Although nearly all of the unaltered specimens that we examined contained some moganite, six samples known to have been exposed either to surface weathering or to hydrothermal fluids revealed virtually no moganite upon Rietveld refinement. Chalcedony stalactites, jaspers from Precambrian banded iron formations, and the weathered white rinds of agate nodules refined as pure quartz. This observation suggests that either moganite readily recrystallizes to quartz in the presence of water or that moganite has a higher solubility in water than does quartz. Boiling 10 g of powdered chert containing 73% moganite in a flask of water for 2 months at surface pressure induced no measurable change in the relative concentrations of the two phases. However, numerous studies (*16*) have demonstrated that chalcedony is significantly more soluble than macrocrystalline quartz in water. In light of the ubiquitous presence of moganite in chalcedony, we suggest that the higher solubility of chalcedony may be attributed to its moganite component. Our results indicate that moganite is so prevalent in unaltered specimens that its absence in microcrystalline quartz varieties may be useful as an indicator of fluid-rock interactions.

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6. Samples were ground in porcelain mortars under acetone and smeared onto low-background quartz plates, sieved onto glass fiber-filters, or pressed into pack mounts. The data were obtained on a Scintag computer-automated powder x-ray diffractometer with CuKα radiation and an intrinsic-Ge solid-state detector. Counting times ranged from 2 to 10 s per 0.03° step for the 2θ range 3° to 80°. Rietveld refinement was carried out using the computer program DBW3.2 by D. B. Wiles and R. A. Young [*J. Appl. Cryst.* **14**, 149 (1981)] as modified by S. A. Howard. Only data from $28° < 2\theta < 80°$ were used for refinement. Refined parameters included scale factor, background, sample displacement, peak width, peak shape, and unit cell dimensions. Starting unit cell parameters for quartz were taken from A. F. Wright and M. S. Lehmann [*J. Sol. State Chem.* **36**, 371 (1981)], and starting parameters for moganite were taken from Miehe *et al.* (*3*). Final ratios for R_{wp} to expected R_{wp} (where R_{wp} is the agreement index of the refinement) ranged between 1.1 and 2.3, and most values were less than 1.5.
7. Quantitative analysis with Rietveld refinement is outlined by R. L. Snyder and D. L. Bish in *Modern Powder Diffraction*, D. L. Bish and J. E. Post, Eds. (Mineralogical Society of America, Washington, DC, 1989), pp. 101–144.
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24 July 1991; accepted 30 October 1991

Shocked Quartz at the Triassic-Jurassic Boundary in Italy

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Quartz grains that appear to have been shock-metamorphosed occur within three closely spaced shale beds from the uppermost Triassic ("Rhaetian") Calcare a Rhaetavicula in the Northern Apennines of Italy. The upper shale coincides with the abrupt termination of the distinctive, uppermost Triassic *Rhaetavicula* fauna and is overlain by the Hettangian (Lower Jurassic) Calcare Massiccio; no extinctions appear to be associated with the two lower layers, which occur 1.2 and 2.4 meters below the boundary shale. Approximately 5 to 10% of the quartz grains within these layers exhibit one or more sets of planar deformational features whose orientations cluster around the rational crystallographic planes (basal, ω, and π) most commonly observed in shocked quartz. Textural and stratigraphic observations support an interpretation of at least three closely spaced impacts at the end of the Triassic.

The Triassic-Jurassic (T-J) boundary represents one of the five most severe marine extinctions in Phanerozoic history (*1, 2*) and is a time of important terrestrial extinctions (*3–7*). Several groups of marine invertebrates experienced particularly heavy losses. Ammonoids, bivalves, gastropods, and corals suffered high familial extinctions, and conodonts disappeared completely (*8–11*). At the species level, the frequencies of molluscan extinction were exceedingly high; Hallam (*8*) estimated that 92% of northwest European bivalve species became extinct, and fewer than three lineages of ammonoids survived (*8, 12*). As with the other major mass extinctions in Earth history, the cause of the T-J extinctions has been uncertain (*3, 4, 8, 9*). Recent developments supporting one or more asteroid or comet impacts as the primary cause of the Cretaceous-Tertiary (K-T) mass extinctions (*13–16*) have led to speculation that extraterrestrial impacts had a role in other mass extinction events (*17*). In order to investigate the possible connection between the T-J extinctions and a possible impact event, it is necessary to locate the ejecta from the impact within a fossil-bearing stratigraphic sequence, a task made difficult by the apparent scarcity of complete T-J sections (*8*).

