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Correlations of Hauterivian and Barremian (Early Cretaceous) stage boundaries to polarity chrons

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Abstract

Recent ammonite finds in Italian Maiolica limestones allow direct correlation of Hauterivian and Barremian ammonite zones (stage boundaries) to polarity chrons. At Laghetto and Alpetto (Lombardy, Italy), Lower Aptian ammonites occur just above polarity zone M0 and below the Selli Level, and Upper Barremian ammonites occur in polarity zone M1n. These correlations are consistent with the Barremian/Aptian boundary being close to older boundary of (polarity chron) CM0. The uppermost Hauterivian ammonite (Faraoni) guide level has been correlated to CM4 at Bosso (Umbria–Marche), confirming the recent correlation of the Hauterivian/Barremian boundary to CM4. At Monte Acuto (Umbria–Marche), ammonites spanning the Valanginian/Hauterivian boundary interval, and the last appearance of the nannofossil *T. verenae*, occur close to the CM11/CM11n boundary. The Valanginian/Hauterivian boundary has previously been placed between the first appearance of *L. bollii* and the last appearance of *T. verenae*, or between CM10 and CM11. The published Polaveno (Lombardy) magnetostratigraphy for the CM3–CM11 interval has now been extended to CM16. This 260 m section, recording the CM3–CM16 interval, is the most complete single-section record of Cretaceous M-sequence polarity chrons. No diagnostic ammonites have been found in this section; however, the correlations of nannofossil and calpionellid events to polarity chrons are consistent with previous studies.

1. Introduction

The correlation of M-sequence polarity chrons to nannofossil events has been derived from magnetobiostratigraphy in the Maiolica Formation, which is a thin-bedded white to gray pelagic limestone deposited from Late Tithonian to Early Aptian and cropping out over large areas of the Southern Alps and Umbria–Marche (central Italy). The remanent magnetization of the Maiolica limestone is carried by magnetite [1] and was acquired during early diagenesis, probably within ~ 10–20 cm of the sediment–water interface. Numerous magnetobiostratigraphic studies in Italian land sections of Maiolica limestone have established a robust correlation of nannofossil and calpionellid zones to polarity chrons for the Tithonian to Aptian interval [3–9]. Direct correlations of polarity chrons to ammonite zones have been achieved in nodular limestones in Spain for the Kimmeridgian to Berriasian stage boundaries [10,11]; however, the Hauterivian and Barremian stage boundaries have not been adequately correlated to

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polarity chrons. In published timescales, Hauterivian and Barremian ammonite zones (which define stage boundaries) have been indirectly correlated to polarity chrons by a two-stage process: (1) correlation of nannofossil events to ammonite zones mainly in southern France [12,13], and (2) correlation of nannofossil events to polarity chrons in Italian land sections.

In the last few years, a concerted effort has been made to search for rare ammonites in the Italian Maiolica limestone in order to allow direct correlation of polarity chrons to ammonite zones, and hence to stage boundaries. At Gorgo a Cerbara (Fig. 1), ammonite finds have been correlated to the CM1n to CM4 [1] (polarity chron) interval [2], utilizing a previously published magnetostratigraphy [3]. This work resulted in the correlation of the Hauterivian/Barremian boundary to the upper part of CM4, in contrast to pre-existing correlations which placed this stage boundary within CM7 (e.g. [14]). We report ammonite finds, nannofossil biostratigraphy and magnetic stratigraphy from four sections of Italian Maiolica limestones (Laghetto, Alpetto, Monte Acuto, Bosso). These data, together with new ammonite finds at Gorgo a Cerbara, lead to a revised correlation of Hauterivian and Barremian stage boundaries to polarity chrons. In addition, we present an extension of the CM3–CM11 magnetobiostratigraphy from Polaveno [8]. The extended magnetic stratigraphy (CM3–CM16) provides an almost complete Early Cretaceous geomagnetic polarity record from a single section.

Nannofossil biostratigraphy was based on splits from the oriented samples collected for magnetic stratigraphy, with additional samples collected in the vicinity of nannofossil events. Sample preparation and operational procedures for identifying nannofossil events follow previous studies [8]. As for other Maiolica sections, preservation of nannofossils is poor to moderate, and the low abundance of marker species required observation of several hundred fields of view for each smear slide. During the systematic sampling for magnetic and nannofossil studies, the sections were measured and marked, for correlation to ammonite finds. The Mediterranean ammonite

