Mantle-lithosphere interactions and their role in the making of mineral systems

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Preamble

- Continental crust is the main host of mineral systems
- Processes of mineral systems formation involve the SCLM and the asthenosphere
- The SCLM has thicknesses of 350 ~250 to 350 km, beneath Archaean cratons and ~150 km beneath Phanerozoic terranes
- The SCLM may be eroded/partially destroyed by thermal events (mantle plumes, delamination)
- Thickened SCLM and continental crust, may become gravitationally unstable and delaminate into the asthenosphere
- The SCLM is subjected to metasomatism

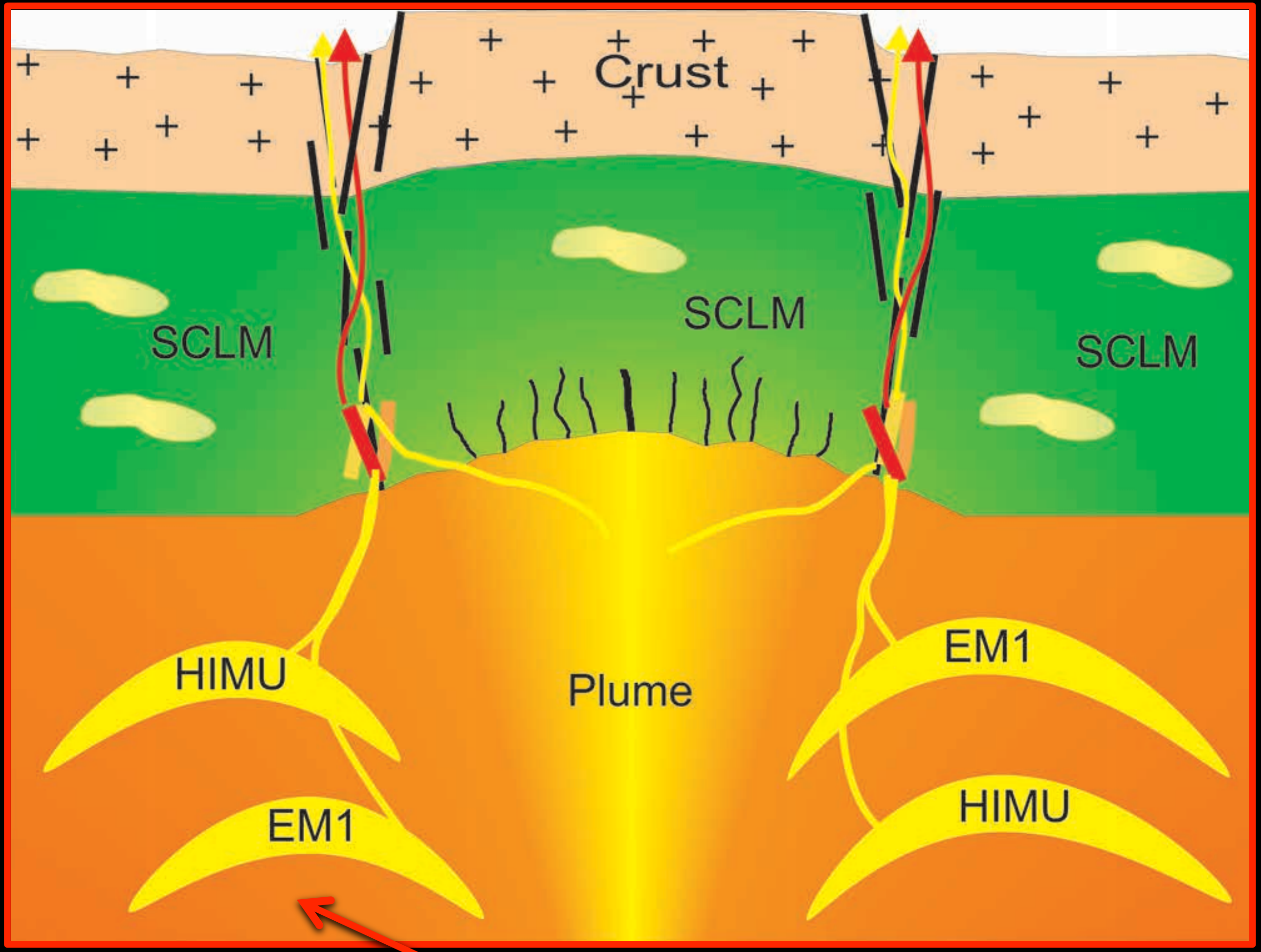
Magmatic-hydrothermal mineral systems: e. g. porphyry, skarns, epithermal, greisens, pegmatites, IOCG, REE in carbonatites and alkaline complexes

May form via partial melting of a metasomatised SCLM

The SCLM is subject to metasomatism either from subduction-derived volatiles (H_2O, Cl, H_2S, etc)

AND/OR

From volatiles (CO_2, F and Cl) released from upwelling asthenospheric melts or mantle plumes degassing



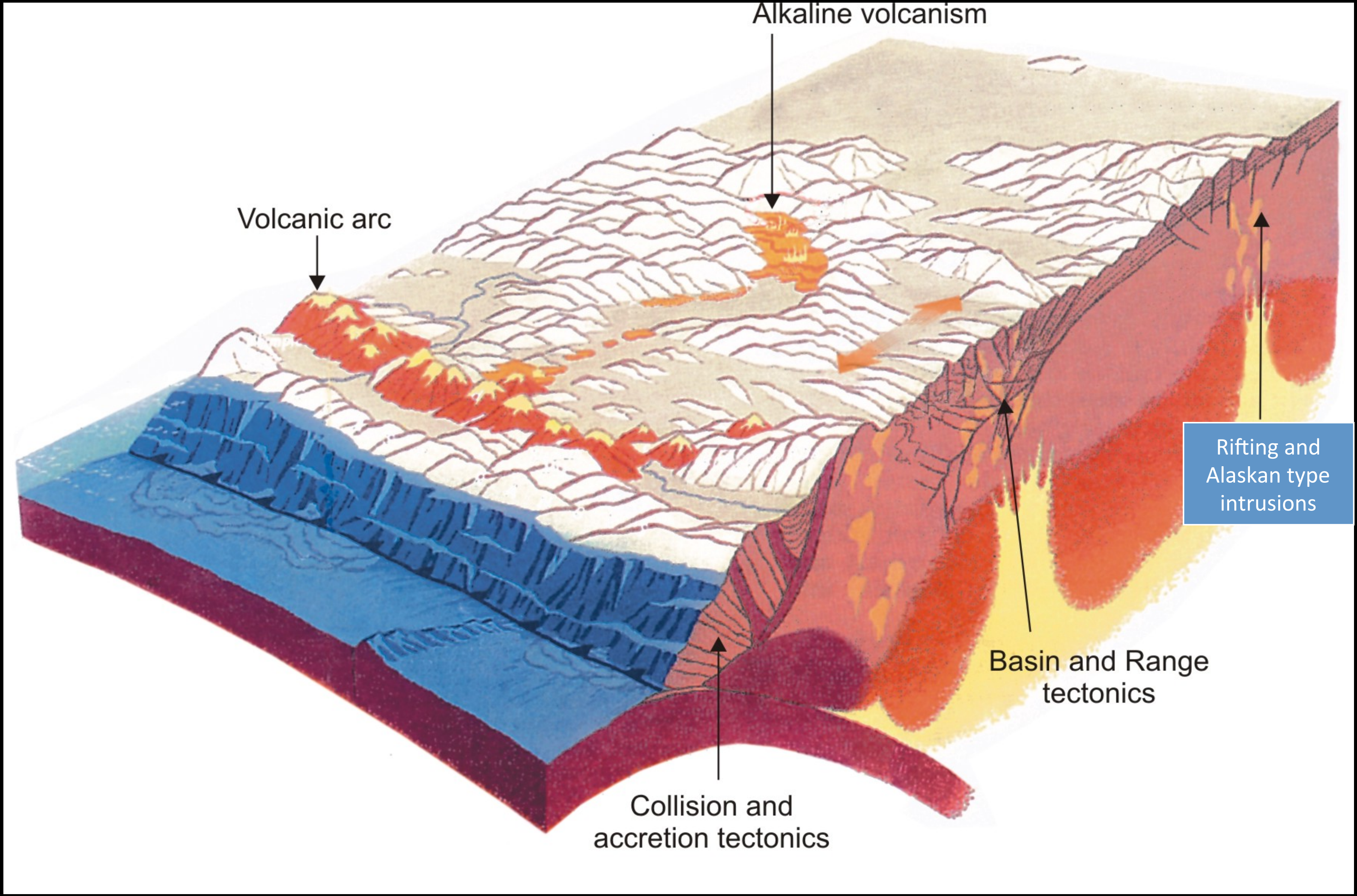
Idealised cross-section of crust, SCLM and mantle and fluids/volatiles flow

Sublithospheric isotopically heterogenous mantle, with pods of HIMU and EM1 material

HIMU μ = $^{238}U/^{204}Pb$ ratio of an Earth reservoir

EM1 enriched mantle with intermediate $^{87}Sr/^{86}Sr$ and low $^{206}Pb/^{204}Pb$

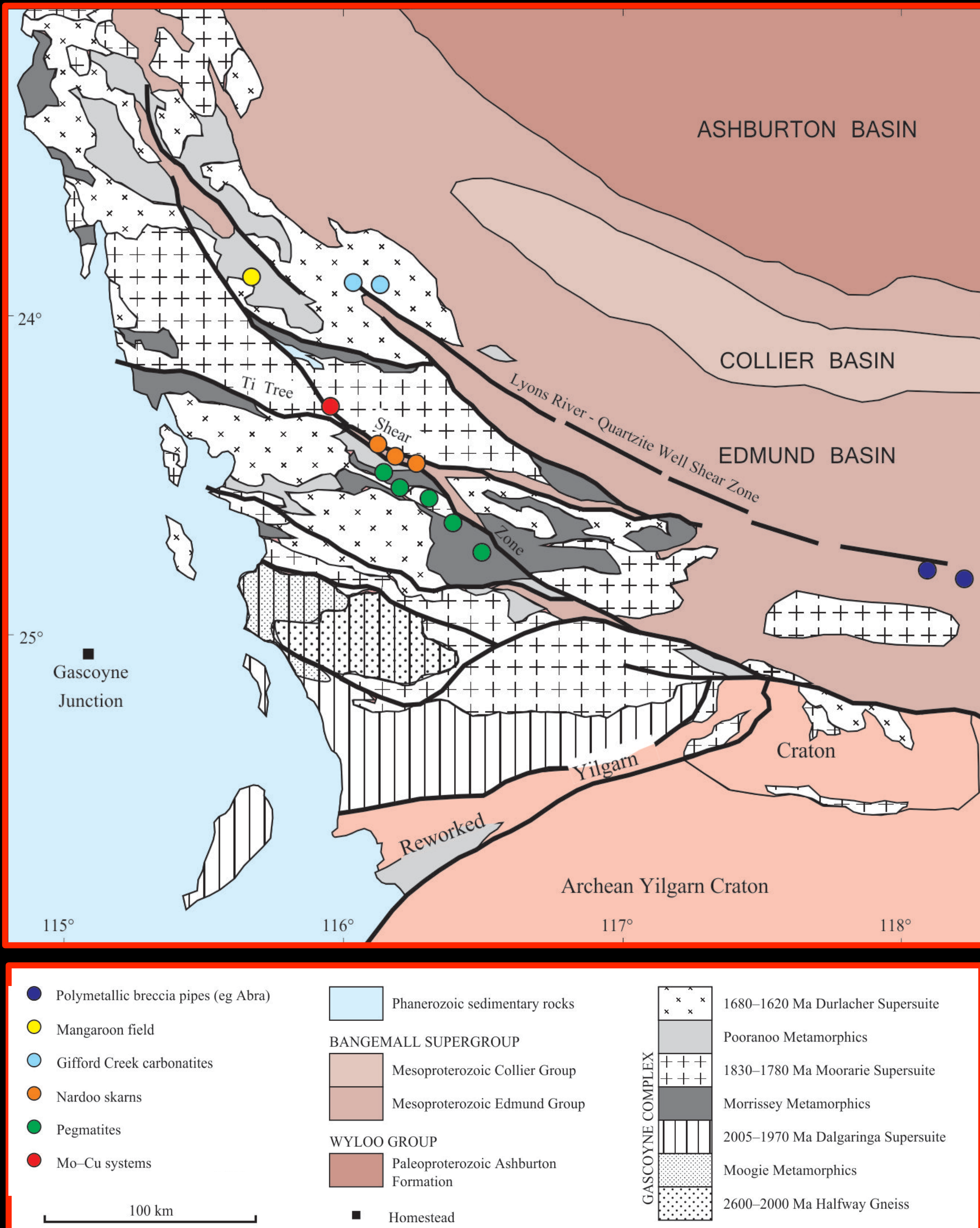
From Keith Bell and Tony Simonetti; 2010, Mineralogy and Petrology, v. 98

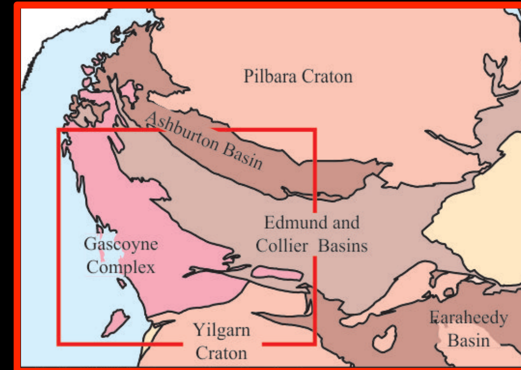


Slab break-off; upwelling of asthenospheric mantle

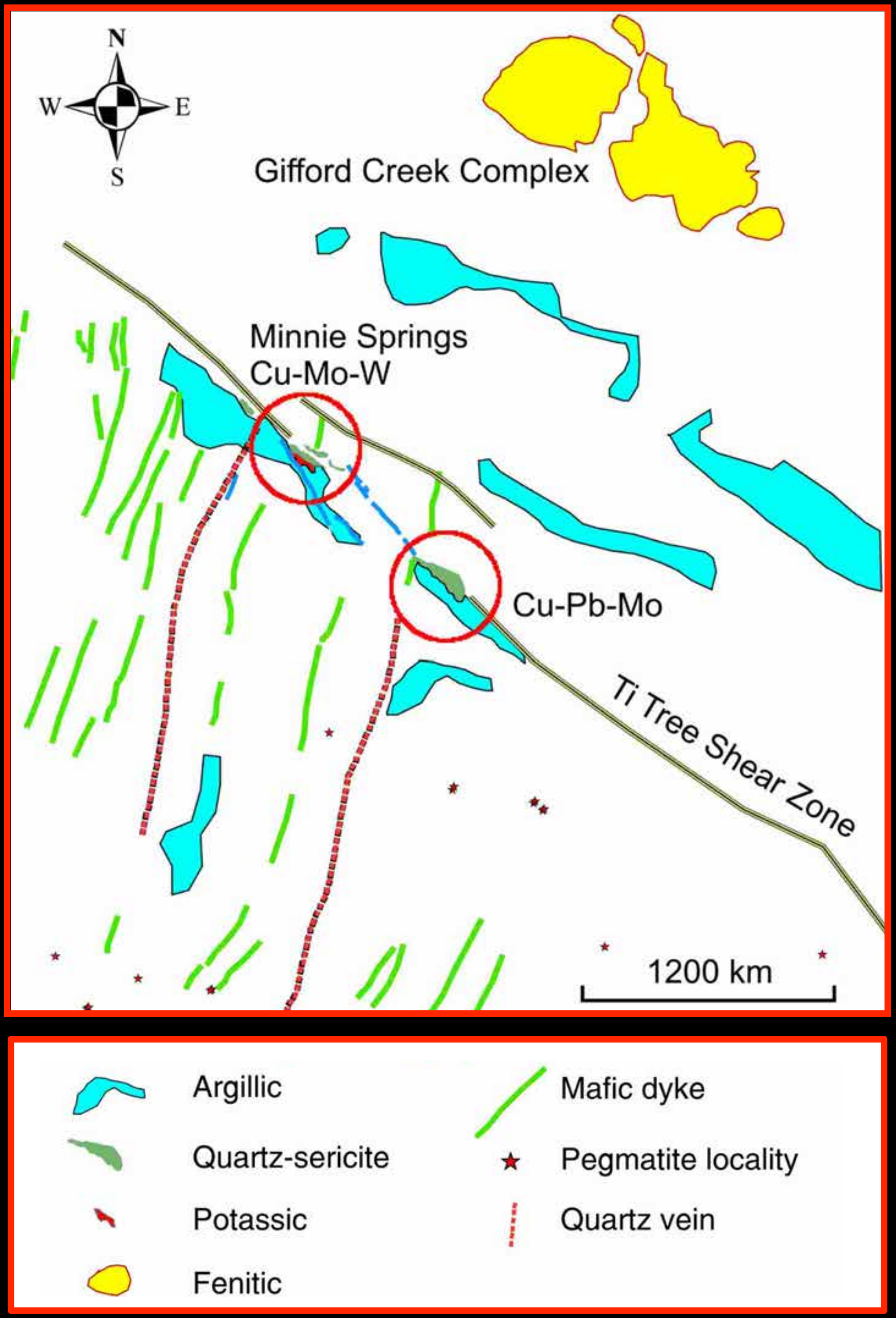
GASCOYNE PROVINCE AND WESTERN CAPRICORN OROGEN

Distribution of selected mineral systems along major structures





Unaltered granite at right, flanked by strong foliation fabric with chloritic (1) and sericitic (2) alteration along Ti Tree shear zone.



