The Alkaline Igneous Source of Cu, Co, Ni, REE, PGE, Au and U in the Mary Kathleen Belt, Mount Isa Block.

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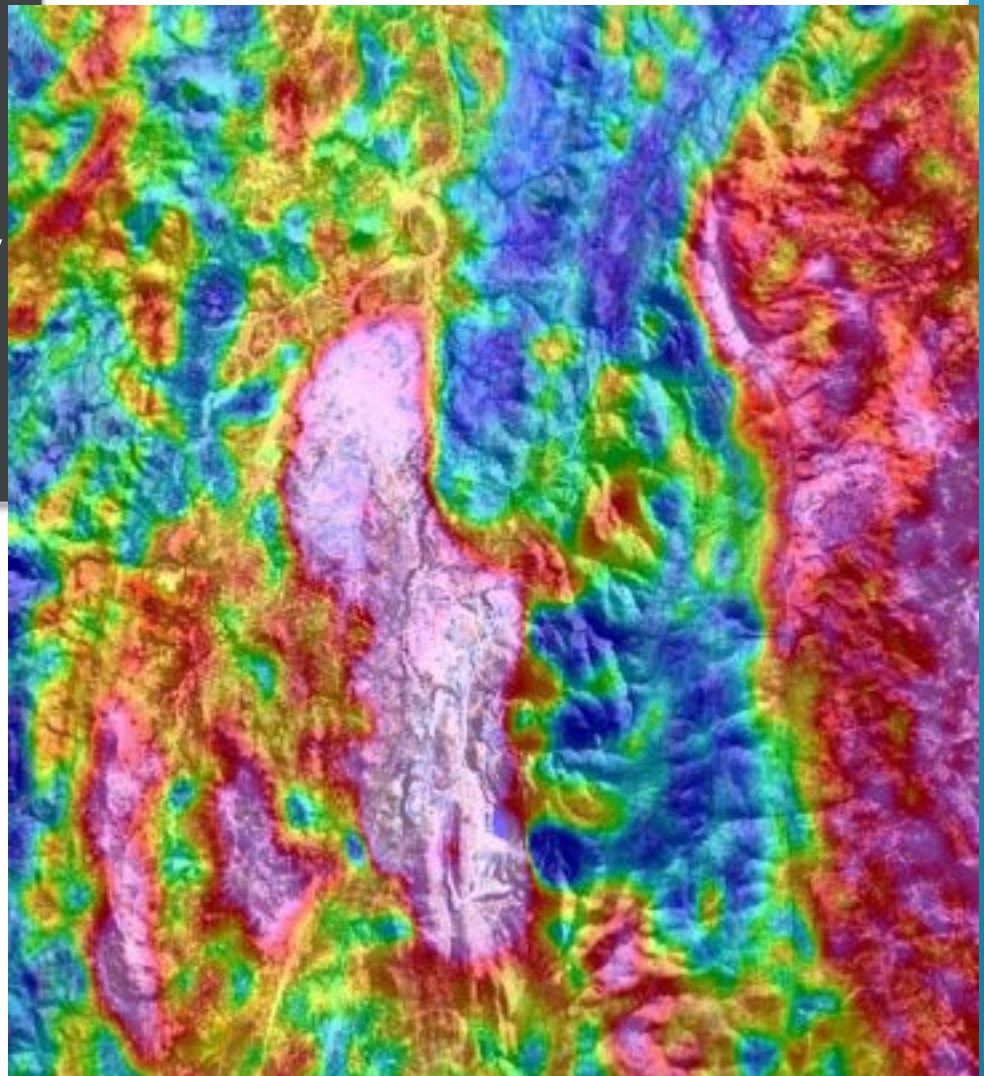

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MESSAGES TO TAKE AWAY

- Cu-Au-Co-PGE-REE mineral deposits in the MKB are not SKARN deposits, they are orthomagmatic and epithermal systems.
- Metal association Cu, Ni, REEs, U, Th and PGEs indicates mineralisation derived from an alkaline magmatic source.
- This post tectonic alkaline mineralisation event occurred at ~1526 Ma.
- Associated epithermal Au and Ag mineralisation indicates that alkaline intrusions were emplaced to shallow depths.
- New model for MKB mineralisation has direct relevance to IOCG exploration in the adjacent Cloncurry Belt.

OUTLINE

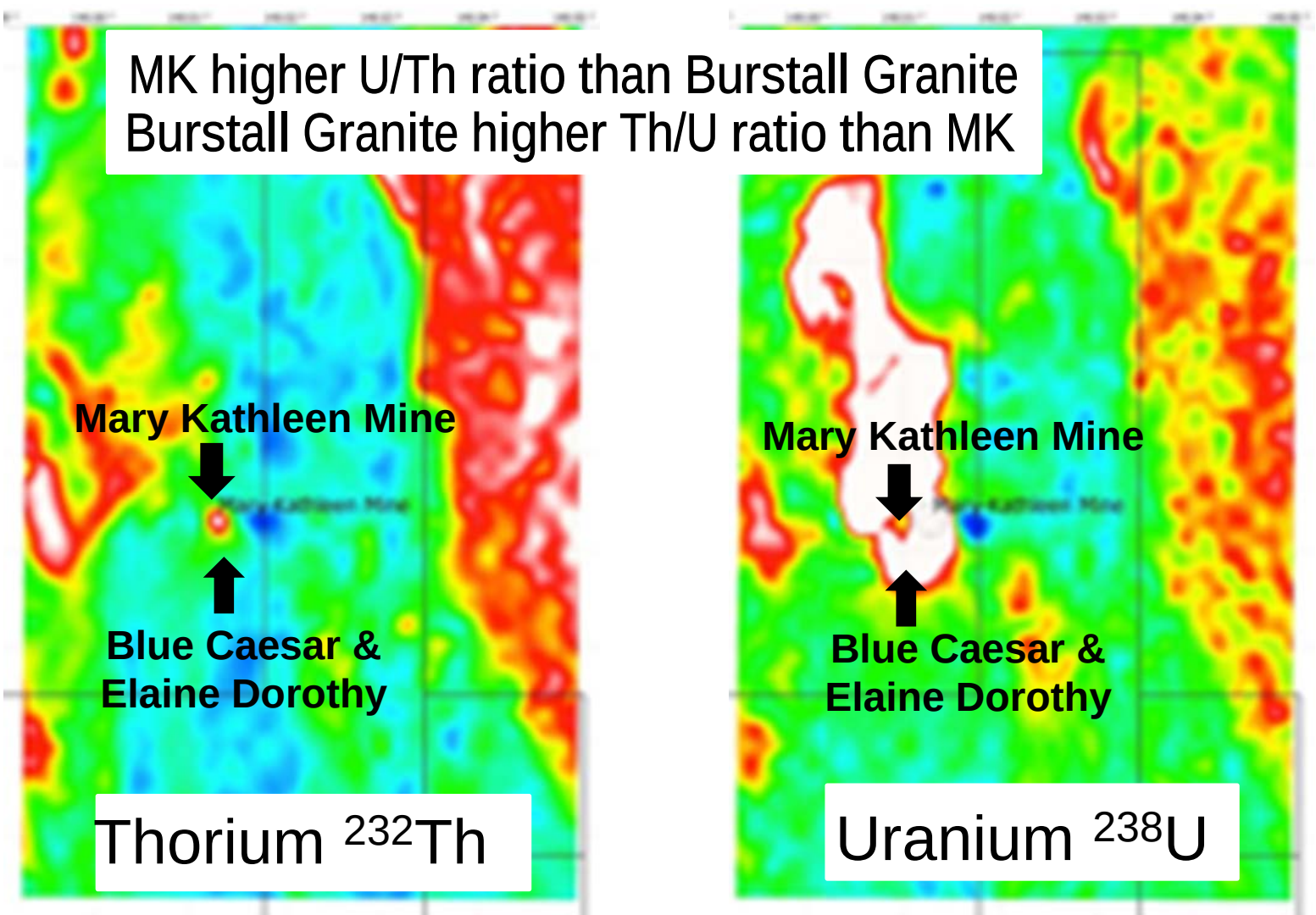
- Review relative chronology based on field and core observation at Elaine Dorothy and Blue Caesar.
- Discuss geochronological (absolute chronology) constraints.
- Present geochemical data for Elaine Dorothy and Blue Caesar cores.

- Demonstrate that multi-element mineralisation is post-tectonic, related to alkaline magmatism at ~1526 Ma.
- Discuss a mineral system geodynamic model.

PROBLEM WITH EXISTING METALLOGENIC MODEL
Cruikshank et al., (1980) Oliver et al., (1999)

- U-REE mineralisation in Corella Fm. “skarns” believed to have been introduced by regional metamorphic/hydrothermal fluids associated with “contact metasomatism”.
- Metals plus heat and fluids derived from the ~1740 Ma Burstall granite.
- **BUT TIMING OF U-Th MINERALISATION is between ~ 1550 and 1500 Ma *NOT* 1740 Ma.**
- ***MKB metal association is also inconsistent with a granitic source skarn deposit!***

MK higher U/Th ratio than Burstall Granite
Burstall Granite higher Th/U ratio than MK



MARY KATHLEEN BELT – OLDEST TO YOUNGEST RELATIVE CHRONOLOGY

- *Deposition of Corella Fm. calc silicate protoliths ~* ***1770 ± 6 Ma***
- *Thermotectonism - isoclinal folding producing transposed layering with rootless intrafolial folds.*
- *Corella Fm. compositional boundaries are tectonic.*
- Intrusion of Lunch Creek Gabbro/ A-type Burstall granite
- Thermotectonism.
- Intrusion of post-tectonic alkali pyroxenites, ijolites and phoscorites (carbonatites?) associated with glimmerite and ultramafic lamprophyre sills and dykes.
- Mineralisation associated with these units constrained by titanite U-Pb geochronology: **^{238}U/^{206}Pb 1526±11 Ma** and **^{207}Pb/^{206}Pb 1524±9 Ma** (Sha *et al.,* 2015)

CALC SILICATES OF THE CORELLA FM.

Protoliths of Corella Formation are marine carbonates and marls.

