Assessing the source of out-of-phase AMS in magnetite rich igneous rocks

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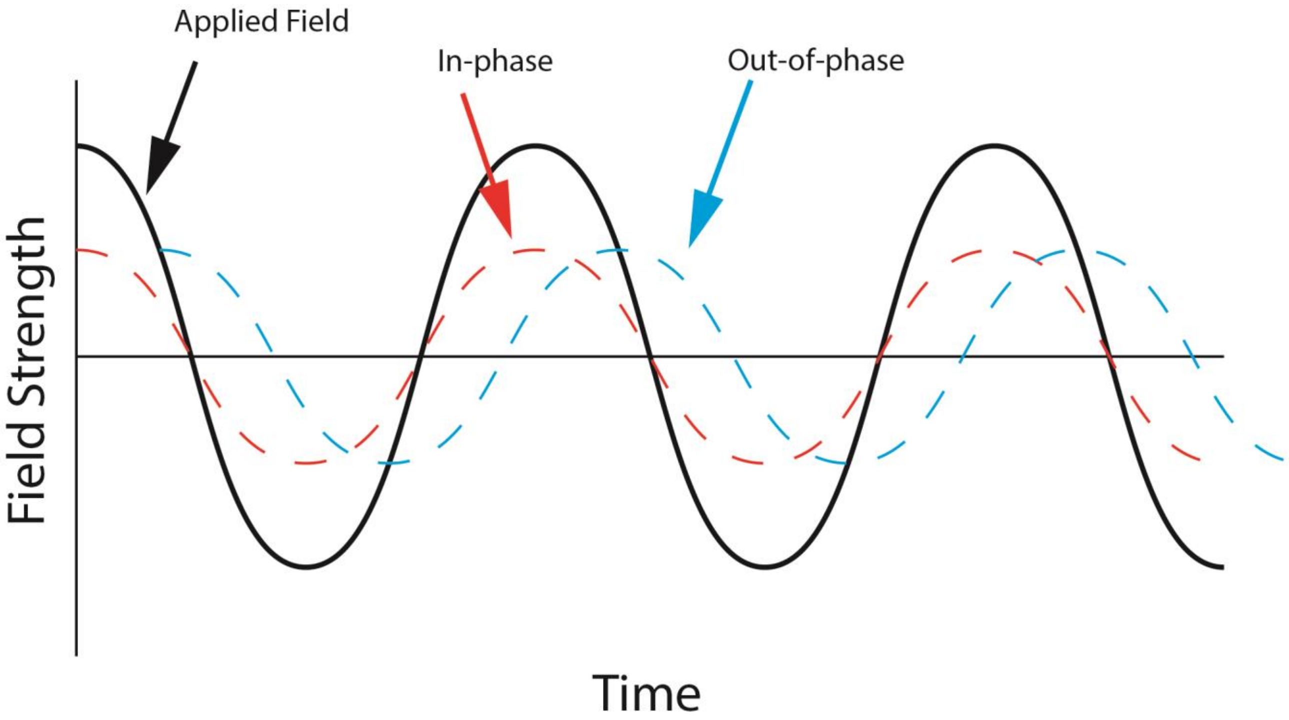
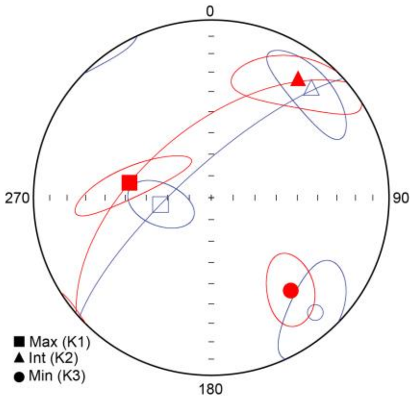
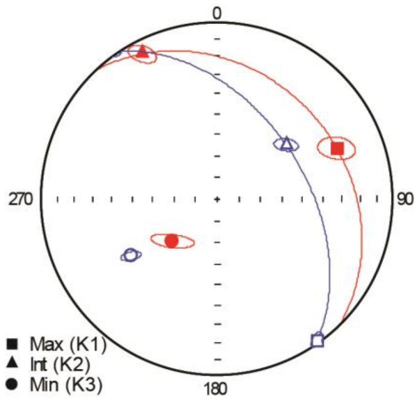
What is out-of-phase AMS?

