Volatile rich Fe-oxide melts: base and precious metals enrichment trends.

Is there an IOCG connection?

Gregory W Lester M.A., MSc., PhD
Curtin University

Queen's University

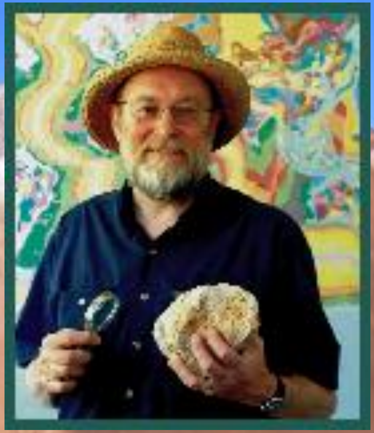
NSERC

Queens Facility for Isotope Research

Society of Economic Geologists Founded 1920

WASM Da Dextram Comitibus

Background



H.R. Dick Naslund
Binghamton University

Nelsonites and Low Ti, FeO deposits in the Adirondacks, New York State

El Laco, Chile and the Missouri, USA FeO-REE deposits, with Fernando Enrique and Jan Nystrom

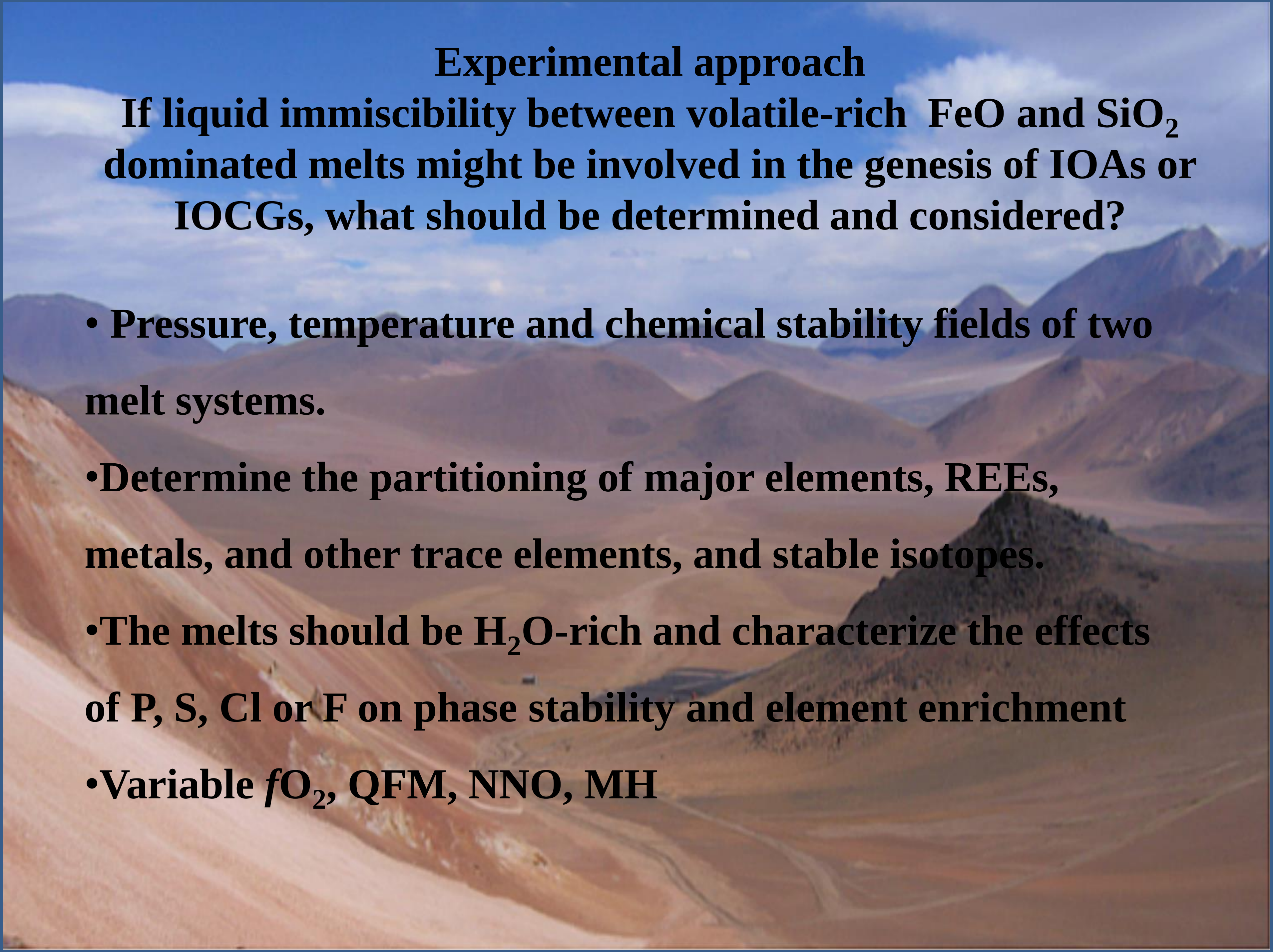
6 years Alan Clarks IOCG group, Queens University, Canada

- Jorge Benivides- Manto Verde, Chile
- Hyong Chen- Marcona , Mina Justa, Peru
- Greg Lester- Pampa De Pongo, Peru

Proprietary deposits in Mexico, Canada and 100+ million pound REO, IOCG-carbonatite hybrid in Mongolia

Observations

- Magmatic-hydrothermal systems
- Usual variations of the typical IOCG alteration/ alteration/mineralogy themes
- Primary early FeO stage volatile rich AAFEs (anions or anion forming elements) e.g. OH, P, S, F
- External or non-primary source of S, and by extension Cu and Au
- REE and U might be primary
- Geochemical and textural evidence of primary FeO magmas in some cases



Experimental approach

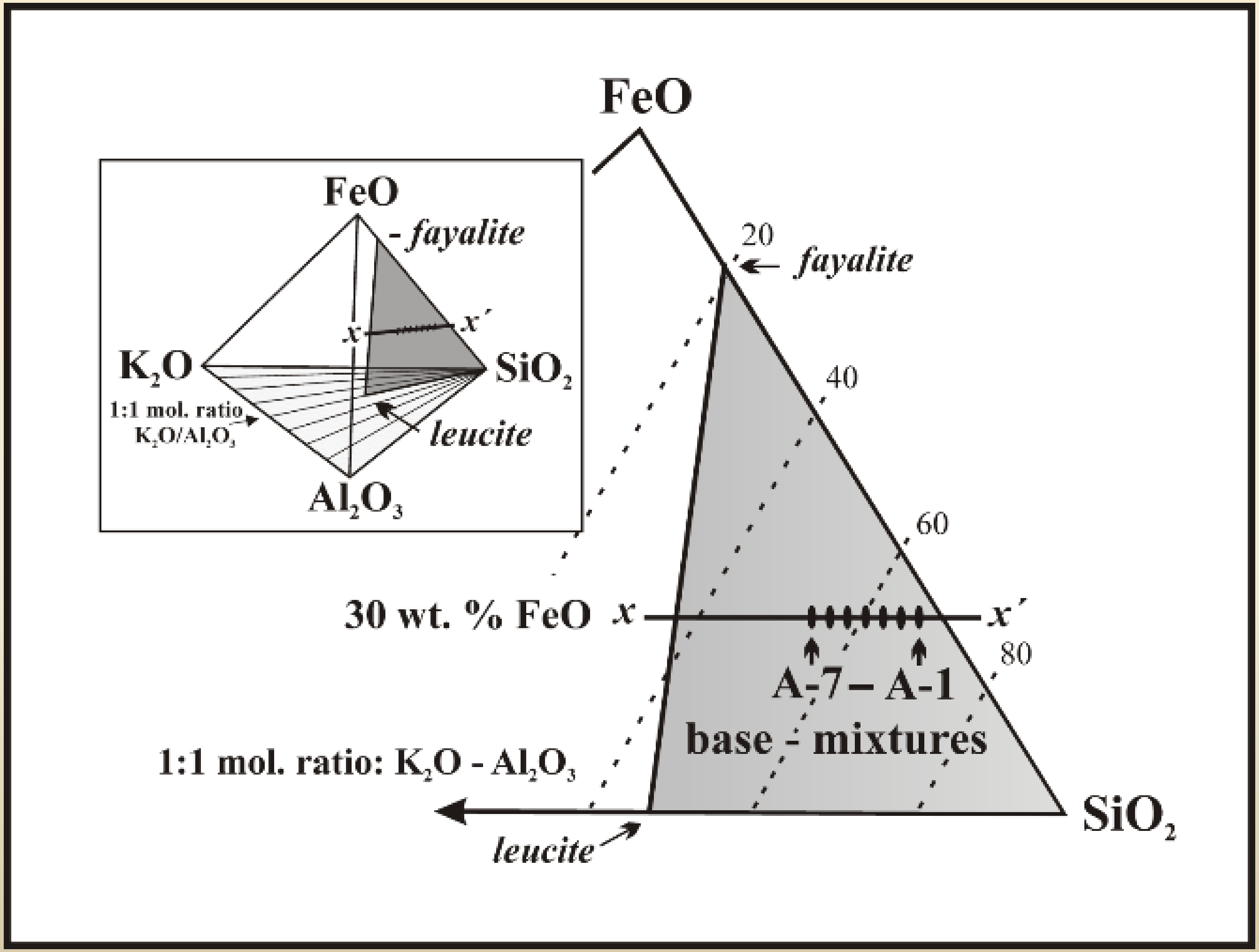
If liquid immiscibility between volatile-rich FeO and SiO_2 dominated melts might be involved in the genesis of IOAs or IOCGs, what should be determined and considered?

