Funded by DFG Deutsche Forschungsgemeinschaft German Research Foundation

EGU General Assembly 2021
vEGU21: Gather Online | 19–30 April 2021

New insights into the Neoproterozoic geomagnetic field: results from a high-resolution paleomagnetic study in South China

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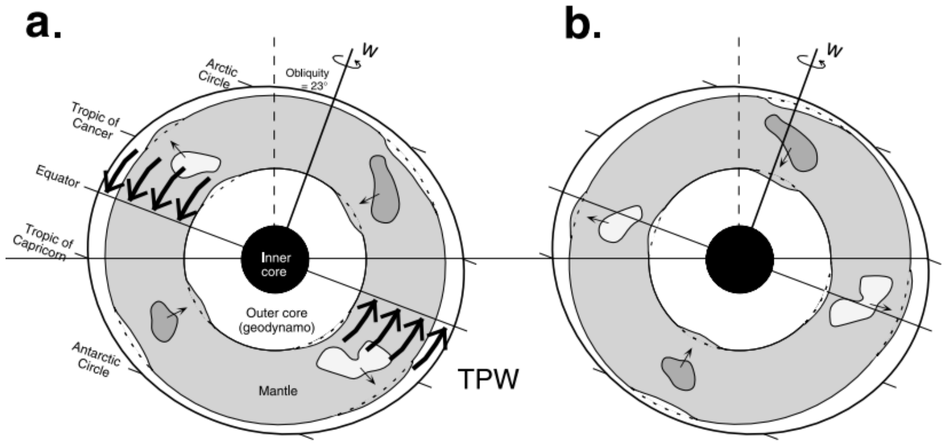
Outline

1. Background and motivation
2. Geology of the section
3. Paleomagnetic results and hypotheses
4. Rock magnetic and geochemistry results
5. Microscopy/SEM images
6. Conclusions and path forward
7. References

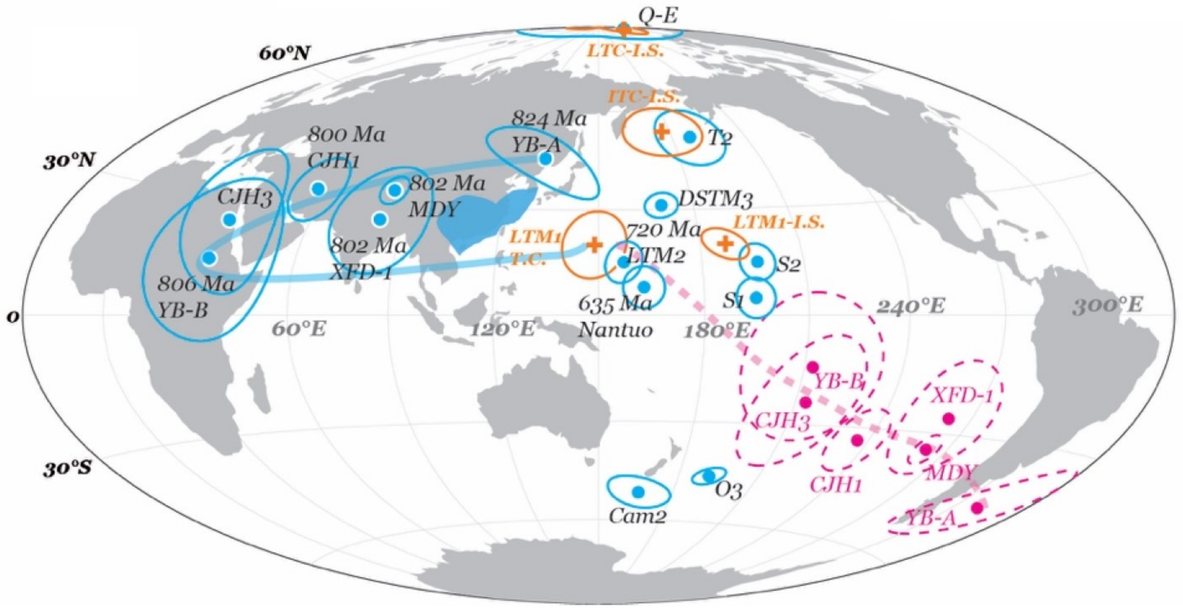
Background and motivation

- Paleomagnetic field and position of South China in the Neoproterozoic (820-800 Ma) remain enigmatic

- Some authors propose one or two large rapid true polar wander (TPW) events to explain observations (e.g. Jing et al, 2020)



