The principle of palaeointensity determination

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During the last cooling cycle in the past:

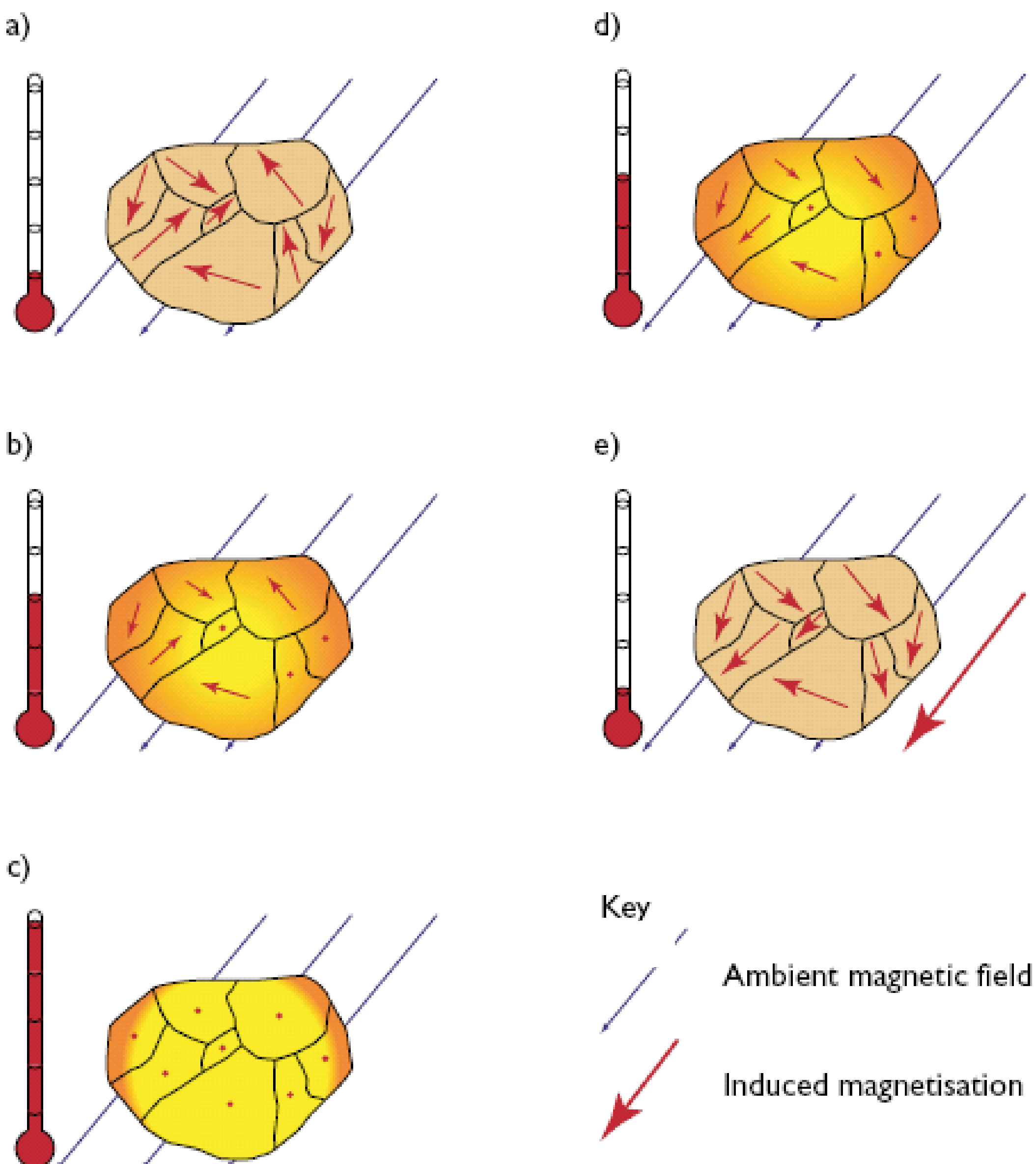
Baked material acquired a magnetisation parallel to the ambient Earth's field at that time.

This information is stored until present day.

Basic approach

Re-heating the sample in the laboratory to get the ancient absolute field intensity.

Thermo remanent magnetisation (TRM)



from Linford (2004)

In baked materials

When a sample is heated above the Curie-temperature and then cooled in the Earth's magnetic field, it acquires a thermo-remanent magnetisation.

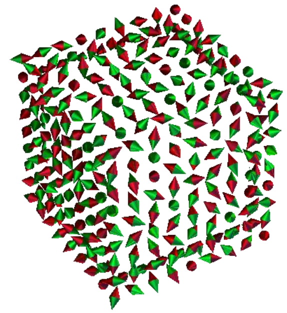
Remanent magnetisation of a sample is in general parallel to the ambient geomagnetic field.

Thermo remanent magnetisation (TRM)

Definition TRM

Cooling

Pierre Curie



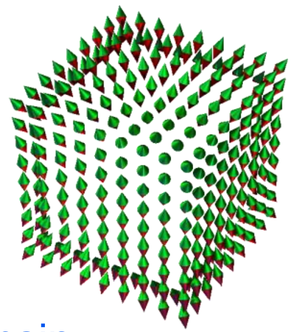
Paramagnetic state:
Uncompensated spins
are disordered

T_C Curie temperature — Phase transition

Ferromagnetic state:
Long range spin order

SP : Superparamagnetic: instable net moment

T_B blocking



T

SD: Stable single domain

Slide by the courtesy of Karl Fabian (2005)

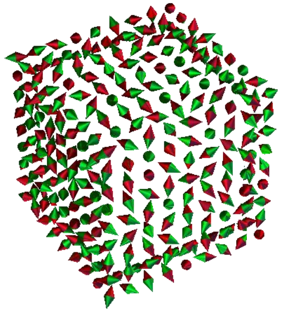
Thermo remanent magnetisation (TRM)

