Tethyan magnetostratigraphy from Pizzo Mondello (Sicily) and correlation to the Late Triassic Newark astrochronological polarity time scale

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ABSTRACT

We present the magnetostratigraphy and stable isotope stratigraphy from an expanded (~430-m-thick) Upper Triassic marine limestone section at Pizzo Mondello, Sicily, and review published biostratigraphic information that can be used to define the location of the conodont Carnian-Norian and Norian-Rhaetian boundaries in this section. Pizzo Mondello offers good potential for magnetostratigraphic correlation of marine biostratigraphic and chemostratigraphic data with the continental Newark astrochronological polarity time scale (APTS) for development of an integrated Late Triassic time scale. The relatively stable average values of $\delta^{18}O$ centered on 0‰ are a strong indication that the Cherty Limestone at Pizzo Mondello suffered very little diagenetic overprinting. The conodont Carnian-Norian boundary is located 12.5 m above a positive shift of $\delta^{13}C$. A statistical approach was applied to evaluate various Pizzo Mondello to Newark magnetostratigraphic correlations. Two correlation options have the highest correlation coefficients. In option #1, the base of Pizzo Mondello correlates with the middle part of the Newark APTS, whereas in option #2, the base of Pizzo Mondello starts toward the early part of the Newark APTS. We prefer option #2 in which the Carnian-Norian boundary based on conodonts, as well as its closely associated positive $\delta^{13}C$ shift, correspond to Newark magnetozone E7 at ca. 228–227 Ma (adopting Newark astrochronology), implying a long Norian with a duration of ~20 m.y., and a Rhaetian of ~6 m.y. duration. These ages are in fact not inconsistent with the few high-quality radiometric dates that are available for Late Triassic time scale calibration. Based on its good exposure, accessibility, stratigraphic thickness and continuity, and multiple chronostratigraphic correlation possibilities, we propose Pizzo Mondello as global stratigraphic section and point for the base of the Norian.

Keywords: magnetostratigraphy, biostratigraphy, Late Triassic, Tethys, Sicily, Newark astrochronological polarity time scale.

INTRODUCTION

Two apparently contrasting options for the Late Triassic geomagnetic polarity time scale, based on magnetostratigraphic data from the Tethys marine realm (Turkey) and continental North America (western United States and Newark Basin), are reported in Gradstein et al. (1995). Resolving uncertainty about the Late Triassic time scale requires correlation of marine stages, historically based on ammonoid biostratigraphy, to continental successions. For the Late Triassic, an astrochronology anchored to magnetostratigraphy and radiometric dates is available from the Newark continental section (Kent et al., 1995; Kent and Olsen, 1999; Olsen and Kent, 1999), while magnetostratigraphy is thus far available in conjunction with marine biostratigraphy in the Tethyan realm. Continental astrochronology and marine biostratigraphy can therefore be correlated using the global record of polarity reversals for the construction of an integrated Late Triassic time scale. Fundamental steps in this direction have already been taken, but the issue is not yet settled (e.g., Muttoni et al., 2001a; Krystyn et al., 2002; Gallet et al., 2003; Channell et al., 2003).

In this paper, we present magnetostratigraphic and chemostratigraphic data and review biostratigraphic data from the literature, from a ~430-m-thick Upper Triassic pelagic limestone section located at Pizzo Mondello in Sicily (Italy). This study represents the continuation and, as far as magnetostratigraphy is concerned, completion of a magneto-biostratigraphic study conducted on the same section from its base up to meter level ~150 across the conodont Carnian-Norian boundary (Muttoni et al., 2001a).

Pizzo Mondello offers good potential for correlation with the Newark APTS by virtue of its simple diagenetic history, which allowed

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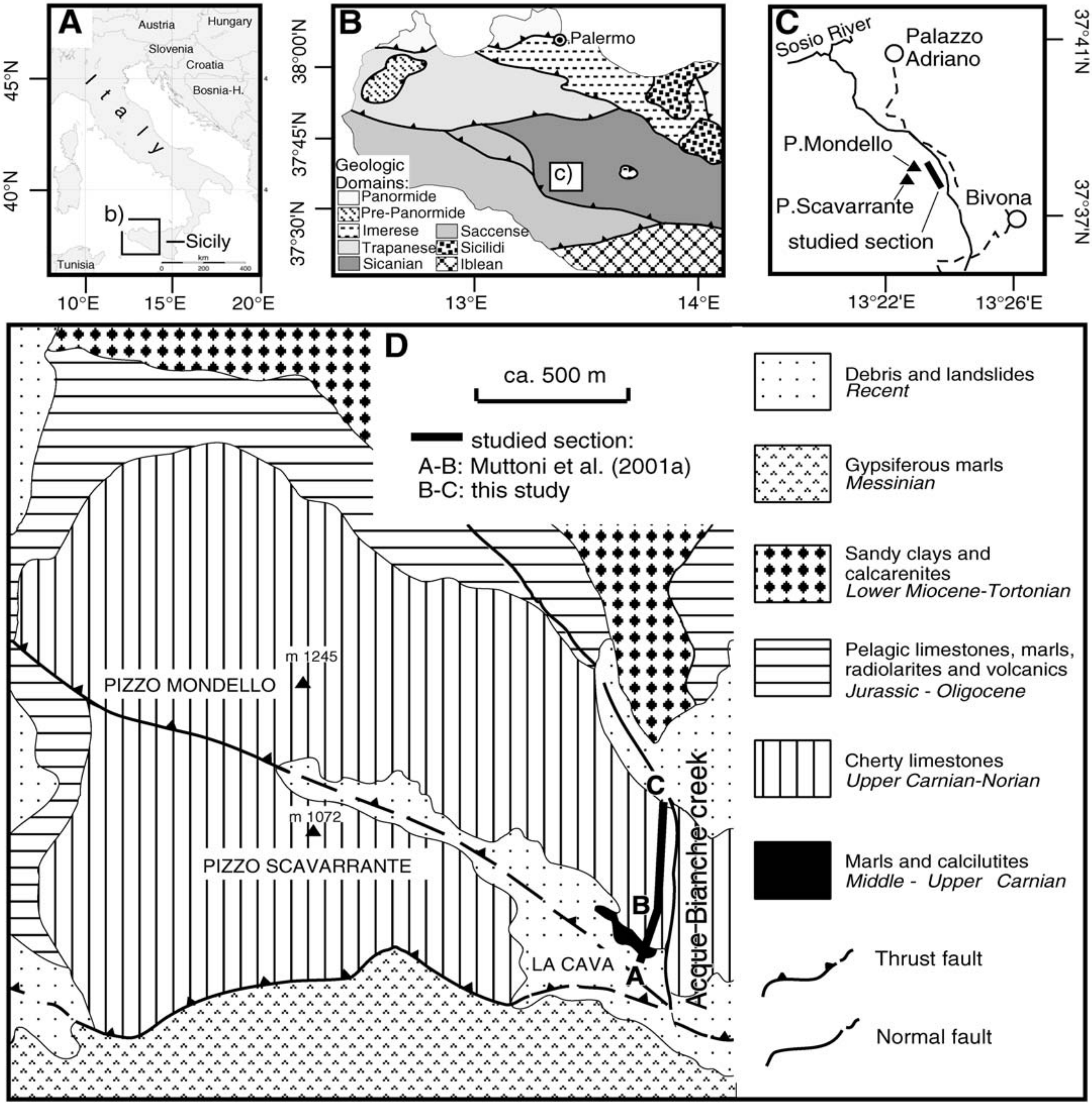


Figure 1. The Pizzo Mondello section is located in Sicily (A), and particularly in the Sicani Mountains of central-western Sicily (B). The section crops out near the village of Bivona at the locality La Cava along the Acque Bianche Creek (C, D) (section coordinates: topographic sheet 266 I NE "Bivona"; lat. 37.6°N, long. 13.4°E).

preservation of the original magnetostratigraphic signal, as well as stratigraphic continuity, with strata in strict stratigraphic superposition, and relatively high rates of sedimentation (20–30 m/m.y.) compared to classic Tethyan sections of the Hallstatt type (e.g., Krystyn et al., 2002). The aim of this paper is to correlate marine age-diagnostic fossils as well as stable isotope data from the Pizzo Mondello magnetostratigraphic section to the Newark APTS for construction of an integrated Late Triassic time scale.

GEOLOGY

The Pizzo Mondello section is located in the Neogene fold-and-thrust belt of the Sicani Mountains of western Sicily (Fig. 1). The Sicani Mountains are composed mainly of

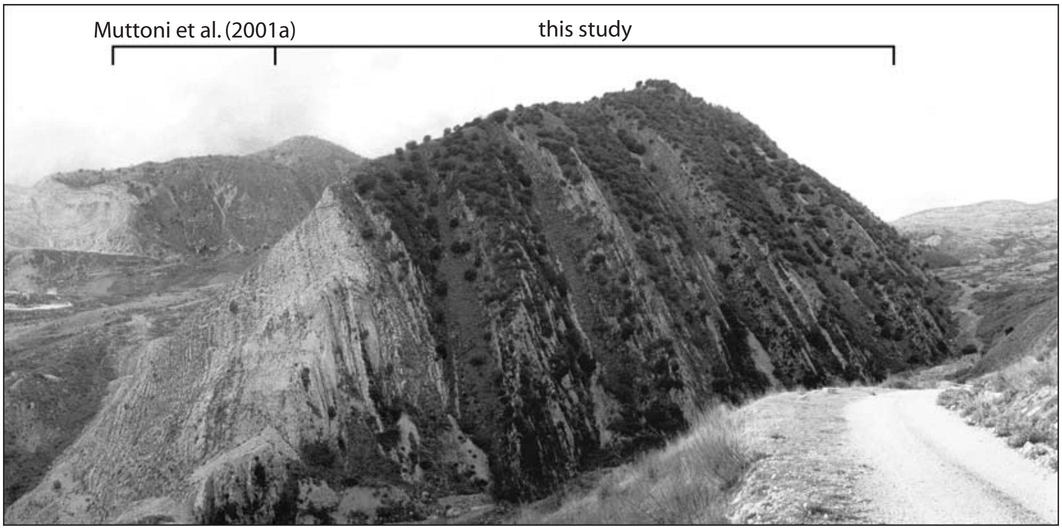


Figure 2. The Late Triassic Pizzo Mondello section, whose ~150-m-thick basal part straddling the conodont Carnian-Norian boundary was studied by Muttoni et al. (2001a). The upper part of the section, up to meter level ~430 in the uppermost Norian, is the subject of this study.

pelagic sediments of Permian to Cenozoic age, deposited in a Tethyan basinal setting of African (Gondwanan) affinity (Di Stefano, 1990; for additional information, see Muttoni et al., 2001a). The section, relatively well exposed and continuous (Fig. 2), starts at the base with a few meters of (unsampled) poorly outcropping marls and marly limestones of early-late Carnian age of the uppermost Mufara Formation (Di Stefano and Gullo, 1997; Buratti and Carrillat, 2002) (Fig. 3). These are overlain by ~430 m of evenly bedded to nodular cherty calcilutites, hereafter referred to as Cherty Limestone (known also as "Halobia" Limestone; De Capoa Bonardi, 1985). The Cherty Limestone is overlain by a few tens of meters of poorly exposed lower to middle Rhaetian calcilutites and marls (Portella Gebbia Formation), which are disconformably overlain by Jurassic sediments (Gullo, 1996).

