INTRODUCTION

Arthaber (1911) and Nopcsa (1929) first described an Early Triassic ammonoid fauna within a reddish nodular limestone succession from the Kçira area of northern Albania. In this area, Muttoni et al. (1996) reported a detailed magnetostratigraphic record of an Olenekian/Anisian boundary section termed Kçira-A that was correlated to the vertical distribution of key conodonts (figured by Meço, 2010 and reported also below), ammonoids, and benthic foraminifera species. Ancillary sections from the same nodular limestone unit were also studied for magneto-biostratigraphy (Kçira-B) and magnetostratigraphy (Kçira-C), and were correlated to the reference Kçira-A section. Ammonoids from Kçira-A and a further ancillary section (Kçira-G) were appraised by Germani (1997). A geologic map of the Kçira area (Muttoni et al., 1996) was recently augmented by additional biostratigraphic and tectonic observations and data (Gawlick et al., 2008, 2014, 2016), which complements geologic studies of Albania (Meço, 2000 and references therein). These studies reveal that the thicker and stratigraphically more complete Kçira-A section has excellent potential as a candidate Global Boundary Stratotype Section and Point (GSSP) for the base of the Anisian Stage of the Triassic System. In this paper, we summarize key magneto-biostratigraphy aspects of Kçira-A and ancillary sections,
describe new carbon and oxygen isotope results, and discuss
future developments aimed at formally proposing Kčira-A as
candidate Anisian GSSP.

**GEOLOGY AND LITHOSTRATIGRAPHY**

Kčira is located in northern Albania about 130 km (2.5
hours by car) north of Tirana. This area is characterized by a
complex mélange of blocks, ranging in size from a few meters to
some kilometers, comprised of Early to Late Triassic limestones,
Triassic volcanics, and Triassic radiolarites, embedded in a thick
Bathonian–Callovian (Jurassic) radiolaritic-ophiolitic unit (Fig.
1A) (Gawlick et al., 2008, 2014, 2016; Gaetani et al., 2015).
The Kčira-A section crops out to the northwest of the new Kčira
village (Fig. 1A, B, C), together with additional ancillary sections
described in this study, that have been correlated by means of
lithostratigraphy, magnetostratigraphy, and biostratigraphy (Fig.
2) as discussed below. These sections are part of an Olenekian–
Anisian nodular limestone belt that probably formed as a single
slab prior to being embedded into the Jurassic radiolaritic-
ophiolitic unit. This tectonic mélange is part of the Kčira-Dushi-
Komani radiolaritic flysch (ophiolitic Mélange) at the sole of the
Mirdita Zone ophiolites (Gaetani et al., 2015; Gawlick et al.,
2016 and references therein).

The Kčira-A (main) section is about 42 m thick, whereas
the ancillary Kčira-B section, located a few meters away
within the same outcrop, is about 4.5 m thick. On the basis of
magnetostratigraphic correlation, projected layers of Kčira-B
partially overlap with the basal portion of Kčira-A (Fig. 2). As
reported in Muttoni et al. (1996), both sections are comprised
of reddish to pale pink wackestones and mudstones arranged in
cm thick nodular beds that are strongly amalgamated to form
meter-scale composite layers. These limestones were termed the
Han-Bulog Limestone by Muttoni et al. (1996), but red nodular
limestones of the Bulog Formation in southwest Serbia are
Anisian in age and developed on top of a drowned Middle Anisian
(Pelsonian) shallow-water carbonate ramp (Sudar et al., 2013).
Therefore, as proposed by Gawlick et al. (2014), the Olenekian–
Anisian red nodular limestones of Kčira (rosenrot Knollenkalk
of Nopcsa, 1929 equivalent to the Han-Bulog Limestone of
Muttoni et al., 1996) should not be termed Bulog (or Hallstatt,
or Han-Bulog) Limestone, at least in the Olenekian section. We

Figure 1 – A, Geological map of the Kčira area (modified after Muttoni et al., 1996 using data from Gawlick et al., 2014). 'A', 'B', 'C', 'G' are
sections Kčira-A, Kčira-B, Kčira-C, and Kčira-G; 'D' and 'E' are additional sites of paleontological or lithological interest described in Muttoni et
al. (1996). B, Aerial view and C, picture of the Kčira area with location of conspicuous points and the Kčira-A GSSP candidate.
provisionally and informally refer to these Olenekian–Anisian limestones as nodular limestones of Kçira.

