Key words: Carnian-Norian boundary, Late Triassic, magnetostratigraphy, biostratigraphy, conodonts, Albania.

Abstract. We present the magnetostratigraphy and conodont biostratigraphy across the Carnian-Norian boundary from a 70 m-thick limestone section located at Guri Zi in northern Albania. A total of 14 magnetozones were observed. The Carnian-Norian boundary is placed in a thin stratigraphic interval between the last occurrence of Paratethysella media and the first occurrence of Epipendella albotiaxis. Data from Guri Zi are in substantial agreement with already published data from Silecka Brezova in Slovakia and Pizzo Mondello in Sicily, which comprehensively indicate that the conodont Carnian-Norian boundary, when magnetostratigraphically traced onto the Newark astrophysical polarity time scale (APTS), has an age of ≈282-227 Ma.


Introduction

This paper presents the magnetostratigraphy and conodont biostratigraphy of a Carnian-Norian (Late Triassic) boundary section located at Guri Zi in northern Albania. This study adds to previous studies on the Tethyan conodont biostratigraphy and magnetostratigraphy across the Carnian-Norian boundary from Pizzo Mondello in Sicily (Muttoni et al. 2002a; Kryszyn et al. 2002; Muttoni et al. 2004); Silecka Brezova in Slovakia (Channell et al. 2003), and Kavalaanni in Turkey (Gallet et al. 2000). At Kavalaanni, however, the Cari- nian-Norian boundary falls in correspondence of a hiatus. Aim of this work is to contribute to constrain magnetostratigraphically the position of the Carnian- Norian conodont boundary on the Newark continental astrochronological polarity time scale (APTS; Kent & Olsen 1999) for construction of a biostratigraphically calibrated time scale for the Late Triassic.

Geology

During the Triassic-Jurassic, the Guri Zi and sor- rounding regions were part of the eastern passive conti- nental margin of Adria – the African promontory (Muttoni et al. 1996a) – and its transition to the adjoining Tethys Ocean. The Krasta-Cukali Zone, which comprises the Guri Zi section (Fig. 1), is interpreted as a rim basin on thinned continental crust located be- tween the Mirida rift shoulders-ocaric basin and the Adria passive continental margin of the Ionian Zone (Meço and Alay 2002; Robertson et al. 1991; Godroli 1992; Kellici et al. 1994). During Alpine deformation in the Mesozoic-Cenozoic, the Krasta Zone was tectonically overridden along its eastern flank by Mirida Zone units consisting
of slabs of mainly Upper Triassic deep-sea sediments and Jurassic ophiolites (Shallo 1992, 1994). Krasta Zone units overrode to the west Mesozoic shallow-water carbonates of the Krupa and Ionian zones, which make transition further to the west to relatively undeformed carbonate successions pertaining to the Adriatic foreland.

The upper Carnian–middle Norian Guri Zi section is located 14 km southeast of the town of Shkodra, approximately 1 km to the east of the village of Guri Zi in northern Albania (42.05°N, 19.02°E, Fig. 1). The section is 70 m thick (Fig. 2) and starts at the base with a few meters of Ladinian radiolarians followed by about 60 meters of Cherty Limestone beds. These consist of thinly bedded calcarenites with pelagic bivalves and chert nodules associated with more massive and sometimes slumped calcarenites and calcilutites. Towards the section top, Cherty Limestone beds are brecciated and form clasts enclosed in red matrix of red clay of unknown age. This brecciated interval is unconformably overlain by Maastrichtian (Upper Cretaceous) grey-green marls with Glabratracanthus, which are in turn overlain by terrigenous deposits of the Paleogene Krasta Flysch.

Biostratigraphy

We performed additional conodont sampling at Guri Zi after Meço (1999). Samples for conodont biostratigraphy were collected with an average sampling resolution of 2 m. A total of 36 samples, about 2.3 kilograms each, were obtained for dissolution in acetic acid.

Triassic stage boundaries are historically established using ammonoids. These have not been found at Guri Zi, whose age is therefore based on conodont biostratigraphy as a proxy for the ammonoid zonation. According to Krystyn et al. (2002), the ammonoid Carnian–Norian boundary is approximated by conodonts using the first occurrences (FOs) of Metapolygnathus communisii A, Metapolygnathus communisii B, or Nor- giondella marisbruts. In addition, the last occurrences (LOs) of Metapolygnathus polygnathiformis and Meta- polygnathus nodosus immediately predate the boundary, whereas the FO of Epigondolella albeopsis A immediately postdates the boundary (Krystyn et al. 2002). Channell et al. (2003) reached similar conclusions regarding the FOs of Norgiondella marisbruts and Epi- gondolella albeopsis (undifferentiated form), as well as the LOs of Metapolygnathus polygnathiformis and Me- tapolygnathus nodosus. These authors indicate in the FO of Epigondolella primitia an additional useful conodont event that immediately predates the Carnian–

boundary.

