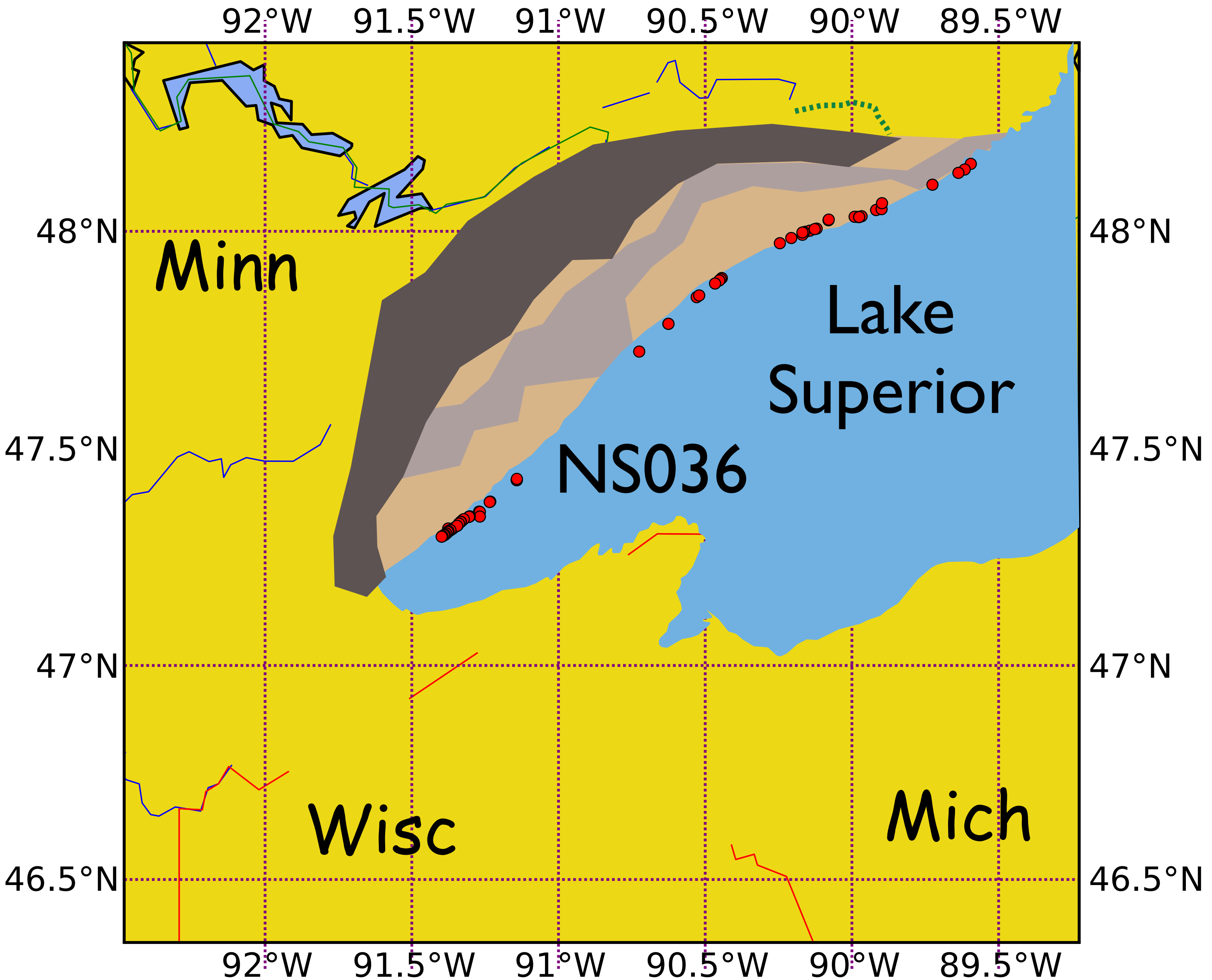
Lecture 9

- Review of location, site, sample, specimen terminology
- Measuring of specimens
- Coordinate systems
- Demagnetization
- Data plotting and analysis of best-fit directions
- Field strategies

Terminology

- Location: study area, stratigraphic section, etc.
- Site: Unit that is homogeneous with respect to the property of interest. A cooling unit or stratigraphic layer
- Sample: A piece that is taken, usually oriented from a site.
- Specimen: A piece that is measured

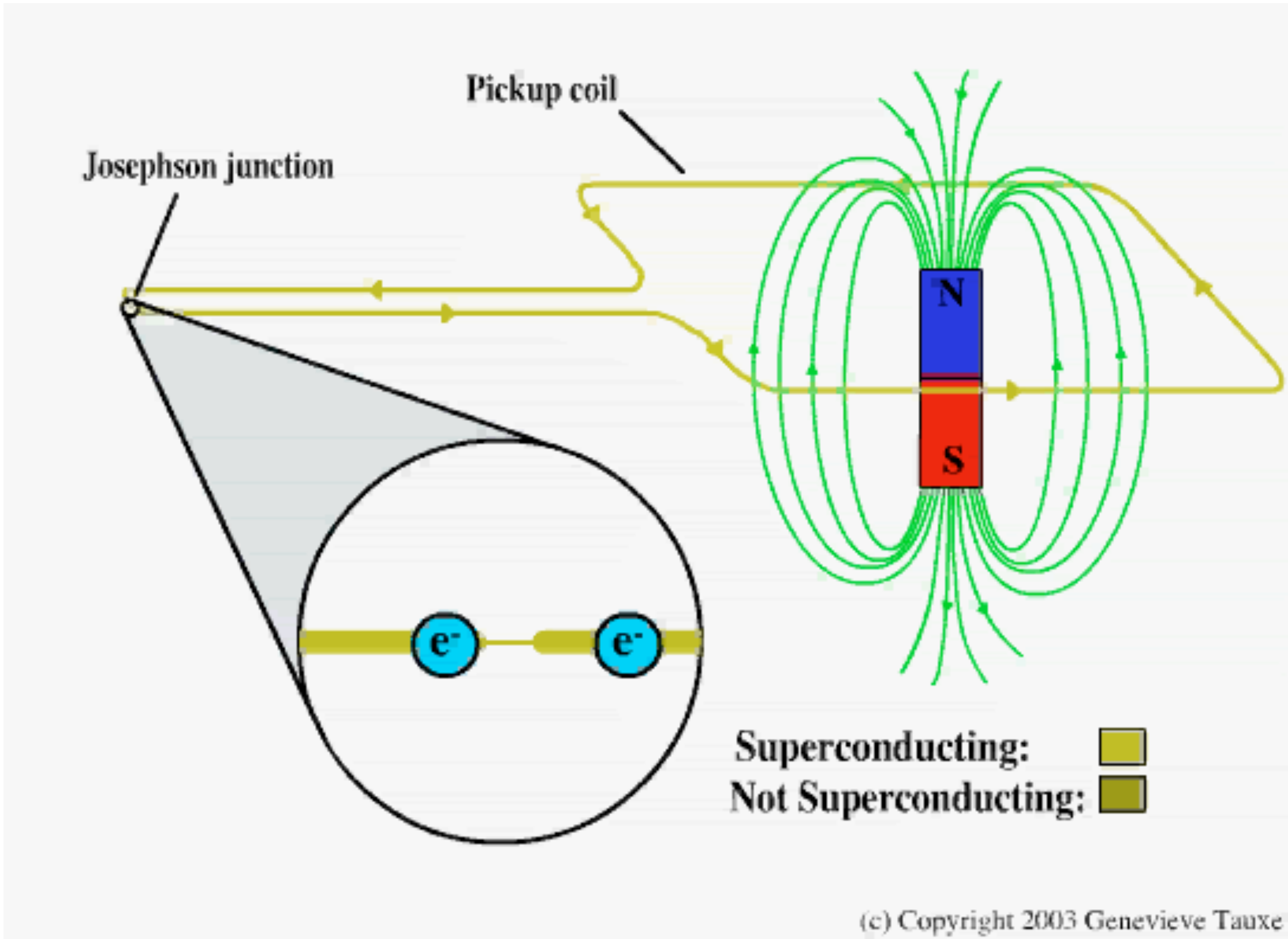
Location: North Shore Volcanic Province



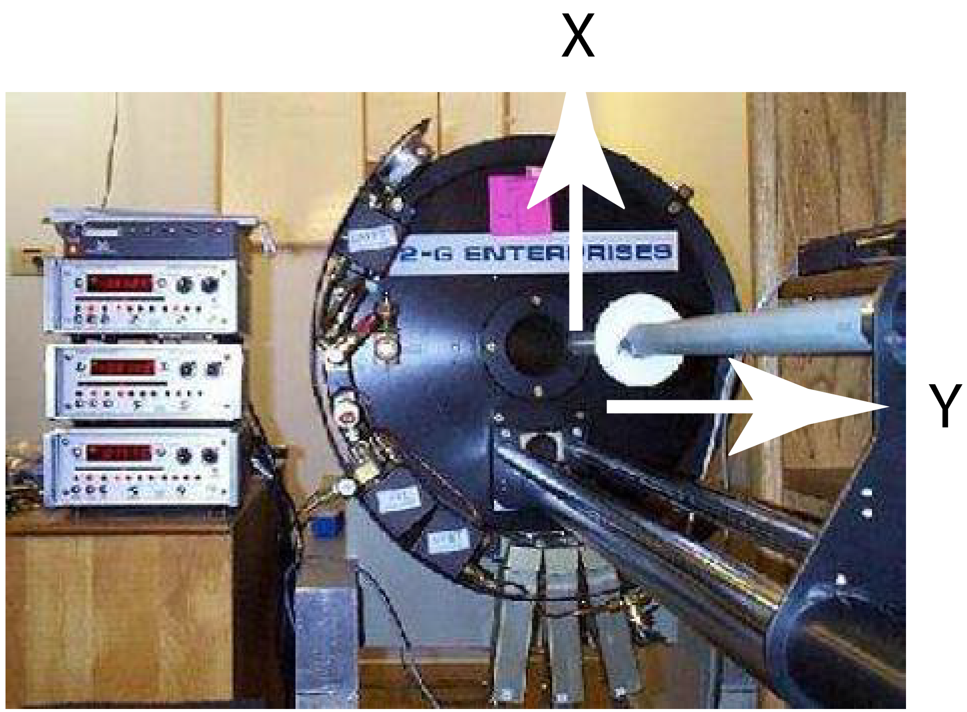
Measurement

- Astatic magnetometers
- Spinner magnetometers
- Cryogenic magnetometers
- Scanning SQUIDs

Cryogenic magnetometers use "SQUIDs"