140° 01.145 E; 20° 47.754 S

RELATIVE CHRONOLOGY OF THE MARY KATHLEEN BELT – OLDEST TO YOUNGEST

- Deposition of Corella Fm. calc silicate protoliths ~ **1770 ± 6 Ma**
- Thermotectonism - isoclinal folding producing transposed layering with rootless intrafolial folds.
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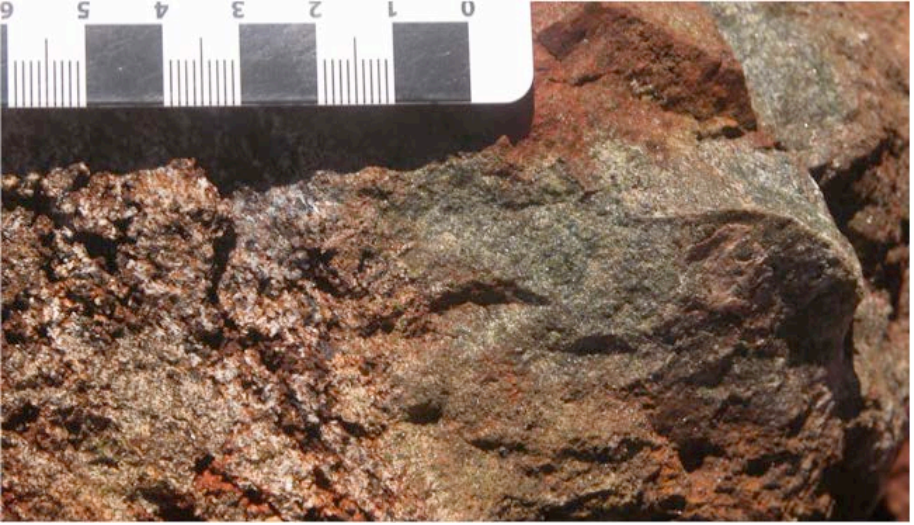

POST-CORELLA MAGMATISM

Meta-gabbro/pyroxenite. Mafic body that cut the Corella Fm. prior to thermotectonism

140° 01.287; E 20° 48.241 S

Harrisitic olivine in ultramafic lithology possibly associated with gabbro/pxite intrusion

140° 01.857; E 20° 46.379 S

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POST-CORELLA MAGMATISM

“Burstall Gr.” Dacite or Rhyolite

140° 02.015 E: 20° 46.336 S

Ophitic and sub-ophitic texture in Lunch Creek Gabbro

140° 01.857 E; 20° 46.379 S

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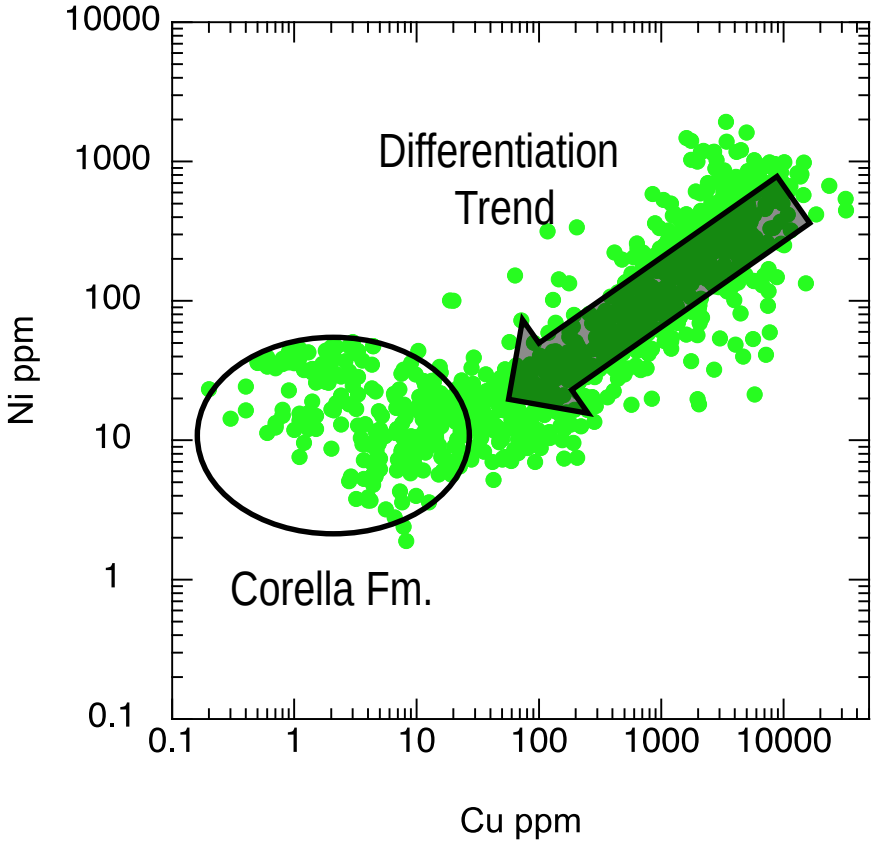
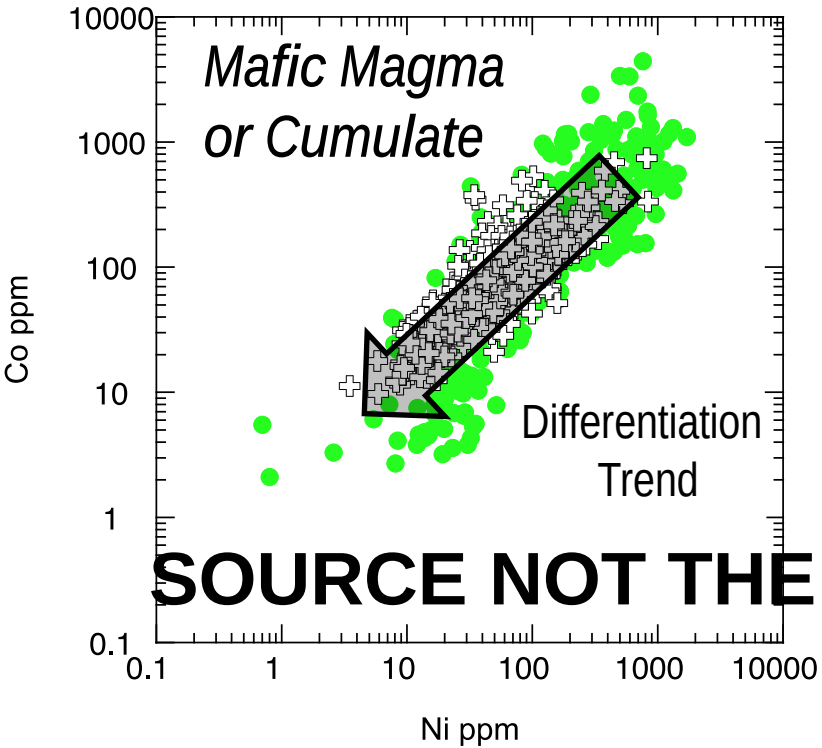
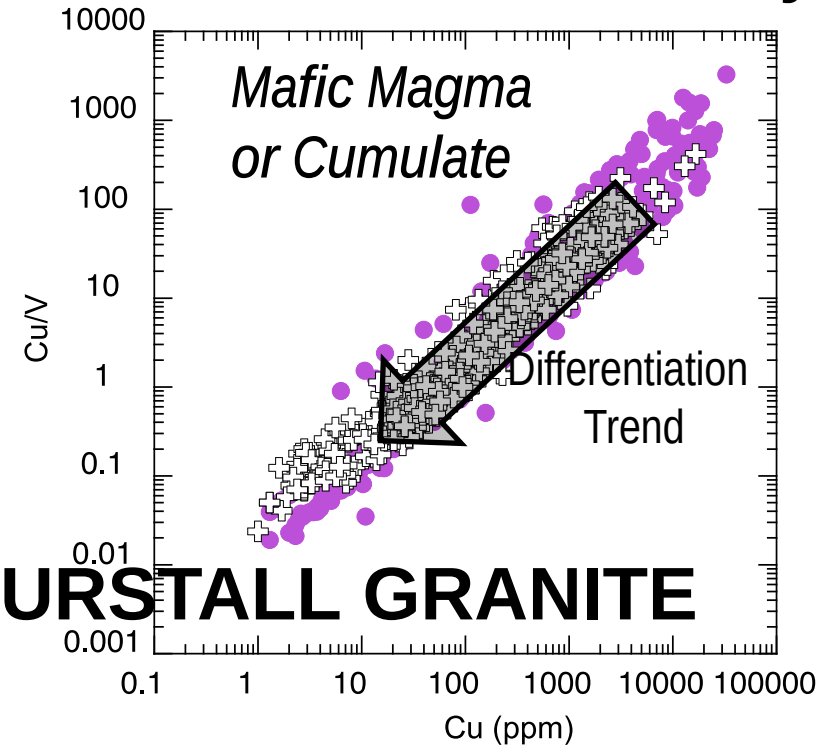
SOURCE OF MARY KATHLEEN BELT METALS
TRANSITION METAL GEOCHEMISTRY



- Covariation between Ni & Cu in Elaine Dorothy and Blue Caesar core.
- Transition metals (Cu, Ni, Co, V) were derived from a differentiated mafic igneous source.
- Granites are not enriched in these elements so Burstal Granite not involved.

