# PALEOINTENSITY OF THE GEOMAGNETIC FIELD DURING LATE CRETACEOUS IN THE APUSENI MOUNTAINS (ROMANIA)

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*Abstract.* We have analyzed ten samples with transitional paleodirections, according to Thellier-modified Coe and pseudo-Thellier methods for recovering paleointensity of the geomagnetic field. We found paleointensity values of 12.22±1.5 μT for Earth's magnetic field. These are lower than the normal ones and they are directly related with intermediary paleodirections.

*Key words*: paleointensity, Late Cretaceous, Apuseni Mountains.

Paleointensity during the Late Cretaceous

## 1. INTRODUCTION

Variations in magnitude of the Earth's magnetic field spread over geological time are regarded as paleointensities [1] and they are of great interest in different modelling studies or when a complete understanding of the vector field is wanted; but finding paleointensity values isn't so easy in hand [2]. A detailed recovery of geomagnetic field paleodirections from the Upper Cretaceous magmatic rocks of the Apuseni Mountains had been done to understand the last 80 Matectonic history of the Transylvanian Basin [3-5]. These previous paleomagnetic studies have shown that most of the rocks investigated have reversed polarity and only few sites have recorded the normal polarity. Several sites have directions that are far beyond the expected secular variation of the geomagnetic field for the mean direction defined for the Upper Cretaceous rocks in Romania [6, 7]. These directions were interpreted as transitional directions of the geomagnetic field during a polarity change [4, 5]. What's causing and what's happening during a polarity transition, for the time being, geomagnetists can only model [8]. The behavior of the geomagnetic field during a polarity transition is complex [9]. There is a general agreement that there is a marked reduction in intensity associated with the reversal, but there is still under debate if the onset of changes in the field direction coincides with the reduction in intensity or start several thousand years later [10]. So an attempt to recover paleointensities appeared as a normal desire.

The magnetic information memorized by the samples investigated in the present study, especially that concerning paleomagnitude, can be of great help for characterizing geomagnetic field vector at a time when a polarity reversal was if not in action sure on the way to be installed [11]. In this study we will use paleointensity determinations of the geomagnetic field during the emplacement of Upper Cretaceous magmatic rocks from the Northern Apuseni Mountains to test if the reported transitional directions can be associated with a low in the intensity of the geomagnetic field. Since studies concerning paleointensity determination for eras prior to Neozoic aren't so many, having as much as possible complete vectorial descriptions of the geomagnetic field is a step forward in understanding the mechanisms, which are producing it.

## 2. SAMPLES SELECTION

We have used for this research the same samples used for previous paleomagnetic studies. A new set of 20 samples was subjected to thermal and alternating field, (AF) demagnetizations in order to obtain vector component diagrams for their natural remanent magnetization, NRM [12]. Analyzing these orthogonal plots we selected 10 samples for paleointensity retrieval experiments. As a basic criterion of selection we considered the existence of a trend toward the origin showed by the trajectory of vector end points (the "origin test"). Figure 1 shows characteristic Zijderveld plots. The specimens, marked with a "b" were demagnetized using alternating field and those marked with an "a" were given a thermal demagnetization. Orthogonal plots for "a" and "b" specimens have similar shape. We can see that a viscous remanent magnetization, VRM, is affecting all samples. It was easy removed using a demagnetizing alternating field of 10-20 mT or temperature not higher than 200 ˚C. Some brief oscillations are present at low field/temperature values. They can be related with unavoidable chemical changes, which affected the samples during their geological history (sample 2254, 2268). Also for some samples deviations from a certain direction appear at higher field/temperature values; they may reflect serious chemical alterations suffered at a certain point in the samples past or during experimental investigations (sample 2386).

Although we knew that the perfect specimen must have a monocomponent remanent magnetization we accepted for the planned paleointensity determination, samples, which showed a well defined secondary component. For example the natural remanent magnetization of sample 2913 (and that of the others "29XX" samples considered here) shows a secondary magnetization with unblocking temperatures lower than 400˚C. It could have been imparted by (re)heating processes or lighting discharge. The inclinations and declinations which correspond to the characteristic remanent magnetization are grouped in table 1. All samples are of inverse polarity, eight of them having intermediate directional angles [13]. Samples lithology is also presented in table 1.

