KRX077 662m - Ironstone

Geochemical facies of Neoproterozoic ‘snowball Earth’ diamictite sequences at the Kansanshi Mine, Zambia: implications for seawater chemistry

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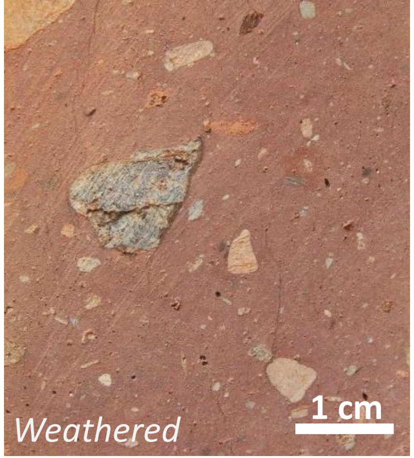
Diamictite

- A non-genetic term for poorly sorted or non-sorted terrigenous sedimentary rock containing particles ranging in size from clay to boulders suspended in a fine-grained matrix

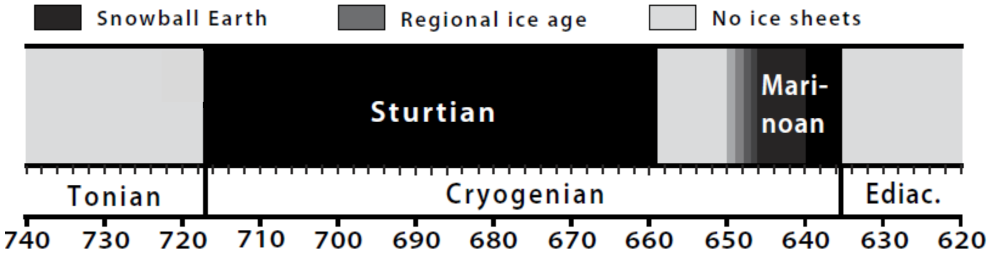
- Most commonly:
    - Mass flows: ‘debrites’
    - Glacially derived: ‘tillites’
    - Volcaniclastic deposits

- The distinctive character of diamictites permits easy recognition

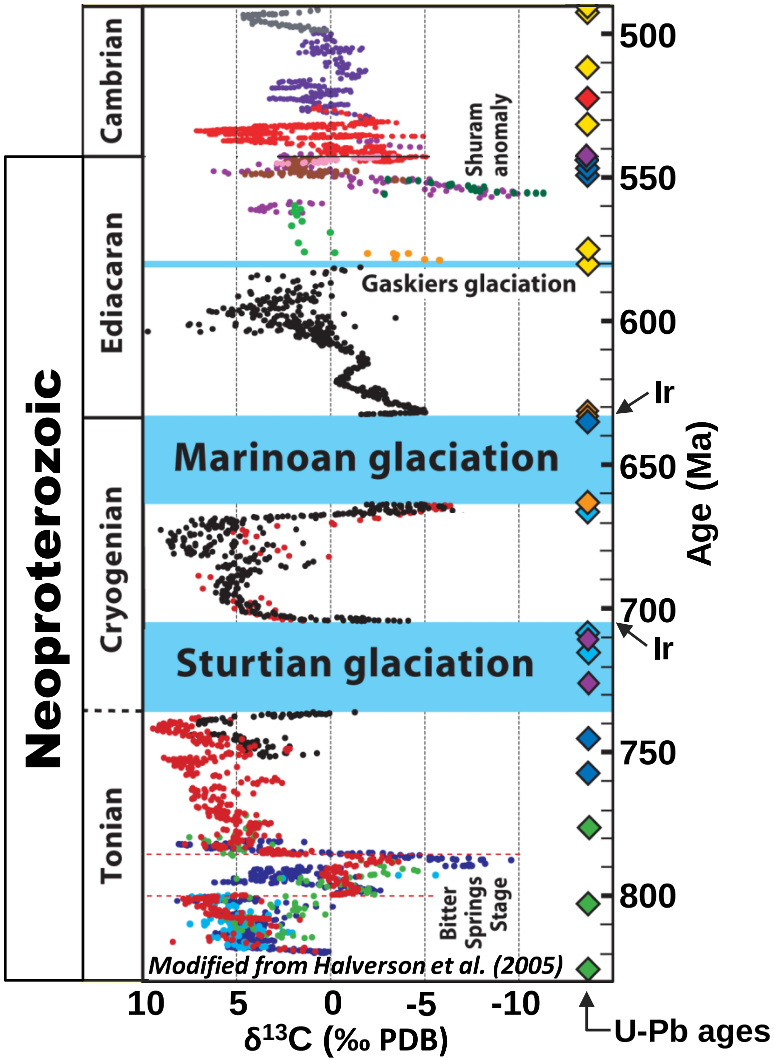


Background

- Neoproterozoic 'snowball Earth' hypothesis
  - Key features:
    - Diamictites/tillites and dropstones
    - Ironstones
    - Cap carbonates
    - $\delta^{13}C$ isotope excursions
    - Ir anomalies



Hoffman et al., 2017



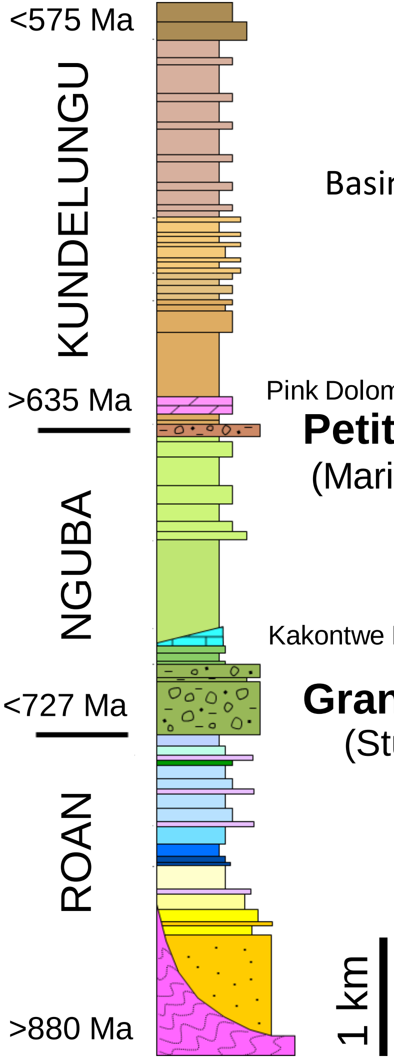
Modified from Halverson et al. (2005)

‘Snowball Earth’

- Controversy
  - Local not global
  - Slushball/Snowball
  - Mixtite not tillite
    - Debris flows on rifted margins
      - e.g. Eyles and Januszczak, 2004
    - “tectonically-driven mass flow destroyed any primary record of glacial climate”
      - Kennedy et al., 2019 – Kamoa, DRC

Chuos Fm. BIF, Namibia

Neoproterozoic Katangan Basin



Basin inversion, Pan-African orogeny

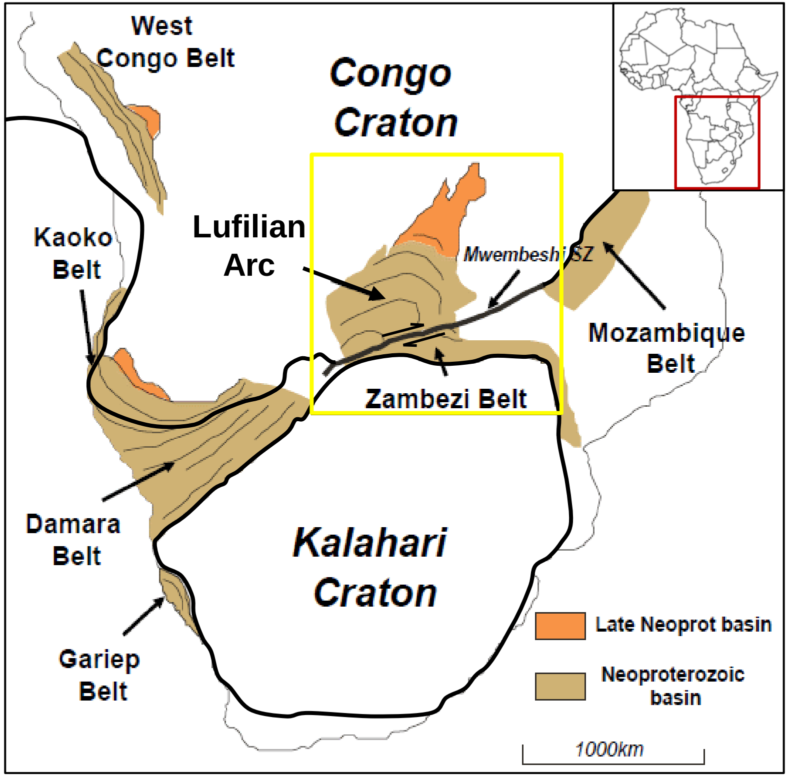
Pink Dolomite (Cap Carbonate)

Petit Conglomérat
(Marinoan Glaciation)

Kakontwe Limestone (Cap Carbonate)

Grand Conglomérat
(Sturtian Glaciation)

