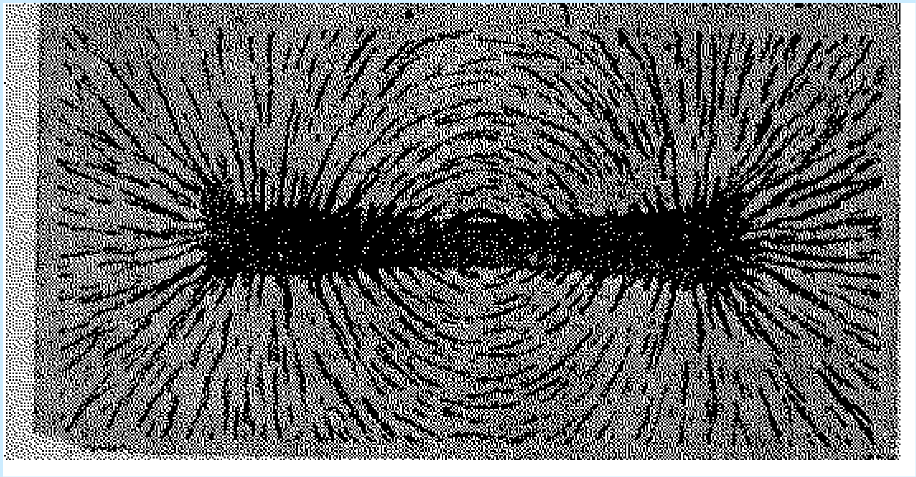
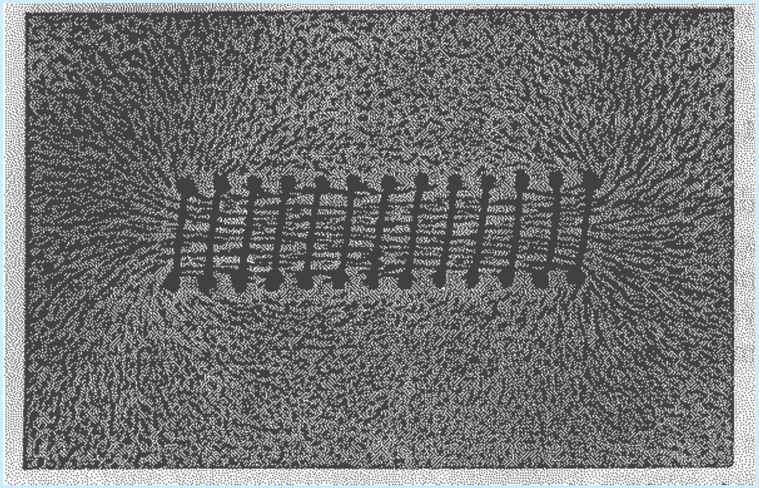
MAGNETIC PROPERTIES OF ROCKS

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

Bar Magnet

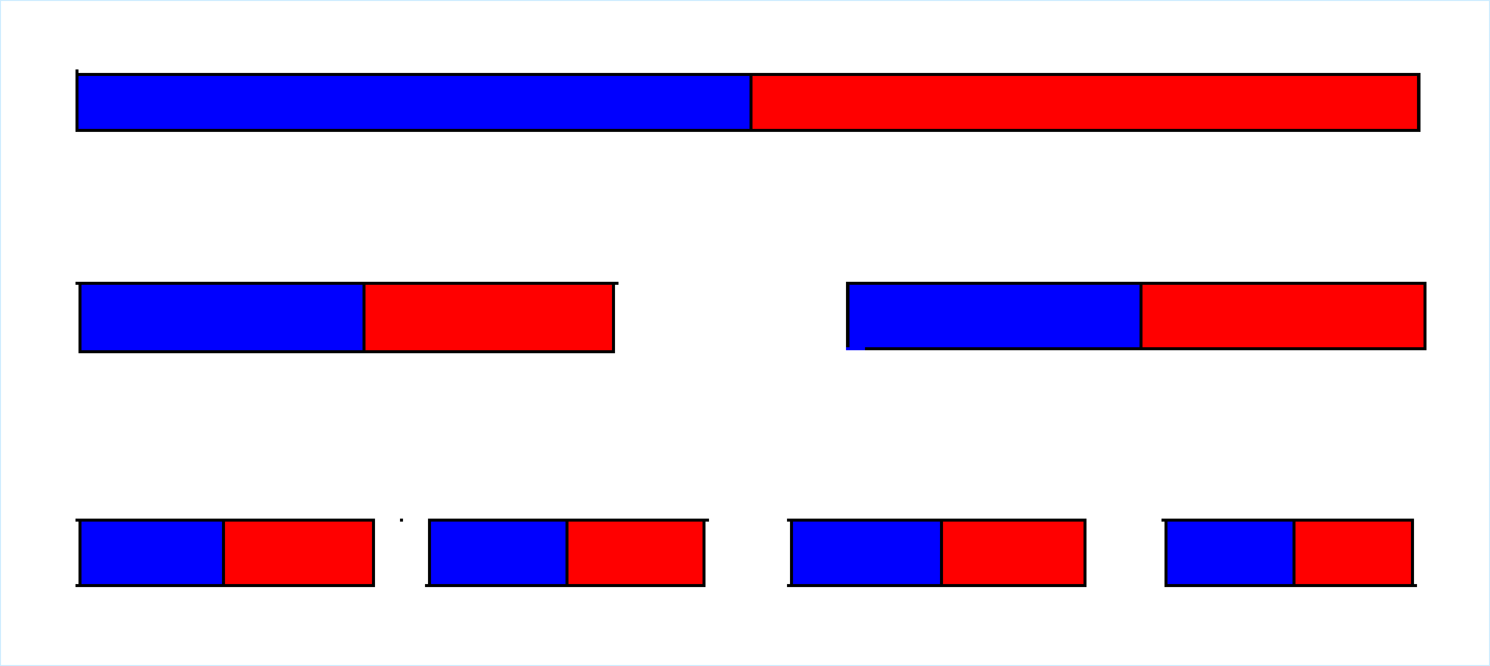


Solenoid



lines of magnetic flux can be visualized by saw dust

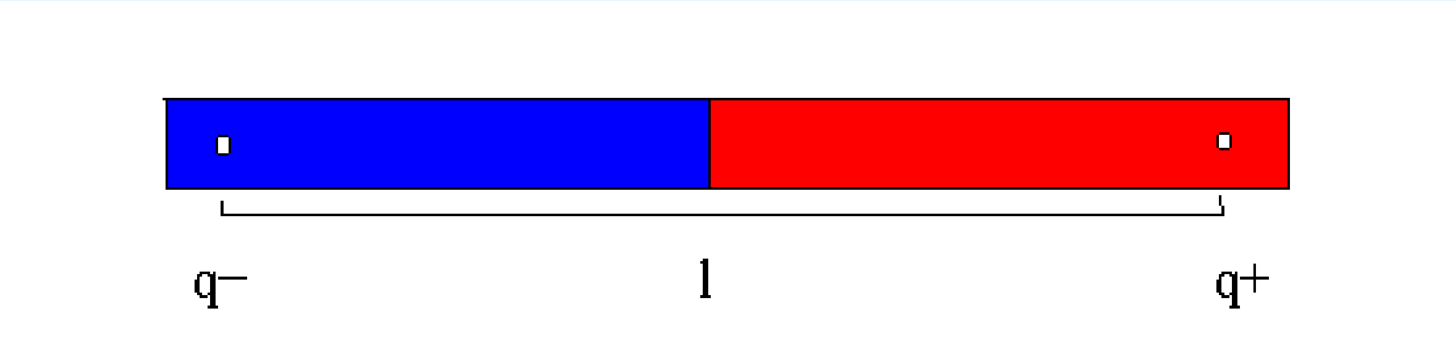
DIPOLE CHARACTER OF MAGNETISM



l

magnets remain dipoles even after cutting them into pieces

Magnetic Moment, Magnetization, Magnetic Susceptibility



$m = ql$ — m – magnetic moment

q - magnetic charge

l - distance

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

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

Magnetization induced by field $M = \boldsymbol{k}\, H$

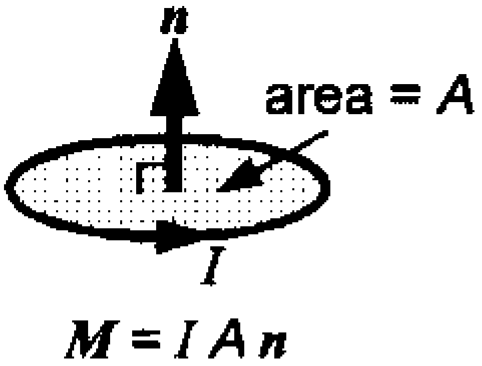
Magnetization of rocks $M = \boldsymbol{k}H + \boldsymbol{NRM}$

M – magnetization, *v - specimen volume*

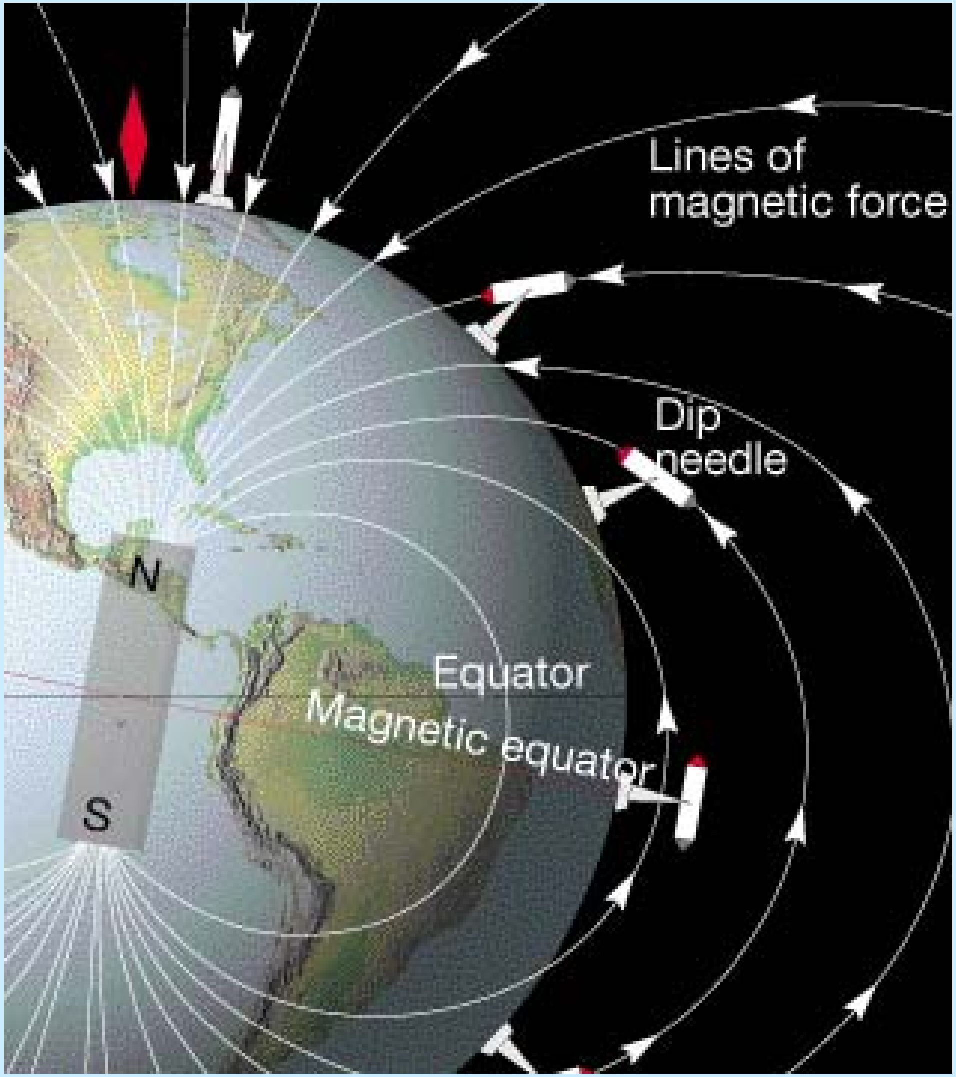
k – magnetic susceptibility, *H – intensity of magnetic field*

NRM – natural remanent magnetization [A/m]

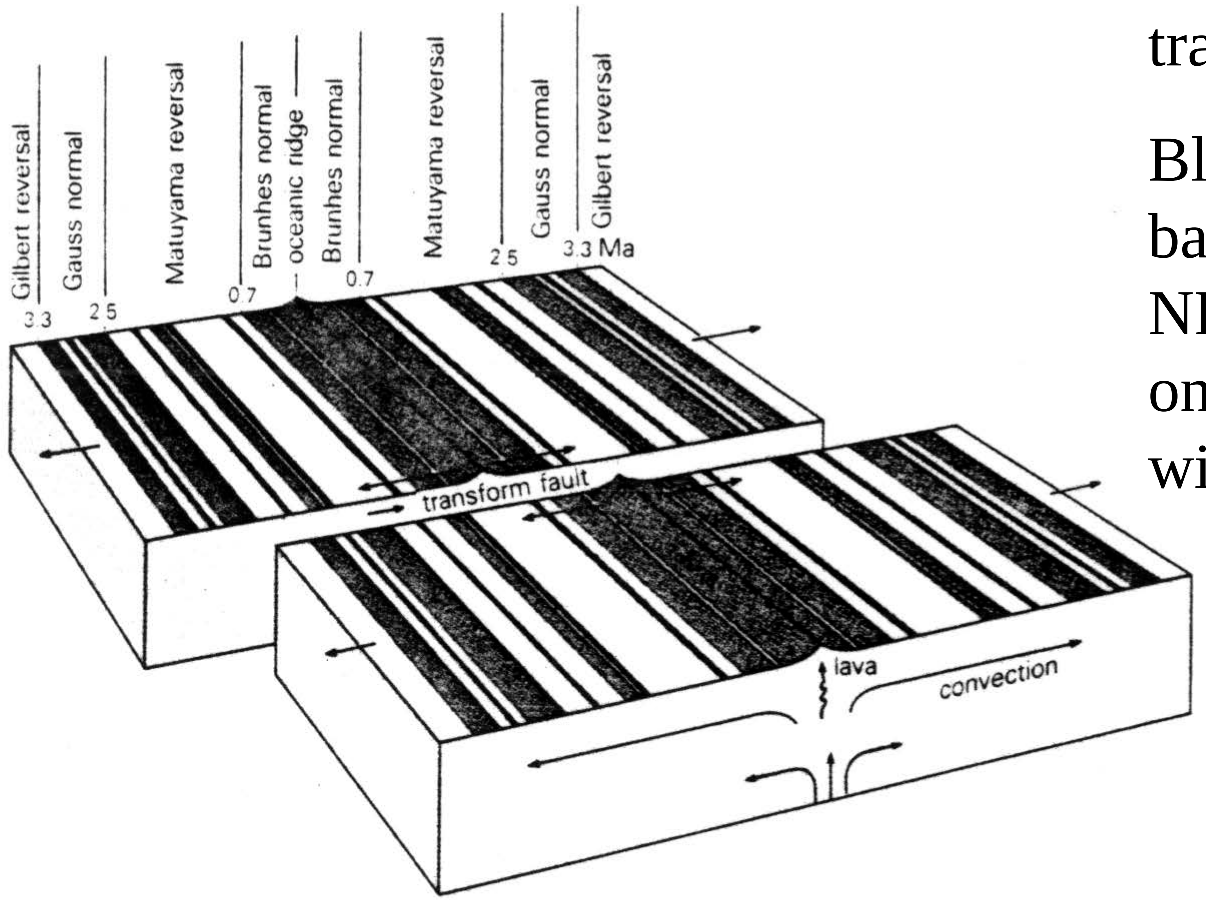
MAGNETIC DIPOLE OF A COIL



Dipole Field of the Earth



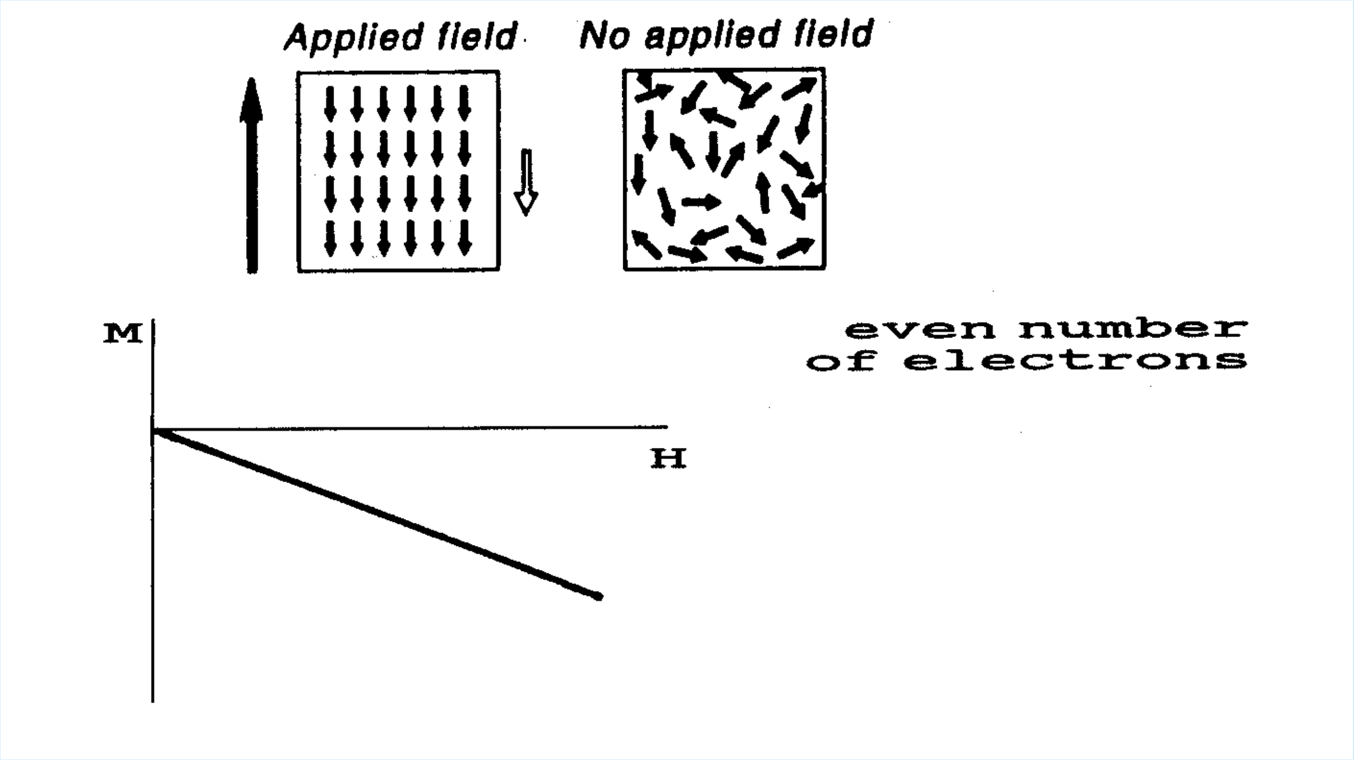
Magnetic anomalies on ocean rift



Shift of anomalies on transform fault.

Black belts indicate basalts with normal NRM polarity, white ones indicate basalts with reverse polarity.

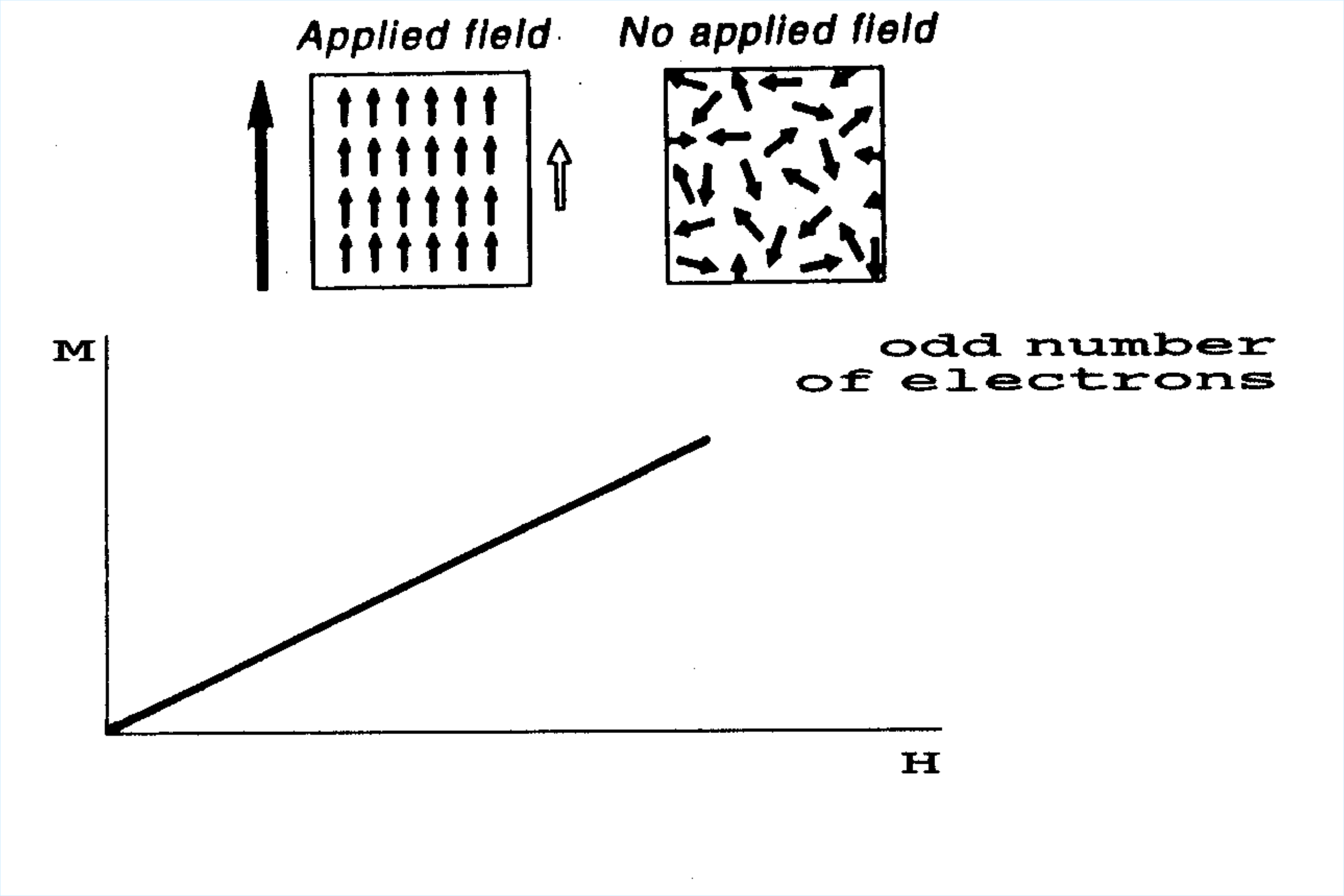
DIAMAGNETISM



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



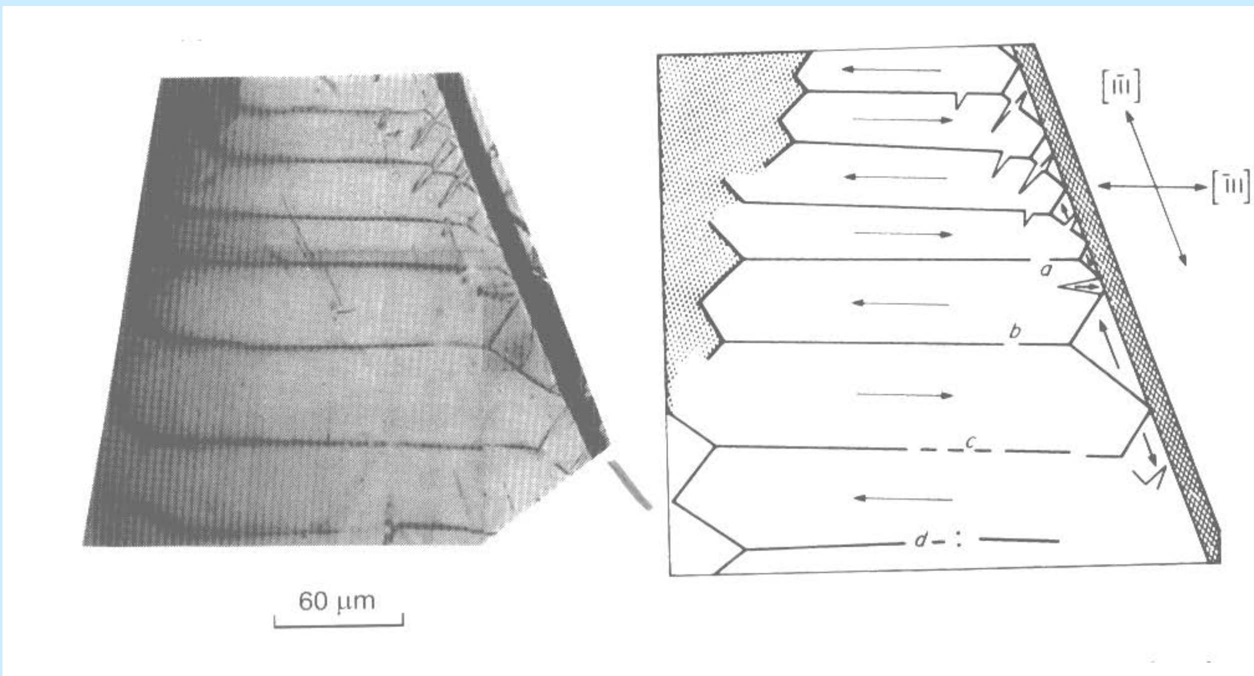
olivine, k = 124 to 4270 x 10^{-6}
pyroxene, k = 121 to 3700 x 10^{-6}
hornblende, k = 750 to 1368 x 10^{-6}

dolomite, k = 11.3 x 10^{-6}
micas, k = 36 to 3040 x 10^{-6}
garnets, k = 502 to 6780 x 10^{-6}

FERROMAGNETISM *sensu lato*

Ferrimagnetism, Antiferromagnetism, Ferromagnetism *sensu stricto*

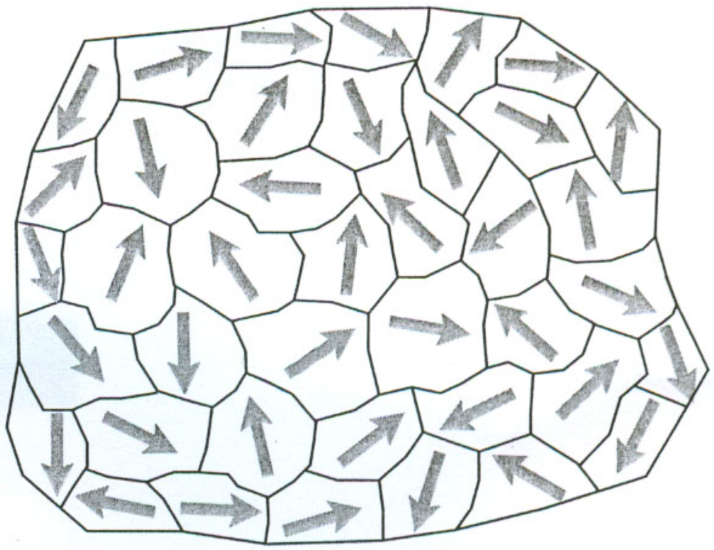
Magnetic Domains – regions with spontaneously oriented magnetic moments



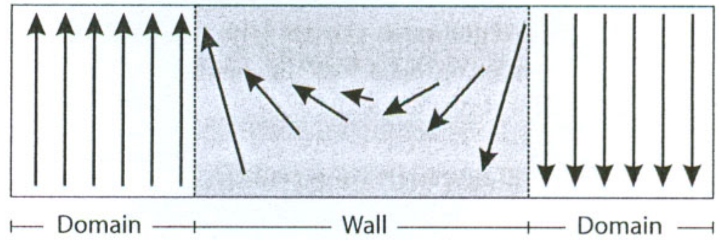
Doménová stavba feromagnetika

Doménová stavba bez vlivu vnějšího magnetického pole

Nulový magnetický moment



Změna magnetizace na hranici domén



Magnetizace feromagnetika

Hysterézní smyčka :

H – magnetické pole (přesněji intenzita magnetického pole)