Areas of hydrothermal alteration based on field observations combined with ASTER data analysis

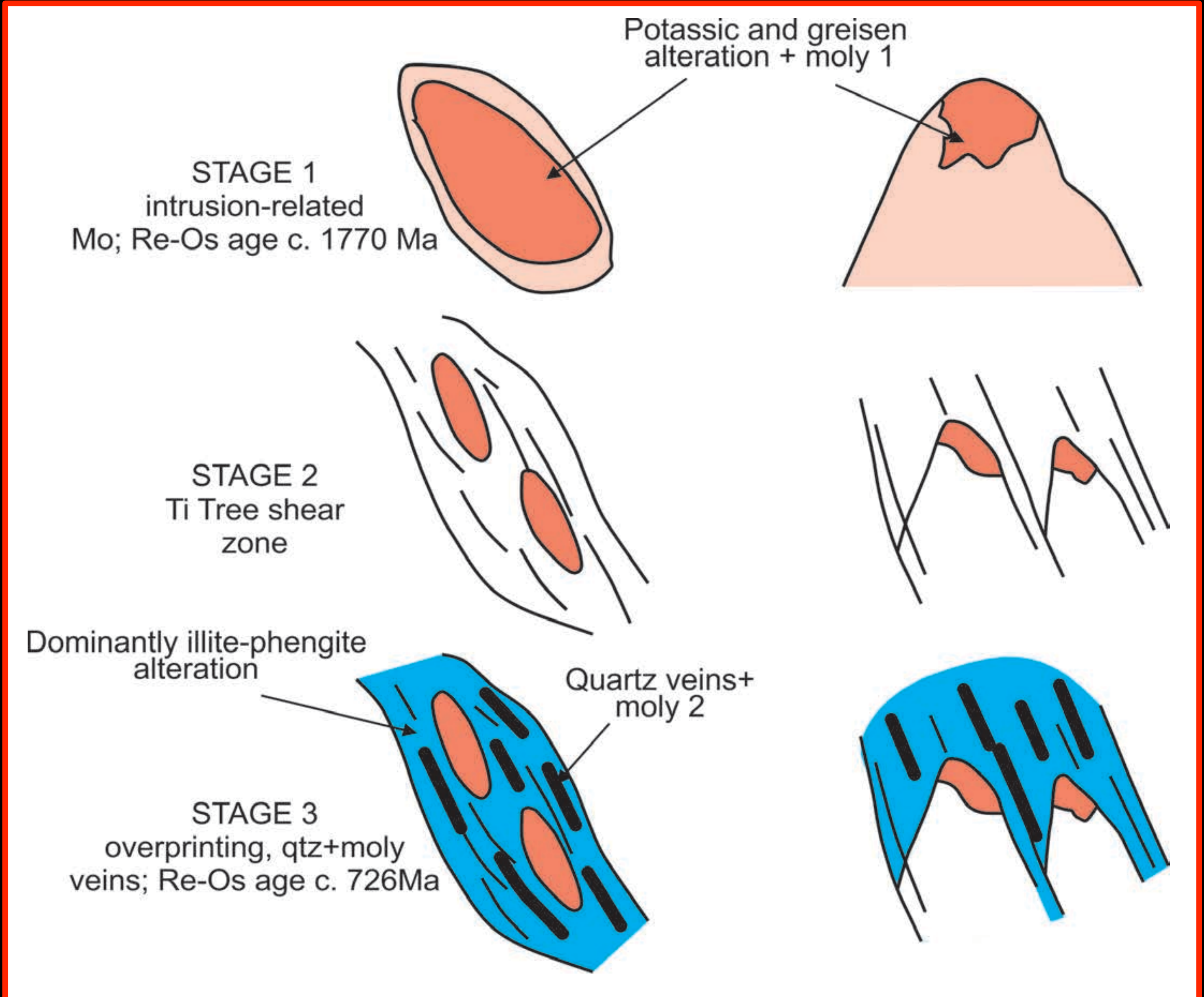
Field and petrographic observations indicate phases of protracted hydrothermal activity within regional planar structures, particularly the Ti Tree Shear Zone;

Importantly, there is evidence that sericitic alteration OVERPRINTS the foliation fabric in the shear zone

Minnie Ck
Cu-Mo-W prospect

Late moly in quartz veinlets

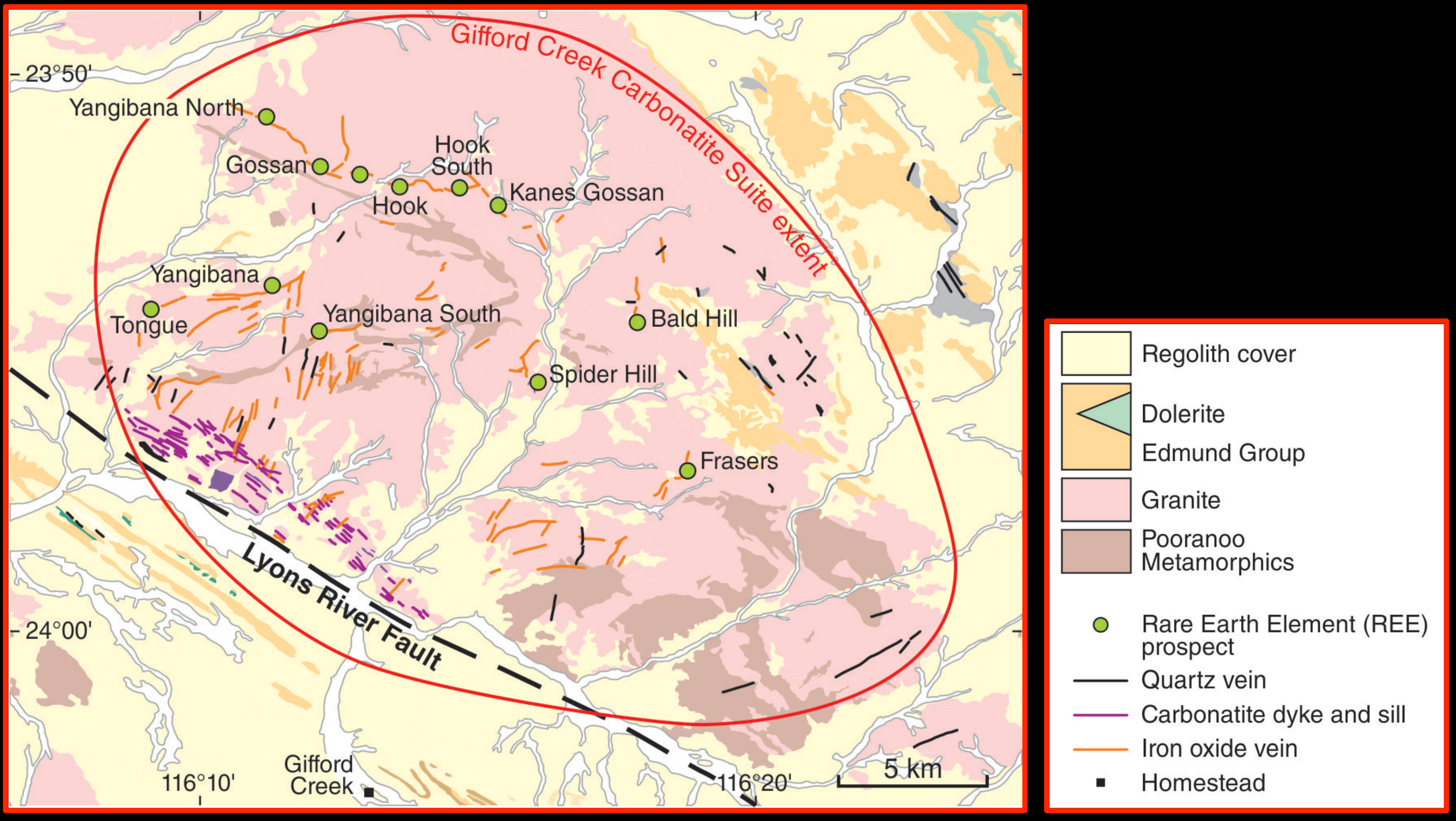
Early disseminated moly



Tentative sequence of events that led to the formation of the Minnie Springs intrusion-related mineral systems

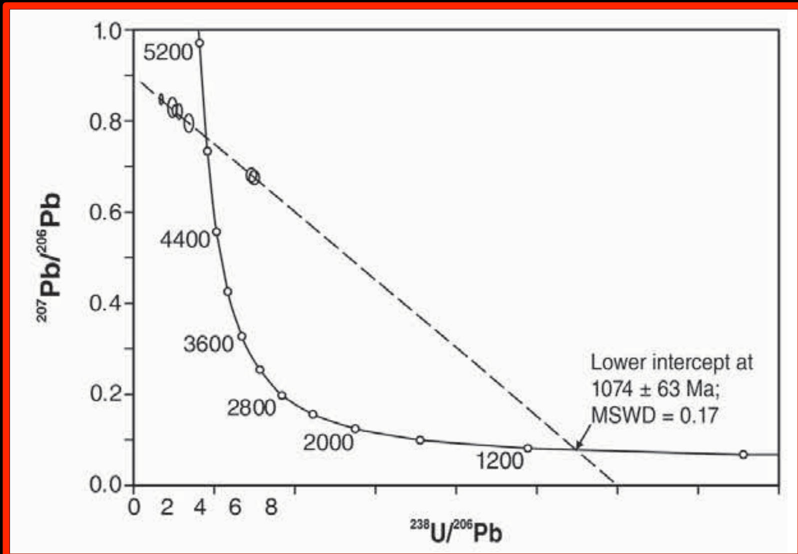
(Re-Os dating, Pirajno, Mao JW, Du A, unpublished)

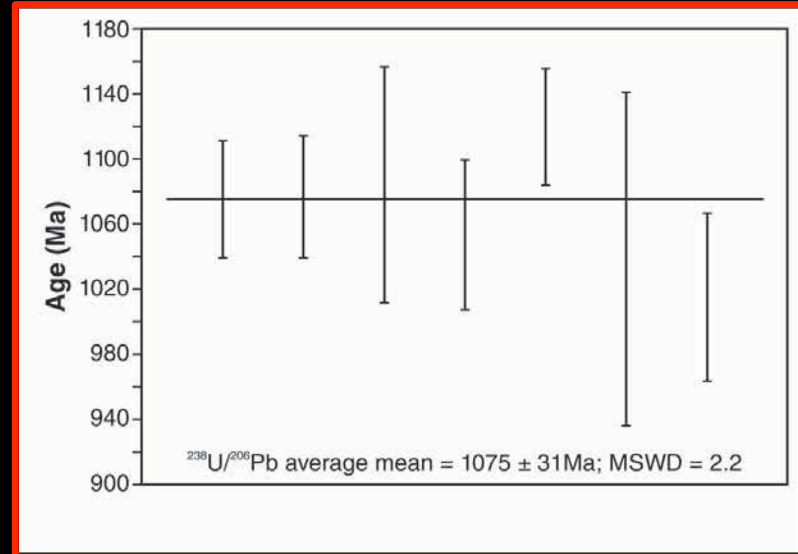
Gifford Creek ferrocarbonatites

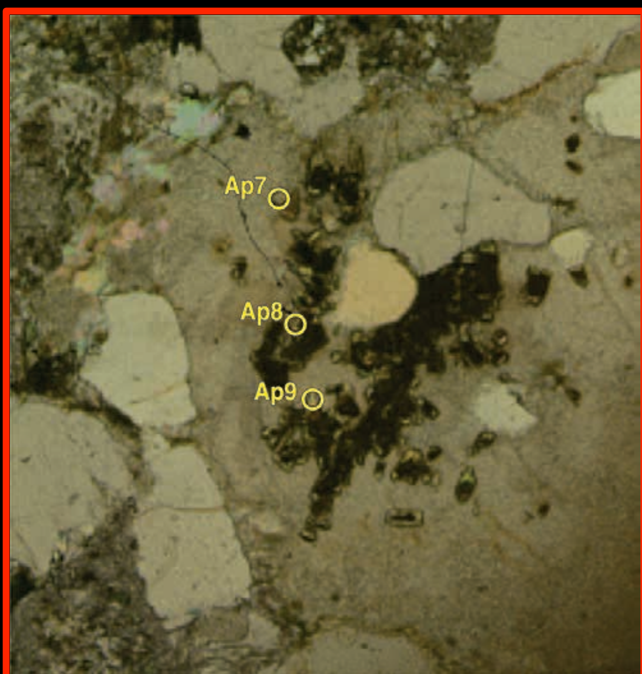


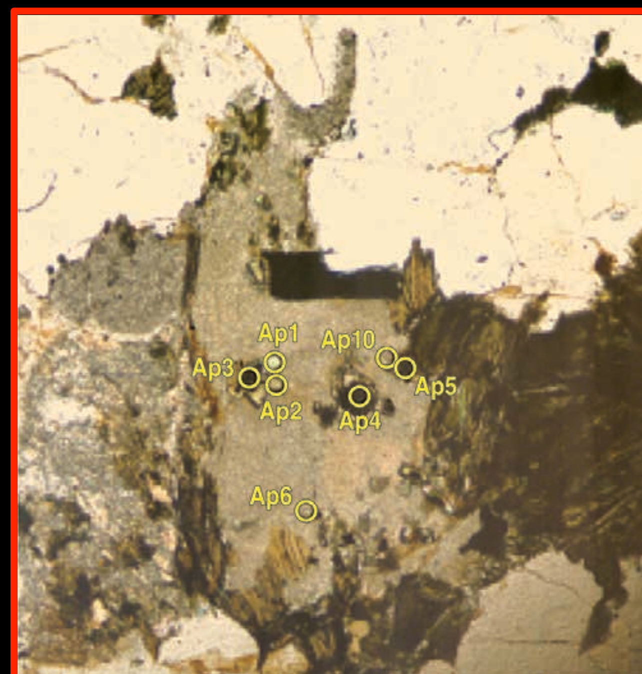
Pirajno and González-Álvarez, GSWA Record 2013/12; and Pirajno et al. in prep

U-Pb age determination of apatite grains of Gifford Creek ferrocarbonatite by LA-ICP-MS (Wei Chen and Antonio Simonetti, Notre Dame University)

