Anomalous Variation of Magnetic Anisotropy with Low-field in some Volcanic Dikes and its Magneto-mineralogical Origin

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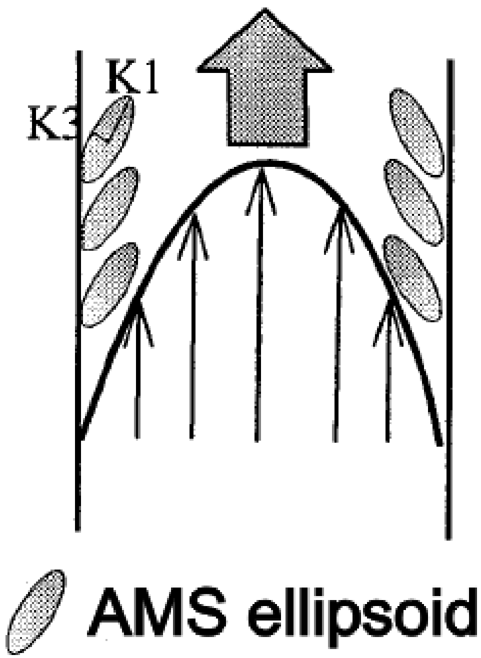
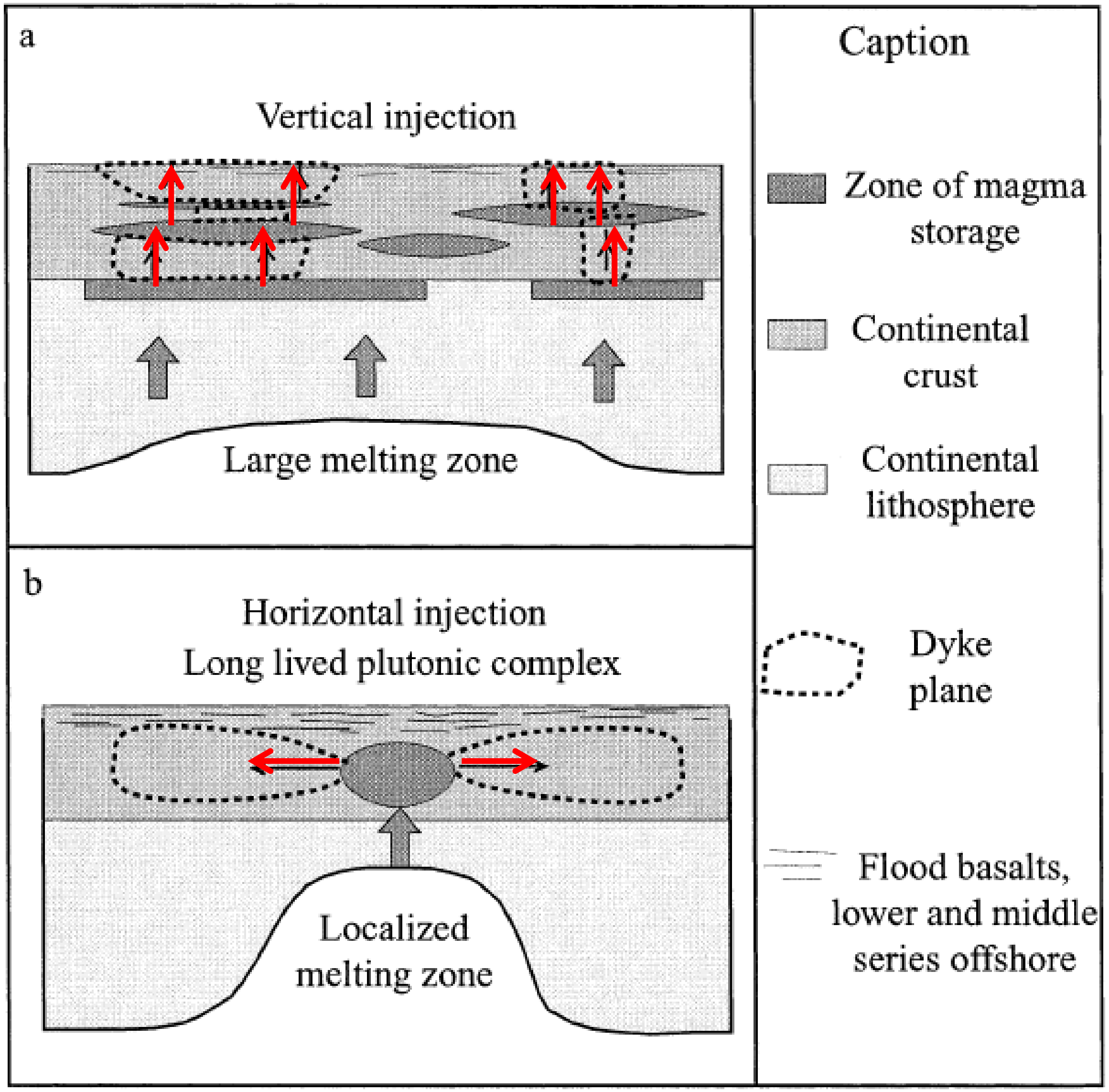
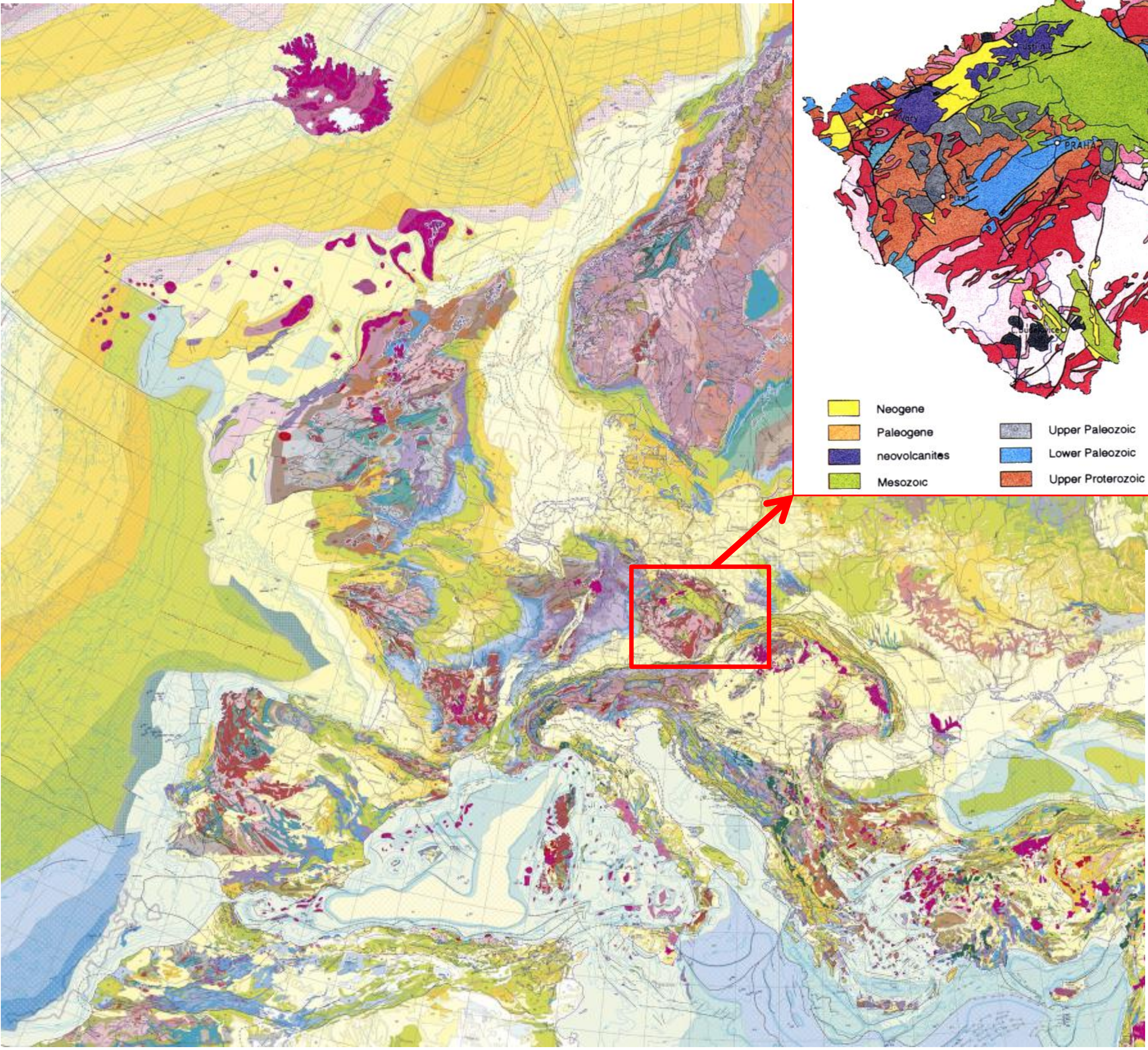
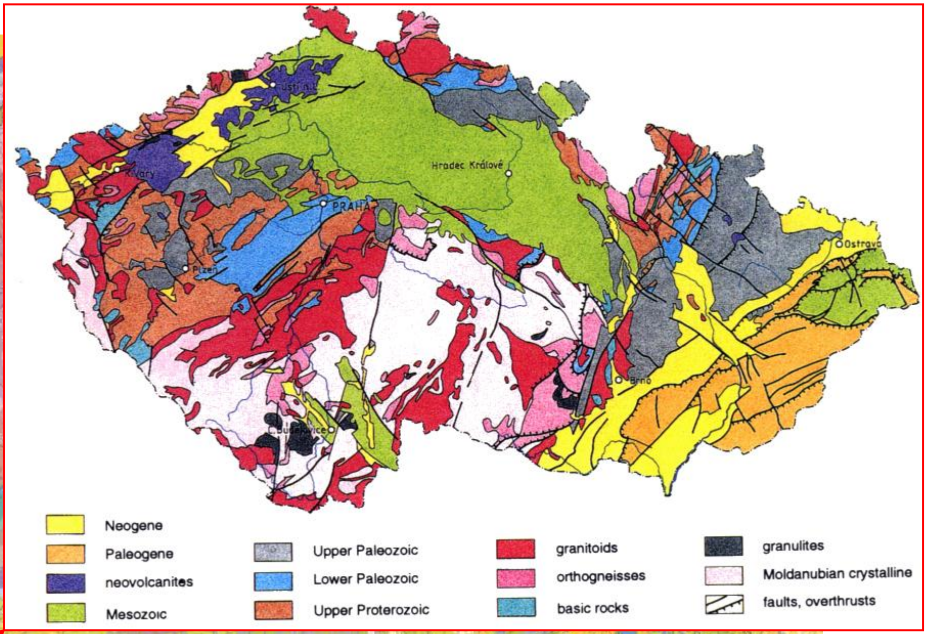
The Objective





Geological Setting





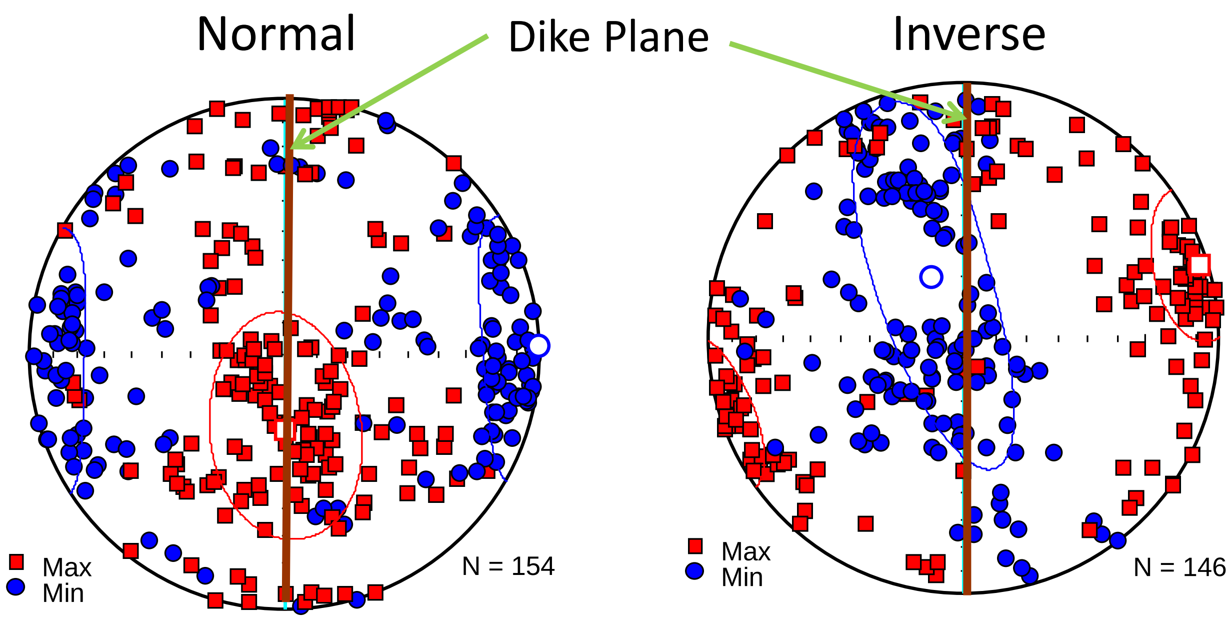
České středohoří, Eger Graben, branch of Rhine Graben.

Rocks: Basanite
Bostonite
Camptonite
Tinguaite

Age: Miocene

Geological Setting

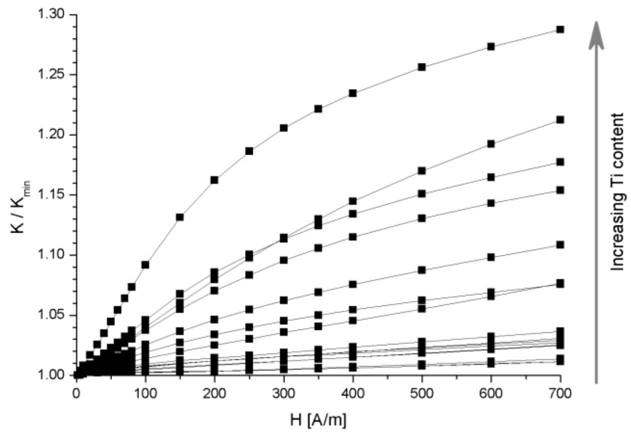
AMS Pattern Observed in Dikes



Most common

Relatively Unfrequent

Magnetic Fabrics are Mostly Normal, Seldom Inverse, and Rarely Oblique.