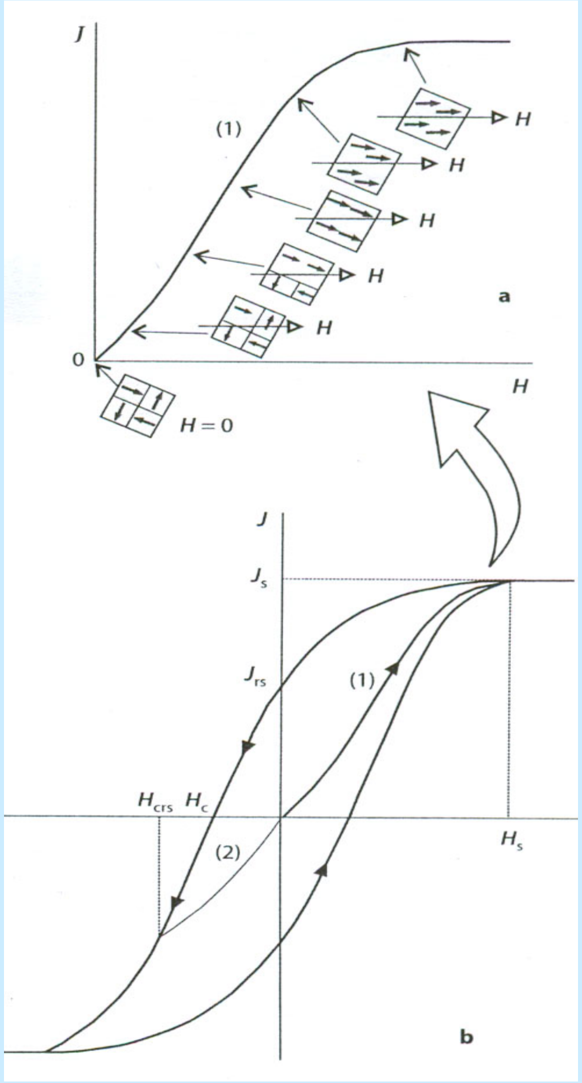
J – magnetizace

Js – sytná magnetizace

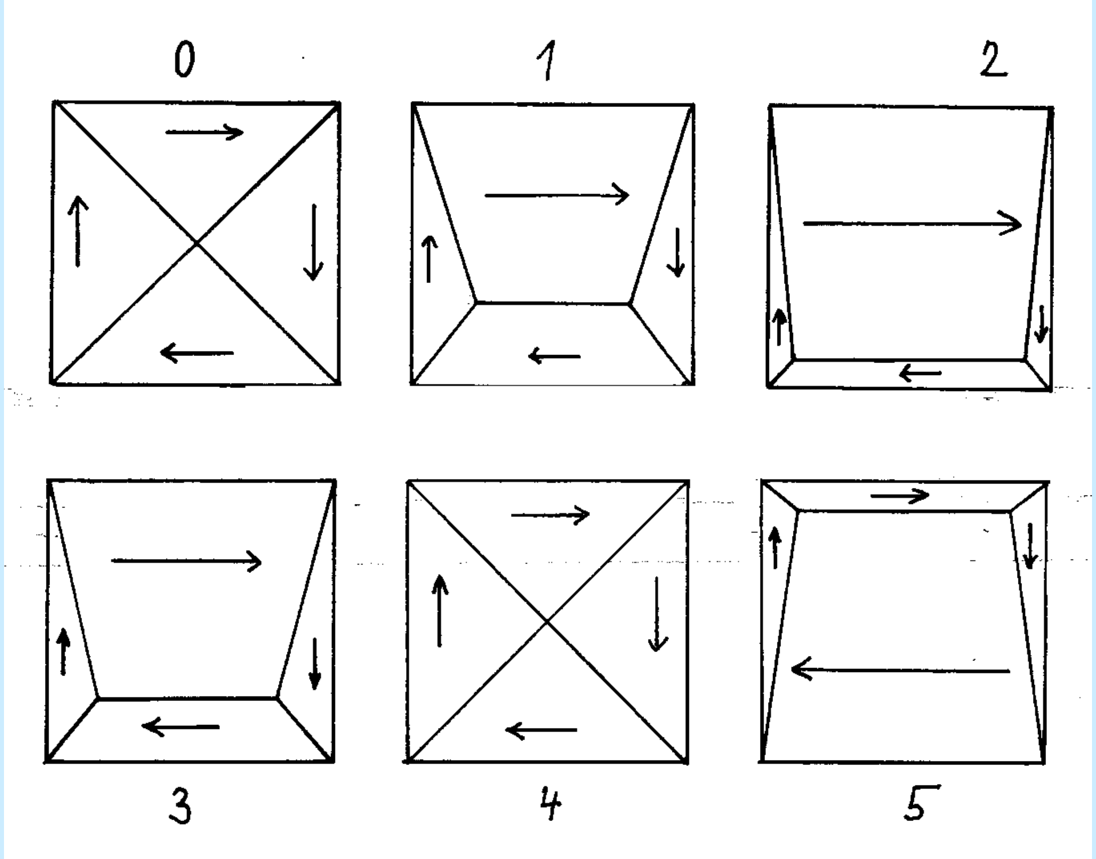
Jr – remanentní magnetizace

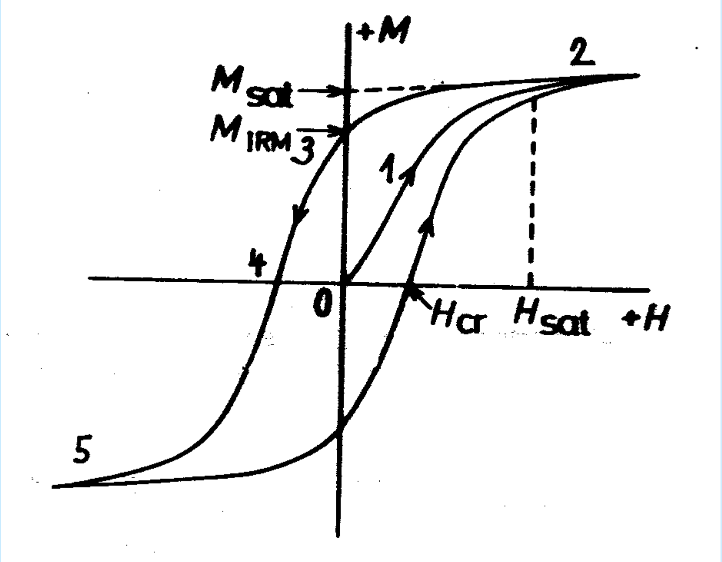
Hc – koercitivní síla

Hcr – koercitivita remanentní magnetizace



HYSTERESIS LOOP in Ferromagnetic *sensu lato* Materials

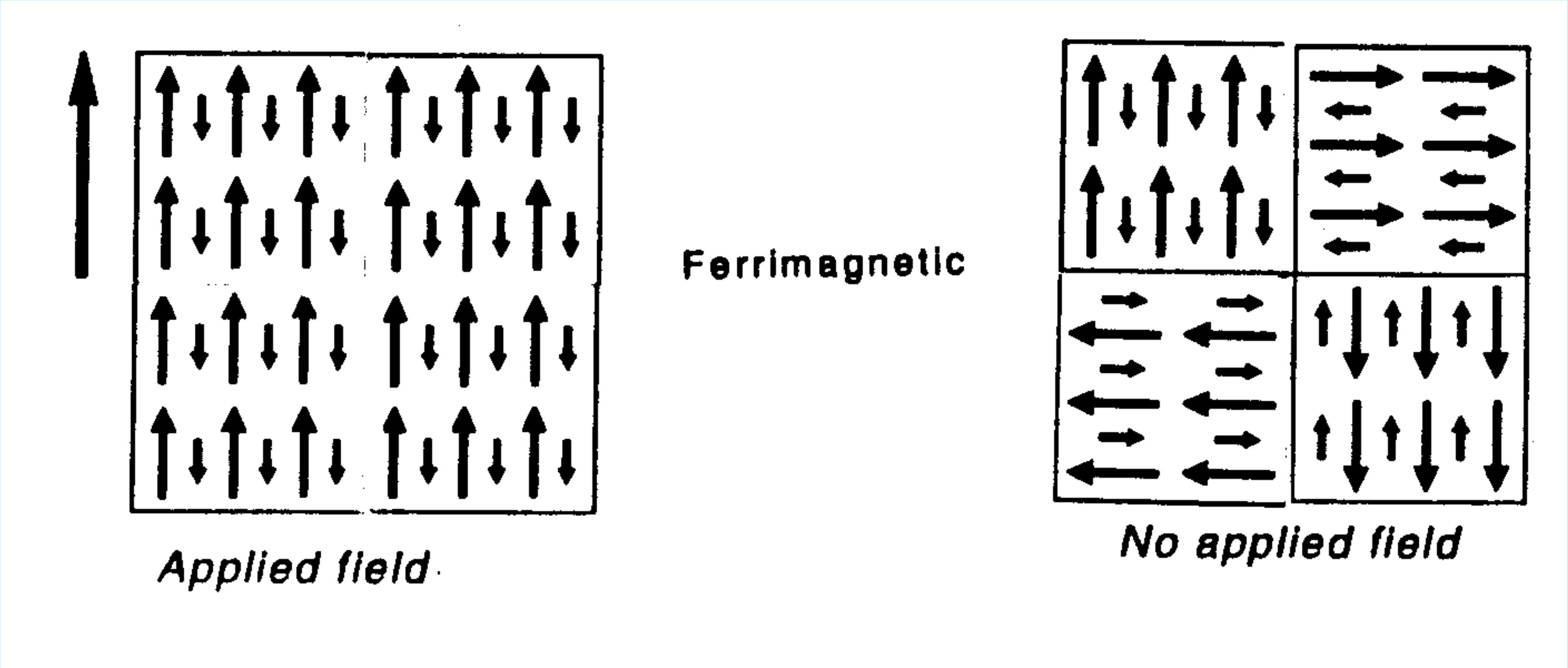




M_{sat} – saturation magnetization, H_{sat} – saturating field

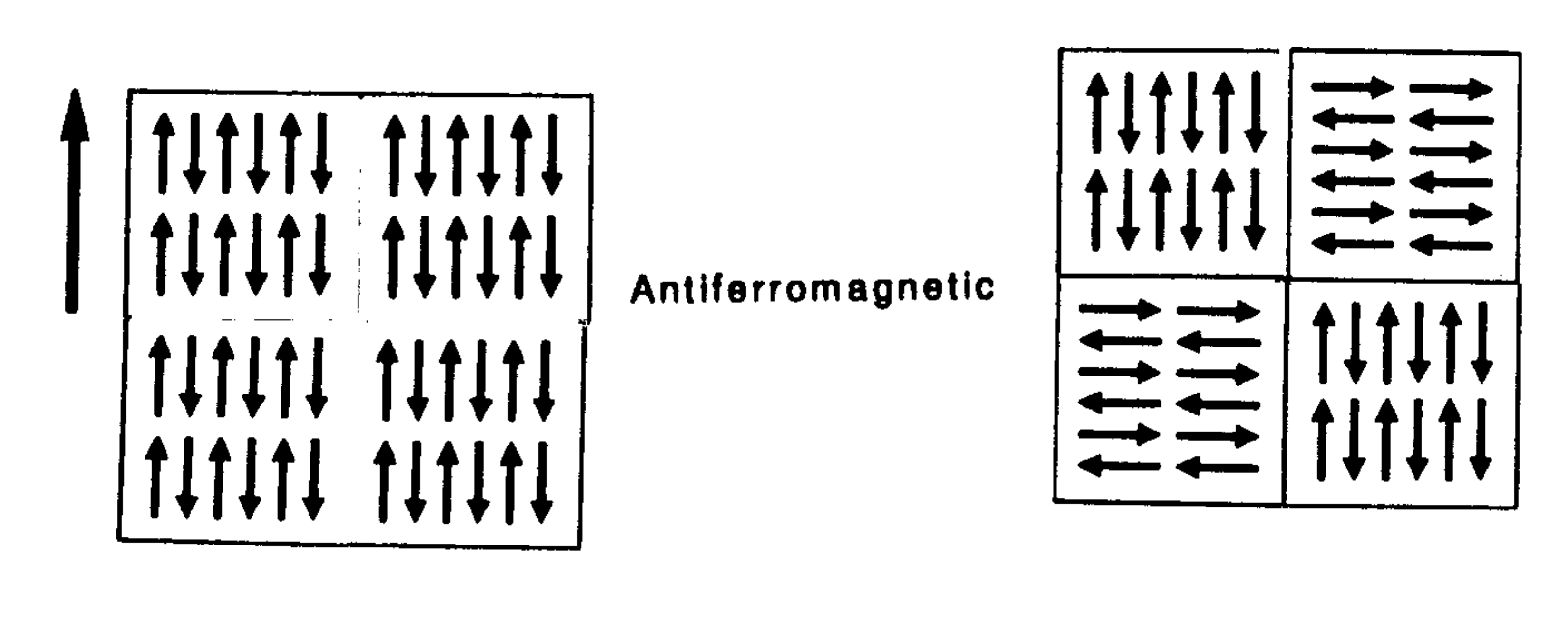
M_{rm} – remanent magnetization, H_{cr} – coercive force

FERRIMAGNETISM



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

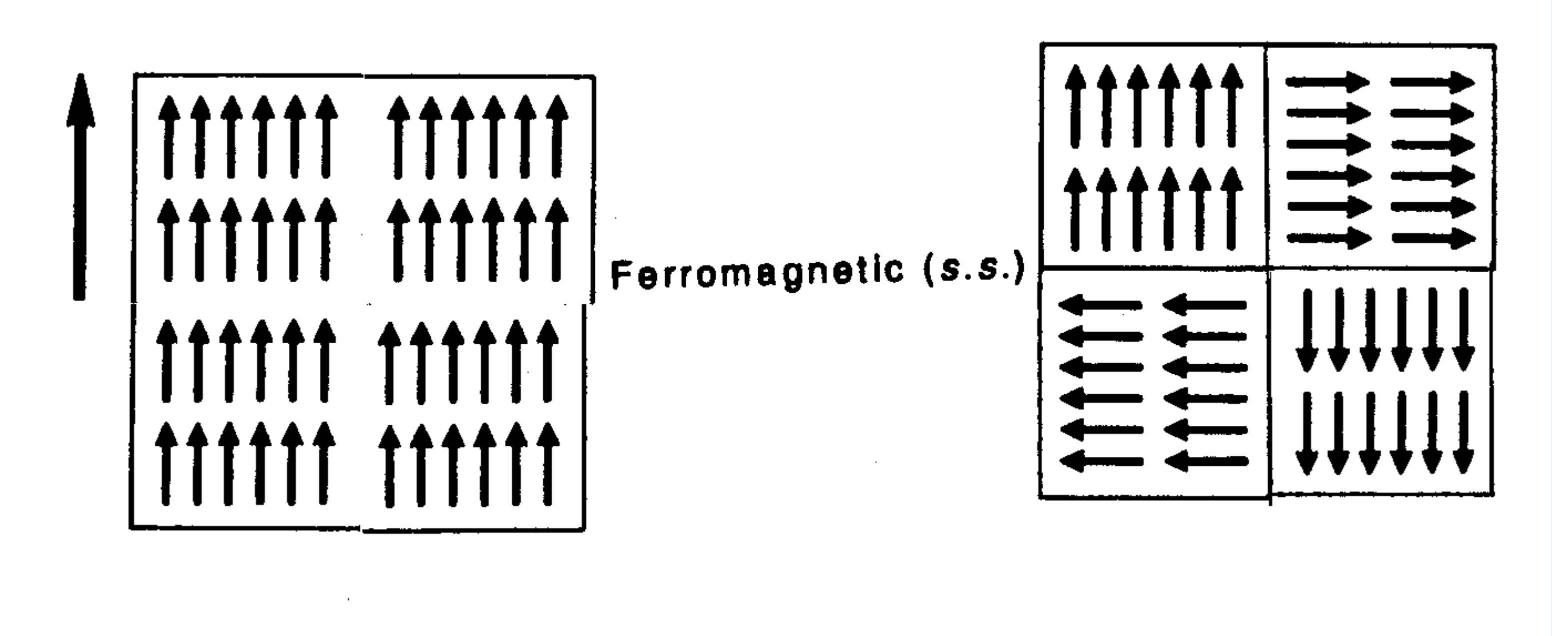
ANTIFERROMAGNETISM



Hematite,
hexagonal Pyrrhotite

$k = 0.001$ to 0.2

FERROMAGNETISM *sensu stricto*

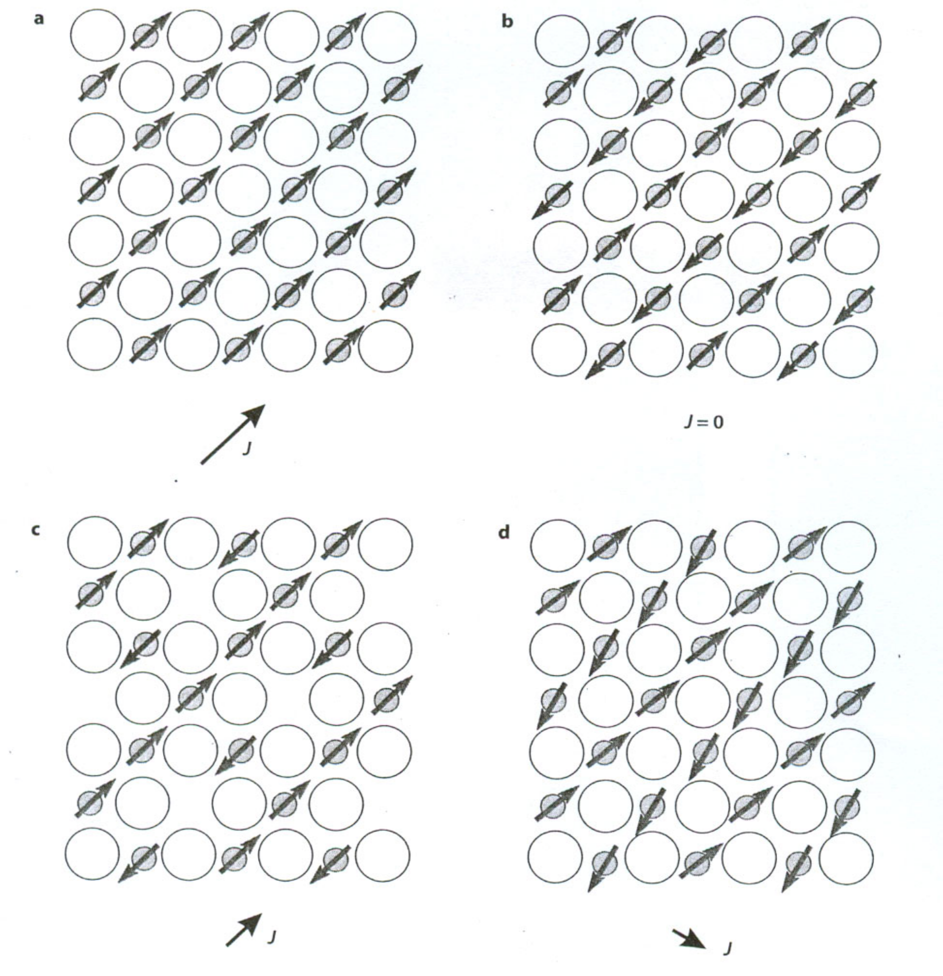


Metallic Iron

Parazitický feromagnetismus antiferomagnetika

feromagnetismus

ferimagnetismus



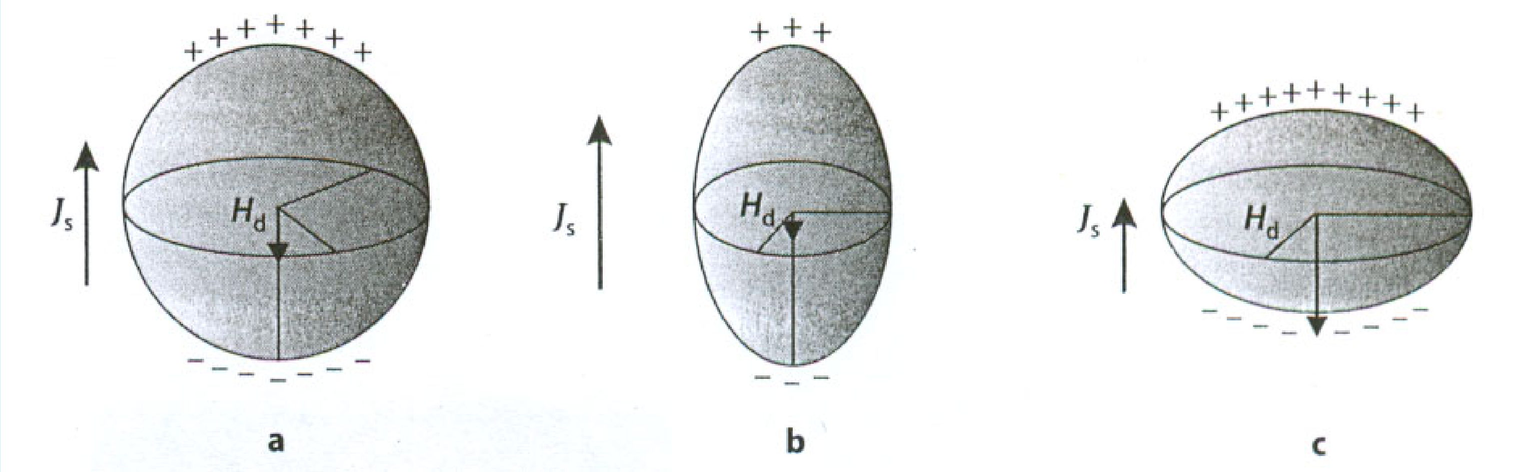
antiferomagneti-smus

čistý

Antiferomagneti-smus s parazitickým feromagnetismem

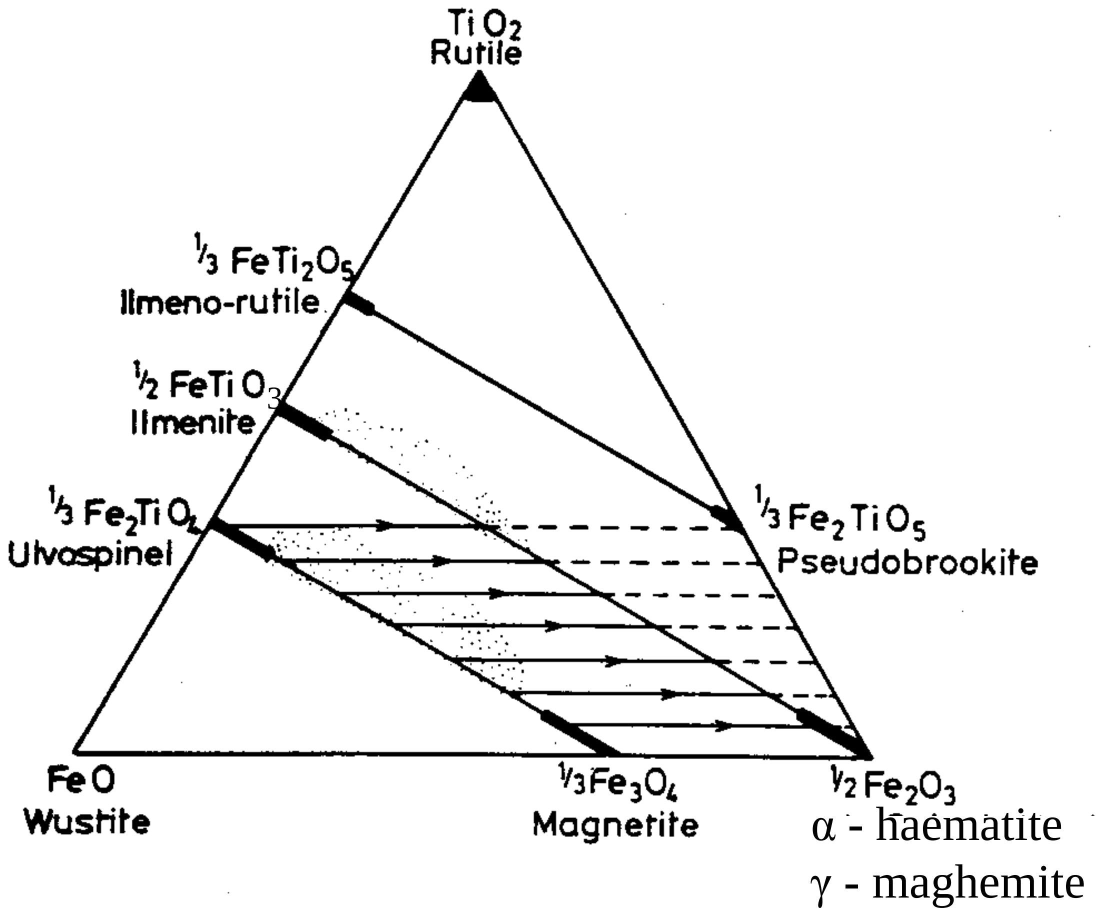
Demagnetizační faktor N

Je definován rovnicí : $k_{ext} = k_{int}/[1 + Nk_{int}]$

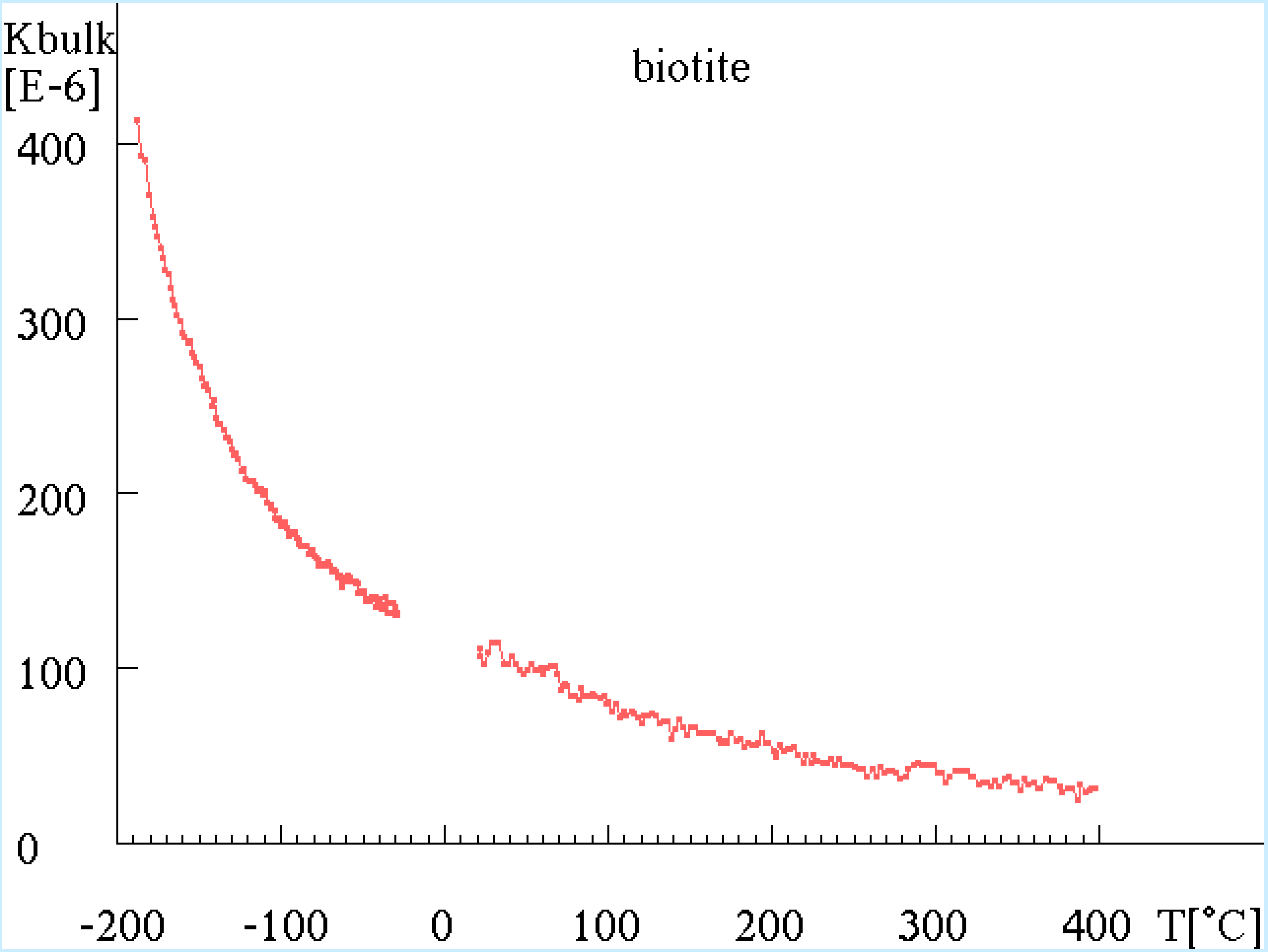


K_{ext} se liší od k_{int} u silně magnetických látek, z minerálů např. u magnetitu a maghemitu. Výsledná magnetizace závisí na tvaru zrna (b,c) a jeho orientaci v magnetickém poli. Demagnetizační faktor je příčinou tzv. tvarové magnetické anizotropie.

