Dynamics of the earth magnetic field in the 10 –75 kyr period comprising the Laschamp and Mono Lake excursions: New results from the French Chaîne des Puys in a global perspective

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Questions:

1. What is a geomagnetic excursion?

   - A deviation of the VGPs by more than 45° from the average pole [Merrill and McFadden, 1994]
   - A deviation of VGPs away from the normal secular variation [Vandamme, 1994]
   - Paleointensity low [e.g., Guyodo and Valet, 1999]
   - Directional deviations associated with paleointensity minima

2. Are excursions a global or regional feature of the geomagnetic field?

3. Are they rare of frequent?

4. Do they show characteristic field behavior that enable unique identification of one excursion?

5. Are they related to geomagnetic secular variation or are they aborted polarity reversals?

Paper goals:

- New paleomagnetic results from the French Massif central;

- Determination of the characteristics of the geomagnetic field, both directional and intensity, during geomagnetic excursions;

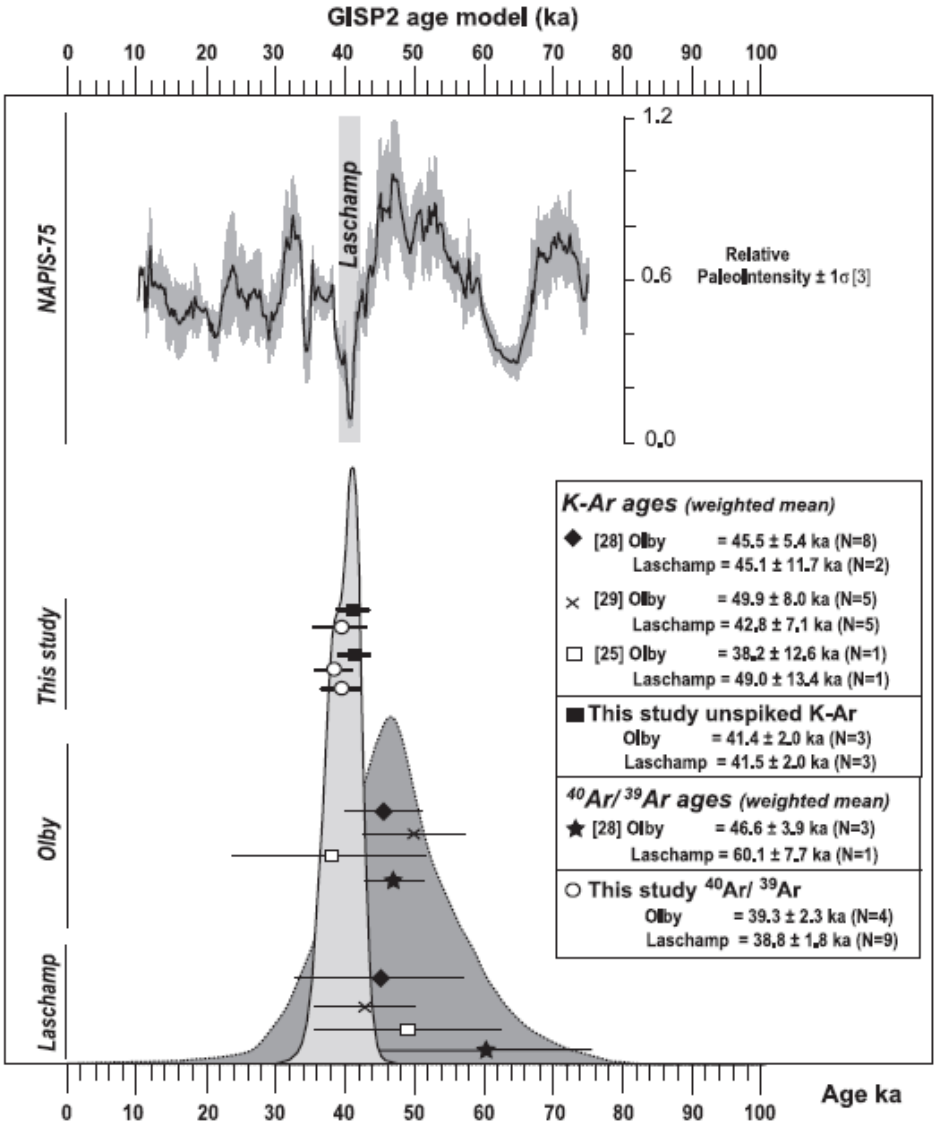
- High precision age determination;

- Comparison of volcanic data with sedimentary and cosmogenic isotopes continuous records, during a time interval when the geomagnetic field has undergone large variations;

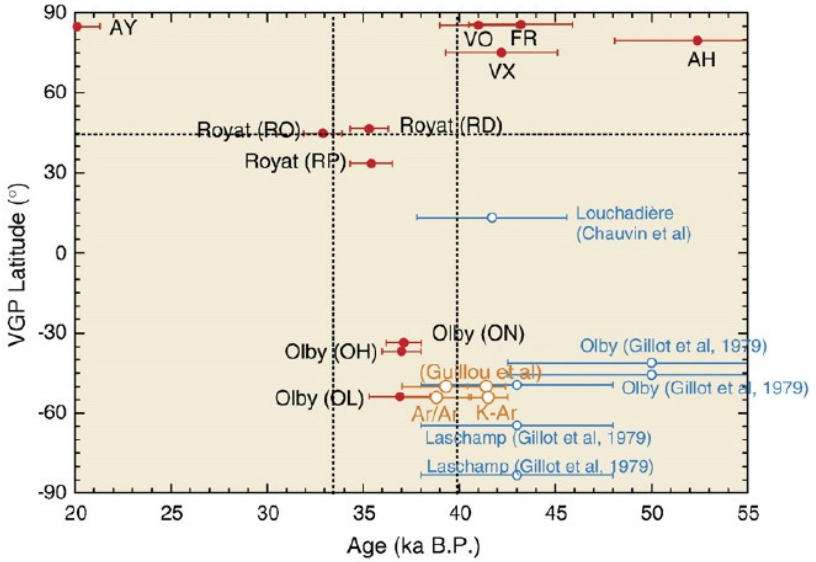
- Understanding the origin of the excursions and acquiring a deeper knowledge of the mechanisms of the Earth's dynamo.

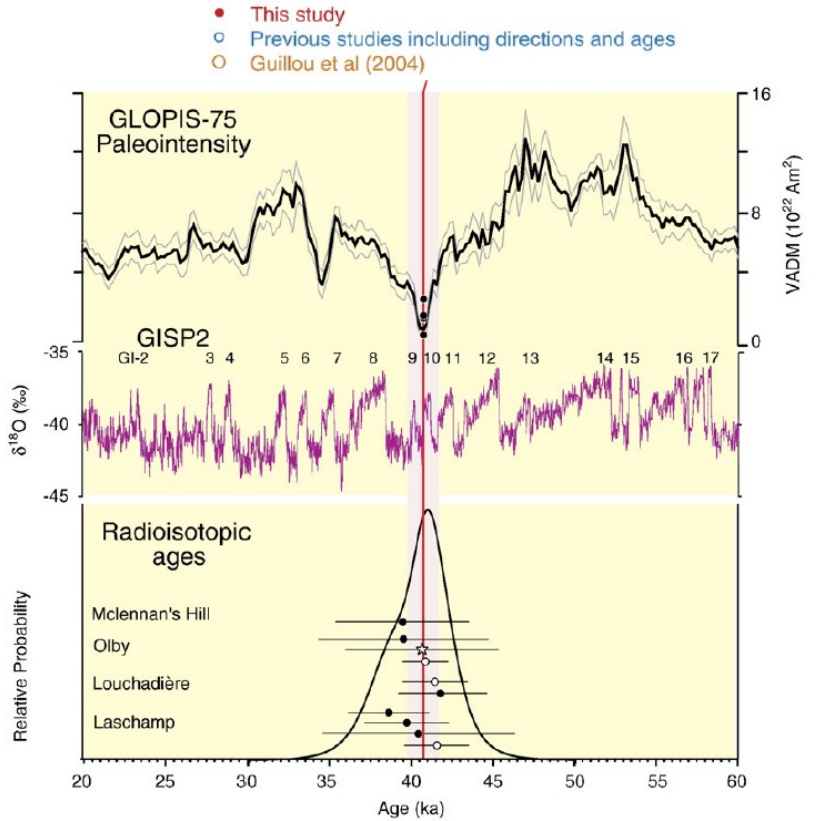
French Massif Central: Previous results

Guillou et al. (2004)



