High-precision U-Pb zircon age from the Triassic of Italy: Implications for the Triassic time scale and the Carnian origin of calcareous nannoplankton and dinosaurs

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ABSTRACT

The Triassic time scale is poorly constrained due to a paucity of high-precision radiometric ages. We present a ^{206}Pb/^{238}U age of 230.91 ± 0.33 Ma (error includes all known sources) for zircon from an ash bed in the upper Carnian (Upper Triassic) of southern Italy that requires a major revision of the Triassic time scale. For example, the Norian stage is lengthened to more than 20 m.y. The section containing the ash bed is correlated with other Tethyan sections and, indirectly, with the Newark astronomical polarity time scale (APTS). The dating provides also a minimum age for some important climatic and biotic events that occurred during the Carnian. We note a coincidence between these events and the eruption of the large igneous province of Wrangellia, but the possible link between volcanism and climatic and biotic events requires further scrutiny.

Keywords: geochronology, geologic time scale, Late Triassic, dinosaurs, calcareous nannoplankton, large igneous provinces.

INTRODUCTION

The Late Triassic time scale is based upon a few U-Pb zircon dates, separated by ~40 m.y. between the early Ladinian and the Triassic-Jurassic boundary (see Table 17.2 in Ogg, 2004). The orbitally tuned geomagnetic polarity time scale of the Newark Basin (Kent and Olsen, 1999) is often used to interpolate between tie points in the Upper Triassic. Unfortunately, the Late Triassic time scale has two fundamental problems. First, the Milankovitch forcing of the Newark playa-lake cycles, upon which the orbital tuning of the Newark APTS is based, has never been tested with high-precision geochronology: there is only one published age from the Newark Supergroup, from a caliche deposit biostratigraphically correlated to the Newark APTS (^{238}U/^{207}Pb-^{206}Pb/^{207}Pb isochron age of 211.9 ± 2.1 Ma; Wang et al., 1998). The Triassic-Jurassic boundary is marked by eruption of voluminous basalts associated with the Central Atlantic Magmatic Province (CAMP) that yield numerous Ar-Ar dates centered ca. 200 Ma (Marzoli et al., 1999). The North Mountain Basalt of the Newark Supergroup in Nova Scotia, Canada, that erupted in the earliest Jurassic, is dated by U-Pb zircon geochronology as ca. 201 Ma (Hodych and Dunning, 1992; Schoene et al., 2006). Pálfy et al. (2000) proposed an age of ca. 200 Ma for the Triassic-Jurassic boundary in marine rocks from British Columbia, Canada. Second, the palynostratigraphic correlation between the continental Newark Supergroup and the marine Tethyan realm is problematic, as shown by the extremely different magnetostratigraphic correlations that have been proposed (Channell et al., 2003; Krystyn et al., 2002; Muttoni et al., 2004). New geochronological constraints from the Upper Triassic are needed to reconcile this discrepancy. The U-Pb dating of rhyolite from southern Alaska gave a 225 ± 3 Ma age constrained to be late Carnian–earliest Norian based on conodonts and macrofossils (Gehrels et al., 1987). However, Kozur (2003) suggested that the biostratigraphic constraints adjacent to the dated rhyolite need improvement.

We report a U-Pb zircon age for a volcanic ash bed within the upper Carnian of the Pignola 2 section in southern Italy. The ash bed is well constrained by conodont and palynomorph biostratigraphy and may be correlated with other sections of the Tethys, as well as with the Newark Basin. The age has several implications for Late Triassic stratigraphy; the most important perhaps is a new constraint on the minimum age of a global-scale climatic and biotic crisis that occurred within the Carnian, known as the Reingrabener turnover (Schlager and Schöllnberger, 1974; Hornung and Brandner, 2005) or Carnian pluvial event (Simms and Ruffell, 1989). This event was first recognized in the Tethyan realm, but evidence exists that it was global in nature (e.g., Roghi, 2004; Prochnow et al., 2006). The biotic crisis is recorded 3 m below the dated ash bed and is characterized by the absence of carbonates and by the sudden input of siliciclastics. There is no general consensus on the magnitude of the extinction and the climatic nature of the event; however, several observations suggest that it may have had global consequences. First, the demise of rimmed carbonate platforms occurred at this time in the Tethys (e.g., Schlager and Schöllnberger, 1974; Preto and Hinnov, 2003; Hornung and Brandner, 2005). Second, sedimentological, paleontological, and geochemical proxies support a global climatic shift especially pronounced within the tropics (e.g., Gianolla et al., 1998; Prochnow et al., 2006). Third, and most intriguing, some important groups originated, or had a strong radiation, in the late Carnian, including dinosaurs (Benton, 2004), scleractinian reef builders (Stanley, 2003), and calcareous nannoplankton (e.g., Erba, 2006).