At Guri Zi, the following succession of biostratigraphic events defines comprehensively the Carnian–Nor- ian boundary interval (Fig. 1):

(i) the LO of Paragondolella polygnathiformis (=Metapolygnathus polygnathiformis) juvenile (Figs. 1-3 in Plate 1);

(ii) the LO of Metapolygnathus nodosus (Figs. 11-14 in Plate 2);

(iii) the occurrence of Epigondolella primitia (Figs. 1, 2, 4 in Plate 3);

(iv) the FO of Epigondolella albeopsis (Figs. 3, 6, 8 in Plate 3).

In particular, we locate the Carnian–Norian boundary in a thin stratigraphic interval around meter level 50 between the LO of Metapolygnathus nodosus and the FO of Epigondolella albeopsis.

In the upper part of the section, around meter level 68, the occurrence of Epigondolella multidentata is recorded (Fig. 2). This conodont is regarded as middle Norian in age (Channell et al. 2003). We assume, there- fore, the existence of a major hiatus at this level, which marks at a guess scale the base of the uppermost interval of brecciated limestones.
Fig. 2 - The Carnian–Norian boundary Guri Zi section. To the left of the figure are the lithology column and the stratigraphic position of samples for paleomagnetism and biostratigraphy; the age-determination is based on conodont biostratigraphy. To the right of the figure is a plot of VGP latitude as a function of stratigraphic depth with polarity interpretation. Magnetic polarity zones, defined by at least two stratigraphically superposed samples, are shown by filled (open) bars for normal (reverse) polarity. Polarity zones defined by one sample are shown by half bars.

Paleomagnetism

Samples from Guri Zi were drilled and oriented in the field at an average resolution of 50 cm giving 110 standard specimens (11 cc) for analysis. The extremely weak magnetization of Guri Zi limestones required the use of a high sensitivity magnetometer with DC SQUID technology, located in a magnetically shielded room at the paleomagnetic laboratory of ETH Zürich.
Fig. 3 - (a) The intensities of the natural remanent magnetization (NRM) and initial susceptibility at room temperature are plotted as a function of stratigraphic depth; (b) basic rock-magnetic properties have been studied by thermal decay of a 3-component isothermal remanent magnetization (IRM). See text for discussion.

<table>
<thead>
<tr>
<th>Location</th>
<th>Site</th>
<th>In Situ</th>
<th>Tilt Corrected</th>
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<tbody>
<tr>
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<td>N: 4</td>
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<td>&quot;D&quot; core</td>
<td>108/89</td>
<td>145.9</td>
<td>80.1 8 5.7</td>
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<td>LATE TRIASSIC-EARLY JURASSIC REFERENCE PALEOMAGNETIC DIRECTION AND POLE:</td>
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<td>354.5</td>
<td>41.3</td>
<td>71.1 2148 A95  4.3 24 ± 3</td>
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</table>

N: number of standard 11 cc specimens collected. N: number of paleomagnetic directions used to calculate the mean. Dec., Inc.: declination and inclination, in geographic or tilt corrected coordinates. k, A95: Fisher precision parameter and radius of cone of 95% confidence about the mean direction, respectively. Lat., Long.: paleomagnetic pole latitude and longitude. k, A95: Fisher precision parameter and radius of the 95% ellipse of confidence about the mean pole, respectively. A95: radius of cone of 95% confidence about the mean pole. Pl. paleolatitude expressed in °N.

| Stable end point directions only. |

From Matatini et al. (2003a).
Rock-magnetic properties and palaeomagnetic directions

The mean intensity of the natural remanent magnetization (NRM) is 0.1 mA/m and increases up to 0.5 mA/m in the middle part of the section. The room temperature magnetic susceptibility is in the diamagnetic range (i.e., small negative values) and does not follow the NRM intensity trend (Fig. 3a).

Thermal unblocking characteristics of orthogonal components of isothermal remanent magnetization (IRM) (Lowe 1990) revealed the presence of a dominant low coercivity and ~570 °C maximum unblocking temperature phase interpreted as magneitite, coexisting, in the uppermost part of the section, with a subsidiary high-coercivity and ~680 °C maximum unblocking temperature phase interpreted as hematite (Fig. 3b).