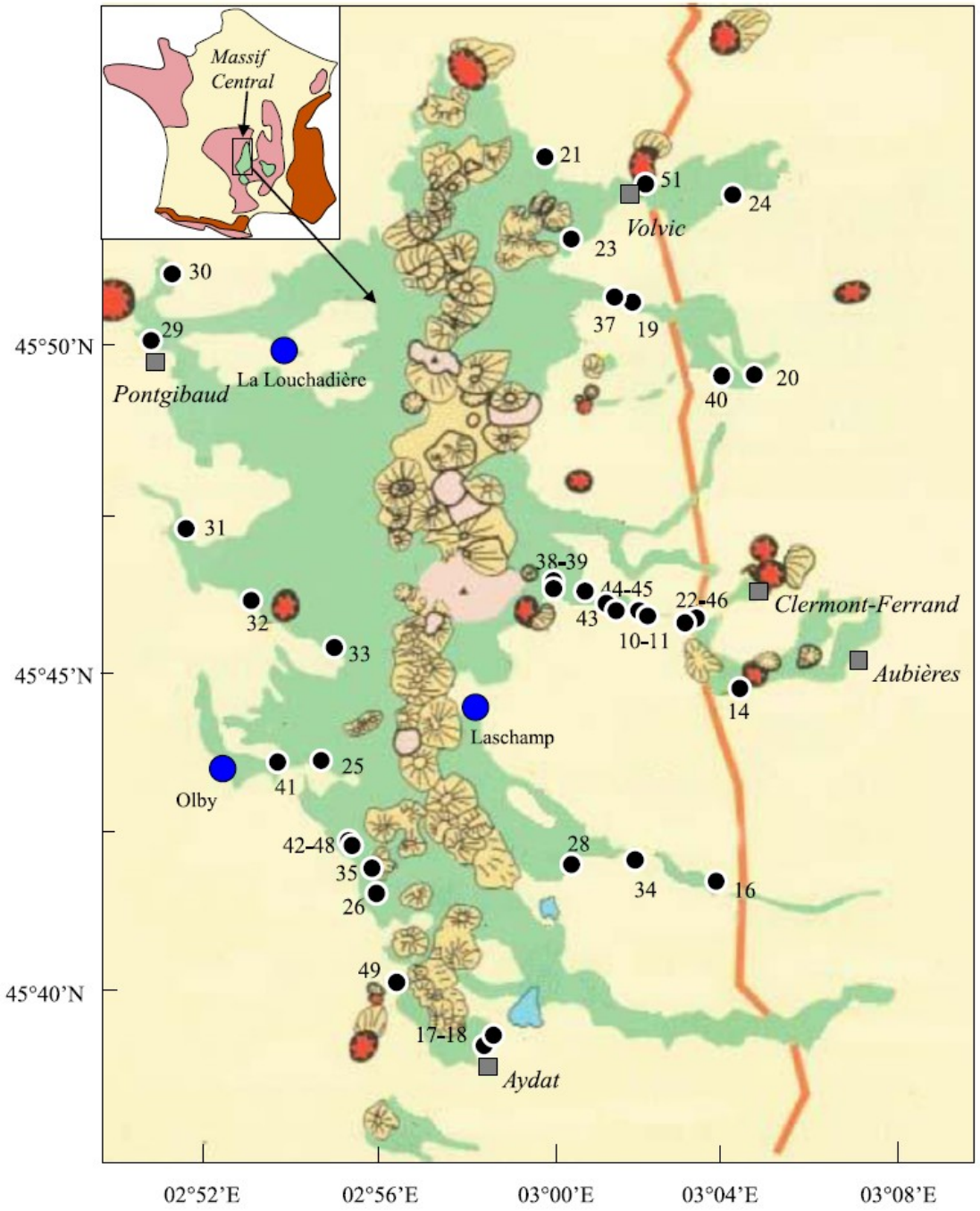
Plenier et al. (2007)





Singer et al. (2009)

Schematic map of the French Massif Central



Sampling:

- 35 sites (black dots) and a total of 334 cores have been collected

- blue dots correspond to the first lavas on which the Laschamp excursion has been identified;

- for paleomagnetic samples: 8 oriented cores (13-15 cm long) drilled at each site;

- At each site, a larger core (20-25 cm long) was drilled for radiometric dating.

Radiometric dating

- Unspiked K/Ar method
- $^{40}Ar/^{39}Ar$ method
- Combined K/Ar and $^{40}Ar/^{39}Ar$
- Thermoluminescence (when the Ar content is too low)

Table 2
K/Ar and $^{40}Ar/^{39}Ar$ age determinations on lava flows from Massif Central.

Lava flow	$^{40}Ar/^{39}Ar$ plateau age $\pm 2\sigma$ (ka)	Unspiked K–Ar age $\pm 2\sigma$ (ka)	Weighted mean (ka)	Final age (ka)
MC10	40.1 ± 4.0	34.8 ± 2.8*		40.1 ± 4.0
MC22	40.9 ± 4.3	41.5 ± 1.4	41.4 ± 1.3	41.4 ± 1.3
Tiretaine "old" flow unit				**41.3 ± 1.3**
MC38	32.0 ± 3.7	35.5 ± 1.3	35.1 ± 1.2	35.1 ± 1.2
MC39		33.2 ± 1.7		33.2 ± 1.7
MC43	33.3 ± 3.9	32.7 ± 1.6	32.8 ± 1.5	32.8 ± 1.5
Tiretaine "young" flow unit				**33.8 ± 1.7**
MC14	39.4 ± 9.7	44.3 ± 2.7	43.9 ± 2.6	43.9 ± 2.6
MC16		28.2 ± 2.2		28.2 ± 2.2
MC17		44.6 ± 3.3		44.6 ± 3.3
MC18	64.0 ± 5.4	68.3 ± 3.3	67.1 ± 2.8	67.1 ± 2.8
MC19		71.6 ± 2.9		71.6 ± 2.9
MC20	18.4 ± 5.4			18.4 ± 5.4
MC21		18.5 ± 3.1		18.5 ± 3.1
MC25	25.0 ± 4.4	24.2 ± 2.1	24.3 ± 1.9	24.3 ± 1.9
MC30	56.9 ± 4.4	65.7 ± 2.5*		56.9 ± 4.4
MC32	34.5 ± 4.0	35.6 ± 1.9	35.4 ± 1.7	35.4 ± 1.7
MC33	41.2 ± 4.0	40.1 ± 2.1	40.3 ± 1.9	40.3 ± 1.9
MC34	34.8 ± 5.8	35.4 ± 1.8	35.3 ± 1.7	35.3 ± 1.7
MC40	43.9 ± 5.8	41.1 ± 1.2	41.2 ± 1.2	41.2 ± 1.2
MC41	41.5 ± 1.8	42.9 ± 1.1	42.5 ± 1.0	42.5 ± 1.0
MC49		39.0 ± 1.5		39.0 ± 1.5
MC51	42.9 ± 9.4	42.3 ± 1.8	42.3 ± 1.8	42.3 ± 1.8

* The values reported with ∗ are not taken into account (see text).

