

Petrofyzika – Magnetické vlastnosti hornin



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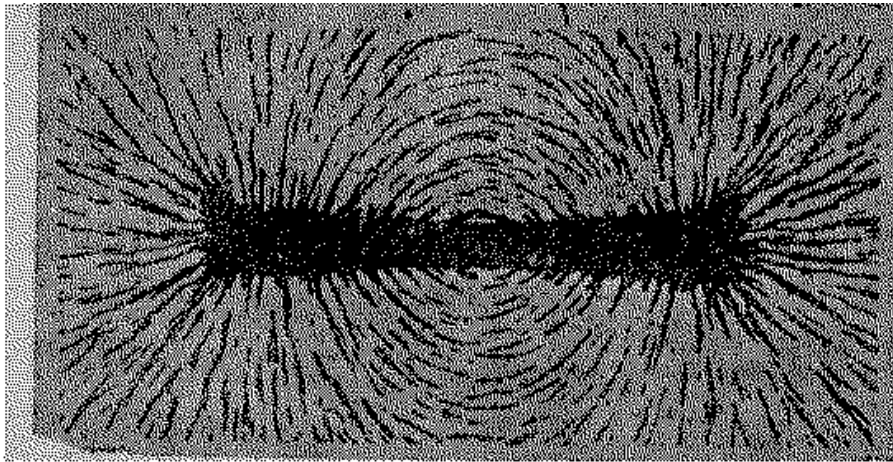
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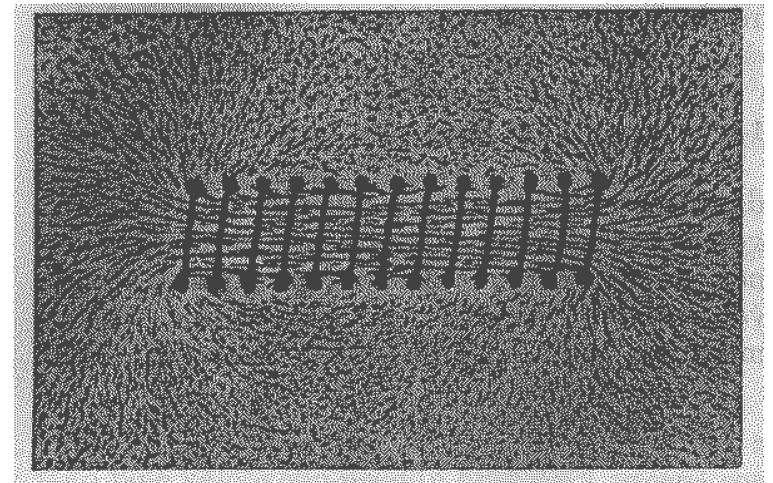
Institute of Geology of the CAS, v. v. i.

Magnetic Field – magnet and/or coil fed by electrical current exerts force effect on magnetic particles in its vicinity

Bar Magnet



Solenoid



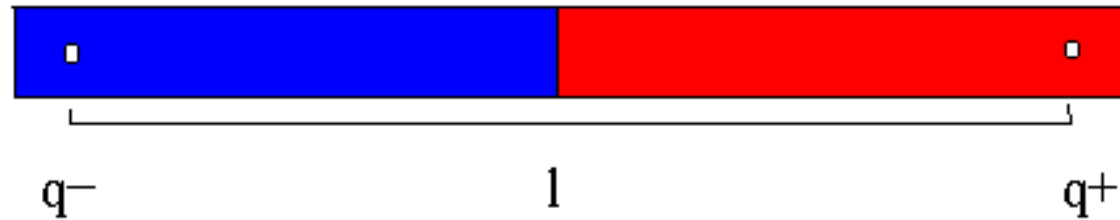
lines of magnetic flux can be visualized by saw dust

DIPOLE CHARACTER OF MAGNETISM



magnets remain dipoles even after cutting them into pieces

Magnetický moment, magnetizace, magnetická susceptibilita



$$m = ql$$

m – magnetic moment
 q - magnetic charge
 l - distance

Magnetization $M = \Sigma m/v$ [A/m]

Magnetic susceptibility k [10^{-6} SI]

Magnetization induced by field $M = k H$

Magnetization of rocks $M = kH + \mathbf{NRM}$

M – magnetization, v - specimen volume

k – magnetic susceptibility, H – intensity of magnetic field \mathbf{NRM} – natural remanent magnetization [A/m]

Remanentní a indukovaná magnetizace

- Stupeň namagnetování látky v magnetickém poli popisuje magnetizace

$$\bullet \mathbf{M} = \mathbf{M}_i + \mathbf{M}_r \text{ [A/m]}$$

indukovaná magnetizace

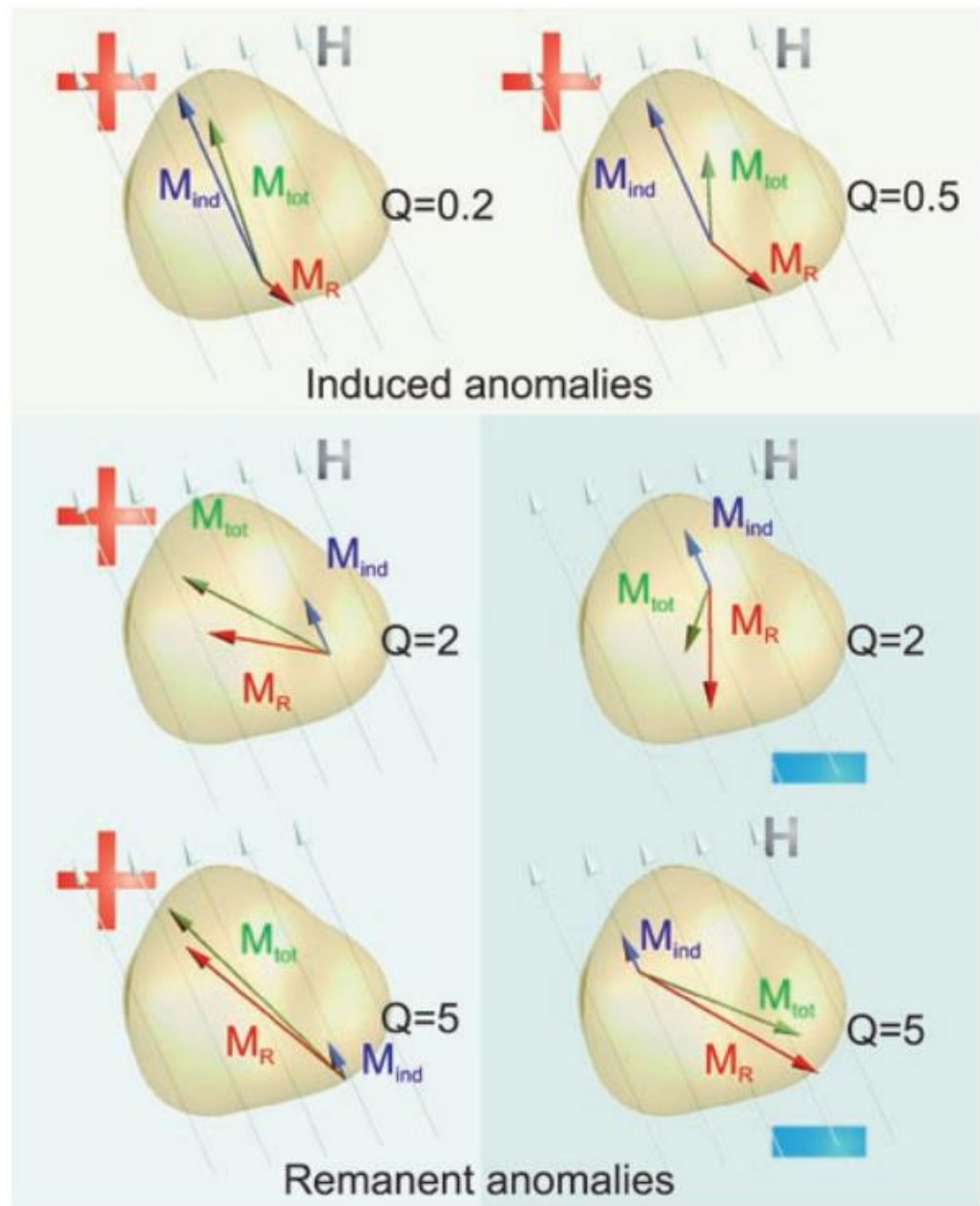
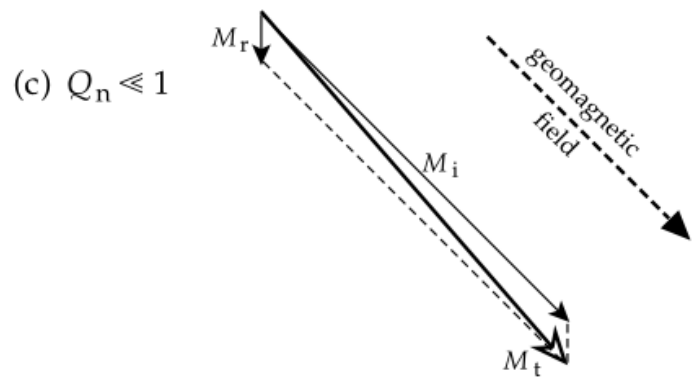
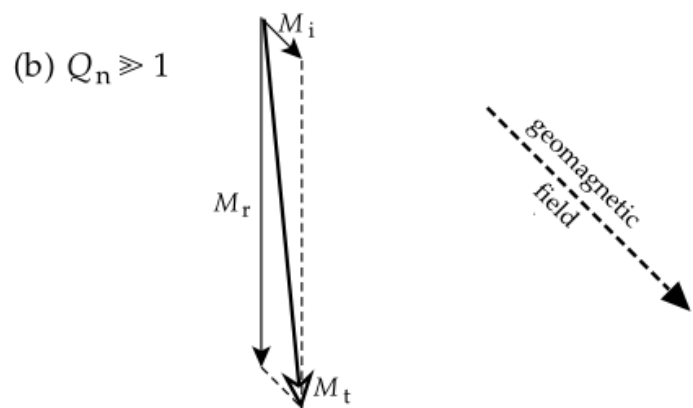
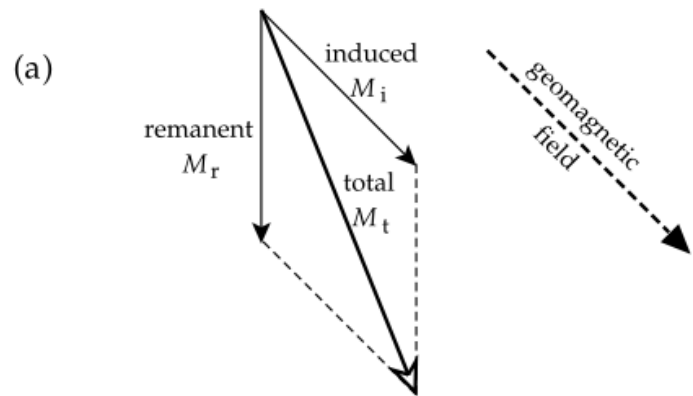
remanentní magnetizace

$$\mathbf{M}_i = k \mathbf{H}$$

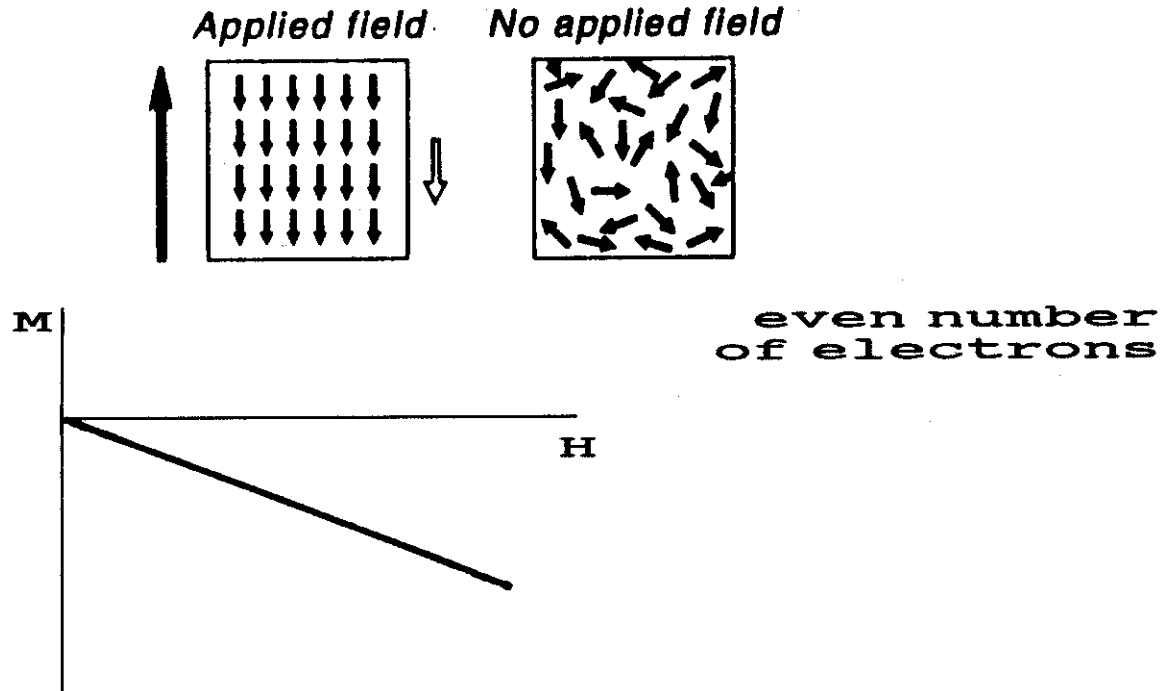
magnetická susceptibilita

$$\mathbf{Q} = \mathbf{M}_r / \mathbf{M}_i$$

Königsberger ratio



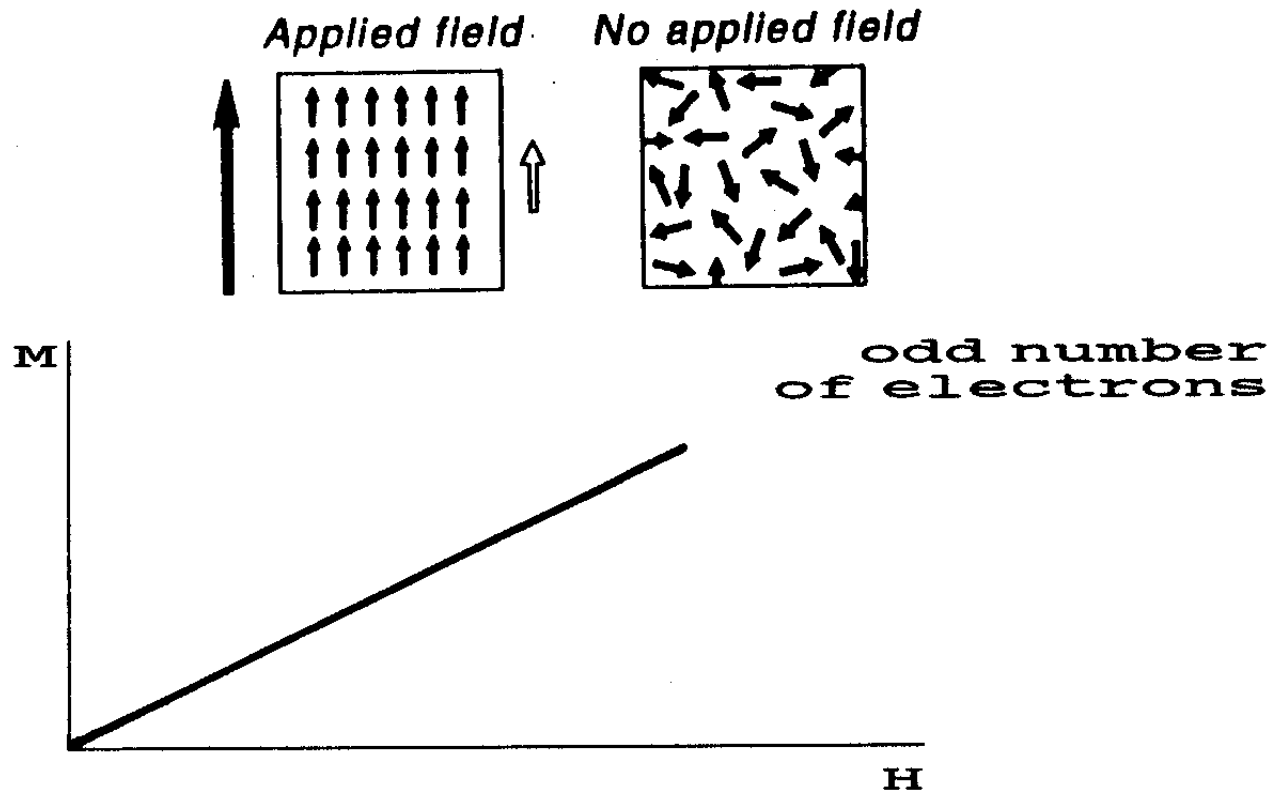
DIAMAGNETISM



quartz, $k = -15.4 \times 10^{-6}$
orthoclase, $k = -13.7 \times 10^{-6}$
calcite, $k = -13.1 \times 10^{-6}$

opal, $k = -12.9 \times 10^{-6}$
halite, $k = -10.3 \times 10^{-6}$
aragonite, $k = -15.0 \times 10^{-6}$

PARAMAGNETISM



olivine, $k = 124 \text{ to } 4270 \times 10^{-6}$

pyroxene, $k = 121 \text{ to } 3700 \times 10^{-6}$

hornblende, $k = 750 \text{ to } 1368 \times 10^{-6}$

dolomite, $k = 11.3 \times 10^{-6}$

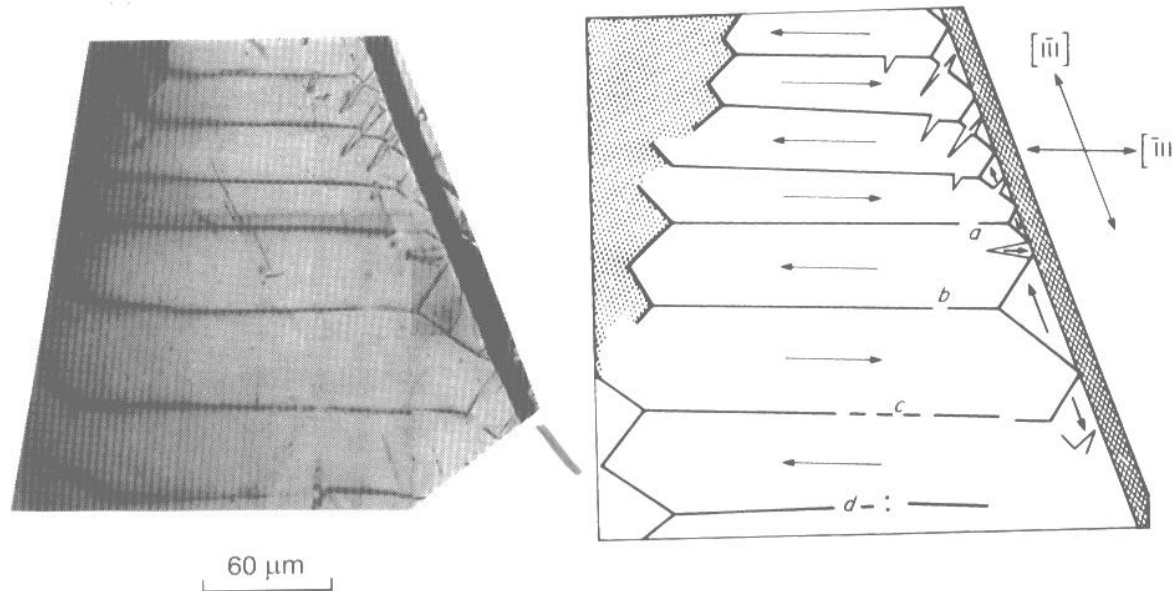
micas, $k = 36 \text{ to } 3040 \times 10^{-6}$

garnets, $k = 502 \text{ to } 6780 \times 10^{-6}$

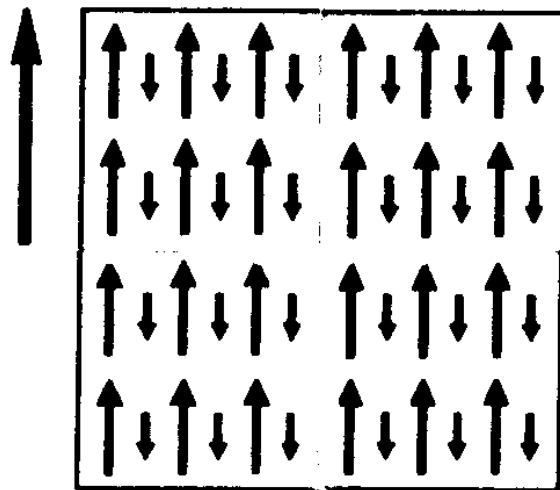
FERROMAGNETISM *sensu lato*

Ferrimagnetism, Antiferromagnetism, Ferromagnetism *sensu stricto*

Magnetic Domains – regions with spontaneously oriented magnetic moments

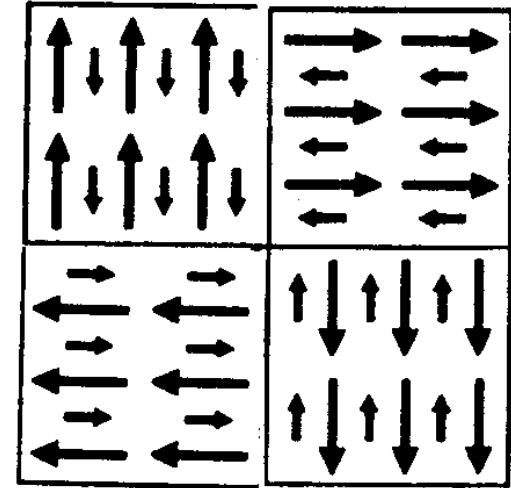


FERRIMAGNETISM



Applied field.

