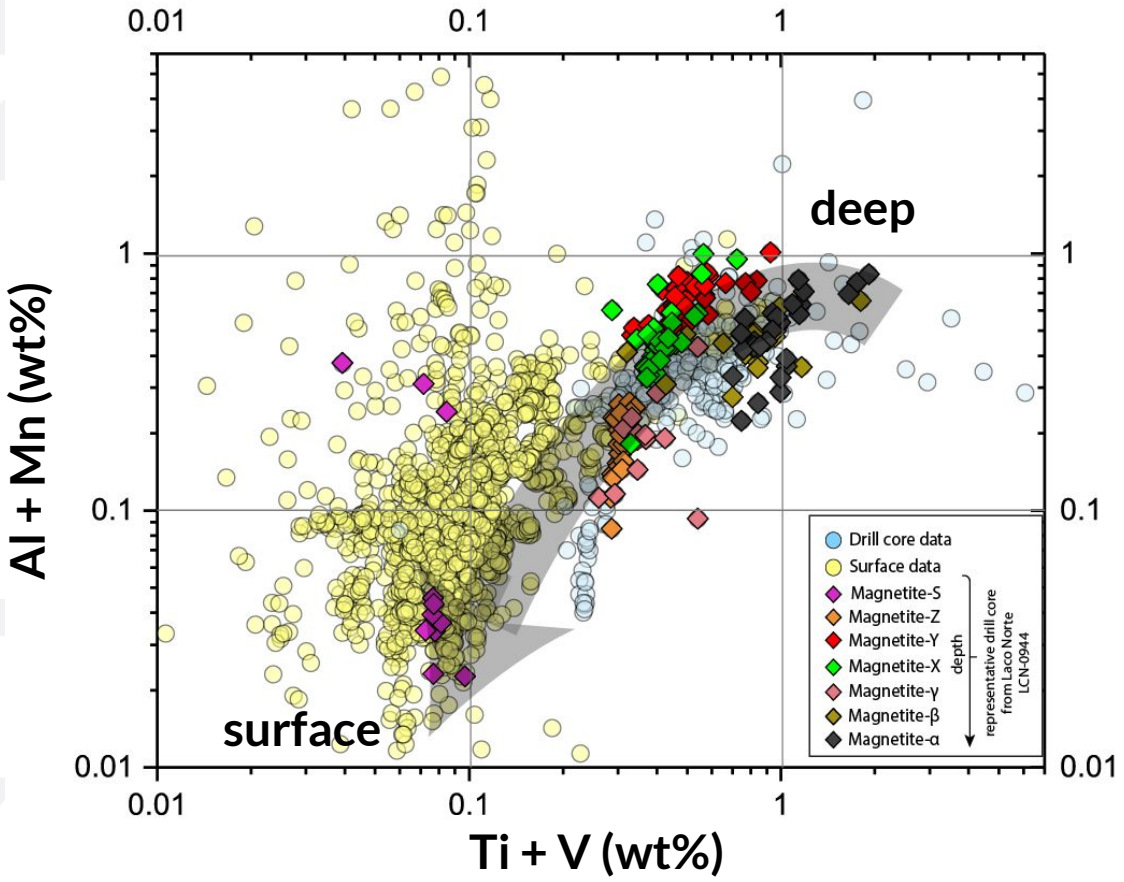
Magnetite chemistry and temperature



These data highlighted by the grey arrow are from a single dill core at El Laco.

These data show a systematic trend of decreasing trace element concentrations from depth to surface.

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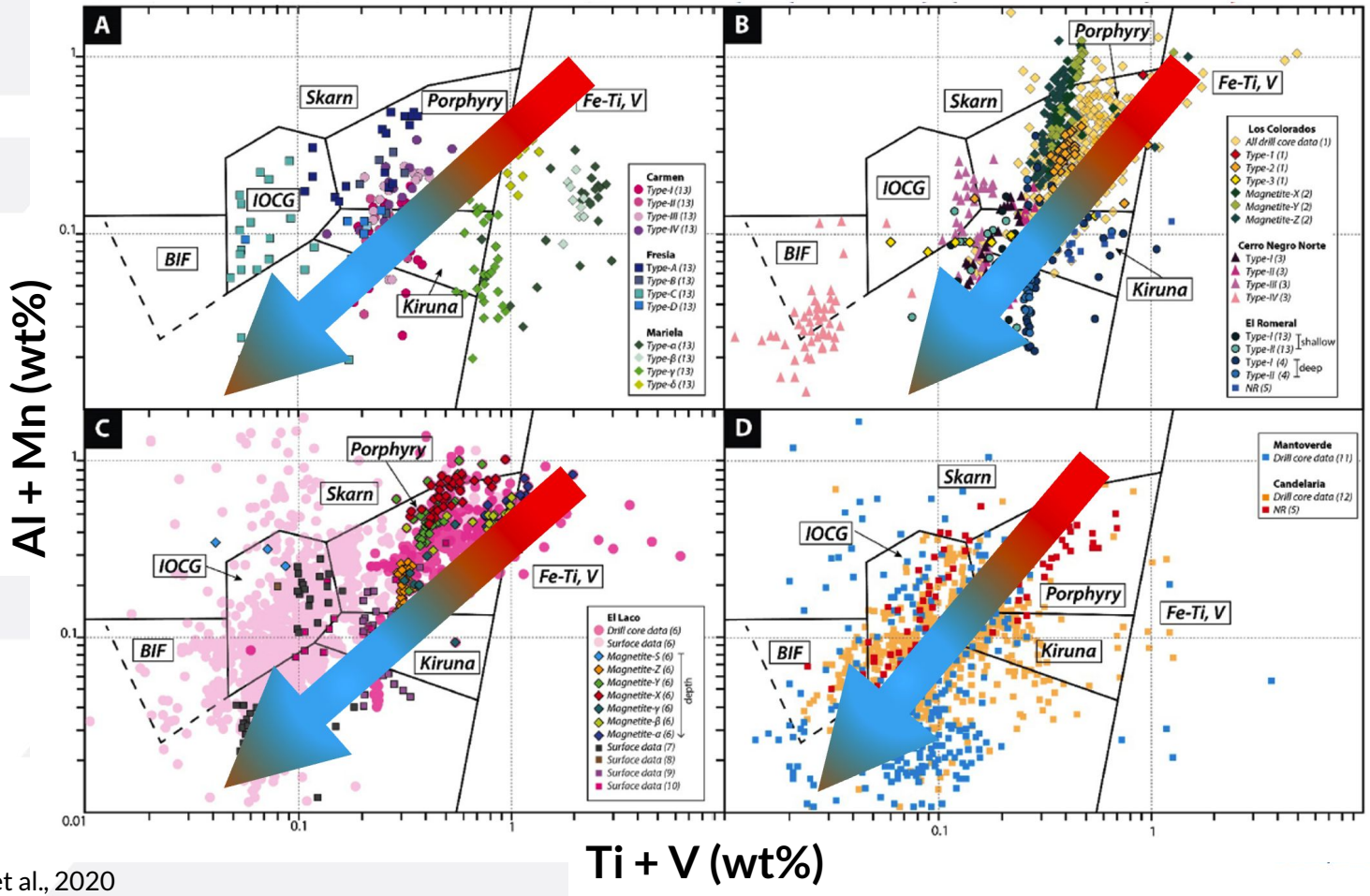
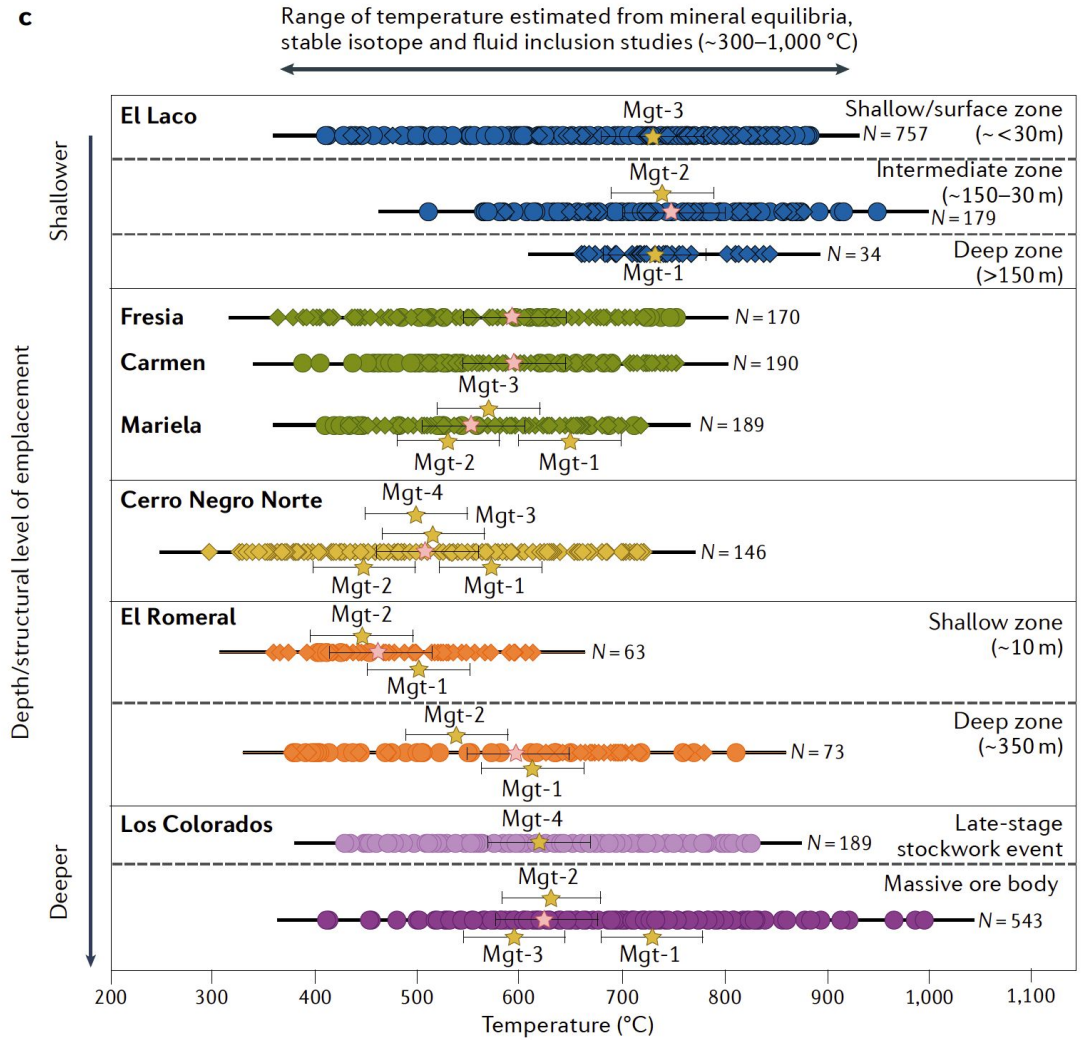
Magnetite chemistry and temperature