TERNARY DIAGRAM FOR IRON-TITANIUM OXIDES



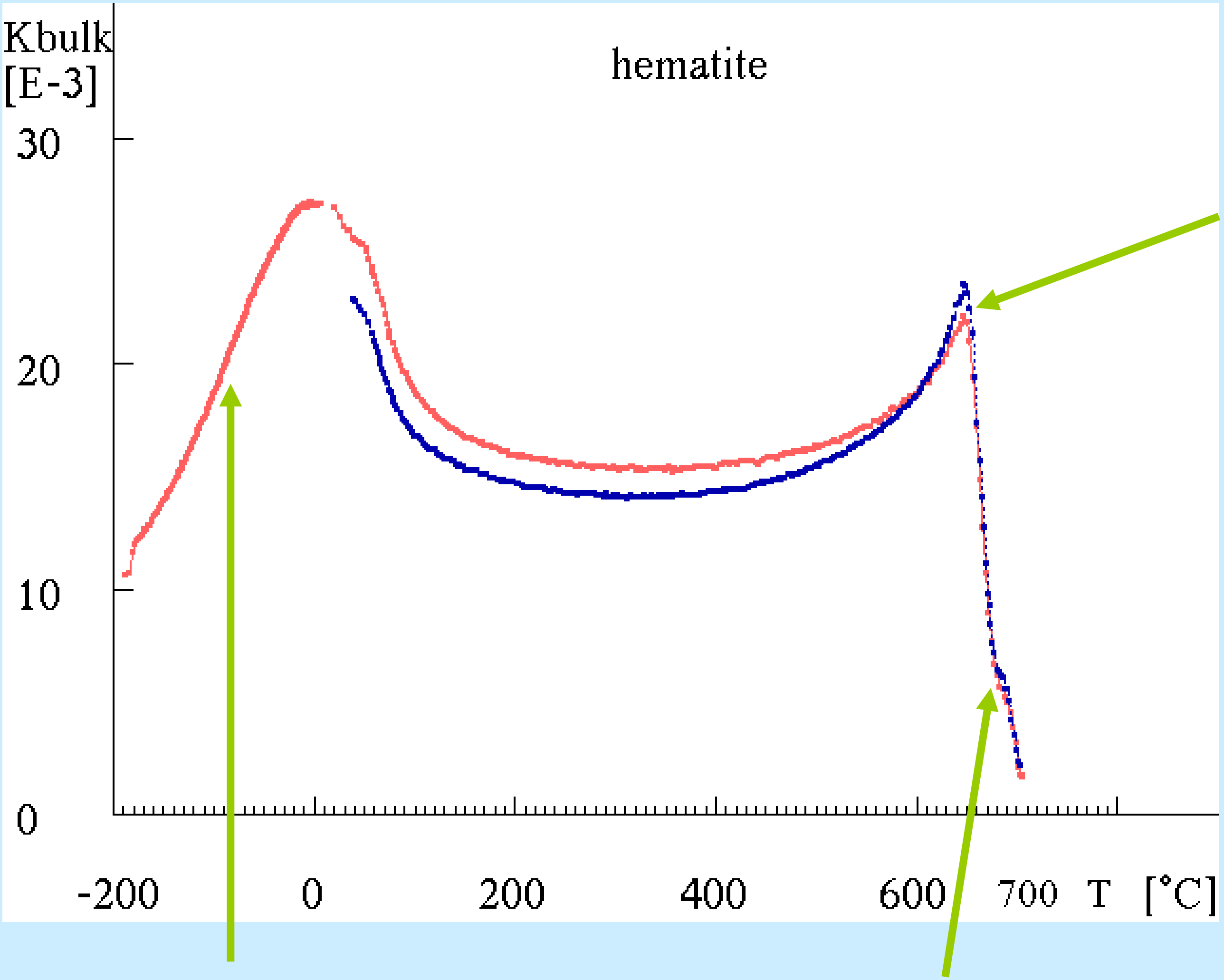
Temperature Variation of Susceptibility in Paramagnetics



Hyperbolic course according to the Curie Law, $k = C/T$

C – proportionality constant, T – absolute temperature

Temperature Variation of Susceptibility in Hematite

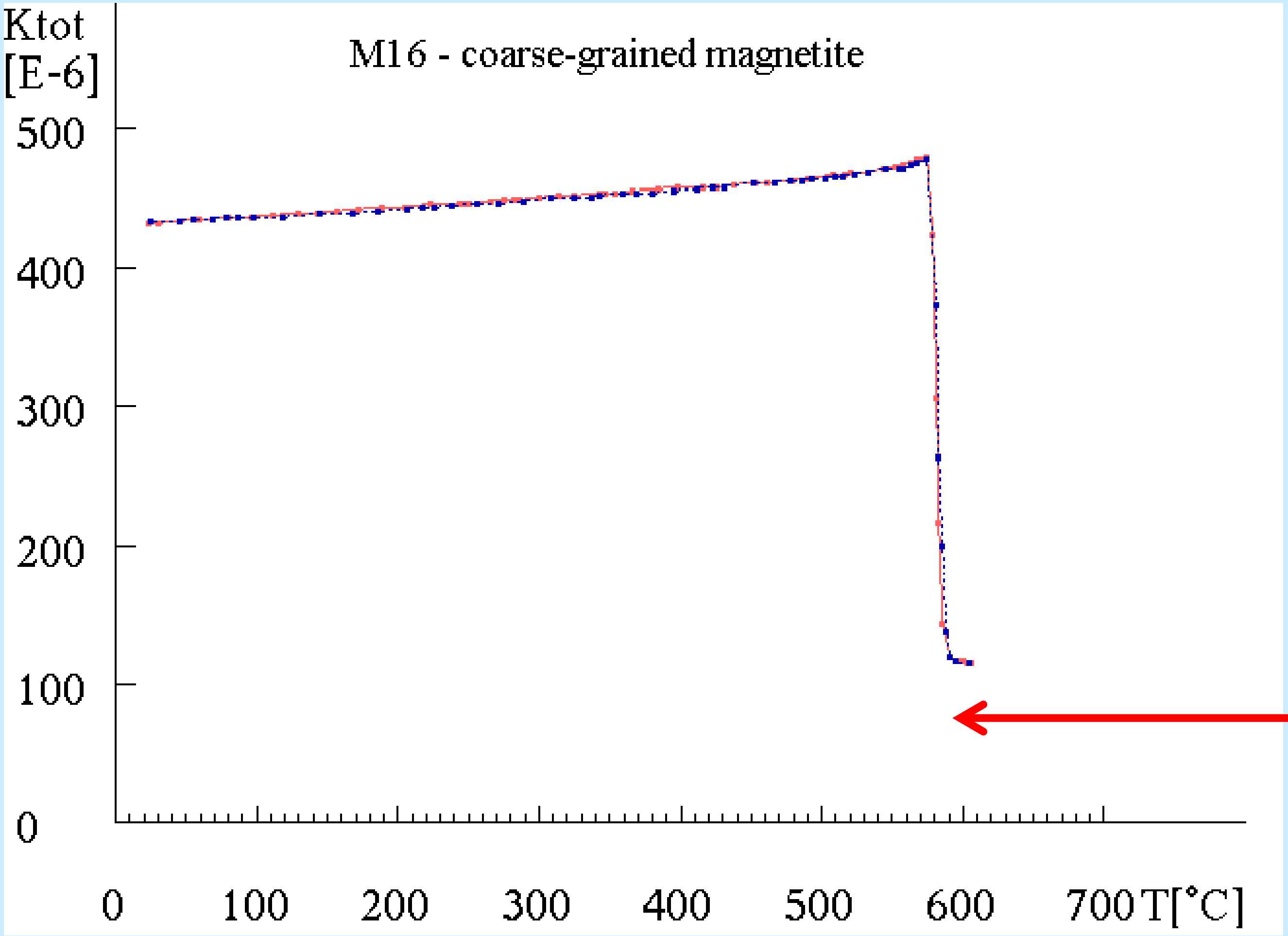


Hopkinson Peak

Morin Transition

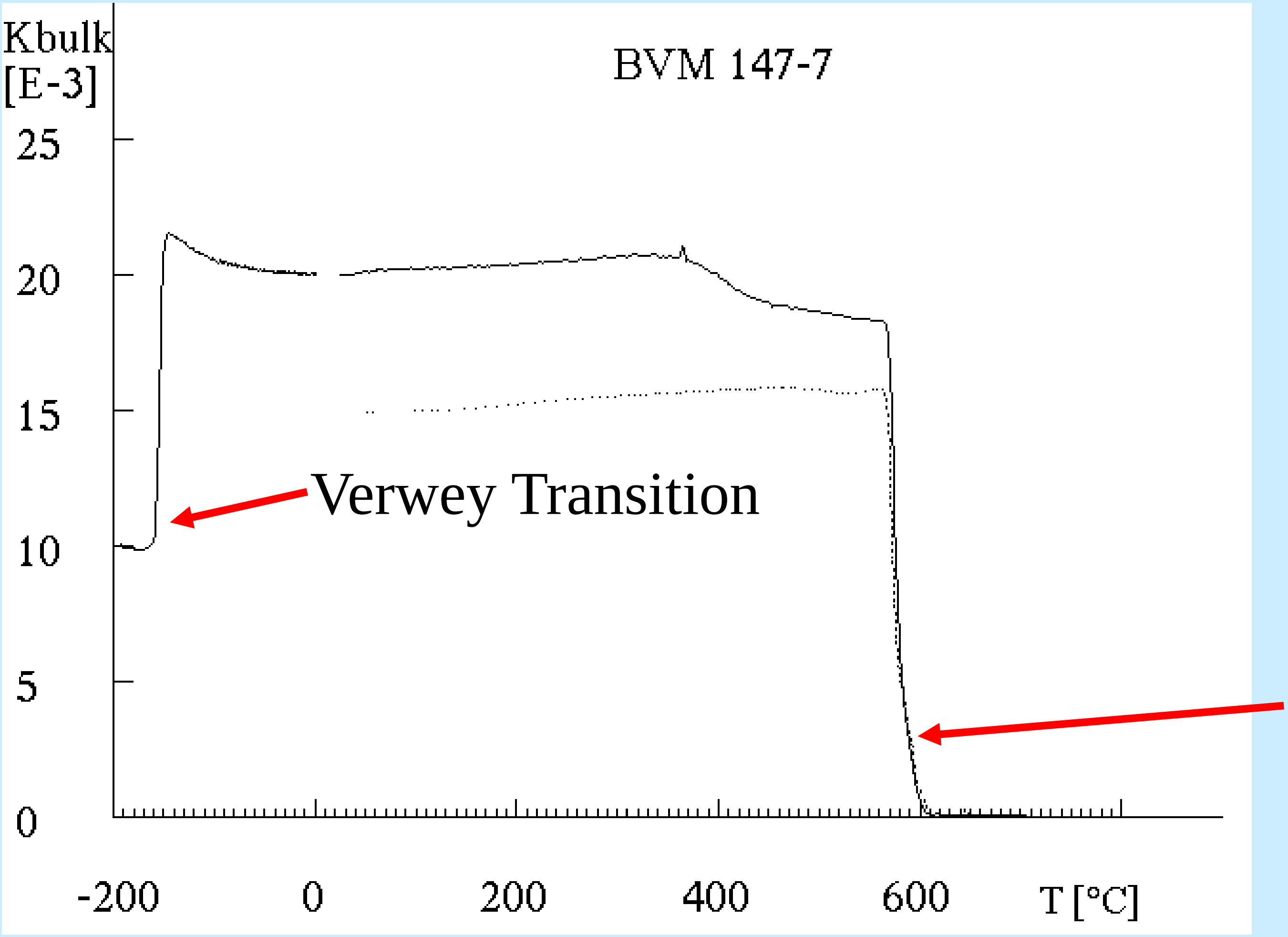
Curie Temperature

Temperature Variation of Susceptibility in Magnetite



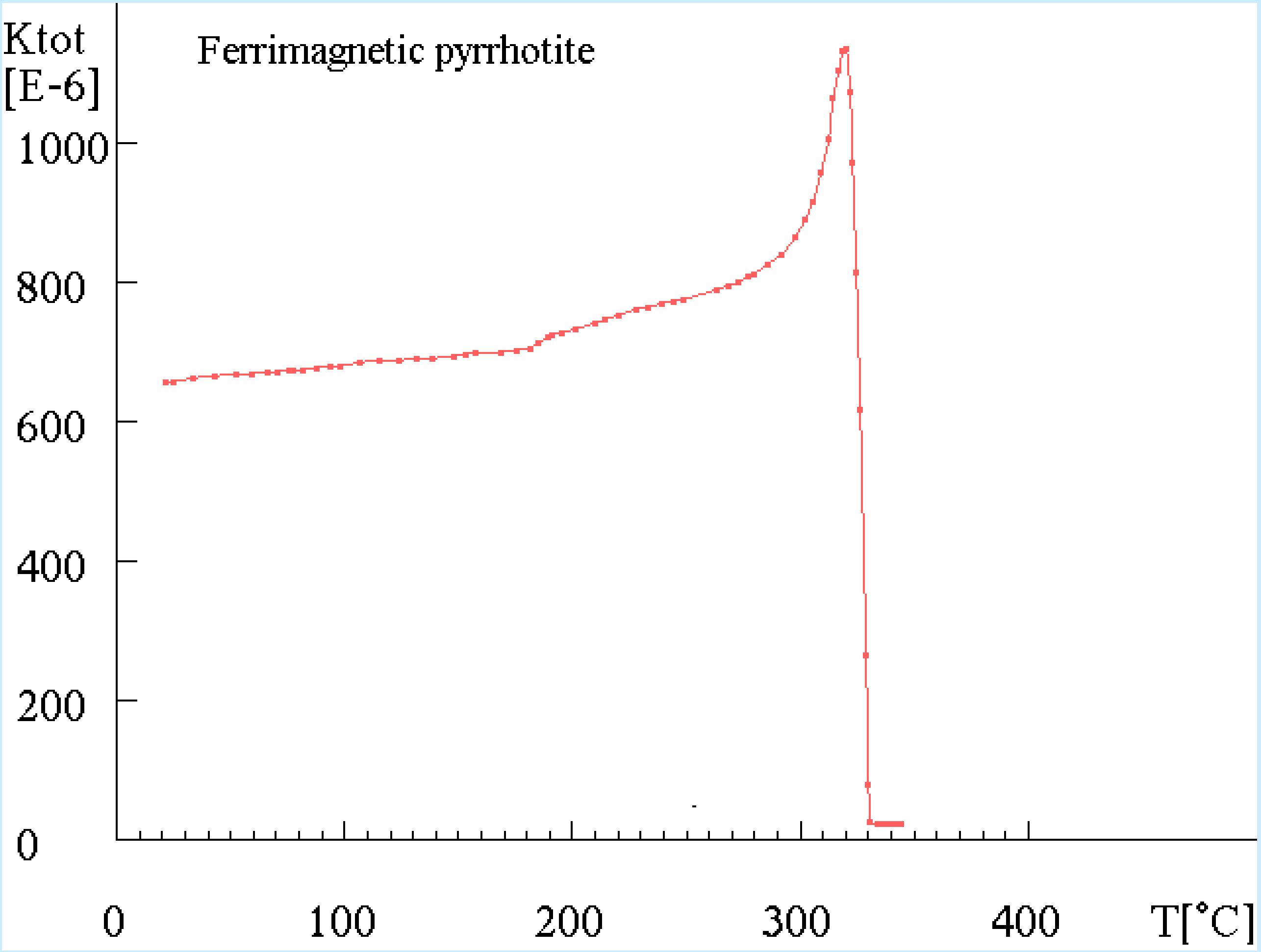
Curie Temperature
$T_c = 585^oC$

Temperature Variation of Susceptibility in Magnetite



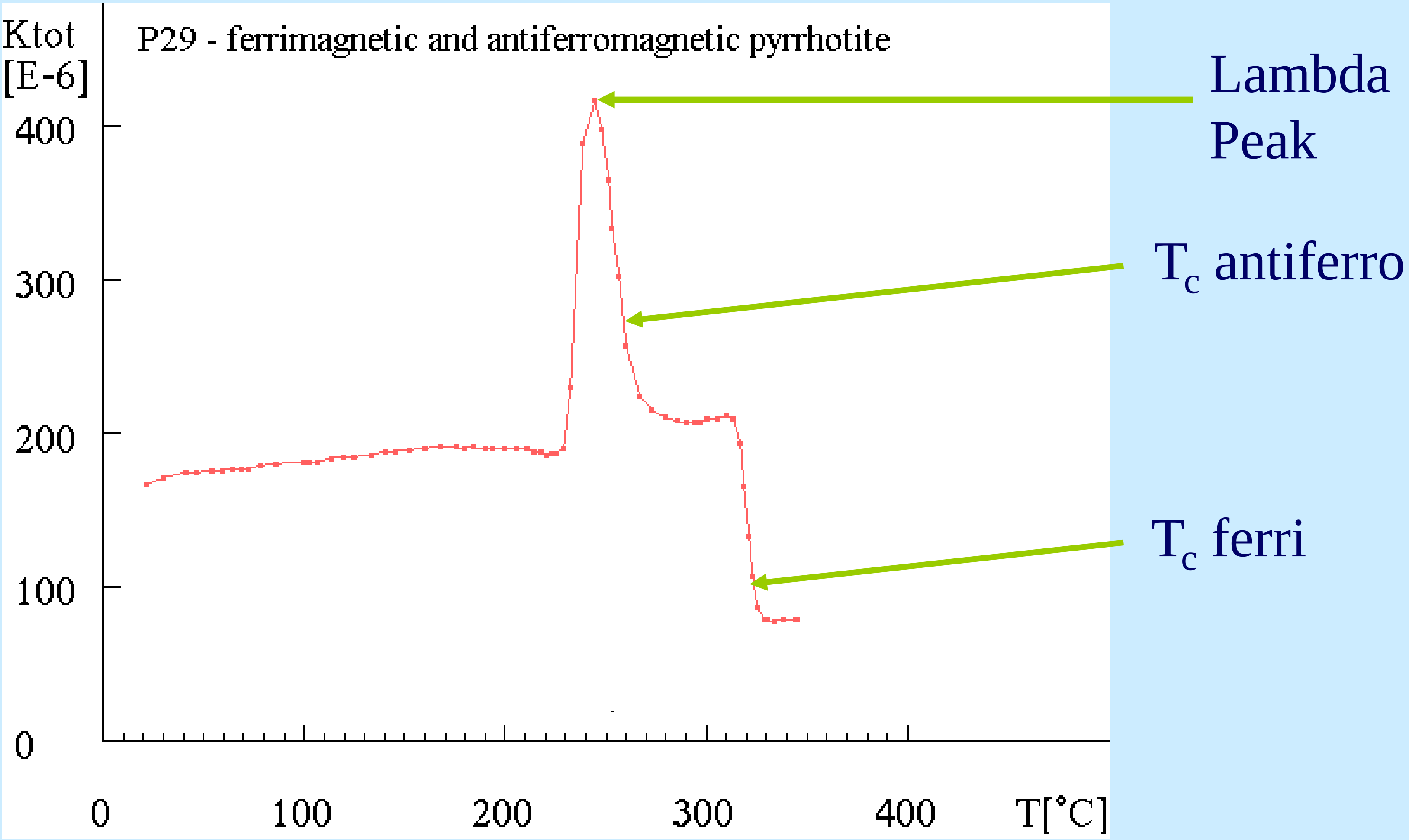
Curie Temperature
$T_c = 585^oC$

Temperature Variation of Susceptibility in Monoclinic Pyrrhotite

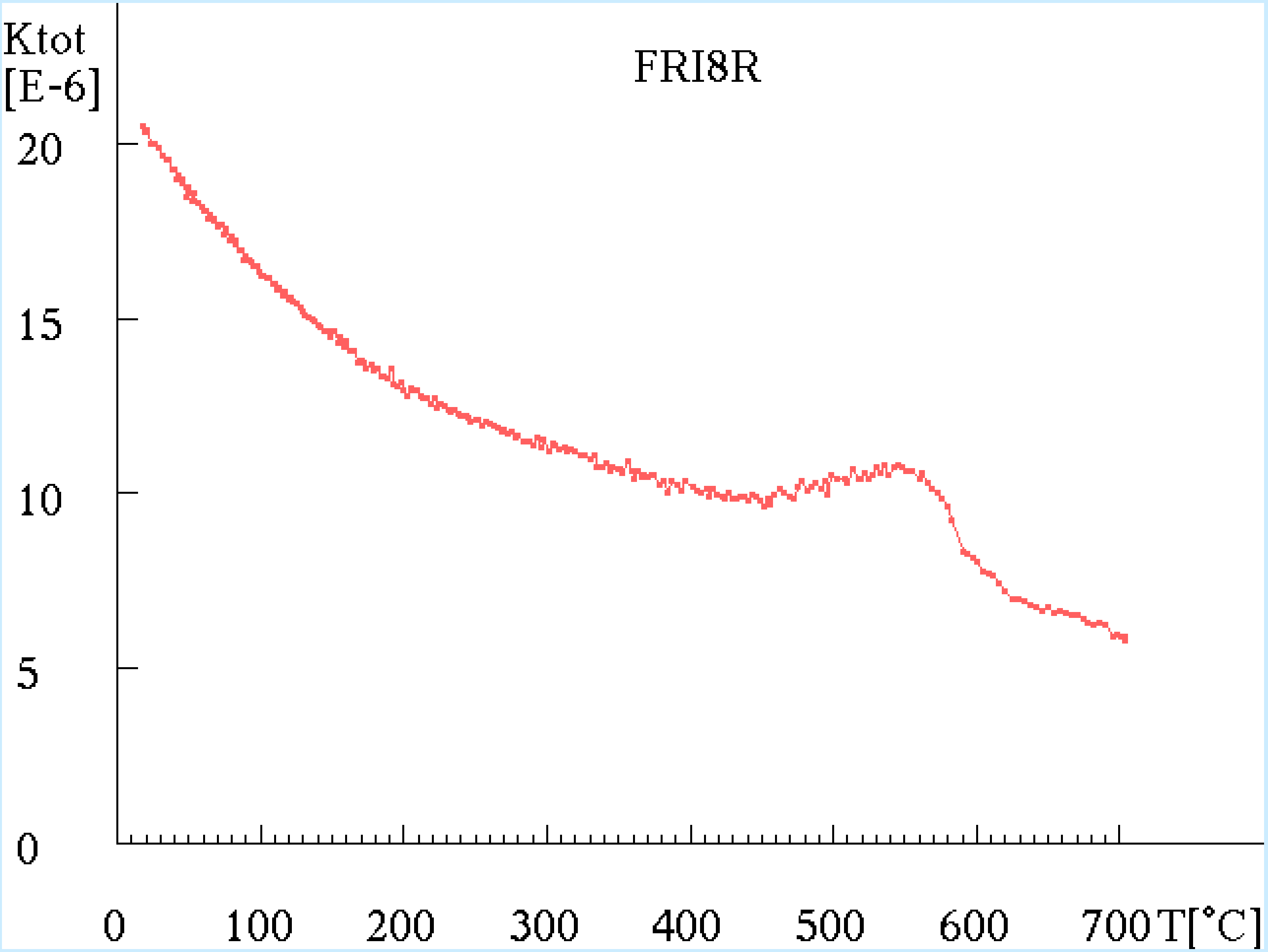


$T_c = 325^oC$

Temperature Variation of Susceptibility in mixture of monoclinic and hexagonal pyrrhotite

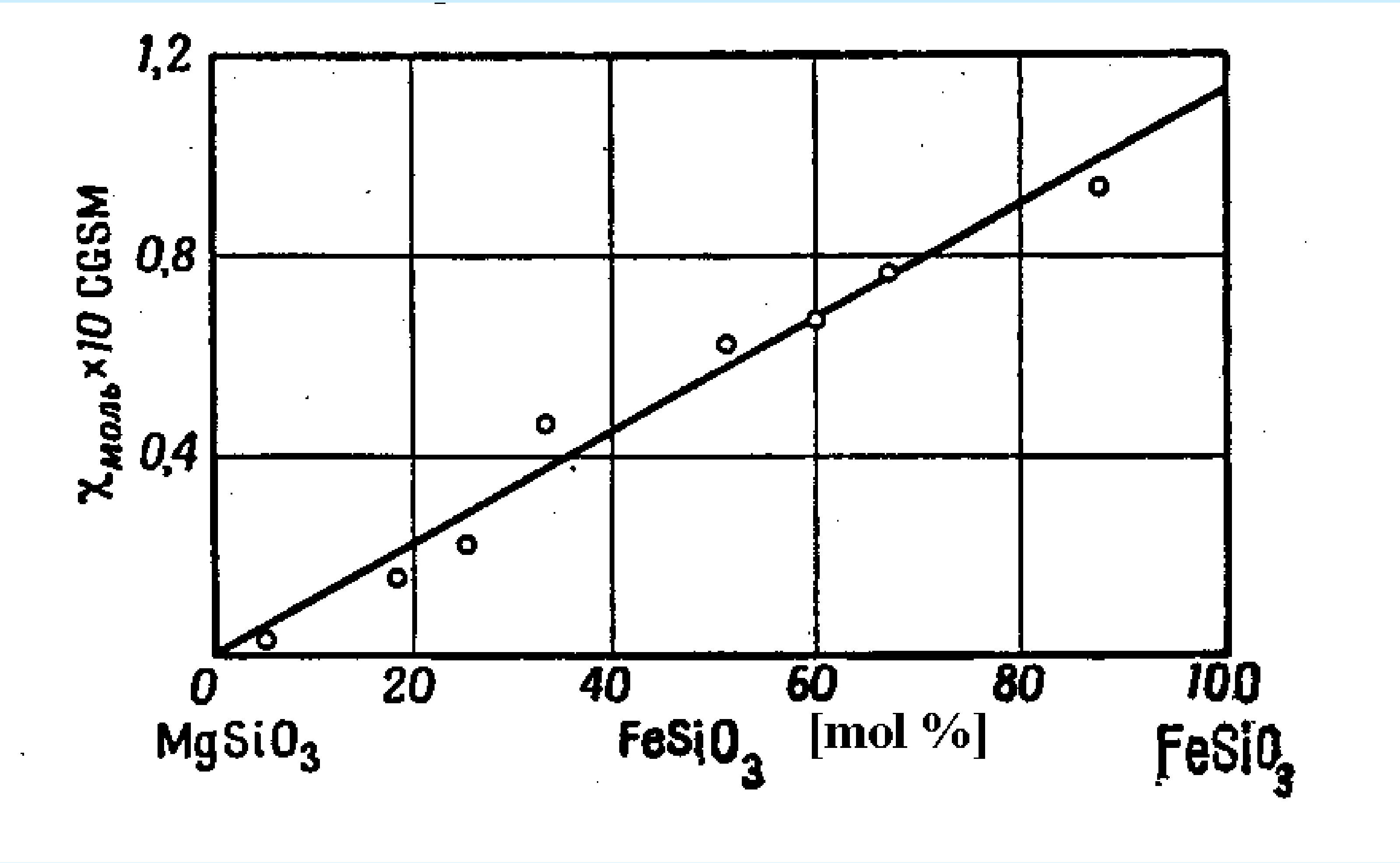


AMPHIBOLITE (Hornblende + Magnetite)



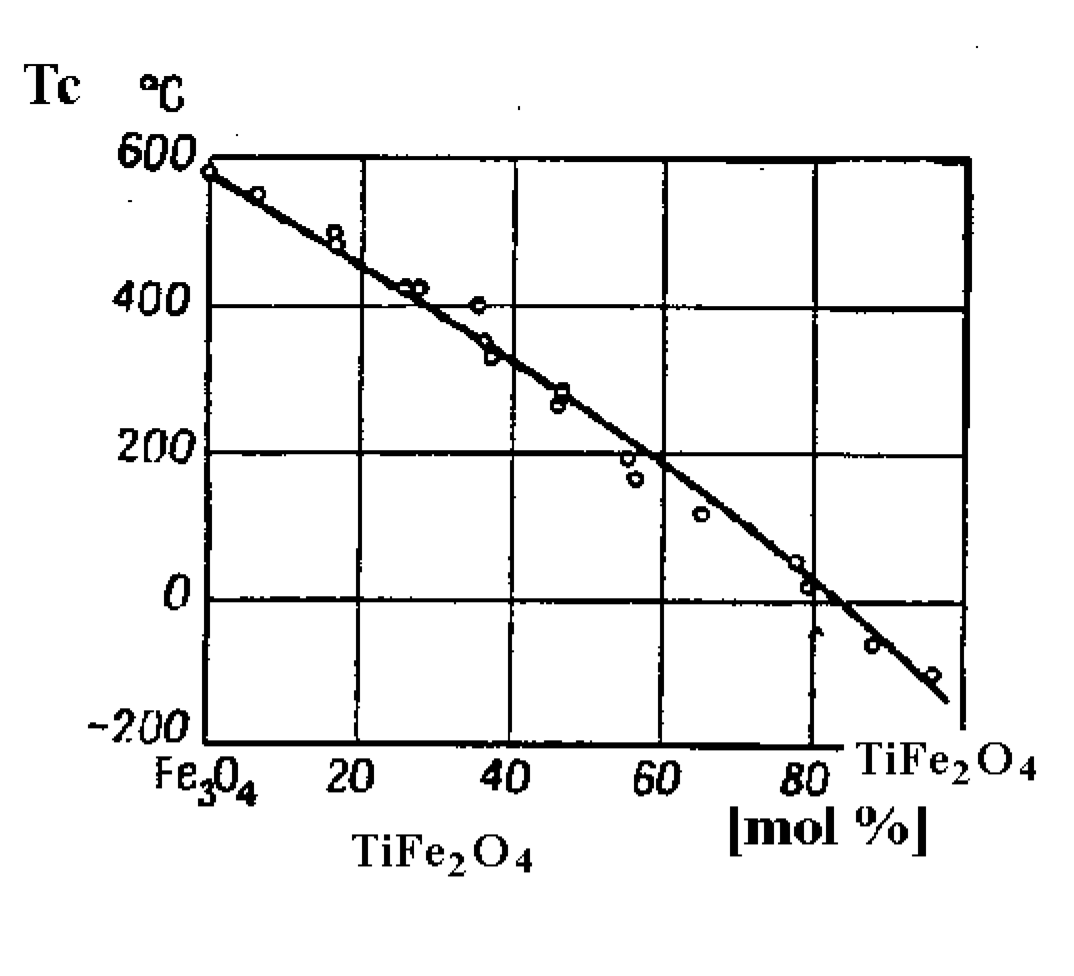
Susceptibility Variation with Mineral Composition

