Albertiana 36

The Carnian/Norian boundary interval at Pizzo Mondello (Sicani Mountains, Sicily) and its bearing for the definition of the GSSP of the Norian Stage

Nicora A.1, Balini M.1, Bellanca A.2, Bertinelli A.3, Bowring S.A.4, Di Stefano P.5, Dumitrca P.6, Guaiumi C.7, Gullo M.8, Hungerbuehler A.6, Levera M.1, Mazza M.1, McRoberts C.A.9, Muttoni G.1, Preto N.7, & Rigo M.7

1Dipartimento di Scienze della Terra “A. Desio”, Via Mangiagalli 34, 20133 Milano, Italy.
2Dipartimento di Chimica e Fisica della Terra ed applicazioni alle Georisorse, Via Archirafi 36, 90123 Palermo, Italy.
3Dipartimento di Scienze della Terra, Piazza Università, 06123 Perugia, Italy.
4Earth, Atmospheric and Planetary Sciences, Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge MA 02139, U.S.A.
5Dipartimento di Geologia e Geodesia, Università di Palermo, via Archirafi 22, 90123 Palermo, Italy.
6Istitut de Géologie et Paléontologie, UNIL, BSFH-2, 1015 Lausanne, Suisse.
7Dipartimento di Geoscienze, Università degli Studi di Padova, via Giotto 1, 35137 Padova, Italy.
8INAIL-CONTARP Piemonte, Corso Orbassano 366, 10137 Torino, Italy.
9Department of Geology, SUNY at Cortland, P.O. Box 2000, Cortland, NY 13045, USA.

Introduction

Pizzo Mondello in the Sicani Mountains (Western Sicily, Italy) is one of the best sites in the world for the study of the Carnian/Norian boundary. At this site, a 450 m thick pelagic-hemipelagic limestone succession is exposed. The succession belongs to the Cherty Limestone (Calcari con selce or Halobia limestone Auctorum), and is impressive for the combination of great thickness, almost uniform facies, good exposure and easy accessibility.

Besides fulfilling these basic conditions for the examination as GSSP candidate section, Pizzo Mondello is located in an area that is very important for the paleontology for the Upper Triassic pelagic facies. The Cherty Limestone of Western Sicily, and especially of Sicani Mountains, is well known all over the world for the exceptionally rich and well preserved Late Carnian-Early Norian ammonoid faunas studied by G.G. Gemmellaro (1904) and for the very rich halobiid record (Gemmellaro, 1882; Montanari & Renda, 1976; Cafiero & De Capoa Bonardi, 1982; De Capoa Bonardi, 1984).

Although Sicani Mountains have been known in literature since XIX century, the Pizzo Mondello section is a rather new locality presented in international journals in mid ‘90s (Bellanca et al., 1995; Gullo, 1996). In the second half of the ’90s, integrated paleomagnetic, isotopic and conodont stratigraphic investigations were carried out, and Pizzo Mondello soon became one of the world references for the unusual combination of Late Carnian-Early Norian magnetostratigraphic, stable isotope and conodont record (Muttoni et al., 2001; 2004).

However, the investigations carried out in the late ’90s were not detailed enough from the paleontological point of view to support the presentation of a GSSP proposal, as pointed out by Krystyn & Gallet (2002). For this reason a new multidisciplinary research programme started in 2006. Aims of this programme, which involves researchers from Milano, Padova, Palermo, Perugia and Lausanne Universities, are, besides the sedimentology, the high resolution integrated bio-chronostratigraphy based on conodonts, ammonoids, halobiids and radiolarians, and the recalibration of magnetostratigraphy and of stable isotope curves.

Here we present the new data available. Two new very dense conodont samplings were carried out in fall 2006 and spring 2007. The first ammonoid and halobiid bed-by-bed sampling was done in spring 2007, and radiolarian sampling was done in 2005 and summer 2007.

Geological setting

Pizzo Mondello is located in the Sicani Mountains, about 4 km SE of the worldwide known Permian megablocks of the Sosio Valley (Fig. 1.1).

The Sicani Mountains belong to the western Sicily segment of the Maghrebian thrust and fold belt. The structural setting of this area consists of a pile of south-verging thrust sheets formed by Permian to Cenozoic deep-water sediments. They are known as Sicarian structural units (Catalano et al., 1995), and are regarded as to be derived from the Neogene contraction of a deep-water basin (Sicanian basin) located along the southern margin of the Ionian Tethys (Di Stefano, 1990; Muttoni et al., 2004). Pizzo Mondello is the exposed part of a large thrust sheet that overthrusts upper Tortonian-Messinian clays. The roughly East-West trending thrust front is dissected by a later (Pliocene) NW-SE right transpressional fault separating the Pizzo Mondello ss. from Pizzo Scavarrante to the West (Fig. 1.1).
Late Miocene-Pliocene thrusting and transpressional movements, associated to clockwise rotations (Muttoni et al., 2001), resulted in a polyphasic folding of the Pizzo Mondello Meso-Cenozoic succession. Northward the Pizzo Mondello unit is in turn overthrust by another Sicanian-type structural unit known as Monte Rose Unit (Mascle, 1979; Di Stefano & Gullo, 1997).

**Stratigraphic setting**

The Pizzo Mondello succession consists of deep-water Upper Triassic to Eocene calcilutites with a Middle Jurassic intercalation of radiolarites and pillow lavas, covered by Oligo-Miocene clays and glauconitic sandstones. The total thickness can be estimated at about 1500 m.

The Carnian to Rhaetian succession can be easily subdivided into three lithostratigraphic units (Di Stefano, 1990; Gullo, 1996; Di Stefano & Gullo, 1997). The lowermost unit (Fig. 3) consists of a few meters of Upper (p.p.) Carnian dark gray marls alternating to marly limestones. These beds are assigned to the Mufara Formation (Schmidt di Friedberg, 1962), an about 200 m thick lithostratigraphic unit well known from the deep water successions in western Sicily. The Mufara Formation has played the role of major décollement level during the Neogene Maghrebian accretion. At Pizzo Mondello this formation lies tectonically on Tortonian-Messinian clays. An upsection change from marls-calcilutite alternations to monotonous calcilutite beds marks the transition from the Mufara Formation to the next thick unit, informally known as Portella Gebbia Limestone. Gullo (1996) as Portella Gebbia Limestone.