ASH BED OF LATE CARNIAN AGE IN PIGNOLA 2 SECTION

A 5-cm-thick volcanic ash bed (here named Aglianico) occurs within the hemipelagic to pelagic Calcari con Selce Formation (i.e., cherty limestones) of the Pignola 2 section in the southern Apennines, southern Italy (Scandone, 1967). It is a semi-lithified, coarse, sandy, green volcaniclastic layer. Several lines of evidence lead us to interpret this horizon as a primary ash fall: (1) feldspar, quartz, and zircon grains are angular to subangular; (2) lamination and sedimentary structures are absent, except for normal grading; (3) the depositional environment is weakly bioturbated deep marine; (4) volcanic or volcaniclastic rocks from which the ash bed could have been reworked are unknown from the underlying succession. Thus, we interpret the U-Pb age of the ash bed as the time of deposition. The Pignola 2 section yields abundant conodonts and palynomorphs that allow the position of

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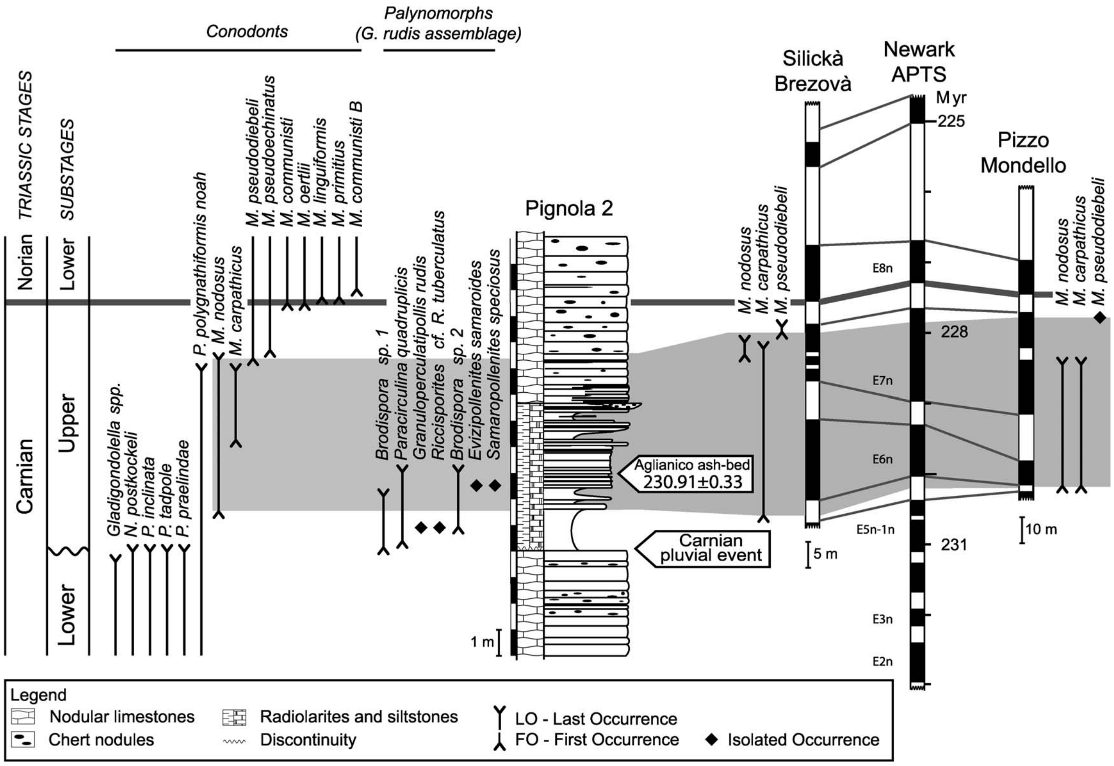

Figure 1. Correlation of Pignola 2 section to Silickà Brezovà (Channell et al., 2003), Pizzo Mondello (Muttoni et al., 2004), and astronomical polarity time scale (APTS) of Newark Basin (Kent and Olsen, 1999). Carnian–Norian boundary and magnetostratigraphic correlations according to Muttoni et al. (2004); distribution of conodonts at Pizzo Mondello is from Muttoni et al. (2001). Position of dated ash bed and inferred position of Carnian pluvial event are given by arrows. Gray shading represents suggested correlation.