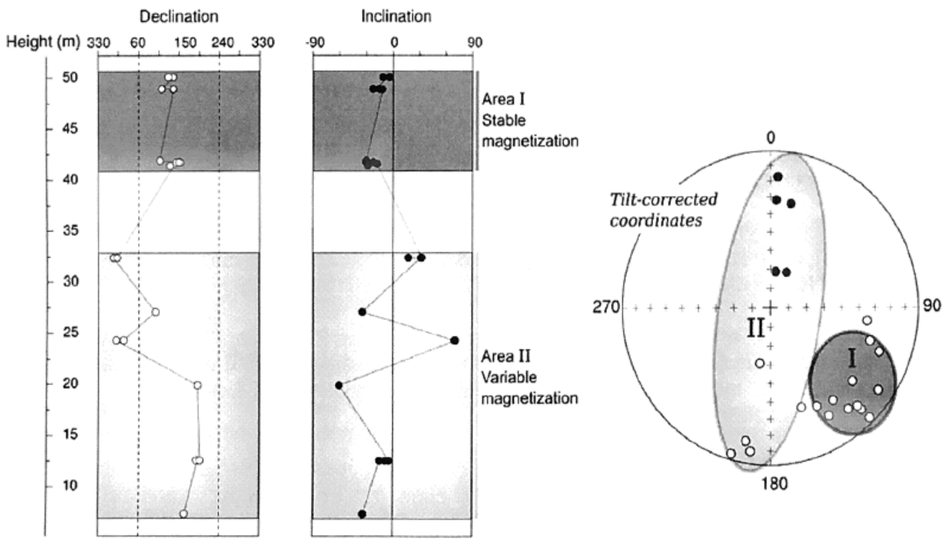
Simplified true polar wander (Evans, 2003)



Discordant paleomagnetic poles for South China (Jing et al, 2020)

- High-resolution data from continuous sections needed to investigate cause of discordant directions:
  - True polar wander
  - Rapid plate motion
  - Non-dipolar fields?
  - Remagnetisation

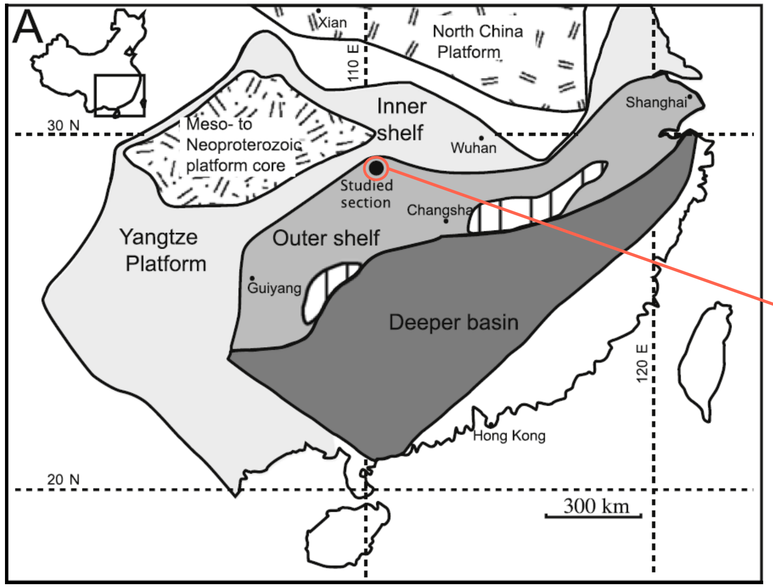
Background and motivation



Results from pilot study (Gilder et al, unpublished)

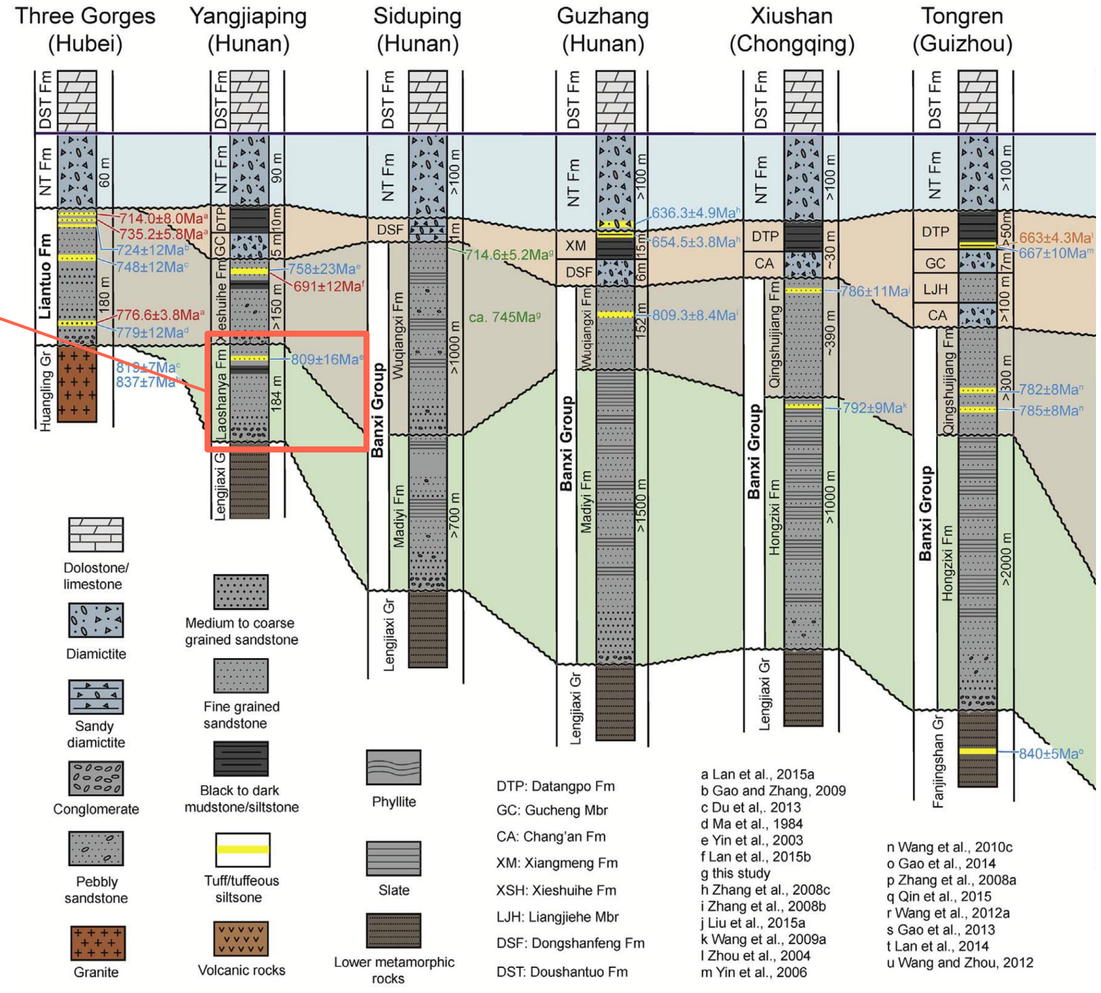
- 50m of Laoshanya Formation (820-810 Ma) in Hunan (South China) previously sampled as part of pilot study in 1990s
- Stepwise thermal demagnetisation of 30 samples revealed discordant directions residing in hematite between 660-680°C
- Mesozoic overprint, pervasive in South China, present <660°C
- Objective: resample section at high resolution (5-10 cm spacing) and combine paleomagnetic/rock magnetic results with detailed chemistry and petrography to unravel discordant directions
- Unique aspects – density of sampling, ability to perform precise thermal demagnetisation on large number of samples