Instrument software coordinates

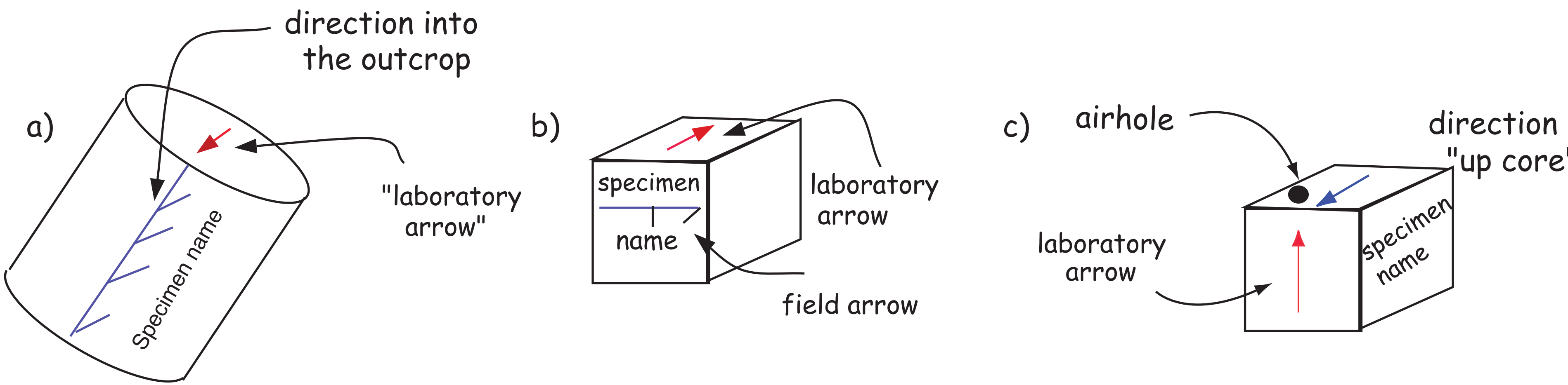


Z is positive into the magnetometer

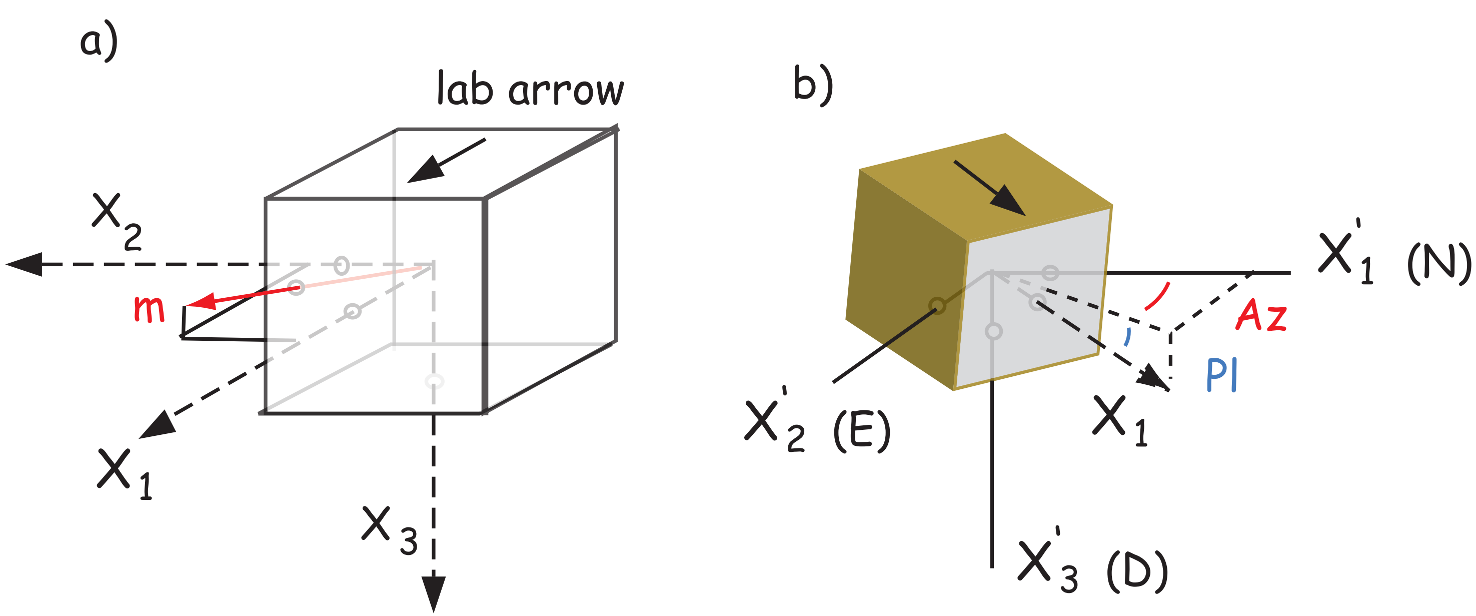
Changing coordinate systems

- Field => Lab (sample to specimen)
- Lab => Geographic (N, E, V in situ)
- Geographic => tilt corrected
- Present geographic => reconstruction for plate drift (e.g. fixed reference frame) [will cover in future lecture]

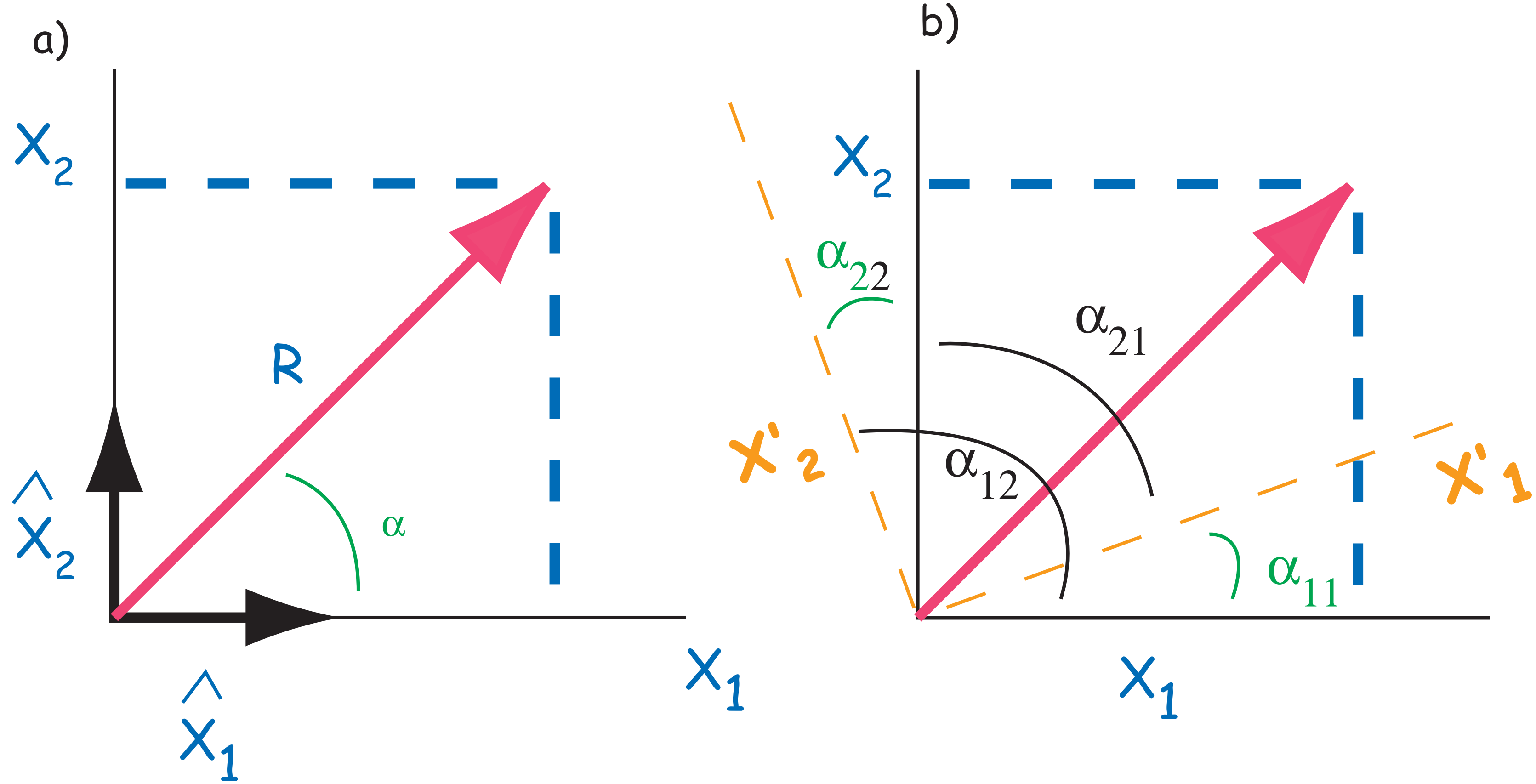
Coordinate systems: Sample=>specimen



Lab=>geographic=>correcting for tilt



Changing coordinate systems



Appendix A.3: Direction cosines

$$a_{11} = \cos\alpha_{11}, a_{21} = \cos\alpha_{21}$$

$$x_1' = a_{11}x_1 + a_{12}x_2$$

In 3D we have:

$$x'_1 = a_{11}x_1 + a_{12}x_2 + a_{13}x_3,$$
$$x'_2 = a_{21}x_1 + a_{22}x_2 + a_{23}x_3,$$
$$x'_3 = a_{31}x_1 + a_{32}x_2 + a_{33}x_3$$

