Out-of-Phase Susceptibility and Viscous Magnetization: Alternative Tools for Magnetic Granulometry of Loess and Paleosols

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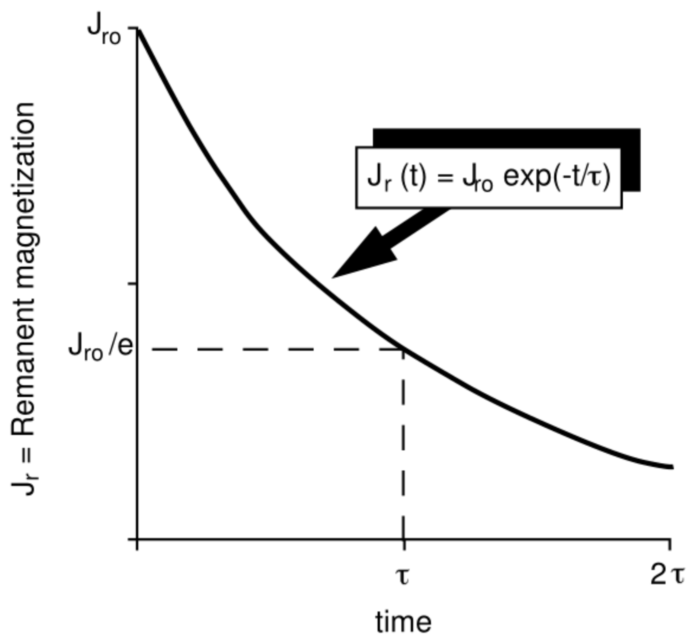
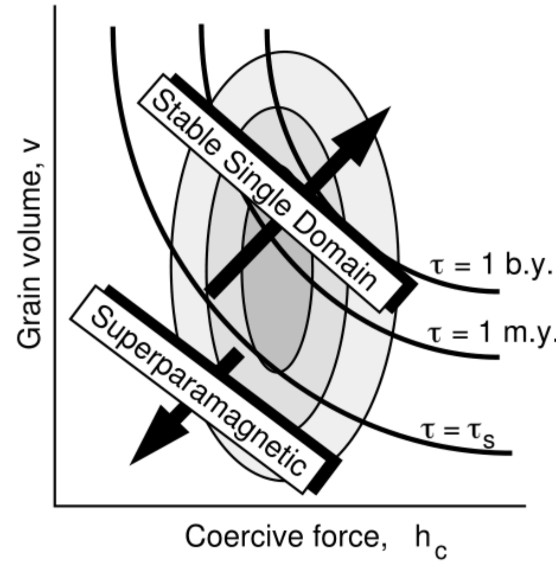
1. Theory → Magnetization on SP/SSD Boundary





Butler 1992

Exponential decay of remanent magnetization, $J_r(t)$, after removal of the magnetizing field is

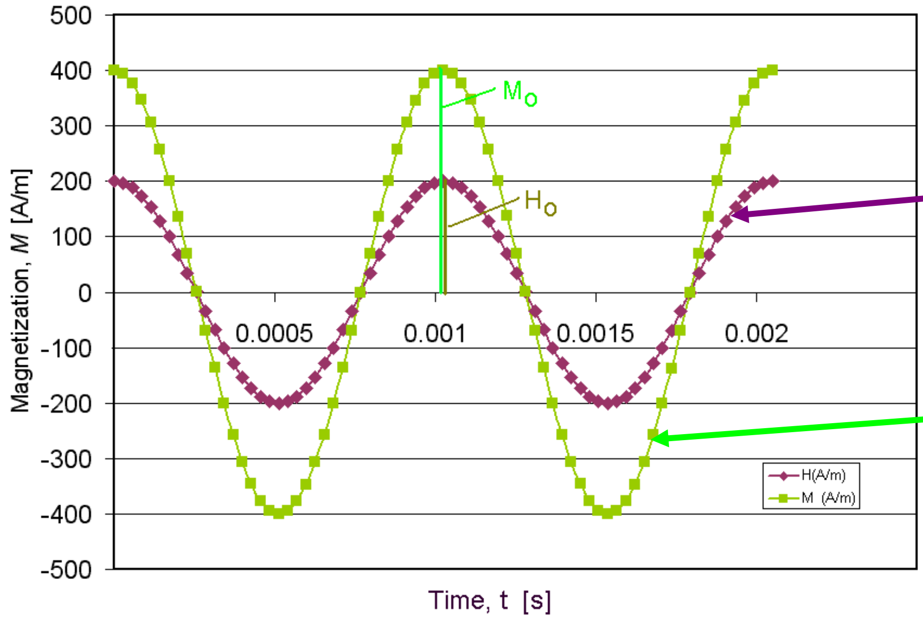
$$J_r(t) = J_{r0} \exp(-t/\tau) \qquad (3.13)$$

where J_r = initial remanent magnetization
t = time (s)
τ = charact*eristic relaxation time* (s), after which $J_r = J_{r0} / e$.

Magnetic relaxation was studied by Louis Néel, who showed that the characteristic relaxation time is given by

$$\tau = \frac{1}{\mathrm{C}} \exp\left(\frac{v\, h_c\, j_s}{2\mathrm{k}T}\right) \qquad (3.14)$$

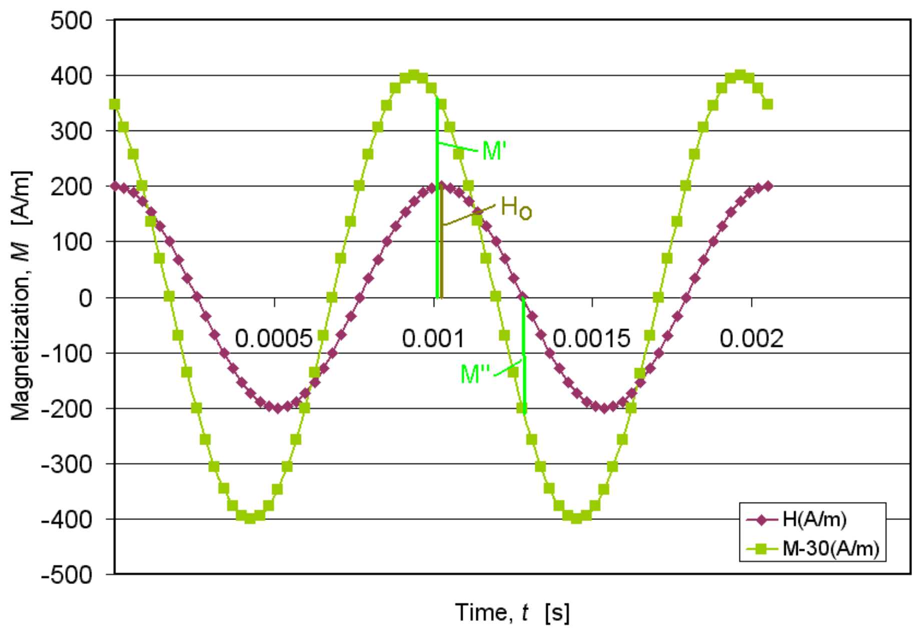
where C = *frequency factor* ≈ 10^8 s^{-1}
v = volume of SD grain
h_c = microscopic coercive force of SD grain
j_s = saturation magnetization of the ferromagnetic material
kT = thermal energy