In this report, we provide evidence that suggests a contemporaneous relation between impact ejecta and extinctions from a boundary section in the Il Fiume gorge near the village of Corfino in Northern Tuscany. In this region, the T-J boundary is considered to occur at the stratigraphic contact between the uppermost Triassic ("Rhaetic" or upper Norian) Calcare a Rhaetavicula and the Lower Jurassic (Hettangian) Calcare Massiccio (*18, 19*).

At Corfino, Rhaetic limestones consist of two principal facies: about 80% of the section is skeletal packstone and wackestone; the remaining 20% is biomicrite and sparse biomicrite (Figs. 1 and 2A). Calcareous shale is interbedded with the limestone. The skeletal packstone-wackestone facies is abun-

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dant throughout the Rhaetic section and occurs immediately below the boundary shale. This facies contains bivalves, benthic foraminifera, and subordinate echinoderms, gastropods, and rare serpulids. We interpret this facies as representing a fully marine, shallow subtidal habitat that supported a diverse fauna. The biomicrite facies is in mainly the lower part of the Rhaetic section (Fig. 1) and contains rare uniserial foraminifera and anomuran micropellets. The boundary shale is an unfossiliferous micritic shale (Fig. 2B); illite is the principal clay mineral in this and in two prominent lower shales (see Fig. 1).

Immediately above the boundary shale, the first 26 cm of the Hettangian Calcare Massiccio (see Fig. 1) is unfossiliferous,

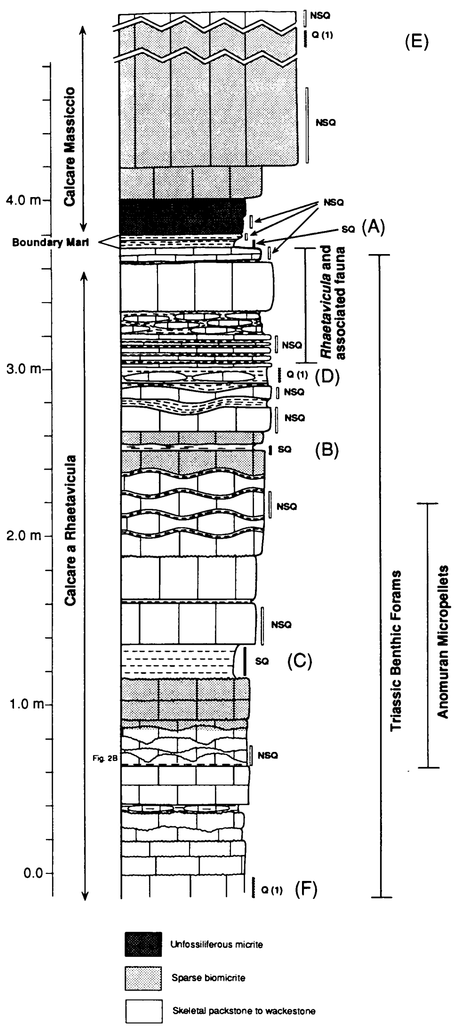

Fig. 1. Stratigraphic column of the section at Il Fiume. Vertical bars to the right of the lithologic column represent sample locations; NSQ means no shocked quartz was found in a sample, Q(1) denotes occurrence of quartz with single sets of lamellae, SQ denotes occurrence of shocked quartz. Letters in parentheses are referred to in text and Figs. 3 and 4. Together, the samples represent approximately 60% of the entire stratigraphic section.

laminated micrite (Fig. 2C). This zone is overlain by sparsely fossiliferous (uniserial foraminifera) biomicrite that grades upward into increasingly fossiliferous rocks. The scarcity of fossils in the lower Calcare Massiccio makes it difficult to date, but Fazzuoli *et al.* (*19*) assigned these rocks to the lower Hettangian.