Source: Palma et al., 2020

Magnetite chemistry and temperature



○ EMPA
◇ LA-ICP-MS
$T_{Mg\text{-}mag}$ average for deposit
$T_{Mg\text{-}mag}$ average for magnetite generation
N = Total number of $T_{Mg\text{-}mag}$ data points

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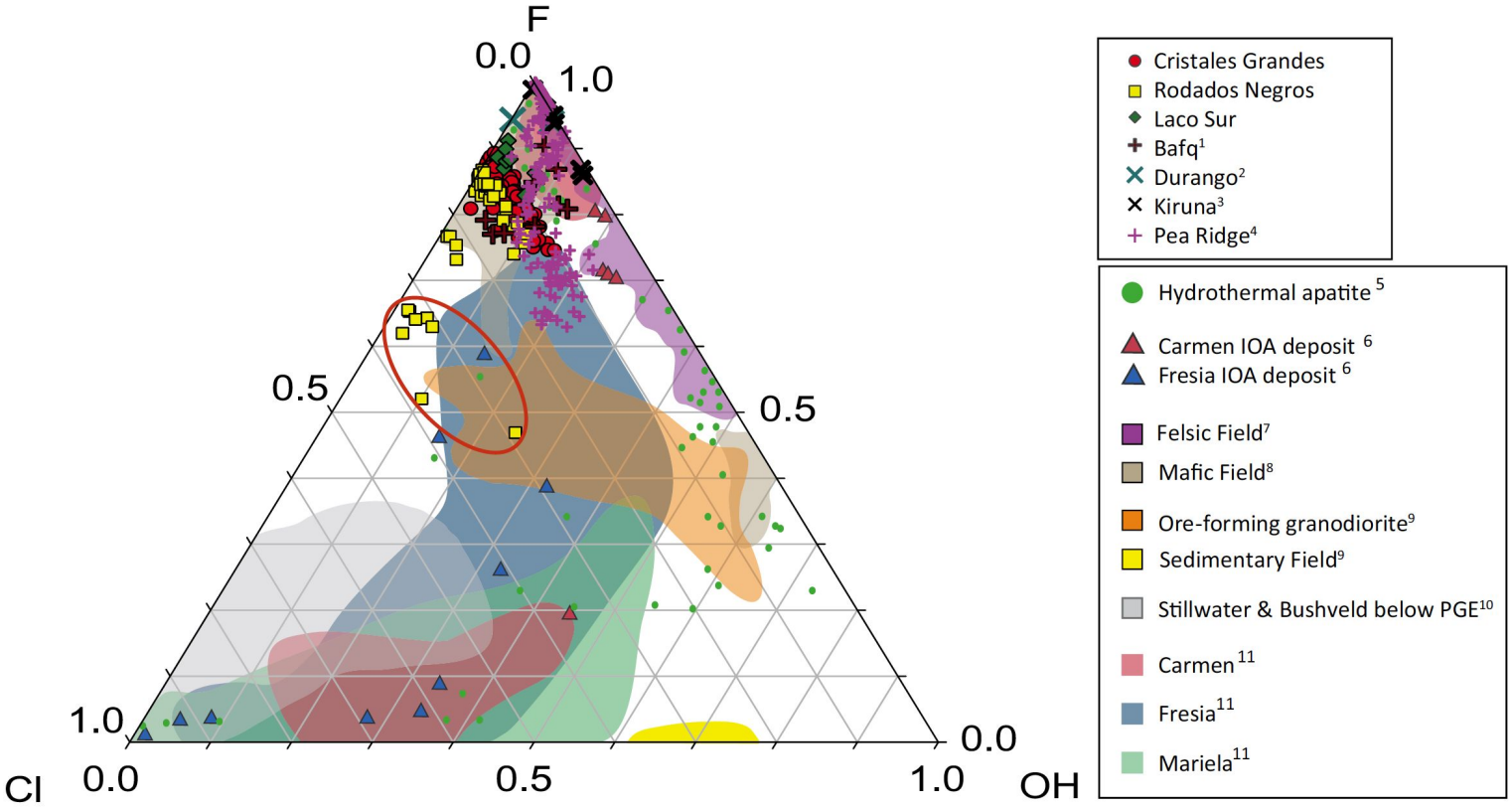
Apatite chemistry



