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Asteroid impact vs. Deccan eruptions: The origin of low magnetic susceptibility beds below the Cretaceous–Paleogene boundary revisited

Alexandra Abrajevitch[a,*], Eric Font[b], Fabio Florindo[c], Andrew P. Roberts[d]

[a] Institute of Tectonics and Geophysics, Kim-Yu-Chen 65, Khabarovsk 680000, Russia
[b] IDL-FCUL, Instituto Dom Luís, Faculdade de Ciências, Universidade de Lisboa, Campo Grande, 1749-016, Portugal
[c] Istituto Nazionale di Geofisica e Vulcanologia, Via di Vigna Murata 605, 00143-Rome, Italy
[d] Research School of Earth Sciences, Australian National University, Canberra, Acton 0200, Australia

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ABSTRACT

The respective roles of an asteroid impact and Deccan Traps eruptions in biotic changes at the Cretaceous–Paleogene (K–Pg) boundary are still debated. In many shallow marine sediments from around the world, the K–Pg boundary is marked by a distinct clay layer that is often underlain by a several decimeter-thick low susceptibility zone. A previous study of the Gubbio section, Italy (Lowrie et al., 1990), attributed low magnetization intensity in this interval to post-depositional dissolution of ferrimagnetic minerals. Dissolution was thought to be a consequence of downward infiltration of reducing waters that resulted from rapid accumulation of organic matter produced by mass extinctions after the K–Pg event. We compare the magnetic properties of sediments from the Gubbio section with those of the Bidart section in southern France. The two sections are similar in their carbonate lithology and the presence of a boundary clay and low susceptibility zone. When compared to background Cretaceous sediments, the low susceptibility zone in both sections is marked by an absence of biogenic magnetite, a decrease in total ferrimagnetic mineral content, and a preferential loss of magnetite with respect to hematite – features that are consistent with reductive dissolution. However, unlike the Gubbio section, where the low susceptibility zone starts immediately below the boundary clay, the low susceptibility zone and the clay layer at Bidart are separated by a ∼4-cm carbonate interval that contains abundant biogenic magnetite. Such separation casts doubt on a causal link between the impact and sediment bleaching. More likely, the low susceptibility layer marks a different environmental event that preceded the impact. An episode of increased atmospheric and oceanic acidity associated with Deccan Traps volcanism that occurred well before the K–Pg impact is argued here to account for the distinct magnetic properties of the low susceptibility intervals.

1. Introduction

The Cretaceous–Paleogene boundary (K–Pg) marks the end of the Mesozoic Era and the beginning of the Cenozoic Era, is characterized globally by a major mass extinction event (e.g., Raup and Sepkoski, 1986; MacLeod et al., 1997), and is one of the best-studied time intervals in Earth history. Two major catastrophic events, the Chicxulub asteroid impact and the Deccan Traps eruptions, have been implicated in complex climatic changes that culminated in the mass extinction, but their respective roles are still much debated (e.g., Schulte et al., 2010; Courtillot and Fluteau, 2010; Renne et al., 2013; Keller, 2014).

Since discovery of an iridium (Ir) and other platinum-group elements anomaly at the K–Pg boundary clay at Gubbio, Italy, the impact hypothesis formulated by Alvarez et al. (1980) has become firmly entrenched in the popular and scientific literatures. In addition to its great imaginative appeal, with dinosaurs wiped out in a single day in a ball of fire caused by a meteorite impact, the impact hypothesis is supported by the presence of impact-derived microtektites, shocked quartz grains and Ni-rich spinels in K–Pg boundary deposits (e.g., Sharpton et al., 1993; Robin et al., 1993; Smit, 1999; Arenillas et al., 2006), as well as by discovery of a giant impact crater on the Yucatán Peninsula, Mexico (Hildebrand et al., 1991; Gulick et al., 2013). As recently as 2010, an international panel of scientists singled out the Chicxulub impact as the ultimate cause of the end-Cretaceous extinction (Schulte et al., 2010).