Source of MK Metals - Transition Metal Geochemistry





SOURCE NOT THE BURSTALL GRANITE

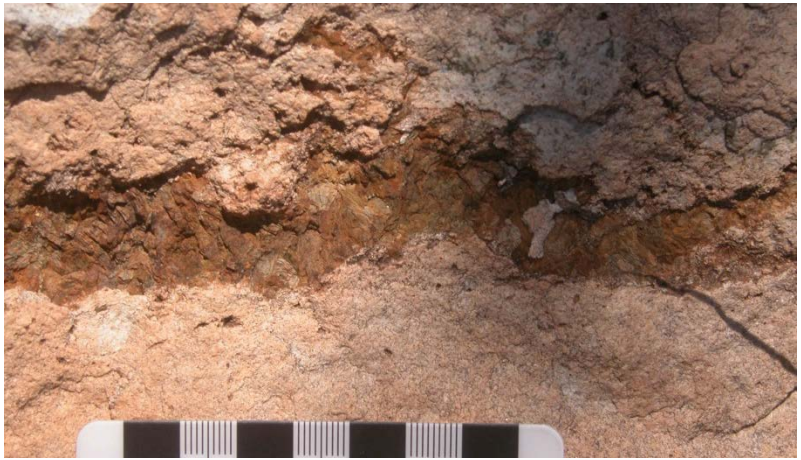
Covariation between Ni and Co also supports derivation of the transition metals from a mafic igneous source

Fractionation of a mafic igneous magma explains the covariation between Cu and Cu/V

RELATIVE CHRONOLOGY OF THE MARY KATHLEEN BELT – OLDEST TO YOUNGEST

- Deposition of Corella Fm. calc silicate protoliths ~ **1770 ± 6 Ma**
- Thermotectonism - isoclinal folding producing transposed layering with rootless intrafolial folds.
- Corella Fm. compositional boundaries are tectonic.
- Intrusion of Lunch Creek Gabbro/ A-type Burstall granite
- Thermotectonism.
- ***Intrusion of post-tectonic alkali pyroxenites, ijolites and phoscorites (carbonatites?) associated with glimmerite and ultramafic lamprophyre sills and dykes.***
- Mineralisation associated with these units constrained by titanite U-Pb geochronology: $^{238}U/^{206}Pb$ 1526±11 Ma and $^{207}Pb/^{206}Pb$ 1524±9 Ma (Sha *et al.,* 2015)

PHOSCORITE (APATITE-PYROXENITE) DYKES INTRUDE GRANITES AND CORELLA FM. CALC SILICATES



Pyroxenite dyke cutting outcrop of deformed aplite
140° 00.867 E 20° 47.793 S

Pyroxenite cutting transposed layering in Coralla Fm.
Core @ 185 m

POST CORELLA FM. ALKALINE DYKES

Evidence for post tectonic intrusions.

Pyroxenite dykes

- **Titanite yields: $^{238}U/^{206}Pb$ 1526±11 Ma and $^{207}Pb/^{206}Pb$ 1524±9 Ma** (Sha *et al.,* 2015).
- Within error of Sm-Nd isochron for Mary Kathleen mineralisation; **1557±40** Ma Maas *et al.,* (1987)
- **Cu and U-REE mineralisation derived from same source.**

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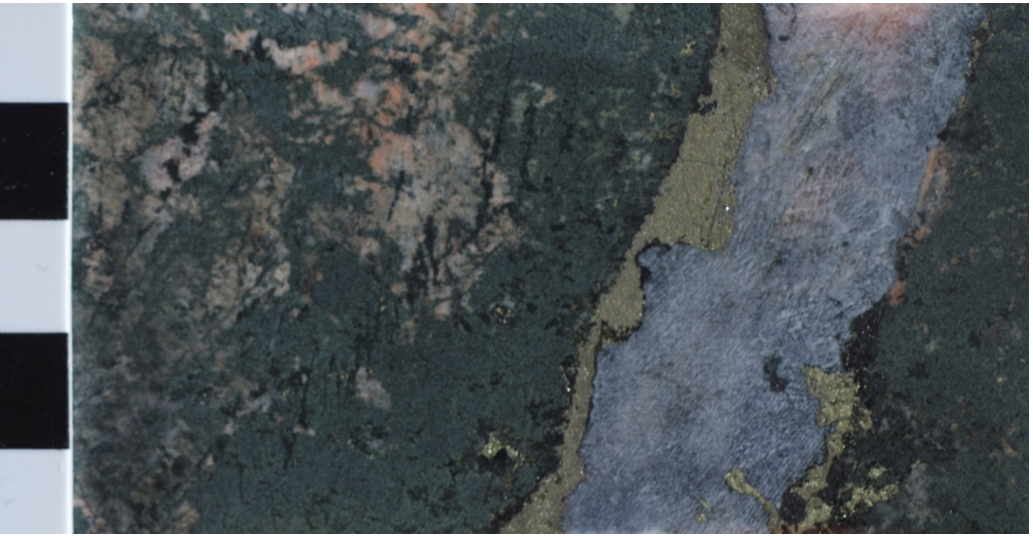
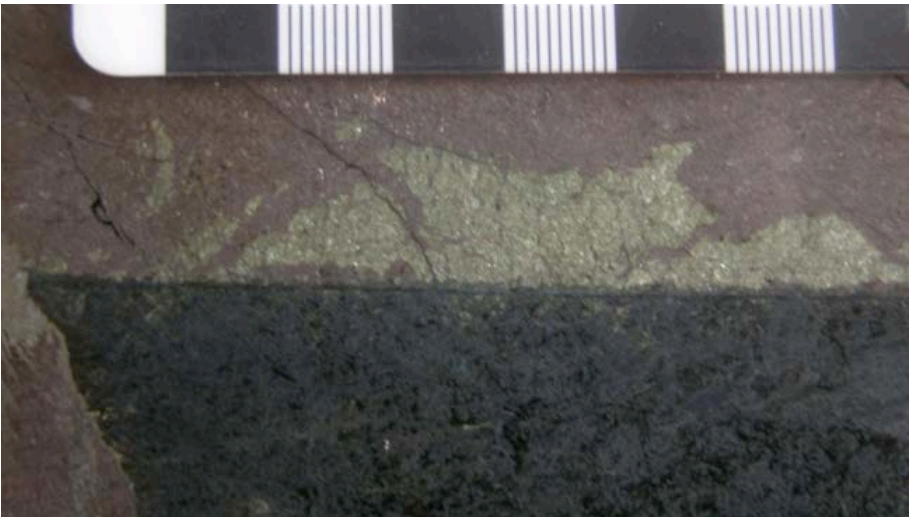


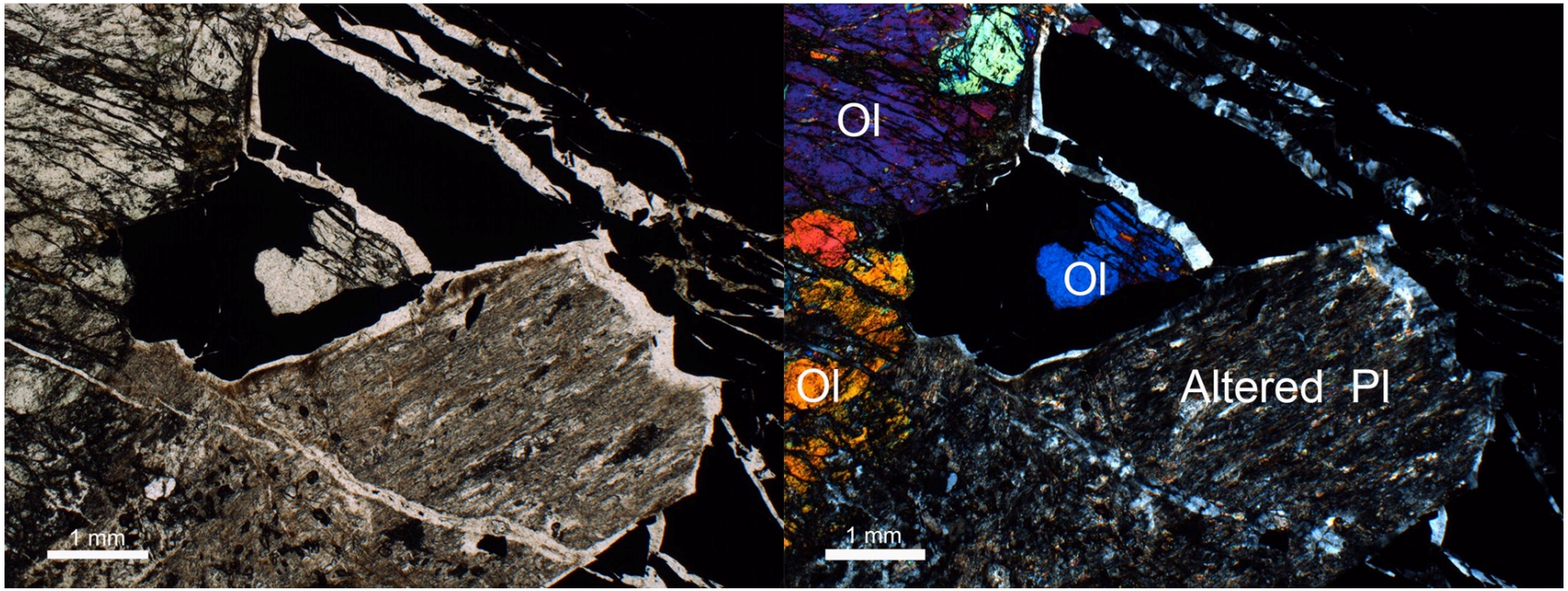
TIMING AND SOURCE OF METALS

- Alkali syenite and aegirine-bearing pyroxenite
- Cut by carbonate fluorite vein with chalcopyrite and pyrite.



- Sulphide mineralisation pyrrhotite, pyrite, chalcopyrite and digenite.
- Mineralisation intrudes and brecciates units of pyroxenite.
- Segregation and emplacement of sulphide mineralisation occurred at ~1526 Ma.