- **Pressure, temperature and chemical stability fields of two melt systems.**
- **Determine the partitioning of major elements, REEs, metals, and other trace elements, and stable isotopes.**
- **The melts should be H_2O-rich and characterize the effects of P, S, Cl or F on phase stability and element enrichment**
- **Variable fO_2, QFM, NNO, MH**

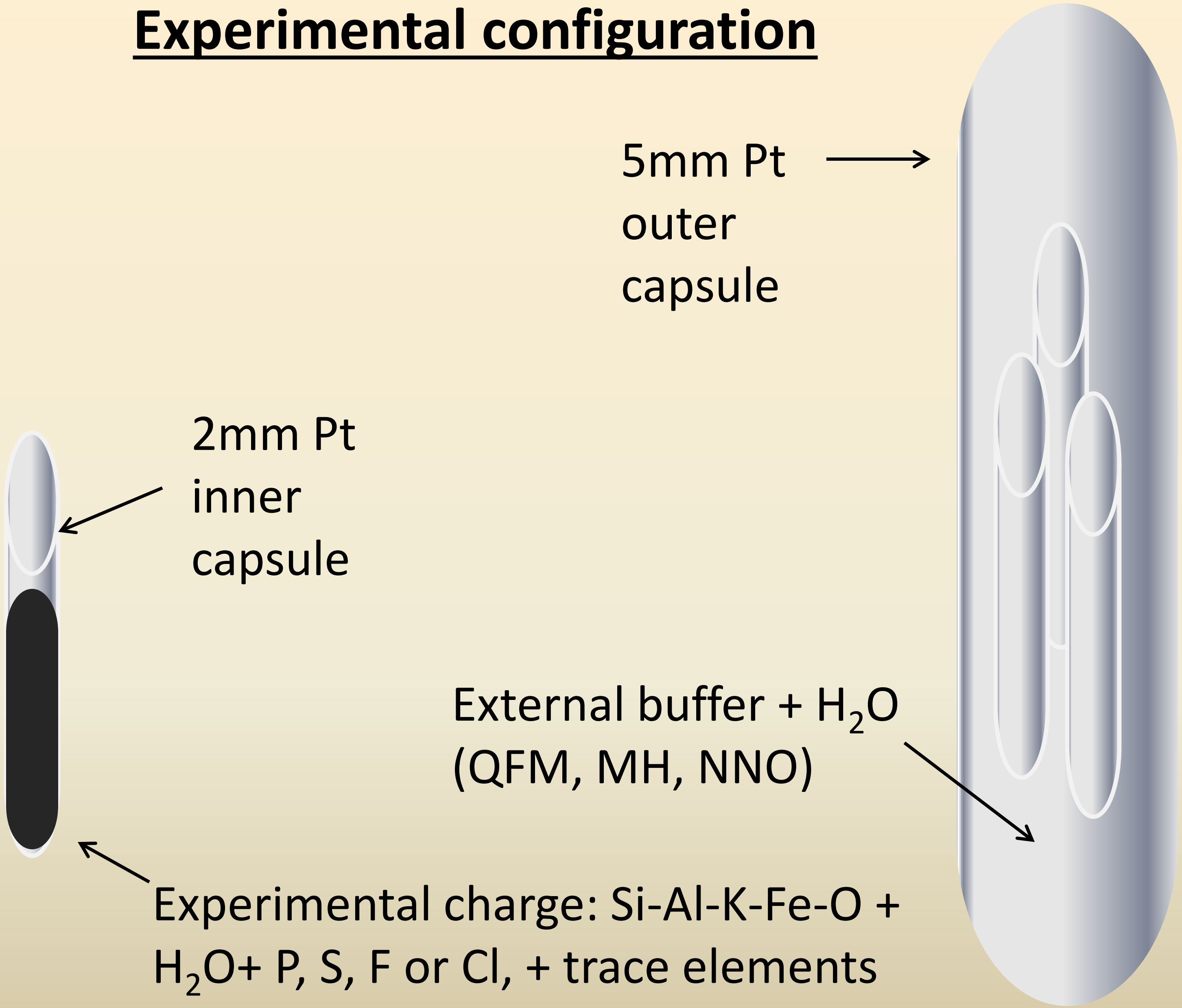
>200 experiments

T-X- 7 base mixtures (~basaltic andesite-granite comp.) + H_2O +P,S, F, or S

Part.- base-mixture + 10 wt% H_2O + 6.67 x 10^{-4} mol/g P, S, F, or Cl + trace elements (peraluminous, An_{50})



Experimental configuration



5mm Pt outer capsule

2mm Pt inner capsule

External buffer + H_2O (QFM, MH, NNO)

Experimental charge: Si-Al-K-Fe-O + H_2O+ P, S, F or Cl, + trace elements

Rotating, rapid-quench IHPV

Argon pressure media

Argon density at 200 MPa ~ density water at 1 atm.

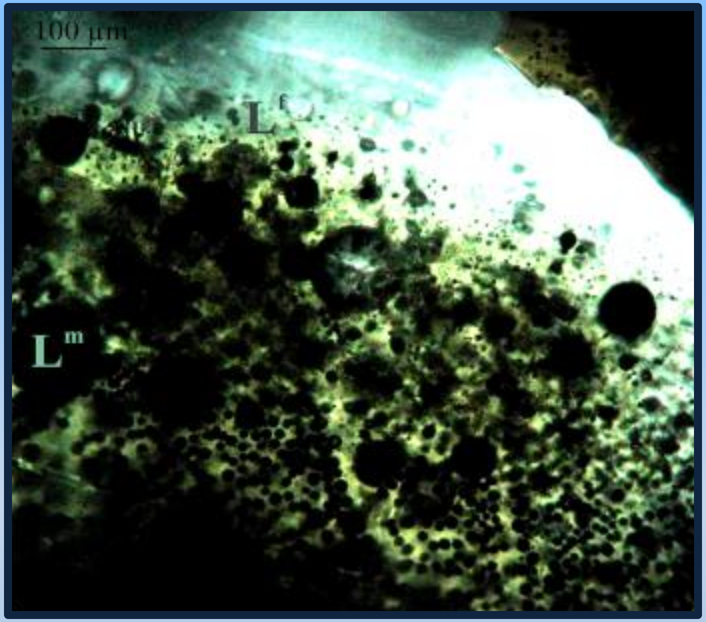
Stellite bomb

Quench orientation

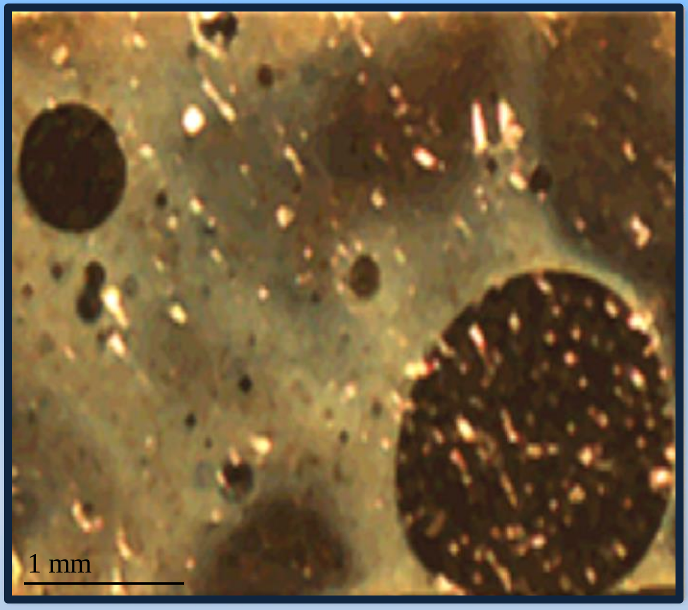
blast shield

Run orientation

Experimental product for analysis: phase assemblage (microscopy, B.S.E), major and trace element (W.D.S., ICP-ms) and isotope (IR-ms) partitioning