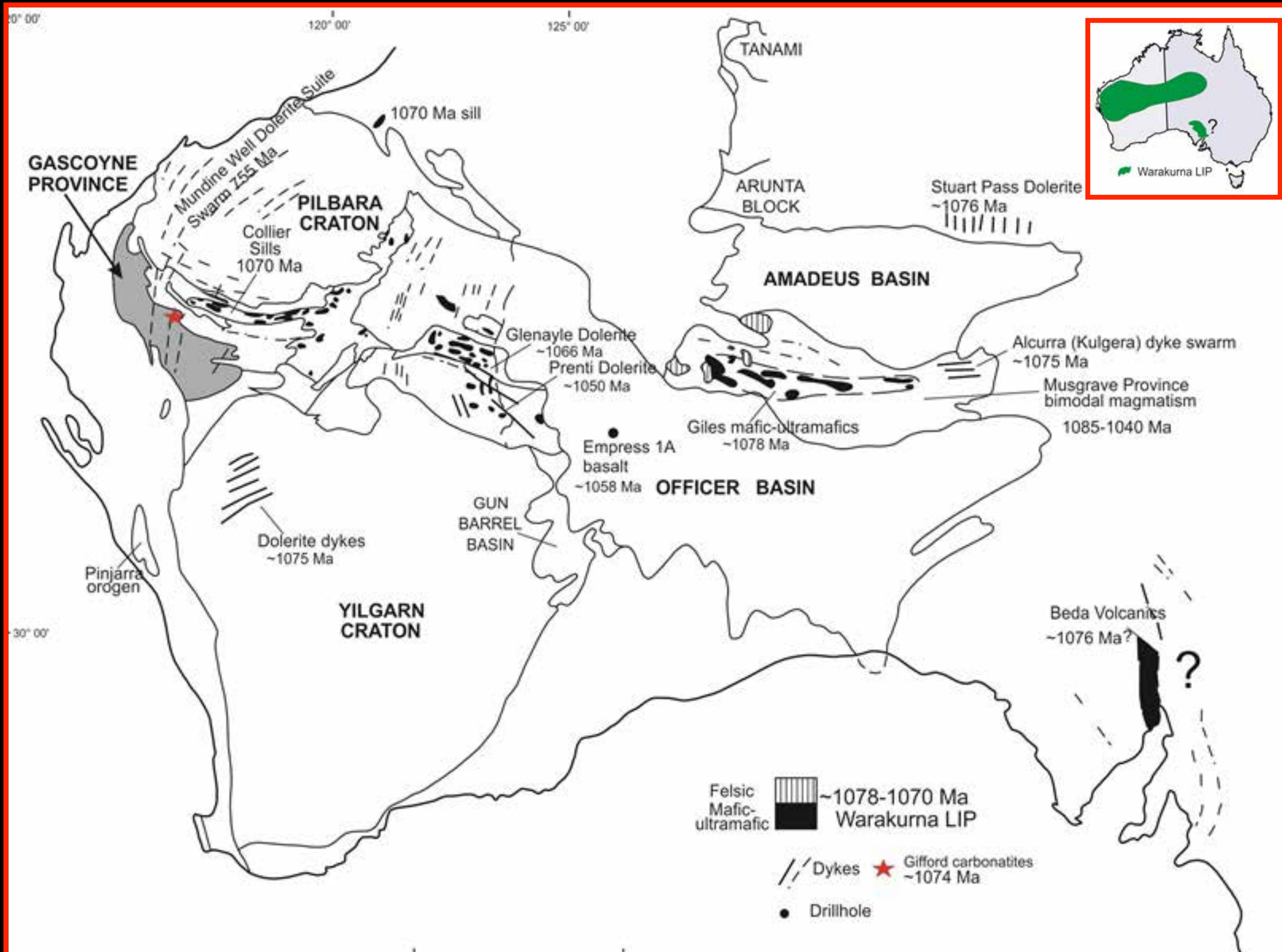






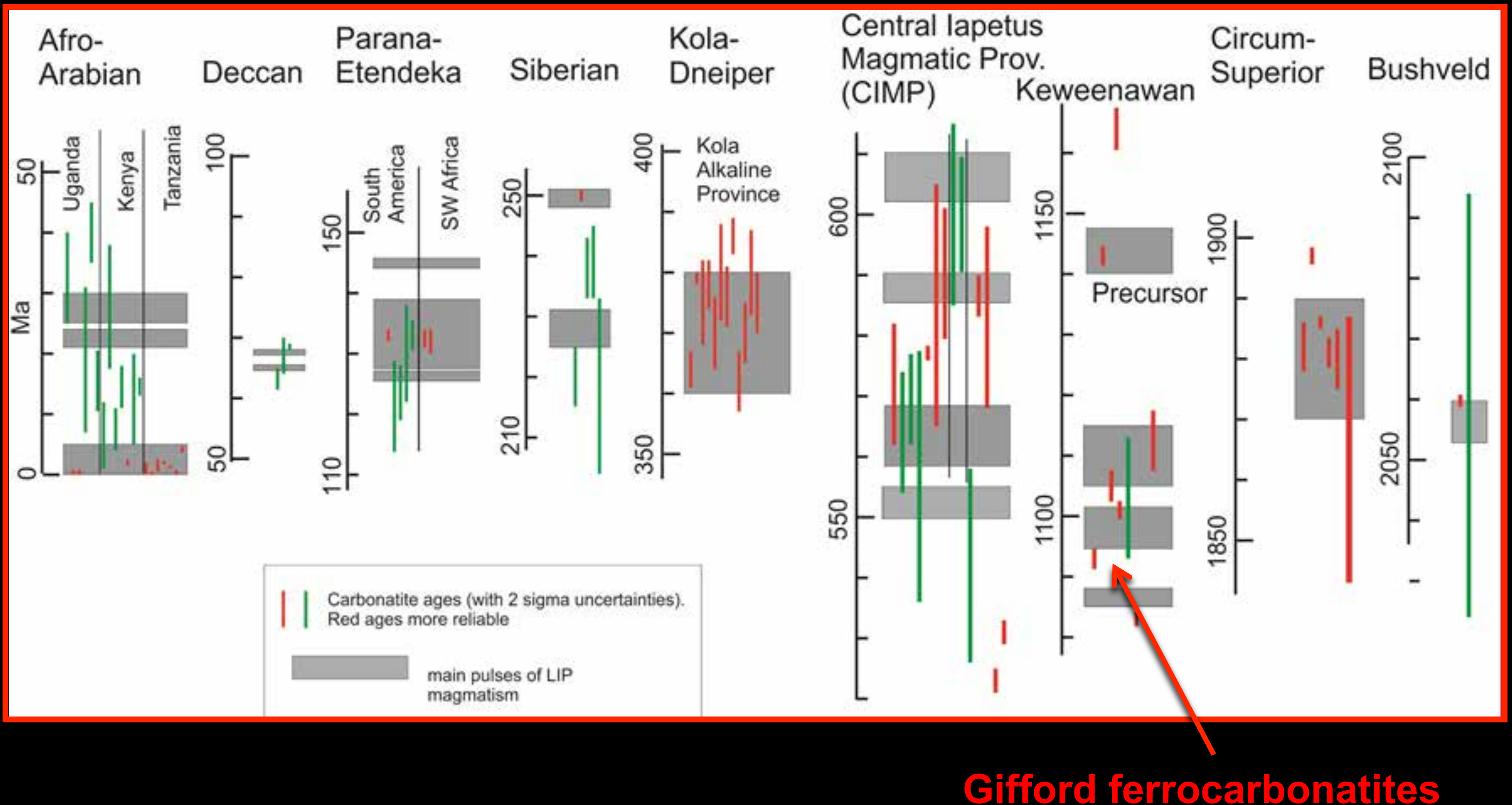


Pirajno et al. in prep

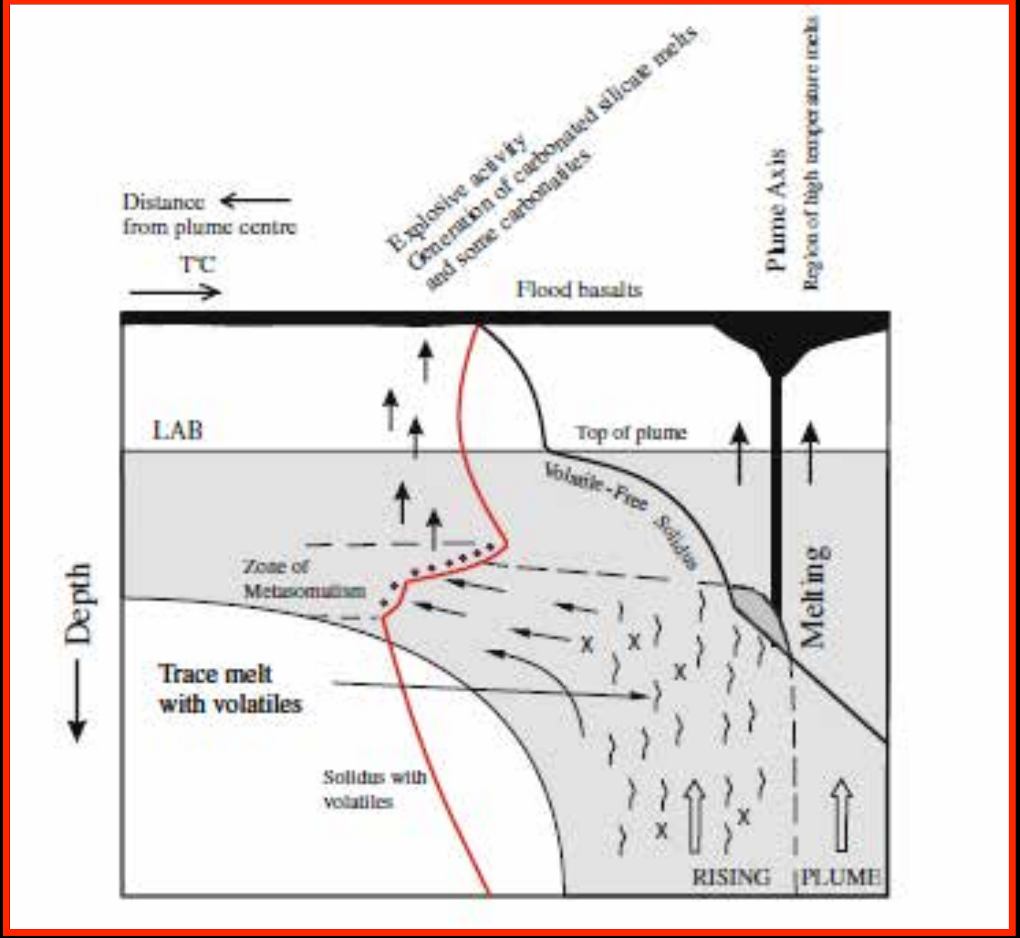


Pirajno and Hoatson, 2013, OGR and Pirajno et al. in prep

Temporal association of carbonatites and LIPs, based on age distribution in selected provinces

