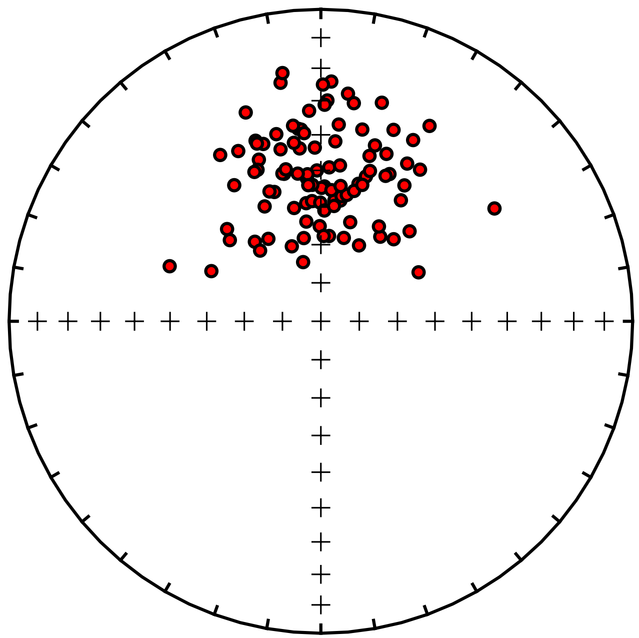
Finishing up Fisher statistics

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)

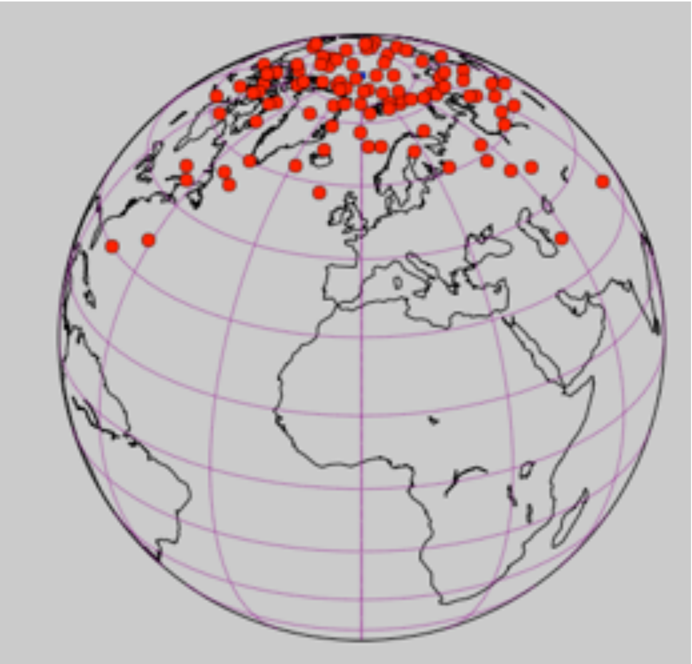
Mapping of D,I to VGP

- Review Chapter 2 for how to do it



Directions measured at latitude of 30

=>



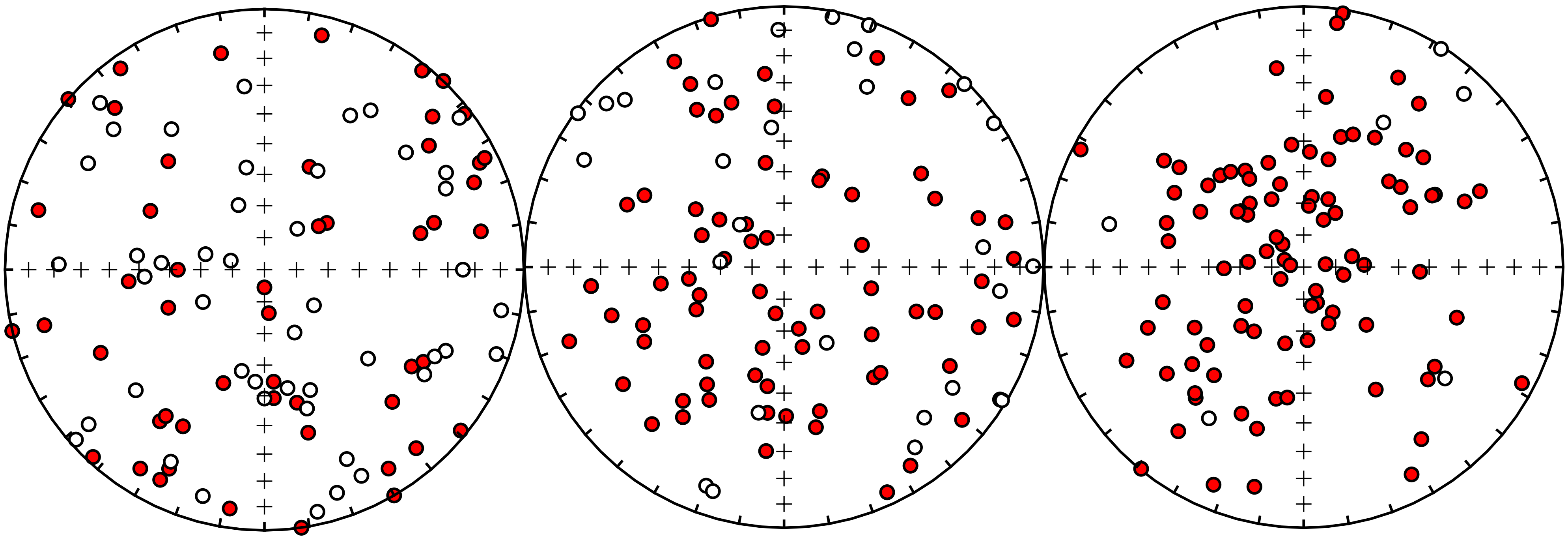
Not a circular distribution!

$$dm = \alpha_{95} \frac{\cos \lambda}{\cos \bar{I}}, \quad dp = \frac{1}{2} \alpha_{95} (1 + 3 \sin^2 \lambda)$$

Randomness: who wants to know?

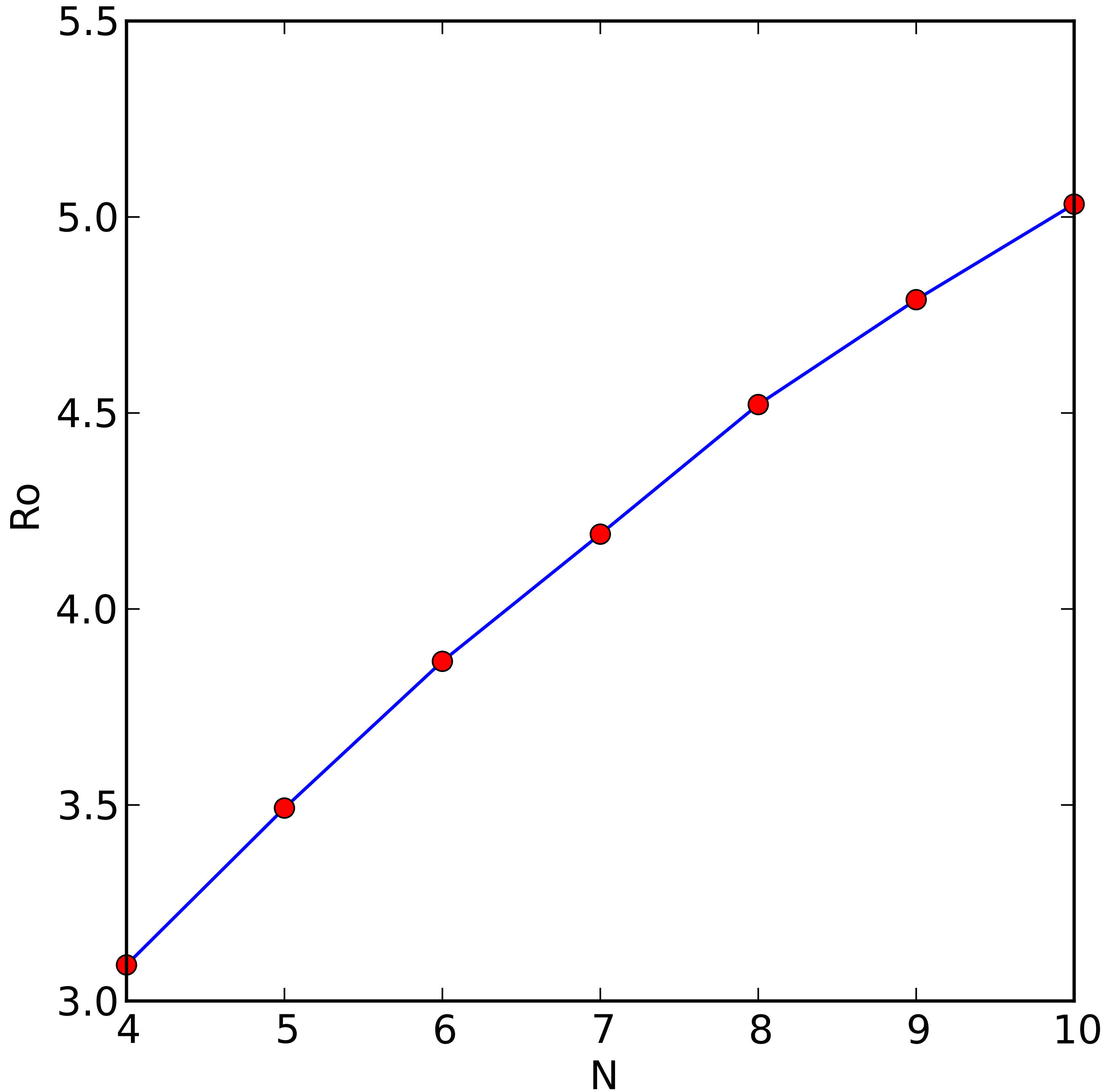
- The conglomerate test (Chapter 9) relies on a test for randomness - if cobble directions are not random, then they were magnetized AFTER deposition
- If a paleomagnetic site has random directions, then the mean is meaningless

Random $\kappa = 1$ $\kappa = 3$



Basic approach

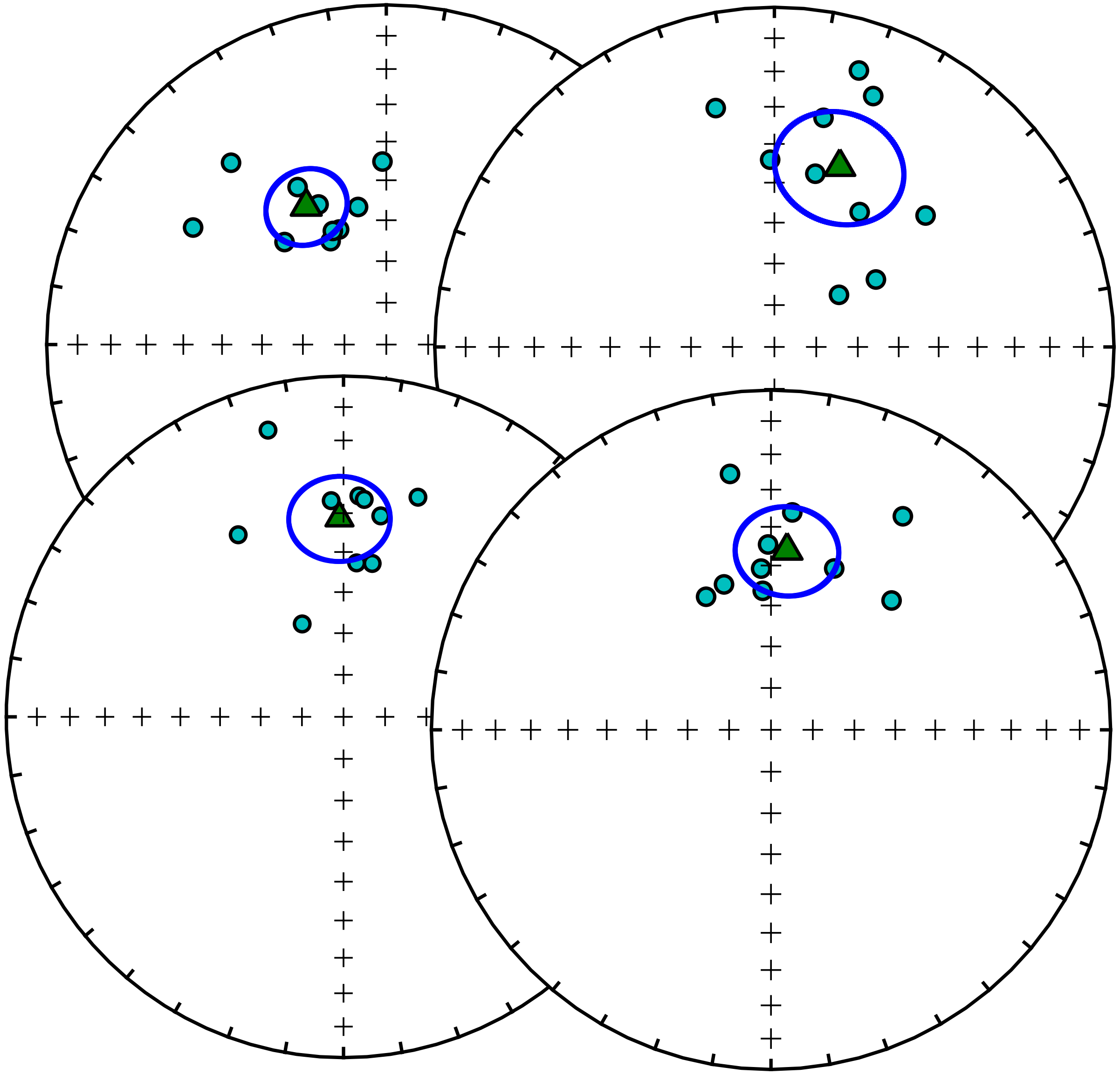
- Scatter is related to R
- We can generate distributions that are spread uniformly on a sphere (random) [use program uniform.py in PmagPy]
- Generate a bunch (10,000) of sets of uniform directions with N data points; calculate R and find the 95th percentile of these (95% of the Rs are smaller than that). Call that R_o [This is a "Monte Carlo" type of approach.]
- If R in a given set of directions is > R_o, 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)