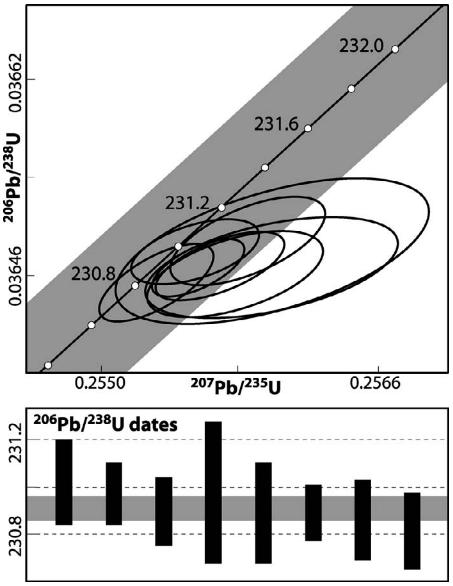

Figure 2. Concordia plot and ^{206}Pb/^{238}U dates. Weighted mean ^{206}Pb/^{238}U age is 230.91 ± 0.06/0.09/0.33 Ma (2σ) (see text); mean square of weighted deviates = 0.7; data point ellipses are 2σ; gray envelope represents decay constant error. Gray bar in lower panel shows weighted mean ^{206}Pb/^{238}U age; black columns represent single analyses; age error is expressed as including internal error only/including calibration error/including tracer calibration and decay constant errors.

the ash bed to be precisely placed within the biochronostratigraphic framework of the Triassic time scale (Ogg, 2004). The ash bed is within the range of the conodont *Metapolygnathus nodosus*, which is an upper Carnian species (e.g., Orchard, 1991; Krystyn et al., 2002; Channell et al., 2003; Muttoni et al., 2004). Lower Carnian conodonts (*Gladigondolella* spp., *Nicoraella postkockeli*, *Paragondolella inclinata*, *P. tadpole*) abruptly disappear 3 m below the ash bed, at a level corresponding to the Carnian pluvial event. *M. pseudoechinatus* and *M. pseudodiebeli* first occur ~4 m above. The ash bed thus is within the *P. carpathica* or the *Eokochaspis nodosa* zones of Channell et al. (2003), because the top of the *E. nodosa* zone is defined by the first appearance datum (FAD) of *M. pseudodiebeli*. Furthermore, palynomorphs belonging to the *Granuloperculatispollis rudis* assemblage (Fig. 1) were found 70 cm below the ash bed. The base of the *Granuloperculatispollis rudis* assemblage is within the upper Carnian (Roghi, 2004). The Carnian-Norian boundary can be placed ~6 m above the ash bed, with the first occurrence of *Metapolygnathus communisti* (Fig. 1; Muttoni et al., 2004).

U-Pb ZIRCON AGE

Zircon was separated from a 5 kg sample using standard crushing, heavy liquid, and magnetic separation techniques. Needle-like, acicular, euhedral, colorless, doubly terminated grains lacking visible inclusions or fractures were selected for analysis. The grains were annealed and chemically abraded using the method reported in the GSA Data Repository[1].

As discussed in Schoene et al. (2006), high-precision zircon dating shows a systematic discrepancy between the ^{207}Pb/^{206}Pb, ^{207}Pb/^{235}U, and ^{206}Pb/^{238}U dates; the discrepancy is most likely due to uncertainties in one or both of the U decay constants. The ^{206}Pb/^{238}U date is the most precise for dates younger than 1000 Ma, and therefore most useful for Phanerozoic time-scale work. Caution must be used when comparing U-Pb and ^{40}Ar/^{39}Ar dates, and systematic errors for both methods should be included. U-Pb errors are reported here as ±X/Y/Z, where X is the internal error in absence of all systematic errors, Y includes the tracer calibration error, and Z includes the tracer calibration and decay constant errors of Jaffey et al. (1971). The mean square of weighted deviates (MSWD; York, 1967) of equivalence refers to the probability that a weighted-mean population of isotopic ratios is statistically equivalent and is calculated prior to the addition of systematic errors (Ludwig, 1998).