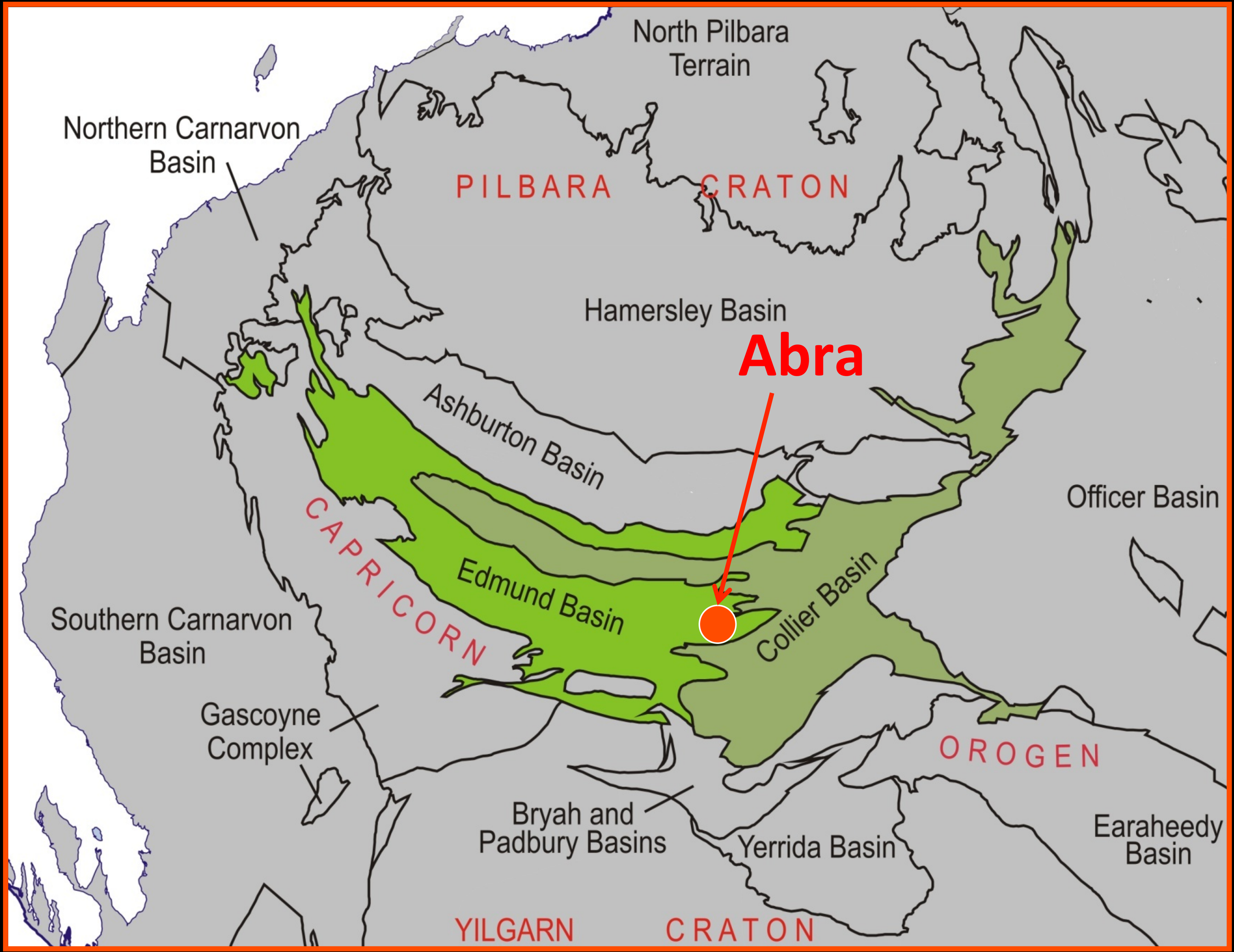


From Ernst and Jowitt, Econ Geol, 2013; by courtesy of R. Ernst

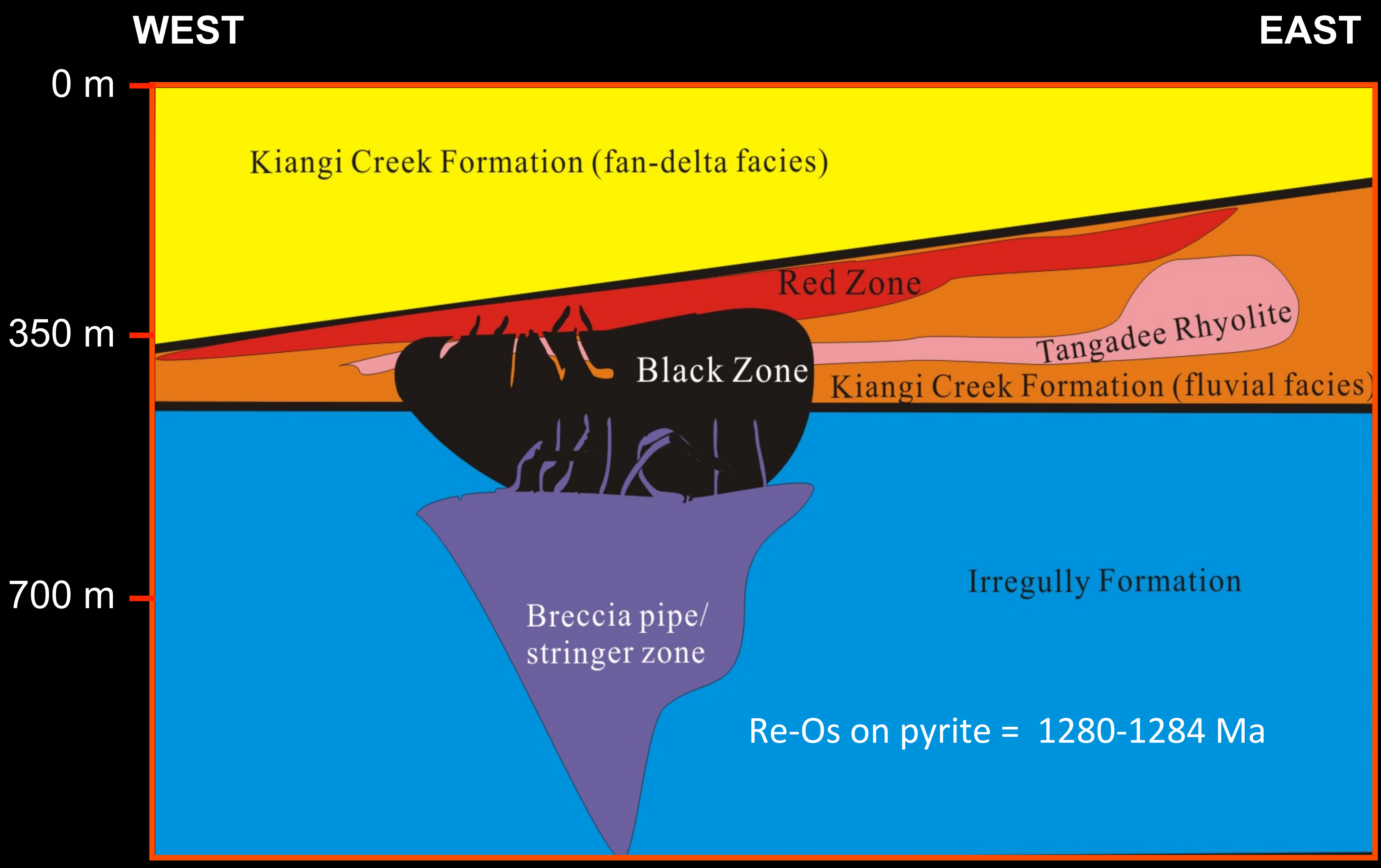


From Ernst and Bell, 2010, Mineralogy and Petrology, v. 98

Regional geological setting

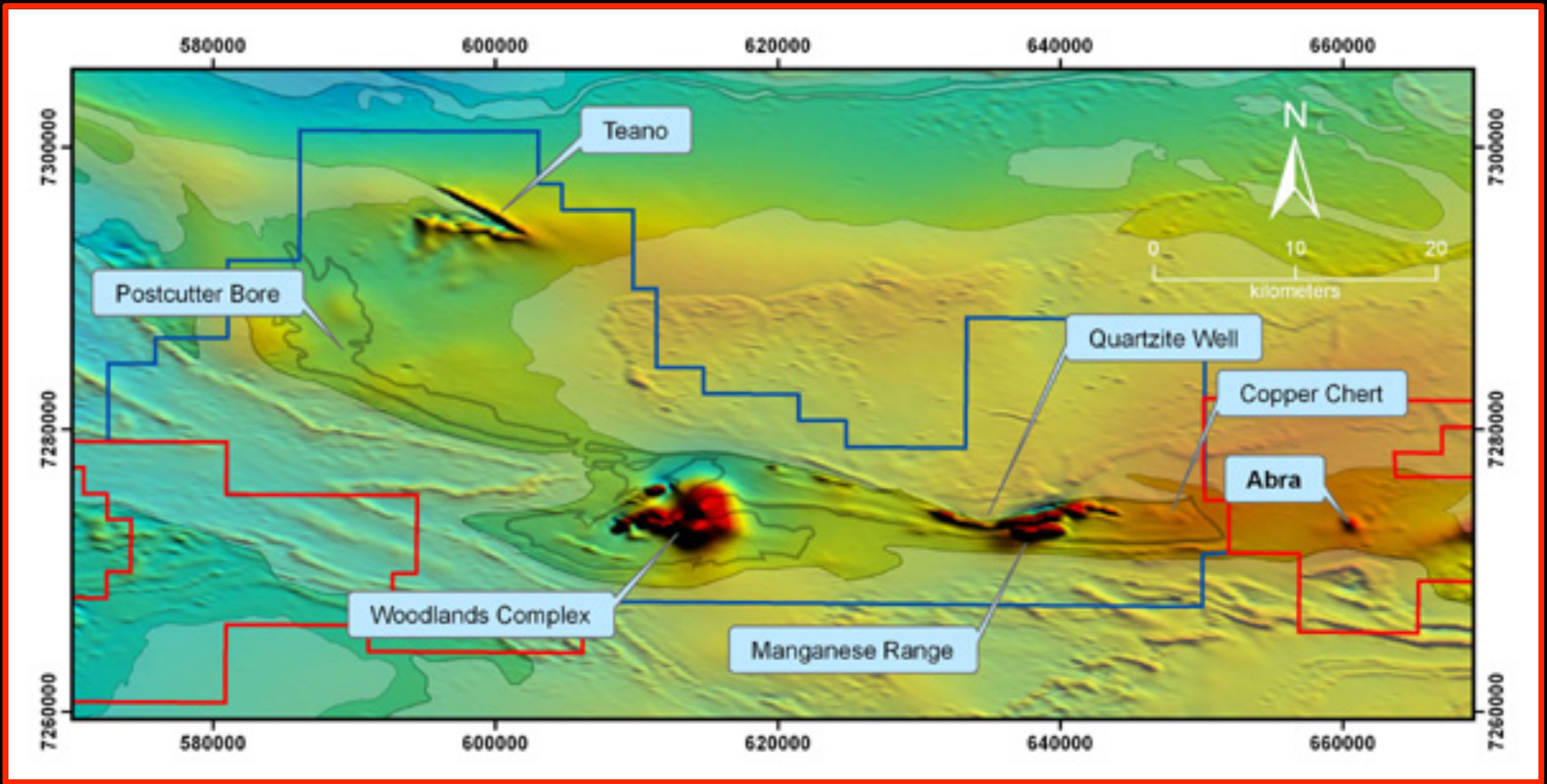


Stratigraphic setting and interpreted geometry of the Abra mineralisation

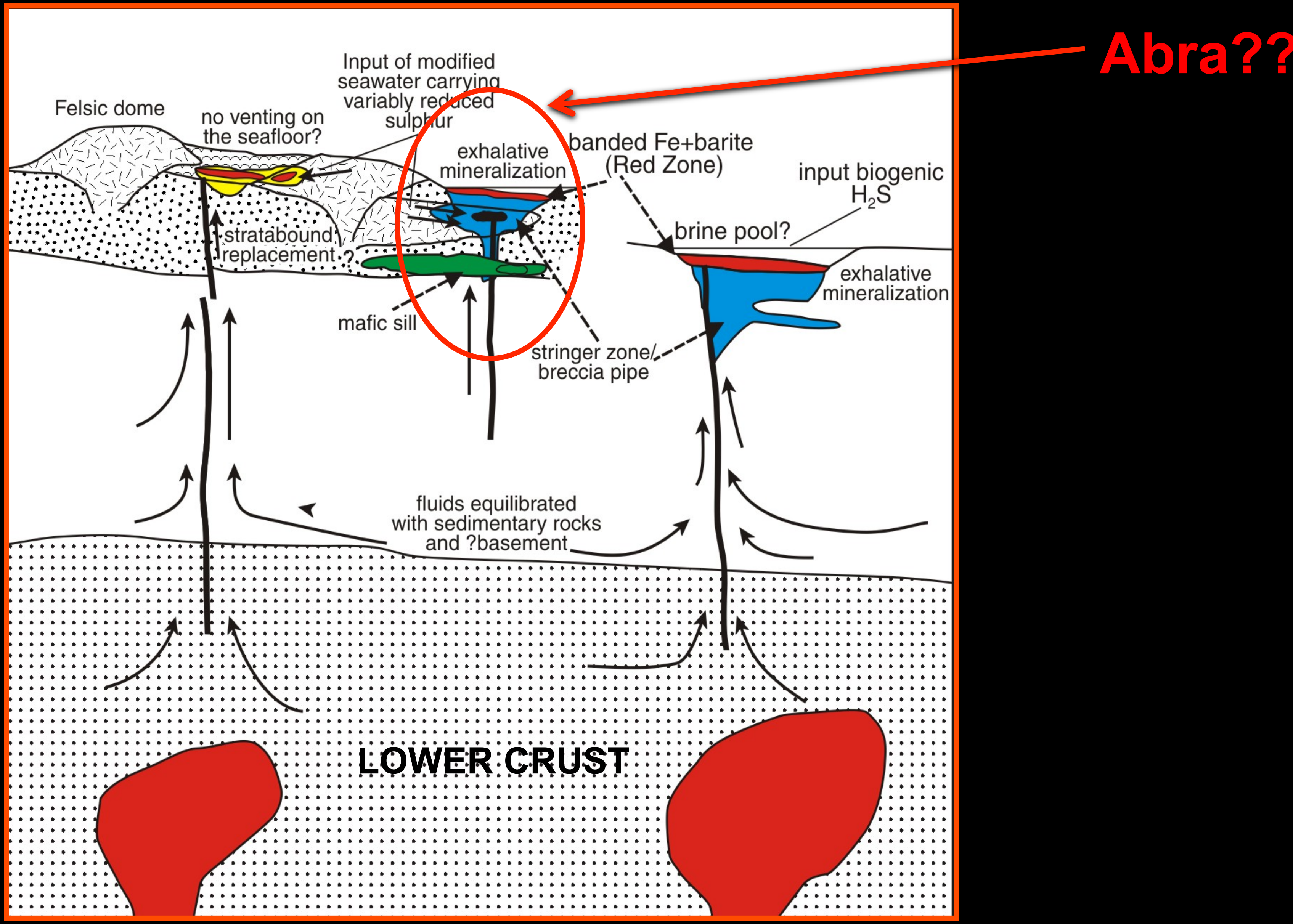


Pirajno et al. 2010, IAGOD Congress Ext Abs and Pirajno et al. GSWA Report In prep)

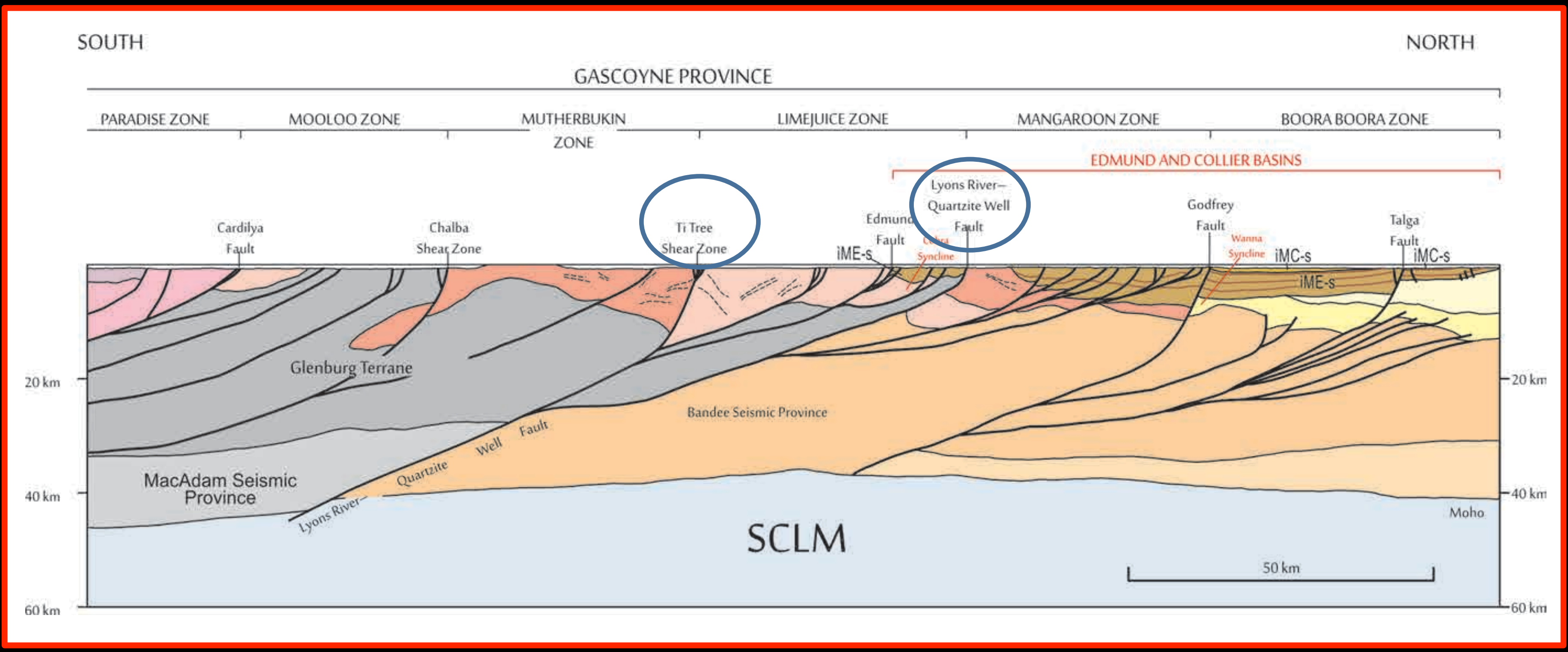
Distribution of mineral systems along the Quartzite Well shear zone on a TMI (total magnetic intensity) image



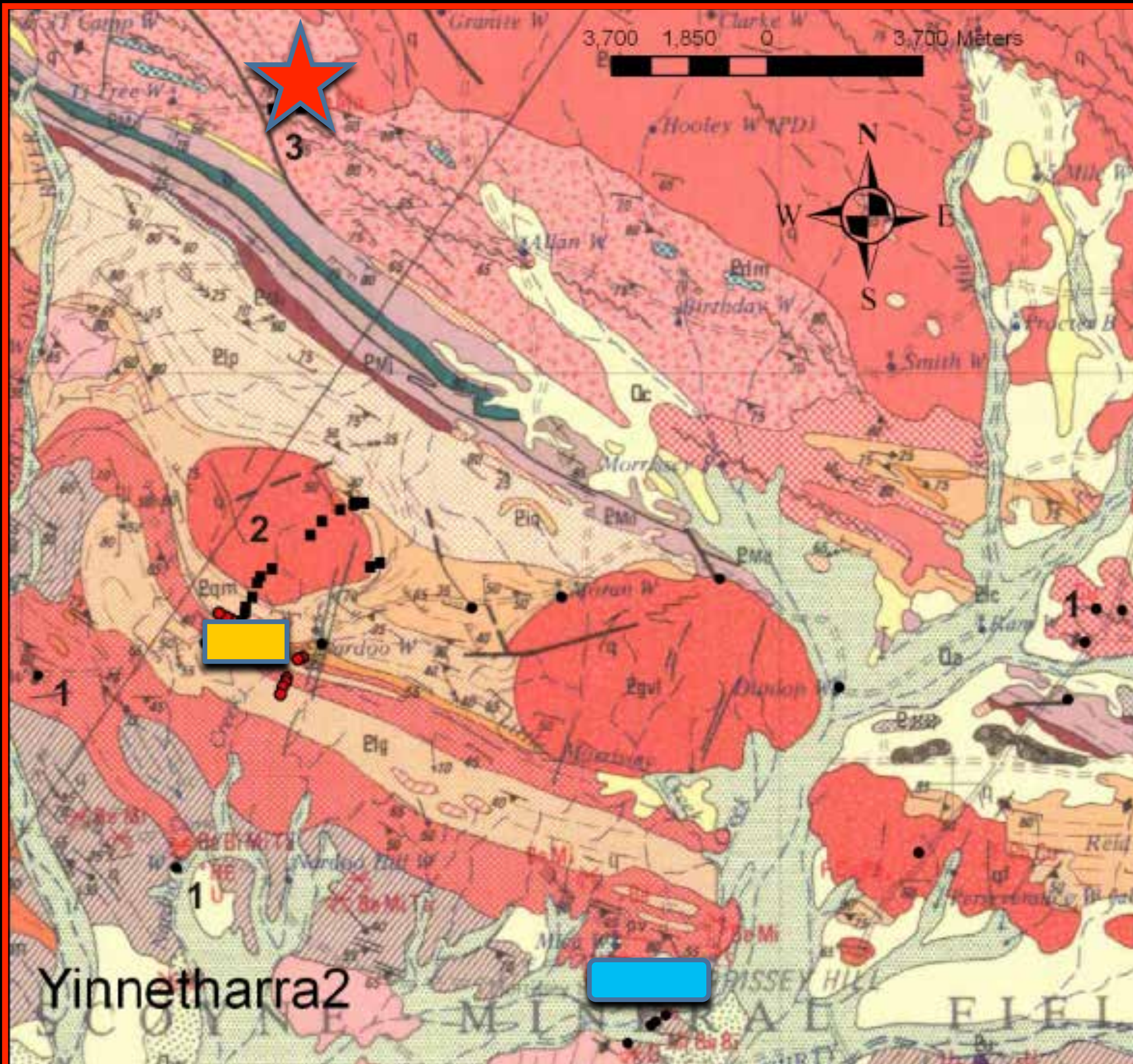
Possible genetic model for the Abra polymetallic breccia pipe



Model based on Iberian Pyrite Belt (IPB); after Tornos (2006), OGR, v. 28, Interpretation of seismic transect across the Gascoyne Province



After and details in
Johnson SP et al. 2013, Aus J E S, v. 60



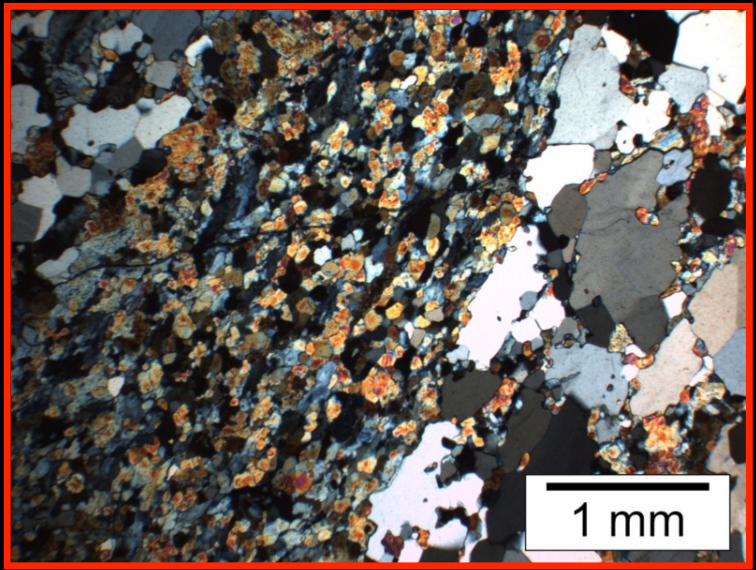
1) Pegmatites and Quartz veins
950 Ma

2) W skarns*

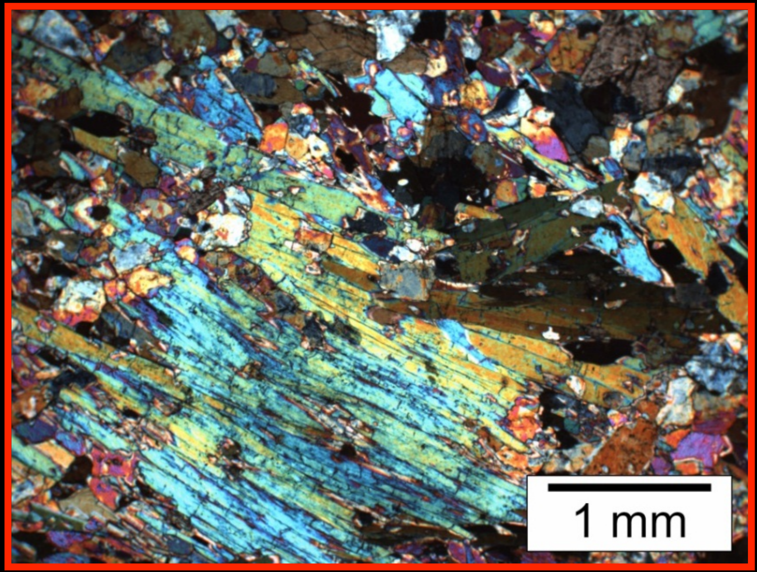
3) Intrusion-related Pb-Cu-Mo
1770-975 Ma