- Anisotropy of magnetic susceptibility is a measure of magnetic fabrics
- KLY-5a Kappabridge AMS response can be decomposed into an in-phase (ipAMS) and out-of-phase (opAMS) component
- **Poorly understood**





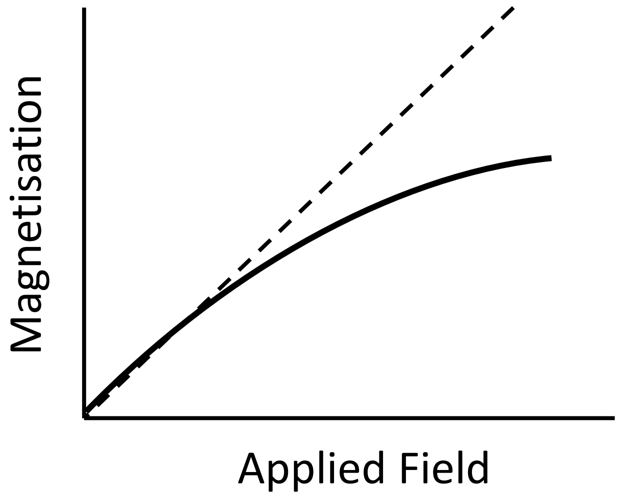


Sources of opAMS response

- Electrical Eddy Currents
    - Highly Conductive materials (e.g. Native Cu, Graphite)

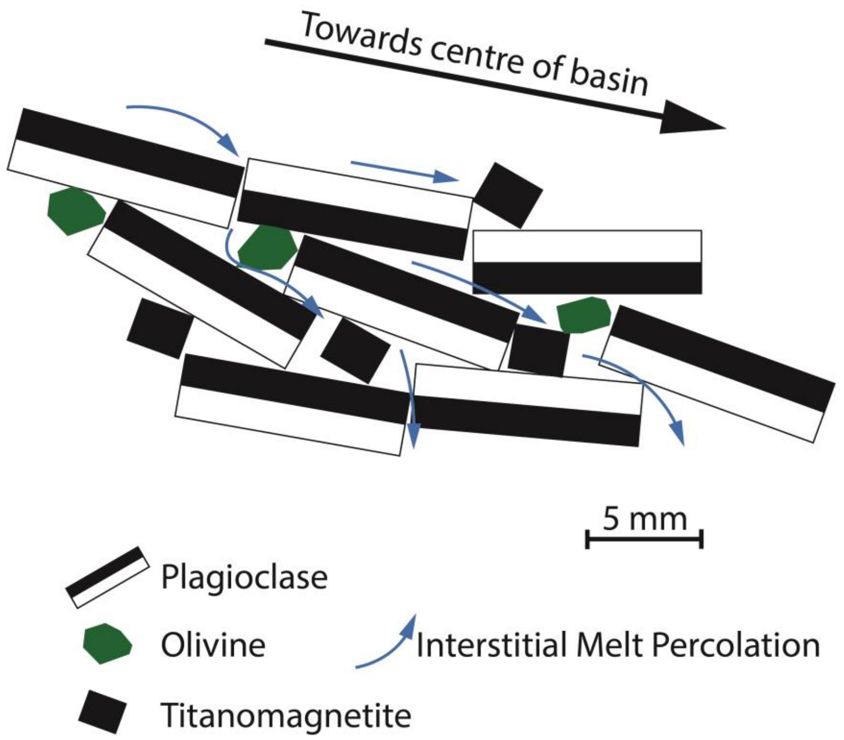
- Viscous Relaxation
    - SPM/SD magnetite (under normal AMS measurement conditions)
    - Frequency dependent
- Weak Field Hysteresis
    - Ferromagnetic phases (e.g. Magnetite, Pyrrhotite)
    - Field dependent

$$M = kH$$



Why study opAMS?

- Controlled exclusively by ferromagnetic grains (in most geological examples)
- Can record distinct magnetic subfabrics
- In igneous rocks, can it record late-stage remobilization of melt?
  - Compaction-driven?