Definition of TRM

Cooling

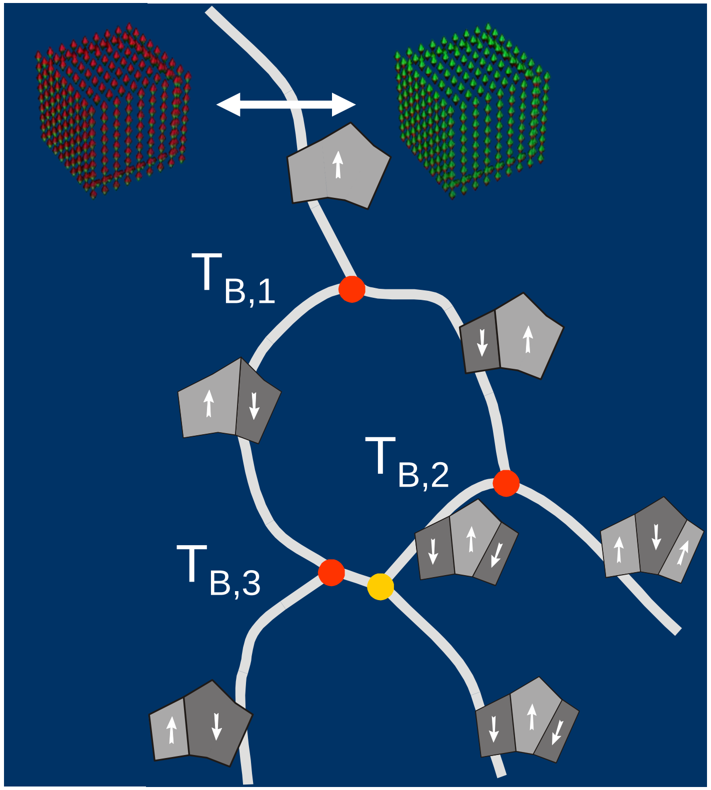
Pierre Curie

T_C Curie temperature



Paramagnetic state:
Uncompensated spins
are disordered

Phase transition



Ferromagnetic state:
Long range spin order

S_j

MD:
Cascade of possible
domain configurations
and sub-blocking temperatures

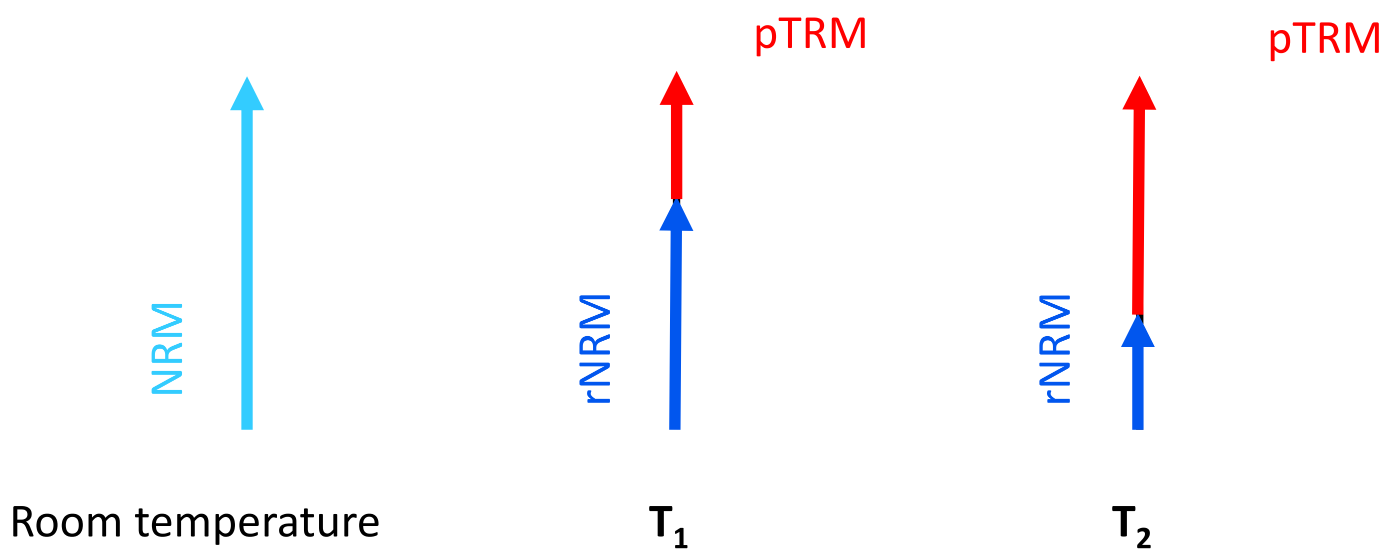
Transdomain processes

T

Slide by the courtesy of Karl Fabian (2005)

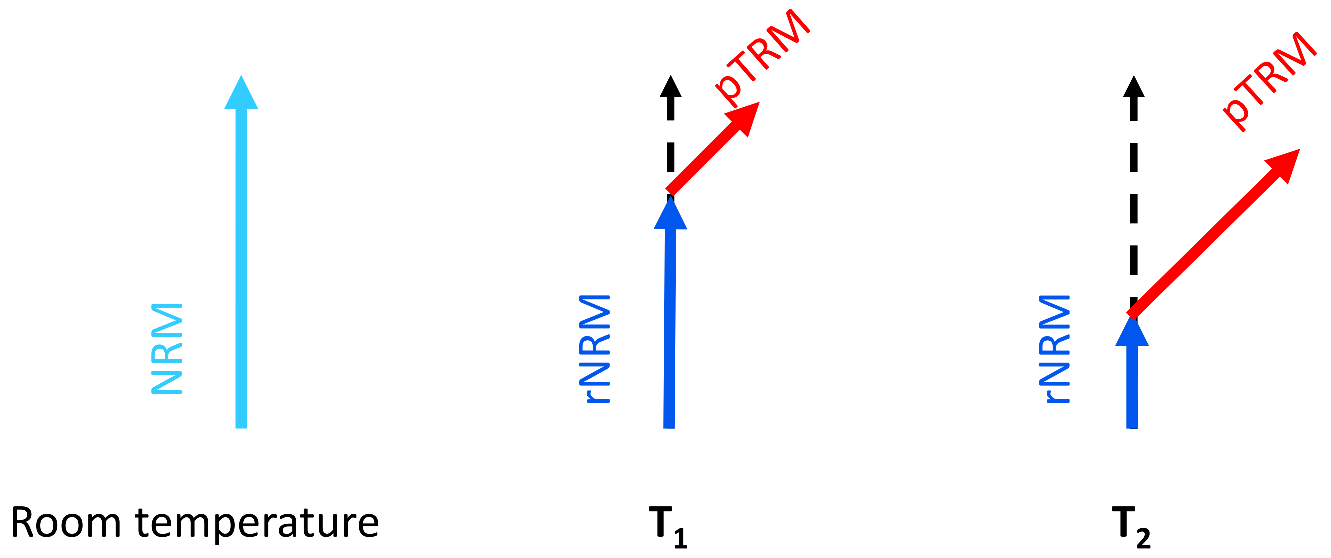
rNRM = residual Natural Remanent Magnetisation

pTRM = partial Thermo Remanent Magnetisation



rNRM = residual Natural Remanent Magnetisation

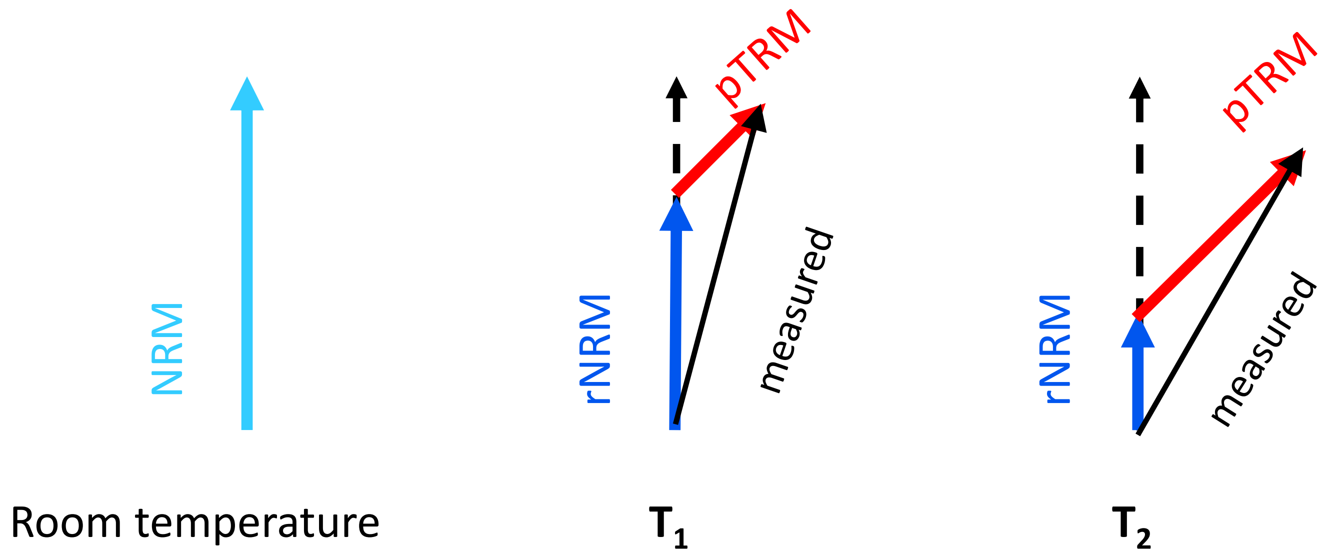
pTRM = partial Thermo Remanent Magnetisation



Reheating a sample and cooling in a magnetic field replaces the orignial NRM by a TRM.

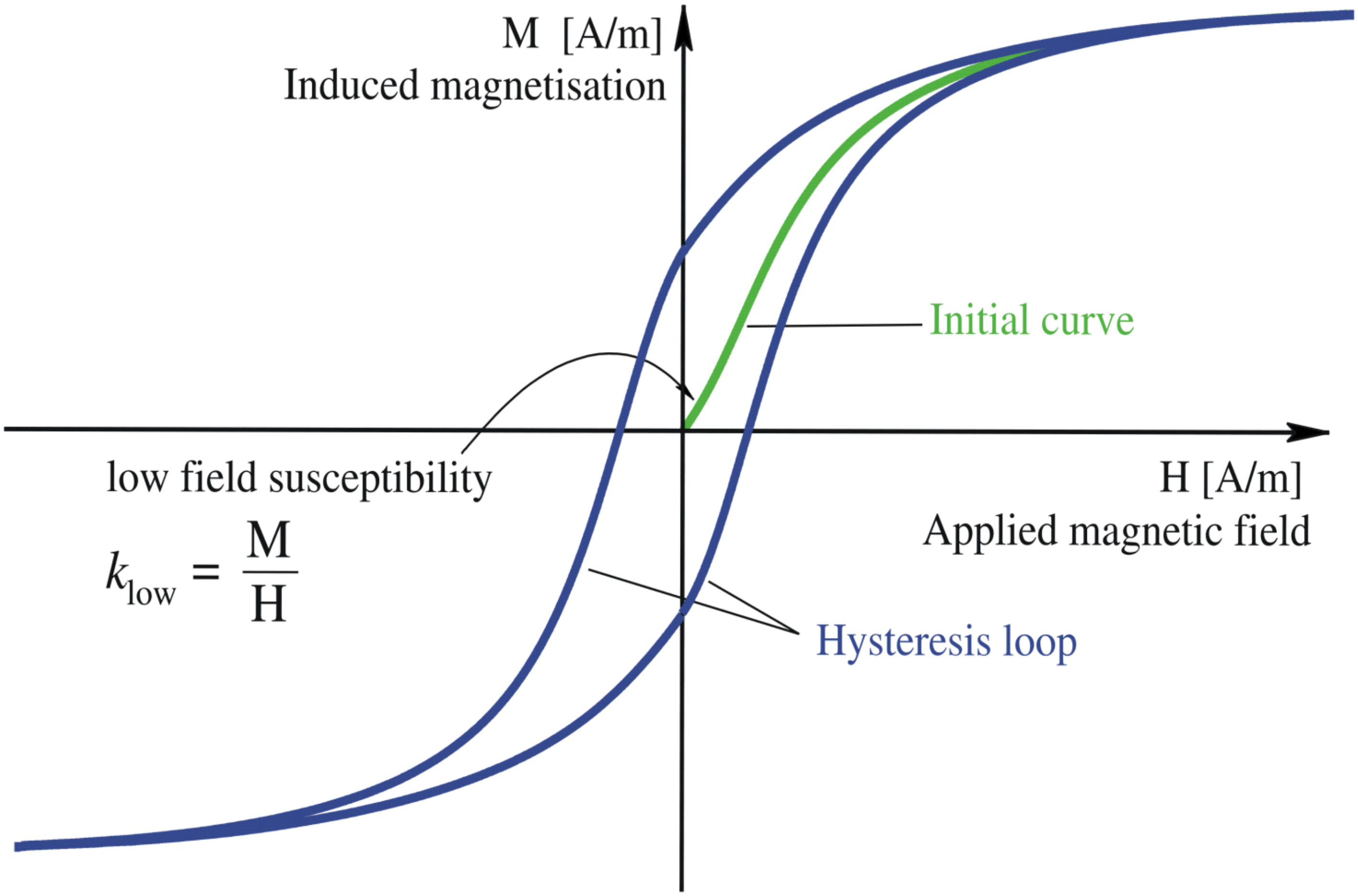
rNRM = residual Natural Remanent Magnetisation