Eight dated zircon grains yield an equivalent cluster on a concordia diagram with an MSWD of 1.1 (Fig. 2) and a weighted mean ^{206}Pb/^{238}U age of 230.91 ± 0.06/0.09/0.33

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[1] GSA Data Repository item 2006222, analytical methods used in U-Pb geochronology and U-Pb isotopic data table, is available online at www.geosociety.org/pubs/ft2006.htm, or on request from editing@geosociety.org or Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301, USA.

Ma that we interpret as the depositional age of the ash bed. The weighted mean ^{207}Pb/^{235}U age is 231.12 ± 0.13/0.16/0.44 Ma.

CORRELATIONS WITHIN TETHYS AND TO NEWARK BASIN

Our attempts to recover an original magnetization from the Lagonegro Basin yielded no results. However, the Pignola 2 section can be correlated with other successions of the Tethyan realm through conodont biostratigraphy. Two hemipelagic sections with magnetostratigraphic constraints largely overlap with Pignola 2: Pizzo Mondello in Sicily (Muttoni et al., 2004) and Silickà Brezovà in Slovakia (Channell et al., 2003). These allow an indirect correlation with the Newark APTS.

The dated ash bed is late Carnian and is within the total range of *M. nodosus* (Fig. 1). Following Muttoni et al. (2004), the first occurrence (FO) of *M. nodosus* at Pizzo Mondello is much older than at Silickà Brezovà (Fig. 1). This might be due to differences in the determination of this species between different authors (Channell et al., 2003), or it reflects the elusiveness of the FAD of *M. nodosus*, which might be rare in the lower part of its range. However, in the Pignola 2 section the FOs of *M. pseudodiebeli* and *M. pseudoechinatus* are immediately above the last occurrence of *M. nodosus* (Fig. 1), so the dated ash bed is within the *P. carpathicus* or the *E. nodosa* zone of Channell et al. (2003). *M. pseudodiebeli* is present also at Pizzo Mondello and Silickà Brezovà, thus an interval including the *P. carpathicus* and *E. nodosa* zones of Channell et al. (2003) can be correlated between the three sections (gray band in Fig. 1). The correlated interval corresponds to the lower and middle part of the *M. nodosus* zone of Orchard (1991), also reported in the Triassic time scale of Ogg (2004). Using this correlation, the dated ash bed is within the rather broad interval between the reverse part of chron E5 and the normal part of chron E7 of the Newark APTS, corresponding to the time interval 230.5–228 Ma.

DISCUSSION

The ^{40}Ar/^{39}Ar and U-Pb geochronology have been used to obtain high-precision dates for ash beds in the Triassic. It has been apparent for several years that there is systematic discrepancy between ^{40}Ar/^{39}Ar and U-Pb dates that can be as much as 1% (e.g., Schoene et al., 2006). Possible explanations for this include inaccuracies in the decay constants for one or both systems, an incorrect assumed age for Ar standard minerals, and residence time of zircons in a magma chamber prior to eruption. This paper reports a precise age determination within the upper Carnian using U-Pb geochronology. The implications for the Triassic time scale (Ogg, 2004) are evident: an age of 230.91 ± 0.06/0.09/0.33 Ma would be in the Ladinian. This age is instead late Carnian, implying a full stage and age discrepancy. As a consequence, the interval upper Ladinian to upper Carnian is compressed to ~7 m.y. (Mundil et al., 1996; Pálfy et al., 2003), compared to an assumed duration of >15 m.y. (Ogg, 2004). Furthermore, the Norian becomes longer than 20 m.y. (base of Rhaetian as in Ogg, 2004), thus spanning nearly half of the Triassic Period.

The Newark APTS appears remarkably consistent with our new age constraint. Following the correlation of Muttoni et al. (2004), and given the biostratigraphic uncertainty related to the distribution of *M. nodosus*, the age of our dated ash bed was predicted to be 228–230.5 Ma based on the Newark APTS (Kent and Olsen, 1999). However, the cyclostratigraphy of the lower Stockton Formation (lower part of the Newark cores) is less certain, as this formation does not contain playa-lake cycles (Olsen et al., 1996). The absolute ages of the Newark APTS are thus reliable to as old as ca. 226.5 Ma, but are obtained by extrapolation of sediment accumulation rates downward. Ages of the Newark APTS older than ca. 226.5 should be used with caution. Thus, considering also the uncertainty of ~2 m.y. for the age of the top of the Newark APTS (Kent and Olsen, 1999), the model age of 228–230.5 Ma for the interval containing the dated ash bed can be considered in good agreement with its zircon age of 230.91 ± 0.06/0.09/0.33 Ma. This strongly suggests that the playa-lake alternations of the Newark Basin have been correctly interpreted as Milankovitch driven.

