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The influence of terrestrial processes on meteorite magnetic records

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Abstract

In early solar system history there are several electromagnetic processes (electric discharges, pressure shock waves, electric discharges and currents) capable of magnetizing the primitive solid particles condensating from the solar nebula. The record of these magnetic events is the main objective of rock magnetic laboratory studies of meteorites found on the Earth. However, terrestrial environment can affect the magneto-mineralogy, can cause changes in magnetic parameters and can overprint the primary magnetic record.

The entry of a meteorite into the terrestrial atmosphere causes surface heating and pressure effects due to large initial velocity. The effect of surface heating was the subject of the study with the CM2 Murchison meteorite. Results show the remagnetised zone to be at least 6 mm thick. On CM3, Allende meteorite we studied an effect of pressure during the atmospheric entry. According to our results the pressure does not seem to be a source responsible for meteorite remagnetization. Some meteorites are found several days after the fall, some are deposited in a desert or on the Antarctic ice for thousands of years. Most of them contain visible traces of terrestrial oxidation and weathering. We used the sample of an L6 chondrite DaG 979 found in the Libya desert, sample of the iron meteorite Campo del Cielo (found in Argentina 5000 years after the fall), and sample of the H5 Zebrak meteorite (found several days after the fall) for weathering simulations. Weathering plays an important role in the meteorite terrestrial history and is capable of complete remagnetization of the meteoritic material.

To document the terrestrial processes that influence meteorite magnetism we monitored changes in magnetic remanence and magnetic hysteresis parameters. Our results indicate that the terrestrial processes are capable of changing magnetic properties and can overprint the primary magnetic record. Therefore, an extreme care is required when selecting the meteorite samples for primary magnetic component study.

Keywords: Meteorite magnetism; Fusion crust; Terrestrial residence; Meteorite fall

1. Introduction

Just after its formation, the Sun was much more active. The solar activity increase was accompanied by massive solar mass ejections, higher solar magnetic field activity and pressure shock waves (Desch and Connolly, 2002). The solar mass ejections made of hot plasma clouds are capable to carry “frozen” solar magnetic field deep into the solar system. There are also massive electric discharges and currents expected between clouds of solar system nebula (Desch and Cuzzi, 2000; Desch and Connolly, 2002). Their origin could be related to turbulent and convection flows electrically charging small dusty particles (Dominik and Nübolt, 2002; Nübold

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and Glassmeier, 1999, 2000). The massive electric discharges can be responsible for synthesis of aminoacids which are necessary for life development and evolution (Miller, 1957; Wolman et al., 1972; Kletetschka et al., 2003).

The primitive chondritic meteorites contain material of early solar system and their falls represent most effective way to transport this material from different areas of our solar system to Earth (Krot et al., 1995). Extraterrestrial magnetic information can be imprinted in magnetic record of meteoritic material for billions of years. The conditions in our solar system have been stable for last 4 billions years. Most of the known meteorites are orbiting the Sun on "safe" trajectories far away from Sun and giant planets surrounded with strong magnetic field. This fact gives good chance to preserve magnetic record of described magnetic events till the final meteorite landing on Earth's surface. For this reason meteorites are subject of intensive paleomagnetism and rock magnetism studies (Brecher and Arrhenius, 1974; Kletetschka et al., 2001, 2003; Morden, 1992; Terho et al., 1993; Wasilewski and Dickinson, 2000). However, less attention in magnetic studies is directed to the events and processes following the meteorite fall and the terrestrial residence (Kletetschka et al., 2001). As will be described later in this work in more details, different terrestrial processes can cause changes in magnetic parameters, and can overprint the primary magnetic record. Thus the terrestrial history of meteoritic samples must be considered while interpreting magnetic record data.

2. Instruments and methods

The laboratory work has been performed partly in the Paleomagnetic Laboratory of the Institute of Geology, Academy of Sciences of the Czech Republic and partly in the Laboratory for Extraterrestrial Physics, NASA's Goddard Space Flight Center, Greenbelt, Maryland, United States of America.

The Agico spinner magnetometers JR-5A and JR-6 (Institute of Geology) and SCT (Super Conducting Technology) superconducting rock magnetometer (NASA) were used for remanent magnetization (RM) measurements.

The Agico magnetometer's spinning speed of the sample holder during the measurement is 89.3 rev/s (JR-5A) and 89.3 rev/s or 16.7 rev/s (JR-6). The sensitivity of the instrument is 1.92×10^{-11} A m^2/kg. The spinner magnetometers are constructed for measurements of terrestrial rock samples shaped to cube (a = 2 cm) or cylinder (d = 2.54 cm, h = 2.50 cm). However, the meteorite samples subjected to measurements varied between 1 and 5 mm in size. This problem has been solved using adjusted plastic box for loose sample measurements (Fig. 1). The box was filled up to half of its height with non-magnetic plastic foam matter. The sample was placed in the middle of the box onto foam fill and covered with the cover made of the same material. Once the box is closed, the sample is fixed properly in the center of the box and the change of the sample orientation due to the spinning measurement process is avoided. The magnetization of the empty adapter is the same order of magnitude as the original sample holder and is compensated from all measurements. The samples are measured in three positions in automatic mode and in six positions in manual mode.

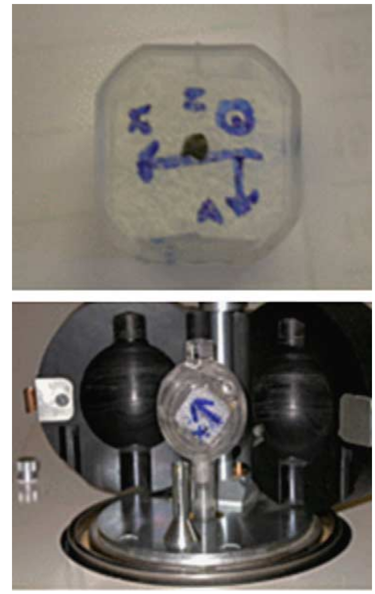

Fig. 1. The piece of the Allende meteorite in the non-magnetic plastic adapter used with Agico's spinner magnetometers (up). The plastic adapter in the JR-6 sample (down).

