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Cyclostratigraphy of Cretaceous shallow-water carbonates. Case-histories from central and southern Italy.

Abstract
Centimetre-scale analysis of shallow-water carbonate sections has allowed to recognize orbital forced cycles in the Cretaceous of Italy. Three case-histories from Late Barremian to Early Albian of central and southern Apennines (Italy) are presented here. We show that the vertical arrangement of depositional and early diagenetic features allows elementary cycles and their organization in bundles and superbundles to be recognized. This hierarchy of cycles, controlled by high-frequency sea-level changes, is related to the Earth's orbital periodicities and appears to be superimposed on lower frequency cyclic intervals (Transgressive/Regressive Facies Trends). Based on the above stacking pattern of cycles, both superbundles (corresponding to long-eccentricity cycles, about 400 ky) and Transgressive/Regressive Facies Trends are interpreted in terms of depositional sequences in order to attempt a regional- to global-scale high-resolution correlation. Finally, for each studied succession the minimum sedimentation time is estimated.

Introduction
Many shallow-water carbonates carry clear evidences of astronomic control on the sedimentation via the climatic signature on it (allocyclicity), even though some local interference may give rise to non-periodic cycles (see e.g. Einsele et al., 1991; De Boer and Smith, 1994). Microstratigraphy (centimetre-scale analysis) is among the main tools to recognize high-frequency cyclicity recorded in carbonate platform strata (D'Argenio et al., 1997; 1999; see also D'Argenio and Ferreri, this volume). We have used this approach to essay high-precision chronostratigraphic correlations. To this purpose three Lower Cretaceous case histories are discussed here (Fig.1): the 165 m thick Upper Aptian-Lower Albian Serra Sbregavitelli section (Matese Mountains, central-western Apennines, D'Argenio et al., 1999; 2003), the 280 m thick Lower Barremian-Lower Albian Monte Raggeto section (Maggiore Mountains, southern Apennines, D'Argenio et al., 2003; Wissler et al., 2003) and the 130 m thick Aptian S. Maria 4 AGIP core (drilled in central-eastern Italy, Amodio, 2000).

Microstratigraphy and Cyclostratigraphy
For each studied succession microstratigraphic analysis has allowed us: a) to recognize lithofacies and their associations as well as to assign them to different sedimentary environments of a large carbonate platform domain (from peritidal-supratidal to open lagoon, Table 1); b) to individuate early meteoric diagenetic modifications (e.g. paleokarst-microkarst, paleosols), recurring at specific horizons (normally bed surfaces); c) to tabulate the above data as columnar sections showing elementary cycles (Fig.1, column a) and their grouping (bundles, superbundles, Fig.1, column b), as well as lower-frequency cycles (Transgressive/Regressive Facies Trends, T/RFTs, Fig.1, column c).

A high-frequency eustatic control, modulated by Earth's orbital perturbation is suggested by early meteoric diagenesis directly superimposed on subtidal deposits, as well as by the hierarchic cyclic organization (2 to 5 elementary cycles form a bundle, while 2 to 4 bundles form a superbundle). In a more rescricted domains sometimes few bits lack due to non sedimentation and/or erosion. In this context the elementary cycles are considered to record the precession (about 20 ky) and/or the obliquity (about 40 ky) periodicities, while bundles and superbundles correspond to the short- (about 100 ky) and long-eccentricity (about 400 ky) cycles, respectively (Brescia et al., 1996; D'Argenio et al.,