The basal 4.8 m of nodular limestones at Kçira-A (as well as the entire Kçira-B) are reddish and clay-rich, with pervasive bedding-parallel stylolites (lithologic Unit I, Fig. 2). Above a cover extending up to meter level 8.5, amalgamated nodular limestones become pink (Unit II) and then pale pink (Unit III) (Fig. 2). A set of cm thick calcite veins cut the bedding between meter 18 and 23 at Kçira-A. The uppermost few meters of Kçira-A contain packstones, which are more pink, richer in bioclasts, and are more distinctly bedded (Unit IV, Fig. 2). The top of the Kçira nodular limestone is marked by small neptunian dikes sealed by a cm thick silicified crust of uncertain age, as observed at site D (Fig. 1A).

The Kçira-C section is 10.2 m thick and located about 100 m east of Kçira-A and Kçira-B (Fig. 1A). Although a detailed lithological description was not made for Kçira-C, an upsection decrease in red pigmentation to pink closely resembles that observed at site D (Fig. 2). The Kçira-C section is 10.2 m thick and located about 100 m east of Kçira-A and Kçira-B (Fig. 1A). Although a detailed lithological description was not made for Kçira-C, an upsection decrease in red pigmentation to pink closely resembles that observed at site D (Fig. 2). The Kçira-C section is 10.2 m thick and located about 100 m east of Kçira-A and Kçira-B (Fig. 1A). Although a detailed lithological description was not made for Kçira-C, an upsection decrease in red pigmentation to pink closely resembles that observed at site D (Fig. 2).

Two sections were previously studied for magnetostratigraphy and biostratigraphy (Kçira-A and Kçira-B; Muttoni et al., 1996), Kçira-C only for magnetostratigraphy (Muttoni et al., 1996), and Kçira-G only for biostratigraphy (Germani, 1997). The Kçira-A and Kçira sections are most likely the localities described by Nopcsa (1929). Bedding attitude (azimuth of dip/dip) varies from 347°E/34° at Kçira-A to 12°E/45°E at Kçira-B and Kçira-C.

**BIOSTRATIGRAPHY**

**Conodonts**

Conodonts from Kçira-A and Kçira-B sections originally reported by Muttoni et al. (1996) have been revised in this study according to recent advances in conodont taxonomy. Some conodont species of Muttoni et al. (1996) were later illustrated by Meço (2010) and are reported in Figure 3. The conodont fauna from these sections is abundant and well preserved. The CAI (Color Alteration Index, Epstein et al., 1977) is 3, indicating that the host rock reached burial temperatures of 110°–200°C. The conodont main events are grouped as follows from the base to the top (Fig. 4; see also key species in Fig. 3):

1. The conodont association from lithologic Units I and II is represented by *Triassospathodus abruptus* Orchard, 1995, *T. triangularis* (Bender, 1970), *Spaticicus spathi* (Sweet, 1970), *T. homeri* (Bender, 1970), *Gladigondolella carinata* Bender, 1970, *T. symmetricus* (Orchard, 1995), *T. brochus* (Orchard, 1995), *Neogondolella sp.*, *N. sp. A*, *Triassospathodus sp.*, and *Gladigondolella tethydis* (Huckreide, 1958). This fauna is mostly consistent with fauna 3 of Orchard (1995) and with the fauna described in the lower part of the Deşli Caira section (North Dobruja, Romania) by Gradinaru et al. (2007) and Orchard et al. (2007a), as well as in the Lower Guandao section (Guzhizhou Province, China) by Orchard et al. (2007b). These faunas are altogether attributed to the late mid Spathian.

2. The appearance of *Chiosella gondolelloides* (Bender, 1970) (sample AK28, 20.2 m) is an easily recognized datum that predates the occurrence of *C. timorensis* (Nogami, 1968; AK30, 22.4 m). This is in broad agreement with data from Chios (Gaetani et al., 1992; Muttoni et al., 1995), Deşli Caira (Gradinaru et al., 2007; Orchard et al., 2007a and Lower and Upper Guandao (Orchard et al., 2007b). The appearance of *Chiosella timorensis* (=*Gondolella timorensis* in Gaetani et al., 1992; Muttoni et al., 1995) may be used to approximate the base of the Anisian (Gradinaru et al., 2006, 2007; Orchard et al., 2007a, 2007b) especially when ammonoids are absent. Orchard (1995), Gradinaru et al. (2007), Orchard et al. (2007a, 2007b) have well summarized and described the taxonomy of these species.