The vertical construction of the SCT superconducting rock magnetometer allows us to measure RM under the temperature of liquid nitrogen and to study the time stability of sample's RM magnetization in different external fields by rising the sample step by step from zero field (~40 nT) inside the shielded instrument (sample holder in lowermost position) up to ambient terrestrial field intensity (~50,000 nT, sample holder in uppermost position above the instrument). The intensity of magnetic field penetrating inside the magnetometer's tube in different levels has been measured prior to the experiment for calibration purposes. The advantage of this instrument is that the measuring routine is fast, static (sample is not rotating as in spinning magnetometer), and that all three components of the sample's magnetization vector are measured at once (no need to change sample position within the holder during measuring routine). This allows us to measure irregular (no need to balance the sample) or fragile samples.

To test sample's magnetization stability and to determine its components the demagnetization process has been used. We used AF (Alternating Field) demagnetization process to avoid any change in magneto-mineralogy and oxidation of the meteorite. The instruments used for demagnetization were Agico LDA-3 AF unit (Institute of Geology) and 2G AF unit (NASA). The AF field range of LDA-3 instrument is from 1 mT up to 100 mT in steps of 1 mT. We used fast taper feature of the AF field, linear shape of field taper and time of residence in the AF field 10 s in each position. The AF field range of 2G instrument is from 1.3 mT up to 240 mT in steps of 0.1 mT. The time of residence in the AF field have been set to 3 s.

Lake Shore vibrating sample magnetometer (VSM) is designed to measure hysteresis parameters. The DC magnetic field can be set from 0 T up to 2 T. The precision of sample's magnetization measurement on external field background is 10^{-4} A m^2/kg. The VSM has been used to magnetically saturate our samples.

3. Murchison meteorite—from the remagnetised fusion crust to the magnetic record of meteorite interior

The chance to preserve the primary space magnetization and to its measurement depends on the meteorite terrestrial history. The first process capable of changing the primary magnetic record occurs already during meteorite atmosphere passage. The surface areas of

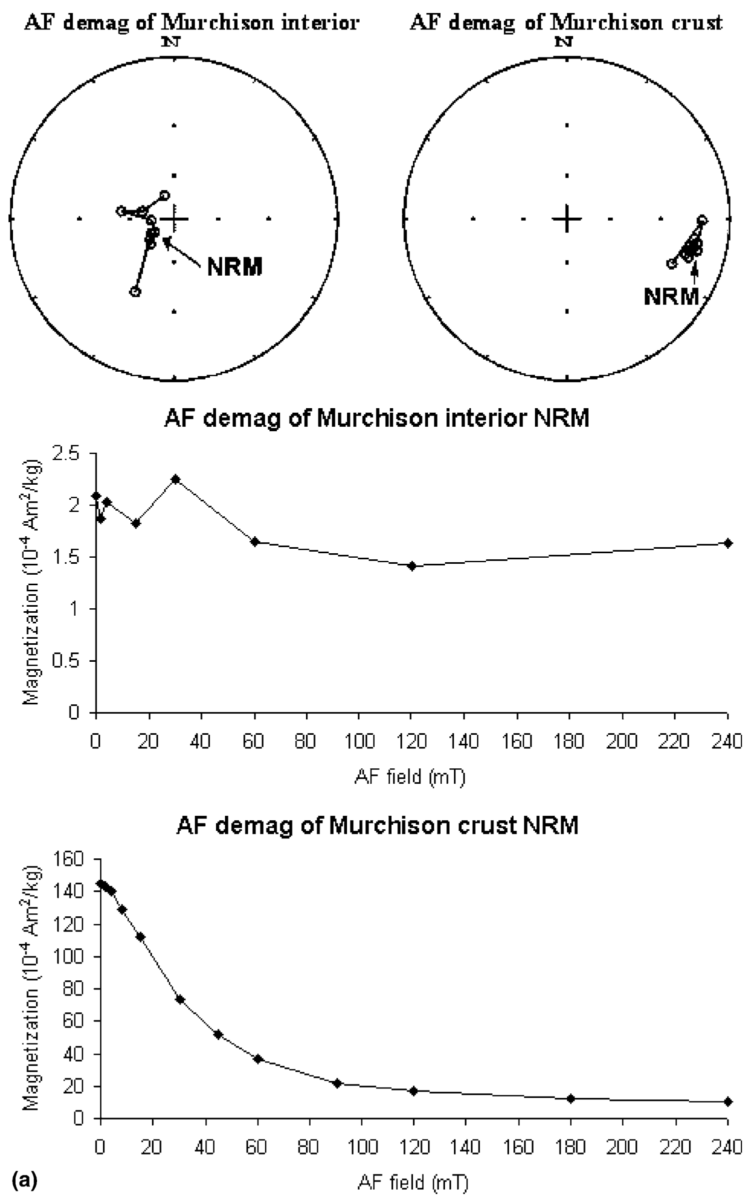

Fig. 2. (a) NRM behavior during AF demagnetization of Murchison's interior and fusion crust sample, (b) SIRM behavior during AF demagnetization of Murchison's interior and fusion crust sample.

meteorites during fly through the atmosphere are subject of extreme heating, melting and evaporation resulting in surface ablation. The witness of the meteorite melting is fusion crust—a completely recrystalized thin layer surrounding the meteorite surface. Fusion crust can be preserved on early finds. The stony meteorites are bad heat conductors. It takes only several tenths of seconds to pass though Earth's atmosphere—too little time to heat the whole meteorite body. This fact results in the thickness of the affected surface layer. Optically distinguishable fusion crust is around 1 mm thick. The temperature in the meteorite internal parts grows up slowly from the interplanetary space temperature up to the Earth's surface temperature. Thus we have a chance to study material of the meteorite body interior. The meteorite interior suffers only a warming to a room temperature, an exposure to the geomagnetic field, a pressure increase during the entry and surface residence and an exposure to gases and water molecules contained in the Earth's atmosphere.