(*) calc-silicate alteration (skarn) NOT associated with carbonate rocks

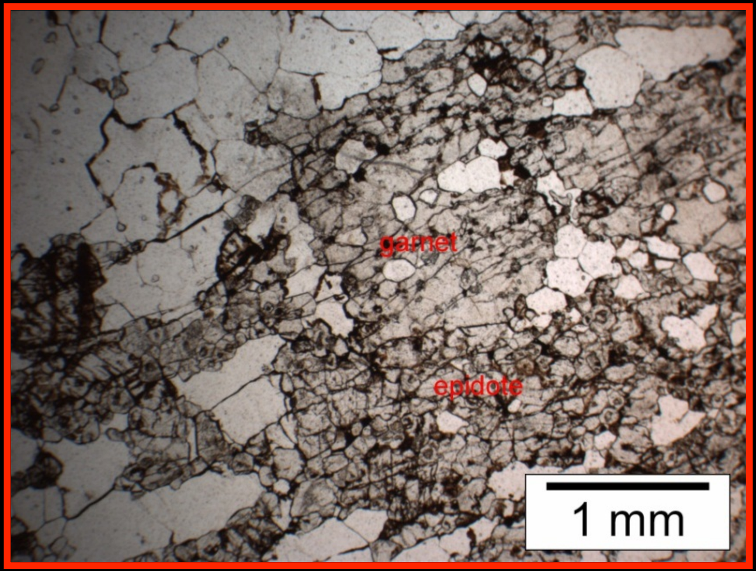
Nardoo W skarns, Gascoyne Province



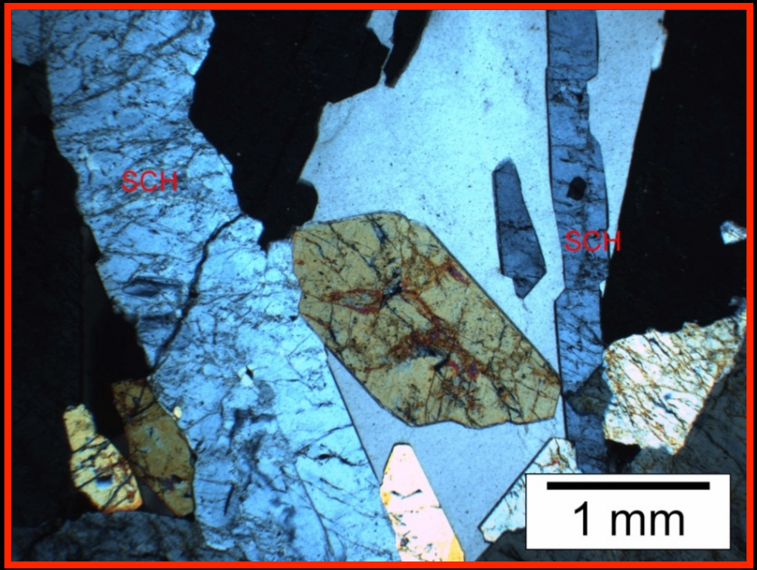
187873 epidote-rich band overprinting
a quartz polygonal aggregate



187878; actinolite sheafs replacing epidote
+quartz assemblage

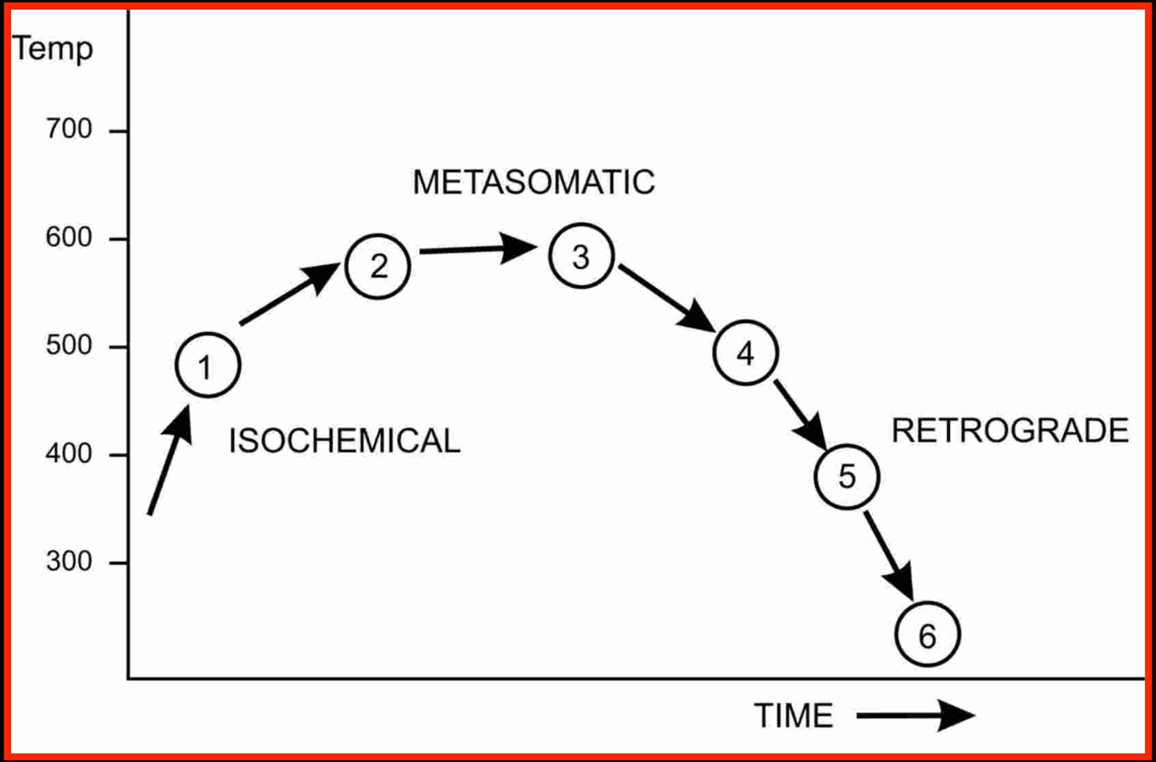


187869; garnet and epidote replacing polygonal
quartz assemblage



187867; scheelite crystals

SKARNS
(contact metasomatic; intrusion-carbonate rocks)



Skarn mineral system and stages of its formation:
1) isochemical, hornfels;
2) metasomatism, exo- and endo-skarn;
3) Retrograde stage

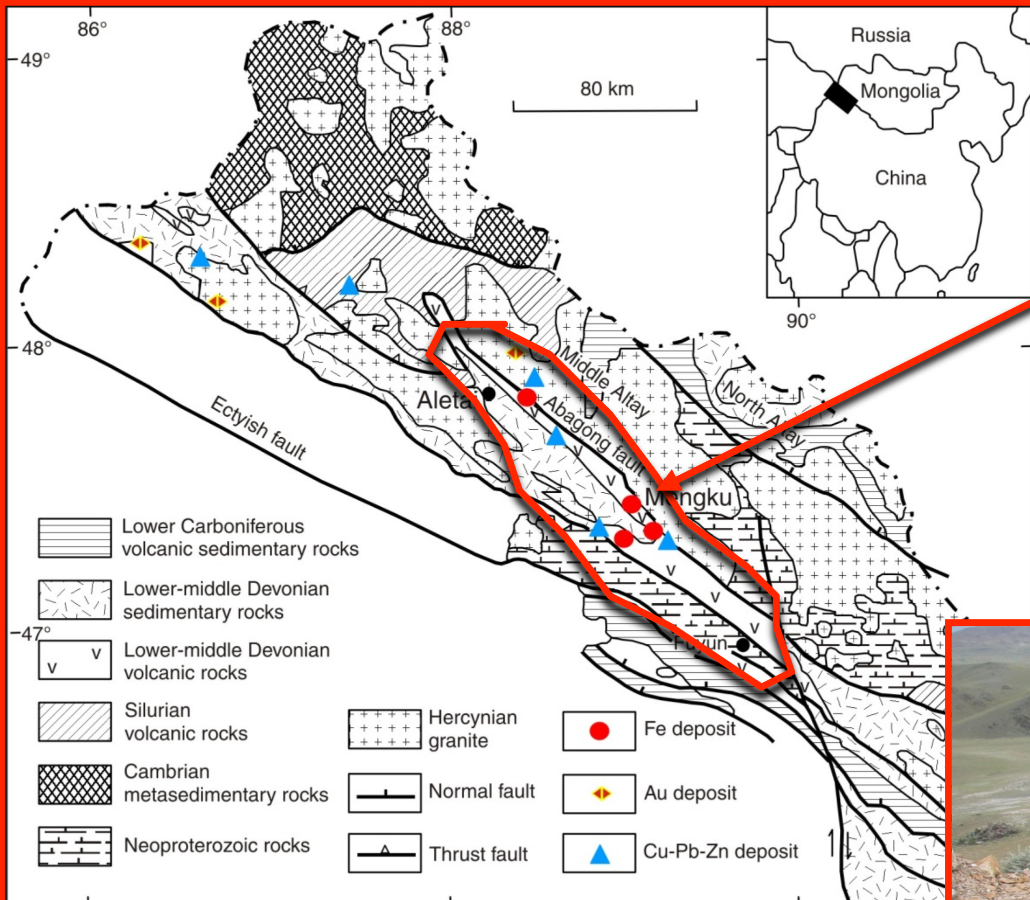
After Einaudi et al. , 1981

The skarn alteration and associated mineralisation (usually W, Mo-W, Fe-P) affects rocks other than carbonates

This calc-silicate alteration has regional extent and has no genetic relationship with spatially associated granitoids

How are these skarn formed?

High-T, Low-P metamorphism associated with upwelling asthenospheric mantle along major strike-slip shear zones/sutures



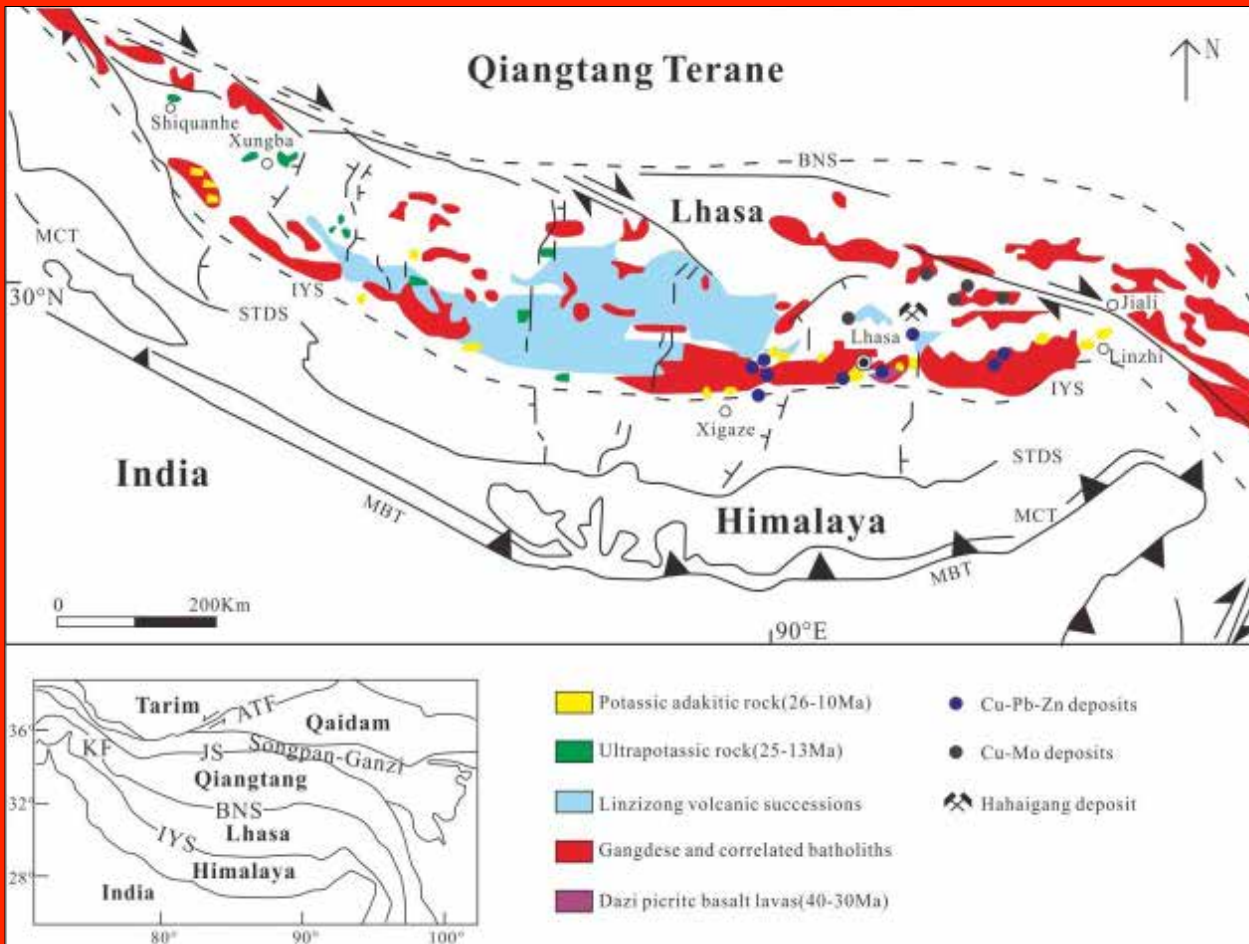
Skarn and listwaenite belt

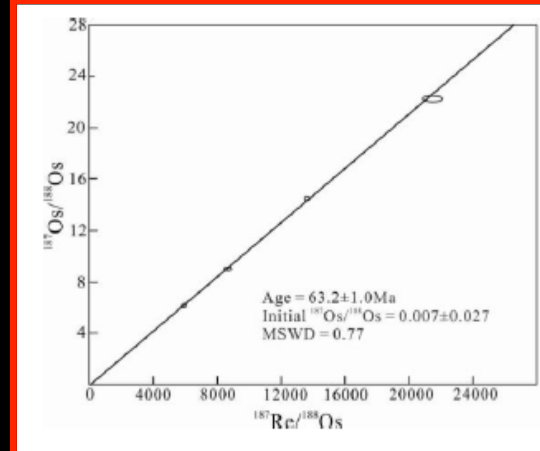
Altai orogen (NW China; Xinjiang Province), part of the Central Asian Orogenic Belt

Listwaenite outcrop, qtz stockworks

Abagong “”skarn”” (Fe-P) deposits (black lines in Google Earth image)

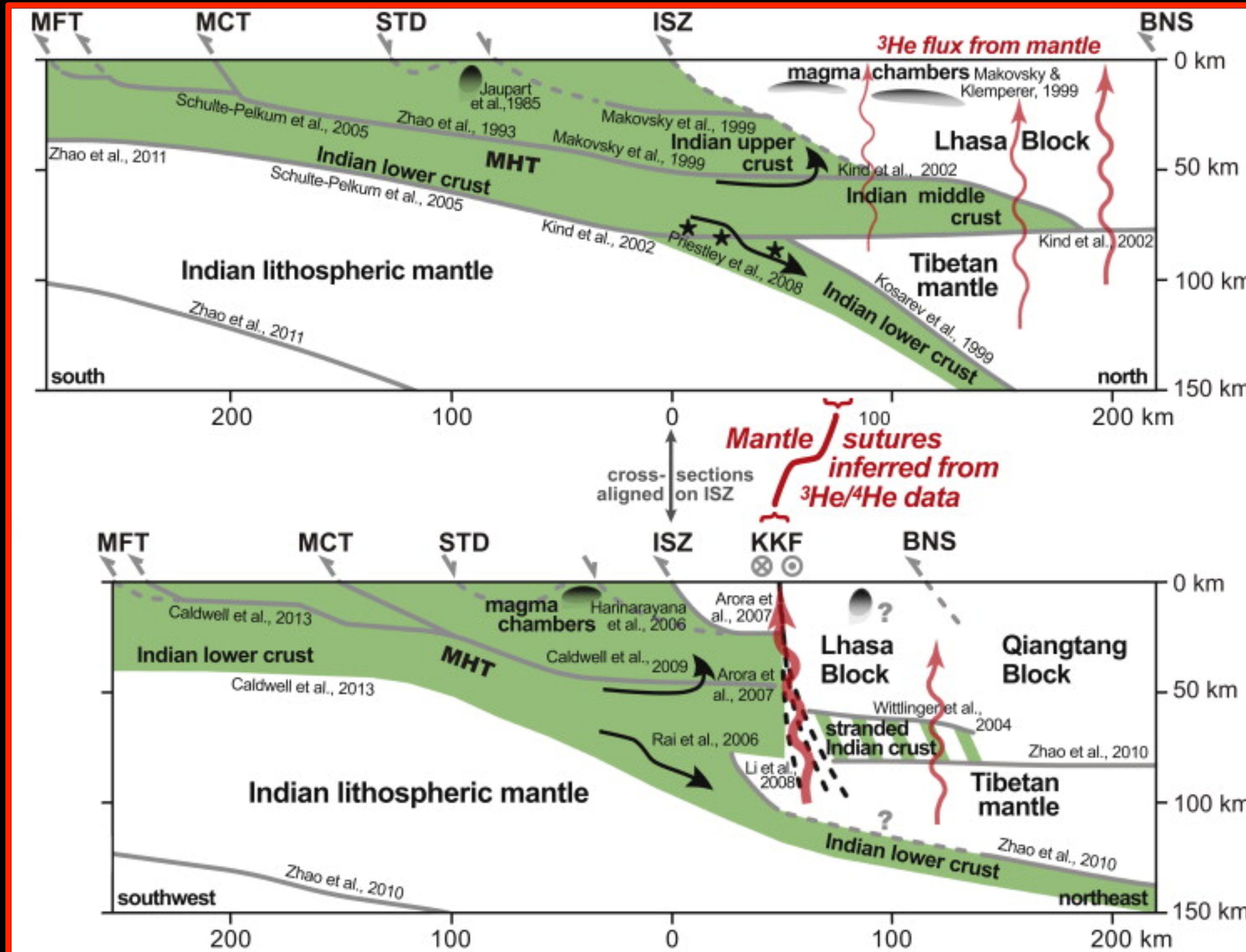
A) Massive wollastonite skarn
B) Garnet-magnetite skarn