The lower part of the Cherty Limestone, straddling the Carnian/Norian boundary (unit 2 of Muttoni et al., 2001; 2004), is studied in detail.

**Lithofacies and sedimentology**

Muttoni et al. (2001, 2004) divide the Cherty Limestone of Pizzo Mondello into four parts or lithozones (Fig. 3):

I. The basal 3 m, above the Mufara Formation, is characterized by calcilutites with rare cherty nodules;

II. 143.5 m of dm-thick, well-bedded white-yellow calcilutites with black chert nodules, intercalated with cm-thick marly levels, follow. In the calcilutites of this lithozone, thin-shelled bivalves (halobiids), foraminifers, radiolarians, sponge spicules, sparse ammonoids and ostracods (Gullo, 1996), as well as calcispheres and calcareous nanofossils (Bellanca et al., 1993; 1995) are present;

Figure 1: Location map of Pizzo Mondello (Sicani Mountains, Sicily). 1. Geological map of the Sicani Mountains (from Di Stefano et al., 1996). 2. Detailed map of Pizzo Mondello area (from Muttoni et al., 2004).

Figure 2: General view of Pizzo Mondello (La Cava) section showing 1) the entire succession of the Cherty Limestone; 2) the interval under study, with the position of the two sampling sites (A and B).
Figure 3: Pizzo Mondello section from Muttoni et al. (2004), with δ¹³C and δ¹⁸O isotope curves and magnetostratigraphy. The lower part of the log, representing the Carnian/Norian boundary interval, is studied in detail in this paper (Fig. 4 and 5).
The ammonoids are sparse within the beds, but the collection is possible because of the very good exposure of the succession. The beds can be easily followed along strike for tens or even hundreds of meters and some specimens can be recognized on surface.

At the present some tens of ammonoids have been collected. Most of them are of small size. Sometimes the specimens are hard to extract from the matrix. However, some medium- to large-sized very well preserved specimens can also be found (Pl. 2). Preliminary examination of the collection lead to identify some stratigraphic markers.

**Discotropites plinii** (Mojisovics) has been collected from level PMAM17 (Pl. 2.5), in the lower part of the studied interval (Fig. 4). This species is index of the **D. plinii** subzone (Krystyn, 1974, 1980), first subzone of the uppermost Carnian **Anatropites spinosus** Zone.

In the middle part of the studied interval, in level PMAM7 a well preserved **Gonionotites maurolicoi** Gemmellaro has been found (Pl. 2.6). The genus **Gonionotites** ranges across the Carnian/Norian boundary in both the Tethyan realm and North America. In the Tethys it can be found from the **Gonionotites cf. italicus** subzone (Krystyn, 1980) of the **Anatropites spinosus** Zone to the **Guembelites jandianus** Zone (Krystyn, 1982), while in North America it is found in the **Macrolobatus** and** Kerri** zones (Tozer, 1994). At the rank of species, the Upper Carnian **Gonionotites** differ from the Lower Norian ones (Krystyn, 1982; Tozer, 1994). Unfortunately **G. maurolicoi** Gemmellaro has been reported only by Gemmellaro from western Sicily, then the stratigraphic position of this species has never been calibrated with respect to the Carnian/Norian boundary.

The ammonoid record documents also the very base of the succession. A specimen of **Anatropites spinosus** (Mojsisovics) has been collected from the “slump-breccia” level; this specimen obviously can be recognized on surface. The “slump-breccia” is characterized by brownish clays, which are rarely laminated (Pl. 1 C1-3).

In the logged section (Fig. 4), these three facies alternate following the scheme A-B-C-B-A with interval C centered at m 73 ca.

This facies alternation may represent a combination of oscillations in the carbonate sediment supply from surrounding carbonate platforms, varying dissolution rates at the sea-bottom, and different autochthonous carbonate productivity (e.g., benthic thin-shelled bivalves or calcispheres, supposed to be pelagic according to Bellanca et al., 1993; 1995).

**Ammonoid distribution**

The biostratigraphic analysis of ammonoids and halobiids started in May, 2007. Two segments of Muttoni et al. (2001) interval II (lower half and upper part of the section in Fig. 4) were selected to test a bed-by-bed sampling for megafossils (Fig. 4). This sampling yielded sparse ammonoids together with very common halobiids. The occurrence of ammonoids is especially interesting because it solves a problem of apparent inconsistency in literature. Gemmellaro (1904) described a large collection of about 4,000 well preserved ammonoids from Cherty Limestone of several localities in western Sicily. However, since that time only very few citations of ammonoids have been done (i.e., De Wever et al., 1979; Mascle, 1979; Gullo, 1996; Krystyn & Gallet, 2002), but no description of new specimens has never been provided.

Halobiid distribution

At present, about 300 halobiid specimens (from 44 beds) have been collected (Fig. 4). Halobiids have a wide distribution within the succession, ranging from almost the base (sample PM6), to the top of...
Within this interval, we recognize different distribution patterns for fossils. The base and the first half of the succession show a quite homogeneous alternation of levels bearing only halobiids or levels bearing only ammonoids, with some intercalated levels bearing both halobiids and ammonoids (e.g. levels FNP52, FNP75, FNP112 in Fig. 4). The halobiids are recorded as small prints of single valves (frequently not more than 1-1.5 cm in diameter for lenticular forms, and not more than 1.5-2 cm in length for elongated forms). The skeletal material is very rarely preserved –mostly recrystallized shells.

The second half of the succession is characterized by a thick beds-set of levels bearing halobiids only, with ammonoids distributed below and over it (i.e. levels from NA44 to FNP153). The halobiids from these levels are recorded as small prints of single valves (frequently not more then 1-1.5 cm in diameter for lenticular forms, and not more than 1.5-2 cm in length for elongated forms). The skeletal material is very rarely preserved –mostly recrystallized shells.