Atmospheric heating can penetrate more deeply inside the meteorite body and the affected zone can be thicker than the optically distinguishable fusion crust is. Magnetic record is sensitive to material heating what can affect the primary (space) magnetic record (if present). If the temperature exceeds the blocking temperatures of the magnetic minerals (carriers of the magnetization), the primary record will be lost and the new terrestrial TRM (Termo-Remanent Magnetization) magnetization will occur during the following cooling phase. (The cooling occurs in geomagnetic field.) Even if the heating does not reach the blocking temperature of all magnetic minerals present, the p-TRM (partial-TRM) can take place. The TRM or p-TRM component introduces contamination component that can be easily mistaken for the primary one.

To complete the study of the thermally affected zone we used two samples of the Murchison meteorite (CM2) (Fuchs and Olsen, 1973). First specimen was an edge fragment of Murchison sized 6 mm with fusion crust on one side present. This sample was from collections of the National Museum, Prague, Czech Republic. Second Murchison fragment was 3 mm in size and was part of a larger meteorite interior specimen, obtained from Smithsonian Institution, Washington DC, USA (see Kletetschka et al., 2003 for additional magnetic properties of the rest of the Murchison meteorite sample).

3.1. Laboratory work

Four sections of the edge fragment were prepared perpendicular to the fusion crust plane in order to obtain samples with variable distance (0, 2, 4 and 6 mm) from the fusion crust of the edge meteorite fragment. The sections were broken into smaller samples (sized 1–3 mm) used for measurement. The lower boundary

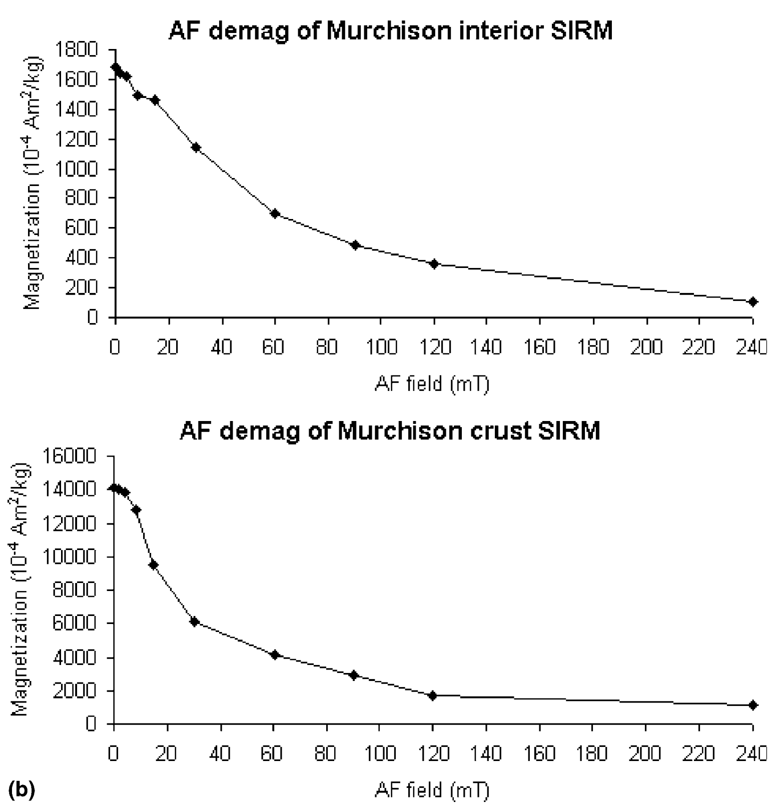

Fig. 2 (*continued*)

(0 mm) is the fusion crust itself and the upper boundary (6 mm) is determined by the dimensions of the original meteorite edge fragment. Following methods have been applied: Stability of NRM and stability of SIRM (Saturation Isothermal Remanent Magnetization).

3.2. Experiment results

Magnetic screening of the edge area related to Murchison meteorite indicates that at least 6 mm thick layer is affected by terrestrial TRM acquisition during the atmospheric heating phase. The fusion crust NRM is about hundred times higher than NRM of meteorite interior.

The interior material of Murchison meteorite is magnetically very soft and unstable (Kletetschka et al., 2003). The unstable behavior of the Murchison meteorite material is caused by the presence of soft magnetic component susceptible to the external magnetic field. Leaving the specimen in laboratory geomagnetic field overnight produces soft magnetic component of dominant intensity in direction parallel to the external field. Shielding the sample for the same time from external field reduces this component up to a negligible value (Kletetschka et al., 2003).

In contrast the TRM of fusion crust is stable and single component (Fig. 2a). Its demagnetization stability is similar to the SIRM (2 T saturating field, (Fig. 2b). There was no evidence of soft behavior observed on fusion crust samples and samples from meteorite edge fragment (up to 6 mm). The TRM intensity of the affected layer decreases rapidly towards meteorite interior. The value of magnetization of the sample 6 mm from meteorite fusion crust is the same magnitude as the NRM of the Murchison interior fragment (Fig. 3). However, from the NRM stability point of view, looking on the demagnetization signature of all the samples from edge meteorite fragment (up to 6 mm from fusion crust) the magnetization is still single component and keeps its stabile behavior similar to the demagnetization behavior of saturated sample. The direction of magnetization of all affected samples is identical. The difference in the magnetic record of the Murchison interior fragment and edge fragment is significant.