5.5
5.0
4.5
4.0
3.5
3.0
Ro
4
5
6
7
8
9
10
N

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

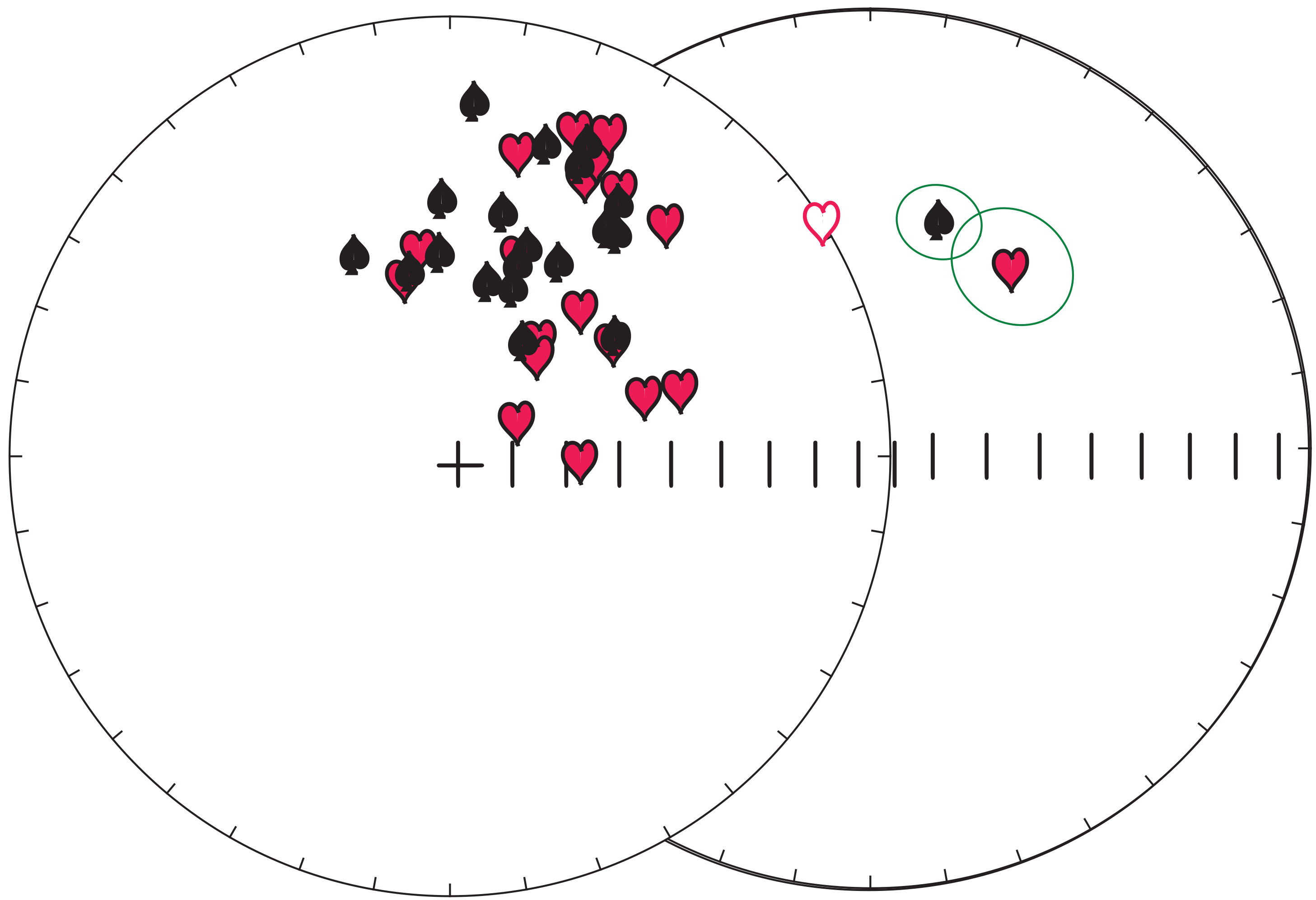


α_{95}s don't overlap means of other dataset

clearly different

α_{95}s 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

/	df_1=1	2	3	4	5	6	7	8	9	10	12	15	20	
df_2=1	161.4476	199.5000	215.7073	224.5832	230.1619	233.9860	236.7684	238.8827	240.5433	241.8817	243.9060	245.9499	248.0131	249
2	18.5128	19.0000	19.1643	19.2468	19.2964	19.3295	19.3532	19.3710	19.3848	19.3959	19.4125	19.4291	19.4458	19
3	10.1280	9.5521	9.2766	9.1172	9.0135	8.9406	8.8867	8.8452	8.8123	8.7855	8.7446	8.7029	8.6602	8
4	7.7086	6.9443	6.5914	6.3882	6.2561	6.1631	6.0942	6.0410	5.9988	5.9644	5.9117	5.8578	5.8025	5
5	6.6079	5.7861	5.4095	5.1922	5.0503	4.9503	4.8759	4.8183	4.7725	4.7351	4.6777	4.6188	4.5581	4
6	5.9874	5.1433	4.7571	4.5337	4.3874	4.2839	4.2067	4.1468	4.0990	4.0600	3.9999	3.9381	3.8742	3
7	5.5914	4.7374	4.3468	4.1203	3.9715	3.8660	3.7870	3.7257	3.6767	3.6365	3.5747	3.5107	3.4445	3
8	5.3177	4.4590	4.0662	3.8379	3.6875	3.5806	3.5005	3.4381	3.3881	3.3472	3.2839	3.2184	3.1503	3
9	5.1174	4.2565	3.8625	3.6331	3.4817	3.3738	3.2927	3.2296	3.1789	3.1373	3.0729	3.0061	2.9365	2
10	4.9646	4.1028	3.7083	3.4780	3.3258	3.2172	3.1355	3.0717	3.0204	2.9782	2.9130	2.8450	2.7740	2

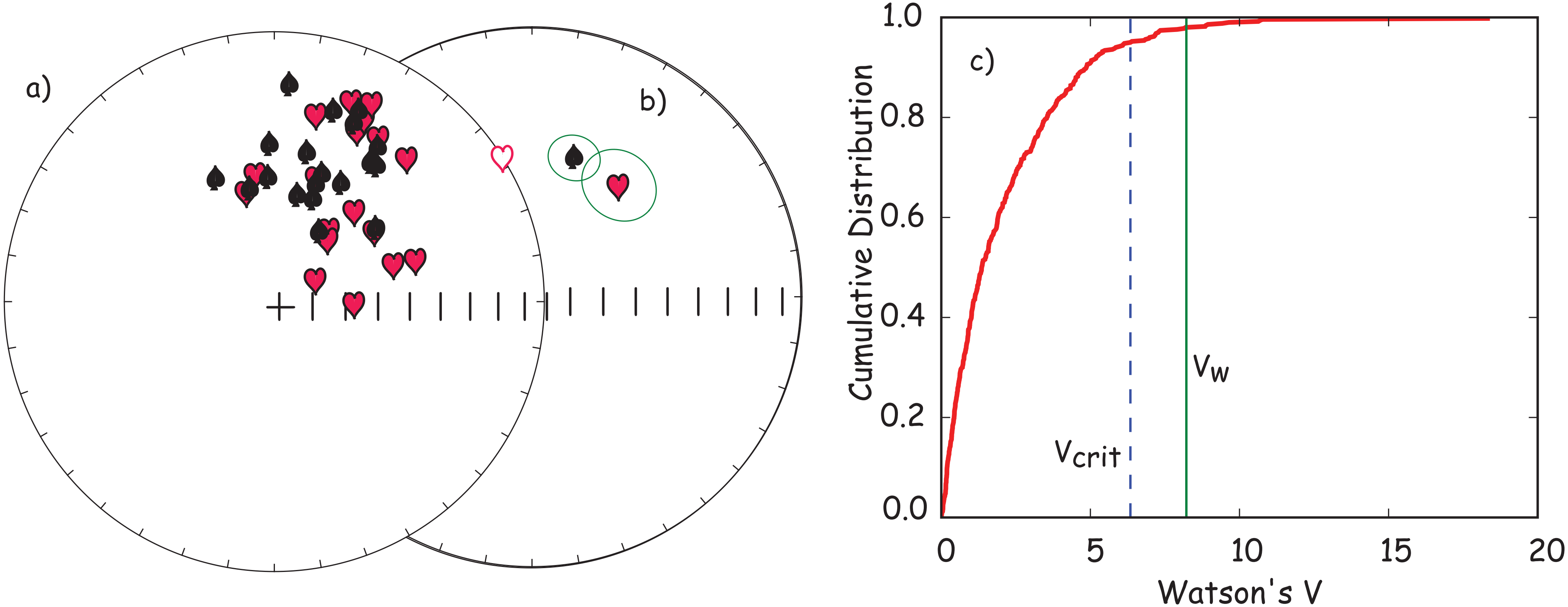
Watson's Vw

- use statistic Vw - 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 Vw is bigger than some critical value.

- Use Monte Carlo simulation to determine Vcrit by calculating Vws for lots of data sets with same Ns and ks that DO share a common mean (e.g., fishrot.py in PmagPy). Determine 95th percentile for Vcrit

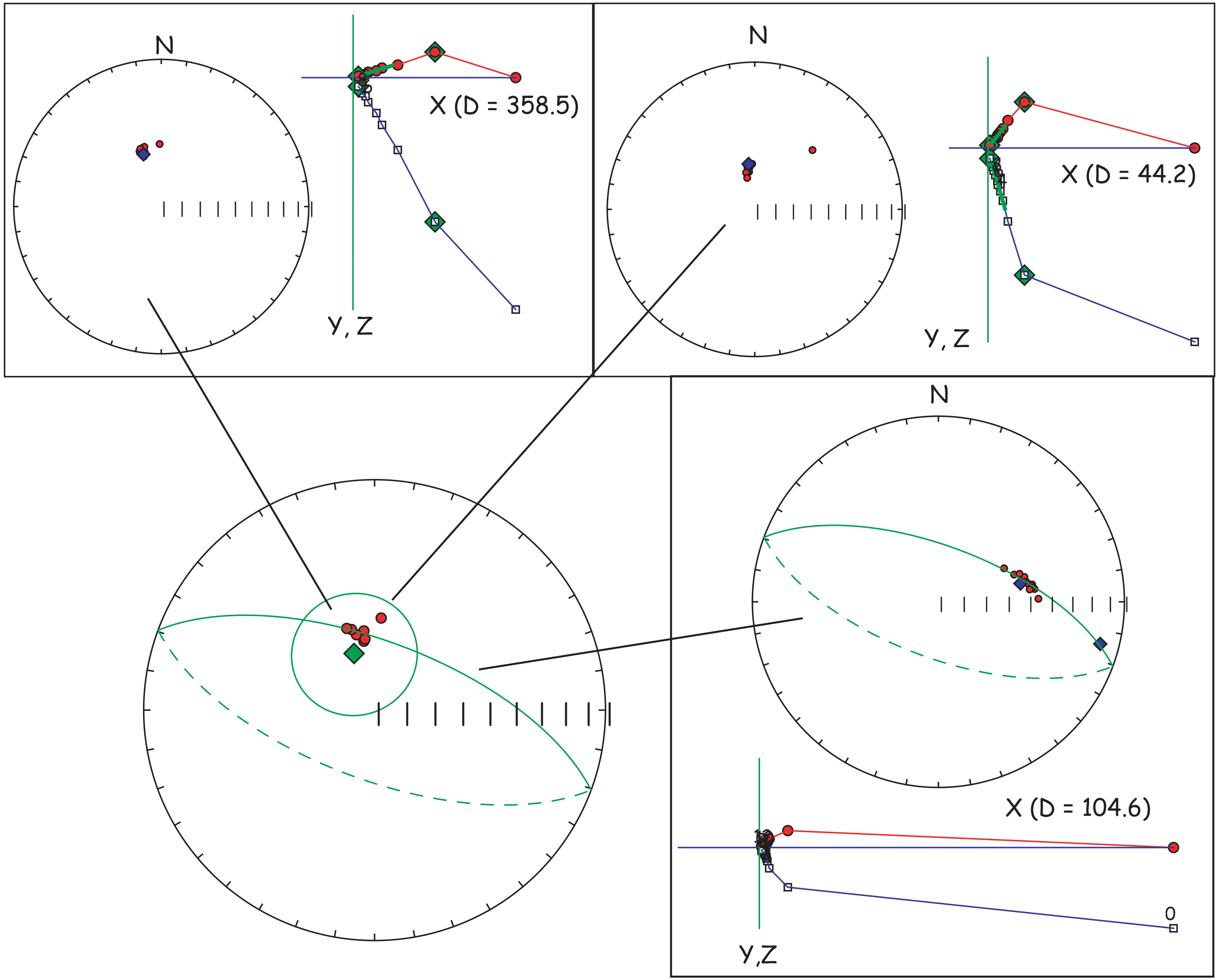
- If Vw>Vcrit, two data sets are different (95% confidence)