The Cherty Limestone is subdivided, from base to top, into four lithostratigraphic units (Fig. 3):

i. A basal 3-m-thick interval located just above the Mufara Formation and characterized by calcilutites with rare chert nodules;

ii. A 143.5-m-thick interval of dm-thick, well-bedded white calcilutites with black chert nodules, intercalated with cm-thick marl levels. The calcilutites contain abundant pelagic bivalves (Halobids), foraminifers, radiolarians, sponge spicules, sparse ammonoids and ostracods (Gullo, 1996), as well as calcispheres and calcareous nannofossils (Bellanca et al., 1993, 1995);

iii. An 11.5-m-thick interval of brecciated limestones, hereafter referred to as the "breccia" level;

iv. An upper 267.5-m-thick interval of dm- to cm-thick, well-bedded to nodular whitish calcilutites with chert nodules. Chert ends at meter level ~290.

Muttoni et al. (2001a) analyzed the magnetostratigraphy and conodont biostratigraphy of units (i) and (ii) (Fig. 3). In this paper, we present magnetostratigraphic data essentially from unit (iv), chemostratigraphic data from the whole section [units (i) to (iv)], as well as an overall interpretation of the available biostratigraphic data from the literature.

BIOSTRATIGRAPHY

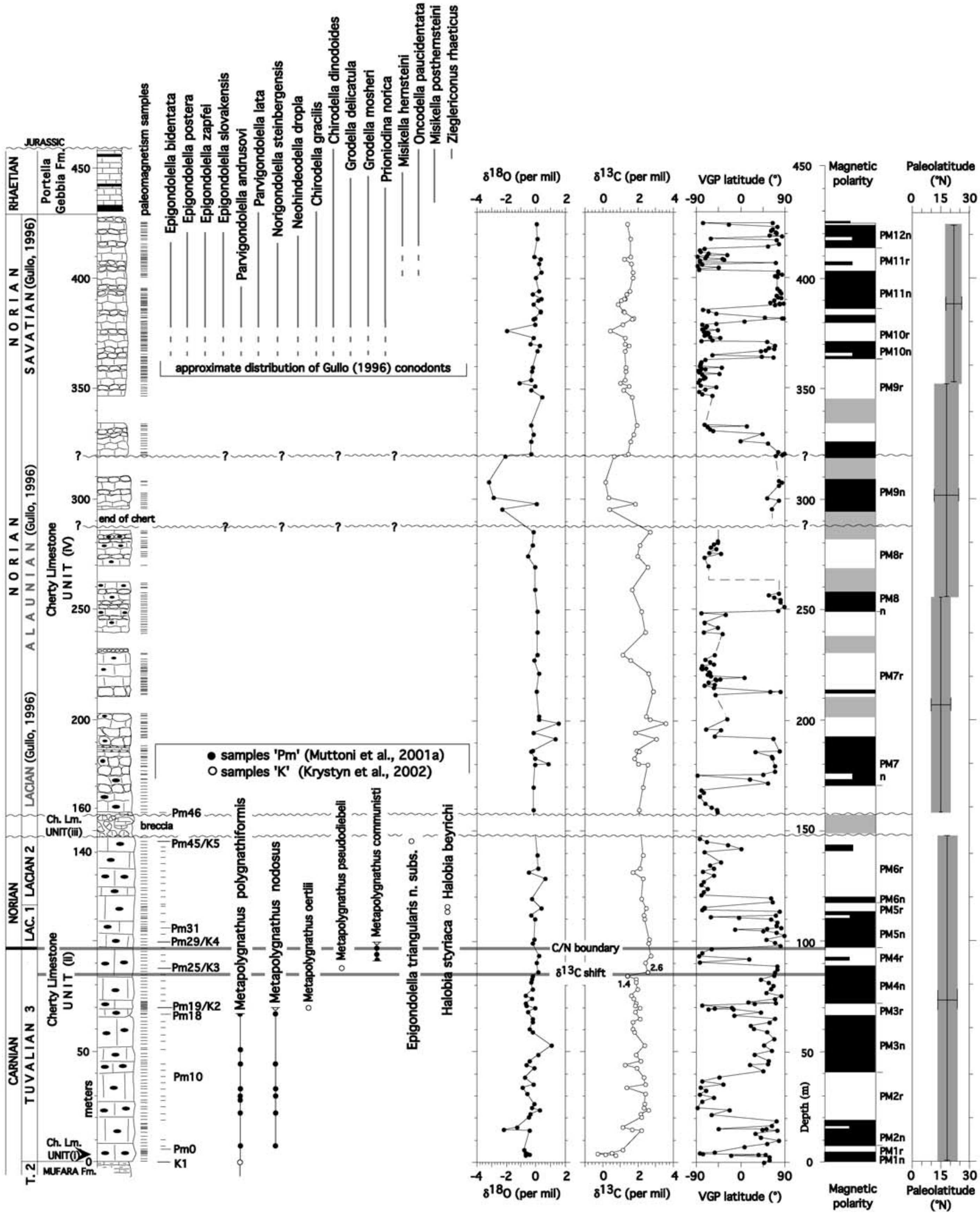
Triassic stage boundaries are historically established using ammonoids. These are present at Pizzo Mondello (Gemmellaro, 1904); however, they have not yet been studied with modern stratigraphic criteria. The age of the Pizzo Mondello section is therefore based on conodont biostratigraphy as a proxy for the ammonoid zonation (e.g., Krystyn, 1980; Krystyn et al., 2002).

The Carnian-Norian Boundary

The ammonoid Carnian-Norian boundary is approximated by conodonts using the first appearances of *Metapolygnathus communisti* A, *M. communisti* B, or *Norigondolella navicula* (Krystyn et al., 2002). The last appearances of *Metapolygnathus polygnathiformis* and *M. nodosus* predate the first appearances of both *M. communisti* and *N. navicula* in the late Tuvalian (Krystyn et al., 2002). Similar conclusions regarding *N. navicula, M. polygnathiformis,* and *M. nodosus (Epigondolella nodosa)* were reached also by Channell et al. (2003). After an early account by Gullo (1996), the conodont biostratigraphy across the Carnian-Norian boundary at Pizzo Mondello was reported by Muttoni et al. (2001a) based on 46 samples from the lower ~150 m of the section (samples Pm1–46; Fig. 3). These authors placed the Carnian-Norian boundary in a conservative stratigraphic interval between the last occurrences of *M. polygnathiformis* and *M. nodosus* at meter level 66.5 (sample Pm18) and the first occurrence of *E. triangularis* at meter level 105.5 (sample Pm31). Krystyn et al. (2002) reported data from five new samples (samples K1–5; Fig. 3), made an overall reinterpretation of the conodonts distribution of Muttoni et al. (2001a), and placed the Carnian-Norian boundary close to the last occurrence of *M. communisti* at meter level ~97 in the upper part of the stratigraphic interval of Muttoni et al. (2001a). A positive carbon isotope shift (described below) is located 12.5 m below Krystyn et al.'s (2002) conodont Carnian-Norian boundary (Fig. 3).

The Norian and Rhaetian

The breccia level of unit (iii) is within the early Norian (Gullo, 1996; A. Nicora, 2003, personal commun.) and does not seem to be associated with a major biostratigraphic gap. The overlying unit (iv) contains Norian conodonts that extend to the latest Norian (latest Sevatian) age with *Parvigondolella lata* and *Misikella hernsteini* (Gullo, 1996; A. Nicora, 2003, personal commun.). The conformably overlying Portella Gebbia Formation is of Rhaetian age. It contains at the base the first occurrence of *Misikella posthernsteini,* which is a proxy marker of the Norian-Rhaetian boundary (Gullo, 1996), and in the uppermost part, the first occurrence of *Zieglericonus rhaeticus,* which was found in Great Britain immediately below the *Psiloceras* fauna of Liassic age (Gullo, 1996). Disconformably overlying the


JURASSIC
RHAETIAN
Portella Gebbia Fm.
N O R I A N
S A V A T I A N (Gullo, 1996)
A L A U N I A N (Gullo, 1996)
LACIAN (Gullo, 1996)
Cherty Limestone UNIT (IV)
end of chert
Ch. Lm. UNIT(iii)
breccia
NORIAN
LACIAN 2
LAC. 1
CARNIAN
TUVALIAN 3
Cherty Limestone UNIT (II)
Ch. Lm. UNIT(I)
T. 2
MUFARA Fm.
meters
paleomagnetism samples
Pm46
Pm45/K5
Pm31
Pm29/K4
Pm25/K3
Pm19/K2
Pm18
Pm10
Pm0
K1
Epigondolella bidentata
Epigondolella postera
Epigondolella zapfei
Epigondolella slovakensis
Parvigondolella andrusovi
Parvigondolella lata
Norigondolella steinbergensis
Neohindeodella dropla
Chirodella gracilis
Chirodella dinodoides
Grodella delicatula
Grodella mosheri
Prioniodina norica
Misikella hernsteini
Oncodella paucidentata
Misikella posthernsteini
Zieglericonus rhaeticus
approximate distribution of Gullo (1996) conodonts
● samples 'Pm' (Muttoni et al., 2001a)
○ samples 'K' (Krystyn et al., 2002)
Metapolygnathus polygnathiformis
Metapolygnathus nodosus
Metapolygnathus oertlii
Metapolygnathus pseudoddiebeli
Metapolygnathus communisti
Epigondolella triangularis n. subs.
Halobia styriaca
Halobia beyrichi
C/N boundary
δ13C shift
2.6
1.4
δ18O (per mil)
δ13C (per mil)
VGP latitude (°)
Magnetic polarity
Paleolatitude (°N)
Depth (m)
PM12n
PM11r
PM11n
PM10r
PM10n
PM9r
PM9n
PM8r
PM8 n
PM7r
PM7 n
PM6r
PM6n
PM5r
PM5n
PM4r
PM4n
PM3r
PM3n
PM2r
PM2n
PM1r
PM1n
?

Z. rhaeticus limestones are strata of Liassic or Maastrichtian age (Gullo, 1996).

The Pizzo Mondello biostratigraphic section therefore straddles the late Carnian (Tuvalian 2) to middle Rhaetian time interval. Sampling for magnetostratigraphy and chemostratigraphy was restricted to the late Carnian–latest Norian interval of Cherty Limestone deposition.