pTRM = partial Thermo Remanent Magnetisation



- Field during laboratory heating not always applied along the direction of the NRM
- pTRM has a different direction than the rNRM
- Dubble heating in opposite fields to separate between rNRM and pTRM

After Thellier and Thellier 1959


M [A/m]
Induced magnetisation
Initial curve
low field susceptibility
$k_{low} = \frac{M}{H}$
H [A/m]
Applied magnetic field
Hysteresis loop

In the past

$$M_{TRM_{Pal}} = \kappa_{Pal} \cdot H_{amb_{Pal}}$$

In the laboratory

$$M_{TRM_{Lab}} = \kappa_{Lab} \cdot H_{amb_{Lab}}$$

If during laboratory re-heating κ does not change

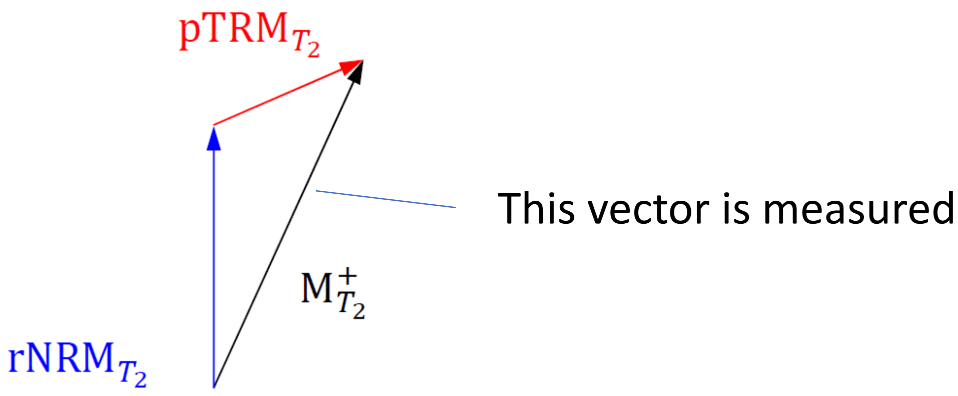
i.e., $\kappa_{Pal} = \kappa_{Lab}$

One can determine the palaeointensity as follows:

$$H_{amb_{Pal}} = \frac{M_{TRM_{Pal}}}{M_{TRM_{Lab}}} H_{amb_{Lab}}$$

Regular step at temperature T_2

1st heating at T_2



B > 0

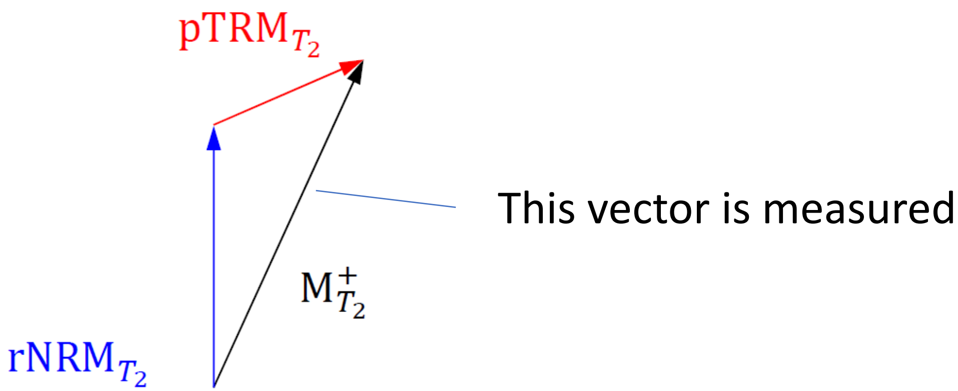
$$M^{+}_{T_2} = rNRM_{T_2} + pTRM_{T_2}$$

TRM not in NRM direction

Double heating with TRM in two opposite field directions to separate NRM & TRM

Regular step at temperature T_2

1st heating at T_2



B > 0

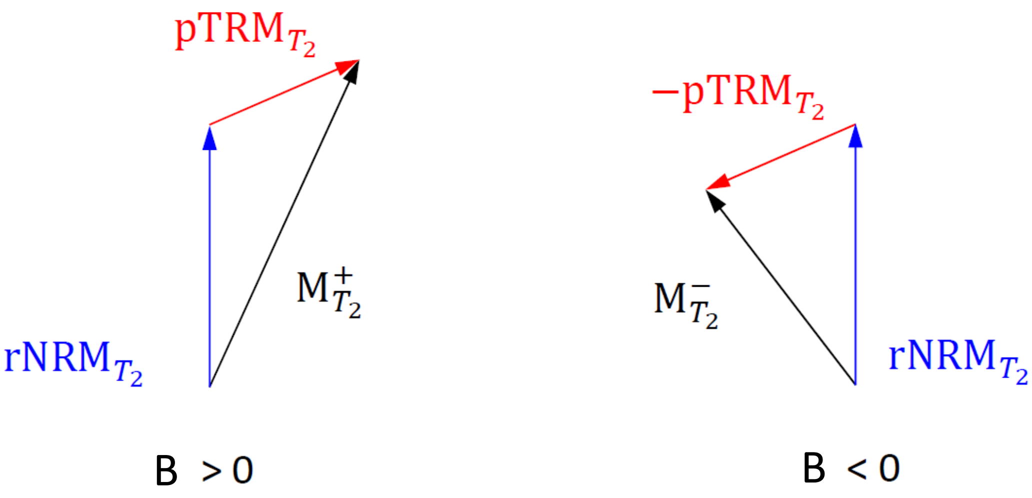
$$M^+_{T_2} = rNRM_{T_2} + pTRM_{T_2}$$

TRM not in NRM direction

Double heating with TRM in two opposite field directions to separate NRM & TRM

Regular step at temperature T_2

1^{st} heating at T_2 | 2^{nd} heating at T_2



$$M^{+}_{T_2} = rNRM_{T_2} + pTRM_{T_2}$$

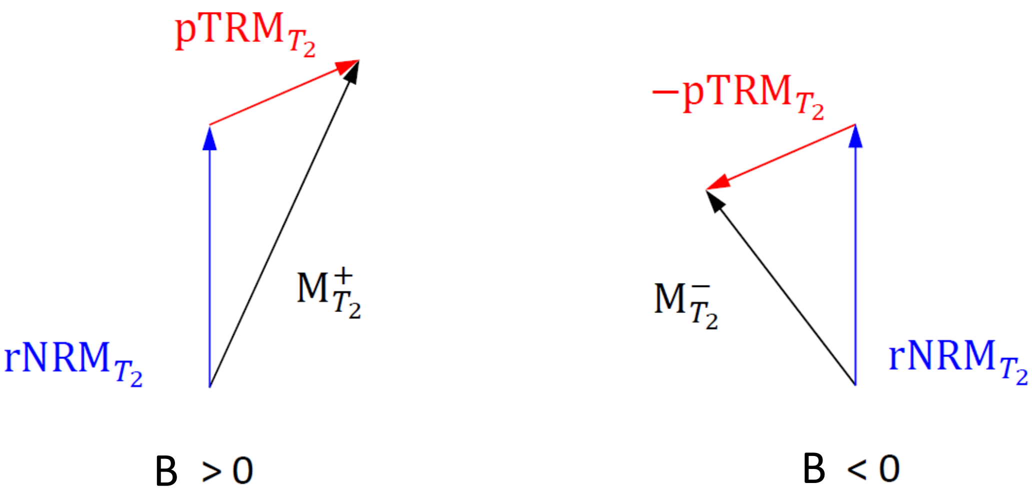
$$M^{-}_{T_2} = rNRM_{T_2} - pTRM_{T_2}$$