LITHOFACIES ASSOCIATIONS	***LITHOFACIES***	**LITHOFACIES LOCATION**	ENVIRONMENTAL INTERPRETATION
ORBITOL-SPONGE LIMESTONES **(OS)**	**OS1**: Orbitol-sponge B. and B./P. with echinoids, molluscan shells, rare brachiopods and corals	S. Maria 4 core	PLATFORM MARGIN *RAMP*
	OS2: Orbitol-sponge P. and P./W. with echinoids, molluscan shells rare green algae and intraclasts		
MOLLUSCAN LIMESTONES **(M)**	**M1:** Molluscan P./W. with echinoids, small sponges, peloids, orbitolinids and green algae	S. Maria 4 core	OPEN PLATFORM *MARGINAL SETTING*
	M2: Molluscan F. with P. and P./W. matrix (echinoids, rare small sponges, orbitolinids and green algae)	S. Maria 4 core	
	M3: Molluscan F. with W., W./P. and P./W. matrix (benthonic foraminifers green algae and molluscan shells fragments)	Serra Sbregavitelli section	
	M4: Molluscan F. with G. matrix (benthonic foraminifers green algae and molluscan shells fragments)	Serra Sbregavitelli section	
BIOCLASTIC LIMESTONES **(B)** and LAMINATED BIOCLASTIC LIMESTONES **(LB)**	**B1:** Bioclastic R., G. and G./P. with intraclasts	S. Maria 4 core	OUTER SHOALS *MARGINAL TO LAGOONAL* (SERRA SBREGAVITELLI) *AND PERITIDAL* (S. MARIA) *SETTINGS*
	B2: Bioclastic P. with benthonic foraminifers and rare small intraclasts	S. Maria 4 core	
	LB1: Bioclastic R. and G./P. with crossed, oblique and/or parallele lamination	Serra Sbregavitelli section	
	LB2: Bioclastic G. and G./P. with crossed, oblique and/or parallel lamination and with keystone vugs	Serra Sbregavitell section	
FOR-ALGAL LIMESTONES **(FA)**	**FA1:** Foraminiferal, green-algal W. and bioturbated W./P. with gastropods and molluscan shells	Serra Sbregavitelli and M. Raggeto sections	OPEN PLATFORM *LAGOONAL SETTING*
	FA2: Foraminiferal, green-algal W. and W./P. with ostracods	Monte Raggeto section	
BIO-PELOIDAL LIMESTONES **(BP)**	**BP1**: Locally laminated bioclastic P./G. and G. with rounded intraclasts	Serra Sbregavitelli section	INNER SHOALS *LAGOONAL TO PERITIDAL SETTING*
	BP2: Locally laminated biopeloidal G. and G./P. with small intraclasts	Monte Raggeto section	
	BP3: Locally laminated peloidal P. with miliolids and rare small intraclasts and bioclasts	Serra Sbregavitelli and Monte Raggeto sections	
MILI-OSTRACOD LIMESTONES **(MO)**	**MO1**: Miliolid W. with small gastropods and /or pelecypods	Serra Sbregavitell section	RESTRICTED PLATFORM *PERITIDAL SETTING*
	MO2: *Salpingoporella* Wackestone	Serra Sbregavitelli section	
	MO3: Foraminiferal W. and bioturbated W./P. with small *Thaumatoporella* sp. ostracods *Salpingoporella* sp. and rare small molluscan shells	S. Maria 4 core	
	MO4: Ostracod W and W./M. with small benthonic foraminifers (Miliolids) and *Thaumatoporella* sp.	M. Raggeto section and S. Maria 4 core	
	MO5: Barren M. and bioturbated M. locally with ostracods and/or small miliolids	Serra Sbrgavitelli section and S. Maria 4 core	
	MO6: Cryptalgal Bindstone alternating with mm-thick grain-supported peloidal laminae locally with small arenaceous foraminifers and *Thaumatoporella* sp.	Serra Sbregavitelli and M. Raggeto sections S. Maria 4 core	
LAMINATE LIMESTONES **(L)**	**L1**: Stromatolitic and loferitic Bindstones; loferitic M.	S. Sbregavitelli and M. Raggeto sections S. Maria 4 core	TIDAL FLAT *TIDAL TO SUPRATIDAL SETTING*

Table 1. Lithofacies and lithofacies associations of Serra Sbregavitelli and Monte Raggeto sections and of the S. Maria 4 core their environmental interpretation. M.: mudstone; W.: wackestone, P.: packstone; G.: grainstone; F.:floatstone; R.: rudstone; B.: boundstone.

1997; 1999; 2003). Finally, the T/RFTs may be related to extended eccentricity periodicities (Fischer 1991, Ferreri et al., 2003). On this assumption, a minimum time-duration of 4.5 my and of 13.5 my may be estimated, for Serra Sbregavitelli and for Monte Raggeto sections, respectively, while about 4.6 my are suggested for the S. Maria 4 core (Fig.1, column b).