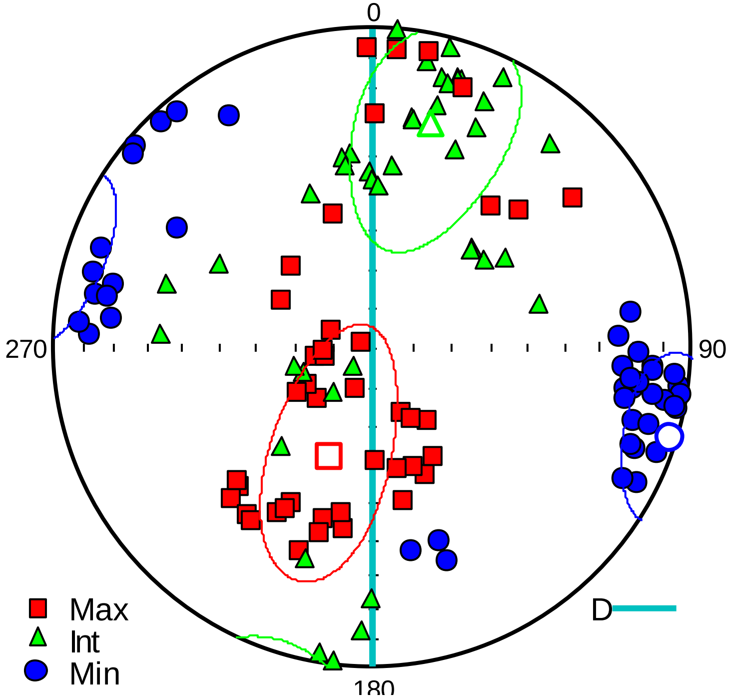
Variable Low-field Variation of Susceptibility Depends on Ti Content in Titanomagnetite.

Purpose of this study:

Variation of Anisotropic Susceptibility with Low-field.

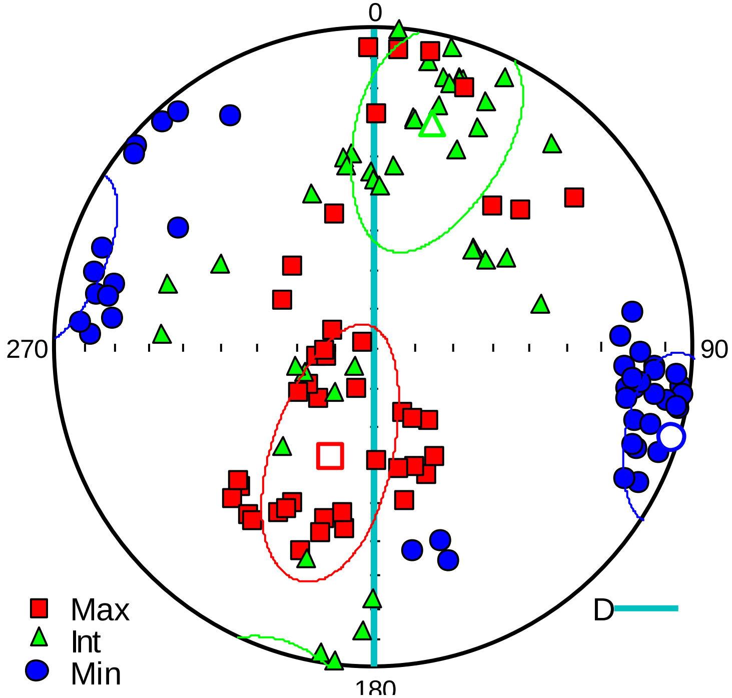
AMS Fabric in Two Selected Dikes

CS10 Bostonite (low Ti)



Normal Fabric

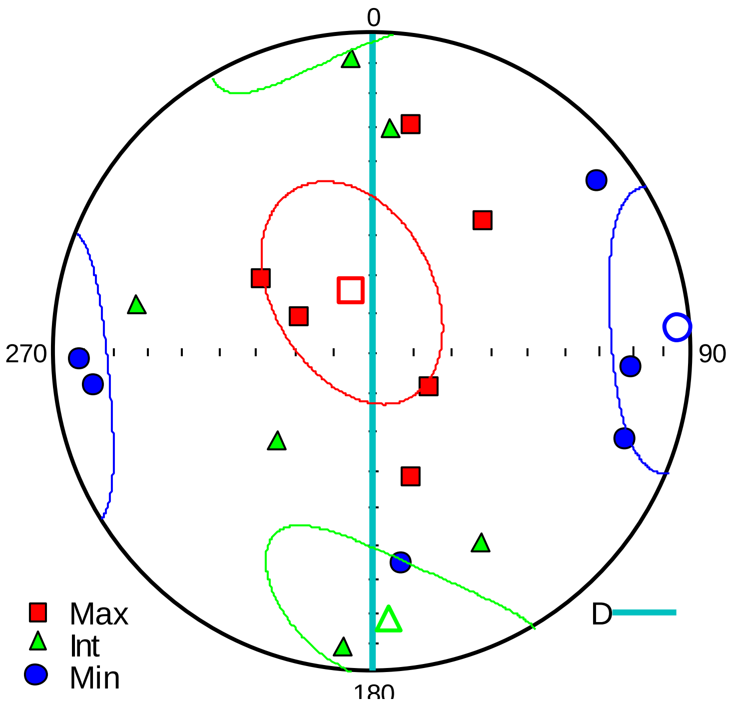
CS34 Camptonite (high Ti)



Inverse Fabric

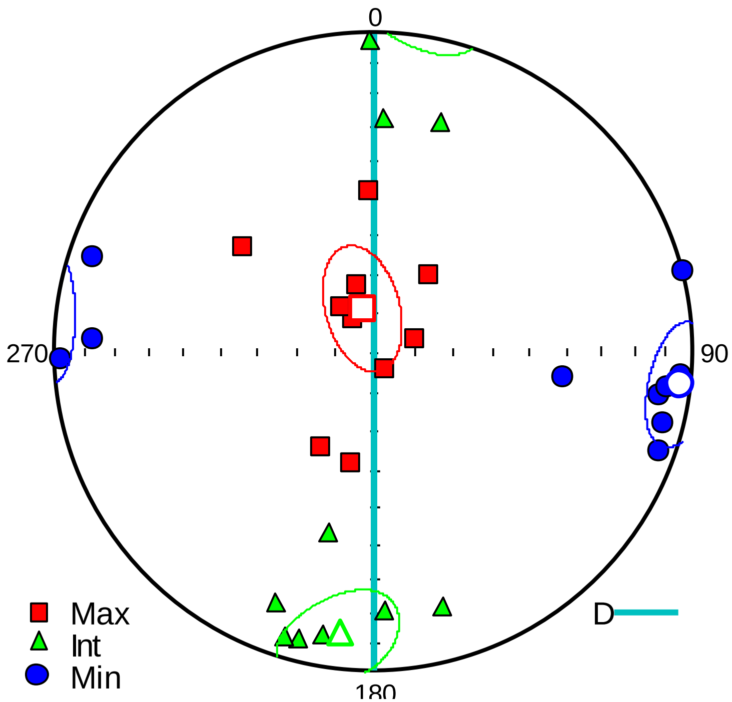
Respective AAMR Fabric

CS10 Bostonite (low Ti)



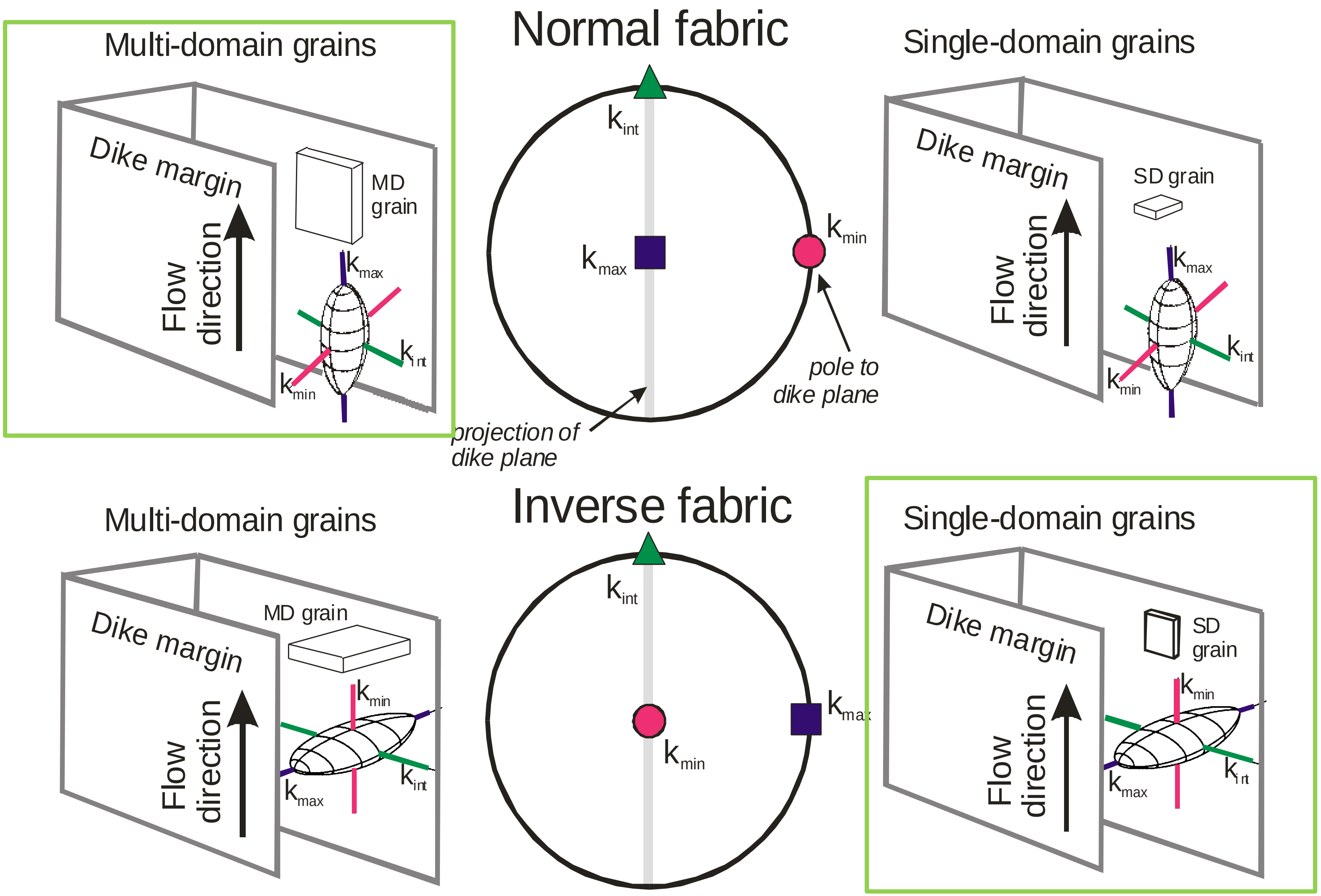
Normal Fabric

CS34 Camptonite (high Ti)



Normal Fabric

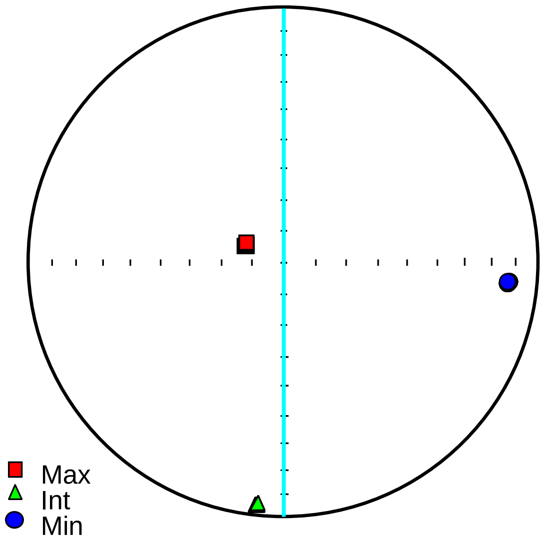
Four End-Point Scenarios



(Chadima et al. 2008)

Low-field Variation of Principal Directions (PD)

CS10-14-02



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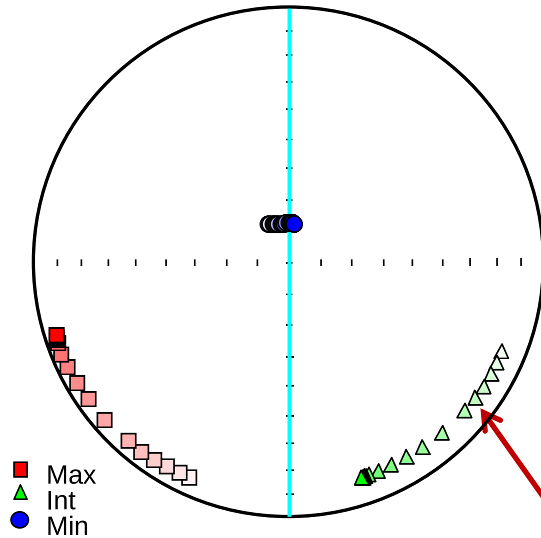

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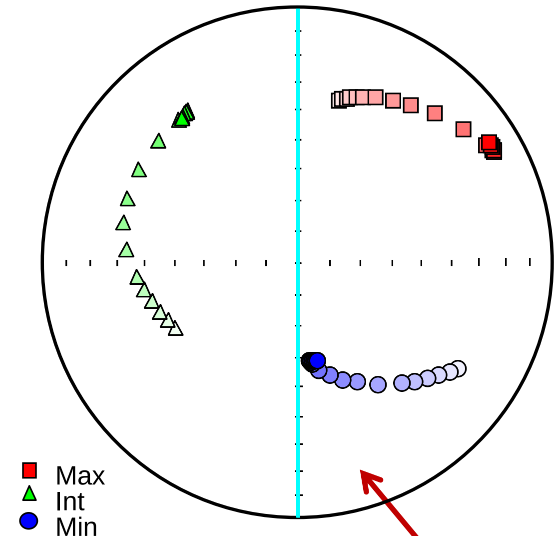
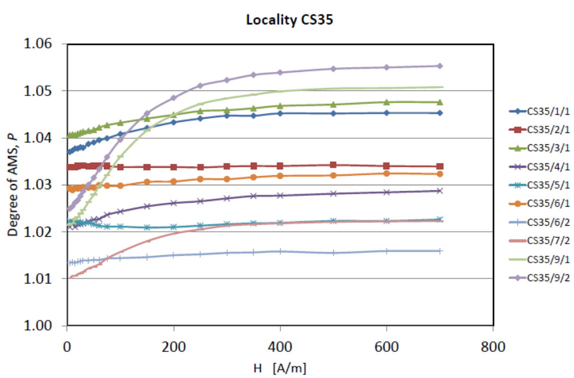
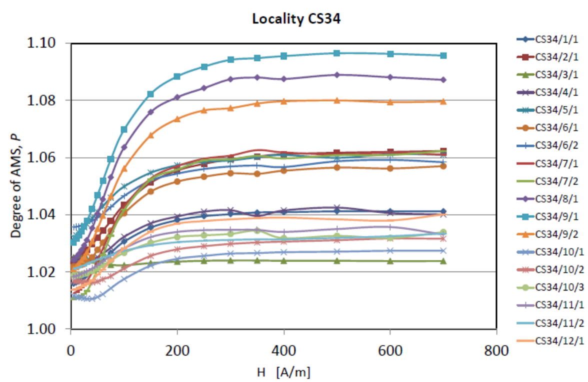