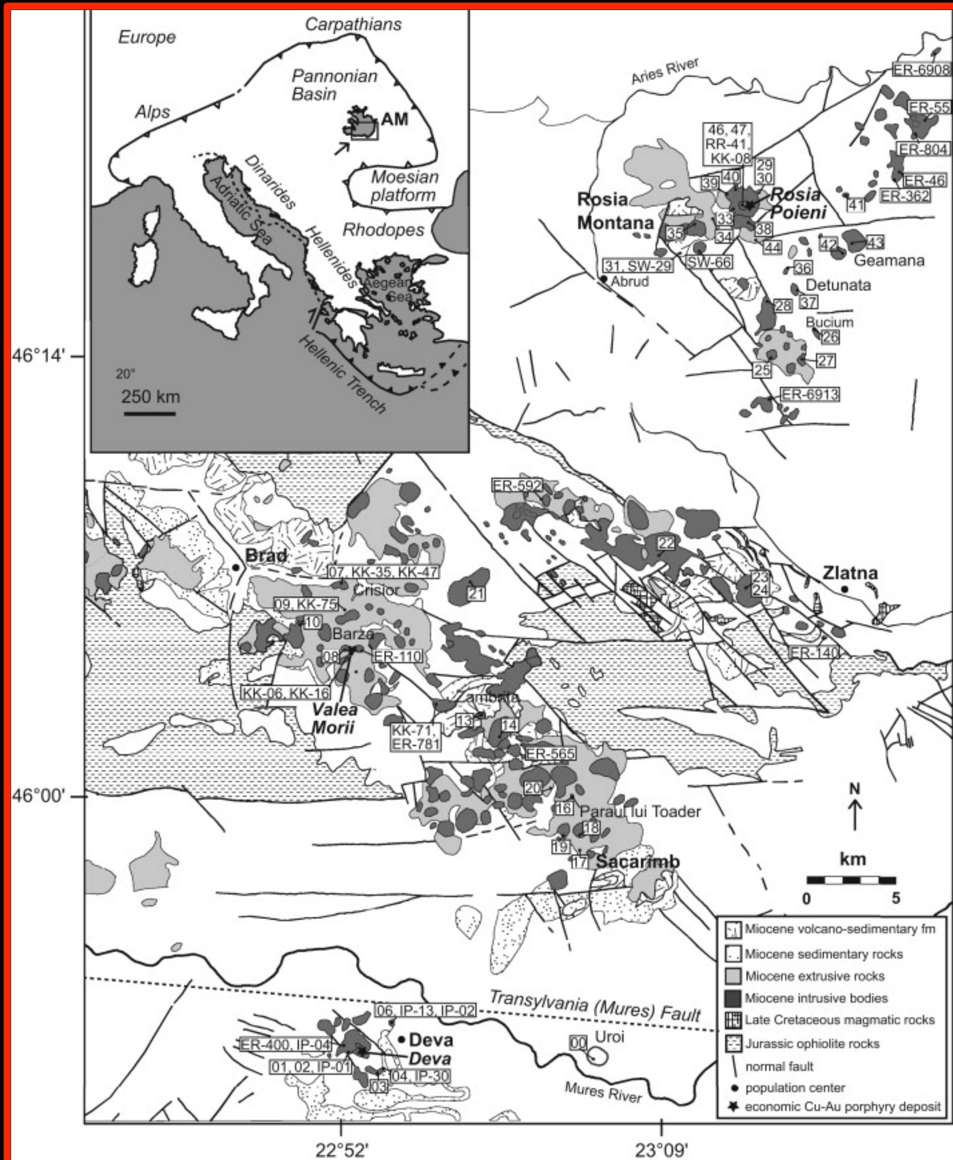
Skarn-type Hahaigang deposit of Gangdese metallogenic belt, unrelated to carbonate rocks and older (c. 63 Ma) than spatially associated granitoids (c. 57 Ma)

After Xiaofeng Li et al. (in press) OGR



Comparative cross-sections of southeastern and western Tibet at present day. Both sections are true scale, from MFT across the Himalayan orogenic wedge (MHT: Main Himalayan Thrust, STD: South Tibet Detachment), to Tibetan terranes (Lhasa and Qiangtang)

Simon L. Klemperer , B. Mack Kennedy , Siva R. Sastry , Yizhaq Makovsky , T. Harinarayana , Mary L. Leech
Earth and Planetary Science Letters Volume 366 2013 59 – 70 http://dx.doi.org/10.1016/j.epsl.2013.01.013

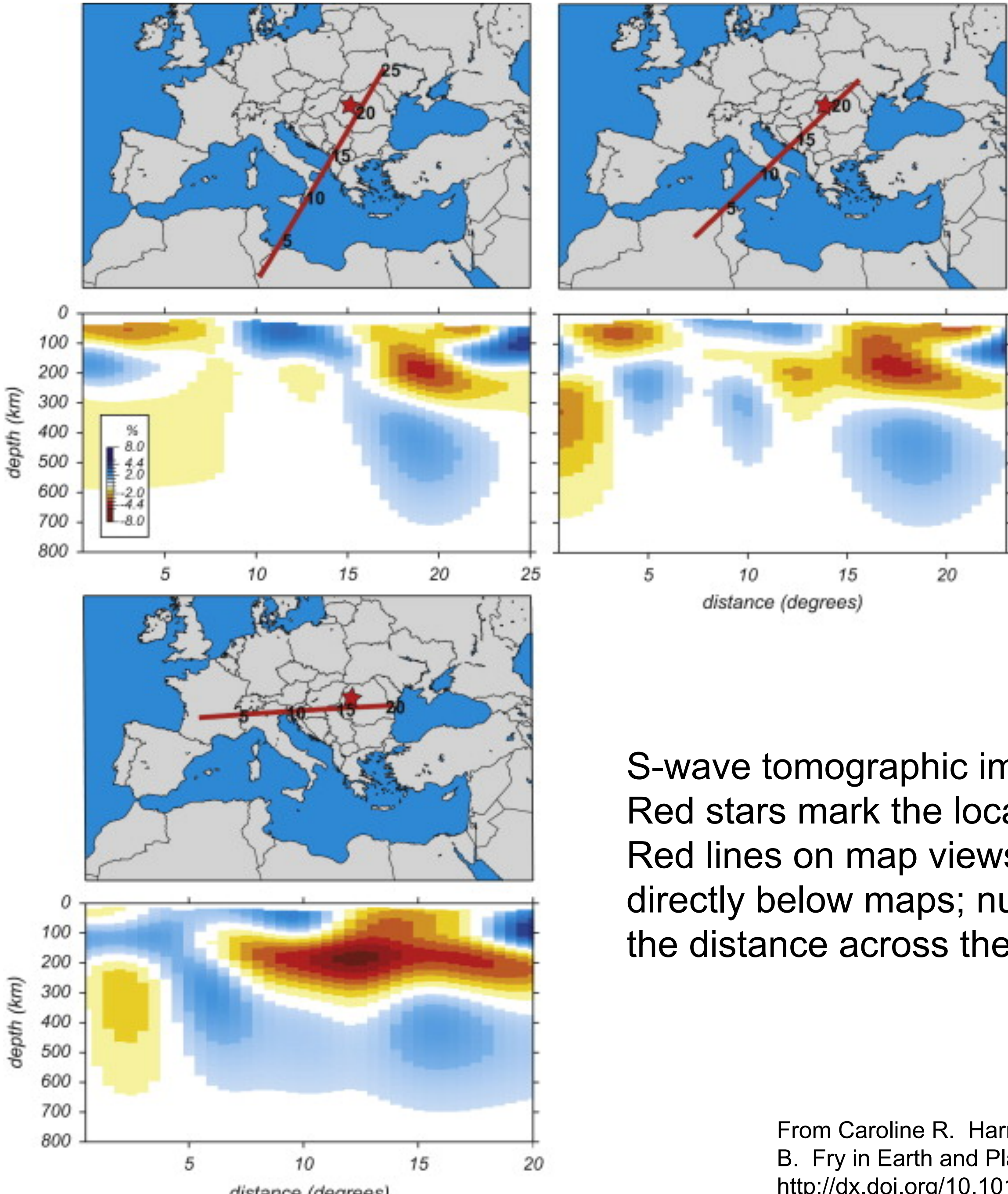


Au-Ag-Te epithermal and Cu-Au porphyry systems, related to partial melting of volatile- and incompatible elements-
enriched lithospheric mantle

Lithospheric mantle fertilisation due to subduction metasomatism 50 Myrs ahead of the extensional regime that produced the magmas and associated mineral systems

Inset shows the Apuseni Mountains (AM), the current location of the Adriatic subduction front

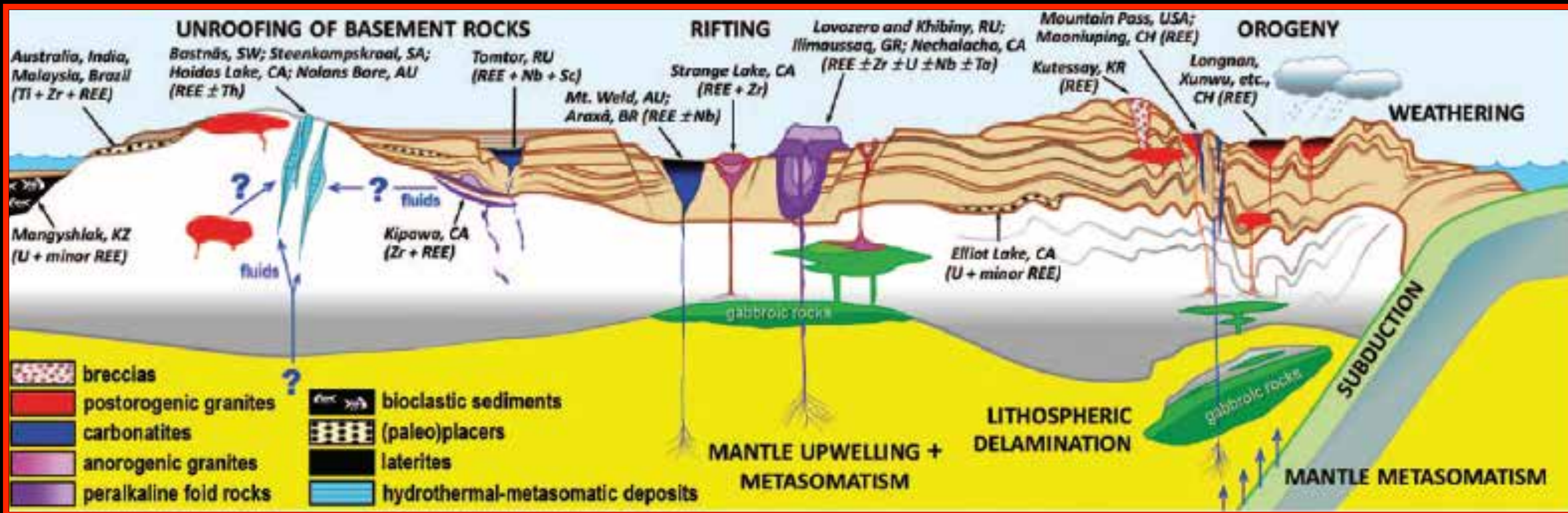
From Caroline R. Harris , T. Pettke , C.A. Heinrich , E. Rosu , S. Woodland , B. Fry in Earth and Planetary Science Letters Volume 366 2013 122 – 136 http://dx.doi.org/10.1016/j.epsl.2013.01.035



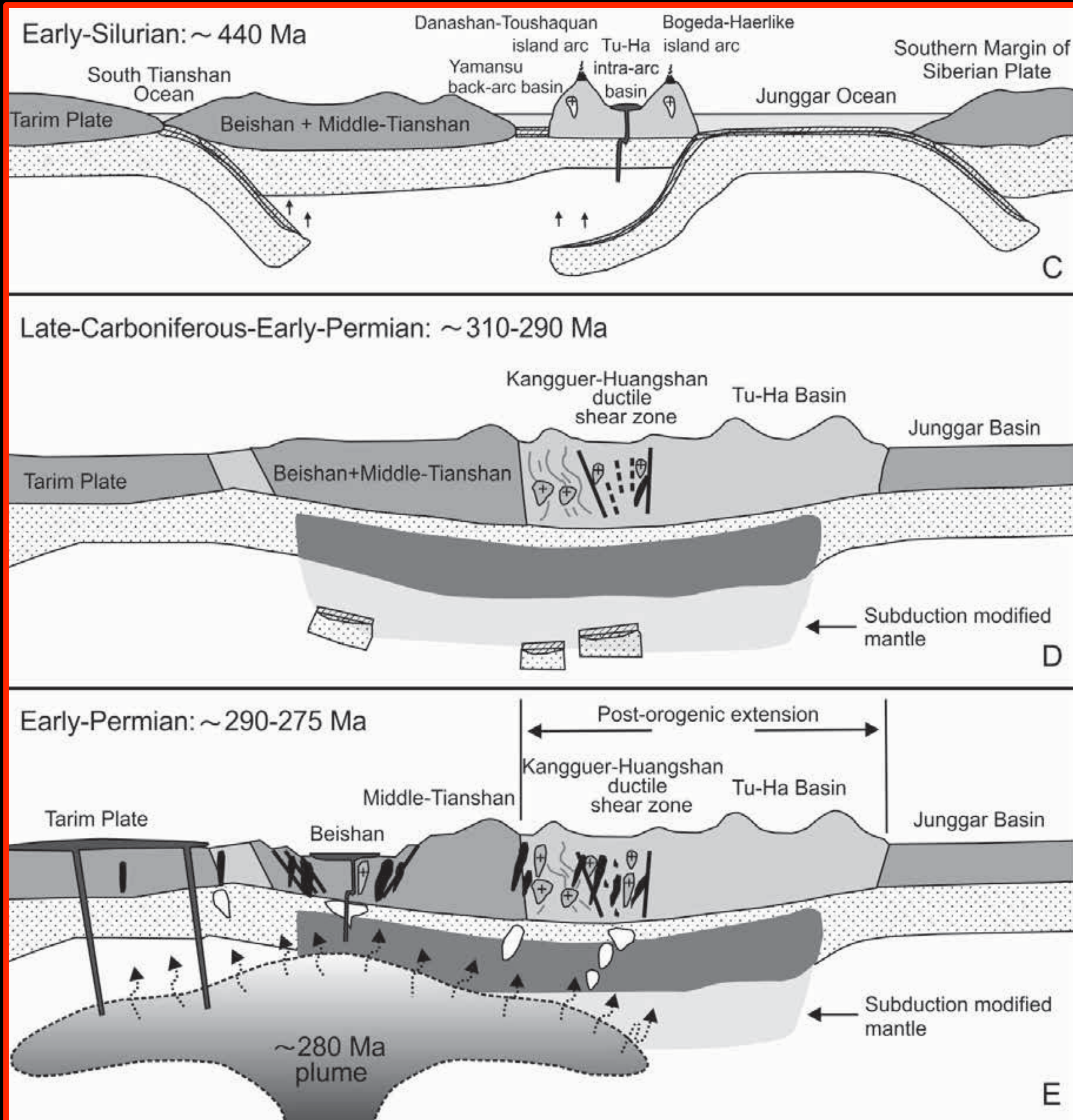
S-wave tomographic images of the regional subsurface. Red stars mark the location of the Apuseni Mountains. Red lines on map views show location of depth sections directly below maps; numbers on the lines correspond to the distance across the transect in degrees

From Caroline R. Harris , T. Pettke , C.A. Heinrich , E. Rosu , S. Woodland , B. Fry in Earth and Planetary Science Letters Volume 366, 2013, 122 – 136
http://dx.doi.org/10.1016/j.epsl.2013.01.035