TRM not in NRM direction

Double heating with TRM in two opposite field directions to separate NRM & TRM

Regular step at temperature T_2

1st heating at T_2 — 2nd heating at T_2



$$M^{+}_{T_2} = rNRM_{T_2} + pTRM_{T_2}$$

$$M^{-}_{T_2} = rNRM_{T_2} - pTRM_{T_2}$$

$$rNRM_{T_2} = \frac{1}{2}\left(M^{+}_{T_2} + M^{-}_{T_2}\right)$$

$$pTRM_{T_2} = \frac{1}{2}\left(M^{+}_{T_2} - M^{-}_{T_2}\right)$$

TRM not in NRM direction

Double heating with TRM in two opposite field directions to separate NRM & TRM

The 3 Thellier's laws of pTRM for single domain grains

- *Linearity*
  TRM intensity is a linear function of field intensity

- *Additivity*
  The total TRM is a sum of different partial TRM's ($pTRM$) acquired at different temperatures

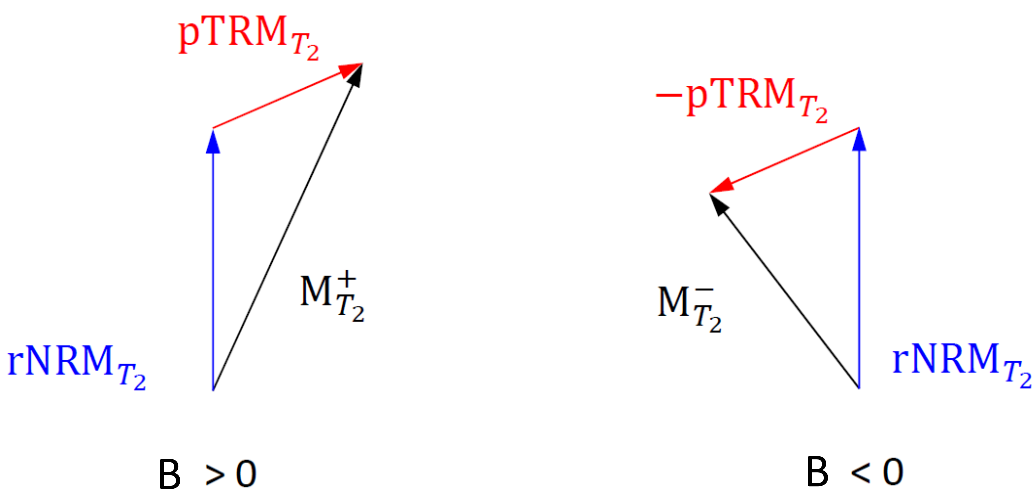
- *Independence*
  A $pTRM\,(T_1,T_2)$ is not influenced by heating and cooling below T_1 and is completely removed above T_2

This requires an additional fact: $T_B = T_{UB}$

For each SD particle blocking and unblocking temperatures are equal, but not for MD grains

Regular step at temperature T_2

1st heating at T_2 — 2nd heating at T_2



Repeating a double heating step at lower temperature (T_1) in order to:

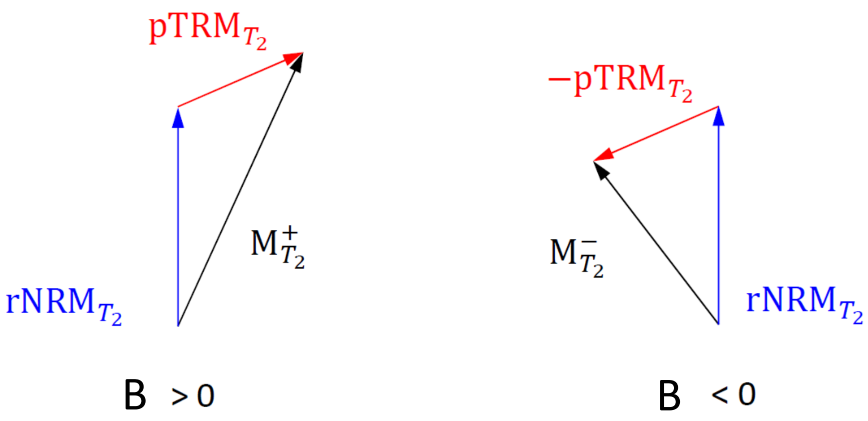
1. to check for thermal alteration
2. to see if a *pTRM* (at T_2) can be completely removed

$T_{blocking} = T_{unblocking}$

rNRM **at T_2 should equal the *rNRM* of the check**

Regular step at temperature T_2

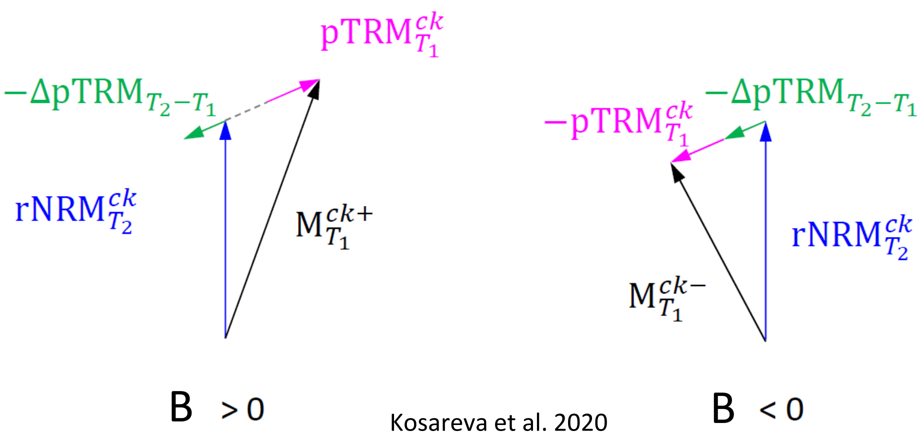
1st heating at T_2 2nd heating at T_2



Regular measurement at T_2

Check step at temperature $T_1 < T_2$

1st heating at T_1 2nd heating at T_1



Kosareva et al. 2020

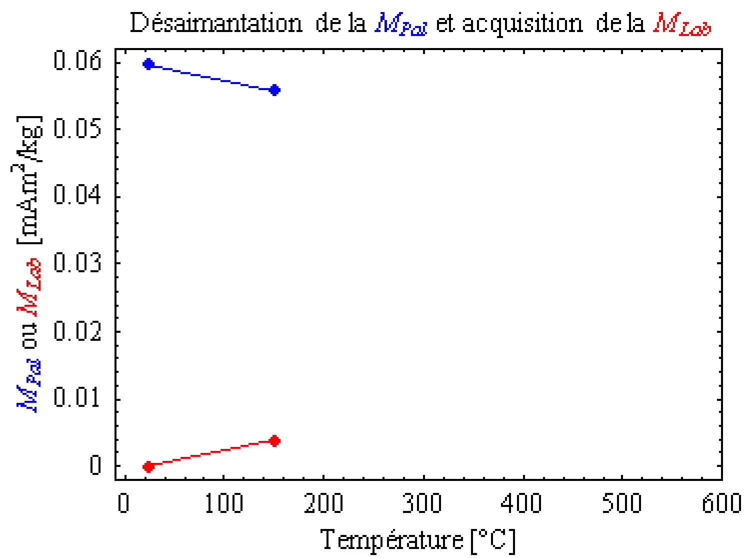
Check measurement at T_1

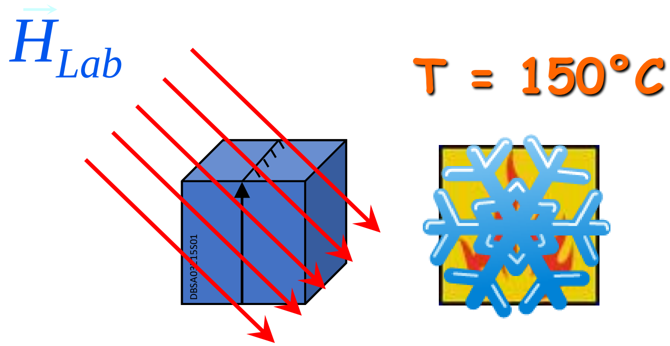
with $T_1 < T_2$

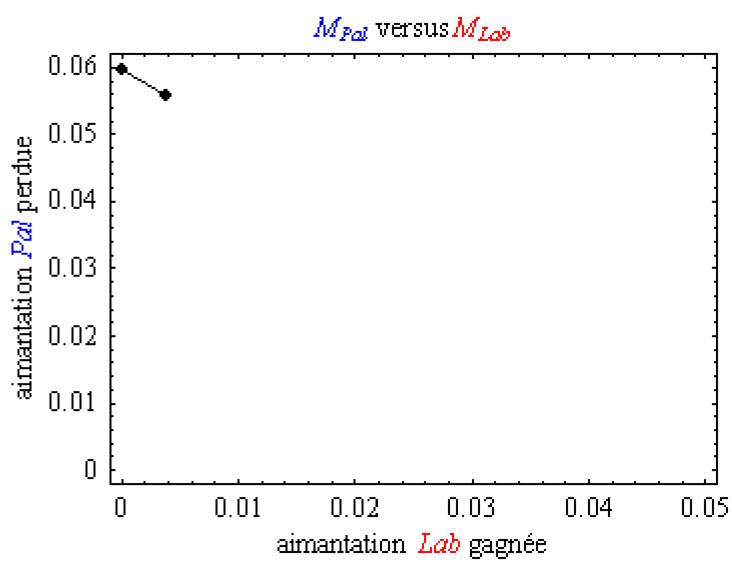
$$pTRM^{ck}_{T_1} \triangleq pTRM_{T_1}$$

