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Rochechouart impact crater melt breccias record no geomagnetic field reversal

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ABSTRACT

Impact melt breccias from the Rochechouart (France) meteorite crater possess paleomagnetic directions with both normal and reverse polarities, raising the question whether shock from the collision initiated a geomagnetic field reversal. Stepwise thermal demagnetization together with a suite of rock magnetic experiments, optical microscopy, Raman spectroscopy and electron microprobe analyses identify adjacent, multiphase, titanohematite in the samples containing normal and mixed polarities—typical of lithologies bearing self-reversal behavior stemming from magnetic exchange interaction. Melt breccias possessing mostly titanium-free hematite as the magnetic remanence carrier have solely reverse-polarity directions, leading to the conclusion that the Rochechouart meteorite impact did not spawn a geomagnetic event. Samples displaying paleomagnetic directions with normal or mixed polarity yield unreliable paleointensity data. 30 samples with reverse polarity that pass stringent data selection criteria from Thellier–Thellier paleointensity experiments with alteration, tail and additivity checks define an average field value of 12.8 ± 3.7 μT. This translates into a virtual dipole moment of $2.7 \pm 0.8 \times 10^{22}$ A m^2, which is relatively low, but within uncertainty of other Mesozoic paleointensity data.

1. Introduction

Meteorite impact craters form common topographic features on several planets and moons in our solar system. They are also found throughout the geologic record on Earth. The energy released during an impact can exceed that of the strongest terrestrial earthquakes by several orders of magnitude, leading one to question whether such events can perturb the magnetohydrodynamic regime in planetary interiors and influence the magnetic field generation process.

Glass and Heezen (1967) first argued that the Australasian microtektite field was deposited during the period coinciding with the last known reversal (Bruhnes–Matuyama) thereby linking changes in the geomagnetic field to a meteorite impact event. Durrani and Khan (1971) suggested that the slightly older Ivory Coast microtektite field was deposited just above the base of a brief magnetic chron known as the Jaramillo event. Further drilling in the Atlantic Ocean led Glass and Zwart (1979) to conclude that the Ivory Coast microtektite field was four times larger than previously thought. They correlated the tektite layer with the beginning of the Jaramillo event.

The association of meteorite impacts with geomagnetic field reversals led several workers to explore how an impact event could perturb the geodynamo (see Schwarzschild, 1987, for an overview). Won and Kuo (1973) worked out the conditions for which the solid inner core begins oscillating from translational motion due to an earthquake. They found that a magnitude 8.8 earthquake (10^{18} J of energy released) would provoke an inner core oscillation with an amplitude of 58 cm. The amount of inner core oscillation required to modify the magnetohydrodynamic regime in the outer core is unknown.

Muller and Morris (1986) postulated that the link between impacts and geomagnetic perturbation occurred through climate change. They calculated that if sea level fluctuations were large ($\geqslant$10 m) and rapid (few hundred years) enough before adjustments in the moment of inertia could take place, then shear would occur between the Earth's mantle and its solid core, which would deform convection cells in the liquid outer core and influence the Earth's magnetic field. Their scenario predicts that the dipole component of the geodynamo would diminish with a concomitant increase in multipole components, which are characteristics of field reversals and transitions. Pal and Creer (1986) performed a statistical analysis of field reversals and found a correlation with episodes of bombardment. Like Muller and Morris (1986), and later Burek and Wänke (1988), Pal and Creer (1986) postulated that meteorite impacts would create turbulence in the outer core leading to lower field strength and a departure from axial symmetry, consistent with reversal models. Roberts et al. (2009) proposed that bombardment by very large meteorites producing craters >2500 km in diameter could have completely stopped the Martian dynamo.

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Loper and McCartney (1990) computed that dynamical coupling between the core and mantle is too strong to allow large angular displacements to occur and thus refuted the extraterrestrial origin models for field reversals of Muller and Morris (1986) and Pal and Creer (1986). Rice and Creer (1989) calculated that shock spallation, either at the core-mantle or inner–outer core boundaries, would not provide enough energy to significantly disturb the geomagnetic field. More detailed work on the Australasian and Ivory Coast microtektite fields, including a more detailed examination of sedimentation rates, led to further pessimism. Schneider and Kent (1990) and Glass et al. (1991) found the Ivory Coast field was laid down at least 8 kyr after the Jaramillo event started and 40 kyr before it ended, indicating that the impact responsible for the Ivory Coast tektites was not causally related to the Jaramillo polarity subchron. Burns (1990), de Menocal et al. (1990) and Schneider et al. (1992) placed the deposition of the Australasian microtektite layer 12–15 kyr before the Bruhnes–Matuyama polarity reversal, leading Schneider et al. (1992) to conclude against a casual link between impacts and geomagnetic reversals. Hartl and Tauxe (1996) subsequently found a global decrease in paleointensity approximately 15 kyr prior to the Bruhnes–Matuyama reversal, suggesting that it may have commenced earlier than previously thought—precisely at the time when the Australasian microtektites were deposited.