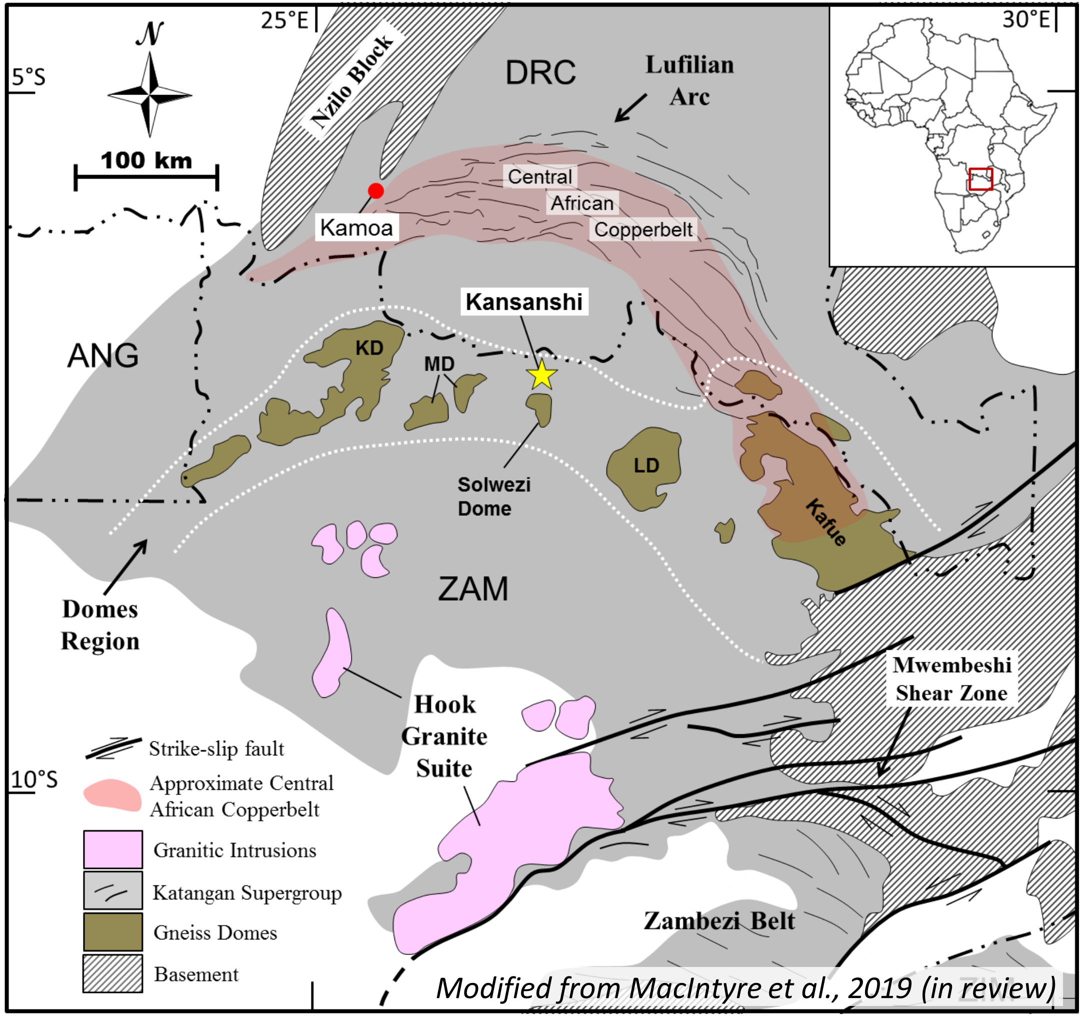
Intracratonic rift basin



Modified from M. Hitzman (after Kampunzu and Cailteux, 1999)

Central African Copperbelt

- Worlds largest concentration of stratiform Cu-Co deposits
- Sturtian diamictite found throughout
- Marinoan limited to northern portions of basin
- Metamorphic grade increases around Domes Region



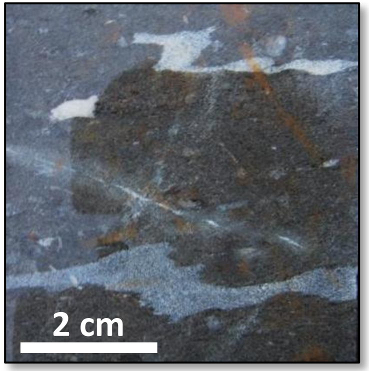
Modified from MacIntyre et al., 2019 (in review)

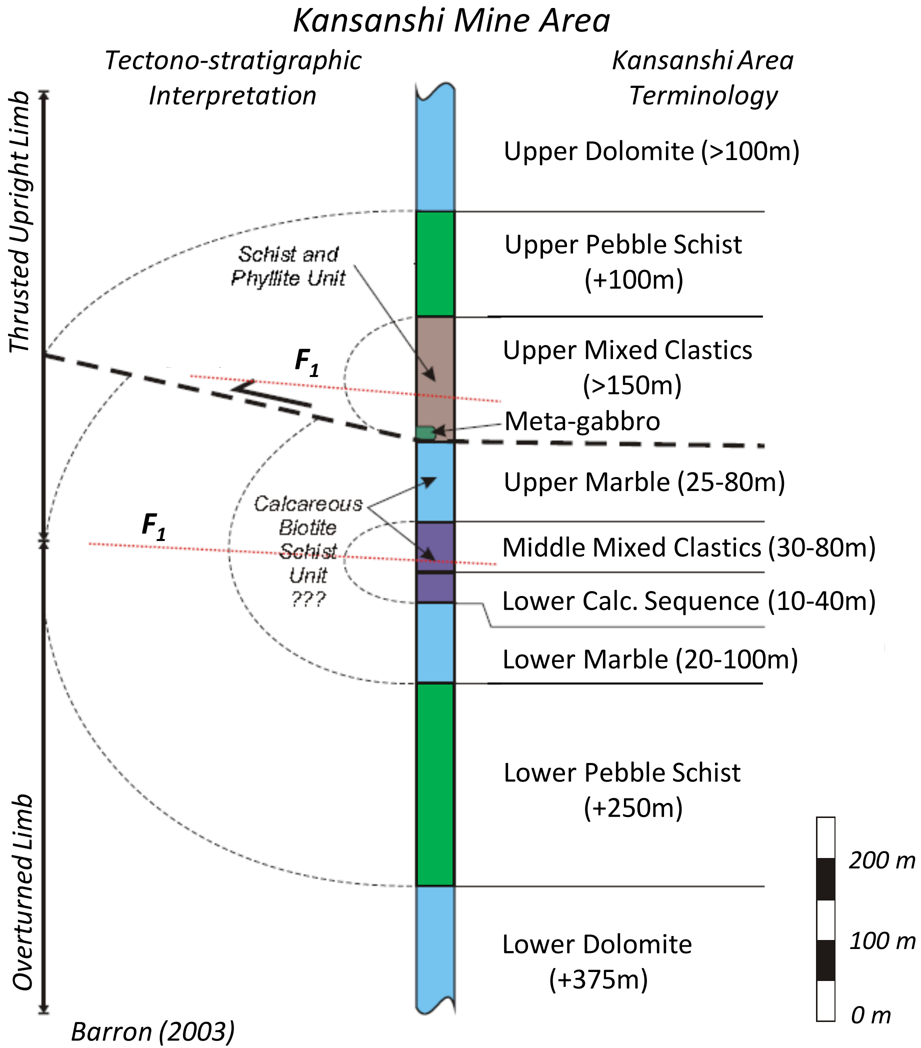
Metadiamictite

- Amphibolite-facies metamorphism in western Domes Region
- Clasts strongly flattened, occasionally folded, but recognizable
- Typically garnet-biotite-quartz-schist, but varies with chemistry of protolith
- Locally termed "Pebble Schist"

Kansanshi Geology

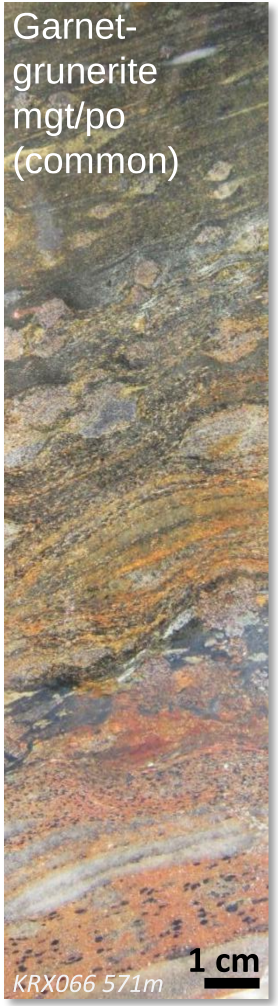
- How to correlate stratigraphy?
- Are multiple metadiamictite units fold repetition?
    - Locally three
- 84 km of recent deep drilling with 48-element geochemistry





Kansanshi Ironstone

- Logging of new drill holes noted ironstones
  - Base of lower metadiamictite
  - Locally at top of upper metadiamictite
  - Not always present
- Lends support for folding
  - Uncertainty regarding discontinuous nature
  - Recent work proposed late hydrothermal model
    - Hendrickson et al., 2015 – Fishtie
- More common in Sturtian rocks
  - Especially near base of sequence
  - Also present in Marinoan
  - Not certain which metadiamictite is upright
    - Barron (2003) suggested upper metadiamictite upright