$$rNRM^{ck}_{T_2} = M^{ck-}_{T_2} + \frac{1}{2}\left(M^{+}_{T_2} - M^{-}_{T_2}\right) \triangleq \frac{1}{2}\left(M^{+}_{T_2} + M^{-}_{T_2}\right) = rNRM_{T_2}$$

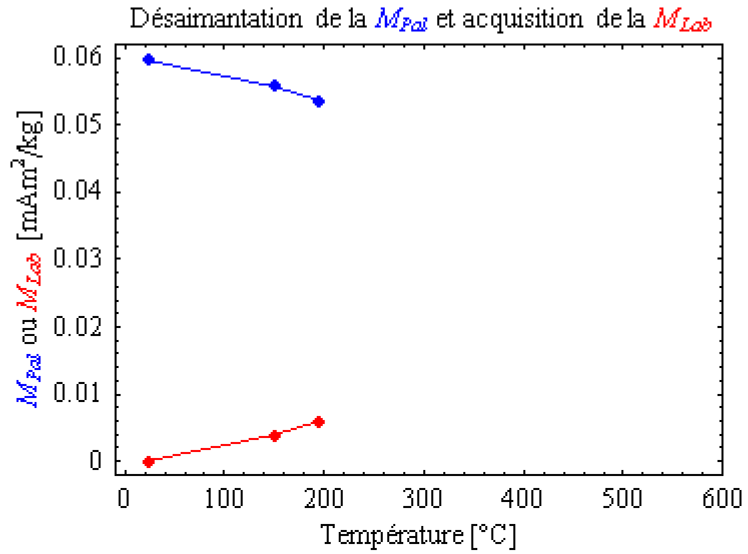
Thellier, É. & Thellier, O. 1959: ***T* variable and *H*$_{Lab}$ = const**

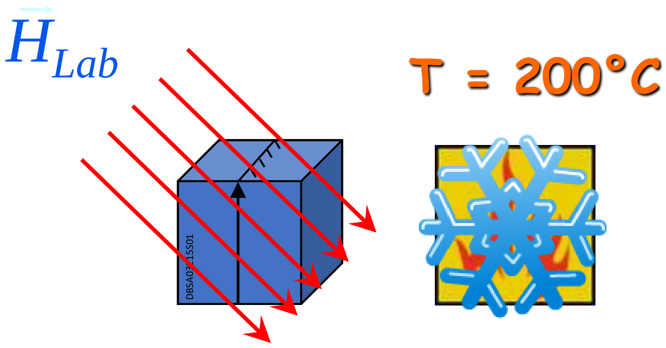


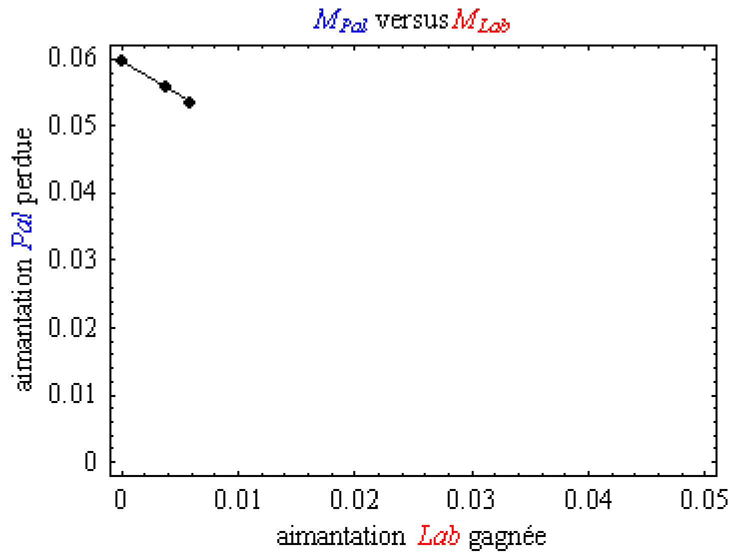


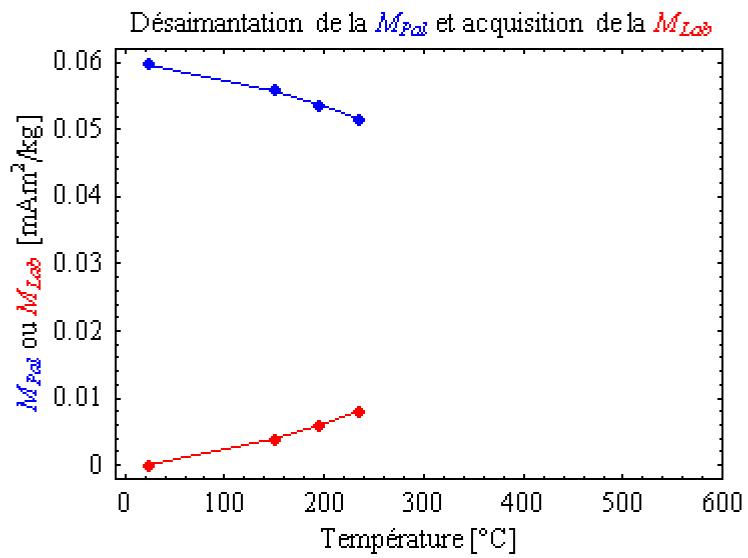


Thellier, É. & Thellier, O. 1959: T variable et H_{Lab} = const

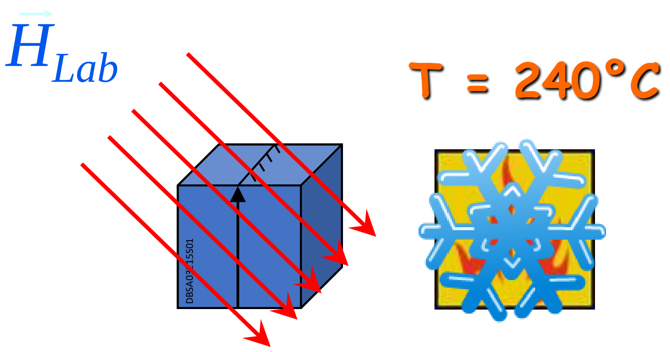




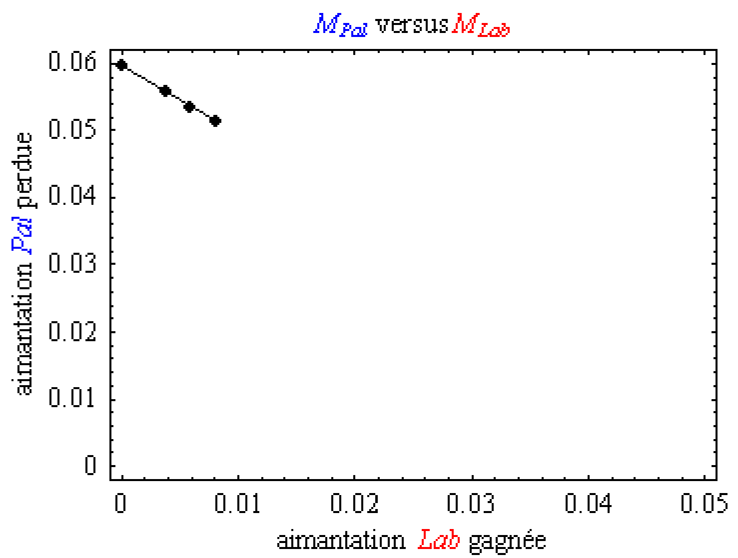




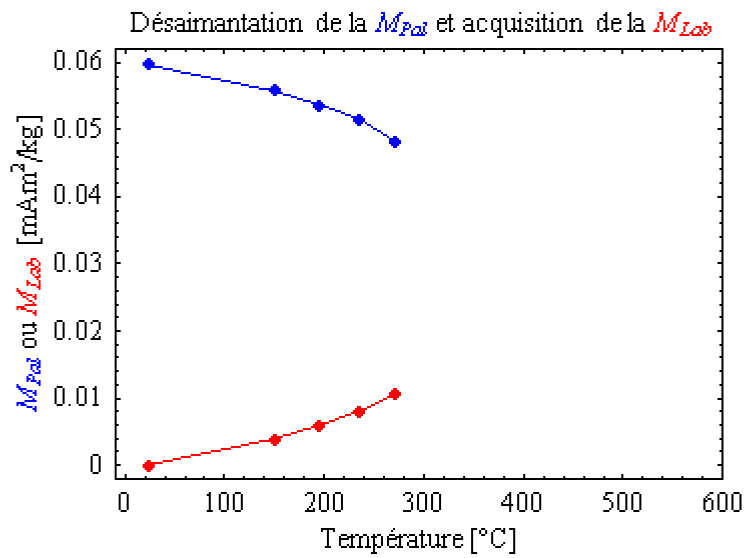
Désaimantation de la M_{Pal} et acquisition de la M_{Lab}
M_{Pal} ou M_{Lab} [mAm^2/kg]
0.06
0.05
0.04
0.03
0.02
0.01
0
0
100
200
300
400
500
600
Température [°C]