Despite evidence for an end-Cretaceous bolide impact, this hypothesis fails to explain the selective nature of the K–Pg mass

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[*] Corresponding author.
E-mail address: alexandra.abrajevitch@gmail.com (A. Abrajevitch).

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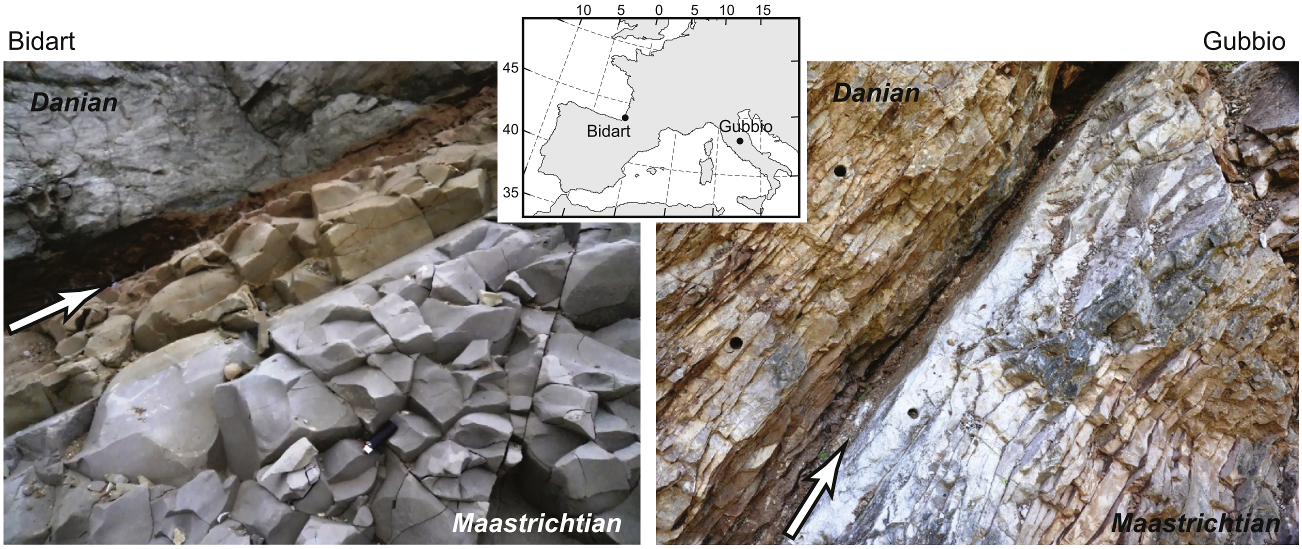

Fig. 1. Location and field photographs of the Gubbio and Bidart sections. Arrows indicate the base of the boundary clay layer (formal K–Pg boundary). Scales: disposable ~8-cm cigarette lighter (Bidart) and standard ~2.5-cm diameter paleomagnetic drill-cores (Gubbio).

extinction (Archibald and Bryant, 1990; Keller et al., 1996), its geographically variable patterns (e.g., Keller et al., 1993), and a long-term decline in species diversity prior to the K–Pg boundary (e.g., Marshall and Ward, 1996; MacLeod et al., 1997). Mounting evidence that the end-Cretaceous mass extinction was the result of a complex multi-event catastrophe brought about by the coincidence of major climate fluctuations, volcanism and impacts (Keller, 2014) warrants re-evaluation of the impact hypothesis to explain geological observations around the K–Pg transition interval.

The Global Stratotype Section and Point for the K–Pg boundary was selected by the International Commission on Stratigraphy (ICS) at a section near El Kef, Tunisia. The boundary is primarily defined by a lithologic marker – the boundary clay layer with the 2–3 mm oxidized layer at the base that contains a peak of Ni-rich spinel and an Ir anomaly (Molina et al., 2006). Formally, the K–Pg boundary is placed at the base of the boundary clay layer. According to the ICS definition, Ni-rich spinels and an Ir anomaly in the boundary clay are interpreted as impact ejecta features, so formation of the boundary clay is regarded as a consequence of an asteroid impact (Molina et al., 2006).