Mary Kathleen Belt 1526 Ma Alkaline Suite - Ijolite – Phoscorite – Foid Syenites



Plane Polarised Light

Cross Polarised Light

MKED 014 – 268.7 m

Opaques are Ni-rich pyrrhotite

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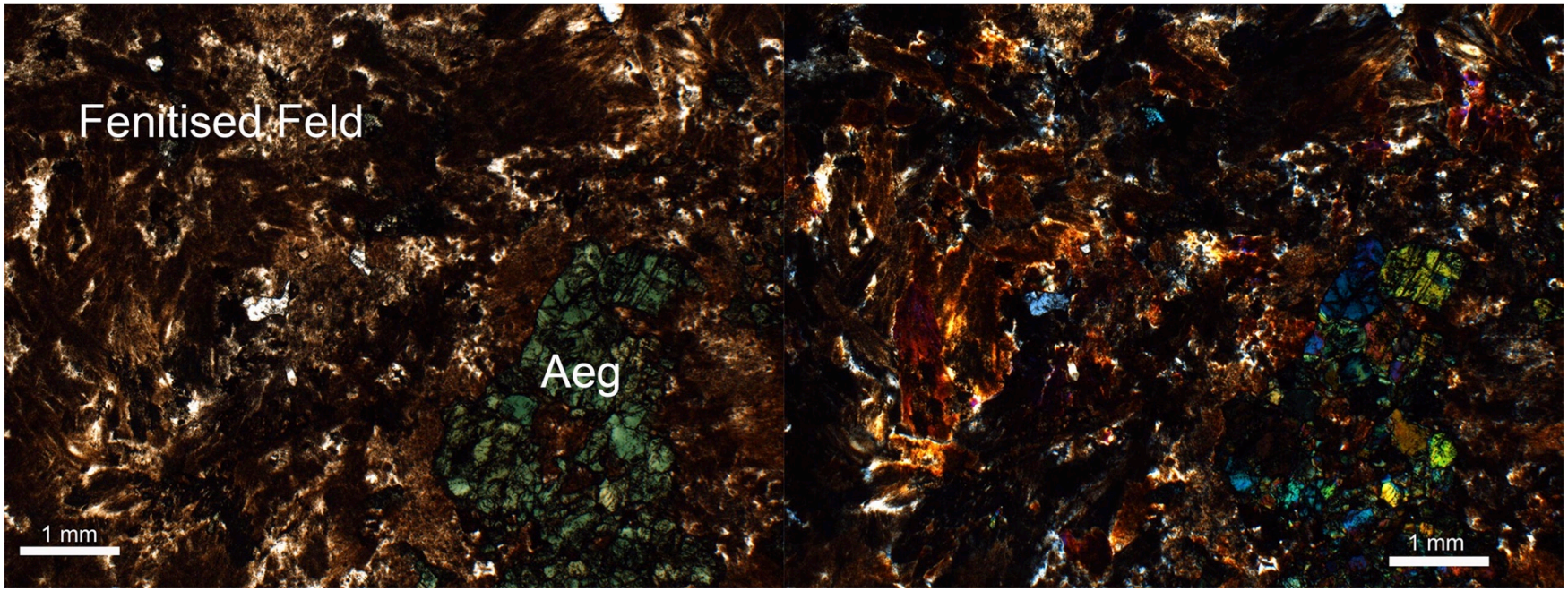
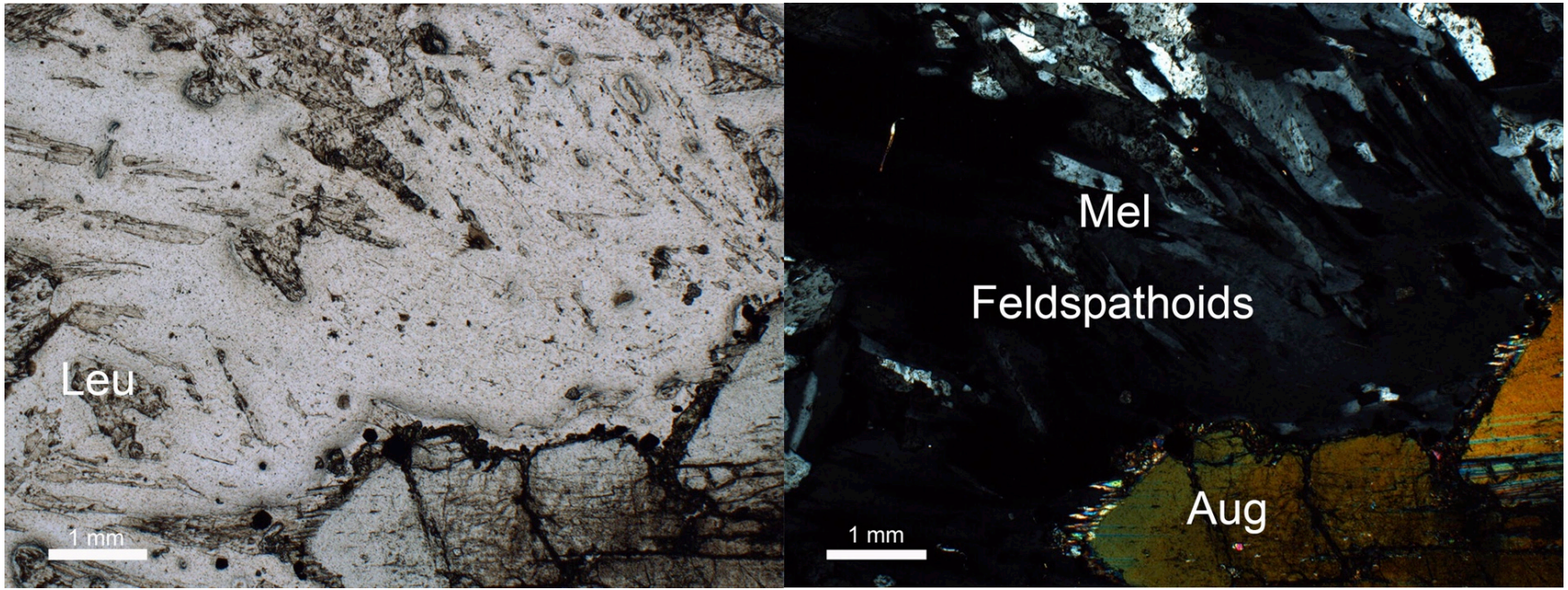
1526 Ma Alkaline Suite – Mary Kathleen Belt
Aegirine Syenite



Plane Polarised Light MKBC 004 – 143.5 m Cross Polarised Light

Post-tectonic Panidiomorphic granular feldspar textures showing pervasive alteration by carbothermal fluids