Stepwise thermal demagnetization was applied to isolate magnetic components of the NRM. Samples typically show the presence of a linear "A" component of magnetization isolated by means of least-square line-fits (Kirschvink 1980) on vector endpoint demagnetization diagrams between room temperature and ~200 °C. This component has in situ steep positive inclinations (Fig. 4) and is broadly consistent with viscous magnetization acquired along the present-day field direction (Fig. 5; Decl = 18°E, Inc = 68°). In the temperature range between ~200 °C and 300-350 °C, a linear "B" component overprints with in situ southwest and negative directions was resolved in 33% of the samples. In the remaining 66% of the samples, this "B" component of magnetization migrates along great circle paths toward a dual polarity characteristic ("Ch") component with either southeast and positive or northwest and negative in situ directions (Figs. 4, 5). "Ch" endpoint components were successfully isolated in 81% of the samples between ~400 °C and ~550 °C up to a maximum of 680 °C (Figs. 4).
4, 5). The "Ch" components turn east and positive or west and negative after application of bedding tilt correction (Fig. 5; Tab. 3). Although normal and reverse populations are clearly seen, their means depart from antipodal by -23° and the reversal test sensu McAden & McElhinny (1990) resulted negative. We attribute this departure from antipodality to residual contamination of the "Ch" by the "B" component overprint. In order to minimize this biasing effect, we invert the reverse "Ch" directions to common normal polarity and calculate an overall mean direction of Dec = 88.1°, Inc = 32.6° (α95 = 5.2°, k = 9, N = 89).

**Magnetostratigraphy:**

We interpret the "Ch" component in tilted corrected coordinates as the original Triassic magnetization. The stratigraphic evolution of Albania has Gondwana affinity, therefore, we assume that the "Ch" and "B" components were originated at or close to the northern margin of Africa, which was located in the northern hemisphere during the Mesozoic (e.g., Muttoni et al. 1996a; Decourt et al. 2000; Stampfli 2000). Consequently, positive "Ch" directions represent normal polarity, whereas negative ones represent reverse polarity. A virtual geomagnetic pole (VGP) was calculated for each "Ch" component direction in tilted corrected coordinates. The latitude of the specimen VGP with respect to the overall mean north paleomagnetic pole was used to delineate magnetic polarity stratigraphy. VGP relative latitudes approaching -90°N or -90°N were interpreted as recording normal or reverse polarity, respectively. For polarity magnetozoon identification, we adopted the nomenclature used by Kent et al. (1995). The latitude of the specimen VGPs defines

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**Figure 5** - Equal-area projections before (in situ) and after bedding tilt correction of the "A", "B", and "Ch" endpoint component directions, and of the "B" component remagnetization gear circles. See text for discussion.

**Figure 6** - The palaeomagnetic poles from Gori Zi and Kërria (squares) are compared to the Gondwana apparent polar wander path (solid circles). The suffix attached to the pole designation refers to the magnetization component used to calculate the pole: "Ch" is the characteristic component, "B" a secondary component. eP is Early Permian, eP is Early Permian, eT is Early Triassic, eTr is Middle Triassic, eTr is Early Triassic, eTr is Late Triassic, eT is Late Triassic, eJ is Early Jurassic, eJ is Late Jurassic, eK is Early Cretaceous, eK is Late Cretaceous, eO is Oligocene, eE is Eocene, eO is Oligocene, eM is Miocene, eP is Pliocene. See text for discussion.
at Guri Zi a sequence of 14 magnetozones from GZ1r to GZ3n (Fig. 2).

Paleomagnetic poles

The Late Triassic "Ch" component at Guri Zi in the Krača-Cukal Zone gives a paleomagnetic pole (pa-
lepole) rotated -85° clockwise with respect to the Late
Triassic-Early Jurassic reference paleopole of Gondwana
(Muttoni et al. 2021b) (Fig. 6, Tab. 1). A "Ch" com-
ponent of Middle Triassic age was observed at Kčira in the
External Mirdita Zone (Muttoni et al. 1994b) (Fig. 8). It defines a paleopole rotated -40°-45° clockwise
with respect to the reference paleopole of Gondwana of corresponding age (Fig. 6). The age of acquisition of the "B" component at Guri Zi is unknown; it is here conservatively considered post-folding because its pa-
lepole plotted in an isotope coordinates is by far less re-
moved from the Gondwanan apparent polar wander path then after bedding tilt correction. In detail, the "B" component paleopole is rotated -40° clockwise with respect to the Late Cretaceous-Early Cenozoic Gondwana paleopoles, and falls close to the Kčira "Ch" component paleopole (Fig. 6).