3. *Neogondolella regalis* Mosher, 1970 appears at 26.7 m (AK37) and is interpreted to span the late Aegan and mid Bithynian (Mosher, 1970; Gedik, 1975; Nicora, 1977; Kovacs & Kozur, 1980).

4. *Paragondolella bulgarica* Budurov and Stefanov (1975) appears at 28.7 m (AK40) and is a proxy for the base of the Bithynian substage. It ranges up to the boundary interval of the *Binodosus* and *Trinodosus* ammonoid Zones (Budurov & Stefanov,

5. *Nicoraella kokaeli* (Tatge, 1956) appears at 35.3 m (AK49) and approximates the base of the Pelsonian substage (Nicora, 1977; Kovacs & Kozur, 1980; Balini & Nicora, 1998; Farabegoli & Perri, 1998).

6. *Paragondolella bifurcata bifurcata* (Budurov and Stefanov, 1972) appears at 33.4 m (AK47) while *P. bifurcata hunbuloghi* Sudar and Budurov, 1979 appears at 35.3 m (AK49). These species are attributed to the Pelsonian substage (Budurov & Stefanov, 1972, 1975; Sudar & Budurov, 1979; Kovacs & Kozur, 1980; Balini & Nicora, 1998; Kovacs & Ralisch-Felgenhauer, 2005).

Based on the conodont fauna, the Kçira-A section covers the late mid Spathian to Pelsonian while Kçira-B section is restricted to the late mid Spathian.

**Ammonoids**

The lower part of the Kçira-A section (Unit I of Figs. 2–4) is rich in ammonoids. From this part of the section, Germani (1997) described a small fauna with high diversity that is middle Spathian (*Subcolumbites* Zone sensu Guex et al., 2010).

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and Jenks et al., 2013). This fauna (Fig. 5) is dominated by *Subcolumbites* and *Albanites*, in addition to leiostraceans, and is almost equivalent to the fauna described from Kčira by Arthaber (1911). Ammonoid assemblages also indicate middle Spathian at Kčira-B and Kčira-G (Germani, 1997). Ammonoids also are reported from the middle and upper part of the Kčira-A section (Germani, 1997) in Units III and IV (Fig. 5), but they are long-ranging leiostracan that verify the presence of Anisian strata, but thus far a more refined age assignment is not possible.

**Benthic Foraminifera**

As outlined in Muttoni et al. (1996), benthic foraminifera are very scarce in the lower part of Kčira-A (Fig. 5). *Gaudryina* sp. n. is discontinuously present from meter 14.3 (AK17) to 22.4 (AK30), where *Meandrospira dieneri* appears. A more diversified and abundant fauna was recovered from meter 28.1 to 34.2 at Kčira-A (samples AK39 to AK48). This assemblage is characterized by *Ophtalimidium aff. O. abriolense*, *Areonovidarina chialingchiangensis*, *Pilammina densa*, *Meandrospira dinarica*, *Eartlandia amplimuralis* and *E. gracilis*. An Anisian age not younger than Pelsonian is attributed to this assemblage. It is noteworthy that *P. densa* occurs in association with conodonts of Bithynian age.