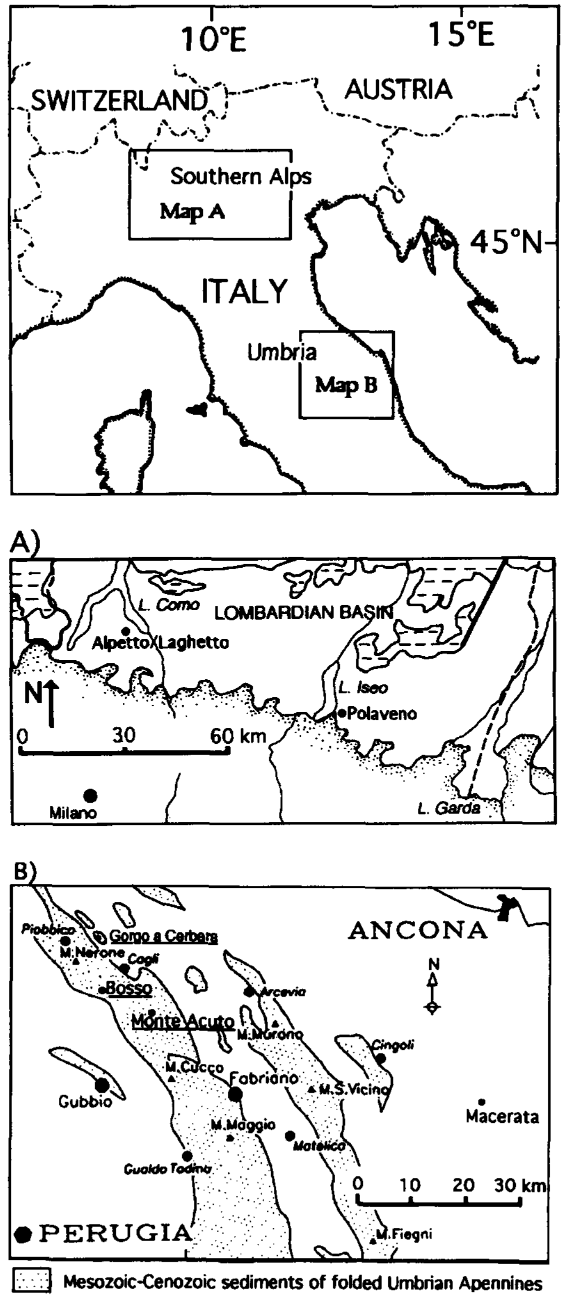

Fig. 1. (A) Location of Alpetto, Laghetto and Polaveno sections. (B) Location of Bosso, Gorgo a Cerbara and Monte Acuto sections.

[1] The prefix "C" denotes polarity chron, M-sequence polarity chron nomenclature follows [8],[9].

zonation used in this study is from Hoedemaeker et al. [15].

2. Laghetto and Alpetto sections

The Laghetto and Alpetto sections are located in the Southern Alps of northern Italy (Fig. 1), in a large limestone quarry close to the village of Pusiano. The sections are in the Upper Barremian–Lower Aptian (uppermost) part of the Maiolica Formation [16,17].

The Laghetto section (Fig. 2) was previously named Section A [18]. The outcrop comprises the Upper Barremian portion of the Maiolica Formation consisting of light gray, well bedded calcilutites.

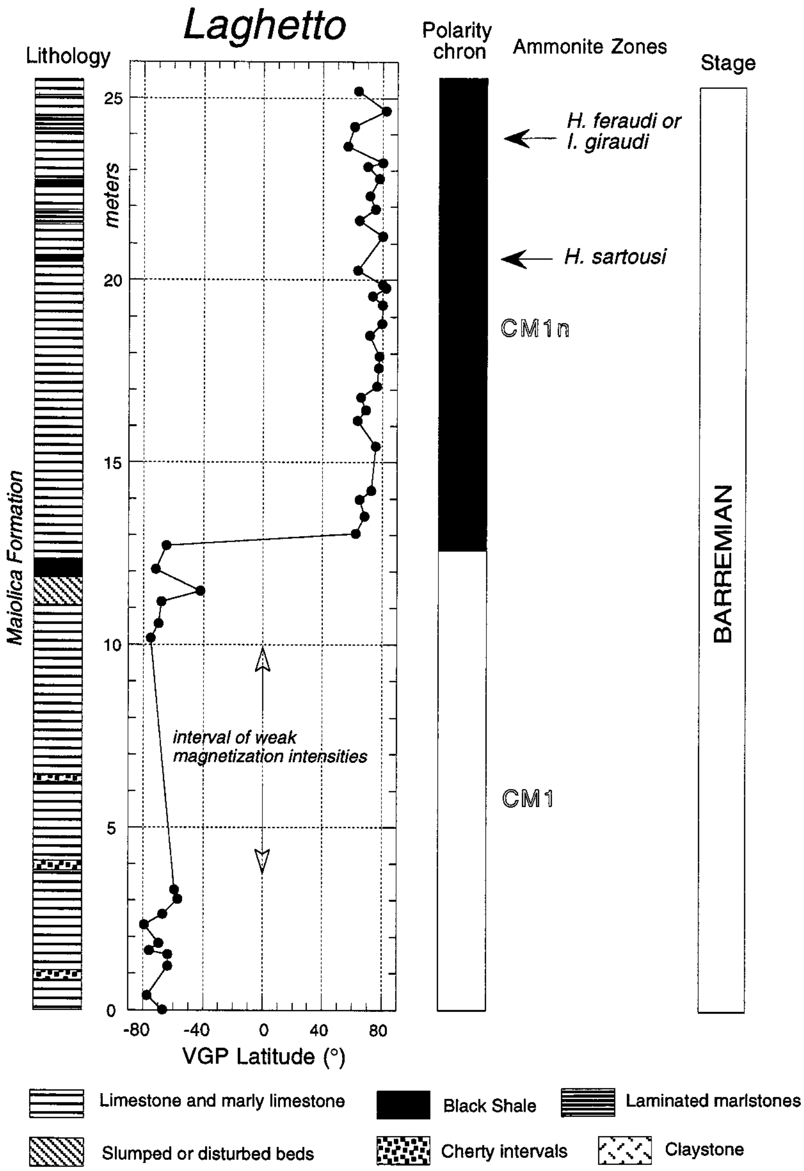

Fig. 2. Virtual geomagnetic polar (VGP) latitudes for Laghetto section with polarity chron interpretation and position of ammonite finds.

Black chert nodules and lenses are common in the lower 10 m of the section. Dark gray shaly interbeds increase in frequency up section. Distinctive, dark gray to black, laminated marlstones occur at 21.75 and 24.4 m.