1526 Ma Alkaline Suite – Mary Kathleen Belt
Leucite Syenite

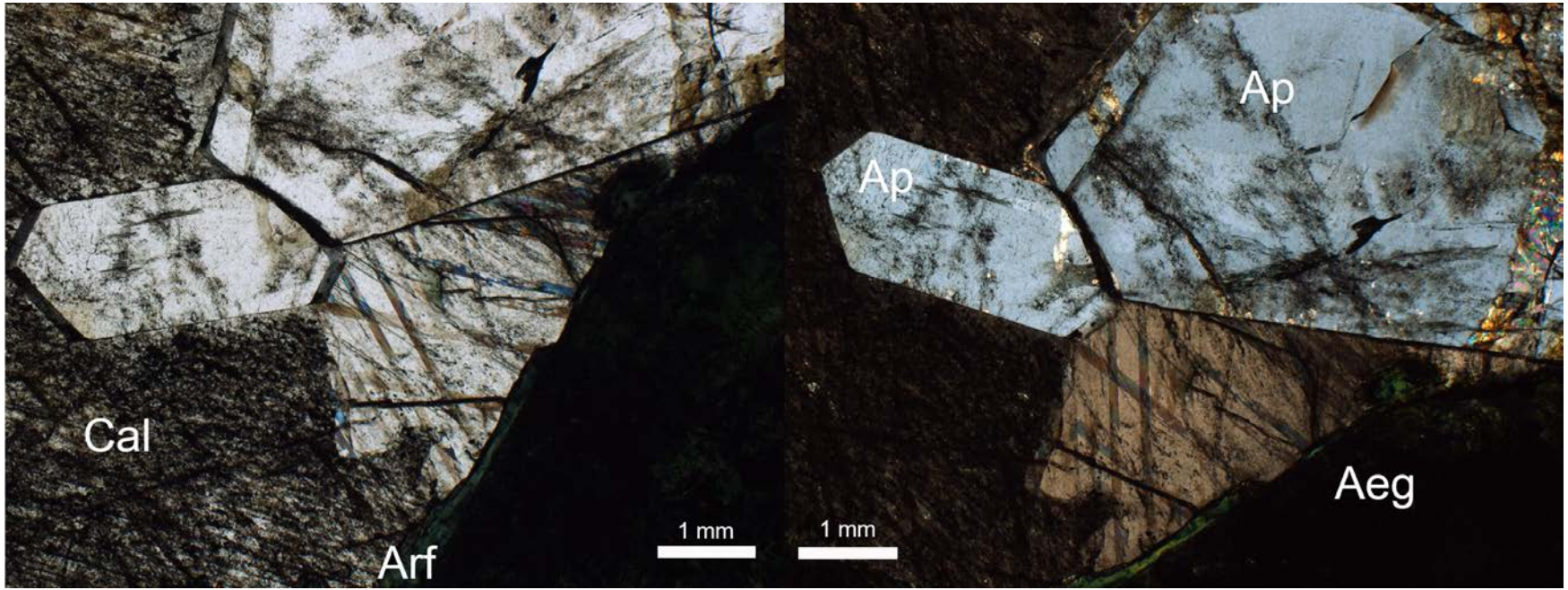


Plane Polarised Light

Cross Polarised Light

MKED 014 – 260 m

1526 Ma Alkaline Suite – Mary Kathleen Belt
Post-tectonic Carbothermal Veins

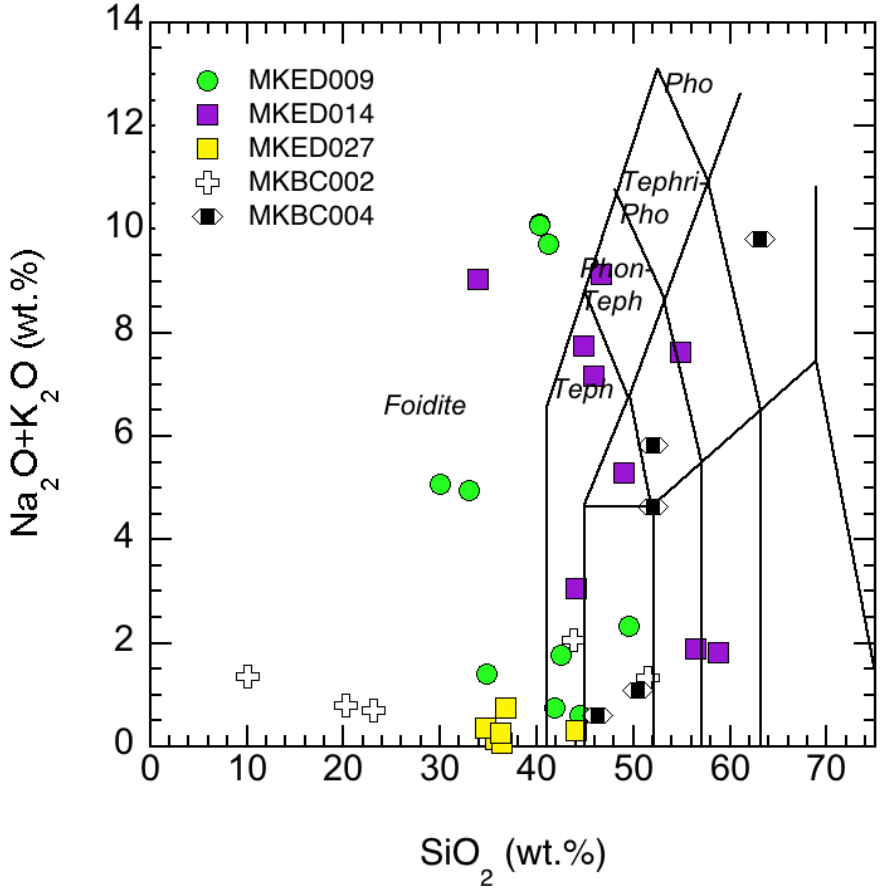


Plane Polarised Light

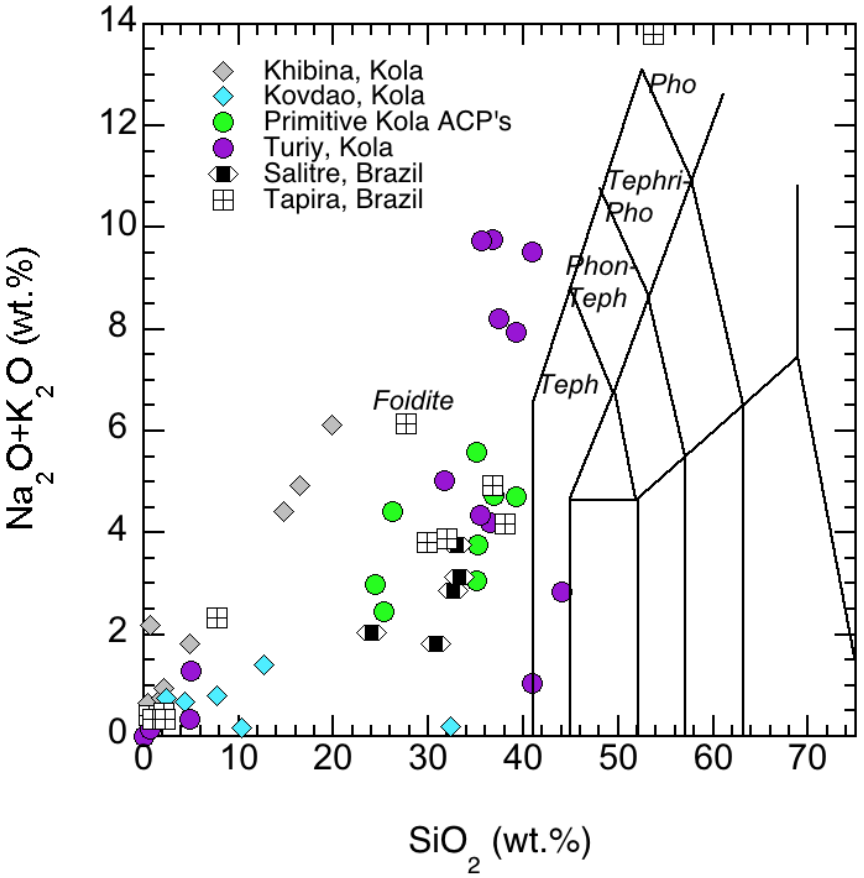
Cross Polarised Light

MKBC 004 – 142 m

CRYPTIC RECORD OF ALKALINE LITHOLOGIES IN MKB BLUE CAESAR AND ELAINE DOROTHY CORES



Kola Peninsula and Brasilian Intrusions



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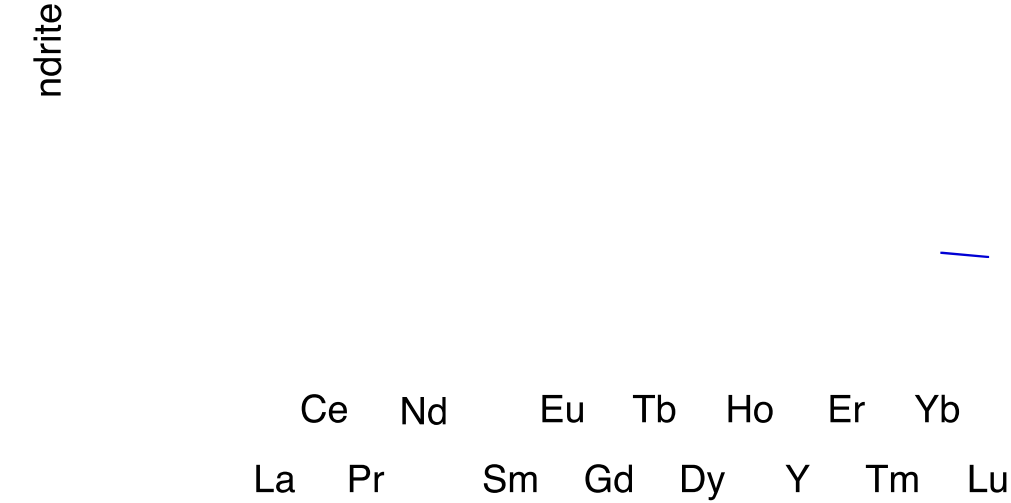
Constraints on Source of MK Deposits from REE Chemistry

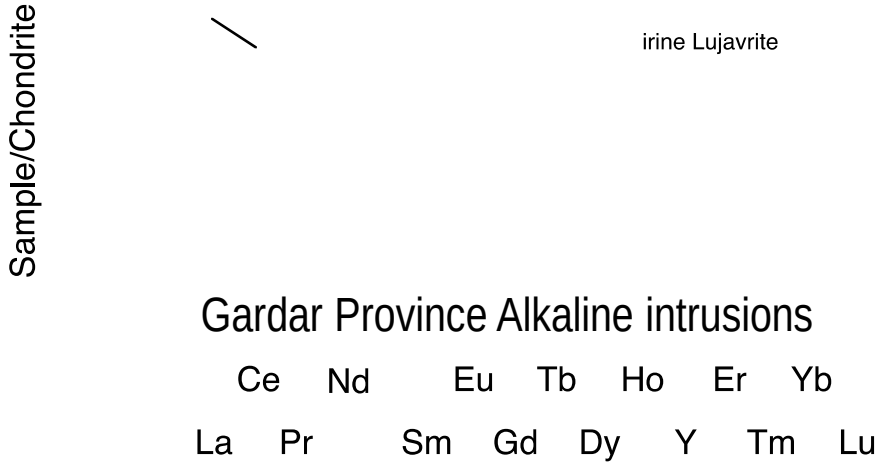


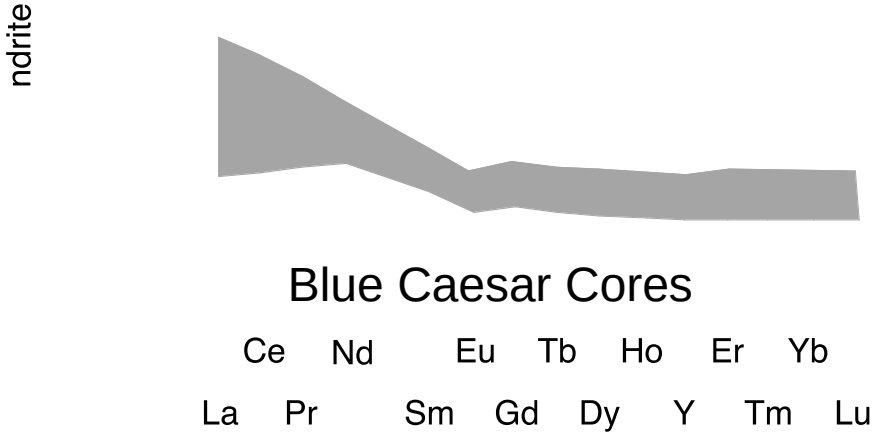
Data from Maas *et al.,* (1987)

- Mary Kathleen Belt ore is strongly LREE enriched.
- Burstall granite pattern typical of A-type (alkali) granites.
- Non-fractionated pattern.
- Similar levels of LREE and HREE with strong negative Eu .

REE ENRICHMENT IN ALKALINE INTRUSIONS

- Mary Kathleen Belt samples patterns and levels of REE enrichment are similar.
- REEs most likely derived from an alkaline igneous intrusion.