**PALEOMAGNETISM**

**Paleomagnetic properties**

Samples for paleomagnetic analyses were collected with a portable water-cooled rock drill and oriented with a magnetic compass. Sections Kčira-A and Kčira-B were sampled at an average interval of 20–25 cm, while sampling at 40–50 cm was applied at Kčira-C (Fig. 6; Muttoni et al., 1996). Based on standard rock-magnetic experiments, Muttoni et al. (1996) concluded that nodular layers of the lower half of Kčira-A (Units I–II), as well as of Unit I of Kčira-B, were characterized by abundant hematite, contributing to the relatively high natural remanent magnetization (NRM) (Fig. 6A) and magnetic susceptibility, as well as the pervasive reddish-pink hues typical of this part of the succession. In contrast, pale-pink nodular layers above (Unit III) preserve a mineralogical association of less abundant magnetite coexisting with hematite, giving lower NRM and magnetic susceptibility, although the lowest values between meter 18 and 23 at Kčira-A are also associated with a dense network of calcite veins (Fig. 6A). The top of Unit III has a few samples with very high NRM intensities and univectorial component trajectories during thermal demagnetization that are interpreted as due to lightning-induced IRM (isothermal remanent magnetization), whereas the uppermost few meters of the Kčira succession (Unit IV) are richer in resedimented carbonate layers that might have enhanced the concentration of detrital magnetite (see Muttoni et al., 1996 for details).

Upon application of thermal demagnetization, a characteristic (Ch) component with either northeast-and-down or southwest-and-up directions was resolved in 88% of the samples in the temperature range between about 400°C and either 520–575°C or 650–680°C (Fig. 7A). These Ch component directions display variable mean angular deviation (MAD; Fig. 6B) values depending on NRM intensities (Fig. 6A). They show dual polarity at all investigated sections (Fig. 7B), albeit the normal and reverse mean polarity directions depart from antipodality by up to 27°, perhaps due to contamination of the Ch magnetizations by an initial viscous component broadly aligned along the present-day field direction (Fig. 7A). The three mean directions from Kčira-A, Kčira-B, and Kčira-C (Fig. 7B) show some degree of convergence after correction for bedding tilt, the Fisher precision parameter k increasing by a factor of 3 with a full (100%) tilt correction, suggesting that the Ch magnetizations were acquired before deformation. However, the limited difference in bedding attitudes makes the fold test statistically inconclusive (see Muttoni et al., 1996 for details).

**Magnetostratigraphy and correlations with sections from the literature**

A virtual geomagnetic pole (VGP) was calculated for each sample Ch component direction after correction for bedding tilt. The latitude of the sample VGP with respect to the overall mean (north) paleomagnetic pole (i.e. VGP latitude) was used to delineate the magnetic polarity stratigraphy (Fig. 6C, D). At Kčira-A, the VGP latitudes define a sequence of polarity intervals extending from Kč1n.1n at the base to Kč3r at the top. Submagnetozone Kč1n.1r near the base of Kčira-A nicely correlates to the short reverse polarity interval at Kčira-B, lending credibility to this single sample-based reversal. Finally, the magnetic polarity stratigraphy at Kčira-C shows an excellent match with Kčira-A across multiple polarity reversals in the Kč1r interval (Fig. 6), which also contain several biostratigraphic events potentially useful to define the base of the Anisian.

According to the recent Triassic geomagnetic polarity scale of Maron et al. (2019), the magnetostratigraphic sequence of Kčira-A correlates reasonably well with the Lower and Upper Guandao (Lehrmann et al., 2015), Chios (Muttoni et al., 1995), and Desli Caira (Gradinaru et al., 2007) sections (see Figures 11 and 12 in Maron et al., 2019). According to this correlation scheme that incorporates U-Pb age data from Guandao (Lehrmann et al., 2015), Kčira-A should extend from approximately 248 to 244 Ma, and the level containing the appearance of *Chiarella timorensis* should have an interpolated age of ~247.3 Ma (Lehrmann et al., 2015; see also Maron et al., 2019).

**CHEMOSTRATIGRAPHY**

Carbon isotope stratigraphy provides additional means to correlate among marine sections, and under the right circumstances (and with the independent magnetostratigraphic constraints above) can allow correlation between terrestrial and marine sections (see review by Salzman & Thomas, 2012). The δ¹³C.carb of bulk sedimentary carbonate can be an important tool to use in sections that lack sufficient biomagnetostratigraphy, especially in older time periods (e.g., Paleozoic, Cramer and
The detailed biomagnetostratigraphic framework at Kçira will provide the necessary context to identify and constrain useful carbon isotopic events and trends associated with the base of the Anisian, which then can be used as a template for carbon isotope stratigraphy elsewhere. The Olenekian–Anisian boundary interval is known to contain carbon isotope excursions (e.g., Richoz et al., 2007) that, by virtue of their large amplitudes and global nature, represent useful markers for the base of the Anisian. Therefore, we will analyze carbon stable isotopes on bulk CaCO$_3$ from the Kçira section, and the attendant oxygen isotopes will be used as a metric of the degree of diagenetic alteration (in general, carbon isotopes of calcite are more resistant to diagenetic alteration than oxygen isotopes [Marshall, 1992]).