Magnetic mineralogy

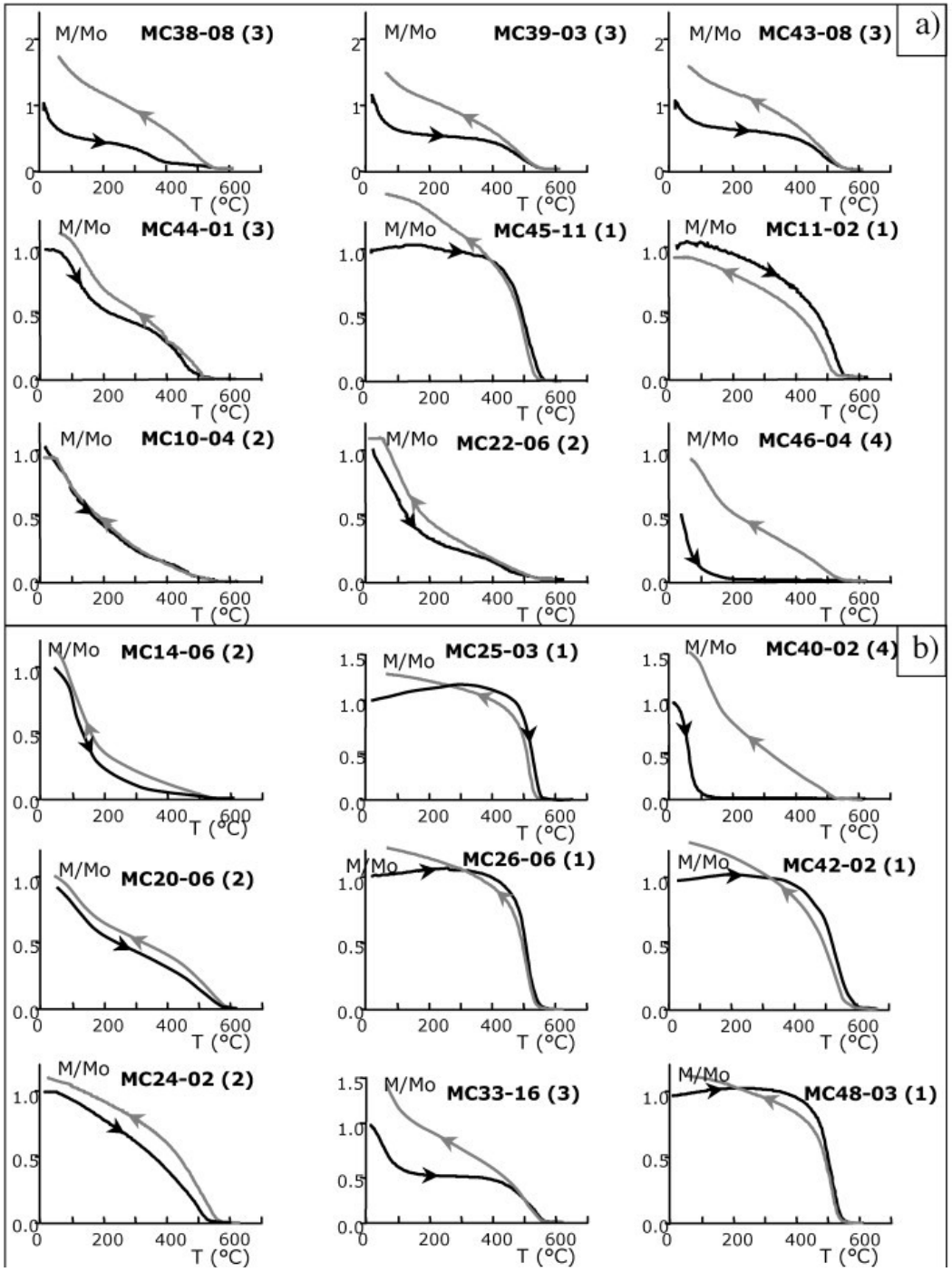
Type of thermomagnetic curve:

(1) low Ti-content magnetite, complete removal at 560–580°C

(2) Progressive decrease of the magnetization between RT and 580°C

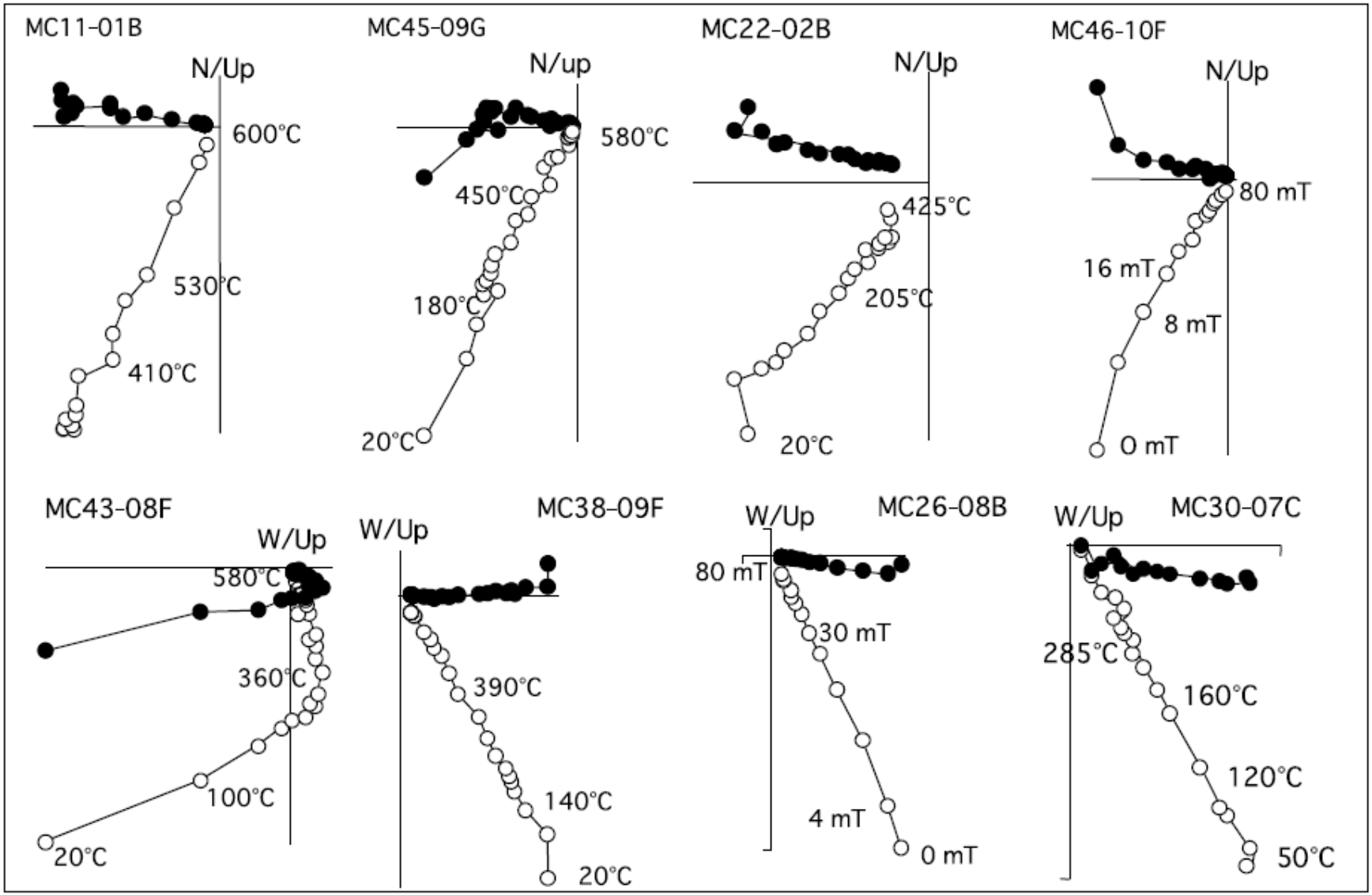
(3) Two-step decrease. The first one occurs below 100°C and the second one between 400°C and 580°C.