STABLE ISOTOPE GEOCHEMISTRY OF CARBONATES

Stable oxygen (δ^{18}O) and carbon (δ^{13}C) isotope compositions were analyzed in 115 samples of bulk carbonate (Fig. 3). The samples were reacted at 90 °C with 100% phosphoric acid on an automated carbonate device connected to a VG-PRISM mass spectrometer calibrated with NBS 18, NBS 19, and NBS 20. Analytical reproducibility of the method is better than ±0.1‰ for both carbon and oxygen.

The relatively stable average value of δ^{18}O centered on ~0‰ is a strong indication that these rocks have suffered little diagenetic overprinting, except at three intervals—i.e., near the base of the section, at ~290–320 m, and at 375 m—where δ^{18}O values of ~ –2‰ to ~ –3‰ and δ^{13}C values of ~1‰ to ~0‰ are attained (Fig. 3).

The most prominent feature observed in the carbon isotope curve is a positive shift of ~0.8‰ at meter level 84.5, from average values of ~1.8‰ to ~2.6‰. This shift is located 12.5 m below Krystyn et al.'s (2002) conodont proxy of the Carnian-Norian boundary, and almost exactly in the middle part of the conodont Carnian-Norian boundary interval of Muttoni et al. (2001a) (Fig. 3). Values of δ^{13}C averaging 1.4‰ are reestablished at meter level ~300 m in apparent association with the disappearance of chert nodules (Fig. 3). The δ^{13}C positive shift at 84.5 m is interpreted as a consequence of a global increase in burial rate of organic carbon compared to the burial of carbonate carbon. This could be the consequence of an increased preservation of organic carbon (Weissert et al., 1998; Kump and Arthur, 1999). The generally simple diagenetic history of the Pizzo Mondello pelagic carbonates, indicated by their oxygen isotope composition, suggest that the carbon isotope shift at 84.5 m is a primary feature reflecting changes in the global carbon cycle and is therefore potentially useful to approximate the location of the biostratigraphic Carnian-Norian boundary on a global scale.

PALEOMAGNETISM

Paleomagnetic samples from Pizzo Mondello were drilled and oriented in the field at an average sampling interval of ~1.6 m. Muttoni et al. (2001a) collected 119 samples from the 0–146.5 m interval [units (i) to (ii)]; in this study, an additional 14 samples were collected from this same stratigraphic interval, as well as 277 samples from the base of unit (iv) at meter level 158 up to the top of unit (iv) at 424.8 m. The total number of standard ~11 cc specimens for analysis is 410 (Fig. 4). All new samples were thermally demagnetized and analyzed at the paleomagnetic laboratory of ETH Zürich. The extremely weak magnetization of Pizzo Mondello limestones required the use of a high-sensitivity magnetometer with DC SQUID technology.

Rock Magnetic Properties

The intensity of the natural remanent magnetization (NRM) is on average 0.01 mA/m, with higher values (>0.1 mA/m) between meter level ~350 and ~400 (Fig. 4A). Magnetic susceptibility is in general in the diamagnetic range (i.e., small negative values).

Figure 3. The Late Triassic Pizzo Mondello section, with indication of biostratigraphic age (T. 2—Tuvalian 2, LAC. 1—Lacian 1), lithology units (i) to (iv) (Ch. Lm.—Cherty Limestone), paleomagnetism samples from this study (i.e., from unit [iv]) as well as Muttoni et al. (2001a) (i.e., from units [i] to [ii]), and conodont samples across the Carnian-Norian boundary from Muttoni et al. (2001a; samples Pm0 to Pm46; solid circles) as well as Krystyn et al. (2002; samples K1 to K5; empty circles). The conodont Carnian-Norian boundary falls at meter level ~97 according to Krystyn et al. (2002). The approximate distribution of late Norian-Rhaetian conodonts from Gullo (1996) is also indicated. The bulk-carbonate oxygen (δ^{18}O) and carbon (δ^{13}C) isotope compositions are reported in ‰ with reference to VPDB (Coplen, 1996). A well-defined δ^{13}C positive shift is located at meter level 84.5. The latitude of the sample VGP (virtual geomagnetic pole) relative to the north pole of the mean paleomagnetic axis is plotted as a function of stratigraphic depth, with magnetic polarity zones shown by filled (open) bars for normal (reverse) polarity. Single-sample polarity zones are shown by half-bars. Gray-shaded bars represent portions with no data. At the far right of figure is shown the long-term paleolatitude drift of Pizzo Mondello derived from the characteristic magnetization inclinations (Table 1, data entries #2 to #5).

A representative suite of samples was subjected to rock magnetic analysis using isothermal remanent magnetization (IRM) acquisition (up to 2.5 T) and thermal demagnetization experiments. Samples showed three types of behaviors: (1) saturation IRM reached by ~500 mT field (Fig. 4B, case "a"); (2) IRM reached an apparent plateau but began to climb again once fields in excess of 1.5 T were applied (case "b"); or (3) IRM showed no tendency to saturate even in a field of 2.5 T (case "c"). This suggests a composite magnetic mineralogy with contrasting coercivities.

Thermal demagnetization of three-component IRM (Lowrie, 1990) showed the presence of a ubiquitous and dominant low-coercivity and ~570 °C maximum unblocking temperature mineral interpreted as magnetite, coexisting with a higher-coercivity and ~680 °C maximum unblocking temperature phase interpreted as hematite (Fig. 4C). This subsidiary mineral is more common within units (i) and (iv). Minor amounts of a sulfide or Ti-rich magnetite phase are also suggested by an inflection in the low- and intermediate-coercivity curves occasionally observed between 200 and 400 °C (Fig. 4C).

The dominant magnetite phase that carries the natural remanence at Pizzo Mondello is interpreted to be of mainly detrital origin (Moskowitz et al., 1993) as inferred from the application of the method of Egli (2004) on two selected samples.

Paleomagnetic Directions and Magnetostratigraphy

The results of stepwise thermal demagnetization of NRM displayed as standard vector end-point demagnetization diagrams show a multicomponent 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 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 (Figs. 5 and 6). Subordinate intermediate components at polarity transitions or resulting from contamination of the characteristic magnetization by the present-day field direction are also present. Directional scattering often observed close to the origin of the demagnetization diagrams (Fig. 5) is associated with the weakest and most unstable part of the characteristic remanence, which, toward the end of the demagnetization

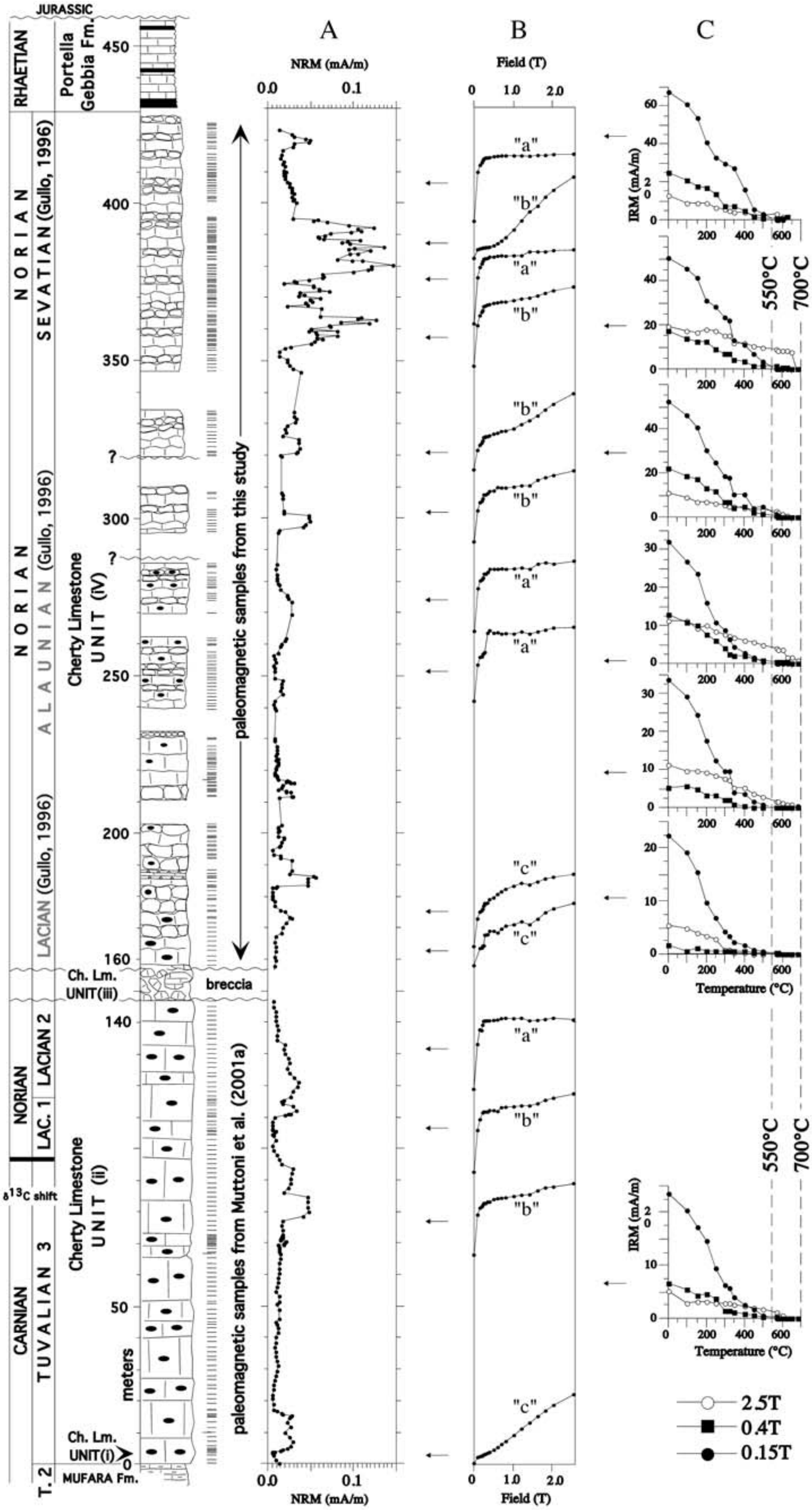


Figure 4. The natural remanent magnetization (NRM) intensities of the Pizzo Mondello section are on average less than 0.01 mA/m (A). Basic rock magnetic properties using isothermal remanent magnetization (IRM) acquisition curves (B), and thermal decay of three-component IRM (C) indicate that samples have a dominant magnetic phase that is probably magnetite coexisting with a higher-coercivity fraction interpreted as hematite. T. 2—Tuvalian 2, LAC. 1—Lacian 1.

process, approached the background noise level of the DC SQUID magnetometer (i.e., NRM < ~10^{-6} A/m at 400 °C).