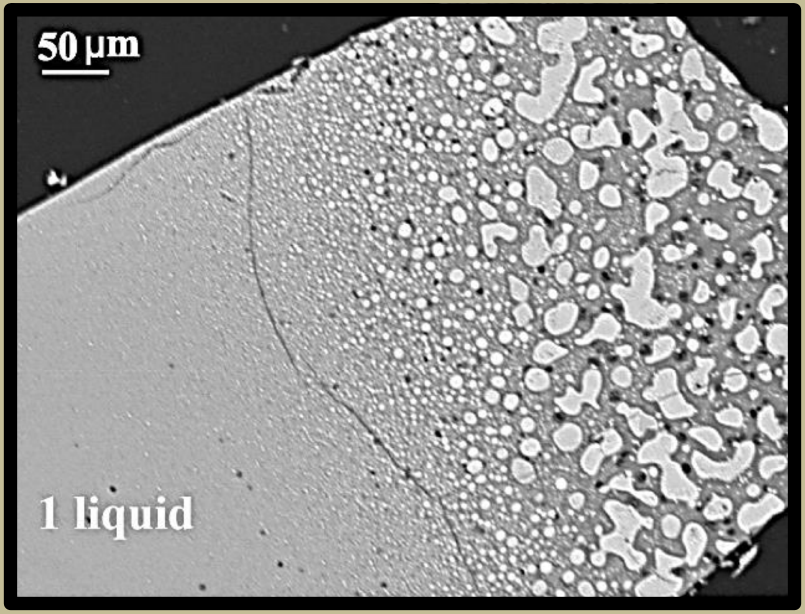


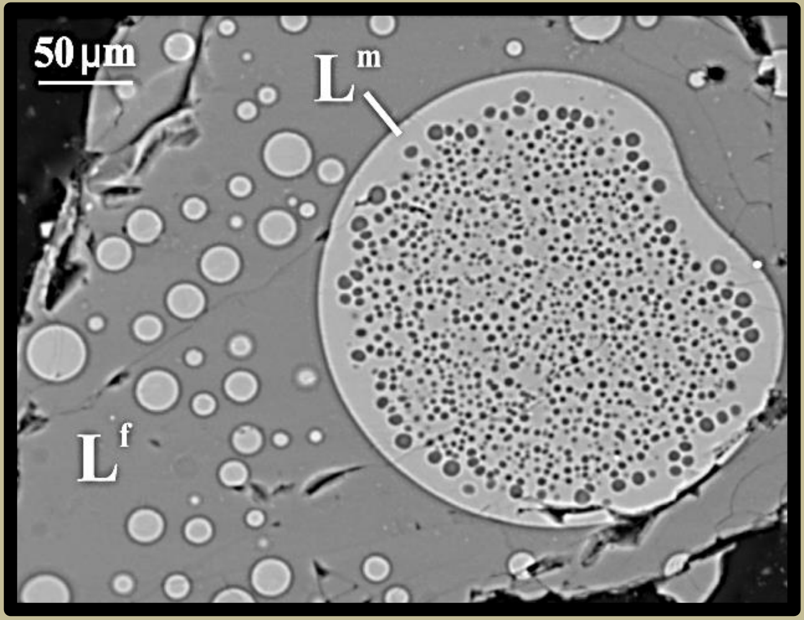
trans. light

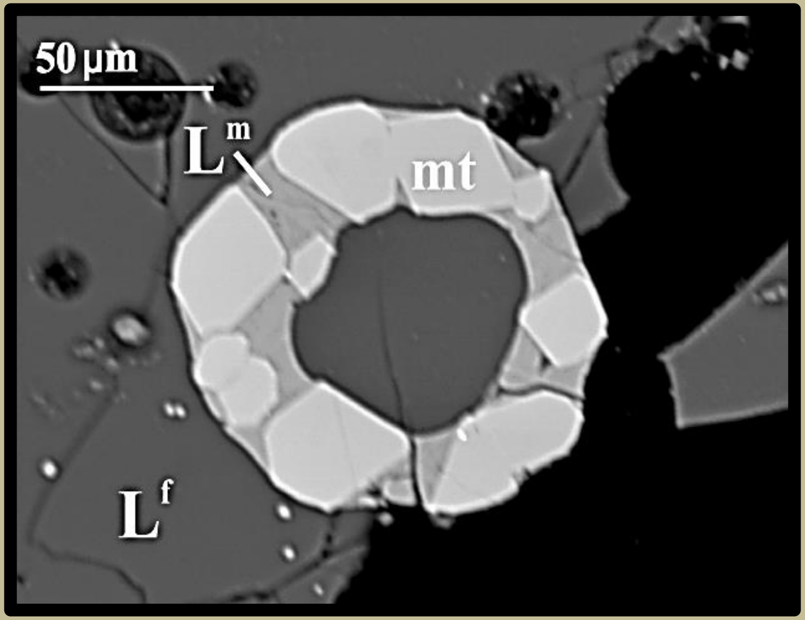


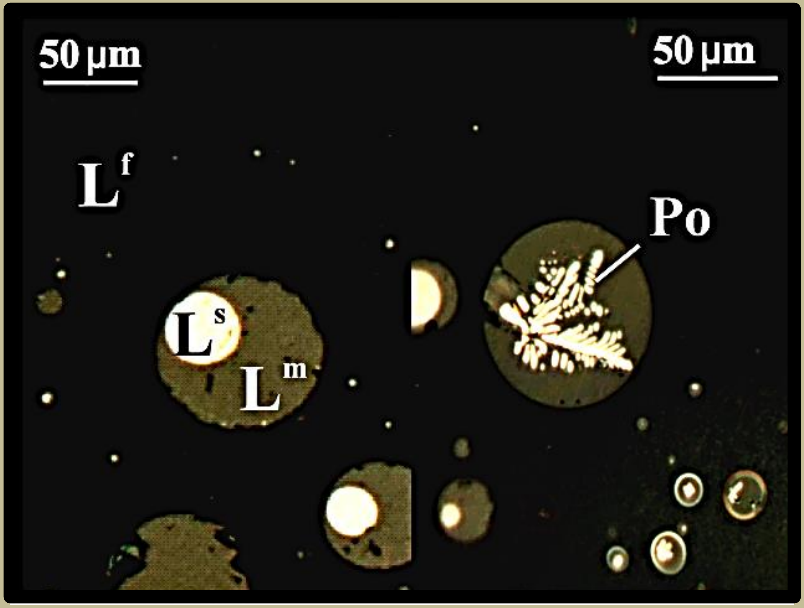
refl. light

B.S.E. images of conjugate immiscible melts

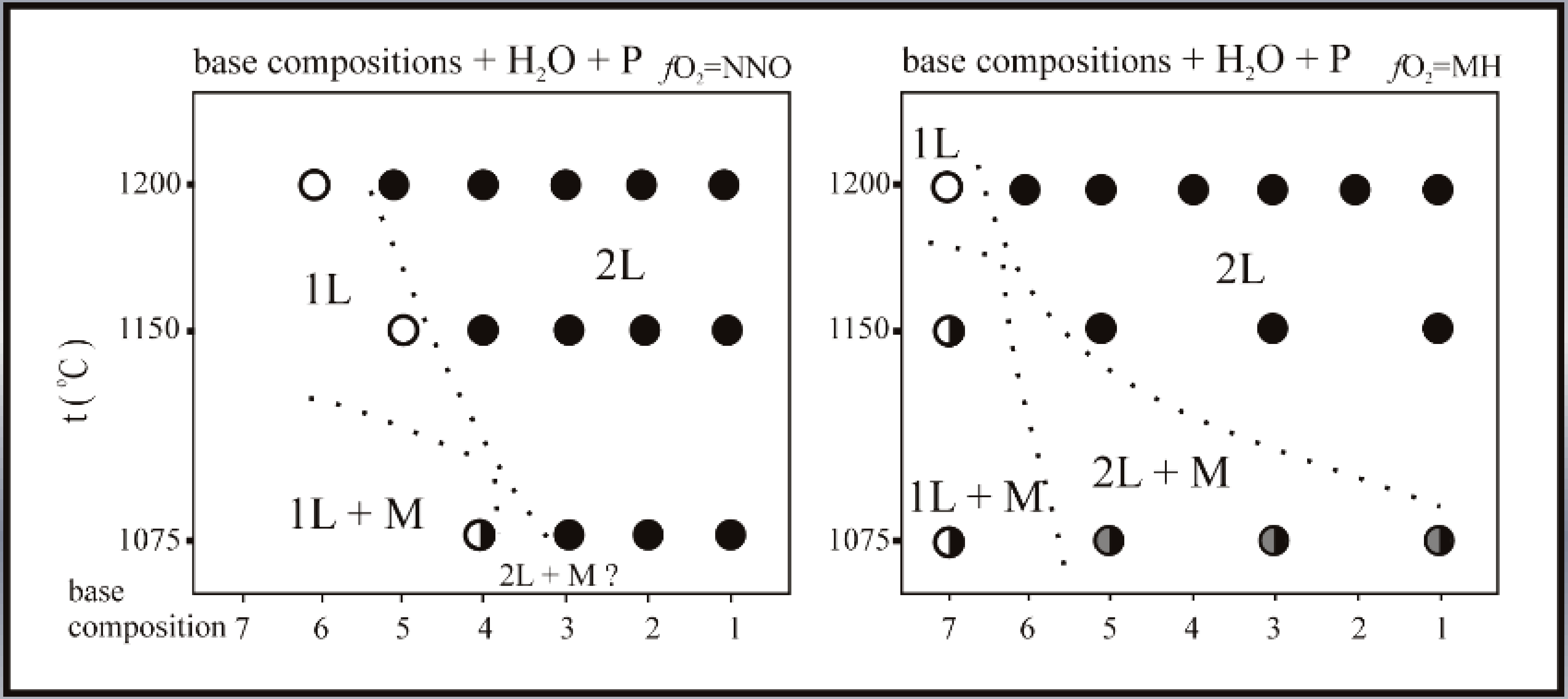






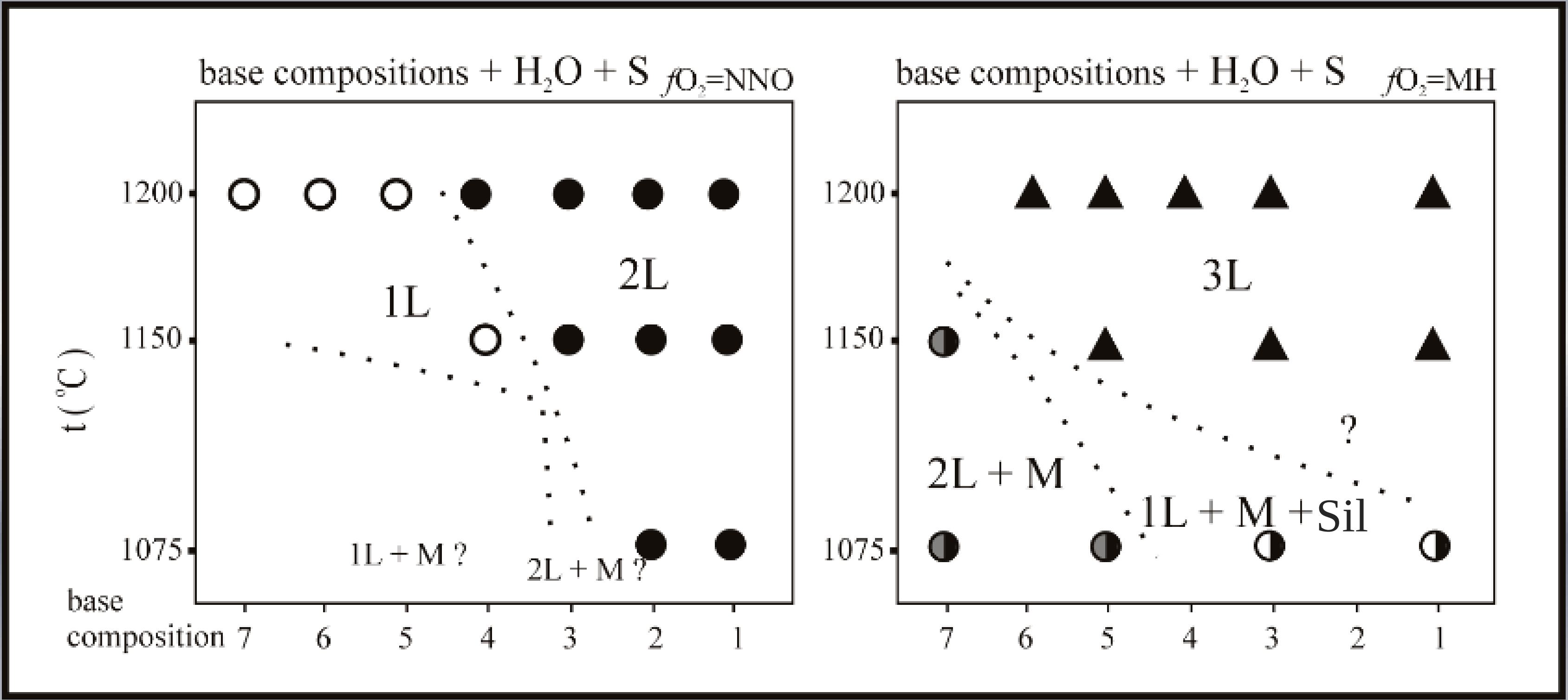


Experimental results for H_2O + P