$\vec{H}_{Lab}$
T = 240°C



M_{Pal} versus M_{Lab}
aimantation Pal perdue
0.06
0.05
0.04
0.03
0.02
0.01
0
0
0.01
0.02
0.03
0.04
0.05
aimantation Lab gagnée



Désaimantation de la M_{Pal} et acquisition de la M_{Lab}
M_{Pal} ou M_{Lab} [mAm^2/kg]
0.06
0.05
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0.02
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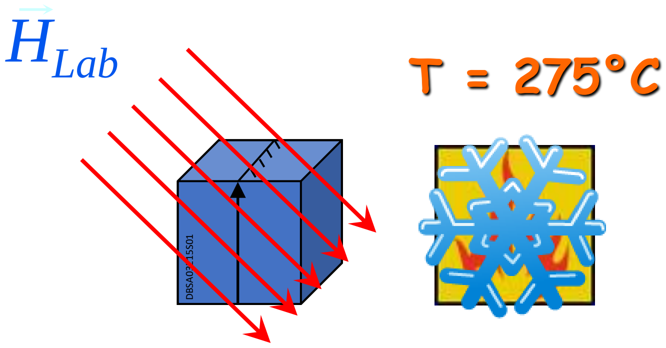
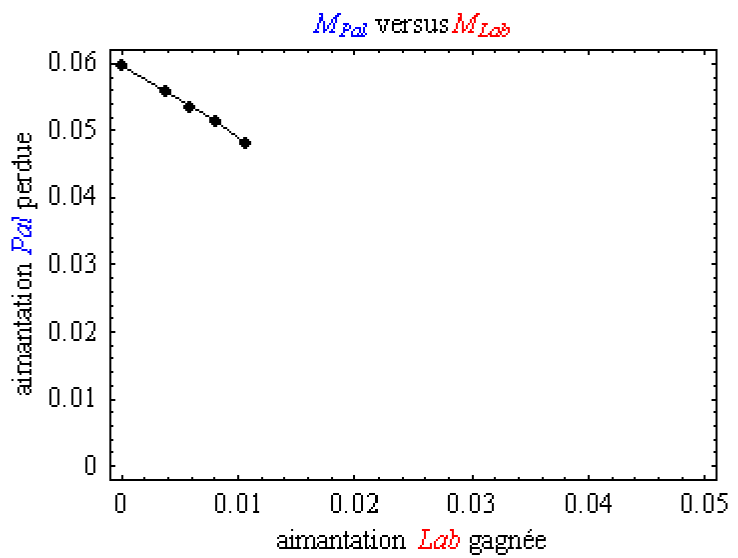
0
0
100
200
300
400
500
600
Température [°C]

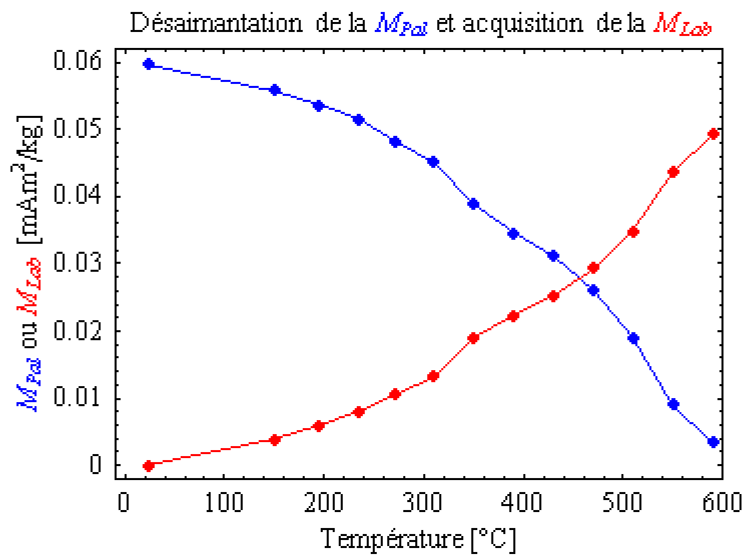


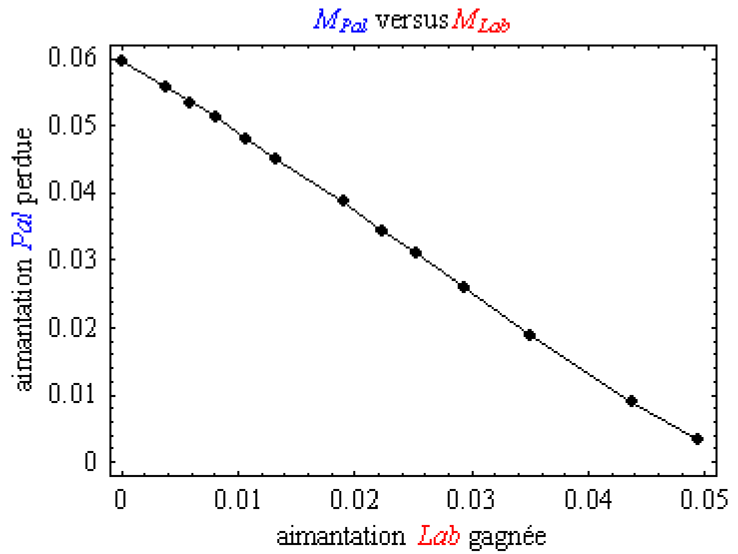
$\vec{H}_{Lab}$
T = 275°C



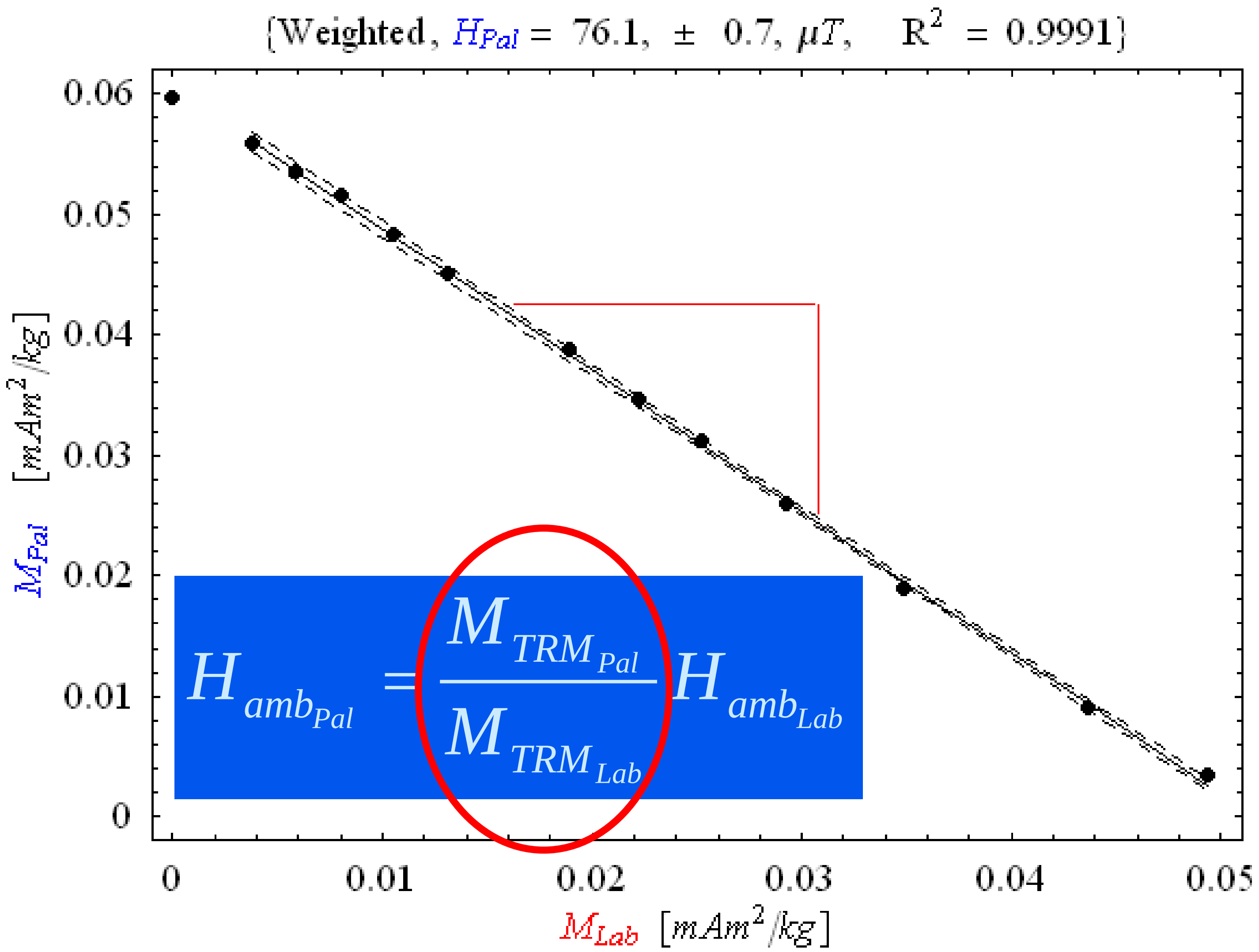
M_{Pal} versus M_{Lab}
aimantation Pal perdue
0.06
0.05
0.04
0.03
0.02
0.01
0
0
0.01
0.02
0.03
0.04
0.05
aimantation Lab gagnée