Dia, para, MD ferro grains

Driving field

In-Phase response



SP to SSD grains

The response is in time lag, phase δ

Susceptibility resolves into

- In-Phase (χ')
- Out-of-Phase (χ'')

Phase angle

$\tan \delta = \chi'' / \chi'$

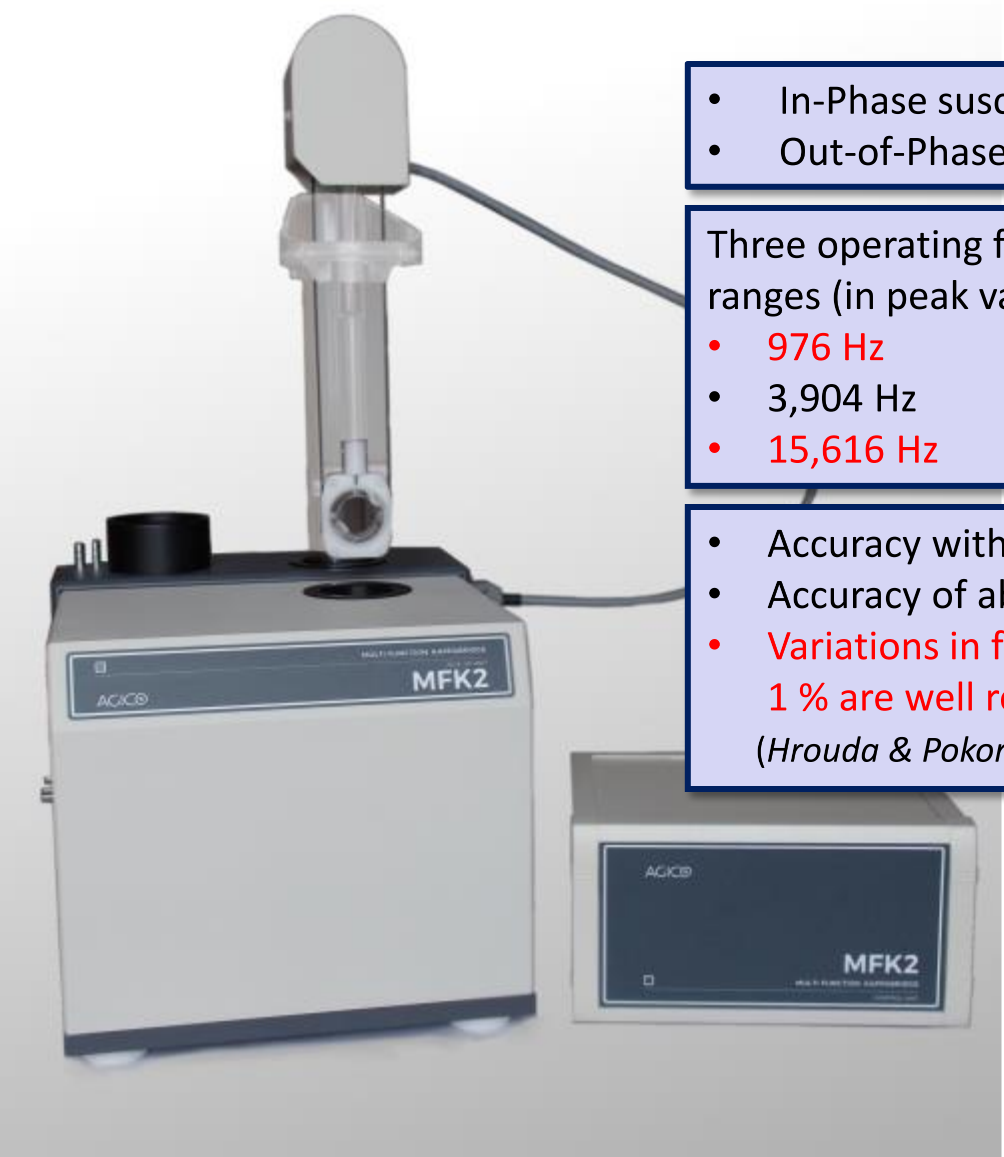
Physical Mechanisms of Out-of-Phase Response

1. Viscous relaxation
2. Electrical eddy currents (induced by AC field in conductive materials)
3. Weak field hysteresis (non-linear and irreversible dependence of M on H)

The mechanisms (1), (2) result in **frequency dependence** of both **In-Phase** and **Out-of-Phase** responses, the mechanism (3) yields signal that is frequency independent, but **amplitude dependent**.

Jackson, 2003-2004, IRMQ

MFK2 Kappabridge



Depends on:
- Absolute value of susceptibility
- Time & Temperature

- In-Phase susceptibility
- Out-of-Phase susceptibility (relative value)

Three operating frequencies and magnetizing respective field ranges (in peak values)

- 976 Hz (~1 kHz) 2 - 700 A/m
- 3,904 Hz (~4 kHz) 2 - 350 A/m
- 15,616 Hz (~16 kHz) 2 - 200 A/m

- Accuracy within one range ±0.1 %
- Accuracy of absolute calibration ±3.0 %
- Variations in frequency-dependent susceptibility in the order of 1 % are well reproducible

(*Hrouda & Pokorny 2011, Stud. Geoph. Geod.*)

LDA5/PAM1 Magnetizer & JR-6(A) Magnetometer

Specifications

LDA5

Specimen shape: cube: 20x20x20 mm
cylinder: 25.4 mm diameter
22 mm height

AF Demagnetizing Field: 1 to 200 mT

Power requirements: 230 V / 50 Hz, 400 VA
(optionally 120 V / 60 Hz)

Dimensions, Mass:

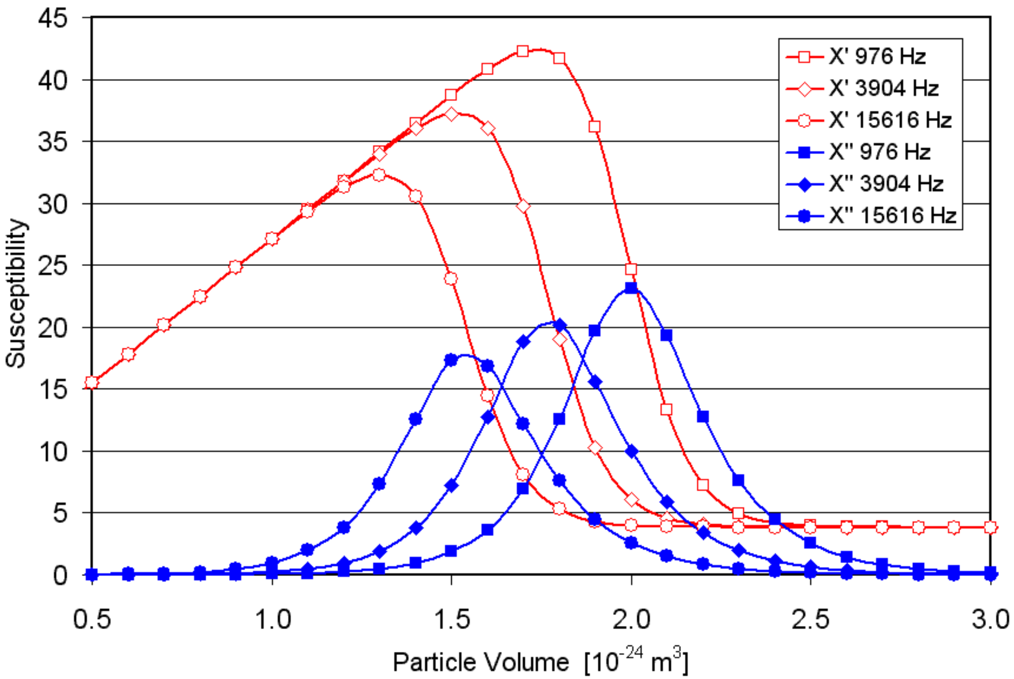
Specimen Unit: 110 x 39 x 46 cm, 95 kg
Electronic Unit: 47 x 38 x 17 cm, 30 kg

