Remarks on the supposed bolid impacts at the T/J boundary in the Corfino Section (Northern Apennines, Italy)

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Key-words: latest Triassic, Rhaetian, Impact Event, foraminifers, Northern Apennines.

ABSTRACT: In 1991, American scientists found "shocked" quartz grains, indicating extraterrestrial bolide impacts, near Corfino (Northern Tuscany) in shaly beds at the boundary between the Rhaetian *Calcare a Rhaetavicula* and the inferred Lower Jurassic (Hettangian) *Calcare Massiccio*. According to our observations of the same section, the top interval of the *Calcare a Rhaetavicula* consists of beds of oolitic grainstone, interlayered with thin levels of marls where the shocked quartz grains were found. In the overlying *Calcare Massiccio* the rock consists mostly of dolomitised and recrystallised mudstone up to about 30 m, where abundant Rhaetian benthic foraminifers occur. The occurrence of shocked quartz in the upper part of the *Calcare a Rhaetavicula* suggests that one or more impact events took place at this time; however, Triassic fossils occur well above the shocked quartz levels and any impact events therefore occurred within the Rhaetian.

INTRODUCTION

The Triassic/Jurassic boundary

The Triassic/Jurassic (T/J) boundary represents a time of major global environmental changes and is associated with one of the five largest mass extinctions of the Phanerozoic, with the loss of about 76% of species (Raup 1992). It is now recognized that this decline took place in several stages through the Late Triassic, culminating in the boundary extinction (*e.g.* Hallam 2002). Mechanisms proposed as causes for the extinction include gradualistic and catastrophic processes (Tanner *et al.* 2004), sea level change (resulting in habitat reduction from regression or anoxia from transgression), climate change, bolide impact leading to an increase in atmospheric opacity, atmospheric effects from large scale volcanism, and catastrophic green-house warming caused by sudden release of methane hydrates from the sea floor.

The impact hypothesis

With regard to a bolide impact, diagnostic evidence in the stratigraphic record includes high-pressure mineral polymorphs (stishovite, coesite), planar deformation features (PDFs) in quartz and feldspar, impact glass (tektites, microtektites), microspherules, Ni-rich spinels, anomalies in iridium and other platinum group elements (PGEs).

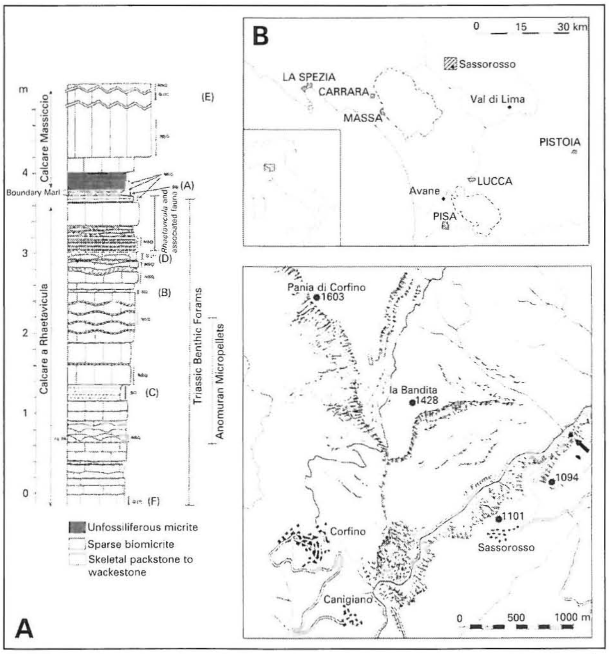

Fig. 1. A – Stratigraphy of the Il Fiume section (from Bice *et al.* 1992); B – topographic map of the Pania di Corfino – Il Fiume Gorge – Sassorosso area; the arrow and black dot indicate the position of the section studied.

Recognition of impacts in the stratigraphic record commonly focuses on the identification of PDFs in quartz (the so-called "shocked quartz"), because they are identifiable with a standard petrographic microscope, although confirmation by SEM or TEM is necessary.