Based on the above, we propose that Guri Zi in the
Krača-Cukal Zone rotated -45° clockwise with respect to
Gondwana after the acquisition of the "Ch" compo-
nent in the Late Triassic and prior to the acquisition of the "B" component in the Late Cretaceous-Early Cen-
ozoic. An additional -40° clockwise rotation occurred after the acquisition of the "B" component in the Cen-
ozoic in concert with rotations of External Mirdita Zone units as observed at Kčira (Fig. 6). Tectonic rotations of
thrust sheets may be related to Alpine deformation, which in the Albanian belt commenced as early as latest Jurassic and continued into the Cenozoic. For example, the inferred post-"B" component clockwise rotation at
Guri Zi and Kčira may be associated with the rotation of the external zone of Albania since the Early-Middle
Miocene (Speranza et al. 1995; Mauritius et al. 1996).

Correlation to literature sections and the age of the Car-
nian-Norian boundary

Magnetostatigraphic and biostratigraphic data from Guri Zi are tentatively correlated to data from
the Silica Brezoa marine limestone section from Slo-
vskia (Channell et al. 2003), the Pizzo Mondello marine limestone section from Sicily (Muttoni et al. 2004), as
well as the continental Newark astrochronological pol-
arity time scale (AFTS, Kent & Olsen 1999) (Fig. 7).
Details on the correlation between Silica Brezoa, Piz-
zo Mondello, and the Newark AFTs are given in Muttoni
et al. (2004).

Guri Zi, Silica Brezoa, and Pizzo Mondello bear a
gross scale a similar assemblage of Carnian-
Norian boundary conodonts comprising, among the
most significant events:

(i) the LO of Paragondolella polymorphithalamis (Guri Zi and Silica Brezoa) and the LO of the equi-


paleoconodonts (Pizzo Mondello);
(ii) the LO of Metapolygnathus nodosus (Guri Zi
and Pizzo Mondello) and the LO of the equiva-

cent Epigondolella nodosa (Silica Brezoa);
(iii) the FO of Epigondolella primitius (Guri Zi
and Silica Brezoa);
(iv) the FO of Neogondolella natricola (Silica Brezoa);
(v) the FO of Metapolygnathus communis (Piz-
zo Mondello);
(vi) the FO of Epigondolella abruptus (Guri Zi
and Silica Brezoa).

These biostratigraphic events define at Silica Brezoa and Pizzo Mondello a Carnian-Norian bound-
ary that was magnetostatigraphically traced onto New-
ark magnetozone E7 in the -228-222 Ma interval (Fig. 7; Muttoni et al. 2004). Guri Zi magnetozones GZ3n to
GZ7r may correlate to magnetozones SB-3n to SB-3r at
Silica Brezoa and PM3n to PM3r at Pizzo Mondello, which correspond as a whole to magnetozone E7 in the
Newark basin (Fig. 7). In particular, Guri Zi magnetoz-
zone GZ3n containing the Carnian-Norian boundary may correlate to SB-3n at Silica Brezoa, PM3n at
Pizzo Mondello, and E7n in the Newark basin. This being the case, the location of the Carnian-Norian
boundary onto the Newark AFTs would find additional confirmation. The correlation between Guri Zi and Piz-
zo Mondello-Silica Brezoa-Newark AFTs is at places
visually elusive because of distortion of the magneto-
stratigraphic sequence by variations in sedimentation
rate triggered by turbiditic redeposition of calcareous

Conclusions

The following conclusions can be drawn from this
analysis. Biostratigraphic data from Guri Zi indicate the
occurrence of the Carnian-Norian boundary at around
meler level 50 between the last occurrence of Metapo-
lygnathus nodosus and the first occurrence of Epigondo-
lella abruptus. This boundary has been magnetostatig-
raphically traced onto Newark magnetozone E7 dated
at -228-222 Ma (adopting Newark astrochronology).
Finally, paleomagnetic pole position analysis indicates that a complex history of clockwise tectonic rotations -
still poorly resolved - occurred in the Balkan region since Triassic times.

Repository: The conodont identification is made by S. Mező
and conodont species are stored in Palaeontological Cabinet at the
Faculty of Geology and Geodetics (FGG) K. Lehotai, Trnava, Slovakia
in the boxes X1 under the label KFZ (Krača Zoot) GZ (Guri Zi) and
the figure of the level.
Fig. 7 - Comparison of magnetostratigraphic and biostratigraphic data from this study and the literature across the Carnian-Norian boundary. The Guri Zi section is tentatively correlated to the lower part of the Silika Brestova section of Channell et al. (2020), the lower part of the Pizzo Mondello section of Mamoni et al. (2004), as well as the lower part of the Newark APTS (Kent & Osorn 1999). See text for discussion.