Variation in k_1, k_2, and k_3

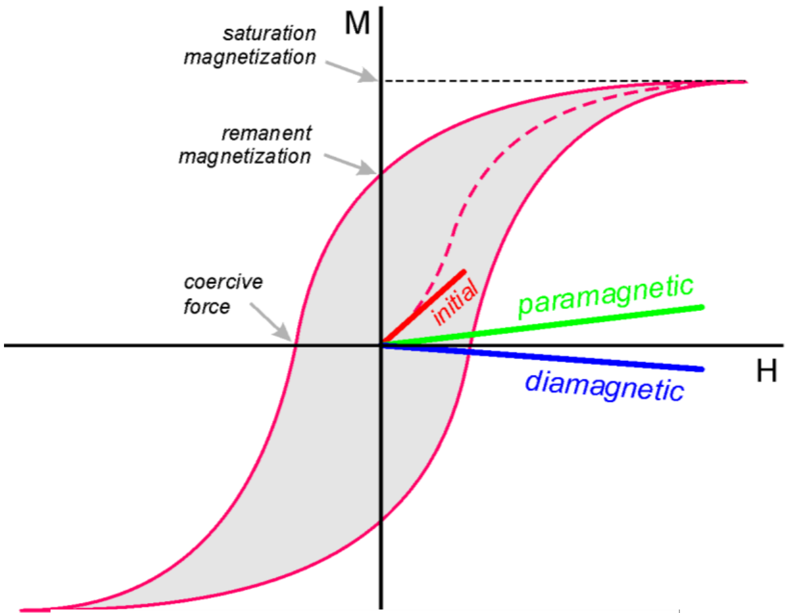
Variation in k_1 and k_3

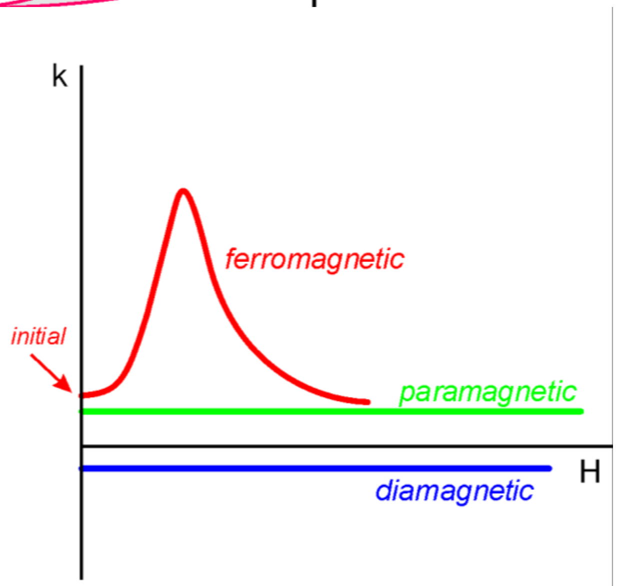
What is the Nature of Low-field Variation of AMS ??

Locality CS10 – moderate variation in *P*, no variation in PD

Locality CS34 – strong variation in *P*, strong variation in PD

Low-field Anisotropy of Susceptibility





Standard AMS Theory: $\boldsymbol{M} = \mathbf{k}\,\boldsymbol{H}$

Magnetization (vector ***M***) is linearly related to field intensity (vector ***H***) , susceptibility (second rank tensor **k**) is constant. Valid for para, dia, initial susceptibility of ferro.

AMS in Rayleigh Law Region:

$$\boldsymbol{M} = \mathbf{k}_{fi}\boldsymbol{H} + \boldsymbol{\kappa}\boldsymbol{H} + \boldsymbol{\alpha}H\boldsymbol{H}$$

$$\mathbf{k} = \mathbf{k}_{fi} + \boldsymbol{\kappa} + \boldsymbol{\alpha}H$$

$\mathbf{k}_{fi}$ dia-, paramag. susc., $\boldsymbol{\kappa}$ initial susc., $\boldsymbol{\alpha}$ Rayleigh coefficient tensors are all field independent. Field-dependent is $\boldsymbol{\alpha}H$.

AMS above Rayleigh Law Region:

$$\boldsymbol{M} = \mathbf{k}_{fi}\boldsymbol{H} + \boldsymbol{\kappa}\boldsymbol{H} + \mathbf{F}(\boldsymbol{\kappa},H)$$

$\mathbf{F}(\boldsymbol{\kappa},H)$ matrix function of M vs. H relation

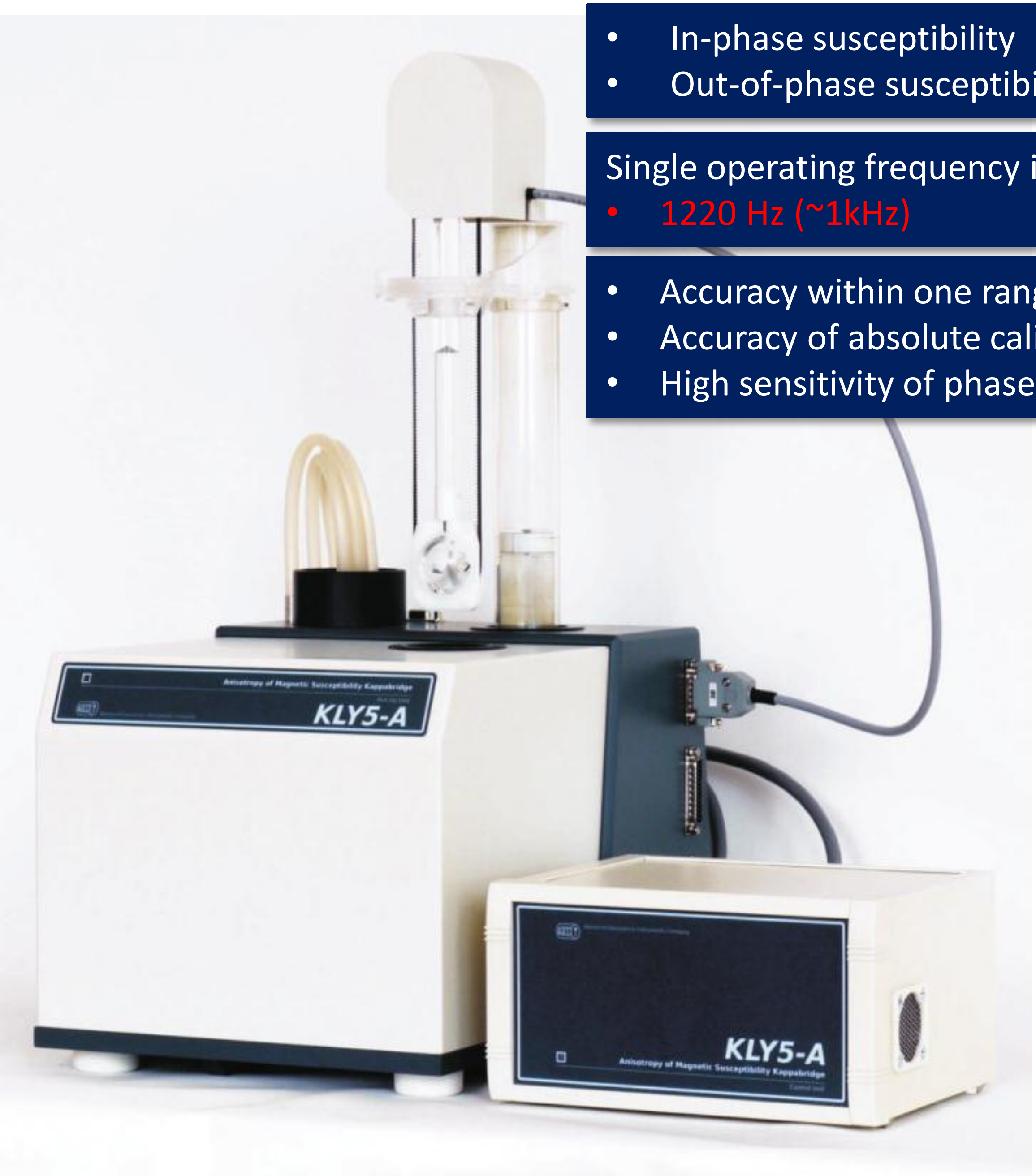
Possible Causes of AMS Variation

1. Susceptibility Tensor is of higher rank than rank two
2. Superposition of field-independent and field-dependent contributions

Solution:

1. Study of low-field variation of large set of directional susceptibilities
2. Evaluation of quality of fit by second rank tensor
3. Calculation of field dependent and field-independent tensors

The Instrument – KLY5 Kappabridge



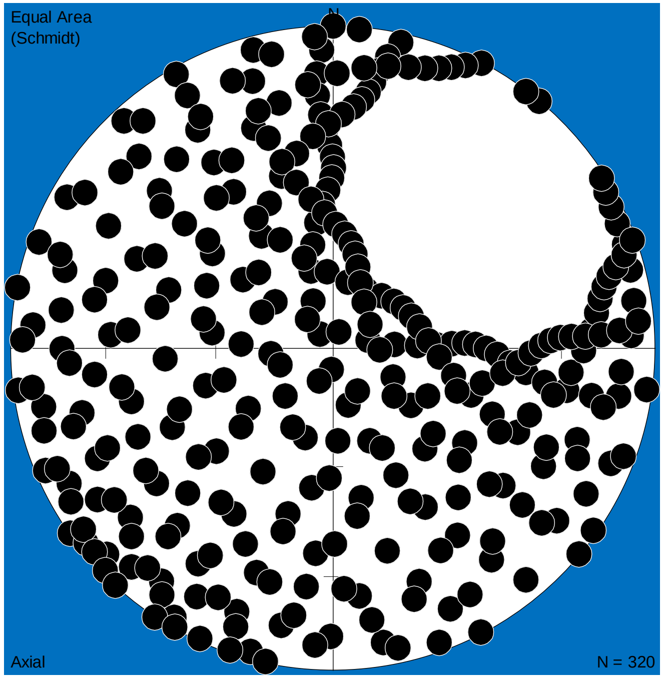
- In-phase susceptibility
- Out-of-phase susceptibility (Precise and Calibrated!)

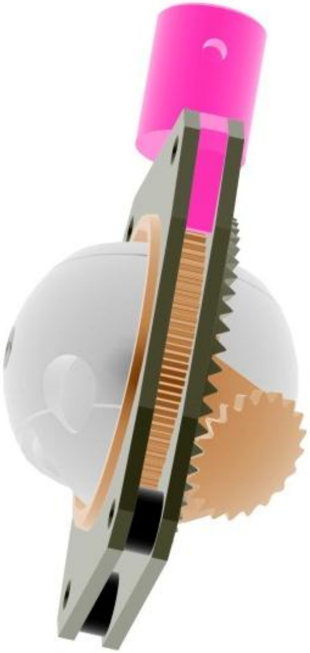
Single operating frequency in field range (in peak values)

- 1220 Hz (~1kHz) 5 - 750 A/m

- Accuracy within one range: ±0.1 %
- Accuracy of absolute calibration: ±3.0 %
- High sensitivity of phase determination 0.1°

3D Rotator (640 Directional Susceptibilities)





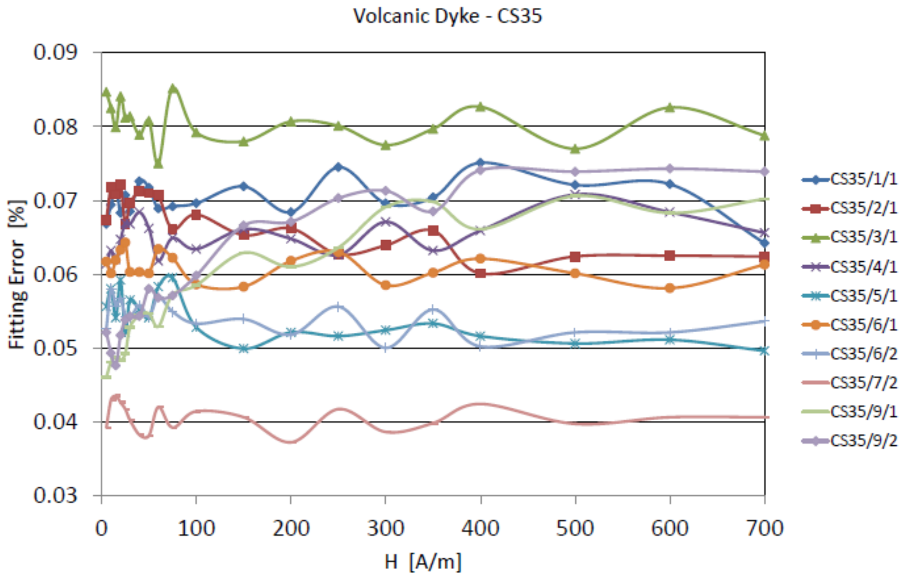
- 320 independent directions
- 2 rotations, i.e. 640 directional susceptibilities
- 1.5 min to measure AMS

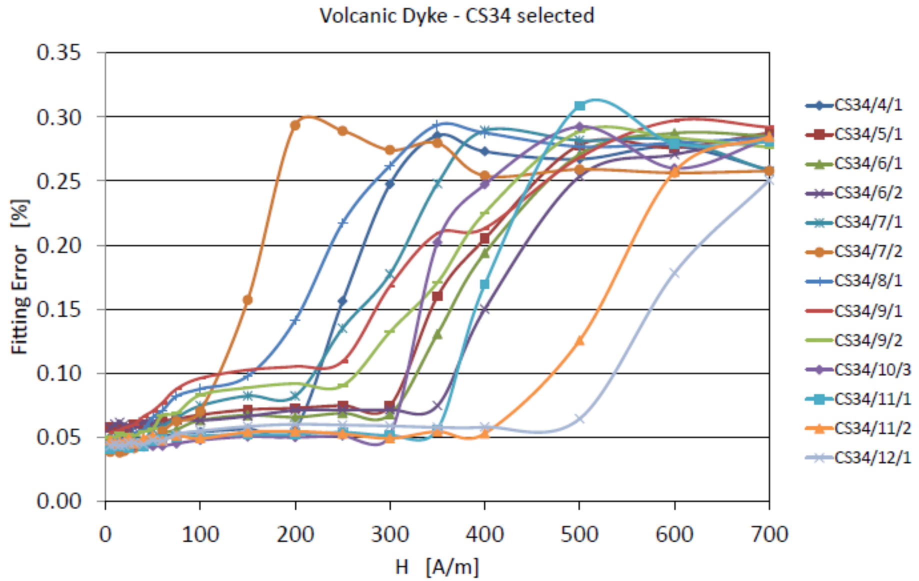
Even a baby can handle it….