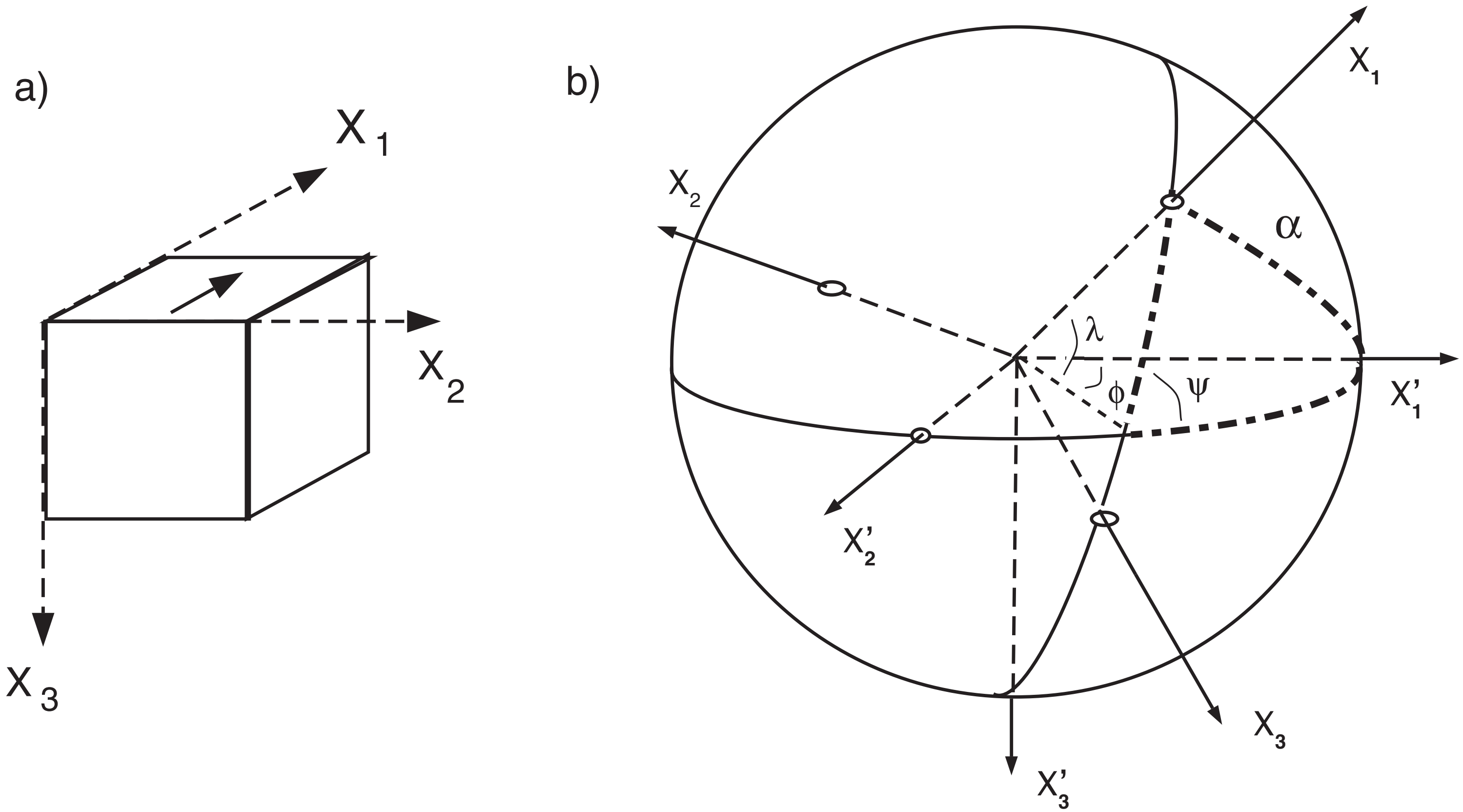
Which is the same as:

$$\begin{pmatrix} x'_1 \\ x'_2 \\ x'_3 \end{pmatrix} = \begin{pmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \\ x_3 \end{pmatrix}$$

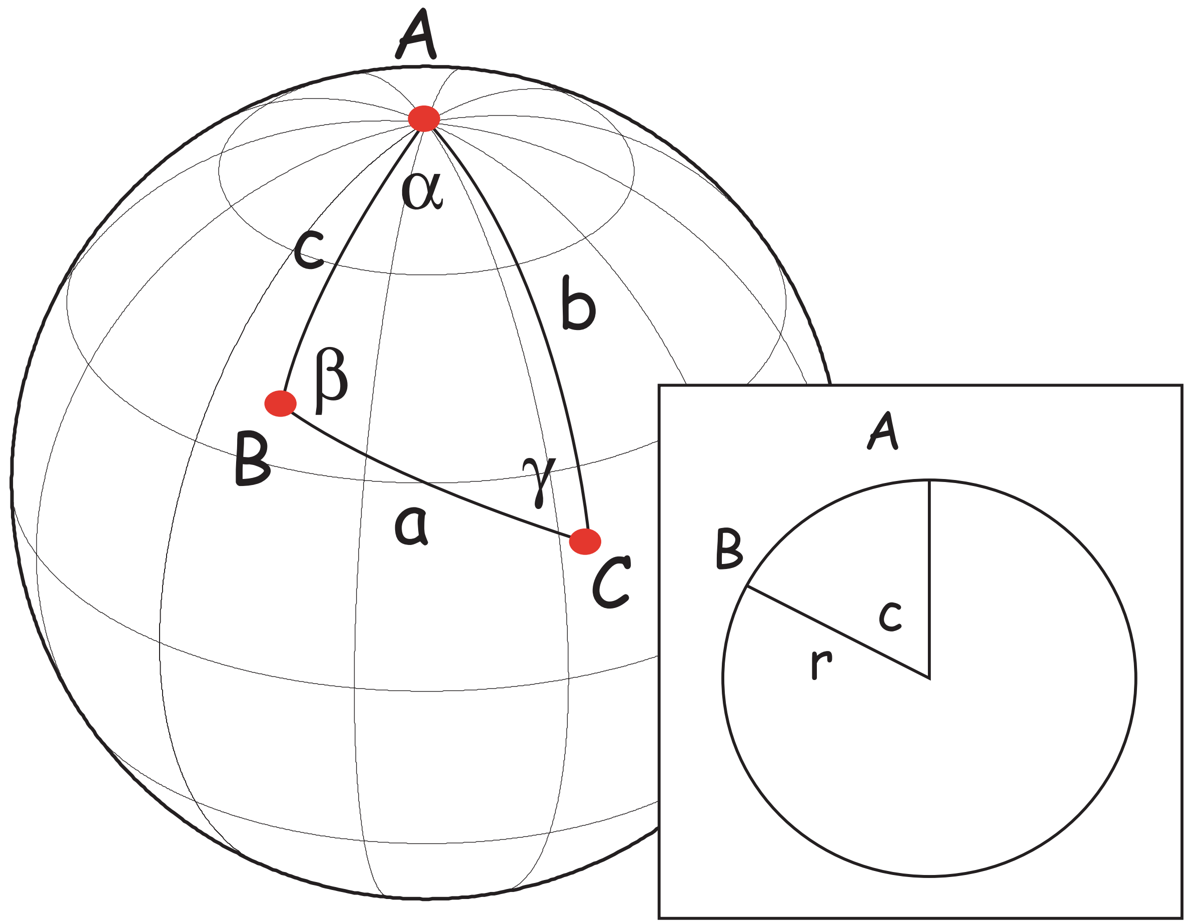
And this:

$$x'_i = a_{ij}x_j$$

So all we need are the direction cosines.

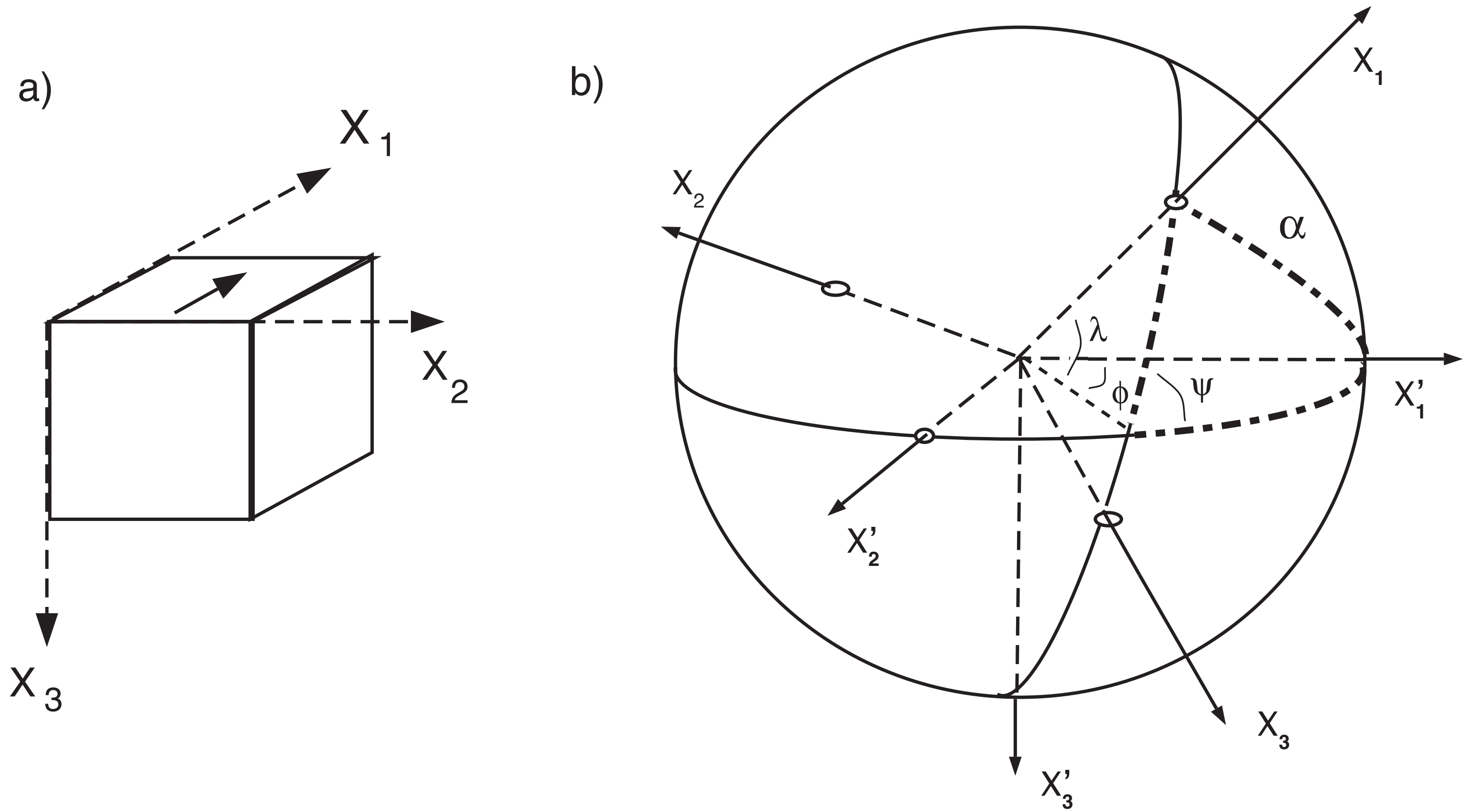


(YIKES!)