(4) Magnetization is removed at very low temperature (100–200°C).



Paleomagnetic directions (ChRM)

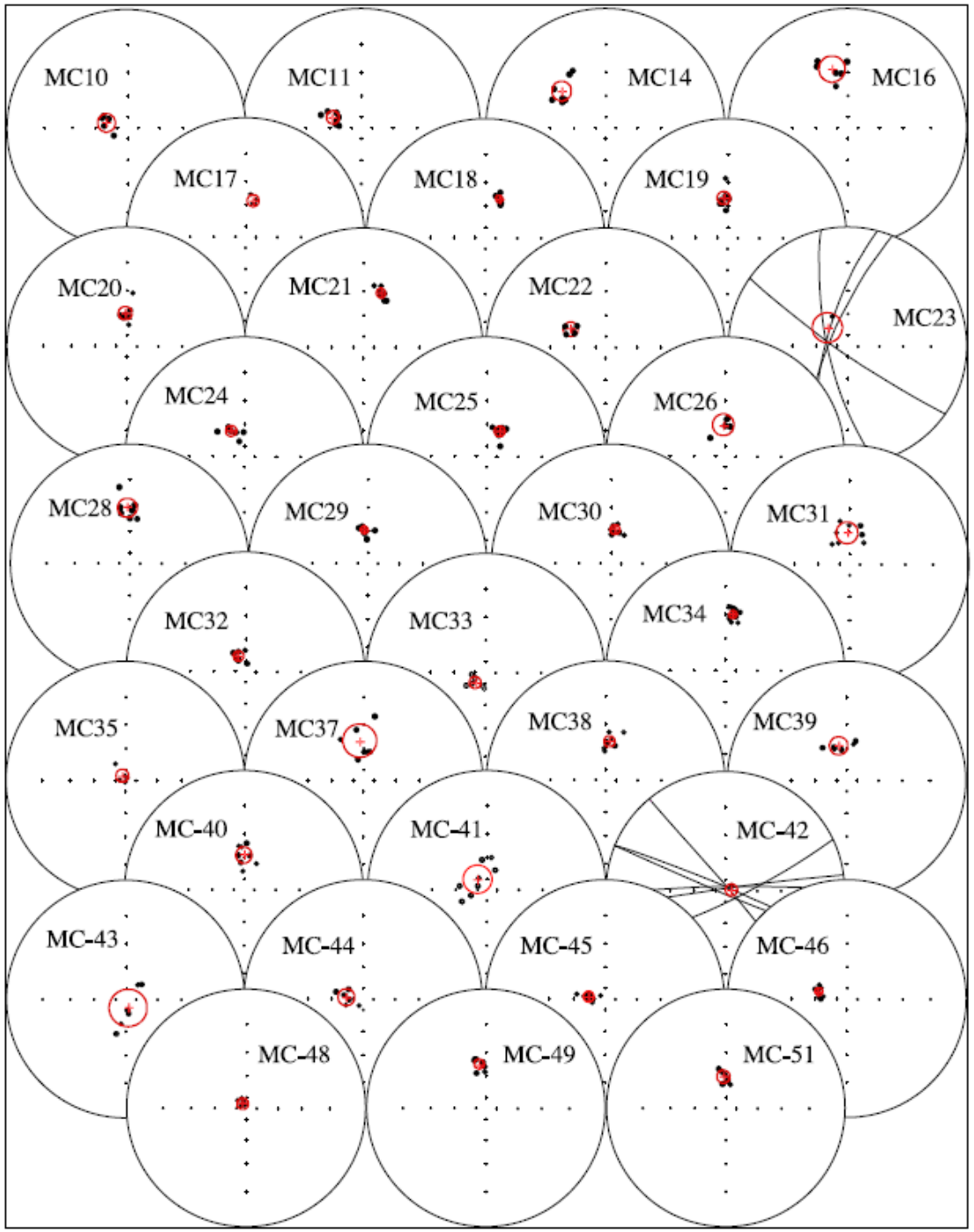
1) Thermal demagnetisation (70% of the samples)
2) AF demagnetisation using AF from 0 to 80 mT with 4 mT step (30%)



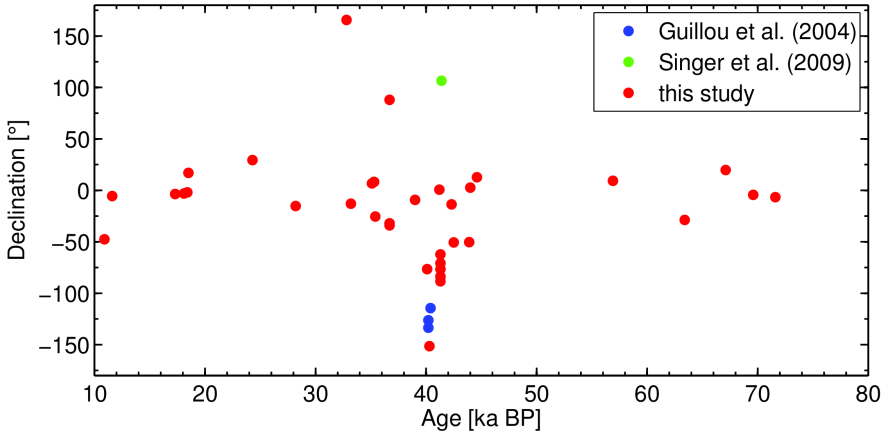
Mean directions

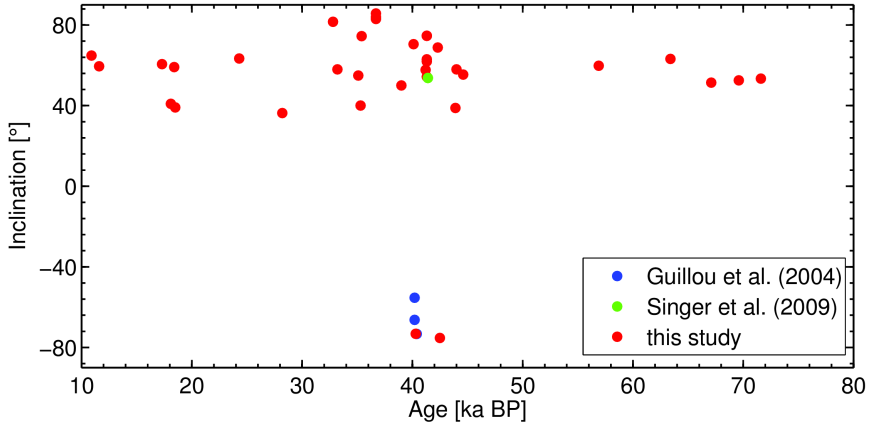
- A minimum of 5 stable directions (and up to 17) was used per side to calculate the mean directions;