Quality of Tensor Fit

Fitting Error $E = 100\sqrt{\frac{1}{320}\sum_{i=1}^{320}[(Kf_i - Km_i)/Km_i]^2}$

Km_i – measured value
Kf_i – fit value



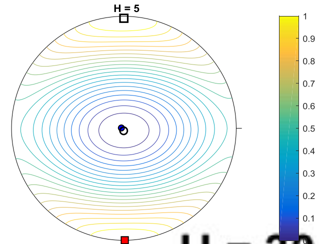


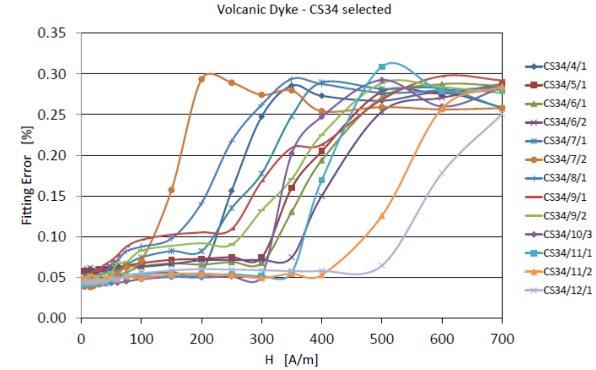
Excellent fit, which is more or less field independent.

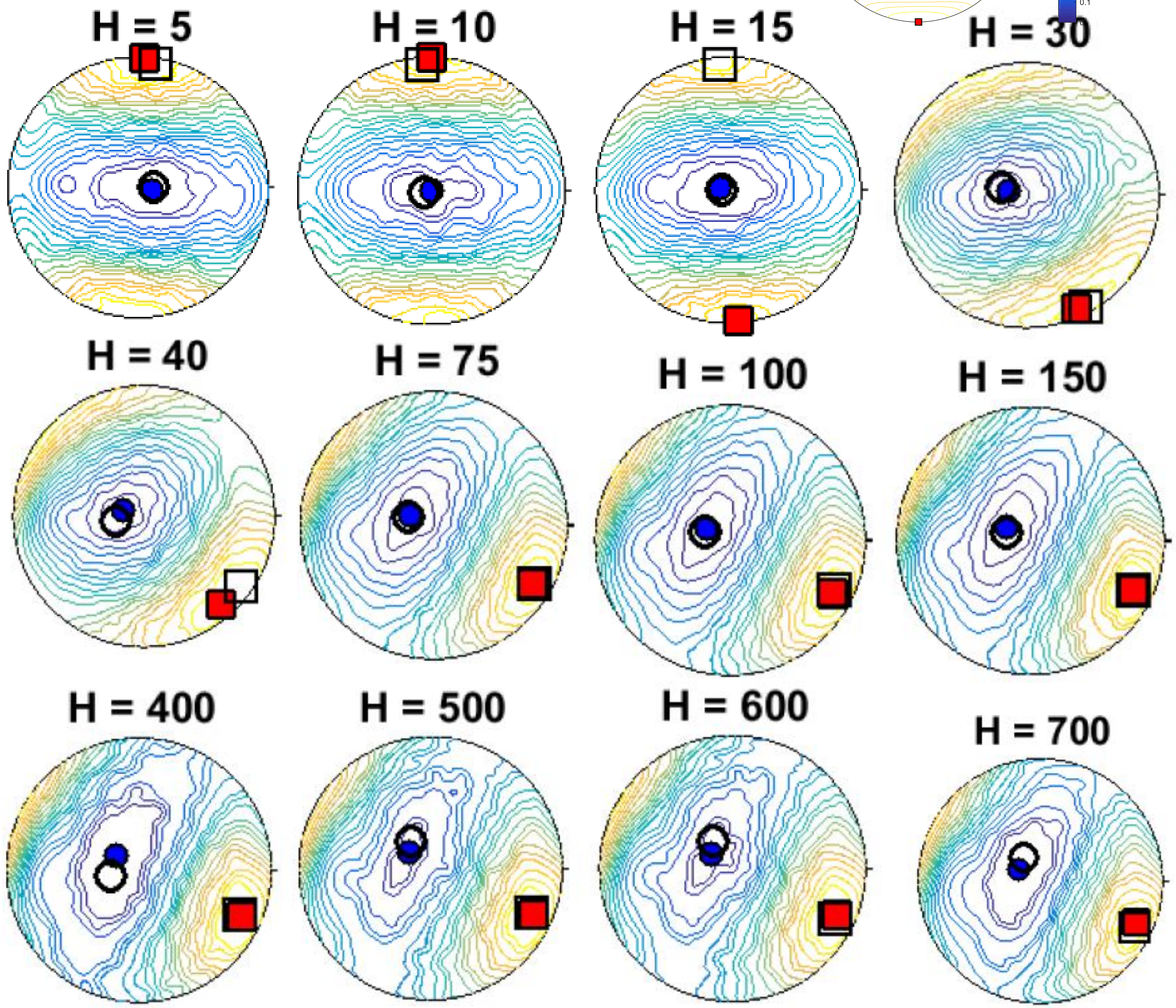
Directional variation of susceptibility is satisfactorily represented by ellipsoid varying with field in volume and eccentricity !!!

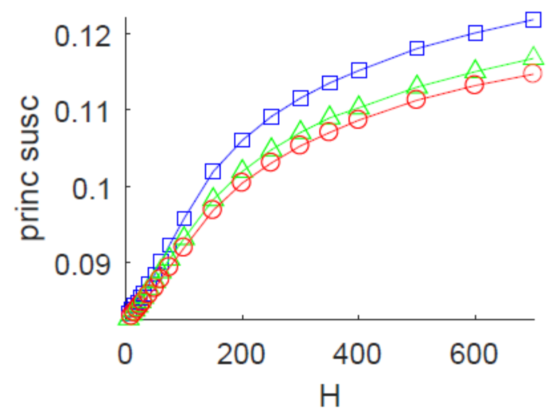
Excellent fit in very low fields. With increasing field the fitting error increases substantially. In high low-fields, the fit is more or less constant, but almost an order worse than in very low fields.

Camptonite CS34-07-02



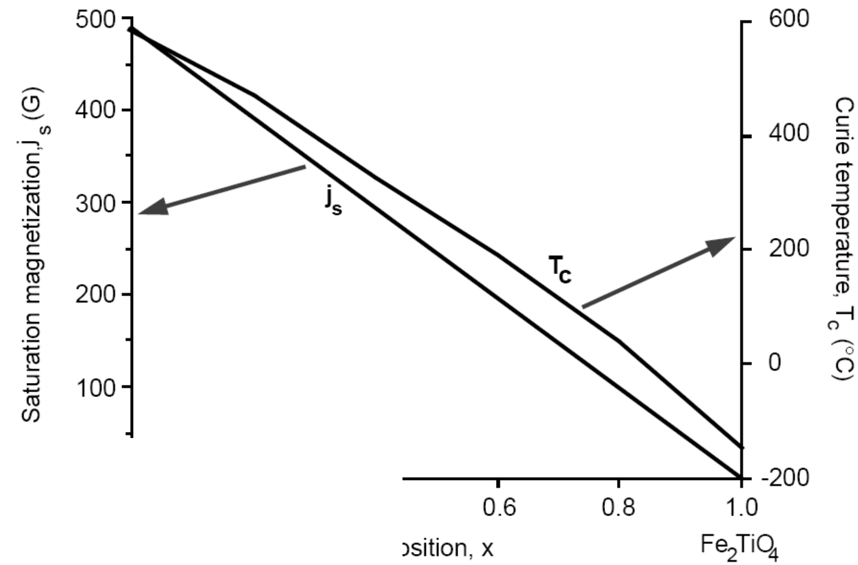






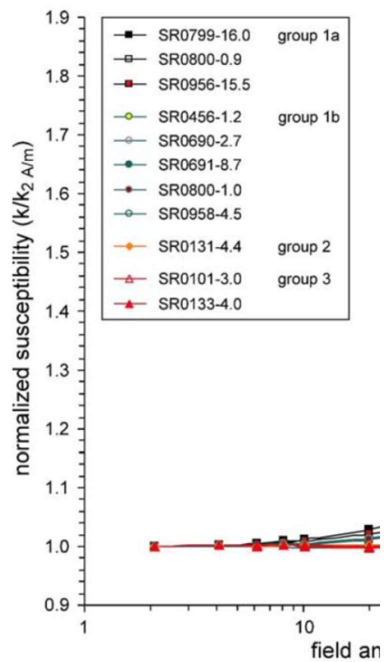
Very high susceptibility
Strong field variation.
Contour pictures differ according to field.
PD strongly vary with field.

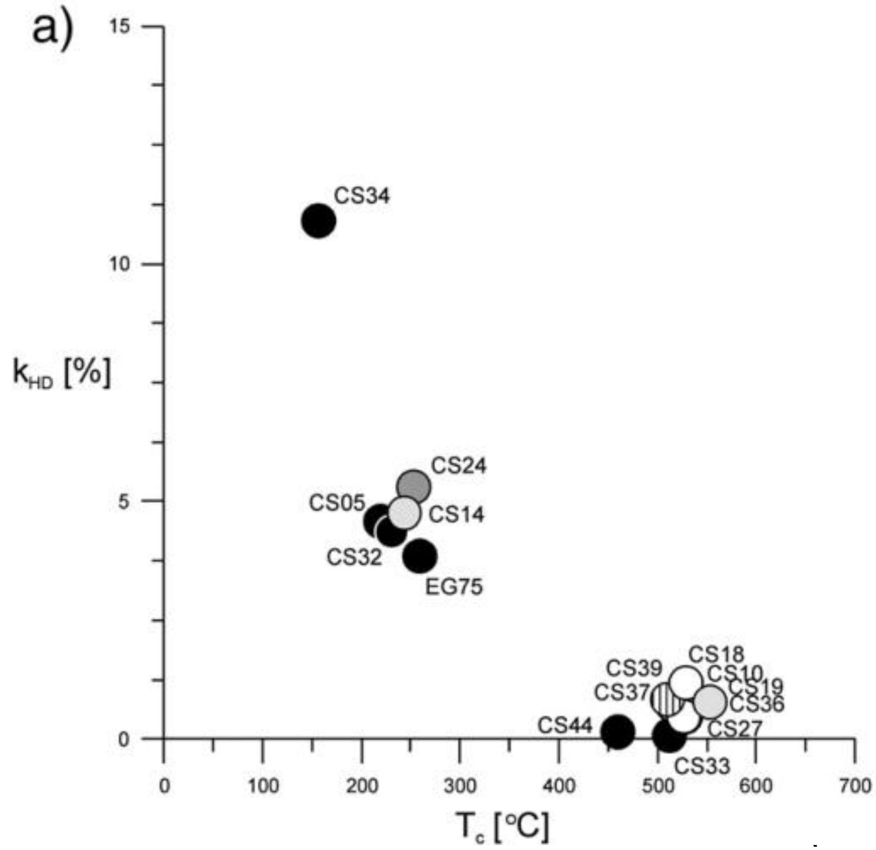
Titanomagnetites – Field and Temperature Variations

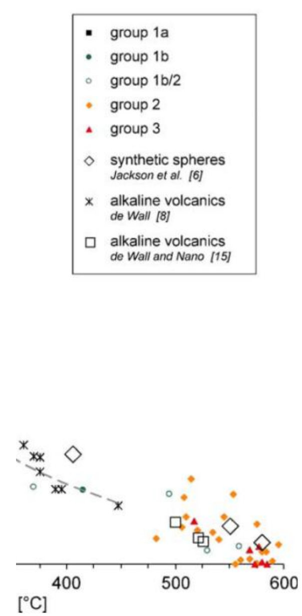


No Ti - magnetite, very high susceptibility, no field variation of susceptibility, Tc = 585 °C

Increasing Ti Content - decreasing susceptibility, increasing field variation of susceptibility, decreasing Curie temperature

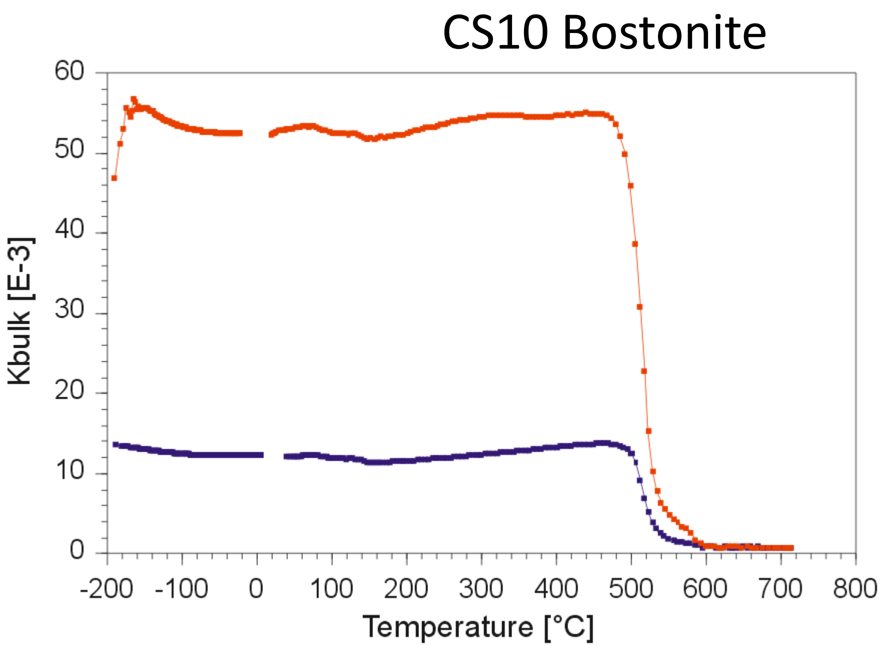


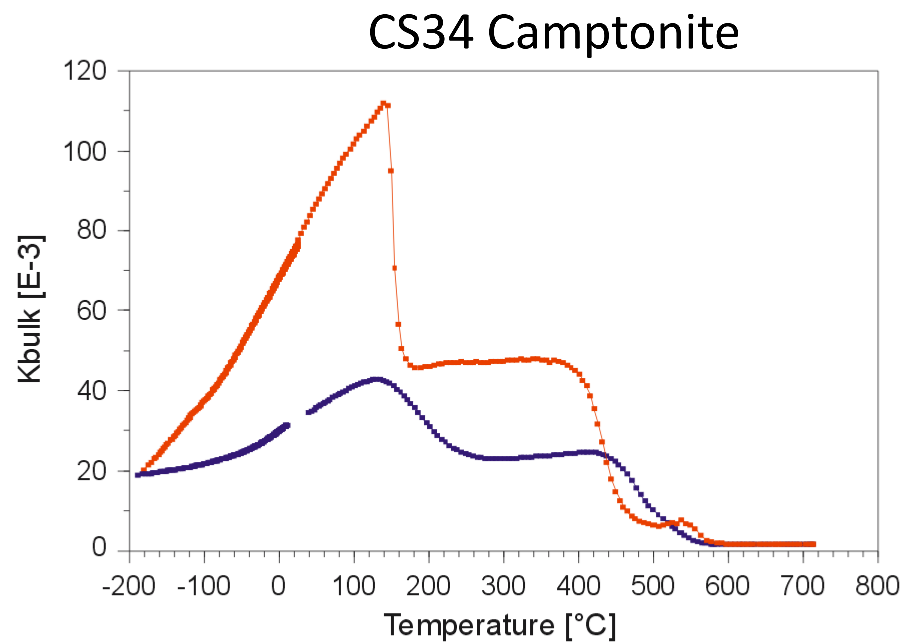




and Kontny, 2005, EPSL)

Temperature Variation of Susceptibility





Magnetically “Monomineralic” Rock. Mostly no variation in PD and AMS ellipsoid shape, moderate variation in susceptibility and degree of AMS.