At the moment, the study of the collection is in progress, but we recognize seven species, and four assemblages. The lower part of the succession is dominated by *Halobia lenticularis* and *H. austriaca*, with rare *H. simplex* and only one specimen of *H. superba* (levels from NA15B to FNP67/68; Fig 5). The middle part is dominated by *H. radiata* forms (levels from FNP75 to FNP115; Fig. 4). The halobiids from levels NA44 to FNP153A are *H. styriaca* (Mojsisovics, 1874) or *H. styriaca*-group specimens (levels from FNP150 to FNP153A; Fig. 4). Finally, the uppermost part of the succession (levels FNP170.2 and FNP170.3; Fig. 4) contains few specimens of *H. mediterranea*.

We identify four halobiid assemblages, named for their dominant species, from bottom to top: *H. lenticularis* (with subordinate *H. austriaca* and *H. simplex*), *H. radiata*, *H. styriaca*, and *H. mediterranea*.

The conodont distribution

At Pizzo Mondello, conodont samples were collected at different times and by different researchers in the past.

---

### Table: Conodont Distribution

<table>
<thead>
<tr>
<th>taxa samples</th>
<th>LATE CARNIAN</th>
<th>EARLY NORIAN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acanthocircus (?) sp. A PESSAGNO, 1979</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Braginastrum curvatus TEKIN</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Bulbocyrtium reticulatum KOZUR &amp; MOSTLER</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Capnodoce sp. cf. C. anapetes DE WEVER</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Capnodoce sp.cf. C. longibrachium TEKIN</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Capnuchosphaera deweveri KOZUR &amp; MOSTLER</td>
<td>x x x</td>
<td></td>
</tr>
<tr>
<td>Capnuchosphaera triassica DE WEVER</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Capnuchosphaera lea DE WEVER</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Capnuchosphaera sp. cf. C. lea DE WEVER</td>
<td>x x x x</td>
<td></td>
</tr>
<tr>
<td>Capnuchosphaera theloides DE WEVER</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Capnuchosphaera sp. aff. C. crassa YEH</td>
<td>x x x</td>
<td></td>
</tr>
<tr>
<td>Capnuchosphaera tricornis DE WEVER</td>
<td>x x x</td>
<td></td>
</tr>
<tr>
<td>Capnuchosphaera sp. indet.</td>
<td>x x x</td>
<td></td>
</tr>
<tr>
<td>Carinaheliosoma carinata (KOZUR &amp; MOSTLER)</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Dumitricasphaera (?) sp.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Entactinosphaera (?) sp.1 BRAGIN</td>
<td>x x x x x x</td>
<td></td>
</tr>
<tr>
<td>Enoplocampe sp.</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Kahlerosphaera sp. cf. Eptingium sp. A DE WEVER</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Icrioma tetrancistrum DE WEVER</td>
<td>x x x</td>
<td></td>
</tr>
</tbody>
</table>

---

**Figure 5:** Radiolarian distribution in the studied samples.
Hayashi. But a clear (Orchard) (Plate 3.5) is (Mosher) (Plate 3.10), Orchard (Plates 3.8, 3.9) and Paragondolella polyg (Kozur) according to Kozur from NA33 upwards.

4.10) is present from NA30 upwards. 4.5) occurs in NA27. from FNP88A. E. orchardi

Epigondolella quadrata oertlii to NA25. with the aforementioned species, in NA15 and ranges up from NA12 up to NA37. 3.4) is fromNA12 up to NA37. - Carnepigondolella pseudodiebeli (Kozur) (Plate 3.4) is from NA12 to NA37.

- Carnepigondolella pseudoechinata (Kozur) and Metapolygnathus stephanus Orchard occur from NA17.

- Neocavitella cavittata Sudar & Budurov appears, along with the aforementioned species, in NA15 and ranges up to NA25.

- Norigondolella sp. (Plate 3.1) and Metapolygnathus oertlli (Kozur) (Plate 3.2) occur in NA16.

- Carnepigondolella samueli (Orchard) (Plate 3.5) is present from NA19.

- Metapolygnathus primitius (Mosher) (Plate 3.10), Epigondolella quadrata Orchard (Plates 3.8, 3.9) and E. orchardi Kozur (Plates 3.7, 3.11) are rather abundant from FNP88A.

- Epigondolella praetriangularis Kozur & Moix (Plate 4.5) occurs in NA27.

- Epigondolella triangularis (Budurov) (Plates 4.8, 4.9, 4.10) is present from NA30 upwards.

- Epigondolella rigoi Kozur (Plates 3.12, 4.6) was obtained from NA33 upwards.

-Metapolygnathus parvus Kozur (Plates 4.2, 4.3), Epigo-ndolella spatulata (Hayashi) and M. echinatus (Hayashi) (Plates 4.1, 4.4) characterize the conodont fauna from NA36 upwards.

According to the recent literature, the bio-chronostratigraphic value of the species proposed to determine the Carnian/Norian boundary is here briefly discussed.

- The first conodont association ([Paragondolella polygnathiformis (Budurov & Stefanov), Carnepigondolella carpatica (Mock), Carnepigondolella nodosa (Hayashi) along with Metapolygnathus stephanus Orchard and Carnepigondolella ex gr. zoae (Orchard)) can be related to the Middle-Late Tuvalian according to Orchard (1991a,b), Orchard & Tozer (1997), Carter & Orchard (2000), Orchard et al. (2001), Muttoni et al. (2001), Krystyn et al. (2002), Channell et al. (2003), Kozur (2003), Moix et al. (2007)].

- Metapolygnathus communisti Hayashi (Muttoni et al., 2001) seems to have a regional distribution (Kozur, 2003; Channell et al., 2003). In the Northern Tethys it appears just before the FAD of Norigondolella navicula (Huckriede) and disappears just before the FAD of Epigondolella quadrata Orchard, while in Neotethys and North America it occurs significantly earlier below the FAD of Norigondolella navicula (Huckriede) (Kozur, 2003).

- Neocavitella cavittata Sudar & Budurov range is restricted to the upper part of the Carnian according to Sudar and Budurov (1979), Budurov and Sudar (1990).

- Norigondolella navicula (Huckriede) has been regarded as marker for the base of the Norian Stage by Krystyn (1980) and Orchard (1991, b). According to Carter & Orchard (2000) and Kozur (2003), Norigondolella navicula seems to be facies controlled and thus not usable as boundary marker.