The answer to thermal demagnetization was used to identify the magnetic minerals which carry the primary thermoremanence. As expected for volcanic rocks the principal magnetic carrier is (titano)magnetite, $Fe_{3-x}Ti_xO_4$, with $x < 0.15$ ($T_C \sim 500$-580 °C) as well as different fractions with x less than 0.5 [1,14]. Curie temperatures in the 600-700 °C interval is an indicator of hematite which even if not a predominant magnetic carrier is present among them. The origin of this (titano)hematite is controversial. It could have been from the beginning in the rock mass but it could have appeared due to (titano)magnetite oxidation [15]. Dealing with this samples propensity for chemical alteration we appealed two ways of recovering paleointensity values, both variations of the recognized Thellier method [16], one in which the specimens are heated up to the Curie point of magnetite, than cooled in zero and nonzero magnetic field, so as a partial thermoremanence, (pTRM), is imparted to the specimens, known as Thellier-modified Coe method [17], and an alternative method in which the specimens are given an anhisteretic remanent magnetization, (ARM), thus the possibility of heating induced chemical changes will be eliminated [18].

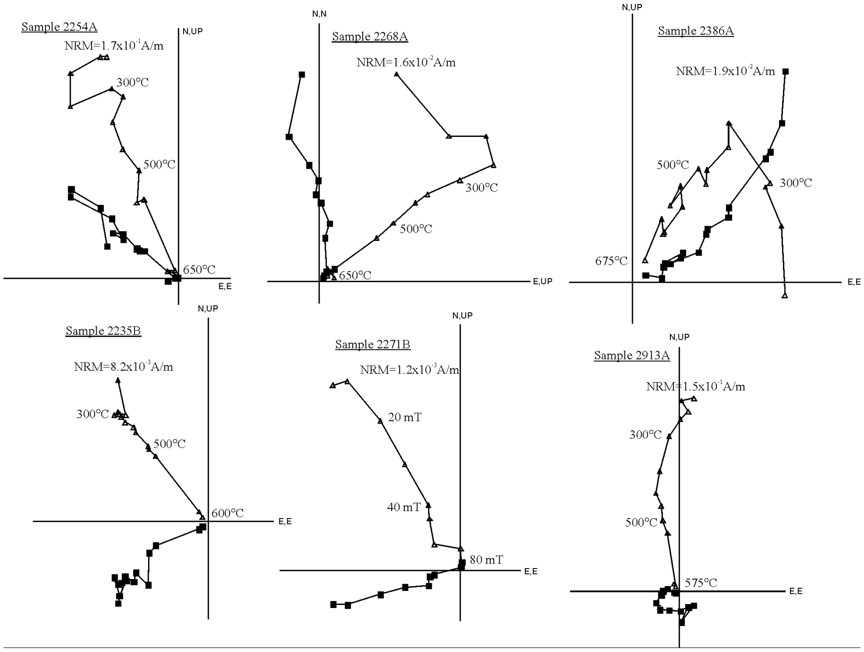

Fig. 1 - Orthogonal projections of representative progressive thermal or AF demagnetization. Squares = projection onto horizontal plane; triangles = projection onto vertical plane.

*Table 1*

Location, lithology, paleofield declination and inclination for studied specimens

| Specimen | Locality | Rock type | Declination (°) | Inclination (°) |
|---|---|---|---|---|
| 2242a | Draganului | Andezite | 307.4 | -60.7 |
| 2254b | Poieni | Dacite | 307.6 | -63.5 |
| 2268b | Sacuieu | Andezite | 16.4 | -76.0 |
| 2271a | Paniceni | Dacite | 251.2 | -54.4 |
| 2335b | Draganului | Dacite | 92.9 | -18.1 |
| 2348b | Botii | Dacite | 331.3 | -36.7 |
| 2386a | Bologa | granodiorite | 59.6 | -51.7 |
| 2913b | Barisor | andezite | 261.0 | -51.7 |
| 2917a | Visagului | Dacite | 63.4 | -66.1 |
| 2928a | Sacuieu | andezite | 129.1 | -36.6 |