Three carriers of AMS: with (1) Tc = 155 °C, (2) Tc = 430 °C, and (3) Tc =570 °C.

(1) Strongly field-dependent
(2) Moderately field-dependent
(3) Weakly field-dependent

CS34 Camptonite:

In very low fields the AMS is affected by all three phases. In moderate fields, increasing effect of (1) phase can be observed. In strong low-fields the AMS is dominantly controlled by phase (1), which is most strongly field-dependent.

Tensor Separation: Directional Susceptibility Method

Contributions to whole-rock susceptibility

$$k_r = K_d + K_p + K_{ma} + K_{sd} + K_{md} + A_{md}H$$

contribution of field-dependent susceptibility of MD fraction

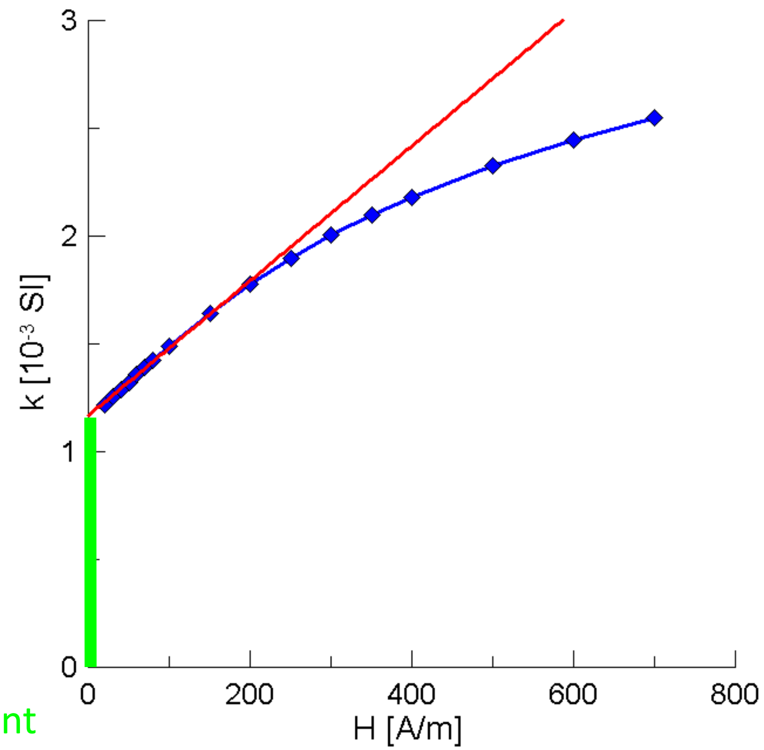
initial susceptibility of MD fraction

Contribution of field-independent susceptibility

$$\Psi = K_d + K_p + K_{ma} + K_{sd} + K_{md}$$

$$k_r = \Psi + A_{md}H$$

field-independent susceptibiility

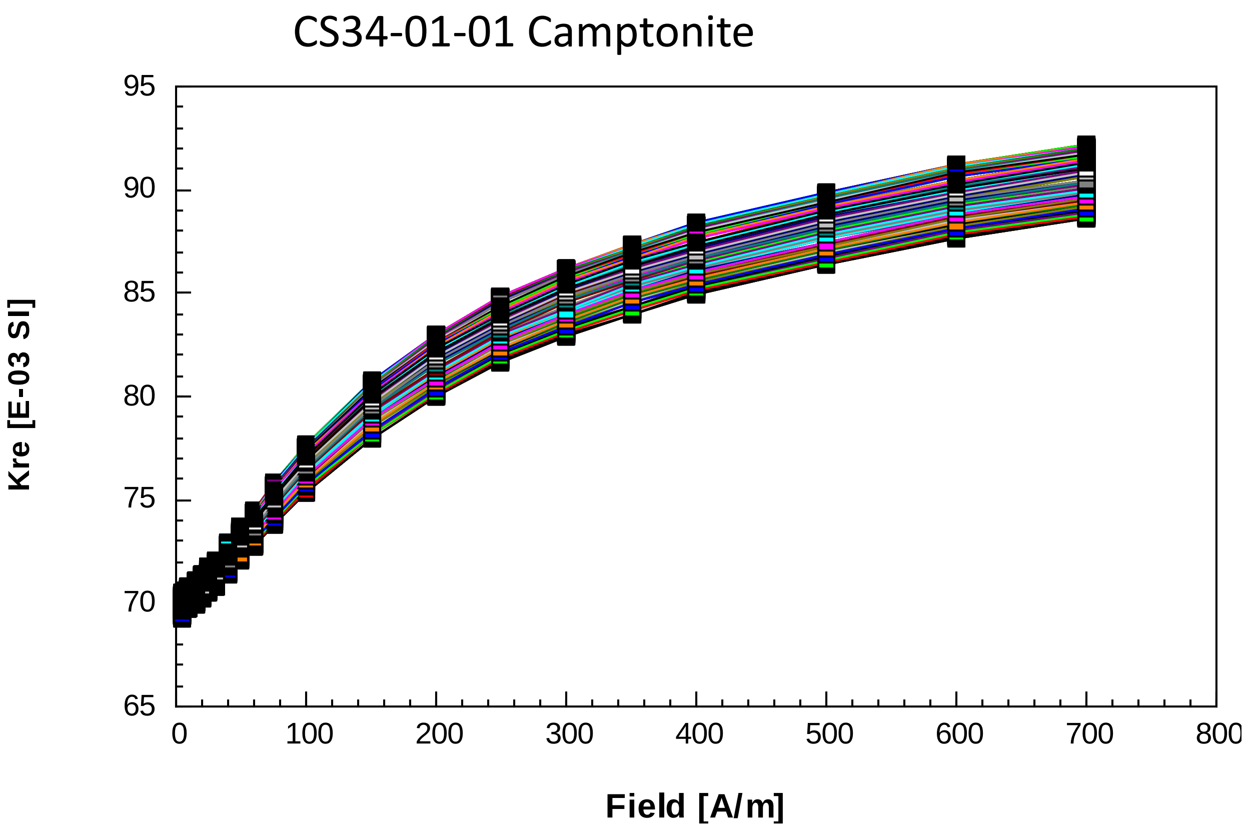


•From fitting straight lines to the susceptibility vs. field data for each direction we are able to determine the field-independent directional susceptibilities and field-independent susceptibility tensor

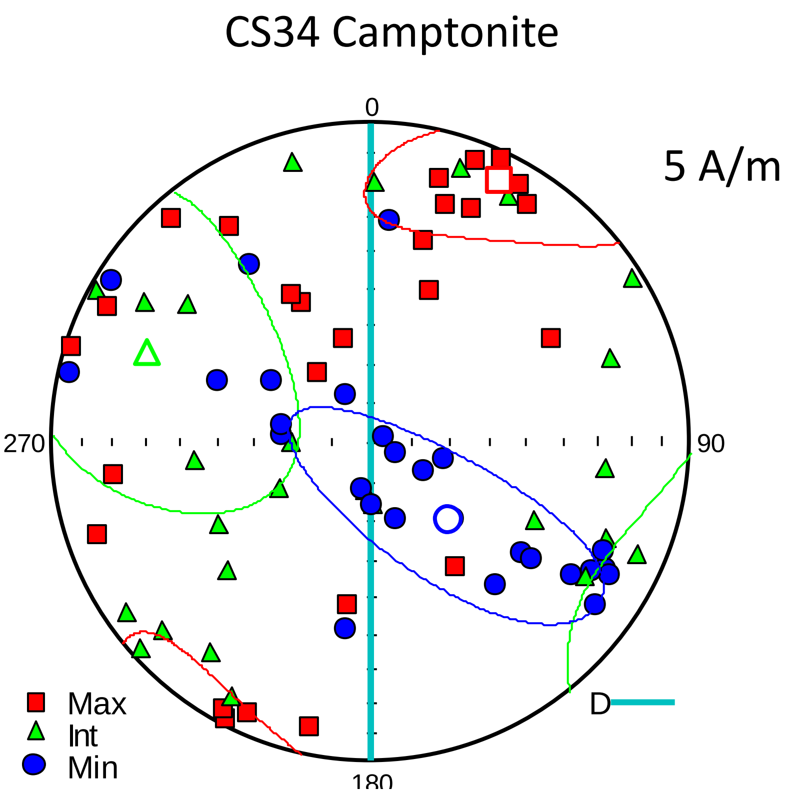
•Using $\alpha = ck^2$ (Néel, 1942), the initial susceptibility tensor of MD ferro (except for mean susceptibility) can be determined from A_{md}

(Hrouda 2008)

Tensor Separation: Directional Susceptibility Method



Field Variation of AMS



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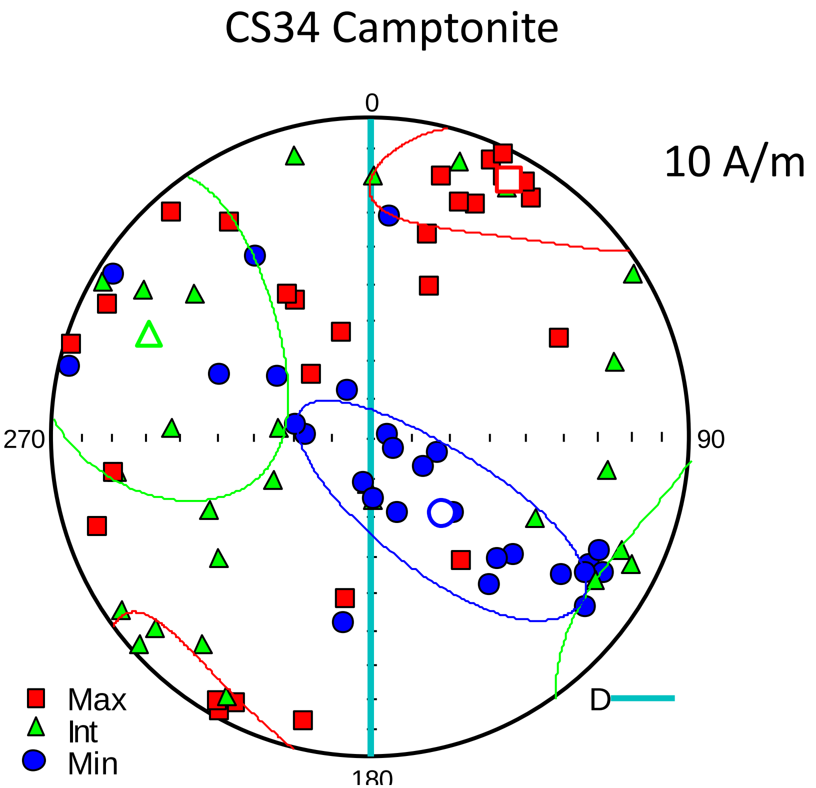

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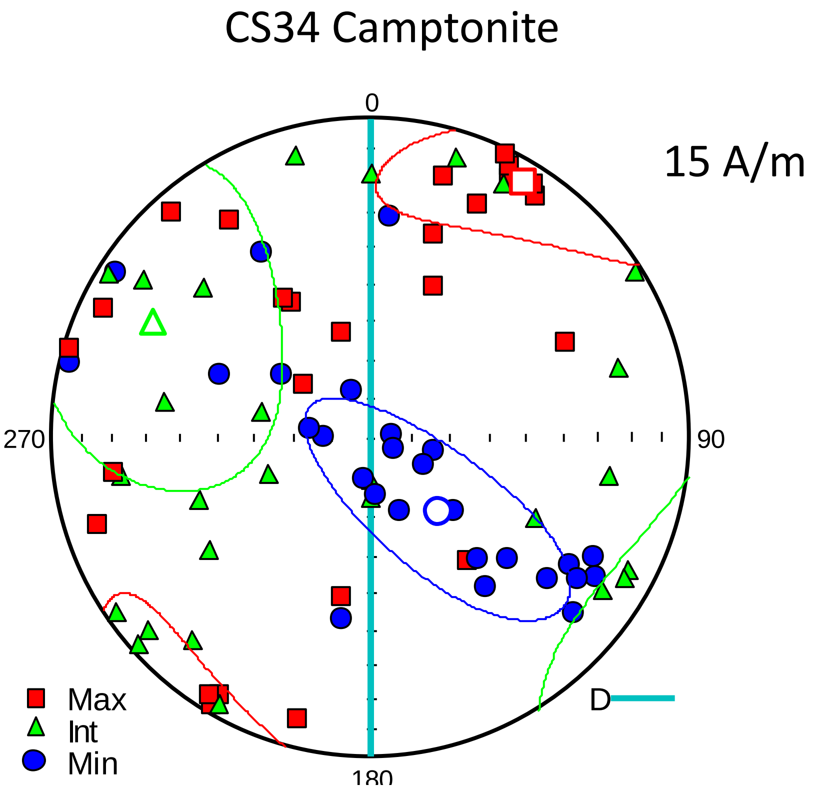

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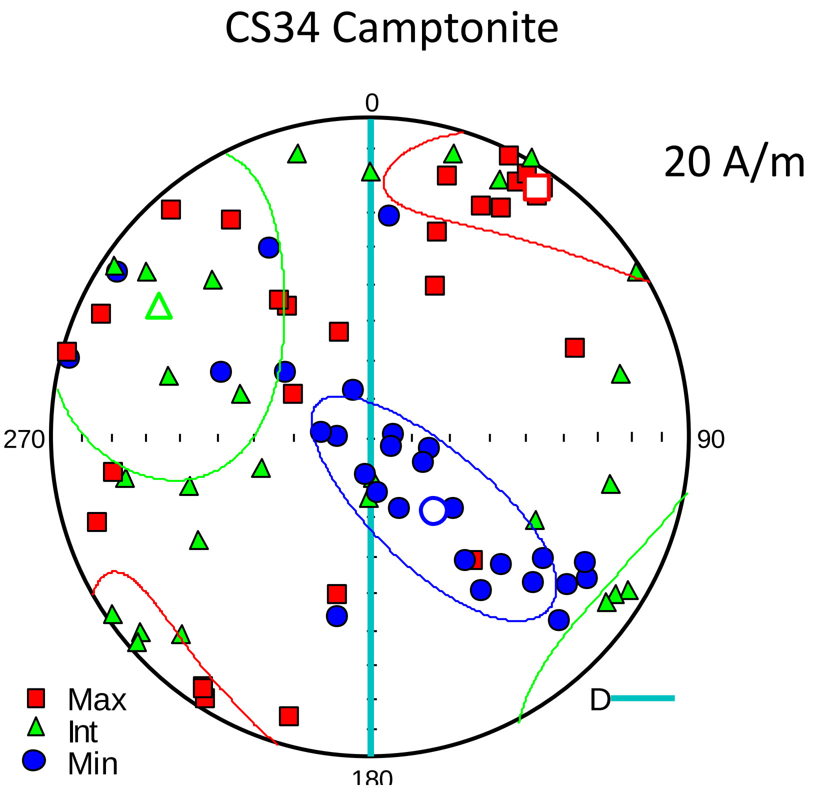