Geology of the section



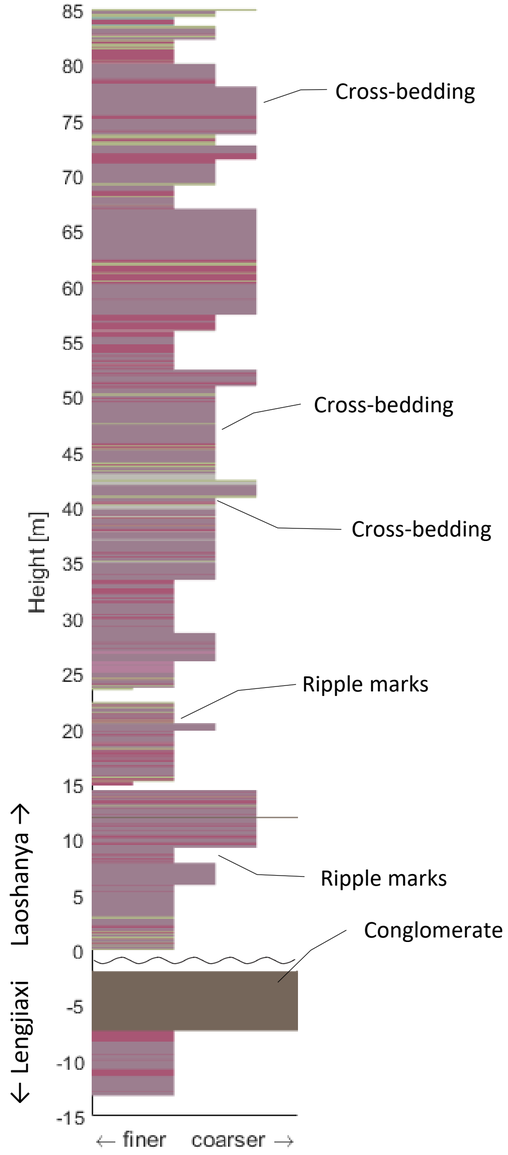
Location of Yangjiaping section in South China (Macouin et al, 2012)

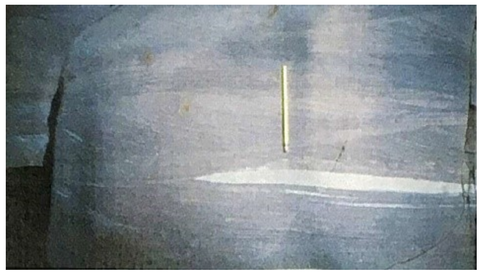
- Laoshanya Formation of the Banxi Group in Yangjiaping (Qingbaikou System)
- Tuff above section dated to 809±16 Ma (Yin et al, 2003), SHRIMP zircon U-Pb dating
- Overlies ~820 Ma metamorphic basement of Lengjiaxi Group (Wang et al, 2003), SHRIMP zircon U-Pb dating



Geology of the Nanhua basin in South China (Song et al, 2016)