After correction for the homoclinal bedding tilt, the mean normal and reverse characteristic component directions become more easterly and westerly, respectively (Figs. 5 and 6). 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 declination = 107.0°, inclination = 34.5° (Table 1, data entry #1). The corresponding overall paleomagnetic pole, calculated by averaging the virtual geomagnetic pole (VGP) for each characteristic component direction, is located at lat. 0.4° S, long. 78.0° E (Table 1, data entry #1).

The Pizzo Mondello paleomagnetic pole is rotated 104° clockwise with respect to the broadly coeval (Late Triassic–Early Jurassic) Gondwanan reference paleomagnetic pole located at lat. 71.1° N, long. 214.8° E (Table 1, data entry #6; Muttoni et al., 2001b). By subdividing the section into four stratigraphically superposed intervals, i.e., from 0 to 146.5 m (late Carnian–early Norian), 158.0 to 255.3 m ("early Norian"), 256.3 to 352.8 m ("middle Norian"), and 353.8 to 424.8 m ("late Norian"), the general amount of clockwise tectonic rotation does not substantially change, with only a moderate apparent increase from 93° in the 0–146.5 m interval to an average of ~110° in the 158.0–424.8 m interval (Table 1, data entries #2 to #5). Tectonic rotations in the fold-and-thrust belt of Sicily were mostly clockwise and occurred essentially during the Neogene (see discussion and references in Muttoni et al., 2001a). Nevertheless, a paleolatitude of 19° ± 3° N, calculated from the average paleomagnetic direction for the entire Pizzo Mondello section (Table 1, data entry #1), agrees nicely with the paleolatitude expected at Pizzo Mondello

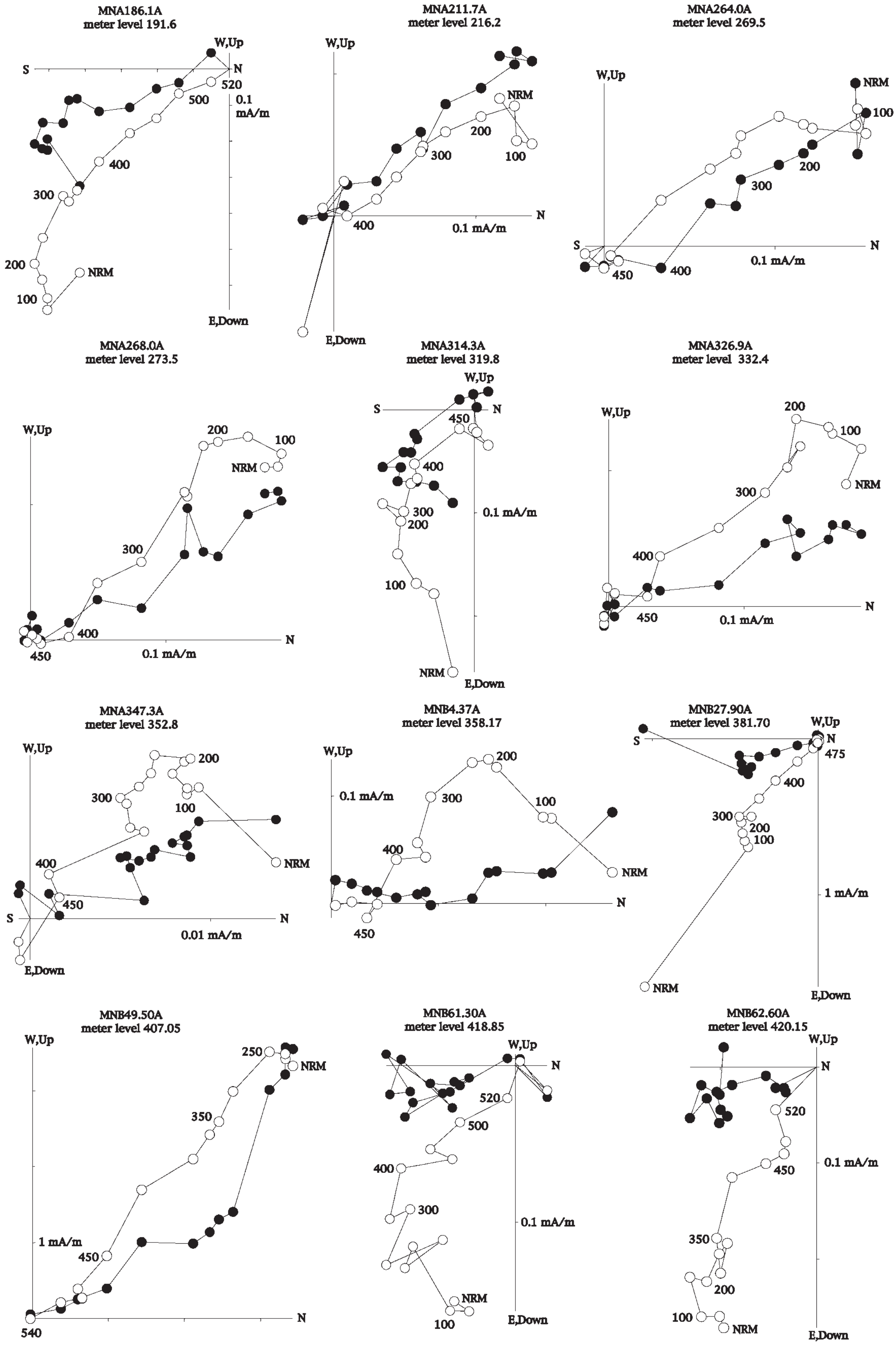


Figure 5. Vector end-point demagnetization diagrams of representative samples from Pizzo Mondello. Closed symbols are projections onto the horizontal plane, and open symbols onto the vertical plane in geographic (in situ) coordinates. Demagnetization temperatures are expressed in °C.

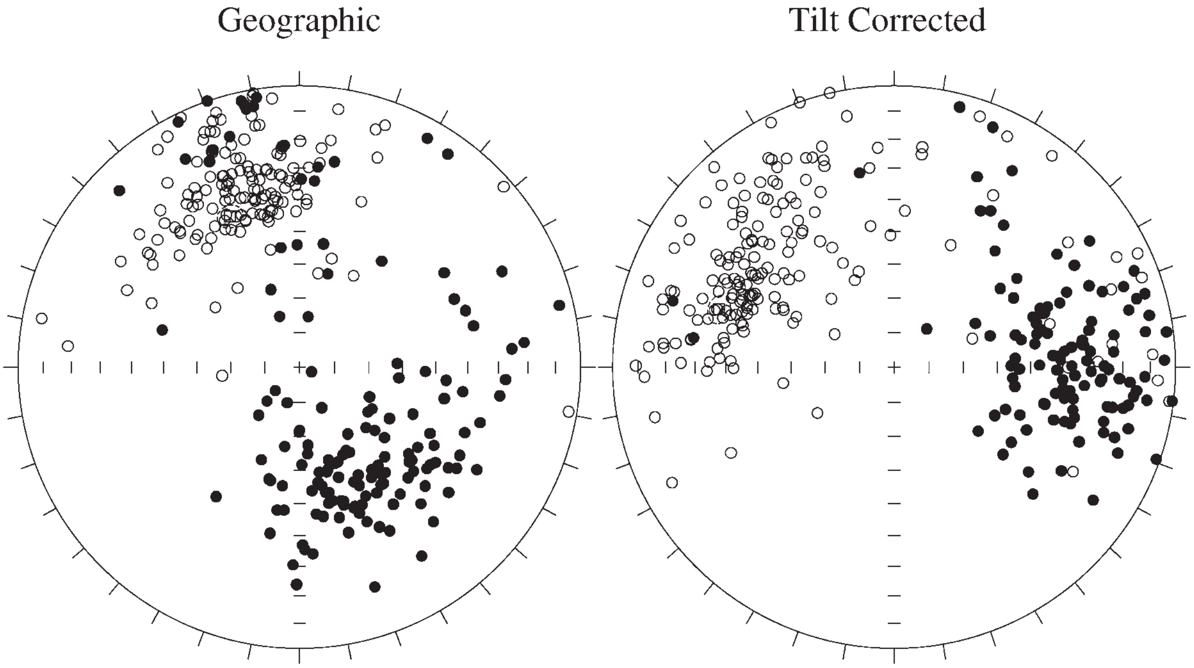


Figure 6. Equal-area projections before (in situ) and after bedding tilt correction of the characteristic component directions from Pizzo Mondello (Table 1, data entry #1). Closed symbols are projections onto the lower hemisphere and open symbols onto the upper hemisphere.

TABLE 1. PALEOMAGNETIC DIRECTIONS AND POLES FROM PIZZO MONDELLO

No.	Age	Meters	N_1/N_2	In situ				Tilt-corrected										
				Dec. (°E)	Inc. (°)	k	α_{95} (°)	Dec. (°E)	Inc. (°)	k	α_{95} (°)	Lat. (°)	Long. (°E)	K	A95 (°)	Plat. (°N)	Rot. (°CW)	Ref.
Paleomagnetic directions and pole from overall Pizzo Mondello section																		
1	late Carnian–late Norian	000.0–424.8	410/296	154.7	41.7	6	3.5	107.0	34.5	6	3.6	0.4°S	78.0	6	3.6	19 ± 3	104	(1)
Paleomagnetic directions and poles from Pizzo Mondello individual subsections																		
2	late Carnian–early Norian	000.0–146.5	133/107	147.4	40.8	5	7.2	95.6	33.8	4.5	7.3	8.1°N	88.0	5	6.9	18 ± 5	93	(1–2)
3	“early Norian”	158.0–255.3	100/56	151.2	38.8	7	7.8	114.1	28.5	6	8.2	7.0°S	77.9	6	8.2	15 ± 5	110	(1)
4	“middle Norian”	256.3–352.8	56/36	156.7	43.7	7.5	9.4	117.8	33.7	7	9.5	11.5°S	69.1	7	9.6	18 ± 6	117	(1)
5	“late Norian”	353.8–424.8	121/97	163.3	42.9	10.5	4.7	108.8	38.6	10	4.7	0.1°S	74.3	10	4.8	22 ± 3	105	(1)
Reference Gondwanan paleomagnetic direction and pole																		
6	Late Triassic–Early Jurassic		N = 4					352.8	35.7			71.1°N	214.8	458	4.3	20 ± 3		(3)

Note: Pizzo Mondello is located at lat. 37.6°N, long. 13.4°E.

No.—data entry number; Age—biostratigraphic age of Pizzo Mondello strata; Meters—stratigraphic thickness in meters of Pizzo Mondello strata; N_1—number of standard 11.4 cc specimens collected; N_2—number of paleomagnetic directions used to calculate the mean; Dec., Inc.—declination and inclination, in geographic or tilt-corrected coordinates; k, α_{95}—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 cone of 95% confidence about the mean pole, respectively; Plat.—paleolatitude at Pizzo Mondello, expressed in degrees; Rot.—great circle distance between the paleomagnetic poles observed at Pizzo Mondello (i.e., data entries #1 to #5), and the reference Gondwanan paleomagnetic pole (i.e., data entry #6), expressed in degrees clockwise (CW); Ref.—literature reference, (1) is this study, (2) is Muttoni et al. (2001a), (3) is Muttoni et al. (2001b).