- Metapolygnathus oertlli (Kozur) according to Kozur (1980) and Krystyn et al. (2002) is a short-ranged species of the Latermost Tuvalian that ends at the FAD of Metapolygnathus communisti Hayashi. But a clear overlapping of Metapolygnathus communisti Hayashi with Metapolygnathus oertlli (Kozur) has been recently illustrated in Rigo et al. (2007).

- The FO of Carnepigondolella samueli (Orchard) identifies the Upper nodosus Zone sensu Orchard (1991, a) of Middle-Late Carnian age.

- Metapolygnathus primitius (Mosher) straddles the Carnian/ Norian boundary (Orchard, 1991, a,b; Orchard & Tozer, 1997; Muttoni et al., 2001). According to Kozur (2003), in North America the FAD of M. primitius is partly coincident with the FAD of Norigondolella navicula while in the Neotethys it is coeval to the FAD of Epigondolella orchi Kozur. However the occurrence of Metapolygnathus primitius is very close to the base of the Norian. At Pizzo Mondello M. primitius occurs along with E. orchardi and E. quadrata, and become very abundant after the FO of M. echinatus and M. parvus.

- Epigondolella orchi Kozur is Latermost Carnian-Low-
er Norian in age according to Kozur (2003) and Moix et al. (2007). It occurs along with Metapolygnathus communisti and Metapolygnathus primitius in the Neothetics while in the Northern Tethys it is associated with Nortigondolella navicula and transitional forms to Carnepigondolella pseudodiebeli (Kozur), as well argued in Kozur (2003).

- Epigondolella quadrata  Orchard (= Epigondolella abneptis subspecies A; Orchard, 1991, b) is Early Norian in age according to Orchard (1991 a, b), Krystyn et al. (2002), Channell et al. (2003), Kozur (2003) and Moix et al. (2007).

- Epigondolella praetriangularis Kozur & Moix occurs from the uppermost Tuvalian to the Earliest Norian (Late Norian); Carter & Orchard, 2000).

- Epigondolella triangularis (Budurov) (= Epigondolella abneptis subspecies B sensu Orchard, 1991 a) is Late Carnian (Early Norian) according to most of the Authors (e.g.: Orchard, 1991 a, b; Krystyn et al., 2002; Channell et al., 2003; Kozur, 2003 and Moix et al., 2007).

- Epigondolella rigoi Kozur ranges from Earliest Norian to Alauinian (Middle Norian; Moix et al., 2007)

- Metapolygnathus parvus Kozur, according to Kozur (1972), is restricted to the Tuvalian (Late Carnian).

- Metapolygnathus echiatus (Hayashi): Orchard (1991b) refers this species to Metapolygnathus pseudoechinatus (Kozur) and assigne it to the Latermost Tuvalian.

Radiolarian distribution

The radiolarian faunas from the latest Carnian to Early Norian interval are fairly well to very well preserved in the Pizzo Mondello section and show a rather high diversity. Common spumellarian genera include Capnuchosphaera De Wever, Spongotorillispinus Kozur, Moix & Mostler, and Kahlerosphaera Kozur & Mostler. Nassellarians are usually less abundant and are often represented by various Xiphothecidae and Pseudodictyomitridae.

Many of these forms are well known from coeval sections in the Tethys (De Wever et al., 1979; Kozur & Mostler, 1972, 1978, 1979, 1981; Tekin, 1999, etc.), as well as from British Columbia (Carter & Orchard, 2000) and Oregon (Blome, 1984; Yeh, 1989) and can represent useful markers for global correlations. There are, however, some differences between the faunas known in North America and in Western Tethys, as for example, the abundance of genus Xiphothecella De Wever & O’Dogherty in Western Tethys and its scarcity in North America.

As can be seen in Tekin (1999) and was pointed out especially by Carter (in Carter & Orchard, 2000), radiolarians show a gradual change across the Carnian/Norian boundary. However, Carter & Orchard proposed several potential radiolarian datums for the boundary calibrated with conodont zonation.

The study of the present radiolarian sequence is in a preliminary state. A closer sampling around the Carnian/Norian boundary was done quite recently and the study of the new samples around the boundary is in progress. Anyway, this preliminary study shows that some taxa, previously known as having their LAD in the Late Carnian (Praeorbiculariformella, Spongotorillispinus, Weverella, Dumitricasphaera, Monospengella) range till the Early Norian, and other taxa known until present from the Early Norian (Tekin, 1999) are still present in the latest Carnian.

In the present state of knowledge, A9a (located 1 m above the sample PM28, see Fig. 4, and around 12 meters above the δ13C shift, see Fig. 3) is the oldest sample showing noticeable Norian affinities by containing the FAD of certain taxa known only to appear in the lower Lacian: for example some species of Mesosaturnalis, and especially Monicapuchosphaera (M. inflata Tekin, Pl. 6 fig. 9), etc. (Pl. 5, figs. 14-16 and Pl. 6, figs. 8-16). This sample and some upper samples (A10a, NA41) contain numerous new taxa besides many already known species typical of Early Norian assemblages as reported in particular in Turkey (Tekin, 1999). Other species, as for example Carinaheliosoma carinata (Kozur & Mostler) (Pl. 6 fig. 13), known as having their LAD in the Early Norian, are present in this sample. A detailed content can be seen in the occurrence table (Fig. 5).

The sample A10a (2 meters above the sample PM29) is Early Norian on the basis of the presence of Kahlerosphaera kemerosis adentata Tekin (Pl. 6, fig. 1), known so far only from the Early Norian. Besides it there are species ranging from the Late Carnian to Early Norian (Capuchosphaera deweveri Kozur & Mostler, C. tricornis De Wever, Kahlerosphaera norica Kozur & Mock, etc., see Plates 6-7).