Shocked quartz has been found in the Kendelbach section, Austria (Badjukov *et al.* 1987) and in Italy, in the Corfino section, Northern Apennines (Bice *et al.* 1992). However, these reports, based on petrographic techniques alone, are now considered insufficient for clear identification of shock metamorphism (Grieve, Pesonen 1996).

THE IL FIUME GORGE SECTION (NORTHERN APENNINES)

Previous work

Bice *et al.* (1992) reported shocked metamorphosed quartz grains from three closely spaced shaly beds from the uppermost Triassic ("Rhaetian") *Calcare a Rhaetavicula* (Fig. 1A) in the "section in the Il Fiume Gorge, near the village of Corfino of Northern Tuscany", and suggested "that multiple impacts occurred in the latest Triassic, one of which coincided with a locally, and perhaps globally significant extinction at the T/J boundary". The paper lacks a map or other information useful for identifying the exact position of the section studied.

Geological setting

On both sides of the Il Fiume river, in the Pania di Corfino area (Fig. 1B), the Upper Triassic-Lower Jurassic succession, comprises, in ascending order, the *Formazione della Pania di Corfino*: thick-bedded carbonates, 340 m thick; the *Formazione della Spezia* (= *Calcare a Rhaetavicula Auctt.*): carbonates, marls and shales in beds of variable thickness, 20 m thick (Fazzuoli and Turi 1981; Fazzuoli *et al.*1988) and the *Calcare Massiccio*: massive carbonates, 210 m thick (Fazzuoli 1974).

The *Calcare Massiccio* forms a prominent almost vertical cliff on both sides of the Il Fiume Gorge, but, as the structure of the Pania di Corfino

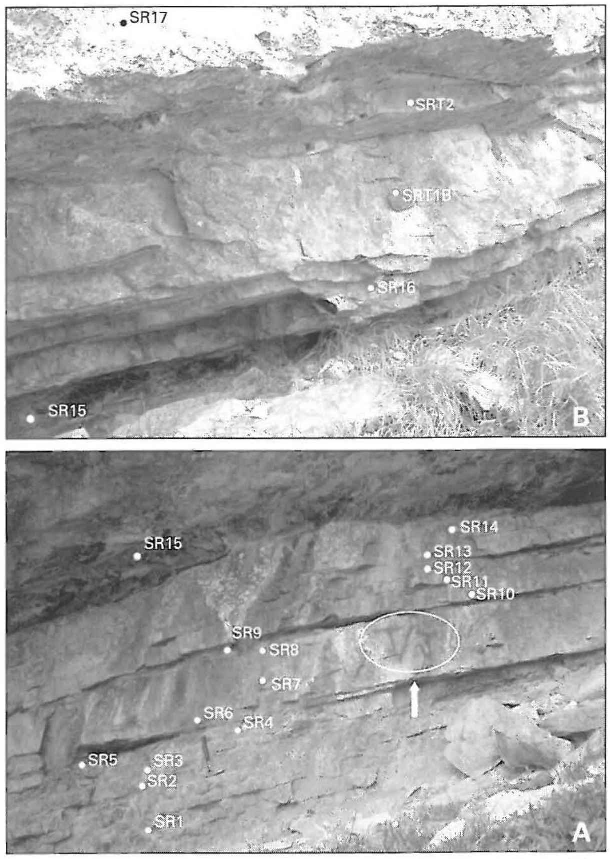

Fig. 2. A – Top of the *Formazione della Spezia* with the position of the samples. The circle and arrow indicate the red T/J mark; B – Base of the *Calcare Massiccio* with the position of samples: =SR 15 indicates the relative position of sample SR15 from the *Formazione della Spezia* in Fig. 2A.