The Alpetto section (Fig. 3) is located in the easternmost part of the quarry, 600 m NE of the Laghetto section, where the uppermost part of the Maiolica Formation and the transition to the overlying Scaglia Variegata/Marne di Bruntino are well exposed in a road cut. This section was previously named the Cesana quarry section [17]. Black chert nodules and layers occur in the lower 13 m, and we place the upper boundary of the Maiolica Formation at the top of the youngest black chert. The Maiolica/Scaglia transition is represented by a thick Transitional Lithozone [17,19] consisting of gray calcilutites, marlstones, pelagic turbidites, claystones and black shales. Nodules of gray chert are more frequent in the lower part of this lithozone. At the top of the Transitional Lithozone, dark gray shales and marlstones define the Livello Selli Equivalent (Fig. 3, *LSE*), which is more calcareous and thicker than the typical Livello Selli in the Umbria–Marche

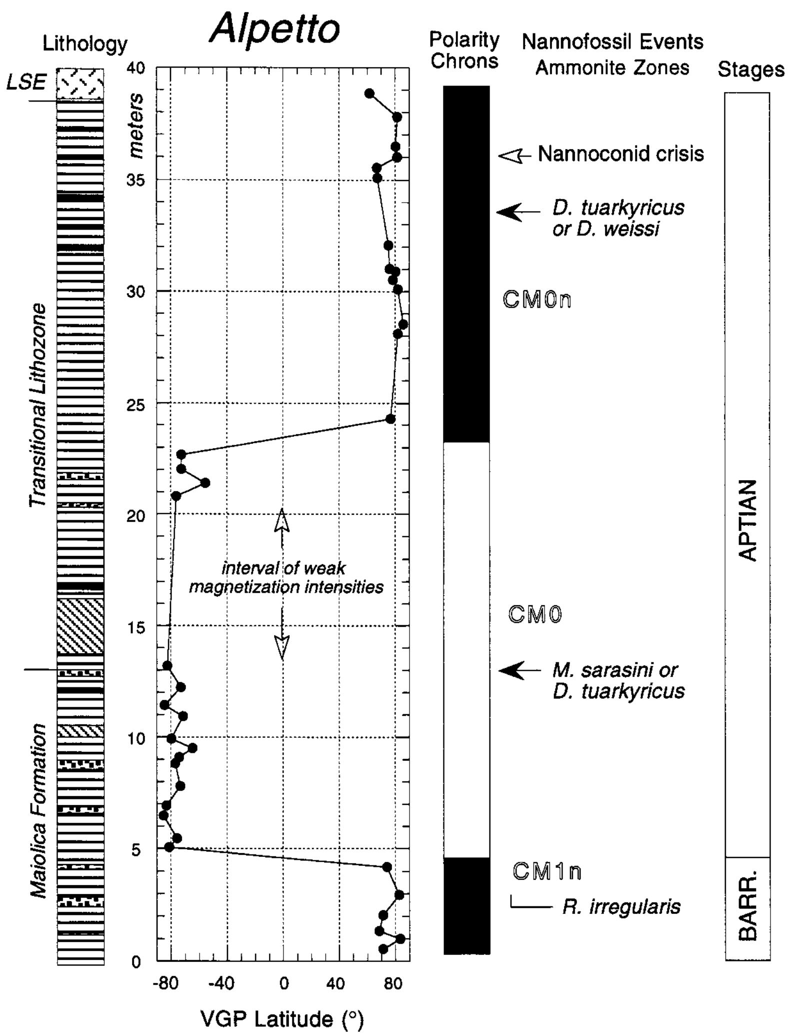

Fig. 3. Virtual geomagnetic polar (VGP) latitudes for Alpetto section with polarity chron interpretation, positions of nannofossil events and ammonite finds (see Table 2). *LSE* = Livello Selli Equivalent. For key to lithology, see Fig. 2.

area. A slump occurs between 10 and 10.65 m, and the 13.83 to 16.70 m interval is characterized by disturbed bedding.

Stepwise thermal demagnetization of oriented samples indicate a well defined characteristic magnetization component for most samples (Fig. 4); however, there are intervals in both sections where weak magnetization intensities precluded the resolution of component directions. The standard least-squares method [20] was used to calculate magnetization