orthopyroxene

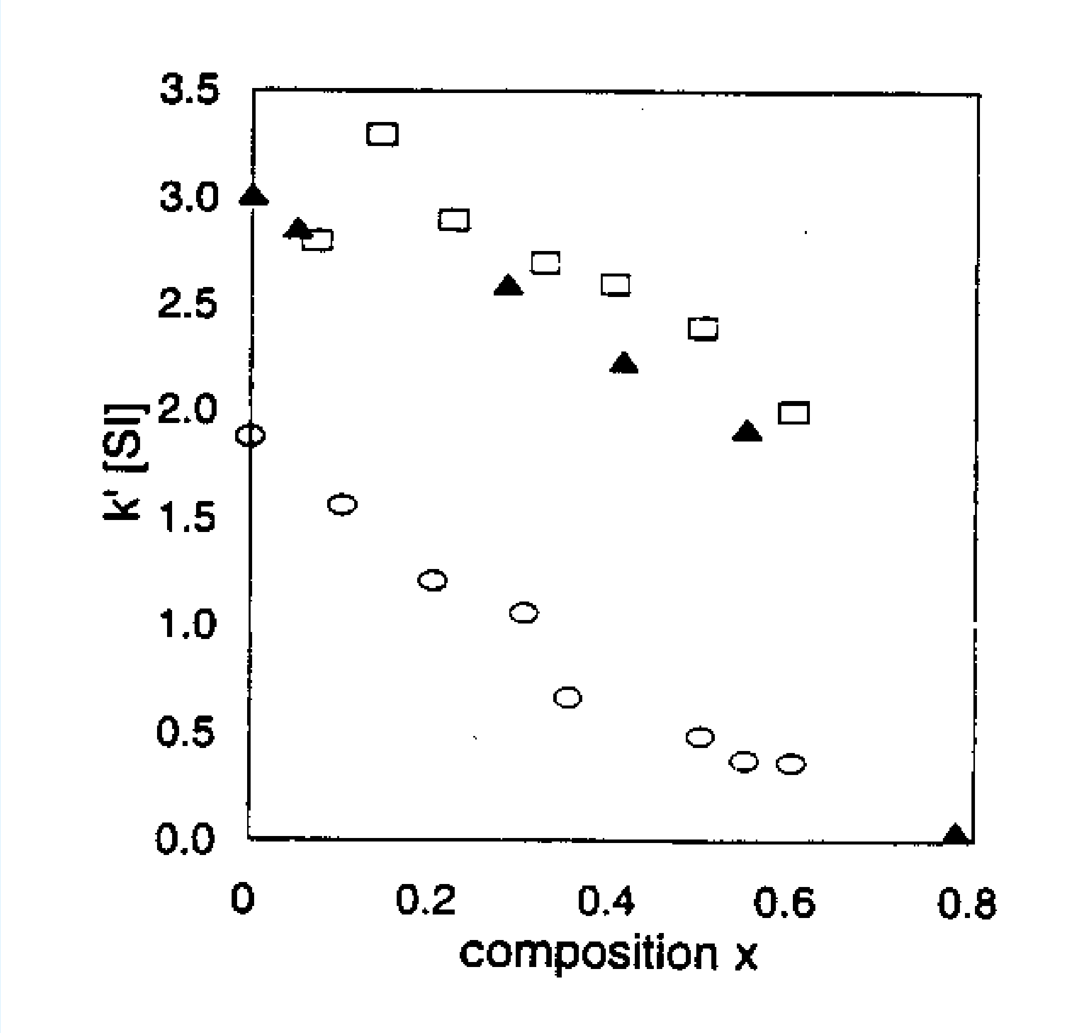


Variation of Curie Temperature with Mineral Composition

magnetite – ulvospinel series

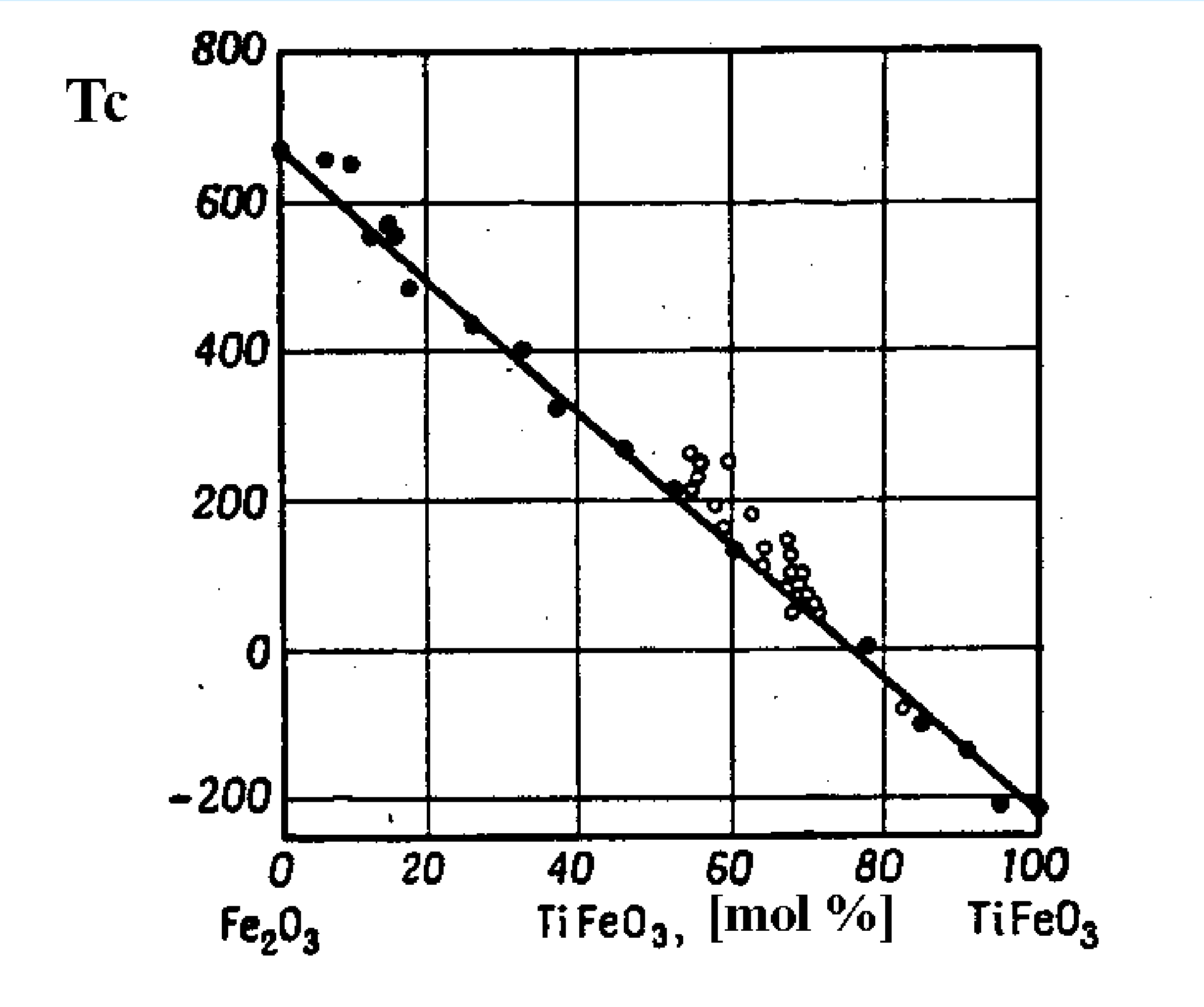


Susceptibility Variation with Composition in Titanomagnetites

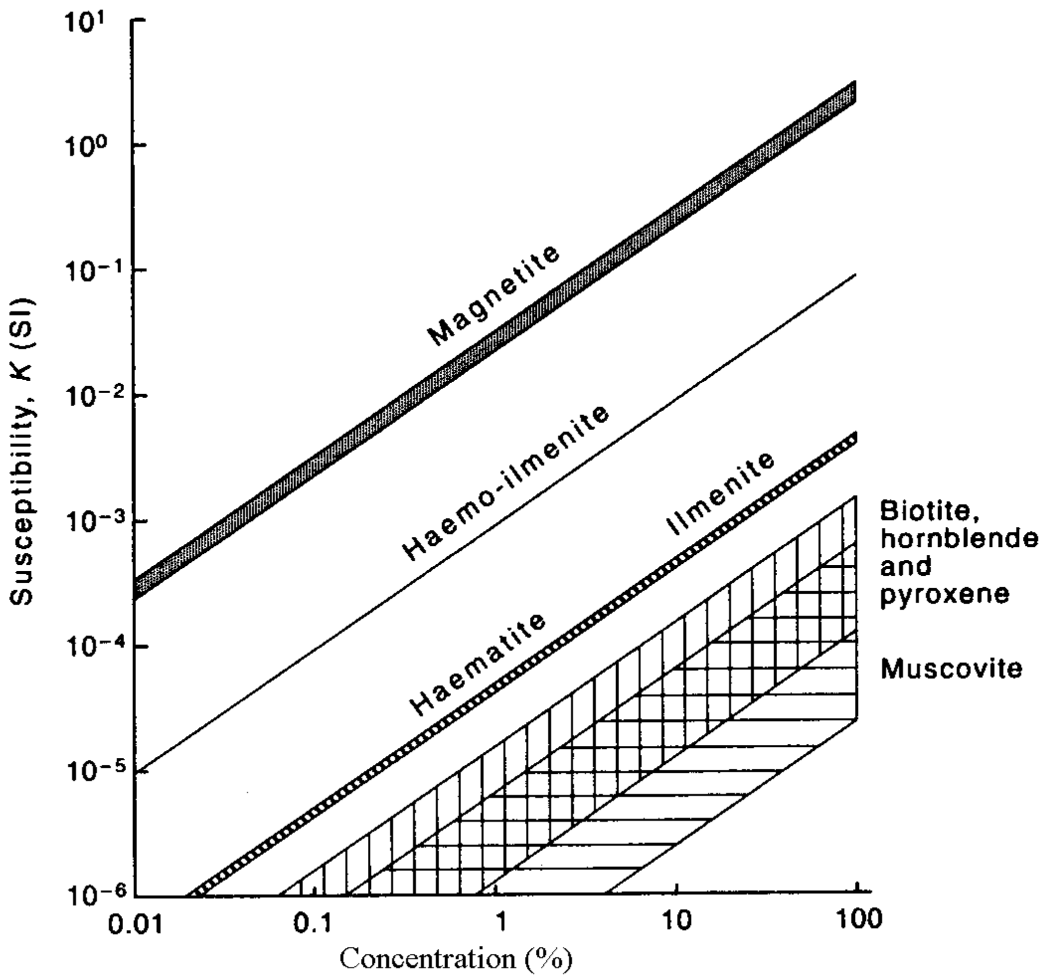


Variation of Curie Temperature with Mineral Composition

ilmenite – hematite series



Magnetic Susceptibility of Minerals

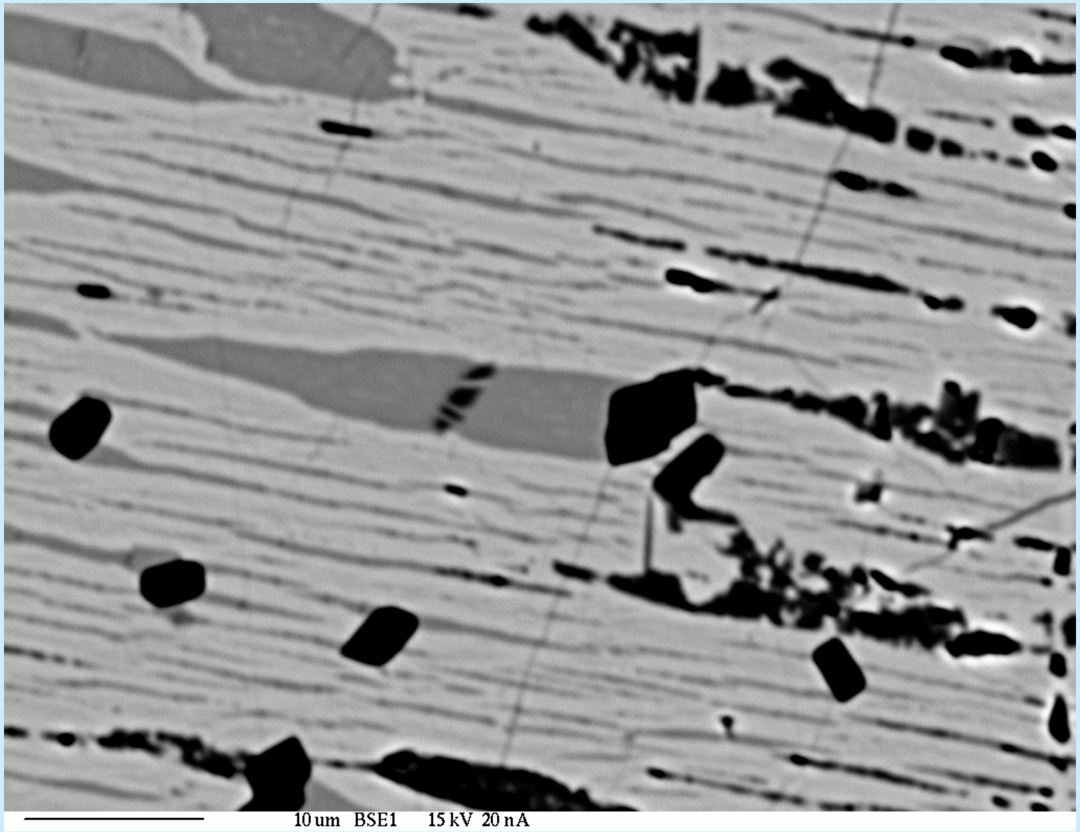


Oxidace Fe-Ti minerálů

V průběhu geologického vývoje dochází ke změnám PT podmínek vzhledem k těm, ve kterých se původně horniny vytvářely. U vulkanitů, intruzív a výše metamorfovaných hornin dochází při jejich ochlazování a výstupu k povrchu k tzv. oxidaci Fe-Ti minerálů, a to jak titanomagnetitů, tak ilmenohematitů a hemoilmenitů.

Oxidace se projevuje lamelováním původních zrn, tj. vznikem lamel bohatších na Ti a lamel naopak chudých na Ti. Proces končí lamelami ilmenit-magnetitovými nebo ilmenit-hematitovými.

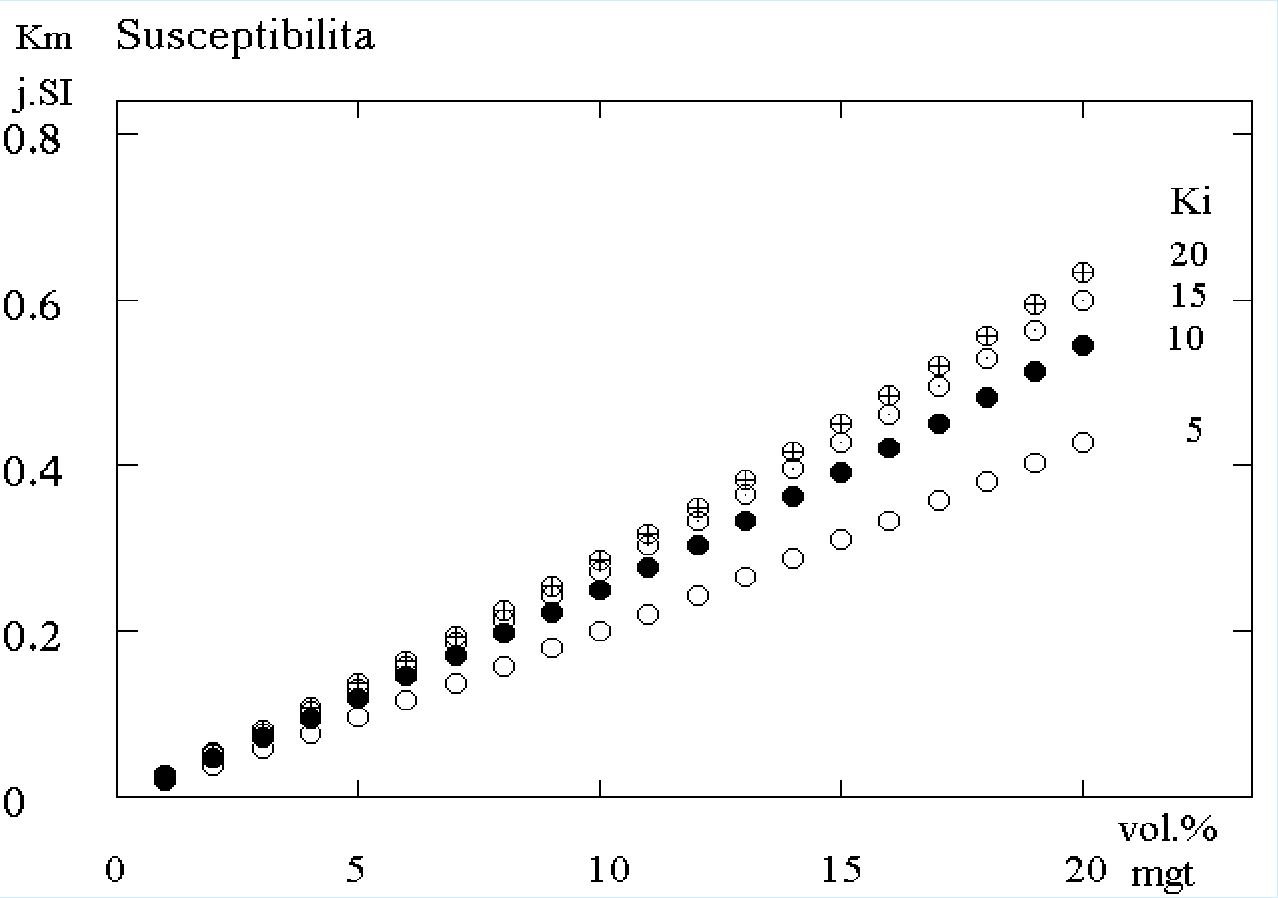
Oxidace ferimagnetických minerálů v horninách



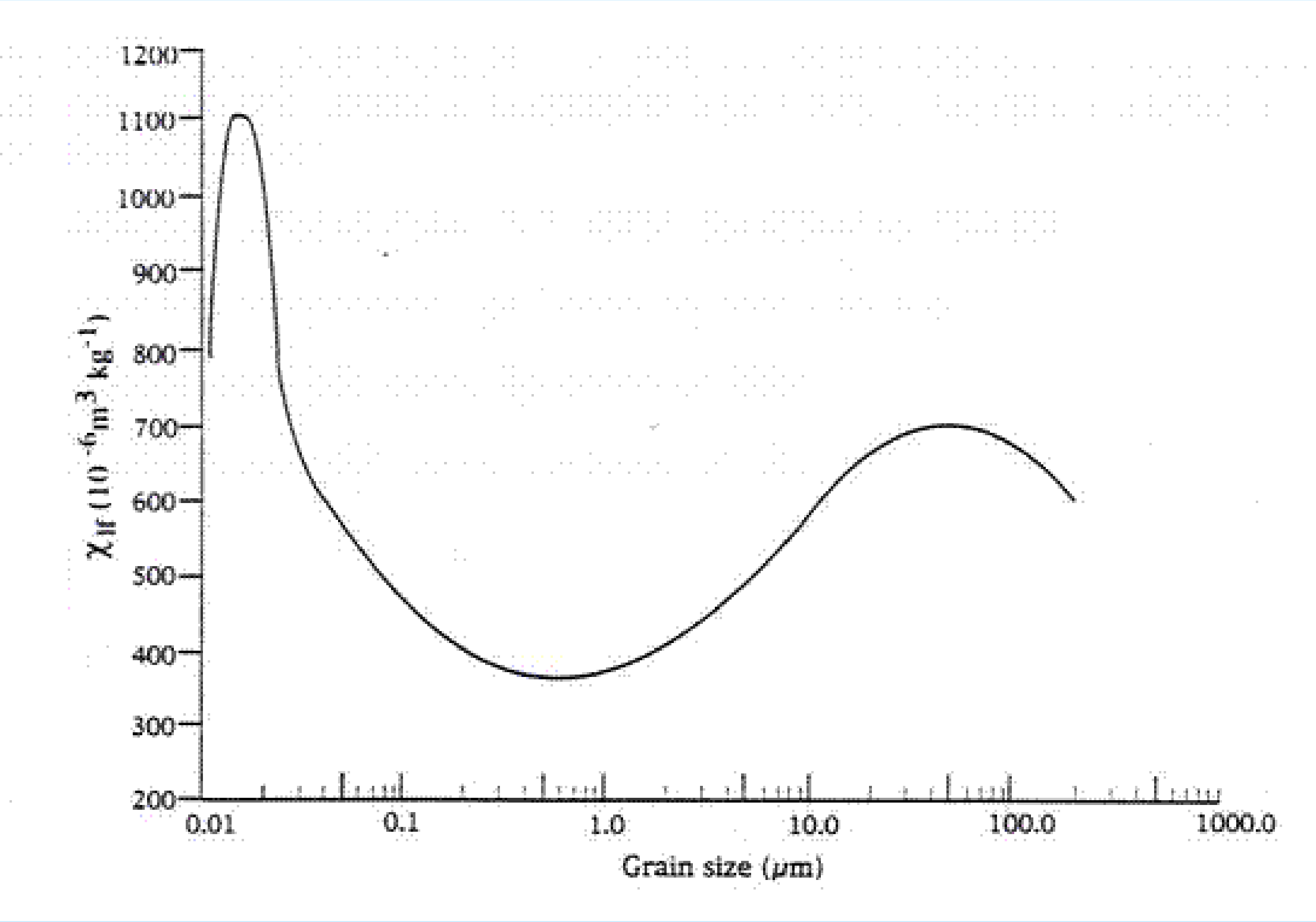
Hemoilmenit s magnetitem z lokality Orlík u Humpolce (foto V. Procházka)

Tenké lamely hemoilmenitu (šedé) v hematitu (světlý), magnetit je černý.

Bulk susceptibility and magnetite content



Závislost susceptibility na velikosti zrna

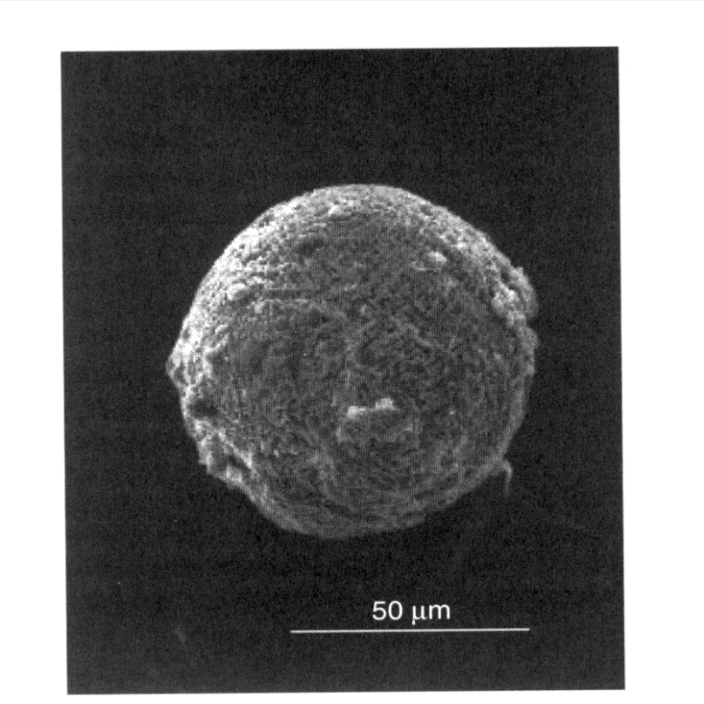


Iron-rich spherule

Magnetic spherule from

the topsoil from Jaworzno power

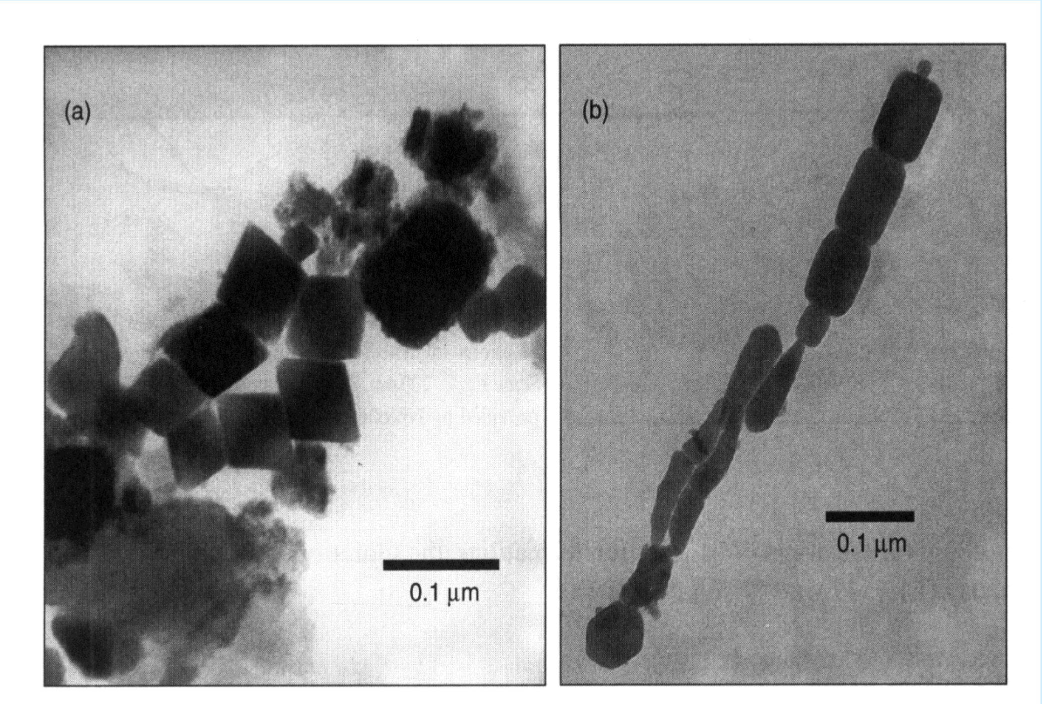
Station (Poland)



Bacterial magnetites

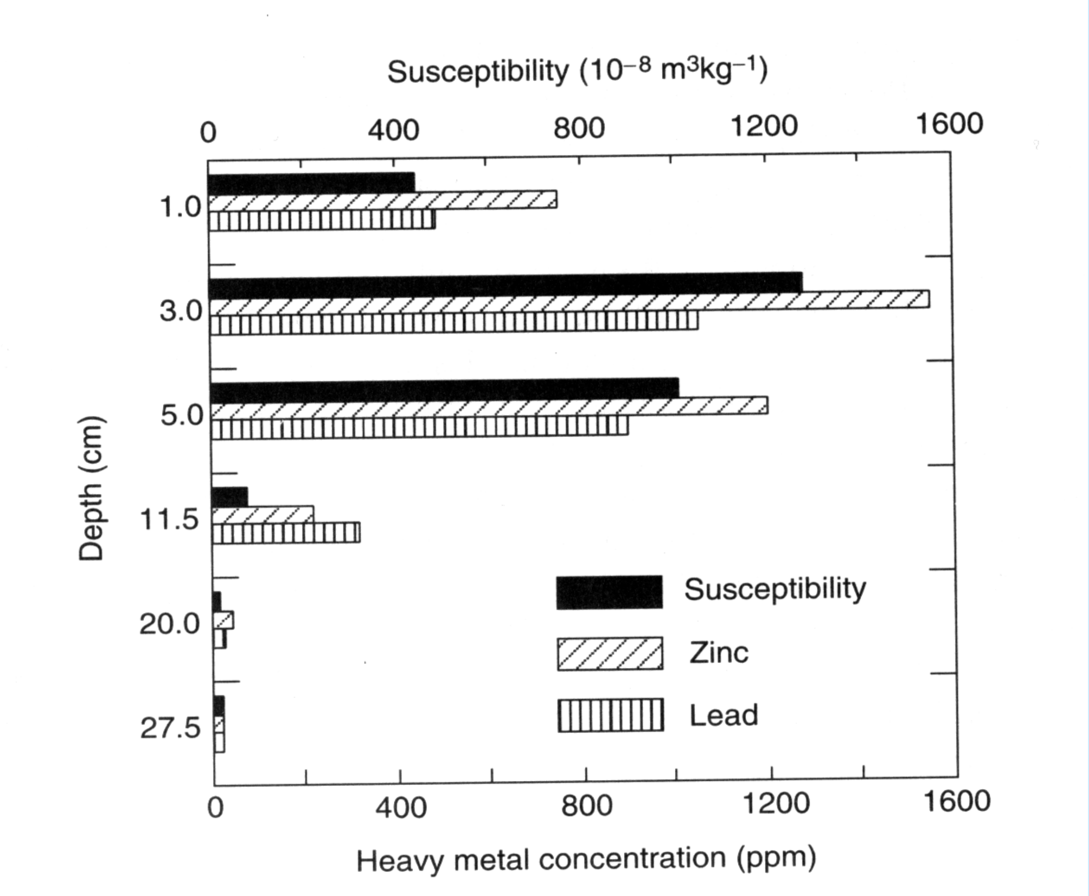
TEM images of different shapes of bacterial magnetites in a core from the Tasman Sea, 4520 m water depth

Different species produce different shapes of magnetosome particles



Susceptibility and HM polution

Correlation of magnetic susceptibility with lead and zinc contents in a soil pit near Jaworzno power station (Poland)

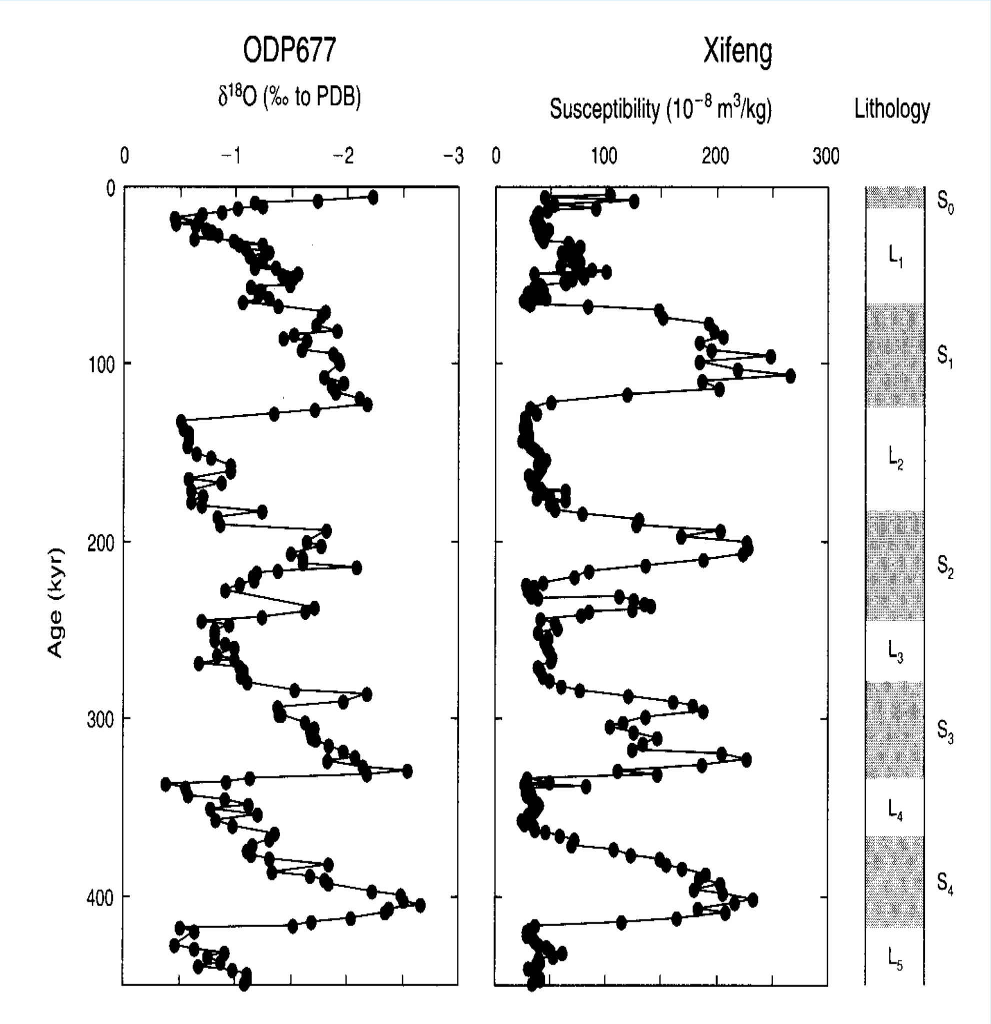


Susceptibility profile, China

Susceptibility profile at Xifeng, China, compared with oxygen isotope profile

The sequence of soils (S) and Loess (L)