PAM1

Anhysteretic Magnetizer
Direct Magnetizing Field: 0 to 500 μT

Direct field: 0 to 20 mT
Length of Pulses: 10 ms to 10 s

- Both instruments controlled from one computer
- Timer starts when magnetization pulse terminates
- Repeated measurement of viscous decay of IRM



$\tan\delta = \chi''/\chi'$

...for population of grains with a wide distribution of relaxation times (Neél 1949)

$$\frac{\partial \chi'}{\partial \ln f_m} = -\frac{2}{\pi}\chi''$$

Frequency-dependent susceptibility

$X_{FD} = 100 \times (\chi'_{LF} - \chi'_{HF}) / \chi'_{LF}$ [%]

$$X_{OD} = \frac{200 \times (\ln f_{mHF} - \ln f_{mLF})}{\pi} \tan\delta$$

Dearing et al., 1996, GJI

Normalized Frequency-dependent susceptibility

$X_{FN} = X_{FD} / (\ln f_{mHF} - \ln f_{mLF})$ [%]

$$X_{ON} = \frac{200}{\pi} \tan\delta$$

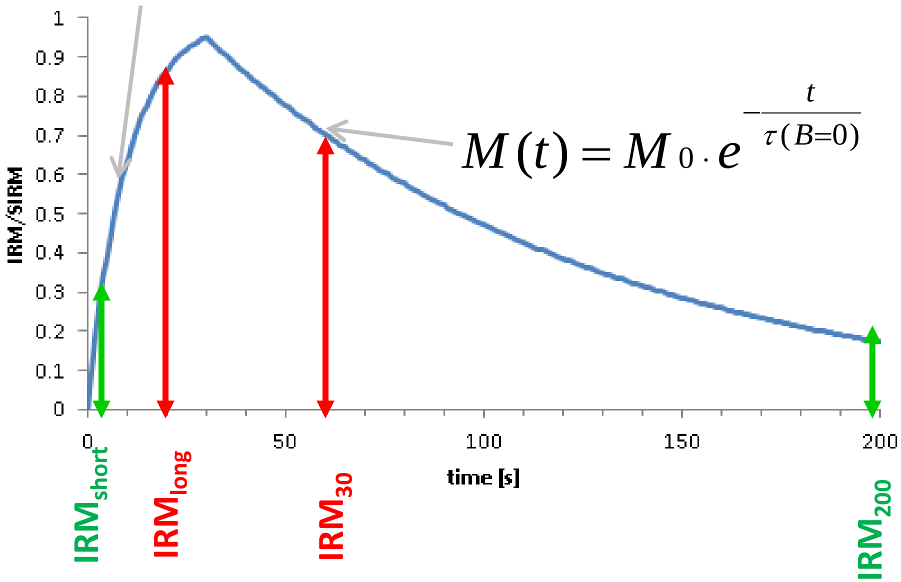
LF → 976 Hz (~1 kHz) @ 200 A/m
HF → 15,616 Hz (~16 kHz) @ 200 A/m

Hrouda, 2011, GJI

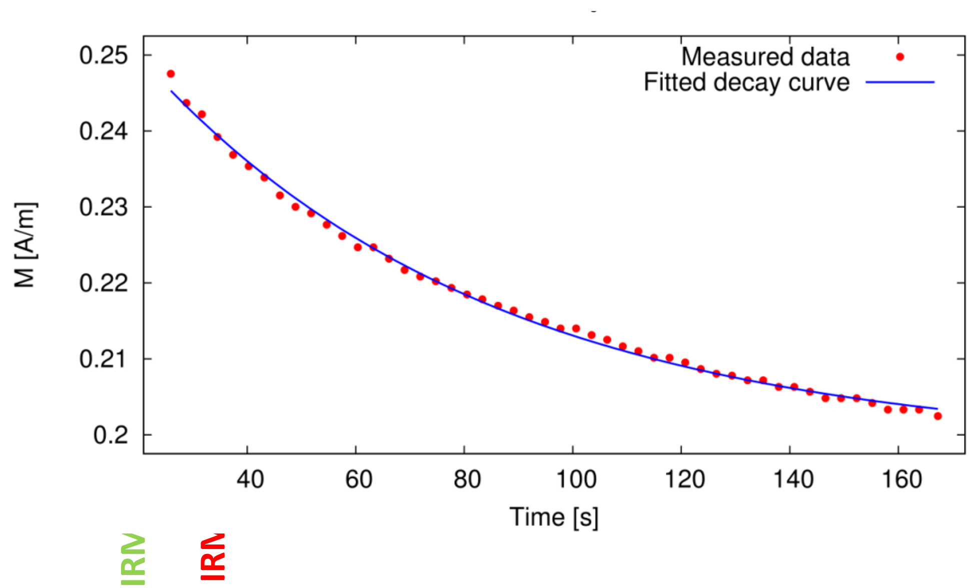
Hrouda et al., 2013, GJI

Viscous behavior

$$M(t) = M_{eq}(1 - e^{-\frac{t}{\tau(B=Bext)}})$$



Non-viscous behavior



Viscous Acquisition

$M_{VA} = 100 \times (IRM_{long} - IRM_{short}) / IRM_{long}$ [%]