$$F = 4.15, F(2,70) = 3.12 \qquad V_w = 8.2, V_{crit} = 6.3$$

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

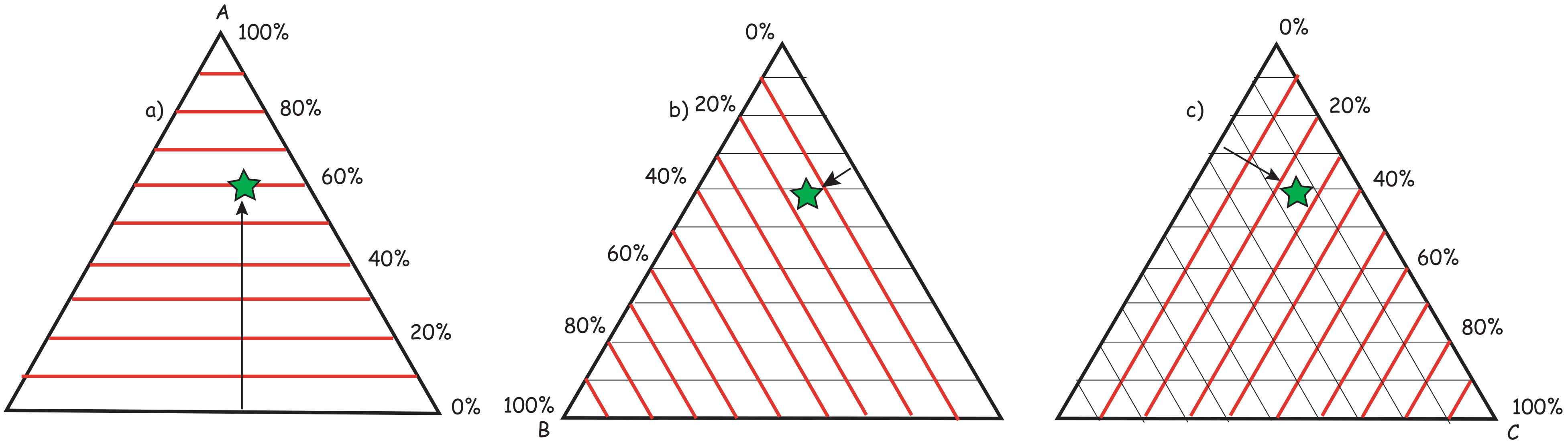
- Magnetic mineralogy
- Iron Oxides
- Iron oxyhydroxides
- Iron sulfides
- Sources of magnetic minerals
- Intro to Natural Remanence (if time)

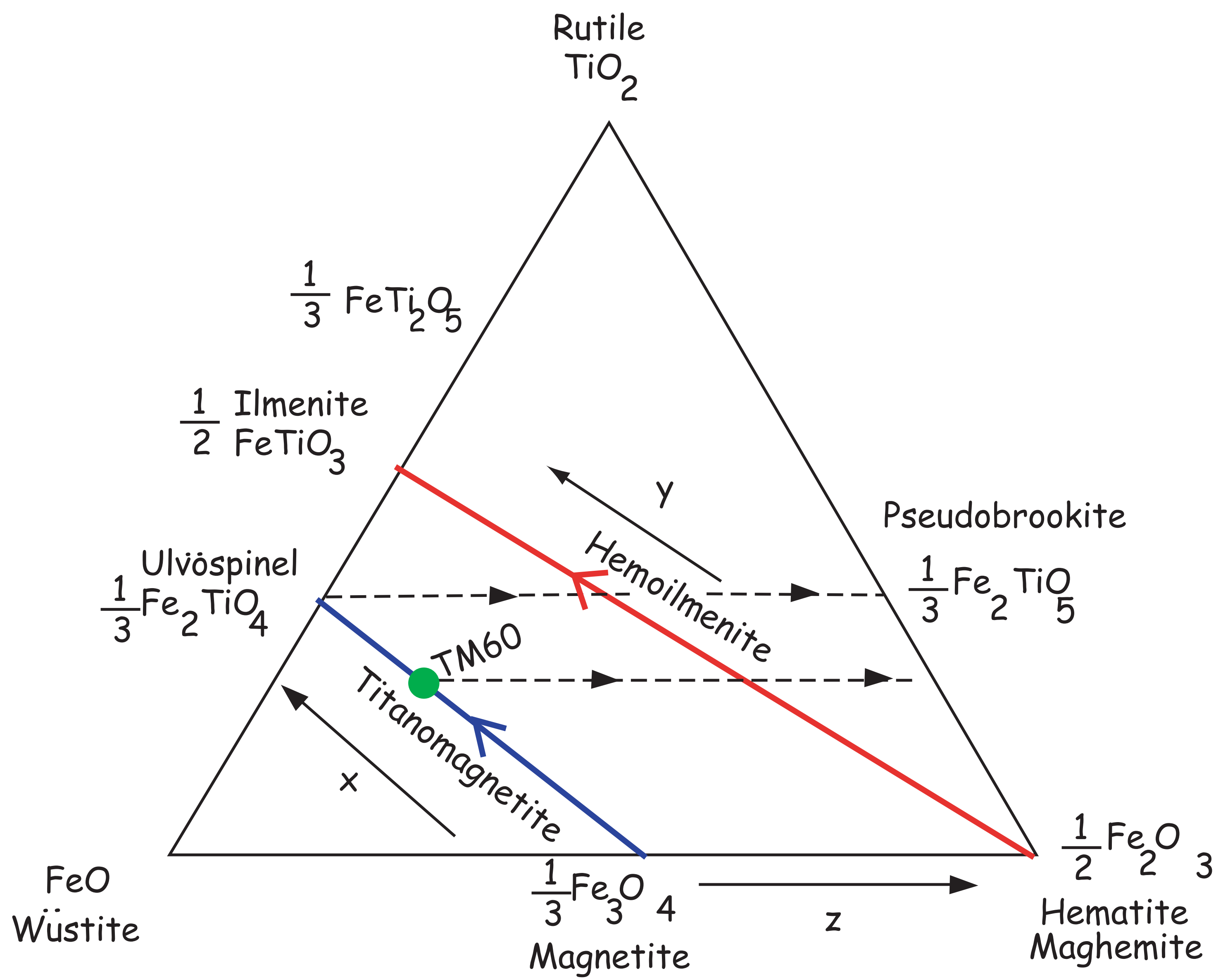
Iron oxides

- 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

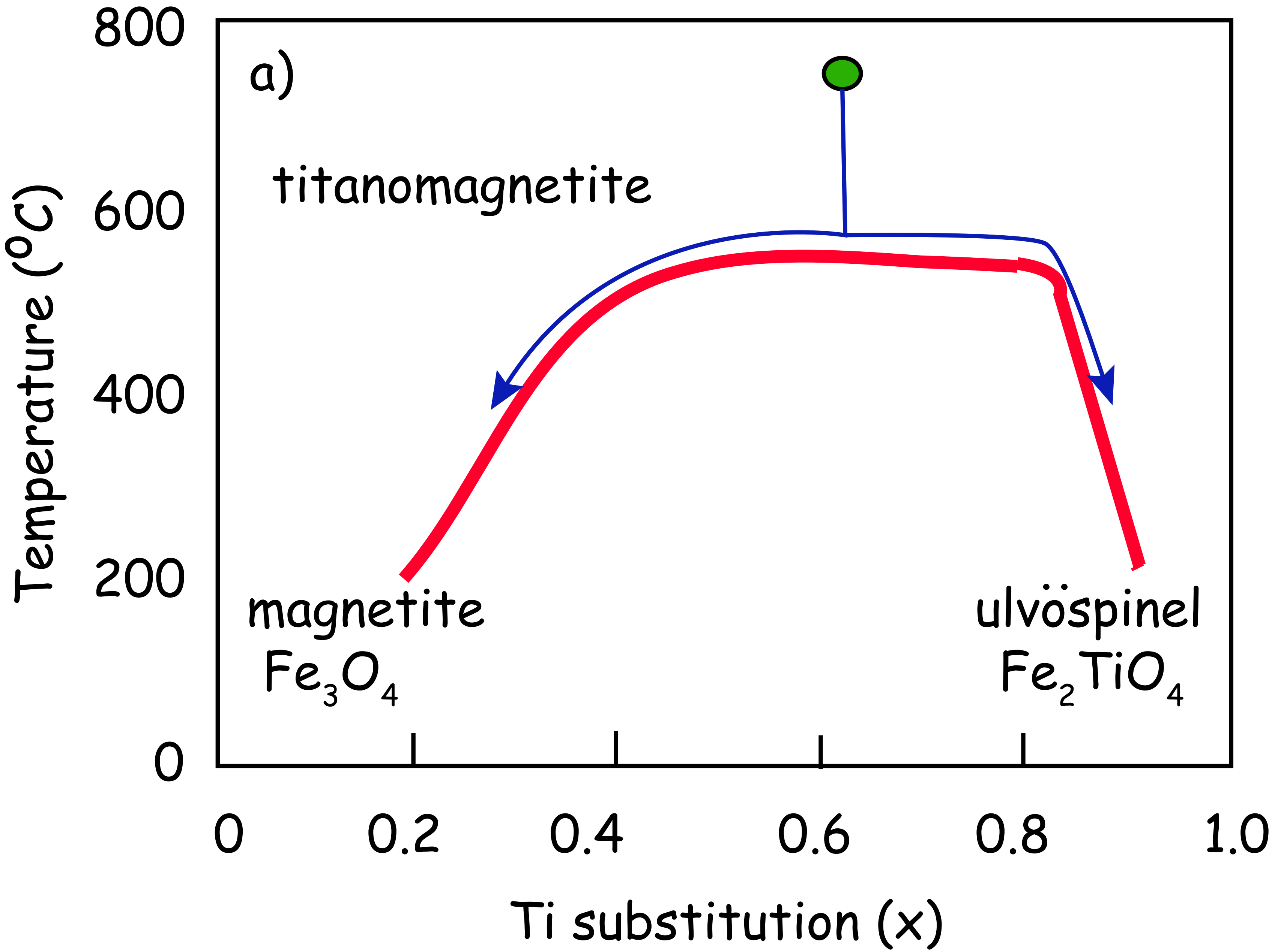
- Definition: A homogeneous crystalline structure in which one or more types of atoms or molecules may be partly substituted for the original atoms and molecules without changing the structure.
- two important ones in paleomagnetism:
  - ulvospinel-magnetite
  - ilmenite-hematite


A
100%
a)
80%
60%
40%
20%
0%
0%
b)
20%
40%
60%
80%
100%
B
0%
c)
20%
40%
60%
80%
100%
C

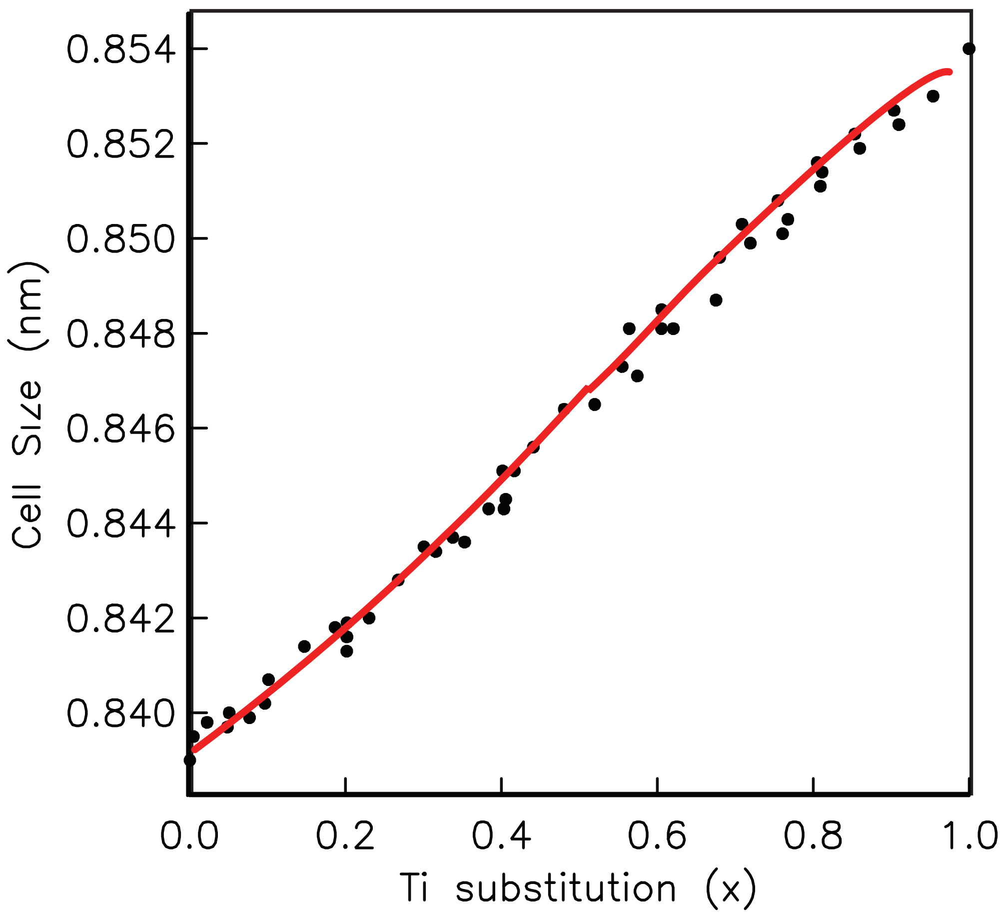


Rutile
TiO2
1/3 FeTi2O5
1/2 Ilmenite FeTiO3
y
Pseudobrookite
Ulvöspinel
1/3 Fe2TiO4
Hemoilmenite
1/3 Fe2TiO5
TM60
Titanomagnetite
x
1/2 Fe2O3
FeO
Wüstite
1/3 Fe3O4
Magnetite
z
Hematite
Maghemite