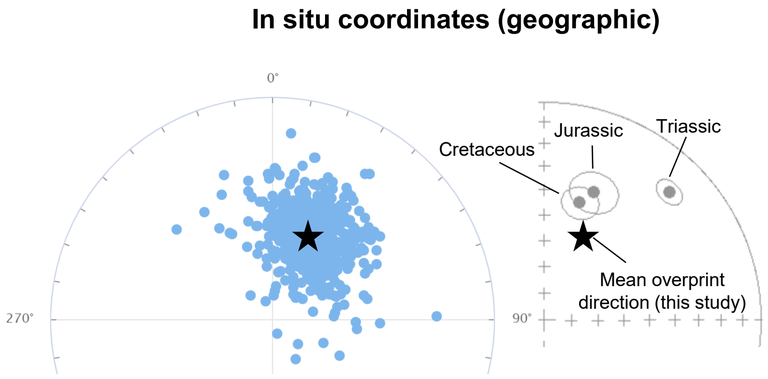
Geology of the section



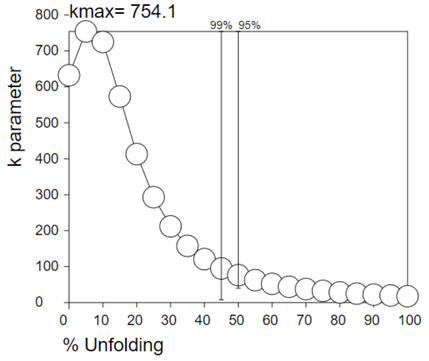


- Purple-red and green-grey sandstones and siltstones
- Minimal deformation, with cross-bedding and ripple-marks indicating near-shore environment
- Some evidence of bleaching and low-grade metamorphism, calcite and quartz veinlets
- Base of formation well-defined by angular unconformity and ~5 m thick conglomerate
- In September 2019: 1069 cores drilled over ~100 m

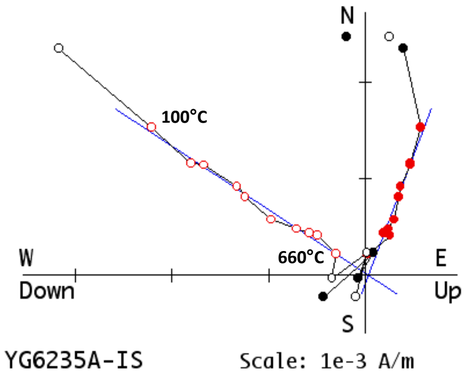
Paleomagnetic results



Mesozoic overprint compared with expected directions from South China pole means (calculated from Huang et al, 2018)

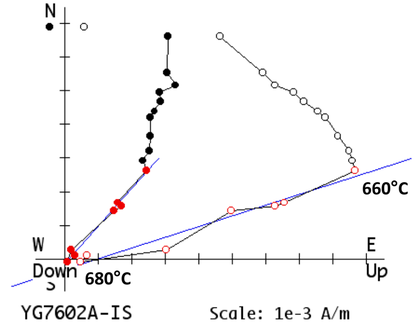


Formation below also contains overprint – fold test suggests overprint acquired syn/post-folding

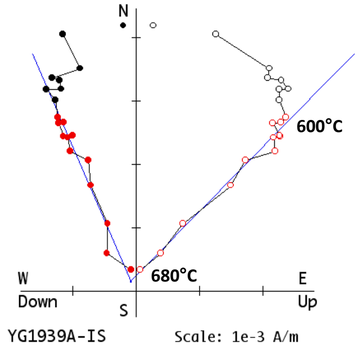


Overprint only

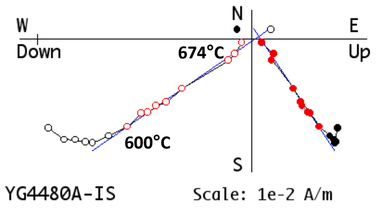
- Precise (2° steps) thermal demagnetisation of 891 samples with large capacity purpose-built oven and automated 'Sushibar' measurement system
- ~90% of samples contain component which unblocks below 660°C and is similar to Mesozoic poles from South China
- <15% of samples demagnetise above 665°C and show a variety of characteristic directions…
- Base (0-20 m) and top (54-85 m) of section contain mid-inclination SE directions (tilt-corrected), unblock up to 680°C
- Middle of section (20-54 m) presents steep, NE/SW antipodal directions (tilt-corrected), generally unblock <676°C



Overprint + SE reversed (up)