Age in kYr, mass susceptibility in 10^{-8} m^3kg



GEOLOGICAL APPLICATIONS OF MAGNETIC SUSCEPTIBILITY

Geological Mapping of Magnetically Different Rocks

Delineation of Metamorphic Zones

Discrimination of I-type and S-type Granites

Indication of Alteration Processes

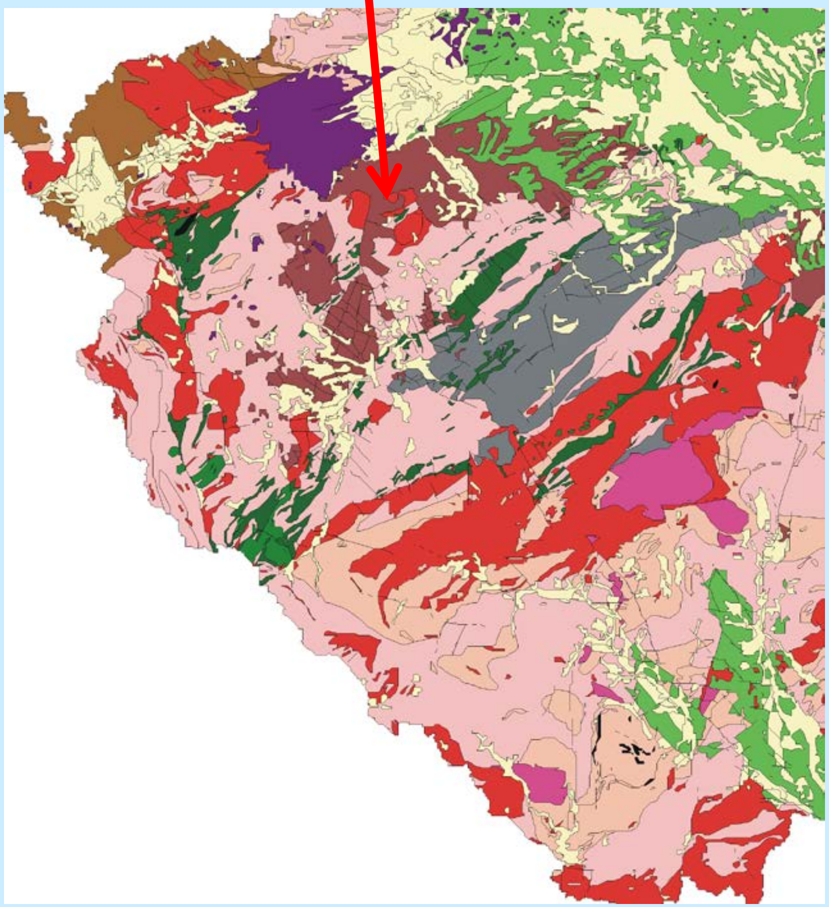
Tracing Metasomatic Changes

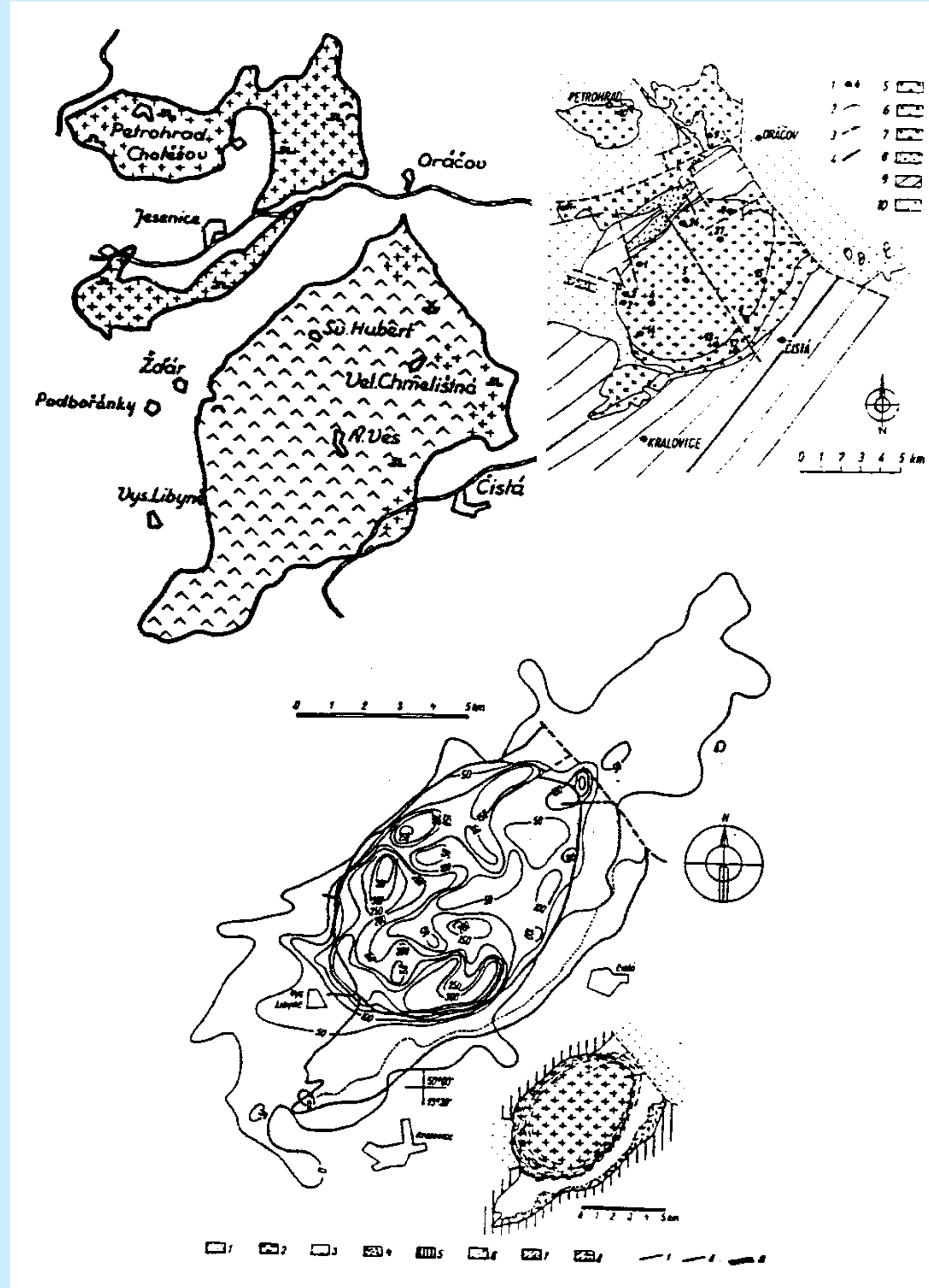
Interpretation of Magnetometric Anomalies

Application to Volcanology

Susceptibility in Economic Geology

Čistá - Jesenice Pluton





Granite Classifications

(after Clarke, 1992)

20 *Classification and occurrence*

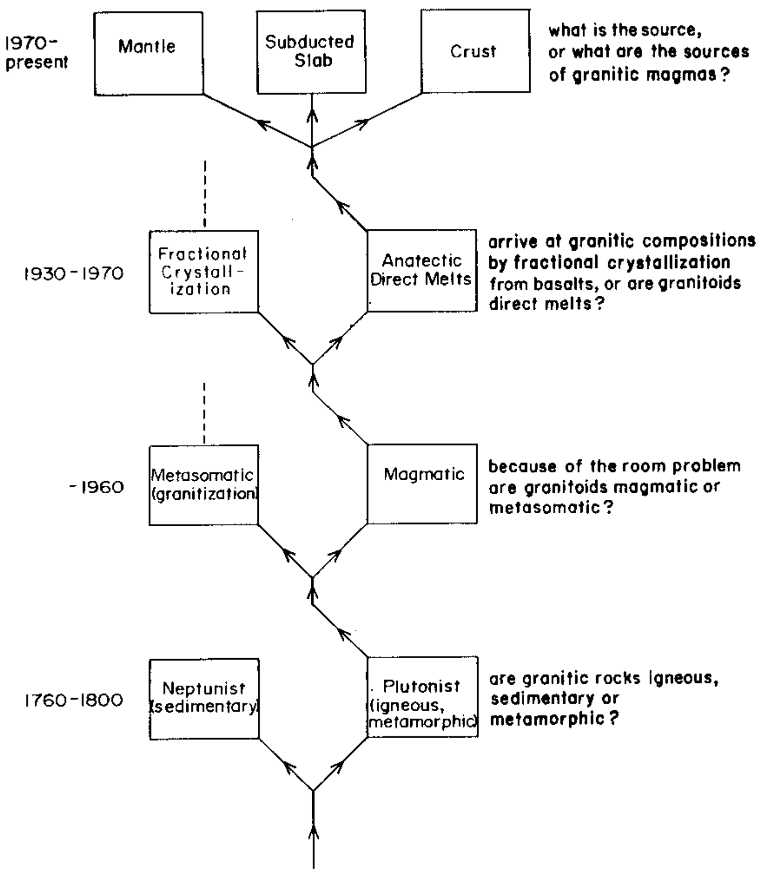
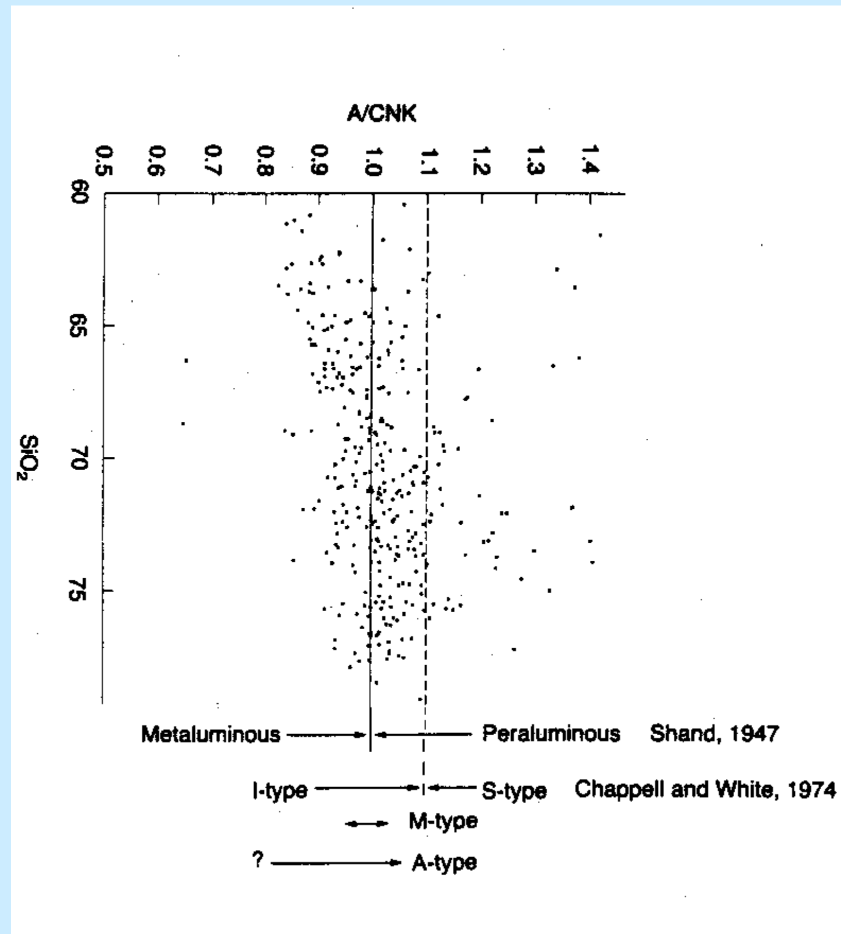


Fig. 1.6 Schematic flow chart to show the evolution of the granite problem over the past 200 years. Philosophical dead-ends have no exits; ideas that are largely discredited as general explanations, but which may still apply in specific cases, have dashed exit lines.



Granite Tectonic Setting (*I* and *S* Types)

(after Beckinsale & Mitchell, 1981)

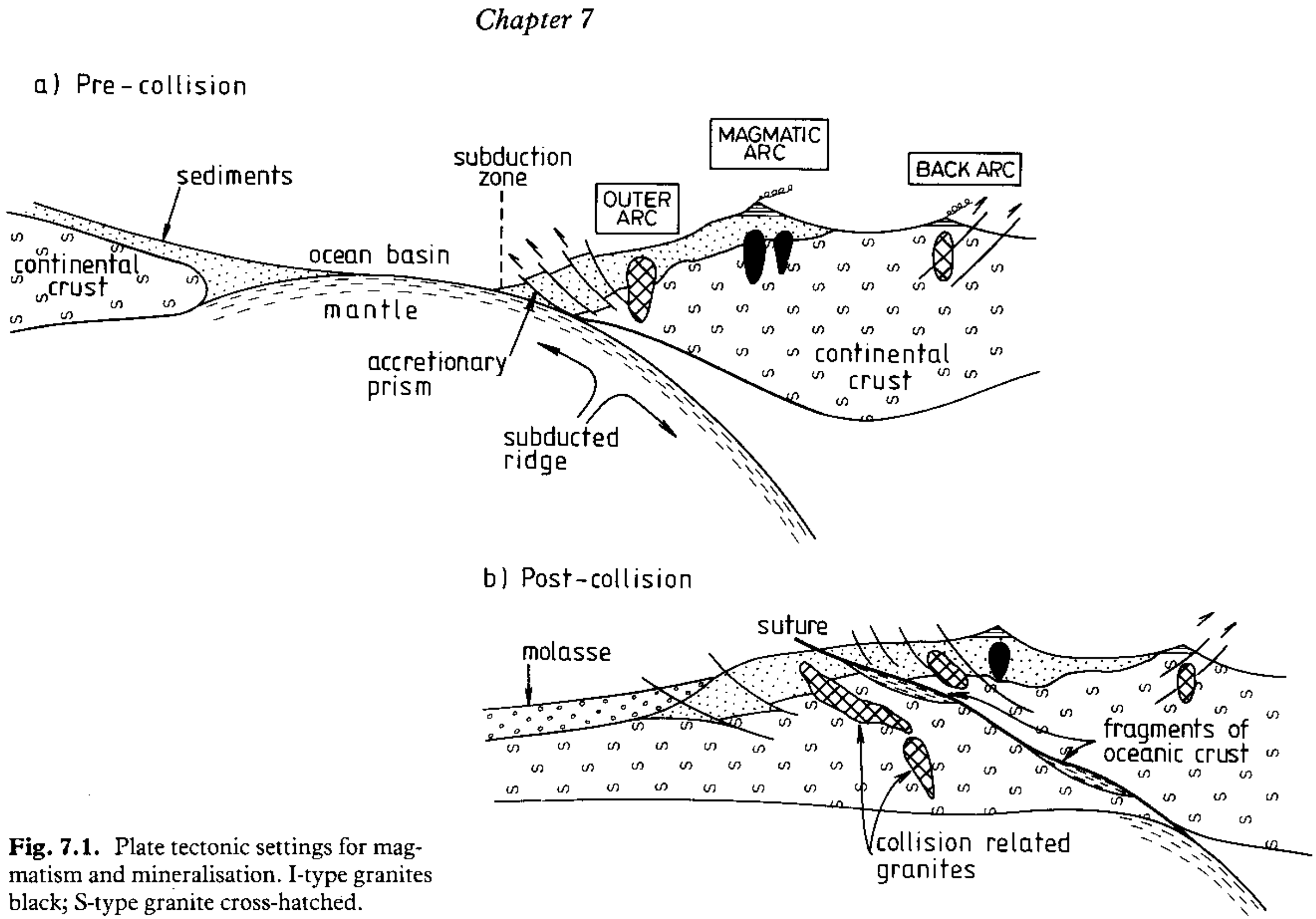


Fig. 7.1. Plate tectonic settings for magmatism and mineralisation. I-type granites black; S-type granite cross-hatched.

Magnetite and Ilmenite Series Granites

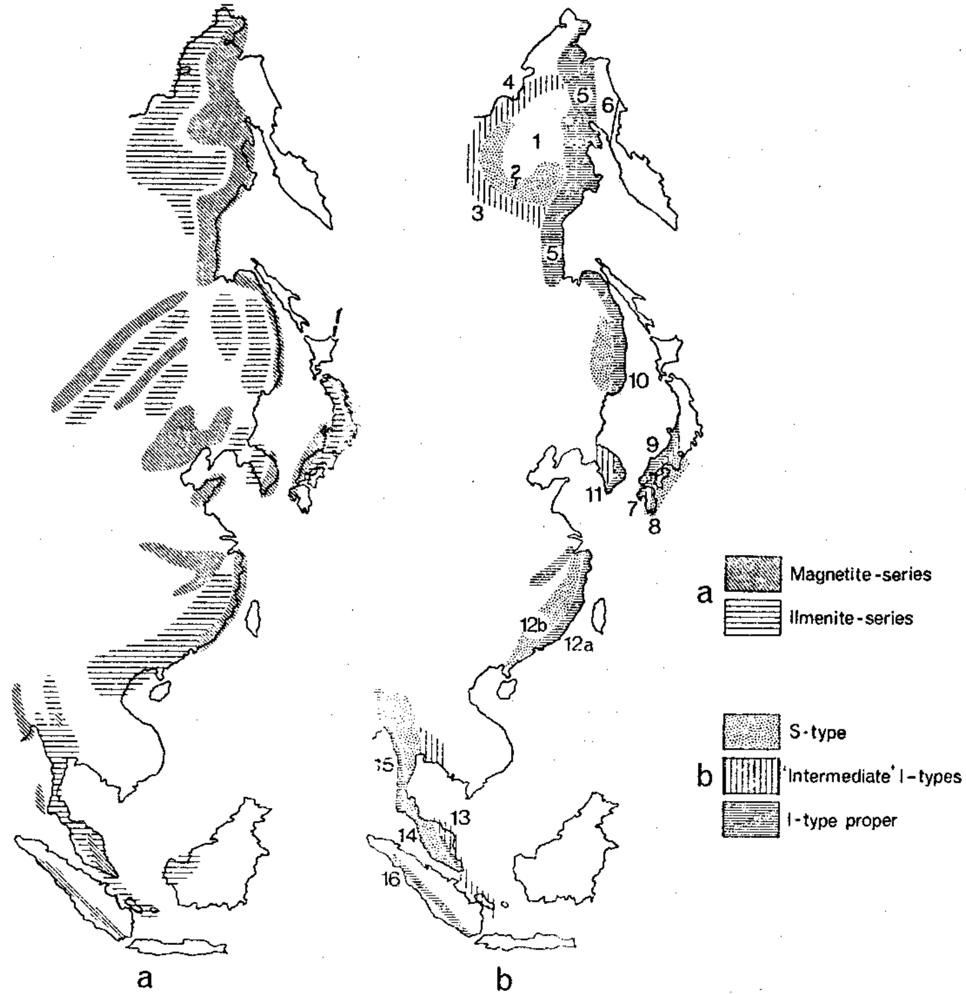
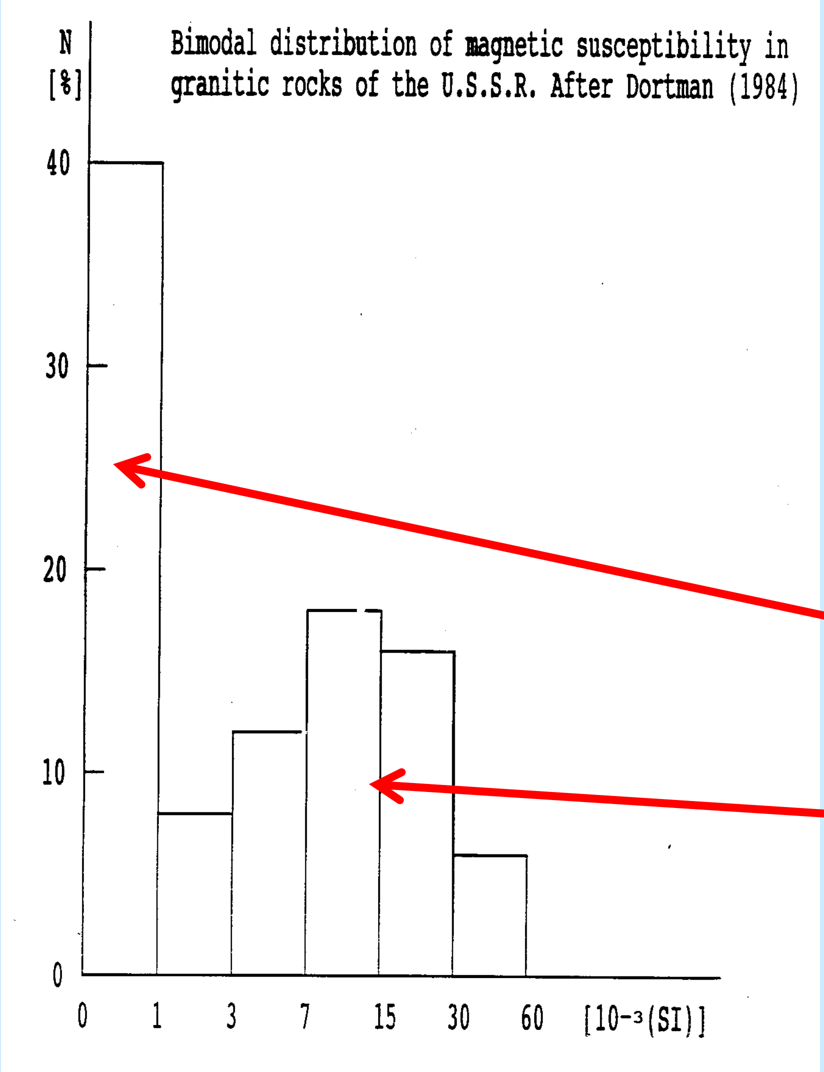


Fig. 3 Inferred distribution of (a) magnetite-series/ilmenite-series rocks, and (b) S- and I-type granitoids, in the Mesozoic and early Cenozoic orogenic belts of eastern Asia. (Modified from Takahashi *et al.*, 1980). Numbers refer to locations mentioned in the text.

Magnetic Susceptibility in Granites

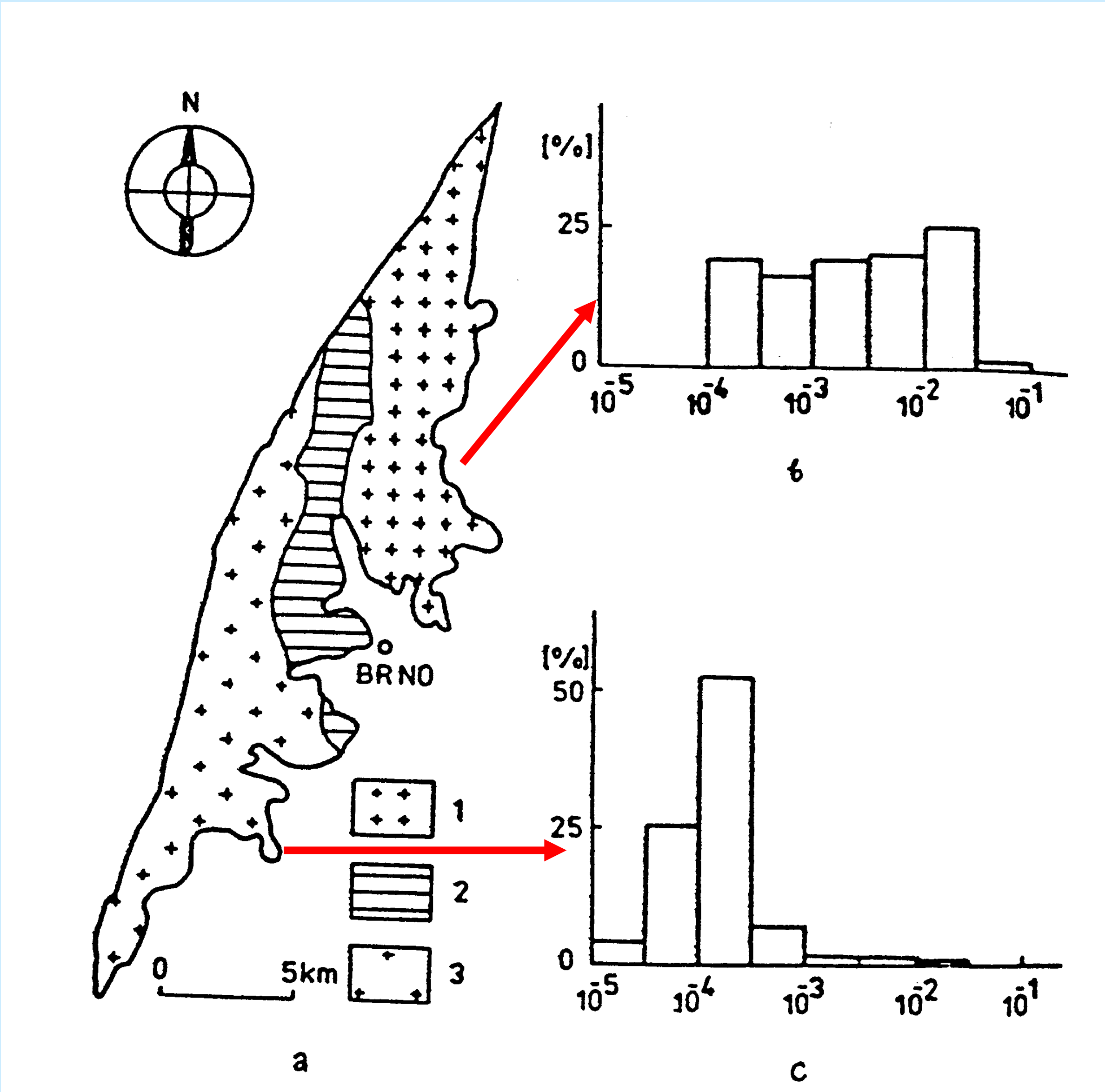


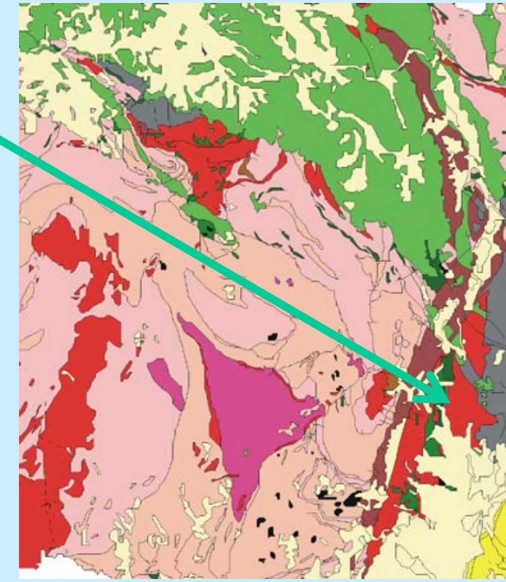
Magnetic susceptibility of granites is extremely variable, ranging from 10^{-6} [SI] to 10^{-1} and displaying a bimodal distribution.