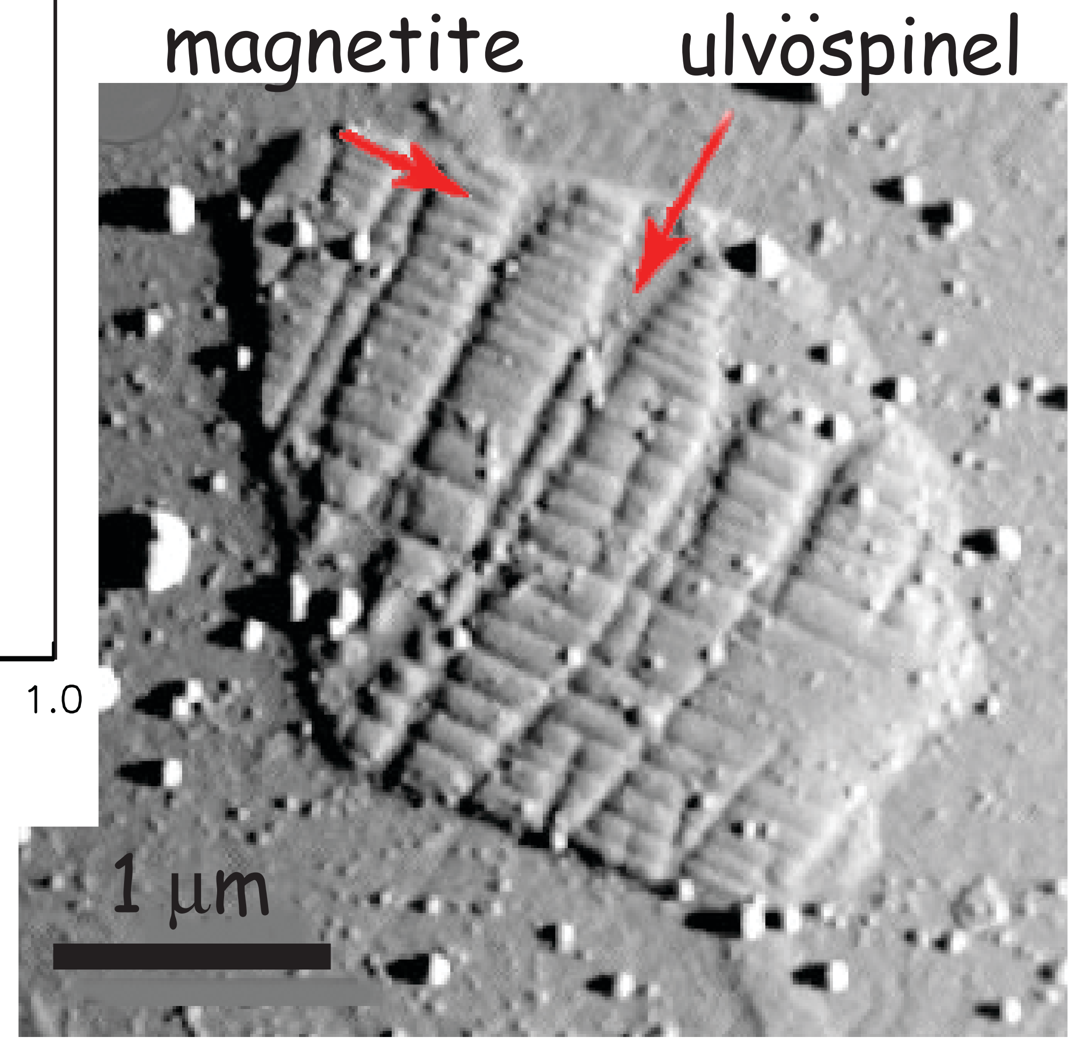
ulvospinel - magnetite



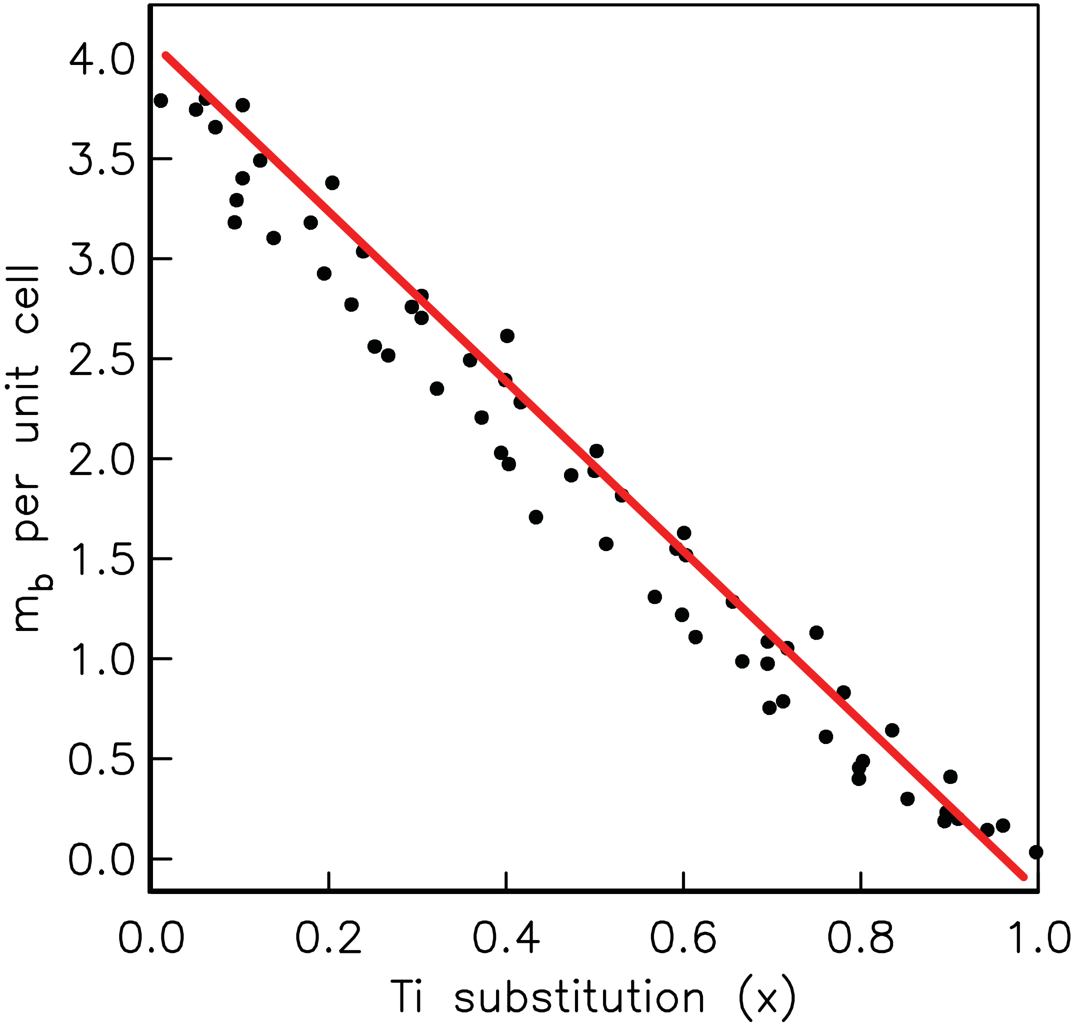
a)
titanomagnetite
magnetite
Fe_3O_4
ulvöspinel
Fe_2TiO_4
800
600
400
200
0
Temperature (°C)
0
0.2
0.4
0.6
0.8
1.0
Ti substitution (x)



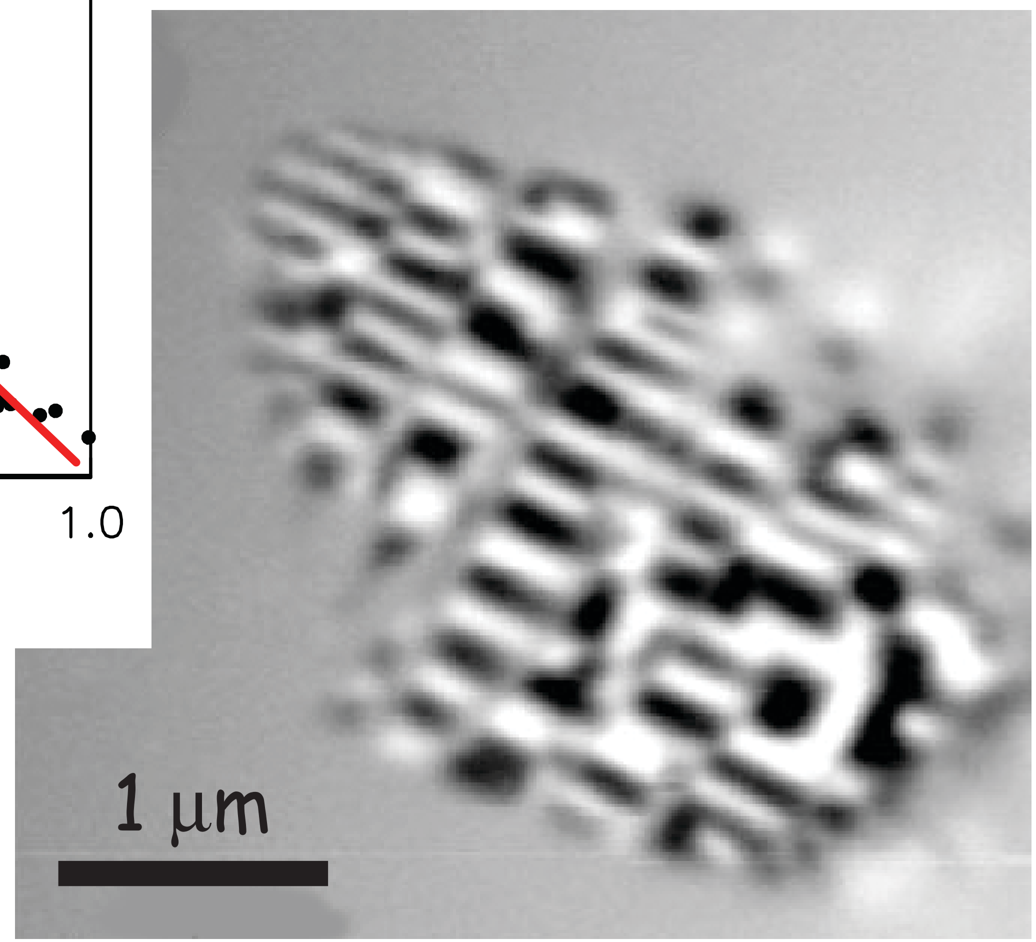
0.854
0.852
0.850
0.848
0.846
0.844
0.842
0.840
Cell Size (nm)
0.0
0.2
0.4
0.6
0.8
1.0
Ti substitution (x)

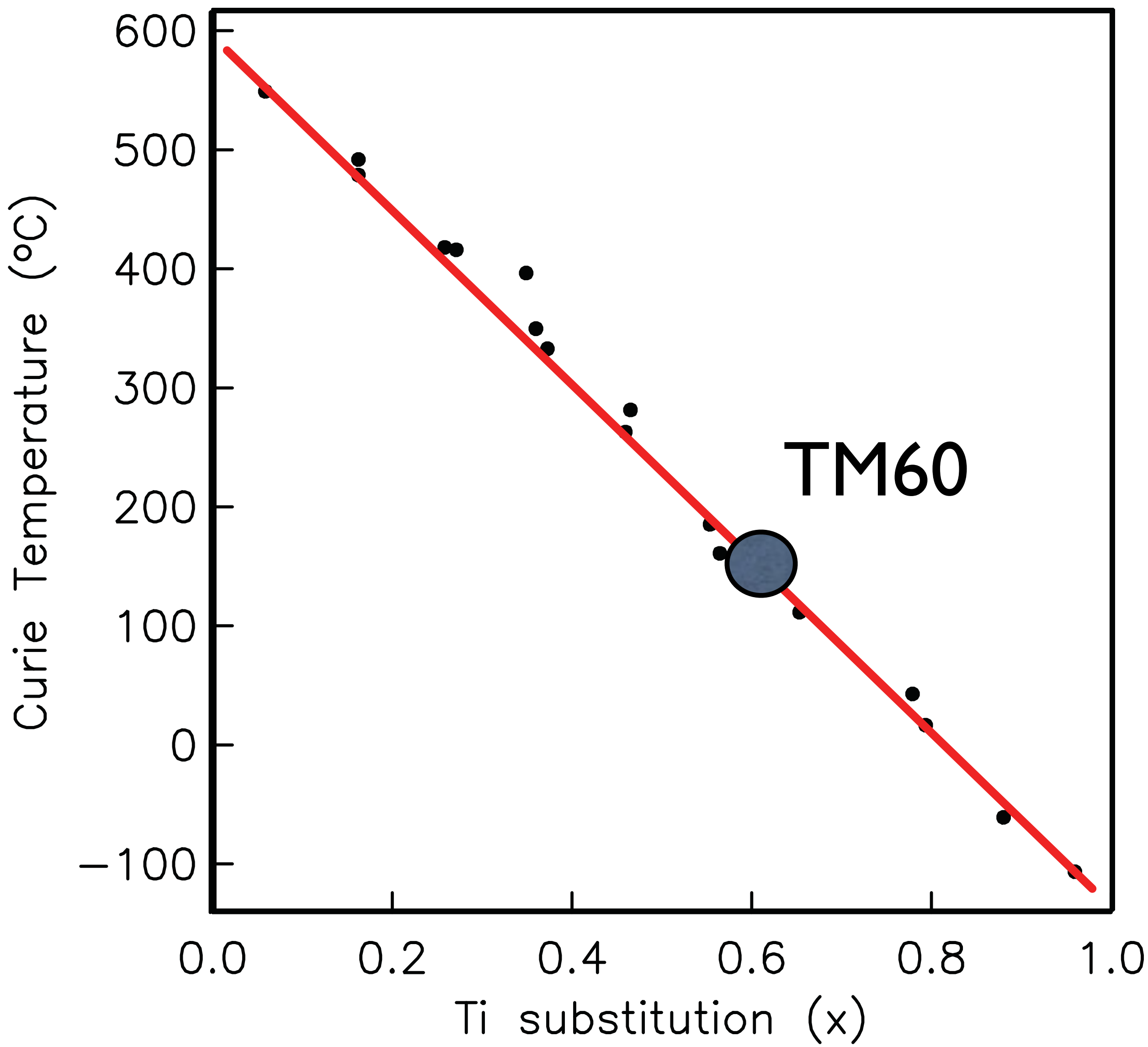


magnetite
ulvöspinel
1 μm


4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
m_b per unit cell
0.0
0.2
0.4
0.6
0.8
1.0
Ti substitution (x)