The bivalve faunas of the Rhaetic limestones are strongly dominated by the characteristic uppermost Triassic bivalve *Rhaetavicula contorta*, along with an associated, dwarfed fauna of other marine bivalves, gastropods, echinoderm plates, and scarce serpulids. Triassic benthic foraminifera are common to abundant; included are the species *Agathammina passerii, Gandinella apennininica*, and *Glomospirella rosetta*, all of which are characteristic of the upper Norian (Rhaetian) sections of central Italy (*20, 21*). The highest stratigraphic occurrence of the *Rhaetavicula contorta* and associated fauna at the Corfino section is the bedding surface immediately below the boundary shale; the Triassic benthic foraminifera, which are less common, extend to within at least 10 cm of the boundary shale. None of the Rhaetic fossils recur in the overlying Calcare Massiccio. There are no clear indications of a hiatus or missing section at the boundary, such as a hardground, evidence of dissolution, or lag deposits.

The paleontologic and sedimentologic observations thus support the hypothesis that the shale marking the contact between the Calcare a Rhaetavicula and the Calcare Massiccio represents the T-J boundary and that there is an abrupt extinction of marine fauna at this boundary. Because ammonoid cephalopods do not occur in the Tuscan T-J sections, there is some uncertainty as to the precise correlation between the Corfino section and the T-J boundary sections in Kendelbach (Austria) and New York Canyon (Nevada, United States). In addition, the lack of fossils in the lowermost Calcare Massiccio makes it difficult to rule out the possibility that the boundary shale is actually in the uppermost Triassic.

We searched the sand-sized fraction of shales and limestones of the Corfino section (sample locations shown in Fig. 1) for shock-metamorphic features in quartz, which are diagnostic of an impact event. We identified three shale layers at the Corfino section that appear to contain shocked quartz grains (Fig. 3)—the lower half of the boundary shale ("A" in Fig. 1) and two shale beds located 1.2 m ("B") and 2.4 m ("C") below the boundary (see Fig. 1).

Each of these three shale layers consists of between 0.5 to 0.1% by weight of sand and coarse silt grains, and these grains can be grouped into two different populations: (i) a dominant population (60 to 80%) of well-rounded to sub-rounded grains of typical detrital minerals, although the mineralogy varies slightly from one layer to another; (ii) sand-sized clasts of angular quartz and minor amounts of angular, unweathered feldspar (found principally in the boundary shale) ranging from about 75 to 250 μm in diameter. Approximately 20 to 30% of the quartz grains from this second population contain what we interpret to be planar deformation features (PDFs) produced by shock metamorphism (Fig. 3); none of the rounded quartz grains displays PDFs.

The PDFs generally appear as very thin (1 to 2 μm), closely spaced (2 to 5 μm) planar zones that are optically discontinuous with the rest of the grain, although in some grains the PDF are decorated with numerous small inclusions or bubbles, making them appear somewhat thicker (up to 5 μm). In most of the grains, the planar features are well de-