Tektite production represents only a small fraction of the material created/expulsed during meteorite impacts, whereas a much larger volume of the target rocks is heated, often melted, and deposited near the crater. For this reason, a more straightforward test for a relationship between meteorite impacts and geomagnetic field changes can be performed by examining the thermal remanent magnetization of the melt rocks and impact breccias (suevites) acquired during cooling through the Curie temperatures of the magnetic minerals after the impact. In a study of the ca. 15 Ma Ries crater (Germany), Pohl (1977) found that suevites had reverse polarities while sediments deposited on top of the suevites had normal polarities, leading to the suggestion that the impact may have triggered a field reversal. Paleointensity determinations on the suevite and impact melts from Ries yielded a virtual dipole moment of $3.2 \pm 0.2 \times 10^{22}$ A m^2 (Koch et al., 2012). Although relatively low, it is indistinguishable from the global paleointensity database between 20 and 10 Ma. A very small dispersion in magnetization directions (Pohl, 1977), together with limited variation in paleointensity, led Koch et al. (2012) to conclude that either the energy released from the Ries impactor was too small to affect the geodynamo, the Ries impactites cooled too fast to record any effect on the geodynamo and secular variation was not averaged, or the Ries impactites cooled slowly enough to record secular variation, but the geodynamo was remarkably stationary over secular variation time scales, either naturally or due to the impact.

In order to further examine the potential connection between geomagnetic disturbances and impact events, we now focus on the Rochechouart (France) meteorite crater where Carporzen and Gilder (2006) previously identified antipodal (normal and reverse) magnetization directions in the impact breccias. We collected new samples specifically to test the existence of a geomagnetic field reversal. In addition to stepwise thermal demagnetization, the samples were subjected to a suite of rock magnetic analyses and Thellier–Thellier paleointensity experiments.

2. Geological setting and sampling

Located in west-central France (Fig. 1), the Rochechouart structure is a heavily eroded crater with no morphological expression, yet possesses a negative Bouguer anomaly 26–28 km in diameter centered on the impact-related lithologies (Pohl and Ernstson, 1994). Its maximum possible original size was estimated by

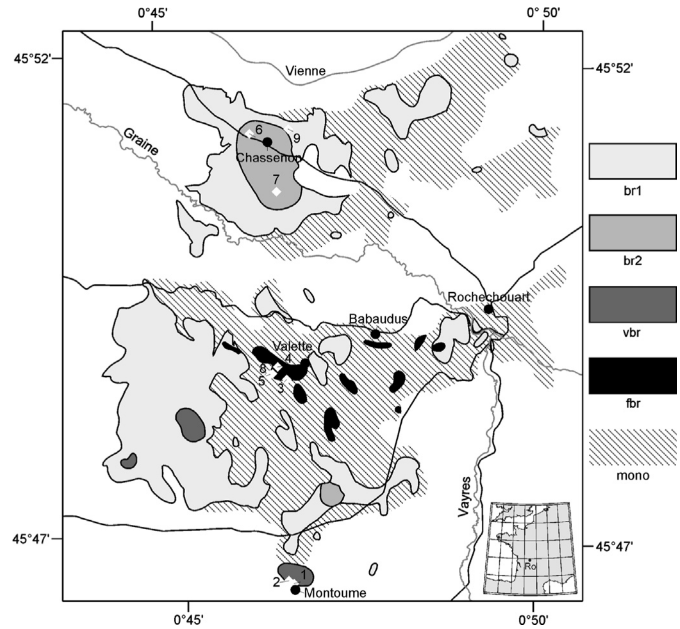

Fig. 1. Locality and geologic map of the Rochechouart crater region (after Chèvremont et al., 1996) in western France (Ro in inset). Numbers are the sampling sites from this study. Abbreviations for the geologic units are: br1 – polymict, lithic breccia with no glass; br2 – polymict, lithic, glass-bearing breccia (Chassenon type suevite); vbr – red, melt-rich breccia (Montoume type suevite); fbr – polymict breccia with high degree of melting (Babaudus type suevite); mono – momomict breccia and cataclastite.

Lambert (2010) in the 40–50 km-diameter range based on comparison with other craters. The presence of impact breccias, planar deformation features and shatter cones all attest that the area was struck by a bolide (Kraut and French, 1971; Lambert 1974, 1977a, 1977b; Reimold et al., 1984; Bischoff and Oskierski, 1987). Diaplectic quartz glass found in the crater indicates maximum shock pressures exceeded 35 GPa (Trepmann, 2008). Assuming a minimum diameter of 26–28 km for the Rochecouart crater, the impact energy would be on the order of 10^{22} J, which translates into a radiated seismic magnitude of $\sim$9.0 based on the relation that the seismic energy equals 10^{-4} of the impact energy (Pierazzo and Melosh, 2013).

Several workers have dated the structure, yet those using the Ar–Ar technique are likely the most precise. $^{40}Ar/^{39}Ar$ laser spot fusion dating of pseudotachylite from the Champagnac quarry yielded a matrix age of 214 ± 8 Ma (Kelley and Spray, 1997). $^{40}Ar/^{39}Ar$ step heating of potassium feldspar from shocked gneiss yielded two plateau ages of 201 ± 2 Ma (Schmieder et al., 2010). Three types of impact breccia (suevite), classified by increasing degrees of melting, are identified at Rochechouart: Chassenon, Montoume and Babaudus (Lambert, 1974, 1977b; Chèvremont et al., 1996), with thicknesses ranging from a few meters up to 50–70 m (Lambert, 2010). Pohl and Soffel (1971) reported paleomagnetic results from the Chassenon and Montoume type suevites, while Carporzen and Gilder (2006), from the Montoume and Babaudus types. Chassenon and Montoume suevites yielded reverse-polarity magnetizations and Babaudus, normal-polarity magnetizations.

We collected 71 cores from nine sites with a gas-powered drill and oriented them using magnetic and, whenever possible, sun compass measurements with an automated orientation sensor linked to a small portable computer (Wack, 2012). The average measured magnetic declination anomaly of $-0.3° \pm 2.2°$ ($N = 31$) conforms well to that predicted by the international geomagnetic reference field ($-0.8°$). Only nine samples from the Fonceverane Forest (near the village of Valette, Fig. 1) were found to possess normal polarities by Carporzen and Gilder (2006), so