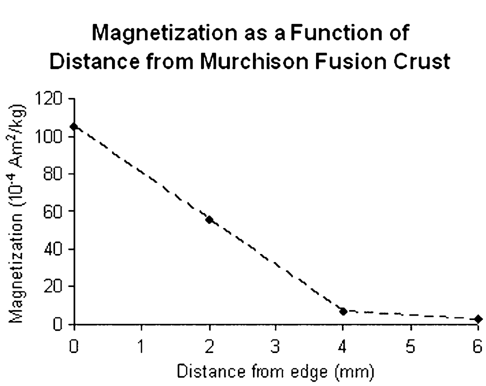

Fig. 3. NRM as a function of distance from meteorite edge. Sample at distance 0 mm represents fusion crust.

The stable single component magnetization is what we are searching for. In the case of edge sample it is of terrestrial origin, but on the other samples of unknown position within meteorite body it can be incorrectly interpreted as stable extraterrestrial component!

4. Pressure shock and Allende's stabile NRM

During the meteorite aerobreaking in the terrestrial atmosphere the meteorite body is subjected to intensive pressure. According to the study of pressure related cracks within different meteorites (Borovička et al., 2002; Bronshten, 1983) the pressure during atmospheric entry can reach several megapascals. The effect of the pressure on the survival of the body is critical. Depending on the material fragility, the pressure shock is responsible for fragmentation of the stony meteorites and reduces the chance of the body to reach the Earth surface.

There have been many works done on the influence of pressure on the magnetic parameters (Kapička, 1984, 1990, 1992). Applying those ideas on meteorite and atmosphere entry event three questions arise:

Is the pressure within the material effective in changing the magnetic parameters of the meteorite?
According to the fact, that this process takes part in Earth's magnetic field, can the material be magnetized or remagnetised due to a pressure exposure?
If so, how stable is the magnetization acquired due to this process?

To answer those questions we choose the Allende meteorite as a subject of laboratory simulation. Comparing to others primitive chondritic meteorites (for example Murchison interior sample), Allende is a carrier of a relative stable single component NRM (Brecher and Arrhenius, 1974).

The question is, whether this magnetization is space or terrestrial origin. Allende meteorite carries no visible traces of intensive terrestrial weathering. Therefore, the weathering process may not be responsible for a possible remagnetization. The results from different fragments of meteorite interior (Brecher and Arrhenius, 1974) point to the same level of NRM/SIRM stability as observed on our fragment. That eliminates the heating during atmospheric entry as a possible remagnetization process of our fragment (our fragment was not close to the edge of the meteorite).

An experiment has been designed to test the pressure shock effects on the meteorite magnetization (pressure

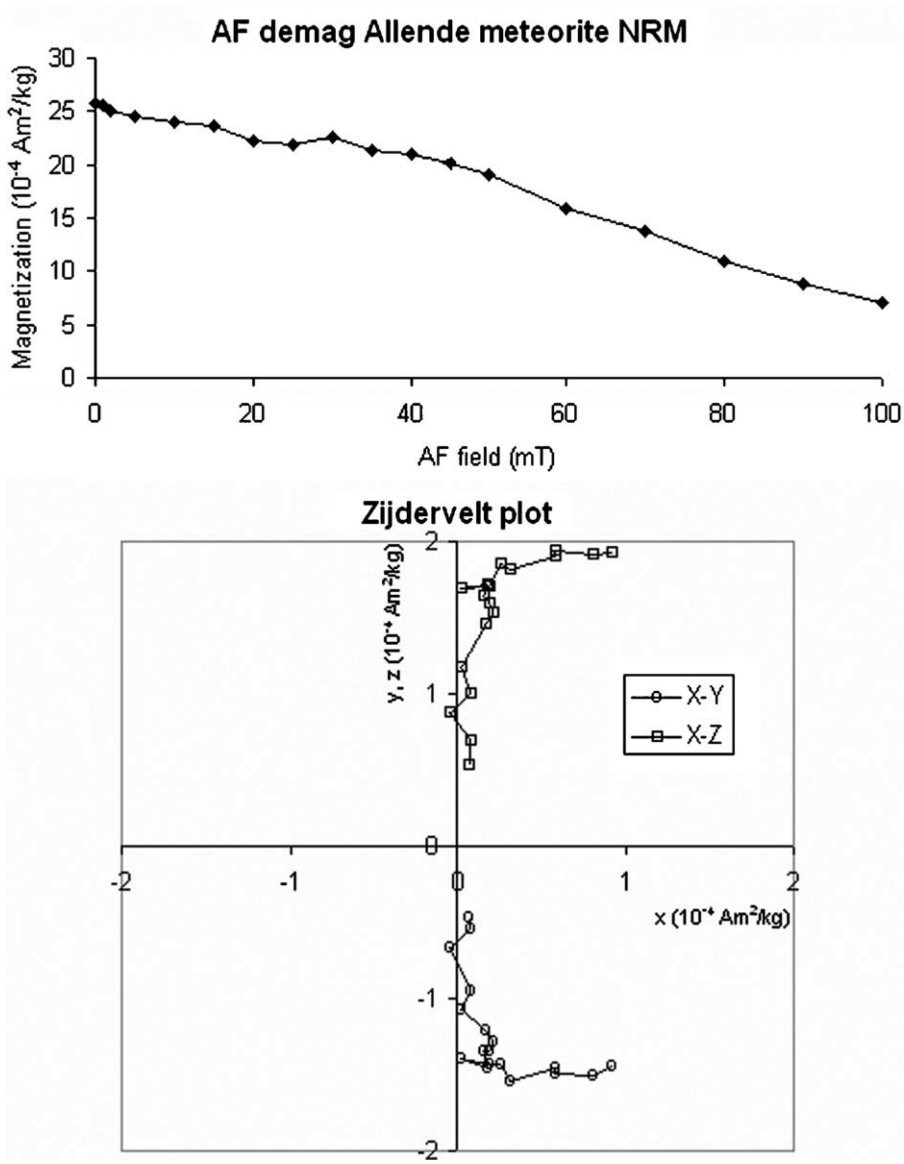

Fig. 4. Demagnetization of Allende's interior sample. Allende carries stable single component NRM.