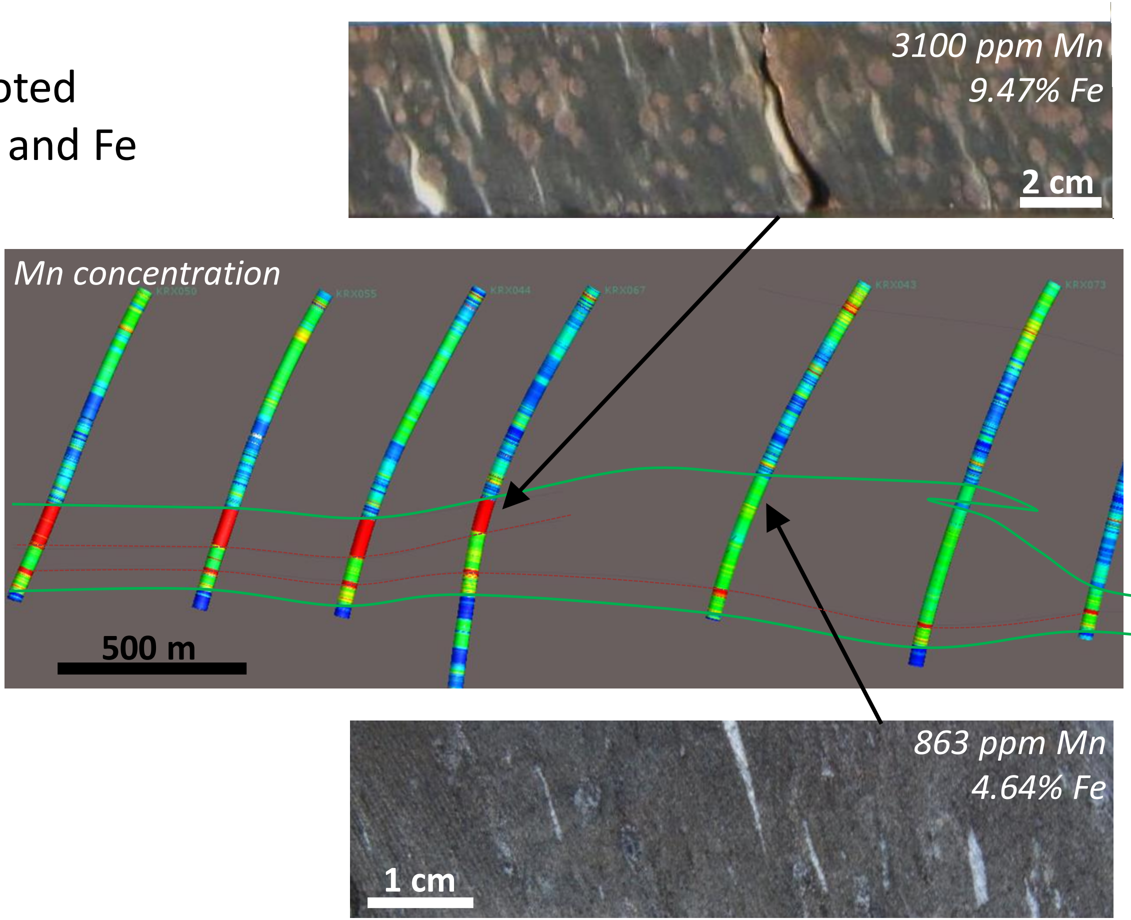


Textural and Geochemical Variations

- Variations in garnet abundance noted
  - linked to variations in Mn and Fe

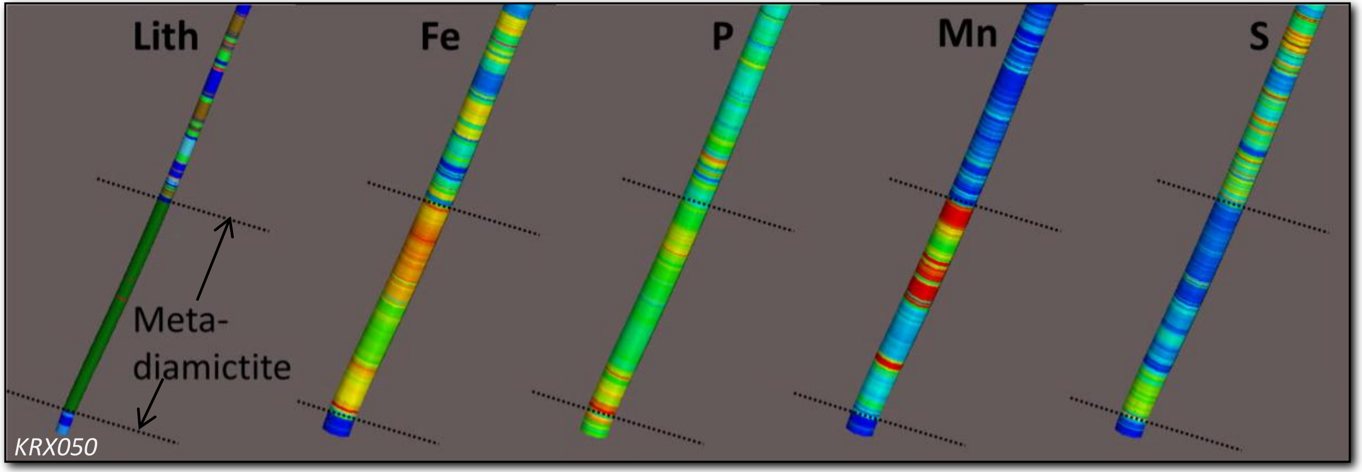
- Further investigation shows distinct geochemical patterns for S, in addition to Fe+P associated with ironstones

- This lead to a more formal geochemical analysis utilizing IoGAS software



Methods

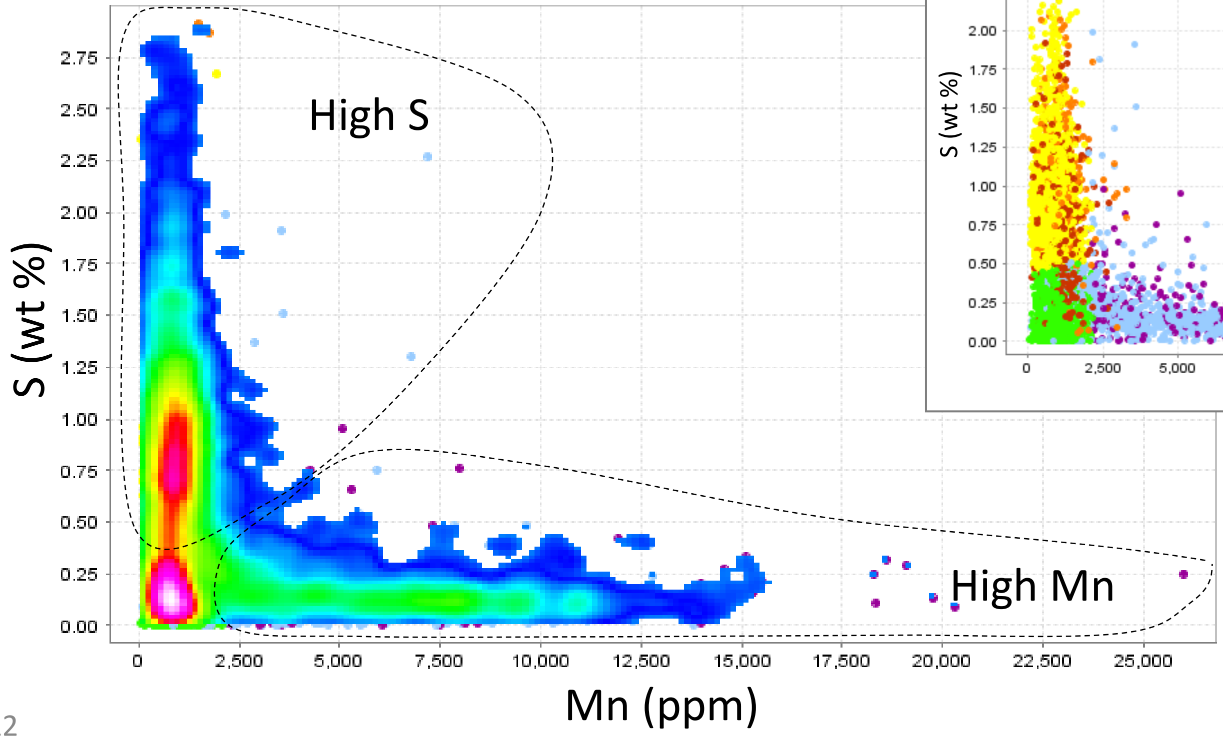
- >12000 samples from rocks logged as metadiamictite (pebble schist)
- 48 elements, 4-acid digestion, ICP-MS (*ALS Chemex, ME-MS61 package*)
- After QA/AC and outlier removal, 10674 samples from 103 drill holes remain
- Analysis in IoGAS to identify population clusters (point density tool)