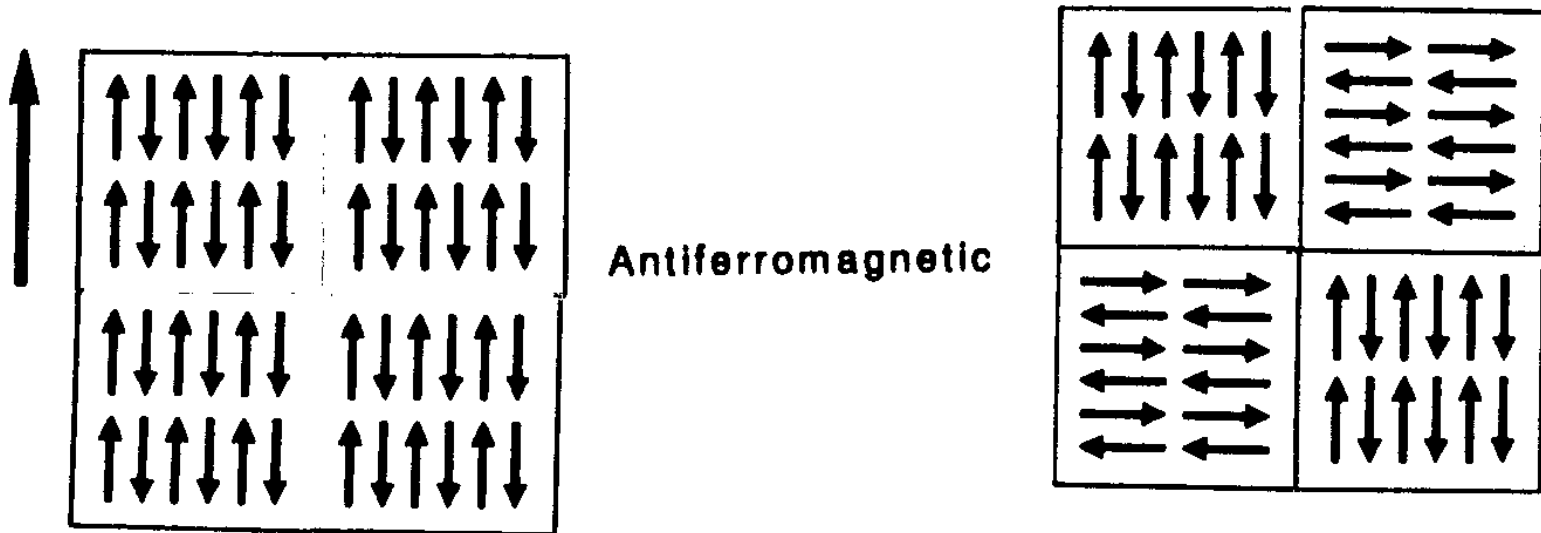
Ferrimagnetic



No applied field

Magnetite, $k = 3$ to 6
Titanomagnetite, $k = 0.5$ to 3.5
monoclinic Pyrrhotite, $k = 0.2$ to 0.7

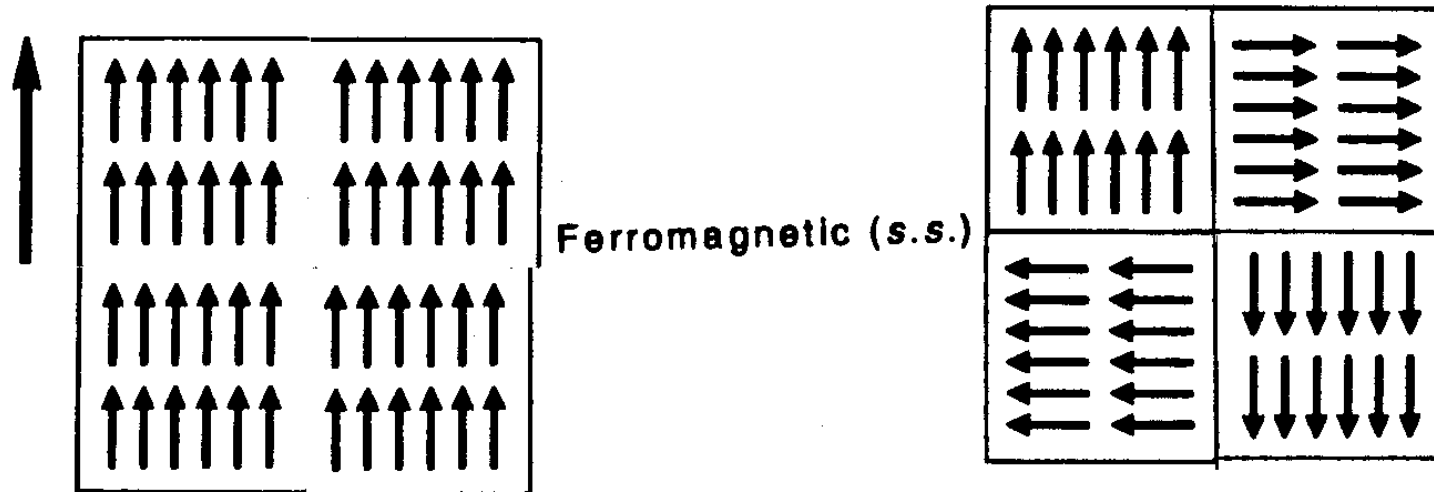
ANTIFERROMAGNETISM



Hematite,
hexagonal Pyrrhotite

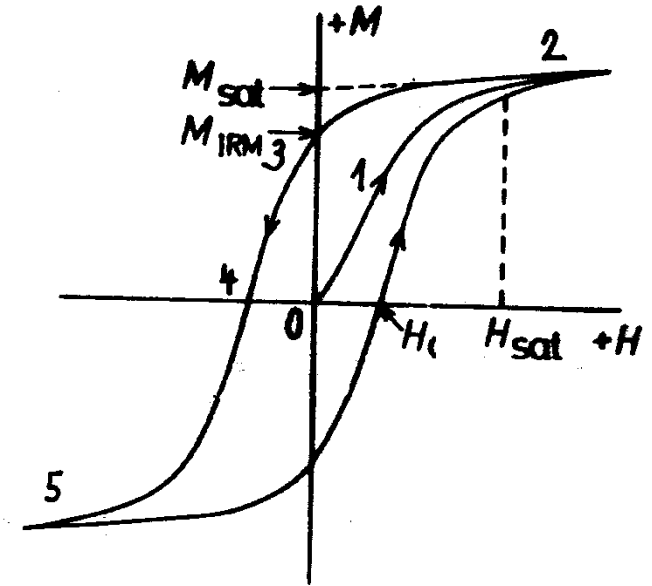
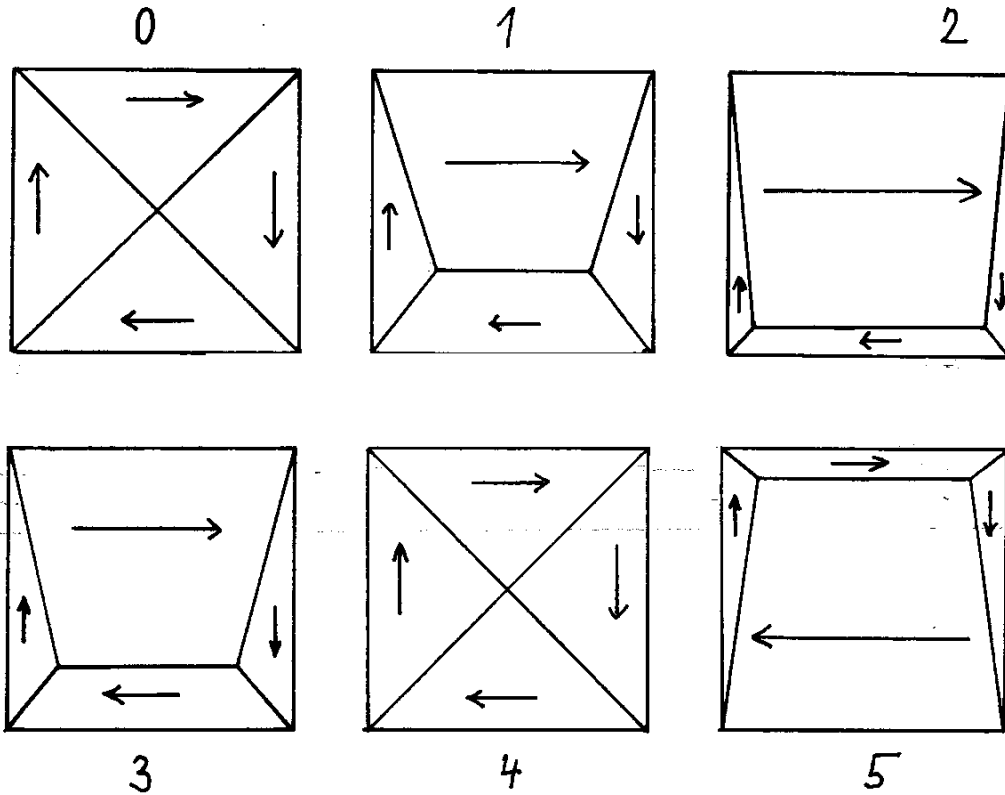
$k = 0.001$ to 0.2

FERROMAGNETISM *sensu stricto*



Metallic Iron

Hysterezní smyčka



M_{sat} – saturation magnetization, H_{sat} – saturating field
 M_{rm} – remanent magnetization, H_{cr} – coercive force

Hysterezní smyčka

k - initial susceptibility

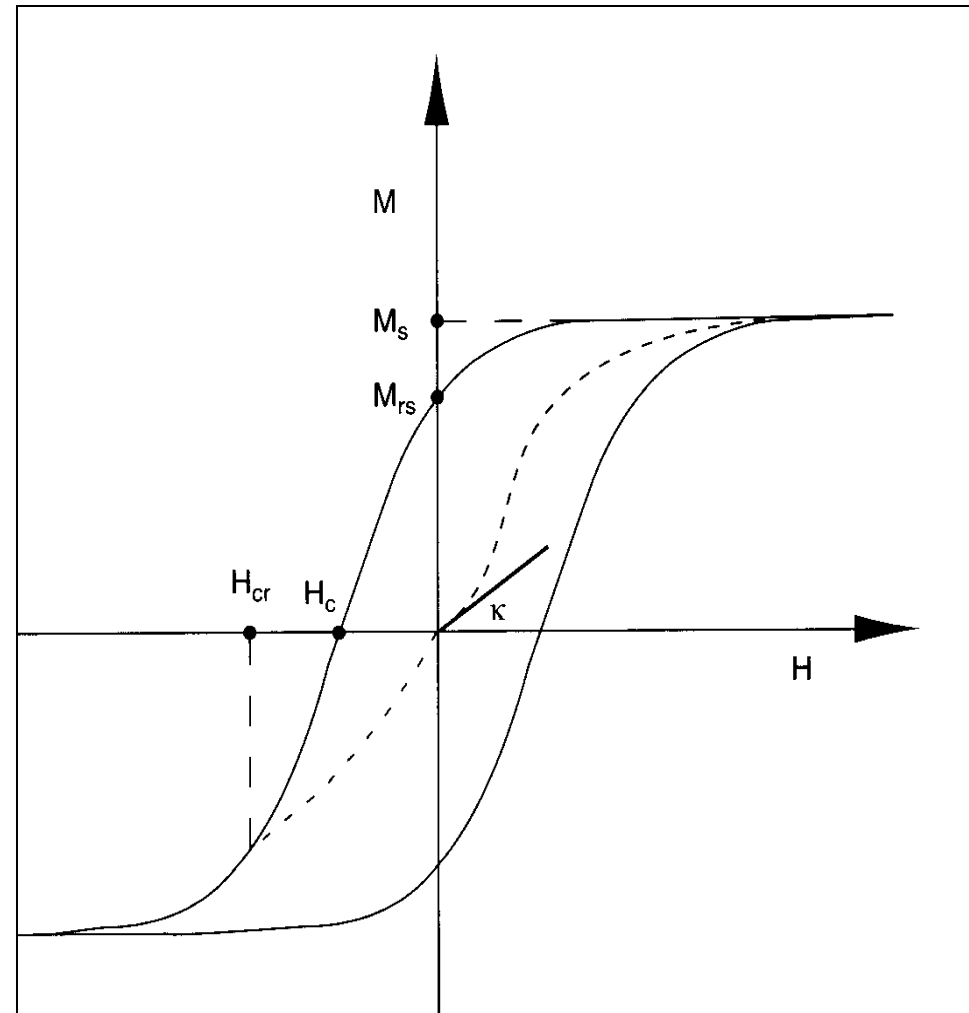
H_c - coercive force

H_{cr} - coercivity of remanence

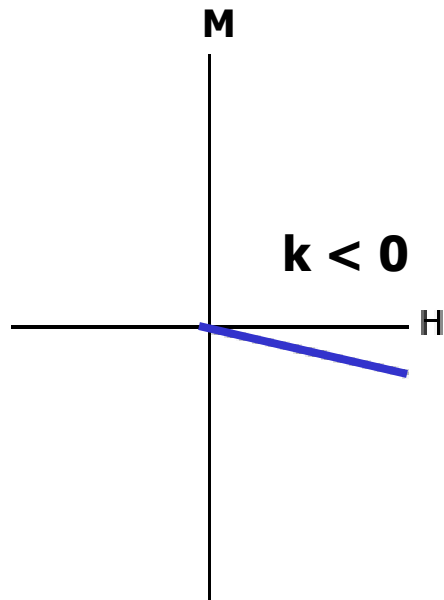
Initial susceptibility – počáteční susceptibilita

Coercive force - koercitivní síla

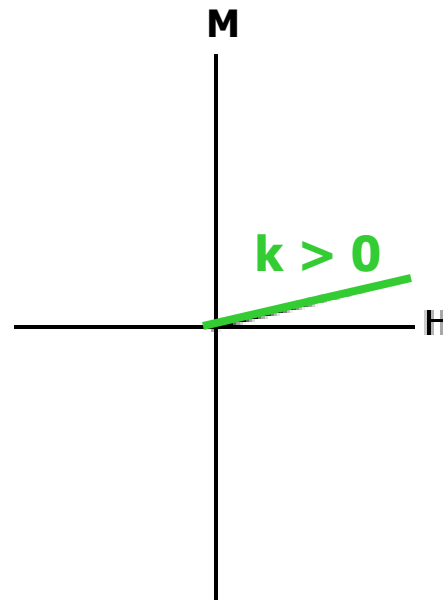
Důležité : susceptibilita se mění s polem, jen v počáteční oblasti je konstantní



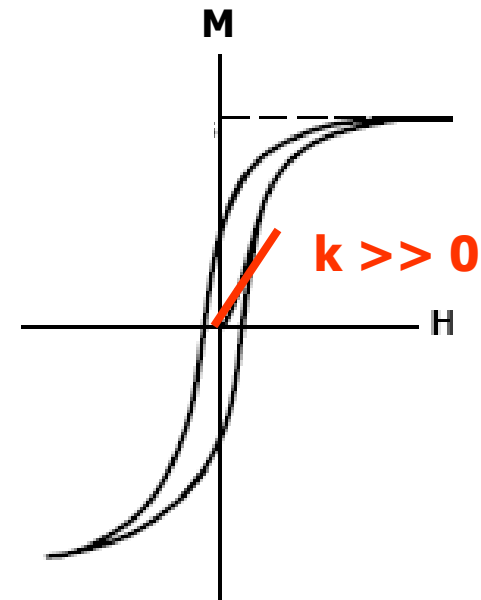
Diamagnetismus



Paramagnetismus



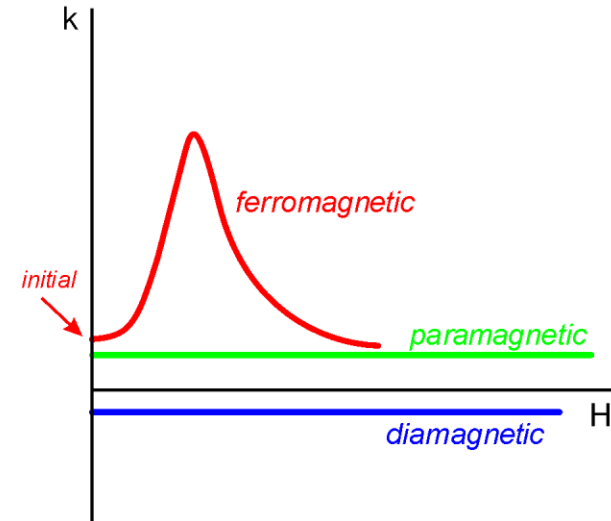
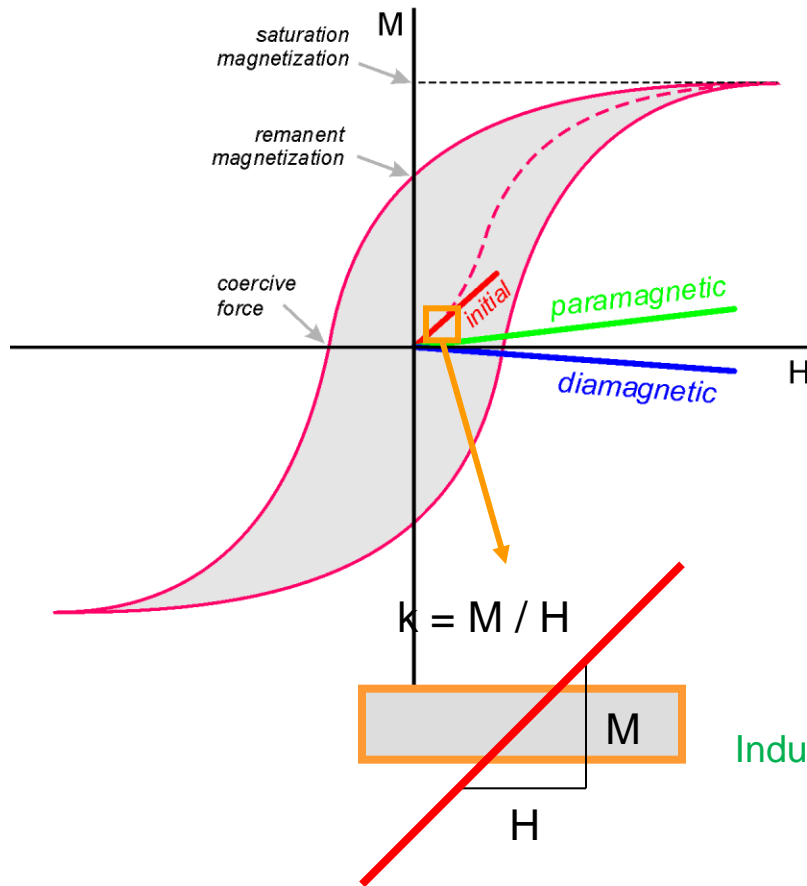
Feromagnetismus



Indukovaná magnetizace působí proti směru vnějšího pole	Indukovaná magnetizace ve směru vnějšího pole	Složitější závislost mezi vnějším polem a indukovanou magnetizací
Magnetická susceptibilita je relativně malá, záporná	Magnetická susceptibilita je relativně malá, kladná	Magnetická susceptibilita je relativně vysoká
Bez vnějšího pole je indukovaná magnetizace rovna nule	Bez vnějšího pole je indukovaná magnetizace rovna nule	Bez vnějšího pole zůstává remanentní (zbytková) magnetizace
<i>křemen</i> <i>kalcit</i>	<i>pyroxeny</i> <i>amfiboly</i> <i>olivín</i> <i>slídy</i>	<i>železo</i> <i>magnetit</i> <i>hematit</i> <i>pyrhotin</i>

Magnetická susceptibilita

- **Magnetic susceptibility** is the ability to acquire induced magnetization, i.e. ability to get magnetized



$$M = M_i + M_r$$

Induced magnetization

Remanent magnetization

$$M_i = k \times H$$

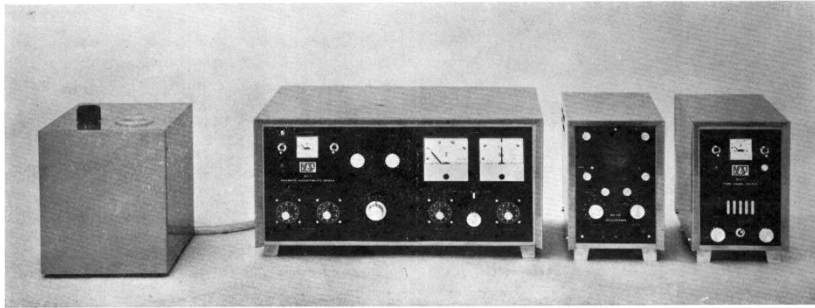
Magnetic susceptibility

$$k = M_i / H$$

Laboratorní měření magnetické susceptibility

Kappabridge (and PC) evolution

KLY-1 (1967)



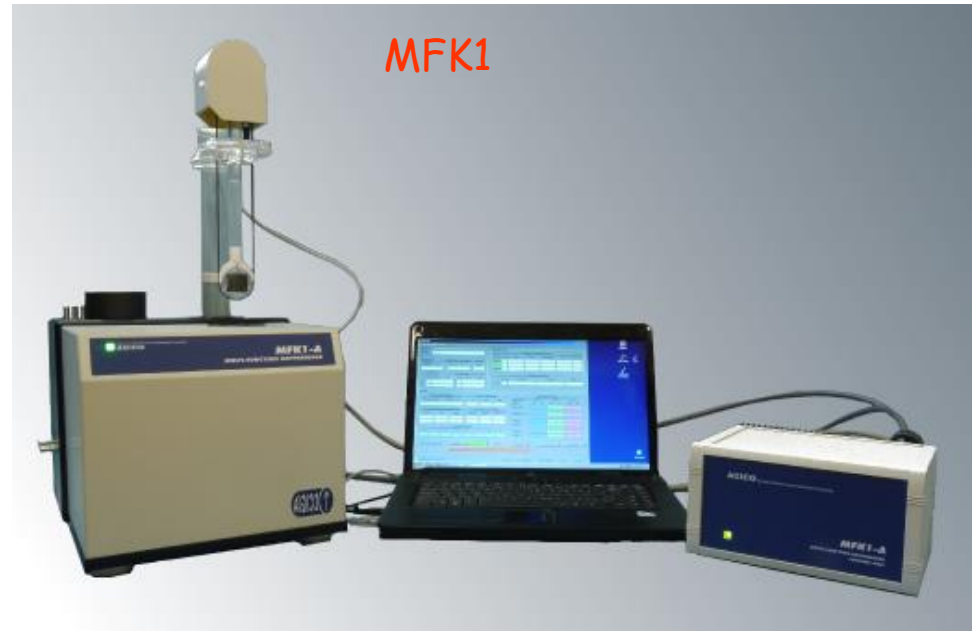
KLY-2



KLY-3 & 4



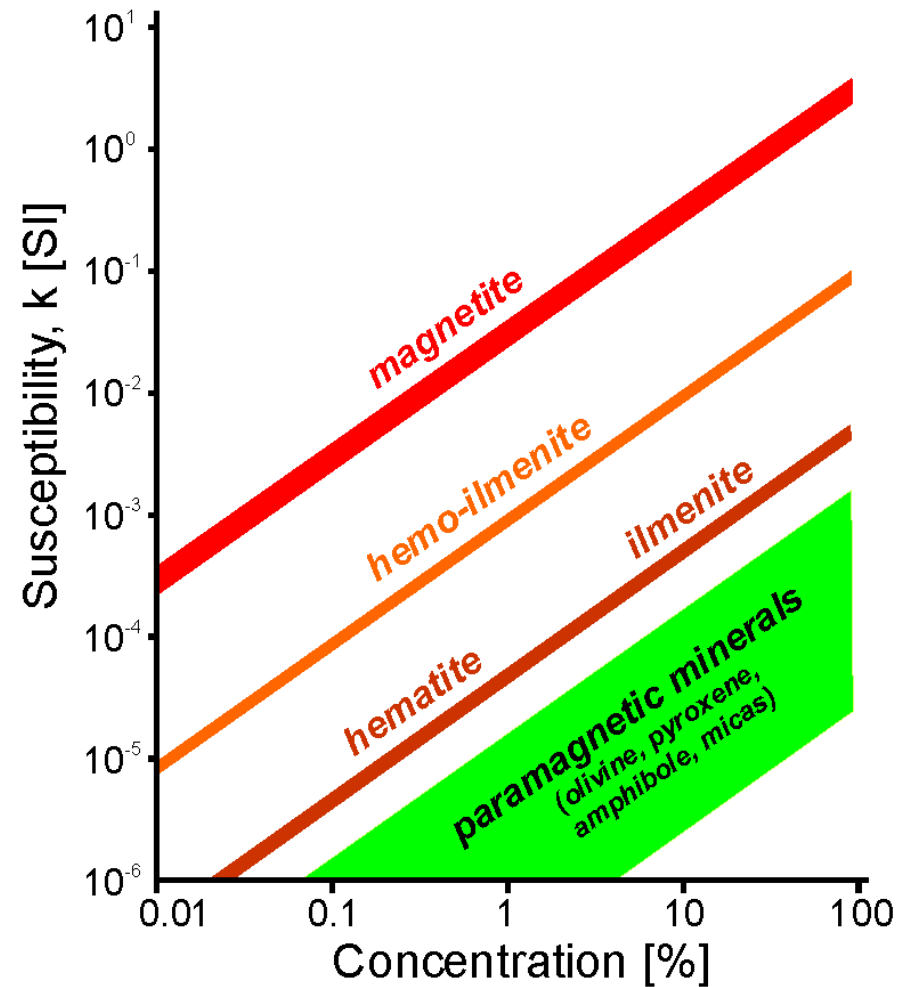
MFK1

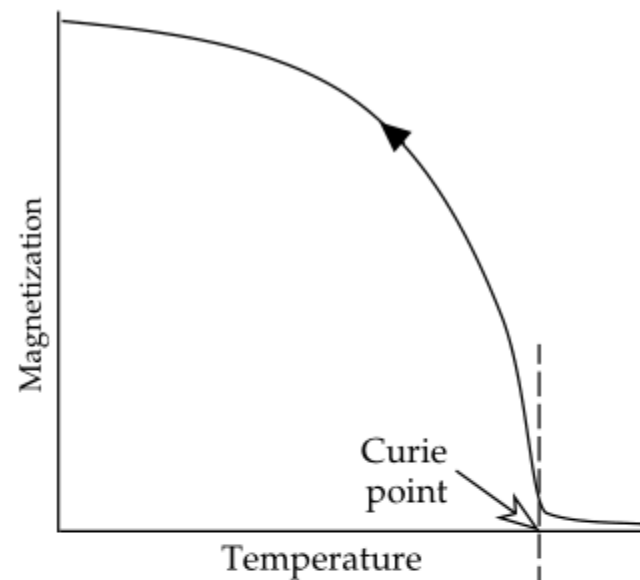
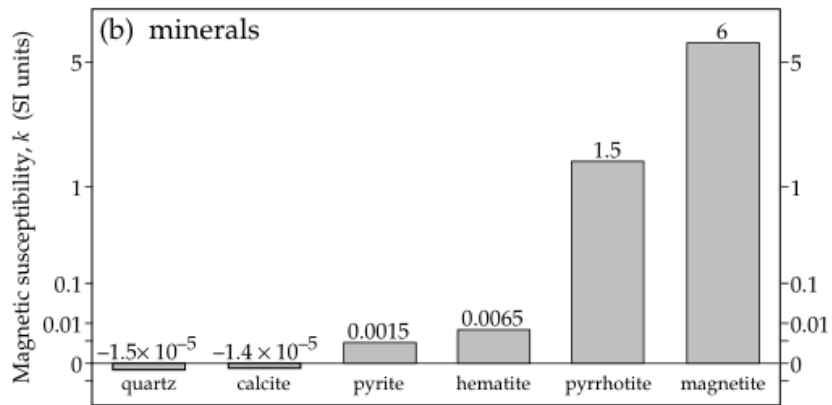
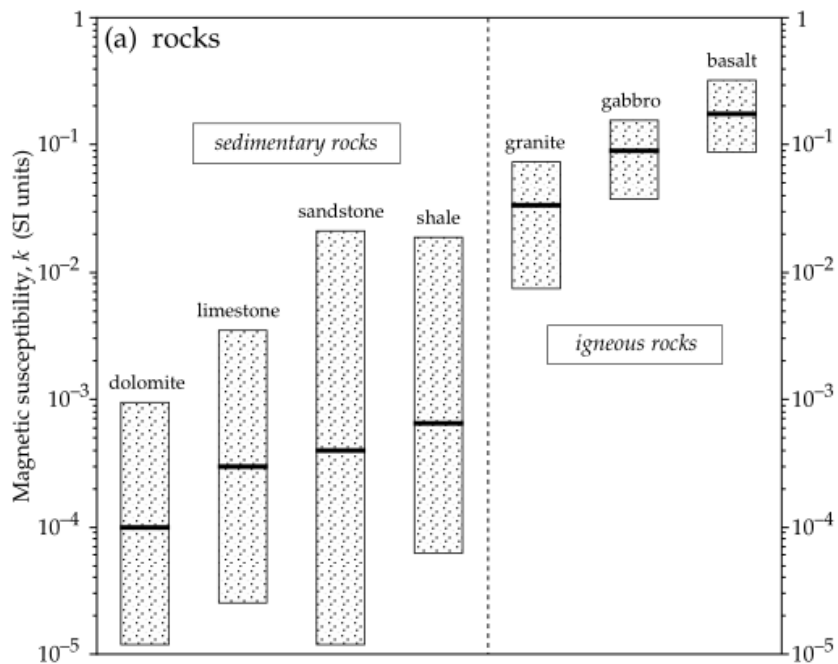