Source: La Cruz et al., 2020

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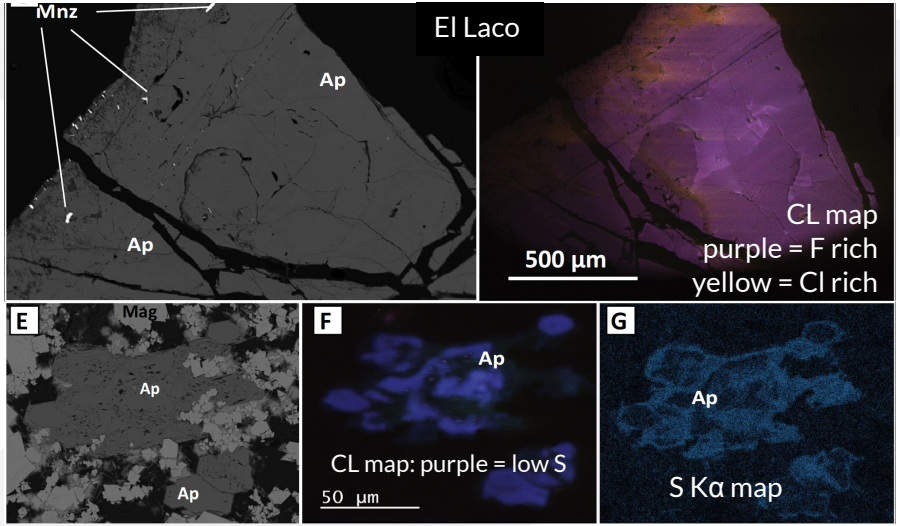
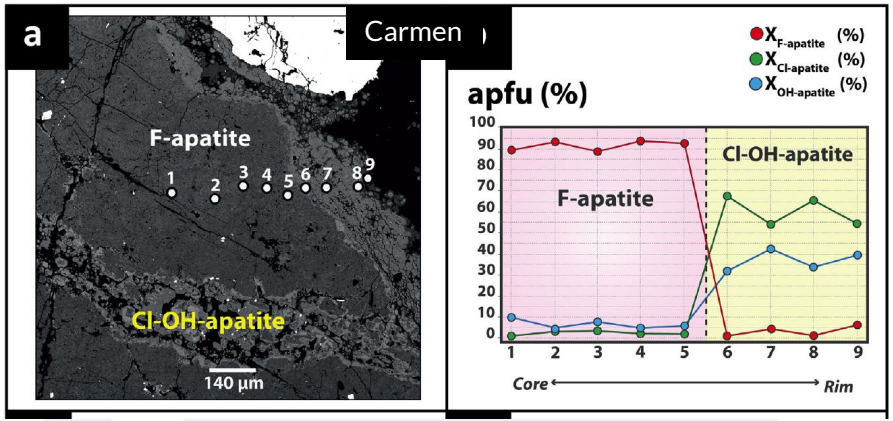
Apatite chemistry



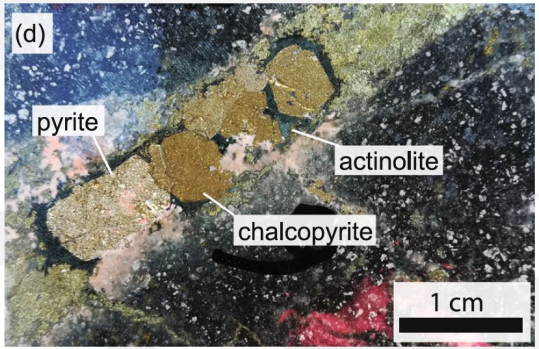


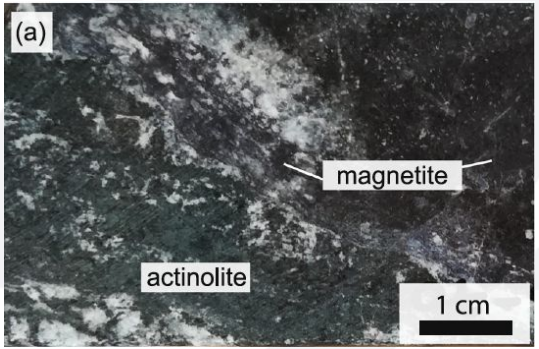
$^{87}Sr/^{86}Sr$ and ε_{Nd} of F-rich apatite indicate a magmatic source for the ore fluid that precipitated fluorapatite.
(Palma, 2019).

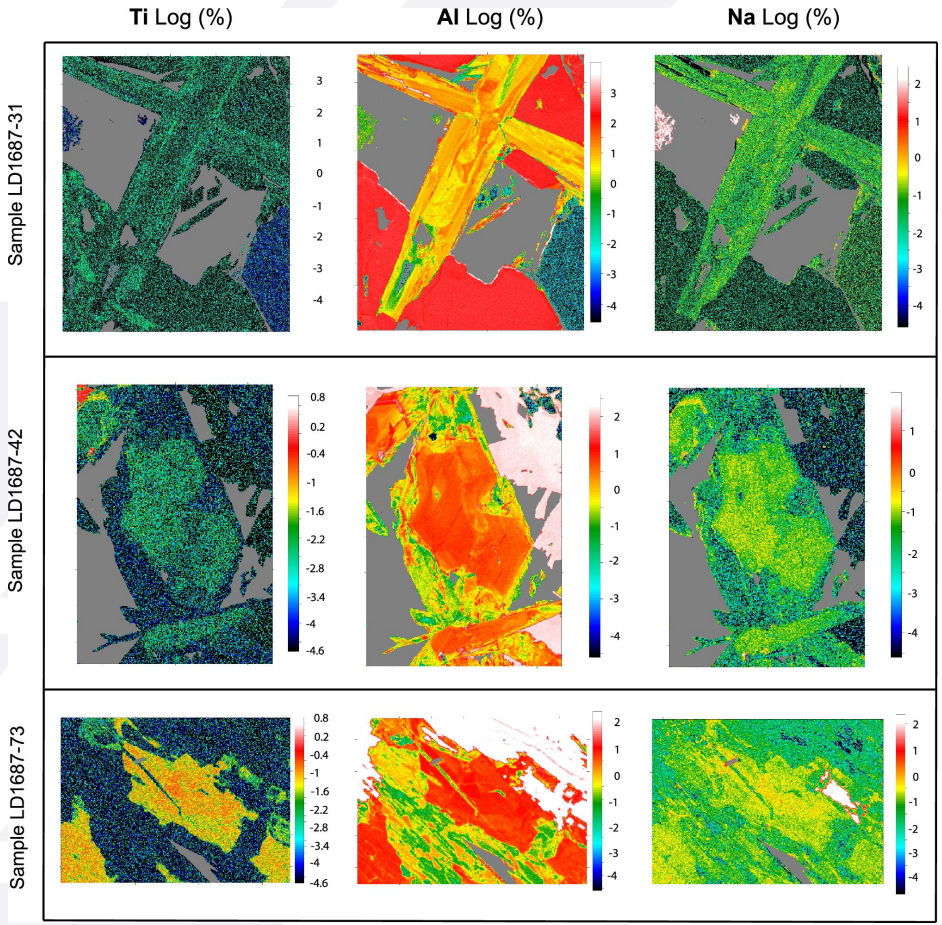
El Laco apatite up to 1 wt% S, indicating precipitation from oxidized fluid.
(La Cruz, 2020)