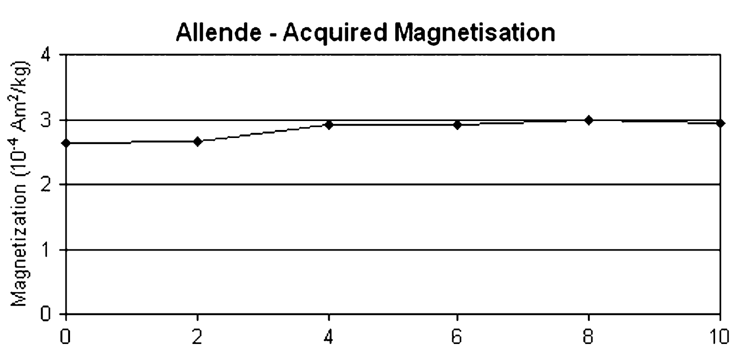

Fig. 5. Magnetic acquisition related to the exposure of Allende's sample to uniaxial pressure.

induced domain displacements or grain growth and possible superparamagnetic (SP) to single domain (SD) transitions).

4.1. Experimental procedure

The fragment of Allende meteorite has been demagnetized prior to the experiment using LDA-3 AF demagnetizer up to maximum field of 100 mT to test the stability of NRM. However, the field of 100 mT was not enough to completely demagnetize Allende.

To expose Allende sample to high pressures we used a non-magnetic apparatus (designed to expose rock samples to high pressures up to 120 MPa for magnetic properties experiments) located in the laboratory of the Institute of Geophysics, Academy of Sciences of the Czech Republic.

The standard rock samples used are 1 cm high and 0.8 cm in diameter cylinders. Due to this requirement Allende sample (sized 2 mm) has been fixed within the non-magnetic organic resin and worked to the required dimensions. Prior the experiment two types of resin have been tested (ChS Epoxy® 1200 resin and Dentacryl® resin). As exposed to the pressure the cylinders made of Epoxy® resin showed more solid behavior with less degree of deformation. Thus Epoxy® resin was selected for our experiments.

The resin cylinder with the sample was exposed to pressure in the presence of ambient geomagnetic field. Nominal pressures were from 2 MPa in steps of 2 MPa up to 10 MPa. The residence time under the pressure was approximately 5 s.

4.2. Experiment results

The NRM of Allende sample was 26×10^{-4} A m^2/kg. After 100 mT AF field was applied RM decreased to 7×10^{-4} A m^2/kg (Fig. 4). The magnetization of sample fixed within the resin after additional AF demagnetization (100 mT) was 2.7×10^{-4} A m^2/kg. During the experiment sample has been exposed to uniaxial pressure up to 10 MPa in geomagnetic field of 60,000 nT. There has been no significant increase in sample magnetization. The slight increase in magnetization (0.3×10^{-4} A m^2/kg) between 2 and 4 MPa (Fig. 5) resulted in final magnetization 3×10^{-4} A m^2/kg (one order of the magnitude lower than the original NRM value 26×10^{-4} A m^2/kg) is within the noise of the experiment.

There were problems with the pressure transfer using organic resin. The deformation of the resin cylinder starts at the pressures around 7 MPa. Only estimates can be done on the efficiency of the pressure transfer through relatively ductile resin to the solid sample during the experiment.

According to these first results, pressure during atmospheric aero-braking seems to be not responsible for Allende stabile NRM. The Allende meteorite with its stable single component magnetization should be the subject of the future study.

5. The desert weathering

At the moment of meteorite landing the process of terrestrial weathering commences. Some meteorites are found several days after the fall some of them spend thousands of years in the polar ice (Calogero et al., 1999; Benoit and Sears, 1999) or in the desert (Schlüter et al., 2002). During this exposure time weathering is active. Terrestrial weathering of meteorites can be very fast under specific conditions. The conditions on orbit in solar system are not oxidizing and a fresh meteoritic material contains no oxidation or low degree of oxidation. The terrestrial oxidation is very rapid. Even under laboratory or museum conditions the terrestrial oxidation is significant and the optically visible traces of oxidation appear within one year (as observed on Moravka meteorite (H5-6), that have been found several days after the fall on May 6, 2000 close to Moravka village in northeast of Czech Republic—own observation).

5.1. Remarks on terrestrial weathering on deserts and in antarctic regions

The weathering under desert conditions is related to the action of variable salts present in desert soil or sand. Salts effective in desert weathering can be associated to different minerals. The salts play double role in weathering process. The first destructive action is chemical processes. Chemical weathering is active when the salt is dissolved. The solutions can penetrate deeply into the rock/meteorite through fractures and pores. The character of chemical processes that take part during the chemical weathering depends upon the composition and condition of the parent rock, solution parameters (character of salts, concentration, temperature, pH, Eh) and ambient conditions (air temperature, humidity, and pressure) (Gaudie and Viles, 1997). The chemical reactions lead to the change of mineral composition of the parent body. The original association of magnetic minerals can be the subject of dissolution. As the primary magnetic carriers disappear, the primary magnetization disappears as well. During the chemical weathering processes production of secondary iron minerals as limonite, goethite and hematite starts. The new generation of magnetic minerals can be the carrier of terrestrial magnetization component that can become dominant. Thus the chemical weathering is often responsible for terrestrial magnetic contamination or remagnetization.