The sample NA41 (18 metres above the δ13C shift and just above the A10a) is Early Norian on the basis of the presence of the same taxa yielded in A10a (Pl. 6) and of Icrioma tetrancistrum De Wever (Early-Middle Norian), Xiphothecella longa (Kozur & Mock) (Early Norian-?Middle Norian), and Xiphothecella rugosa (Bragin) (Late Carnian-Early Norian, Braginias curvatum Tekin, Podobursa akayi Tekin, Capnodoce sp. cf. C. longibrachium Tekin, and Senellella triassica Tekin, almost all referable to Early Norian (Pl. 7).

Magnetostatigraphy

A total of 410 paleomagnetic core samples were analysed for magnetostatigraphy (Muttoni et al., 2001; 2004). Rock magnetic experiments showed the presence in all sampled lithologies of dominant magnetite as carrier of the natural remanent magnetization (NRM). The results of stepwise thermal demagnetization of the NRM showed a multi-component structure. There is an initial magnetization component along the north and steep positive present-day field direction, isolated between room temperature and ~200-300°C in the majority of the specimens. At higher demagnetization temperatures, from ~200-300°C to ~400°C up to a (rare) maximum of 500-550°C, about three-quarters (73%) of the specimens show the presence of a southeast-and-down or northwest-and-up (in geographic coordinates) characteristic component, interpreted as acquired during normal and reverse geomagnetic polarity.
respectively. After correction for the homoclinal bedding tilt, the mean normal and reverse characteristic component directions become more easterly and westerly, respectively. Although normal and reverse populations are clearly seen, their means depart from antipodality by ~36°, which we attribute to residual contamination from present-day field overprinting. The effect of the contaminating bias and/or transitional components on the mean direction can be minimized by first inverting all directions to common polarity, which results in a tilt corrected mean direction of Dec. = 107.0°, Inc. = 34.5°. The corresponding overall paleomagnetic pole, calculated by averaging the virtual geomagnetic pole (VGP) for each characteristic component direction, is located at Long. = 78.0°E, Lat. = 0.4°S.

The latitude of the sample VGP relative to the north pole of the paleomagnetic axis was used for interpreting the polarity stratigraphy. An overall sequence of 27 polarity intervals, labeled from magnetozone PM1 to PM12n has been established starting at the base of the Cherty Limestone (Fig. 3); delineation of magnetozones PM1 to PM6 is from Muttoni et al. (2001). Each magnetozone is subdivided into a lower predominantly normal and an upper predominantly reverse portion, in which submagnetozones can be embedded.

The conodont Carnian-Norian boundary was placed at the PM4r/PM5n boundary, whereas the δ13C positive shift falls within the upper part of magnetozone PM4n (Fig. 3) (Muttoni et al., 2004 and references therein).

Chemostратigraphy

Stable isotopes (δ13C and δ18O) data were already presented in literature, but a new detailed sampling of the boundary interval is scheduled. The data by Bellanca et al. (1995) for the lowermost part (Carnian) of the section, were complemented by Muttoni et al. (2004), who reported the δ13C and δ18O curves for the whole Cherty Limestone succession (Muttoni et al. 2004, fig. 3; Fig. 3). A 1.2 permil shift of δ13C is reported from the upper part of the magnetozone PM4n and immediately below sample PM25 (Muttoni et al., 2004, fig. 3; Fig. 3). As suggested by Muttoni et al. (2004) this shift could be a proxy for the Carnian/Norian boundary, but further investigation is necessary to better calibrate this physical event.

Tuffitic layers

The upper part of the boundary interval (upper lithofacies A) is under study in order to find tuffitic layers. If the occurrence of tuffitic layers is confirmed, we will process samples to separate and date zircons.

Correlations and possible marker events

The following stratigraphically important platform conodont occurrences have been recognized at Pizzo Mondello section from base to top (Fig. 4). A particular attention has been focused to those species which have been historically considered to mark the base of the Norian Stage.

- **Metapolygnathus communisti Hayashi, 1968**: Metapolygnathus communisti was first stated by Hayashi (1968) from Japan. Subsequently Krystyn (1980) differentiated the Metapolygnathus communisti population into two different subspecies: Metapolygnathus communisti s.s. and Metapolygnathus communisti B attributing to M. communisti s.s. a range Latest Carnian-Earliest Norian and to M. communisti B only Early Norian. As suggested by Kozur (2003), Metapolygnathus communisti recovered in the Northern Tethys are always advanced forms, while transitional forms between M. communisti and its forerunner P. polygonathiformis noah (Hayashi) were restricted to North America and Neotethys, allowing the assumption that the FOs of M. communisti are diachronous in between the Northern Tethyan-Western Pantalassa and North America and Neotethys. However the occurrence of M. communisti is world widely below the FADs of Norigondolella navicula and the Epigondolella spp. (e.g. Epigondolella orchardi, Epigondolella quadrata) and at Pizzo Mondello section M. communisti Hayashi occurred below the ammonoid Discotropites plini, which is a guide species for the base of the upper Tuvalian (Krystyn 1974, 1980 and Krystyn et al., 2002). With this consideration the first occurrence of M. communisti is surely Late Carnian in age.

- **Metapolygnathus communisti B Krystyn, 1980**: this species never described and only illustrated in Krystyn (1980) has been proposed by Gallet et al. (1992, 1994) as a guide species for the base of the Norian. Unfortunately, Metapolygnathus communisti B is absent in North America and only sporadically present in the Tethys (Krystyn, 1980; Gallet et al., 1992, 1994; Rigo et al., 2007). At Pizzo Mondello section, the FO of Metapolygnathus communisti B is below the occurrence of Discotropites plini, an Upper Carnian ammonoid (see above). Thus, the sporadic occurrence, its stratigraphical range and the absence of a clear description makes the FAD on M. communisti B not ideal for defining the base of the Norian.