Weakly Magnetic Granites (Dortman)
Paramagnetic Granites (Bouchez)

Magnetic Granites (Dortman)
Ferromagnetic Granites (Bouchez)

Brno Massif



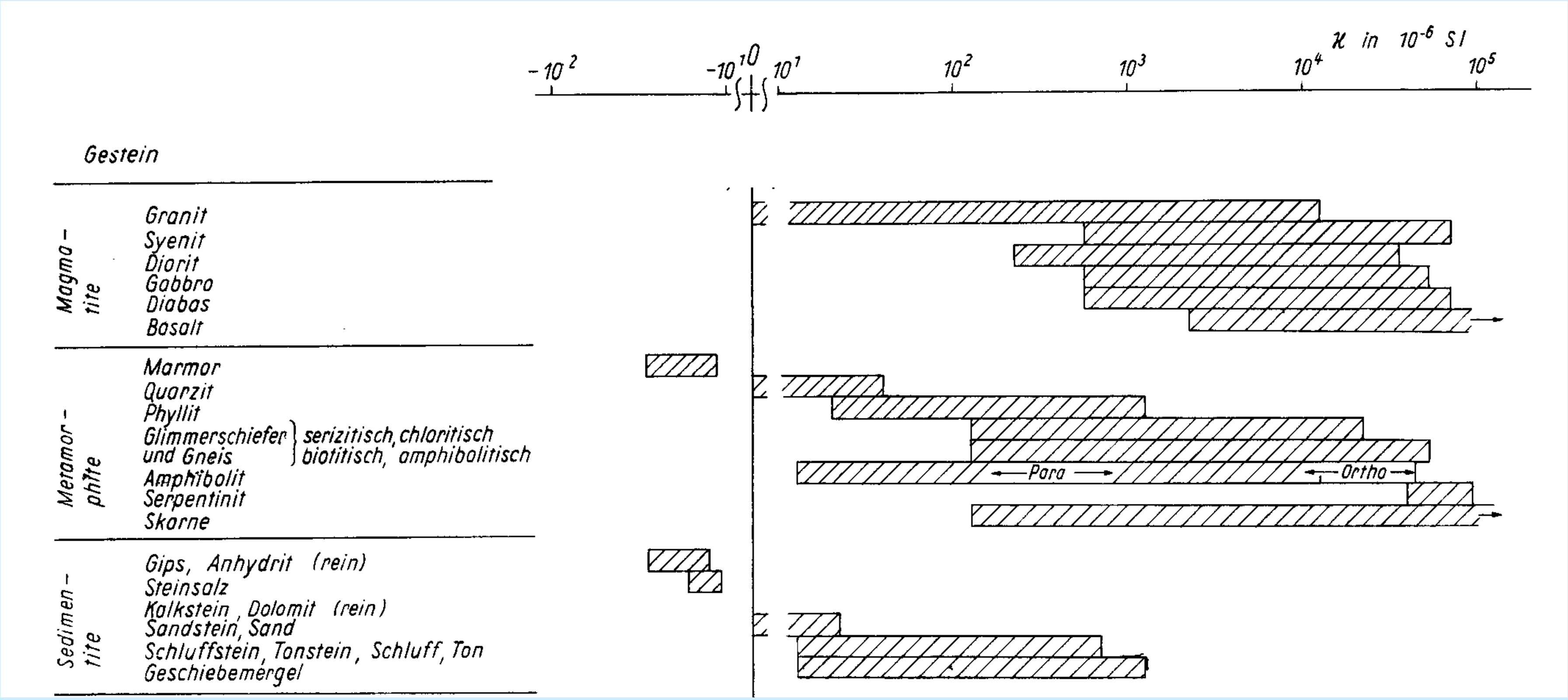


1 - Eastern Zone
2 - Metabasite Z.
3 - Western Zone

Eastern Zone magnetic

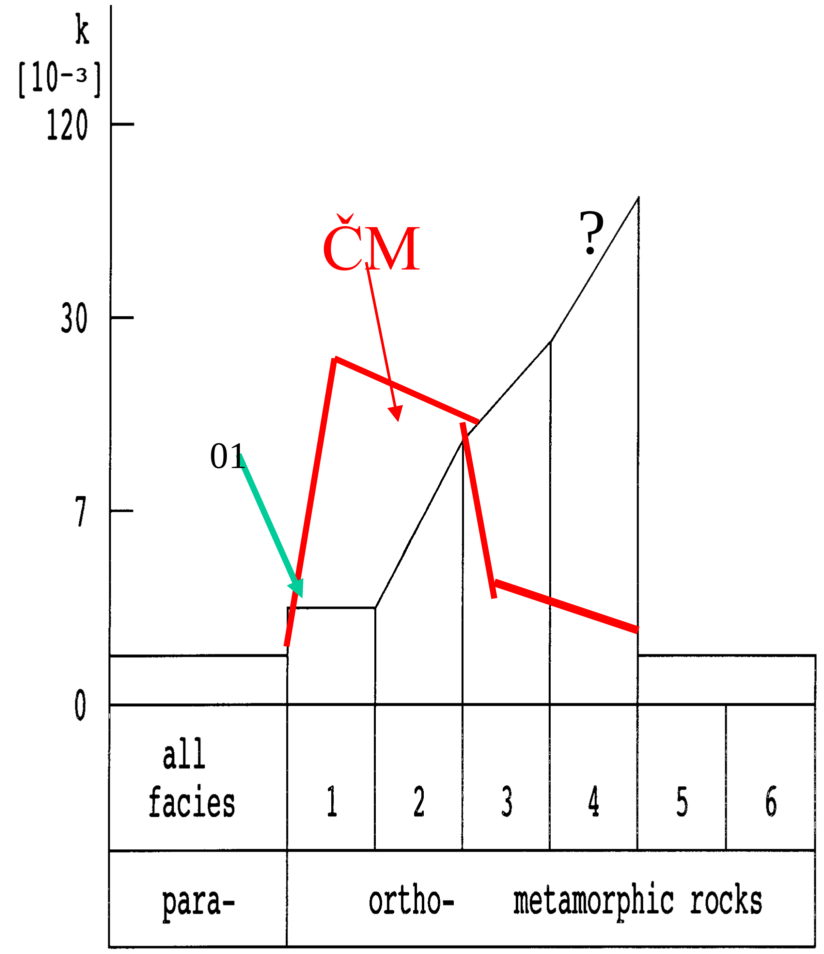
Western Zone weakly magnetic

Magnetic Susceptibility in Various Rocks



Magnetic Susceptibility in Metamorphic Rocks

Susceptibilita anomálních ortometamorfitů stoupá zpravidla až do amfibolitové facie. V ČM mají granulity, i ty tmavé, jen zvýšenou susceptibilitu.

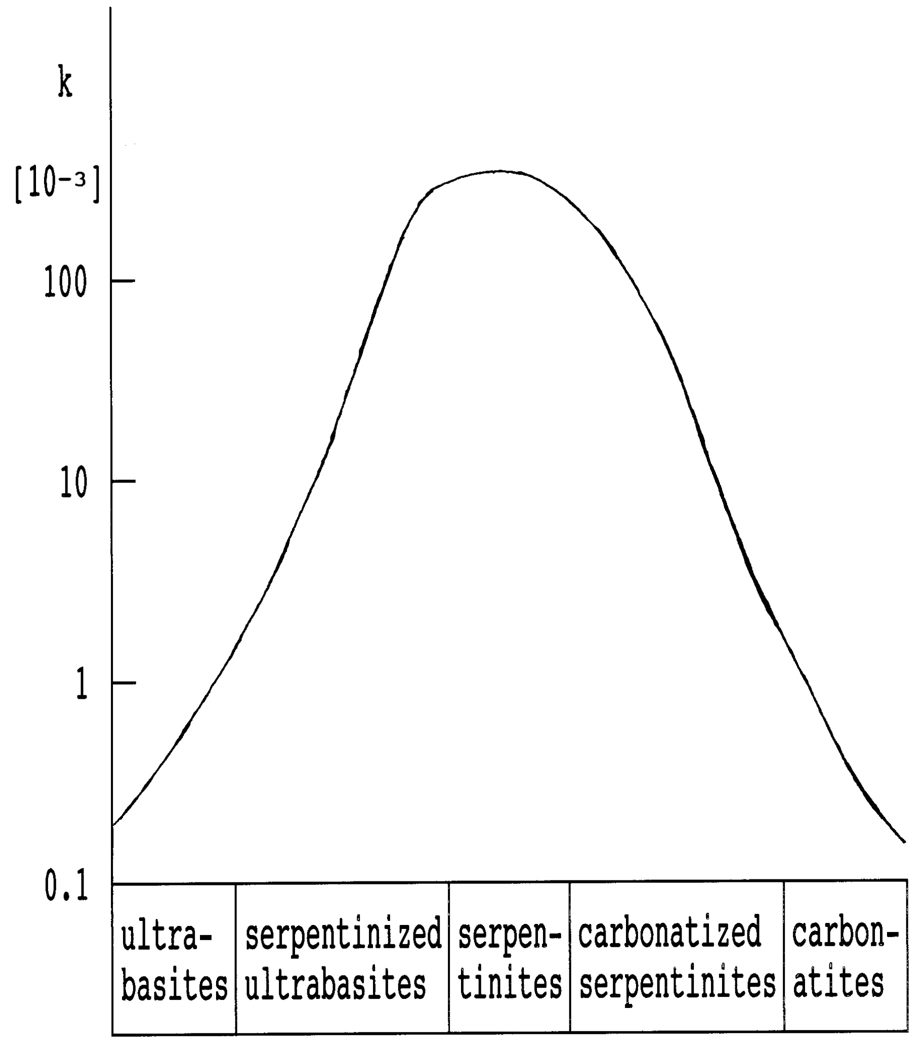


Magnetic susceptibility variation in metamorphic rocks.
Adapted form Dortman (1984).

Legend: 1 - green schist facies, 2 - epidote amphibolite facies,
3 - amphibolite facies, 4 - granulite facies,
5 - granulite-eclogite facies, 6 - eclogite facies.

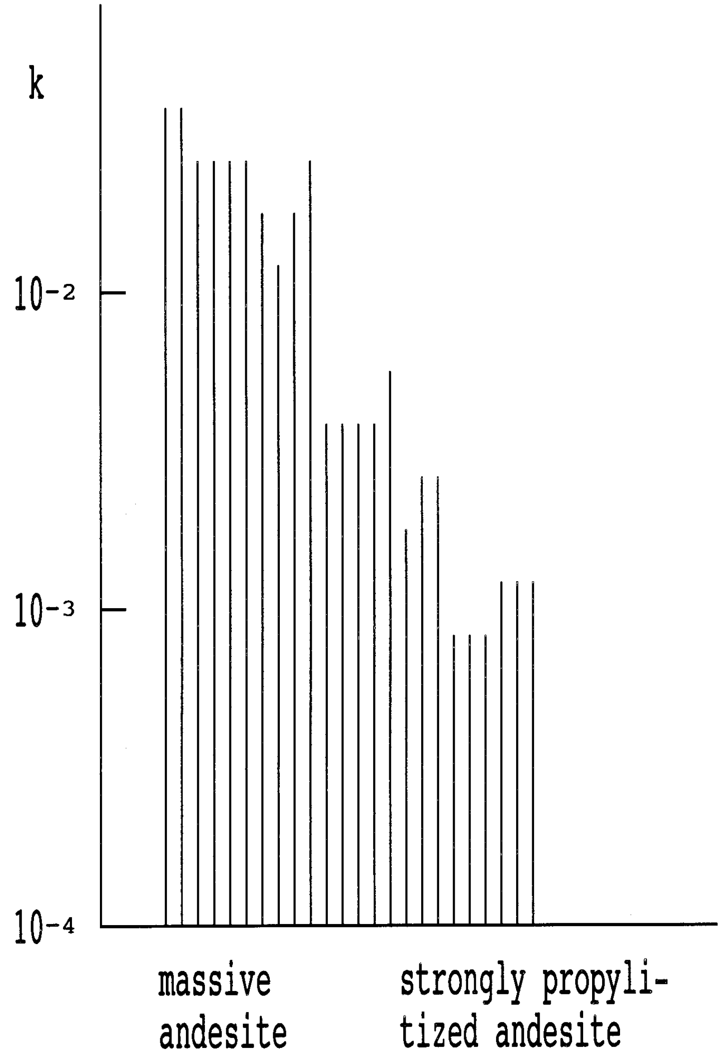
01 – bazika od extruze k prehnit –pumpellyitové facii

Magnetic Susceptibility in Serpentinized and Carbonatized Ultrabasic Rocks



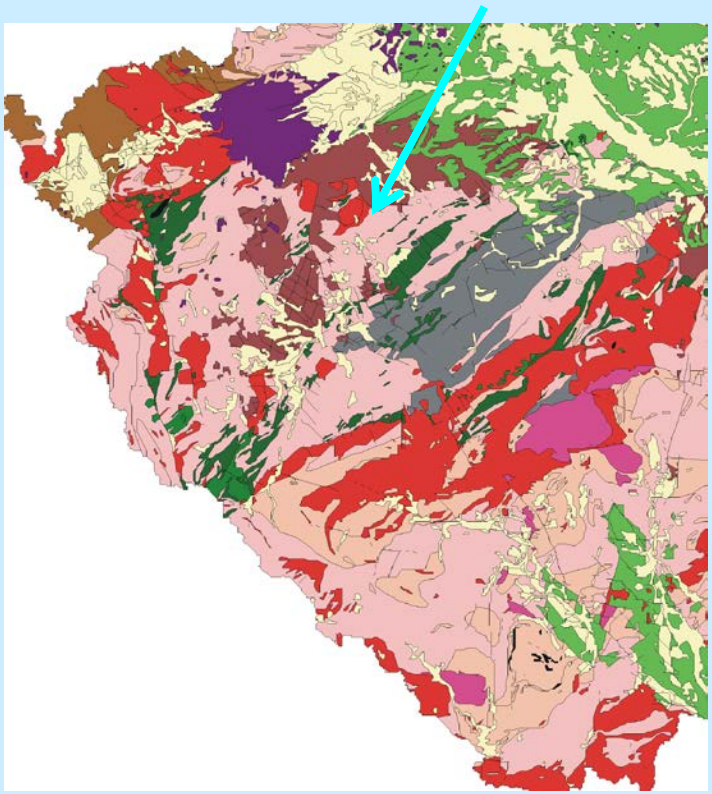
Susceptibility changes during serpentinization and carbonatization of ultrabasic rocks. Adapted from Dortman (1984).

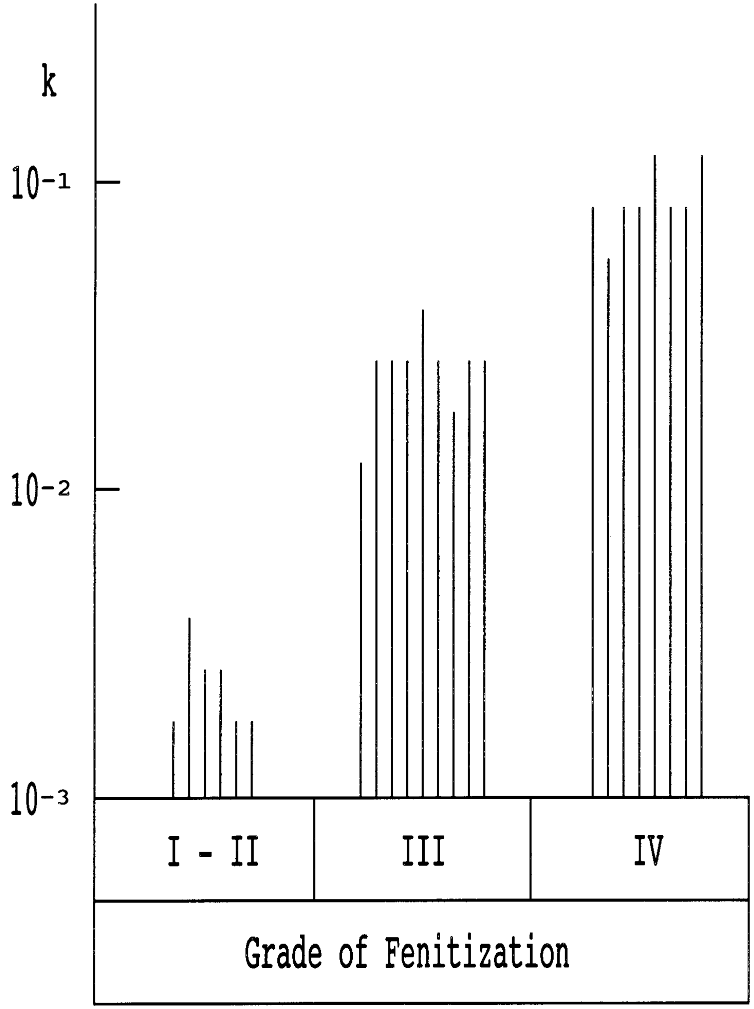
Magnetic Susceptibility in Altered (propylitized) Andesites



Magnetic susceptibility in non-altered and altered andesites of the West Carpathians. Compiled from data of Drs. Ondra and Hanák.

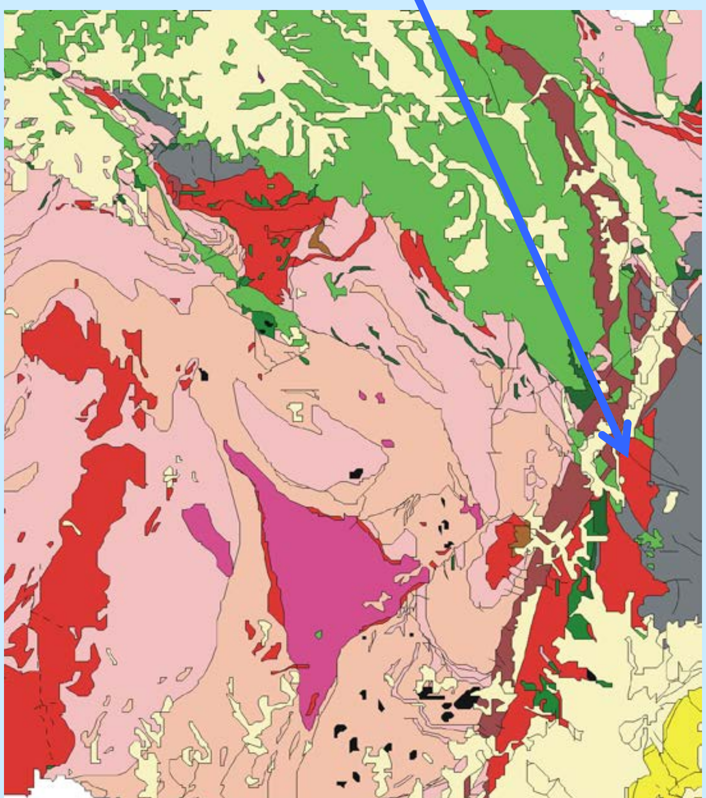
Magnetic Susceptibility in Rocks that Underwent Alkaline Metasomatism

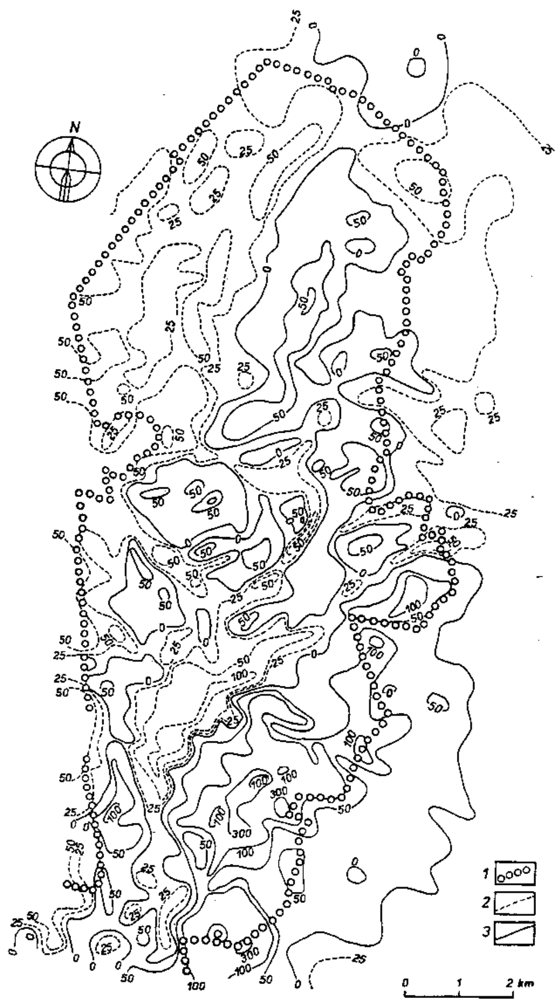


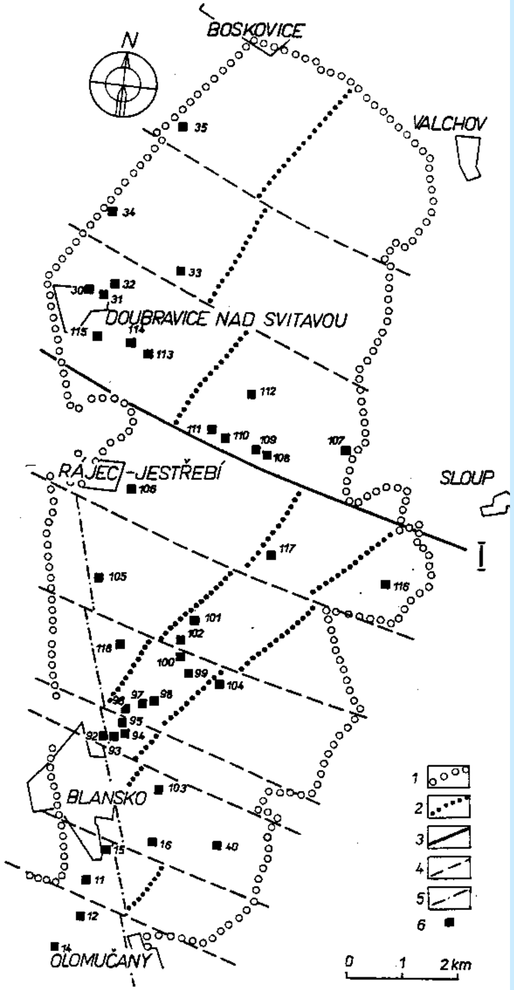


Variation of susceptibility according to the grade of alkaline metasomatism (fenitization) in the Čistá - Jesenice Massif (W. Bohemia).

Magnetic Susceptibility and Magnetometry





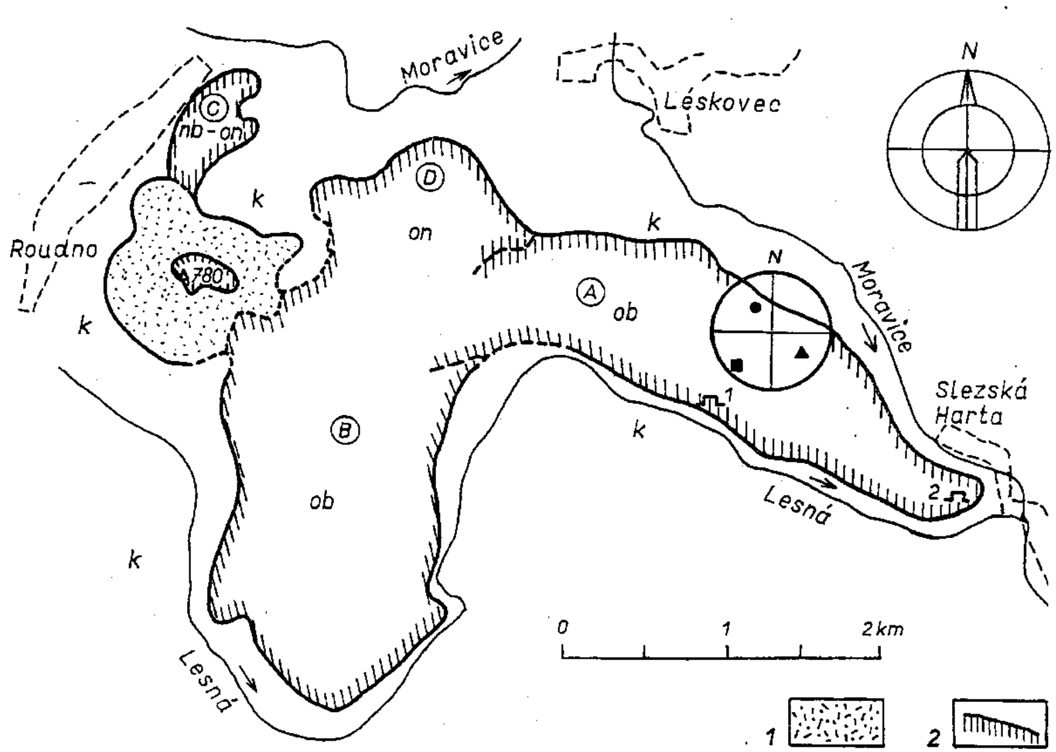


1 — hranice brněnského masívu; 2 — záporné anomálie; 3 — nulové a kladné anomálie. Čísla udávají intenzitu anomálního magnetického pole v γ

Obr. 1. Mapka studovaných lokalit a odvozených tektonických linií. 1 — hranice brněnského masívu; 2 — hranice hojných poloh mylonitizovaných hornin; 3 — nejdůležitější tektonická linie ve zkoumaném území; 4 — předpokládané tektonické linie; 5 — předpokládané tektonické omezení blanenského prolomu; 6 — studované lokality, čísla odpovídají číslům v tabulce 1

Obr. 2. Generalizovaná mapa magnetických anomálií △ T (podle Šalanského et al. 1964, 1970). →

Magnetic Susceptibility in Lava Flows 1



1. Geologická mapa Velkého Roudného. Zjednodušeno podle Bartha (1972)
1 — čedičové tufy; *2* — omezení lávových těles; *A* — lávový proud Chřibského lesa, *B* — lávový proud Černého lesa, *C* — lávový proud Mlýna Roudná, *D* — lávový proud Heroldova Mlýna, *ob* — olivinický čedič, *nb* — nefelinický bazanit; *on* — olivinický nefelinit, *k* — kulm, ▲ ■ ● — směry hlavních susceptibilit pro lokalitu Bílčice jako celek; ⎍ *1* — lokalita Bílčice, ⎍ *2* — lokalita Slezská Harta

Magnetic Susceptibility in Lava Flows 2

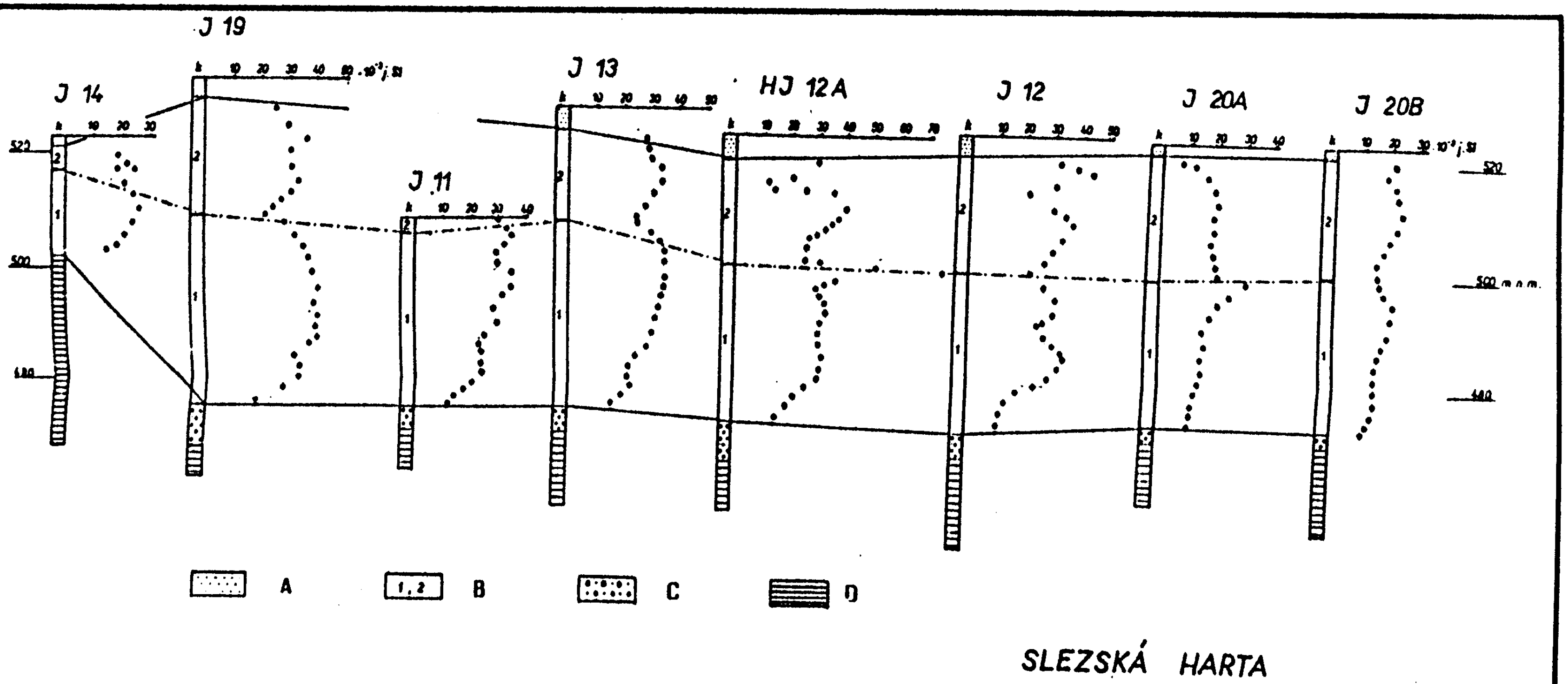


Fig. 18 Depth variation of magnetic susceptibility in several boreholes drilled through the Chřibský les lava flow. Adapted from Müllerová and Müller (1972).