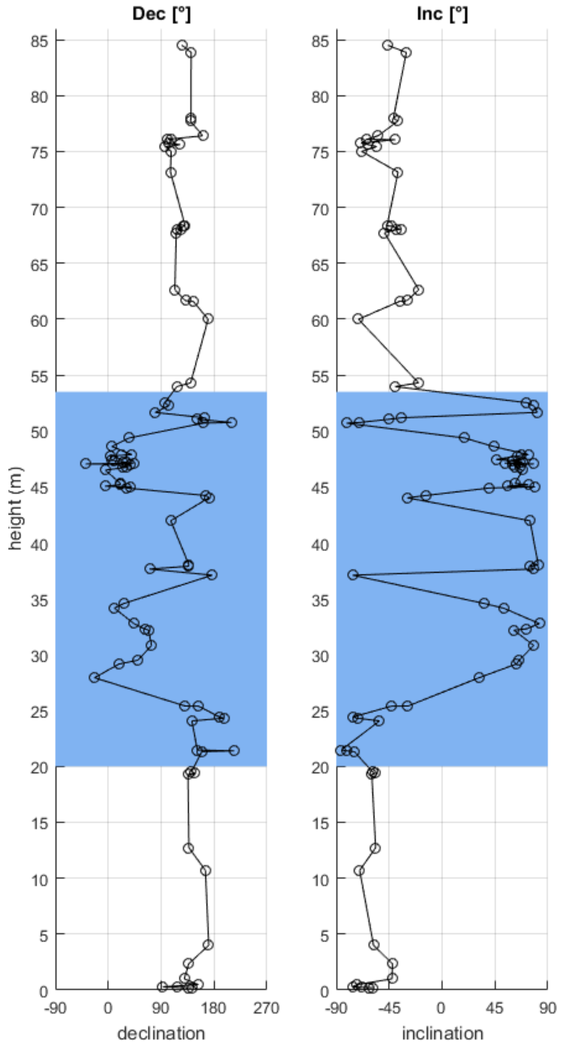


Overprint + SW reversed (up)



Overprint + NE normal (down)

Hypotheses – three scenarios



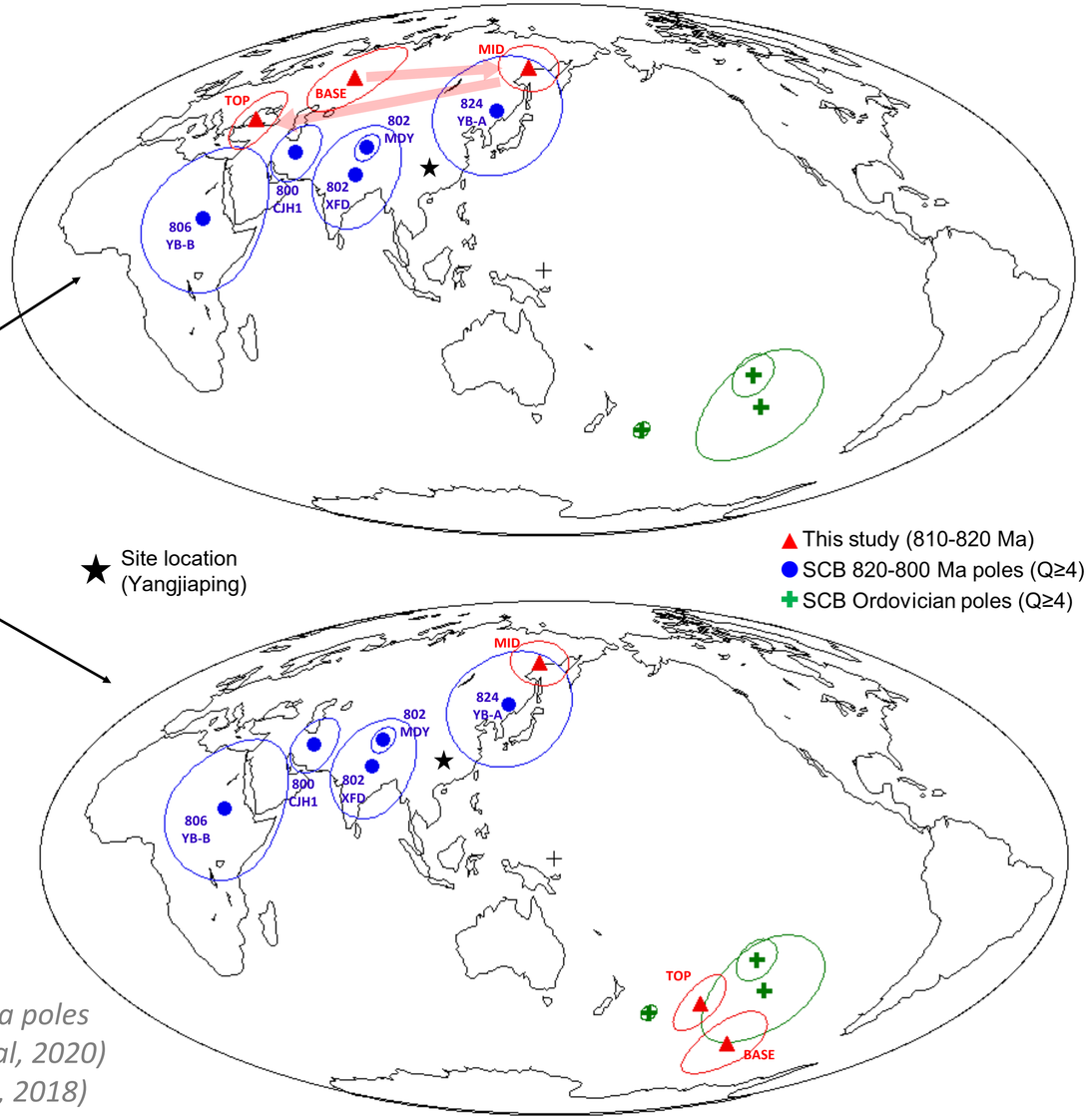
High temperature component in tilt-corrected coordinates (stratigraphic)

- High temperature component (HTC) appears to behave independently of rock type/lithology and is not found in formation below