Worm, 1999, GRL
Machac et al., 2007, GJI

Viscous Decay

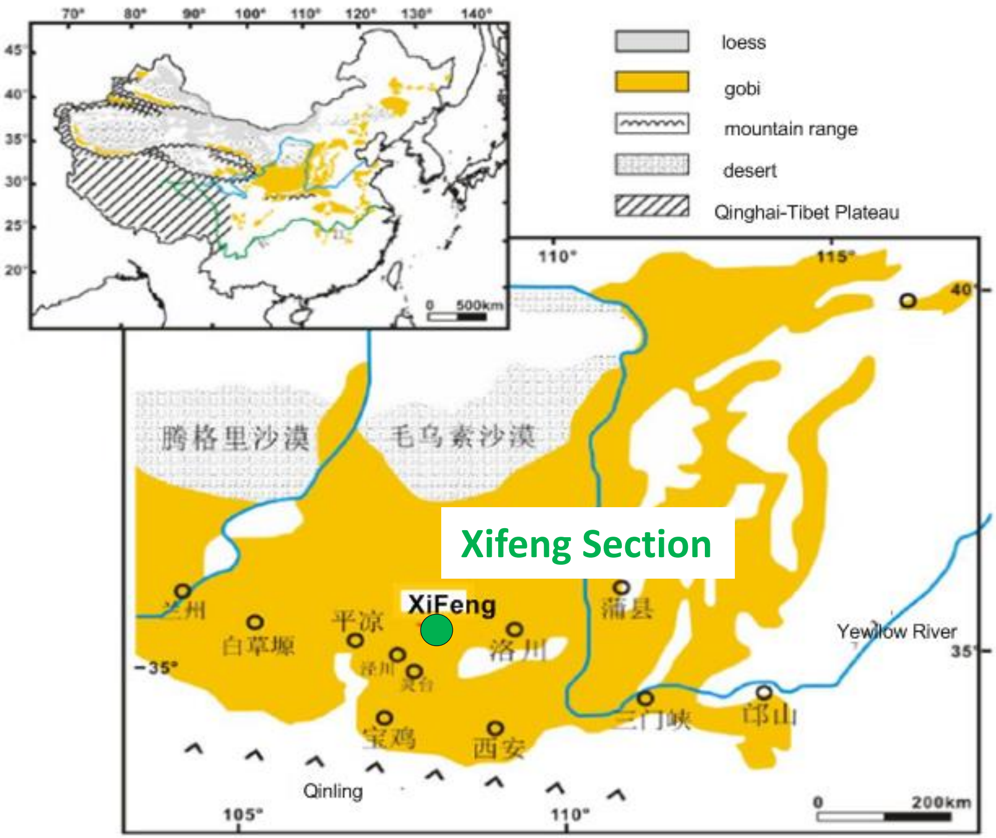
$M_{VD} = 100 \times (IRM_{30} - IRM_{200}) / IRM_{30}$ [%]