Sample set

- 106 Samples measured for AMS; 22 Samples undergone further analyses
  - Younger Giant Dyke Complex, South Greenland (Koopmans et al., 2022)

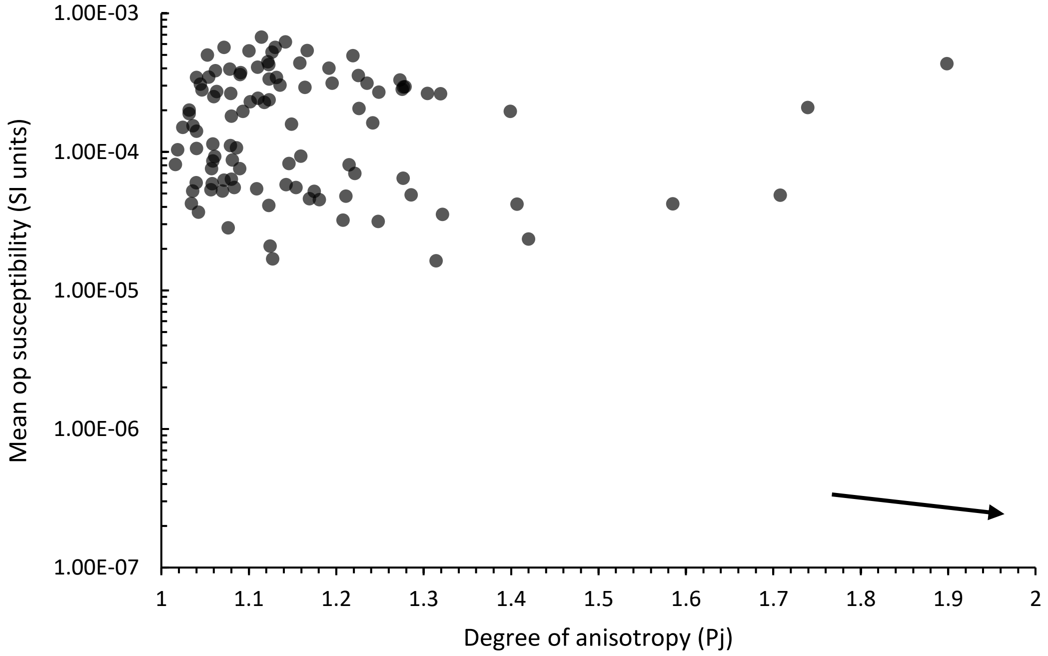
- MD magnetite Dominated (ip)AMS response

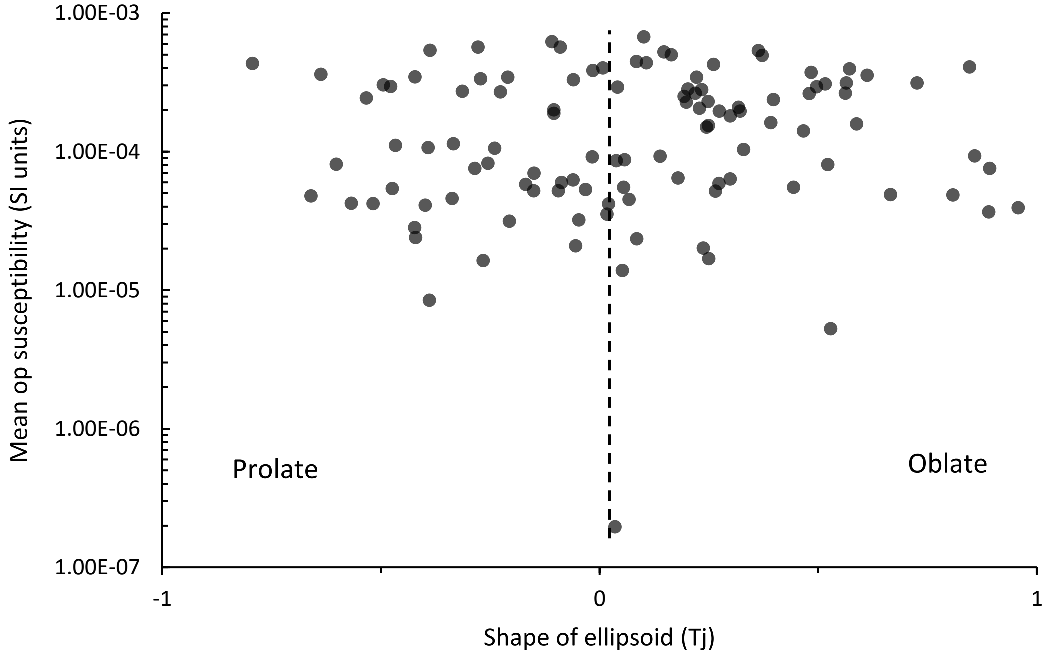
- No other ferromagnetic component observed in petrography

- No evidence of textural anisotropy

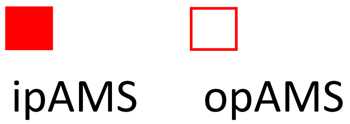
opAMS results

- Absolute opAMS susceptibility between 2×10^{-7} and 6.75×10^{-4}
  - Above detection limit of KLY-5a Kappabridge