Thellier, É. & Thellier, O. 1959: ***T* variable et H_{Lab} = const**

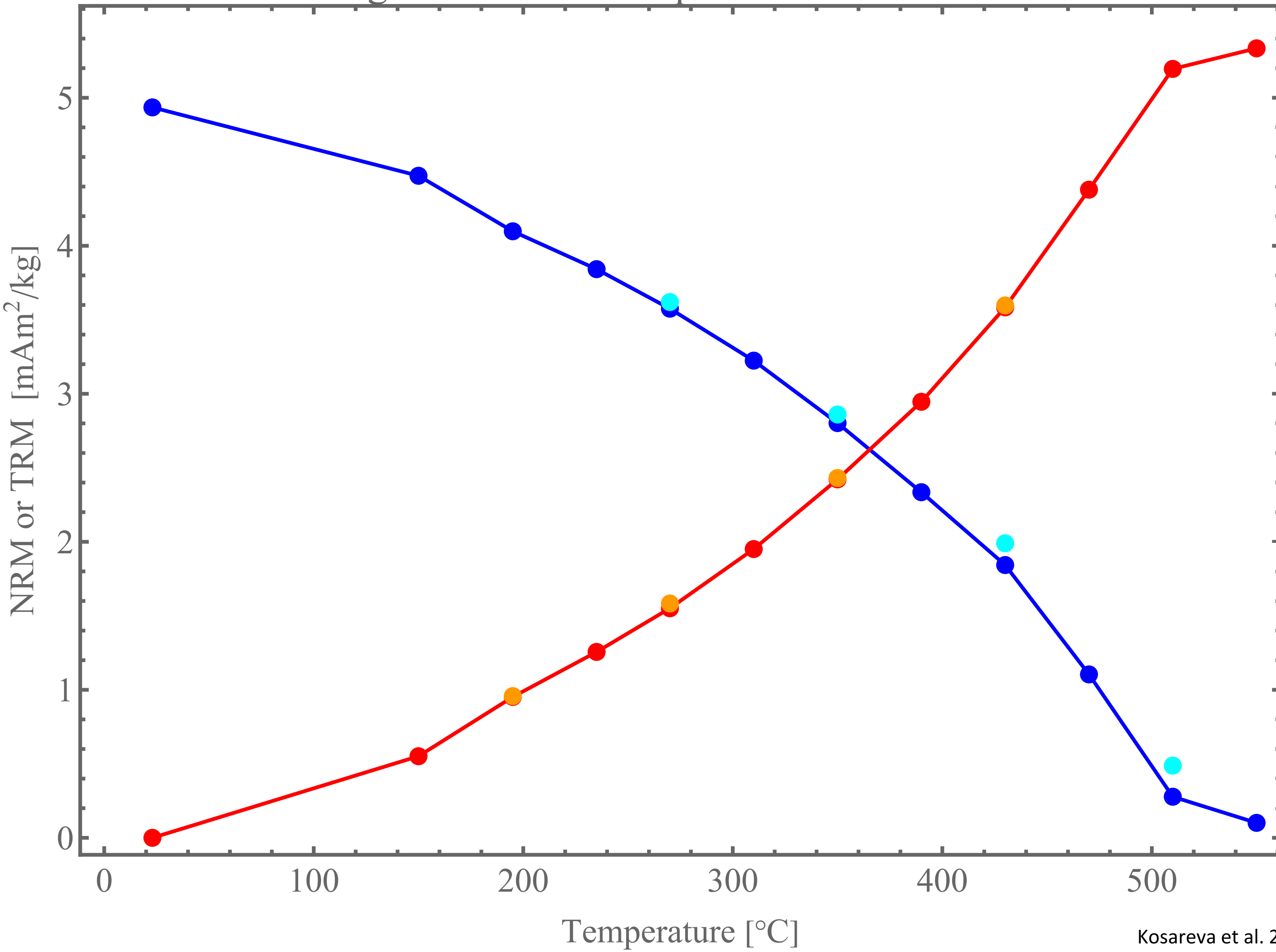




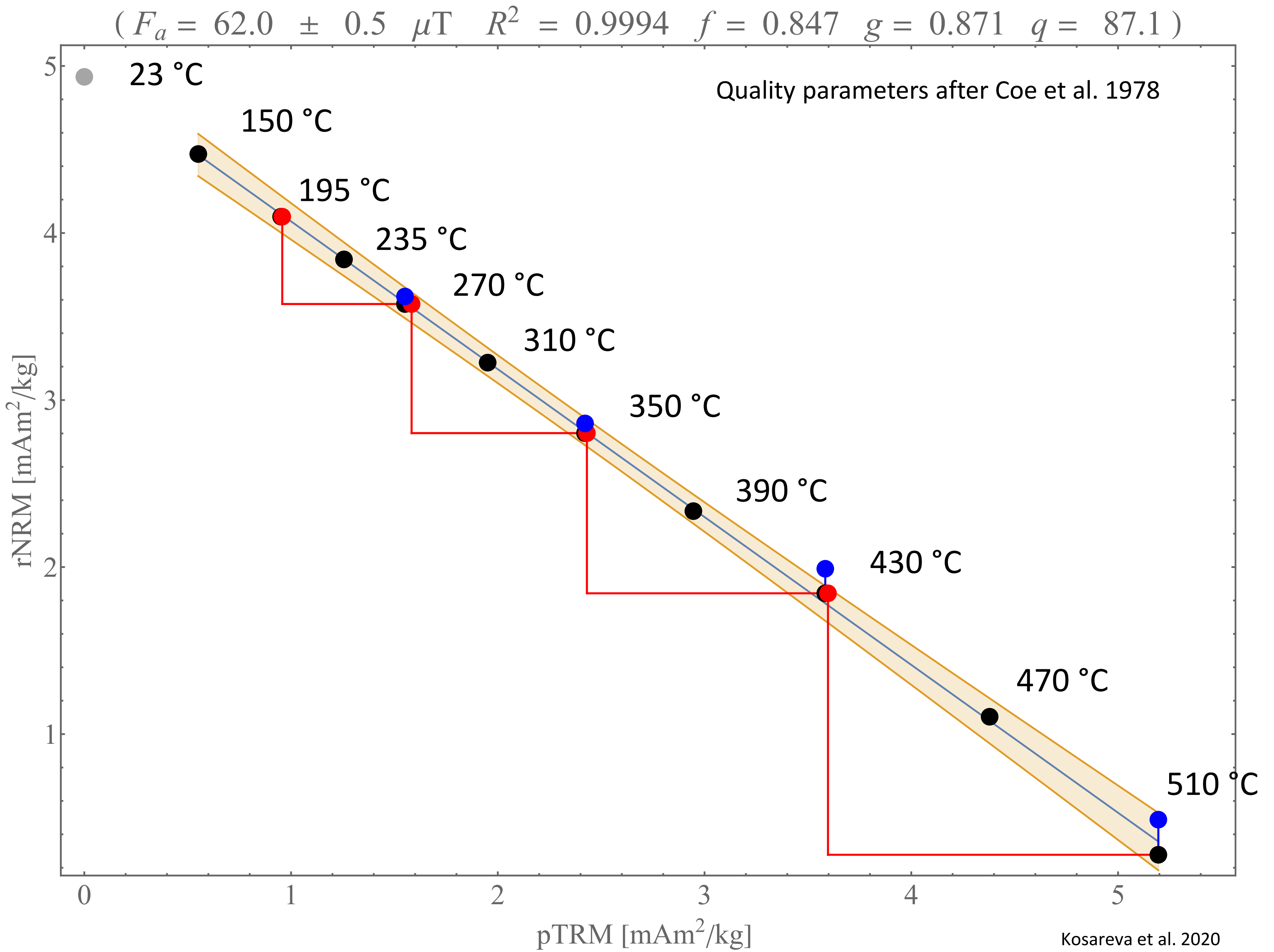
Thellier, É. & Thellier, O. 1959: **T = const. et H_{Lab} variable**



