Finishing up Fisher statistics
More useful statistics

- what about confidence in VGPs?
- Test for randomness
- Are two directions significantly different from each other?
- How to combine best fit lines and planes
- What to do with inclination only data (see book)
- Test for fishiness (see book)
Mapping of D,I to VGP

- Review Chapter 2 for how to do it

Directions measured at latitude of 30

Not a circular distribution!

\[ dm = \alpha_{95} \frac{\cos \lambda}{\cos I} , \quad dp = \frac{1}{2} \alpha_{95} (1 + 3 \sin^2 \lambda) \]
Randomness: who wants to know?

- The conglomerate test (Chapter 9) relies on a test for randomness - if cobble directions are not random, then they were magnetized AFTER deposition.

- If a paleomagnetic site has random directions, then the mean is meaningless.
Random

$\kappa = 1$

$\kappa = 3$
Basic approach

- Scatter is related to $R$

- We can generate distributions that are spread uniformly on a sphere (random) [use program `uniform.py` in PmagPy]

- Generate a bunch (10,000) of sets of uniform directions with $N$ data points; calculate $R$ and find the 95th percentile of these (95% of the $Rs$ are smaller than that). Call that $R_0$ [This is a “Monte Carlo” type of approach.]

- If $R$ in a given set of directions is $> R_0$, then your data set is 95% sure not to be random

- Can use shortcut of Watson (1956) in book. (see Chapter 11 and Table C.2)
Comparing directions

If one is “known”, i.e. has no uncertainty, just see if a95 of other includes it: Is a given direction vertical? Is a given direction coincident with the IGRF direction at the site?

If both have some uncertainty (compare two paleomagnetic directions - for example the normal and reverse data from a study), this is a trickier case
$\alpha_{95S}$ don’t overlap means of other dataset
clearly different

$\alpha_{95S}$ overlap mean of other dataset
clearly the same
What about this case? Not so clear
Two ways to do this (both by Geoff Watson):

- Watson's F test
- Watson's V
Watson’s F test

- Consider two directions data sets with different Ns and different Rs
  \[ N_1, N_2 \text{ and } R_1, R_2 \]

- Calculate the statistic:
  \[
  F = (N - 2) \frac{(R_1 + R_2 - R)}{(N - R_1 - R_2)}
  \]

- where N and R are for the combined data sets.

- if F exceeds the value in the F tables for 2 and 2(N-2) degrees of freedom, the data sets are different (at 95% confidence level)
Don’t know what an F-table is?

look here:
http://www.socr.ucla.edu/Applets.dir/F_Table.html

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</table>
Watson's $V_w$

- Use statistic $V_w$ - it increases with increasing distance between two data sets (see Chapter 11 and Appendix C.2.1) [check out `watsonsV.py` in `PmagPy`]

- Null hypothesis that two datasets share common mean can be rejected if $V_w$ is bigger than some critical value.

- Use Monte Carlo simulation to determine $V_{crit}$ by calculating $V_{ws}$ for lots of data sets with same $N_s$ and $k_s$ that DO share a common mean (e.g., `fishrot.py` in `PmagPy`). Determine 95th percentile for $V_{crit}$

- If $V_w > V_{crit}$, two data sets are different (95% confidence)
Both the F test and Watson’s V show the two data sets are different at the 95% level of confidence.
Combining lines and planes:

McFadden & McElhinny (1988) see Chapter 11
Lecture 10

- Magnetic mineralogy
- Iron Oxides
- Iron oxyhydroxides
- Iron sulfides
- Sources of magnetic minerals
- Intro to Natural Remanence (if time)
Iron oxides

Titanium often substitutes for iron in the crystal structure.

Also have Aluminum as a frequent guest, but much less work has been done on this, so we’ll discuss mostly titanium-iron solid solutions.
solid solutions

Definition: A homogeneous crystalline structure in which one or more types of atoms or molecules may be partly substituted for the original atoms and molecules without changing the structure.

two important ones in paleomagnetism:

- ulvospinel-magnetite
- ilmenite-hematite
a) b) c)
ulvospinel – magnetite
Temperature (°C)

Ti substitution (x)

a) titanomagnetite

magnetite

Fe$_3$O$_4$

ulvöspinel

Fe$_2$TiO$_4$
ulvöspinel

magnetite

1 \mu m
ilmenite-hematite
Rutile $\text{TiO}_2$

Ilmenite $\text{FeTiO}_3$

Ulvospinel $\frac{1}{3} \text{Fe}_2 \text{TiO}_4$

$\frac{1}{3} \text{FeTi}_2 \text{O}_5$

$\frac{1}{2} \text{FeTiO}_3$

Wüstite $\text{FeO}$

Magnetite $\frac{1}{3} \text{Fe}_2 \text{O}_3$

Hematite $\frac{1}{2} \text{Fe}_2 \text{O}_3$

Maghemite $\frac{1}{3} \text{Fe}_2 \text{O}_5$

Pseudobrookite $\frac{1}{3} \text{Fe}_2 \text{TiO}_5$

Titanomagnetite $\frac{1}{3} \text{Fe}_2 \text{TiO}_4$

Hemoilmenite $\frac{1}{3} \text{Fe}_3 \text{O}_4$

X:

Y:

Z:

TM60
b)  

Temperature (°C)

0  200  400  600  800

0.2  0.4  0.6  0.8  1.0

Ti substitution (y)

hematite $\text{Fe}_2\text{O}_3$

titano hematite

ilmenite $\text{FeTiO}_3$
Hematite
hematite

ilmenite host

100 nm
Ti-rich titano-hematite

Ti-poor titanohematite

rare phenomenon of self-reversal
iron oxyhydroxides
Goethite - iron oxyhydroxide

\[ \alpha \text{ FeOOH} \]

Very high coercivity

low \( T_c \) (125°C)
Iron sulfides

- Greigite
- Pyrrhotite
Sources of magnetic minerals

- Igneous and metamorphic processes
- Soil formation and diagenesis
- Industrial pollution
- Cosmic dust
- Bacteria