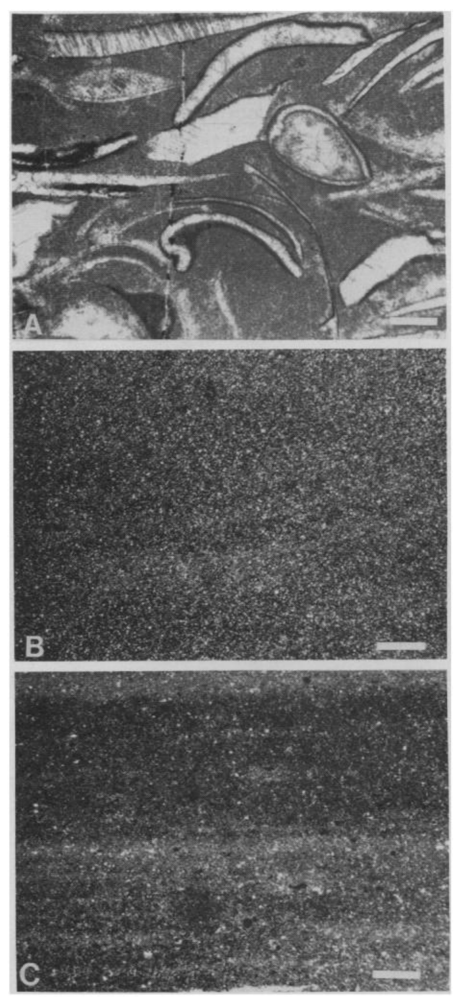

Fig. 2. Photomicrographs of the Il Fiume section. (**A**) Rhaetavicula wackestone from immediately below the T-J boundary; this sample is typical of the wackestone-packstone facies. (**B**) T-J boundary shale, which appears to be unfossiliferous. (**C**) Laminated, unfossiliferous micrite immediately overlying the boundary shale. Scale bar on all photomicrographs is 0.5 mm.

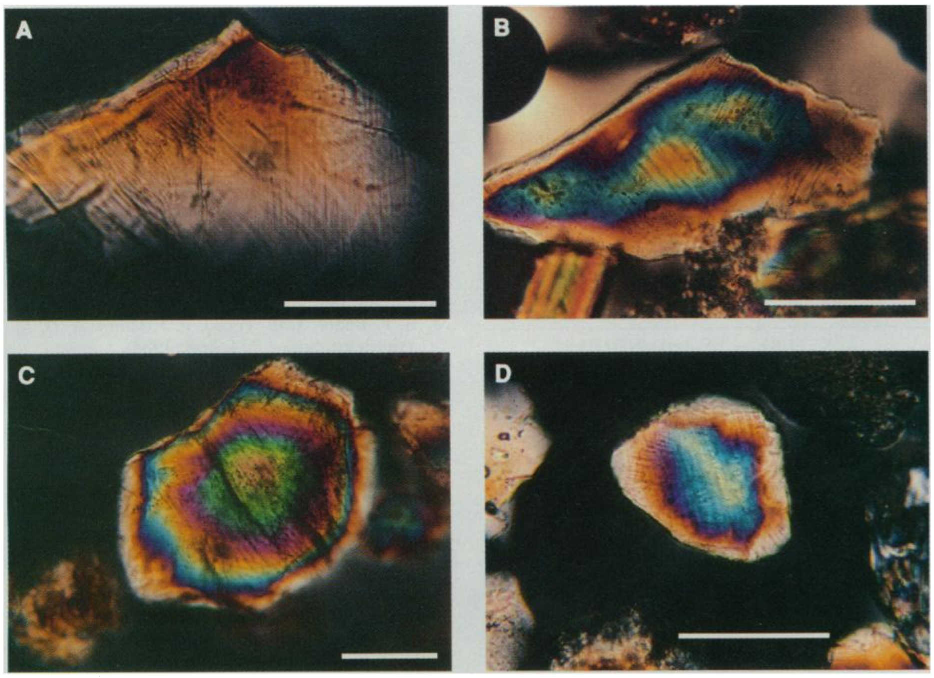

Fig. 3. Representative photomicrographs of suspected shocked quartz grains from the Il Fiume section. (**A** and **B**) Grains with two sets of planar features from theshale layer 2.4 m below the boundary, layer C in Fig. 1. (**C** and **D**) Grains from the boundary shale, layer A in Fig. 1; (C) shows two sets of planar features, (D) shows three sets.

fined, straight, parallel, evenly spaced, and generally extend throughout more than 75% of the grain; they are thus qualitatively similar to PDFs in quartz from the K-T boundary and impact sites (*22–26*). In some grains, however, the planar features are somewhat wavy, unevenly spaced and are not visible throughout the majority of the grain; these planar features may well be tectonically produced deformation lamellae (Böhm lamellae), although PDFs from shocked quartz grains at the K-T boundary occasionally exhibit similar characteristics (*25*).