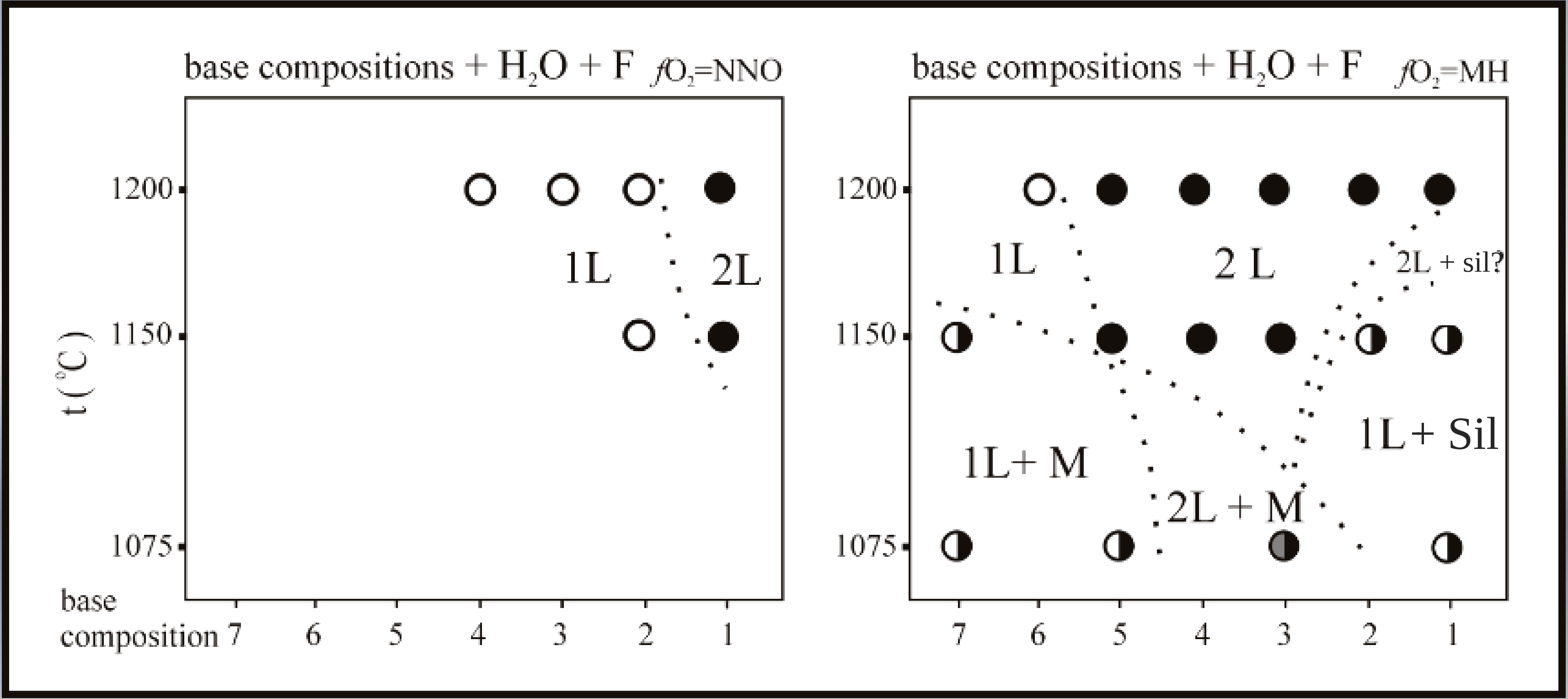
L - liquid
M - magnetite
Sil - silica mineral

Experimental results for H_2O + S



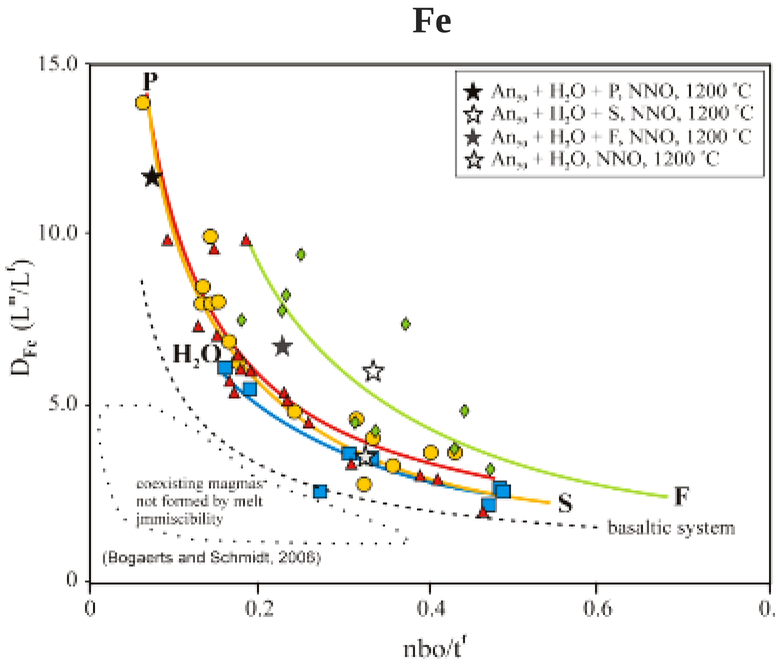
L - liquid
M - magnetite
Sil - silica mineral

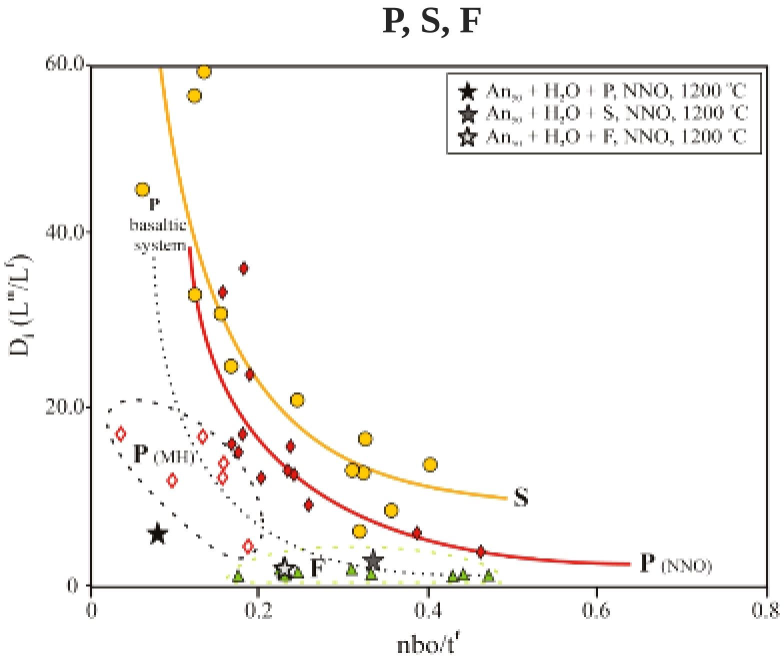
Experimental results for H_2O + F



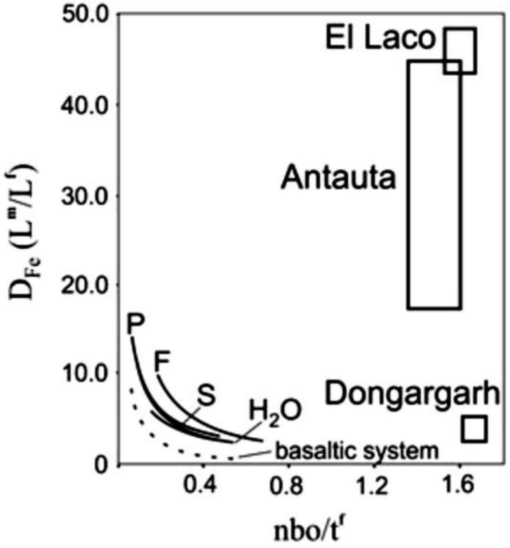
L - liquid
M - magnetite
Sil - silica mineral