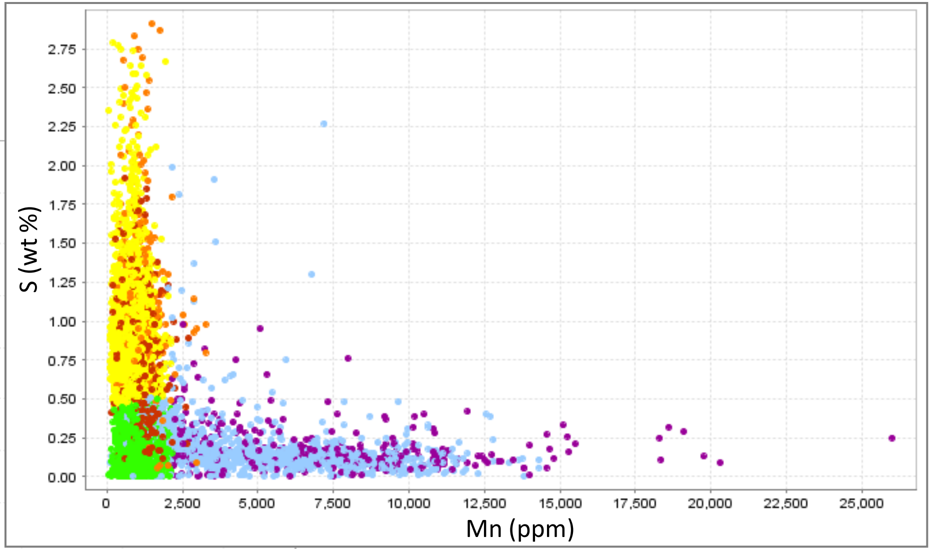


Oxidized and Reduced Facies

1. **Plot S vs Mn**

- use point density tool to visualize and select





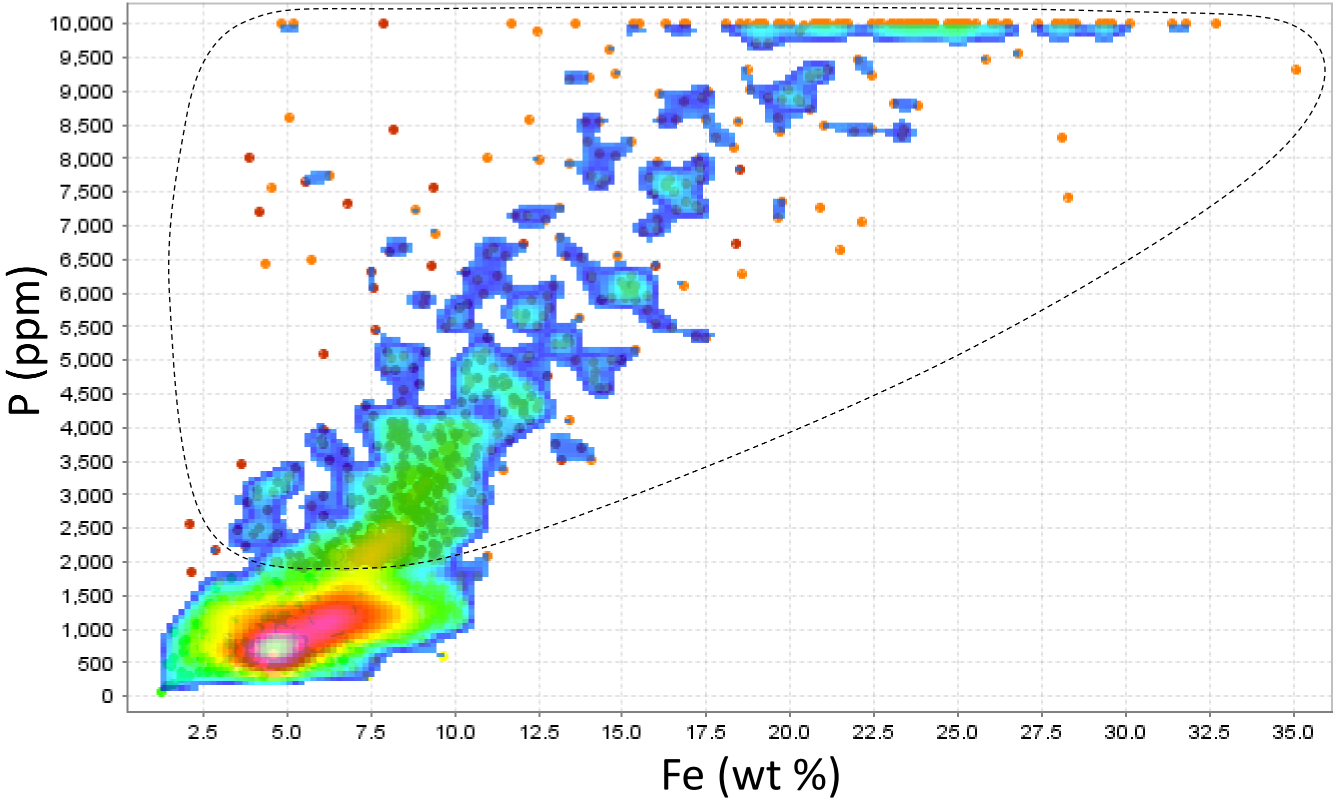
- High Mn population
- High S population
- Remainder = background

Ferruginous Metadiamictite & Ironstone

2. Plot Fe vs P

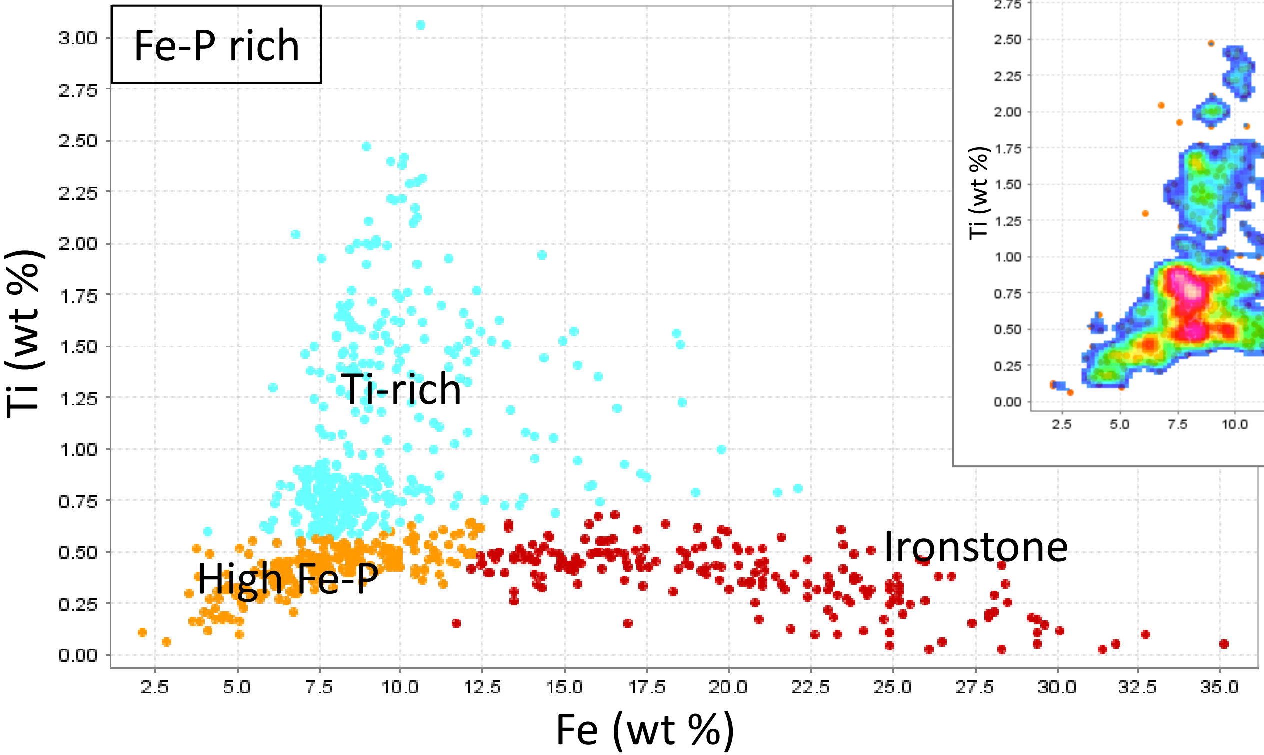
- Samples along this trend are ferruginous metadiamictite and ironstones

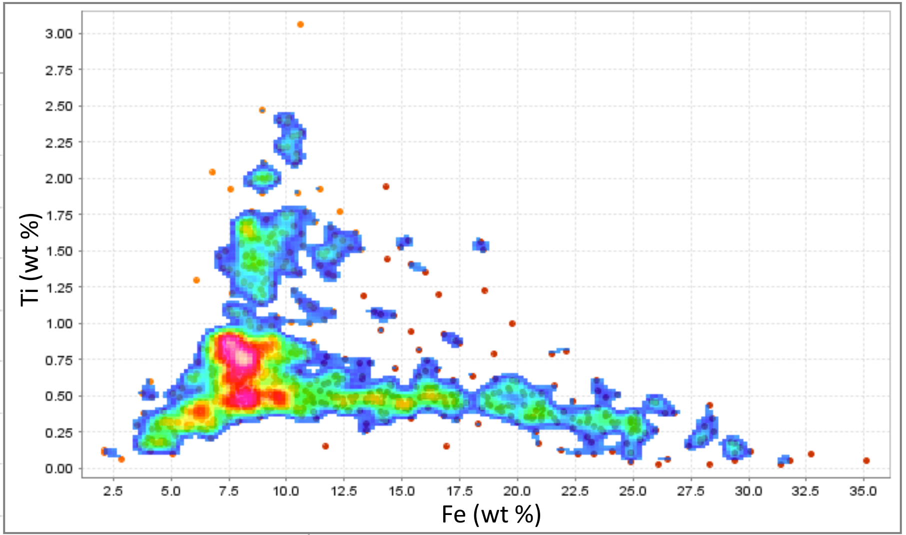
- Plotting Fe vs S shows that majority have Fe/S ratio > Pyrrhotite therefore Fe-enriched