Source: Palma, 2019; La Cruz, 2020

Actinolite chemistry







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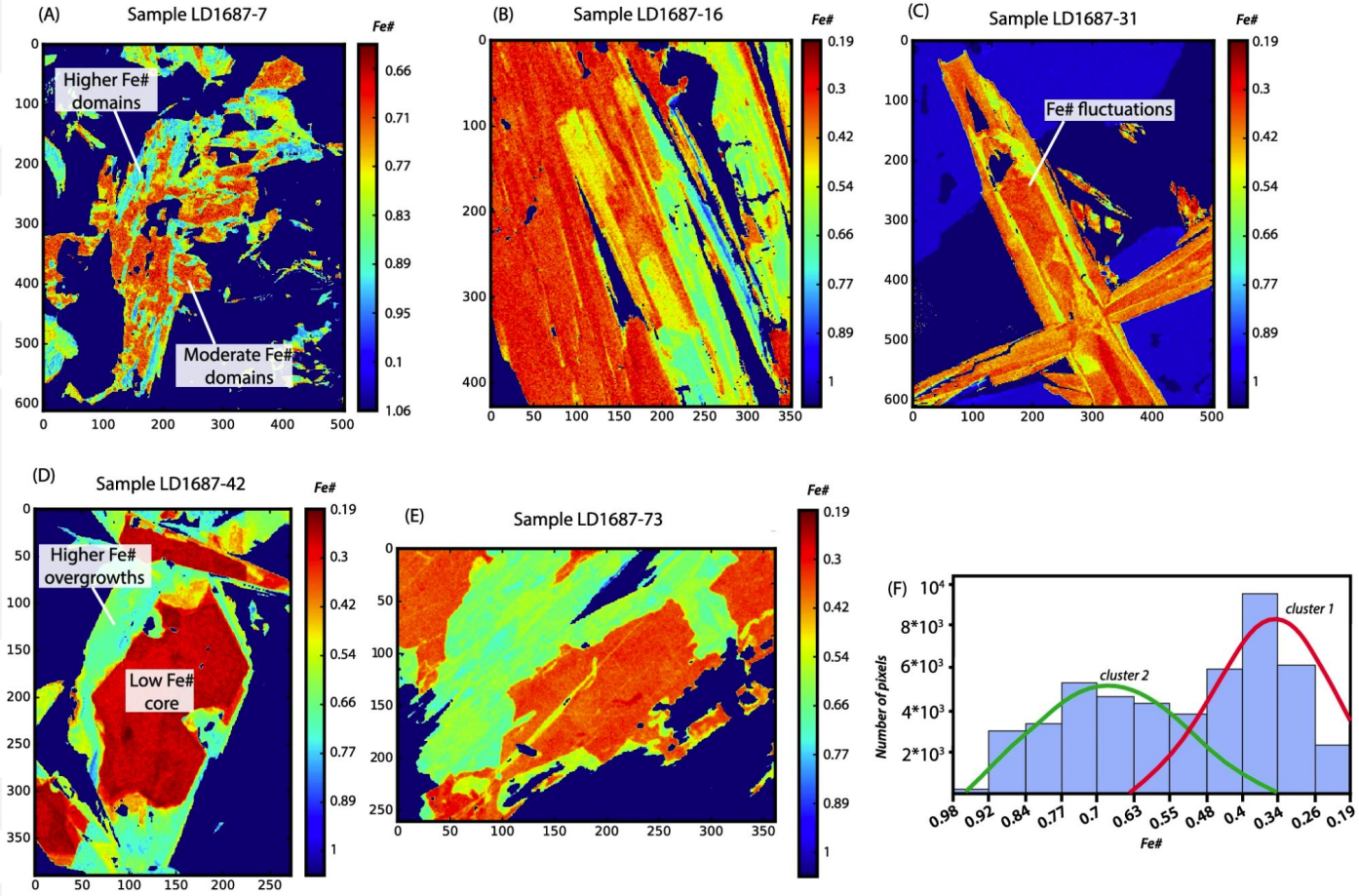
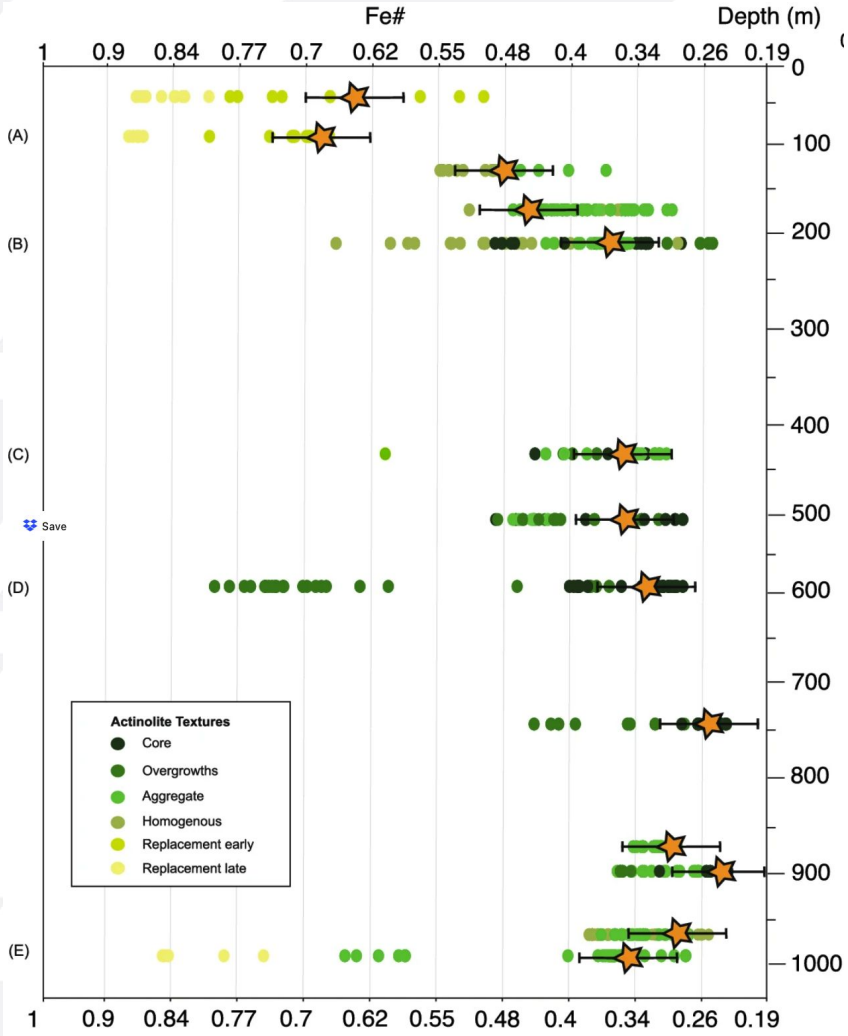
Actinolite chemistry



Actinolite chemistry



Source: del Real

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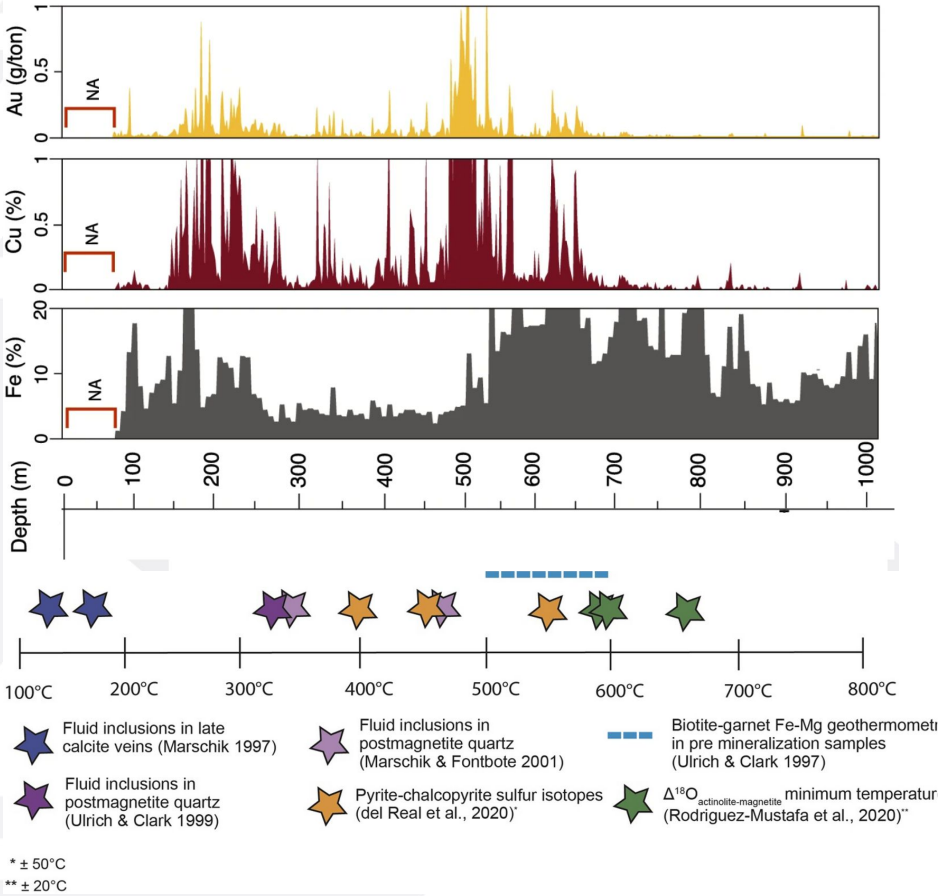
Candelaria metal grades and temperatures