## 3. METHODOLOGY

Thermally blocked magnetic remanence, TRM, is unique among forms of natural remanent magnetism in providing information about past intensities of the geomagnetic field because it laniary depends on various parameters including strength of magnetizing field, F, present during cooling through the blocking temperature, (TRM = const $\cdot$ F). By giving a sample for which initial TRM was measured a new partial TRM (pTRM) in a known field, $F_L$, the paleointensity, $F_{paleo}$, can be obtained [1]. A high level of confidence [19] is obtained if: (1) the blocking temperature of magnetically active minerals existing in rock, $T_b$, is the same as their unblocking temperature $T_{ub}$ (the principle of reciprocity), (2) pTRM acquired by cooling in a laboratory field between two temperatures is independent of a pTRM acquired between other two different temperature steps (the principle of independence), (3) TRM acquired by cooling from the Curie temperature to room temperature is equal to the sum of all of the individual pTRMs that would be acquired by cooling between pairs of independent temperature steps spanning the entire temperature range (the principle of additivity). The principles considered are frequently violated and it is difficult to find samples that respect them all. The most suitable are those specimens containing single domain (SD) magnetic grains, but even these ones, sometimes, can give erroneous results. Our samples are pseudoSD, PSD, or multidomain, MD, like thus for better distinguish the true paleointensities some test can be performed during the experiment (the MD check, the pTRM check and the additivity check).

Analog Thellier type paleointensity determination methods that substitute TRM with an anhysteretic remanent magnetization are suitable when wanting to avoid mineralogical alteration caused by repeated heating. ARM techniques compare alternating field coercivity spectra rather than the unblocking temperature ($T_{ub}$) spectra, which are compared in Thellier type determinations. A pseudo-Thellier method that compares the increments of natural remanent magnetization lost in successive AF demagnetization steps with the increments of partial ARM, (pARM), acquired in the laboratory field in matching AF steps [20], extracts a relative paleointensity information.

For our Upper Cretaceous rocks, we have used both methods.

## 4. EXPERIMENTAL PROCEDURES

For the first part of our investigations we appealed the ‘‘Coe variant’’[21] of the Thellier method. A third specimen was cut from the selected samples and was labeled with an additional “c” for differentiation. We heated the specimens to a temperature Ti and cooled them in a null magnetic field (the ‘‘first zero field step”). After measuring the natural magnetic remanence the specimens were re-heated to the same temperature and cooled in a controlled magnetic field (the ‘‘first in-field step”). After the first zero field step we repeated an in-field step at a lower temperature to determine if the capacity to acquire pTRM has changed (the ‘‘pTRM check”), and after the first in-field step, the specimens were heated again to Ti and cooled in zero magnetic field to check whether all the pTRM acquired in the intervening in-field step was removed by re-heating to the same temperature and cooling in zero field. Because a difference in blocking and unblocking temperature (the latter being higher) is characteristic of multidomain pTRM, the last measurement is a ‘‘MD check”.

Thermal demagnetization was performed between 20°C and 700°C using a home made furnace with automatic control of the heating step. The non-inductive furnace has three μ-metal shields and residual magnetic field inside the furnace is less than 5 nT. Specimens were cooled in air, after 15-20 minutes when they reached room temperature, (RT), they were measured TRM / pTRM a JR5A magnetometer (AGICO). Both the magnetometer and the furnance were placed inside a set of three Helmholtz coils used to reduce geomagnetic field in the working area below 500 nT.

The definite laboratory field, ($F_L$), required in the ‘‘first in-field step” was obtained with a coil carefully assembled in the laboratory. Three specimens were subjected to a magnetic field of about 50 μT while for the others a 20 μT field was used. Before our specimens were to be inserted in the coil the magnitude of the field produced by it was measured with a Flux Magnetometer. The gradient of the magnetic field along the coil length was constant each time. As a supplementary useful measurement, specimens’ magnetic susceptibility after every heating step was monitored using a Bartington susceptibility meter MS2B.

A static AF Demagnetizer Magnon International AFD1.3 was used for measuring all NRM’s AF demagnetizations of the “b” labeled specimens as well as for imparting an ARM in the pseudo-Thellier treatment. The magnetizing field used for ARM acquisition was ~50 μT.

## 5. RESULTS AND DISCUSSION

Numerical data obtained were plotted as Arai / pseudo-Arai diagrams [20, 21], in which the residual NRM is plotted versus the associated acquired pTRM / ARM for each temperature/AF field value.