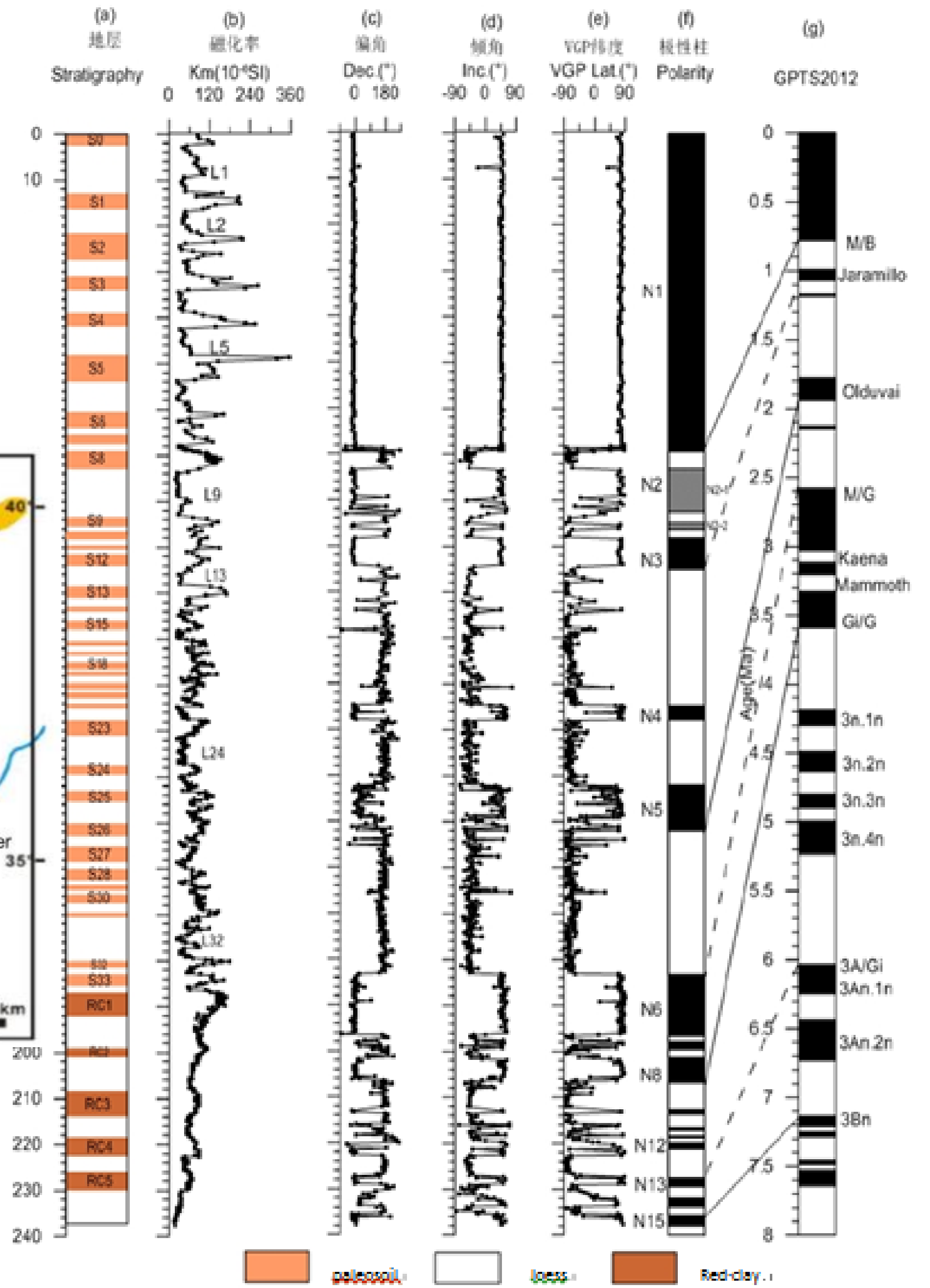
Curve Fitting

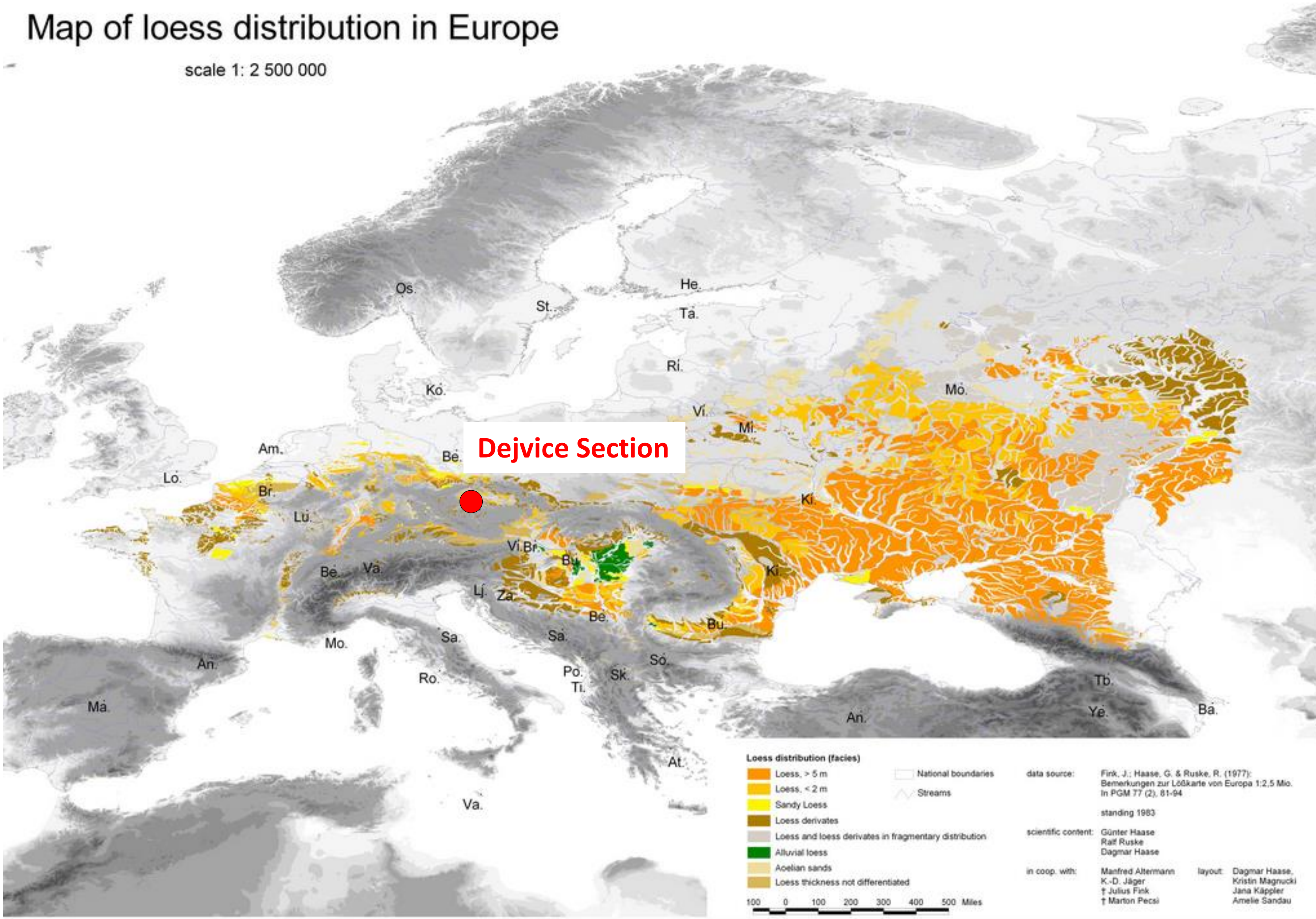
$$M(t) = M_{nv} + M_{vs} \cdot e^{-\frac{t}{\tau(B=0)}}$$

→ $M_{vs} / M_{tot} = 100 \times M_{vs} / (M_{vs} + M_{nv})$ [%]

50 pilot specimens

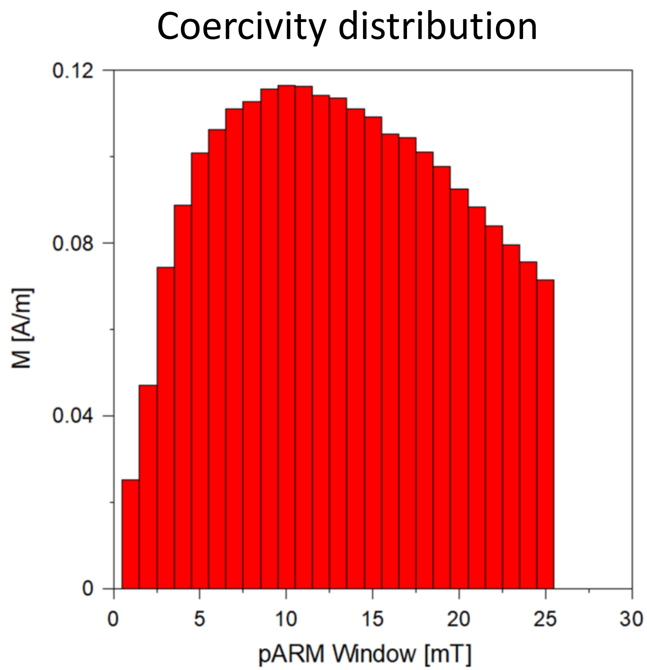




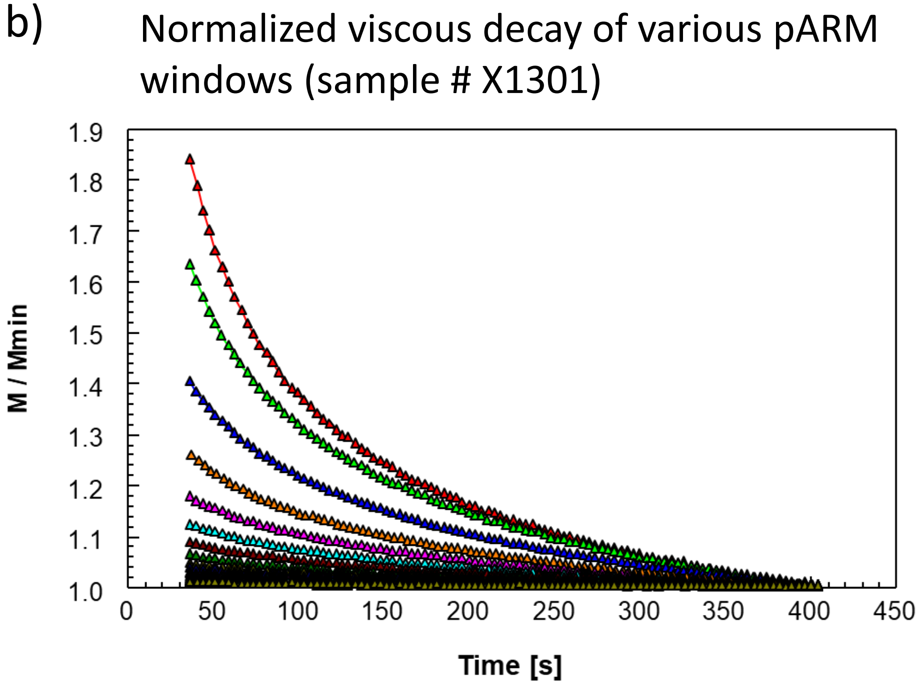

Map of loess distribution in Europe
scale 1: 2 500 000
Dejvice Section
Os.
St.
He.
Ta.
Ri.
Ko.
Vi.
Mi.
Mo.
Am.
Lo.
Be.
Br.
Lu.
Ki.
Vi.Br.
Bu.
Be.
Va.
Lj.
Za.
Ki.
Be.
Bu.
Mo.
Sa.
Sa.
An.
Ro.
Po.
Ti.
Sk.
So.
Tb.
Ma.
An.
Ye.
Ba.
At.
Va.
Loess distribution (facies)
Loess, > 5 m
Loess, < 2 m
Sandy Loess
Loess derivates
Loess and loess derivates in fragmentary distribution
Alluvial loess
Aoelian sands
Loess thickness not differentiated
National boundaries
Streams
100 0 100 200 300 400 500 Miles
data source:
Fink, J.; Haase, G. & Ruske, R. (1977): Bemerkungen zur Lößkarte von Europa 1:2,5 Mio. In PGM 77 (2), 81-94
standing 1983
scientific content:
Günter Haase
Ralf Ruske
Dagmar Haase
in coop. with:
Manfred Altermann
K.-D. Jäger
† Julius Fink
† Marton Pecsi
layout:
Dagmar Haase,
Kristin Magnucki
Jana Käppler
Amelie Sandau