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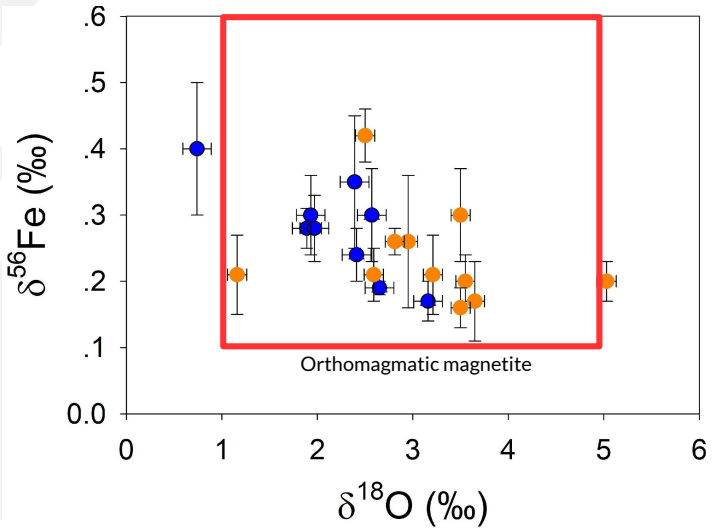
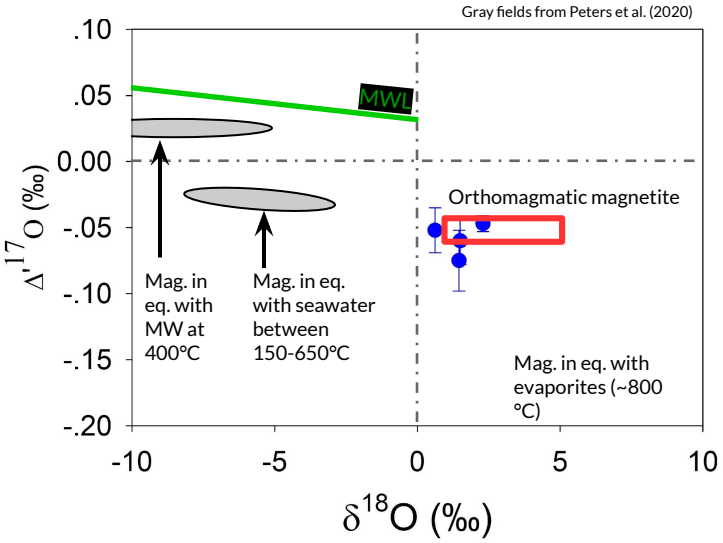
Magnetite Fe and O stable isotopes





Source: Childress et al., 2020

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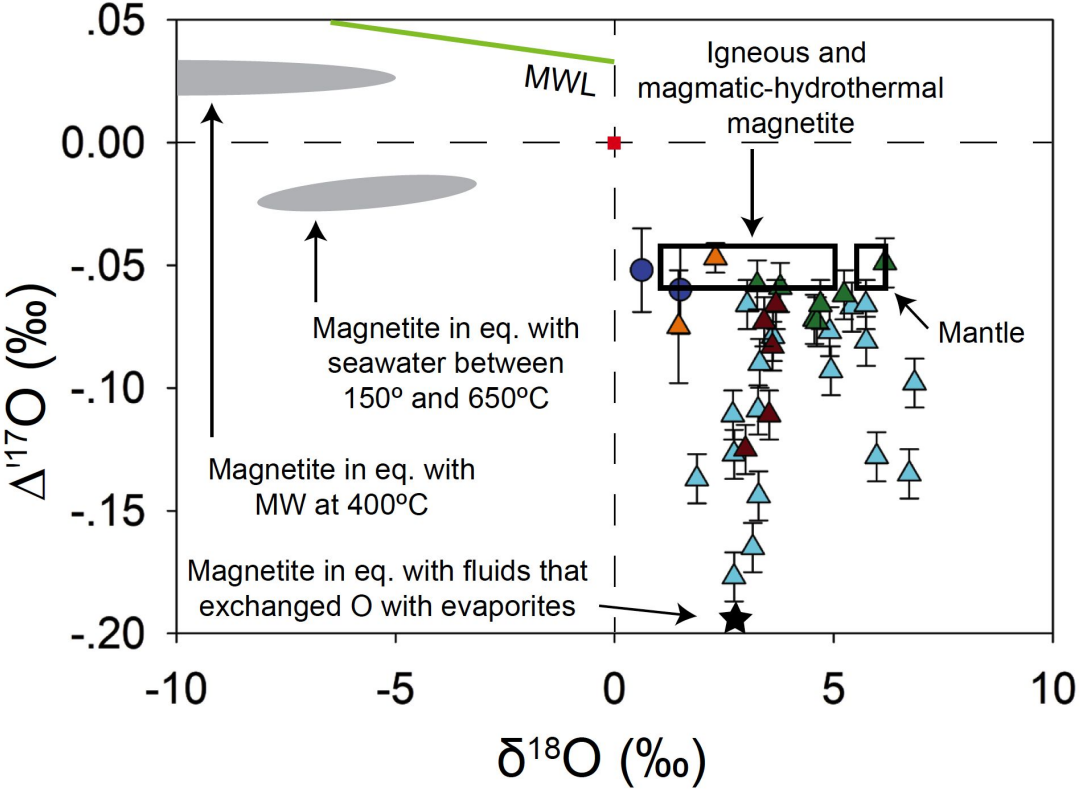
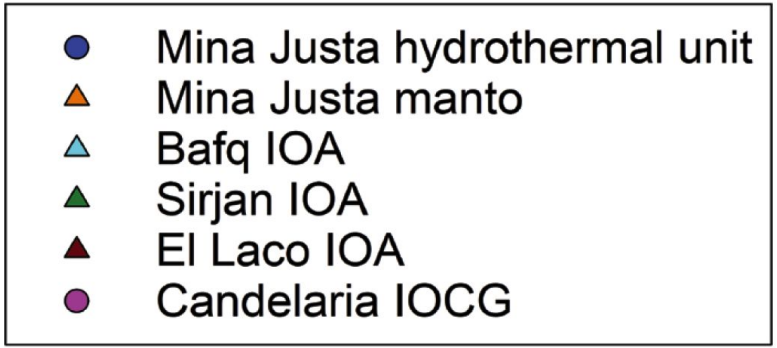
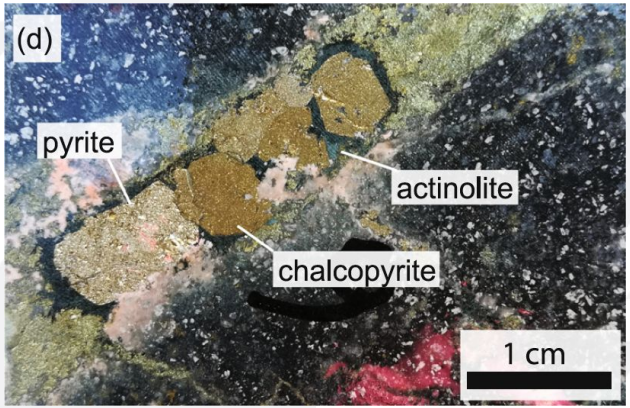
Magnetite Fe and O stable isotopes