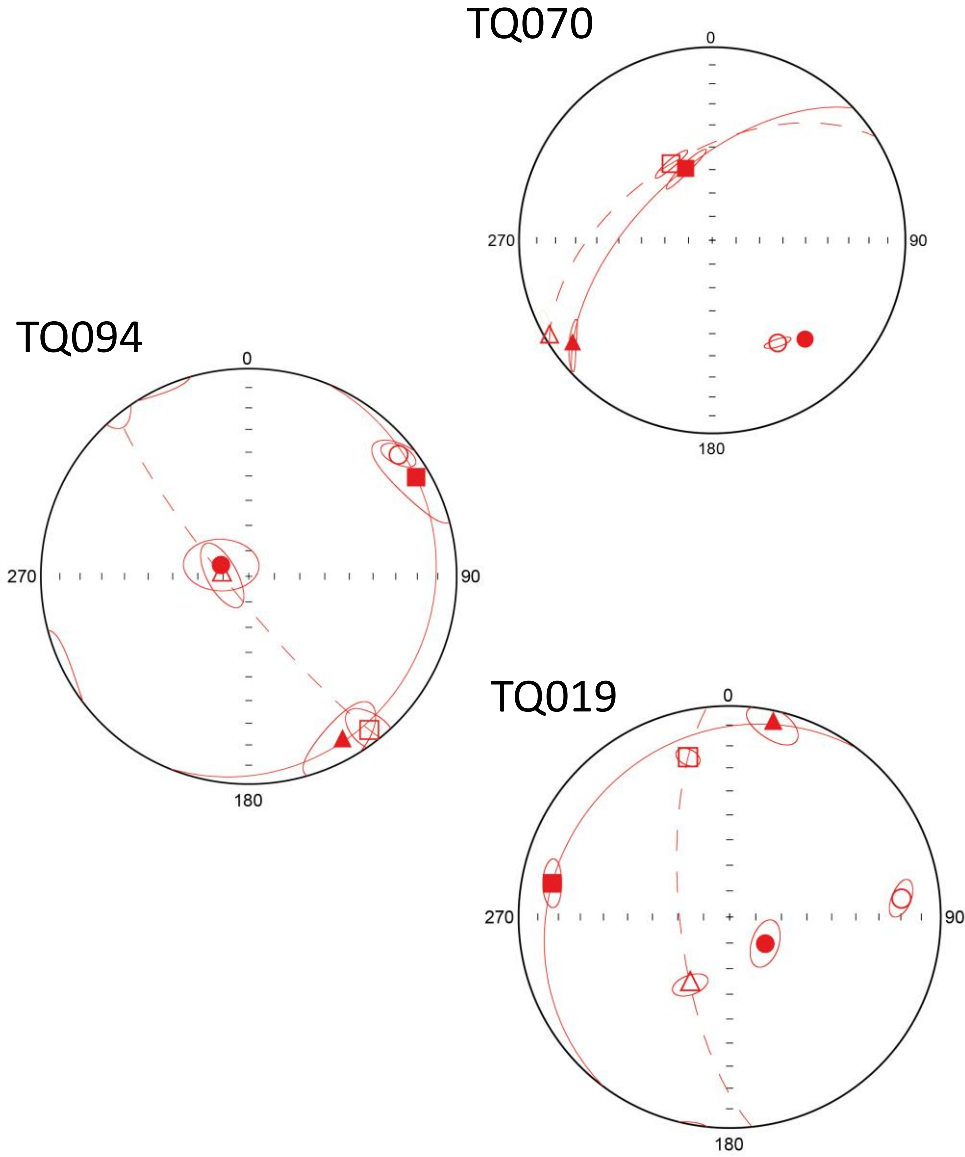


Comparing ipAMS and opAMS



- 3 main ip/op relationships

1) Parallel ip/opAMS responses
   - Same magnetic carrier
2) Perpendicular ip/opAMS responses
   - Mineralogical control (inverse)
3) Oblique ip/opAMS responses
   - Potential magnetic sub-fabric?