Element Partitioning as a Function of Polymerization

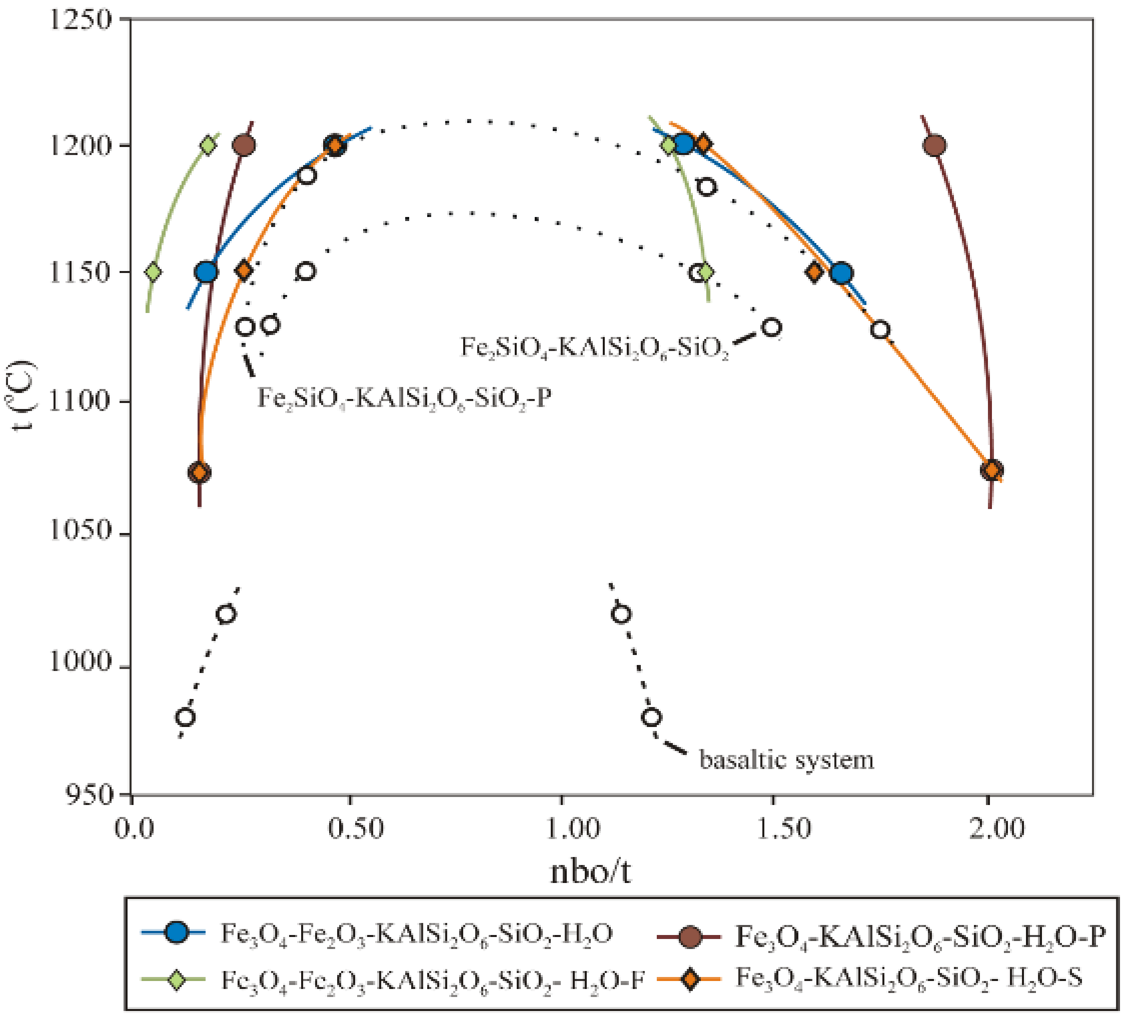

Fe


P, S, F

Immiscible melt inclusions



Effect of H_2O, P, S, and F on miscibility gap



Anhydrous and basaltic data from Bogaerts and Schmidt, 2006

Summary of results and interpretation-P-T-X stability

1. FeO_x-SiO_2 volatile rich immiscible melts are stable over a broad melt composition range, at geologically reasonable temperatures 1000-1200 C^o (800 C^o sub-liquidus). 60-80 wt% FeO FeO-rich melt, andesitic-granitic silicate melt

2. H_2O, P, S, F extend T lower, expand composition field, Cl-limited

Mechanisms

Crystal fractionation, magma mixing, partial melt, assimilation

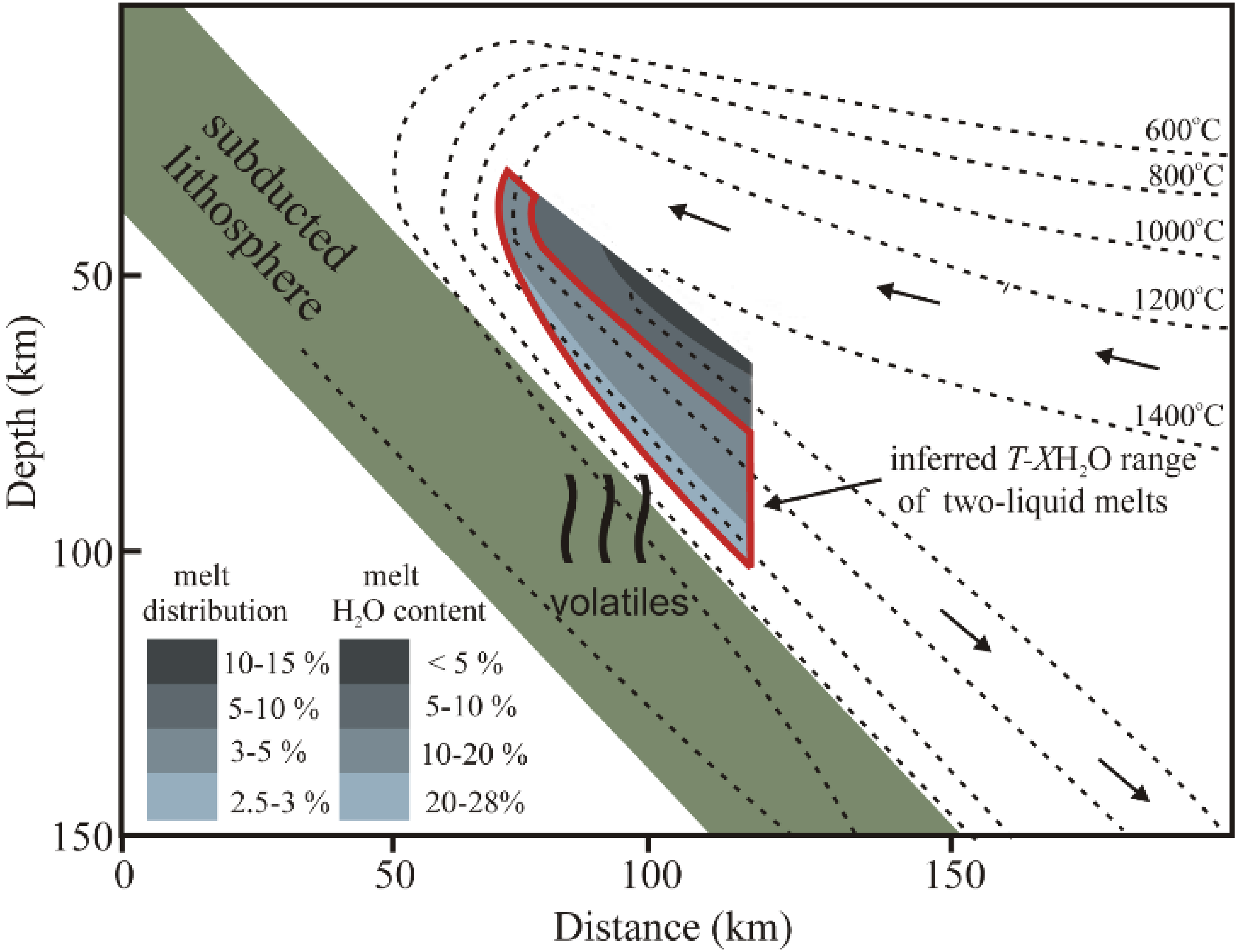
Geological Settings

High H_2O…….. Arc and back-arc are very permissive, especially with deep faults as conduits.

Shallow crustal magma chambers (late LLD, volatile saturation near and sub-liquidus, also magma mixing)