The age reported here is a minimum for a climatic and biotic crisis recognized in the Carnian (e.g., Schlager and Schöllnberger, 1974; Benton, 2004; Simms and Ruffell, 1989; Simms et al., 1995) and identified ~3 m below the dated horizon in the Pignola 2 (Fig. 1). Some major groups seem to originate after this event, and subsequently became fundamental to the marine (calcareous nannoplankton) and terrestrial (dinosaurs) Mesozoic ecosystems. The first undisputed occurrences of calcareous nannoplankton are in the upper Carnian (Erba, 2006). The earliest known dinosaurs come from the Ischigualasto Formation of Argentina, dated by ^{40}Ar/^{39}Ar as 229.2 Ma relative to an age for Fish Canyon Tuff of 28.02 ± 0.3 (originally 227.8 ± 0.3 Ma by ^{40}Ar/^{39}Ar relative to Fish Canyon Tuff of 27.84 Ma; Rogers et al., 1993). In many cases there is a discrepancy between U-Pb and ^{40}Ar/^{39}Ar dates, the latter being 0.5%–1.0% younger (e.g., Schoene et al., 2006). Thus, the age of the Ischigualasto fauna may be approximately coincident with that of the dated ash bed. If we were to correct the date of 229.2 ± 0.3 Ma for a discrepancy of 0.5%–1.0%, it would be 230.3–231.4 Ma.

The causes of the Carnian crisis are mostly unknown. Simms and Ruffell (1989) and Simms et al. (1995) related it to a shift toward humid climates, a conclusion supported by more recent work (Gianolla et al., 1998; Roghi, 2004; Hornung and Brandner, 2005; Prochnow et al., 2006). Nevertheless, a physical explanation is required for this climatic shift. Hornung and Brandner (2005) suggested that the uplift of the Cimmerian orogen triggered an enhancement of the monsoonal circulation in the Tethyan realm. This explanation, however, cannot account for the global nature of the Carnian event and of the subsequent biotic radiation. We suggest that it is noteworthy that the event is approximately coincident with the poorly dated large igneous province (LIP) of Wrangellia. This magmatic province on Vancouver Island, Canada, has an estimated minimum volume of 1×10^6 km^3 (Lassiter et al., 1995). The only published radiometric ages available for this LIP are zircon ^{207}Pb/^{206}Pb dates of 232.2 ± 1 Ma (Mortensen and Hulbert, 1992) and 227 ± 3 Ma (Parrish and McNicoll, 1992). This apparent coincidence needs to be further tested with new radiometric dates for this LIP and of the Carnian crisis. There are, however, other intriguing coincidences. First, the crisis of carbonate platform systems associated with the Carnian event may be analogous to similar crises that occurred after the Permian-Triassic and Triassic-Jurassic extinctions, approximately coincident with the eruption of the Siberian Traps and the CAMP LIPs, respectively (Courtillot and Renne, 2003; Kamo et al., 2003).

CONCLUSIONS

A U-Pb zircon age of 230.91 ± 0.06/0.09/0.33 Ma was obtained from a volcanic ash deposited in a marine basin of southern Italy. Integrated paleontology and geochronology allow recalibration of the Late Triassic time scale. Conodont and palynomorph biostratigraphy constrain the position of the ash bed to the upper Carnian, Upper Triassic, slightly after a climatic and biotic crisis. Our results have four major implications. (1) The Triassic time scale needs to be revised to drastically increase the duration of the Norian. (2) The Newark APTS is in agreement with this new age, and still provides the most precise time framework for the Late Triassic. Our new age supports the Milankovitch nature of the Newark playa-lake cycles. (3) On the basis of currently available data, the origin of dinosaurs and calcareous nannoplankton closely follow the Carnian event, and might have been triggered by it. (4) The cause of the Carnian crisis is unknown, but is similar in age to an LIP of Wrangellia. We suggest that the possible connection between biological crisis, subsequent radiation, and exceptional volcanic activity should be further explored.

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