Kappametr

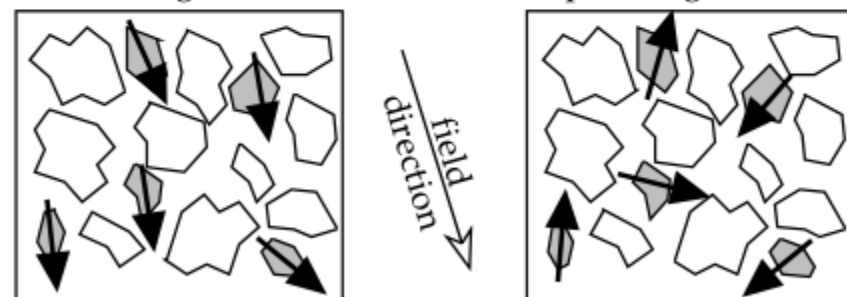





- Identification of magnetic minerals and phases
- Grain size assessment
- Paleotemperature estimation



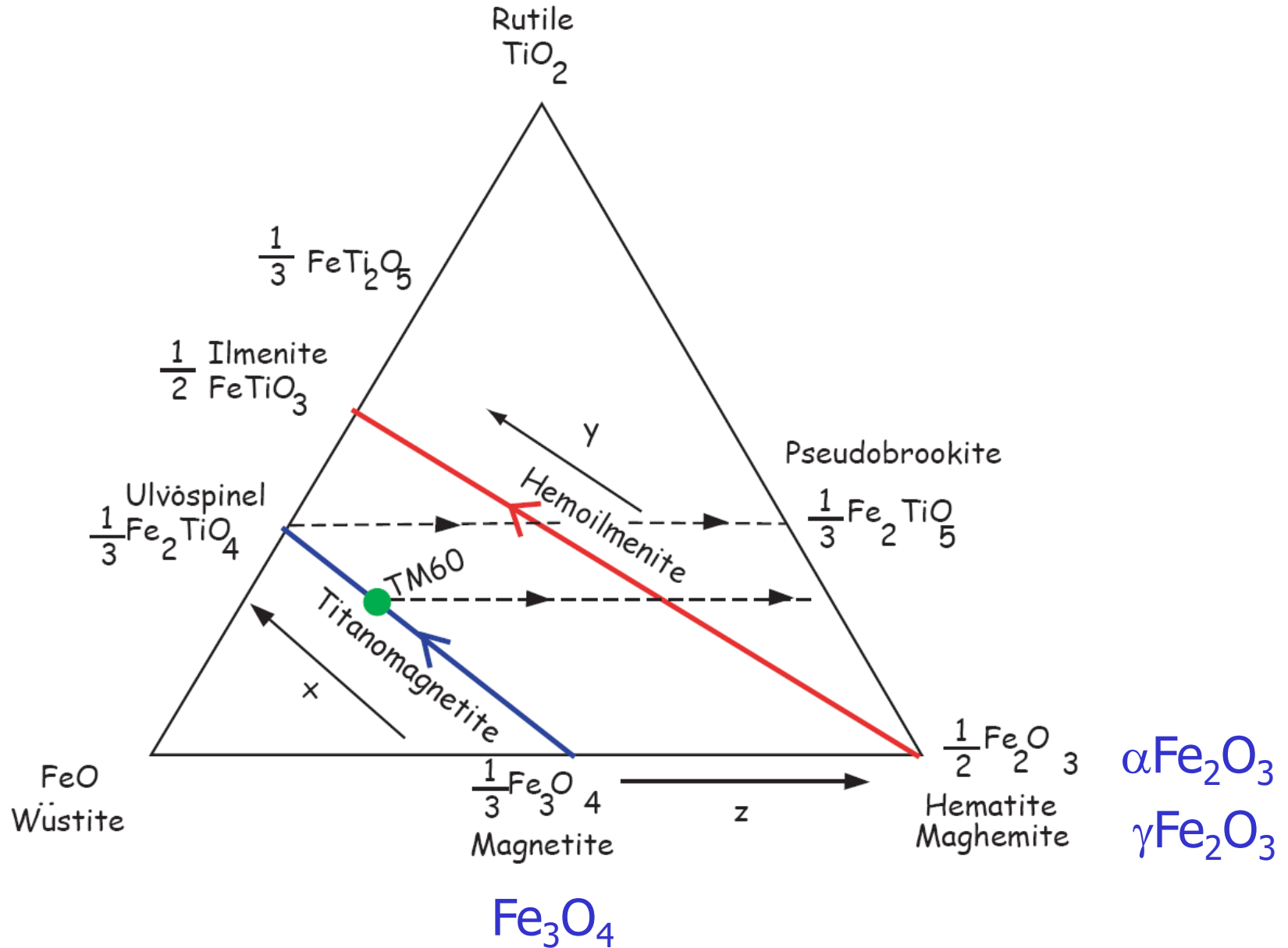


ferromagnetism ← → paramagnetism



 matrix mineral
  magnetite grain
  magnetization direction

Oxidy železa (a titanu)



Susceptibility Variation with Mineral Composition

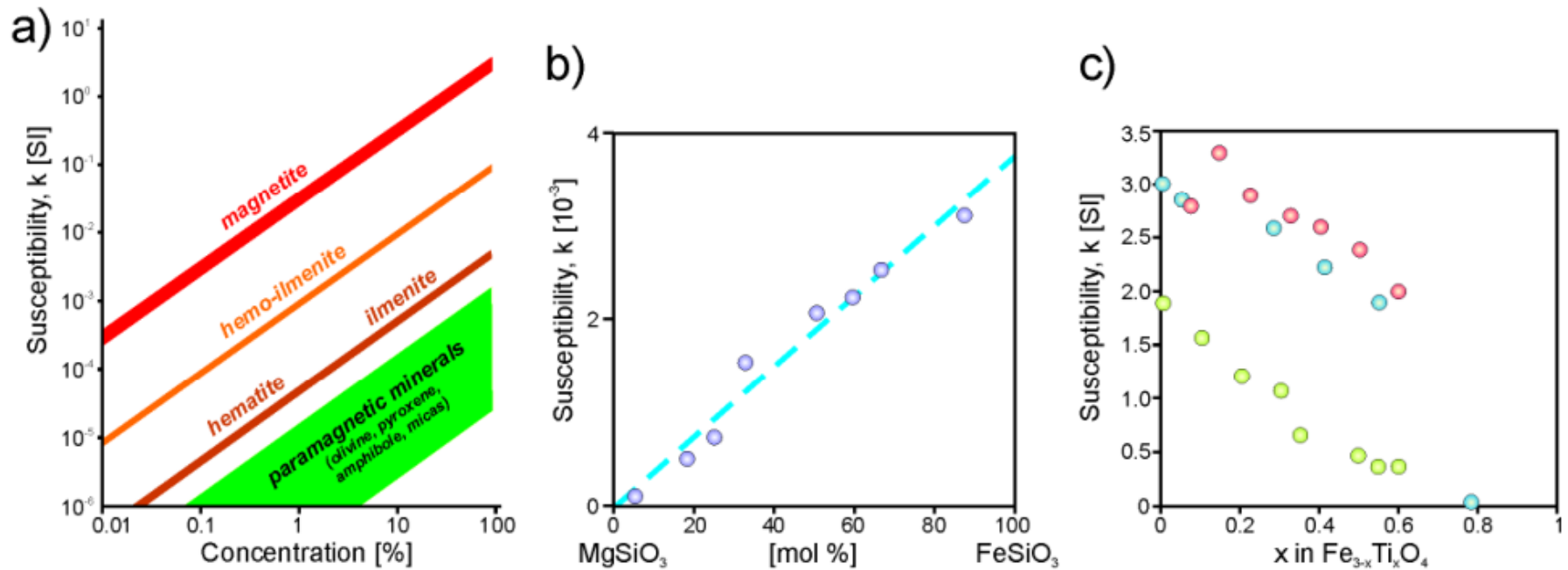
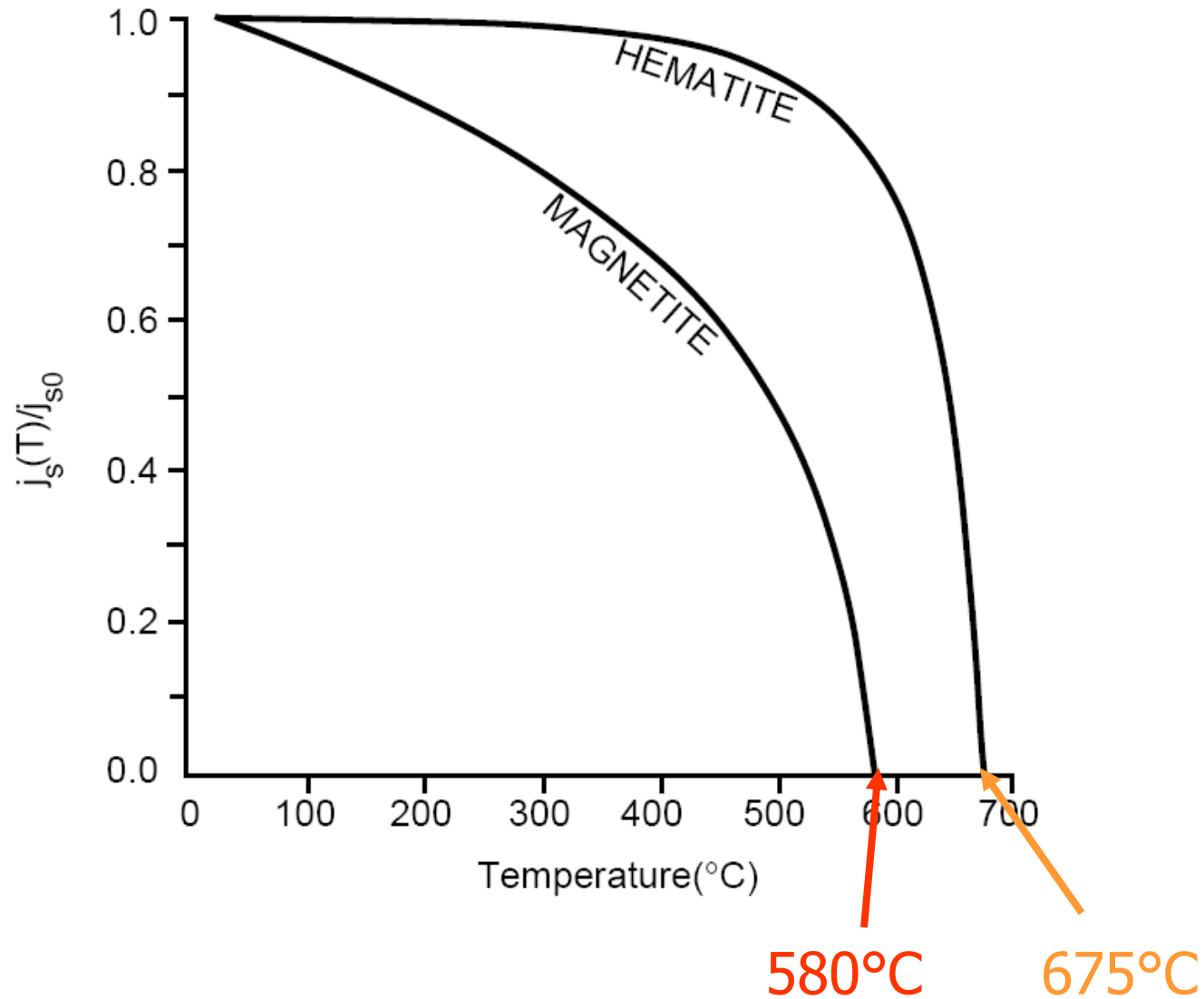
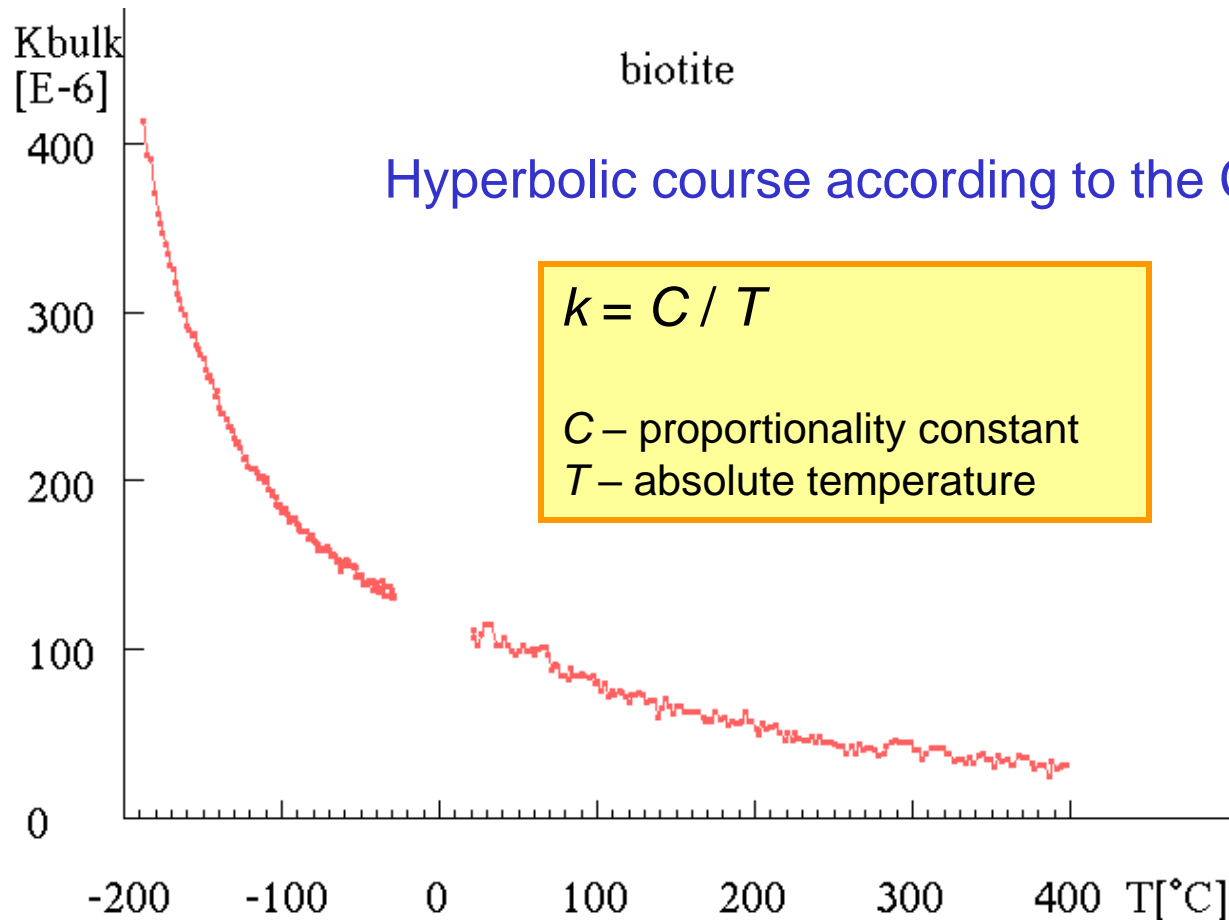


Fig. 2 Magnetic susceptibility of minerals. Adapted from Hrouda & Kahan (1991), Nagata (1961), Jackson et al. (1998).
a – mineral contributions to rock susceptibility, note that 100 % of mafic silicates contribute less than 1% of magnetite
b - susceptibility variation with chemical composition in orthopyroxene
c - susceptibility variation with chemical composition in synthetic titanomagnetite (symbols in different colours denote different experiments producing grains of different sizes)

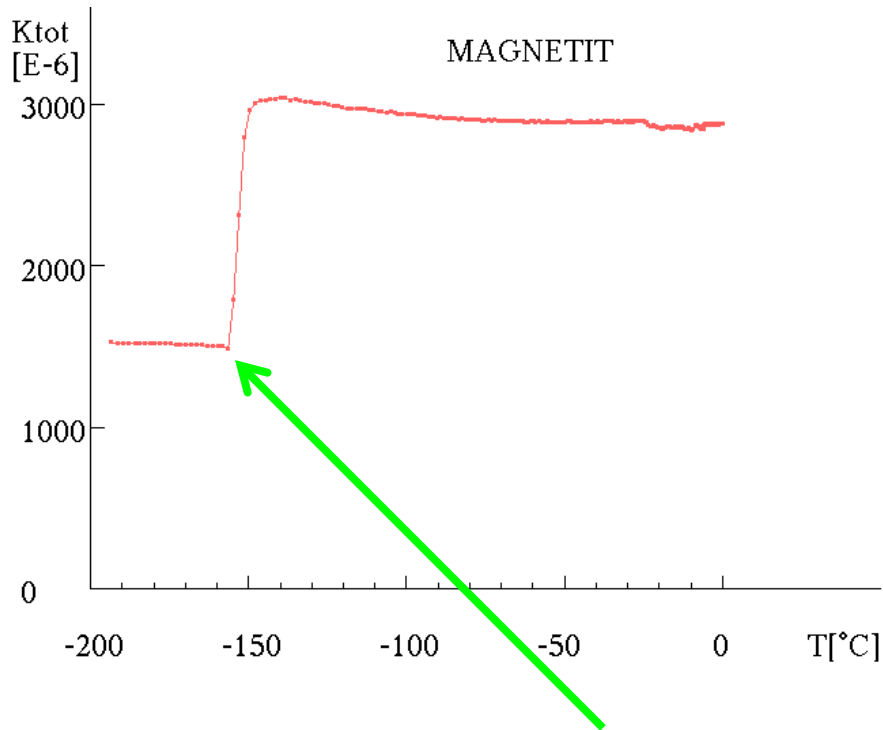
Curiova teplota ferromagnetických minerálů



Paramagnetic minerals

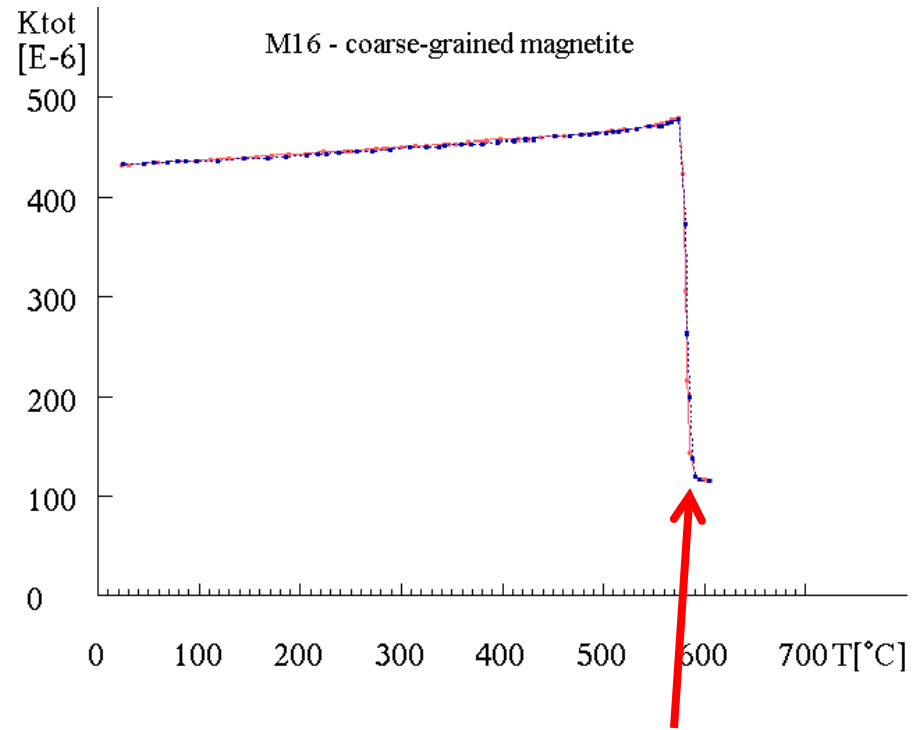


Magnetite



Verwey transition $T_v \sim -150$ $^{\circ}\text{C}$

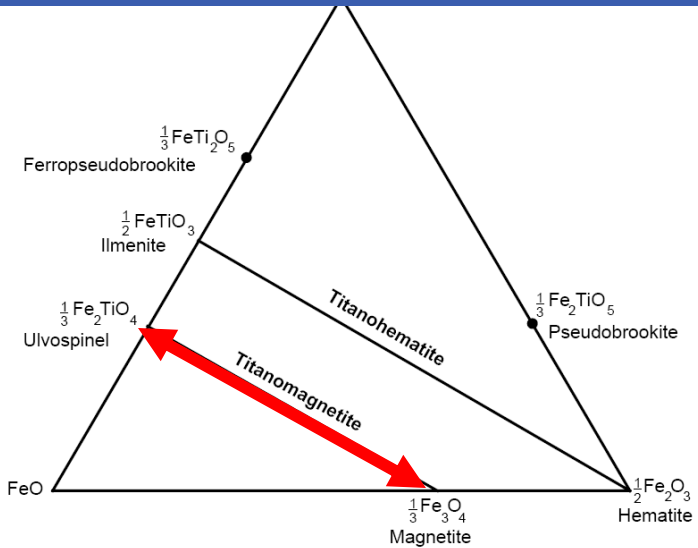
Transition from cubic to ortho-rhombic symmetry, decrease in susceptibility



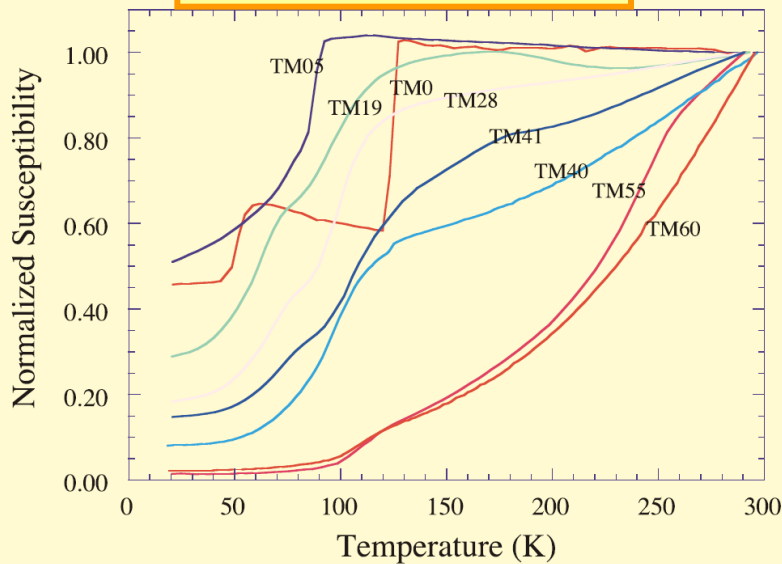
Curie temperature $T_c \sim 585$ $^{\circ}\text{C}$