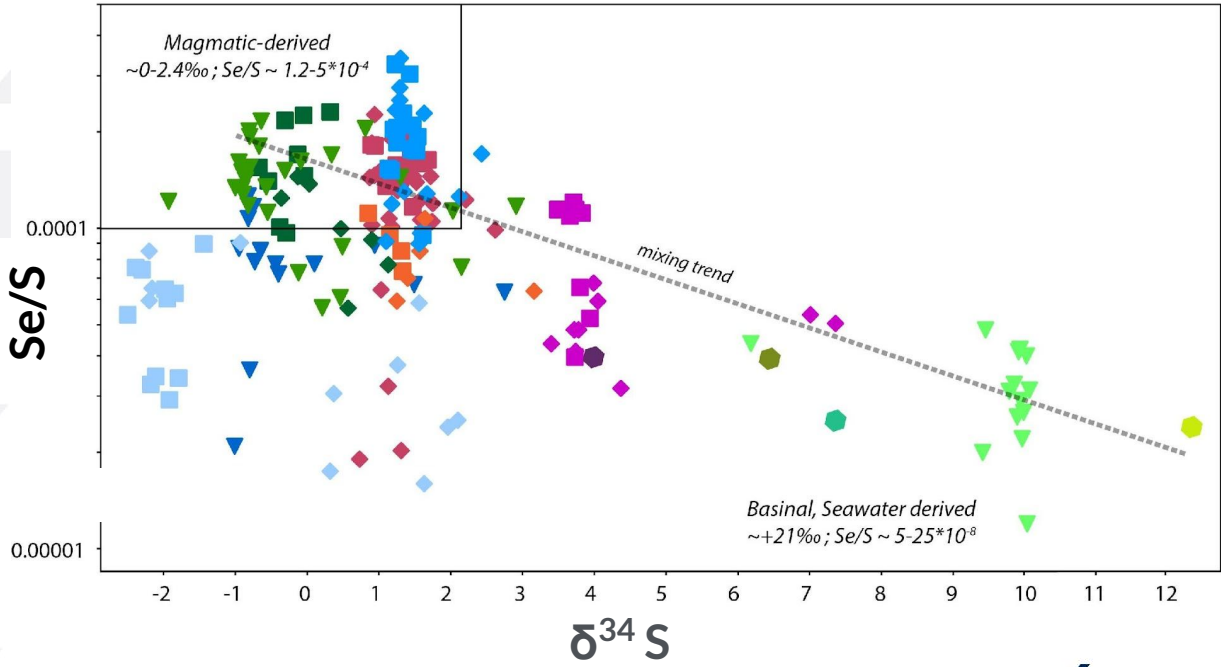




Source: Rodriguez-Mustafa et al., 2022

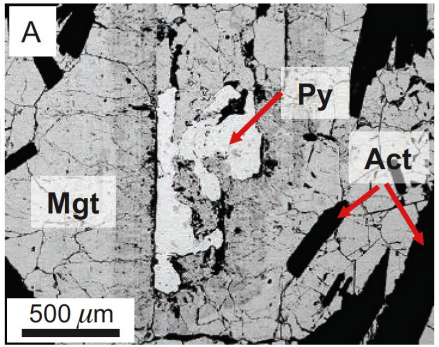
Pyrite chemistry

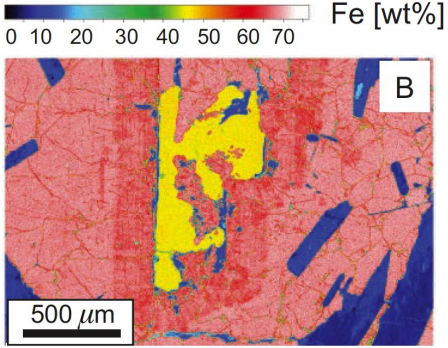


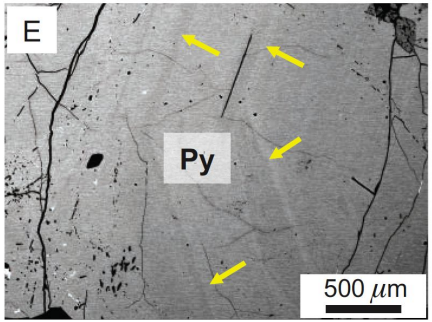


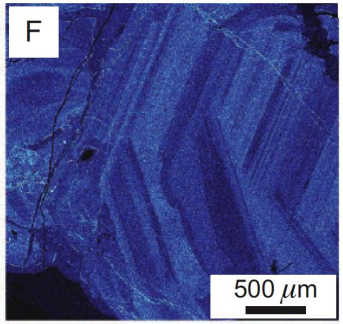
Source: del Real et al.