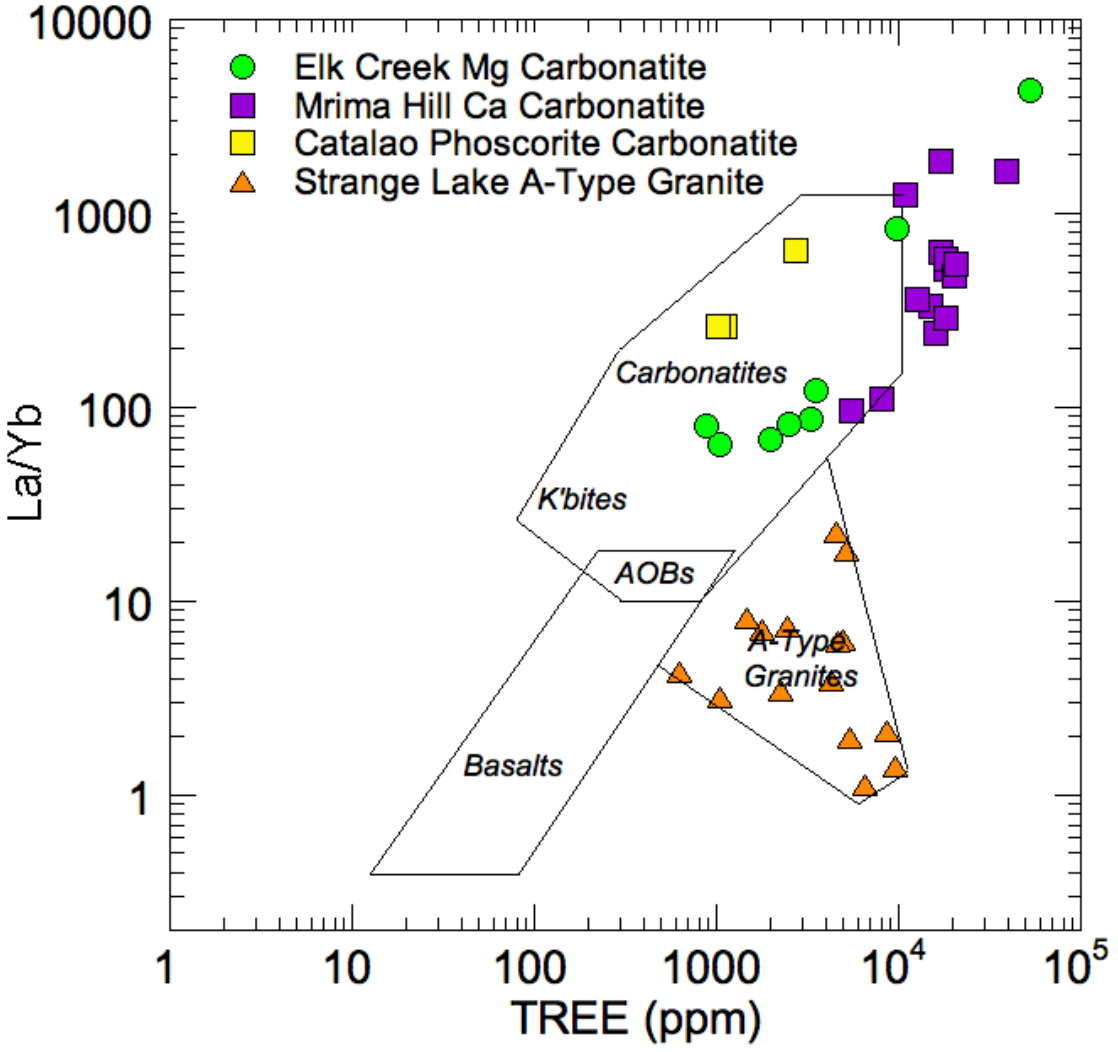


Similar to nepheline syenites - fractionated LREE-enriched patterns, prominent –ive Eu anomalies and slightly fractionated HREEs.

Discrimination Plot for Identifying the Source of Metals Using REE Systematics

- REEs, and alkali metal enrichment in carbonatites reflects concentration and transport in a super critical fluid.
- Not crystal-liquid fractionation

Loubert et al., (1972)



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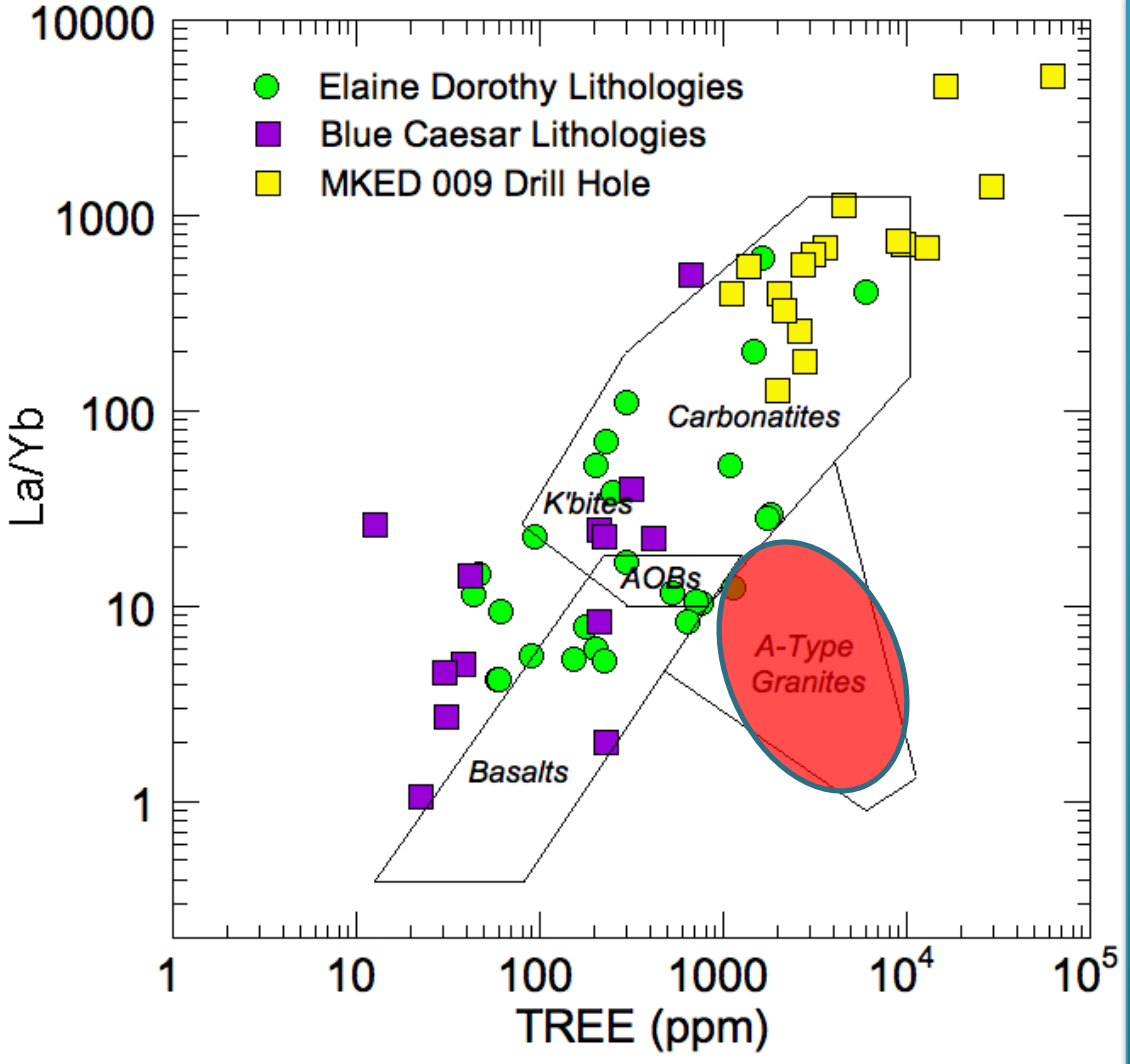
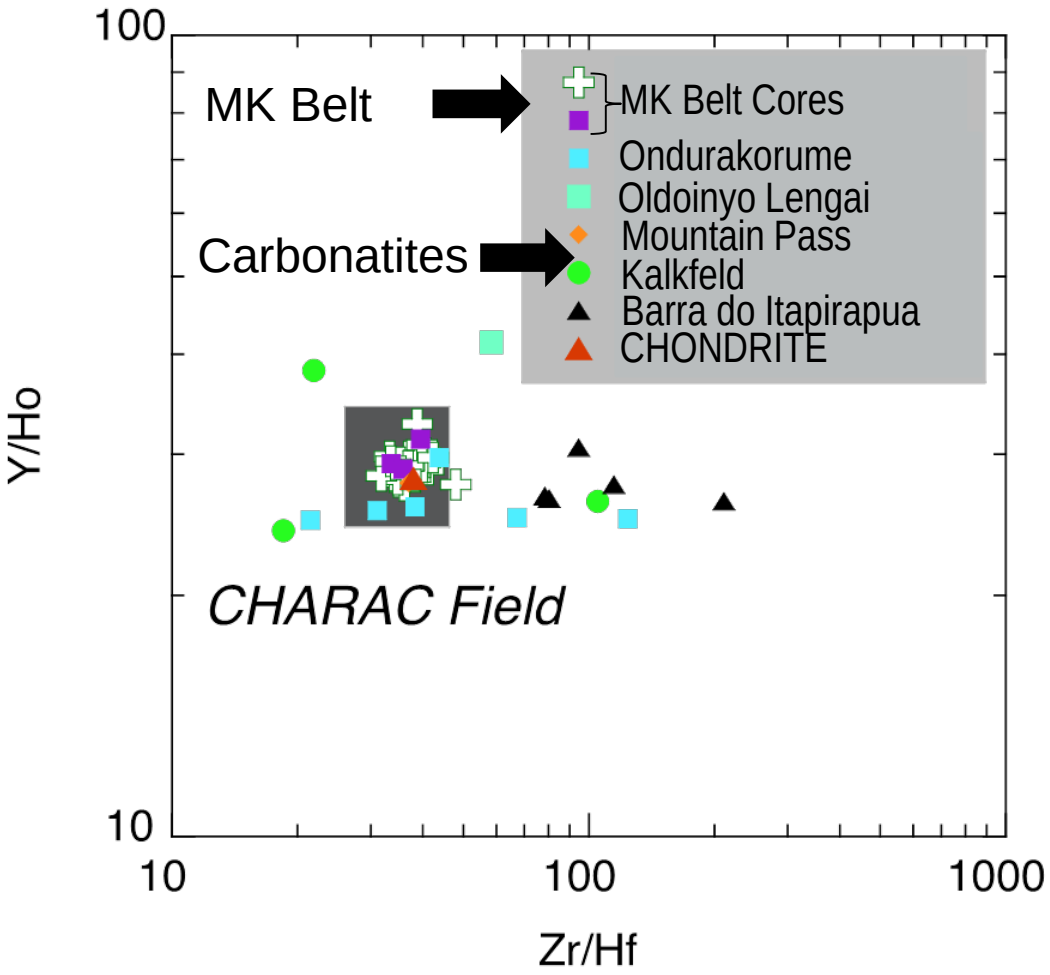
Source of MKB Metals from REE Systematics

- REEs, actinides, PGEs, Ni, Co, Cu and Au in the Mary Kathleen Belt derived from a mafic alkaline magmatic source.
- **The metals in MK deposits were not derived from an A-type granitic "Burstall Source"**



PRIMITIVE METAL SOURCE

- Blue Caesar and Elaine Dorothy Cores cores have CHONDRITIC Y/Ho and Zr/Hf ratios.
- Indicates igneous source
- Most carbonatites plot in the same field for Y/Ho.
- Some exhibit HFSE fractionation – non-chondritic Zr/Hf ratios