Sequence Stratigraphy

Based on their cyclic stacking pattern the studied successions have been also considered in terms of sequence

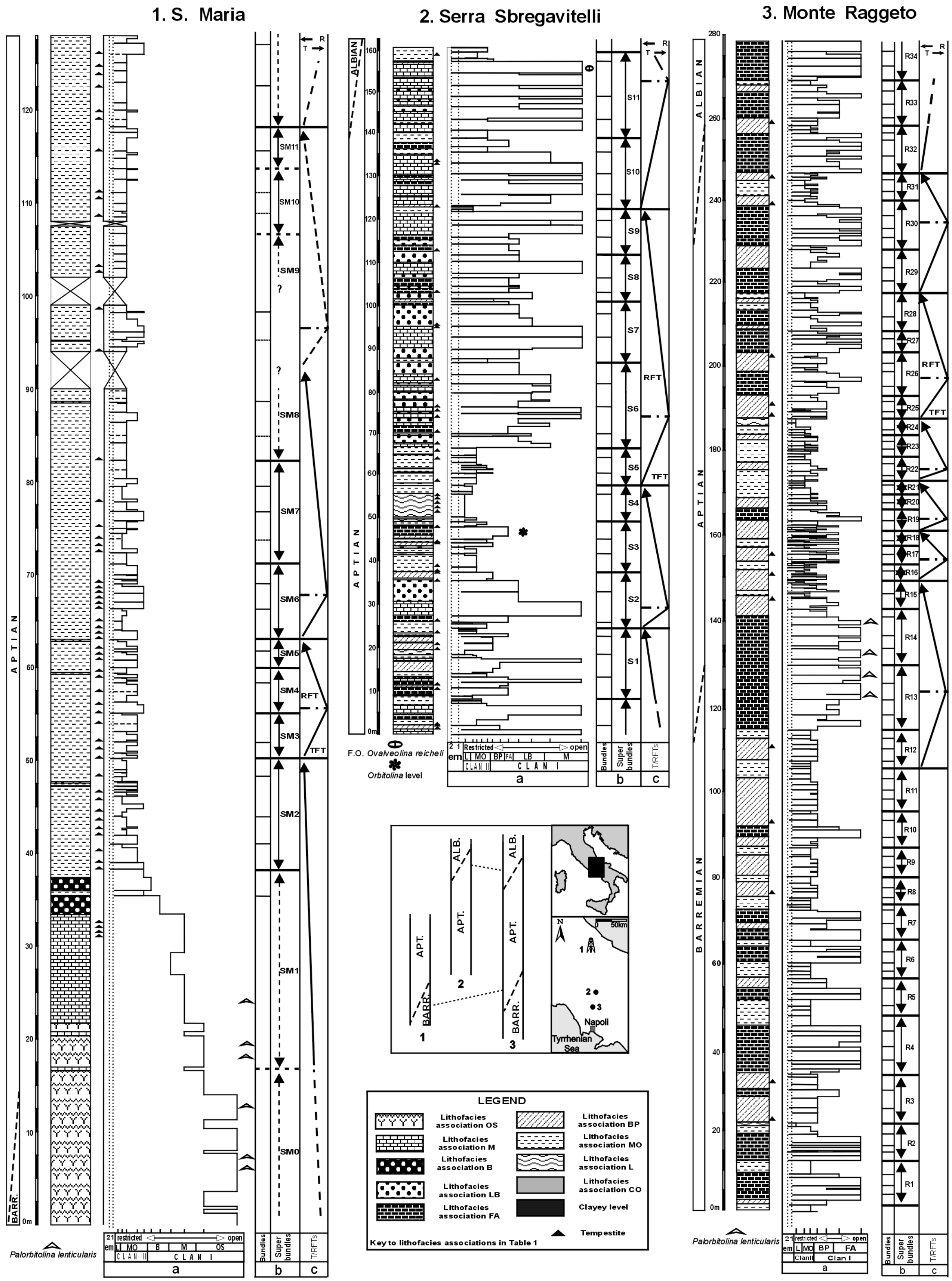

Fig. 1. Composite log of the studied sections and their location. The column on the left of each section represents the vertical distribution of the lithofacies associations (see legend for symbols). Column a) The sharp-cornered curve shows the high-frequency environmental oscillations (elementary cycles) as revealed by vertical succession of lithofacies and lithofacies associations and by the related early diagenetic overprint (em1 indicate microkarst while em2 thicker vadose caps and pervasive paleokarstic features). Key to lithofacies associations see Table 1. Column b) High-frequency hierarchical organization of the elementary cycles into bundles (on the left) and superbundles (on the right). Column c) Transgressive/Regressive Facies Trends (T/RFTs).