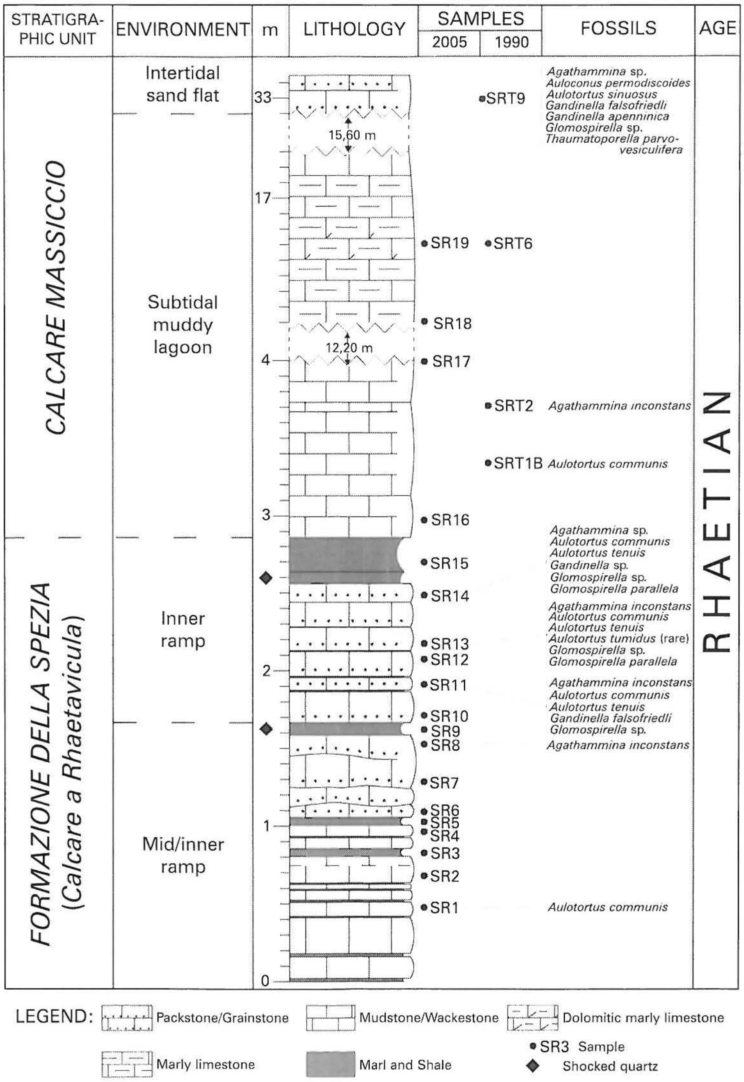

Fig. 3. Stratigraphic sections from the Il Fiume Gorge with the positions of samples taken by Barellini in 1990 (Barellini 1991) and in 2005 (present study).

team, we could not determinate the exact position of their samples, but in all probability this was close to the T/J mark.

We measured and sampled 2.85 m of beds in the upper part of the *Formazione della Spezia*, close to the T/J mark (samples SR1-SR15) (Fig. 2A). Then, as the ceiling of the gallery (corresponding to the base of the *Calcare Massiccio*) is about 2.50 m above the floor at this point, and it was no longer possible to measure and sample, we moved about 20 m to the south-east, following the base of the *Calcare Massiccio*. Here, the uppermost marly bed of the *Formazione della Spezia* still crops out and the morphology of the overlying *Calcare Massiccio* allows the slope to be climbed (Fig. 2B). Here we measured and sampled about 14 m of beds in the upper part of the section (samples SR16-SR19), and from levels marked by the red spots of a previous study of a *c.* 30 m section (Samples (SRT1b, 2, 6 and 9) in the *Calcare Massiccio*, examined by Barellini (1991) (Figs 3, 5). Sample SR19 was taken at the level of the sample SRT6 of Barellini (1991). We also examined the thin sections of Barellini (1991).