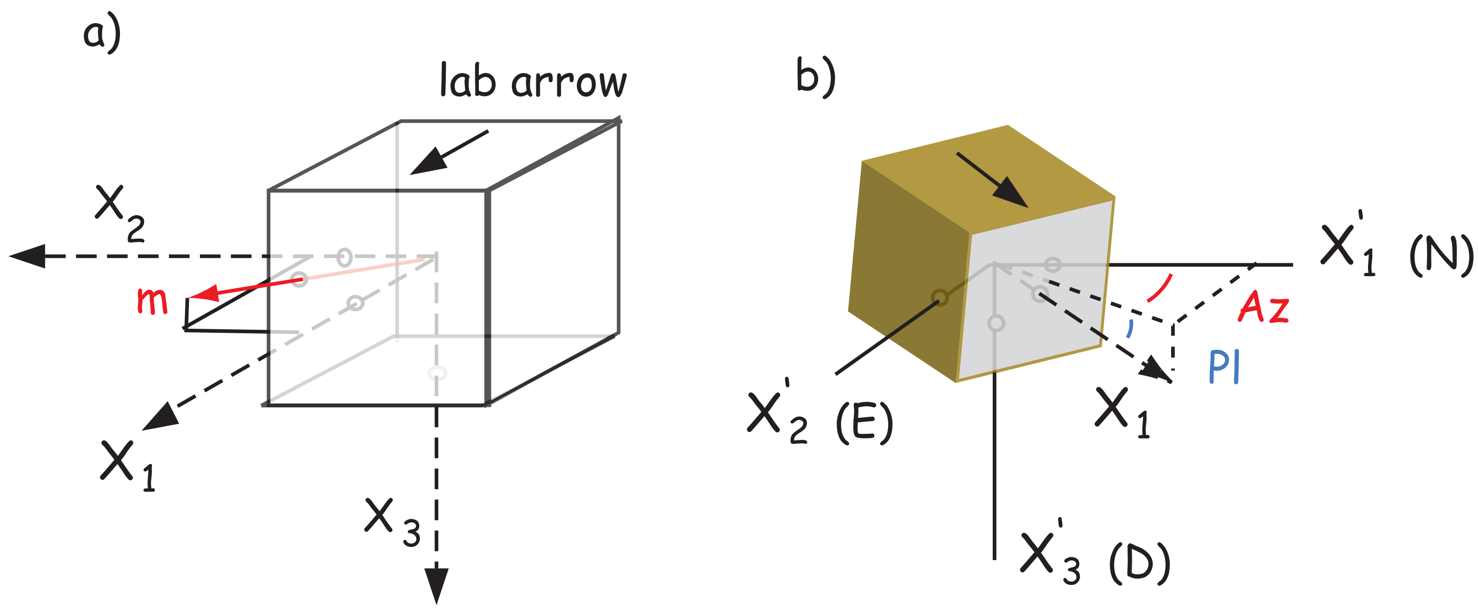


Law of sines: $$\frac{\sin\alpha}{\sin a} = \frac{\sin\beta}{\sin b} = \frac{\sin\gamma}{\sin c}$$

Law of cosines: $$\cos a = \cos b \cos c + \sin b \sin c \cos\alpha$$



$$a = \begin{pmatrix} \cos\lambda\cos\phi & -\sin\phi & -\sin\lambda\cos\phi \\ \cos\lambda\sin\phi & \cos\phi & -\sin\lambda\sin\phi \\ \sin\lambda & 0 & \cos\lambda \end{pmatrix}$$



$$a = \begin{pmatrix} \cos\lambda\cos\phi & -\sin\phi & -\sin\lambda\cos\phi \\ \cos\lambda\sin\phi & \cos\phi & -\sin\lambda\sin\phi \\ \sin\lambda & 0 & \cos\lambda \end{pmatrix}$$

$$\mathrm{Az} = \phi, \mathrm{Pl} = \lambda$$

Stick back into this: $x'_i = a_{ij}x_j$

One more thing:

convert the X' components back into Dec, Inc, Int
(see Chapter 2)

and Bob's your uncle

Same kind of procedure for correcting for bedding tilt
(see Chapter 9)

One more Rm Rm

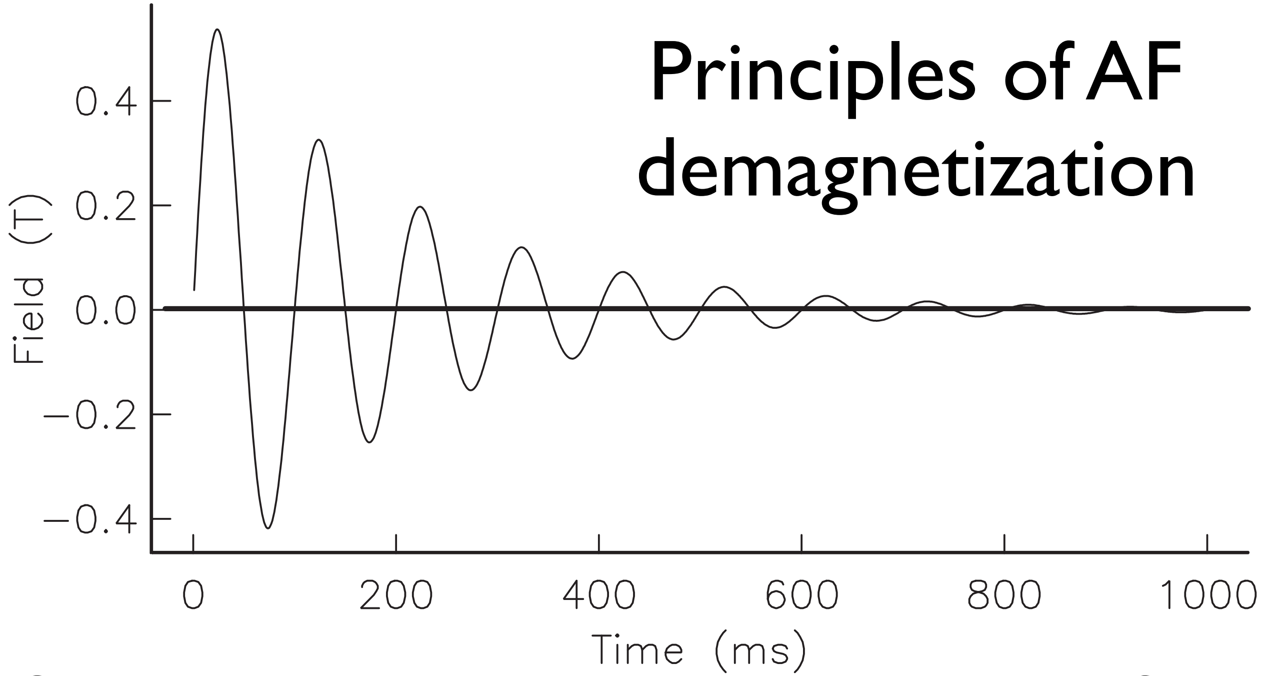
- Natural Remanent Magnetization (NRM)
- What you measure "out of the ground"
- Is composed of one or more components acquired by the mechanisms discussed in the last lecture (e.g., TRM + VRM)
- We must pick apart the NRM to identify the different components
- This is done by step-wise "demagnetization"

Demagnetizing

- Alternating field (AF)
- Thermal
- Low temperature (LTD)
- Microwave (yes like the oven)
- Chemical (dissolve secondary minerals)
- Selective destructive (physically remove parts of specimen)

I'm not going to talk about the yellow ones today.

Principles of AF demagnetization



- Subject specimen to alternating field in zero bias field
- Ramp peak field down
- As each grain reaches its flipping field, it gets “stuck” in that direction
- Randomizes all grains with flipping fields < peak field

Some tips

- MUST do in all three axes (X, Y, Z)
- Some specimens acquire an ARM parallel to last axis - for this must do each axis 2 x in opposite directions and average measurements
- Some specimens acquire GRM perpendicular to last axis - for this must do three step protocol outlined in Section 9.5 in book
- Avoid exposure to magnetic fields after you demagnetize

Principles of thermal demagnetization

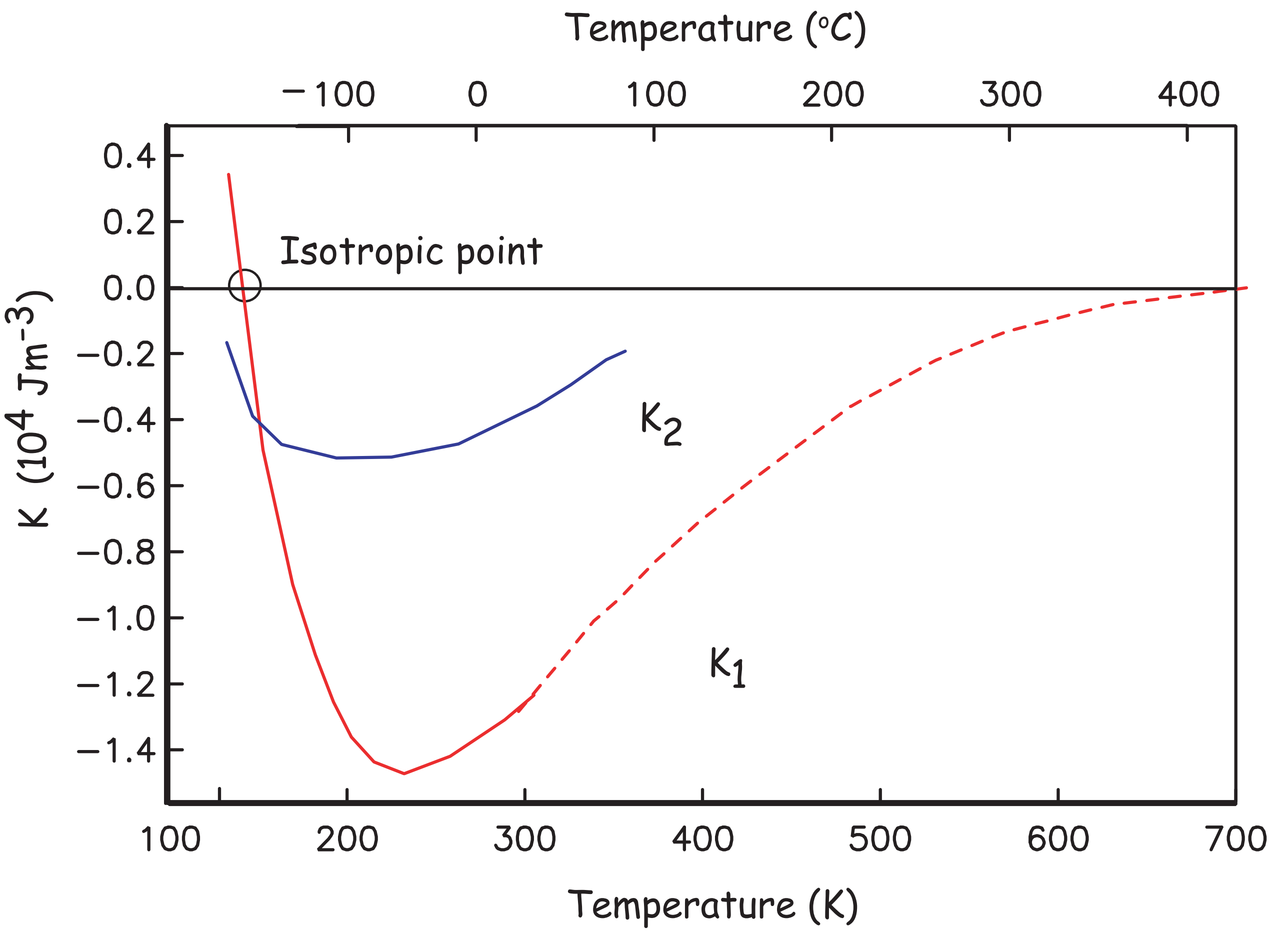
- Insert in oven with zero applied magnetic field
- Raise temperature to some set point
- Allow specimens to reach temperature (~30 min). All grains with Tb < set point will relax to zero bias field and become random.
- Cool back to room T and measure