Transition from ferrimagnetic to paramagnetic state, rapid decrease of susceptibility

Variation of characteristic temperatures with chemical composition in titanomagnetites

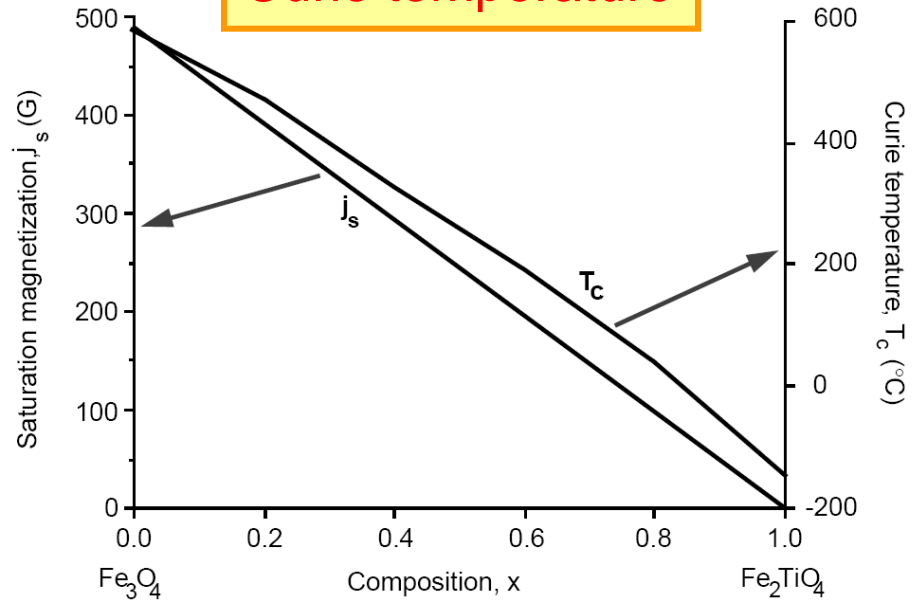


Verwey transition

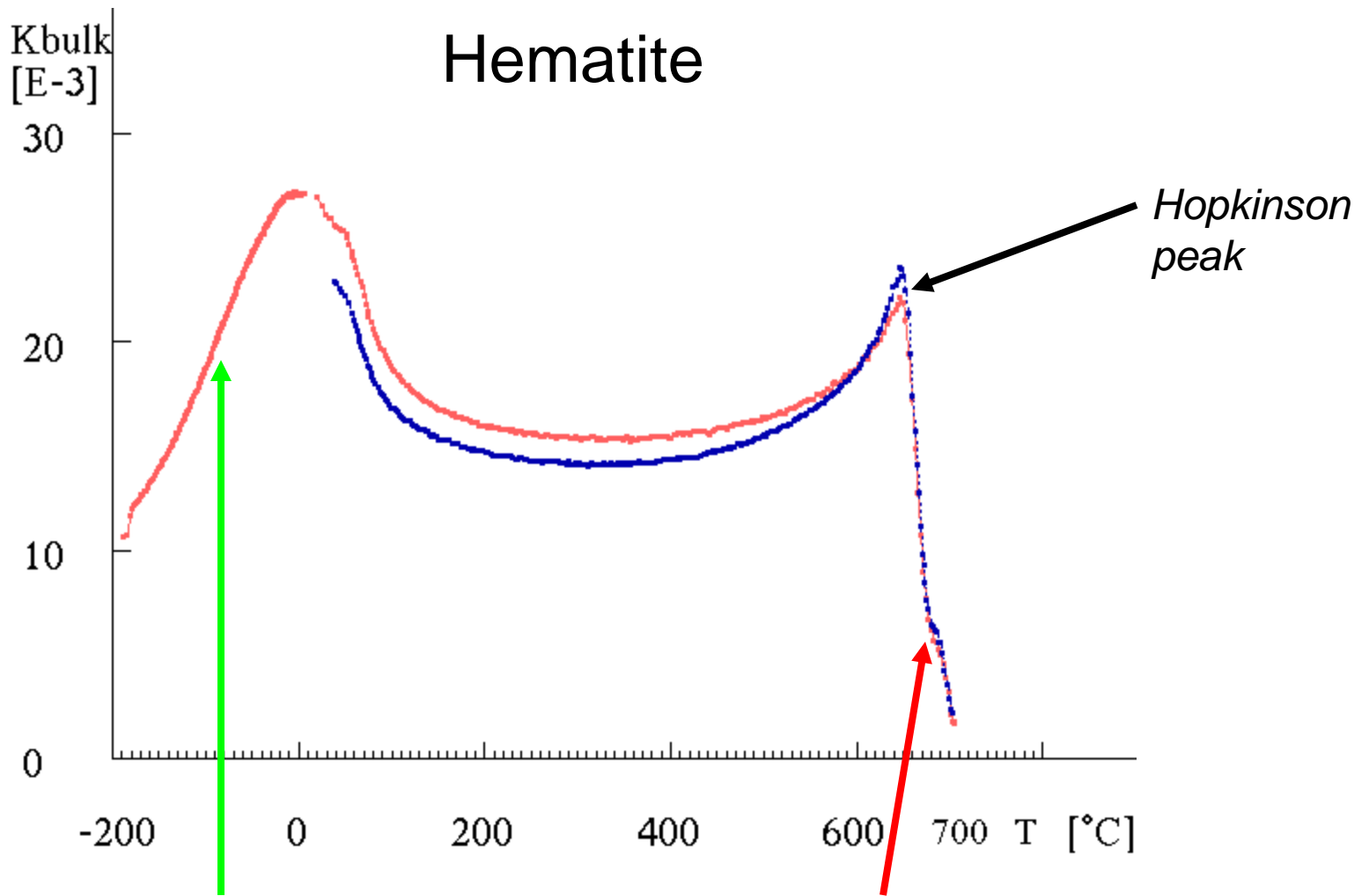


(Moskowitz et al. 1998, EPSL)

Curie temperature

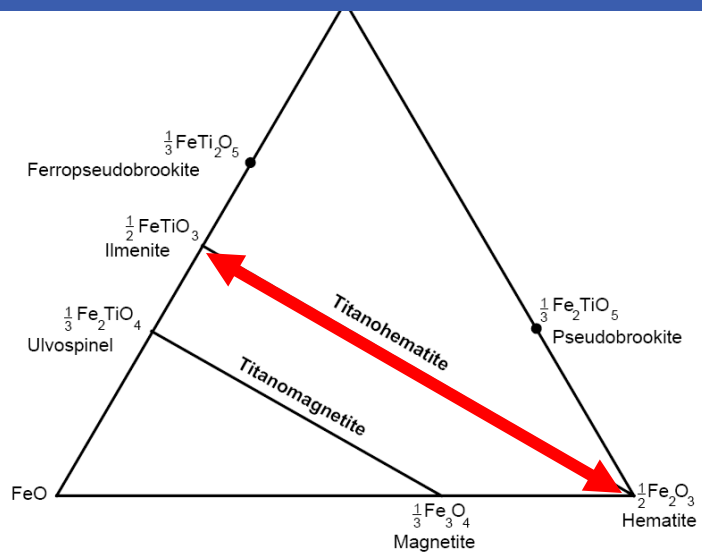


(after Nagata 1961)

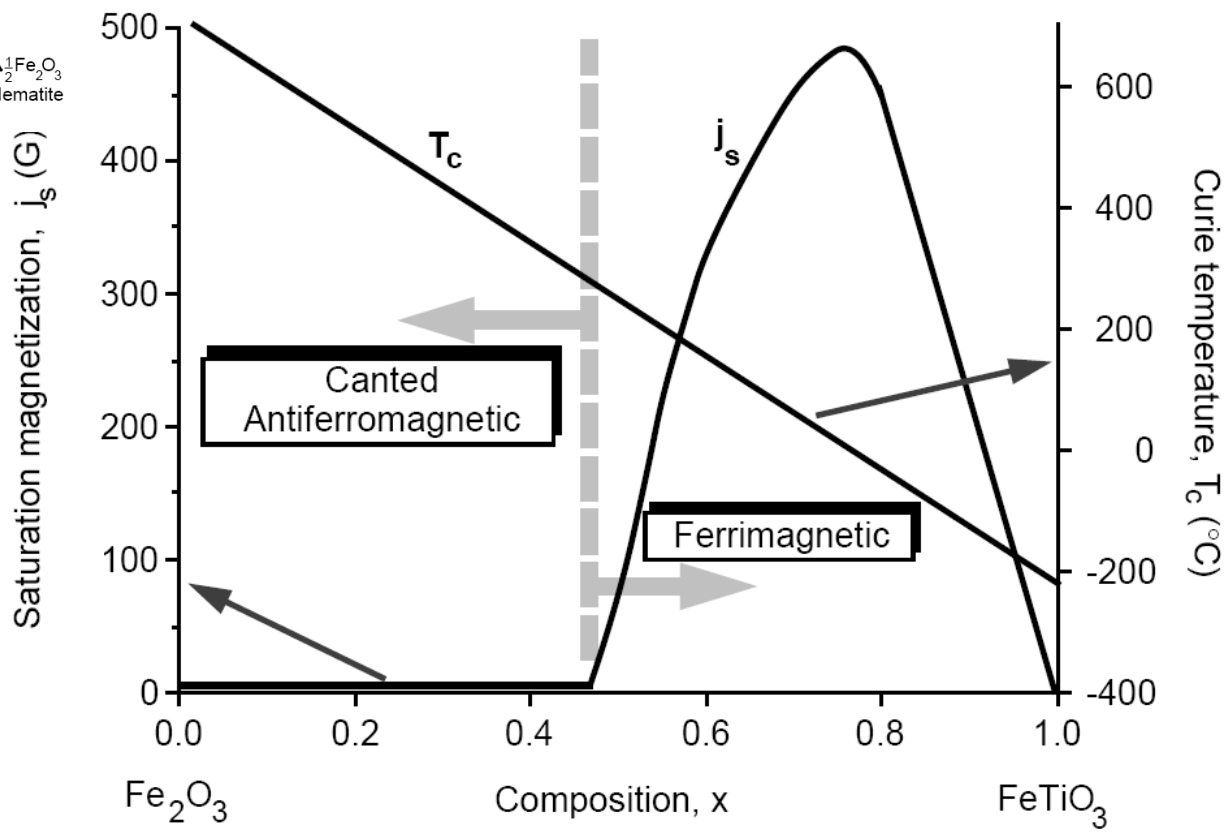


Morin transition
 $T_m \sim -20^{\circ}\text{C}$

Curie temperature
 $T_c \sim 695^{\circ}\text{C}$



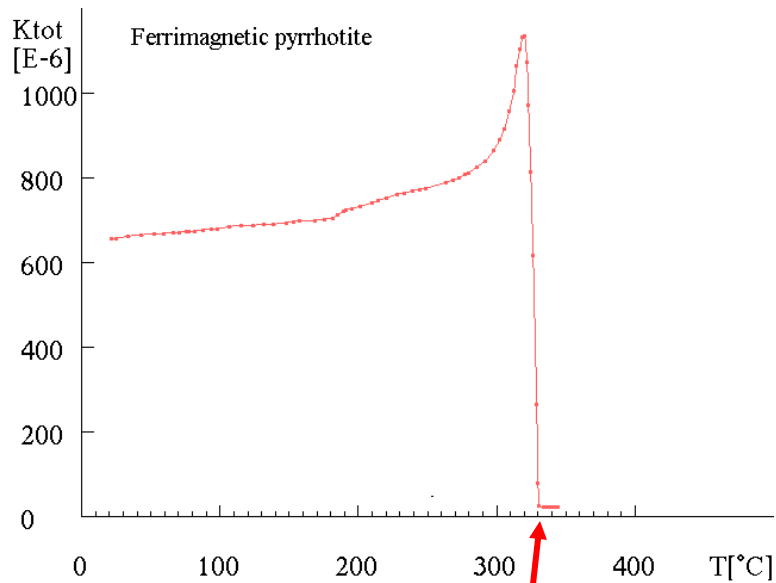
Variation of characteristic temperatures with chemical composition in titanohematites



(after Nagata 1961)

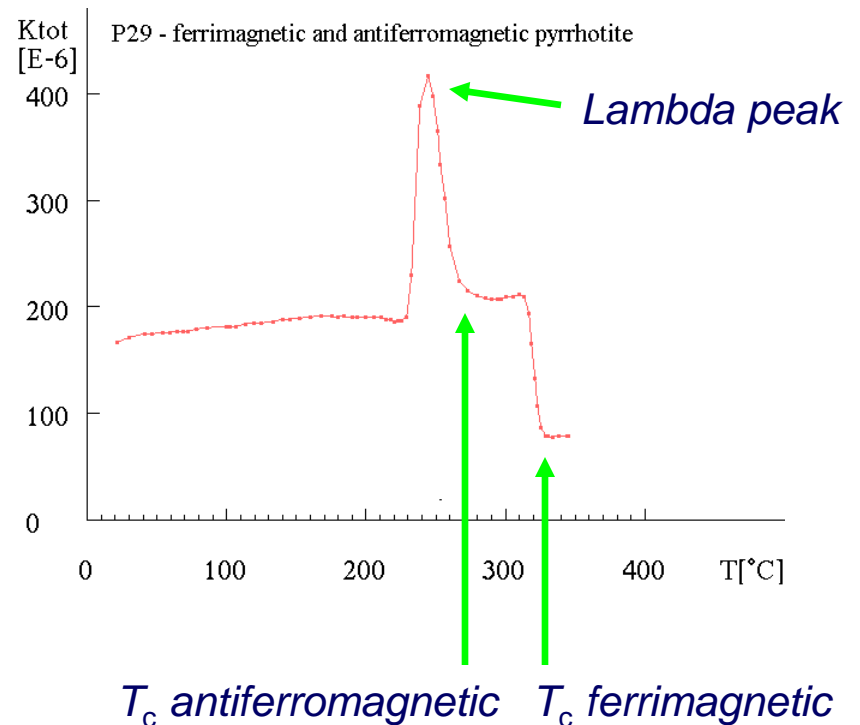
Pyrrhotite

Monoclinic pyrrhotite



Curie temperature
 $T_c = 325 \text{ }^{\circ}\text{C}$

Mixture of monoclinic and hexagonal pyrrhotite



T_c antiferromagnetic T_c ferrimagnetic

Geologické aplikace magnetické susceptibility

- Geological Mapping of Magnetically Different Rocks
- Delineation of Metamorphic Zones
- Discrimination of I-type and S-type Granites
- Indication of Alteration Processes
- Tracing Metasomatic Changes
- Interpretation of Magnetometric Anomalies
- Application to Volcanology
- Susceptibility in Economic Geology

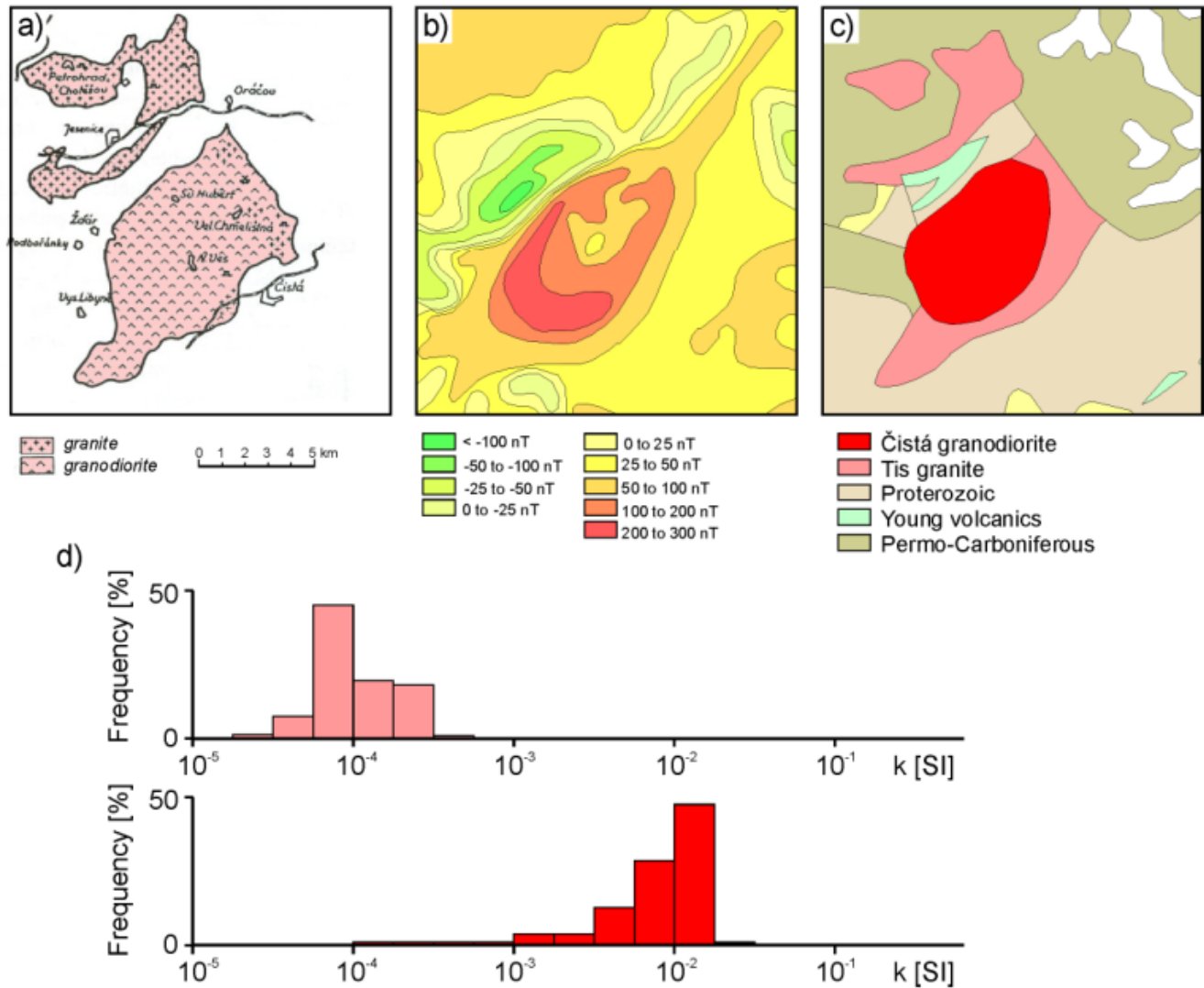


Fig. 12 Geological scheme (a) by Orlov (1933), map of magnetic ΔT anomalies (b), and recent geological scheme (c) of the eastern part of the Čistá - Jesenice massif. Adapted from Chlupáčová et al. (1975) and Šalanský (1995).