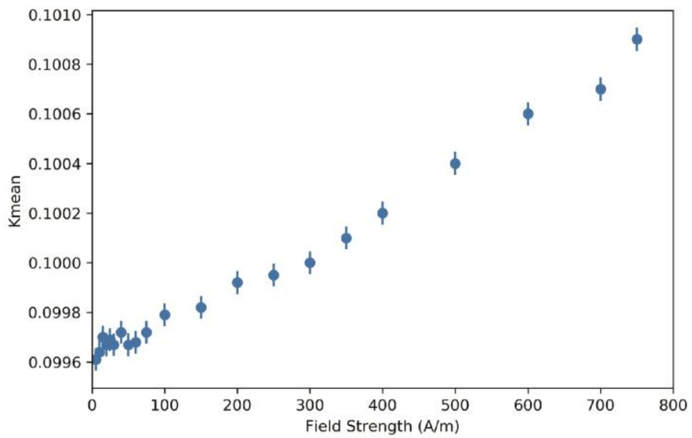
Characterisation methods

- Field and frequency dependency tests
- Remanence experiments
  - (SIRM, ARM, AFD, BIRM, 3-component demagnetization)
- Hysteresis experiments
  - Hysteresis loops, FORC

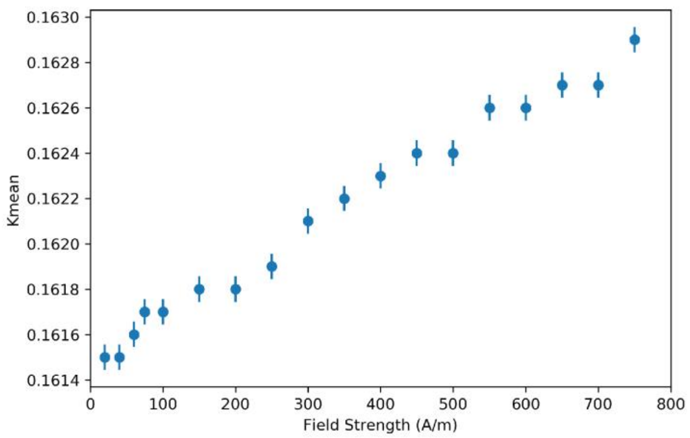
Field Dependent MS

Frequency Dependent MS