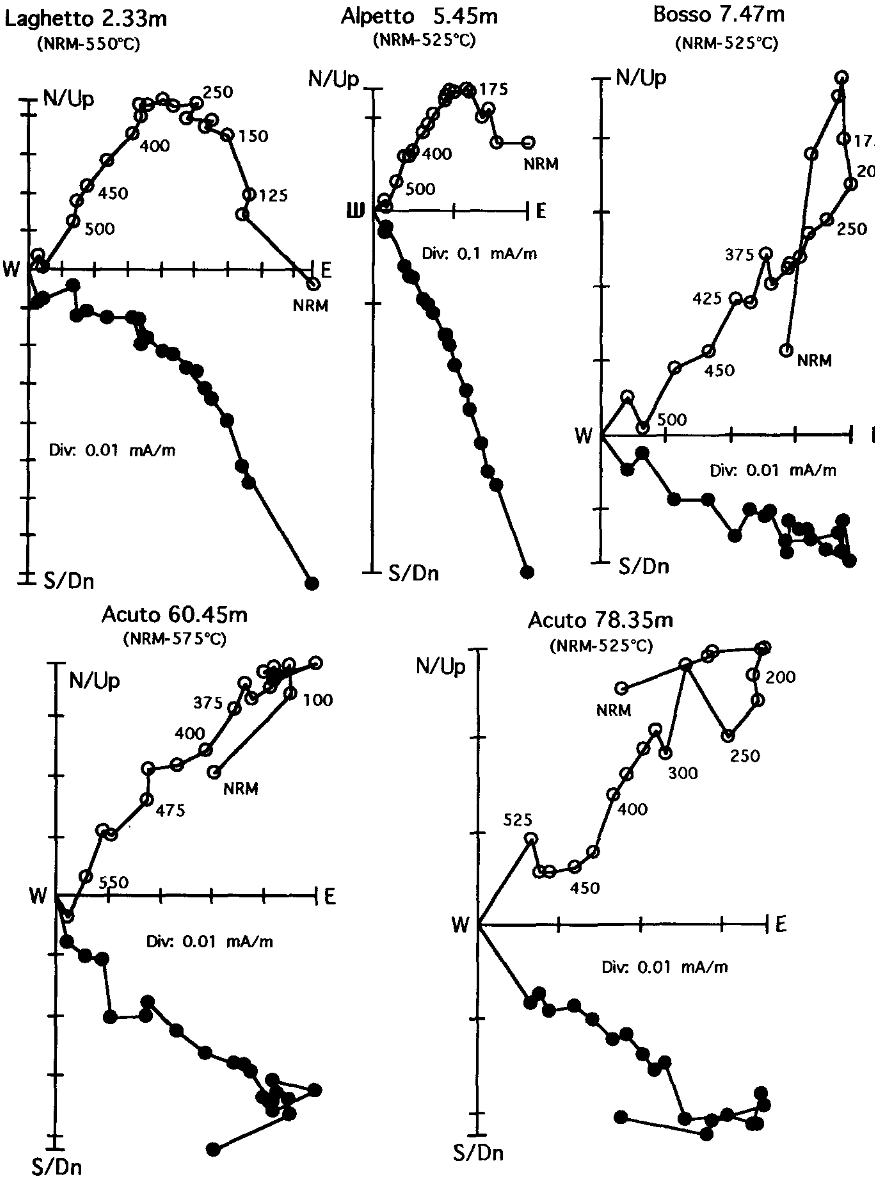

Fig. 4. Orthogonal projection of thermal demagnetization data for samples from Laghetto, Alpetto, Bosso and Monte Acuto. The meter level of the sample and the demagnetization temperature range are indicated. Temperatures associated with some individual points are given in °C. Open and closed symbols represent projection of the vector end point of the magnetization vector on the vertical and horizontal planes, respectively.

component directions (Fig. 5, Table 1) from orthogonal projections of demagnetization data. The magnetic stratigraphy is based on virtual geomagnetic polar (VGP) latitudes (Figs. 2 and 3), the latitude relative to the mean paleomagnetic pole for the individual section.

The magnetic stratigraphy in the Laghetto section (Fig. 2) indicates a single polarity reversal at 12.9 m. An interval of very weak magnetization intensities is observed in the 3.5–10 m interval. The two polarity chrons at Laghetto are interpreted as CM1 and CM1n. There are no nannofossil events present, as this section lies above the last appearance datum (LAD) of *C. oblongata* and below the first appearance datum (FAD) of *R. irregularis* (Fig. 6). There are two levels of ammonite finds in the Laghetto section [19]. At 20.5 m, *Melchiorites* sp. and *Heinzia* sp. have been found. *Heinzia* sp. can be attributed to the Upper Barremian and may be correlated to the *H. sartousi* zone [15]. At 24 m, a rich ammonite fauna has been collected: *Phyllopachyceras* sp., *Lytoceras* sp., *Ptychoceras meyrati* Ooster, *Anahamulina* sp., *Costidiscus recticostatus* (d'Orbigny), *Toxoceratoides sudalpinus* Cecca and Landra, *Spinocrinoceras trachyomphalus* (Uhlig), *S. polyspinosum* Kemper (Fig. 7h), *Barremites* sp., *Melchiorites* sp., *Silesites seranonis* (d'Orbigny), ?*Pararaspiticeras* sp., and ?Heteroceratidae sp. Although no zonal markers are present, the assemblage indicates either the *H. feraudi* or *I. giraudi* zones (Fig. 6).

At Alpetto, two polarity reversals are present (Fig. 3). The first occurrence of the nannofossil

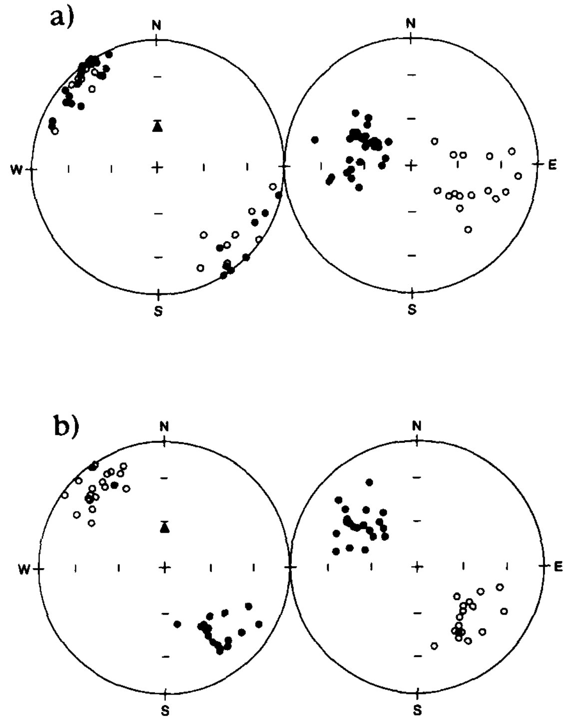

Fig. 5. Equal area projection of characteristic magnetization components before (left) and after (right) structural tilt correction for (a) Laghetto and (b) Alpetto. Open and closed symbols represent upward and downward inclination, respectively.