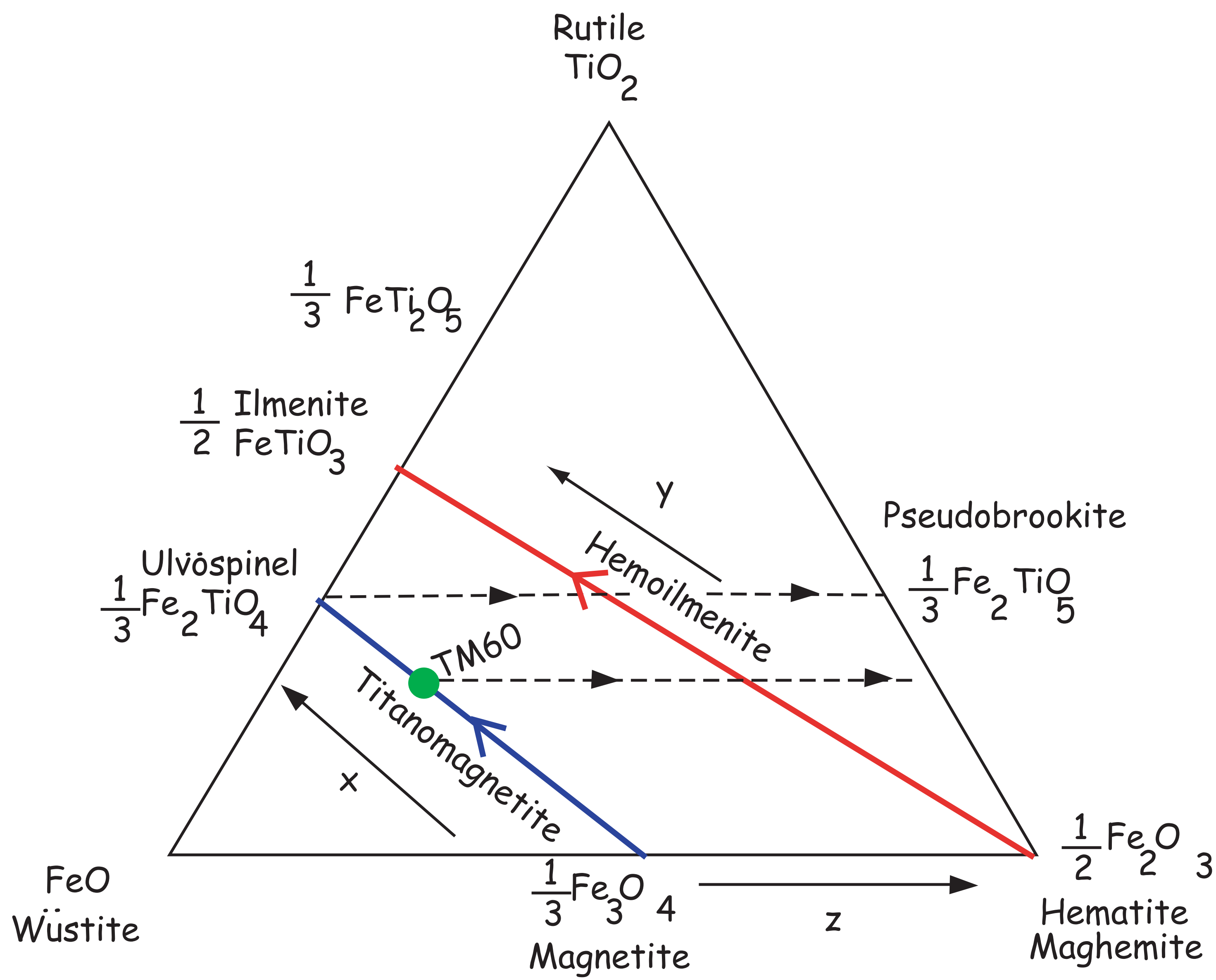
MFM map


1 μm

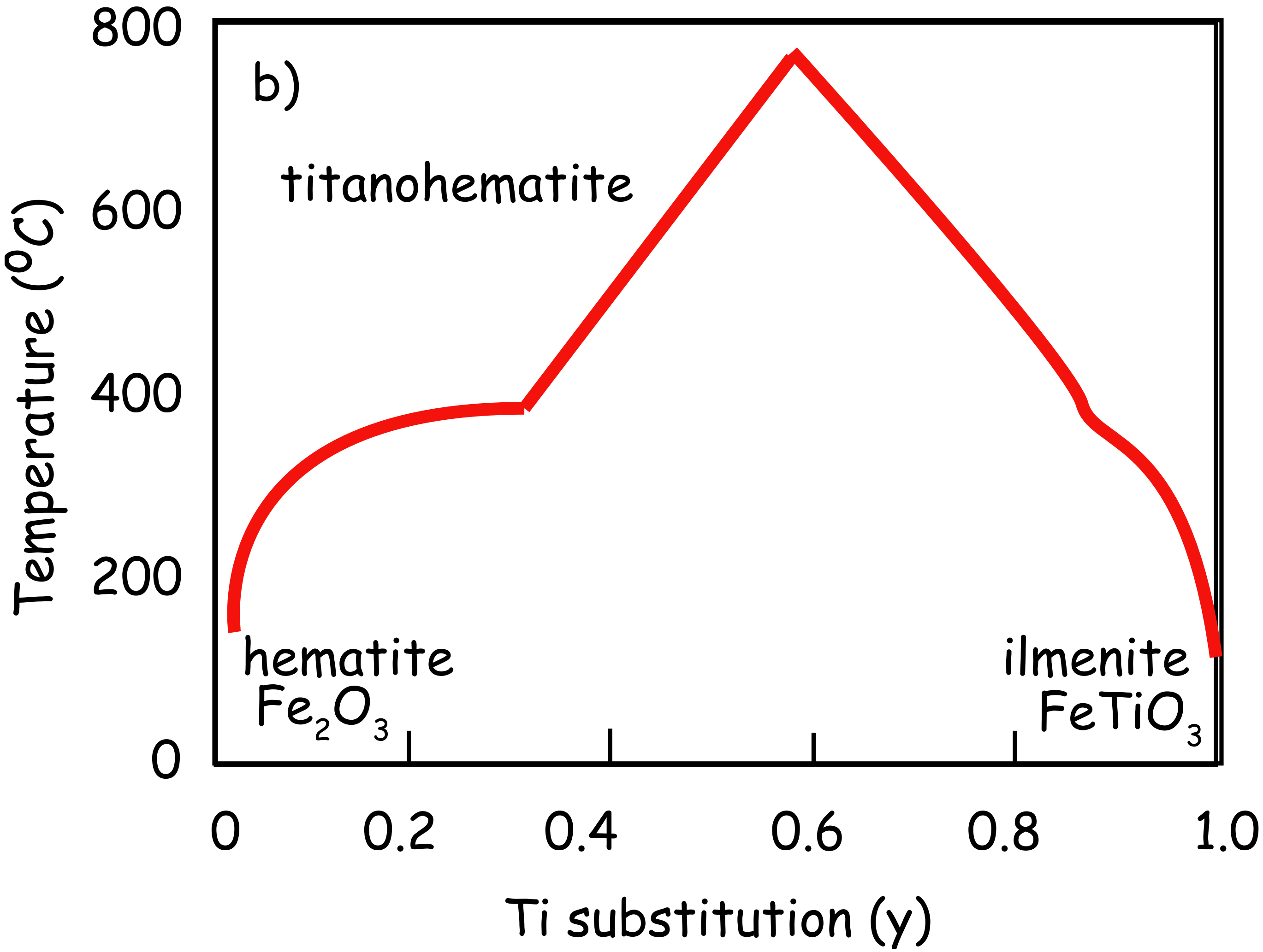


TM60
600
500
400
300
200
100
0
−100
Curie Temperature (°C)
0.0
0.2
0.4
0.6
0.8
1.0
Ti substitution (x)