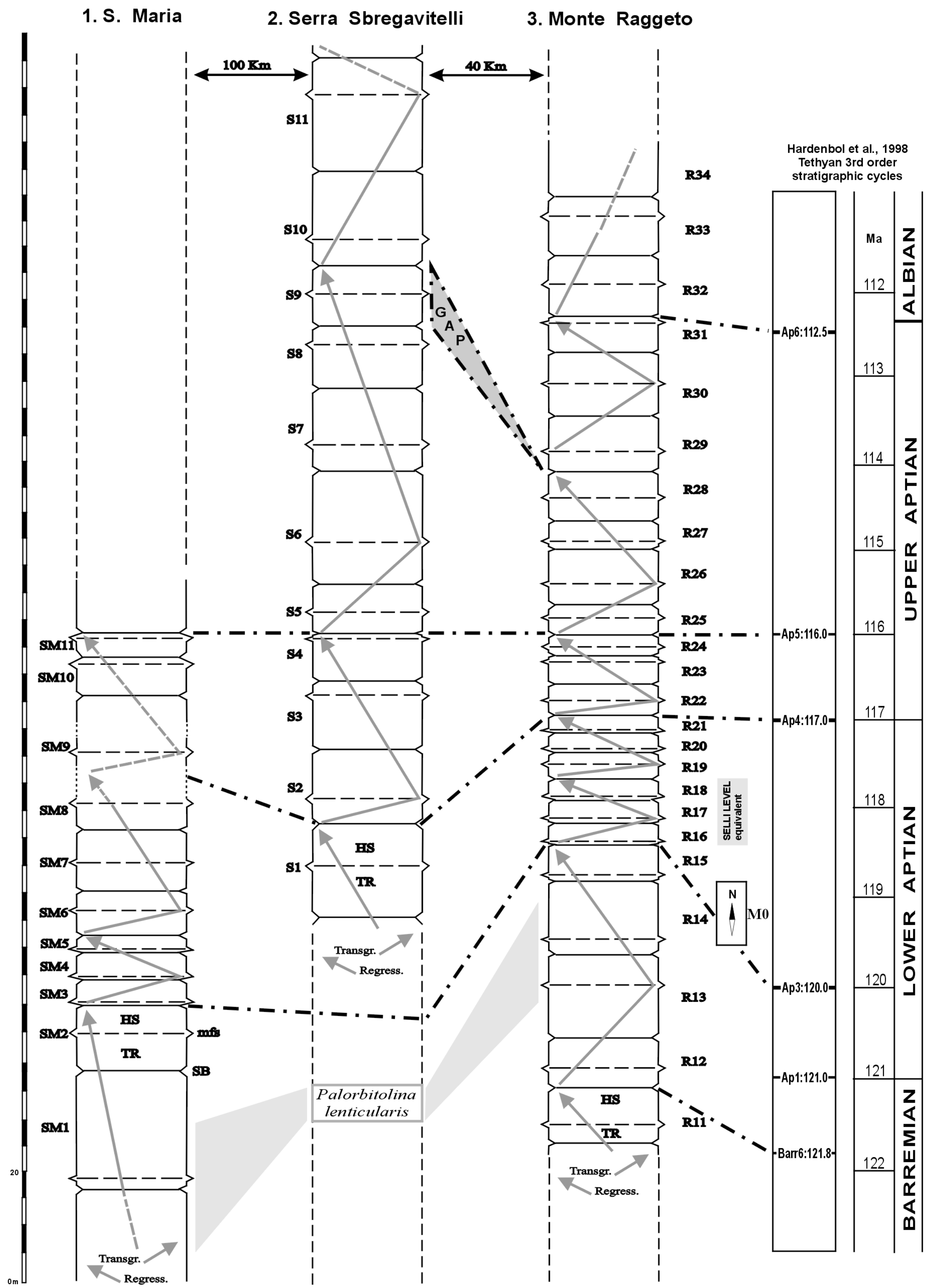

Fig. 2. High-resolution correlation between the discussed Cretaceous sections: S. Maria 4, Serra Sbregavitelli and Monte Raggeto, interpreted in terms of sequence stratigraphy, and plotted against the Tethyan 3rd order stratigraphic cycles of Hardenbol et al., (1998). Our previous studies (Wissler et al., 2003) have shown that both the Magnetozone M0 and the equivalent of the pelagic Selli Level (Oceanic Anoxic Event 1a) can be found at Monte Raggeto (superbundle R14 and superbundles R16-R18, respectively). The correlation proposed here allows the long-distance correlation shown in D'Argenio et al., (2003) to be extended back to the Barremian/Aptian boundary, and the magnetostratigraphic and carbon-isotope events occurring at M. Raggeto to be located in the time-equivalent superbundles of S. Maria core (superbundle SM1 and superbundles SM3-SM5, respectively).

stratigraphy, even though they have a prevailing aggradational expression. To minimise the effects of the lack of one or more elementary cycles, due to the more protracted sea level lowering, we have chosen the superbundles as depositional sequence equivalent (D'Argenio et al., 1997; 1999). On this assumption the sequence boundaries (SB) are located in correspondence of the superbundle limits, while maximum flooding surfaces (mfs) are indicated by the occurrence of the lithofacies suggesting the most open depositional environments. Moreover for each superbundle two basic systems tracts are recognised: a transgressive and a highstand systems tract (Fig. 2). Using the same approach also the Transgressive/Regressive Facies Trends may be discussed in terms of depositional sequences (D'Argenio et al., 1999; 2003), the related sequence boundaries occurring in correspondence of the SB of the more restricted (and normally thinner) superbundles, and the mfs coming about within the more open (and normally thicker) superbundles. On these bases a comparison between our T/RFTs and the third order cycles of Hardenbol et al., 1998 is attempted in order to propose regional- to global-scale high-resolution correlations.