Rucinolithus irregularis at 2.95 m and the onset of the nannoconid crisis at 36.02 m indicates, by correlation to other sections (e.g. [8,21]), that the recorded polarity chrons are CM1n, CM0 and CM0n. Weak

Table 1
Mean directions for the five sections, before and after structural tilt correction

		Before tilt		After tilt				Pole Position	
Location	N	Dec.	Inc.	Dec.	Inc.	k	a95	Lat°N/Long°E	dp/dm
Laghetto	45	316.2	2.6	289.1	52.1	18.9	5.0	35.3 / 292.0	4.7/6.9
Alpetto	37	320.3	-23.3			20.2	5.4		
				310.8	41.9	28.0	4.5	45.2 / 267.7	3.4/5.6
Polaveno*	504	332.8	19.0	319.3	36.7	21.5	1.4	48.3 / 256.7	0.9/1.6
Bosso	126	320.3	30.0	295.6	34.6	58.2	1.7	31.4 / 279.5	1.1/1.9
Mt. Acuto	187	344.0	28.0	312.9	38.2	27.1	2.0	45.3 / 268.5	1.4/2.4

Statistical parameters after Fisher [35].
* includes 367 samples from [8].

magnetization intensities occur in the 13.50–20.50 m interval. At 24.5 m a single specimen of *Costidiscus* cf. *recticostatus* (d'Orbigny) was found. At 33.5 m, a richer ammonite fauna comprising *Ptychoceras emerici* (d'Orbigny), *Melchiorites* sp., *Costidiscus* sp., *Deshayesites* sp., with abundant *Silesites seranonis* (d'Orbigny), can be attributed to the *D. tuarkyricus* or *D. weissi* zones of the Early Aptian. At 13.0 m, a rich ammonite fauna comprising *Phylloceratina* spp. ind. with *Lytoceras* sp., ?*Melchiorites* sp., ?*Anahamulina* sp., *Eoheteroceras* cf. *norteyi* (Myczynski and Triff) (Fig. 7e,f), *E.* cf. *silesiacum* Vasicek and Wiedmann (Fig. 7g), ?*Hamulinites* cf. *parvulus* (Uhlig), *Manoloviceras* aff. *saharievae* (Manolov), and *Silesites seranonis* (d'Orbigny) (Fig. 7i). The occurrence of forms very similar to *Eoheteroceras*, *Hamulinites* and *Manoloviceras* is usually indicative of the Lower Barremian; however, *S. seranonis* appears in the *A. vandenheckei* zone at the base of the Upper Barremian. The ammonite assemblage is problematic in that it is difficult to assign it to a particular ammonite zone. It may correlate to either the *M. sarasini* or *D. tuarkyricus* zones (Fig. 6).

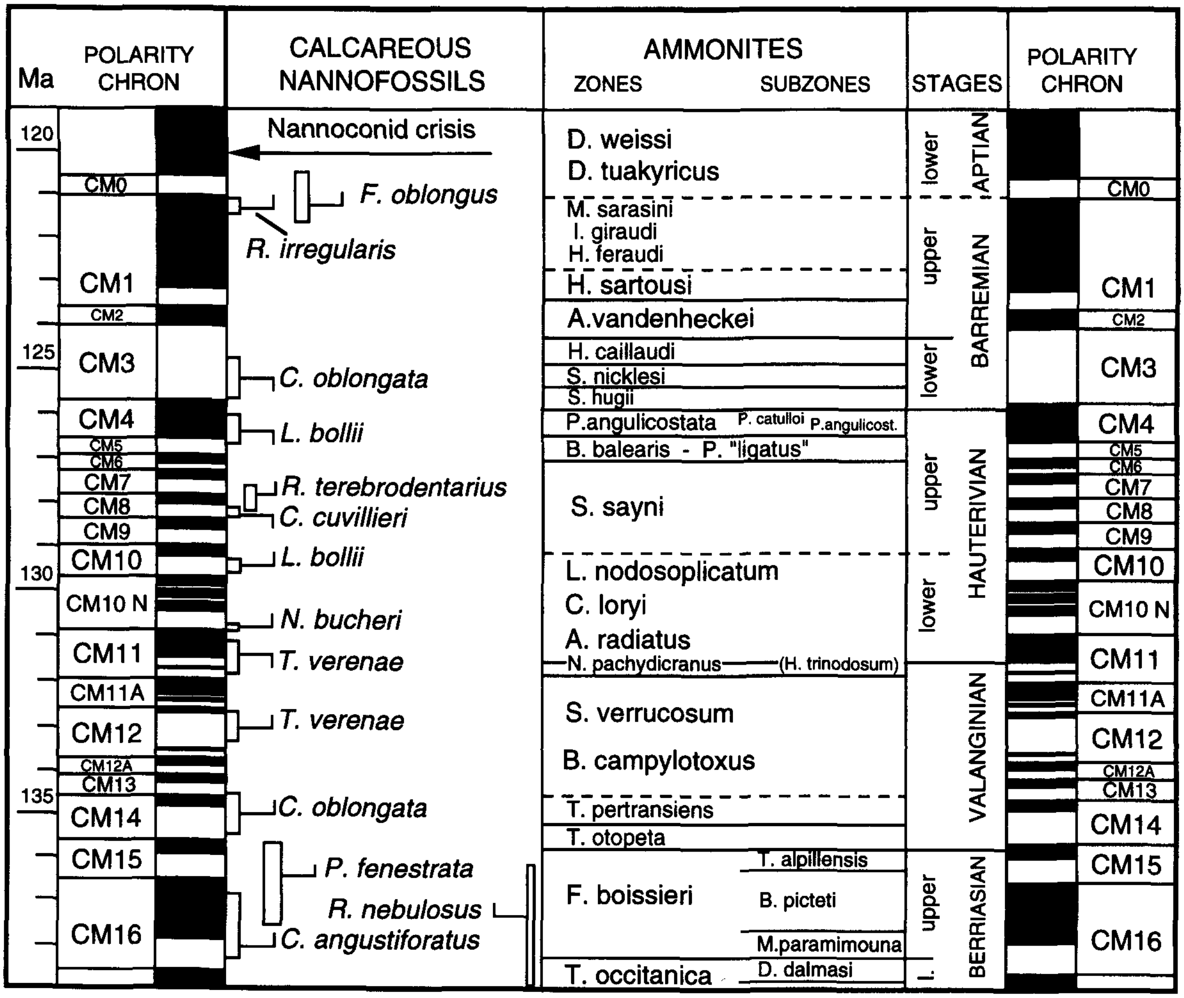

Fig. 6. Correlations of nannofossil events and ammonite zones to polarity chrons for the CM0–CM16 interval. Correlations of nannofossils to polarity chrons from [4],[8],[9],[24]. Correlations of ammonite zones to polarity chrons from [2],[11] and this paper. Ammonite zonation from [15]. Numerical ages from [34].