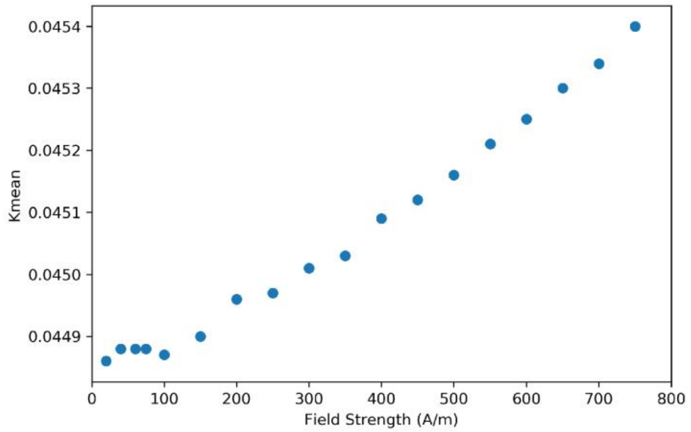
TQ070

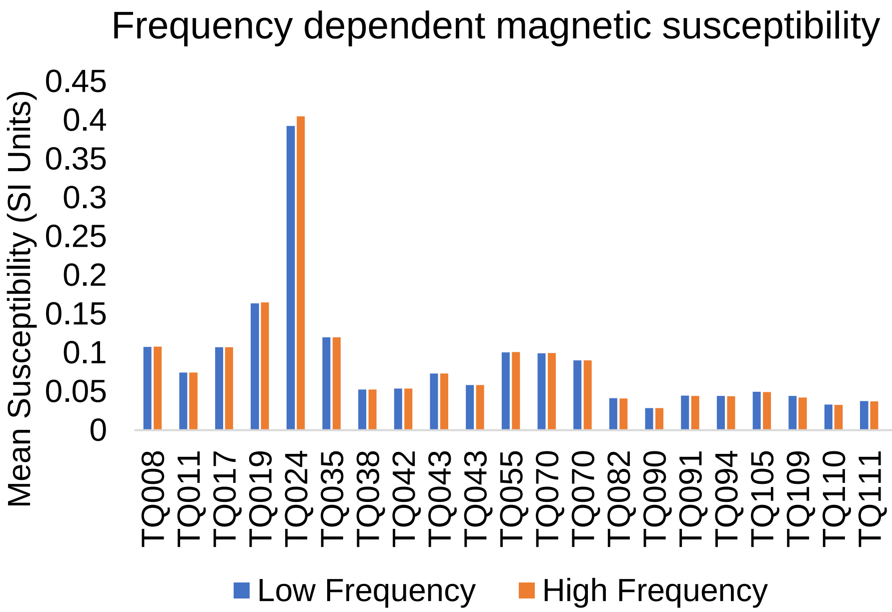


TQ019



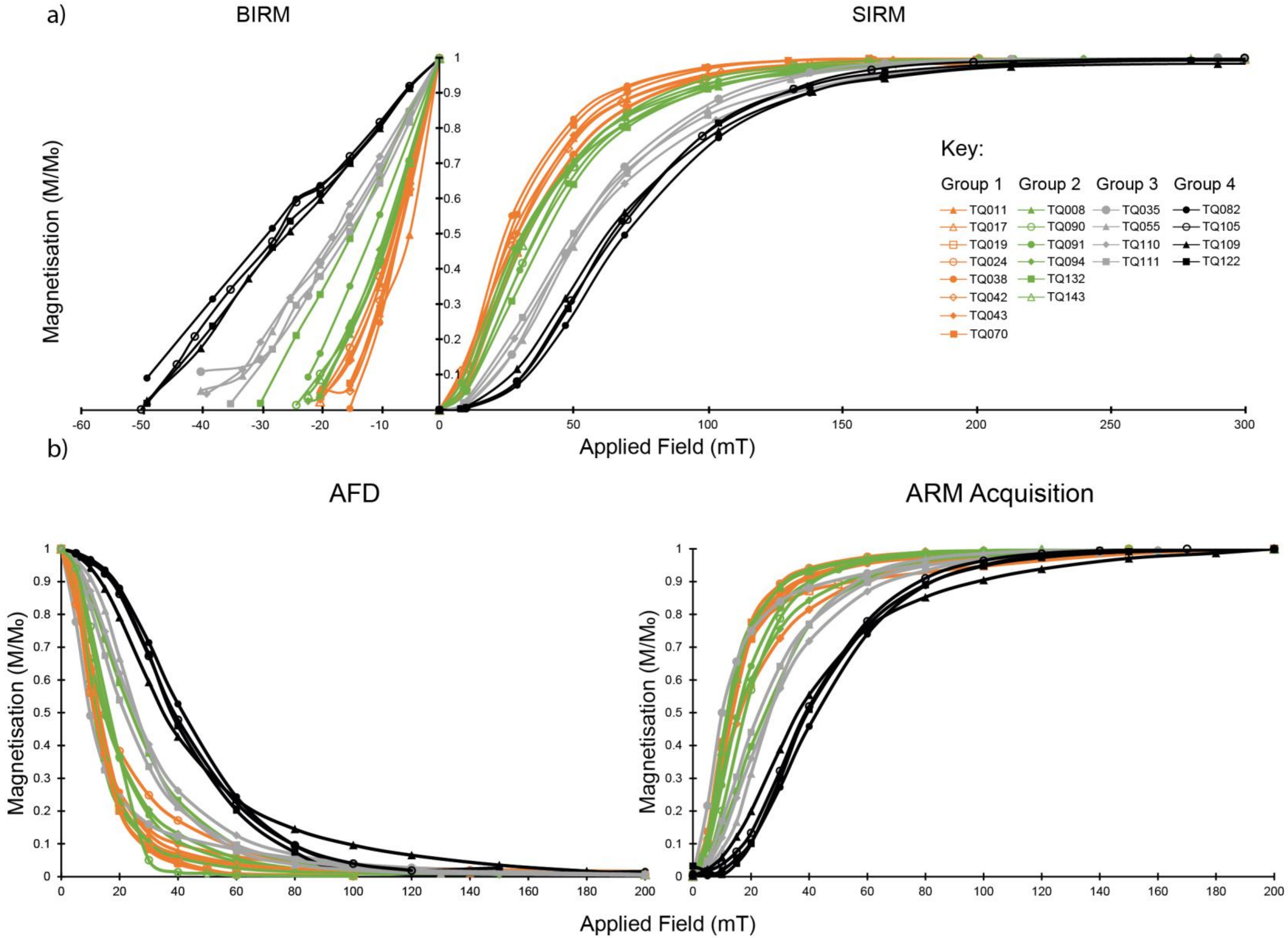
TQ094





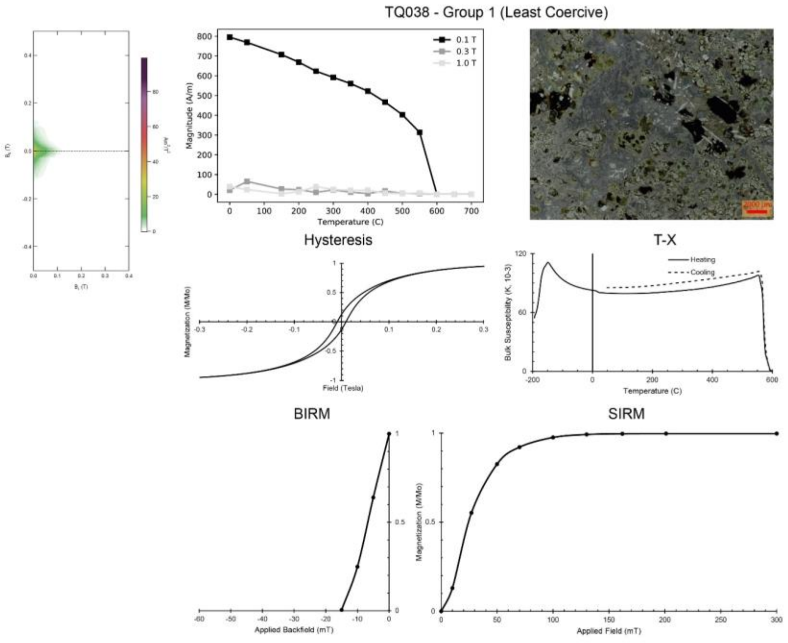
- All samples are field-dependent, frequency independent
- All opAMS should driven by be weak-field hysteresis, not viscous relaxation