ca. 400 specimens

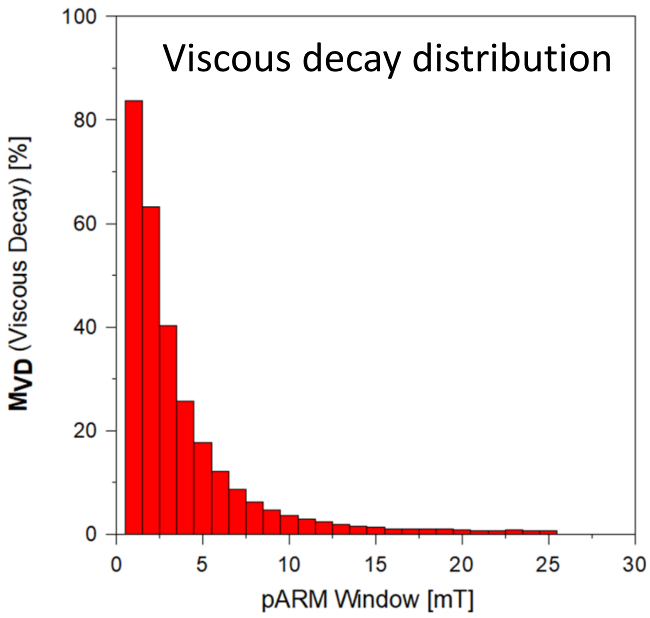
a)


Coercivity distribution
0.12
0.08
0.04
0
M [A/m]
0
5
10
15
20
25
30
pARM Window [mT]

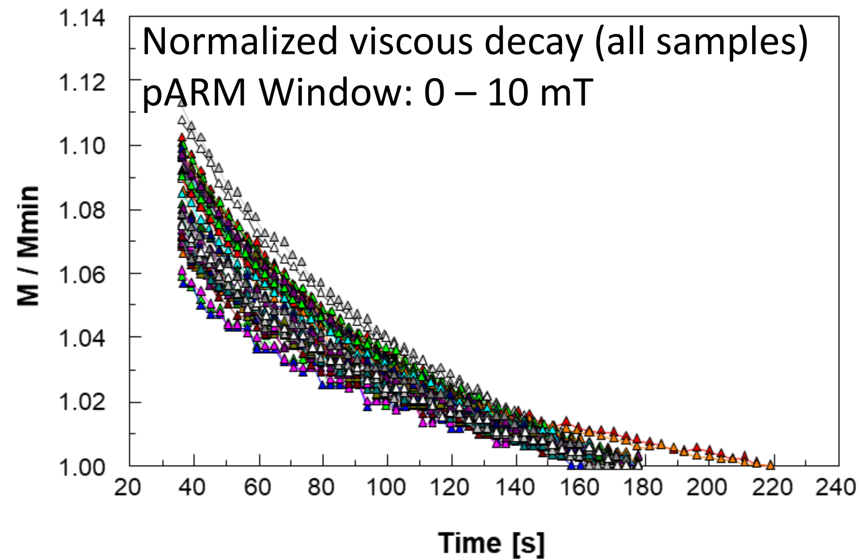
b)

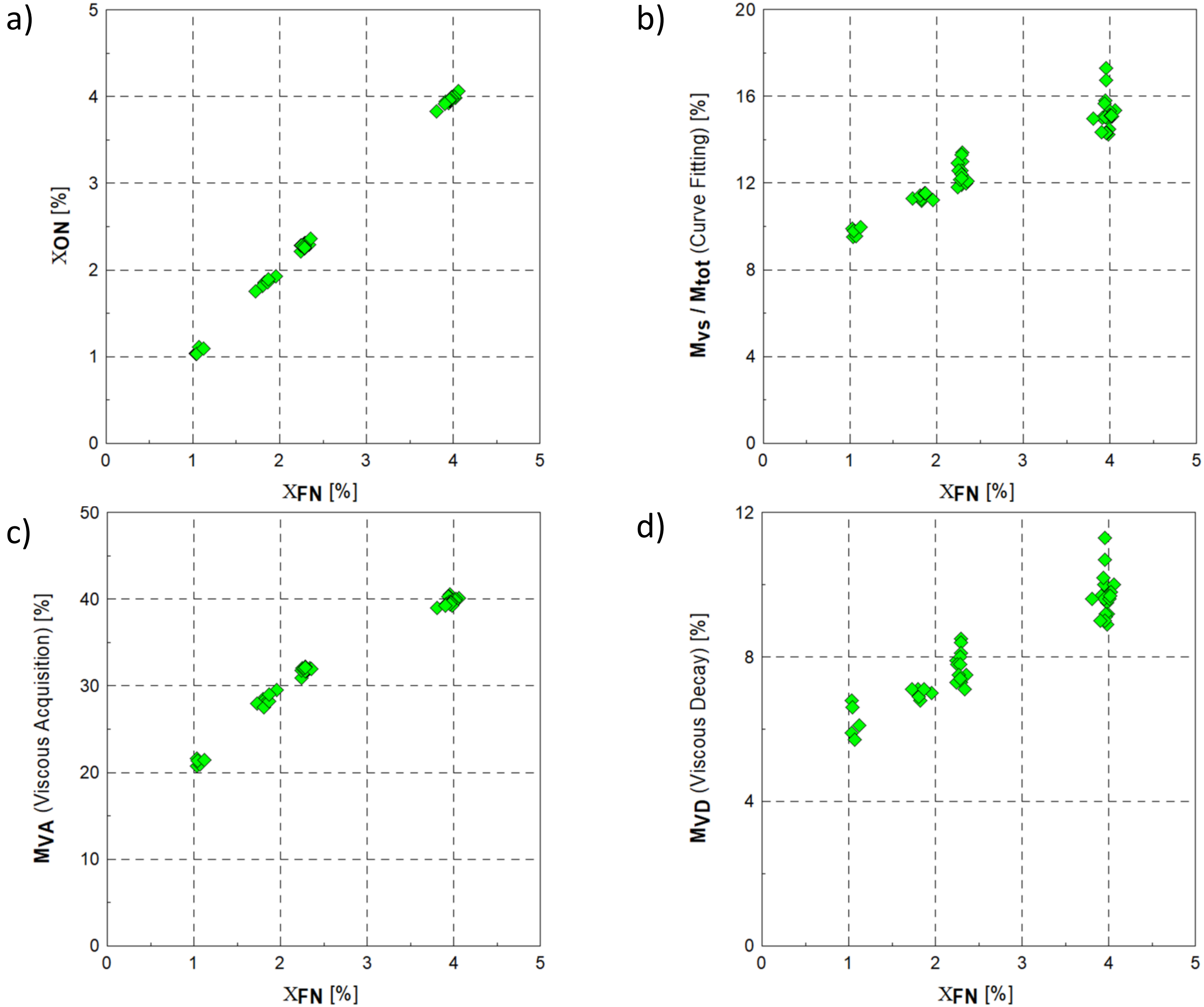

Normalized viscous decay of various pARM windows (sample # X1301)
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
M / Mmin
0
50
100
150
200
250
300
350
400
450
Time [s]