We conducted a pilot study of bulk carbonate stable isotopes ($\delta^{18}O$, $\delta^{13}C$) using rock samples that were prepared with a Buehler Isomet low speed saw to avoid veins. These selected samples were broken into millimeter fragments using a rock hammer, and then crushed for 15 to 20 minutes, or until completely powdered, at low speed in a Fritsch Ball Mill or an Across International HQ-NO4 Vertical Planetary Ball Mill. Between each crushing, the agate bowl (lid, rubber washer, and cup) was cleaned and rinsed thoroughly to remove any remaining powdered sample. Stable isotopes were measured on bulk sediment samples in the Stable Figure 4 – Vertical distribution of conodonts from Kçira-A and Kçira-B after Muttoni et al. (1996) with taxonomic revision from this study (see also Fig. 3 for pictures of key conodonts).
Isotope Lab at Rutgers University using a multiprep peripheral device and analyzed on an Micromass Optima mass spectrometer. Samples were reacted in 100% phosphoric acid at 90°C for 13 min. Values are reported relative to V-PDB through the analysis of an internal standard calibrated with NBS-19 (1.95‰ for δ13C), as reported by Coplen (1995).

Our pilot study of bulk sedimentary CaCO3 shows that Kčira-A samples yield reasonable values, and the δ18O is consistent with an expected marine range (e.g., see Veizer and Prokoph, 2015), indicating good preservation of primary material (Fig. 8). In particular, the pilot bulk δ18O is comparable to that of conodont bioapatite (Trotter et al. 2015) that show correlative temperature changes with pCO2 in the Late Triassic (Knobbe and Schaller 2018). Because of the broadly similar diagenetic and tectonic histories of these sections, we can expect similar results for the Anisian. Relatively little sedimentary carbonate is produced in deep waters, and therefore bulk sediment/rock samples best characterize the average δ13C of the total carbonate produced and preserved in the marine system (Shackleton, 1987).
DISCUSSION AND FUTURE DIRECTIONS

In virtue of its stratigraphic continuity, quality of magnetostratigraphic and biostratigraphic (especially conodonts) records, promising chemosтратigraphic data, relatively simple accessibility (130 km by car from the capital city Tirana and near a village with accommodations and provisions), and logistics support provided by the Geological Survey of Albania, we consider Kçira-A a reliable GSSP to define the base of the Anisian. Potential events under scrutiny and critical discussion to define the base Anisian include at present both biostratigraphic and magnetostratigraphic datums (Fig. 8):

1. The FO of *Gladigondolella tethydis* at meter 15.70 (sample AK20).
2. The FO of *Chiosella timorensis* at meter 22.40 (sample AK30).
3. The last occurrence (LO) of *Gladigondolella carinata* at meter 26.30 (sample AK36), albeit this conodont has at present a very discontinuous distribution at Kçira-A (Fig. 8).
4. The base of magnetozone Kc1r.1r at meter 17.025.
5. The base of magnetozone Kc1r.1n (= MT1n of Hounslow et al., 2007) at meter 22.50 close to the FO of *Chiosella timorensis* at meter 22.40.
6. The base of magnetozone Kc2n at meter 24.675.

Aside magnetostratigraphy that is already well-resolved (Muttoni et al., 1996), these and/or possibly other biostratigraphic events potentially useful to approximate the base of the Anisian would need to be re-assessed and better defined with additional sampling at Kçira-A to demonstrate their ability for global correlation. Dedicated sampling would also be needed to provide the section with a continuous δ¹³C and δ¹⁸O record coupled with microfacies analysis.
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Figure 8 – Summary of magnetostratigraphic and key biostratigraphic events at Kçira-A across the Olenekian–Anisian boundary interval. Also shown are the magnetic stratigraphies of Kçira-B and Kçira-C, as well as the bulk C and O isotopes pilot data from Kçira-A and Kçira-B.


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