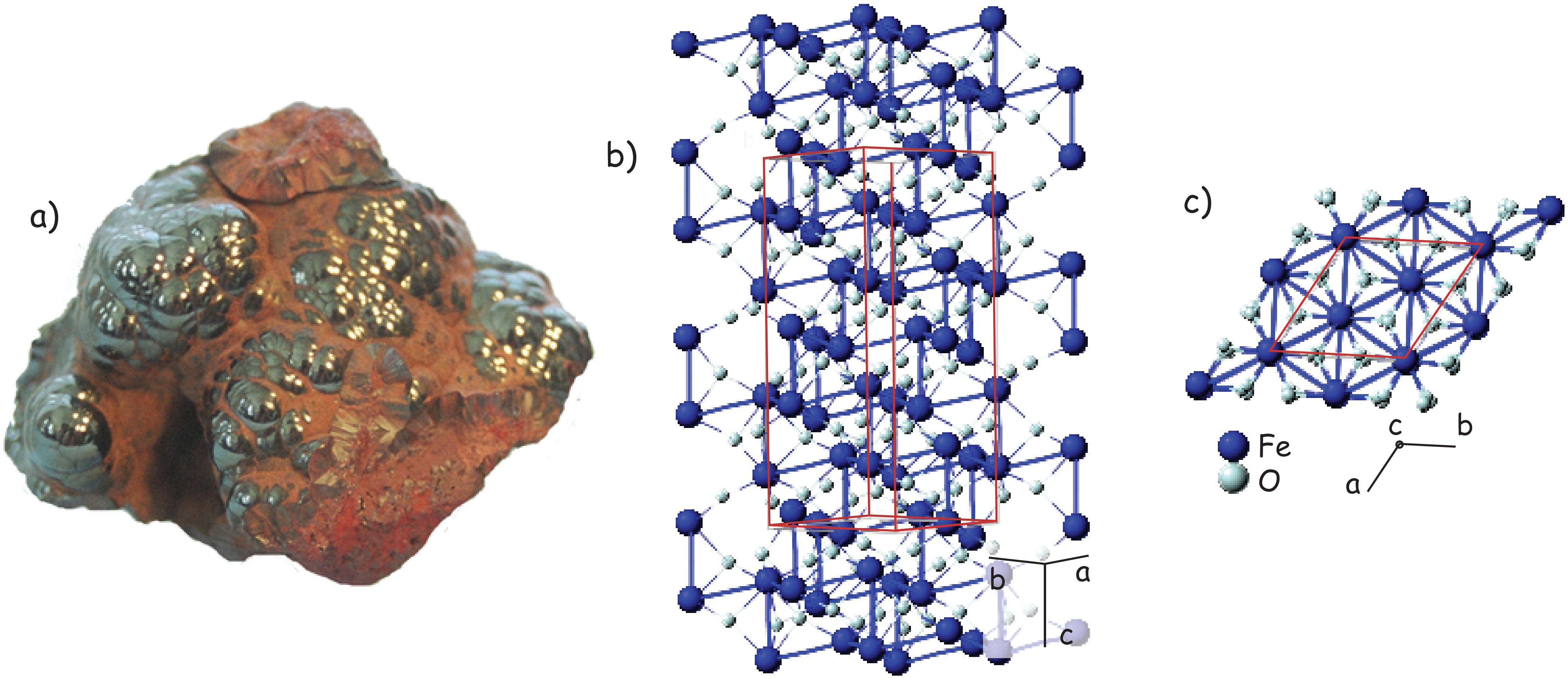
ilmenite-hematite



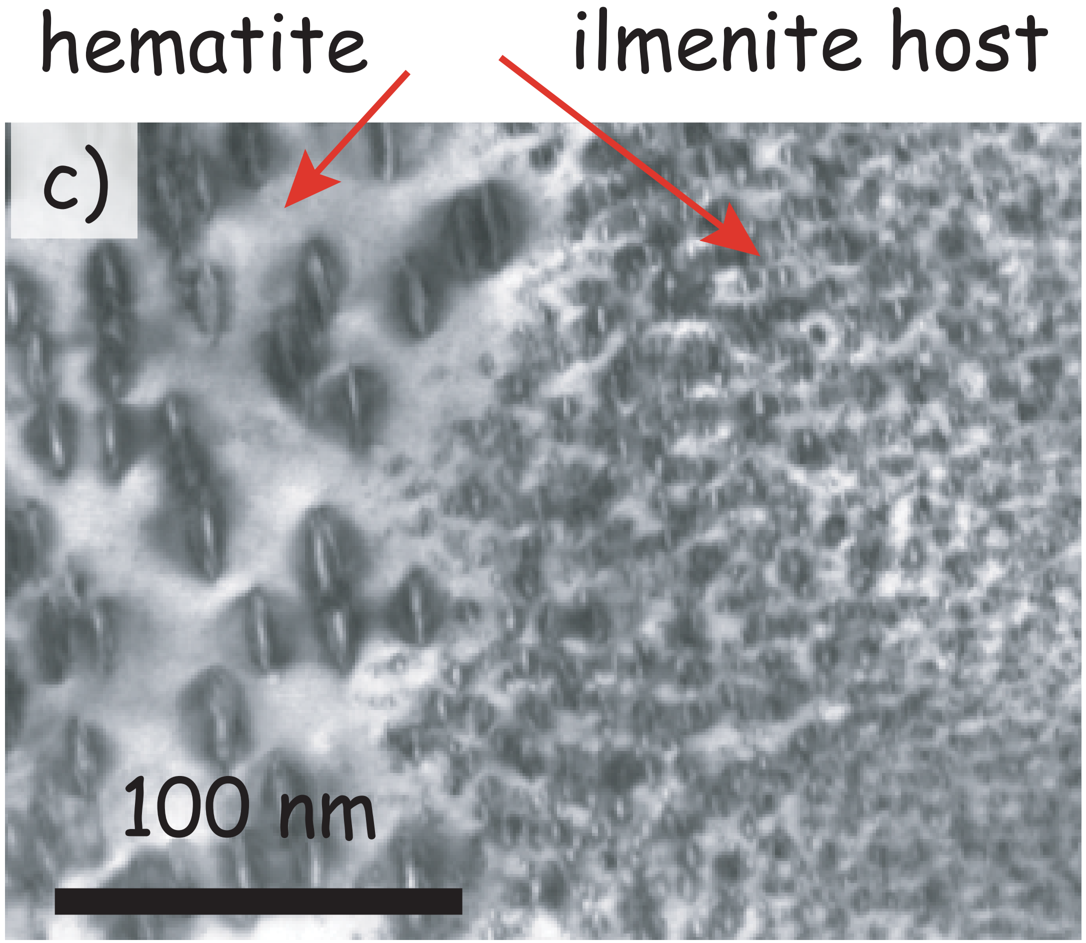
Rutile
TiO2
1/3 FeTi2O5
1/2 Ilmenite
FeTiO3
y
Pseudobrookite
Ulvöspinel
1/3 Fe2TiO4
Hemoilmenite
1/3 Fe2TiO5
TM60
Titanomagnetite
x
1/2 Fe2O3
FeO
Wüstite
1/3 Fe3O4
Magnetite
z
Hematite
Maghemite

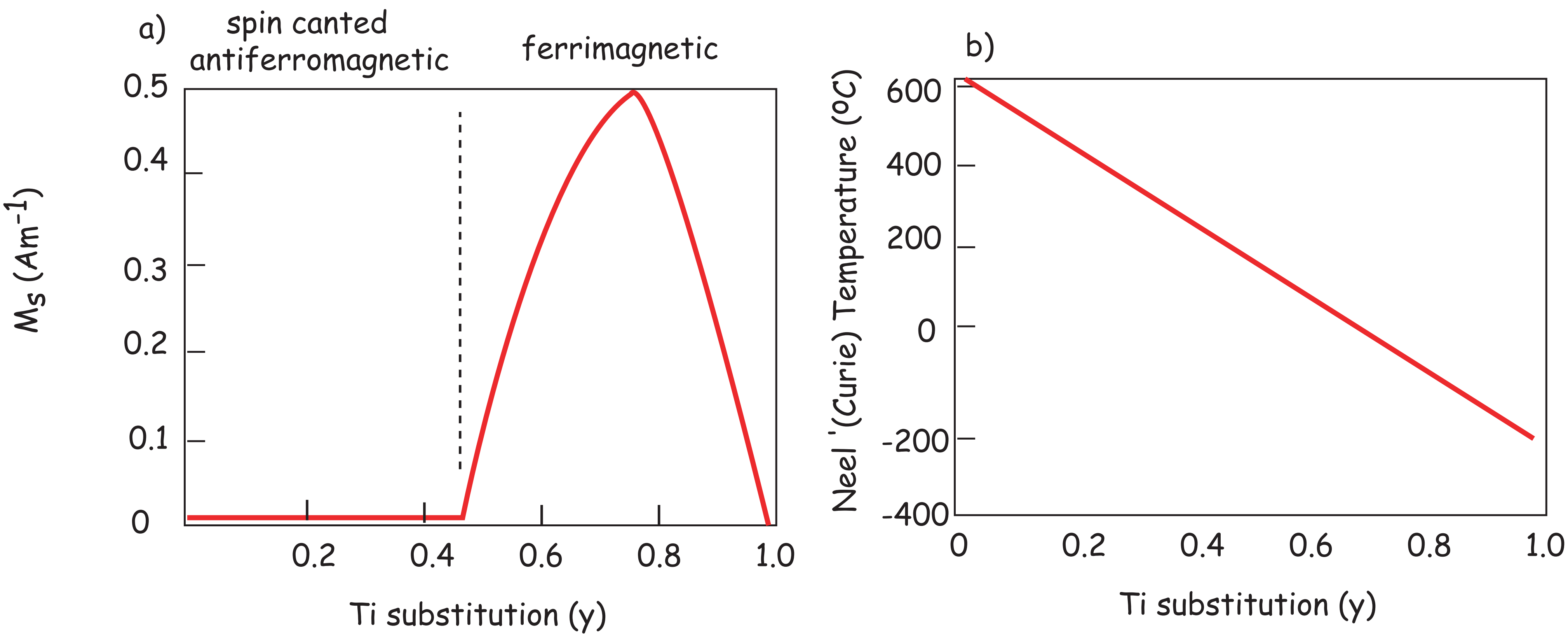


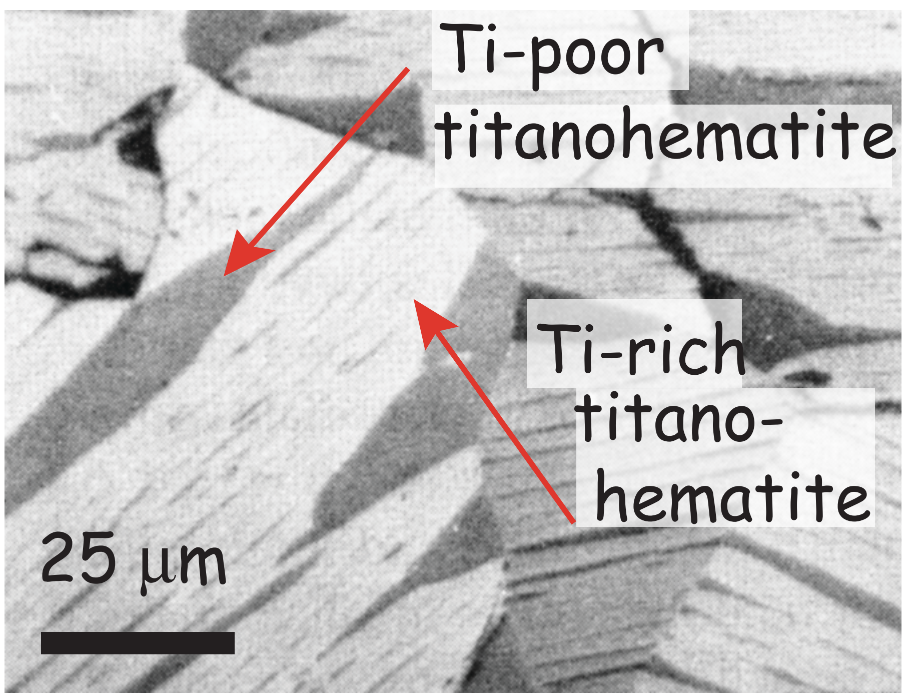
800
600
400
200
0
Temperature (°C)
b)
titanohematite
hematite
Fe2O3
ilmenite
FeTiO3
0
0.2
0.4
0.6
0.8
1.0
Ti substitution (y)