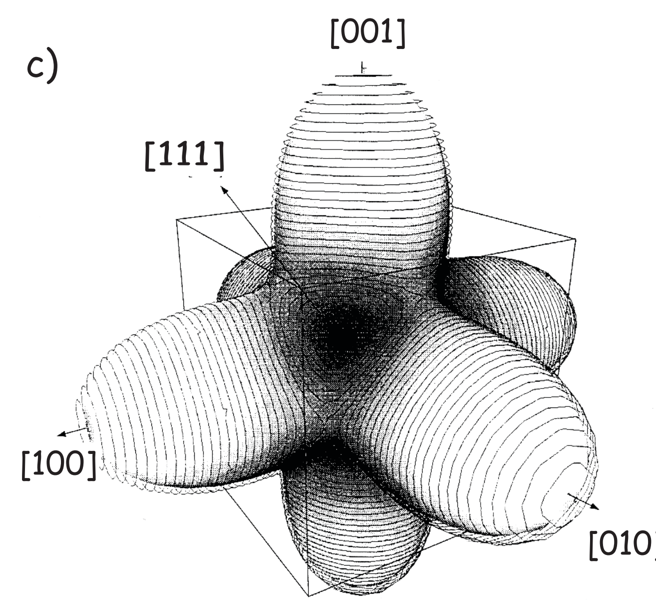
Some tips

- Always check the field in the oven before you start
- Do each step with specimens in the identical positions (helps reproducibility of temperatures)
- Put a non-magnetic spacer between strongly magnetized specimens to avoid interference
- Avoid exposure to magnetic fields after you demagnetize

Principles of LTD

$$\epsilon_a = K_1(\alpha_1^2\alpha_2^2 + \alpha_2^2\alpha_3^2 + \alpha_3^2\alpha_1^2) + K_2\alpha_1^2\alpha_2^2\alpha_3^2,$$





- Remember magneto crystalline anisotropy?

- When K1 changes sign, the easy axis in magnetite switches from the body diagonal to the face centered axis and the magnetization is lost
- It is thought that large particles (with domain walls) are dominated by magneto crystalline anisotropy
- so… when you dunk the sample in liquid nitrogen in zero field, you demagnetize the MD grains.

Some tips

- Don’t burn yourself

Principles of microwave demagnetization

- Microwave ovens can be tuned to supply energy instead of at the resonant frequency of water to the resonant frequency of magnetite
- Applying microwave energy will heat up the magnetic particles, supplying thermal energy without heating up the entire sample
- this is thought to demagnetize particles without chemically altering the samples

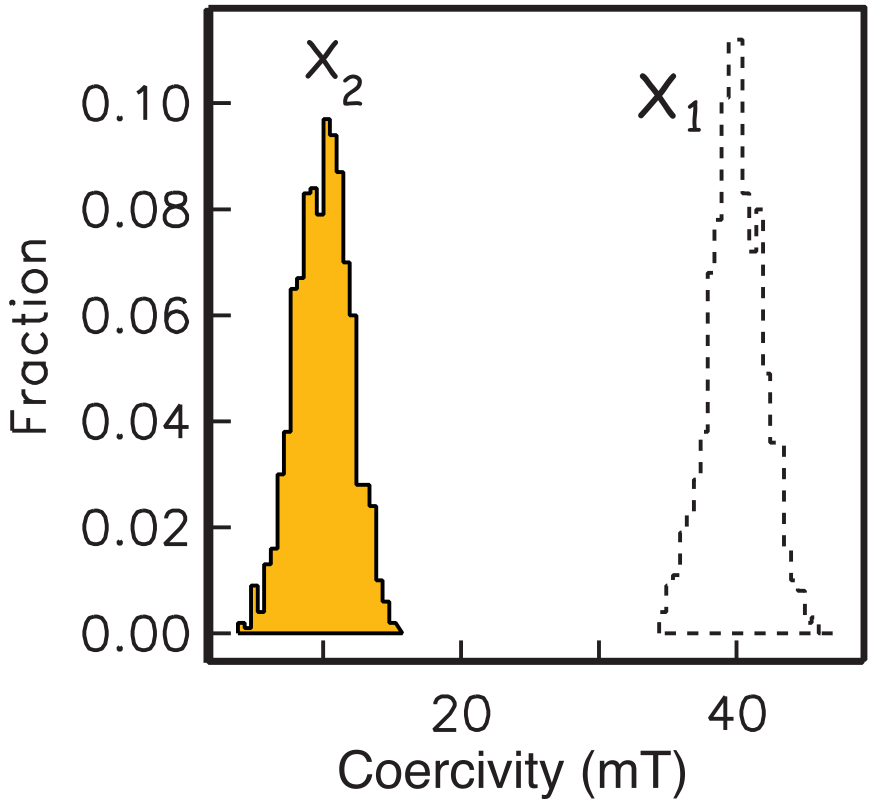
Some tips

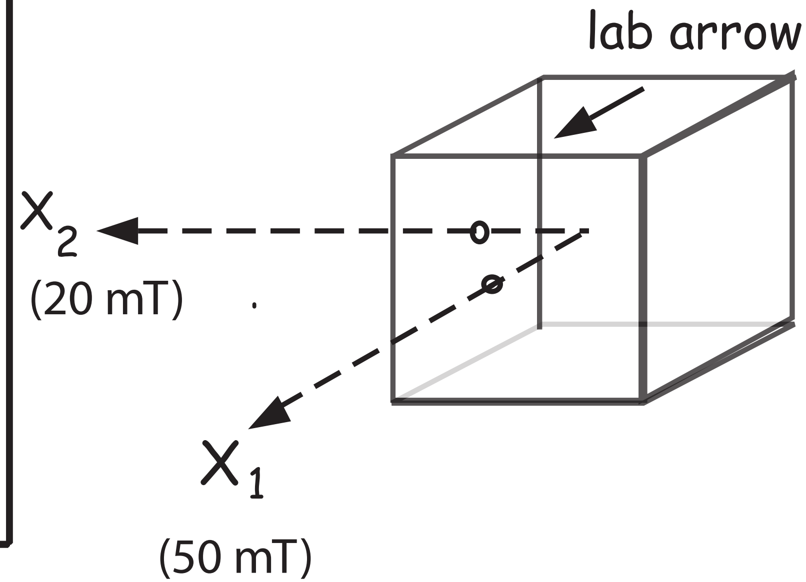
- Only a few labs in the world can do this
- The three times I've tried it the sample MELTED
- It is analogous to thermal demagnetization, but NOT the same thing exactly.
- It is difficult to translate the microwave power to temperature and to reproduce the temperature in repeated steps at the same temperature.

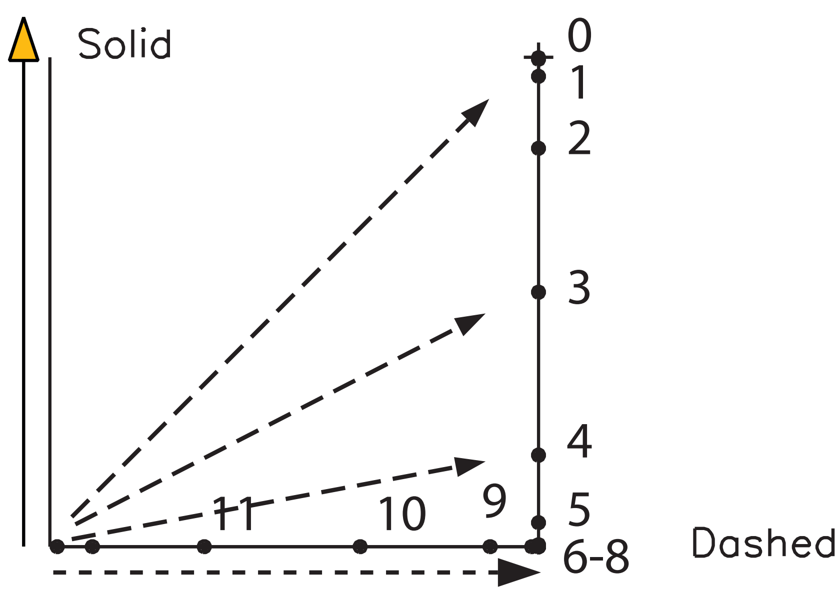
Data plotting

- Equal area projections of directions (see Chapter 2 and Appendix A)
- "Zijderveld" diagrams of demagnetization data
  - pronounciation
  - procedure
  - calculating best-fit lines and planes