Ferruginous Metadiamictite - Subgroups

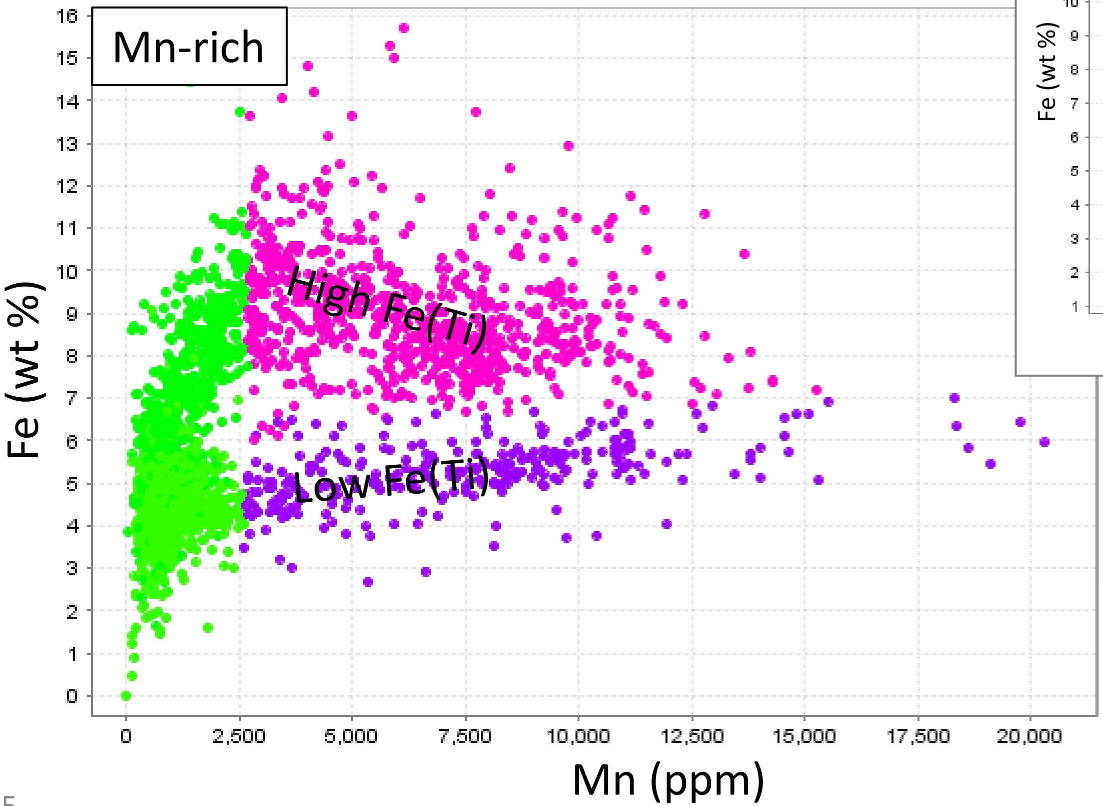
3. Plot Fe vs Ti (for high Fe+P samples only)

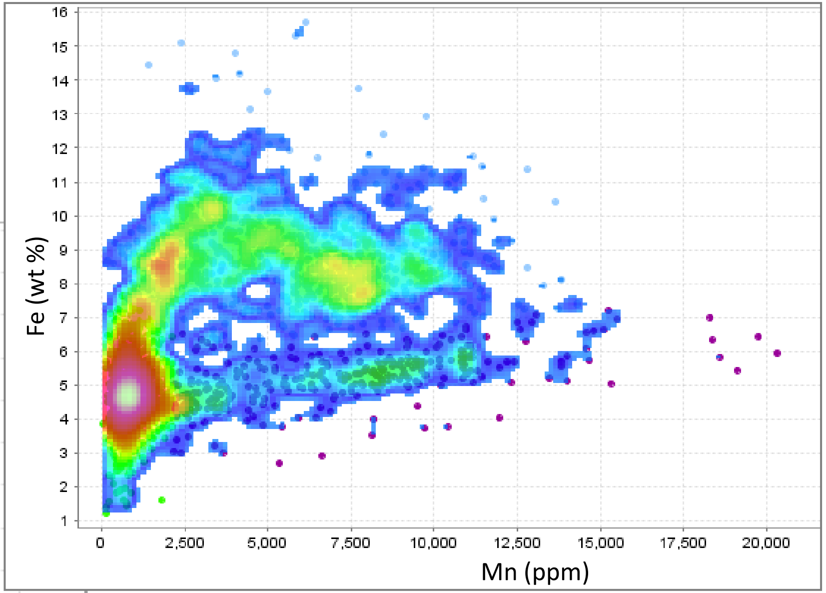




- Create 2 subgroups of the High Fe-P class
- True ironstones are relatively Ti-poor

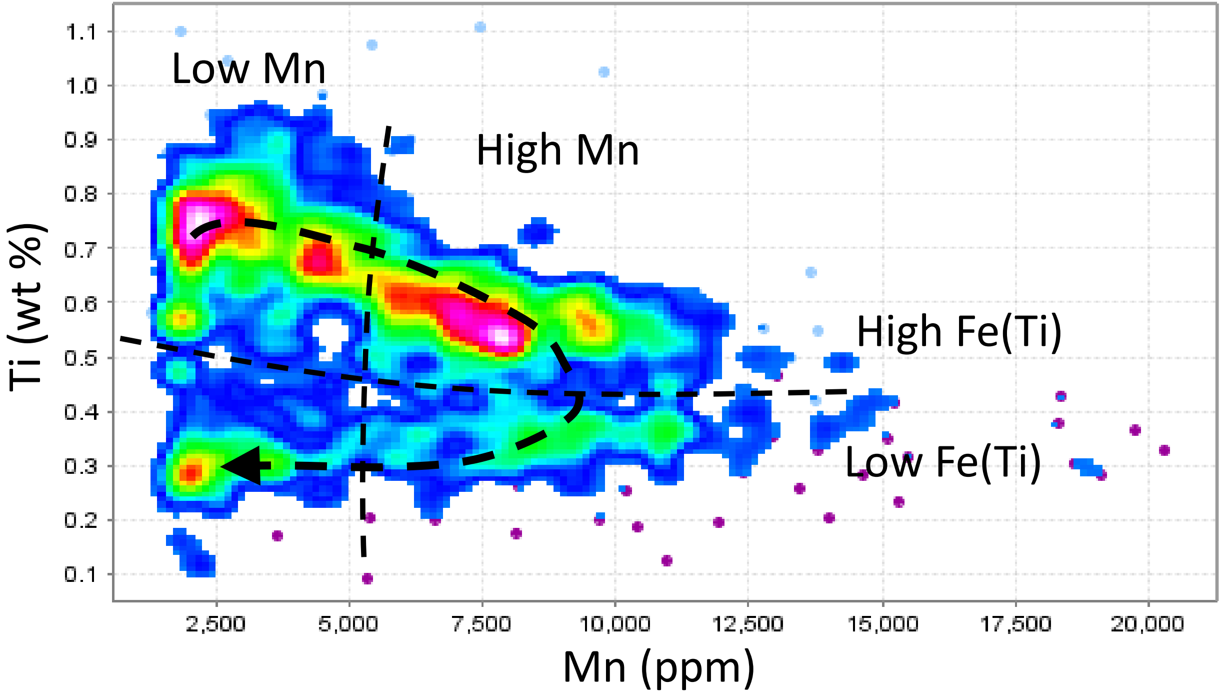
Mn-rich Subgroups





4. **Plot Mn vs Fe**
   - subdivide into high Fe and low Fe subgroups
   - note the same subgroups occur with Ti

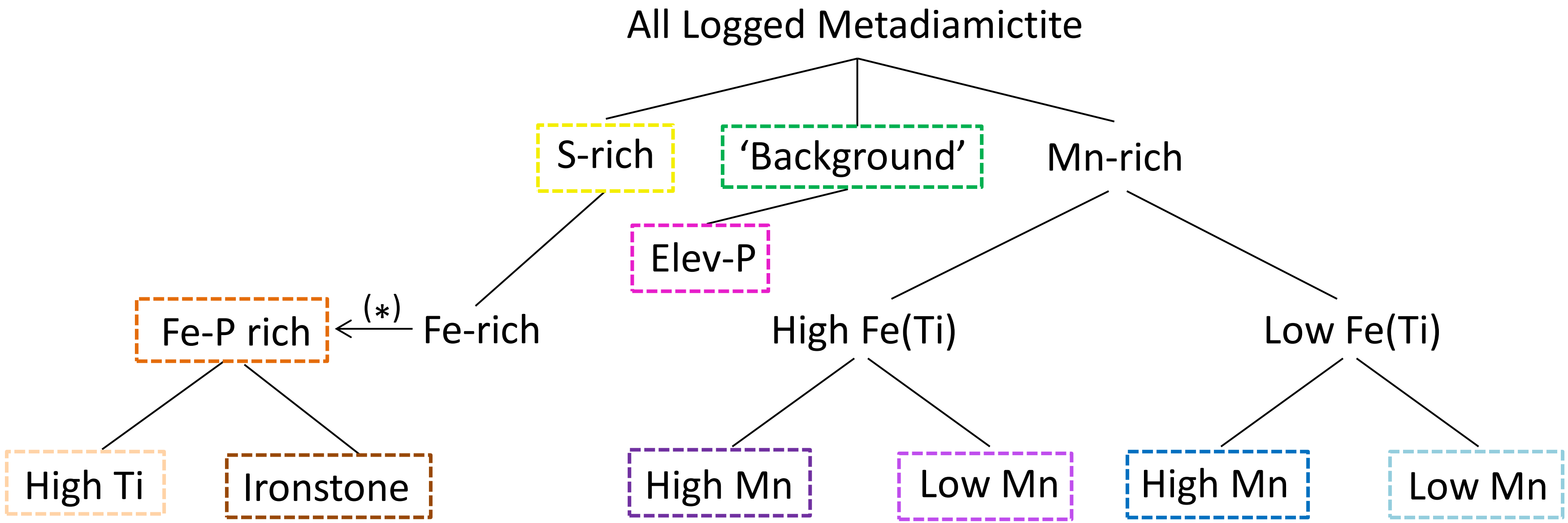
Mn-rich Subgroups



5. Mn vs Ti plot

- Subdivide previous high Fe(Ti) and low Fe(Ti) groups based on Mn concentration
- Subgroups define a sequential progression in the transitional zone