Mid cratonic- Volatile source? Low volatile IO?, IOA

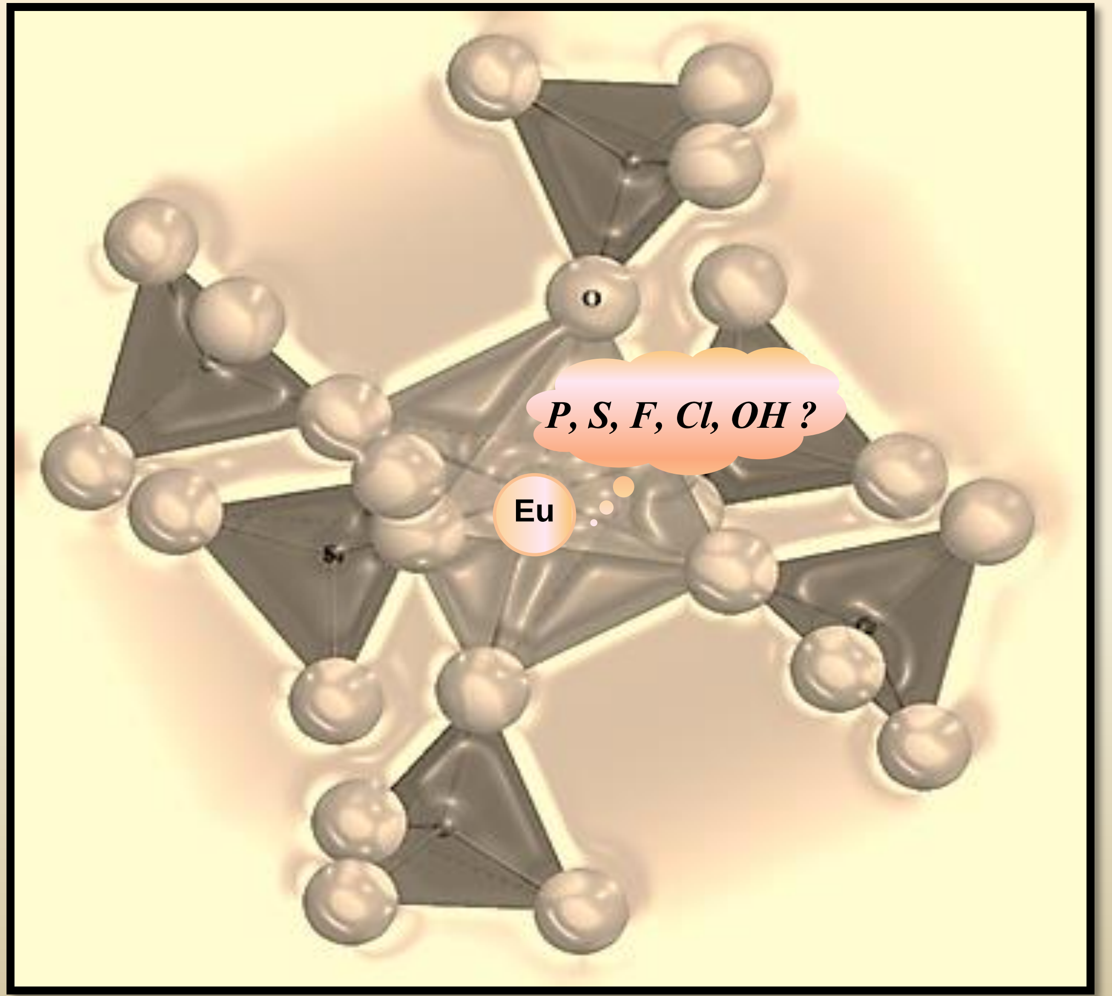
Pressure and two-melt stability in the supra-subduction zone. "magma factory"



Flux-melting model from Grove et al., 2006

Partitioning of HFSE, transition metals and REE between immiscible silicate melts with H_2O, P, S, F, and Cl

General applications



Three suites of trace elements

Alk, HFSE: Rb, Cs, Nb, Zr, Cs, Hf, Th, U

REE: La, Nd, Ce, Sm, Eu, Dy, Er, Yb

VI-XII elements: Ti, V, Cr, Mn, Co, Ni, Cu, Zn, Mo, Ag, Au

Experimental conditions

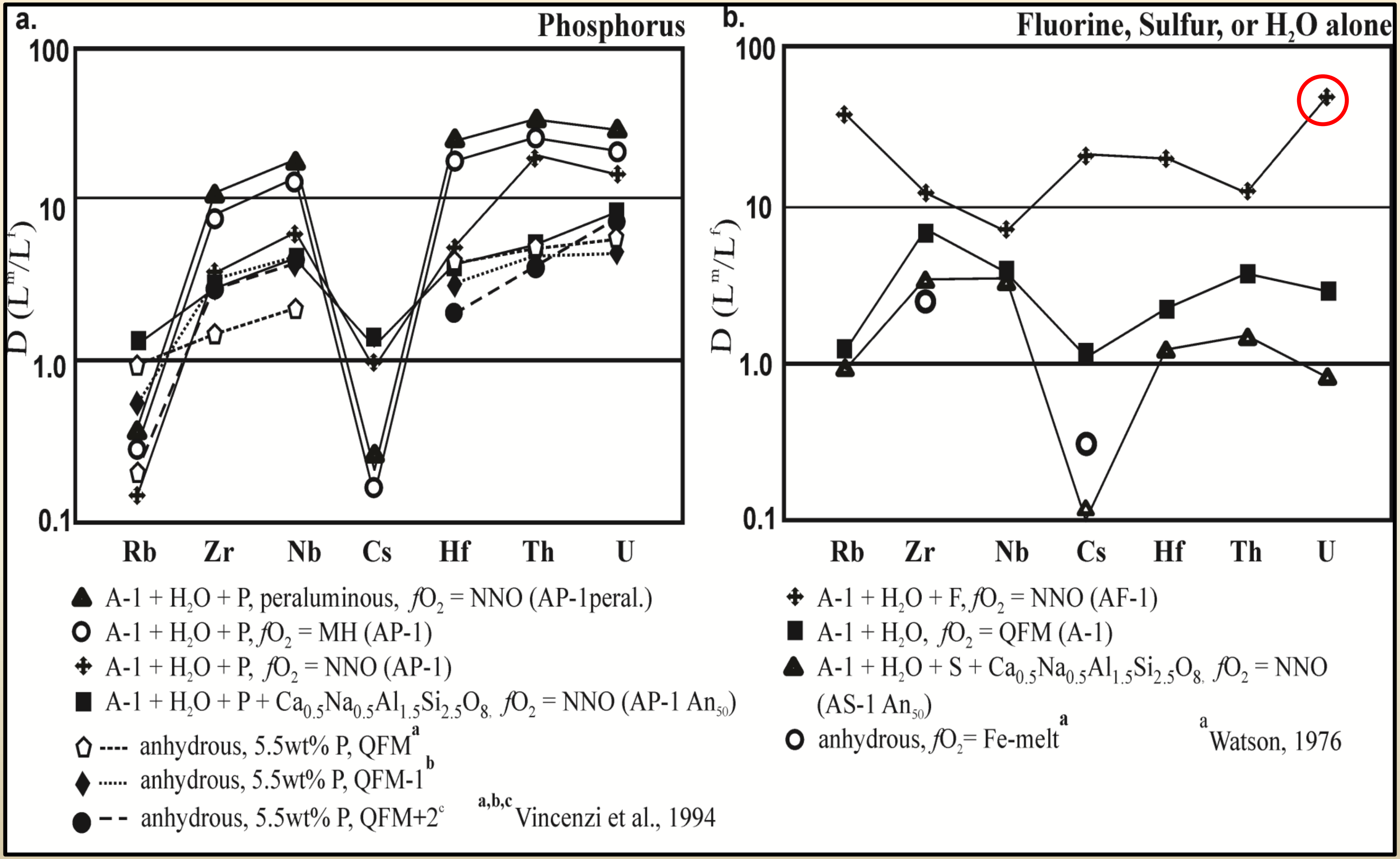
- Temperature: isothermal- 1200 ^{o}C
- Pressure: isobaric- 200 MPa
- Oxygen fugacity: fixed at quartz-fayalite-magnetite, nickel-nickel oxide and magnetite-hematite buffers
- Molar equivalent quantities of P, S, F, and Cl.

Analysis and Results

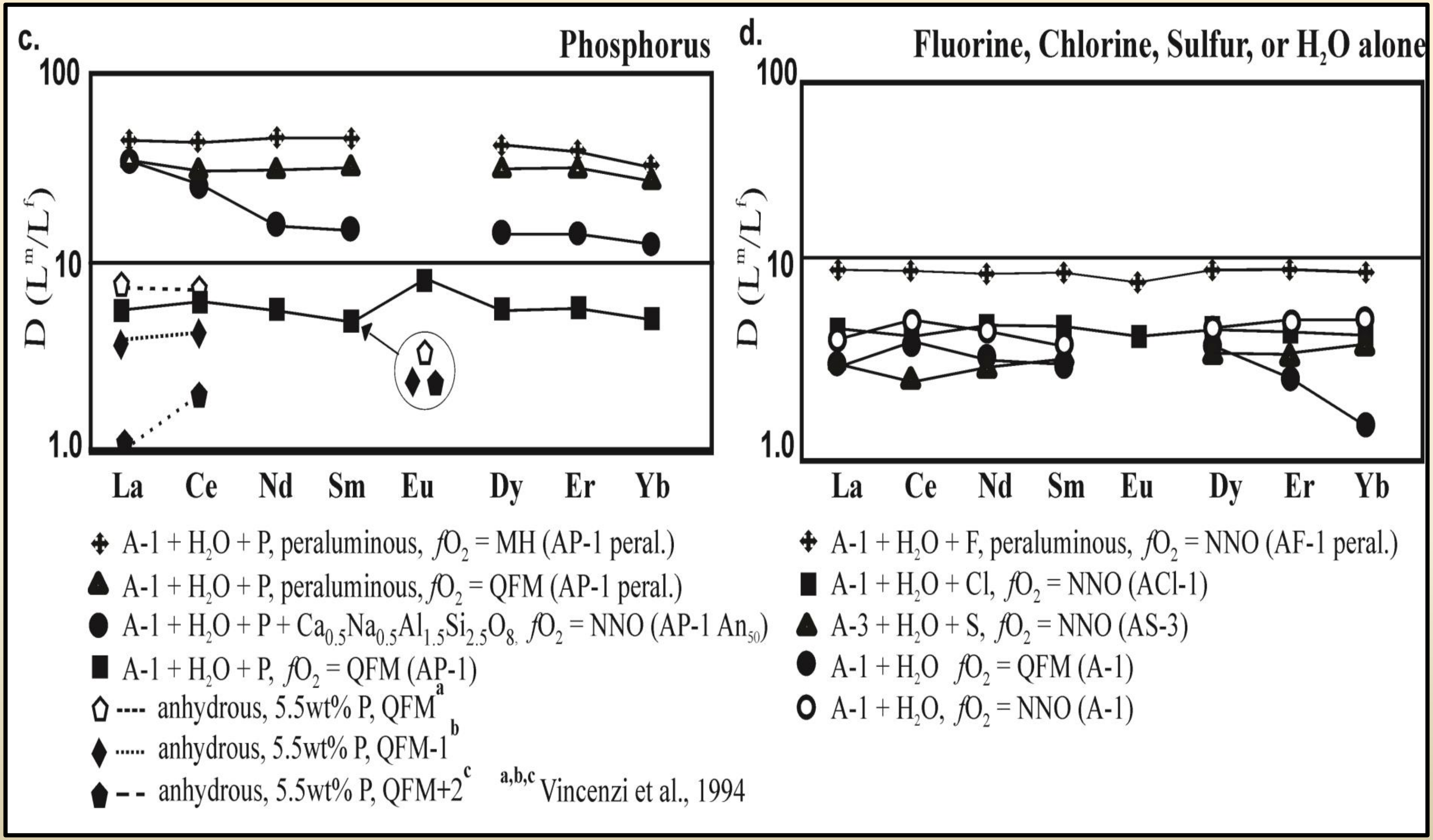
Major element: Electron microprobe, WDS

Trace element: Thermo Scientific XSERIES 2 Quadrupole ICPMS instrument, coupled with a NewWave 213 nmlaser ablation system. The laser beam was fired at 5 Hz repetition rate with the laser energy in the range of 0.36–0.51 mJ per pulse. A spot size of 30 µm.