Data entry #2 from this study and Muttoni et al. (2001a) combined based on N_1/N_2 = 133/107 samples from the 0–146.5 m interval supersedes data of Muttoni et al. (2001a) based on N_1/N_2 = 119/102 samples from the same stratigraphic interval.

(20° ± 3° N) from the Gondwanan reference paleomagnetic pole (Table 1, data entry #6).

In order to investigate more precisely the long-term paleolatitude drift of Pizzo Mondello, we plotted in Figure 3 the mean paleolatitudes from the four directly superposed stratigraphic intervals as described above (Table 1, data entries #2 to #5). A very moderate northward latitudinal drift was observed, in substantial agreement with the general northward motion of Pangea in the Permian-Triassic (Muttoni et al., 2001b), which slowed substantially in the Norian as shown by Newark Basin data (Kent et al., 1993). These conclusions regarding sense and amount of tectonic rotation, and paleolatitude drift, are confirmed also by adopting more stringent criteria in paleomagnetic data selection, i.e., using characteristic component directions with mean angular deviation <15° and not associated with transitional polarities.

We therefore assume a Gondwanan affinity of Pizzo Mondello sedimentation on a slowly moving Late Triassic Pangea. A clockwise rotation of the Pizzo Mondello thrust sheet since the Neogene was evidently not associated with any pervasive remagnetization.

The latitude of the sample VGP relative to the north pole of the paleomagnetic axis was used for interpreting the polarity stratigraphy (Lowrie and Alvarez, 1977; Kent et al., 1995). An overall sequence of 27 polarity magnetozones, labeled from magnetozone PM1 to PM12n according to the Kent et al. (1995) criteria,

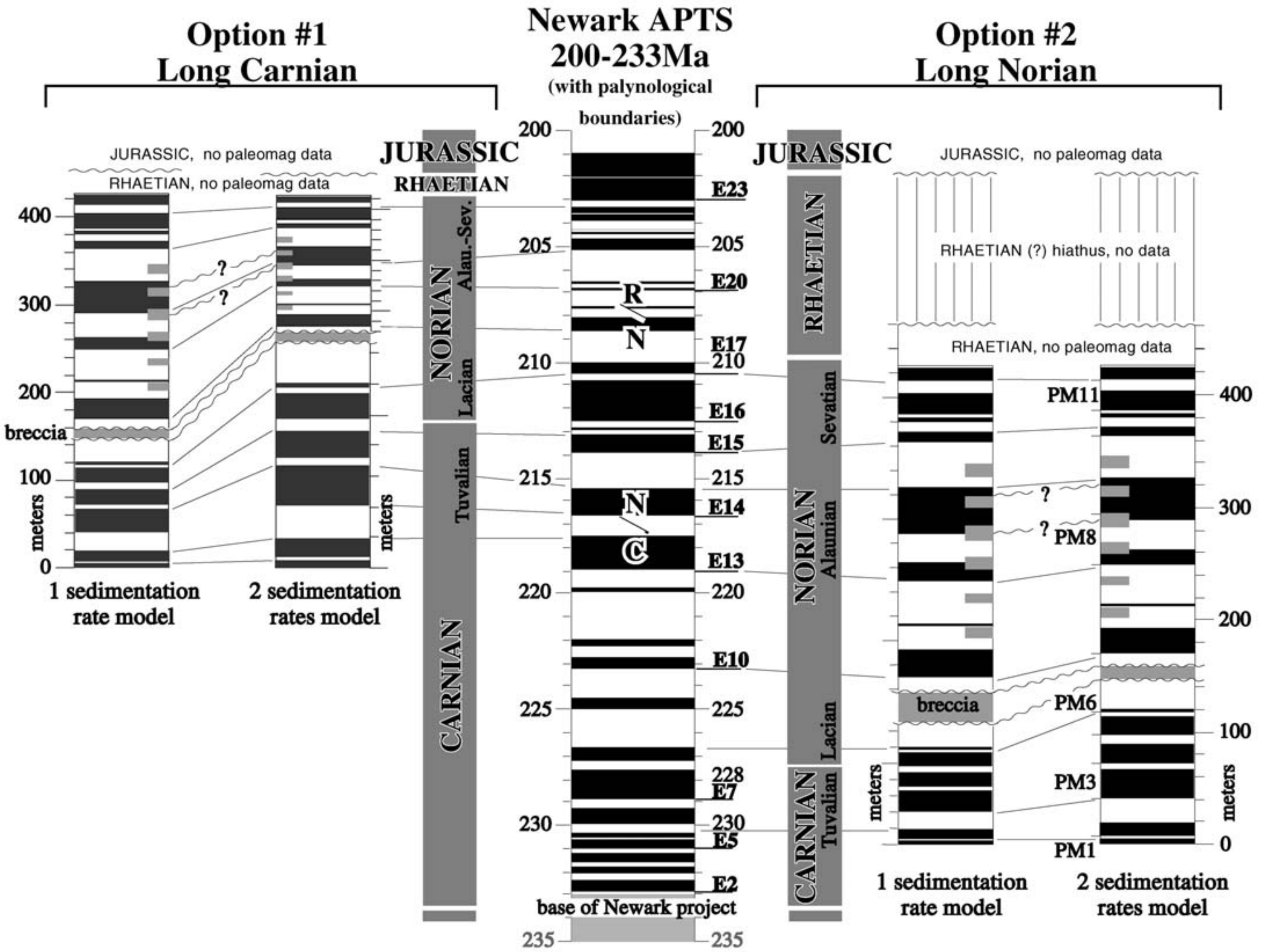


Figure 7. The biostratigraphic stage boundaries from Pizzo Mondello were magnetostratigraphically correlated with the Newark APTS. Two correlation options are proposed and discussed: option #1 (left) and option #2 (right). Preference is given to the statistically more realistic option #2, which predicts a conodont Carnian-Norian boundary located within the basal Newark magnetozone E7 at ca. 228–227 Ma. Tuv.—Tuvalian, Alau.—Alaunian, Sev.—Sevatian. C/N is Carnian/Norian; N/R is Norian/Rhaetian. See text for discussion.

has been established starting at the base of the Cherty Limestone (Fig. 3); delineation of magnetozones PM1 to PM6 is from Muttoni et al. (2001a). 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 by Krystyn et al. (2002) at the PM4r/PM5n boundary, whereas the $\delta^{13}C$ positive shift falls within the upper part of magnetozone PM4n (Fig. 3).

MARINE-CONTINENTAL CORRELATIONS

Continental astrochronology anchored to radiometric dates from the Newark section and marine biostratigraphy and chemostratigraphy from Pizzo Mondello can be correlated using the global record of polarity reversals for the construction of an integrated Late Triassic time scale.

The Late Triassic Newark APTS

The Newark APTS (Kent et al., 1995; Kent and Olsen, 1999; Olsen and Kent, 1999) was constructed by anchoring a Milankovitch chronostratigraphy to the palynological Triassic-Jurassic boundary located a few meters below the oldest basalt flow of the basin's igneous extrusive zone with collective ages of ca. 199–202 Ma (Sutter, 1988; Dunning and Hodych, 1990; Kent et al., 1995; Olsen et al., 1996; Hames et al., 2000). A 199 ± 0.3 Ma age for the Triassic-Jurassic boundary was also found in ammonite-bearing marine strata from North America (Palfy et al., 1998), which we regard as indistinguishable from the Newark date using realistic error assessments. Based on continental palynology and astrochronology relative to a Triassic-Jurassic boundary age of 202 Ma, the Newark Norian-Rhaetian boundary was correlated to within magnetozone E18 at ca. 208 Ma, whereas the Carnian-Norian boundary was correlated within magnetozone ~E13 at ca. 218 Ma (Kent et al., 1995; Olsen et al., 1996; Kent and Olsen, 1999) (Fig. 7, central). However, correlation of the Newark section with the standard marine stages using palynology requires the acceptance of a complex correlation web connecting the marine strata to the largely continental strata of the Germanic facies, which is then somehow tied across climate belts into the wholly continental Newark. A more direct method of relating marine stage boundaries with the Newark APTS is magnetostratigraphic correlation of biostratigraphically calibrated sequences from the Tethys marine realm such as Pizzo Mondello.

Previous Magnetostratigraphic Correlations

Previous marine-continental magnetostratigraphic correlations involving the use of Tethyan marine sections of the Hallstatt facies (i.e., Kavaalani, Bolucektasi Tepe, Kavur Tepe, and Scheiblkogel; Krystyn et al., 2002, and references therein), characterized by very low average sediment accumulation rates, produced ambiguous results, as can be seen by comparing Krystyn et al. (2002) with Channell et al. (2003). The Kavaalani section (Gallet et al., 2000), as a representative example, contains in ~60 m the equivalent of ~18 m.y. of the Newark sequence (Krystyn et al., 2002; Channell et al., 2003), translating into an average sediment accumulation rate of ~3 m/m.y. Higher (but probably still discontinuous) rates of sediment accumulation characterize the ~120-m-thick Hallstatt section at Silicka Brezova (Channell et al., 2003), which can be expected to yield better magnetostratigraphic resolution. However, even better performance should be derived from Tethyan sections like Pizzo Mondello that are composed of a more expanded type of pelagic deposition not of the Hallstatt type. Pizzo Mondello is three times thicker than the thickest published Hallstatt section of comparable age (i.e., Silicka Brezova; Channell et al., 2003) and seven to ten times thicker than typical Hallstatt sections like Kavaalani. The higher rates of accumulation at Pizzo Mondello resulted from closer proximity to the micrite factory of carbonate platforms and/or deposition in more fertile paleowaters, as testified by the occurrence of pelagic fauna and flora, and by the general absence of hardgrounds.

PIZZO MONDELLO TO NEWARK CORRELATION

A magnetostratigraphic correlation is usually accomplished by matching polarity patterns of comparable age by eye. Equivocal correlations may arise from (1) presence of localized remagnetizations, (2) age model uncertainties, (3) incomplete recovery of the magnetic polarity pattern (due to stratigraphic gaps or low sampling resolution), or (4) differing patterns of distortion of the polarity pattern as a consequence of variations of sediment accumulation rate. Each of these problematic factors is potentially present at all the Tethyan sections that we examined, including Pizzo Mondello. The initial Pizzo Mondello to Newark correlation of Muttoni et al. (2001a) relied on only about one-third of the total magnetostratigraphic sequence of this study. The longer and more diagnostic pattern of polarity reversals that is now available, in conjunction with a statistical correlation method (Lowrie and Alvarez, 1984) that could take into account some of the uncertainty factors listed above, allows us to seek a more optimal Pizzo Mondello to Newark correlation.

