POSSIBLE DEMAGNETIZATION BY SHOCK DURING THE SANTE FE CRATER FORMATION

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Introduction: The Santa Fe impact structure is partly within metamorphosed Proterozoic granitoid (1.7 – 1.4 Ga) about 8 km northeast of Santa Fe, New Mexico, USA. Well-developed shatter cones that contain shocked quartz [1] confirm that this granitoid was modified by shock pressure during the impact event [2.3]. While the shatter cones indicate location of a remnant of the central uplift of the impact structure, there is no other supporting morphological evidence for crater features, and thus estimates of crater diameter (6–13 km) are poorly constrained [2]. Occurrence of zircons in the impacted area place constraints on a maximum crater age of < 1.5 Ga [1]. Shock planar deformation features were reported from apatite [4], xenotime and muscovite crystals. The motivation of this study was to investigate the Natural Remanent Magnetization (NRM) of impacted rocks as a result of the shock delivered by meteorite impact. While recent work on impacted material (mostly impact-generated glass) studied primarily induced magnetization [5] the magnetic remanence record may provide more detailed insight into the impact history [7]. We assume that rocks were previously magnetized in a geomagnetic field. Information about the paleomagnetic field intensities can be recorded in the samples' NRM. Elaborated methods were designed to obtain values of such paleofields by analyzing NRM without heating [7] [8]. Rock samples, in general, have NRMs that depends on magnetic minerals, their grain size, aspect ratio, strain and [9] [10] [7].

Material: We collected two large, unoriented rock fragment (2 kg, 0.5 kg respectively) from the granitoid that contained shatter cone features, GPS approximately 35°43'54''N. Lat., -105°56'27'' W. Long, Santa Fe Country, New Mexico, USA. Specimen with 27 subsamples, and 18 subsamples. Samples were cut by a non-magnetic, water-cooled saw blade into multiple cubes (8 cm3). Each of the cubes was marked by two different types of arrow in order to preserve the respective orientation within the cubes. Each of the cubes weighed about 21 g.

Method: Measuring was execute in Department of Paleomagnetism, Pruhonice Research Centre, Institute of Geology of the Czech Academy of Sciences, v. v. i.. We used a non-magnetic plastic holder and measured the Natural Remanent Magnetization (NRM) using a rotating sample magnetometer JR6 (AGICO Inc.), operating in the center of a Helmoltz coil system, thereby minimizing the ambient field down to 100s of nanoteslas. Each sample was step-wise demagnetized using alternating fields of 3, 5, 7, 10, 15, 20, 25, 30, 40, 50 A/m and the remaining remanent magnetization measured after each demagnetizing step. Once the sample was demagnetized by 50 A/m and measured, it was exposed to a 1 T pulsed magnetic field at room temperature in the direction of the original NRM. This process saturated our samples with the maximum remanent magnetization, called Saturation Isothermal Remanent Magnetization (SIRM). Once saturated, samples were step-wise exposed to alternating fields of 3, 5, 7, 10, 15, 20, 25, 30, 40, 50 A/m and measured.

Results and Discussion: Measurements of magnetic remanence were obtained for both directional stability of magnetic remanence as well as for detection of magnetic paleointensity.

Preserving the magnetic orientation during subfragmentation of the hand specimen collected from the same shatter cone-bearing rocks at Santa Fe allowed us to identify the direction of magnetic remanence. While there is experimental and observational evidence that an impact can in some cases generate magnetic remanence acquisition [11], our directional analyses, which show ~120 degree cone cluster in the direction of today's magnetic field, indicate that these rocks contain only soft magnetization induced by prolonged residence in a geomagnetic field. When the soft component was removed by demagnetization, the spread of magnetic directions kept widening until reaching a full 360 degrees. Although this randomization can be achieved by pulverization and subsequent conglomerization this is not the case here as the rock is an equigranular granitoid of Paleoproterozoic age[12]

Shock by impact processes is discussed in the literature as generating a Shock Remanent Magnetization (SRM) [11] [13] It was shown that SRM may be acquired in shocked samples even with an ambient field present [13]. Such magnetization is acquired more efficiently in lower magnetic coercivity grains [13]. Assuming that the SRM is present in the Santa Fe samples, this component would have to be less than 10% of the original magnetization.

Demagnetization by an alternating field in the Santa Fe samples shows that if the SRM were present it would affect the soft component more than the hard component of magnetization. Indeed, we see that while the soft component is ~ 10 percent of the original NRM, the detection of slightly larger paleofield when magnetically cleaning with alternating magnetic fields smaller than 10 mT indicates that it may be present. This component, however, competes with the viscous overprint that may be present in the Santa Fe rocks. The viscous component can also affect the soft magnetic component [14], but in contrast to SRM, this component would be parallel to the present ambient field while SRM, in principle, is directed parallel to the field present at the time of impact [13] [15]. While both viscous and shock components may be present in combination, they would affect only the low coercivity grains, which show vague clustering. The high coercivity magnetization would remain intact, as indicators of shock demagnetization potentially by impact.

The directional randomness observed in our samples and substantial decrease in magnetic intensity is consistent features of superparamagnetism frozen in time [16] [17]. The shock wave provides energy that exceeds the energy required to block the magnetic remanence within individual magnetic grains [14]. After the shock wave leaves the material, it blocks the magnetization in randomized directions.

Magnetic directions that were acquired by processes other than SRM or LRM must have been uniform due to the presence of a uniform geomagnetic field for more than 2 billion of years in the range of tens of microtesla (Smirnov and Evans, 2015). The observation of total randomness of magnetic directions can only be achieved by the passing of a shock wave from an impact process, which facilitated destabilization of magnetic remanence blocking, and freezing the remanence of individual grains in random directions. There is no other process in nature known to us that would allow such randomization while being exposed to the geomagnetic field. If this magnetic feature is shown to be present in rocks affected by other known impact events, this feature would become a new impact characteristic, and for the purpose of this work we call it "Demagnetization by Shock (DS)".

Conclusions: A new method [7] was used to estimate paleofields from the rocks containing large shatter cones and shock minerals due to a significant meteorite impact [3]. Paleofield estimates are based on the properties of hematite that constrain the material constant in equation (10) to 13 microT. In addition to the observation of random magnetization directions within the oriented samples, we show that each of these individual subsamples underwent DS, and thus contains a paleofield that was reduced by more than an order of magnitude from the intensity that would be expected if acquired by a geomagnetic field [7]. The possible inherited existence of DS within the shocked material has implications for studying magnetism of rocks not only on Earth, but also on Mars and Moon, where many impact craters have magnetic evidence of demagnetization by their impact processes [18] [19] [20] [10]. We conclude that if the magnetic characteristics discussed here can be verified by other impact processes, the evidence of demagnetization that was identified as DS, could be used for identifying the substrate rock affected by an impact in the absence of diagnostic indicators, such as crater morphology or shatter cones. We propose that the DS could become a new method for identifying impact structures if it is verified at other known impact sites. The degree of DS we found cannot be achieved by regular igneous/metamorphic rock terrestrial processes within the geomagnetic field.

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