All HTC directions are primary → Abnormal field during Neoproterozoic with rapid switching between dipolar (axial) and non-dipolar (equatorial) states

Mix of primary and secondary directions → Primary/detrital remanence partially remagnetised with a CRM in Paleozoic

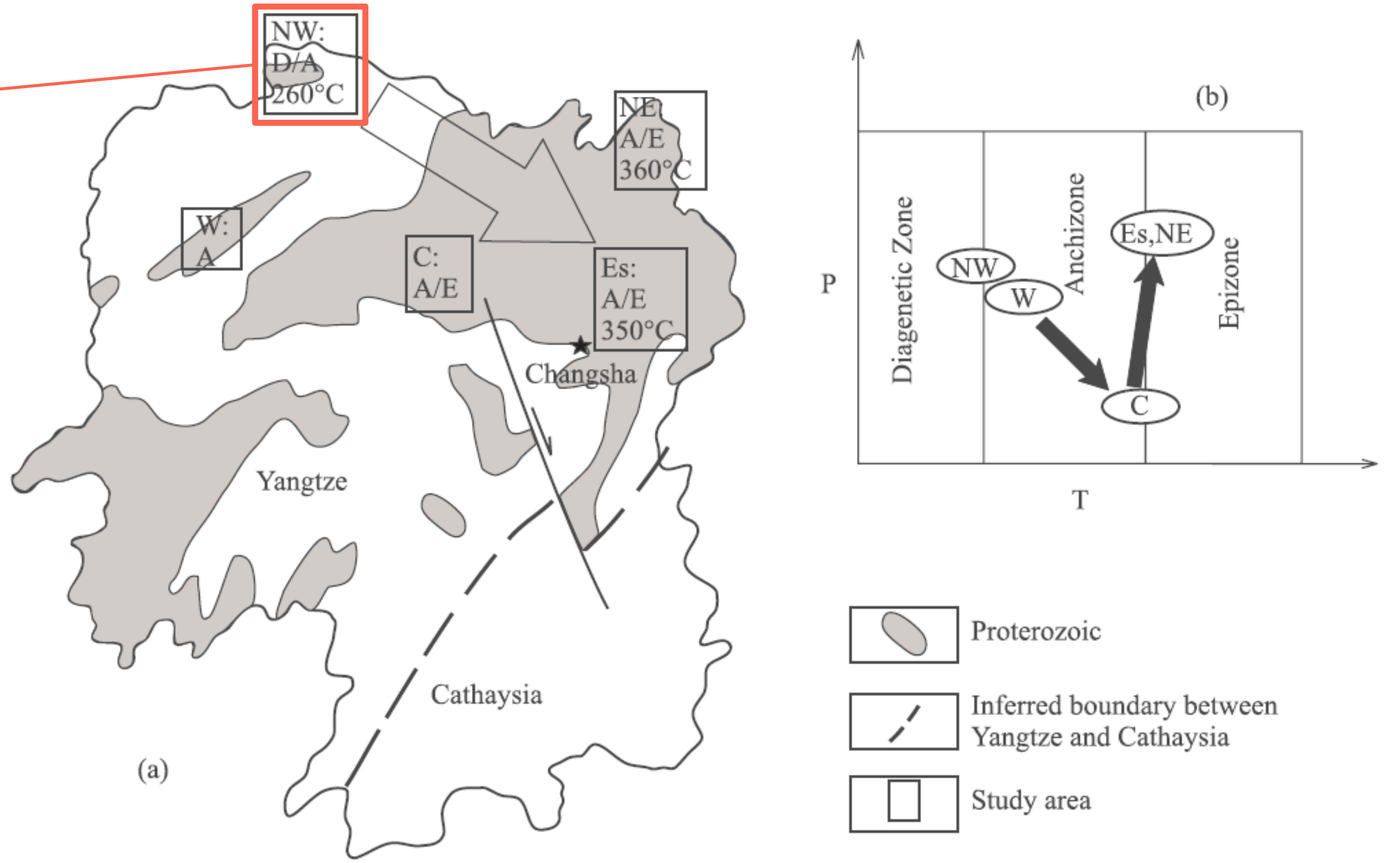
All HTC directions are secondary → Complex remagnetisation behaviour with multiple CRMs, several reversals?



Comparison with South China poles from Neoproterozoic (Jing et al, 2020) and Ordovician (Huang et al, 2018)