3. Monte Acuto and Bosso sections

The Monte Acuto and Bosso sections are located in the Marche region (central Italy) (Fig. 1). The sampled 70 m Bosso section is Late Hauterivian–Early Barremian in age and contiguous with the previously studied Tithonian–Berriasian "Bosso" section [6,22]. Well defined magnetization components are resolved by progressive thermal demagnetization (Fig. 4). The component directions are concentrated into two well defined antipodal groups (Fig. 8a, Table 1). For Bosso, the polarity zone pattern (Fig. 9) is fairly distinctive, however, the match to the geomagnetic polarity timescale (GPTS) is aided by the nannofossil events. In other Maiolica limestone sections (e.g. [8],[9], the LAD of *C. cuvilleri* has been correlated to CM9n or CM8, the FAD of *R. terebrodentarius* (*Lithastrinus* sp. of [4]) to CM8n or CM7, and the LAD of *L. bollii* to CM5 or CM4 (Fig. 6). The observed variability in correlation of nannofossil events to polarity chrons in the Maiolica limestones is attributed to poor nannofossil preservation and low abundance of marker species rather than diachroneity; nonetheless, the three nannofossil events observed in the Bosso section allow unequivocal match of polarity zones to the GPTS (Fig. 9). A level of abundant ammonites has been recognized at 17.6 m in the Bosso section. This level has been recognized elsewhere in Umbria–Marche and is referred to as the Faraoni Level, with Bosso as the type section [23]. The ammonite assemblage can be correlated to the *P. catulloi* subzone of the *P. angulicostata* zone. The *P. catulloi* subzone is the youngest Hauterivian ammonite zone (Fig. 6) and therefore its occurrence aides recognition of the Hauterivian/Barremian boundary and permits correlation of this stage boundary to polarity chrons. In the Monte Petrano outcrops, located less than 1 km from