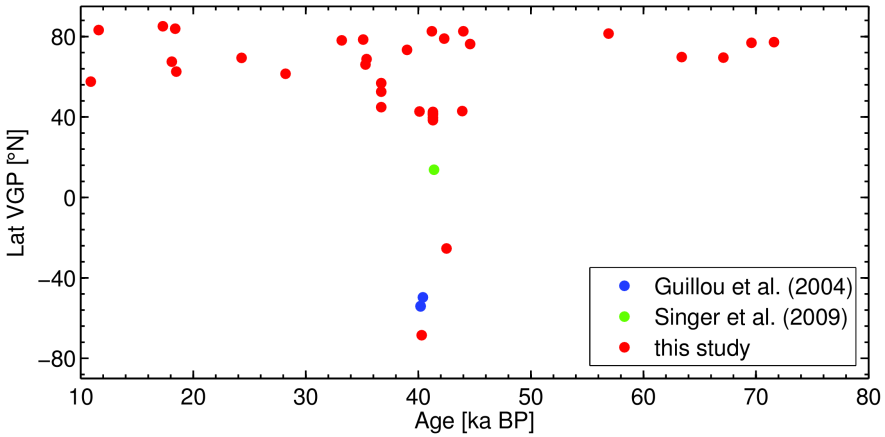
- Except for 4 sites, the site mean directions are defined with α_{95} smaller than 10º.



Directional results







Paleointensity determinations

- Thellier and Thellier (1959) procedure

- PICRIT-03 selection criteria by Kissel and Laj (2004):

(i) Demagnetization diagrams

α <15°(α: angular difference between characteristic remanent directions obtained in zero- and non-zero field experiments).

MAD < 7°(mean angular deviation)

(ii) Individual Arai diagrams

Minimum four points resulting from double heating and three positive pTRM checks

$\beta \leq 0.1$ (β is the standard error/absolute value of the slope of the Arai plot)

$f \geq 0.35$ (f is the fraction of NRM taken into account in the determination)

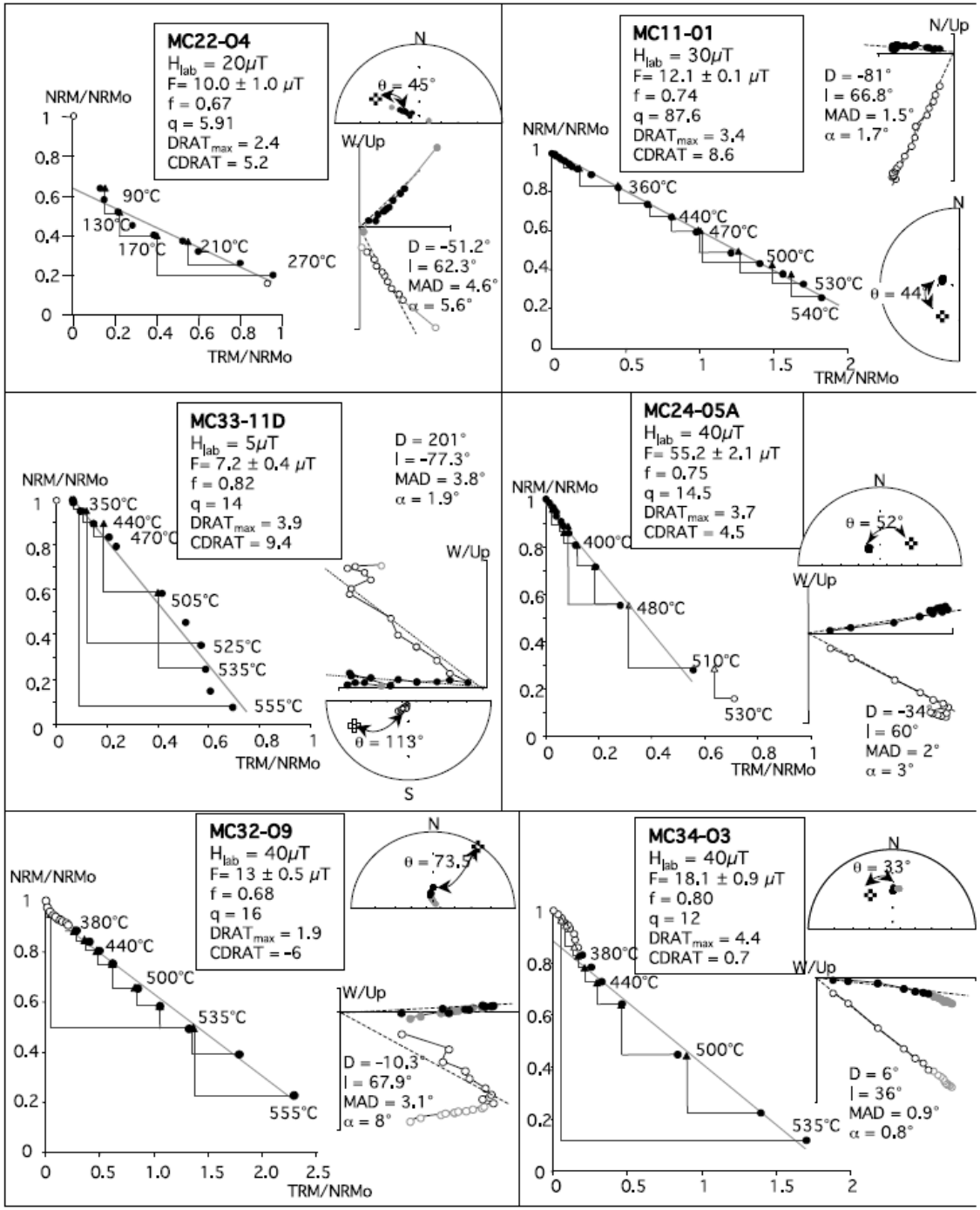
$q \geq 0.2$ ($q = fg/\beta$)

DRAT < 7% (difference ratio)