Imagine a specimen with two coercivity fractions and two magnetizations

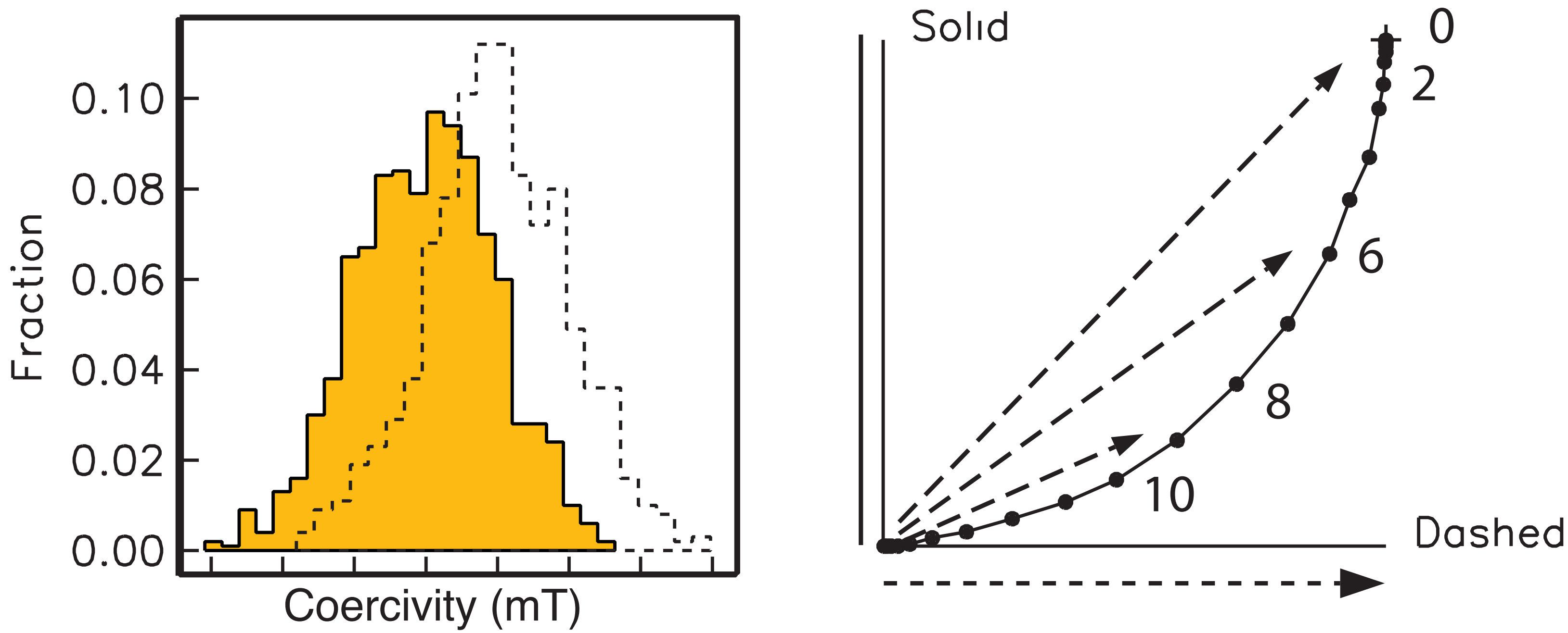




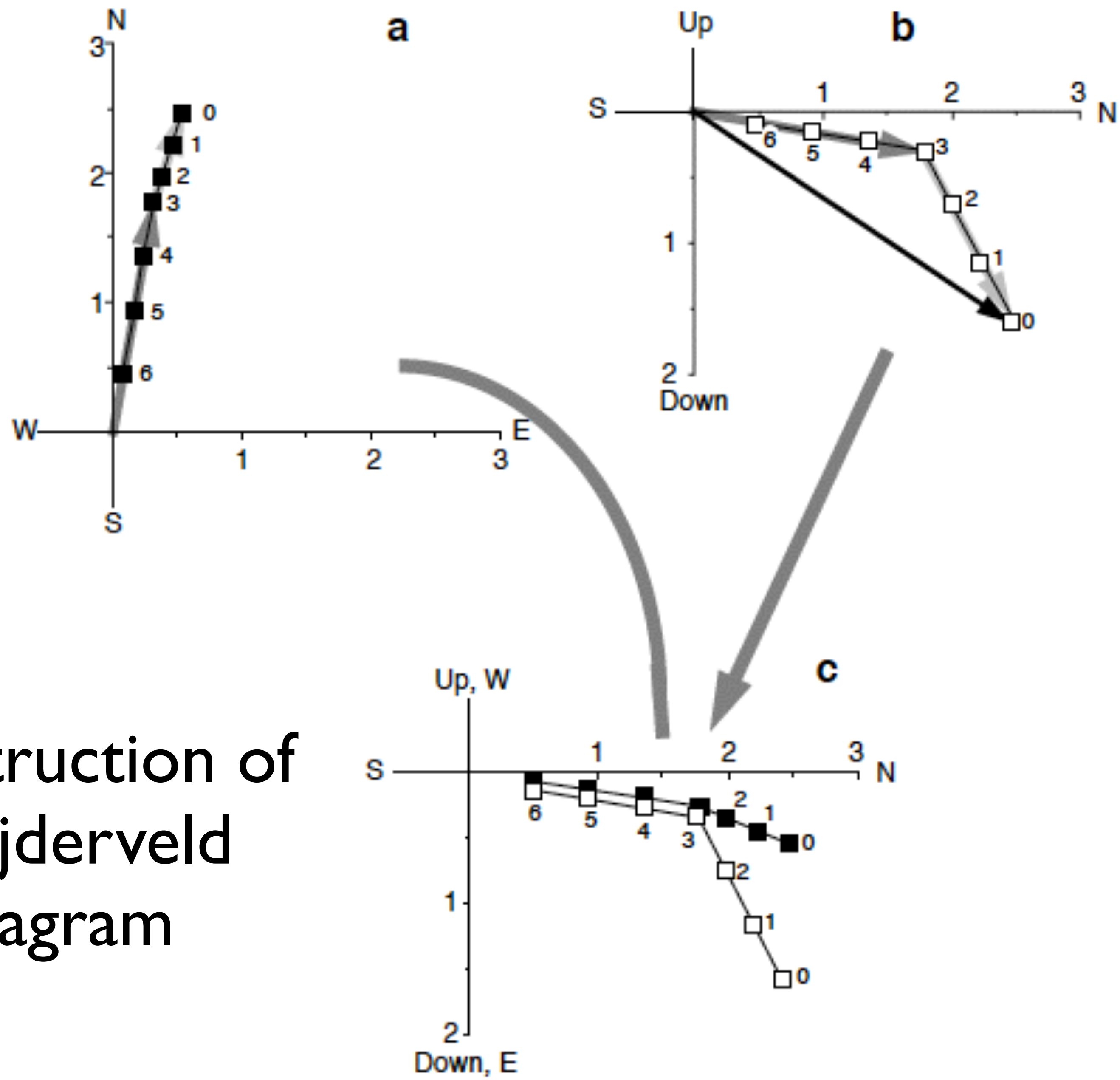


And we AF demagnetize it:
1st remove "soft" direction (0-6)
then remove "hard direction"(8-12)

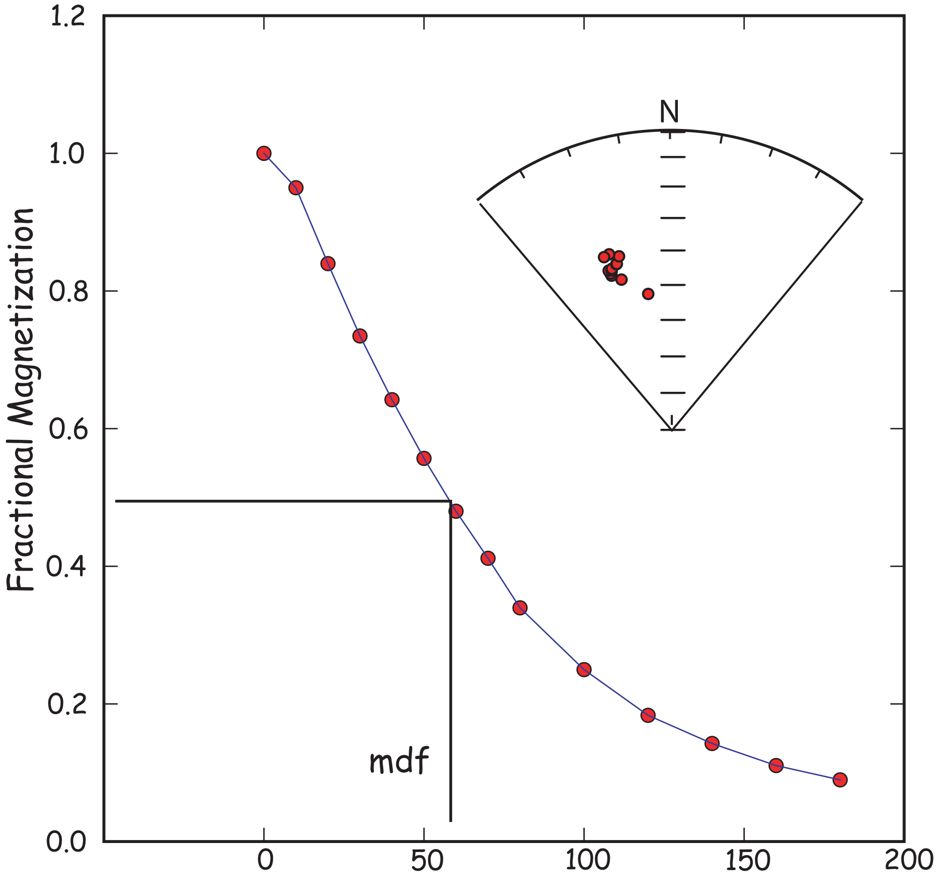
Case with overlapping coercivities

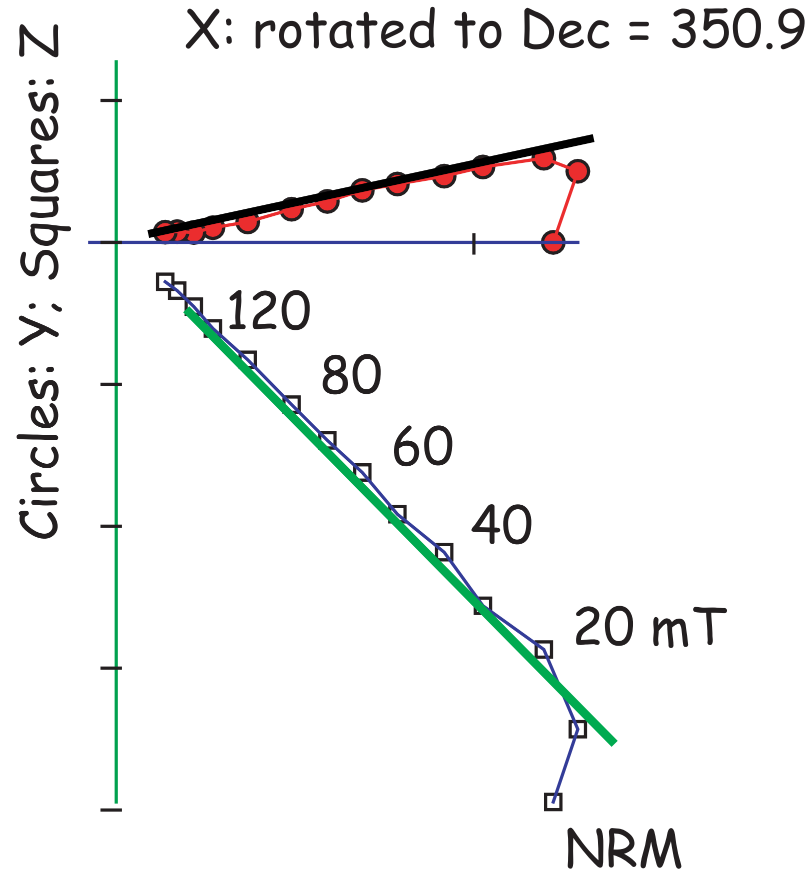


3D case (from Butler, 1992)