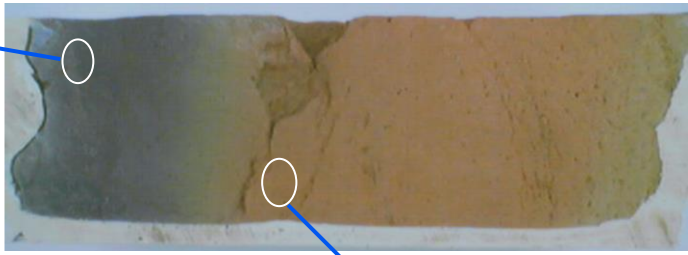
Demagnetisation and acquisition of NRM & TRM



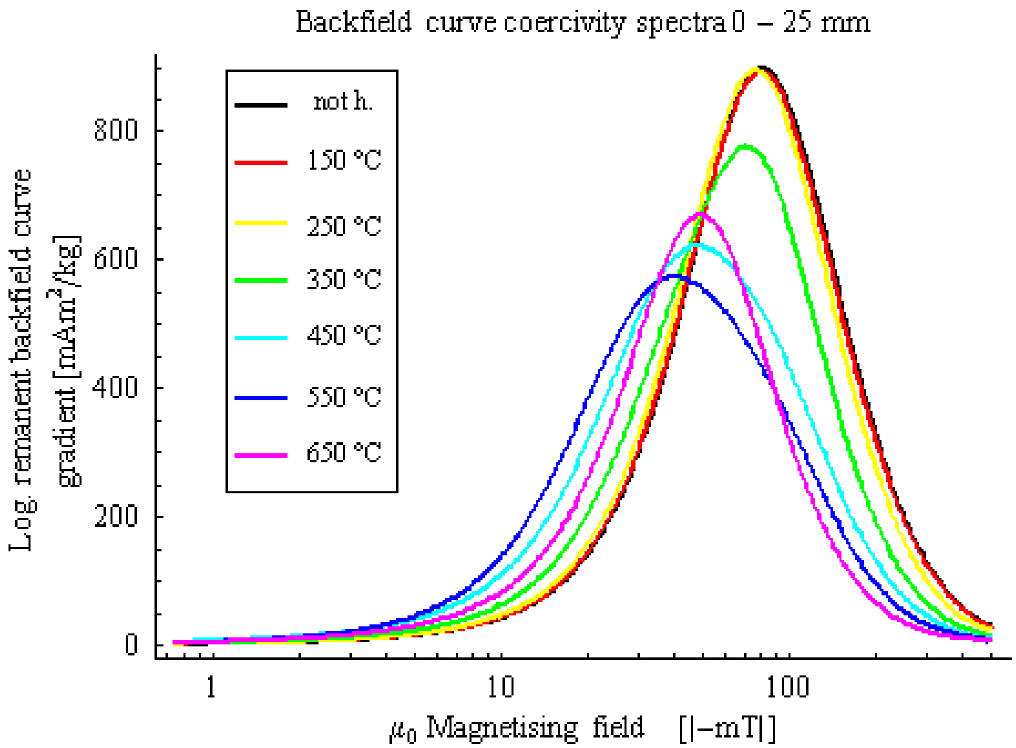
Kosareva et al. 2020

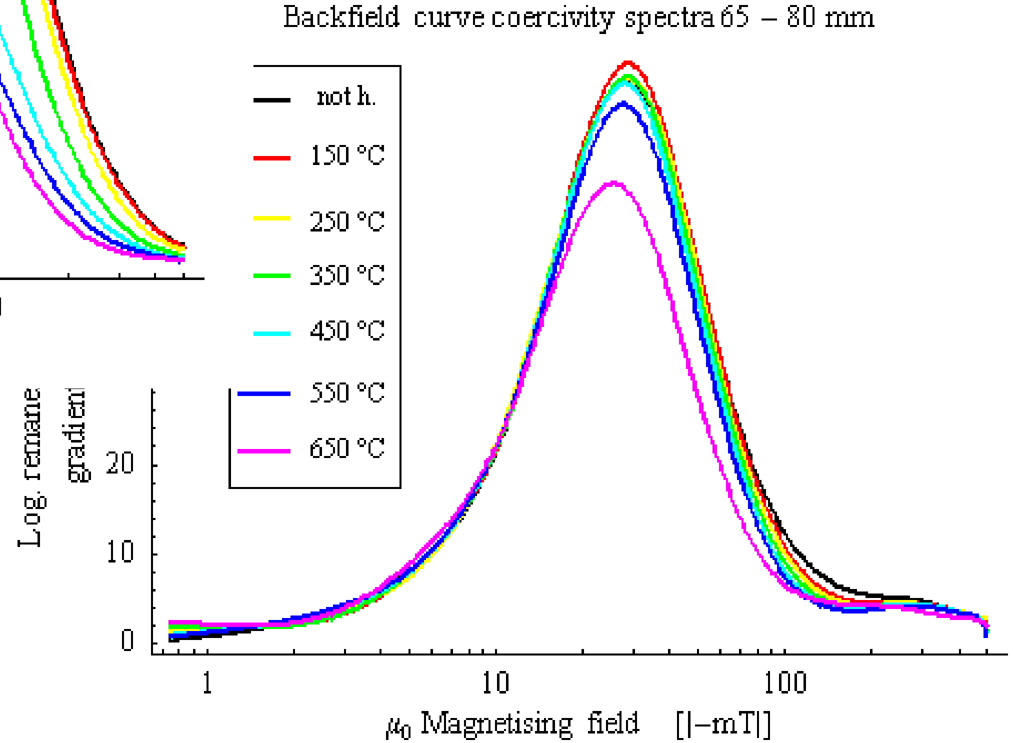

(F_a = 62.0 ± 0.5 μT R^2 = 0.9994 f = 0.847 g = 0.871 q = 87.1)
23 °C
Quality parameters after Coe et al. 1978
150 °C
195 °C
235 °C
270 °C
310 °C
350 °C
390 °C
430 °C
470 °C
510 °C
rNRM [mAm²/kg]
pTRM [mAm²/kg]
Kosareva et al. 2020

Vitrified crust

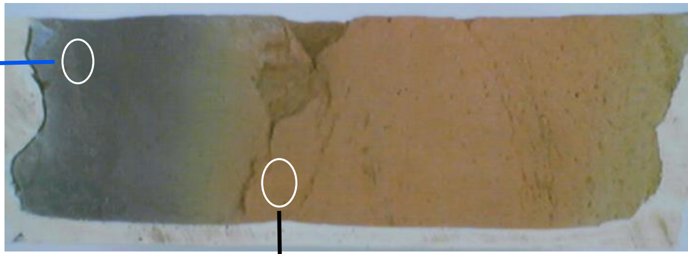


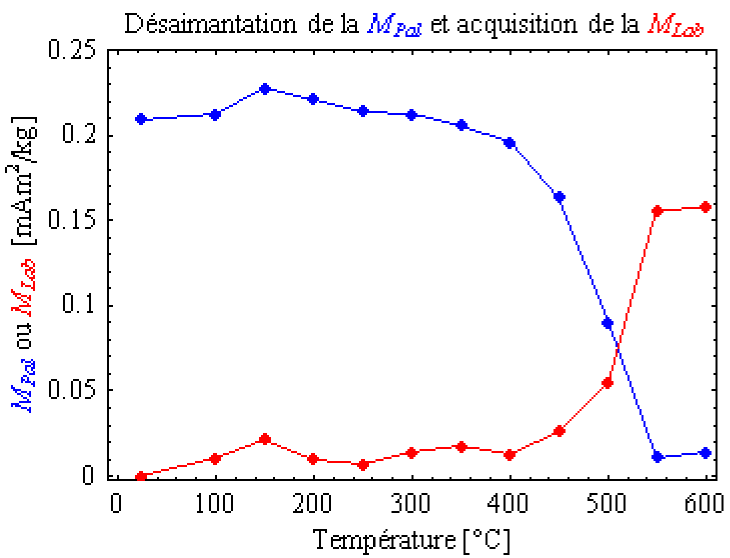
Well baked





Vitrified crust





Well baked