A - soil cover, B - lava suflows (1 - lower, 2 - upper),
C - Lower Pleistocene terraces, D - Culm Formation

Sulphide Deposits

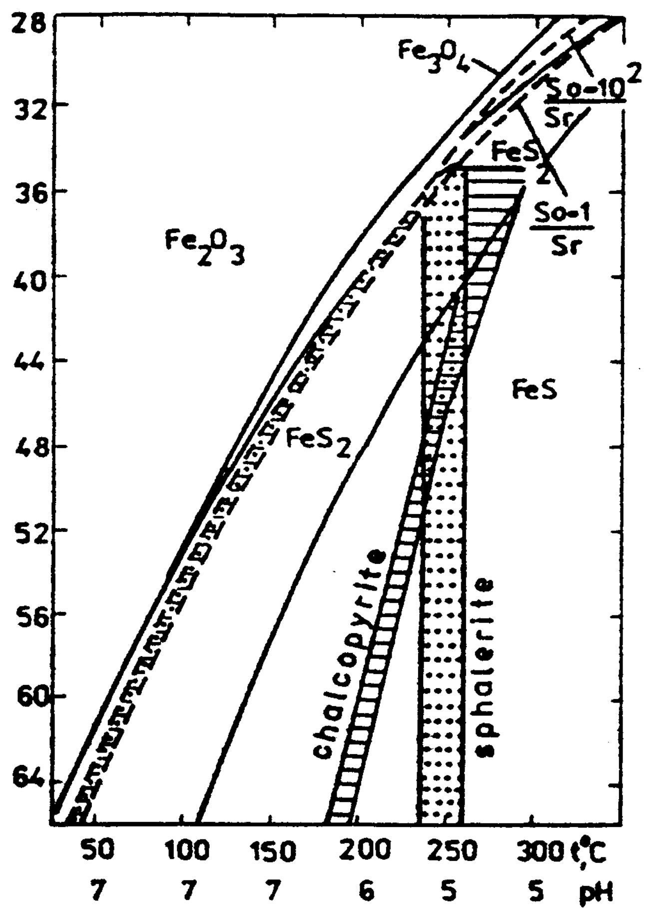


Fig. 19 Creation of volcanic-metasomatic, volcanic-sedimentary sulphide deposits during variable PH factor and temperature and constant concentrations of $\Sigma S = 10^{-2}$ mol and NaCl = 1 mol. Adapted from Smirnov (1982)

Magnetic Susceptibility in Environs of Sulphide Deposits

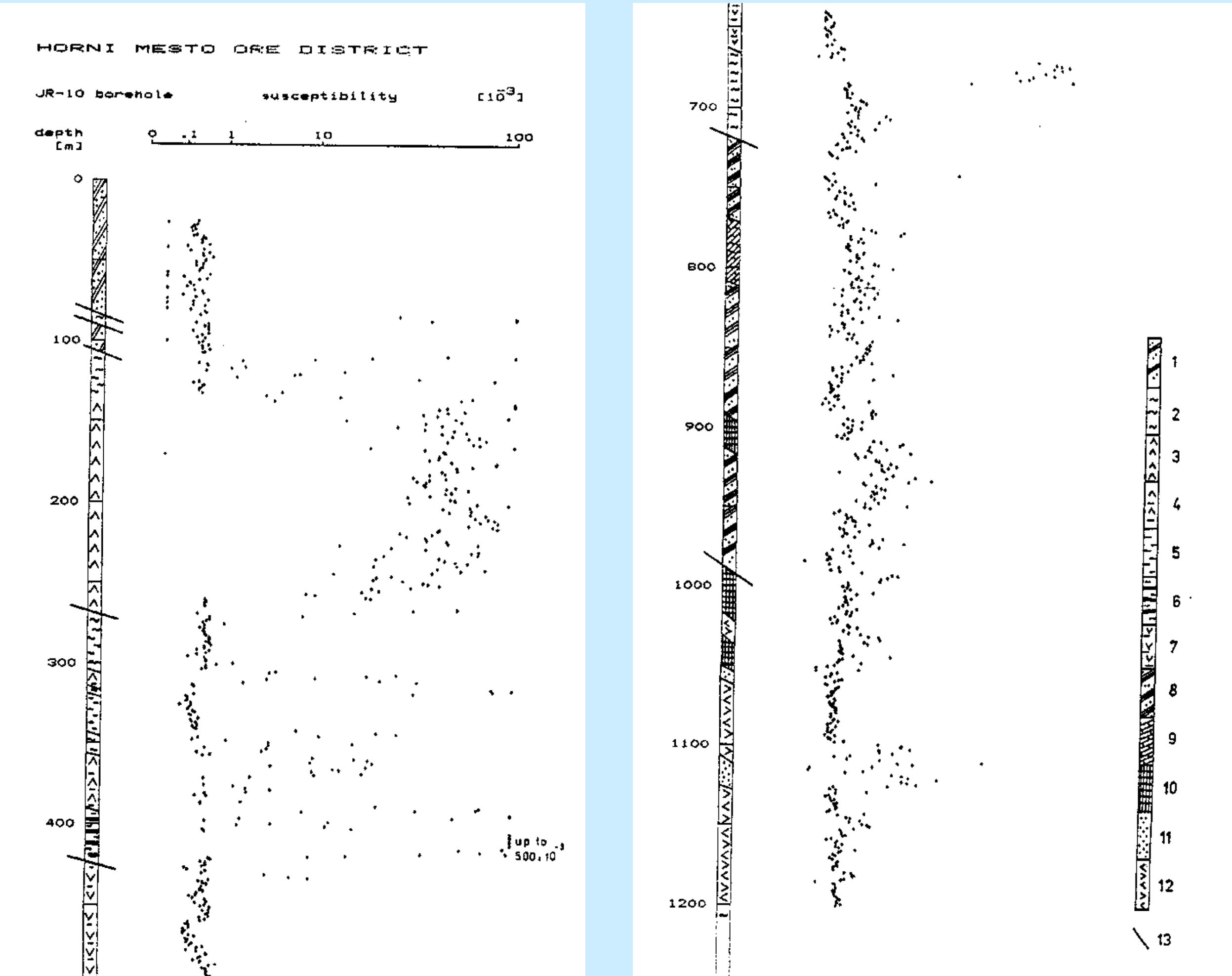


Fig. 20 Depth variation in magnetic susceptibility in the JR-10 borehole

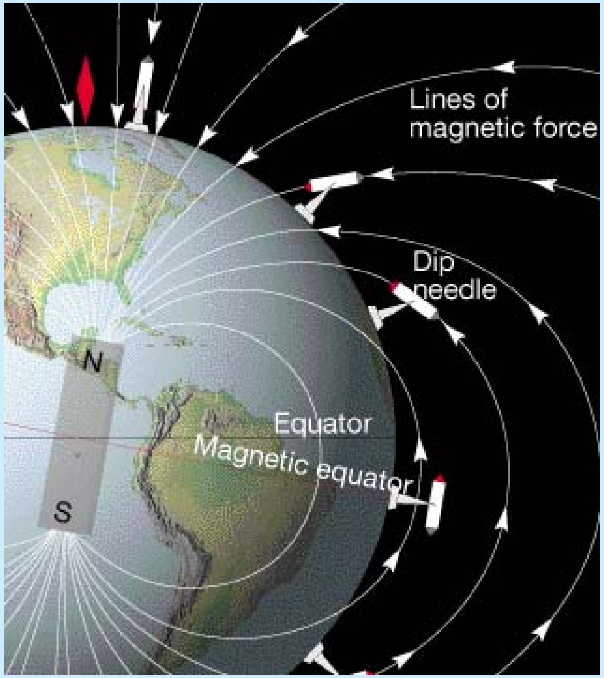
Culm Formation

1 - psammitic to pelitic metasedimentary rocks (phyllites and metagreywackes)

Devonian, Vrbno Group:

2 - chlorite slates and phyllites, 3 - metakeratophyres s.l. (trachyandesites and their tuffs) with magnetite and hematite, 4 - keratophyre metatuffs, mostly with magnetite ± hematite, 5 - sericite slates to phyllites (metatuffites and/or strongly altered volcanic rocks), 6 - sericite slates with intercalations of metaferolites s.l. (trachyrhyolites and their tuffs) with hematite, in places albitized and silicized, 8 - metadolerites.

PALEOMAGNETISM

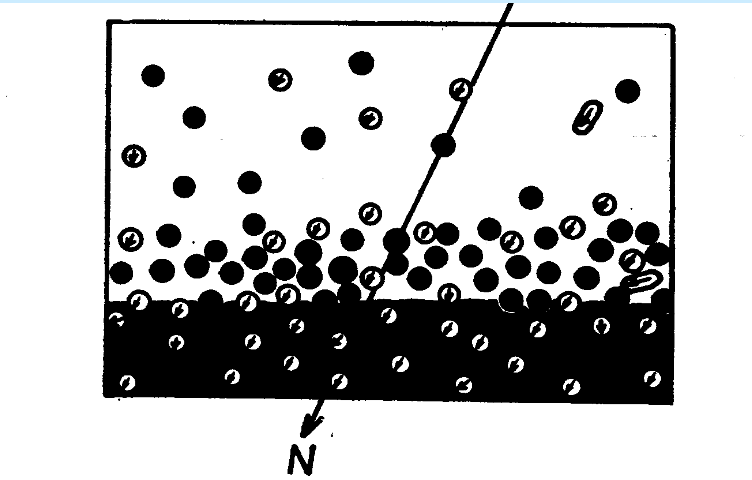


Magnetic field of the Earth - coaxial dipóle

Record in remanent magnetization (RM).

Volcanics – cooling under Curie temperature (rock becomes ferromagnetic).

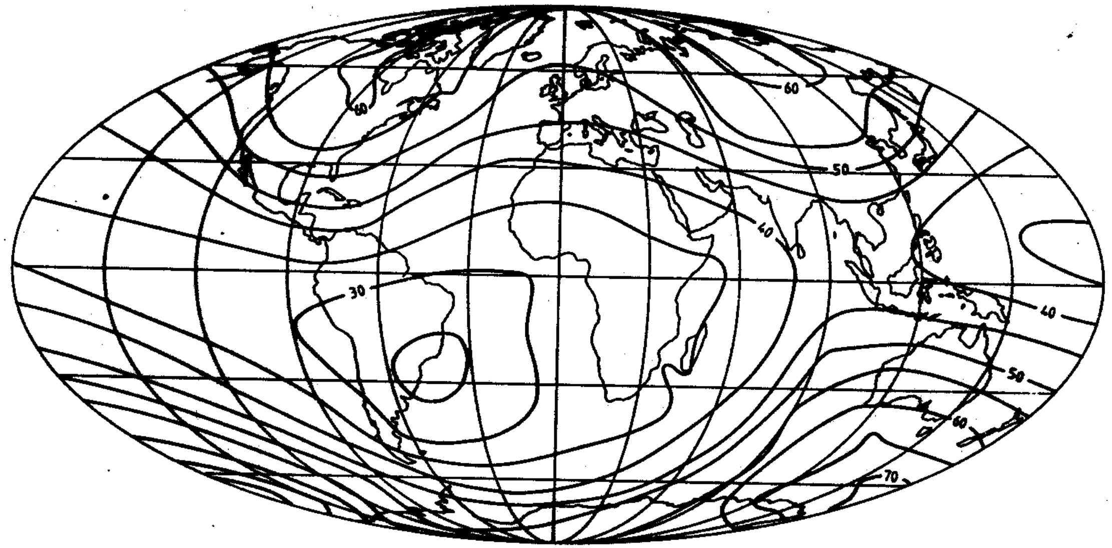
Sediments – during deposition



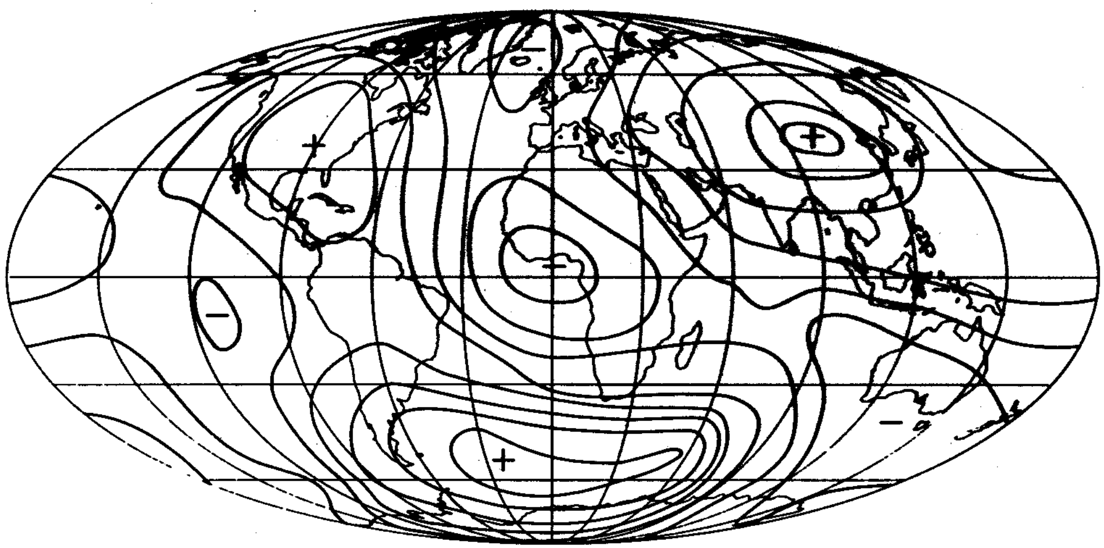
Obr. 72. Orientování zrn feromagnetických minerálů do směru zemského magnetického pole v průběhu sedimentace horniny.

RM may preserve since its origin to present. Methods exist how to find whether the RM is fossil and stable.

Magnetic Field of the Earth

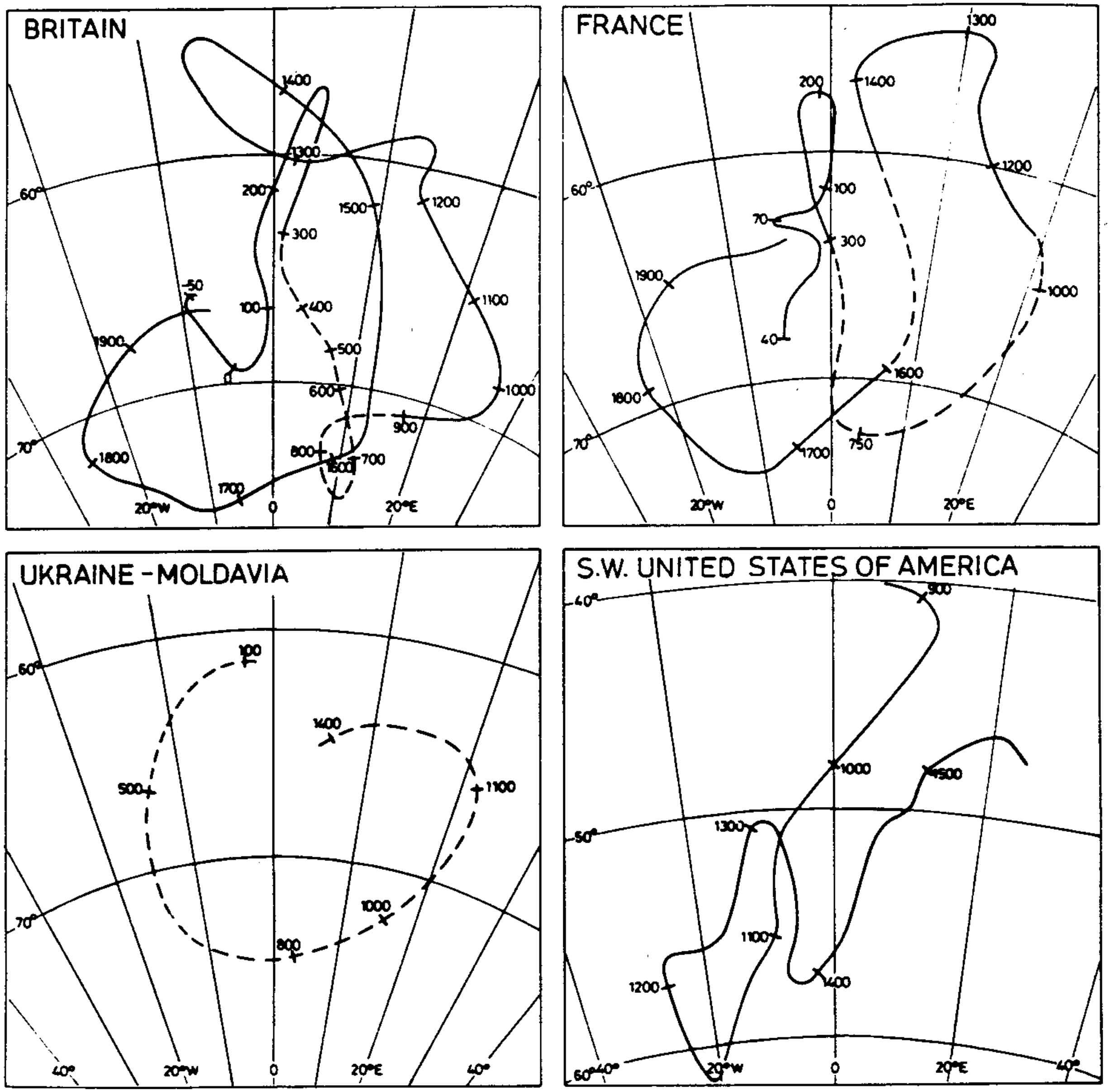


The present geomagnetic field. Total intensity (F) of the field in mT.



The z component of the non-dipole field, contoured in 4 μT intervals.

Variations of Magnetic Field



Secular variations of directions on an archaeological time-scale.

Presentation of Palaeomagnetic Data

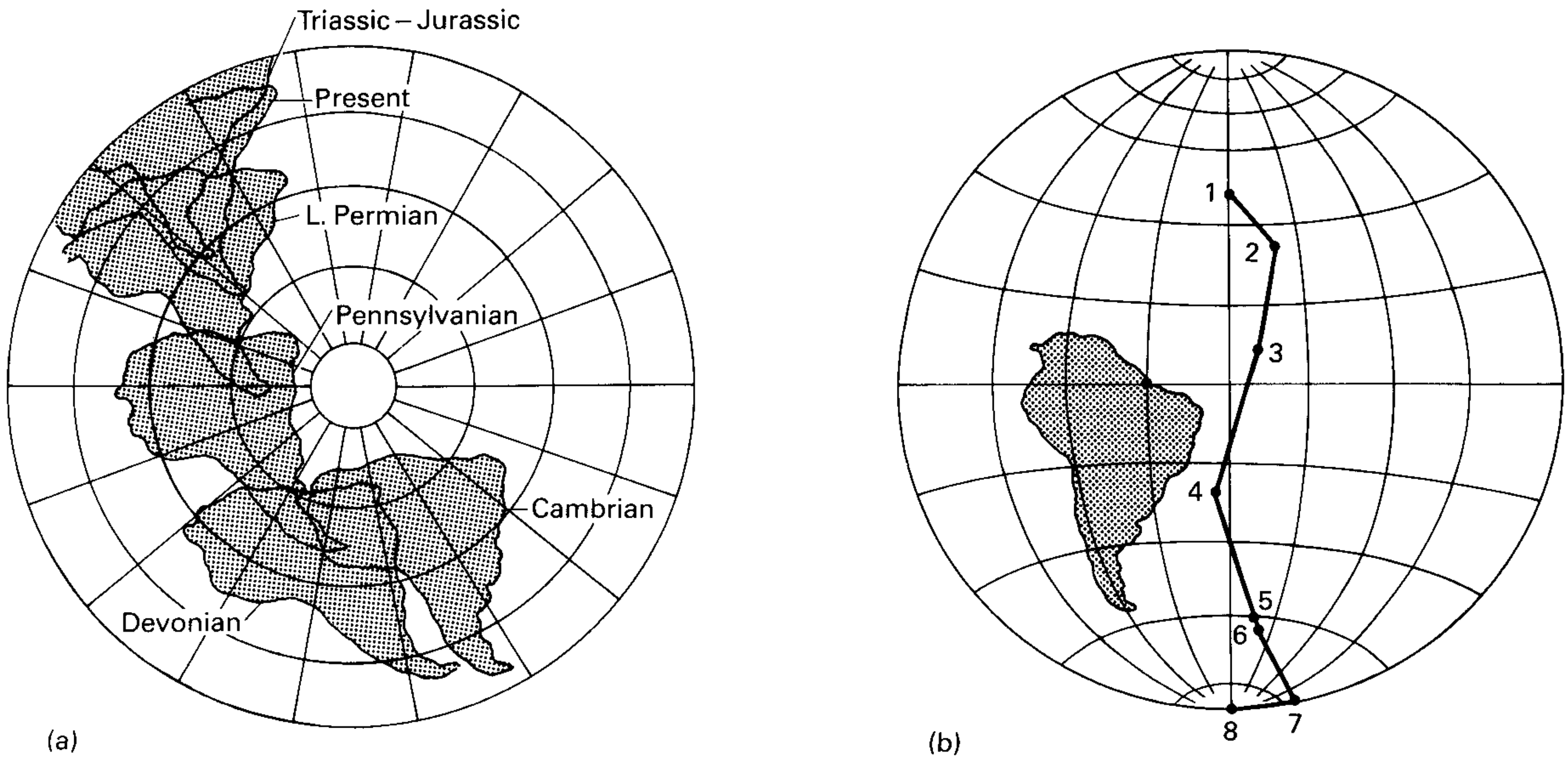
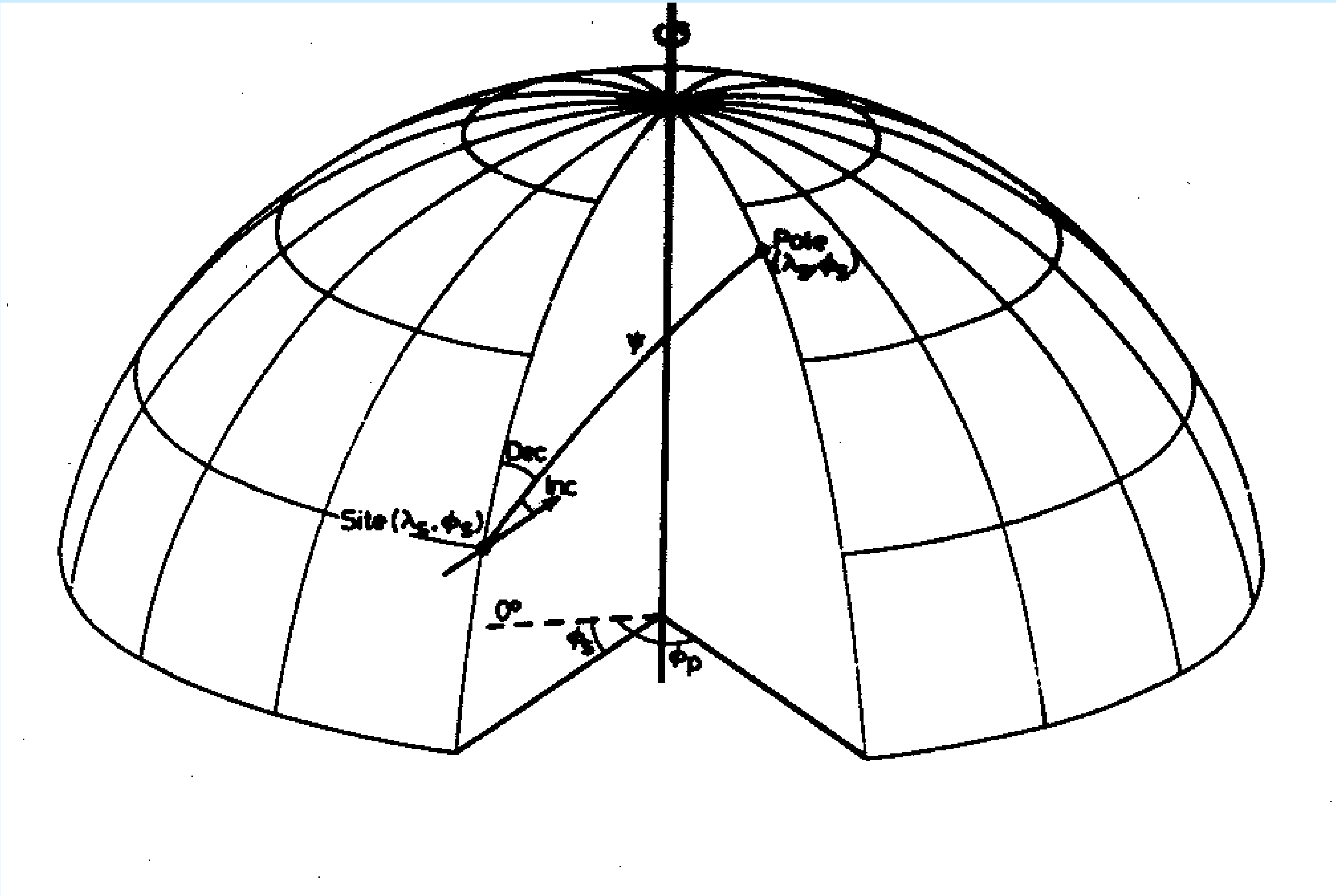


Fig. 3.13 Two methods of displaying palaeomagnetic data. (a) assuming fixed magnetic poles and applying latitudinal shifts to the continent. (b) assuming a fixed continent and plotting a polar wandering path. Subsequent work has modified the detail of the movements shown. Note that the *south* pole has been plotted (redrawn from Creer, 1965, with permission from the Royal Society).

fix pole, plate movement

fix plate, apparent pole path

Construction of Palaeopole



Apparent Polar Wandering Paths for Individual Continents

Key evidence of the continental drift.

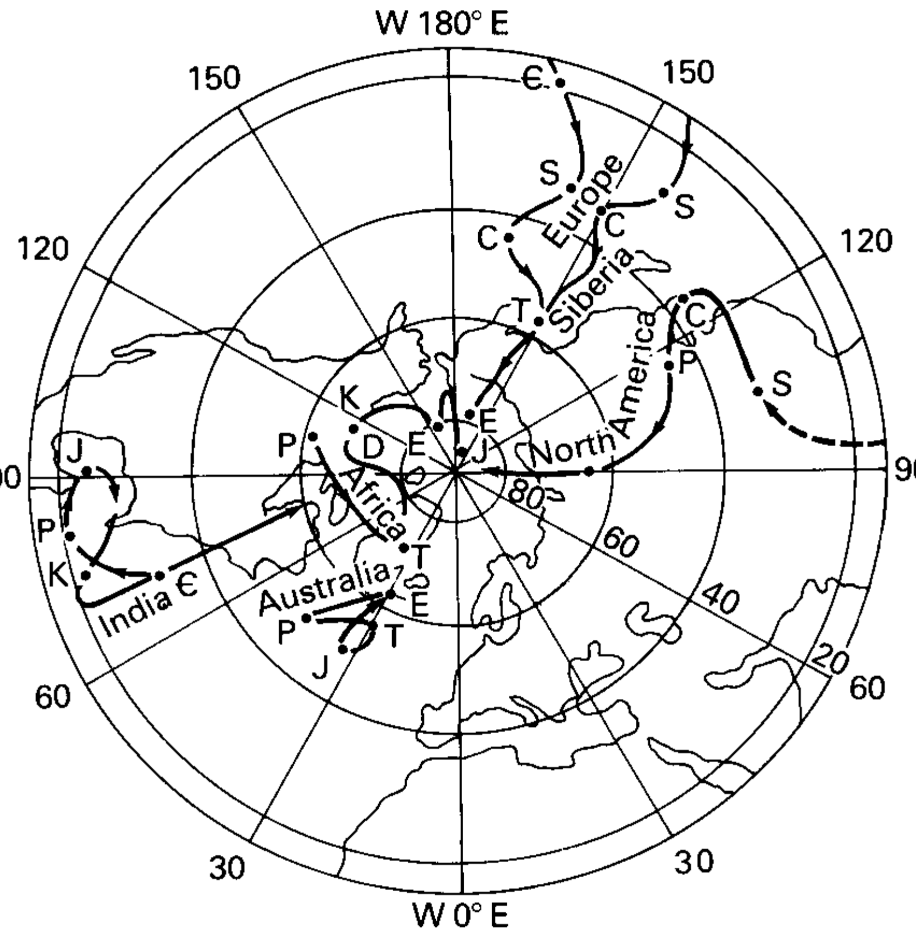
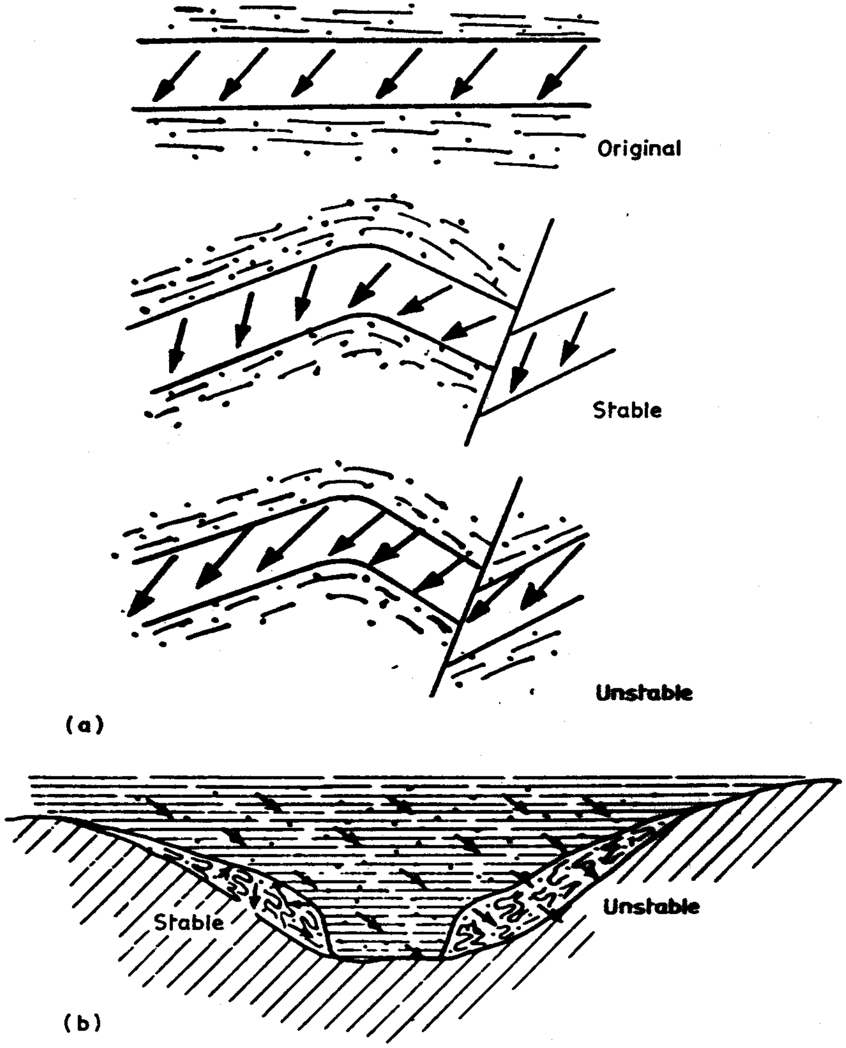


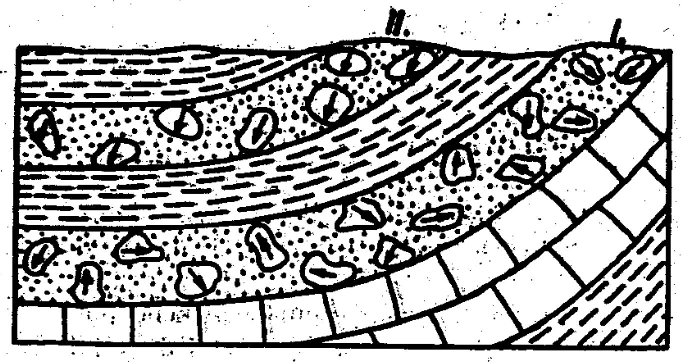
Fig. 3.14 Apparent polar wandering paths for North America, Europe, Siberia, Africa, Australia and India. ϵ, Cambrian; S, Silurian; C, Carboniferous; P, Permian; T, Triassic; J, Jurassic; K, Cretaceous; E, Eocene (redrawn from Condie, 1982, *Plate Tectonics and Crustal Evolution*, with permission from Pergamon Press Ltd).