High-Resolution Correlation and Chronostratigraphy
Based on sequence stratigraphy criteria, taking into account the Barremian/Aptian transition, as suggested by the location of the magnetozone M0 within the superbundle R14 of Monte Raggeto (Wissler et al 2003), and assuming the Palorbitolina lenticularis biostratigraphic interval occurring in the M. Raggeto section (superbundles R13 and R14) and in the S. Maria 4 core (superbundles SM0 and SM1) as coeval, we propose the high-resolution correlation shown in Figure 2. This allows the global chronostratigraphic correlation (D'Argenio et al., 2003) with the Tethyan 3rd order Stratigraphic Cycles of Hardenbol et al. (1998) to be extended back to the Barremian/Aptian boundary. Moreover the equivalent of the Early Aptian Oceanic Anoxic Event Selli Level (OAE 1a, Weissert et al., 1985; 1998; Erba and Larson, 1998), individuated at M. Raggeto (D'Argenio et al., 2003, Wissler et al., 2003) may be also located in the S. Maria 4 core. Based on our cyclostratigraphy studies, that are corroborated by carbon-isotope stratigraphy (D'Argenio et al., 2003) and magnetostratigraphic studies (Wissler et al., 2003), we have assembled an orbital chronostratigraphy for the Aptian interval. On this basis a time duration of about 8.0 my is suggested for the stratigraphic interval from the Barremian/Aptian Boundary to the Aptian/Albian Boundary (Fig.2). This value appears to fit the 8.8 my of the Gradstein et al. (1995) geologic time-scale, whose stages are calibrated in million of years with an uncertainty estimated at each boundary (± 1.4 my for the Barremian/Aptian boundary and ± 1.1 my for the Aptian/Albian boundary).

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