- Rifts tend to form around cratonic margins, usually following weak zones of Proterozoic orogenic belts
- Crustal-scale ductile to brittle-ductile shear zones control the location of rift structures, magma emplacement and ore systems
- Long-lived shear zones and multiple ore-forming events
- Asthenospheric melts, rich in C, F, Cl and S penetrate the overlying SCLM, causing extensive metasomatism
- Metasomatised SCLM partially melts producing alkaline and carbonatitic magmas

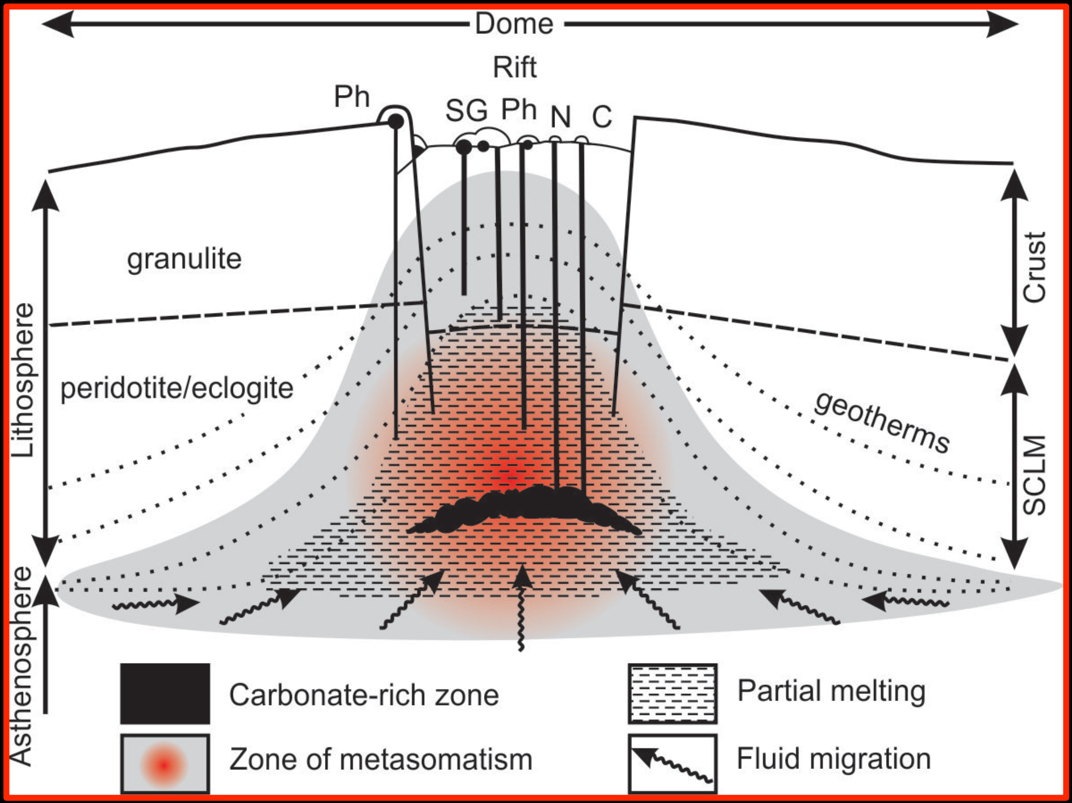


From Chakhmouradian and Wall, 2012, Elements v. 8



Sequence of geodynamic events leading to multiple stages of metasomatism of SCLM

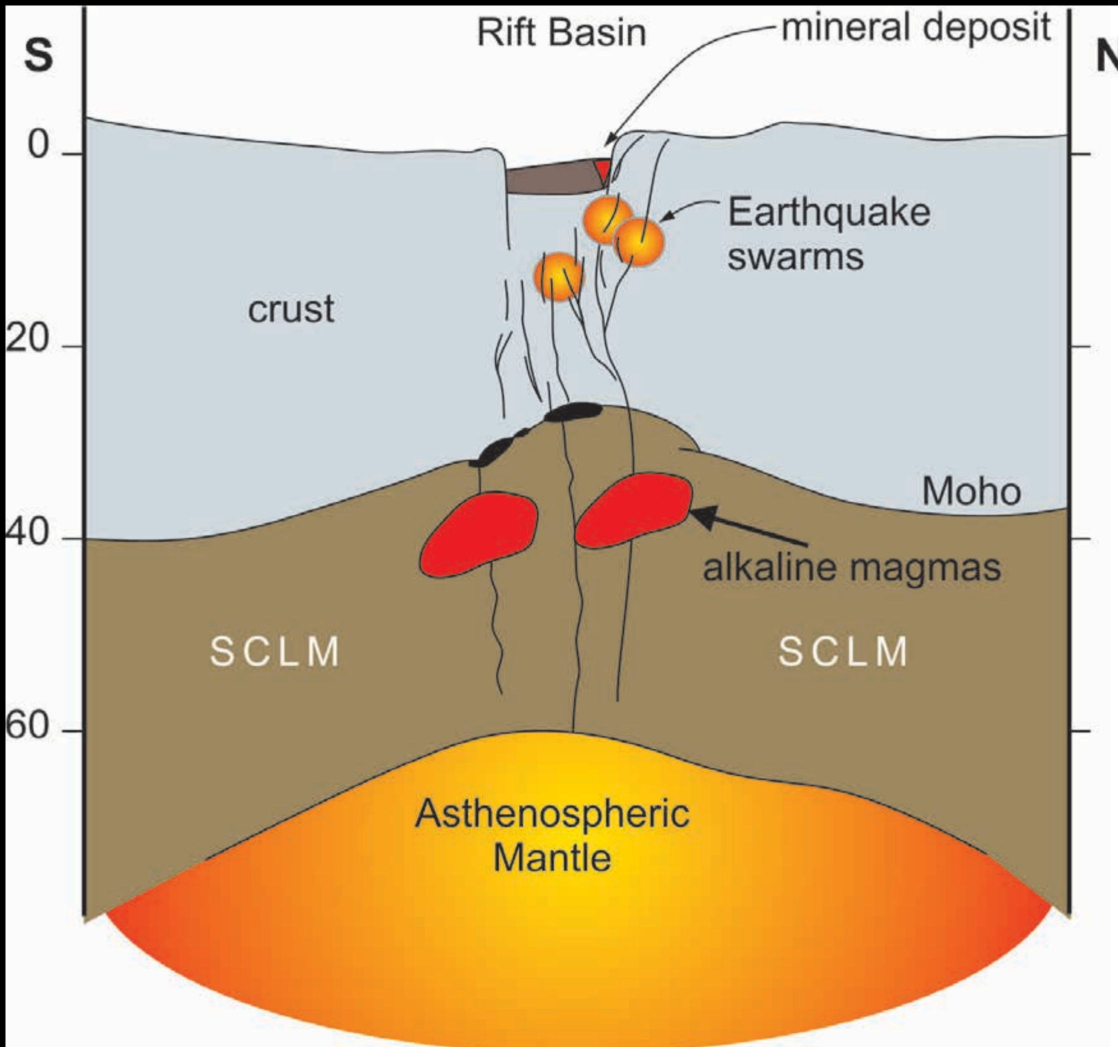
After Su BX et al., 2011, Gondwana Res, v. 20

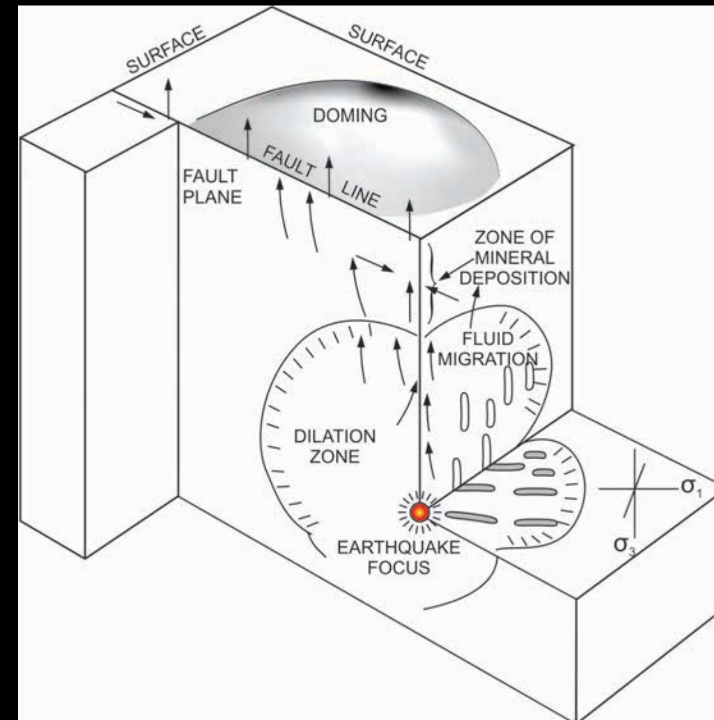


Ph phonolite
C carbonatite
SG syenite, granite
N nephelinite

Model depicting the formation of rift-related magmas (e. g. syenitic, carbonatites; A-type granites, rhyolites) enriched in high-field-strength elements and the rare earths

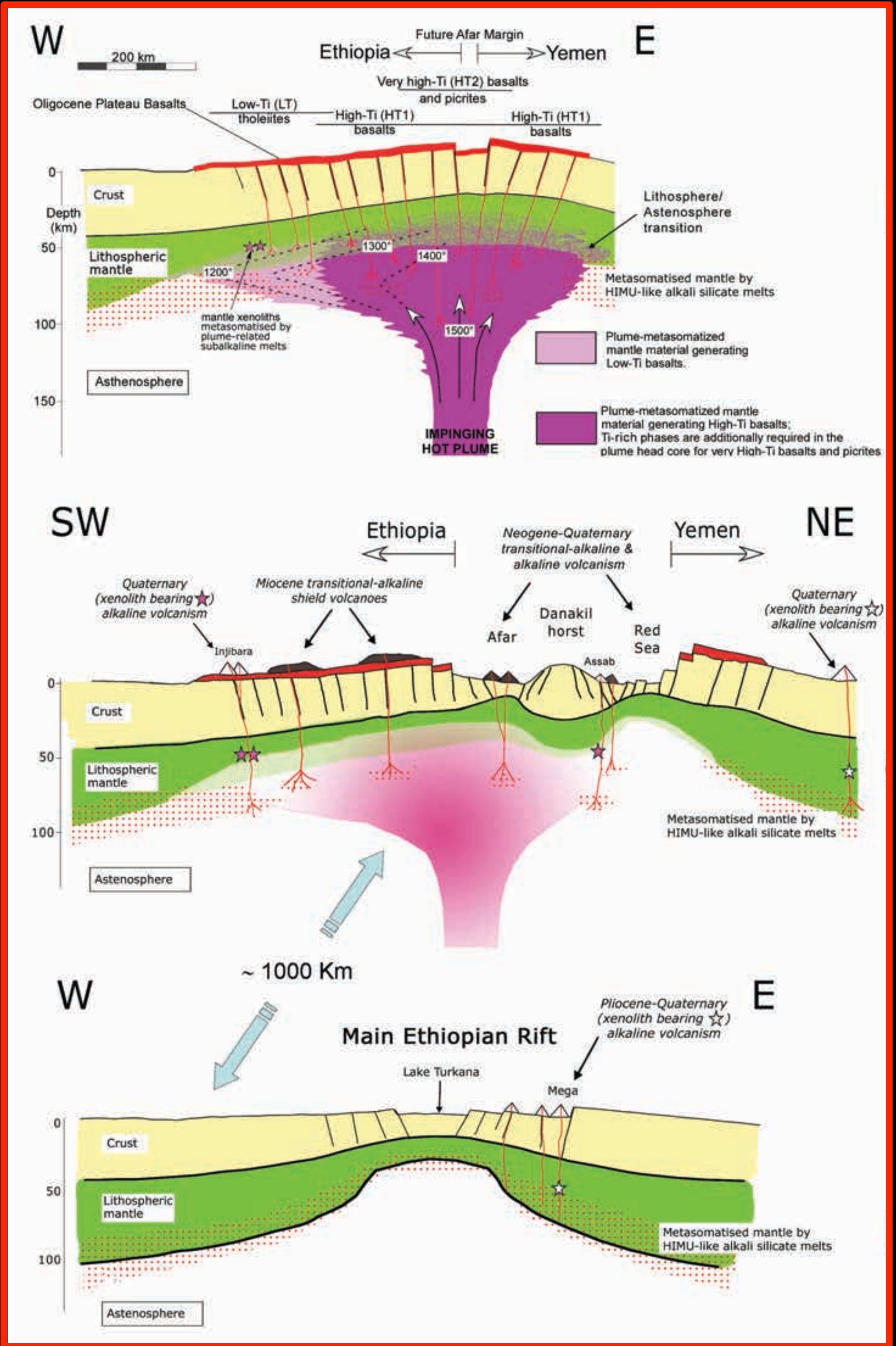
After Martin, 2006, Lithos. V. 91





Modified after Sibson et al. , 1975, Geos Soc London; 131: 653-559

Modified after Lindenfeld et al. , 2012, Tectonophysics 566-562: 95-104

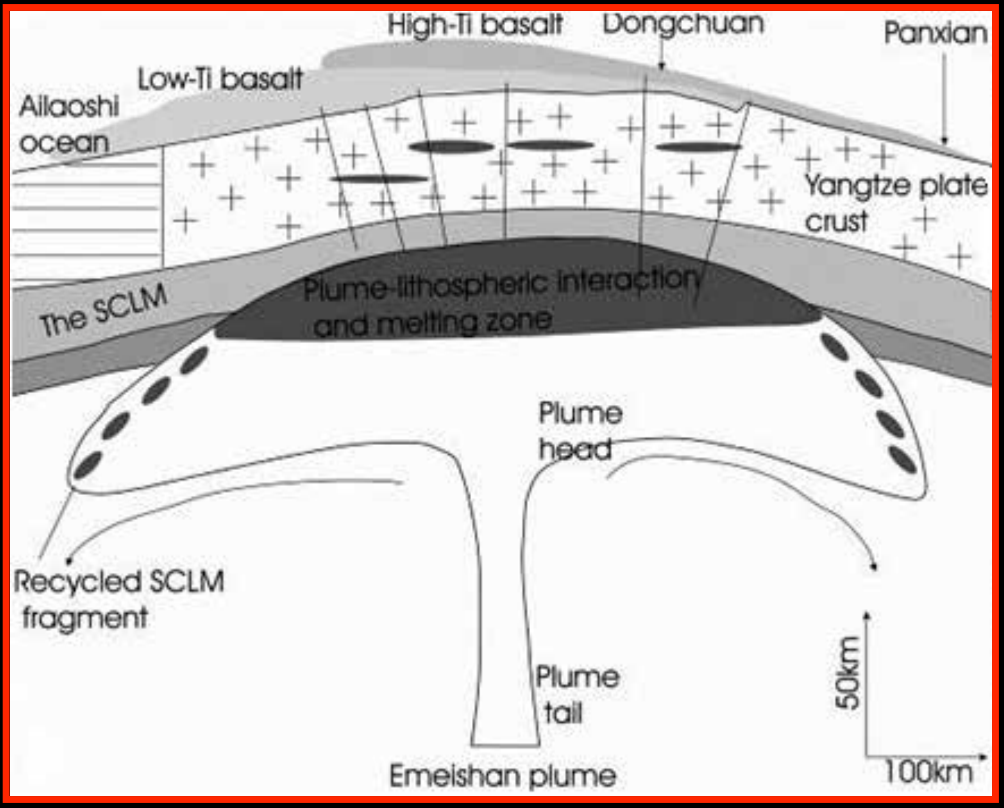


Tectono-magmatic evolution of EARS (African-Arabian sector) plume-rift systems

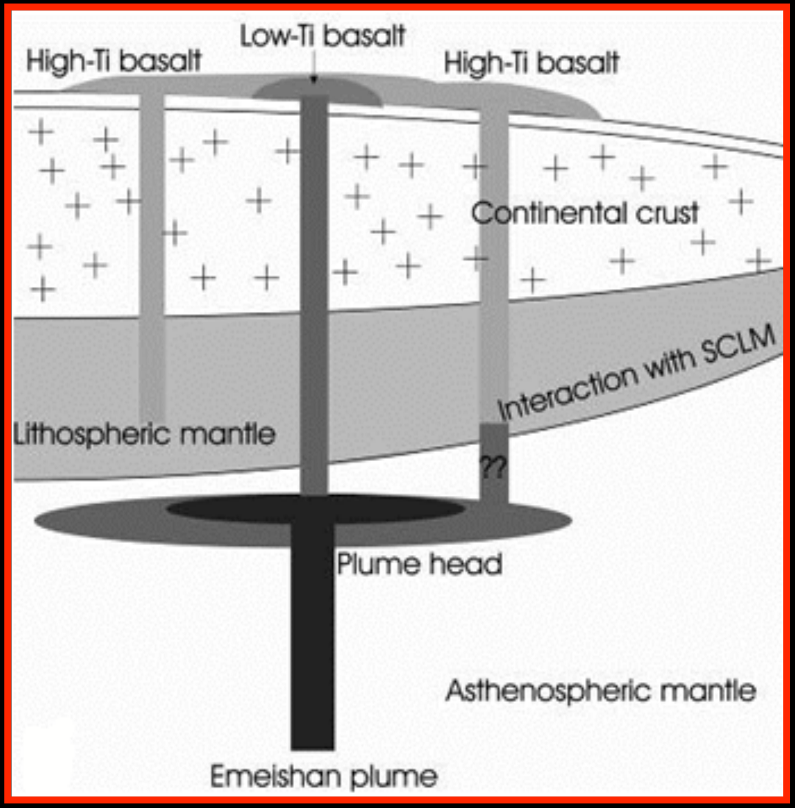
Note lithospheric uplift and developing crustal rifts, accompanied by varying degrees of SCLM metasomatism in different sectors of the EARS