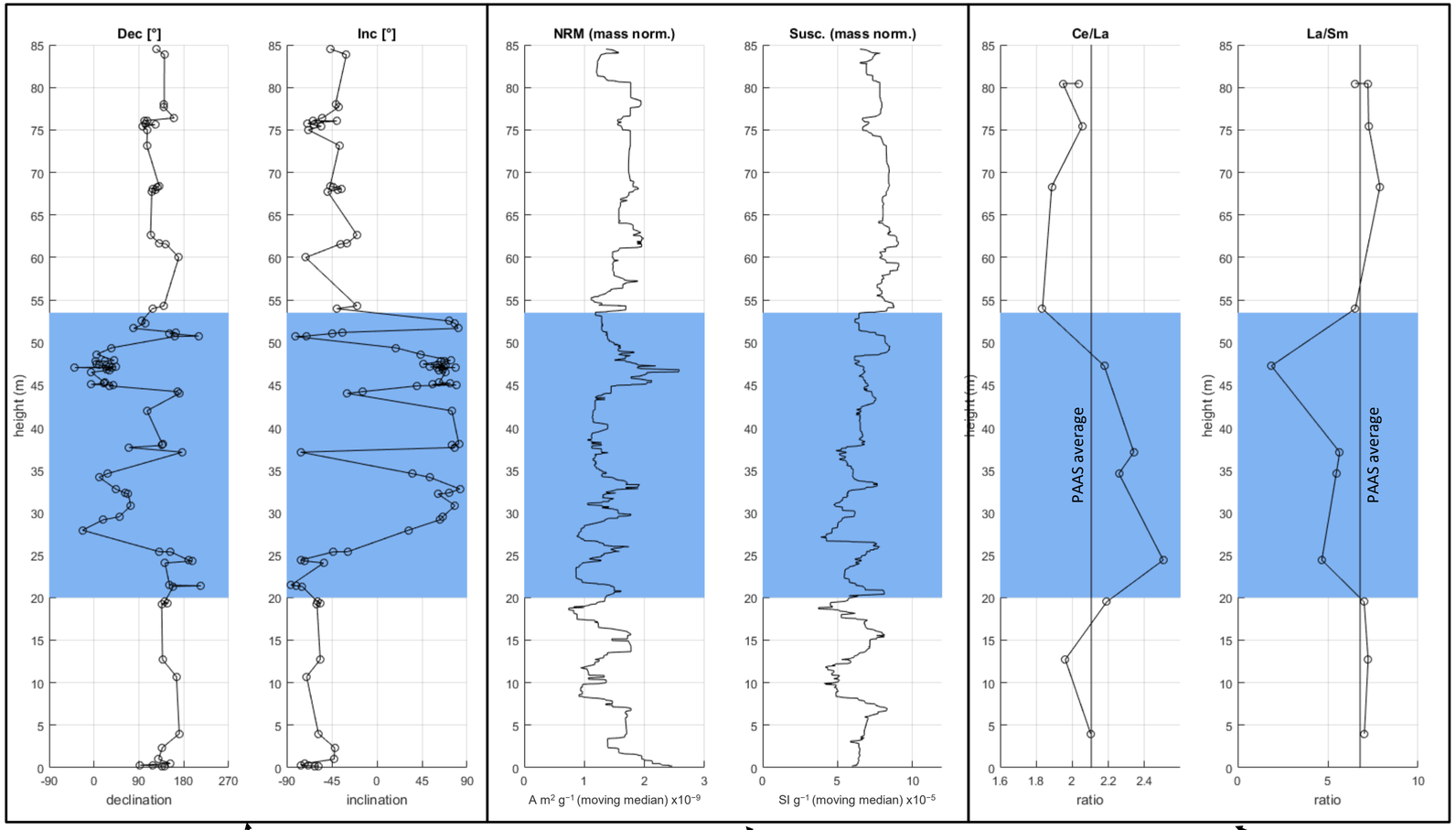
Hypotheses – supporting evidence

- Clay mineralogy suggests Yangjiaping section experienced ‘anchi-metamorphism’ up to 260°C (Wang et al, 2016), increasing temperature toward south-east
- Banxi Group in Jiangnan Belt reworked by Paleozoic (460-420 Ma) orogenic event (Cawood et al, 2018)
- Earlier paleomagnetic studies of Banxi Group show many Paleozoic directions (e.g. Zhang, 1998) – remagnetised?



Estimated temperatures for low-grade metamorphism in Hunan (Wang et al, 2016)

Rock magnetism and chemistry



Experiments:

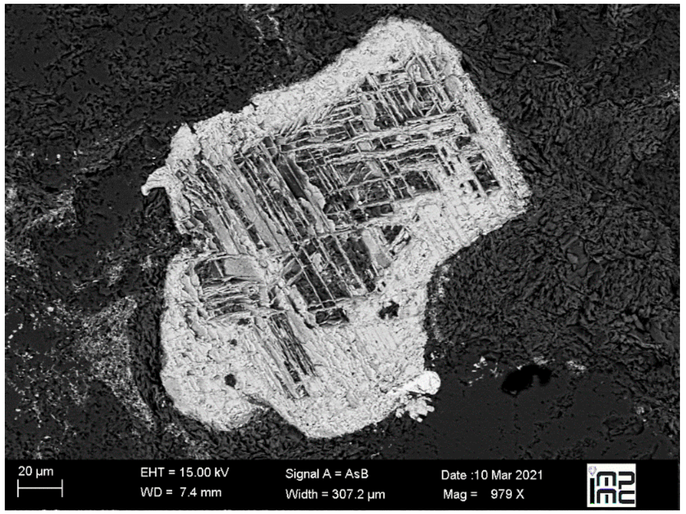
- Bulk susceptibility during heating (Bartington MS2 – Munich)
- Hysteresis parameters, backfield/IRM acquisition curves, low temperature magnetisation to 100K (VSM – Munich)
- High temperature susceptibility to 700°C (AGICO MFK1 – Oslo)
- Anisotropy of ARM (Sushibar – Munich)
- Chemistry, isotopes and trace elements (ICP-MS – Paris)