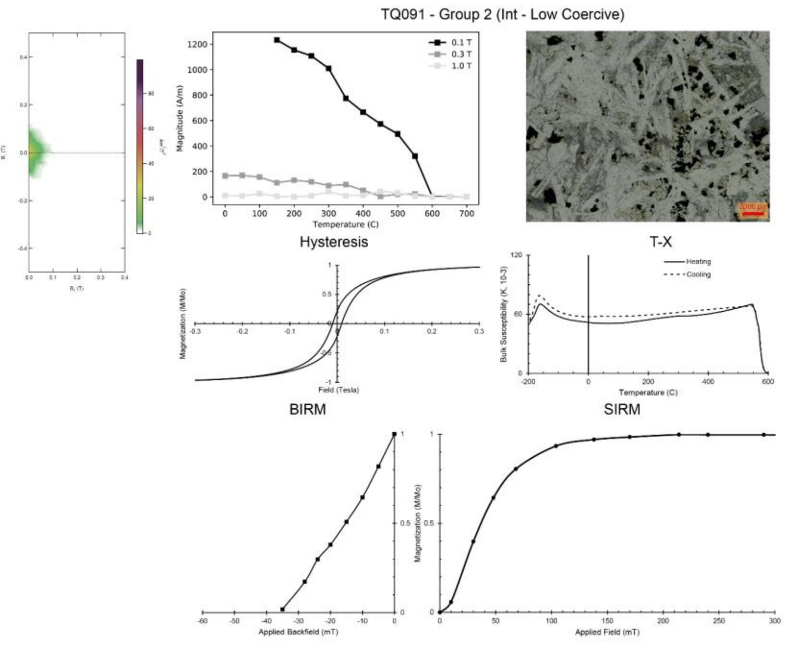
Remanence experiments

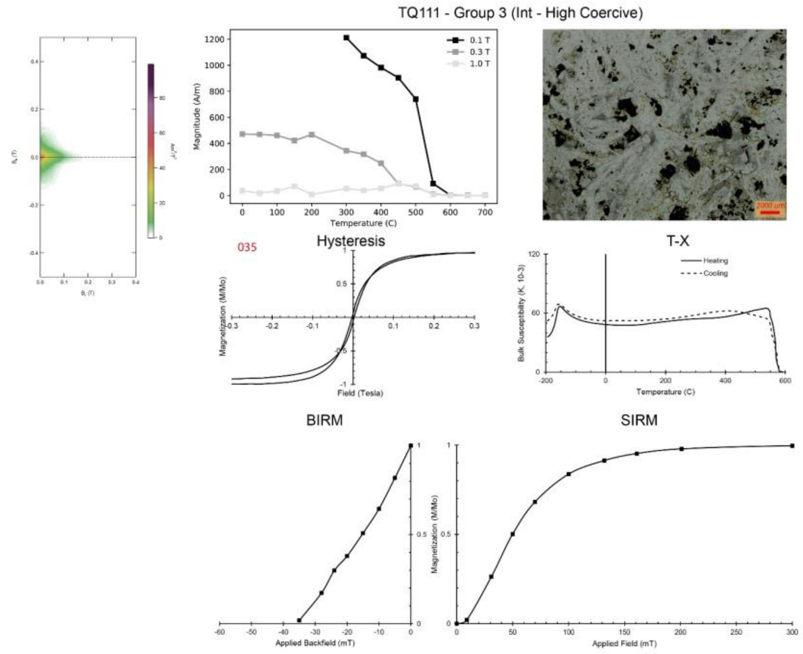


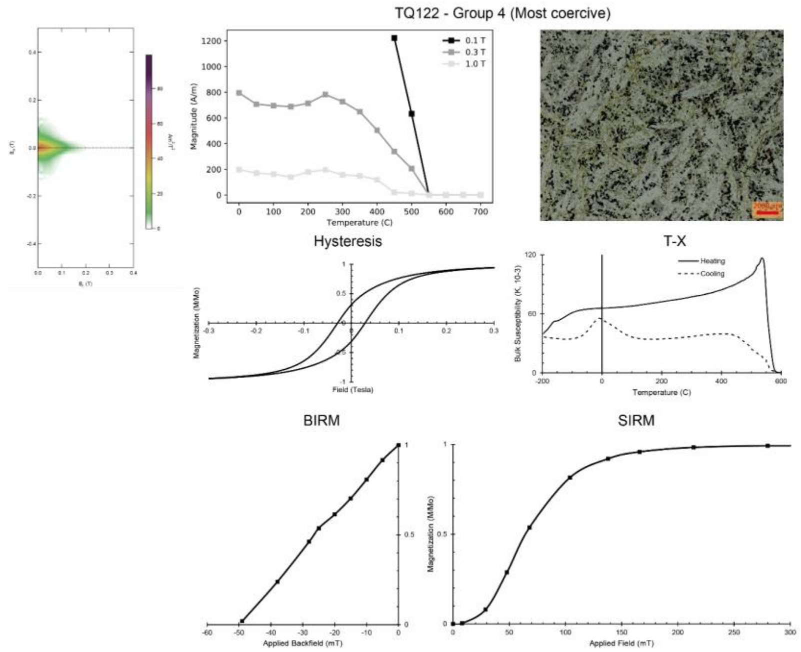
Remanence and hysteresis

- 4 distinct magnetic characterisation groups









FORC PCA

Table 4.1. *Results of FORC PCA unmixing. Modelled multi-domain (MD) and single-domain (SD) components are presented alongside known MD – SD values (for synthetic samples).*

	Sample	Modelled MD (%)	Modelled SD (%)	MD known (%)	SD known (%)
Group 1	TQ017	99.1	0.9		
	TQ024	99.1	0.9		
	TQ038	99.2	0.8		
	TQ042	99.1	0.9		
	TQ043	99.0	1.0		
	TQ070	99.3	0.7		
Group 2	TQ094	99.5	0.5		
	TQ132	98.3	1.7		
	TQ143	99.1	0.9		
Group 3	TQ055	98.5	1.5		
	TQ111	98.6	1.4		
Group 4	TQ105	98.2	1.8		
	TQ122	97.8	2.2		
Standards	W14_1	99.4	0.6	100	0
	W14_2	39.8	60.2	40	60
	W14_4	74.8	25.2	75	25
	W14_7	7.4	92.6	8	92

Standards and method: Harrison, R. J. et al., 2018: An Improved Algorithm for Unmixing First-Order Reversal Curve Diagrams Using Principal Component Analysis. Geochemistry, Geophysics, Geosystems, 19(5), 1595–1610.

Do our groups agree with ip/op relationships?

- (Very) loose relationship between magnetic characterisation groups and ip/op relationship

	Parallel	Perpendicular	Oblique
Group 1	0.625	0.25	0.125
Group 2	0.33	0.33	0.33
Group 3	0.25	0.25	0.5
Group 4	0	0.67	0.33

Conclusions and Hypotheses

- There is a (very) loose relationship between the coercivity/amount of SD magnetite in a sample and its ip/opAMS relationship
- **Does not appear likely that proportion of MD vs. SD/SPM magnetite alone controls relationship**
- **Viscous relaxation may result in a much stronger opAMS response, resulting in a disproportionate influence on opAMS, but be masked by weak-field hysteresis in Field/Frequency dependence tests**
- Nature of opAMS is still unclear, and further work is needed