Geochemical Facies

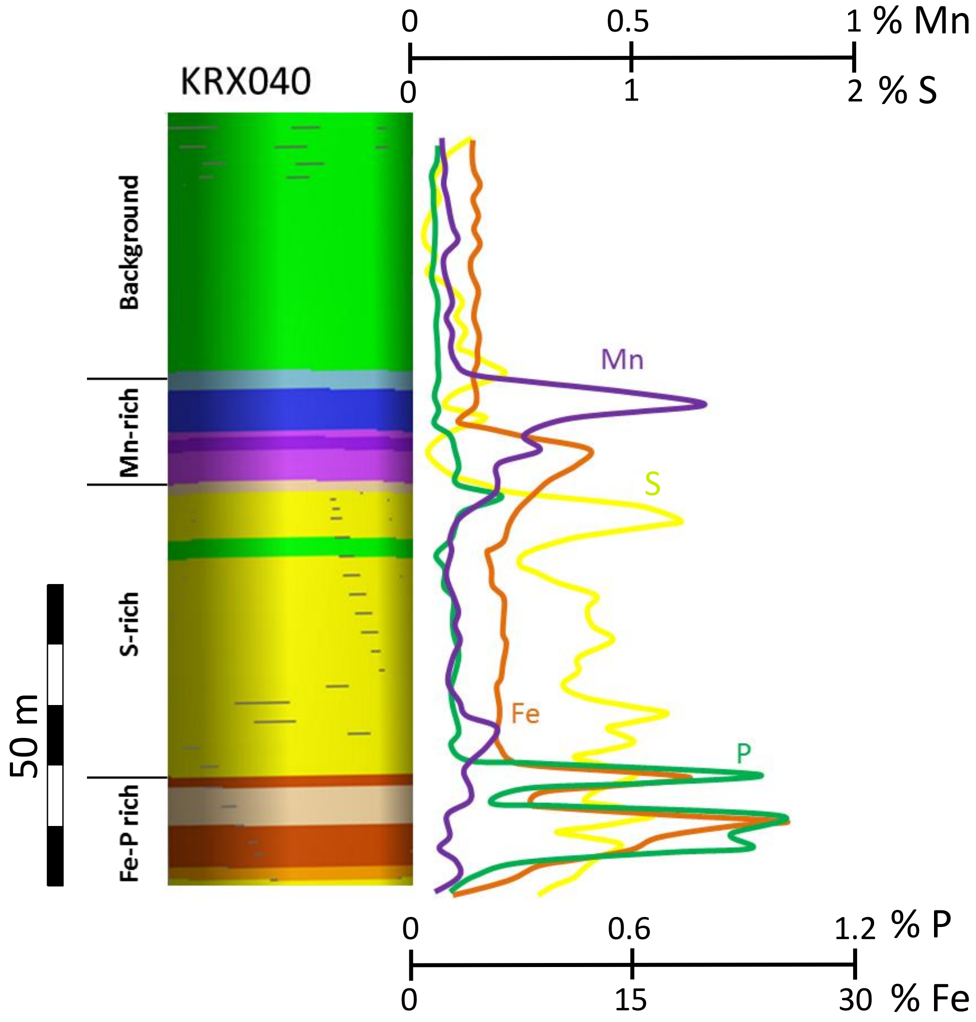


* *This step includes all data points, not just S-rich*

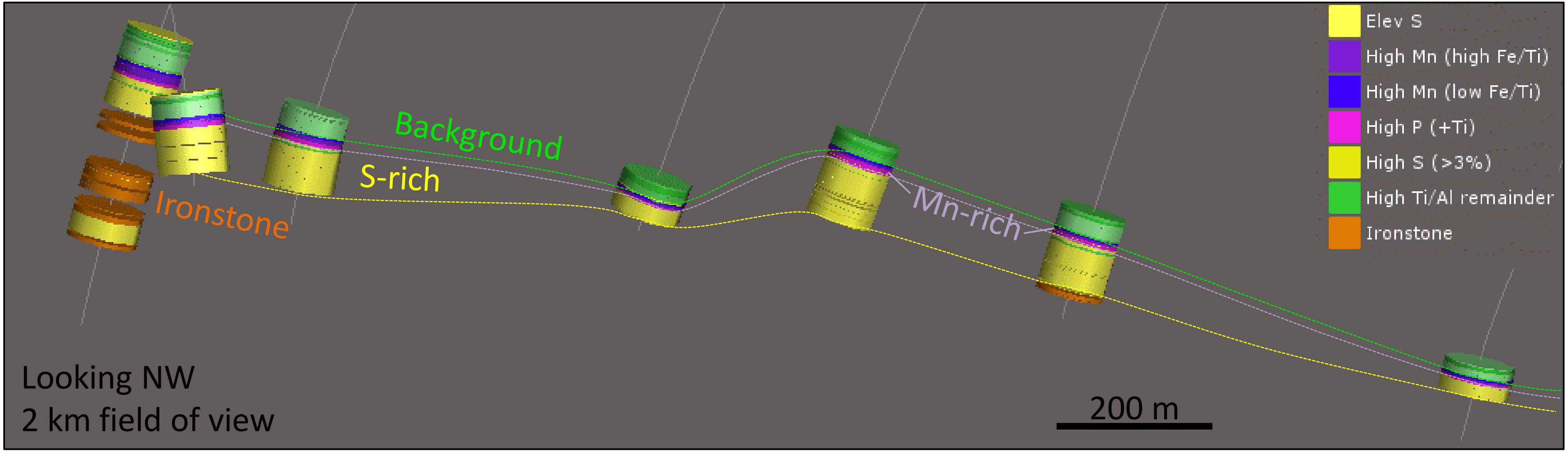
Geochemical Facies

Geochemical Facies

- Background
- Mn-rich (Mn)
  - Low Fe(Ti), low Mn
  - Low Fe(Ti), high Mn
  - High Fe(Ti), high Mn
  - High Fe(Ti), low Mn
- S-rich (S)
- Fe (P) rich (Fe)
  - High Ti
  - Ironstone

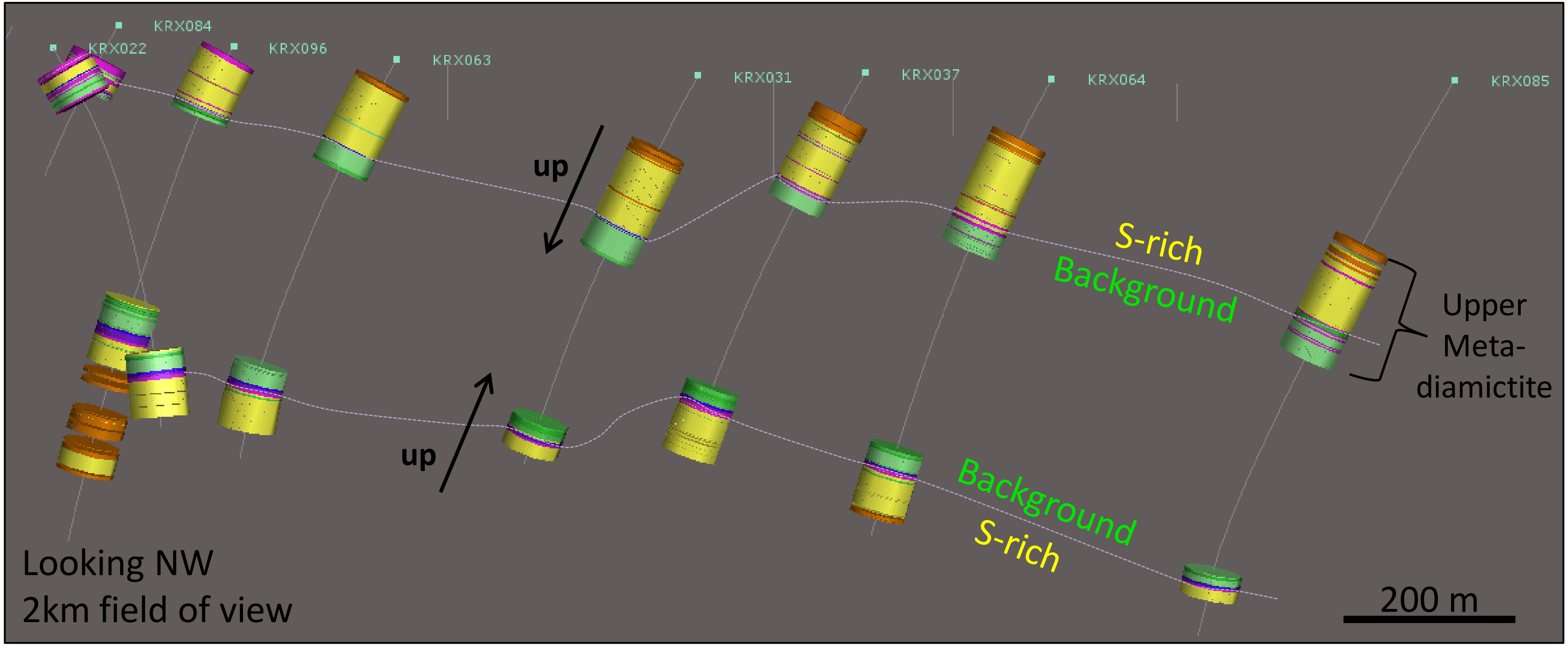


Geochemical Patterns



- Despite the complex deformation at Kansanshi the resulting geochemical patterns are surprisingly consistent