Dissolved and crystalline salts plays important role in the process of mechanical weathering as well. The solubility of each salt is different and is more or less sensitive to the change of ambient conditions. The increase or decrease of solubility results in the crystal dissolution or growth responsible for cracks deploying (Gaudie and Viles, 1997).

There have been many simulations done on desert salt weathering (Gaudie and Viles, 1997). According to the weathering efficiency of different salts and their natural appearance (Gaudie and Viles, 1997; Goudie, 1977 in Gaudie and Viles, 1997) the sodium chloride and sodium sulfide have been selected as most favorable candidates for our weathering simulations.

Under the arctic conditions the situation is different (Calogero et al., 1999; Benoit and Sears, 1999). In arctic areas the calcium chloride is naturally in relative abundance and hence has been also selected for simulations. The low temperatures should in general slow the weathering process (McGreevy, 1982 in Gaudie and Viles, 1997). However, there have been cases shown with relation of the salt presence and an acceleration of the frost weathering (Litvan, 1972; Goudie, 1974; Williams and Robinson, 1981; Williams and Robinson, 1991 in Gaudie and Viles, 1997).

5.2. Meteorite material

At some samples we know exactly the terrestrial age from historic records or chemical analysis (Campo del

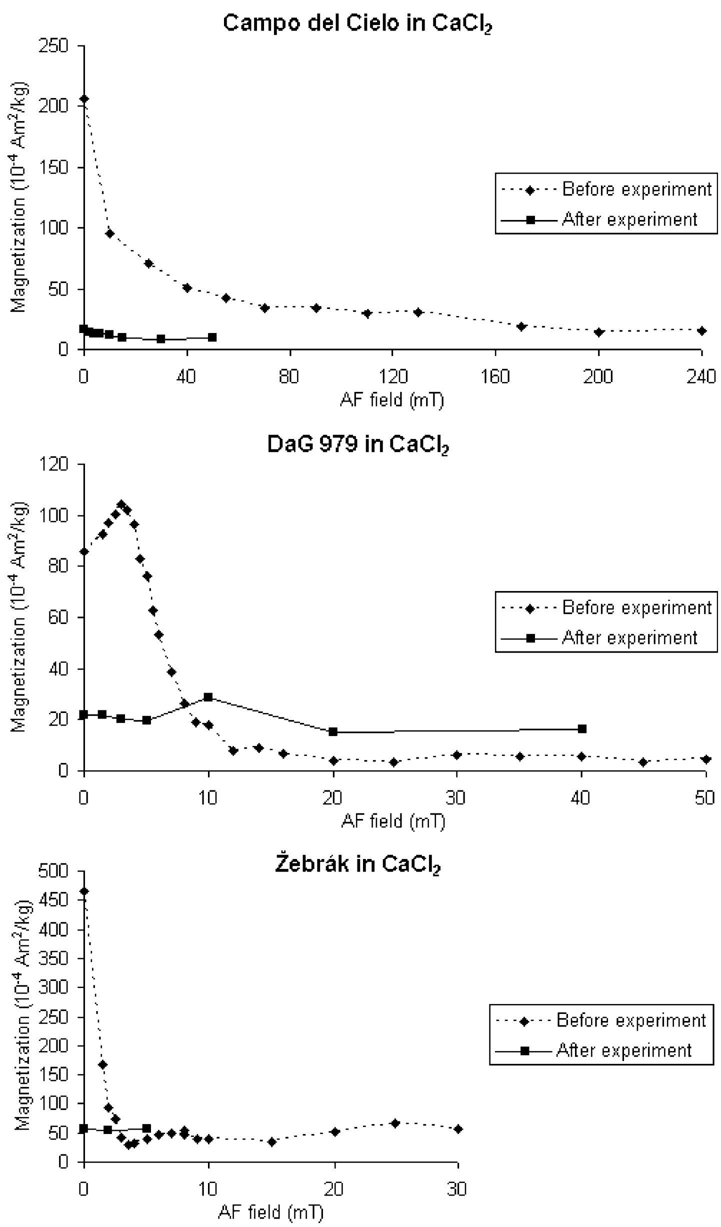

Fig. 6. AF demagnetization before and after leaching the samples in $CaCl_2$.

Cielo, Zebrak), at some we can only make a guess from the apparent physical state of meteorite (Dar al Gáni 979).

The meteorite Dar al Gani 979 is stony ordinary chondrite (L6) and landed in the deserts of south Libya (Schlüter et al., 2002) perhaps thousands years ago. DaG 979 has been recovered by the expedition led by Radek Hanus, Faculty of Science, Charles University in Prague, Czech Republic. The fragment of the meteorite has been provided for laboratory study by Jakub Haloda, Faculty of Science, Charles University in Prague, Czech Republic. The meteorite shows traces of intensive terrestrial weathering related to desert varnish formation. According to preliminary analysis of magnetic record of DaG 979 (unpublished data) the character of magnetic record is complicated and multi component. There is poor correlation between the components of neighboring samples. In general the NRM of optically more weathered samples is higher and more complicated.

There are speculations about the NRM origin of DaG 979 meteorite. One of them points to terrestrial remagnetization after thousands of years long terrestrial desert weathering. Several randomly oriented components present are probably related to the numerous terrestrial weathering events. The meteorite body has been subject of aeolian transport within Sahara sand. The sample rotation during the period of aeolian transport within the sand can be responsible for diversity of component directions.