Magnetite and Ilmenite Series Granites

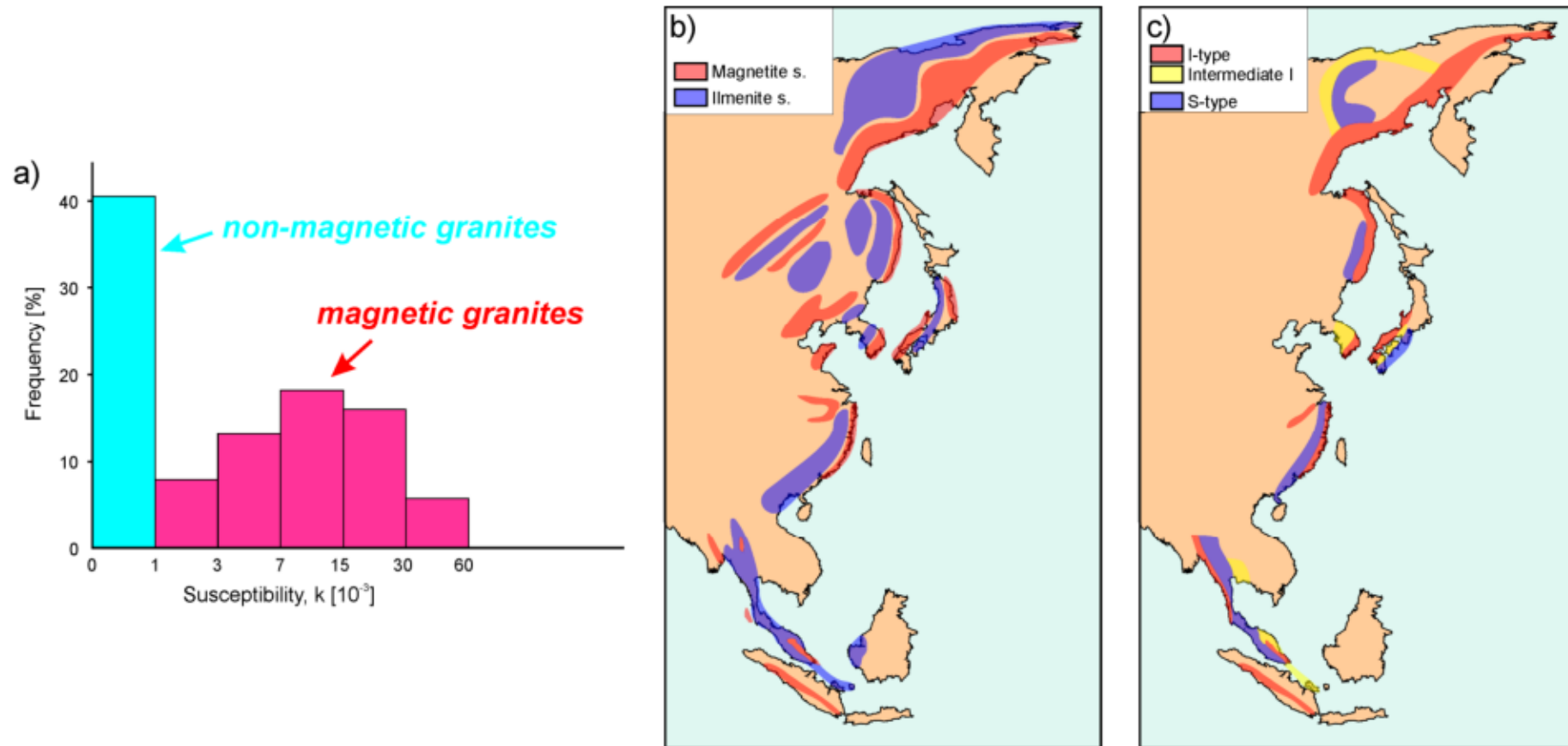
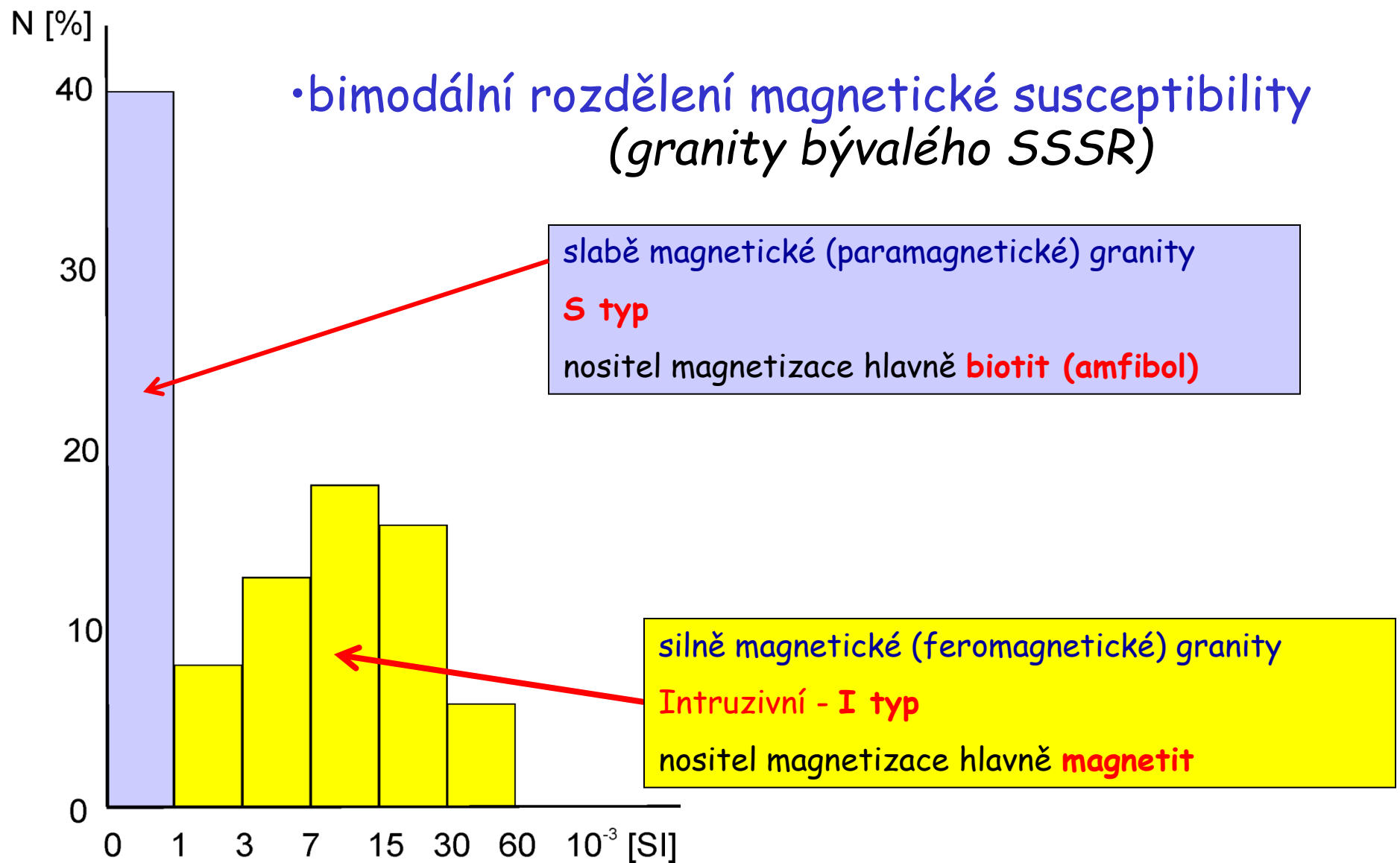
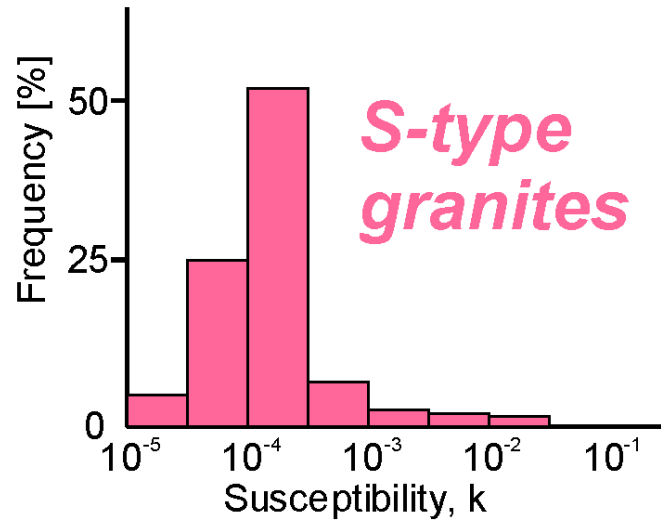
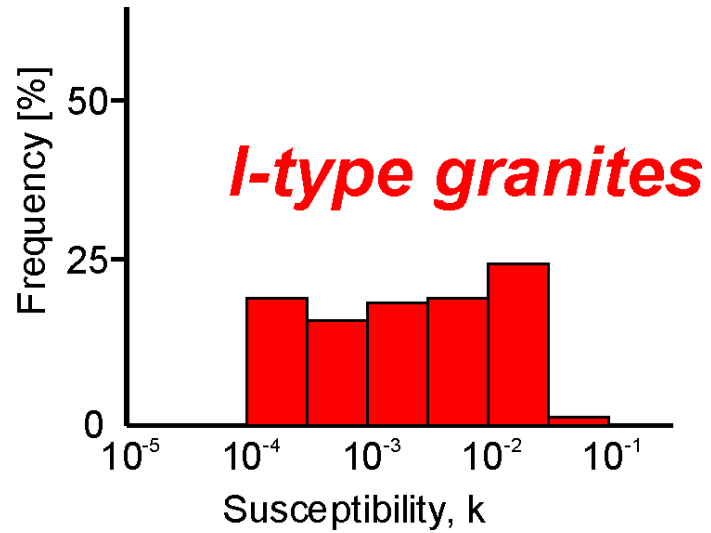
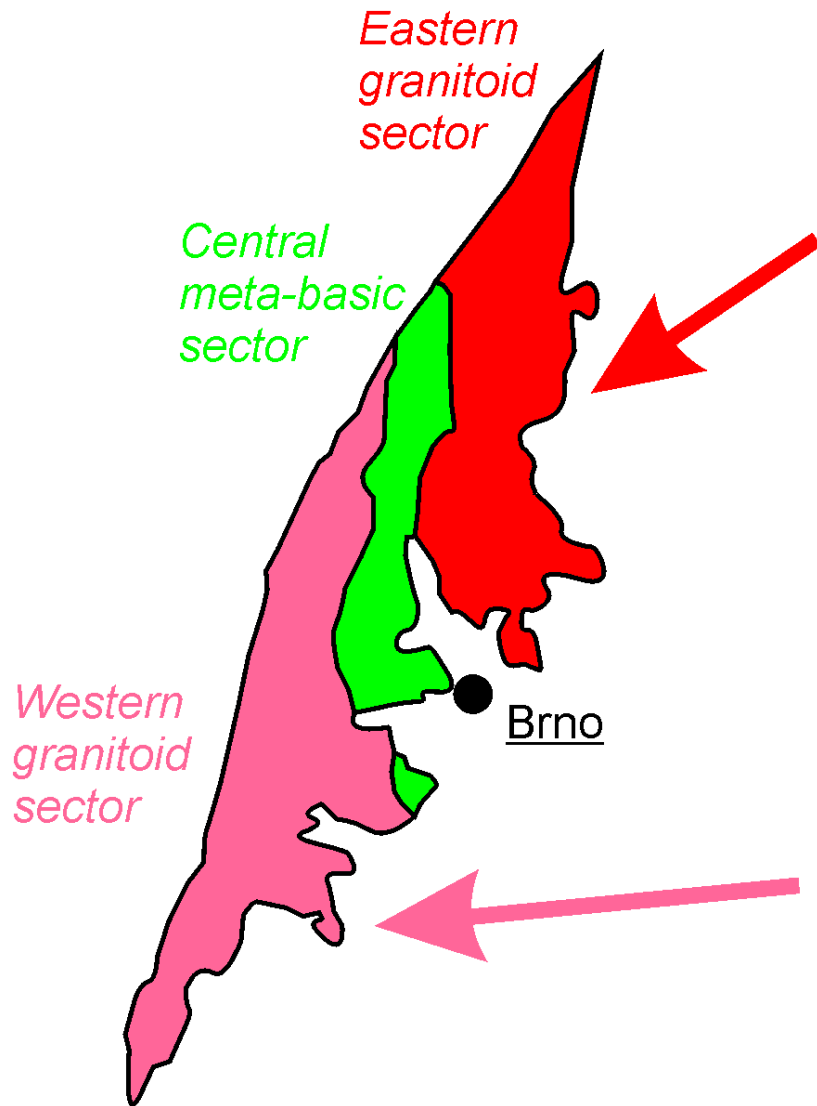


Fig. 3 Bimodal distribution of susceptibility in granitic rocks of the former U.S.S.R (a), inferred distributions of magnetite-series/ilmenite-series rocks (b) and S- and I-types granitoids (c) in eastern Asia. Adapted from Dortman (1984) and Pitcher (1982).

Geologická prospekce



Brno Massif



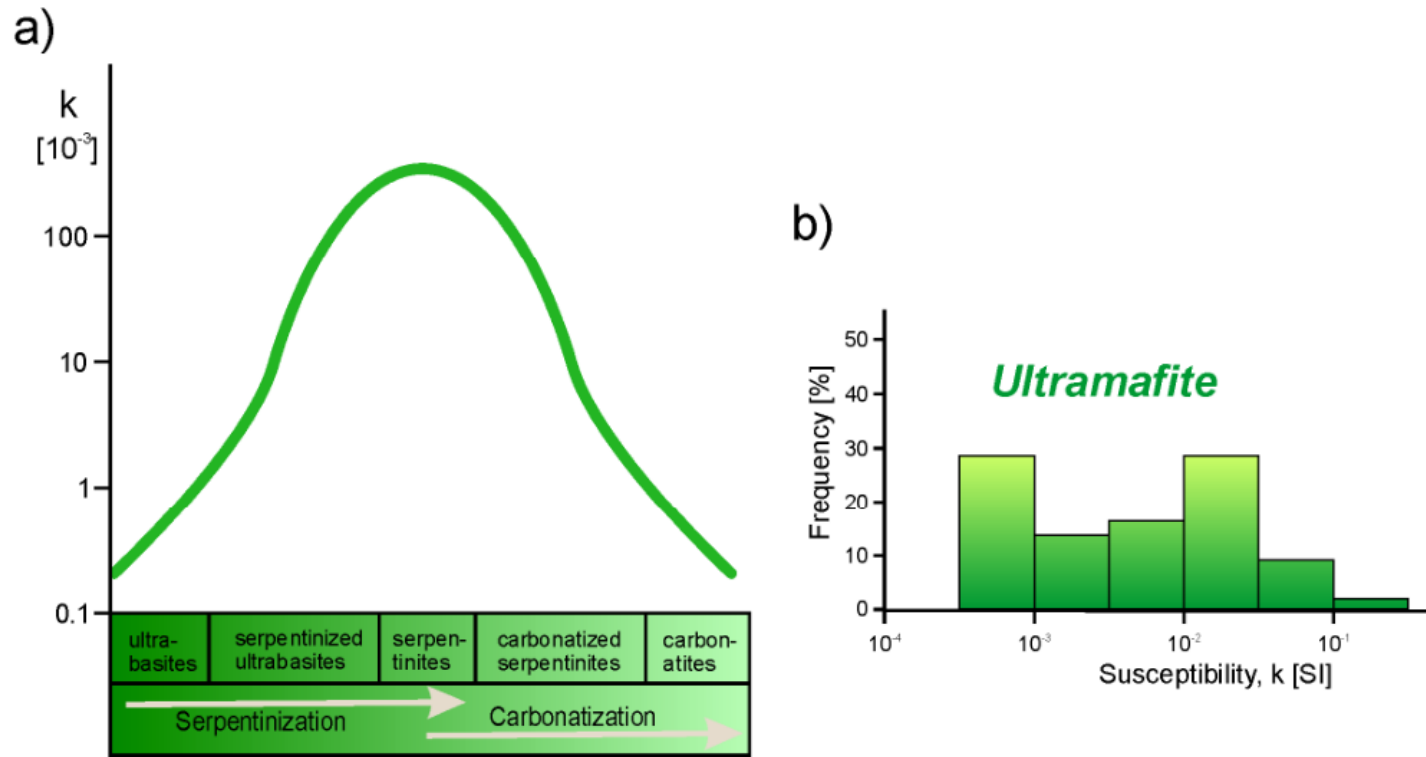
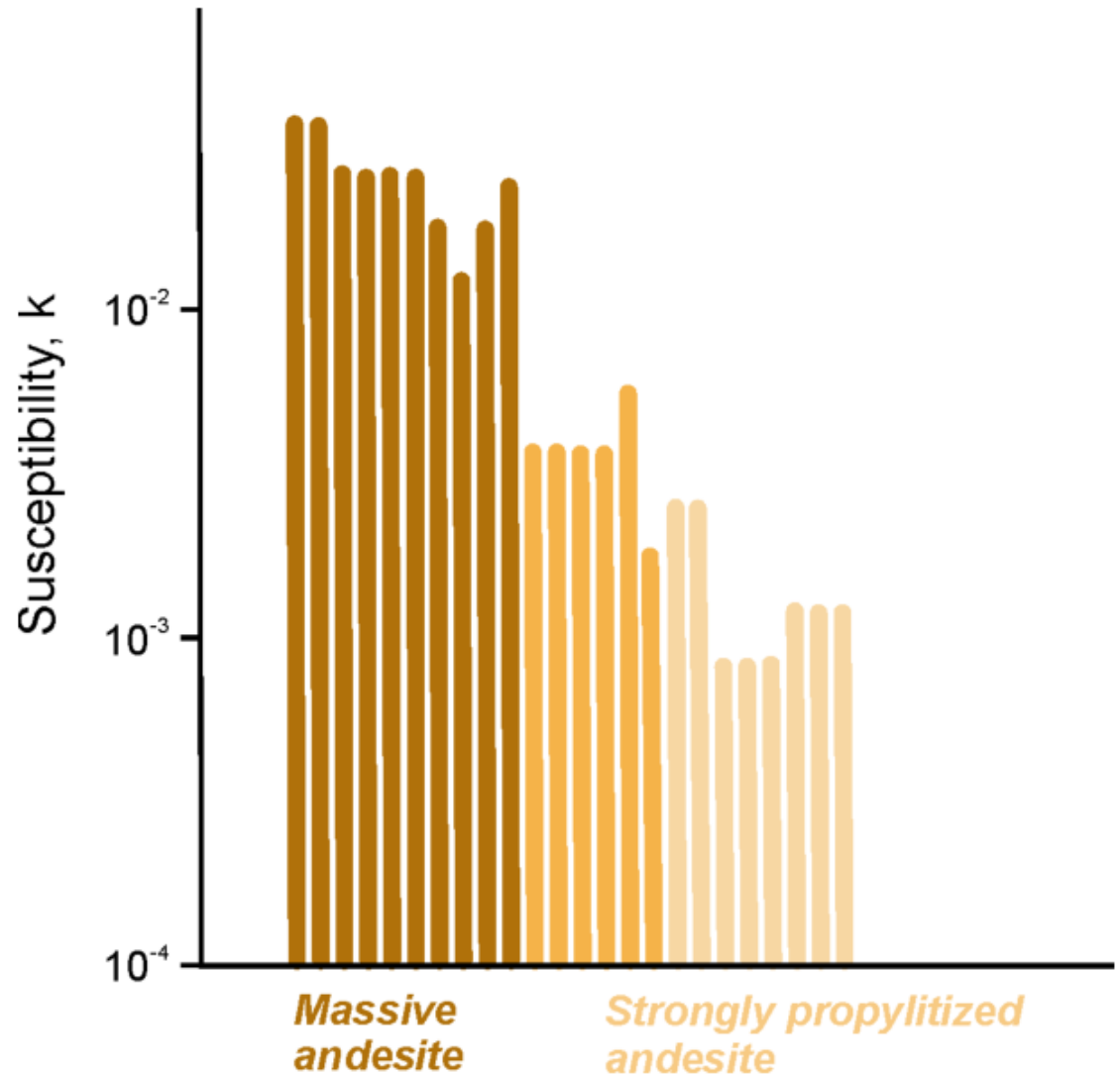
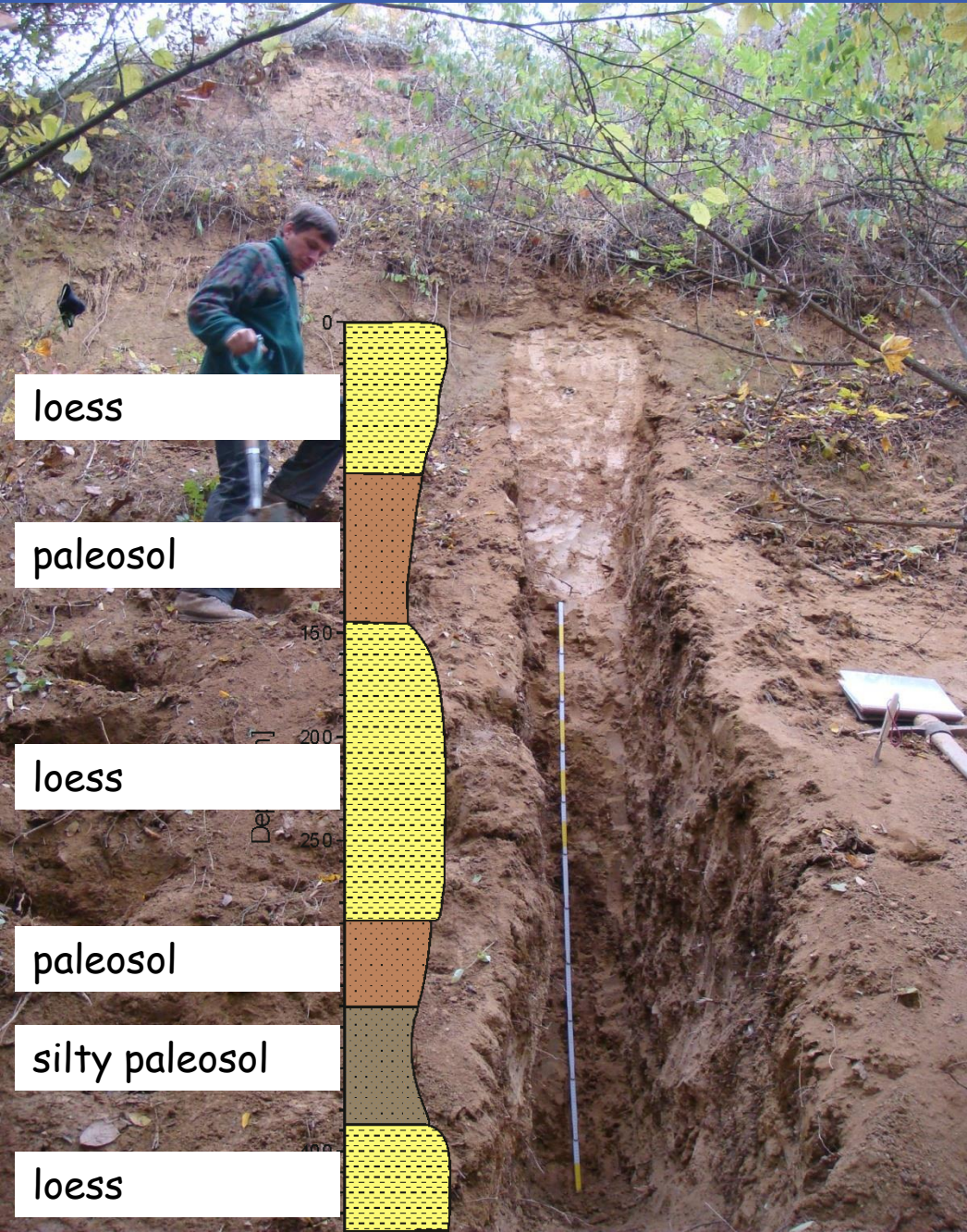


Fig. 14 Susceptibility changes during serpentinization and carbonatization of ultrabasic rocks (a) and susceptibility histogram of ultramafic rocks from the locality of Bory, Western Moravia, Czech Republic (b). Adapted from Dortman (1984) and Hrouda et al. (2008).