The orientations of the PDFs in grains from shales A to C are also similar to those of recognized shocked quartz (Fig. 4). In A, the boundary layer, 32% of the quartz grains with PDFs contain two or three sets of PDFs. As shown in Fig. 4A, the majority of the sets (74%) are approximately parallel (±3°) to the basal {0001}, ω{10$\bar{1}$3}, and π{10$\bar{1}$2} crystallographic planes, three of the more commonly observed orientations for shock-generated PDFs in quartz. In contrast, Böhm lamellae are generally considered to show no preference for the basal, ω, and π planes (*27*). The basal, ω, and π orientations are also prominent in PDFs from the grains with multiple sets (Fig. 4A)—the grains most likely to have a shock-metamorphic origin because Böhm lamellae rarely occur in multiple sets (*27*). In the middle shale layer, B (Fig. 4B), approximately 42% of the grains contain more than one set of PDFs; a maximum of four sets is observed; and about 78% of the PDFs are parallel (±3°) to the basal, ω, and π crystallographic planes. In the lowest shale bed, C (Fig. 4C), about 38% of the grains with PDFs exhibit more than one set, and about 67% of the PDFs are parallel (±3°) to the basal, ω, and π crystallographic planes.

These observations of PDF orientations in quartz from the uppermost Triassic are similar to those reported for shocked quartz grains from the K-T boundary (*22–26*), where approximately 80% of the PDFs are parallel to the basal, ω, and π crystallographic planes and the majority of grains contain multiple sets. The principal differences between the grains at the T-J boundary and recognized shocked quartz grains are: (i) the lack of grains with more than four sets of PDFs; (ii) the majority of grains have only single sets; and (iii) the orientations of the planar features are not as tightly clustered around the basal, ω, and π planes, although at least one study of PDFs from grains at the K-T boundary (*25*) shows a more diffuse angular distribution than observed in the grains from the T-J boundary. These differences make it impossible to demonstrate unambiguously that the grains at the T-J boundary have a shock-metamorphic origin, but the observations presented in Figs. 3 and 4 are at least consistent with the hypothesis of a shock-metamorphic origin. An alternative hypothesis would be that these grains contain highly unusual Böhm lamellae that have many of the characteristics of shock-generated PDFs.

We also looked for shocked quartz in the sand-sized fraction of other shale and limestones beds from the section at Corfino (see Fig. 1). We found minor concentrations of quartz grains with single sets of lamellae in a shale layer located 0.7 m below the boundary ("D") and in two limestone beds located 2.6 m above the boundary ("E") and 3.7 m below the boundary ("F"). The absence of any grains with multiple sets and the observation that the single sets are not confined to the basal {0001} crystallographic plane make it unlikely that these grains have been shock-metamorphosed; a tectonic origin is more likely. Thus it appears that the shocked quartz is confined to layers A to C, although not every bed in this section has been

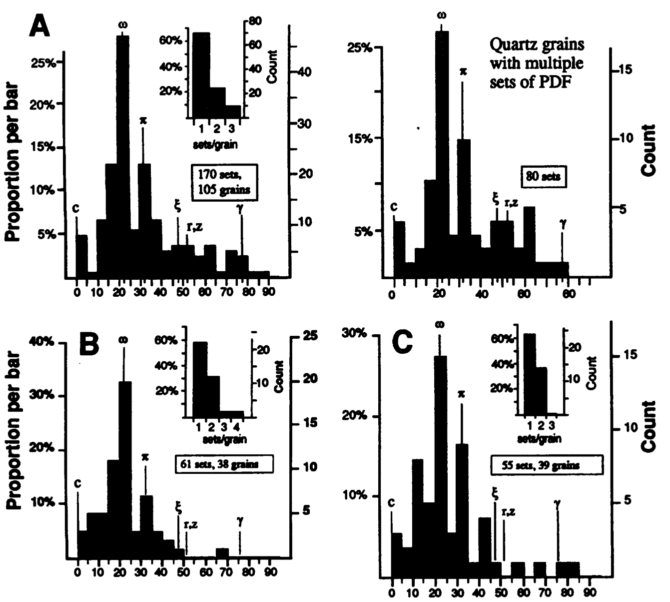

Fig. 4. Histograms showing the orientations of planar deformation features in quartz grains from layers A to C of Fig. 1. In each histogram, the expected orientations of shock-metamorphic PDFs are indicated by vertical bars and labels c, ω, π, ξ, r, z, and γ. The letters (**A**, **B**, and **C**) correspond to the layers identified in Fig. 1; (A) also shows the orientations of PDFs in grains with multiple sets.

searched for shocked quartz (see Fig. 1).