- **Norigondolella sp.**: for many years, the FAD of genus Norigondolella with the species Norigondolella navicula (Huckriede, 1958) has been considered by different authors working both on North American and Tethyan sections to mark the base of the Norian. Krystyn (1980) first supported this occurrence for the definition of the base of the Norian. But genus Norigondolella is often rare throughout the Neotethys suggesting it is a facies-controlled taxon (Kozur, 2003) and also in North America, according to Orchard et al. (2000), the mass occurrence of N. navicula would confirm this hypothesis. Furthermore, according to Kozur in Channell et al. (2003), the FAD of Norigondolella navicula, which is the first representative of genus Norigondolella, is close to FAD of Metapolygnathus communisti B which in Pizzo Mondello section has been recovered from surely Carnian strata (see above). The species recovered at Pizzo Mondello section and illustrated
in Plate 3, Figure 1 a-c belongs for sure to the genus Norigondolella but it is not possible to ascribe this species to Norigondolella navicula (Huckriede). It might be a precursor of Norigondolella navicula from an ancestral forerunner not yet well identified. Thus it means that the genus Norigondolella occurred from Carnian strata but the species Norigondolella navicula might even appear somewhere around the Carnian/Norian boundary as first suggested by Krystyn (1980).

- Metapolygnathus primitius (Mosher, 1970): according to Orchard (1983, 1991 a, b) and Kozur (2003), a set of different species have been gathered in Metapolygnathus primitius. Orchard (1991 a, b) defines a M. primitius Zone subdivided into lower and upper. The lower M. primitius Zone is characterized by the development of M. primitius from Metapolygnathus nodosus Hayashi and it is attributed to the uppermost Carnian. The upper M. primitius Zone is defined by the co-occurrence of Norigondolella navicula and M. primitius and attributed to the kerri Zone (Lower Norian). This association is regarded as definitive of the basal Norian.

Krystyn (1980) locates his Metapolygnathus primitius Assemblage Zone within the upper Anatropites Zone (~Macrolobatus Zone, Upper Carnian) and to the Lower Norian Jandianus (~lower kerri Zone) ammonoid Zones considering “this zone of worldwide utility because the index species is distributed in the Tethyan region as far as Canada and Western North America”.

After Kozur (2003) the FAD of M. primitius occurs contemporaneously or a little earlier than the FAD of E. orchardi, which is common in the Northern Tethys and in the Neotethys and represents a good correlation biomarker. Furthermore, real Metapolygnathus primitius occurs only from the Neotethys (Sicani, Lagonegro and Mersin area) and the Western North America, sometimes as transitional forms between Metapolygnathus communis and Metapolygnathus primitius in the Sicani Basin (Muttoni et al., 2001) as suggested by Kozur (2003). Instead, in the Northern Tethys only rare Metapolygnathus cf. primitius are present but no transitional forms occurred.

The base of the M. primitius Zone both in North America and in the Neotethys is close to the base of the Stikinoceras kerri Zone. It corresponds to the FAD of M. primitius in North America and in the Neotethys, while in the Northern Tethys it corresponds to the FAD of E. orchardi and, insignificantly later, the FAD Norigondolella navicula (Kozur, 2003).

Moix et al. (2007), refer the M. pimitius Zone to the lower part of the kerri Zone, but assign this interval to the uppermost Carnian.

At Pizzo Mondello, M. primitius appears in sample FNP88A, 27m below Gonionotites maurolifici, along with Epigondolella orchardi and Epigondolella quadrata.

- Epigondolella praetriangularis Kozur & Moix, 2007: this species was recently described by Moix et al. (2007) and its range straddles their E. orchardi Zone and E. quadrata Zone. Epigondolella praetriangularis, which represents a transitional form from Carnepigondolella pseudodiebeli (Kozur) to Epigondolella triangularis (Budurov) (Moix et al., 2007), even if not common, may suggest the interval around the Carnian/Norian boundary. At Pizzo Mondello, stratigraphically older representatives of this species occurs, along with Halobia radiata, about 11 meters below Gonionotites maurolifici.

- Metapolygnathus parvus Kozur, 1972: this species has been considered for long time as a juvenile stage of the Metapolygnathus communis (Budurov and Sudar, 1991) probably due to the short platform and the absence of nodes on the anterior margins of the platform. But juvenile forms of metapolygnathids are characterized by a more posterior position of the pit respect to the adult forms, which is situated in or just before the middle of the platform (Kozur, 2003). Instead, in Metapolygnathus parvus the position of the pit is strongly shifted forwards, and this is a very peculiar feature for a Metapolygnathus species. Thus, Metapolygnathus parvus should be considered as an independent species, and a possible biomarker for the base of the Norian.

- Epigondolella triangularis (Budurov, 1972): this species is an advanced Epigondolella, subdivided by Orchard (1991, b) into two subspecies (E. triangularis triangularis (Budurov) and E. triangularis uniformis Orchard). It ranges the middle-upper part of the Lacinian (Early Norian). At Pizzo Mondello, this species occurs 3m below Gonionotites maurolifici.

- Epigondolella orchardi (Kozur, 2003): this species has been restablished by Kozur in 2003, and it is described as a primitive Epigondolella, the perfect transition form between Carnepigondolella and Epigondolella. In detail, E. orchardi is considered to be the transitional species between Carnepigondolella pseudodiebeli (Kozur) and Epigondolella quadrata Orchard (Kozur, 2003). This species is common in the lower Lacinian (upper kerri Zone, Early Norian) of the Northern Tethys together with Norigondolella navicula (Huckriede) while it is rare in the Latemost Carnian, immediately below the kerri Zone (Kozur, 2003).

At Pizzo Mondello, E. orchardi appears together with Epigondolella quadrata Orchard, 10 meters below the finding of Gonionotites maurolifici.

- Epigondolella quadrata Orchard, 1991: this species has been called for many years Epigondolella abneptis, since 1991, when Orchard described it as a new species and named it Epigondolella quadrata. It is considered to be one of the most suitable conodonts to define the base of the Norian. In 2003 Channell et al. still considered E. quadrata as a junior synonym of E. abneptis, and replaced the name E. quadrata Zone by the name E. abneptis Zone. They used this zone to indicate the base of the Norian Stage (Channell et al., 2003), placing it within the Stikinoceras kerri ammonoid Zone, but close to the upper boundary of this zone. The base of the E. abneptis Zone (= E. quadrata Zone) seemed to be ideal to define the Carnian/Norian boundary, because it corresponded closely to the appear-
ance of *Halobia styracea* (Krystyn, 2002), and it was well defined by the FAD of *E. abnepitis* both in the Tethys and in North America (Channel et al., 2003).

Also in Moix et al. (2007), *E. quadrata* is used to mark the base of the Norian, which begins with the FAD of this species and corresponds to the base of the *E. quadrata* Zone.