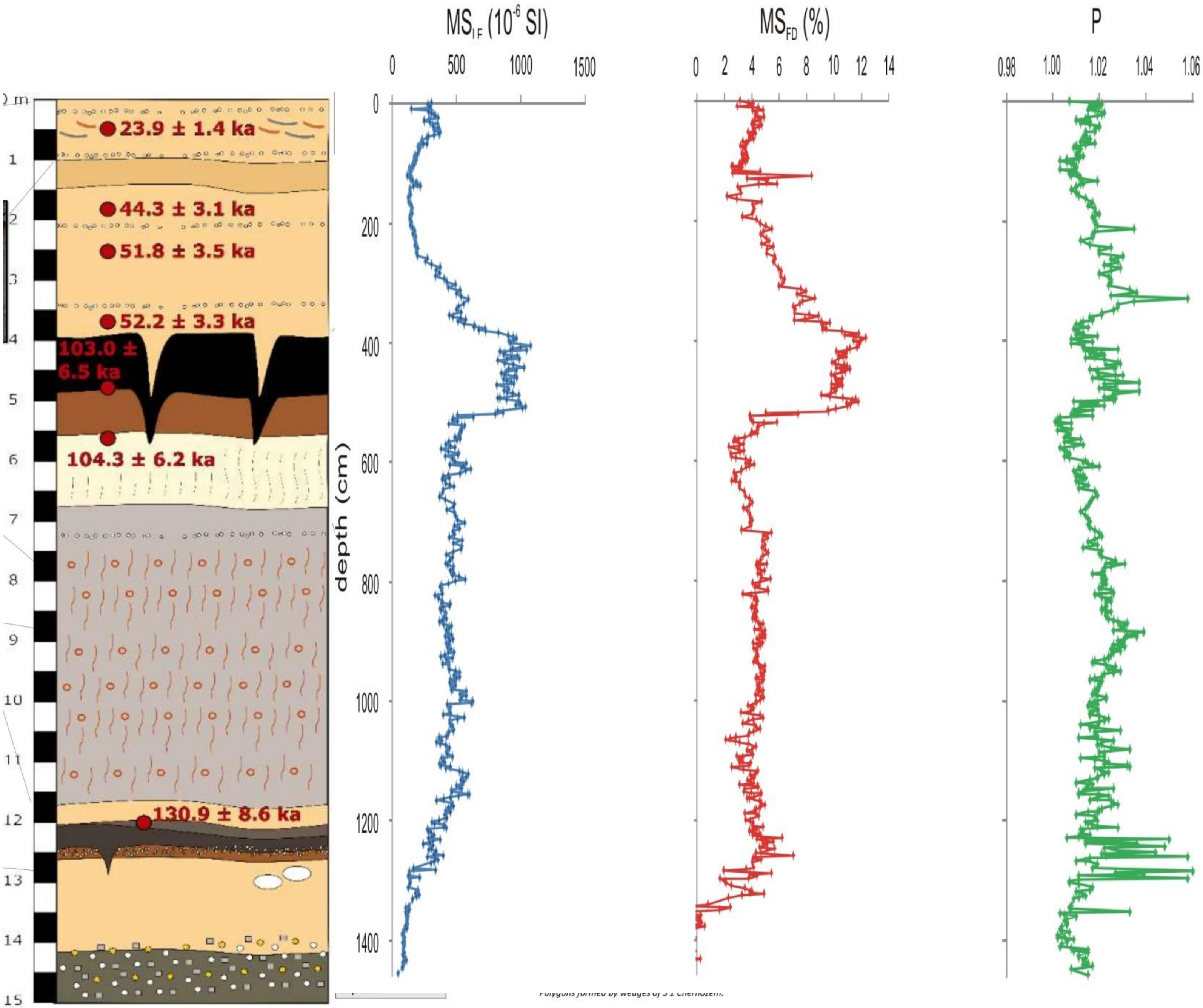
c)