Construction of a Zijderveld diagram





best-fit directions

Direction decaying to the origin called "Characteristic Remanent Magnetization" (ChRM)

Steps to best-fit direction

- Convert D,I,M vector from each step to list of (N,E,D) components (Chapter 2)
- Calculate "center of mass" as average of each component (e.g., <x> from all selected points (Xi)
- Subtract the center of mass from all your points (e.g., x'=Xi-<x>)

Calculate "orientation tensor":

$$\mathbf{T} = \begin{pmatrix} \sum x'_{1i}x'_{1i} & \sum x'_{1i}x'_{2i} & \sum x'_{1i}x'_{3i} \\ \sum x'_{1i}x'_{2i} & \sum x'_{2i}x'_{2i} & \sum x'_{2i}x'_{3i} \\ \sum x'_{1i}x'_{3i} & \sum x'_{2i}x'_{3i} & \sum x'_{3i}x'_{3i} \end{pmatrix}$$

Find eigenvalues and eigenvectors (see Appendix A) $\mathbf{V_i}, \tau_i \qquad \tau_1 > \tau_2 > \tau_3$

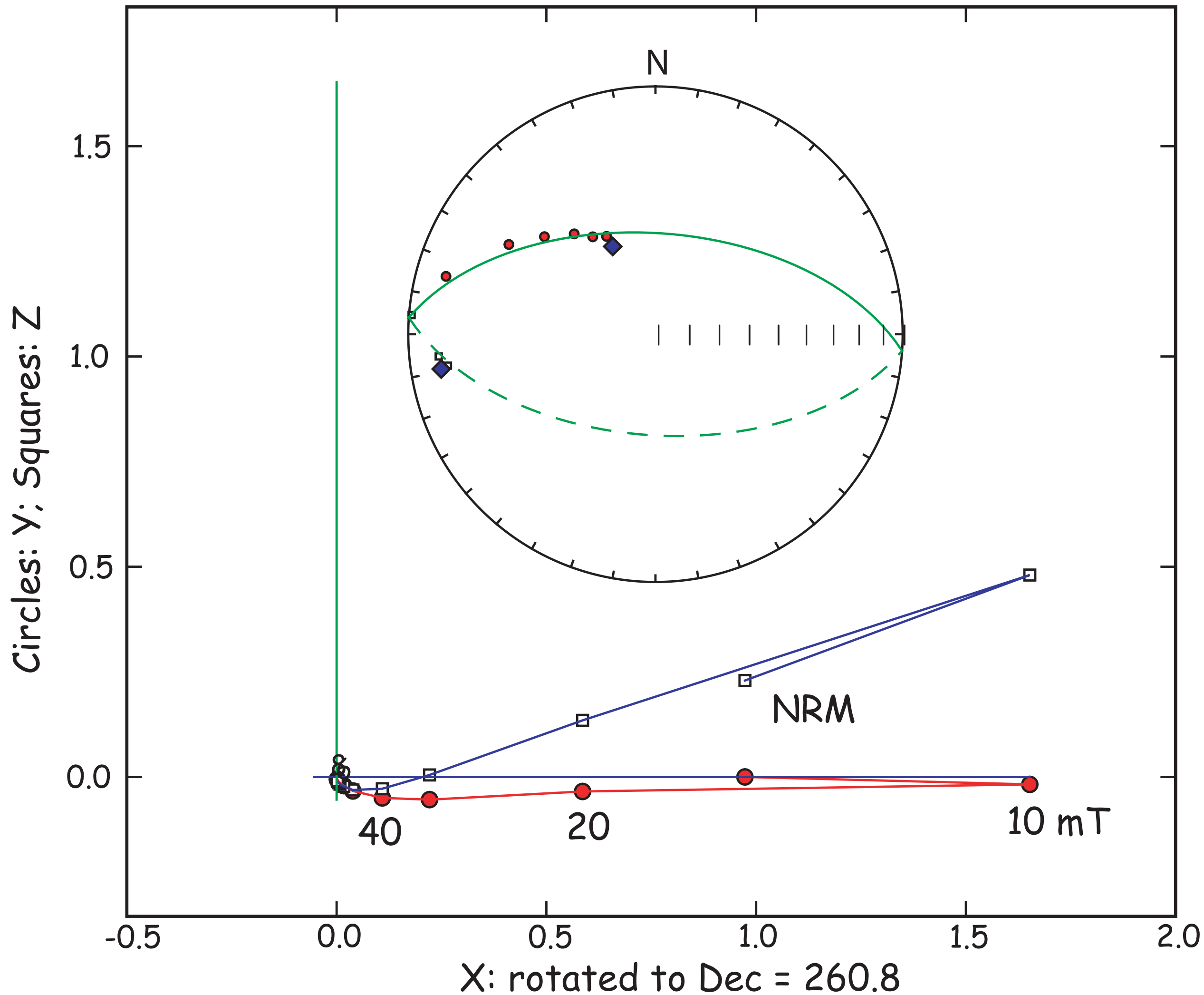
$\mathbf{V_1}$ Principal eigenvector: Axis along which scatter is MOST (= best-fit direction!)

Minor eigenvector: scatter is least

Eigenvalues: reflect scatter along the eigenvectors

Maximum angle of deviation: $\tan^{-1}(\sqrt{(\tau_2^2 + \tau_3^2)}/\tau_1)$.

But what about case with no single direction?



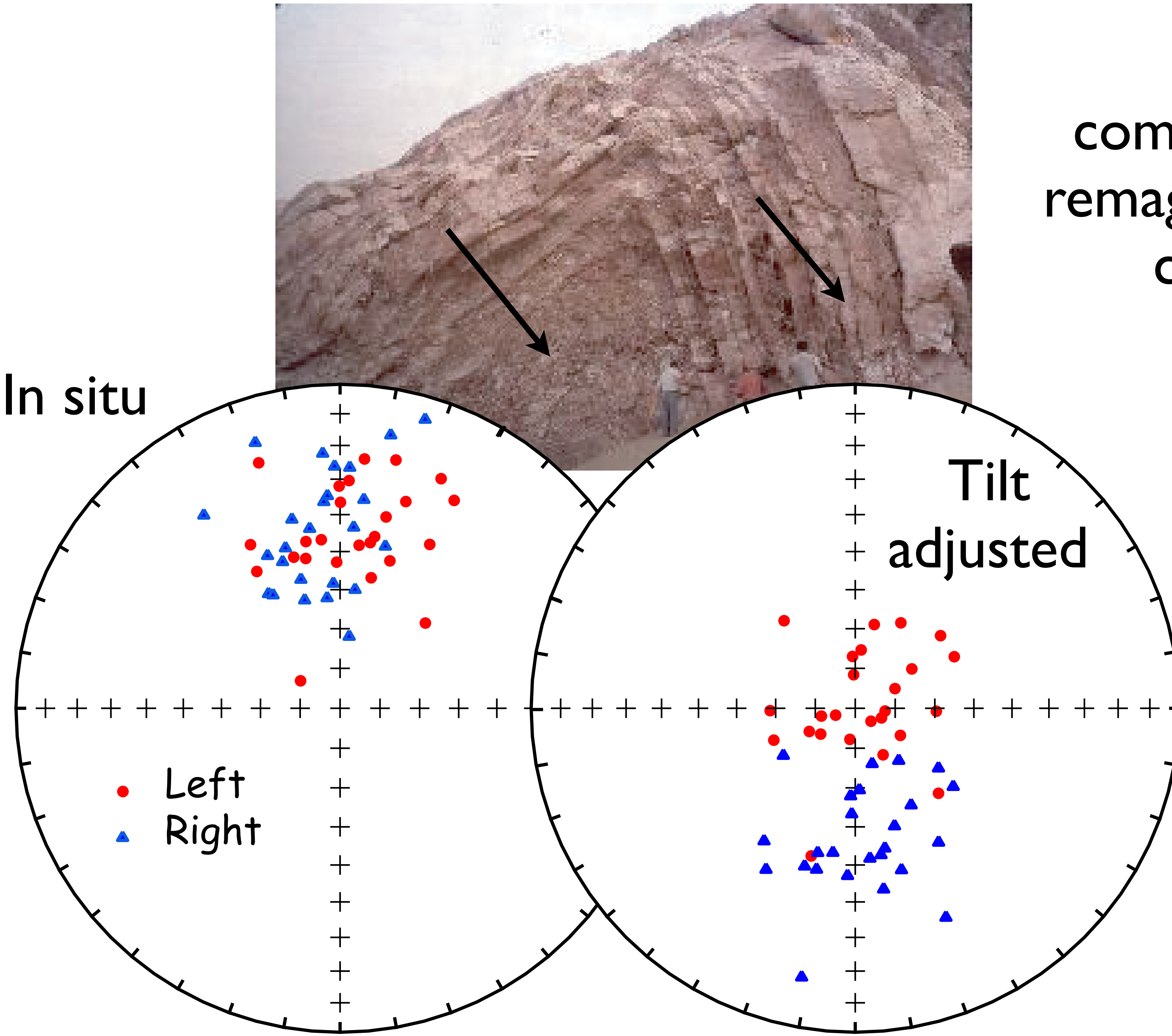
$\mathbf{V}_3$ Minor eigenvector: direction along which scatter is LEAST is pole to best-fit plane