From and by courtesy of Beccaluva et al., 2011, Geo Soc Am Sp Paper 478

Opposing model for the development of High-Ti and Low-Ti flood basalts of the 260 Ma Emeishan large igneous province; SW China

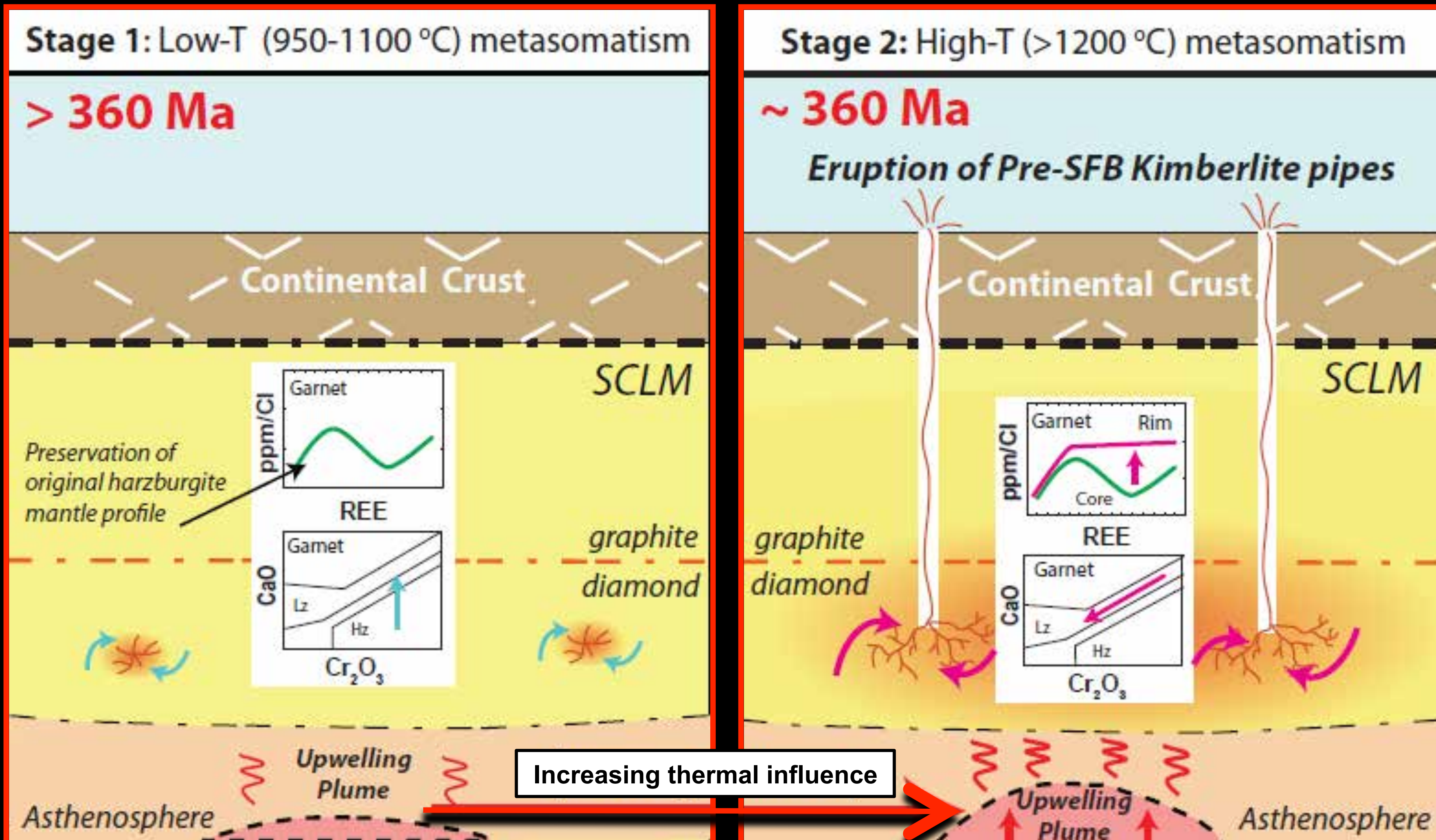


after Xiao, Pirajno, 2003, Acta Petr Sinica



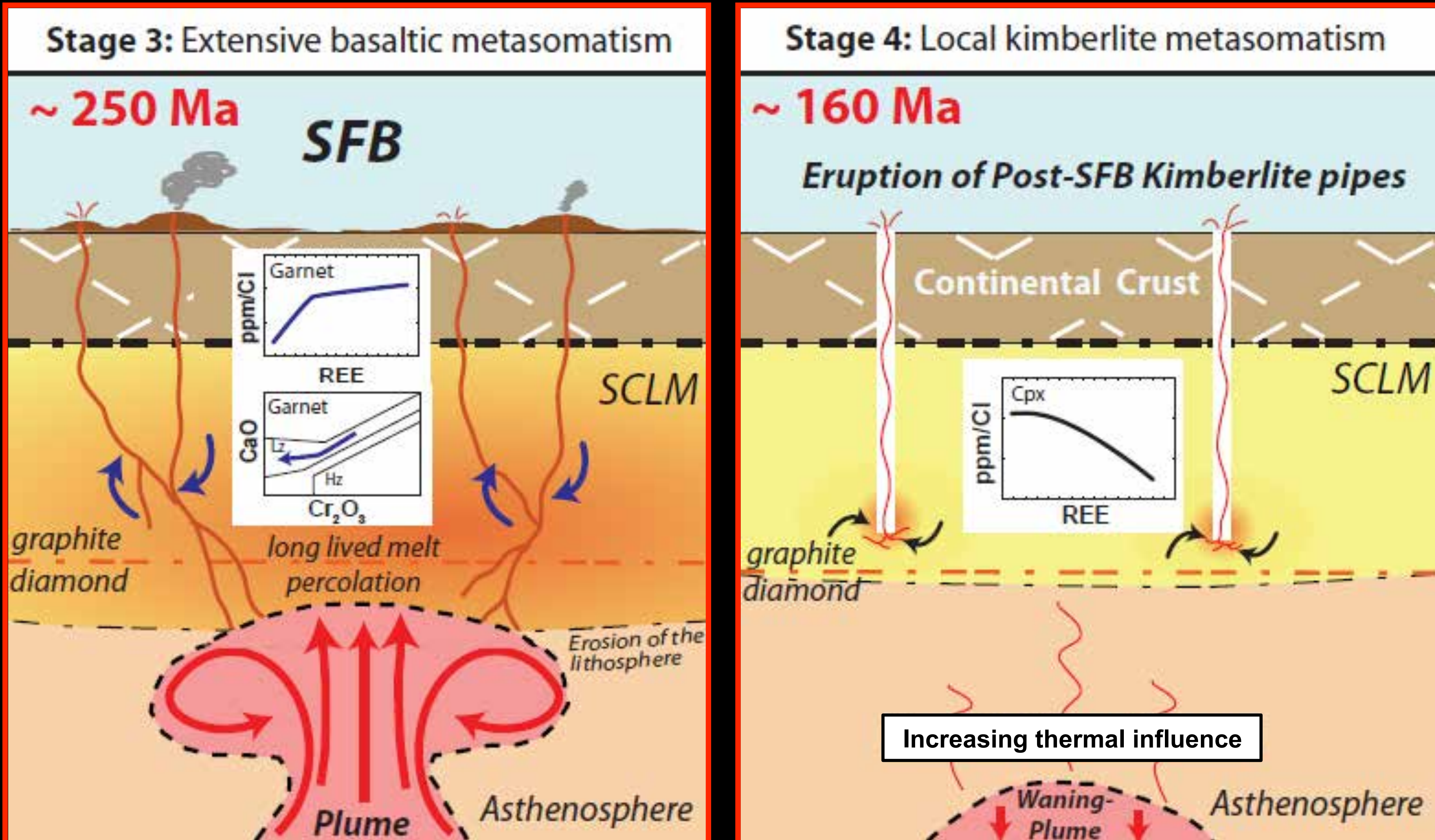
after Xu JF, 2007, Geoch Cosmoch Acta, v. 71

Magmatic-temporal evolution of the Siberian SCLM, stages 1 and 2



After and by courtesy of Howarth et al. 2013, Lithos

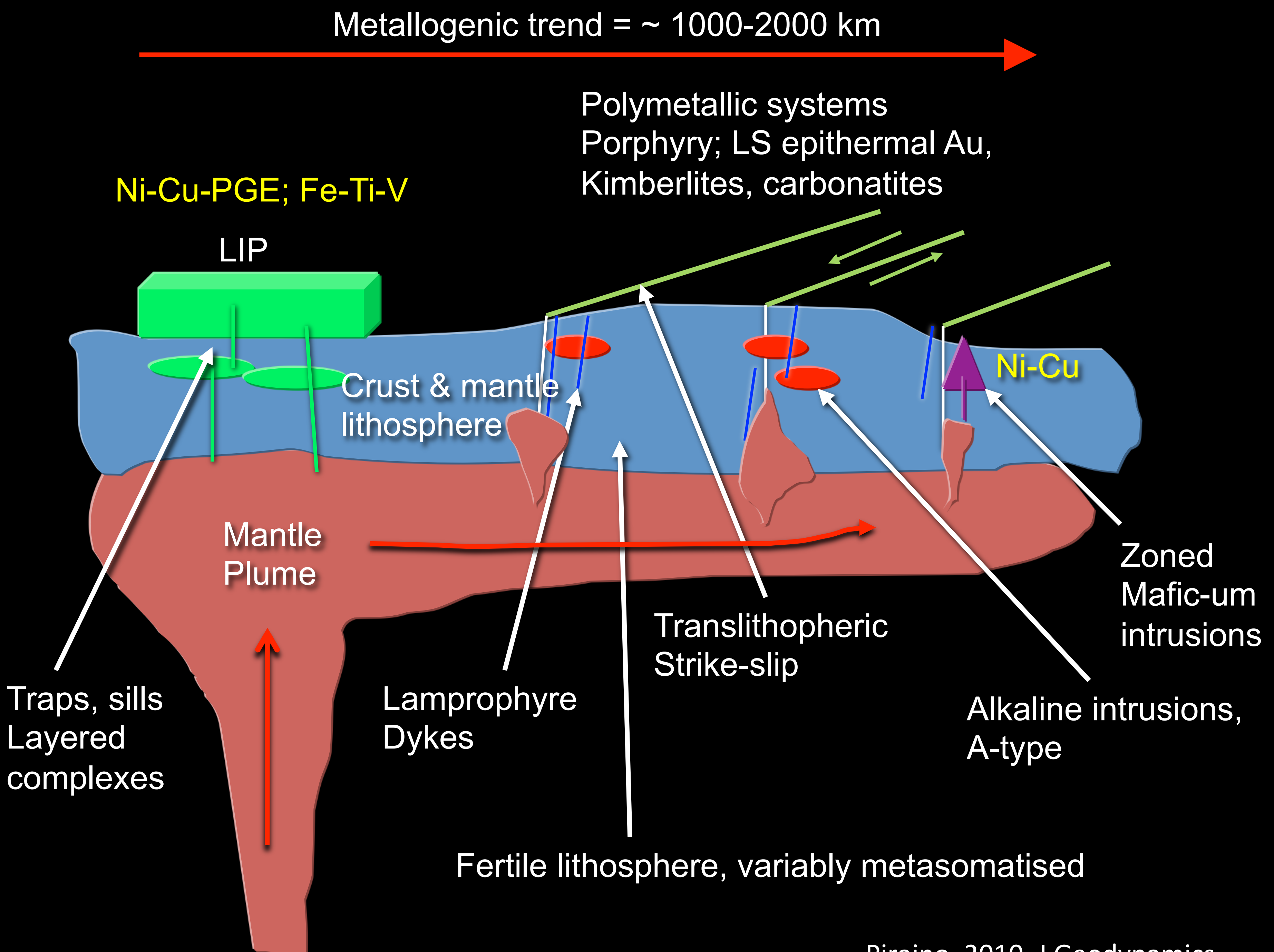
Magmatic-temporal evolution of the Siberian SCLM, stages 3 and 4



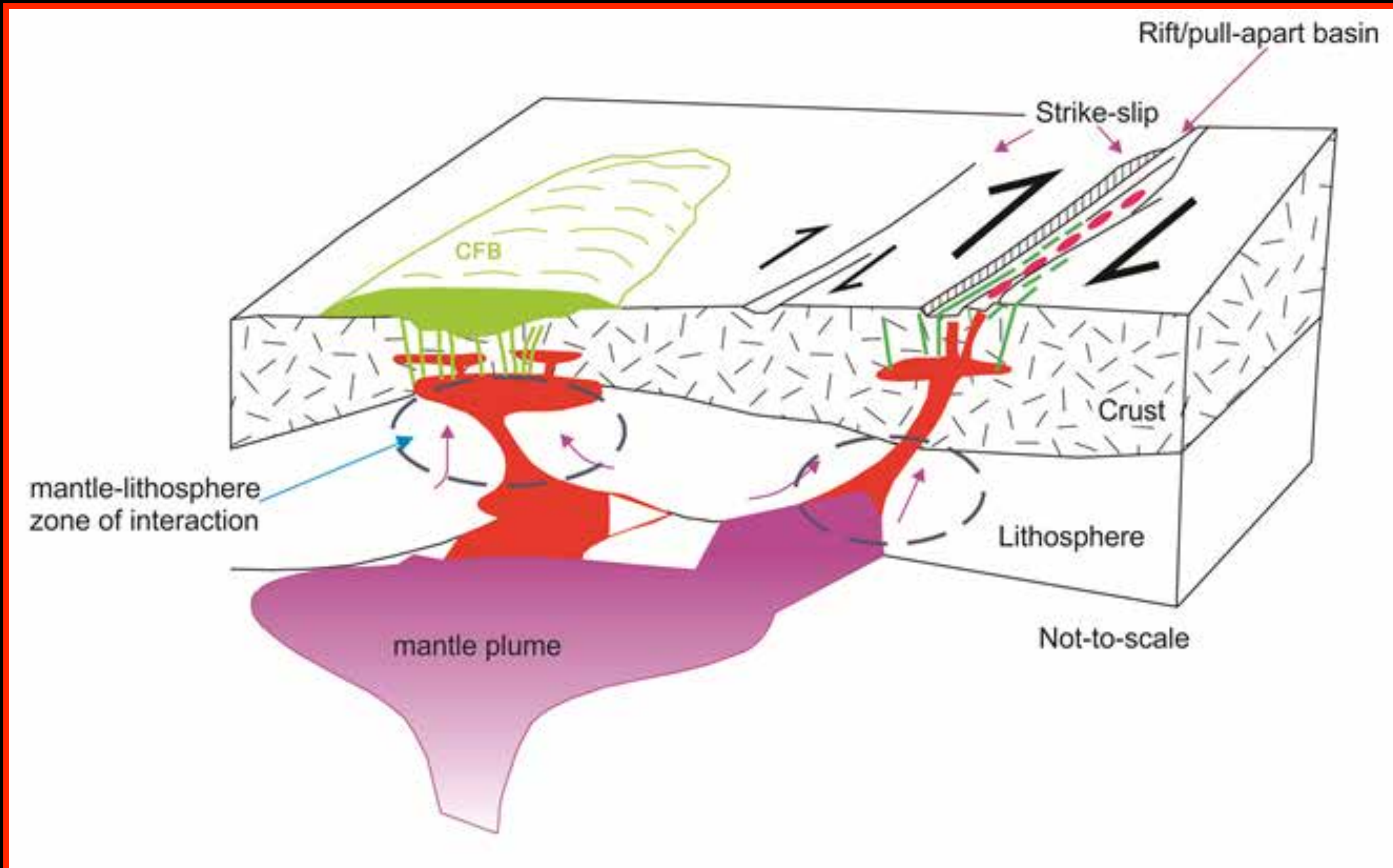
(SFB = Siberian flood basalts)

After and by courtesy of Howarth et al. 2013, Lithos,

See also: Griffin et al. 2013, Nature Geoscience



Pirajno, 2010, J Geodynamics


Rift/pull-apart basin
Strike-slip
CFB
Crust
mantle-lithosphere
zone of interaction
Lithosphere
mantle plume
Not-to-scale

THANK YOU/GRAZIE
FOR YOUR ATTENTION

Acknowledgments

Weronika Gorczyk (CET)
Tom Lenane (GSWA)
Murray Jones (GSWA)