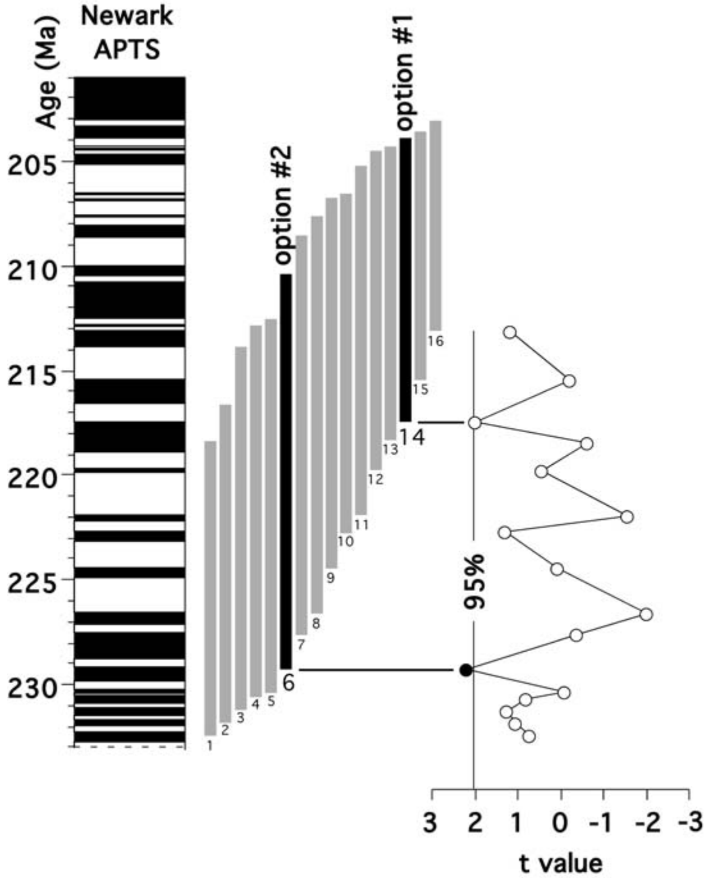


Figure 8. The Pizzo Mondello geomagnetic reversal sequence in linear depth coordinates was slid along the Newark APTS in linear age coordinates maintaining the internal polarity coherency, and a t value was calculated for each of the 16 possible correlation options ($t = R*\mathrm{sqrt}[(N - 2)/(1 - R^2)]$, where R = linear correlation coefficient, and N = number of matching magnetozones in moving window, i.e., 26). Positive (negative) t values refer to positive (negative) slopes of the linear function relating Pizzo Mondello magnetozones thickness to Newark magnetozones duration. According to a Student's t-test, only correlation option #2 has t value significant at 95% confidence. See text for discussion.

Correlation Strategy

As an initial hypothesis, we assumed that stratigraphic thickness, rather than equal biozone duration (Krystyn et al., 2002), is a linear proxy of time. The Pizzo Mondello reversal sequence in linear depth coordinates was placed alongside the base of the Newark APTS in linear age coordinates. A linear correlation coefficient (R) relating the thickness of each of the N = 26 complete Pizzo Mondello magnetozones to the duration of the correlative Newark magnetozones was calculated, from which a t value was derived [$t = R*\mathrm{sqrt}((N - 2)/(1 - R^2))$, where R is the linear correlation coefficient, and N is the number of matching magnetozones in the moving window, i.e., 26]. The Pizzo Mondello sequence was then slid by two polarity zones along the Newark APTS (in order to maintain internal polarity consistency in correlation), R and t were recalculated, and the exercise was repeated until all 16 possibilities were explored (Fig. 8).

Two options prove to have the highest correlation coefficient. In option #1, the base of Pizzo Mondello correlates to the middle part of the Newark APTS (essentially as argued by Muttoni et al., 2001a), whereas in option #2, the base of Pizzo Mondello starts near the base and extends

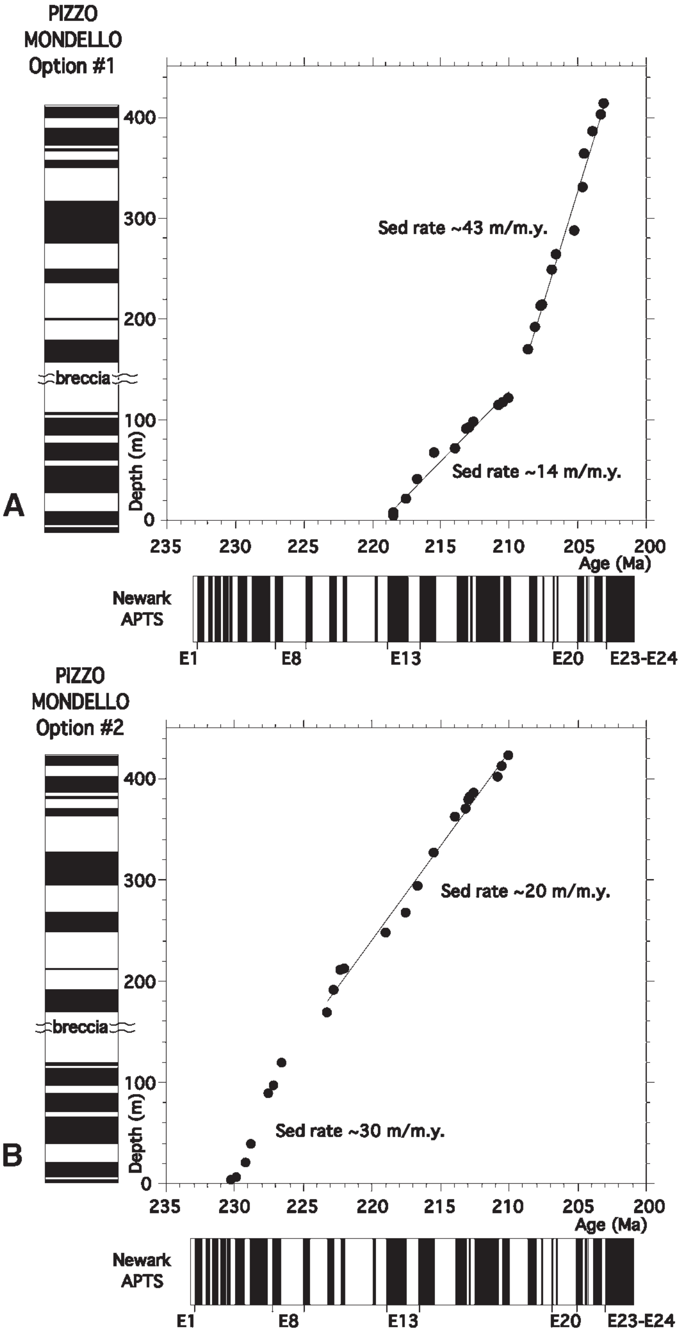


Figure 9. Age vs. depth plot of correlation option #1 (A) and option #2 (B). Sloping lines are average sediment accumulation rates. The breccia level of unit (iii) is associated with an increase (option #1) or decrease (option #2) of average accumulation rates. The general reasoning that more nodular limestones (e.g., above breccia) have lower sedimentation rates than well-bedded limestones (e.g., below breccia) seems to support correlation option #2.

up to the upper-middle part of the Newark APTS (essentially as argued by Channell et al., 2003). From a strict statistical viewpoint, option #2 is more robust than option #1. For N = 26 (the number of matching reversals in the moving window) each correlation has 24 degrees of freedom; a Student's t-test shows that only correlation coefficients with a t value larger than 2.06 are significant at the 95% level. Of the two optimum correlations only option #2 matches are significant (Fig. 8; t = 2.17), whereas option #1 has t = 2.01 and is just barely not significant.

In order to improve the visual correlation, we relaxed the assumption that the sediment accumulation rate at Pizzo Mondello was constant and allowed a single change across the breccia level of unit (iii). The breccia is an obvious discontinuity that separates the Cherty Limestone section into two portions with different main lithological characters, which realistically may have different accumulation rates (compare the lithologic description of unit [ii] and unit [iv]). A two-rate accumulation model for Pizzo Mondello was therefore generated for both correlation options (Fig. 7), which are now discussed as the likely alternative end members with very different (and testable) implications for Triassic chronostratigraphy.

Option #1—Long Carnian

The late Carnian–early Norian part of this correlation (Fig. 7, left) is essentially the same as in Muttoni et al. (2001a). This correlation suggests that the Carnian-Norian boundary at Pizzo Mondello, approximated by conodonts or a $\delta^{13}C$ proxy, has an age of ca. 213 Ma and, assuming that the base of the Newark section (ca. 233 Ma) is still Carnian, implies that the Carnian has a duration of at least 20 m.y. The Rhaetian is much shorter than originally proposed by Olsen and Kent (1999) and has a duration similar to that proposed by Krystyn et al. (2002) on the basis of a Newark-marine correlation using a compilation of Hallstatt data.

Option #1 also implies an abrupt increase in sedimentation rate across the breccia level of unit (iii) at Pizzo Mondello, from values of ~14 m/m.y. to ~43m/m.y. (Fig. 9A).

Option #2—Long Norian

With this correlation (Fig. 7, right), the Pizzo Mondello stratigraphy straddles the Newark APTS from about magnetozone E5 at the base to about magnetozone E17n at the top. This correlation implies that a large portion of the Newark APTS is Norian in age, i.e., ~20 m.y. in duration, and that the Rhaetian may have a duration (~6 m.y.) similar to that originally proposed by Olsen and Kent (1999) (Fig. 7). The correlation of Krystyn et al. (2002) between the Newark APTS and the Hallstatt record is similar to option #2 as far as the general position of the conodont Carnian-Norian boundary is concerned, but differs from option #2 in the position of the Norian-Rhaetian boundary and the duration of the Rhaetian, which is similar to the very short (~2 m.y.) duration derived from option #1 described above. The correlation of Channell et al. (2003) between the Newark APTS and the Hallstatt record is similar to option #2 in the positions of both the Carnian-Norian and the Norian-Rhaetian boundaries.

Option #2 implies smoother average values of sediment accumulation rate at Pizzo Mondello, with only a minor decrease across the breccia level of unit (iii) from ~30 to ~20 m/m.y. (Fig. 9B).

TOWARD AN INTEGRATED LATE TRIASSIC TIME SCALE

Between the two possible correlations described above, preference is given to option #2, which, at least from a statistical viewpoint, is somewhat better founded than option #1. Moreover, the more nodular nature of bedding planes above the breccia level of unit (iii) would qualitatively predict lower sedimentation rates than below the breccia level where beds are evenly bedded, again in agreement with the option #2 correlation (Fig. 9B).