In an ideal Arai diagram, the NRM–pTRM points fall along a straight line, the slope of which, b, gives the ratio between the applied laboratory field, $F_L$, and the earth’s palaeofield, $F_{paleo} = b \cdot F_L$. Arai plots are non-linear when VRM, or other remanences affect NRM carried by the rock. There are several linearity related parameters which were taken into account when result where interpreted:

(I) **β** = $\sigma(b)/|b|$, ($\sigma(b)$ standard error),

(II) **g**, the gap factor [22],

(III) **d(TR)** calculated using data from the MD check tests made at different temperatures; $d(TR) = [1^{st}(TRM_{Ti}) - 2^{nd}(TRM_{Ti})] / NRM_t$ ($NRM_t$ is the “true” NRM and is the value for which the lin ear fit line intersects Oy-axis)

**(IV) Drat** calculated using the pTRM check tests [23], $Drat = [1^{st}(pTRM_{Ti}) - 2^{nd}(pTRM_{Ti})] / \Delta T$ ($\Delta T$ for the considered segment).

(V) **R**, ($R \geq 0.97$) the correlation parameter

(VI) **f** the fraction of the total NRM considered in the calculation [22].

Considering these parameters and their standard acceptance limits [23], “c” labeled specimens used in this study are of B* and C* class. Our B* class specimens have $\beta \leq 0.14\%$, $g \leq 1$, $f \geq 0.3\%$, $d(TR) \leq 10\%$. Class C* specimens have other values for the determination criteria which must be carefully analyzed before accepting $F_L$ values. For B*/C* type Drat is not taken into account.

Figure 3 shows representative Arai plots. Their overall shape is clearly affected by the viscous remanence or/and by pTRM low and high temperature tails [24]. The effects coming from viscous remanence, are minimized avoiding temperatures below 100-200 °C while pTRM tails are searched with d(TR) [25,26]. We have calculated paleointensity values in the 150/250-520/560 °C than we differentiated the results considering as much as possible data. Also pseudo-Arai plots were constructed and used for paleointensity calculation. Unfortunately we were unable to obtain pseudo-Arai plots for samples 2242 and 2271 because rock mass was limited. In table 2 and 3 are gathered the paleointensity values obtained applying Thellier-Coe method and pseudo-Thellier respectively.

If we retain only the values given by the type B* specimens a medium paleomagnitude is 12.22±1.5 μT and it is a realistic value as long as other studies, concerning Cretaceous period, reported it as well, [27].

Neglected Drat values are around 20-30% this means that magnetic minerals suffered chemical alteration during the experiment. Reminding the PSD or MD nature of the magnetic minerals encapsulated in specimens mass we presume that the real paleointensity during Upper Cretaceous in Apuseni Mountains should have been higher. Besides specimen 2386c, with lower $F_{paleo}$, is "by rights" of C class. Its $\beta$ is high and the neglected Drat is also big, chemical changes being present all over its $T_{ub}$ spectrum.

Certainly, the magnetic field strength during Upper Cretaceous in Apuseni Mountains, was not 80 μT and not exactly 40 μT. Specimen 2928c has a very low f and an unacceptable high $\beta$ for the $T_{int}$ considered. For $T_{int}$ 400-600˚C this specimen is the most affected by the thermal treatment, retaining a pTRM three times higher at these temperatures. For specimen 2254c heating induced changes, emerged this time at 200˚C, causing positive deviations for d(TR) up to 400˚C.

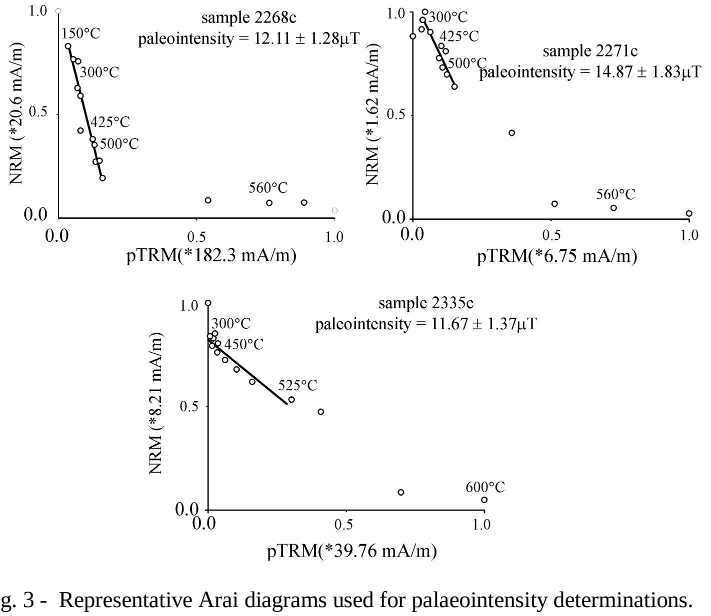

Fig. 3 - Representative Arai diagrams used for palaeointensity determinations.