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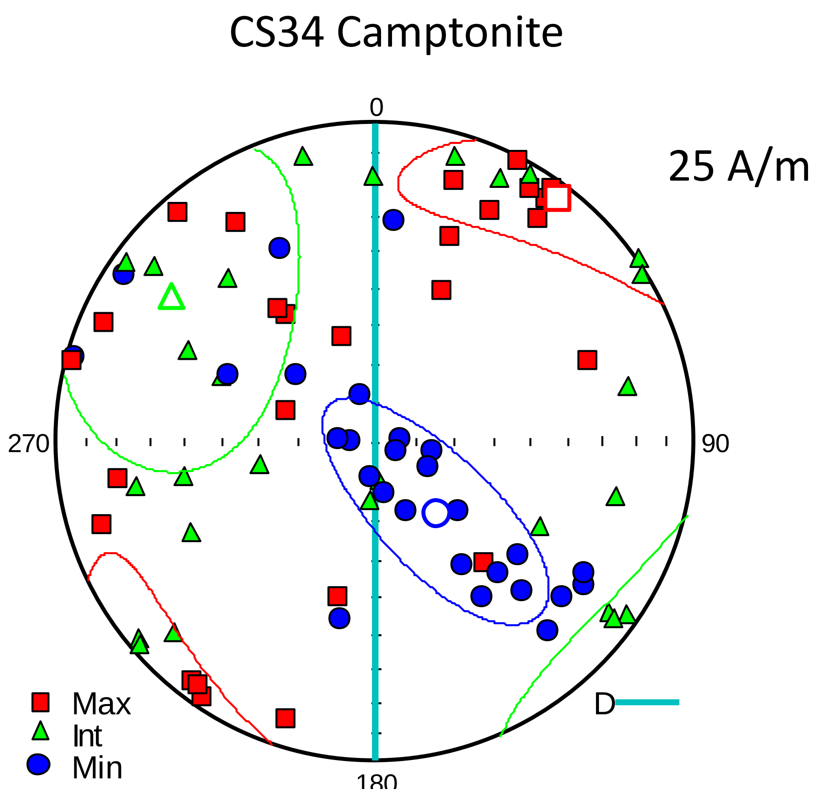
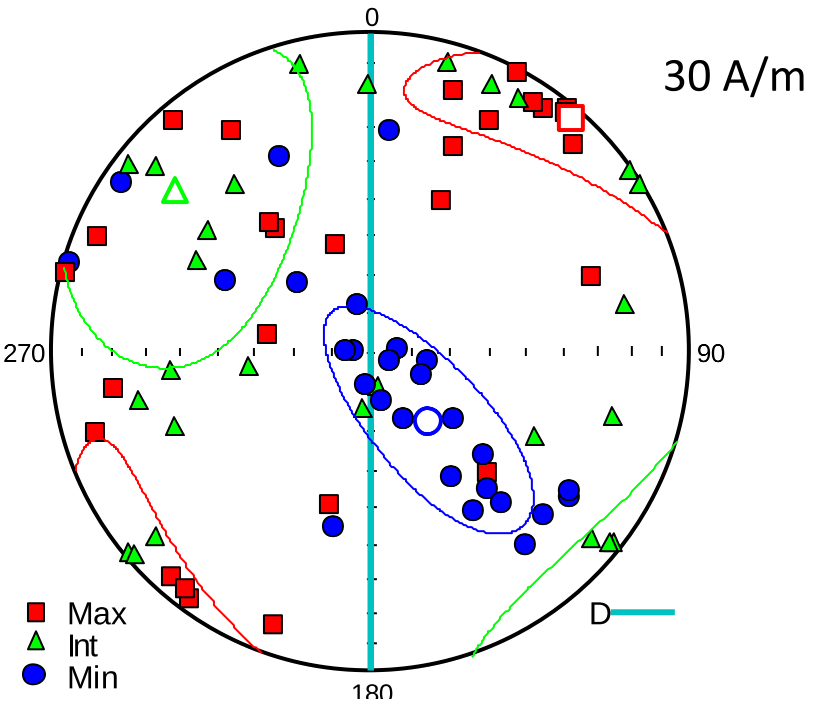


Field Variation of AMS

CS34 Camptonite



Field Variation of AMS

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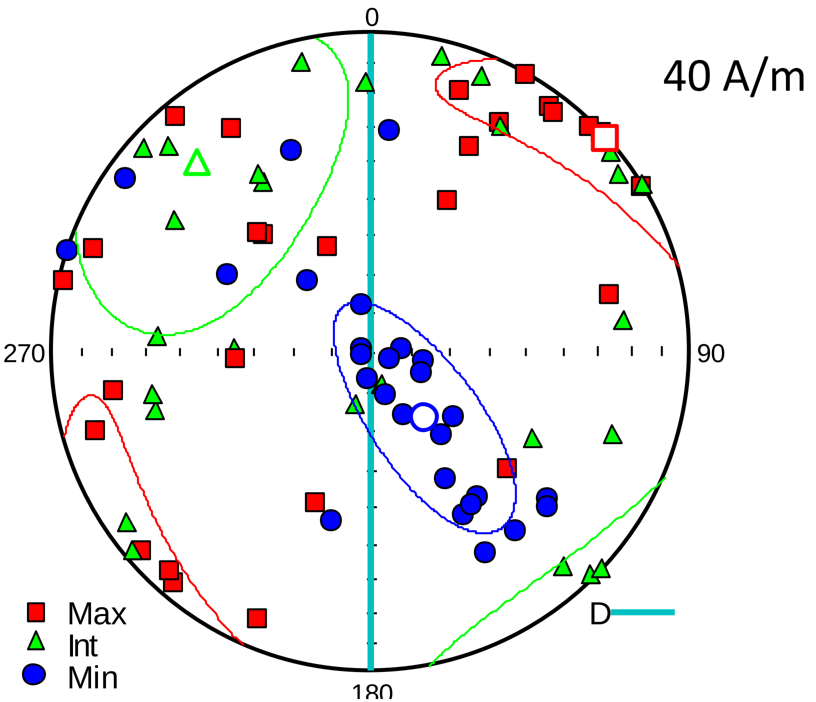

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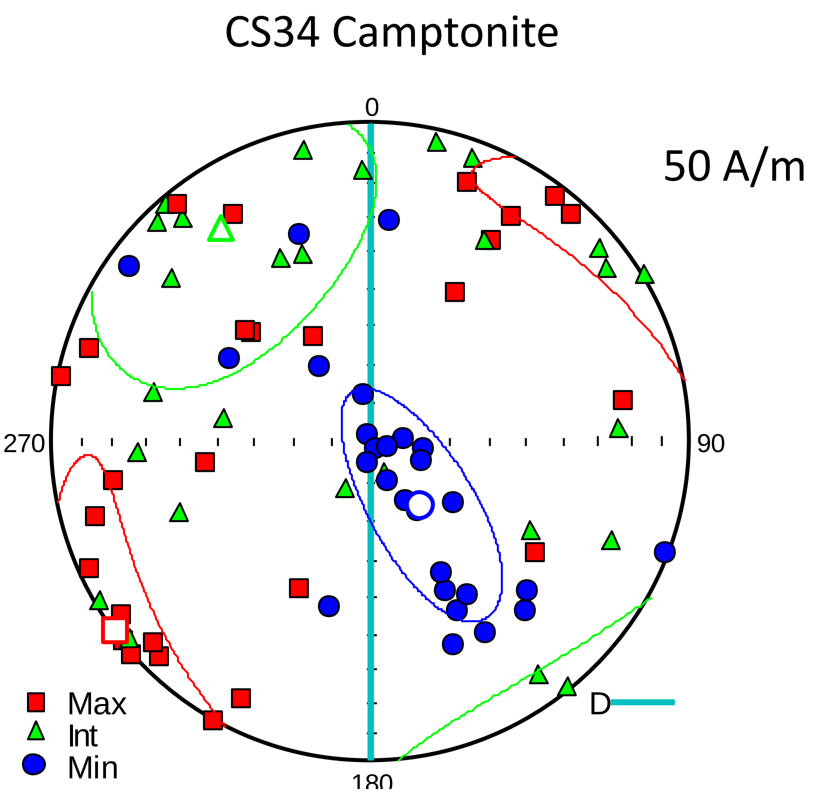

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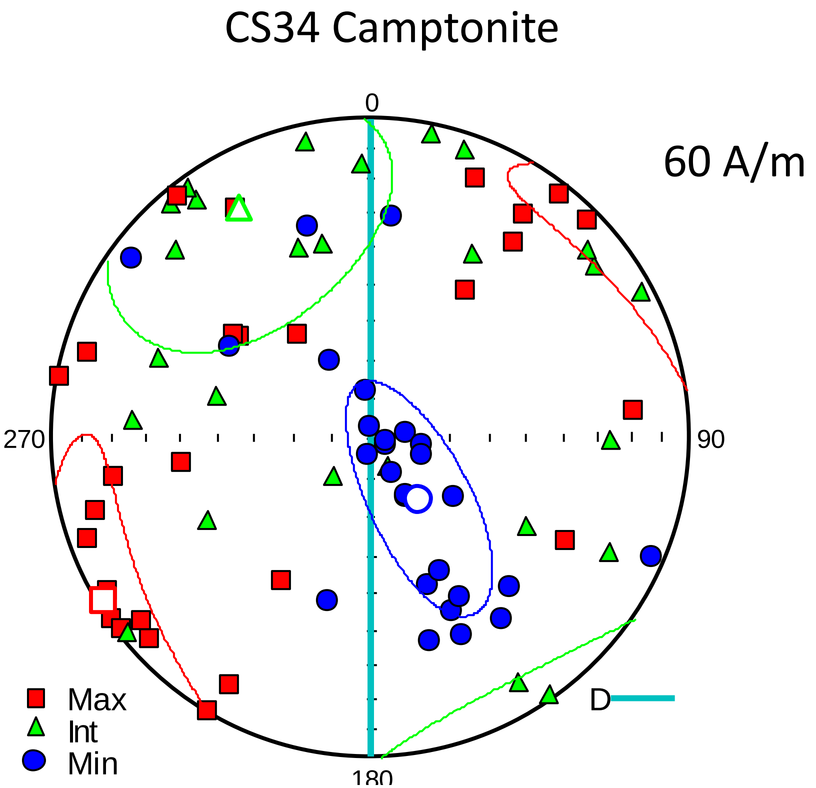

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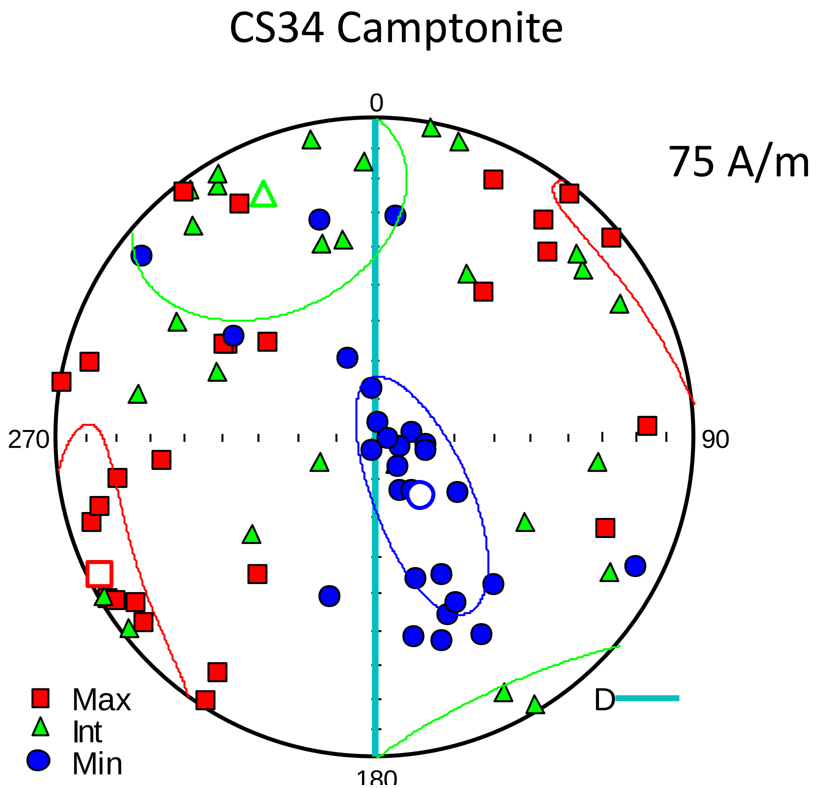

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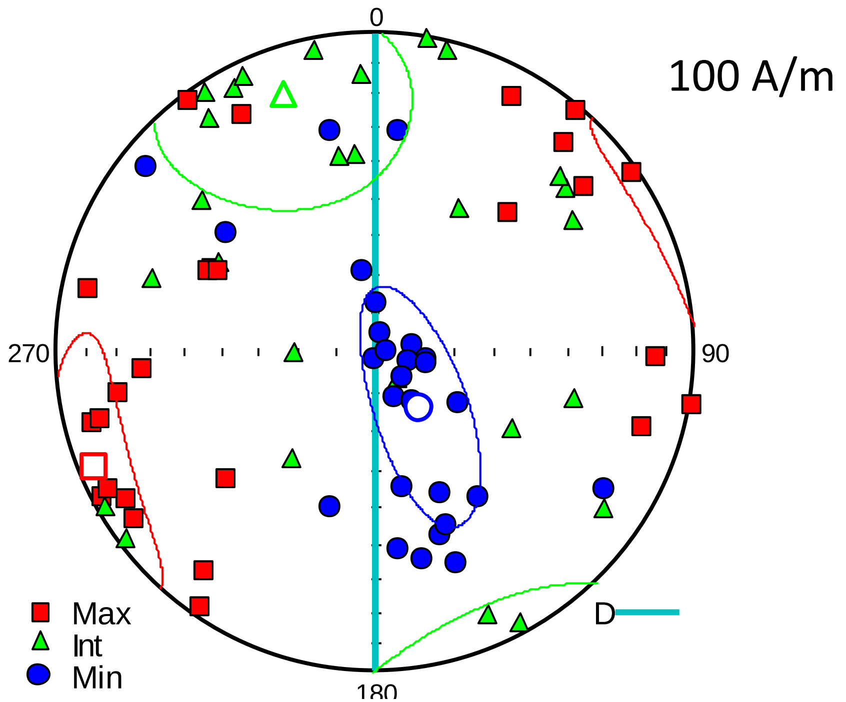