A detailed facies description of the section and their environmental interpretation were performed in order to find possible relationships between the bolid impact and the environmental change at the boundary between the *Formazione della Spezia* and the *Calcare Massiccio*.

area is an anticline plunging to the SE, the base of the *Calcare Massiccio* is about 250 m lower on the southern side of the gorge. We identified the stratigraphic section cited by Bice *et al.* (1992) on this side, along the path descending from the village of Sassorosso to the Il Fiume about 1 km from Sassorosso, at a height of 885 m a.s.l (Fig. 1B). This is the only place where the boundary between the *Formazione della Spezia* and the *Calcare Massiccio* is well exposed: the path runs along the highest beds of the *Formazione della Spezia*, which are strongly eroded, forming a gallery below the base of the *Calcare Massiccio*, which overhangs the path by about 4 m. On the wall of the gallery a large T/J is painted in red (Fig. 2A). As there were no other signs of sampling by Bice's

Litho- and biostratigraphy

The upper part of the *Formazione della Spezia* (*Calcare a Rhaetavicula Auctt.*) consists of an alternation of carbonate (mostly limestone and dolomitic limestone) beds and thinner marly levels. The lower part of the section studied comprises, in ascending order:

a) 1 m of dark grey bioclastic wackestone beds alternating with bioclastic packstone beds (storm layers), both 5 to 30 cm-thick, and with marly shales, 2 to 5 cm thick. The bioclasts in the wackestone are radiolarians, benthic foraminifers (*Aulotortus communis* Kristan) and ostracods; those in the packstone are mainly pelecypods. Silt-sized quartz grains and Fe-oxide are rather abundant. The minerals in the marly levels are illite-muscovite, chlorite, calcite, ankerite and quartz.

The depositional environment was a transition from mid to inner ramp (*sensu* Burchette and Wright 1992).

b) 1,85 m of 8 to 30 cm-thick beds of dark grey bioclastic packstone/floatstone passing upwards into oolitic grainstone, interlayered with three cm-thick levels of marl; another 30 cm-thick marly level (sample RS 15) forms the top of this unit. The bioclasts in the packstones/floatstones are mainly pelecypods and minor benthic foraminifers; those in the grainstones are benthic foraminifers, present both as the nuclei of the ooids and as loose grains. The fauna is very rich and consists of: *Agathammina* sp., *Agathammina inconstans* (Kristan-Tolmann and Tolmann), *Aulotortus communis* (Kristan), *A. tenuis* (Kristan), *A. tumidus* (Kristan-Tolmann), *Gandinella* sp., *Gandinella falsofriedli* (Salaj, Borza and Samuel), *Glomospirella* sp. and *G. parallela* (Kristan-Tolmann). The minerals in the marly levels are illite-muscovite, chlorite, calcite, ankerite and quartz. According to Bice *et al.* (1992), the shocked quartz grains were mainly found in these marly levels (*cf.* Fig. 1A). The depositional environment was a inner ramp.

c) The uppermost marly level is overlain by the *Calcare Massiccio* (massive limestone). In this the lower 110 cm is slightly bedded (Fig. 3) and consists of mudstone with silt-sized quartz grains; a bioclastic wackestone/packstone level with *Aulotortus communis* (sample SRT1B; Fig. 4D) is present in the middle part. Upwards the rock is massive, probably through pervasive bioturbation, and also consists of mudstone, more or less dolomitized, with rare and recrystallized bioclasts (benthic foraminifers: *Aulotortus communis*, *Agathammina inconstans*). The depositional environment was a subtidal muddy lagoon within a carbonate platform. Between 12 and 14 m above the base, the limestone is rather bedded, slightly dolomitic and marly. About 30 m above the base of the *Calcare Massiccio* is a unit of fenestral bioclastic, cortoidal and intraclastic grainstone/packstone (Sample SRT 9, Fig. 4E); this is possibly an intertidal sand flat deposit. In this level abundant Rhaetian benthic foraminifers (*e.g. Agathammina* sp., *Auloconus permodiscoides* (Oberhauser), *A. sinuosus* (Weynshenk), *Gandinella apenninica* (Ciarapica and Zaninetti), *G. falsofriedli* and *Glomospirella* sp.) occur together with *Thaumatoporella parvovesiculifera* (Raineri) (Fig. 3).