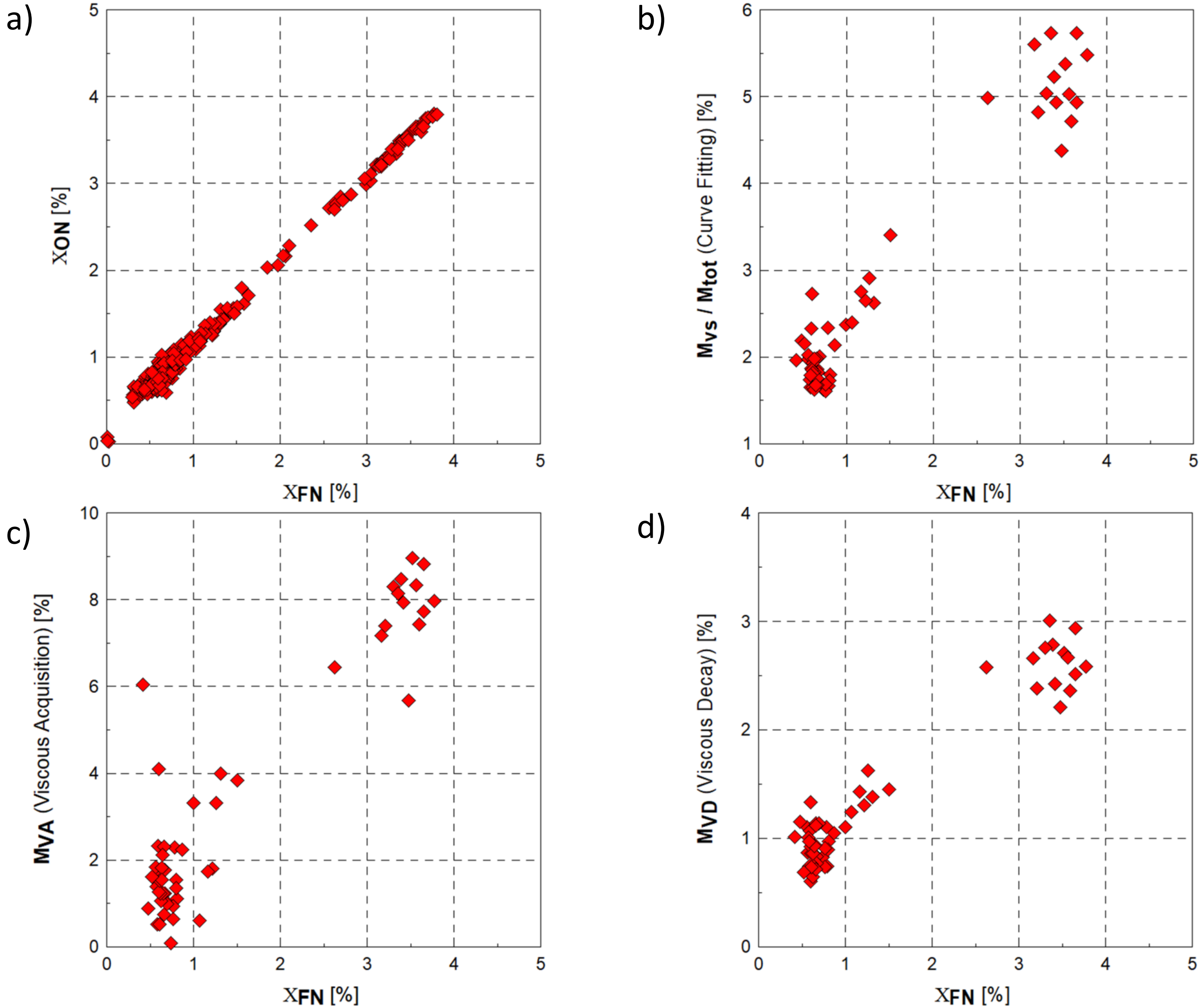

Viscous decay distribution
100
80
60
40
20
0
MVD (Viscous Decay) [%]
0
5
10
15
20
25
30
pARM Window [mT]

d)

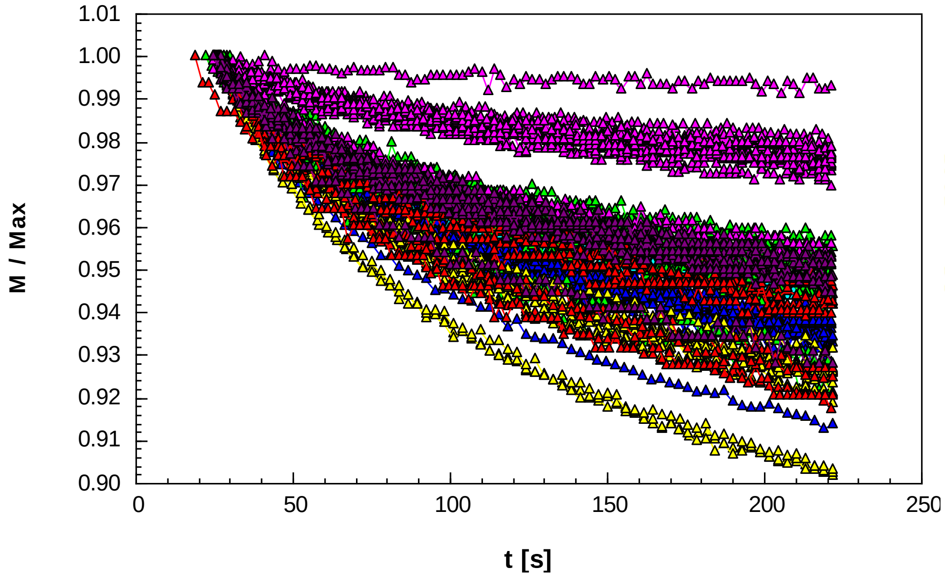

Normalized viscous decay (all samples)
pARM Window: 0 – 10 mT
1.14
1.12
1.10
1.08
1.06
1.04
1.02
1.00
M / Mmin
20
40
60
80
100
120
140
160
180
200
220
240
Time [s]

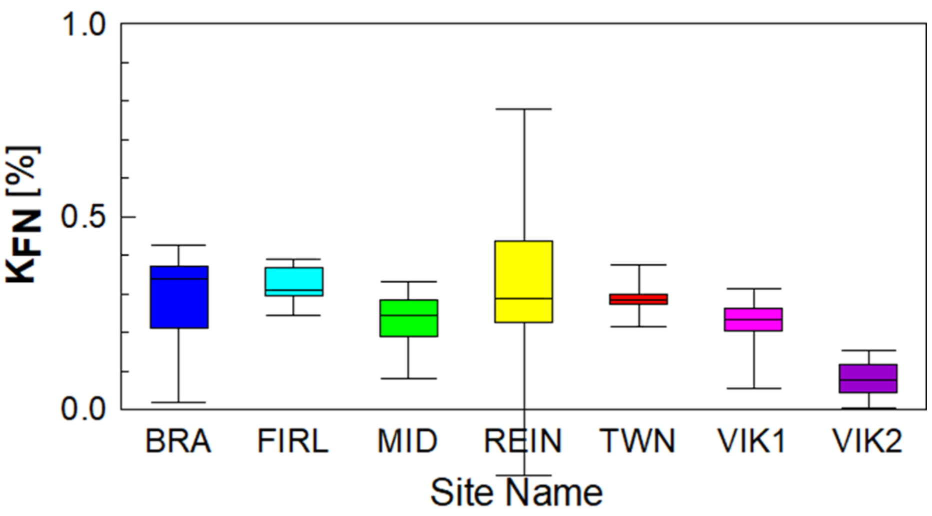

a)
b)
c)
d)
XON [%]
XFN [%]
MVS / Mtot (Curve Fitting) [%]
MVA (Viscous Acquisition) [%]
MVD (Viscous Decay) [%]
0
1
2
3
4
5
4
8
12
16
20
10
20
30
40
50


23.9 ± 1.4 ka
44.3 ± 3.1 ka
51.8 ± 3.5 ka
52.2 ± 3.3 ka
103.0 ± 6.5 ka
104.3 ± 6.2 ka
130.9 ± 8.6 ka
MS$_{LF}$ (10^{-6} SI)
MS$_{FD}$ (%)
P
depth (cm)


a)
XON [%]
XFN [%]
b)
MVS / Mtot (Curve Fitting) [%]
XFN [%]
c)
MVA (Viscous Acquisition) [%]
XFN [%]
d)
MVD (Viscous Decay) [%]
XFN [%]

1. X_{ON} parameter (derived from phase angle) **correlates extremely well** with the “classical” frequency-dependent susceptibility
2. This parameter proved to be a **very efficient tool for magnetic granulometry** for loess/paleosols because each specimen is measured only **one time** which reduces time and errors
3. Parameters based on viscous acquisition/decay **correlate reasonably well** with “classical” frequency-dependent susceptibility because both methods reflect the **relative amount of the ultra-fine particles** close to the SP/SSD threshold
4. These parameters are proposed as **alternative tools for magnetic granulometry** for [not only] loess/paleosols when susceptibility signal is dominated by dia-, para-, or frequency-independent ferromagnetic fractions





4. These parameters are proposed as **alternative tools for magnetic granulometry** for [not only] loess/paleosols when susceptibility signal is dominated by dia-, para-, or frequency-independent ferromagnetic fractions

Thanks for your attention!