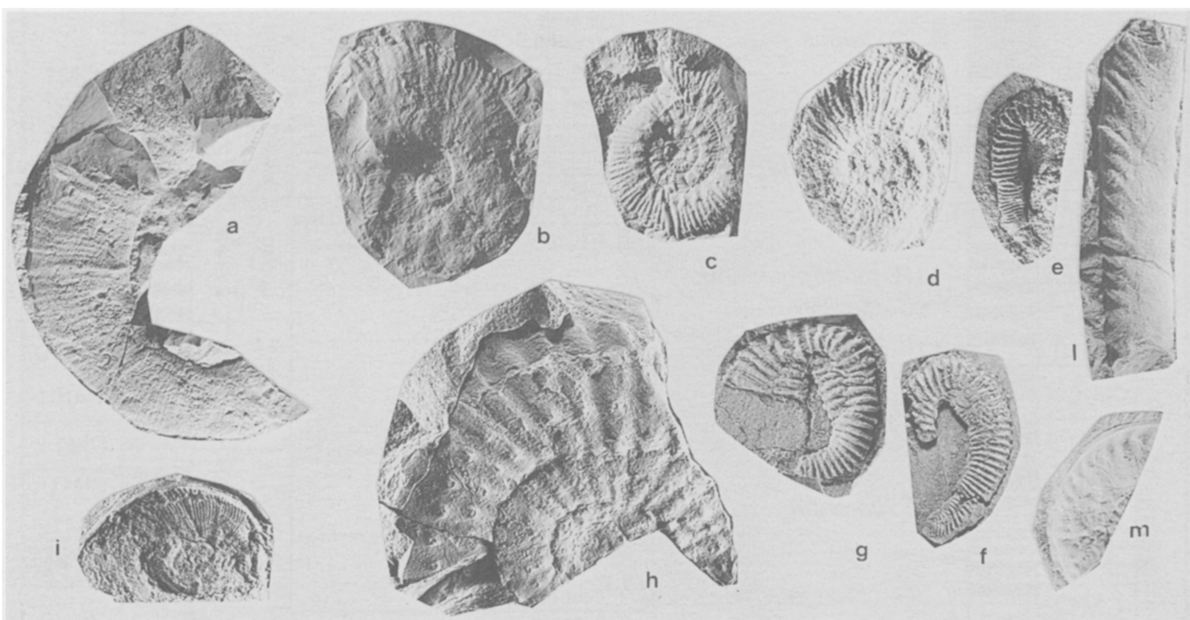

Fig. 7. Ammonites finds. (a) *Crioceratites* gr. *duvali* Léveillé (×0.86). Monte Acuto at 22 m. *S.sayni* zone. (b) *Neocomites* (*N.*) sp. gr. *neocomiemsis* (d'Orbigny) sensu Company [28] (×0.84). Monte Acuto at 88 m. *S. verrucosum* zone. (c) *Olcostephanus* aff. *detonii* (Rodighiero) (×0.8). Monte Acuto at 88.0 m. *S. verrucosum* zone. (d) *Neocomites* (*Teschenites*) sp. (×1). Monte Acuto at 80.0 m. Valanginian/Hauterivian boundary interval. (e,f) *Eoheteroceras* cf. *norteyi* (Myczynski and Triff) (×1). Alpetto at 13 m. Barremian/Aptian boundary interval. (g) *Eoheteroceras* cf. *silesiacum* Vasicek and Wiedmann (×1). Alpetto at 13 m. Barremian/Aptian boundary interval. (h) *Spinocrioceras polyspinosum* (Kemper) (×1). Laghetto at 24 m. Upper Barremian *I. giraudi* or *H. feraudi* zone. (i) *Silesites seranonis* (d'Orbigny) (×1.25). Alpetto at 13 m. (l) *Bochianites neocomiensis* (d'Orbigny) morphotype *goubechensis* Mandov (×1). Monte Acuto at 86.5 m. Upper Valanginian, *N. pachydicranus* zone. (m) *Oosterella garciae* (Nicklès) (×1). Monte Acuto at 80.0 m. Upper Valanginian *N. pachydicranus* zone. Ammonite zonation from [15].

the Bosso section, specimens of *Spitidiscus* of the *hugii/oosteri* group occur 3 m above the *P. catulloi* subzone. In the Bosso section, specimens of *Spitidiscus* sp. gr. *hugii/oosteri* occur at 1.80 m, in CM3 (Fig. 9), about 16 m above the Faraoni Level. This is not the FO level of *Spitidiscus* which defines the base of the *Spitidiscus hugii* zone (the base of the Barremian). We place the Hauterivian/Barremian boundary at 12 m at Bosso, just above the LAD of *L. bollii*, and 5.6 m above the Faraoni Level (Fig. 9).

The Monte Acuto section is located on the southern slope of Monte Acuto (Fig. 1), along the road from Monte Catria to Chiaserna. The sampled section is 90 m thick and comprises typical thin bedded Maiolica limestones. Well defined magnetization components resolved by thermal demagnetization (Fig. 4) give two groups of antipodal component directions (Fig. 8b, Table 1). The VGP latitudes indicate a series of polarity zones (Fig. 10) and for this section the polarity zone pattern is distinctive.

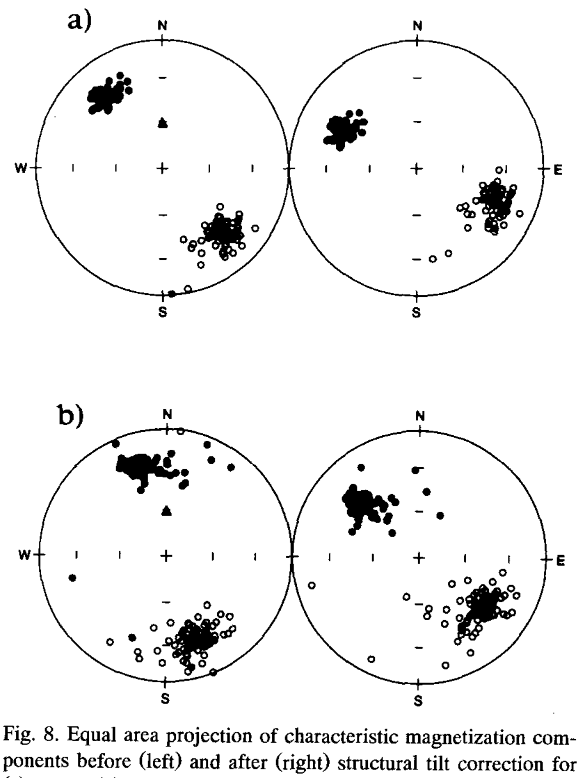

Fig. 8. Equal area projection of characteristic magnetization components before (left) and after (right) structural tilt correction for (a) Bosso (b) Monte Acuto. Open and closed symbols represent upward and downward inclination, respectively.

For example, the two thin reverse polarity zones at 46 and 52 m are diagnostic of CM10Nn. The correlation to polarity chrons is confirmed by nannofossil events with known correlation to the GPTS. From previous work [8,9,24], the LAD of *T. verenae* is correlated to CM11 or CM11n, the FAD *N. bucheri* to CM10N, the FAD of *L. bollii* to CM10 or CM10n, the LAD of *C. cuvilleri* to CM9n or CM8, and the FAD of *R. terebrodentarius* (*Lithastrinus* sp.) to CM8n or CM7 (Fig. 6). An anomalous reverse polarity zone at about 15 m at Monte Acuto (Fig. 10) is inconsistent with the polarity chron interpretation in the upper part of the section. A fault at 16 m appears to have caused repetition of polarity zones correlative to CM9 and CM9n. Magnetization intensities become very weak at the base of the section, below about 75 m. Weak magnetization intensities in Maiolica limestone sections in the vicinity of polarity zone M11 have been observed in several Maiolica limestone sections, coincident with a positive $\delta^{13}C$ anomaly and are attributed to enhanced magnetite dissolution due to increased organic carbon burial [9].