The occurrence of what we interpret to be shocked quartz in several shale beds leads us to suggest 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 abrupt disappearance of the dominant *Rhaetavicula* fauna immediately below a shale containing shocked quartz, followed by an initially barren zone just above the boundary layer is consistent with the interpretation that the extinction was caused by environmental stresses resulting from an impact event. The lower two shale layers containing shocked quartz are in a part of the section where fossils are scarce (Fig. 1); thus, it is difficult to establish whether there were any faunal changes immediately following deposition of these shales, although Triassic benthic forams are found below and above these two lower shale beds.

Although it is possible that reworking of one impact ejecta layer, or normal fluvial transport from a source region with an older impact structure could account for the occurrence of shocked quartz in three layers, the angularity of the shocked quartz in contrast to the roundness of other sand grains and the occurrence of the shocked quartz in three distinct layers are more consistent with the interpretation of a series of impact events. Studies of the same interval from other sites are required to test the hypothesis of multiple impact events and an associated global extinction at the T-J boundary. Badjukov *et al.* (*28*) reported that shocked quartz was present in multiple levels at the T-J boundary at the Kendelbach section in Austria, but Hallam (*9*) was unable to reproduce this finding.

If the multiple-impact hypothesis is correct, then the events surrounding the T-J boundary would appear to fit the model of a comet shower proposed by Hut *et al.* (*29*), in which a perturbation of the Oort cloud results in multiple impacts over a relatively short period of time; an instantaneous perturbation is expected to produce a number of impacts, 75% of which should occur within the first 0.9 million years. It is difficult to estimate confidently the time spanned by the three shocked quartz-bearing shales, but there are at least 250 m of Norian and Rhaetian beds in the Il Fiume gorge, representing about 15 million years. The resulting average rate of accumulation suggests that the beds A to C may span about 150,000 years, well within the expected time of a comet shower (*29*).

At present, there are no good candidate impact structures for the shocked quartz found in the Corfino section. The Manicouagan impact structure in Quebec has been dated at 214 ± 5 million years ago (Ma) (*30*) and would appear to be unrelated to the T-J boundary on the basis of a recent date of 204 ± 4 Ma for the boundary in the Newark Basin (*31*). Several smaller impact structures have dates that overlap the age for the T-J boundary (*32*), but none can be implicated with any confidence, in consideration of the large errors associated with these ages.

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33. Supported by Petroleum Research Fund grant 22784-GB2, the W. Keck Foundation, and the Pew Charitable Trusts (D.M.B., S.M., and P.W.R.), National Science Foundation grant EAR-9016704 (C.R.N. and C.A.M.), and a grant from the Vice President for Research, Syracuse University (C.R.N. and C.A.M.). We thank W. Alvarez, S. Cirilli, G. Ciarapica, M. Fazzuoli, R. A. F. Grieve, A. Hallam, L. Passeri, P. B. Robertson, G. A. Izett, J. L. Macalady, and A. Montanari for help and comments.

24 June 1991; accepted 15 October 1991

Optically Transparent, Electrically Conductive Composite Medium

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The development of an optically transparent yet electrically conductive material made with a composite structure having preferentially arranged conductive paths is described. The medium contains many vertically aligned but laterally isolated chains of ferromagnetic spheres dispersed in a sheet of transparent polymer. The sheet material transmits more than 90 percent of the incident light and is highly conductive only in the thickness direction. When suitably modified, the material exhibits on-off electrical switchability at a certain threshold pressure. These characteristics confer potential usefulness for visual communication devices such as write pads or touch-sensitive screens.

Optically transparent but electrically conductive materials are useful for a variety of visual communication, sensor, or electronic device applications. Transparent materials are in general electrical insulators or high-resistivity semiconductors because they have very low mobile charge carriers. Although some composite materials [such as a glass coated with thin transparent metal or indium–tin oxide (ITO) coating] have both transparency and electrical conductivity, they exhibit only planar conductivity along the surface, and that with relatively high electrical resistivity. A transparent medium with high, through-the-thickness conductivity is potentially useful for a variety of device applications such as write

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