Paleomagnetic directions from high temperature component (tilt-corrected)

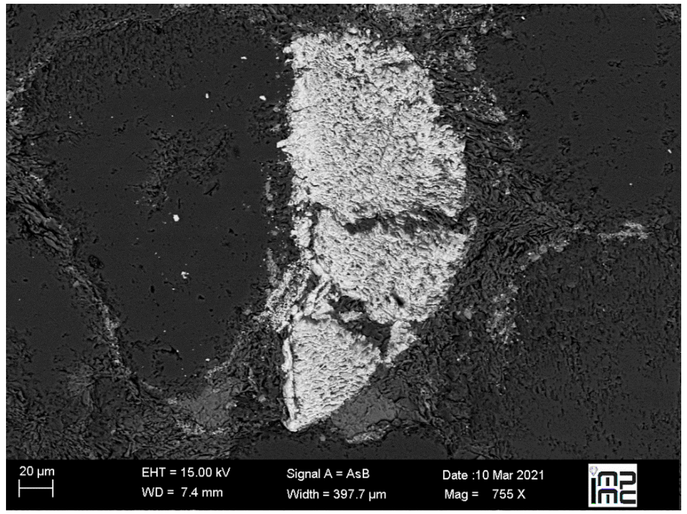
Rock magnetic parameters suggest general decreasing trend in grain size

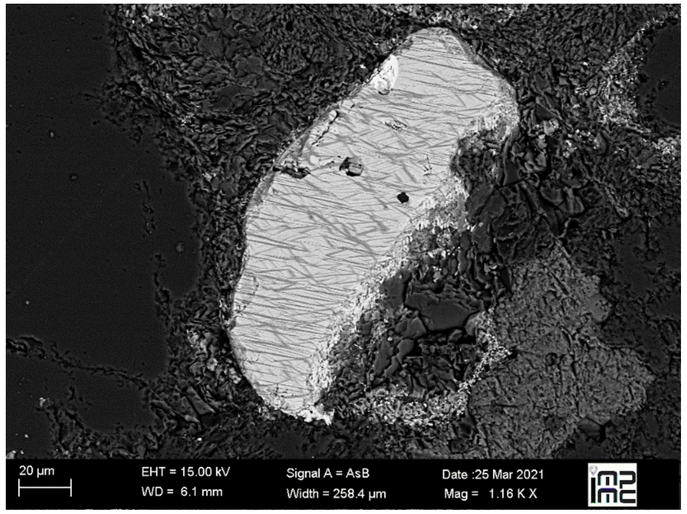
Trace elements may indicate change in source weathering or redox/depositional conditions?

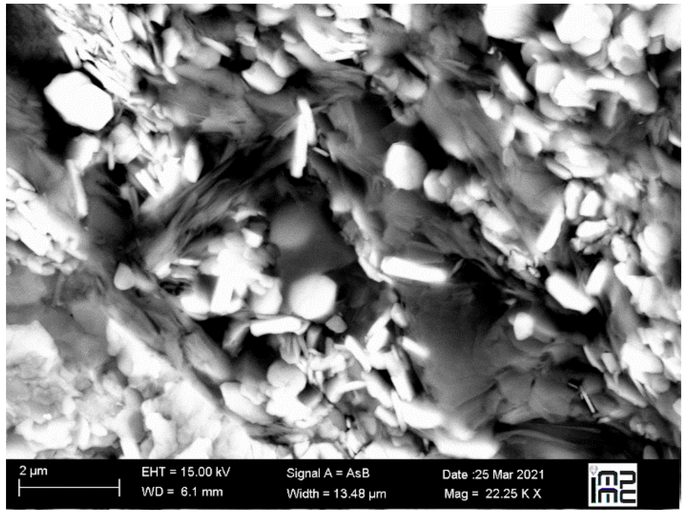
Microscopy/SEM images



- Microscopy and SEM images reveal a range of hematite products
- Middle of section (20-54 m height) has preserved detrital hematite crystals, often with rutile inclusions, which suggest a high-temperature (i.e. volcanic) origin
- Overprint and remagnetisation components probably carried by dense clusters of microcrystalline/platy hematite, as well as flakes scattered throughout matrix, which appear to be authigenic products replacing iron-rich grains







Conclusions and path forward

- Discordant paleomagnetic directions observed in Yangjiaping could be explained by multiple generations of hematite:
  1. Primary magnetisation acquired during basin rifting and deposition (~820 Ma)
  2. Partial remagnetisation acquired during mid-Paleozoic orogeny (460-420 Ma)
  3. Mesozoic (probably Cretaceous) overprint acquired after collision of North and South China blocks
- Path forward:
  - Further experiments to investigate remagnetisation method
  - Detailed SEM analyses on thin sections
  - Sampling of nearby sections and precise U-Pb dating of tuff above section (pending pandemic)
  - Comprehensive analysis of primary signal – reversal paths in Neoproterozoic?

Pre-pandemic fieldwork in Hunan, September 2019

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