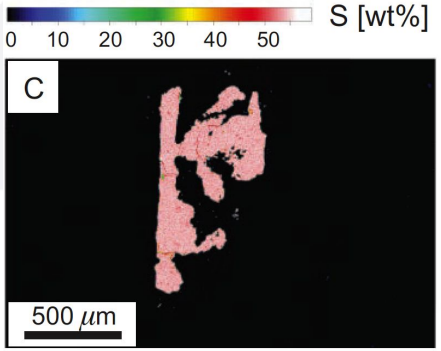
Pyrite chemistry

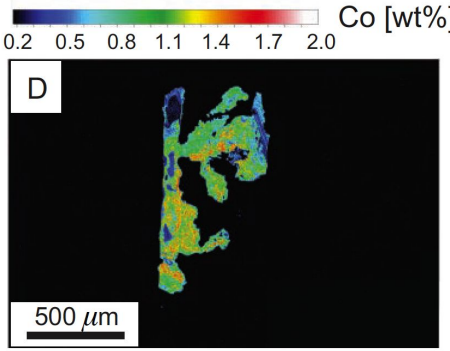


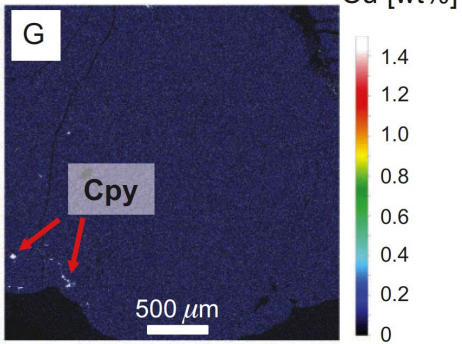


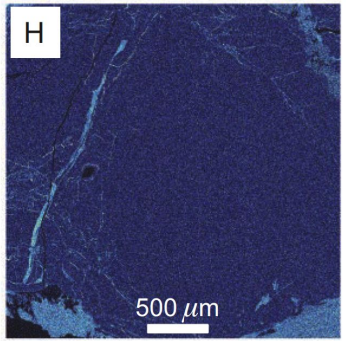






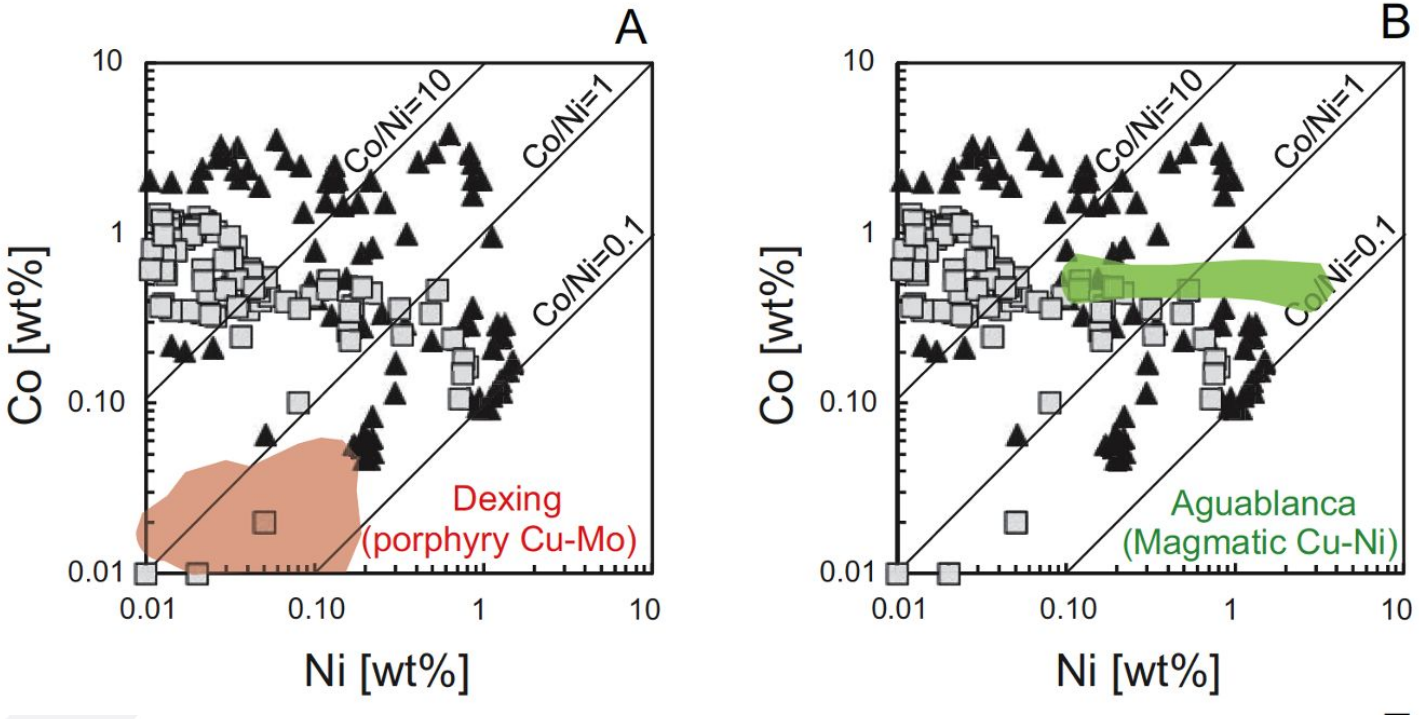






Source: Reich et al., 2016

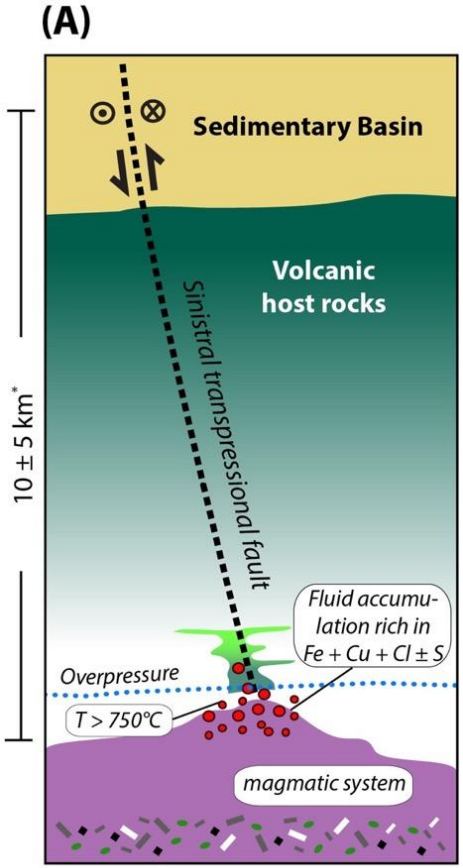
Pyrite chemistry



Source: Reich et al., 2016

Mineral chemistry and textures are consistent with a hydrothermal origin and record multiple pulses of magmatic-hydrothermal fluid.

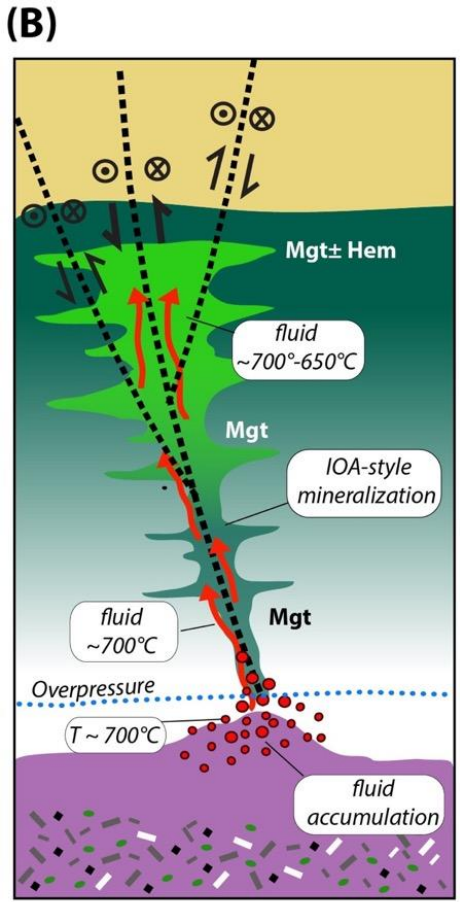
A genetic model for IOCG and IOA deposits

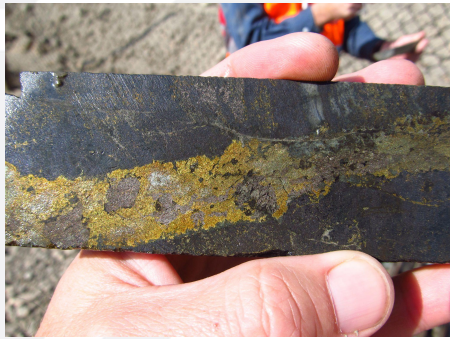


Extension in a back-arc environment allows intermediate to mafic magmas to ascend to shallow levels of the crust.

The high temperature, low viscosity magmas allow exsolved magmatic-hydrothermal fluid to passively leave the magma body.

A genetic model for IOCG and IOA deposits

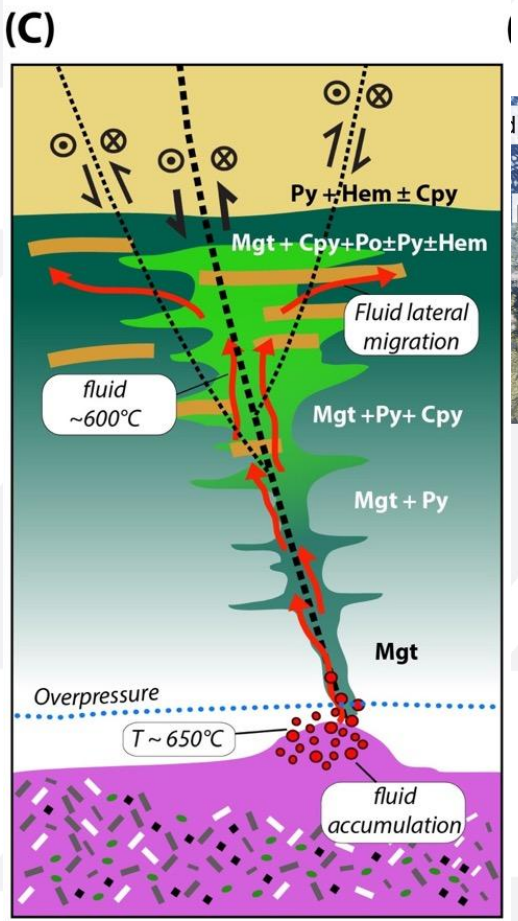


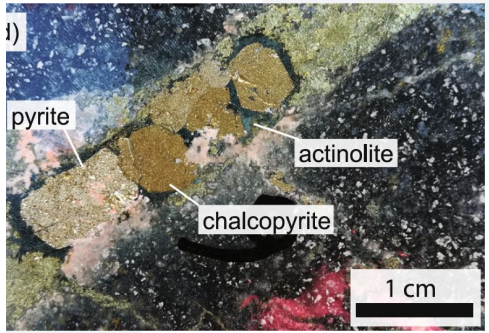


Early hydrothermal fluids evolve from intermediate to mafic magmas and would be enriched in dissolved Fe as well as Ca, Mg and Si to form magnetite + actinolite during cooling and interaction with the host rocks.

The hypogene ore fluid precipitates magnetite and actinolite at temperatures > 650 °C.

A genetic model for IOCG and IOA deposits





Later, lower temperature ore fluids evolve precipitate Cu-Fe-sulfides such.