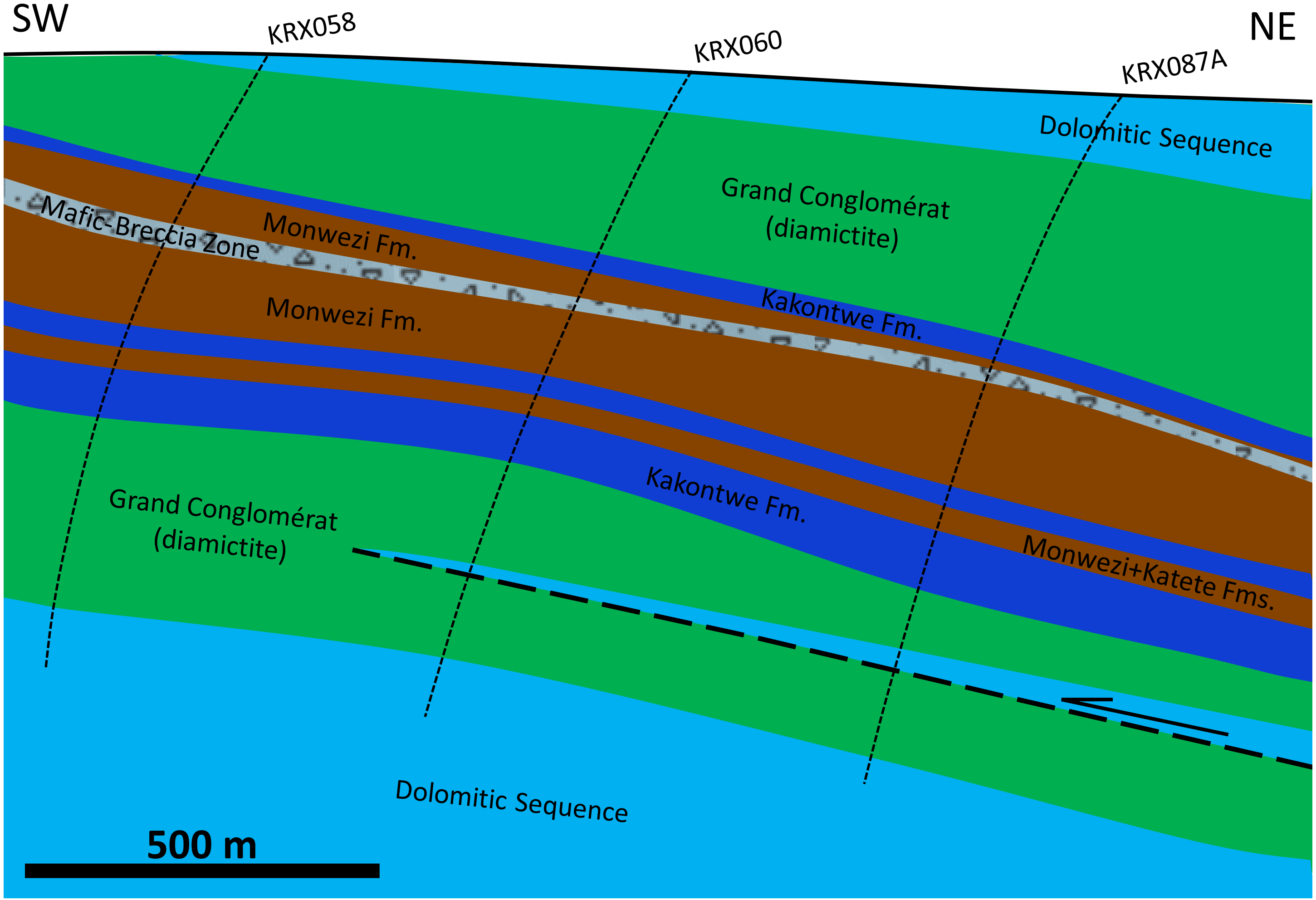
Geochemical Patterns



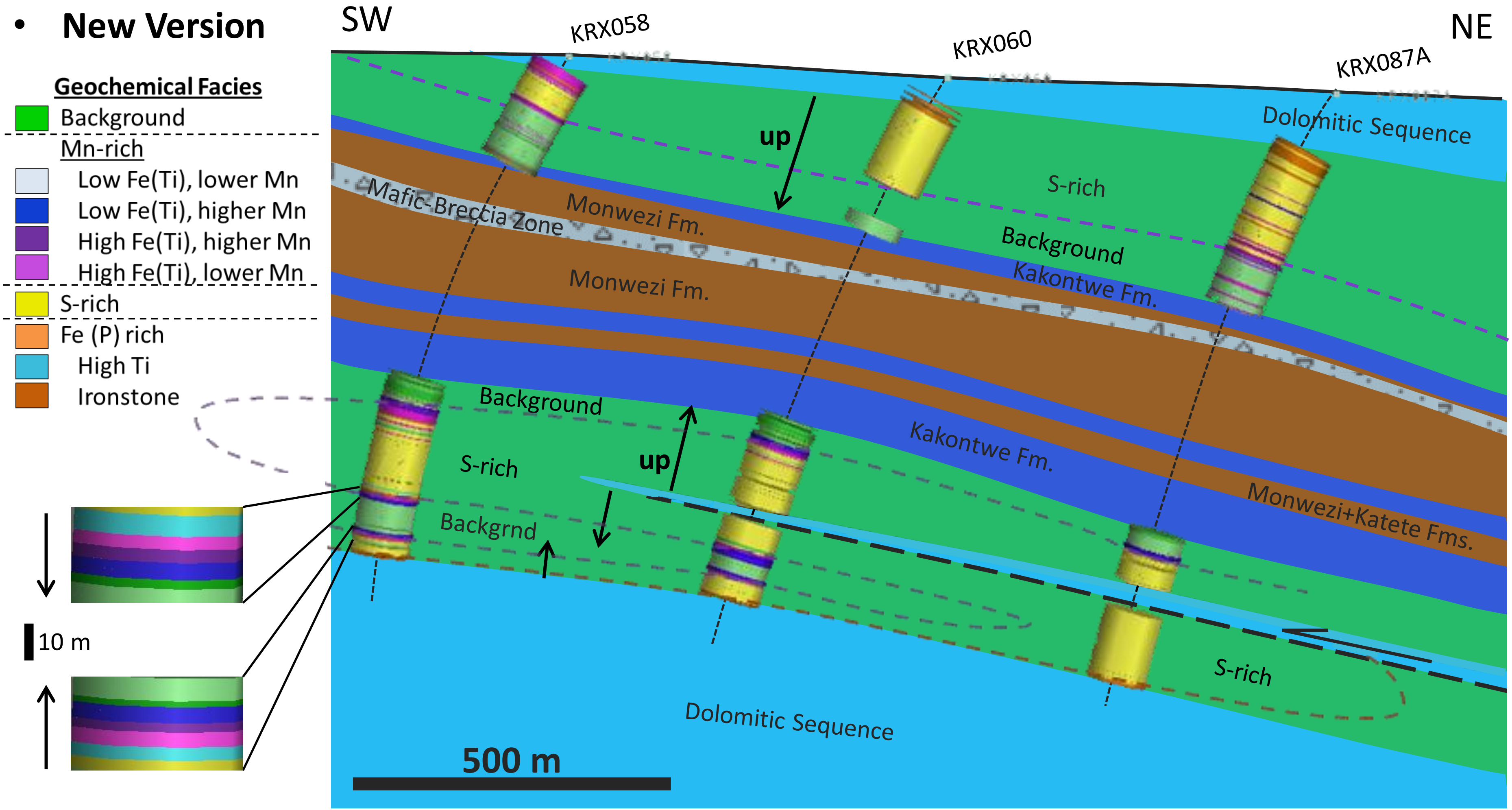
- The gross patterns clearly confirm (even where ironstone is absent) that the upper diamictite sequence is overturned