The iron meteorite Campo del Cielo (I) landed in Argentina 5000 years ago (Buchwald, 1975). Our

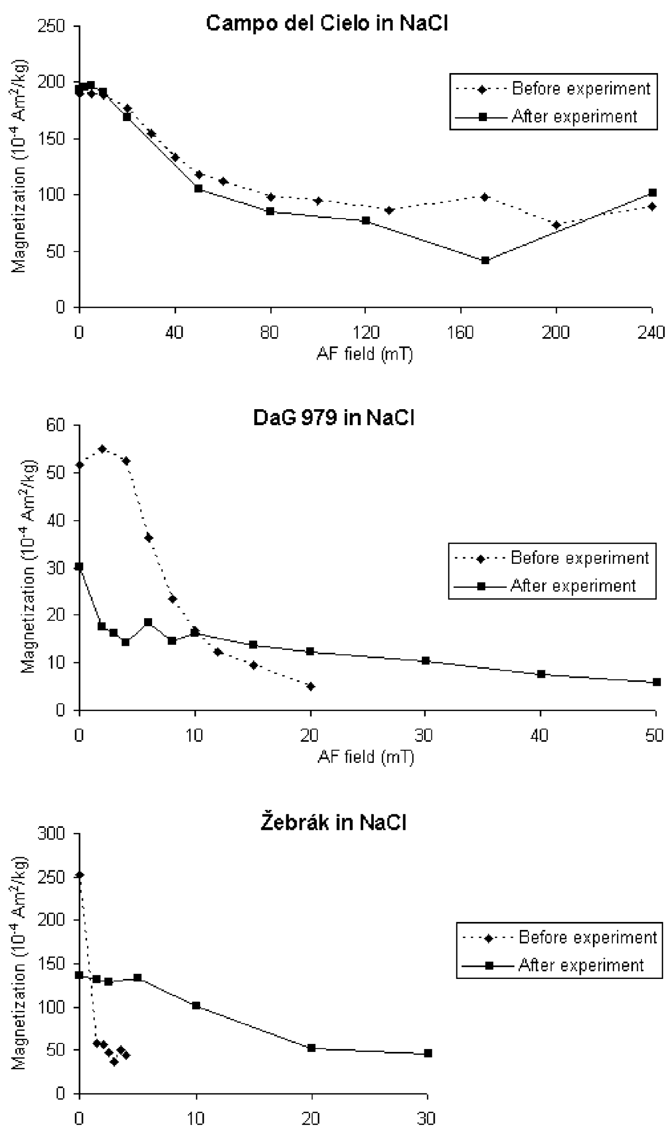

Fig. 7. AF demagnetization before and after leaching the samples in NaCl.

samples subjected to weathering simulations came from the oxidized rusty surface layer of meteorite fragment. Their surfaces have been completely covered by oxide crust and appear fragmented by invasion of rust along cracks. The rusty surface of Campo del Cielo carries a stable single component magnetic record probably related to the terrestrial weathering.

Meteorite Zebrak is a stony ordinary chondrite (H5) (Bukovanska, 1984). The fall occurred on October 14, 1824, close to Zebrak village, central Bohemia, Czech Republic. Two fragments were collected second day after the fall. After more than 150 years in the museum collections the samples contain optically visible oxidation traces. The magnetic record of Zebrak meteorite is very unstable and soft (demagnetizes in 1 mT AF) perhaps dominated by the viscous acquisition.

5.3. Laboratory weathering simulations

The experiment simulating meteorite terrestrial weathering was developed in order to monitor the possible terrestrial remagnetization of meteorite samples. To simulate meteorite weathering, the method based on bathing the meteorite samples in different salt solutions was used.

The simulations were done in the Laboratory for Extraterrestrial Physics, NASA GSFC. We used four sets of samples (one sample from each meteorite set). All the samples were stepwise demagnetized using AF magnetic field up to 240 mT prior to the weathering process to test the stability and character of NRM (Figs. 6–8). Before the initiation of the weathering experiments samples from set 1, 2 and 3 were fixed to its final position

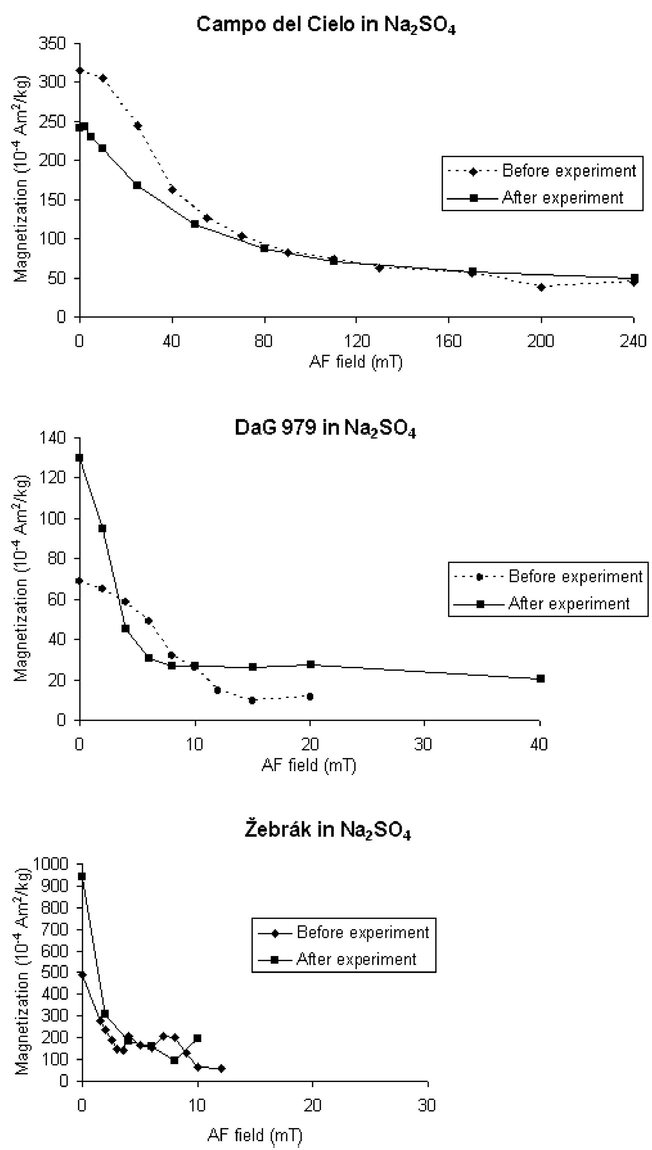

Fig. 8. AF demagnetization before and after leaching the samples in Na_2SO_4.