On a regional scale, fossil assemblages with *Triasina hantkeni* Majzon, *Griphoporella curvata* Guembel, *Gandinella falsofriedli, etc.*, have also been found within the *Calcare Massiccio* at Avane (Fazzuoli *et al.* 1988) and in the Lima Valley (Val di Lima) (Mannori 1991) (Fig. 5).

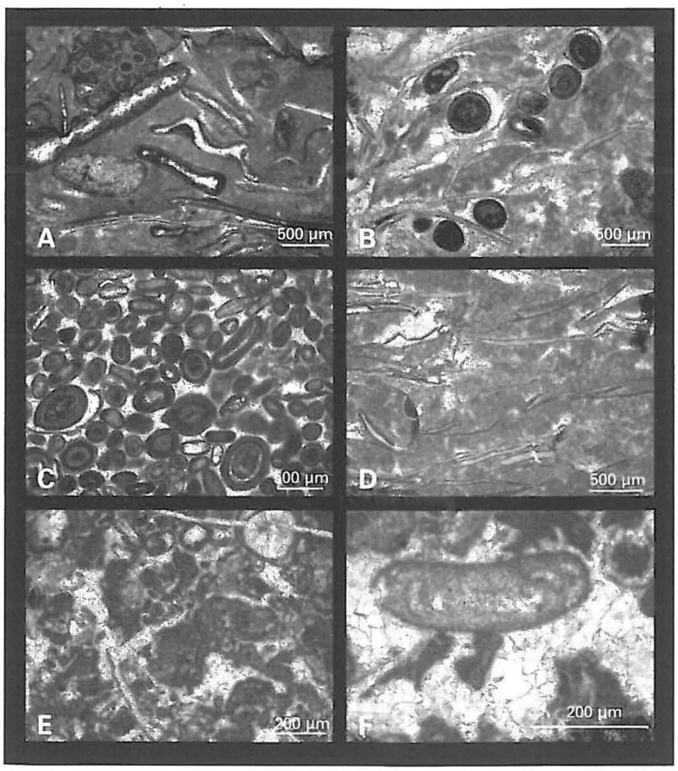

Fig. 4. A – Sample SR6: packstone/floatstone with bioclasts (pelecypods, gastropods), intraclasts, cortoids, ooids, faecal pellets, silt-sized quartz grains; B – Sample SR7: packstone/floatstone with bioclasts (pelecypods, gastropods), ooids, faecal pellets; C – Sample SR13: grainstone with ooids and bioclasts (pelecypods, benthic foraminifers: *Aulotortus communis*, *A. tenuis*, *A. tumidus* (rare), *Glomospirella* spp., *G. parallela*, *Agathammina inconstans*); D – Sample SRT1B: wackestone/packstone with bioclasts (pelecypods, benthic foraminifers: *Aulotortus communis*, *Frondicularia* sp.), faecal pellets; E – Sample SRT 9: fenestral packstone/grainstone with intraclasts, cortoids, bioclasts (benthic foraminifers: *Auloconus permodiscoides*, *Agathammina* sp., *Gandinella falsofriedli*, *Glomospirella* sp., *Aulotortus sinuosus*, Textulariidae, *Valvulina* sp.; algae: *Thaumatoporella parvovesiculifera*), pellets; F – Sample SRT 9: *Aulotortus sinuosus*.