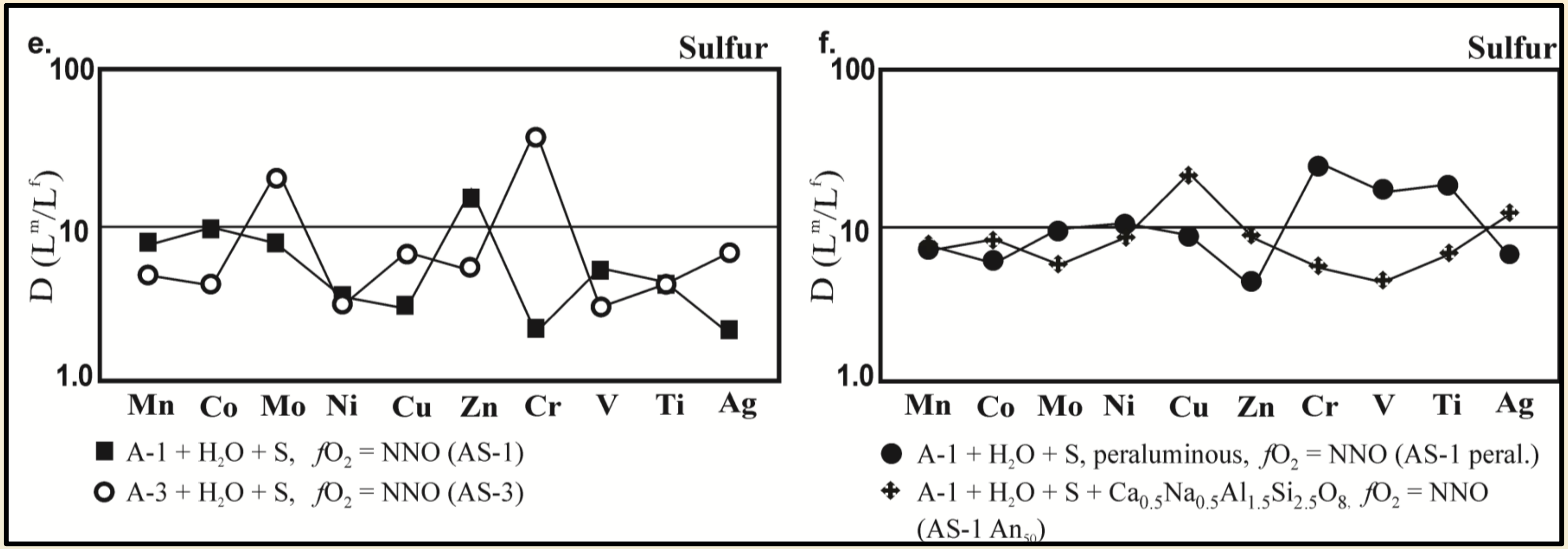
Nernst partition coefficients D (L^m/L^f) for HFSE and Alk. in conjugate immiscible melts, note log scale

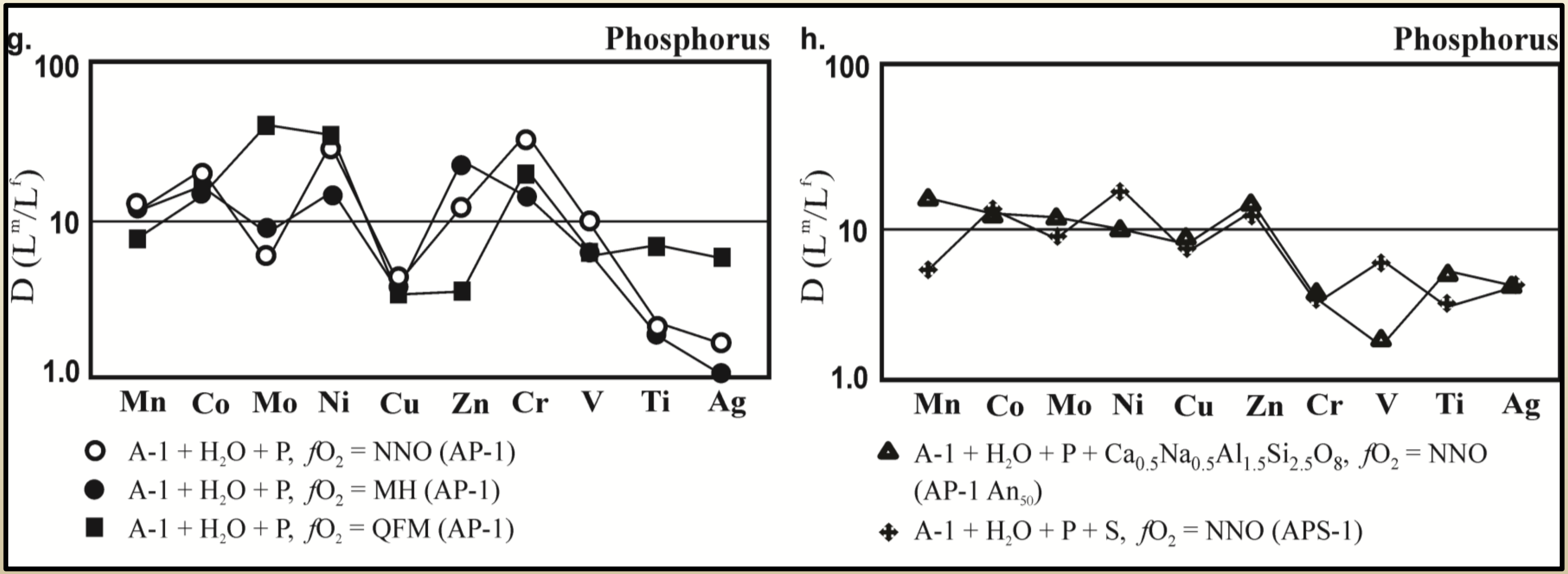


Nernst partition coefficients D (L^m/L^f) for REE in conjugate immiscible melts

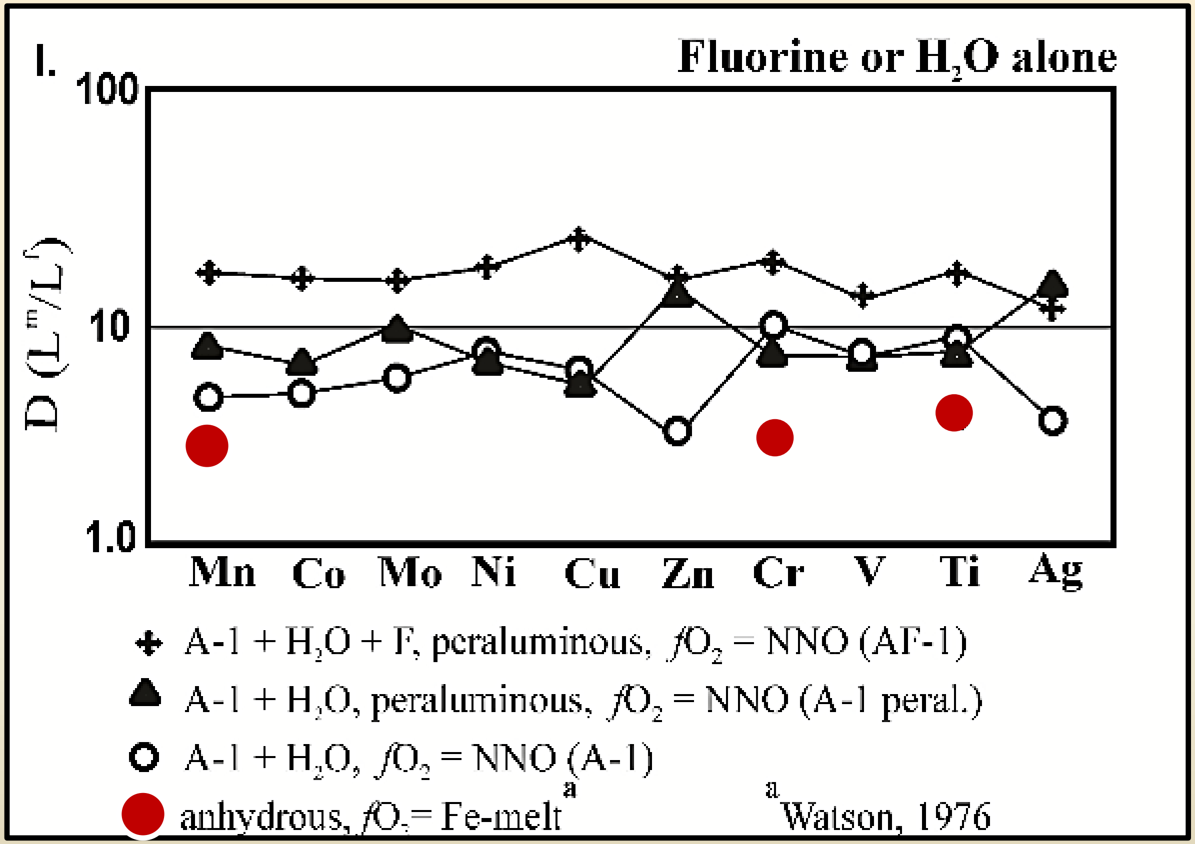


Nernst partition coefficients D (L ^{m}/L ^{f}) for *VI-XII* elements in conjugate immiscible melts