According to the new biostratigraphic data collected at Pizzo Mondello, *E. quadrata* can be considered a possible biomarker for the base of the Norian. The FAD of *E. quadrata* has been found 10 meters below *Gonionotrites maurolicoi*, together with the FAD of *E. orchardi*.

- **Epigondolella rigoi Kozur, 2007**: this species has been recently established by Moix et al. (2007). It defines the homonymous zone (*E. rigoi* Zone, between the *E. quadrata* Zone and the *N. halstattiensis* Zone - *E. triangularis* Zone), and it occurs from the Early Norian to the Alunian. The species is widespread throughout the entire Tethys (Moix et al., 2007).

The stratigraphic position of *E. rigoi* and its zone (above *E. quadrata* Zone), and its wide distribution through all the Tethys, make this conodont a suitable species as candidate to indicate the base of the Norian. At Pizzo Mondello, *E. rigoi* has been found 1.50m above *Gonionotrites maurolicoi*.

- **Metapolygnathus echinatus** (Hayashi, 1968): the species was regarded as an early growth stage of *M. communis* and referred to *Carnepigondolella pseudoechinata* by Kozur (1990). Orchard (1991, a) refers Metapolygnathus echinatus as a very important index species of his Metapolygnathus communis Zone and interprets this species as "the end member in the lineage *M. lindae-M. samueli*". Subsequently, Orchard (1991, b) reviewed Metapolygnathus echinatus and included it in Metapolygnathus pseudoechinatus (Kozur) a "short-ranging species in the Carnian-Norian boundary interval". According to Orchard (1991, b), *M. pseudoechinatus* (= *M. echinatus*) is characterized "by a long blade up to two thirds total unit length, and a short subquadrate platform that bears small, usually sharp marginal denticles, particularly on the anterior part."

At Pizzo Mondello section, Metapolygnathus echinatus is associated with *M. parvus*, *M. communis* and abundant *Carnepigondolella pseudodiebeli*. Our specimens present a shorter blade and platform in respect to those specimens described by Orchard (1991, b). *M. echinatus* occurs 8m above *Gonionotrites maurolicoi* and 7m below a Norian radiolarian assemblage (A9a). Thus this species seems to be a good proxy for the Carnian/Norian boundary in agreement with Orchard and Kozur proposals at Albuquerque (2007).

**Conclusions**

On the basis of the new bio-chronostratigraphic studies, the following points can be emphasized.

1) The Pizzo Mondello succession yields ammonoids. The record is fully consistent with the faunas described by Gemmellaro (1904) and spans from the Late Carnian Discotropites plinii Zone to the Early Norian Guembelites fandianaus Zone.

2) The succession also provides very good Halobiids. Six out of the seven identified species (*H. lenticularis*, *H. superba*, *H. austriaca*, *H. simplex*, *H. radiata*, and *H. styracea*) occur also in North America with the same distribution. This provides a very good tool for correlations. *H. mediterranea* is documented only from the Tethyan realm. *H. radiata* spans from Late Carnian to earliest Norian, while *H. styracea* is traditionally considered Early Norian in age.

3) The conodont studies allow to recognize two main events (Fig. 4):

- the first one is represented by the FO of Metapolygnathus primitius, Epigondolella quadrata and *E. orchardi* in FN18A where *Halobia radiata* is also present.

- the second one is represented by the FO of Metapolygnathus echinatus and *M. parvus* in NA36, 8m above *Gonionotites maurolicoi* and 7m below a Norian radiolarian assemblage (A9a).

At present, we consider the second event, in accordance also with Orchard and Kozur (Albuquerque meeting, May, 2007) and Orchard (2007b), as more suitable to define the base of the Norian Stage.

4) The studies on radiolarian assemblages show that most species cross the C-N boundary, but a few species could have their FAD in the Early Norian as for example Kahl-erosphaera kem erensis adentata Tekin, Podoburska acayi Tekin, Senelella triassica Tekin, or Monocapnuchosphaera inflata Tekin. We do hope to have many more data when all the new samples will be processed and studied.

In summary, Pizzo Mondello section not only provides a very good magnetostratigraphic and chemostratigraphic records as well described in literature (Bellanca et al., 1995; Muttoni et al. 2001; 2004), but also the best intergrated bio-chronostratigraphic record across the Carnian/Norian boundary of the Tethyan realm. Further investigations are necessary to better calibrate the conodont events with ammonoids, halobiids and radiolarians. A high resolution sampling for all the fossil groups of the intervals PM19 to PM22 and PM26 to PM33 of the section is scheduled for spring 2008. New paleomagnetic and chemostratigraphic high resolution samplings will also be done, in order to increase the calibration of the conodont events with the magnetostratigraphic scale and stable isotope curves and to select possible proxys (PM4n boundary8°C shift).

The final goal is the presentation of the GSSP proposal for the Norian Stage at Pizzo Mondello.

**References**


Rigo, M., Preto, N., Roghi, G., Tateo, F. & Mietto, P., 2007 - A CCD rise in the Carnian (Upper Triassic) of western Tethys, deep-water equivalent of the Carnian Pluvial Event. Palaeoecol. Palaeoclimatol. Palaeoecol., 246,