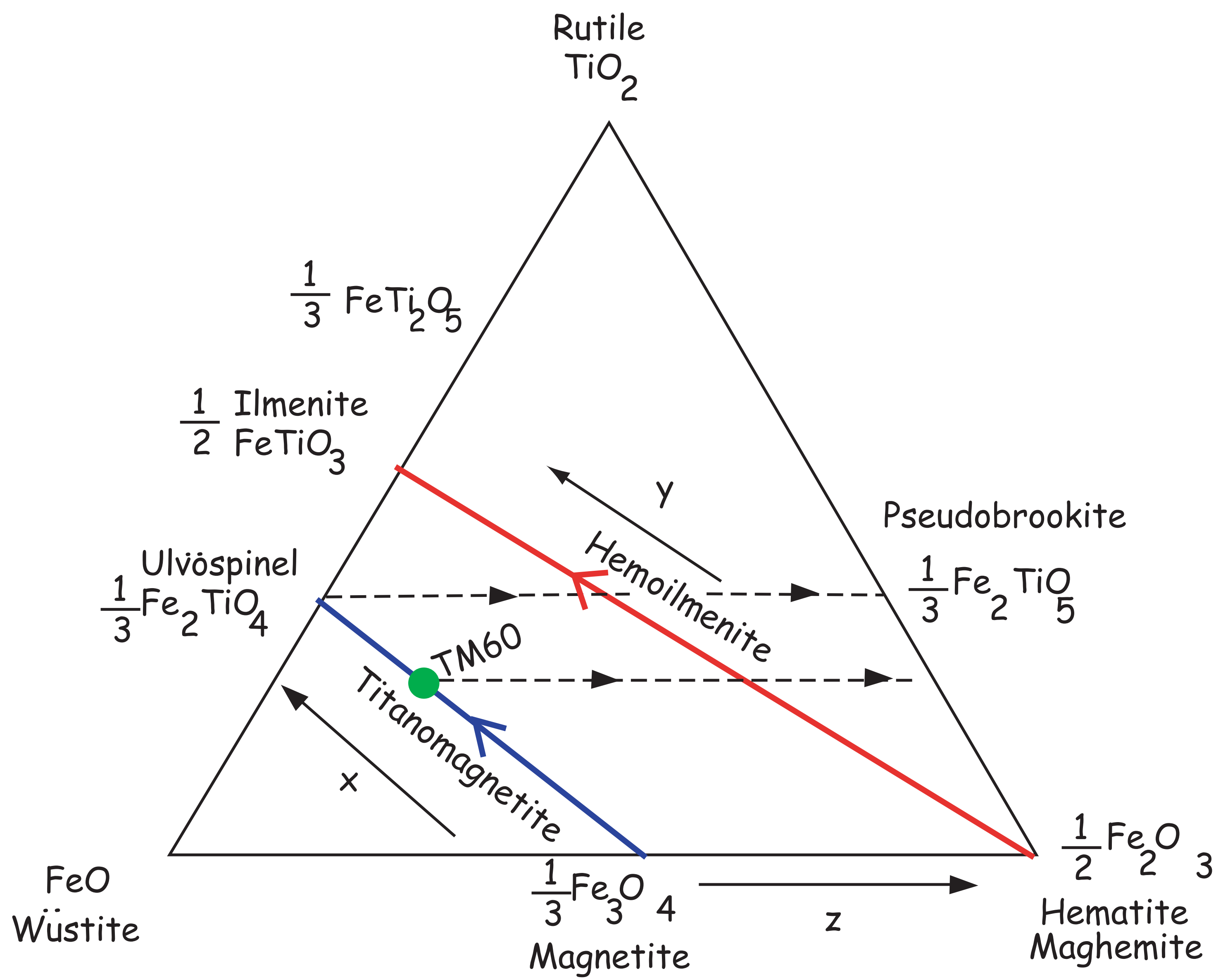
Hematite


hematite
ilmenite host
c)
100 nm

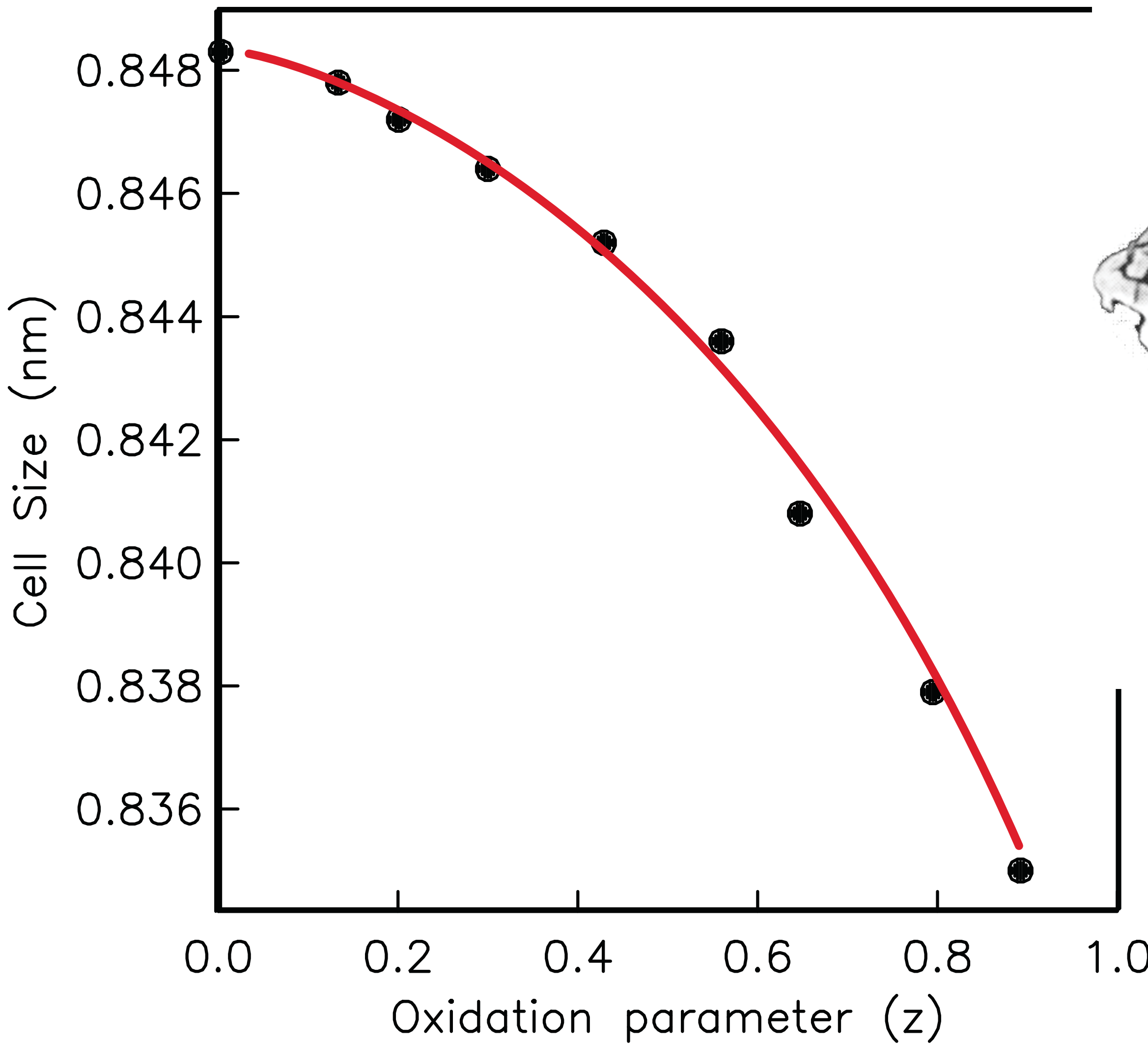


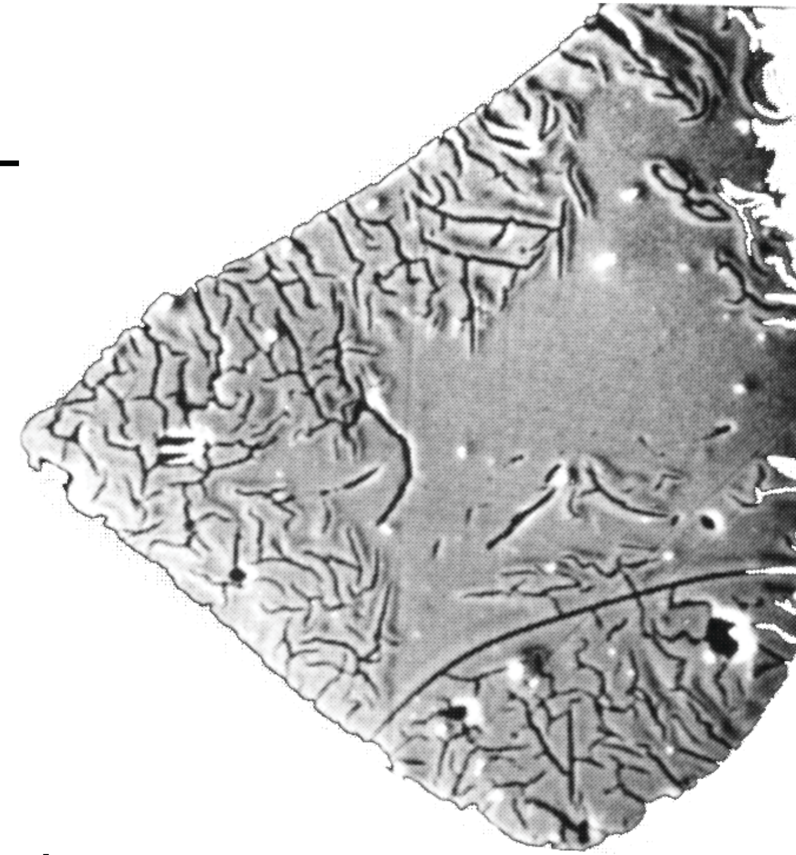


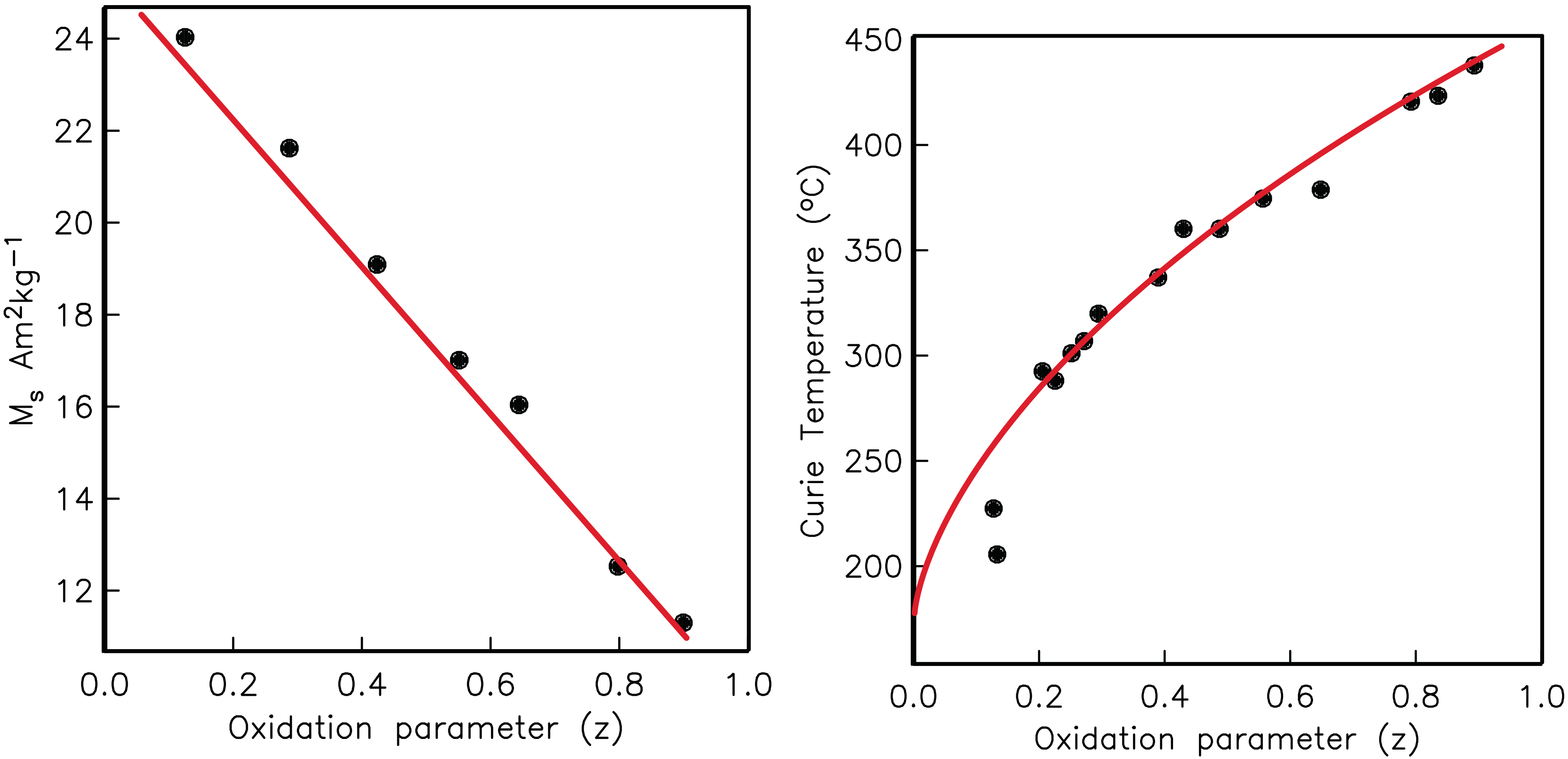
rare phenomenon of self-reversal



Rutile
TiO_2
$\frac{1}{3}$ $FeTi_2O_5$
$\frac{1}{2}$ Ilmenite
$FeTiO_3$
Ulvöspinel
$\frac{1}{3}Fe_2TiO_4$
Pseudobrookite
$\frac{1}{3}Fe_2TiO_5$
y
Hemoilmenite
TM60
Titanomagnetite
x
FeO
Wüstite
$\frac{1}{3}Fe_3O_4$
Magnetite
z
$\frac{1}{2}Fe_2O_3$
Hematite
Maghemite


0.848
0.846
0.844
0.842
0.840
0.838
0.836
Cell Size (nm)
0.0
0.2
0.4
0.6
0.8
1.0
Oxidation parameter (z)