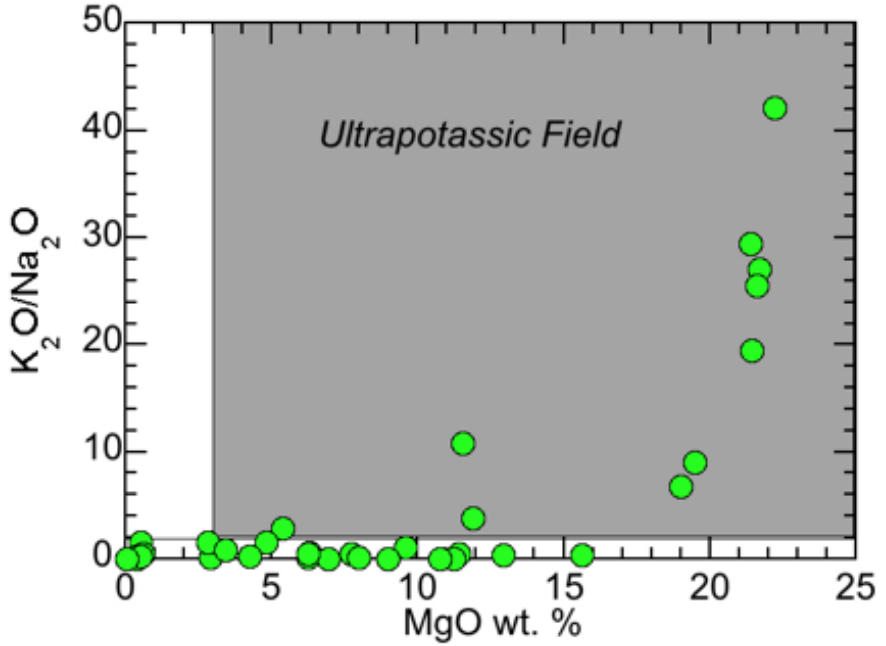


Data from de Andrade et al., (2002)

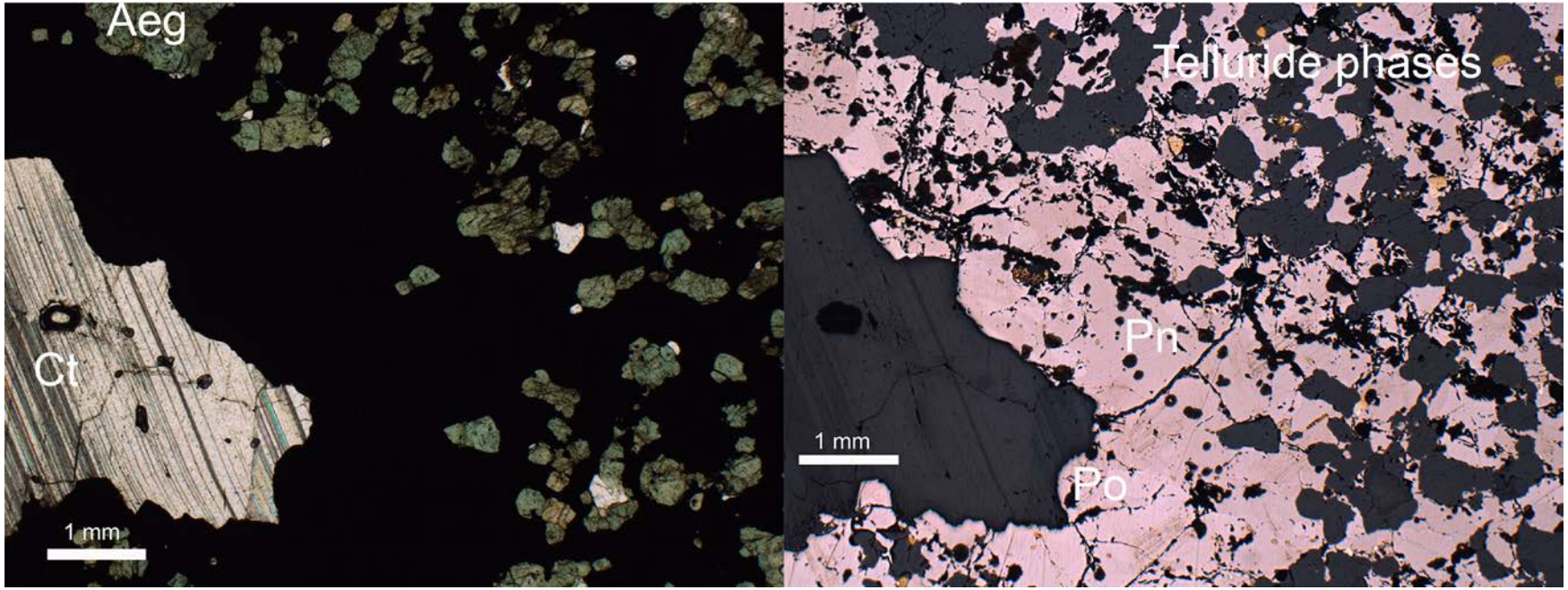
THE SMOKING GUN!!

Presence of ultra-potassic high-Mg alkaline dykes in Elaine Dorothy and Blue Caesar cores

- Post-tectonic ultramafic lamprophyres (glimmerites) occur in some MK Belt cores.
- **Logged as pelitic schists**
- Their ultramafic affinity and intrusive relations were not reported.



1526 Ma Alkaline Suite – Mary Kathleen Belt
Orthomagmatic Mineralisation in Alkali Proxenite



Plane Polarised Light

Reflected Light

MKBC 002 – 47.9 m

MINERALISATION STYLES in THE MKB
Epithermal Ag/Au Mineralisation in MK Belt Indicates Shallow Depth of Emplacement

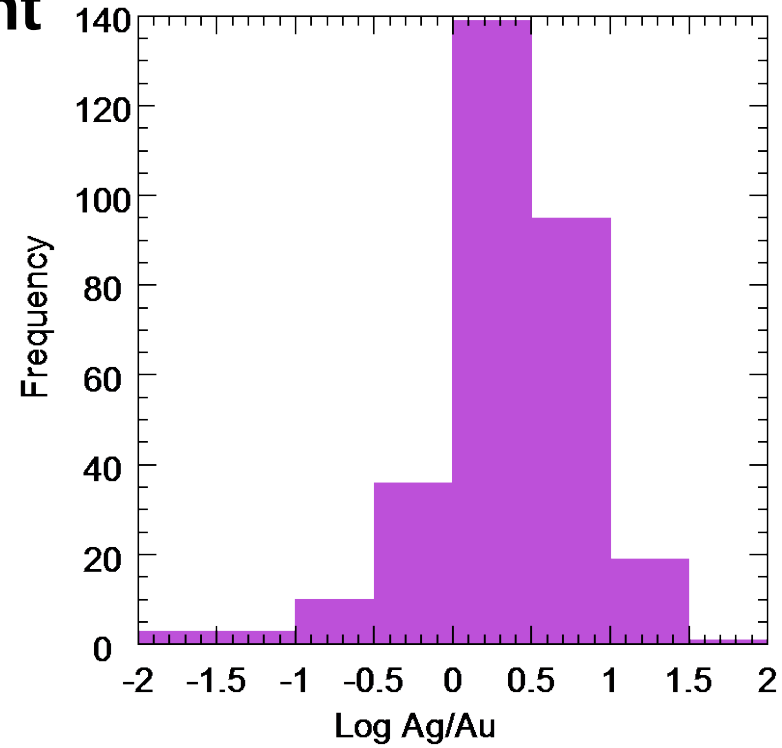
Cole and Drummond, 1986

Variation in Ag/Au ratios in epithermal ore deposits reflects:

- Reflects transport and partitioning of Au and Ag in precious metal-bearing fluids during boiling.

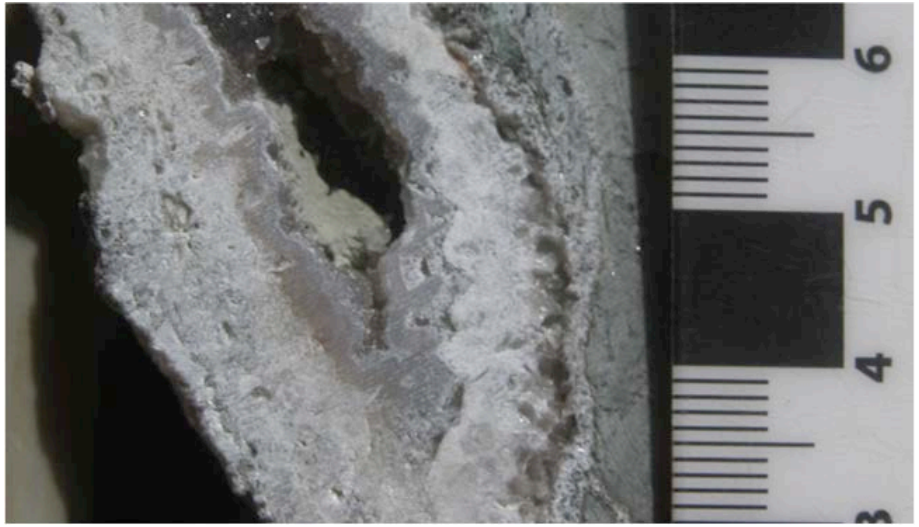
Shikazono and Shimizu,1987

- Decreasing Ag/Au ratio the influence of increasing Cl^- in the fluid and increasing temperature

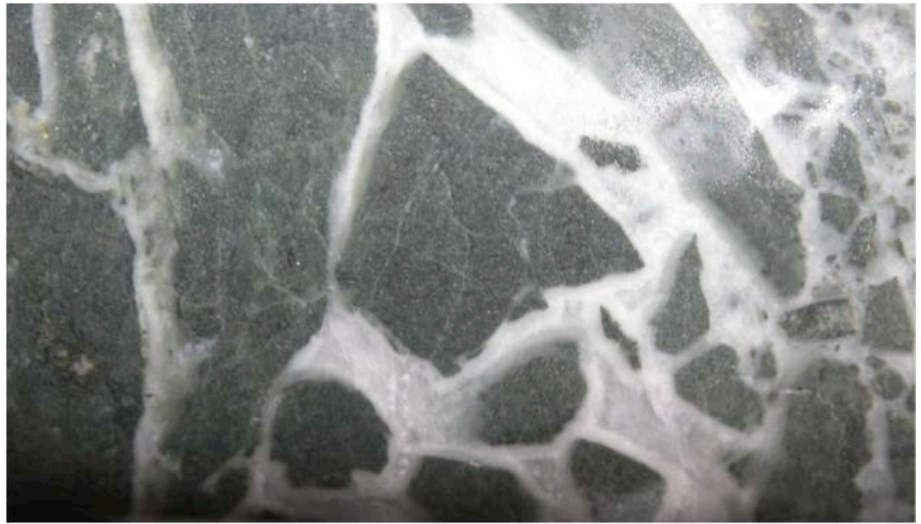


Log normal Ag/Au ratios of Mary Kathleen Belt cores show mineralisation occurred under low pressure conditions.