This later fluid also precipitates magnetite, actinolite, pyrite and other minor phases.

$$CuCl_{(aq)} + H_2O_{(aq)} + Fe_3O_{4(mt)} = \mathbf{CuFeS_{2(cp)}} + H_2O_{(aq)}$$

$$Fe_3O_{4(mt)} + H_2S_{(aq)} + O_{2(aq)} = FeS_{2(py)} + H_2O_{(aq)}$$

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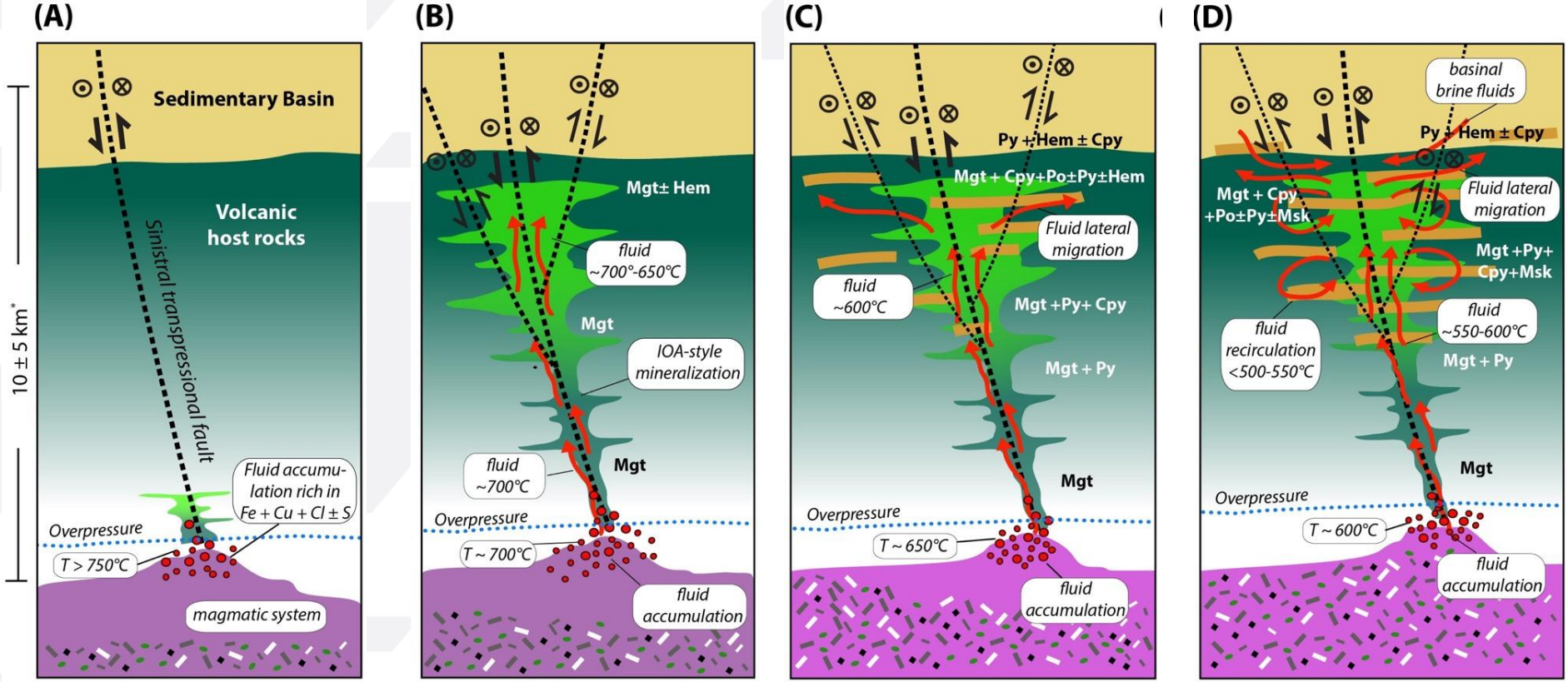
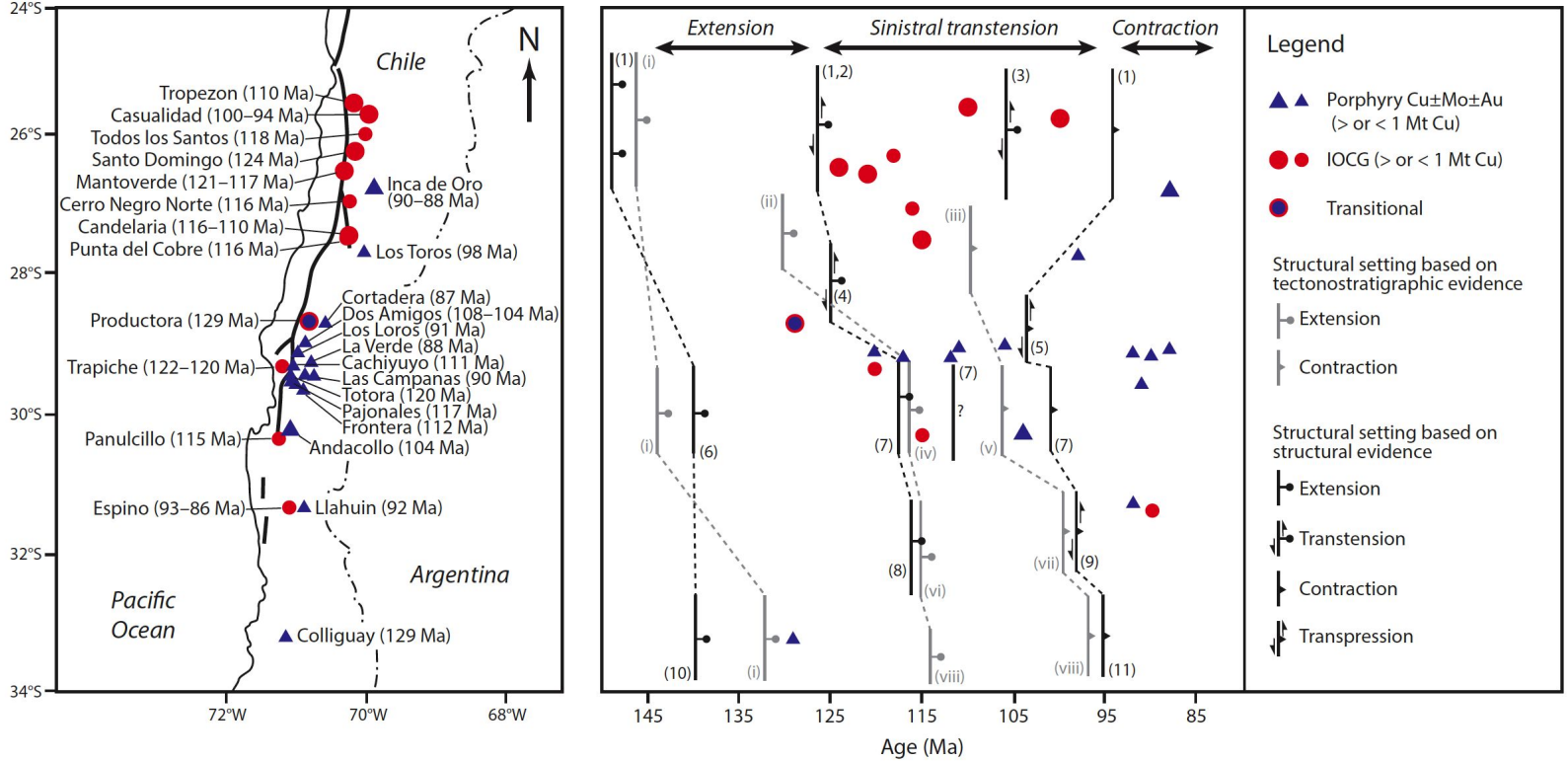
XI SIMPÓSIO BRASILEIRO DE EXPLORAÇÃO MINERAL
XI BRAZILIAN SYMPOSIUM ON MINERAL EXPLORATION

A genetic model for IOCG and IOA deposits



Contrasting Tectonic Settings and Sulfur Contents of Magmas Associated with Cretaceous Porphyry Cu ± Mo ± Au and Intrusion-Related Iron Oxide Cu-Au Deposits in Northern Chile*

Jeremy P. Richards,[1,†] Gloria P. López,[1] Jing-Jing Zhu,[1,2] Robert A. Creaser,[1] Andrew J. Locock,[1] and A. Hamid Mumin[3]



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Obrigado!

Adam Simon

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