Geologic Interpretation

- Old Version
- Facing and internal deformation unclear

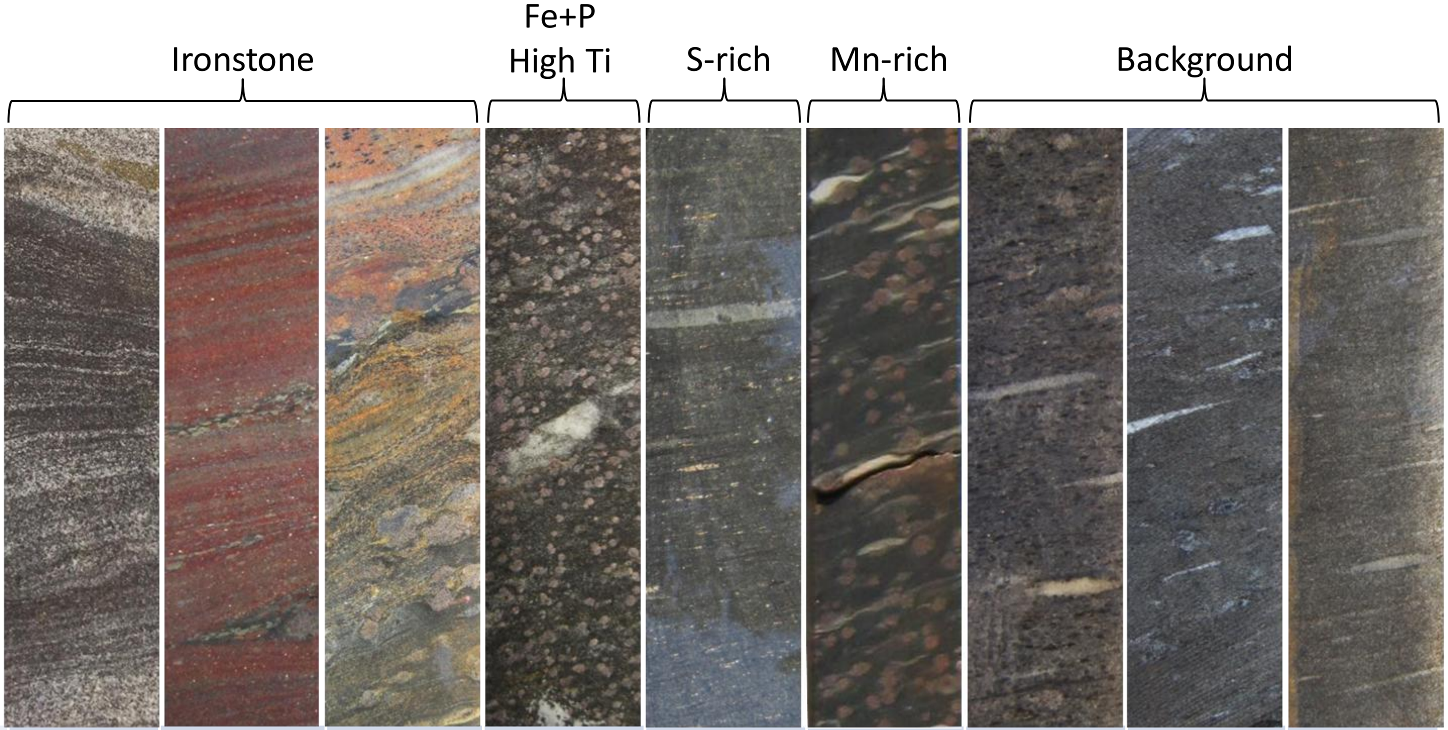


- **New Version**


Geochemical Facies
Background
Mn-rich
Low Fe(Ti), lower Mn
Low Fe(Ti), higher Mn
High Fe(Ti), higher Mn
High Fe(Ti), lower Mn
S-rich
Fe (P) rich
High Ti
Ironstone
10 m
SW
NE
KRX058
KRX060
KRX087A
Dolomitic Sequence
S-rich
up
Mafic-Breccia Zone
Monwezi Fm.
Background
Kakontwe Fm.
Monwezi Fm.
Background
S-rich
up
Kakontwe Fm.
Backgrnd
Monwezi+Katete Fms.
S-rich
Dolomitic Sequence
500 m

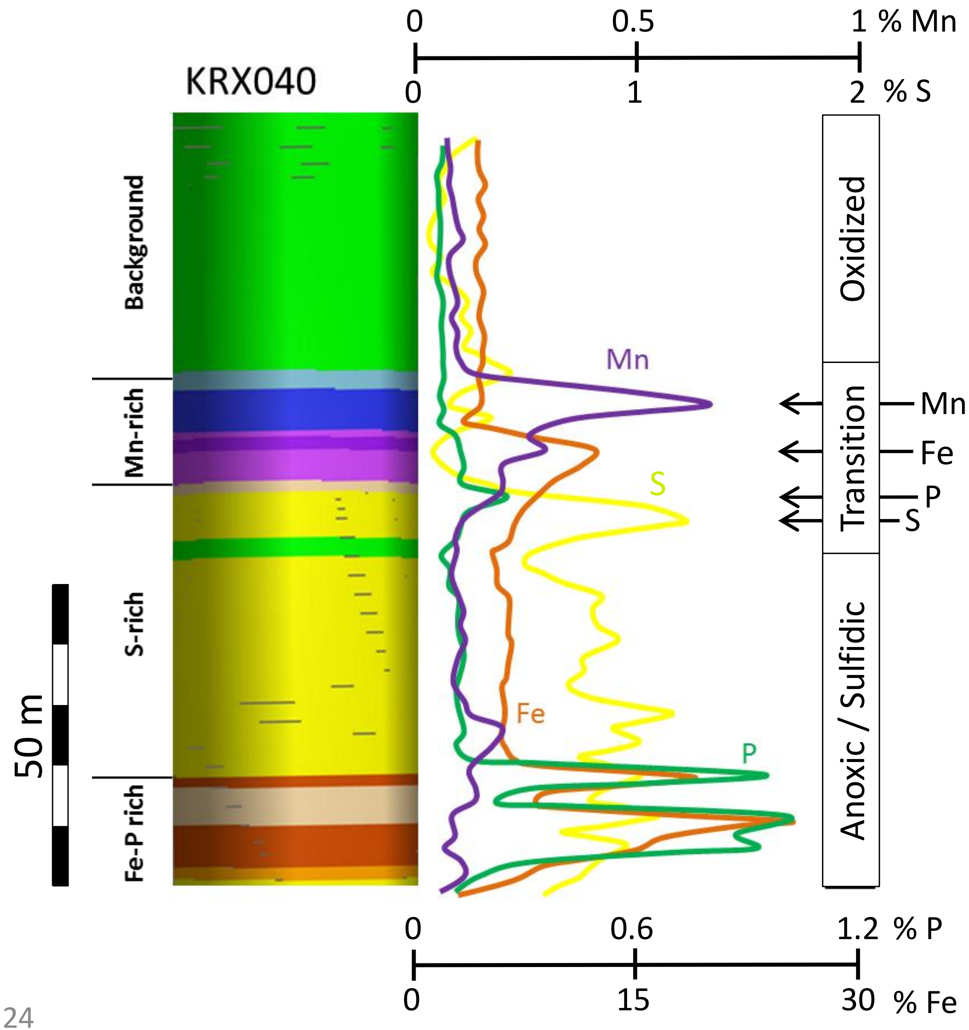
Mineralogic and Textural Variations

- Geochemical facies reflected in mineralogic & textural variations



Fe (%)	**31.8**	**23.8**	**20.2**	**11.0**	**6.98**	**9.47**	**6.56**	**4.64**	**4.69**
S (%)	**0.07**	**0.39**	**1.25**	**0.84**	**1.48**	**0.13**	**0.72**	**0.05**	**0.17**
Mn (ppm)	**2020**	**860**	**1120**	**1440**	**910**	**3100**	**993**	**863**	**703**
P (ppm)	**>10000**	**>10000**	**8880**	**4490**	**1400**	**1100**	**980**	**630**	**690**

Discussion



Fully oxidized mixed ocean conditions

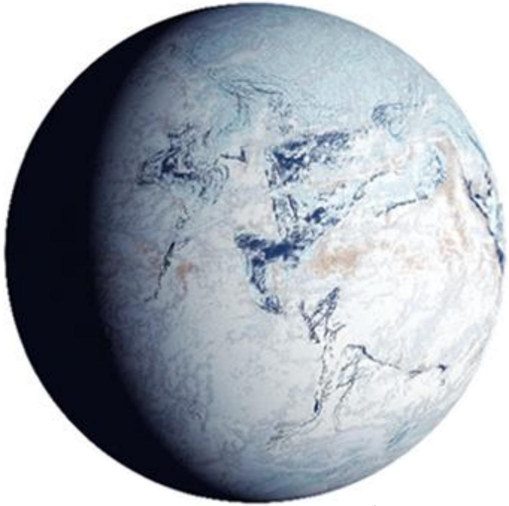
Transition from anoxic to oxidized rocks

1) P-peak (independent of Fe)
   - cyanobacterial bloom (Kirschvink et al.)
2) Progressive oxidation of water column
   - Fe → Mn

Ironstones in S-rich anoxic sediments
   - abiotic adsorbed P

Initial anoxia, sub-ice and/or stratification

Conclusions



Butler/Science Source

- Geochemical patterns suggest that paleo sea water chemistry signatures are preserved
- Progressive oxidation of the water column associated with P → Fe → Mn sequence
  - later than ironstone formation
- Sturtian metadiamictite is recumbently folded at Kansanshi
  - Marinoan diamictite is absent
- Future work should look for similar geochemistry in un-metamorphosed diamictite sequences where sedimentology can be incorporated to merge the depositional environment and chemical architecture of the basin
  - Important implications for redox traps in Cu exploration

Thank You!

Strongly pyritic siltstone with dropstone, Kamoa, DRC

Pyrite cubes in Chuos Formation ironstone, Namibia