FIELD EVIDENCE OF EPITHERMAL SHALLOW MINERALISATION



Vugh in vein cutting pyroxenite. evidence of late epithermal boiling fluids.



Brecciated alkali pyroxenite cemented by siliceous vein deposit.

Implies shallow depth of emplacement <1 km?

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SUMMARY TIMING OF MK BELT MINERALISATION

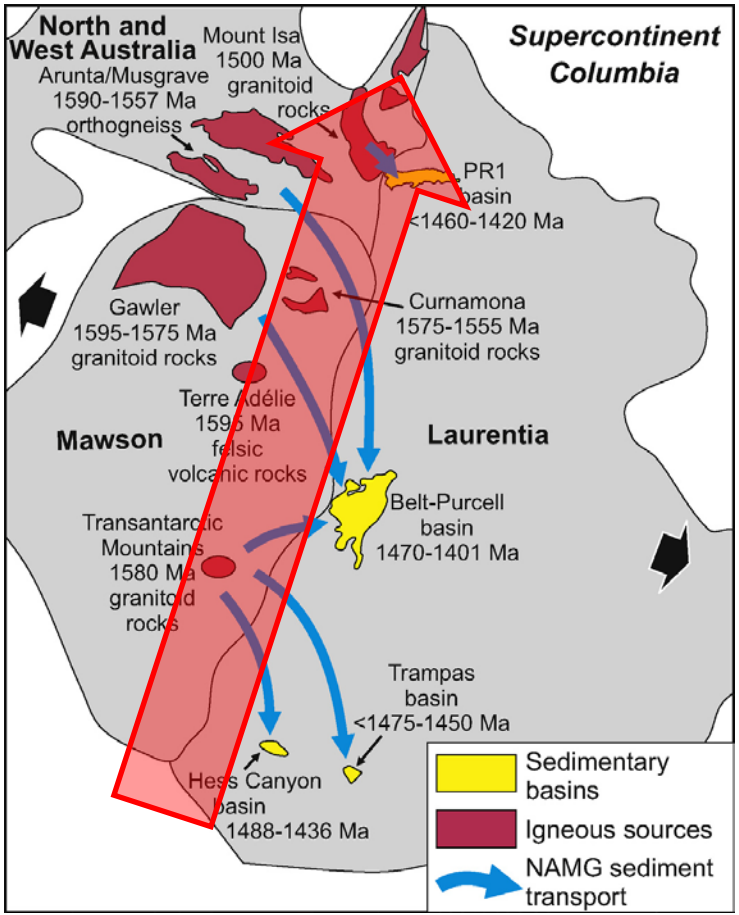
- Mineralisation constrained by ~ 1526±11 Ma U-Pb titanite & Ar-Ar biotite ages of pyroxenite veins (Sha *et al.*, 2015).
- Age of Mary Kathleen uraninite ore 1550±15 Ma (Page 1983) is within error (1535 Ma) of this age.
- Sm-Nd isochron 1472±40 Ma also within error of age (1512 Ma) Maas *et al.,* (1987).
- **THUS Mary Kathleen mineralisation related to a POST TECTONIC ALKALINE EVENT**
- Similar mineralisation age in Cloncurry Belt IOCGs
- Mary Kathleen Belt Deposits and CB IOCGs are related.

METALLOGENIC-GEODYNAMIC INTERPRETATION

Configuration of North and West Australia, Laurentia, and Mawson continent (South Australia Gawler Craton and Antarctica) in the super-continent Columbia at ~ 1450 Ma.

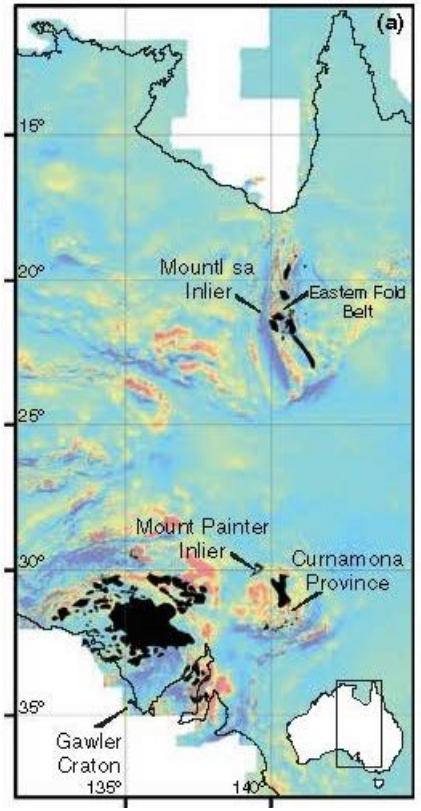
Cause of the Mesoproterozoic break-up of western Columbia is unresolved.

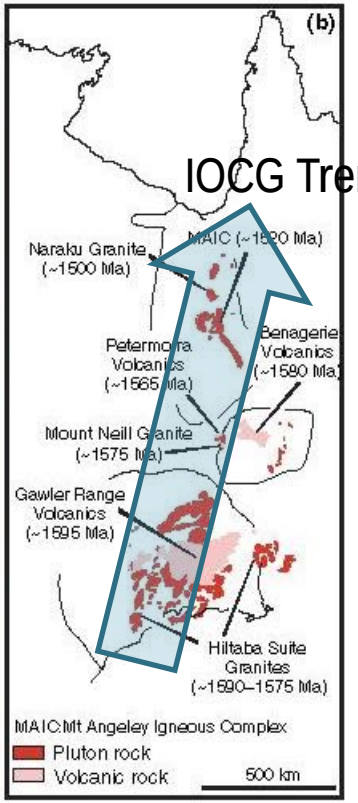
Possibly rifting due to plume impact on the lithosphere,as Columbia passed over the Pacific Superplume.

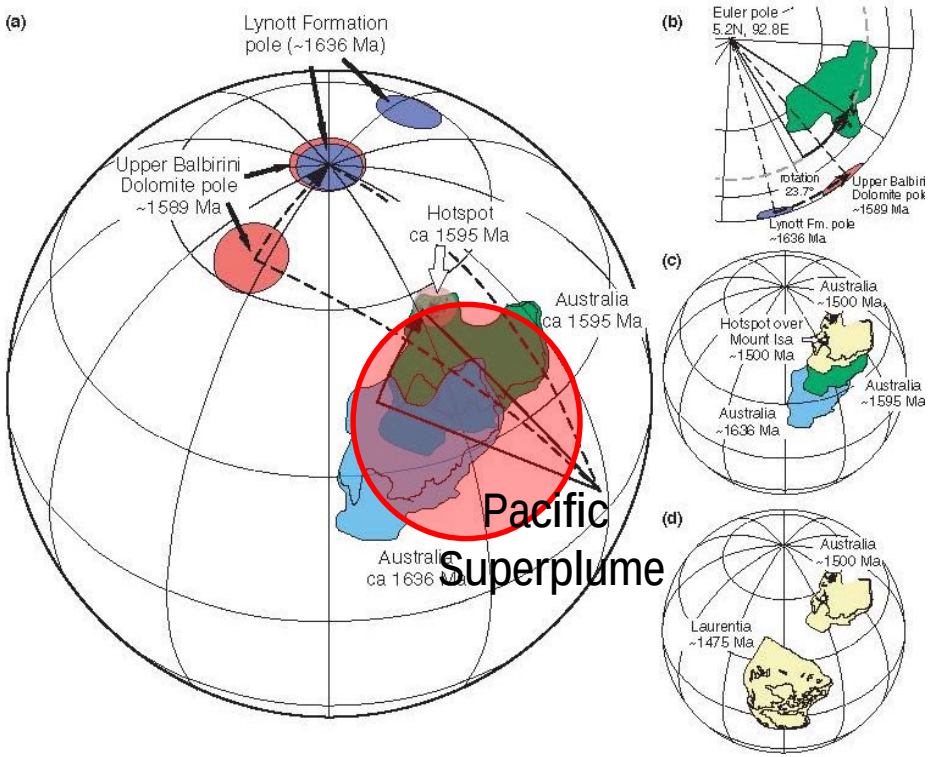


After Medig *et al.*, (2014) Precambrian Research

GEODYNAMIC INTERPRETATION-ALKALINE SYSTEMS DEFINE A MESOPROTEROZOIC PLUME TRACK







From Betts *et al.*, (2007) Terra Nova 19, 496-501

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SUMMARY MESSAGES

- Cu-Au-Co-PGE-REE mineralisation in the MKB are not SKARN deposits, they are orthomagmatic and epithermal.
- Mineralisation was caused by mantle plume generated potassic alkali phoscorite-carbonatite igneous activity.
- Epithermal Au and Ag mineralisation indicates that the alkaline intrusions were emplaced to shallow depths.
- New model for MKB mineralisation has direct relevance for IOCG exploration in the adjacent Cloncurry Belt.
- Confirms link between phoscorite-carbonatite magmatism and IOCG mineralisation (Groves and Vielreicher, 2001).

IMPLICATIONS FOR EXPLORATION

- Development of this new understanding of MKB geology confirms the importance of field observations, petrology, geochemistry and geodynamics in exploration.
- Improved knowledge of the nature of exploration targets in the MKB and the Cloncurry Belt will improve interpretation of geophysical and geochemical anomalies.
- Multi-element targets likely to be pipe-like concentrically zoned intrusions ranging from <1 to >5 km in diameter.
- **Elaine Dorothy and Blue Caesar are the branches of such a target, the trunk has still to be found.**