Plate 1.
Main lithofacies of the Pizzo Mondello section. C1: thin, plane-bedded layers of limestone and siliceous limestones of facies C in outcrop, m 78 ca. C2: concentration of densely packed thin-shelled bivalves (Halobia sp.) of facies C in thin section. Sample FNP 151 (m 80). C3: abundant calcispheres in sample FNP 145 (m 74), facies C, as seen at SEM. B1: dm-scale nodular beds of facies B, outcrop exposure, m 47 ca. B2: wackestone with abundant radiolarian moulds and thin-shelled bivalves, sample 110 (m 51), facies B, thin section. B3: calcispheres are abundant also in facies B; note radiolarian mould filled with large calcite crystals to the right, diameter 50 μm ca. (sample FNP 126, m 62). A1: dm-scale beds with plane to undulate joints and brown chert nodules, outcrop exposure, m 15 ca. A2: wackestone with radiolarian moulds and thin-shelled bivalves, sample FNP 11 (m 29), facies A. Facies A and B are indistinguishable in thin section. A3: calcispheres and fine calcite crystals, sample FNP 11 (m 29), facies A. Calcispheres are usually rarer in facies A. Samples observed at the SEM were etched with 10% HCl for 5 to 10 seconds to highlight crystal boundaries, and coated with graphite.
Plate 2
1: Halobia lenticularis Gemmellaro; FNP67/68.
2: Halobia radiata Gemmellaro; FNP95.
3: Halobia styriaca Mojsisovics; NA45.
4: Halobia mediterranea Gemmellaro; FNP170.2.
5: Discotropites plinii (Mojsisovics), lateral view; PMAM17.
6 a-b: Gonionotites maurolicoi Gemmellaro, a) oral view, b) lateral view; PMAM7.
7: Dimorphites sp., specimen from debris (FNPdet2), lateral view.
Bar scale always 1 cm. All specimens whitened with Ammonium Chloride, except for fig. 5.
Plate 3

1a-b: *Norigondolella* sp., NA16.
2a-b: *Metapolygnathus oertlii* (Kozur), NA16.
3a-b: *Metapolygnathus communisti* B Krystyn, NA22.
4a-b: *Carnepigondolella pseudodiebeli* (Kozur), NA22.
5a-b: *Carnepigondolella samueli* (Orchard), PM19.
6a-b: *Carnepigondolella zoae* (Orchard), PM19.
7a-b: *Epigondolella orchardi* (Kozur), juvenile specimen, FNP88A.
8a-b: *Epigondolella quadrata* Orchard, FNP88A.
9a-b: *Epigondolella quadrata* Orchard, juvenile specimen, NA30.
10a-b: *Metapolygnathus primitius* (Mosher), NA34.
11a-b: *Epigondolella orchardi* (Kozur), NA33.
12a-b: *Epigondolella rigoi* Kozur, NA33.

a= upper view, b= lateral view, c= lower view.
All the bars are 200 µm.
Plate 4

1a-b: *Metapolygnathus echinatus* (Hayashi), NA 33.
2a-b: *Metapolygnathus parvus* (Kozur), NA36.
3a-b: *Metapolygnathus parvus* (Kozur), NA 37.
4a-b: *Metapolygnathus echinatus* (Hayashi), NA38.
5a-b: *Epigondolella praetriangularis* (Kozur & Moix), NA37.
6a-b: *Epigondolella rigoi* Kozur, PM28.
7a-b: *Metapolygnathus communissi* Hayashi, PM29.
8a-b: *Epigondolella triangularis* (Budurov), NA42.
9a-b: *Epigondolella triangularis* (Budurov), NA42.
10a-b: *Epigondollella triangularis* (Budurov), NA68.

*a* = upper view, *b* = lateral view, *c* = lower view.
All the bars are 200 µm.
Plate 5
All scale bars equal 100 µm. Scale A applies to 1-5 and 9-16. Scale B applies to 6 and 7.
Late Carnian:
1: *Capnuchosphaera* sp. indet., A7.
2: *Triassocampe baldii* Kozur Group, A38.
4: *Xiphotecaella longa* Kozur & Mock, A6.
5: *Paronaella* (?) sp., A38.
6: *Capnuchosphaera* sp. aff. *C. crassa* Yeh, A38.

Early Norian, sample A11:
8: *Pachus multinodosus* Tekin.
9: *Pachus multinodosus* Tekin.
10: *Corum perornatum* Blome.
11: *Corum* sp.
12: ? *Castrum* sp. indet.
13: *Latium mundum* Blome.

Early Norian, sample A9a:
14: *Dumitricasphaera* (?) sp.
15: *Entactinosphaera* (?) sp.1 Bragin.
16: *Enoplocampe* sp.
Plate 6

Sample A10a:
1: *Kahlerosphaera kemerensis adentata* Tekin.
2: *Kahlerosphaera norica* Kozur & Mock.
3: *Capnuchosphaera tricornis* De Wever.
4: *Capnuchosphaera deweveri* Kozur & Mostler.
5: *Capnuchosphaera theloides* De Wever.
6: *Vinassaspongus (?)* sp.
7: *Capnuchosphaera* sp.cf. *C. lea* De Wever.

Sample A9a:
8: *Capnuchosphaera lea* De Wever.
9: *Monocapnuchosphaera inflata* Tekin.
10: *Capnodoce* sp. cf. *C. anapetes* De Wever.
11: *Zhamojdasphaera rigoi* Kozur, Moix & Mostler.
12: *Cryptostephanidium* sp.
13: *Carinaheliosoma carinata* (Kozur & Mostler).
14: *Weverella tetrabrachiata* Kozur & Mostler.
15: *Spongotorrilispinus* sp. aff. *S. turkensis* Kozur, Moix & Mostler.
16: *Spongotorrilispinus tortilis* Kozur & Mostler.
Plate 7
Sample NA 41:
1: *Icrioma tetrancistrum* De Wever.
2: *Braginastrum curvatus* Tekin.
3: *Paronaella* (?) sp. cf. *P. norica* Kozur & Mostler.
4: *Capnodoce* sp. cf. *C. longibrachium* Tekin.
5: *Karnospongella capricornis* Bragin.
6: *Karnospongella multispinosa* Kozur, Moix & Mostler.
8: *Spongotortilispinus carnicus* (Kozur & Mostler).
9: *Spongotortilispinus* sp. cf. *S. aequicurvistylus* (Lahm).
10: *Spongotortilispinus* sp. cf. *S. turkensis* Kozur, Moix & Mostler.
11: *Zhamojdasphaera latispinosa* Kozur & Mostler.
14: *Picapora* sp. cf. *P. robusta* Kozur & Mostler.
16: *Spinopoulpus noricus* Kozur & Mock.
17: *Podobursa akayi* Tekin.
18: *Podobursa turriformis* Tekin.
20: *Senelella triassica* Tekin.
21: *Xiphothecaella longa* (Kozur & Mock).
23: *Xiphothecaella rugosa* (Bragin).
24: *Mostlericyrtium sitipesiforme* Tekin.