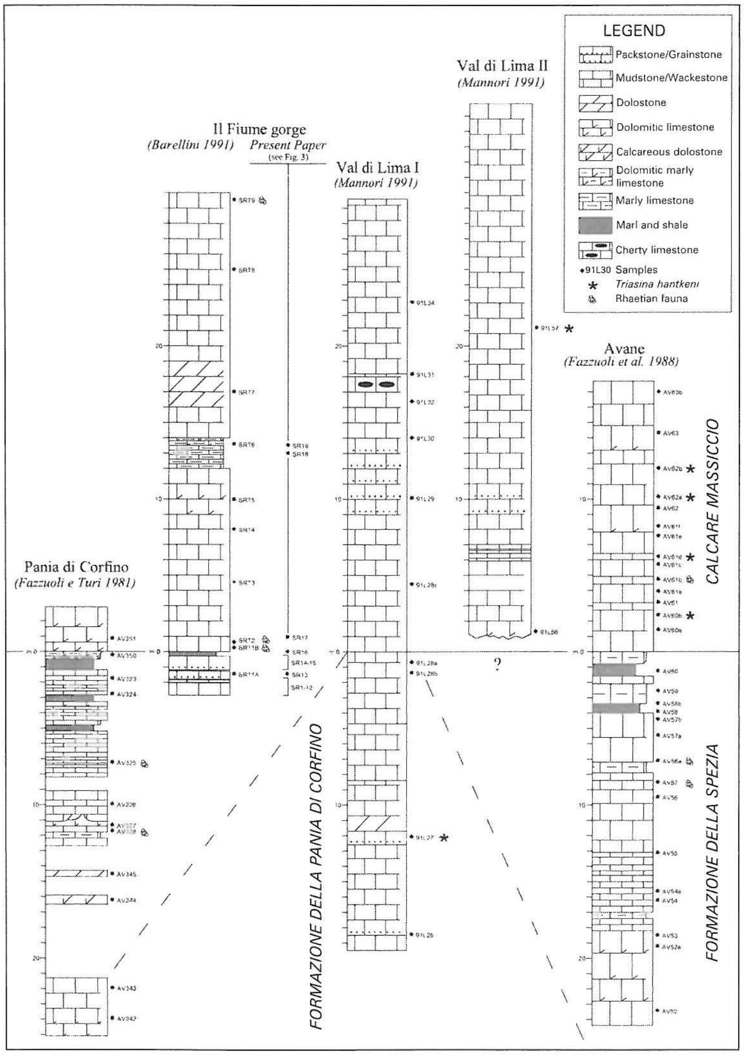

Fig. 5. Sections of the upper part of the *Formazione della Spezia* (or the *Formazione della Pania di Corfino*) and the lower part of the *Calcare Massiccio* in the Il Fiume Gorge region, Val di Lima and Avane (see Fig. 1B).

CONCLUSIONS

All the cited fossils reported from the lower part of the *Calcare Mas*siccio in the Il Fiume Gorge, Avane and Val di Lima sections, indicate a Rhaetian age (Ciarapica and Zaninetti 1984; Mancinelli *et al.* 2005).

In the upper part of the *Formazione della Spezia* the sea level fell and the depositional environment evolved from a mid ramp to a high energy inner ramp and subsequently, in the *Calcare Massiccio*, to a subtidal and then intertidal lagoon within a carbonate platform: the environmental change at the boundary between the *Formazione della Spezia* and the *Calcare Massiccio* is therefore related to a regressive trend. During this lowstand, as indicated by the shocked quartz, one or more impact events took place. Rhaetian fossils occur well above the levels with shocked quartz levels, and any impact event occurred therefore within the Rhaetian, not at the Triassic/Jurassic boundary. The lithostratigraphic boundary between the *Formazione della Spezia* and the *Calcare Massiccio* does not correspond with the biostratigraphic boundary marked by the disappearance of Rhaetian fossil associations.

Acknowledgements

We thank Gloria Ciarapica and Gert Bloos for the important and constructive suggestions and the anonymous referee that patiently improved the text and the English language. This study was financed by the University of Firenze (Grants ex 60% to M. Fazzuoli), Via G. La Pira 4, 50121 Firenze, Italy.

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