Fold Tests of Palaeomagnetic Stability

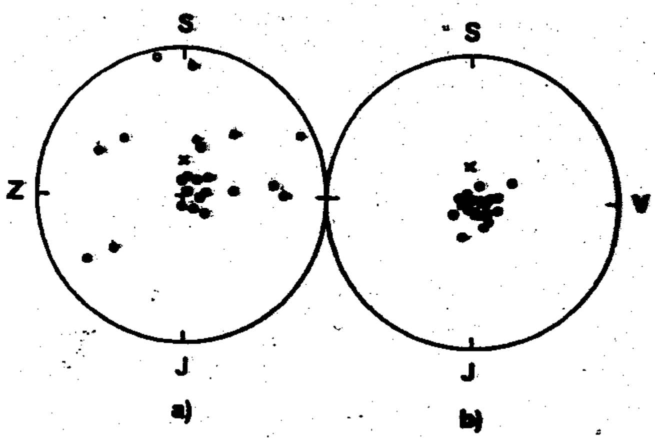


Fold tests. Where the rock strata, or other structures, have been simply tilted, then standard fold tests can be applied to determine the age of the magnetization relative to the age of the folding by testing the scatter of directions before and after correction for the folding (a, b). Magnetization which was acquired before folding, tilting or slumping, will have retained its original direction and will thus have the same angle to the immediately adjacent bedding plane.

Conglomerate Test of Palaeomagnetic Stability



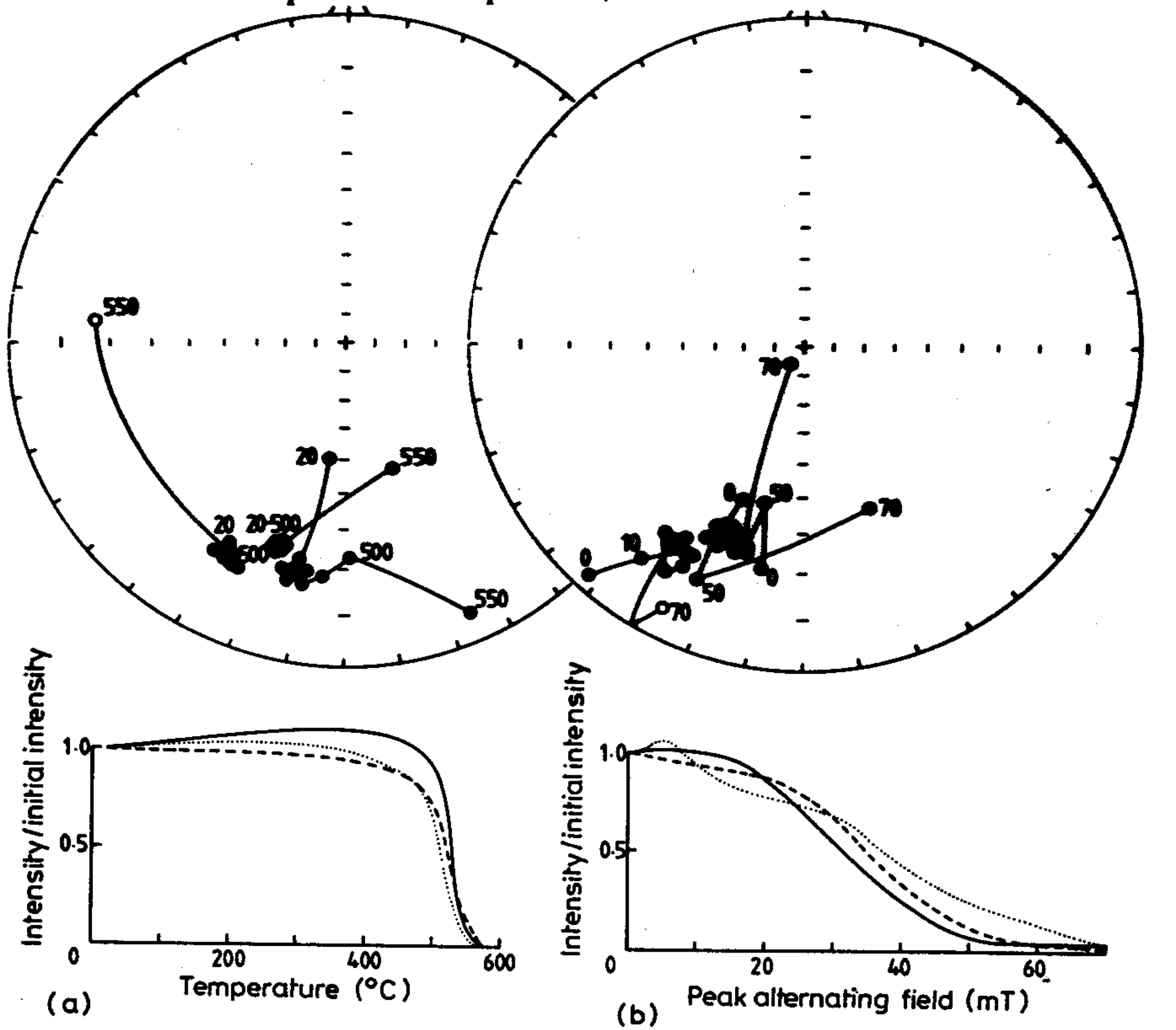
Obr. 3.22 K slepencové zkoušce.
Předpokladem aplikace zkoušky je výskyt slepence s valouny testované horniny. Hornina vytvářející valouny ve slepencovém horizontu I má NRM paleomagneticky stabilní, v horizontu II nestabilní. Šipky vyznačují směr NRM.



Obr. 3.23 **Magnetické čištění vzorků olivinického čediče z lokality Zlatá Lípa, lávový proud sopky Červená hora (podle F. Marka 1969b, 1973).**
a) směry přirozené remanentní magnetizace M_n; b) směry primární remanentní magnetizace M_p (po čištění optimálním střídavým magnetickým polem 17 mT). Vysvětlivky viz obr. 3.13.

Thermal and AF Demagnetization

The relationship between temperature, volume and relaxation time.



CONTINENTAL DRIFT

Reconstruction of continents about Atlantics

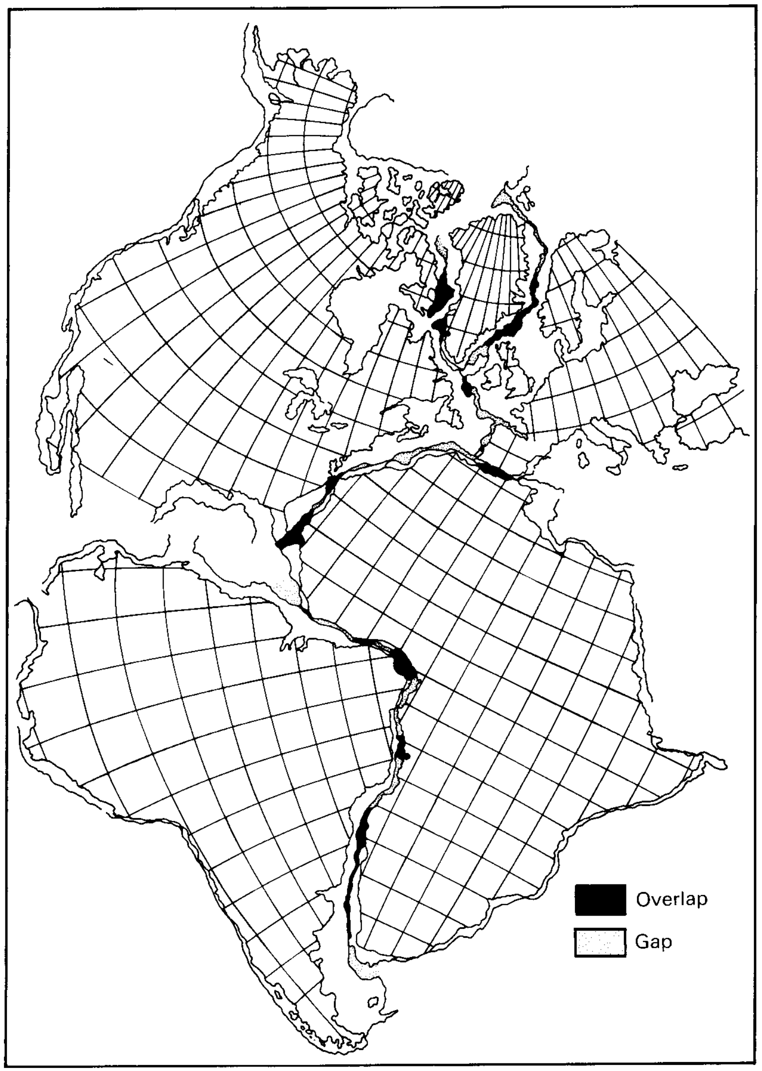
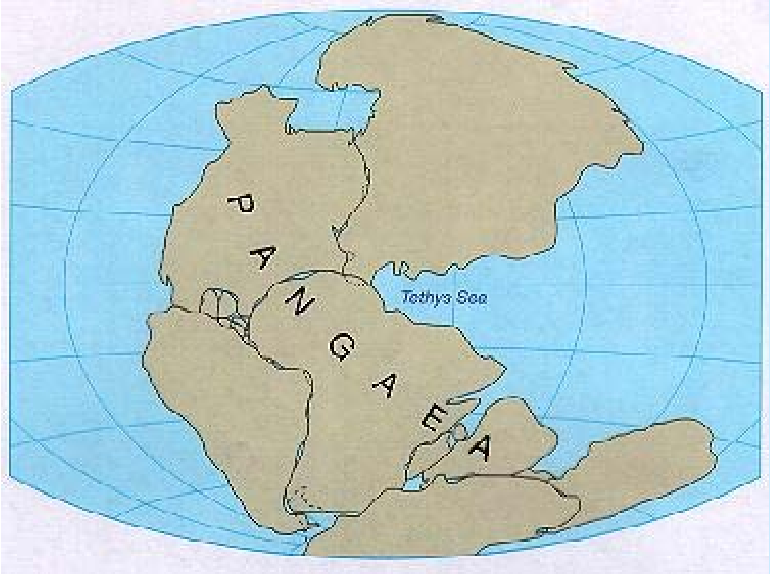


Fig. 3.2 Fit of the continents around the Atlantic Ocean, obtained by matching the 500 fathom (927 m) isobath (redrawn from Bullard *et al.*, 1965, with permission from the Royal Society).



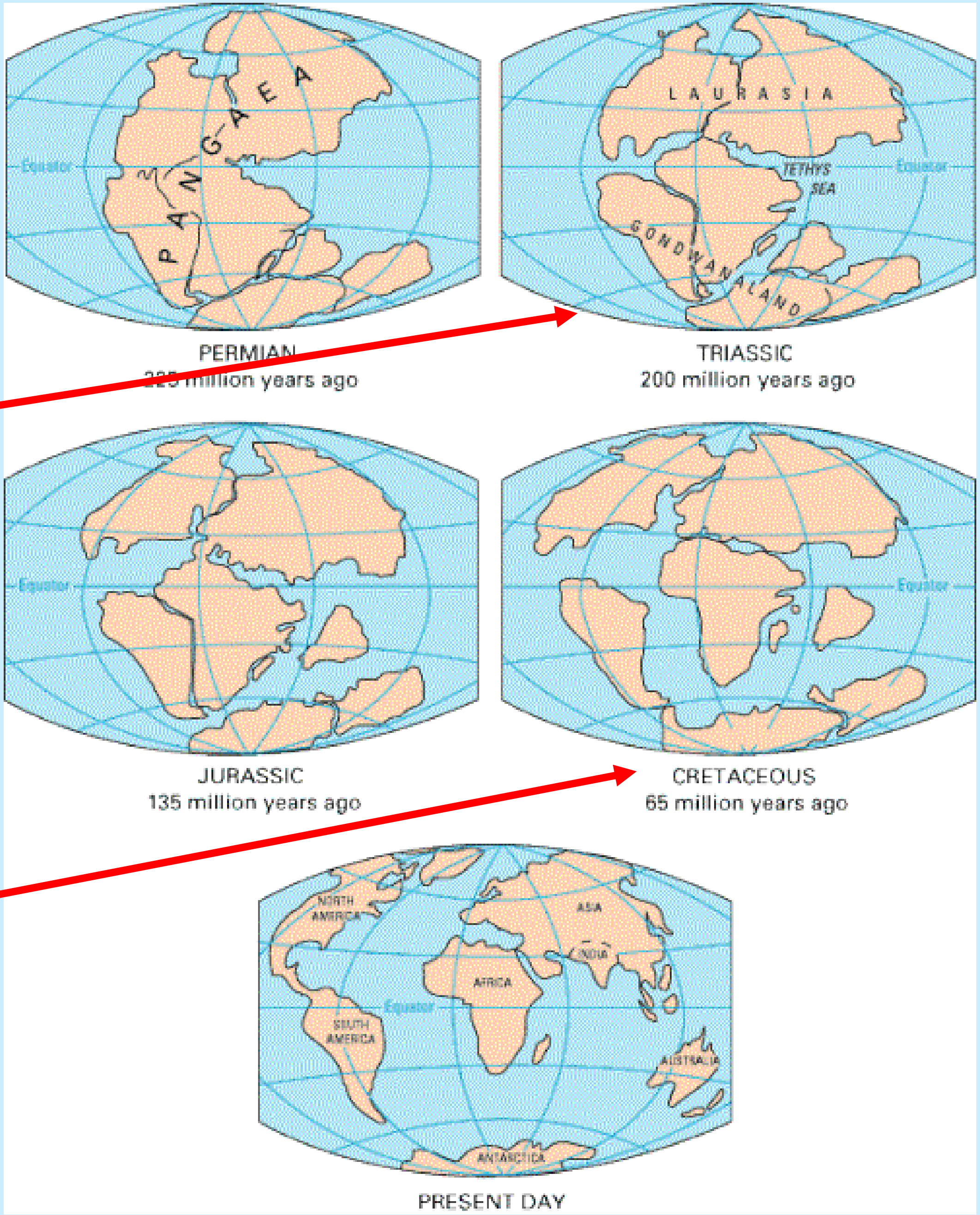
Bullard (1965)

Fit of continental margins in depth of 500 fathoms (927 m)

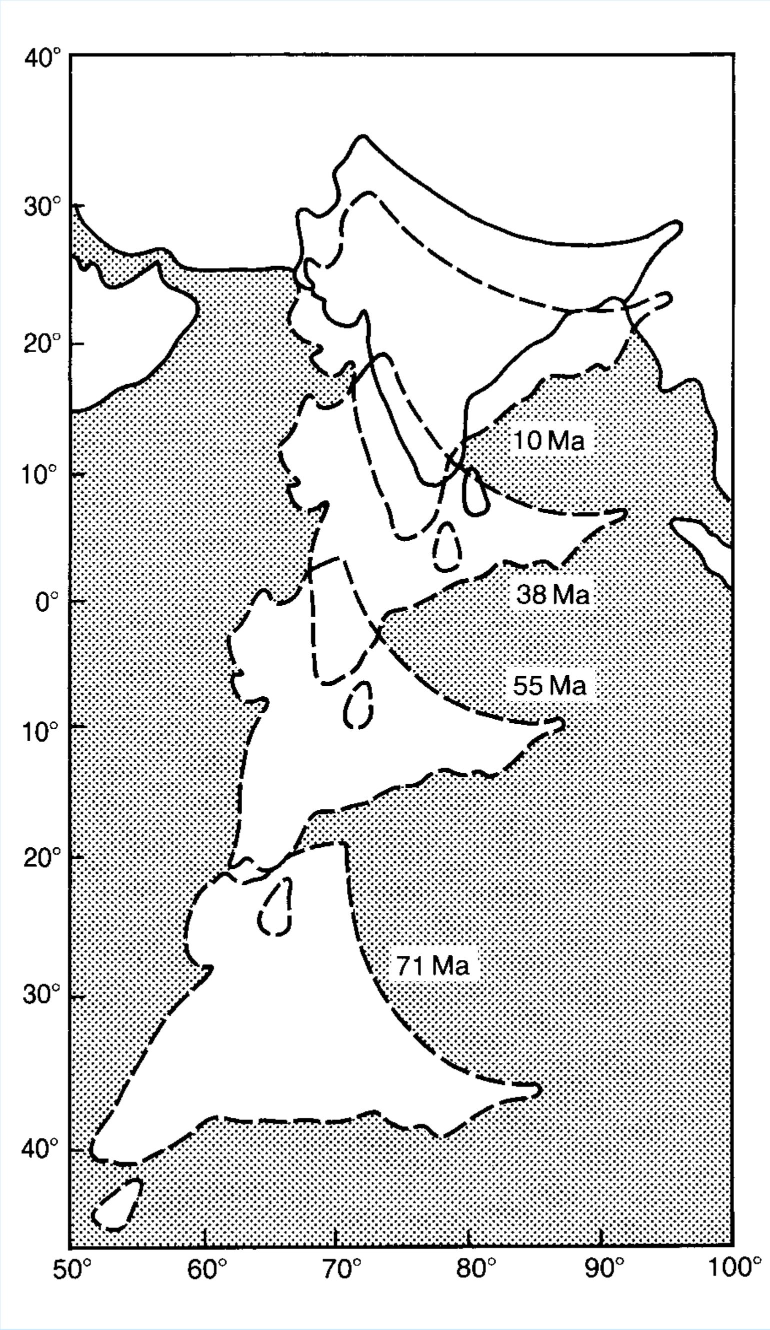
Plate Movements after Breakdown of Gondwana

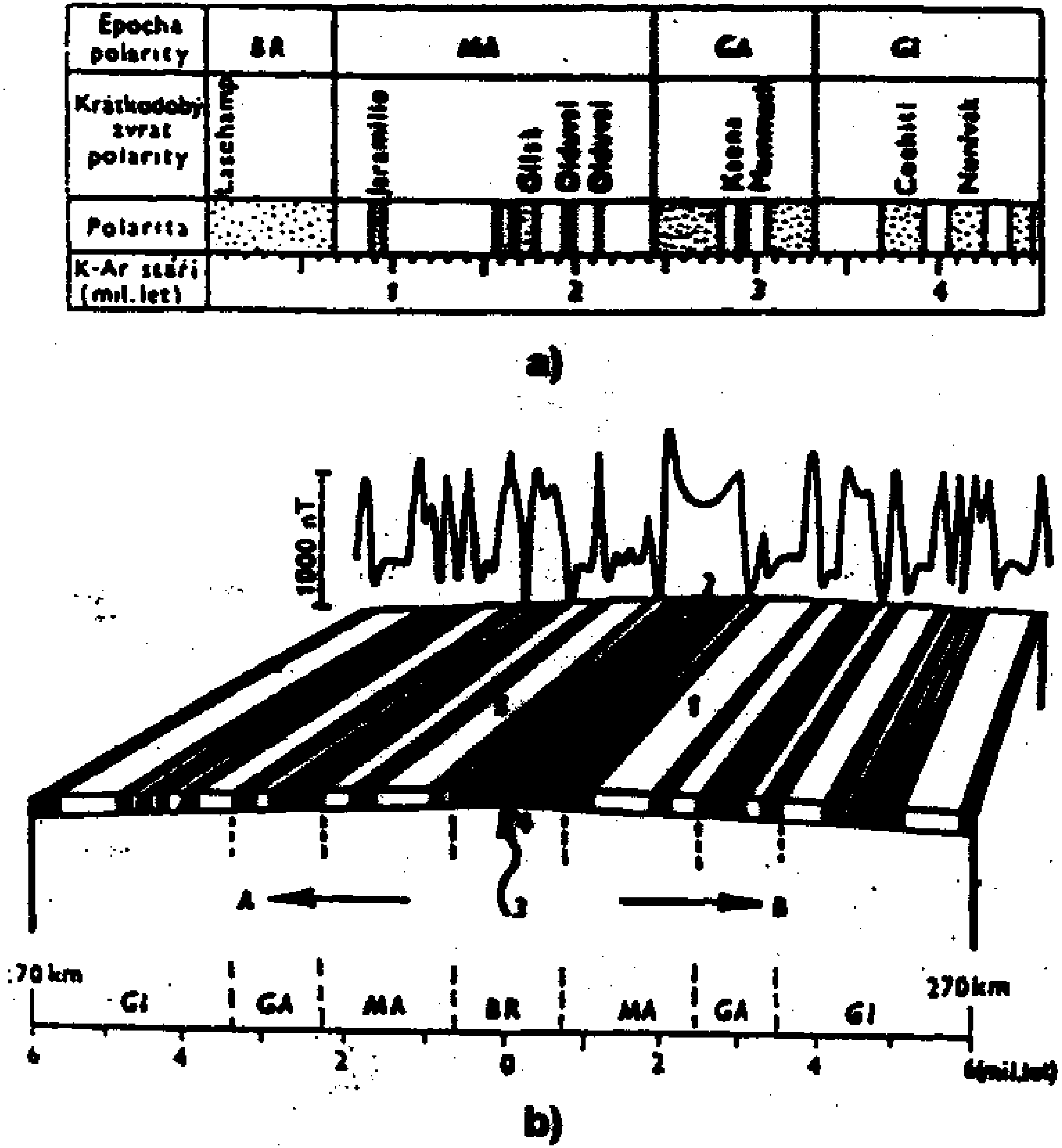
Laurasia and Gondwana.

Atlantic Opening.



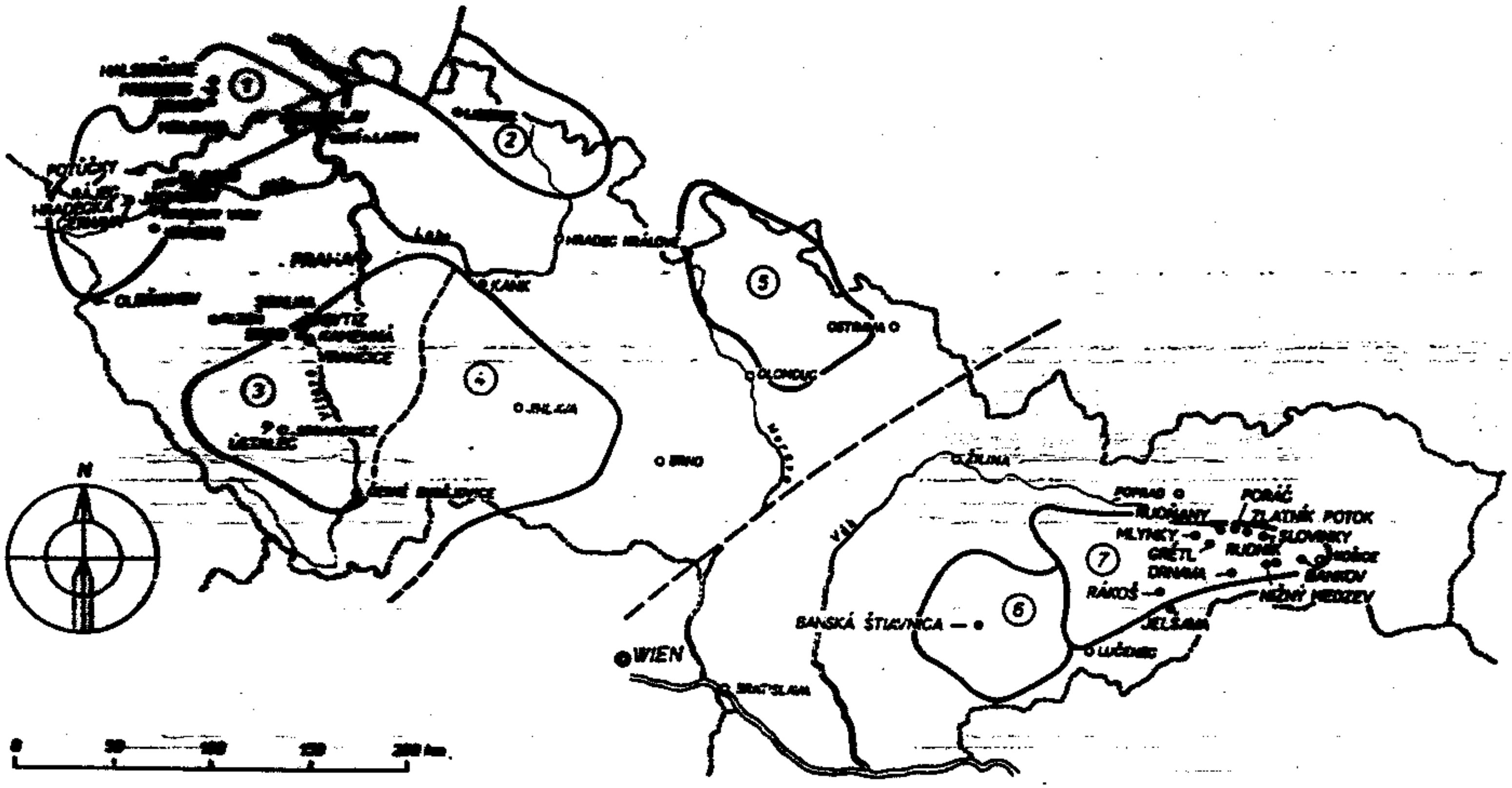
Drifting of India





Magnetic Stratigraphy

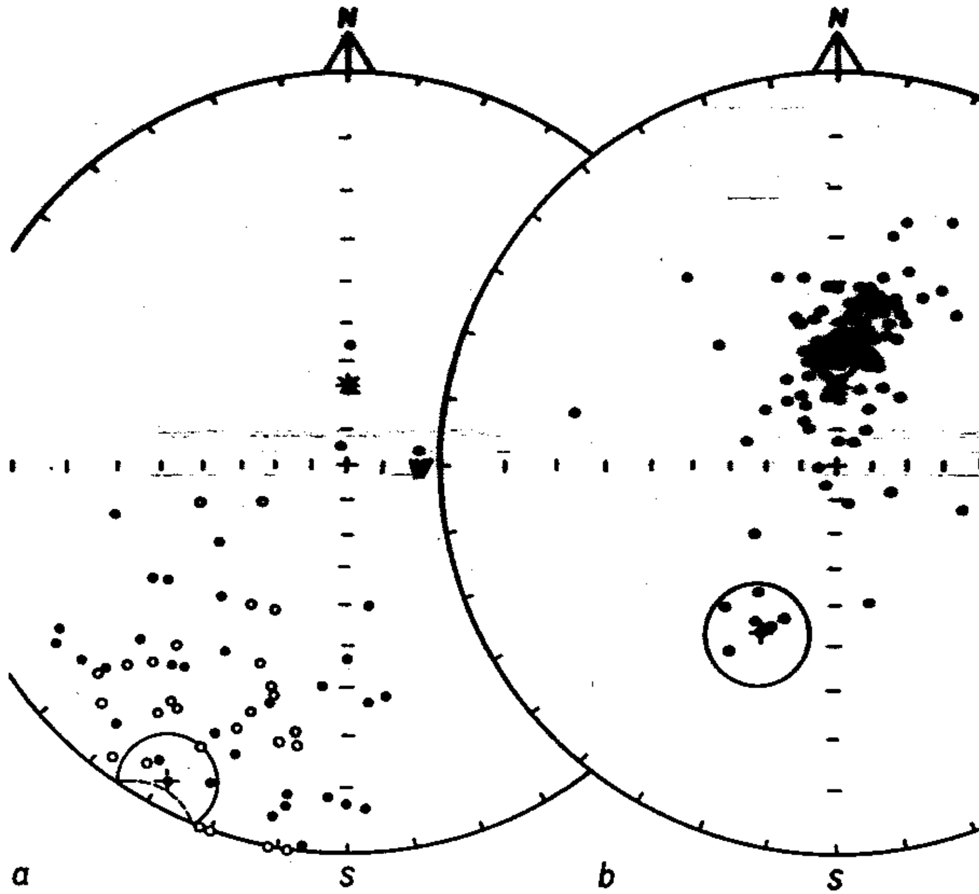
Palaeomagnetism of Ore Deposits



70. **Příklad lokalit** (*plné kroužky*) nerostných ložisek zkoumaných paleomagneticky

Metalogenní oblasti: *1* — Krušné hory a Slavkovský les, *2* — západosudetská oblast, *3* — středočeský pluton, *4* — centrální moldanubický masiv, *5* — východosudetská oblast, *6* — Štiavnické pohoří, *7* — Spišsko-gemerské rudohoří a Nízké Tatry. *Čárkovaně* je označena hranice Českého masivu a západní karpatské soustavy

Krusne hory Ore Deposits



78. Směry J_n hydrotermální mineralizace z širšího okolí Freibergu

a) Halsbrücke, Freiberg, Freiberg-Brand: I. mineralizační cyklus, převládají sulfidy kb-formace pigmentované hematitem; *b*) Halsbrücke, Freiberg, Brand: II. mineralizační cyklus, vzorky barytu a hematito-křemenného agregátu převážně z fba-formace