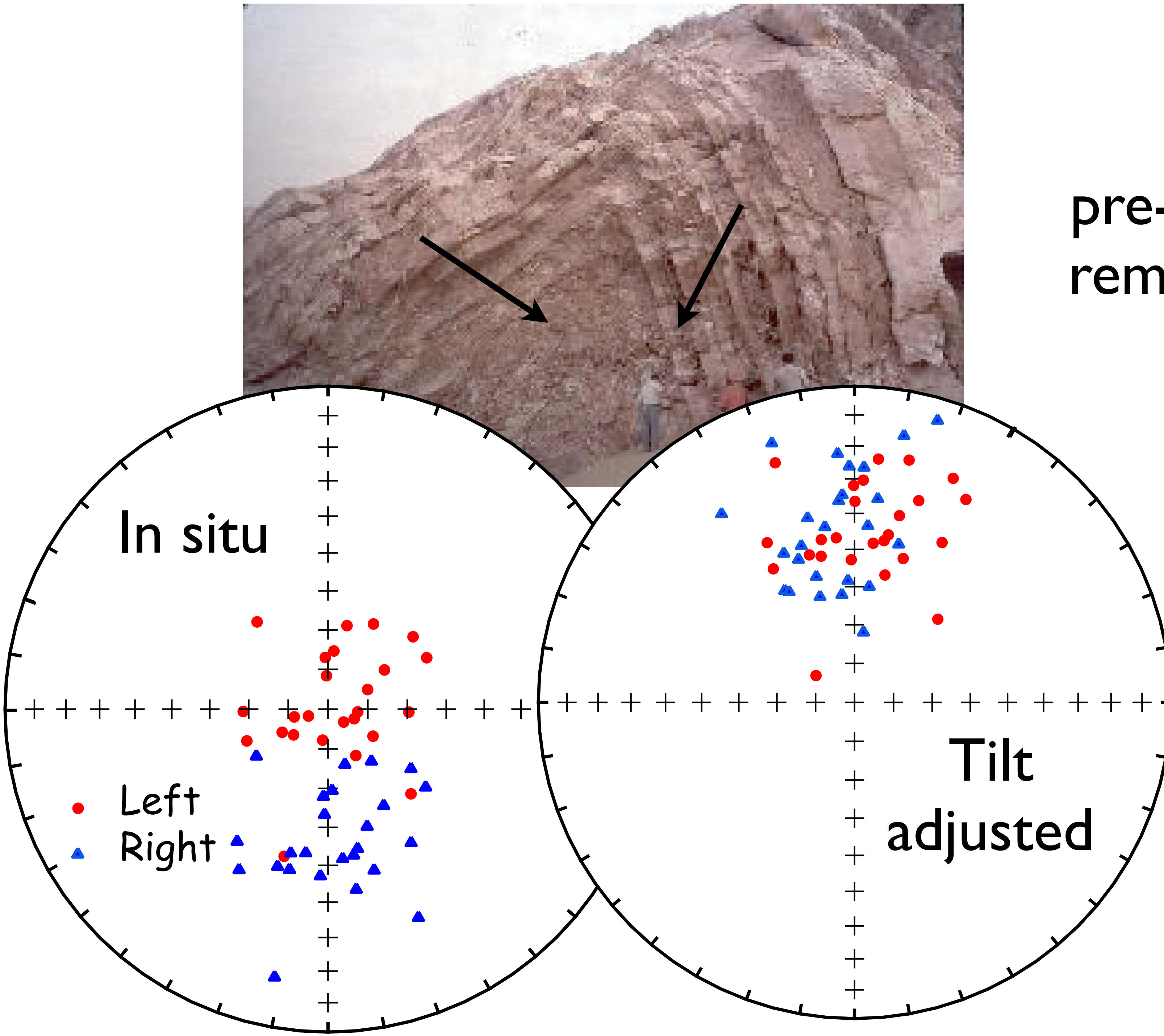
$$MAD_{\text{plane}} = \tan^{-1}\sqrt{\tau_3/\tau_2 + \tau_3/\tau_1}$$

Field strategies

- Goal is to constrain the age of magnetization
- Common test:
  - Fold test
  - Conglomerate test
  - Baked contact test

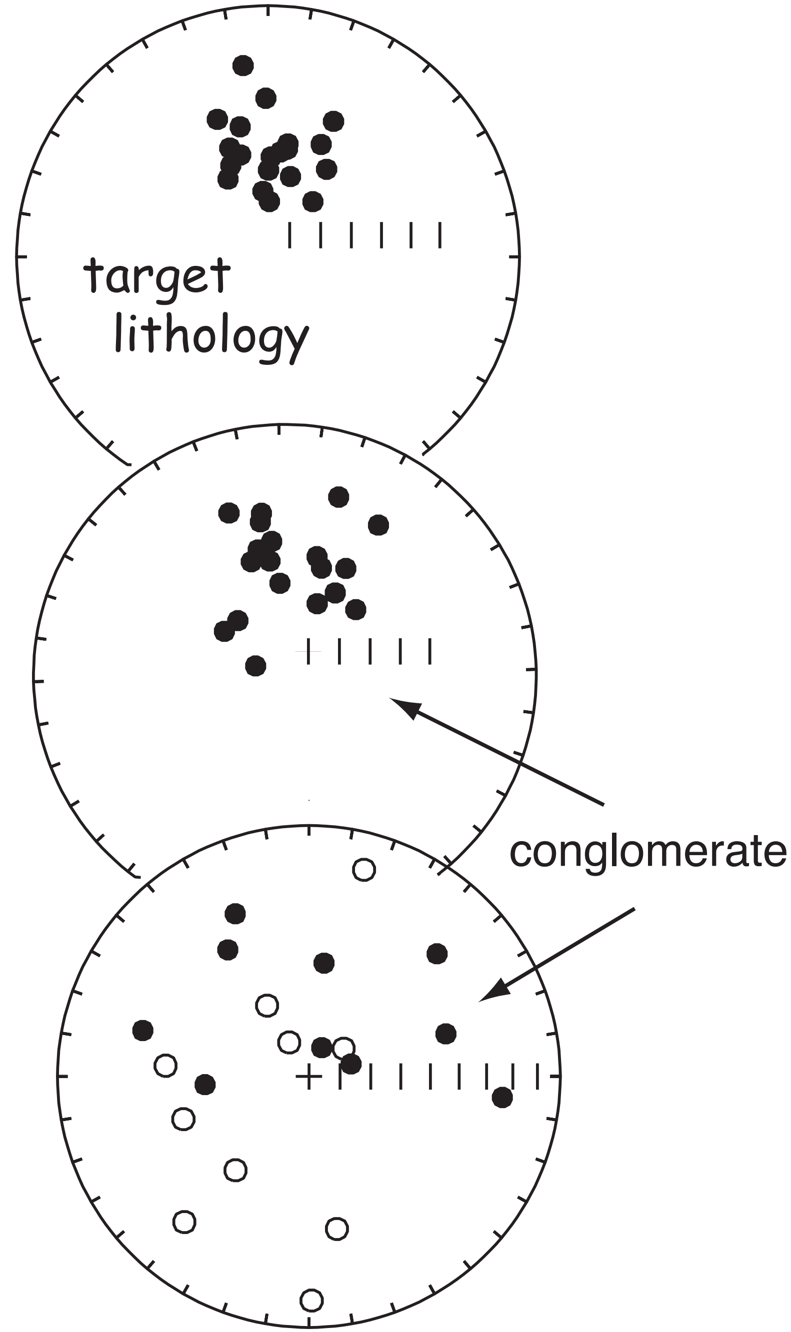
completely remagnetized case



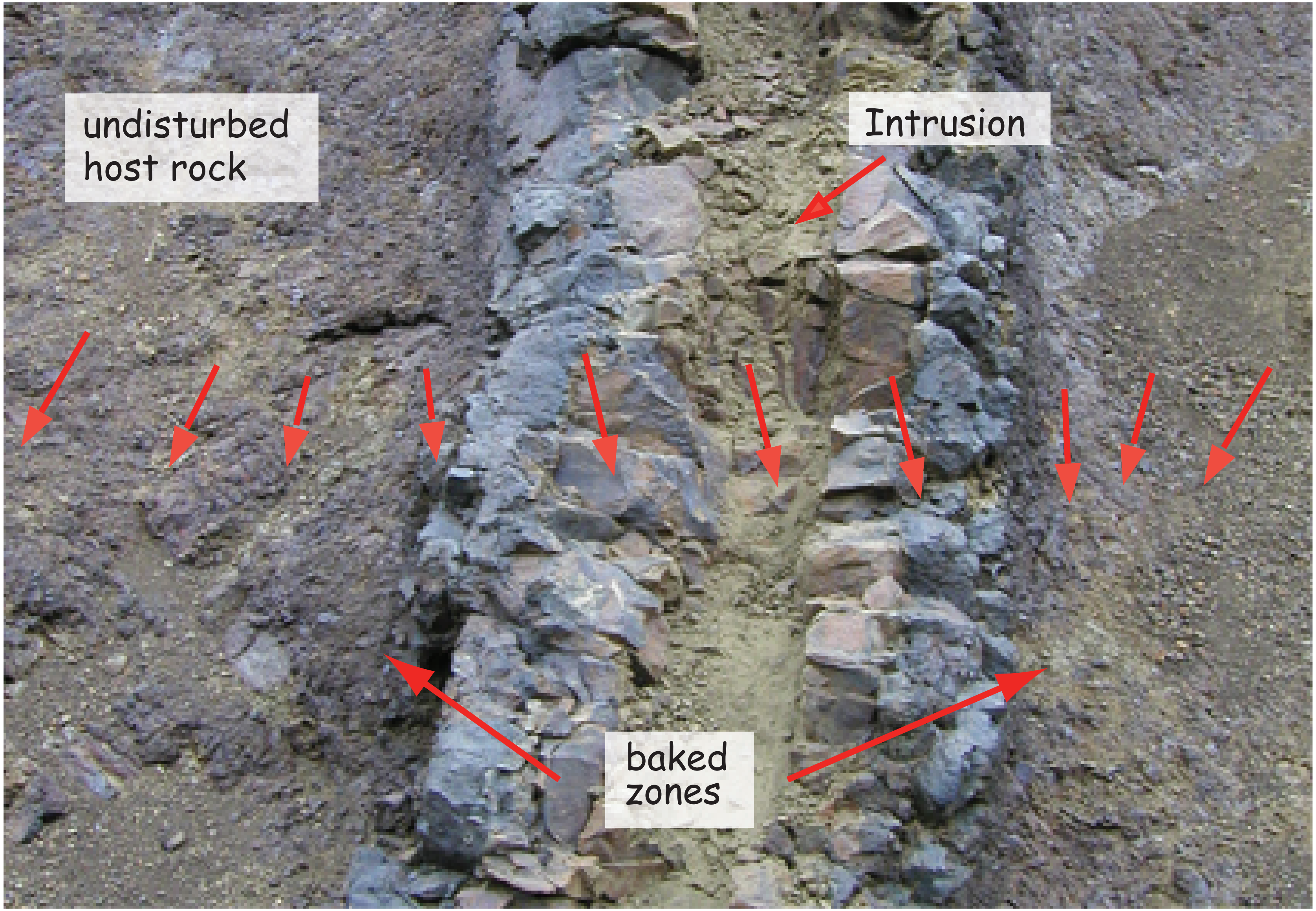


pre-folding
remanence

conglomerate test



baked contact test



Take home message

- the Natural remanent magnetization (NRM) can be made up of one or more components acquired through one or more of the mechanisms discussed in the last lecture.
- the NRM can be "picked apart" through demagnetization procedures
- the age(s) of the component(s) can be constrained through clever field strategies

Assignment

- Problems 9.1 and 9.6 in the online textbook
- Be sure to do a pip install —upgrade pmagpy and pip install —upgrade pmagpy-cli for update versions and use the new data_files for your problem.