A Late Triassic time scale, biostratigraphically calibrated using marine fossils, is constructed by adopting Pizzo Mondello to Newark correlation option #2 (Fig. 10). This time scale is characterized by (1) a Carnian restricted to the basal portion of the Newark APTS (and presumably extending below it); (2) a conodont Carnian-Norian boundary, or its $\delta^{13}C$ proxy, located within Newark magnetozone ~E7 at ca. 228–227 Ma (Figs. 10 and 11); (3) a Norian that becomes the longest stage of the Triassic with a minimum duration of ~20 m.y., from ca. 228–227 to ca. 208 Ma; (4) a Rhaetian with duration (~6 m.y.) possibly similar to the original palynological and astrochronological estimate of Olsen and Kent (1999); (5) a Triassic-Jurassic boundary at ca. 202 Ma based on radiometric dates from the Newark Basin. Some caution should nevertheless be maintained with respect to the Pizzo Mondello to Newark magnetostratigraphic correlation in the Carnian because the lower part of the Newark sequence is in fluvial facies where the polarity signature is in general less well established and the dating is based on extrapolation from the overlying lacustrine facies (Kent et al., 1995).

These conclusions are supported by correlation of Pizzo Mondello magneto-biostratigraphy with the coeval magneto-biostratigraphic sequence from the ~120-m-thick Silicka Brezova composite section of Channell et al. (2003) (Fig. 10). In the Lower Trench and Massiger Hellkalk Quarry individual sections that constitute the lower part of the composite section at Silicka Brezova, the level containing the Carnian-Norian boundary—based on the first occurrence of conodont *Norigondolella navicula,* which was not found at Pizzo Mondello—is located at the SB-3n.3n/SB-3r polarity reversal (Fig. 11). This level is in substantial agreement with the conodont boundary at Pizzo Mondello as defined by Krystyn et al. (2002) at the PM4r/PM5n polarity reversal, and is virtually coincident with the $\delta^{13}C$ isotope shift located at Pizzo Mondello in the uppermost part of magnetozone PM4n (Fig. 11). All these Carnian-Norian boundary events fall within Newark magnetozone E7 at 228–227 Ma. In the Carnian interval below magnetozone PM4r at Pizzo Mondello (SB-3r at Silicka Brezova and E7r at Newark), we propose an alternative correlation to Channell et al.'s (2003) that brings into closer agreement the relative thickness of magnetozones without violating any evident biostratigraphic constraint. This consists essentially in correlating the well-defined magnetozone PM2r at Pizzo Mondello to SB-2r (Fig. 11), and not to the single-sample-based, and therefore dubious, magnetozone SB-3n.2r, which, according to Channell et al. (2003), should also correspond to the relatively thick magnetozone E5r in the Newark sequence.

At Norian levels at Silicka Brezova, after a sedimentologically complicated and largely unsampled Alaunian, the Alaunian-Sevatian boundary, based on the first occurrence of conodont *Mokina bidentata,* at present not identified at Pizzo Mondello, seems to be located within magnetozone SB-9r, correlative with magnetozone PM10r at Pizzo Mondello and E15r at ca. 213 Ma in the Newark sequence (Fig. 10).

A Carnian-Norian boundary at ca. 228–227 Ma may seem anomalously old with respect to estimates given in a time scale of a recent publication (Gradstein et al., 1995). However, it is not obvious that any of the controlling dates listed in Gradstein et al. (1995) would exclude an age significantly older than the cited 220.7 (± 4.4) Ma estimate for this boundary. Items NDS170, NDS171, and NDS178R used by Gradstein et al. (1995) are based on K-Ar dates on igneous rocks in British Columbia that were intruded into host rocks with rather loose stratigraphic constraints, e.g., pre-Norian (?) for NDS170 at 221 ± 6 Ma, Carnian or younger for NDS171 at 220 ± 5 Ma, and Norian or younger for NDS178R at 215.7 ± 2.7 Ma (Odin, 1982), whereas the 215.8 ± 5 Ma date for item PTS160, based on U-Pb dates on pitchblende ores from the Petrified Forest and Moss Back Members of the Chinle Formation (see Webb, 1981), was referred to as Carnian although these members of the Chinle are now regarded as Norian in age (Lucas, 1993), and the date must be postdepositional to some degree in any case. Therefore, the most than can be said, according to available radiometric age constraints, is that the Carnian-Norian boundary should be older than ca. 216 Ma and could be as old as ca. 228–227 Ma.

Extension below the Base of the Newark Sequence

In order to place the Pizzo Mondello to Newark correlation in a broader age context and to estimate the duration of the Carnian Stage, whose base is not identified in the Newark APTS, we discuss available chronostratigraphic and geochronologic data also for the Middle Triassic (Fig. 10). A Ladinian-Carnian boundary at ca. 235 Ma is derived from U-Pb data and field observation from the upper Ladinian granites at Predazzo in the southern Alps. This intrusion, dated at 237.3 (+0.4/–1.0) Ma (Brack et al., 1997), postdates the Ladinian Buchenstein Beds with a youngest U-Pb age of 238.0 (+0.4/–0.7) Ma (Mundil et al., 1996), and predates the sediments of the Wengen volcanosedimentary group and the San Cassiano Formation, which, toward the top, contain the Ladinian-Carnian boundary (Broglio Loriga et al., 1999). Therefore, the Ladinian-Carnian boundary should be just a few m.y. younger than ca. 237 Ma (P. Brack, 2003, personal commun.). The dates employed by Gradstein et al. (1995) are generally poorly constrained and do not exclude an age older than the 227.4 (± 4.5) Ma cited for the Ladinian-Carnian boundary. For example, item NDS201 (Monzoni intrusive of the Southern Alps) has scattered dates of 214–245 Ma and is in any case Ladinian in age and not Carnian (as reported by Odin, 1982), because it is coeval with the Predazzo granites whereas Carnian item NDS193 (Sugars Basalts of Australia) has scattered ages as old as 232 ± 7 Ma (Odin, 1982).

With a Ladinian-Carnian boundary at ca. 235 Ma, and adopting correlation option #2, the Carnian Stage is ~7 m.y. long and straddles a gap in magnetostratigraphic data between the base of the Newark APTS (Tuvalian?) and the top of the Tethyan composite scale (basal Cordevolian; Broglio Loriga et al., 1999). Finally, the Early and Middle Triassic have, as a whole, a duration equal to only about one-half of the Late Triassic or about one-third of the entire Triassic (Fig. 10).

GEOCHRONOLOGIC IMPLICATIONS FOR THE NEWARK APTS

With a Carnian-Norian boundary in Newark magnetozone E7 at an age of 228–227 Ma, the Conewagian land vertebrate faunichron of Huber et al. (1993) in the Newark Basin, as well as the correlative Adamanian and Ischigualastian faunichrons (Lucas, 1998), previously regarded as (late) Carnian in age (Lucas, 1998), would be placed into the (early) Norian (Fig. 10). Similarly, the New Oxford–Lockatong palynofloral zone in the Newark Basin, regarded as (late)

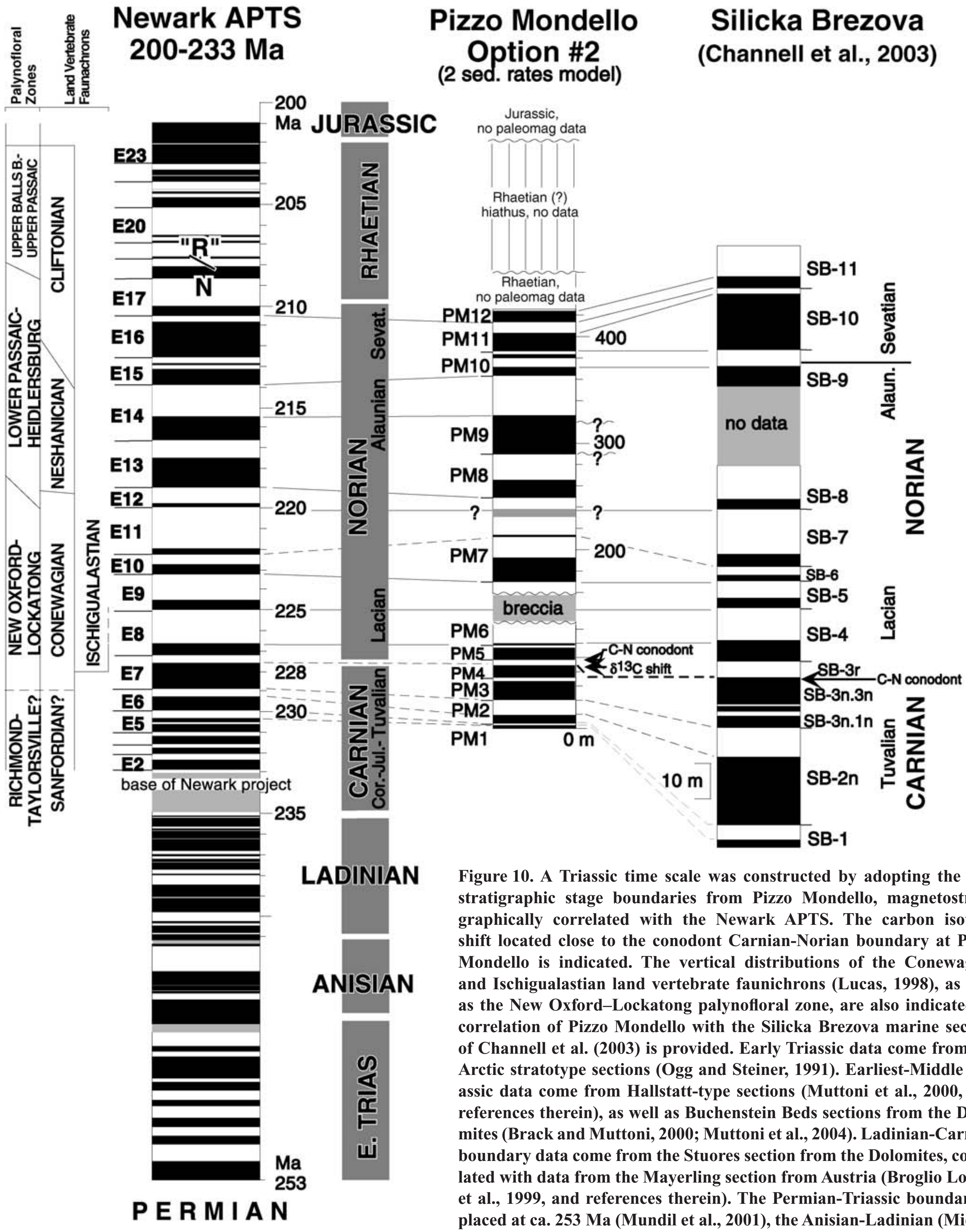


Figure 10. A Triassic time scale was constructed by adopting the biostratigraphic stage boundaries from Pizzo Mondello, magnetostratigraphically correlated with the Newark APTS. The carbon isotope shift located close to the conodont Carnian-Norian boundary at Pizzo Mondello is indicated. The vertical distributions of the Conewagian and Ischigualastian land vertebrate faunichrons (Lucas, 1998), as well as the New Oxford–Lockatong palynofloral zone, are also indicated. A correlation of Pizzo Mondello with the Silicka Brezova marine section of Channell et al. (2003) is provided. Early Triassic data come from the Arctic stratotype sections (Ogg and Steiner, 1991). Earliest-Middle Triassic data come from Hallstatt-type sections (Muttoni et al., 2000, and references therein), as well as Buchenstein Beds sections from the Dolomites (Brack and Muttoni, 2000; Muttoni et al., 2004). Ladinian-Carnian boundary data come from the Stuores section from the Dolomites, correlated with data from the Mayerling section from Austria (Broglio Loriga et al., 1999, and references therein). The Permian-Triassic boundary is placed at ca. 253 Ma (Mundil et al., 2001), the Anisian-Ladinian (Middle Triassic) boundary at 241.2 (+0.8/–0.6) Ma (Mundil et al., 1996), and the Ladinian-Carnian (Middle-Late Triassic) boundary at ca. 235 Ma. Cor.—Cordevolian, Jul.—Julian, Alaun.—Alaunian, Sevat.—Sevatian.