Magnetic Susceptibility in Altered (propylitized) Andesites



Studium změn klimatu v geologické minulosti Země



loess

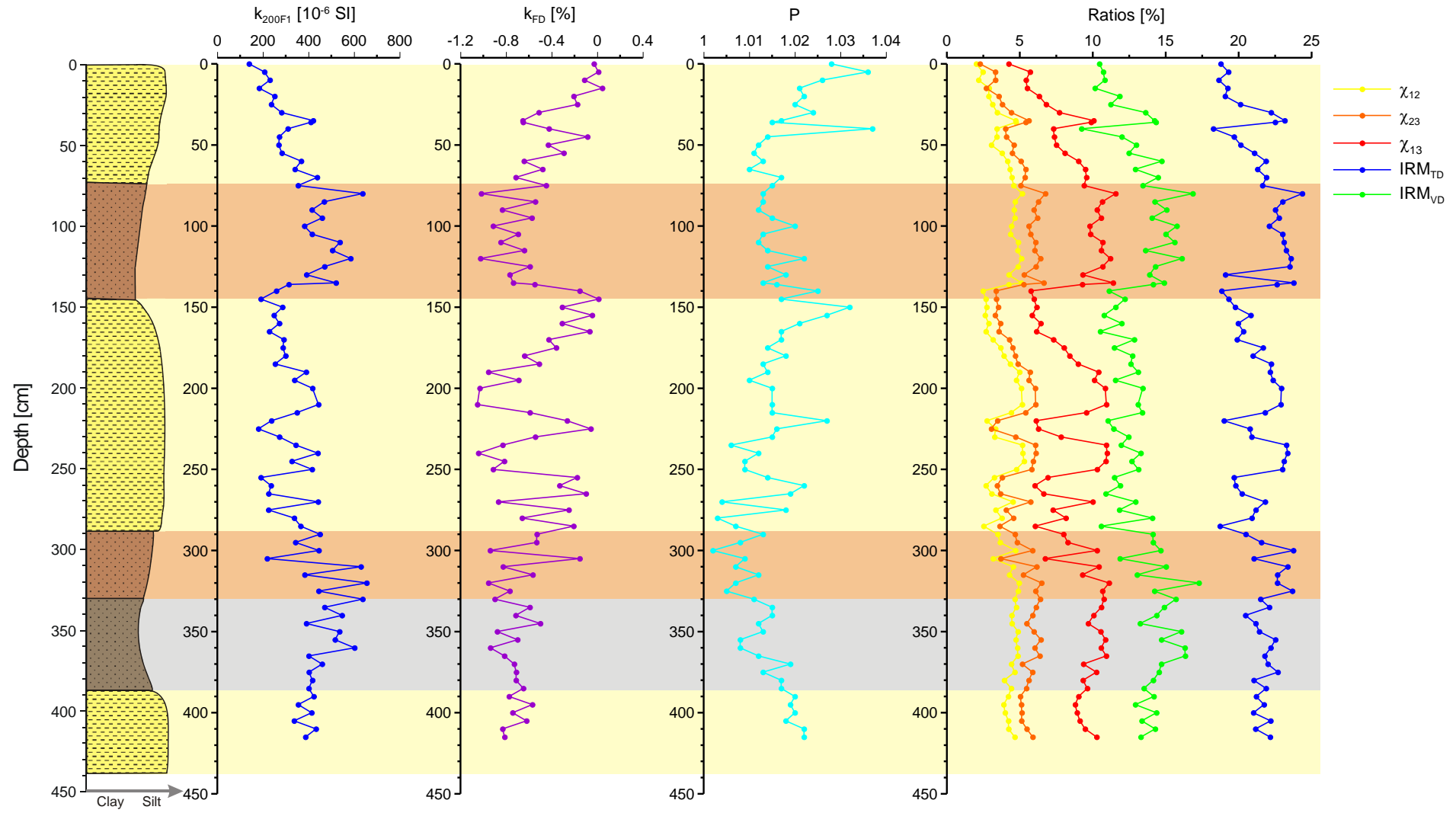
paleosol

loess

paleosol

silty paleosol

loess



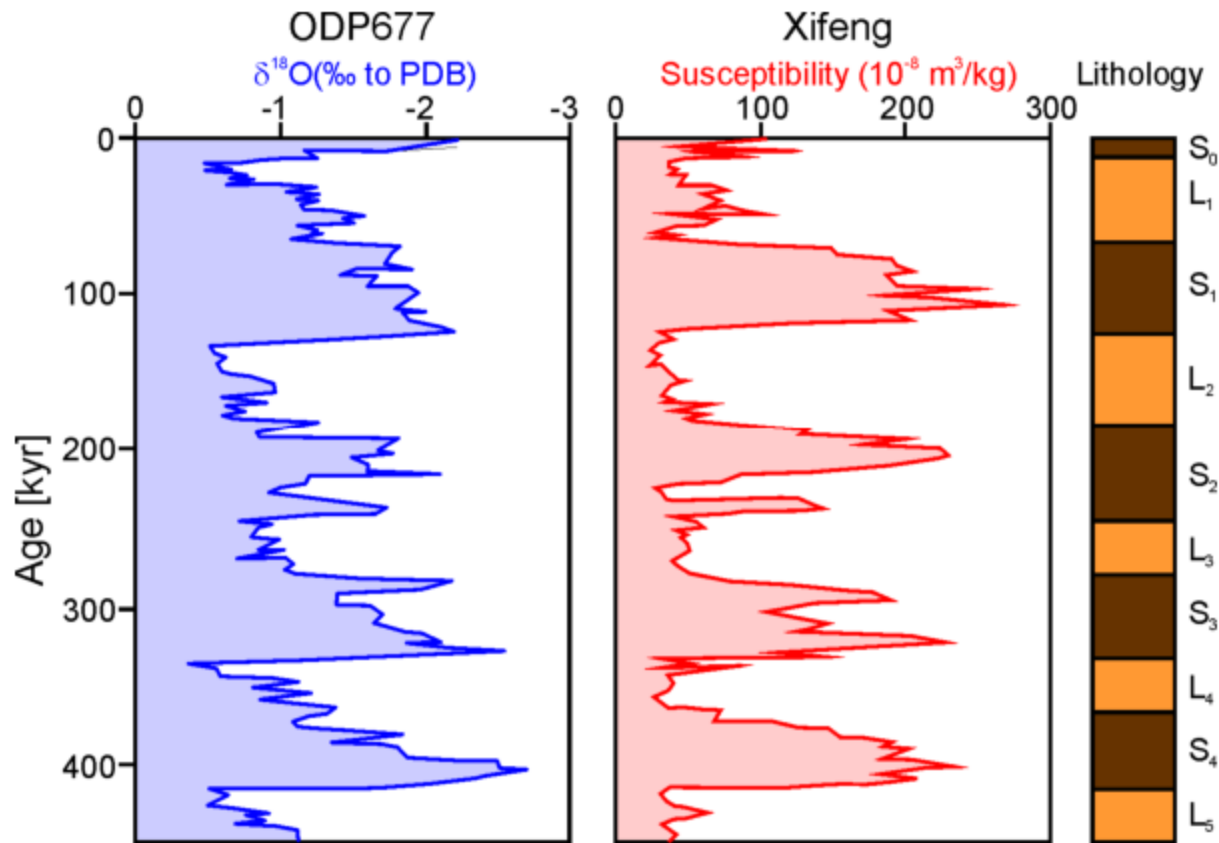
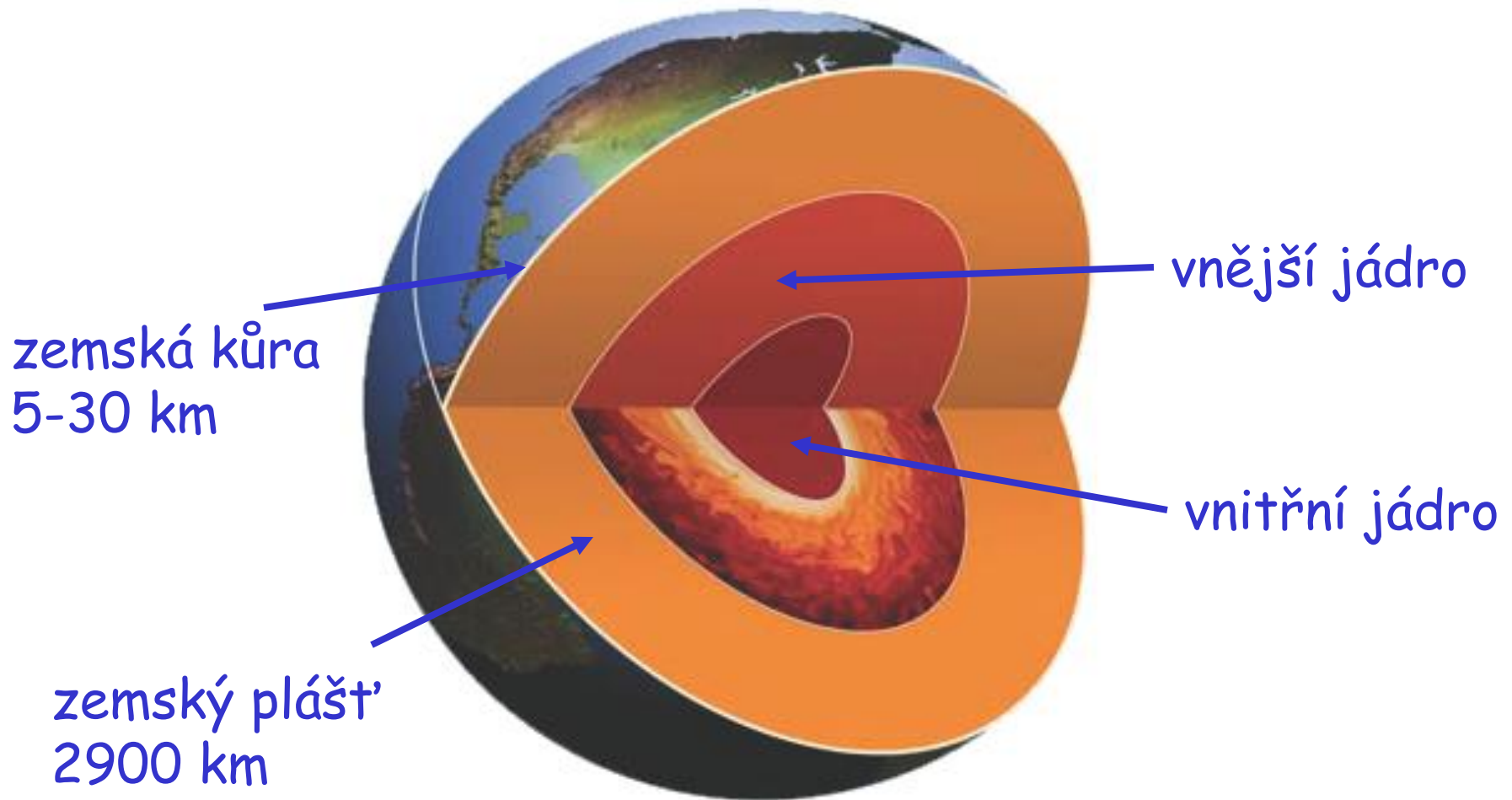


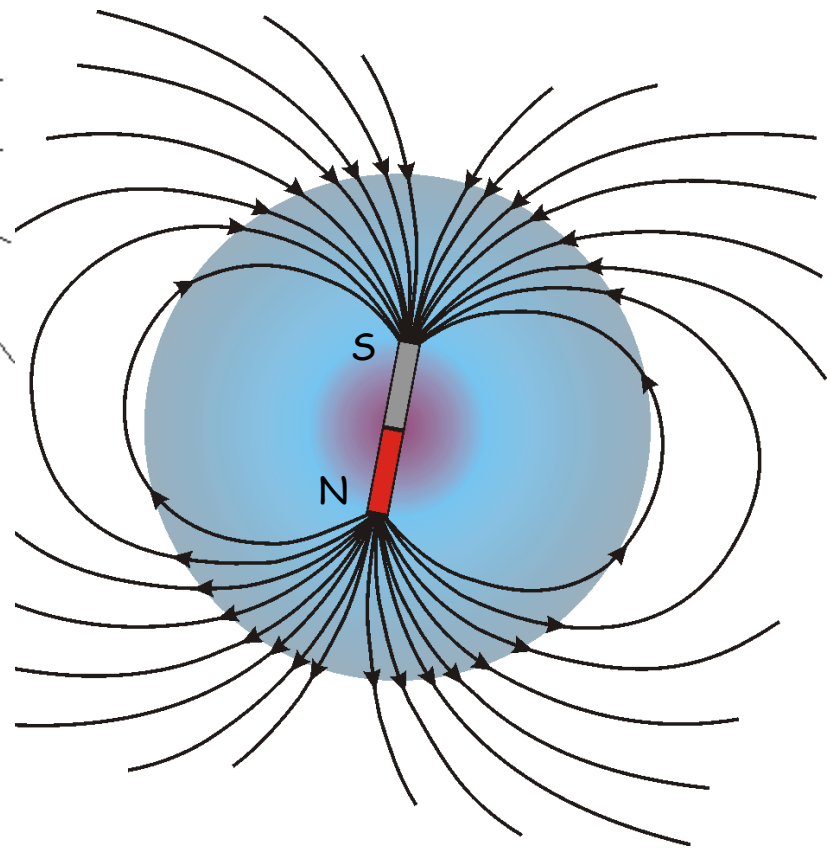
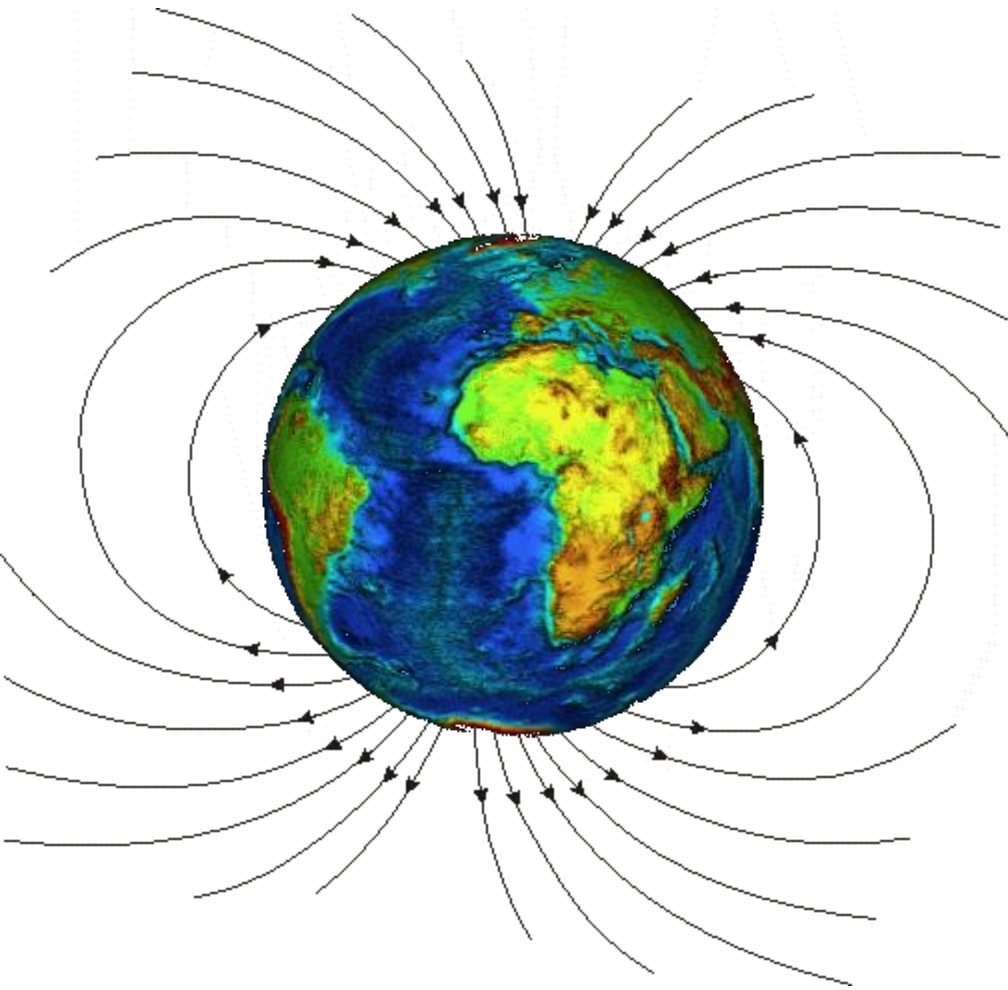
Fig. 22 Magnetic susceptibility profile at Xifeng, China, compared with the oxygen isotope profile at ODP677. The sequence of soil (S) and loess layers (L) at Xifeng is indicated on the right. Adapted from Evans & Heller (2003).

Paleomagnetismus



- vnější jádro tavenina železa
- více než 7 krát objem Měsíce
- na povrchu Země by tvořilo vrstvu vyšší než 300 km

Země jako velký magnet

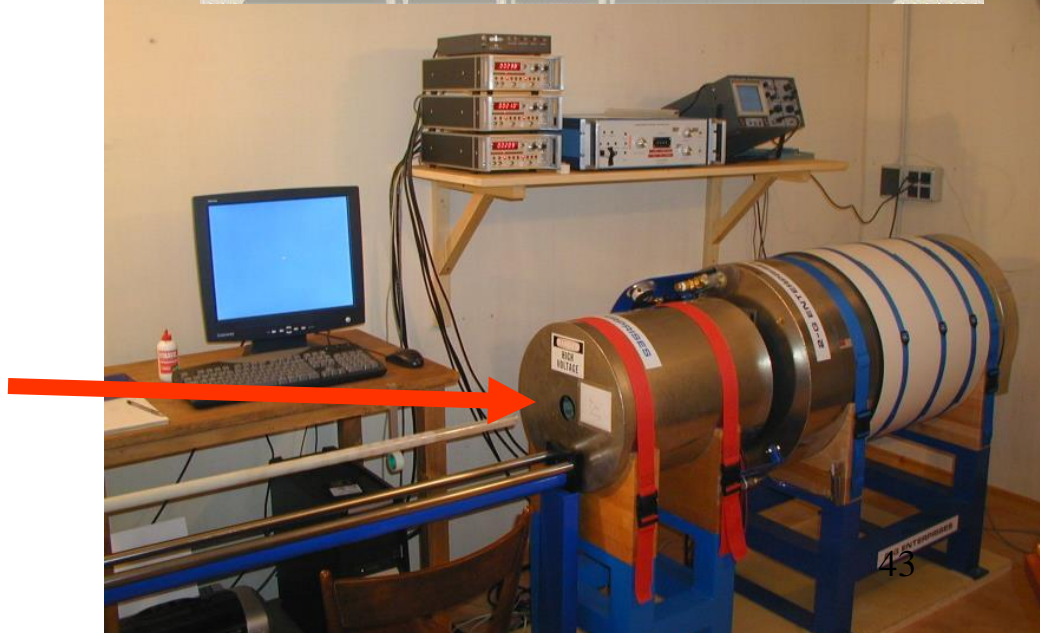
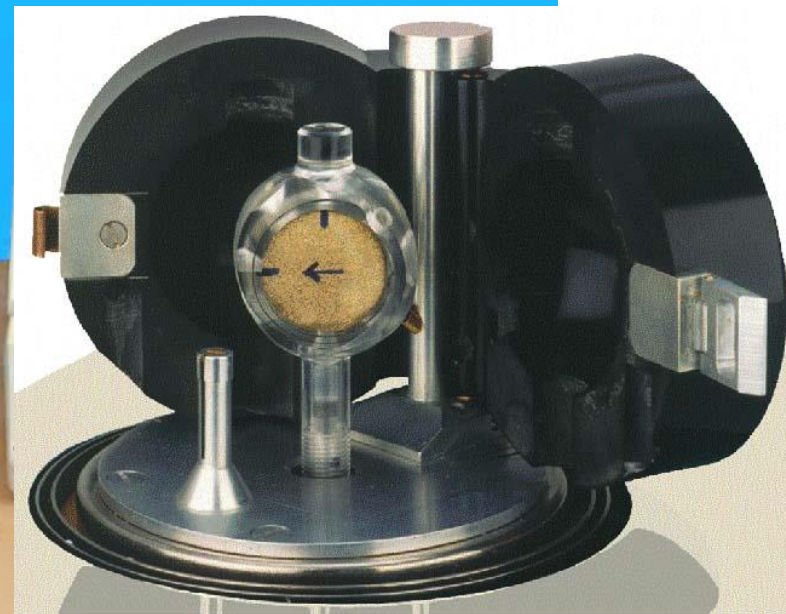


AGICO

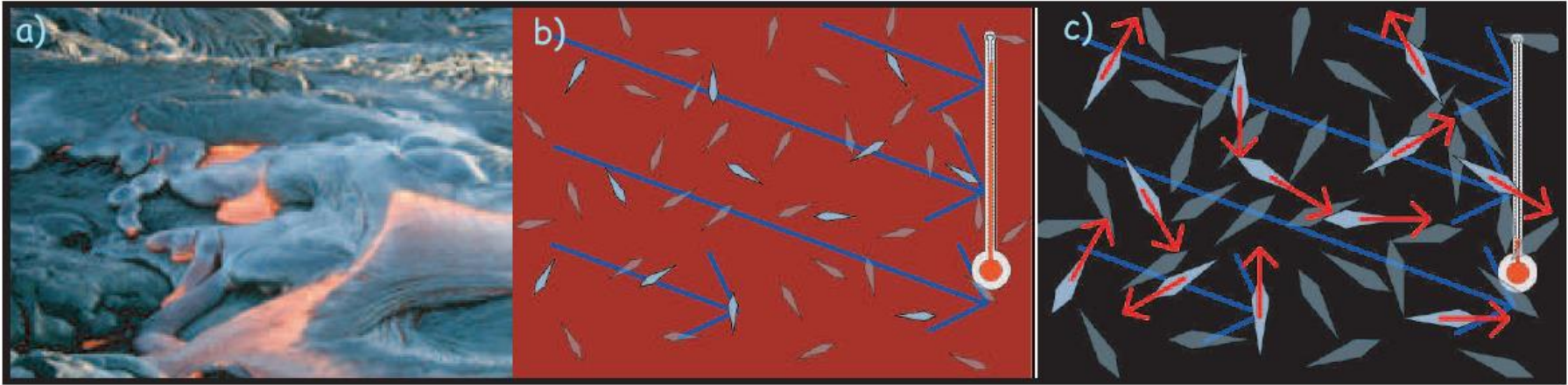


rotační magnetometr

kryogenní magnetometr



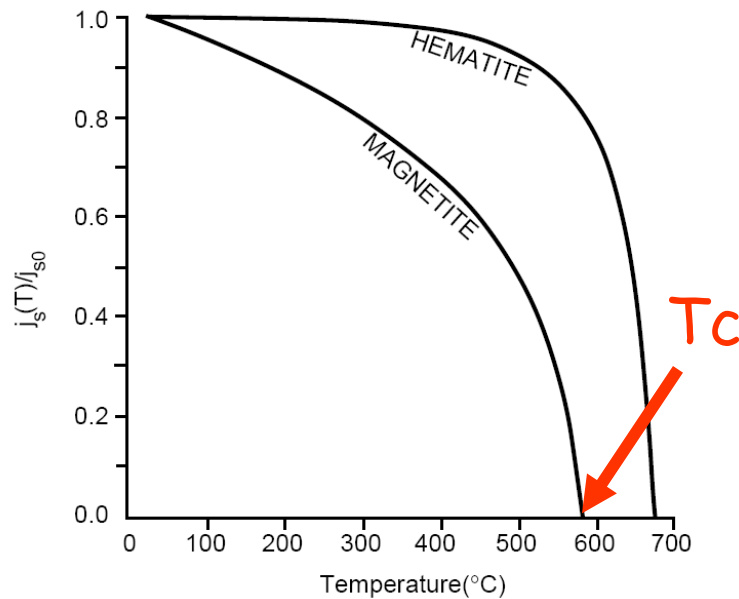
Teplotní remanentní magnetizace



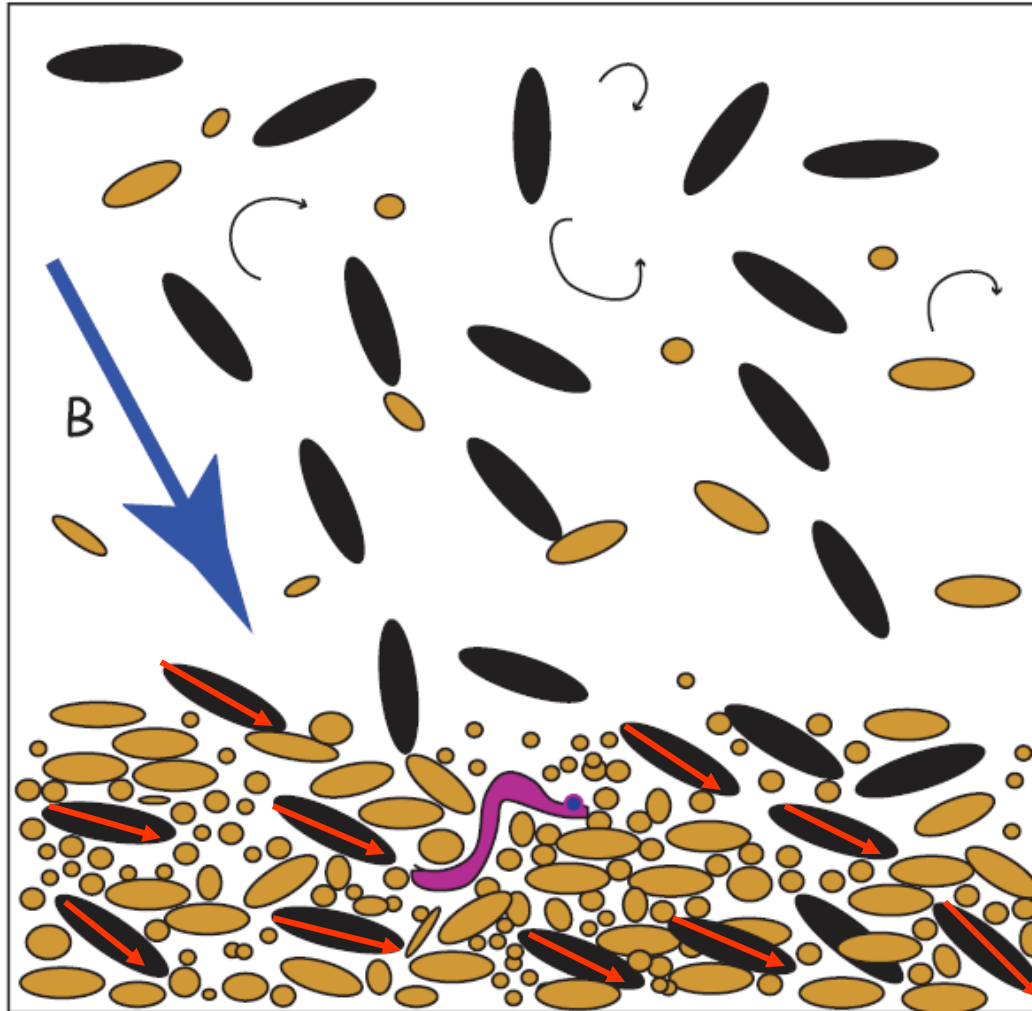
• lávová tavenina

- $T > T_c$
- krystaly rostou
- nejsou magnetické

- $T < T_c$
- magnetické momenty se fixují ve směru „easy axis“ proporcionálně k orientaci krystalu