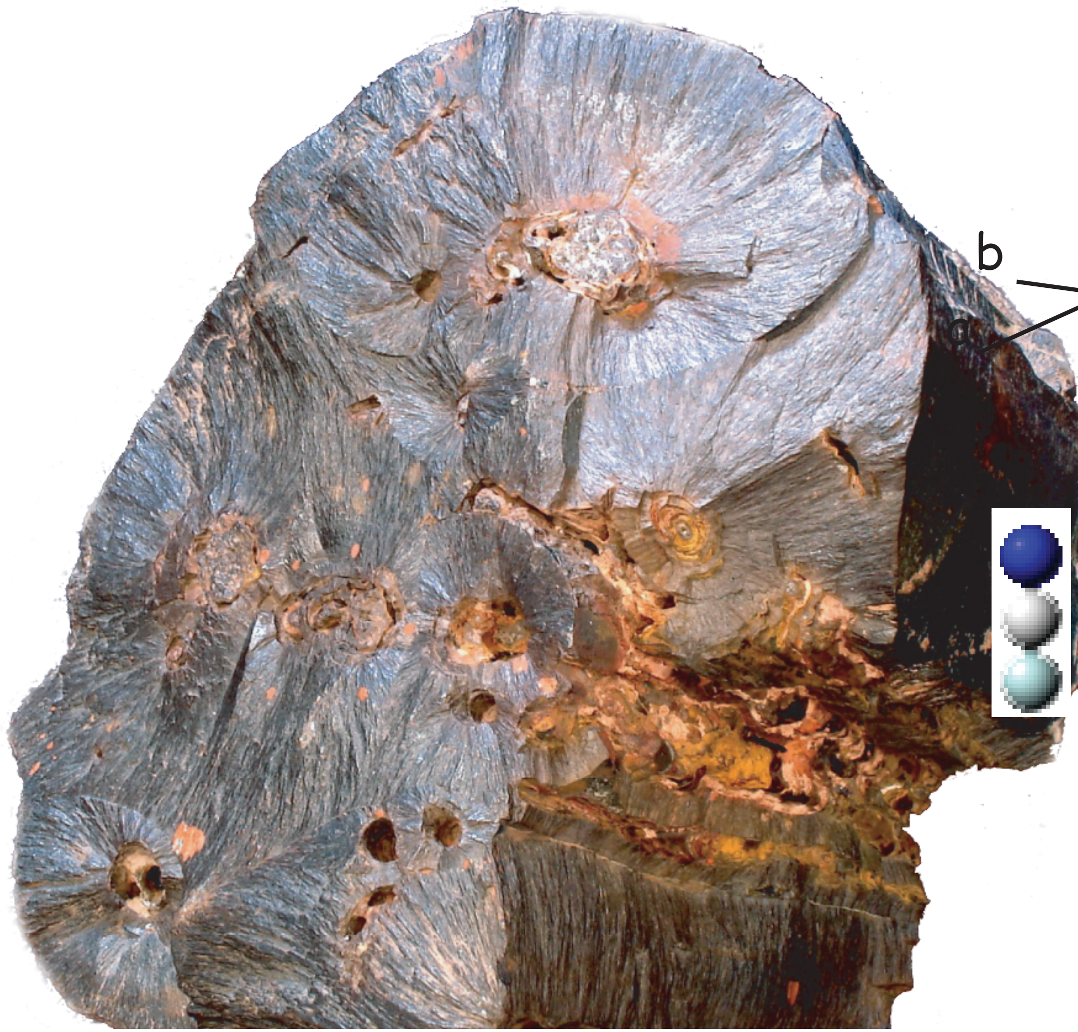


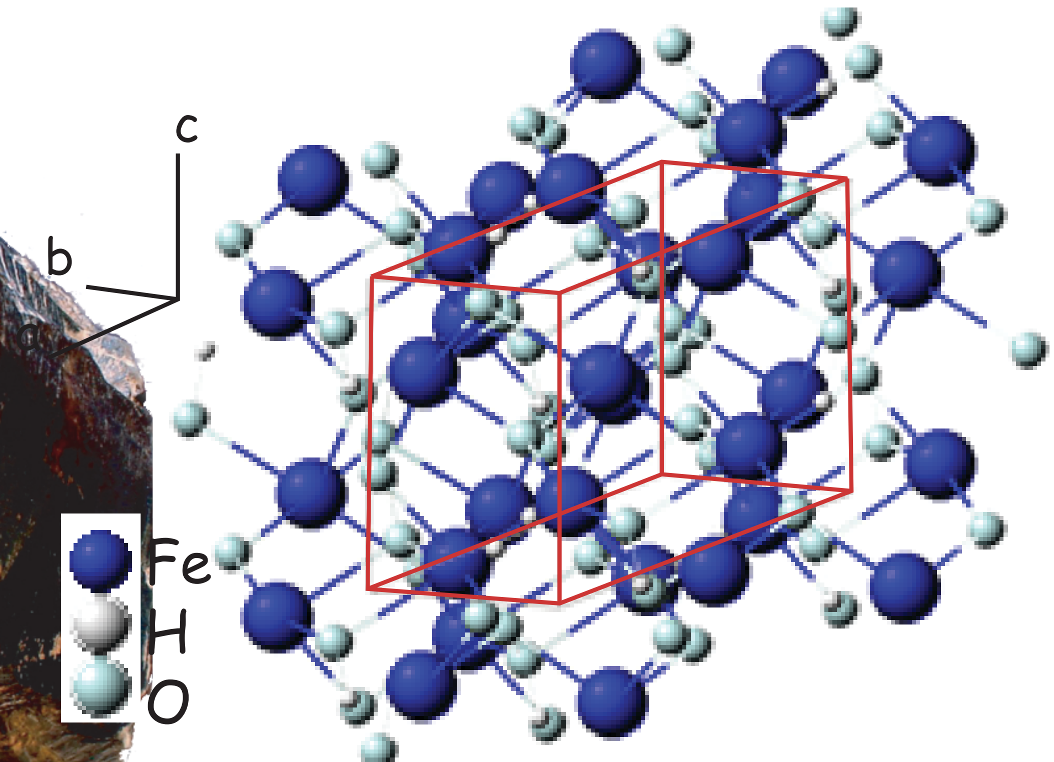


24
22
20
18
16
14
12
M_s Am^2kg^{-1}
0.0
0.2
0.4
0.6
0.8
1.0
Oxidation parameter (z)
450
400
350
300
250
200
Curie Temperature (°C)
0.0
0.2
0.4
0.6
0.8
1.0
Oxidation parameter (z)

iron oxyhydroxides

Goethite - iron oxyhydroxide





Very high coercivity
low Tc (125C)

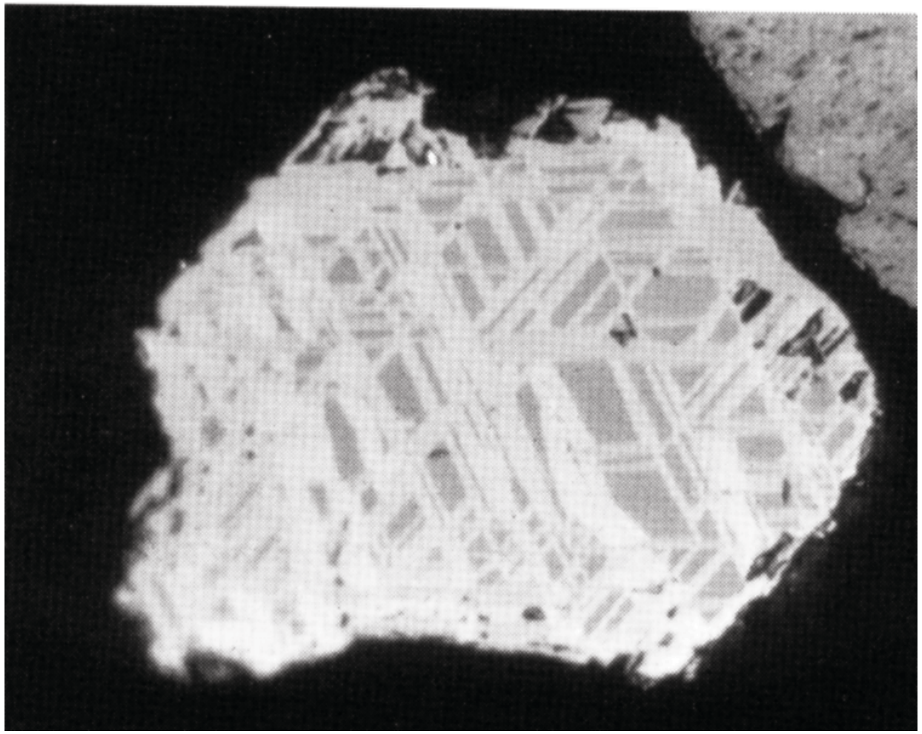
α FeOOH

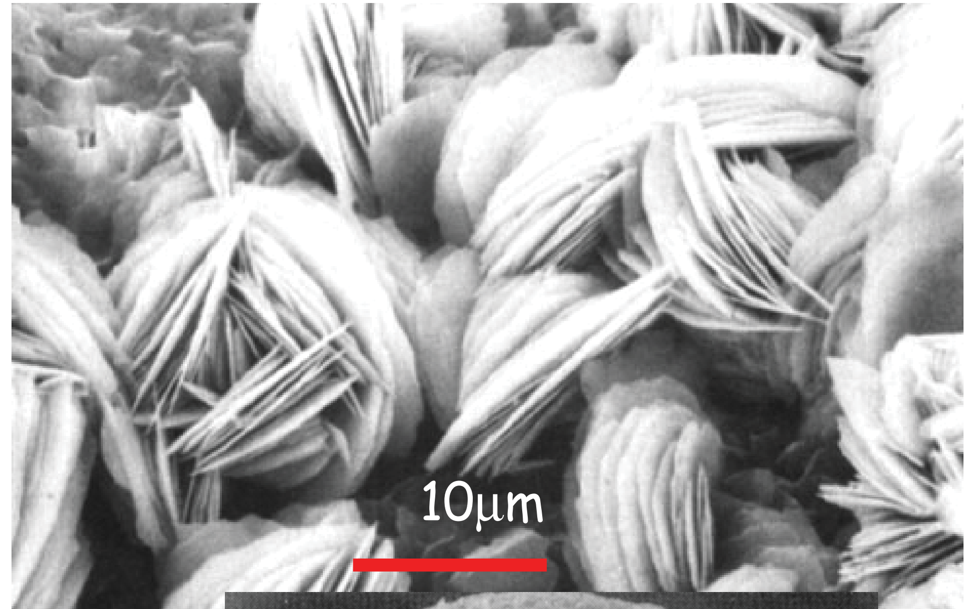
Iron sulfides

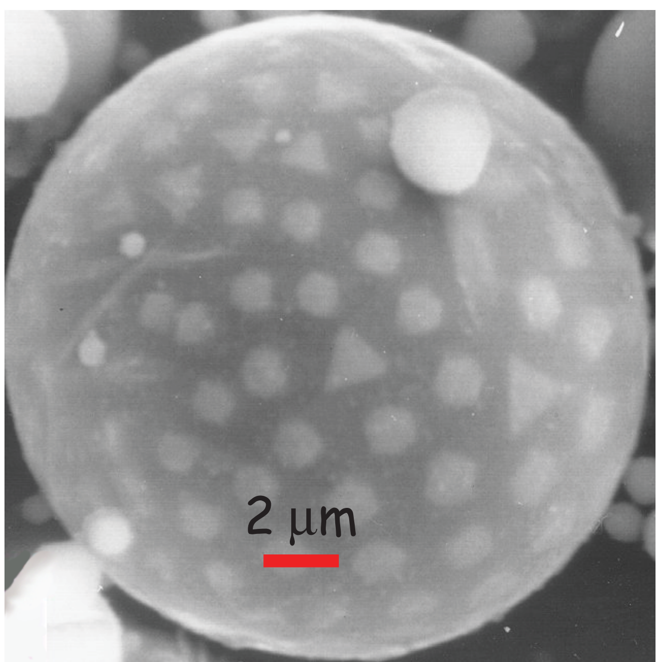
- Greigite
- Pyrrhotite

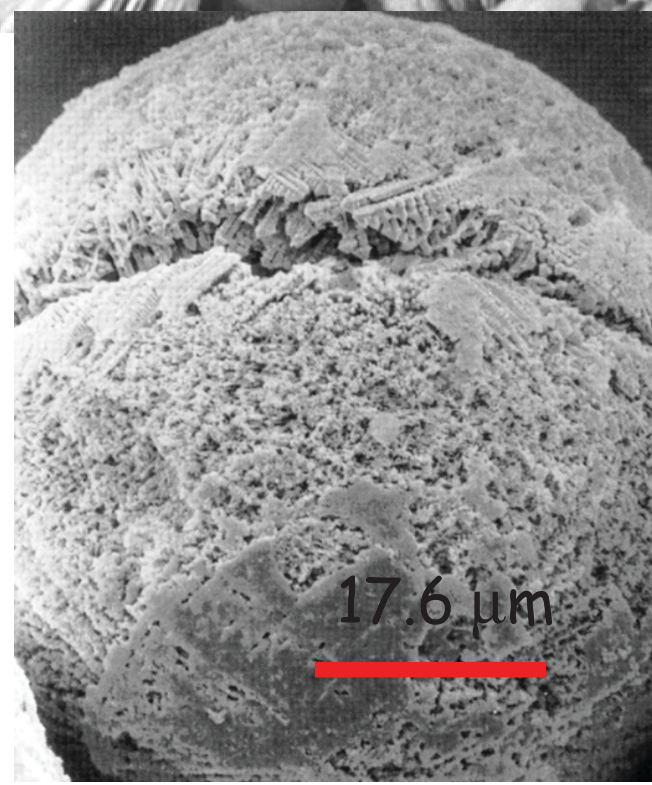
Sources of magnetic minerals

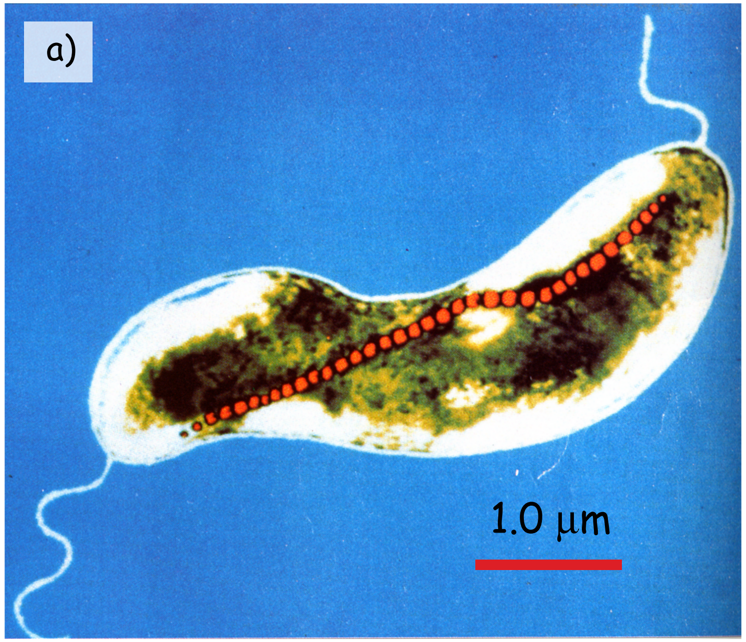
- Igneous and metamorphic processes
- Soil formation and diagenesis
- Industrial pollution
- cosmic dust
- Bacteria

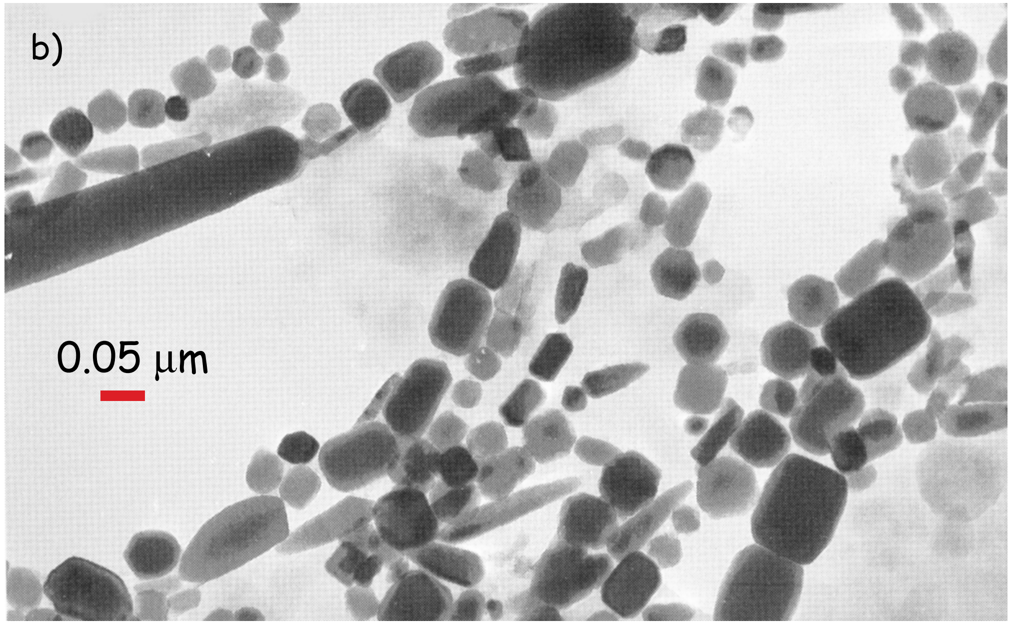



10μm


2 μm


17.6 μm


a)
1.0 μm


b)
0.05 μm