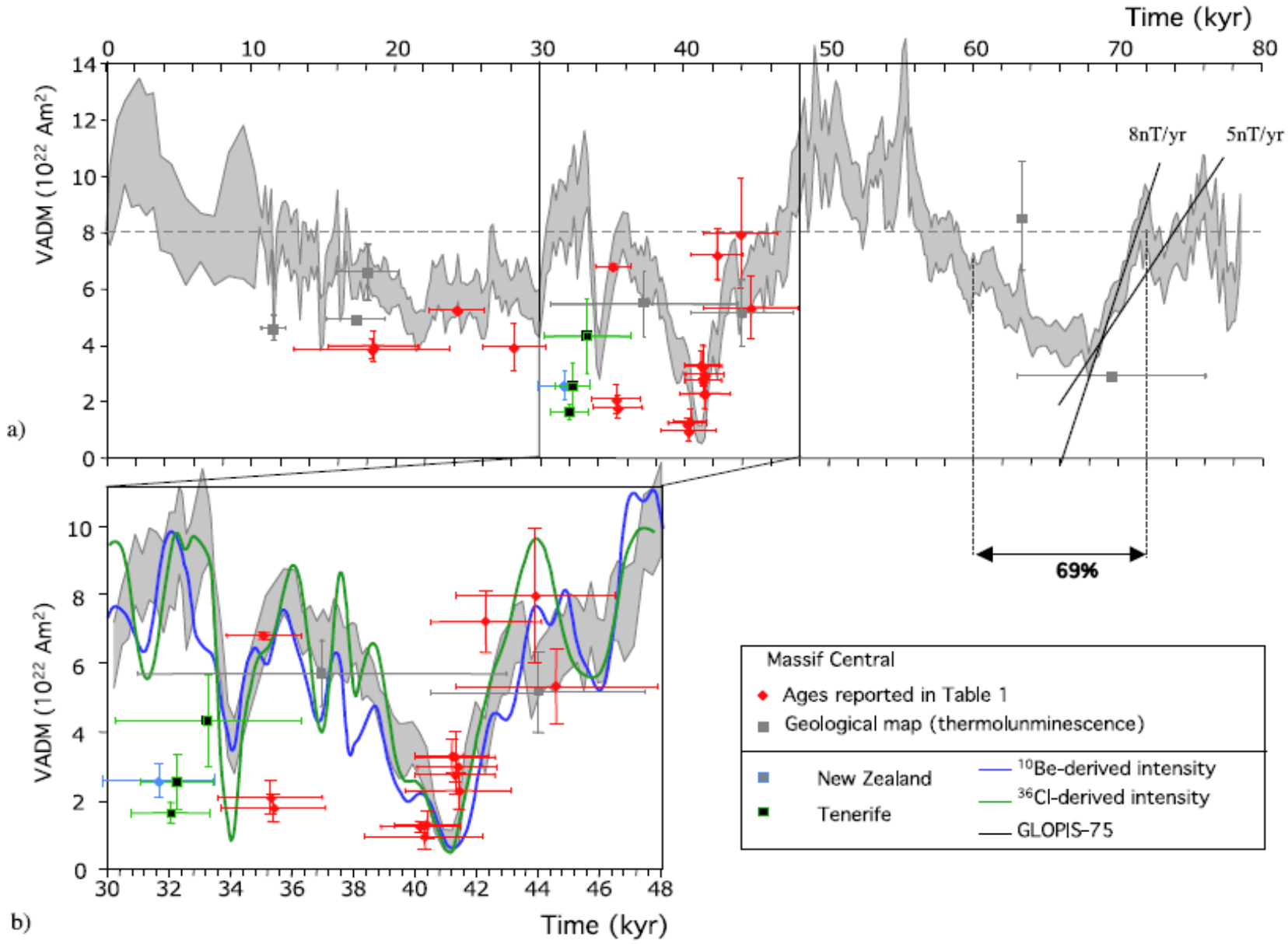
CDRAT < 10% (cumulative DRAT)

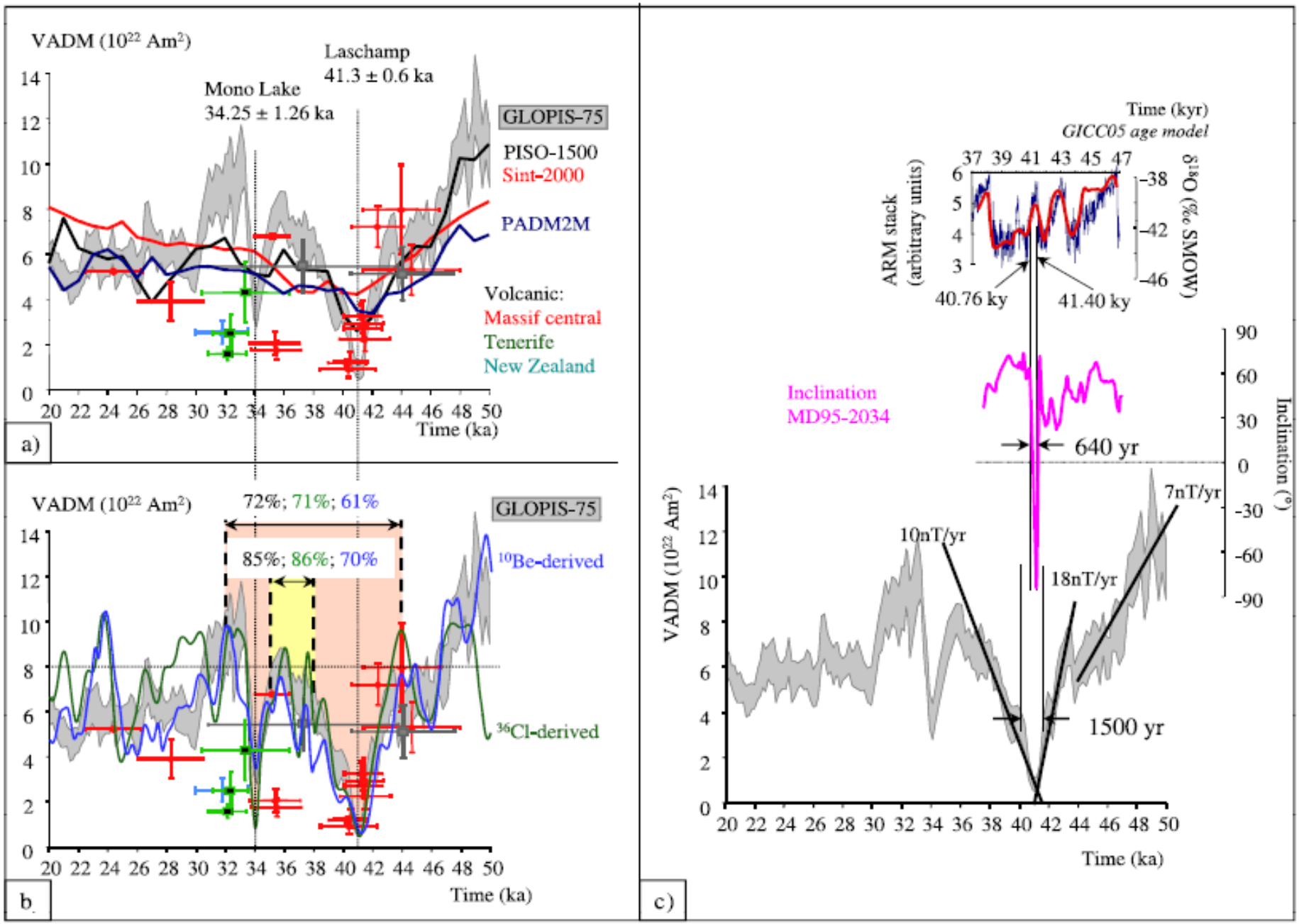
(iii) Within flow average field estimates

σ_B/B < 25% (standard error/mean field)



Results: Paleointensity




VADM (10^{22} Am^2)
Laschamp
41.3 ± 0.6 ka
Mono Lake
34.25 ± 1.26 ka
GLOPIS-75
PISO-1500
Sint-2000
PADM2M
Volcanic:
Massif central
Tenerife
New Zealand
Time (ka)
a)
VADM (10^{22} Am^2)
72%; 71%; 61%
85%; 86%; 70%
GLOPIS-75
^{10}Be-derived
^{36}Cl-derived
Time (ka)
b
Time (kyr)
GICC05 age model
ARM stack
(arbitrary units)
$\delta^{18}O$ (‰ SMOW)
40.76 ky
41.40 ky
Inclination
MD95-2034
640 yr
Inclination (°)
VADM (10^{22} Am^2)
10nT/yr
18nT/yr
7nT/yr
1500 yr
Time (ka)
c)

Conclusions

- New paleomagnetic results (directions and intensity) and coupled K/Ar and $^{40}Ar/^{39}Ar$ analysis of 35 different flows from French Massif Central during the 75 to 10 kyr interval are reported.

- There is a agreement between the new set of absolute volcanic intensities and published sedimentary (GLOPIS-75) and cosmogenic (^{10}Be and ^{36}Cl) records.