Detritická remanentní magnetizace



Turbulent Water

Still water or
laminar flow

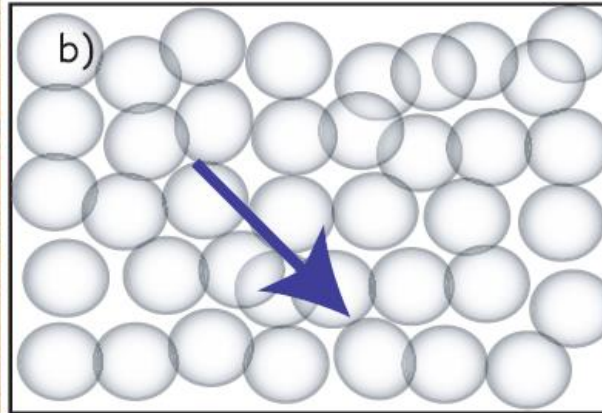
sediment/water
interface
bioturbation
consolidation
"lock-in depth"

compaction

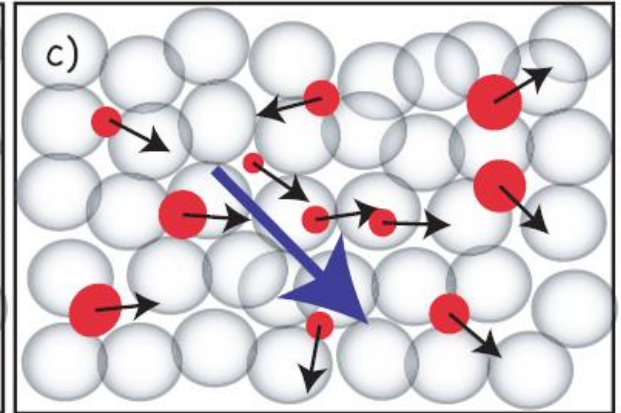
Chemická remanentní magnetizace



*Červené půdní horizonty,
Chiji Formation, Siwaliks,
Pákistán*

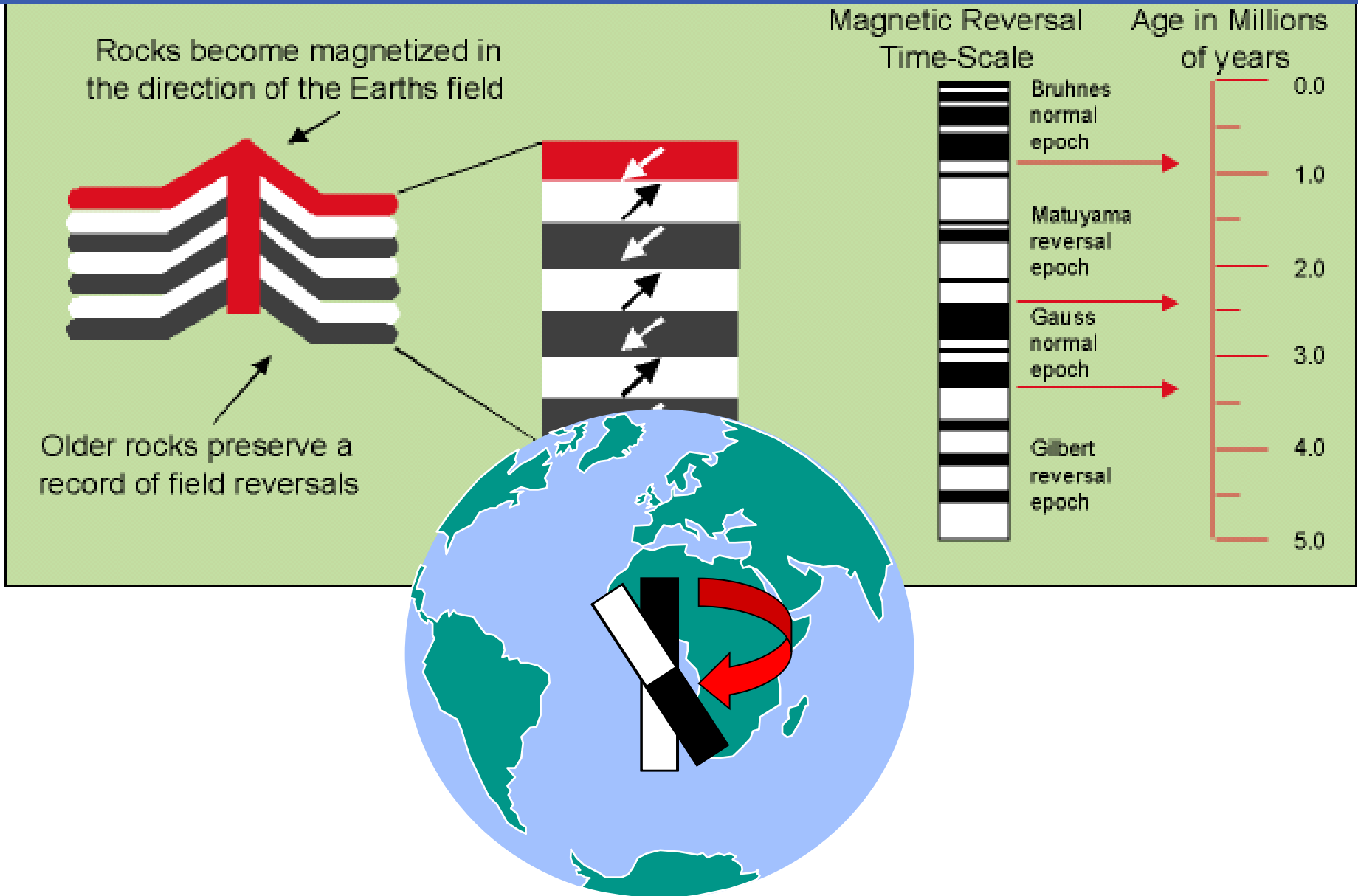


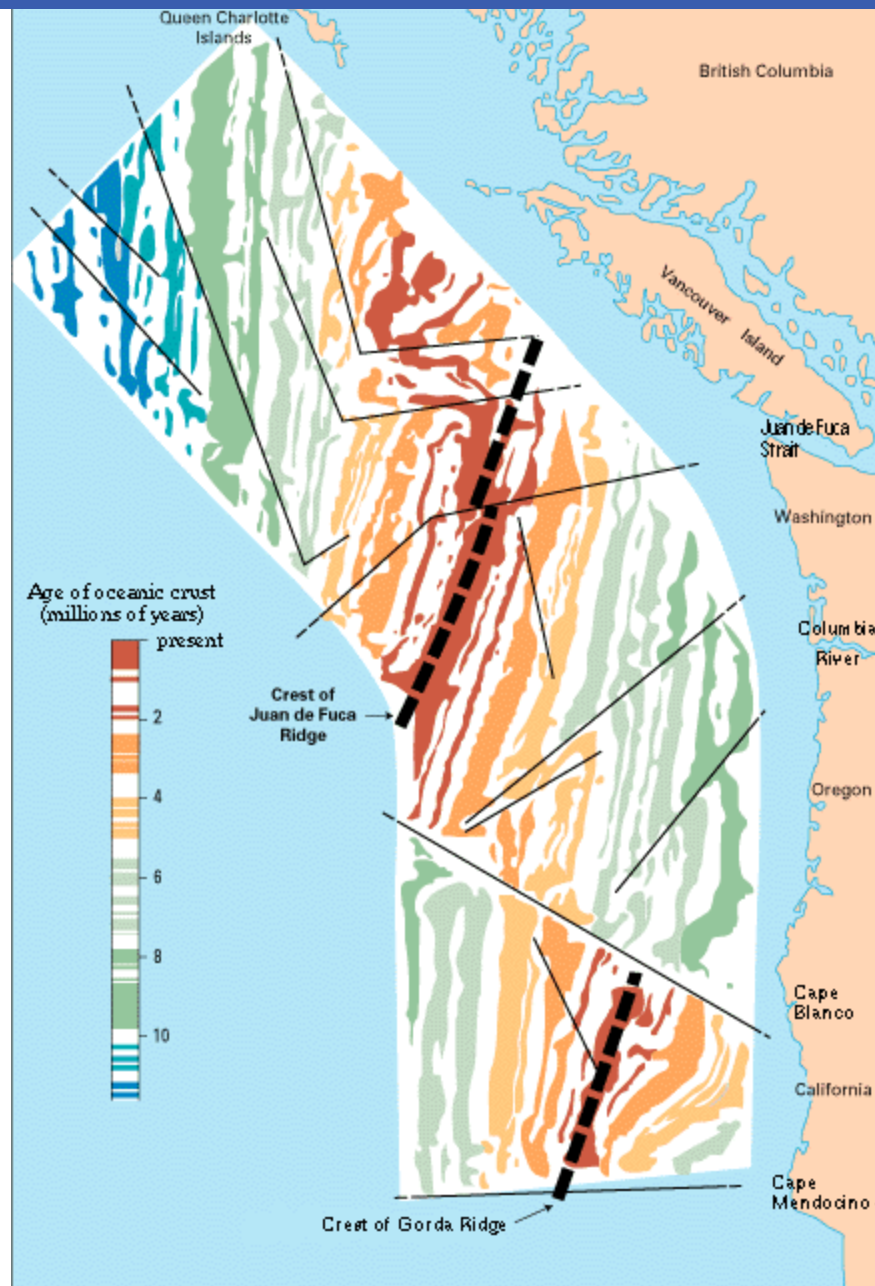
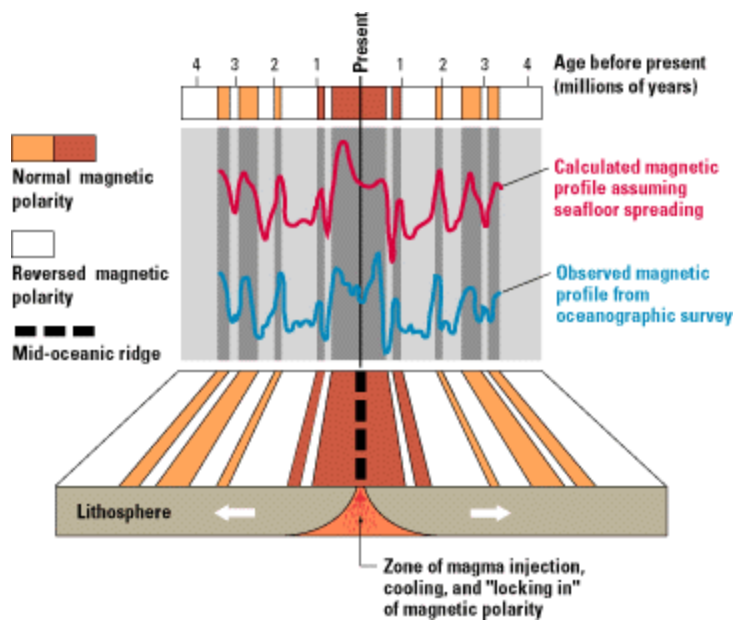
Nemagnetická matrix



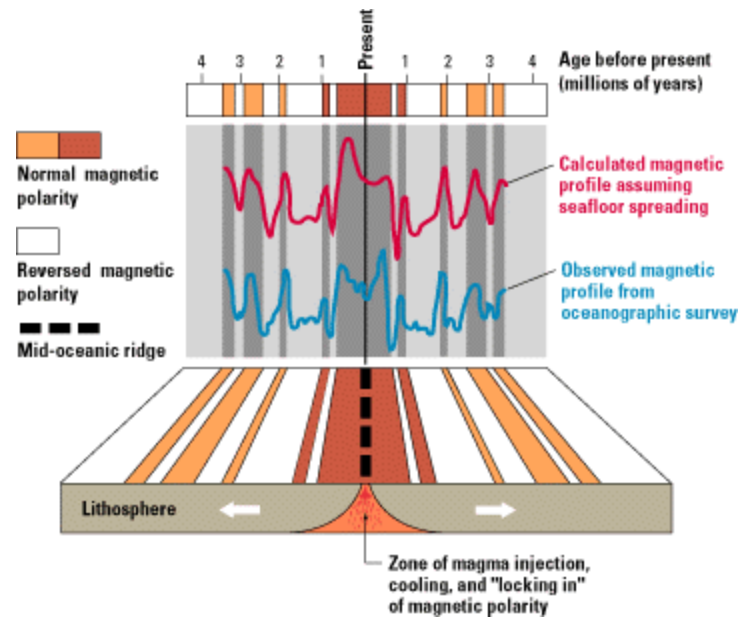
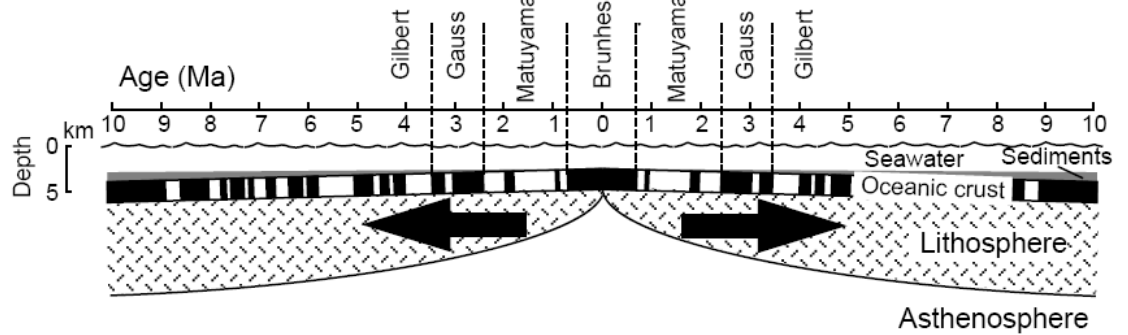
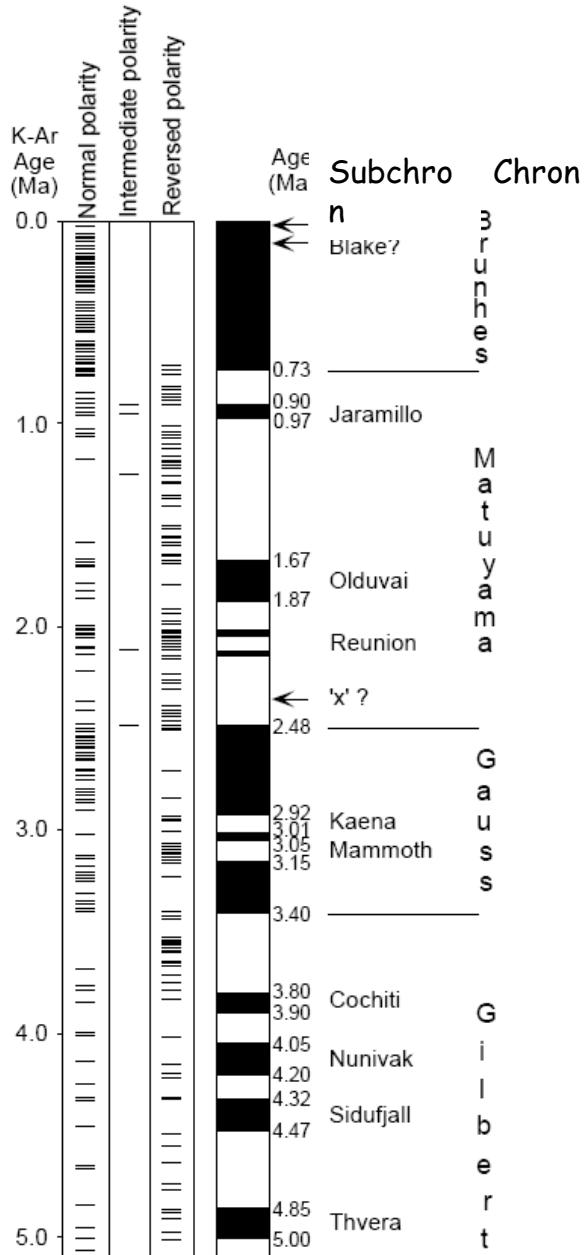
*Růst hematitu s přednostní
orientací odrážející magnetické
pole*

Studium chování magnetického pole Země v geologické minulosti

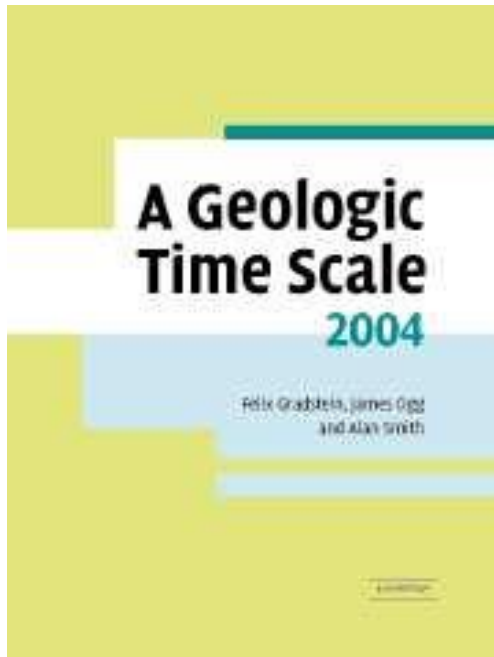




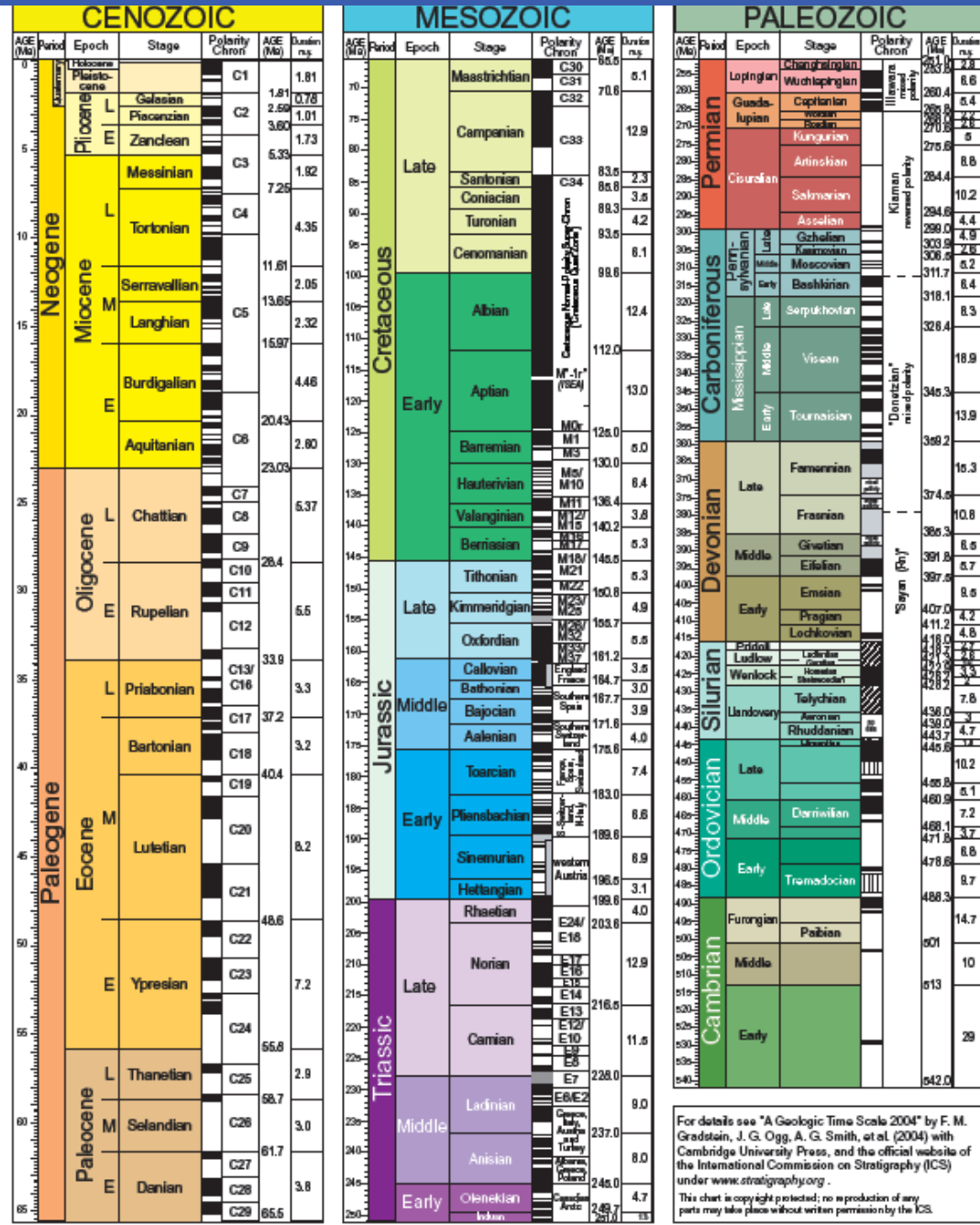
Datování hornin



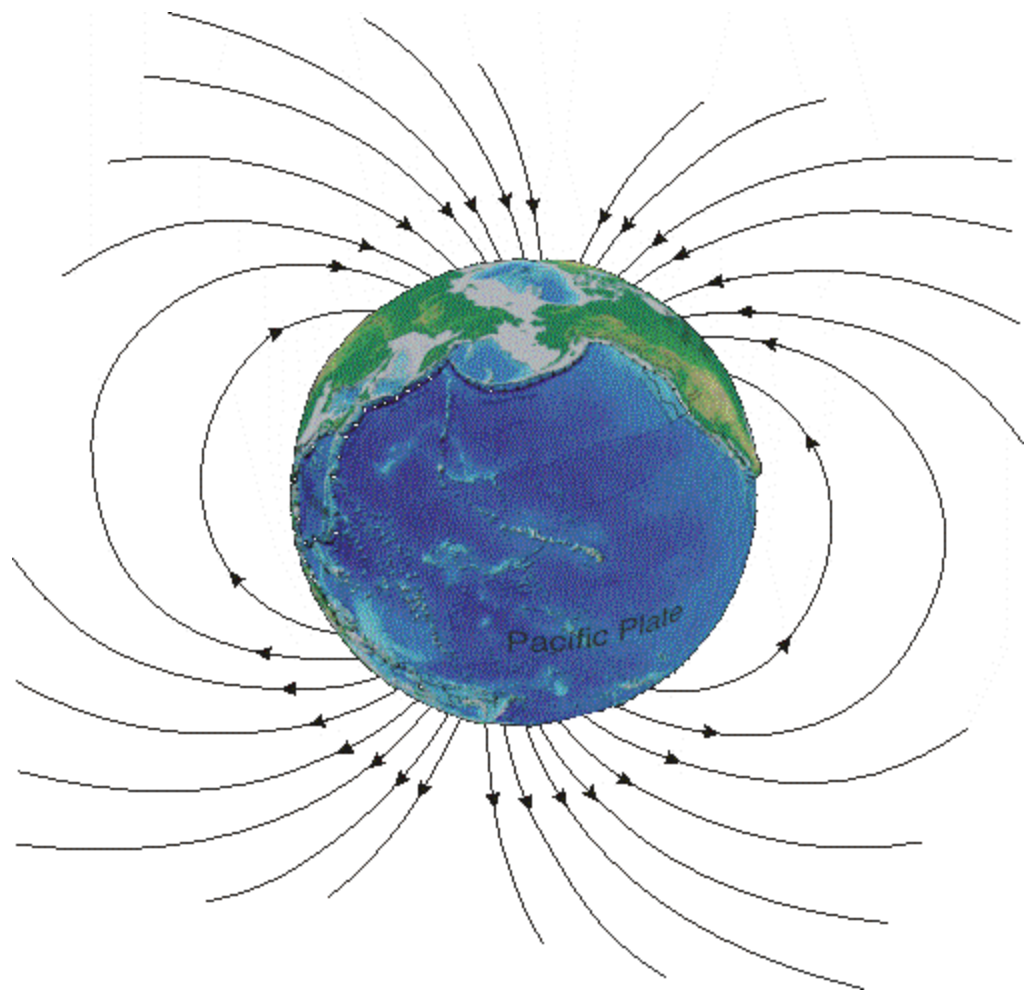
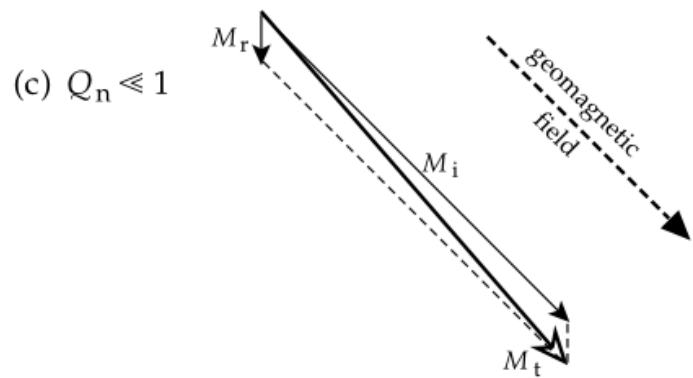
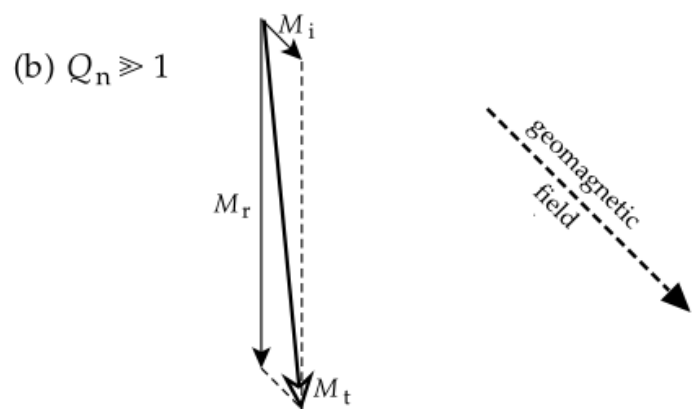
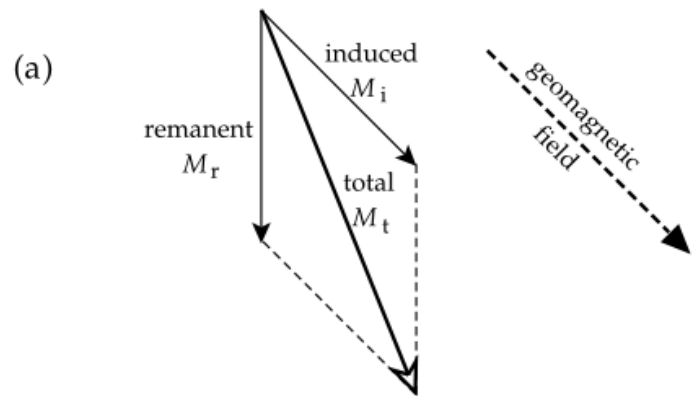
Geomagnetic Polarity Time Scale