Nernst partition coefficients D (L^m/L^f) for *VI-XII* elements in conjugate immiscible melts

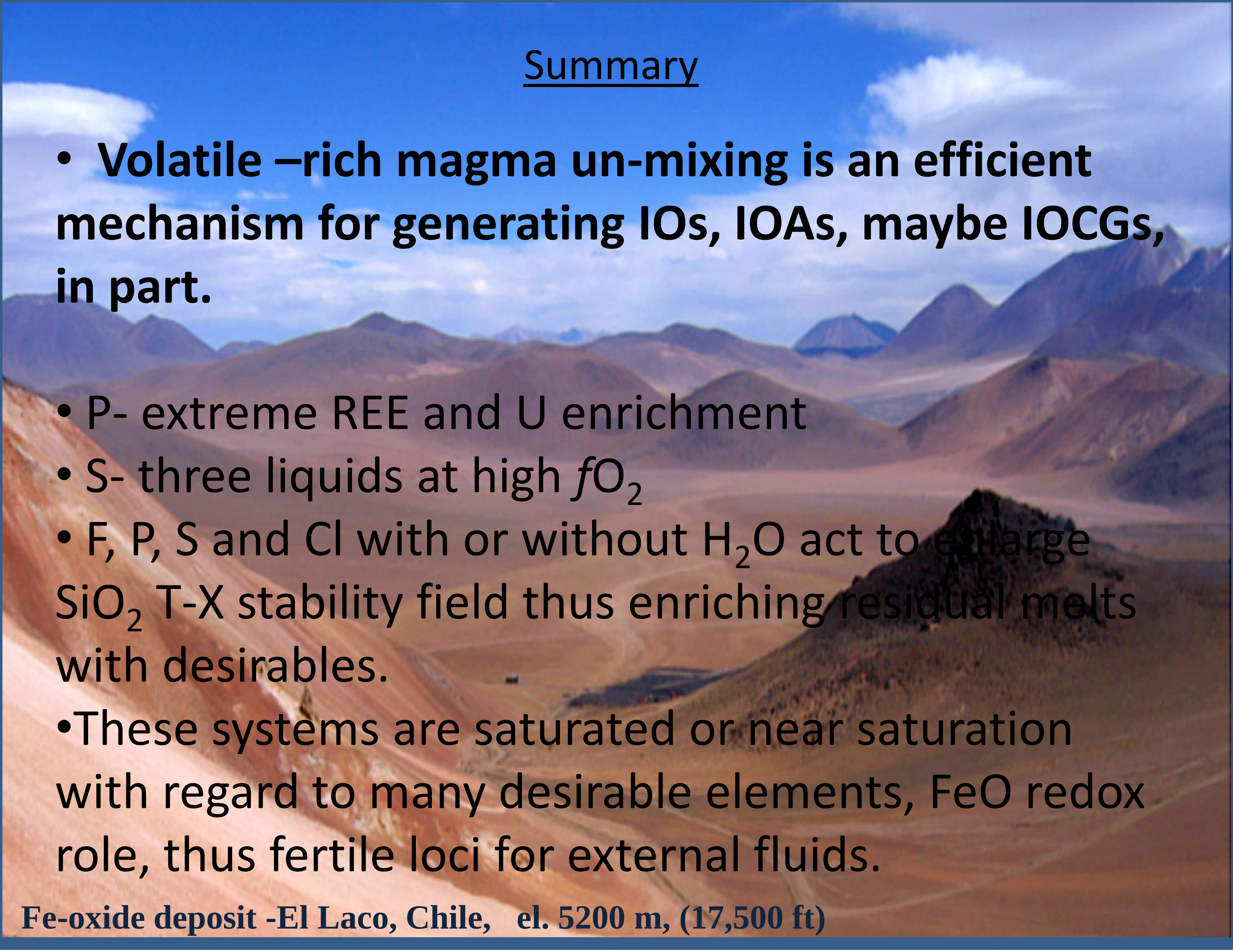


What about gold?

Summary

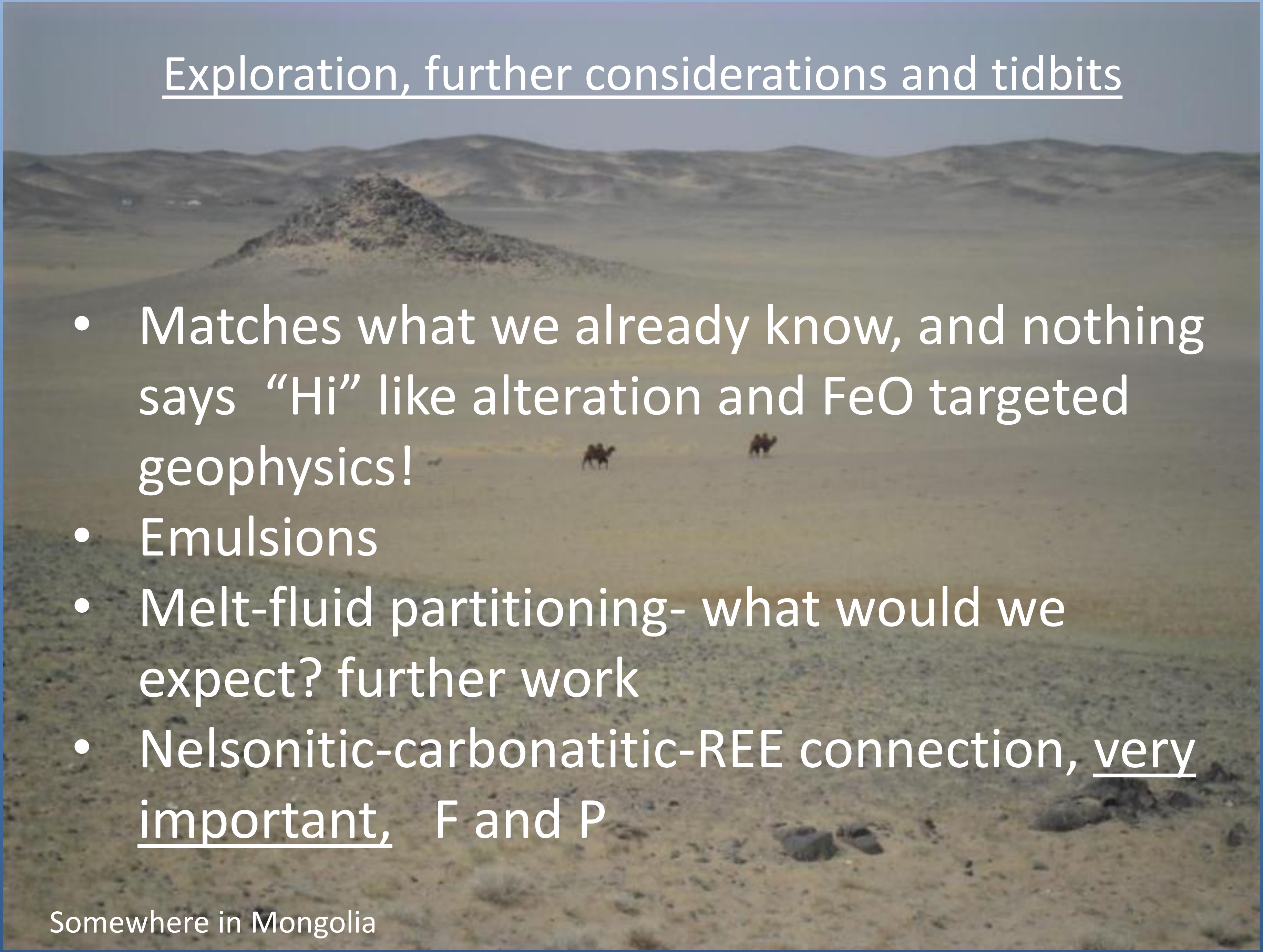
- **Volatile –rich magma un-mixing is an efficient mechanism for generating IOs, IOAs, maybe IOCGs, in part.**

- P- extreme REE and U enrichment
- S- three liquids at high fO_2
- F, P, S and Cl with or without H_2O act to enlarge SiO_2 T-X stability field thus enriching residual melts with desirables.
- These systems are saturated or near saturation with regard to many desirable elements, FeO redox role, thus fertile loci for external fluids.



Fe-oxide deposit -El Laco, Chile, el. 5200 m, (17,500 ft)

Exploration, further considerations and tidbits



- Matches what we already know, and nothing says “Hi” like alteration and FeO targeted geophysics!
- Emulsions
- Melt-fluid partitioning- what would we expect? further work
- Nelsonitic-carbonatitic-REE connection, very important, F and P

Somewhere in Mongolia

Kiruna, Sweden

Acknowledgements

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NSERC

Depth of the Earth Laboratory

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Further interest: Lester et al.; Chemical Geology, 2013, Contributions to Mineralogy and Petrology, 2013, Geochim Cosmochim Acta, 2013