Table 1
Efficiency of various terrestrial processes in remagnetizing the meteorite material

Terrestrial process	Sample	NRM	RM after 10 mT	% of NRM after 10 mT	Noise level after AF demag	Terrestrial component acquired	% of NRM	TC after 10 mT	% of TC after 10 mT	Remagnetization effectivity
Heating in atmosphere	Murchison	1.4	1.2	*86*	<2	145	*10,357*	125	*86*	High
Pressure shock	Allende	26	24	*92*	NA	3	*12*	NA	NA	Poor
Weathering in $CaCl_2$	Zebrak	466	47	*10*	<70	78	*17*	56	*72*	Poor
	Libya	86	18	*21*	<10	21	*24*	28	*133*	Poor
	Campo del Cielo	206	96	*47*	<20	14	*7*	11	*79*	Poor
Weathering in Na_2SO_4	Zebrak	489	66	*13*	<200	941	*192*	194	*21*	High
	Libya	69	26	*38*	<15	130	*188*	27	*21*	High
	Campo del Cielo	316	305	*97*	<60	242	*77*	215	*89*	High
Weathering in NaCl	Zebrak	252	45	*18*	<50	153	*61*	101	*66*	High
	Libya	52	17	*33*	<6	31	*60*	16	*52*	High
	Campo del Cielo	190	189	*99*	<95	208	*109*	191	*92*	High

All magnetization units are 10^{-4} Am^2/kg.

within the test tubes and sample's coordination system was oriented with respect to the geomagnetic field direction. Subsequently the saturated solutions of Na_2SO_4 (to be used with set 1), NaCl (to be used with set 2) and $CaCl_2$ (to be used with set 3) salts were prepared using warm distilled water (approx. 50 °C). As the test tubes were closed and placed into heated water bath, the simulation started. The solution temperature oscillated on a daily basis from room temperature 20 °C up to 90 °C. The range of the variations in the solution temperature was set according to the temperature variations in desert conditions. Daily and seasonal changes in ambient temperature also influence the solubility of the salt, by penetrating the pore space and deploying cracks in the meteorite and speeds up the weathering processes.

After three week leaching the samples were removed from the solution. The RM was remeasured in order to monitor any changes. To test the stability of the new RM the samples were AF demagnetized and the results were compared with the AF demagnetization data taken before the experiment (Figs. 6–8). The data were also compared with the demagnetized set 4 reference samples placed dry in the laboratory geomagnetic field in order to quantify the viscose magnetization acquisition.

5.4. Weathering experiment results

The most effective salt solutions in the three-week magnetic weathering process were NaCl and Na_2SO_4. Magnetizations due to the weathering products resulted in an increase of more then one order of the magnitude and were comparable with the RM prior to AF demagnetization. The post experimental stability against AF demagnetization of the DaG 979 sample was lower than the original magnetization stability. The stability of Zebrak meteorite was higher, and the stability of the Campo del Cielo magnetization was about the same as the original one. The direction of new magnetization related to the oxidation vector was not precisely oriented parallel to the direction of the geomagnetic field during the weathering experiment (may be due to the complicated magnetic fabric of meteorites) or due to tiny sample shifts during the experiments.

There was practically no effect observed in samples leached in $CaCl_2$ solution pointing to (in the term of terrestrial weathering) non-aggressive conditions of Antarctic regions and in reference samples. The measured values can be found in the Table 1.

6. General conclusions

The thermal shock during meteorite fall through the atmosphere plays important role in the sample history and its influence on magnetic record is evident. According to our results from carboniferous chondrite Murchison, the affected zone is at least 6 mm thick. It is important to consider this process during sample selection and magnetic record interpretation. The information of our sample position in the whole meteorite body is essential and should not be underestimated. If the sample comes from the region just below the meteorite edge, there can be an influence of the thermal shock without optically distinguishable evidence. Otherwise we can reach incorrect interpretation. We must select meteoric samples with care and eliminate samples from the meteorite edges.

According to results of the pressure experiment, pressure during atmospheric aero-braking seems not to be responsible for Allende remagnetization. The slight increase in magnetization during the experiment is within the accuracy of our experiment. The experimental process needs to be improved and the pressure shock simulations on other meteorites have to be the subject of future work.

Meteorite weathering appears to be important as a consideration when interpreting meteorite magnetic records. Chemical weathering related to the presence of specific salts (NaCl and Na_2SO_4) in the soil can be very rapid. The presence of cracks within the meteorite body, the daily and seasonal variations in ambient temperatures and mechanical weathering even forces the process. Weathering can affect the whole meteorite body within several years. The influence on the meteorite magnetic record is evident. Weathering is capable to produce stable magnetic component. After relatively short period of intensive terrestrial weathering the extraterrestrial magnetization can be completely remagnetised and the terrestrial component related to weathering becomes dominant. It is important to consider weathering effects during the sample selection and magnetic record interpretation. According to the data observed, it is probable, that the magnetization of our Campo del Cielo, DaG 979 and Zebrak samples has a significant terrestrial component.

Meteoritic samples must be selected with care to eliminate strongly weathered samples and samples close to meteorite edge. The quantitative comparison of all experiments done can be found in Table 1.

One fact should be considered all the time: We do not know whether the primary space magnetization component is present and if so, how strong and stable it is! Due to this fact the most stable component can be the extraterrestrial, but it can be also the terrestrial contamination as well. In some cases the whole magnetic record can be of the terrestrial origin (the meteorite comes without magnetic record and/or it is completely terrestrially remagnetised).

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