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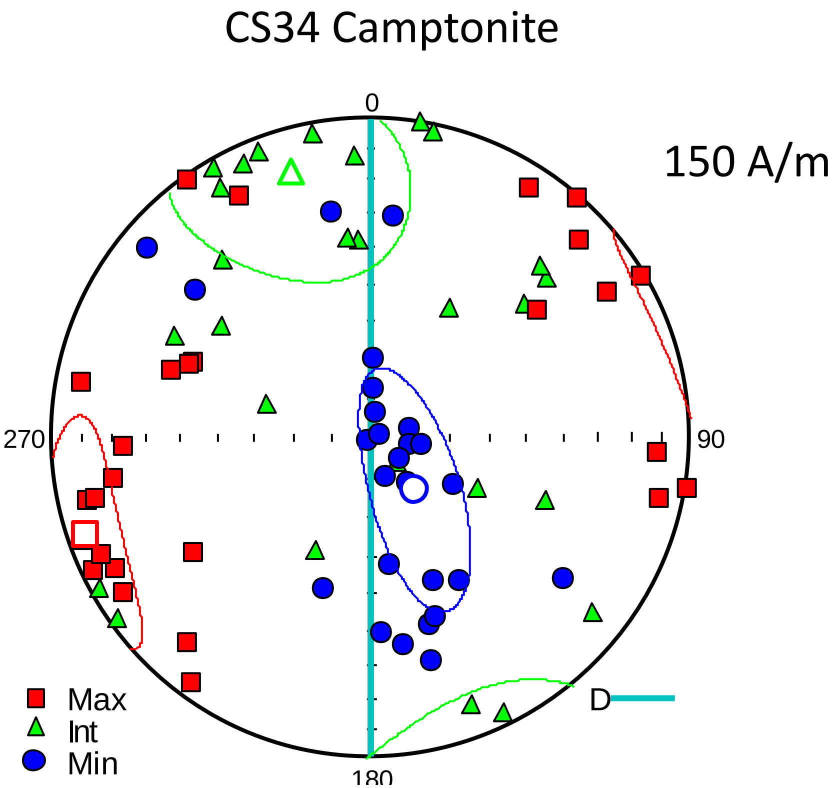

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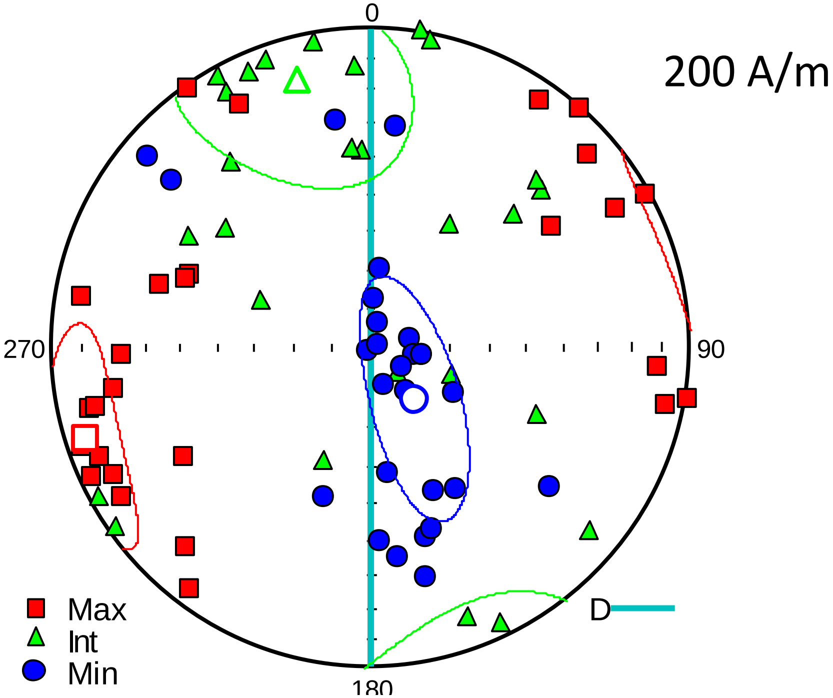

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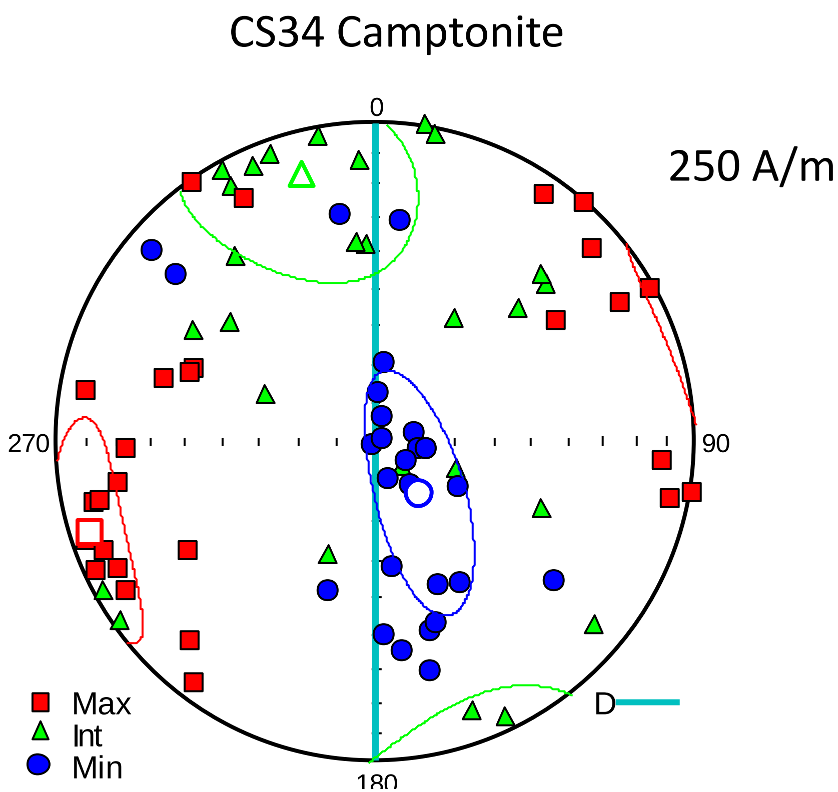

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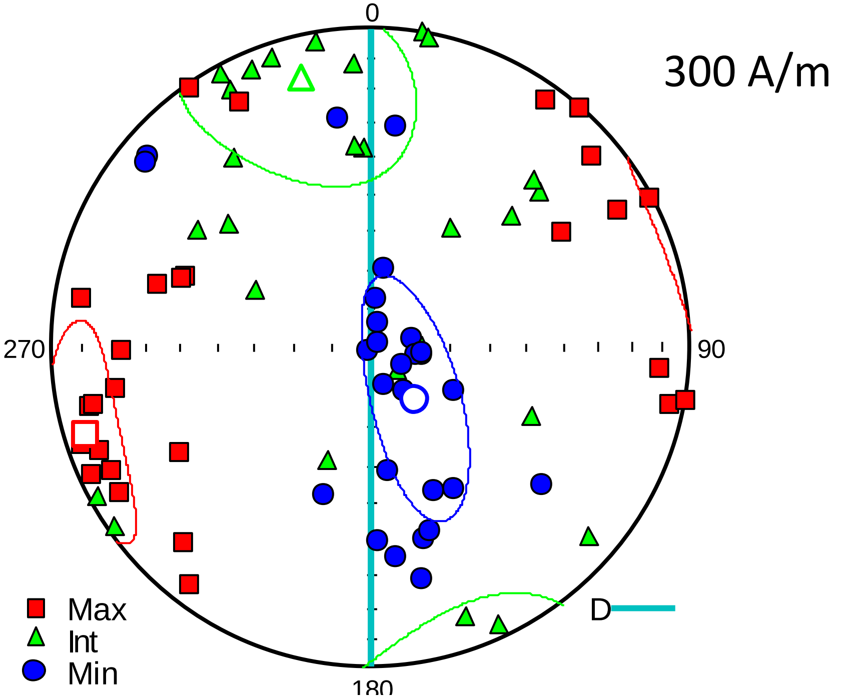

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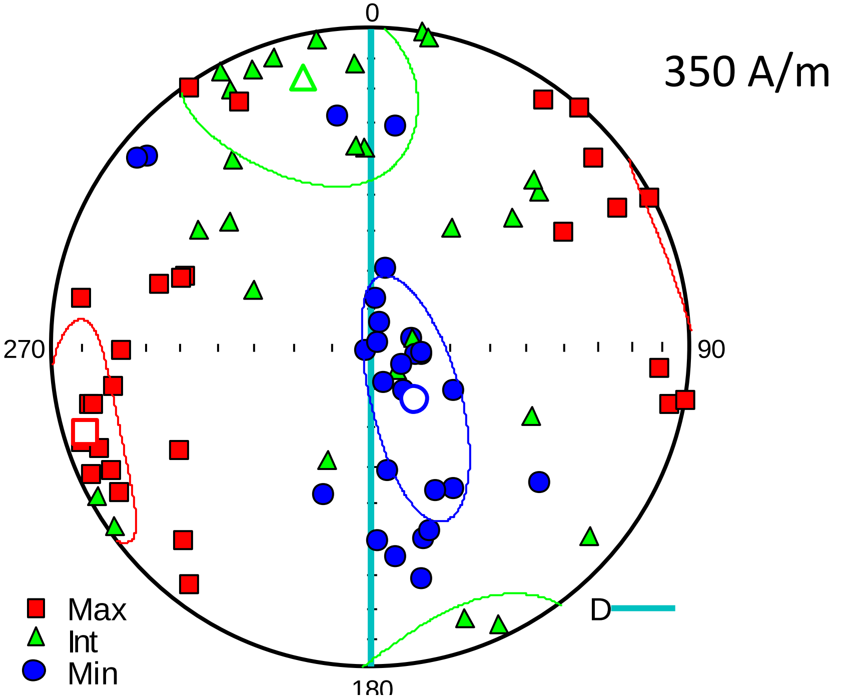

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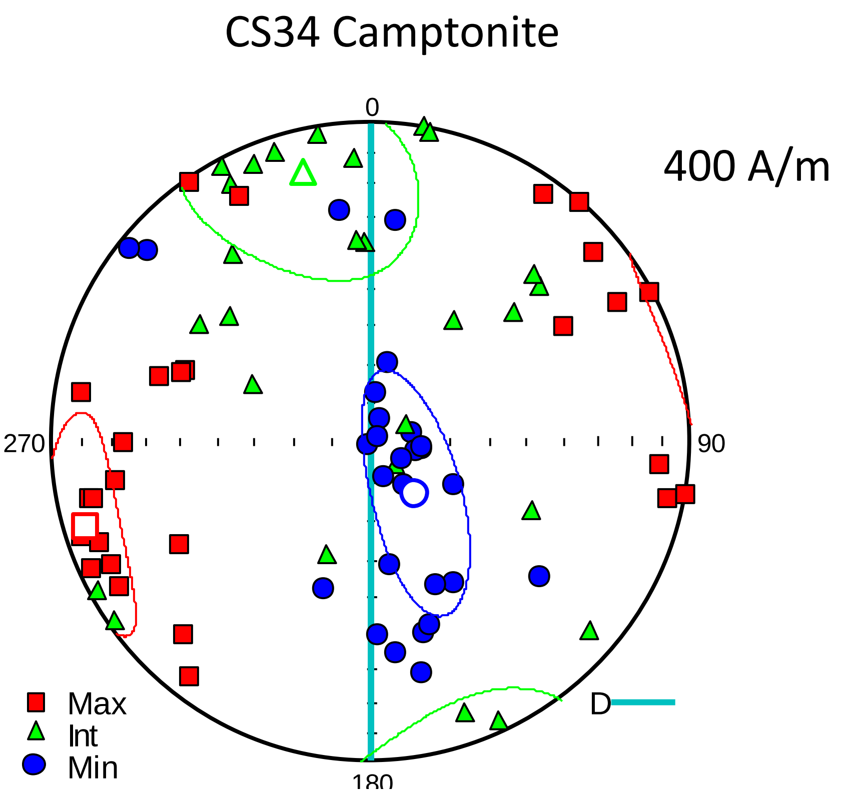

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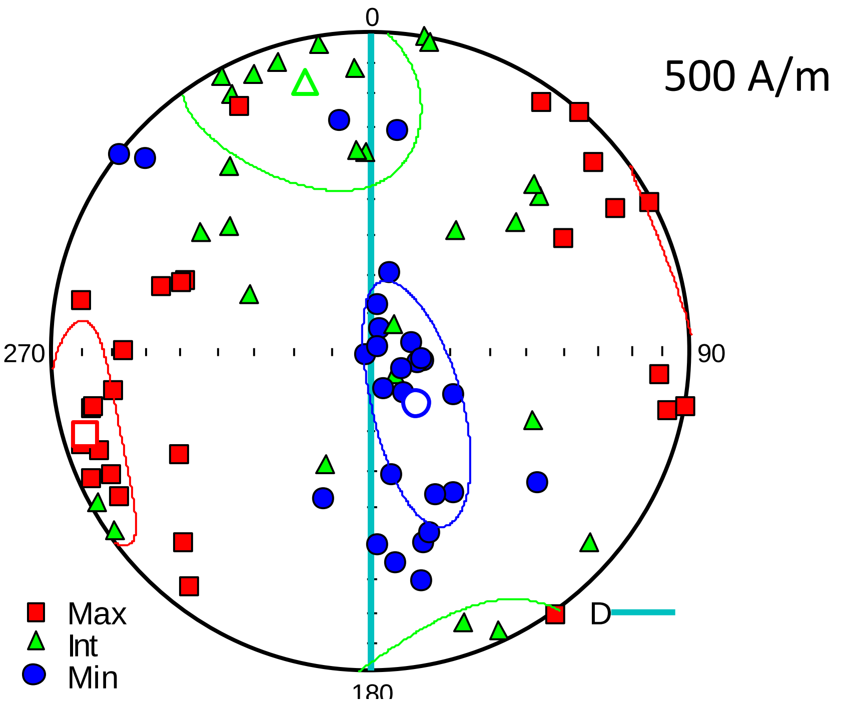