In many marine sedimentary sequences, the distinctive boundary clay layer is often underlain by a several decimeter-thick zone with low magnetic susceptibility (e.g., Lowrie et al., 1990; Ellwood et al., 2003). This low susceptibility interval roughly corresponds to the CF1 and CF2 biozones that contain dramatic changes in planktic foraminifera, nanno- and macro-fossils that led to the K–Pg boundary extinction and is roughly coincident with the timing of the Deccan Phase-2 eruptions (Thibault and Gardin, 2010; Keller et al., 2010; Keller, 2014; Gertsch et al., 2011; Font et al., 2014; Schoene et al., 2015). A widely-accepted interpretation for the origin of the low susceptibility zone (LSZ) was proposed by Lowrie et al. (1990) for the Gubbio section in Italy. These authors attributed the low magnetization intensity in the white beds to post-depositional dissolution of ferrimagnetic minerals. Dissolution is thought to be a consequence of downward infiltration of reducing waters that resulted from rapid organic matter accumulation produced by mass extinctions after the hypothesized impact. In this study, we test this interpretation by comparing the magnetic properties of sediments from the Gubbio section, central Italy, to those from another well-studied carbonate section that contains the complete K–Pg transition interval, the Bidart section in France.

2. Sampling

2.1. Gubbio section

The classic K–Pg transition interval occurs within a well-exposed section of the Scaglia Rossa Formation in Bottaccione gorge near the town of Gubbio in the Umbrian Apennines, Italy (Fig. 1). The Scaglia Rossa Formation mostly consists of bedded red and pink limestones, with Maastrichtian sediments having lighter shades of red compared to Danian sediments. An approximately 0.50-m-thick interval composed of white limestone occurs just below the K–Pg boundary (Fig. 1). The boundary is marked by a 1–2-cm-thick boundary clay layer with anomalously high Ir concentration (Alvarez et al., 1980) and shock-metamorphosed minerals (Montanari et al., 1983; Crocket et al., 1988) that have been interpreted as providing evidence for collision with a large Earth-crossing asteroid (Alvarez et al., 1980).

The distinct bedded appearance of the Scaglia Rossa Formation is due to rhythmic alternation of thin (usually <20 cm thick) limestone beds and thin (a few mm) shale partings. Limestone beds mostly consist of calcareous nannofossils with ~5% aeolian clay (Lowrie et al., 1990). The limestone beds have stylolites and calcite veins that indicate partial calcite dissolution, but undisturbed fossils suggest that pervasive recrystallization has not occurred (Arthur and Fisher, 1977). Shale partings have lower carbonate contents (>60% on average, e.g., Rocchia et al., 1990), and higher concentrations of terrigenous (aeolian) clay and silt (Arthur and Fisher, 1977). Formation of bedding in carbonate sequences is generally not well understood. By analogy with siliciclastic sequences, rhythmic alternation of limestone and shale is conventionally interpreted as reflecting variations in carbonate productivity due to changes in the amount of incoming solar radiation caused by variation of the Earth's orbit. Recent studies, however, suggest that limestone and shale layers may form in carbonate successions as a result of differential diagenesis involving complex carbonate dissolution–reprecipitation processes, differential compaction, and passive enrichment–dissolution of inert non-carbonate components (e.g., Bathurst, 1972; Ricken, 1986; Westphal, 2006; Westphal et al., 2010).

Arthur and Fisher (1977) presented clear evidence that the Scaglia Rossa Formation has been affected by differential diagenesis. They observed systematic trends in detrital elements (Fe, Ti, Si, Al) across bedding couplets, with maximum concentrations