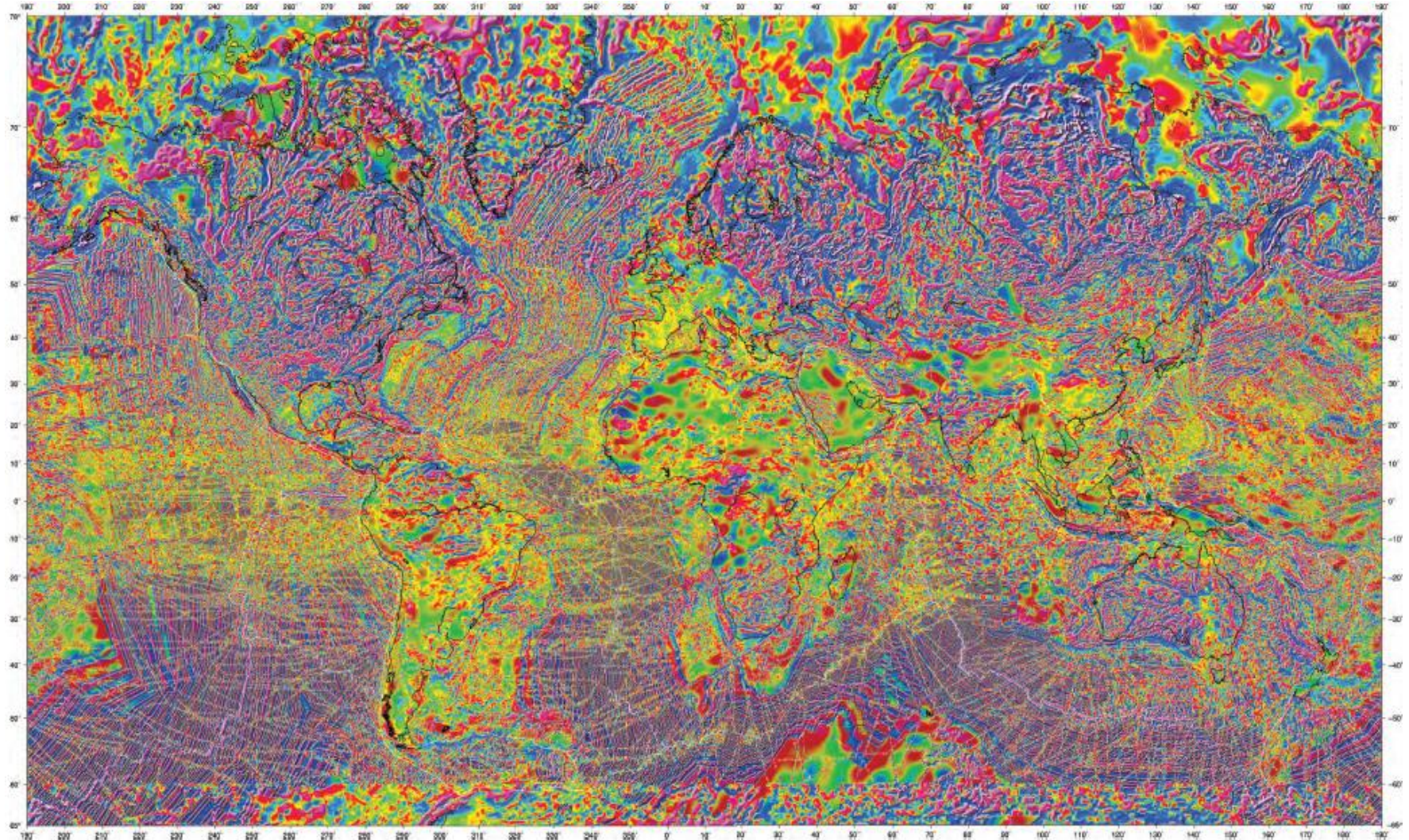
Gradstein & Ogg 2004



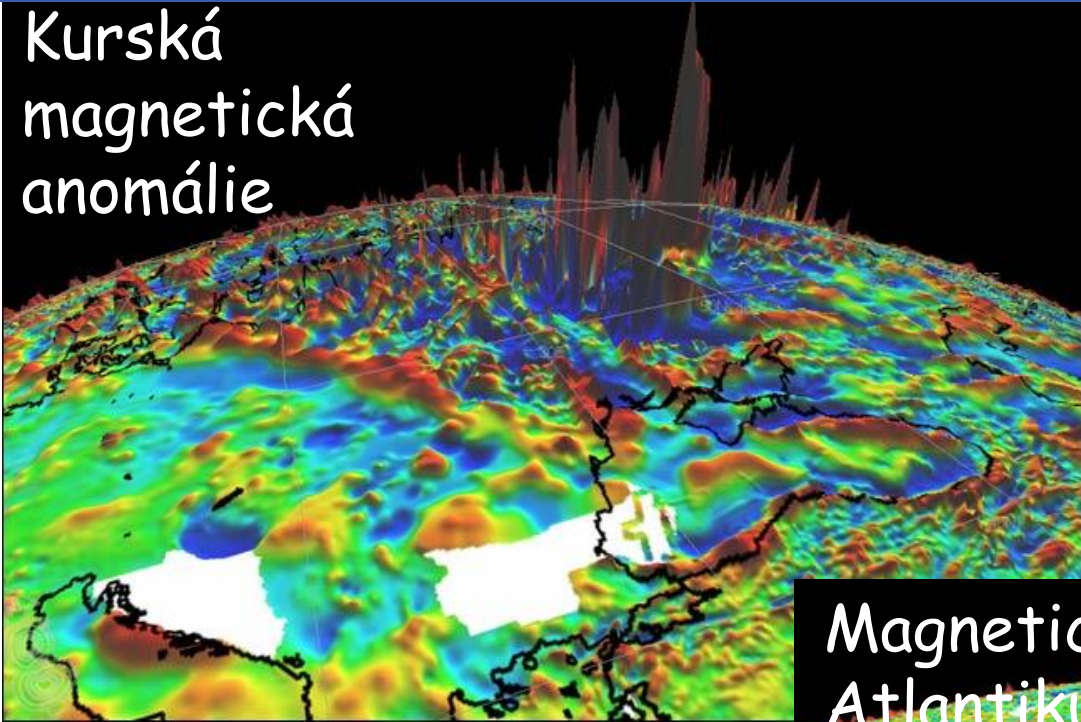
For details see "A Geologic Time Scale 2004" by F. M. Gradstein, J. G. Ogg, A. G. Smith, et al. (2004) with Cambridge University Press, and the official website of the International Commission on Stratigraphy (ICS) under www.stratigraphy.org.
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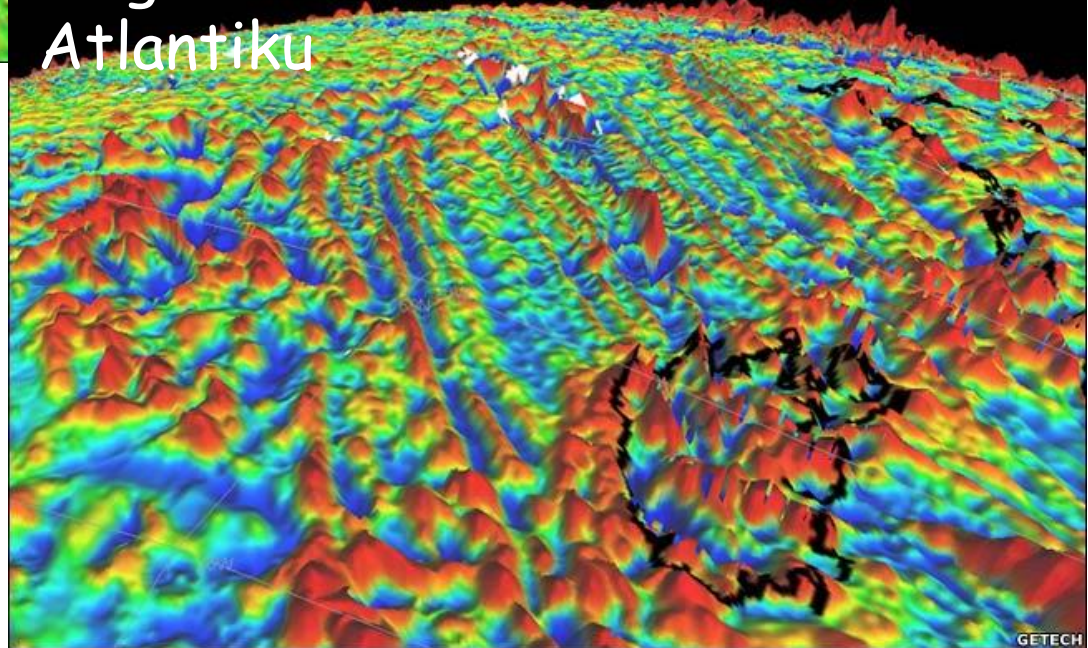
Mapa magnetický anomálií Země



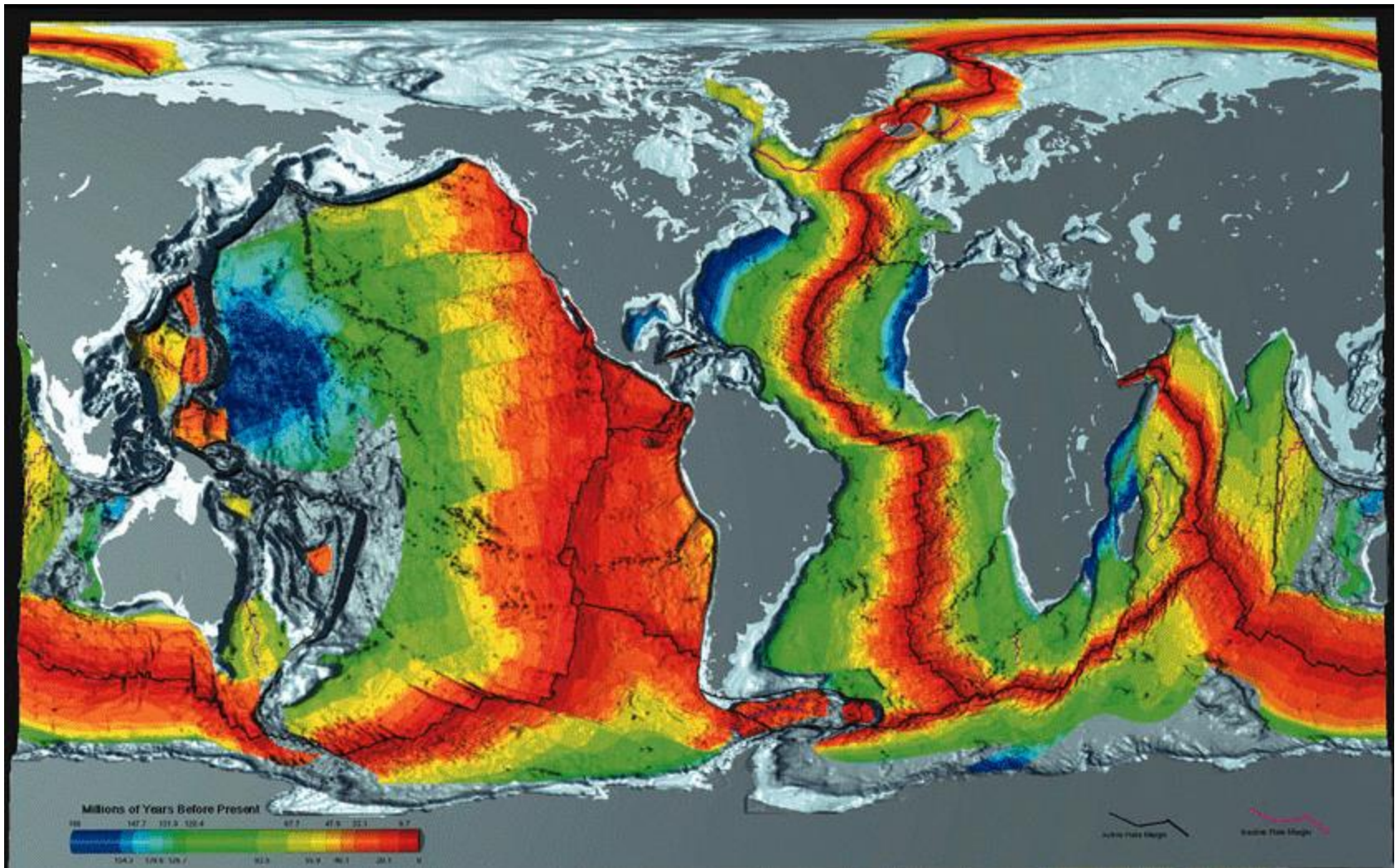
Kurská magnetická anomálie



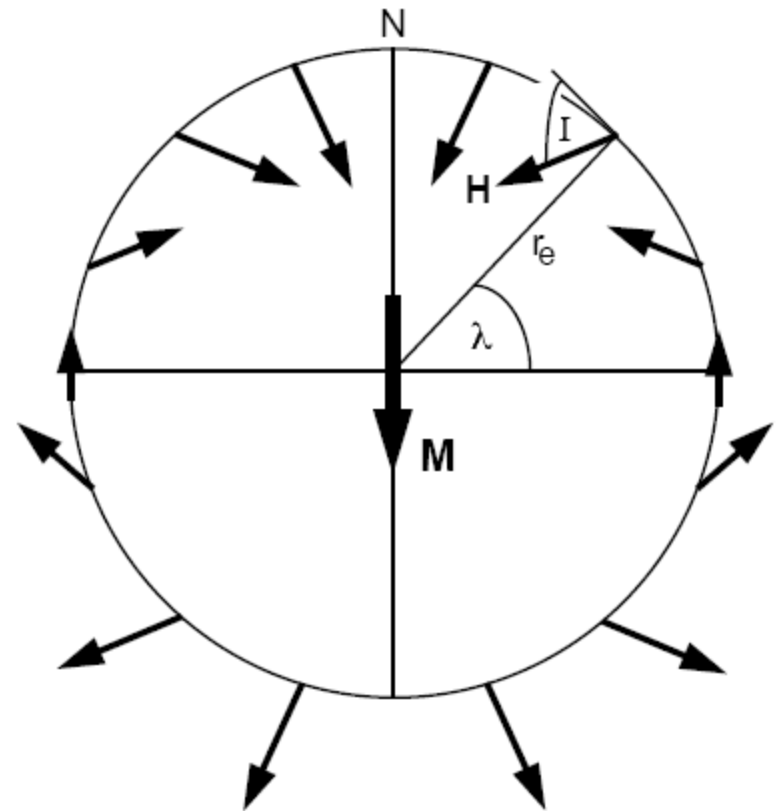
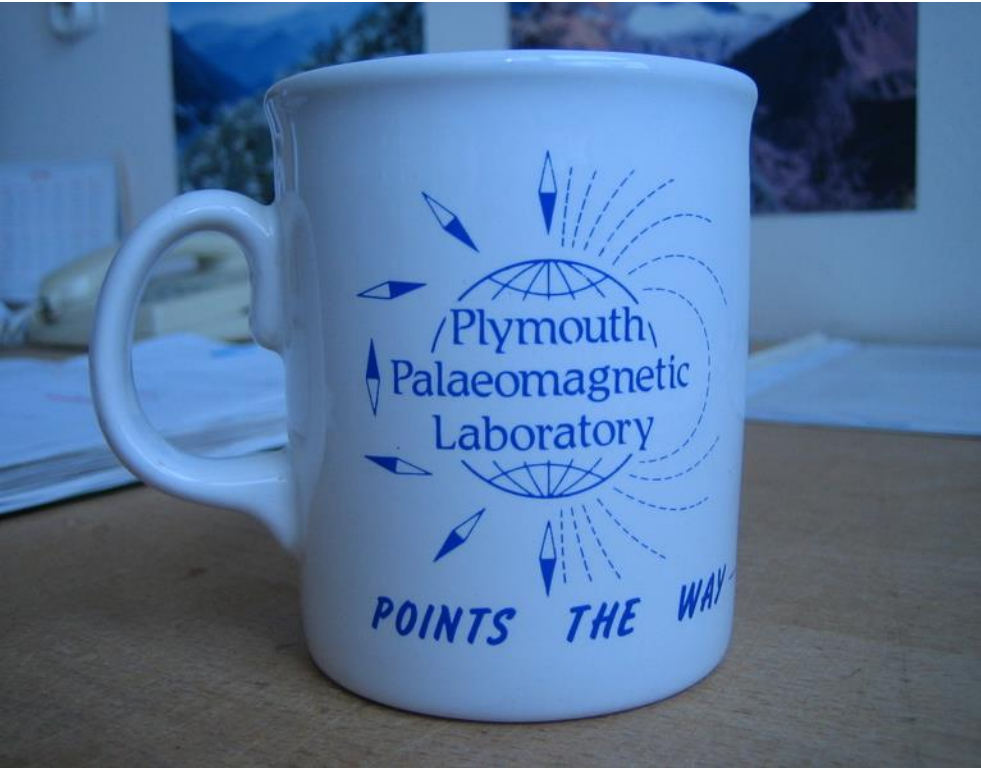
Magnetická anomálie na dně Atlantiku



Stáří oceánského dna

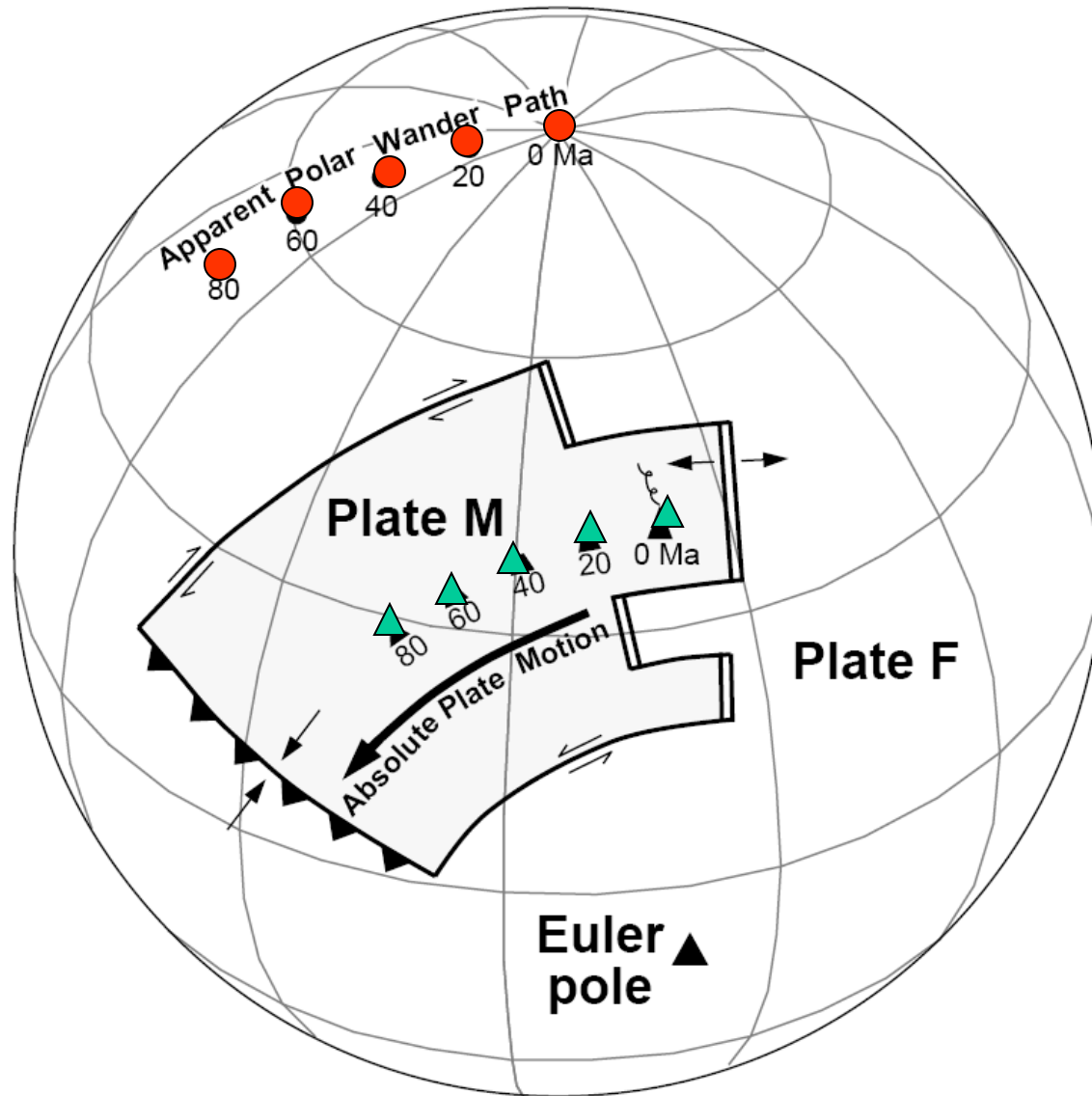


Rekonstrukce pohybu kontinentů a horotvorné činnosti

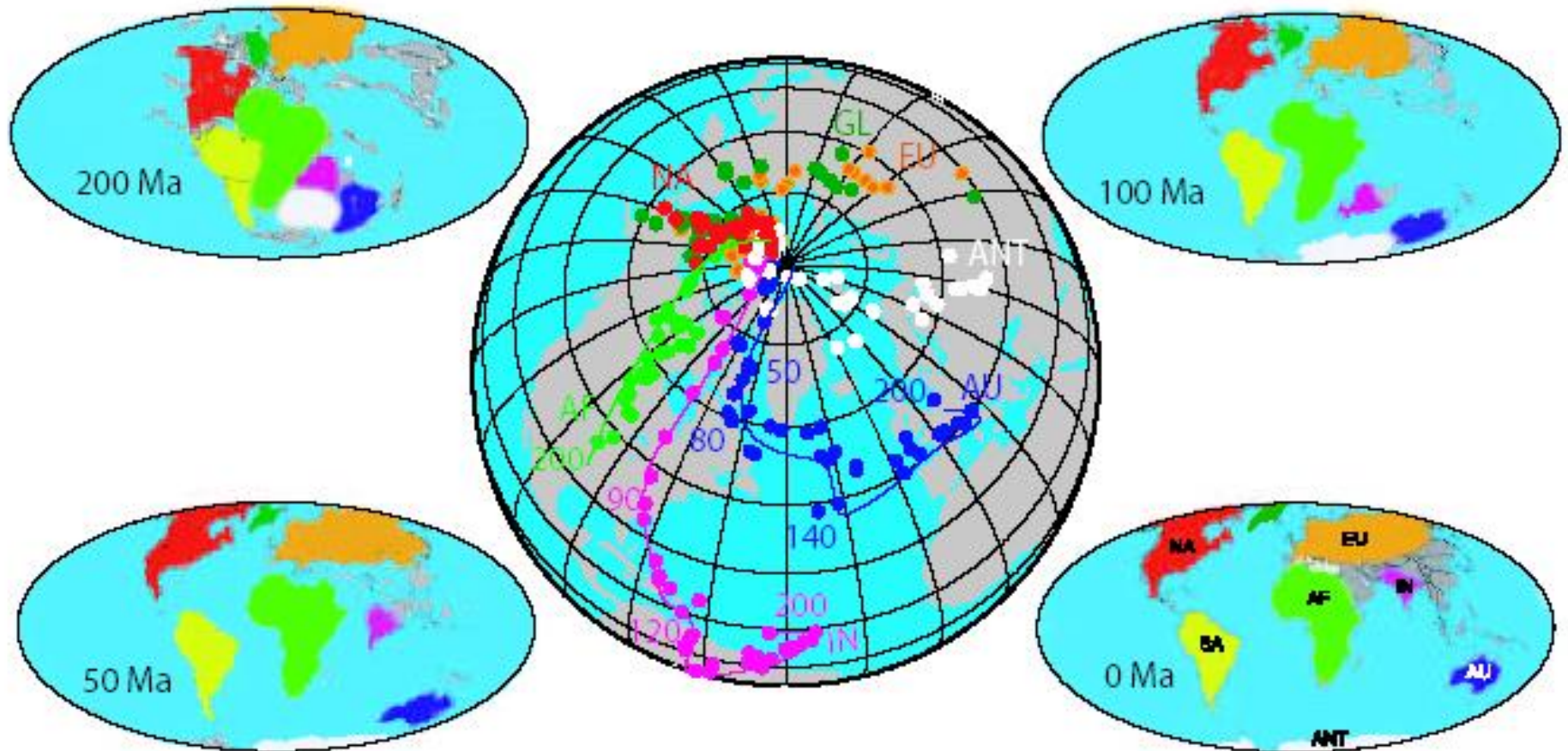


$$\tan I = 2 \tan \lambda$$

Putování virtuálního magnetického pólu



Rekonstrukce poloh kontinentů v geologické minulosti Země



0.00 Ma :: Gondwana Dispersion :: CR09madC :: GSH/PESGB 2009 September 9-10