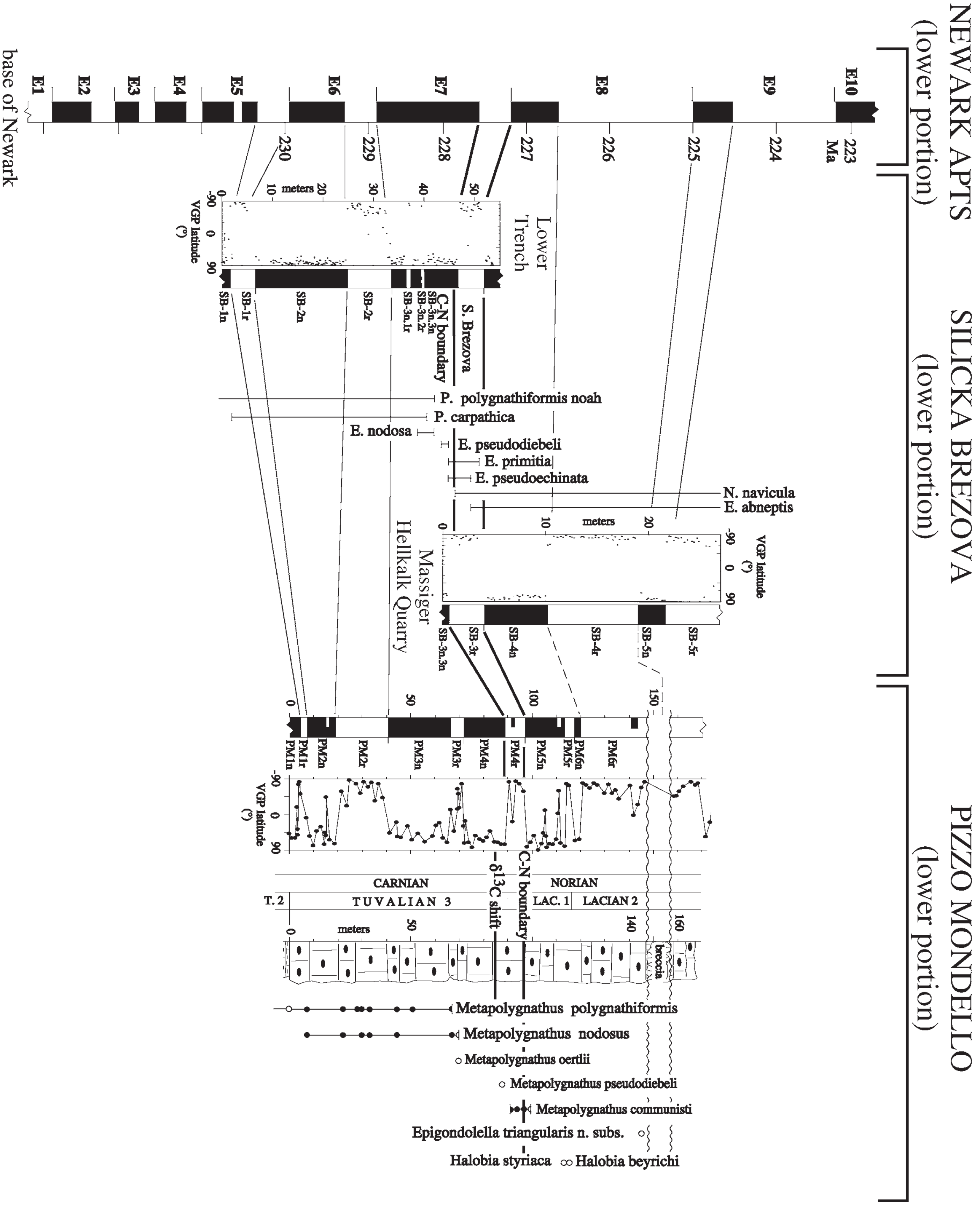

NEWARK APTS
(lower portion)
base of Newark
E1
E2
E3
E4
E5
E6
E7
E8
E9
E10
223
Ma
224
225
226
227
228
229
230
Lower
Trench
meters
0
10
20
30
40
50
VGP latitude
(°)
-90
0
90
SB-1n
SB-1r
SB-2n
SB-2r
SB-3n.1r
SB-3n.2r
SB-3n.3n
C-N boundary
S. Brezova
SILICKA BREZOVA
(lower portion)
P. polygnathiformis noah
P. carpathica
E. nodosa
E. pseudodiebeli
E. primitia
E. pseudoechinata
N. navicula
E. abneptis
Massiger
Hellkalk Quarry
meters
0
10
20
VGP latitude
(°)
-90
0
90
SB-3n.3n
SB-3r
SB-4n
SB-4r
SB-5n
SB-5r
PIZZO MONDELLO
(lower portion)
0
50
100
150
PM1n
PM1r
PM2n
PM2r
PM3n
PM3r
PM4n
PM4r
PM5n
PM5r
PM6n
PM6r
VGP latitude
(°)
-90
0
90
CARNIAN
NORIAN
T. 2
TUVALIAN 3
LAC. 1
LACIAN 2
δ13C shift
C-N boundary
meters
0
50
140
160
breccia
Metapolygnathus polygnathiformis
Metapolygnathus nodosus
Metapolygnathus oertlii
Metapolygnathus pseudodiebeli
Metapolygnathus communisti
Epigondolella triangularis n. subs.
Halobia styriaca
Halobia beyrichi

Figure 11. Detailed correlation between the lower parts of the Pizzo Mondello section, Silicka Brezova composite section (Channell et al., 2003), and the Newark APTS. The lower part of the Silicka Brezova composite section containing the Carnian-Norian boundary is composed of the Lower Trench and Massiger Hellkalk Quarry individual sections. The Carnian-Norian boundary falls within Newark magnetozone E7 at 228–227 Ma. See text for discussion.

Carnian in age (Cornet, 1993), would become Norian in age. It is important to note that the palynological data for the New Oxford–Lockatong palynofloral zone are in fact compatible with either a late Carnian or Norian age and lack definitive Carnian taxa such as *Camerosporites secatus* (e.g., Litwin and Skog, 1991).

Krystyn et al. (2002) questioned the validity of the Newark astrochronology. On the basis of a marine-continental correlation similar to option #2 but assuming the Gradstein et al. (1995) age of 220.7 ± 4.4 Ma for the Carnian-Norian boundary, these authors concluded that there was a need to modify the duration of the (404 k.y.) McLaughin cycles in the Newark sequence. Recalling that the controlling dates listed in Gradstein et al. (1995) do not exclude an age significantly older than 220.7 ± 4.4 Ma for the Carnian-Norian boundary, we also point out that there is independent evidence that the Newark astrochronology is substantially correct. The Ischigualastian land vertebrate faunichron mostly overlies a tuff with an Ar-Ar date of 227.8 ± 0.3 Ma (Rogers et al., 1993). This numerical age is compatible with the Newark astronomical age estimate for the base of the correlative Conewagian land vertebrate faunichron (Fig. 11). There is thus no basis to modify the duration of the Newark McLaughin cycles.

CONCLUSIONS

Biostratigraphic and chemostratigraphic data from the expanded Tethyan marine section at Pizzo Mondello were correlated magnetostratigraphically with the Newark APTS for development of an integrated Late Triassic time scale.

One of the most prominent features observed in the carbon isotope curve at Pizzo Mondello is a positive shift of ~0.8‰ located at meter level 84.5 within the upper part of magnetozone PM4n. This shift is located 12.5 m below the interval containing the conodont Carnian-Norian boundary of Krystyn et al. (2002), and almost exactly in the middle part of the conodont Carnian-Norian boundary interval of Muttoni et al. (2001a).

The favored Pizzo Mondello to Newark correlation (option #2) predicts a conodont Carnian-Norian boundary, and its $\delta^{13}C$ proxy, located within the basal Newark magnetozone E7 at ca. 228–227 Ma (adopting Newark astrochronology). This correlation predicts a Norian with an astrochronological duration of ~20 m.y., from ca. 228–227 to ca. 208 Ma, and a Rhaetian of duration (~6 m.y.) similar to the original palynological and astrochronological estimate of Olsen and Kent (1999). Correlation option #2 is preferred to the statistically less realistic option #1 as well as the Krystyn et al. (2002) correlation, both predicting an extremely short Rhaetian. Correlation option #2 is virtually the same as Silicka Brezova–Newark correlation of Channell et al. (2003).

The Newark Basin astrochronology appears to be substantially correct because it predicts an age of ca. 228–227 Ma for the base of the Conewagian vertebrate faunichron that closely matches the Ar-Ar date associated with the correlative Ischigualastian faunichron from South America. Many of the available radiometric age data used in recent compilations to construct a Late Triassic time scale (e.g., Gradstein et al., 1995) are generally of poor quality or uncertain stratigraphic context and do not contradict a Carnian-Norian boundary age of ca. 228–227 Ma.

We propose Pizzo Mondello as a global stratigraphic section and point for the base of the Norian. Pizzo Mondello is a well-exposed and easily accessible section with a high degree of stratigraphic continuity of strata in strict stratigraphic superposition and relatively high rates of sedimentation (20–30 m/m.y.); it is provided with age-diagnostic conodonts, whereas early findings of ammonoids (Gemmellaro, 1904) allow the possibility to erect also a robust ammonoid-based biostratigraphy. Pizzo Mondello is also provided with a relatively complete chemostratigraphic record, useful to pin down globally the biostratigraphic Carnian-Norian boundary, as well as numerical age control, derived from magnetostratigraphic correlation with the Newark APTS.

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