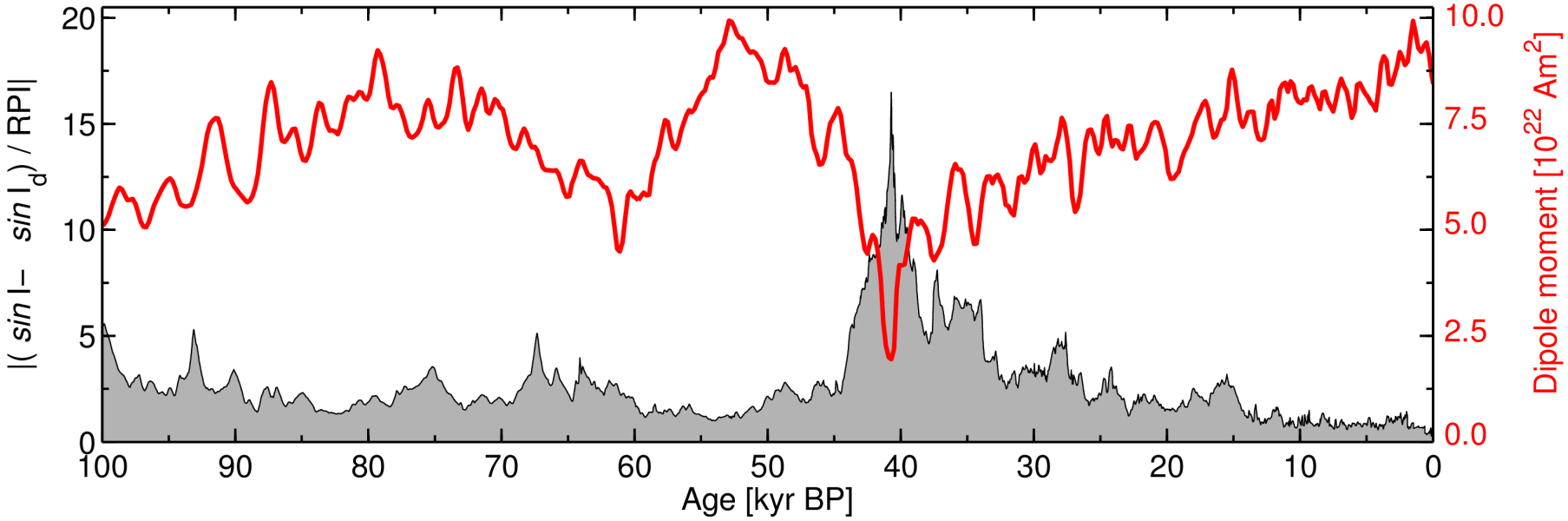
- Age of the Laschamp excursion: 41.3±0.6 ka
  Age of the Mono Lake excursion: 34.2±1.2 ka

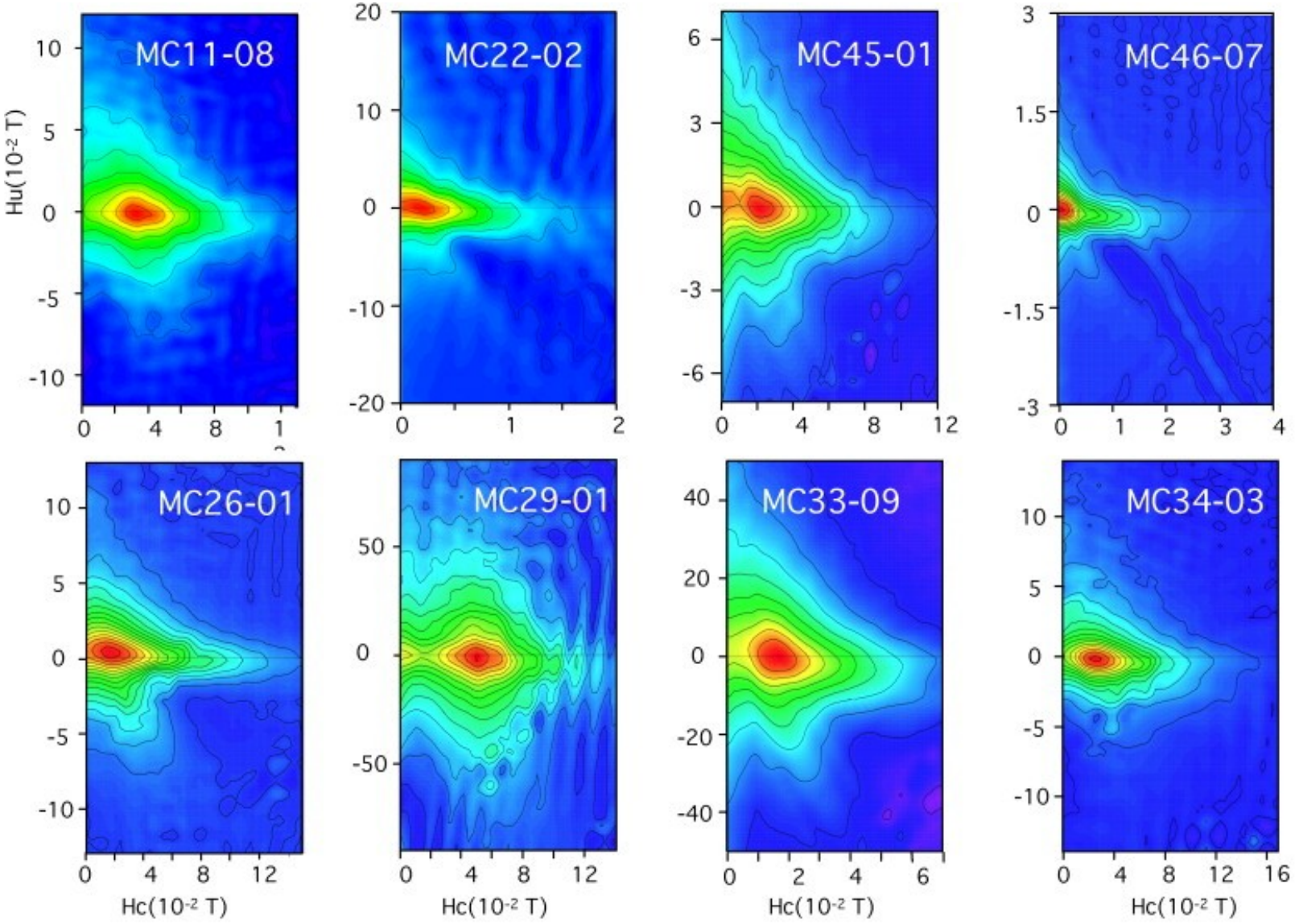
- Duration of the Laschamp excursion: ~1500 yr (a drop of paleointensity) and about 640 yr when the directional change are considered.
  Duration of the intensity low of the Mono Lake excursion is 600–700 yr.

- Rate of decrease of the field intensity during these excursions attains 18 nT/yr for the Laschamp and 33 nT/yr for the Mono Lake excursion.

- Suggestion for changing the name of the Mono Lake excursion to Auckland excursion.

Global geomagnetic field reconstruction for the past 100 ka





Suppl. Fig. 3: Examples of FORC diagrams obtained from the lava of the Chaîne des Puys, Massif Central in France. The diagrams were constructed using FORCinel software (Harrison and Feinberg, 2008), with a smoothing factor of 4 and field increments of 0.6 to 1.8 mT.