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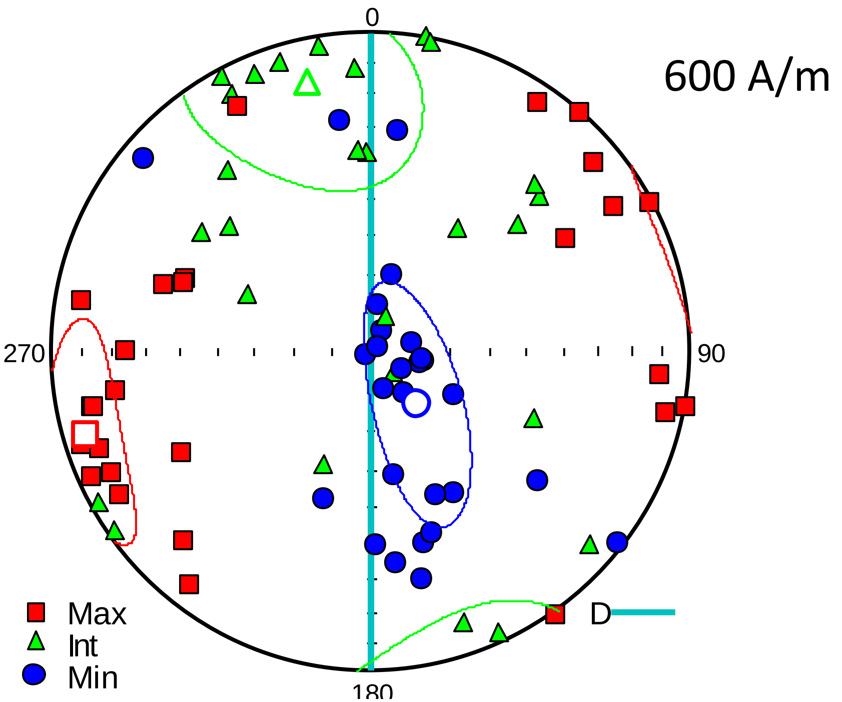

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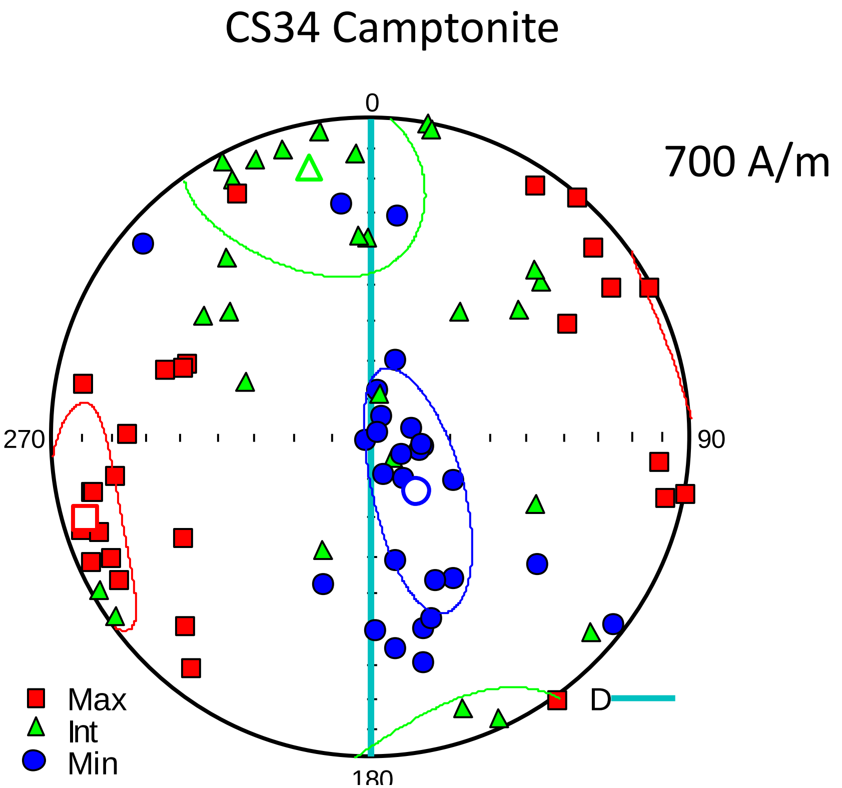
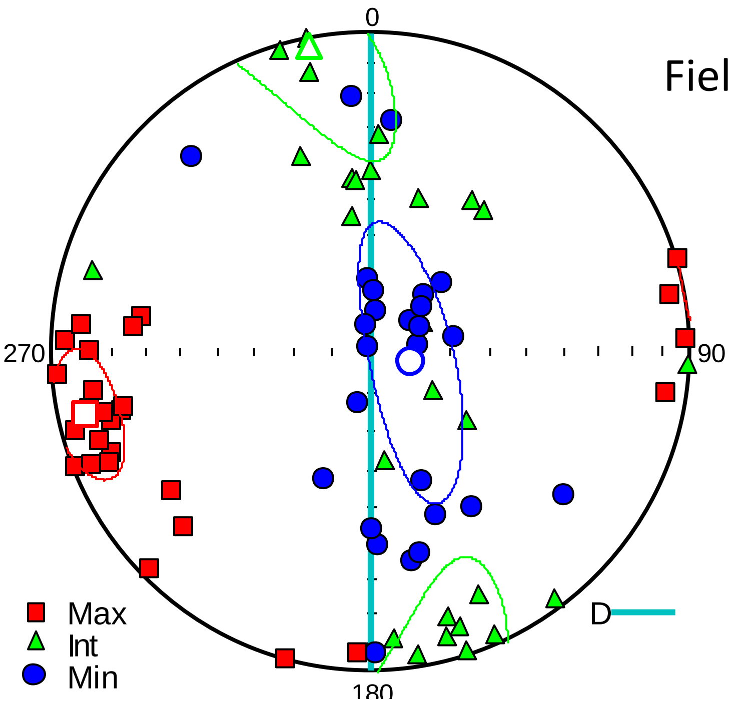


Field-dependent Tensor

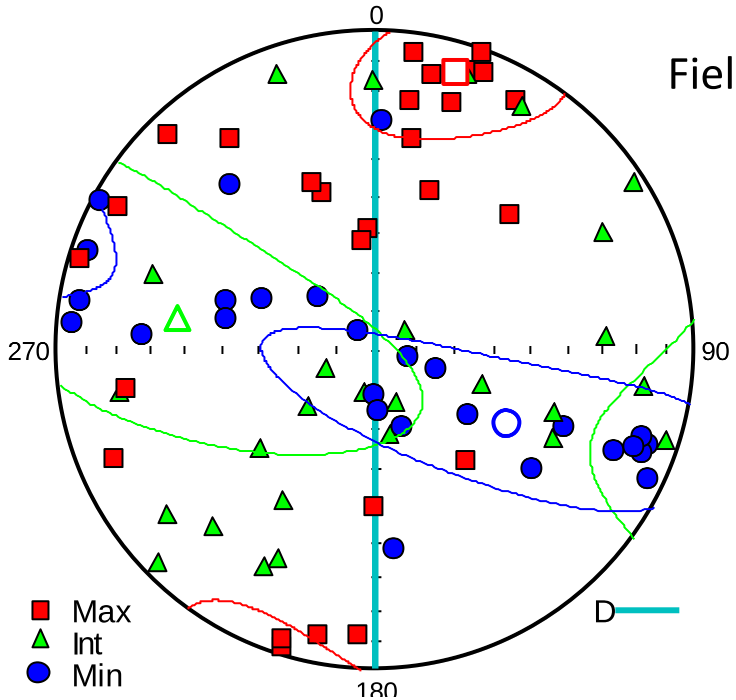
CS34 Camptonite



Field-dependent tensor

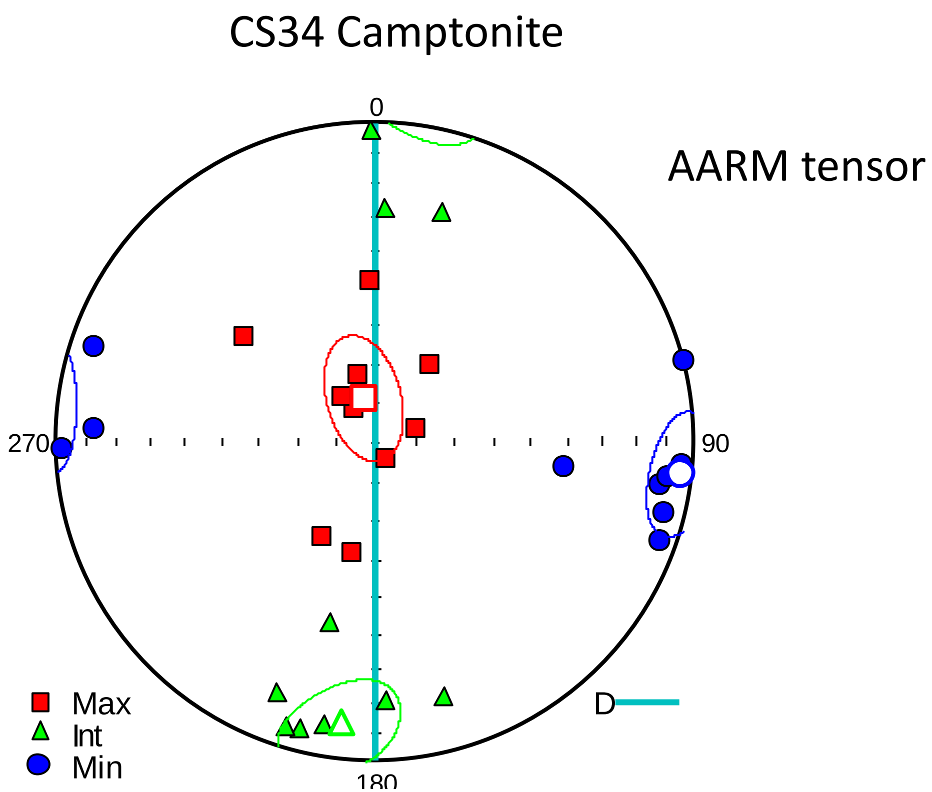
Field-independent Tensor

CS34 Camptonite

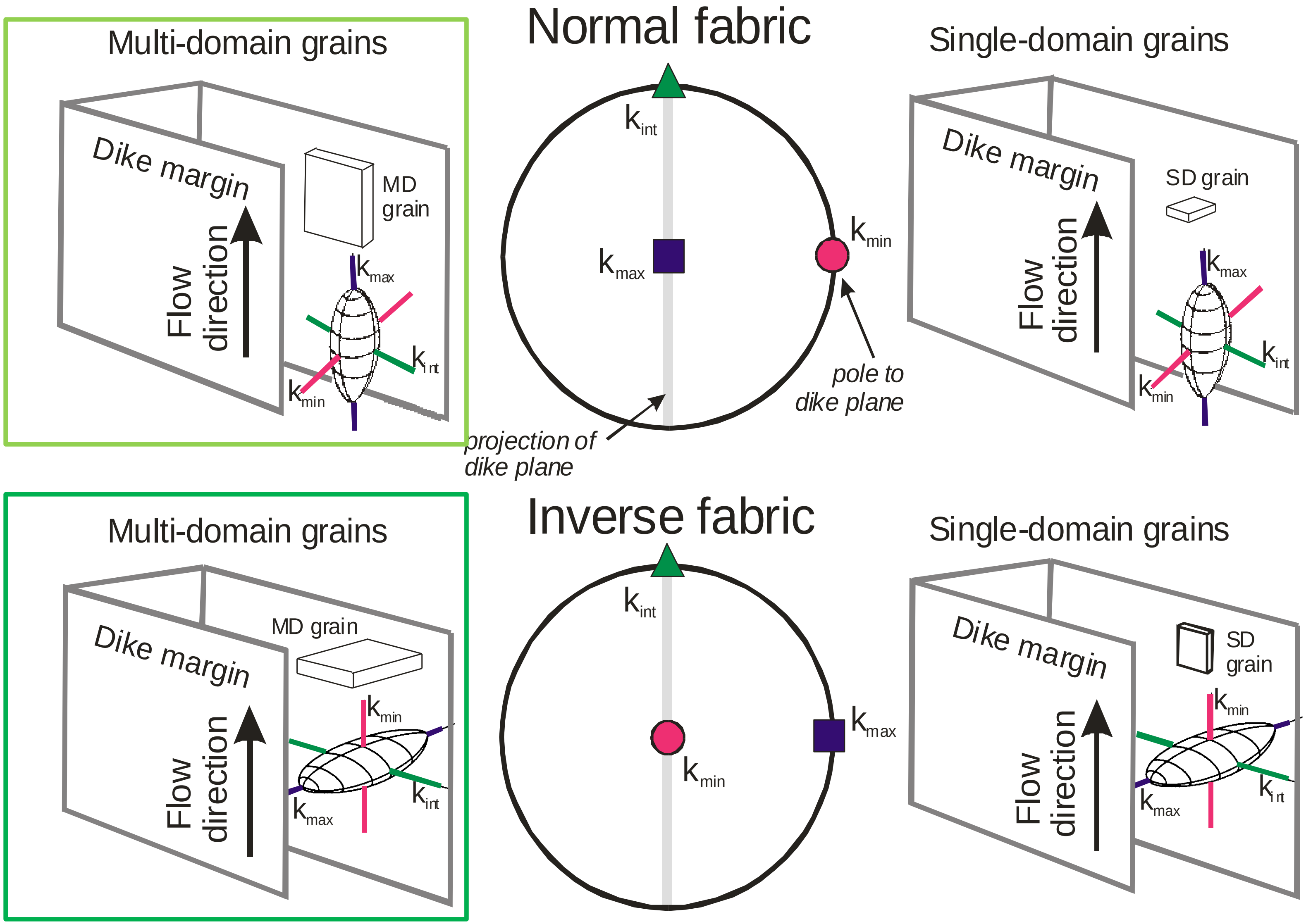


Field-independent tensor

Anisotropy of Anhysteretic Remanence



Tentative Conclusion



Conclusions

- ✓ The volcanic dikes investigated show significant increase of the mean susceptibility and degree of AMS with increasing low-field.
- ✓ In most dikes, the orientations of the principal directions are field independent. The contours of the directional susceptibilities have the shapes similar to those of an ellipsoid and do not change with low-field; they only increase their intensities. This holds not only for the Rayleigh Law Region, but also for the fields slightly stronger up to 700 A/m.
- ✓ In locality CS34, the principal directions vary with the low-field significantly and the contours change their shapes and intensities accordingly. This rock shows three magnetic phases. In very low fields the AMS is affected by all three phases. In moderate fields, increasing effect of the phase with Tc = 155 °C can be observed. In strong low-fields the AMS is dominantly controlled by the same phase, which shows the strongest low-field variation.
- ✓ For the dikes with field invariable PD, the geological interpretation in terms of magnetic foliation and lineation and lava flow is straightforward.
- ✓ It is recommended to investigate the low-field variation on pilot specimens.

¡Gracias por su paciencia!

Obrigado pela sua paciência!

Thanks for your patience!

Děkujeme za Vaši trpělivost!

Kiitos kärsivällisyydestäsi!

მადლობას გიხდით მოთმინებისთვის!

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