*Table 2*

Paleofield results obtained with Thellier-modified Coe method

| No | Specimen | $T_{int}$ (˚C) | β | F | g | d(TR) | $F_L$ | F±σ(F) | Class |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2242c | 250-520 | 0.16 | 0.43 | 0.77 | 2.9 | 19 | 22.21±3.55 | C* |
| 2 | 2254c | 250-520 | 0.10 | 0.45 | 0.83 | 3.3 | 19 | 40.01±3.94 | C* |
| 3 | 2268c | 150-520 | 0.11 | 0.63 | 0.88 | 8.1 | 20 | 12.11±1.28 | B* |
| 4 | 2271c | 150-520 | 0.12 | 0.35 | 0.81 | 3.1 | 20 | 14.87±1.83 | B* |
| 5 | 2335c | 250-525 | 0.12 | 0.38 | 0.76 | 10 | 52 | 11.67±1.37 | B* |
| 6 | 2348c | 150-525 | 0.12 | 0.15 | 0.70 | 1.5 | 52 | 12.75±1.55 | C* |
| 7 | 2386c | 150-520 | 0.18 | 0.52 | 0.83 | 3.9 | 20 | 2.93±0.46 | C* |
| 8 | 2913c | 150-520 | 0.17 | 0.71 | 0.75 | 12 | 21 | 33.08±5.78 | C* |
| 9 | 2917c | 150-520 | 0.14 | 0.37 | 0.81 | 3.1 | 21 | 32.82±4.60 | C* |
| 10 | 2928c | 150-525 | 0.42 | 0.14 | 0.17 | 1.3 | 52 | 84.85±35.4 | C* |

$T_{int}$ is the temperature interval; F is $F_{paleo}$; σ(F) is F's standard error. $F_L$ and F are in μT

Specimens 2913c and 2917c indicate about 30 μT for paleointensity. Parameters written in table 2 for these two specimens are close to those for the B* type specimens but we know these samples have a two distinct component NRM and considering $T_{int}$ as large as for the B* class is not appropriate. A better temperature interval would be 400˚C-600˚C for which the resulted $F_{paleo}$ is around 16-20 μT close to that born by specimen 2242c. We decided that it still could be an overestimated paleointensity due to the pTRM tail influences.

*Table 3*

Paleofield results obtained with pseudo-Thellier method

| No | Specimen | ΔH(Mt) | $F_L$ | F±σ(F) | R |
|---|---|---|---|---|---|
| 2 | 2254b | 20-90 | 50 | 16.24±1.85 | -0.975 |
| 3 | 2268b | 40-100 | 50 | 16.66±0.76 | -0.995 |
| 5 | 2335b | 20-100 | 50 | 17.10±3.14 | -0.992 |
| 6 | 2348b | 20-120 | 50 | 18.63±1.41 | -0.989 |
| 7 | 2386b | 10-70 | 50 | 7.89 ± 0.65 | -0.986 |
| 8 | 2913b | 10-120 | 50 | 41.83±2.1 | -0.990 |
| 9 | 2917b | 30-100 | 50 | 44.35±1.77 | -0.996 |
| 10 | 2928b | 10-160 | 50 | 175.12±4.6 | -0.996 |

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The paleomagnitude found using ARM instead of pTRM we consider to be more realistic as long as heating induced chemical alterations caused an enhance or a decrease for the recovered paleointensity. Results agreed well with those resulted after thermal treatment and they demonstrate that the chemical alteration, of which we were “so afraid”, was not so able to falsify the magnetic information retained by the samples investigated here.

## 6. CONCLUSIONS

We found that magmatic rocks with intermediary paleodirections, consolidated during Upper Cretaceous in Northern Apuseni Mountains, retained a low paleointensity of 12.22±1.5 μT. This means that we can associate transitional paleodirections with low paleointensity for the geomagnetic field. Due to the fact that the magnetic minerals present in the studied rocks belong to the PSD or MD class we have to consider that the real paleointensity of Earth's magnetic field must have been a little higher.

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