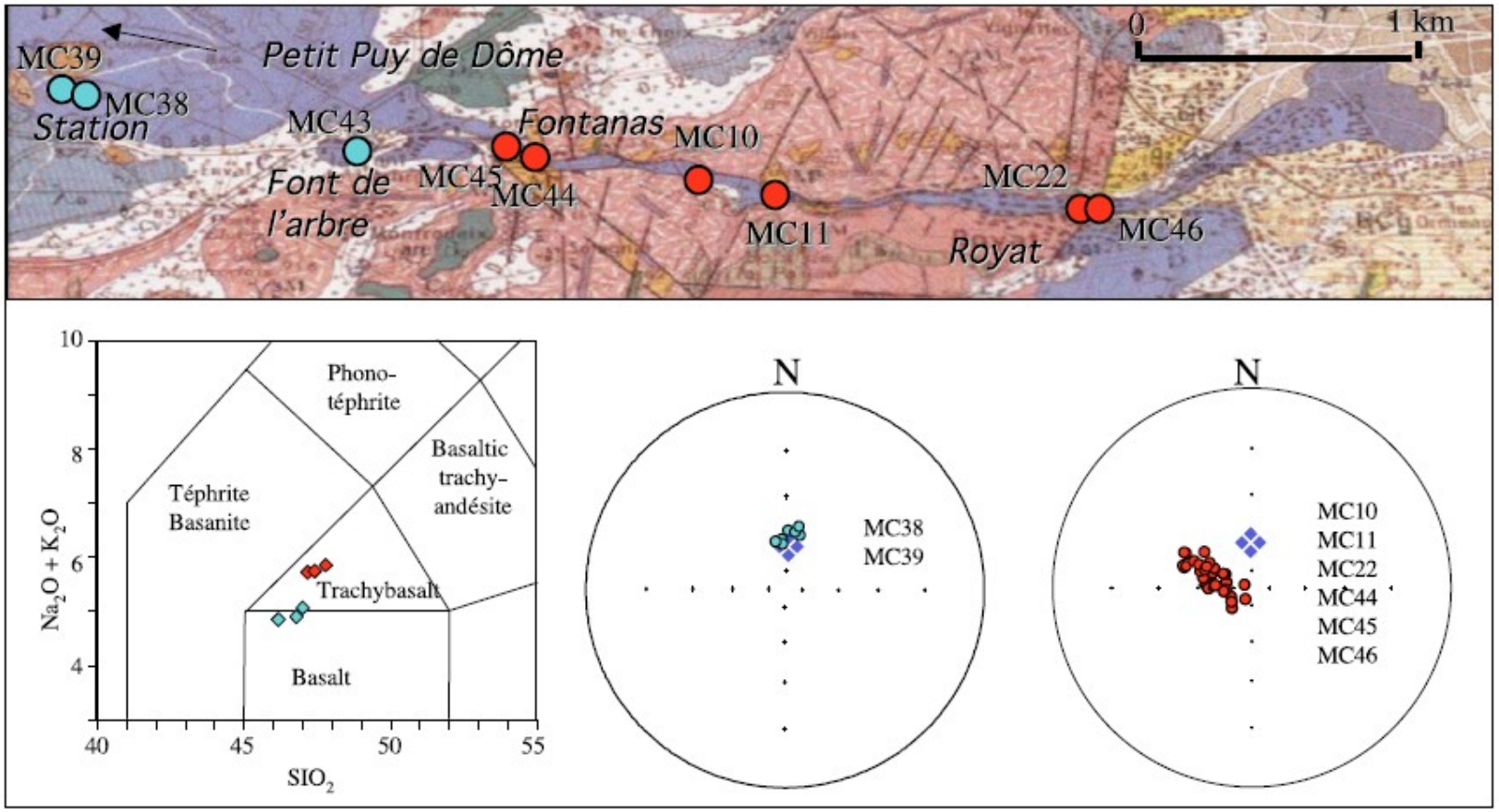


Fig. 2. Enhanced view of the geological map showing La Tiretaine valley (Boivin et al., 2004). The flows emitted by the Petit Puy de Dôme is in blue. The pink formation N and S of the valley is made of metamorphic rocks. Bottom left: alkali vs. silica contents diagram identifying the two groups of sites belonging to two different flow units. Bottom right: stereographic projections (lower hemisphere) of the directions of characteristic remanent magnetizations determined in each unit. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

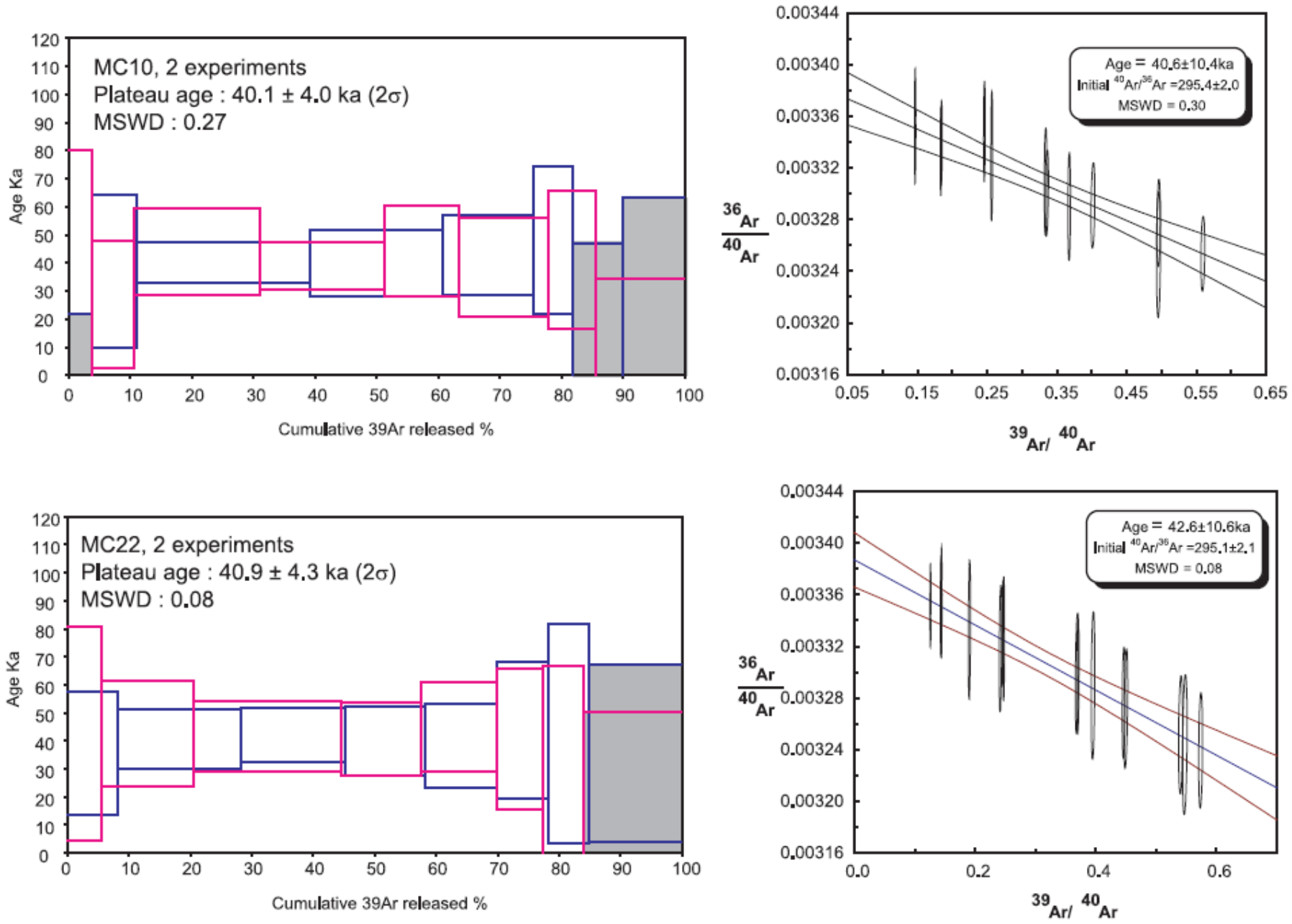


Fig. 3. $^{40}Ar/^{39}Ar$ age spectra and isochron diagrams of replicate incremental heating experiments on groundmass aliquotes from samples of Tiretaine Valley.