At Monte Acuto, the Upper Hauterivian ammonites *Crioceratites* gr. *duvali* Léveillé (Fig. 7a) and *Subsaynella* sp. have been found at 22 and 23 m, respectively, indicating the *S. sayni* zone. The base of this zone marks the boundary between the Lower and Upper Hauterivian (Fig. 6). At 79.7 m, an impression of a *Neocomites* of the subgenus *Teschenites* (Fig. 7d) has ribbing very similar to *N.* (*T.*) *flucticulus* (Thieuloy) indicating that this level is close to the Valanginian/Hauterivian boundary, as *N.* (*T.*) *flucticulus* has limited range spanning the stage boundary [25,26]. At 80.5 m and 83.5 m, specimens of *Oosterella garciae* (Nicklès) (Fig. 7m) and *Oosterella* sp. aff. *stevenini* (Nicklès) were recovered, respectively. These levels can be correlated to the *N. pachydicranus* zone, the uppermost zone of the Valanginian (Fig. 6). At 86.5 m, specimens of *Neolissoceras* sp. and *Bochianites neocomiensis* (d'Orbigny) morph. *goubechensis* Mandov (Fig. 7l) have been recovered. The latter subspecies (or morphotype) is associated with the base of the *N. pachydicranus* zone in southeast France [27] and has been found elsewhere in both in the *N. pachydicranus* and *S. verrucosum* zones [28]. At the base of the section, at 88.0 m, a relatively rich ammonite assemblage includes *Neocomites* (*N.*) sp. gr. *neocomiensis* (d'Orbigny) sensu Company (Fig. 7b), *Oosterella* cf. *begastrensis* Company and *Olcostephanus* aff. *detonii* (Rodighiero) (Fig. 7c). This fauna is ascribed to the upper part of the Upper Valanginian *S. verrucosum* zone [29].

4. Gorgo a Cerbara

The Gorgo a Cerbara section (Fig. 1) has been studied for magnetostratigraphy [3], nannofossil biostratigraphy [4], and ammonite, nannofossil and foraminiferal biostratigraphy [2]. This has become a

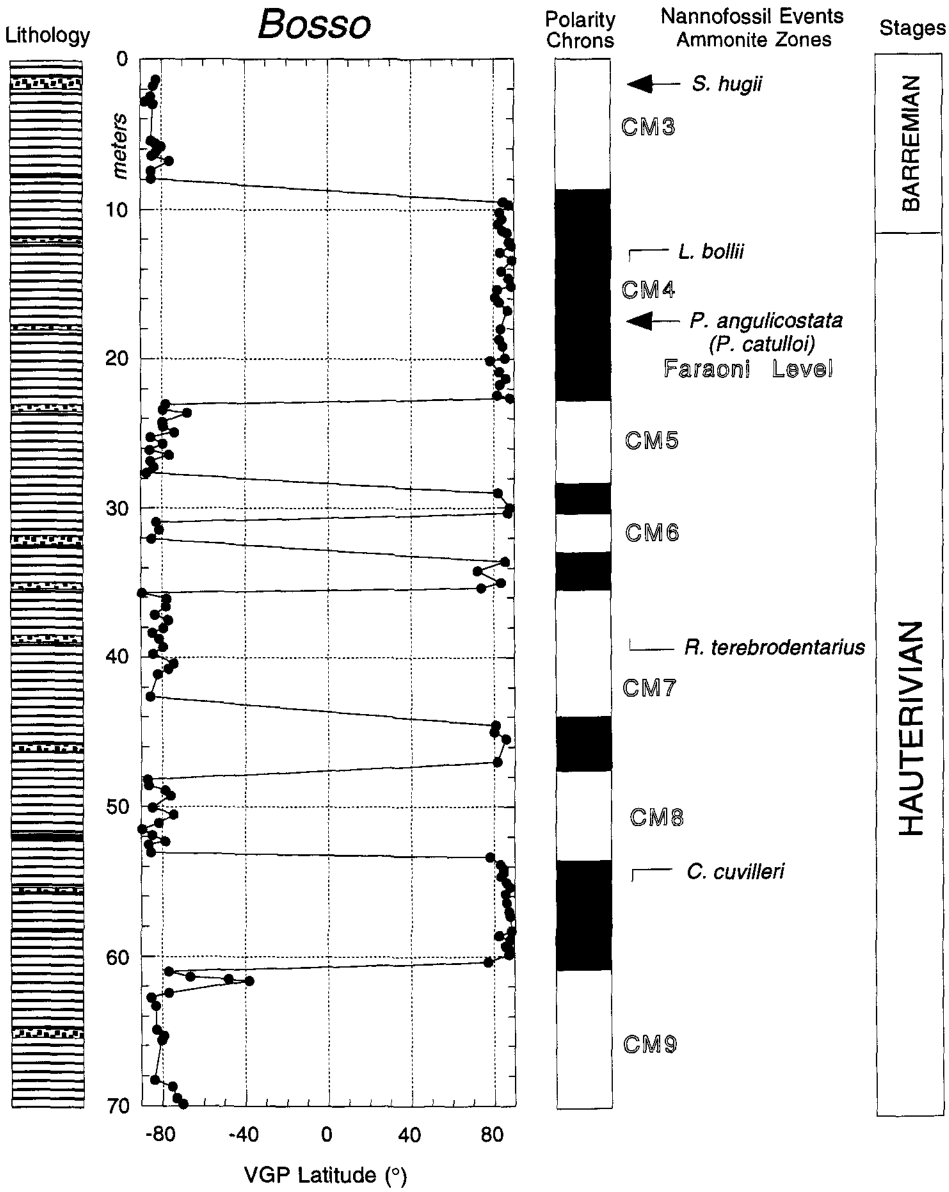

Fig. 9. Virtual geomagnetic polar (VGP) latitude for Bosso section with polarity chron interpretation, positions of nannofossil events and ammonite finds (see Table 2). For key to lithology, see Fig. 2.

very important section for the correlation of polarity chrons to stage boundaries due to the relatively large number of ammonite finds. Since the publication of [2], some new ammonite finds at Gorgo a Cerbara have improved the correlation of polarity chrons to ammonite zones (Fig. 11). At a level close to the top of polarity zone M0, a specimen of *Prodeshayesites* sp. is indicative of the Lower Aptian. At the base of polarity zone M4, new specimens of *Crioceratites duvali* Léveillé/*villiersianus* (d'Orbigny) indicate either the *B. balearis* or, more probably, the *P. ligatus* zone. Near the top of polarity zone M6n, a

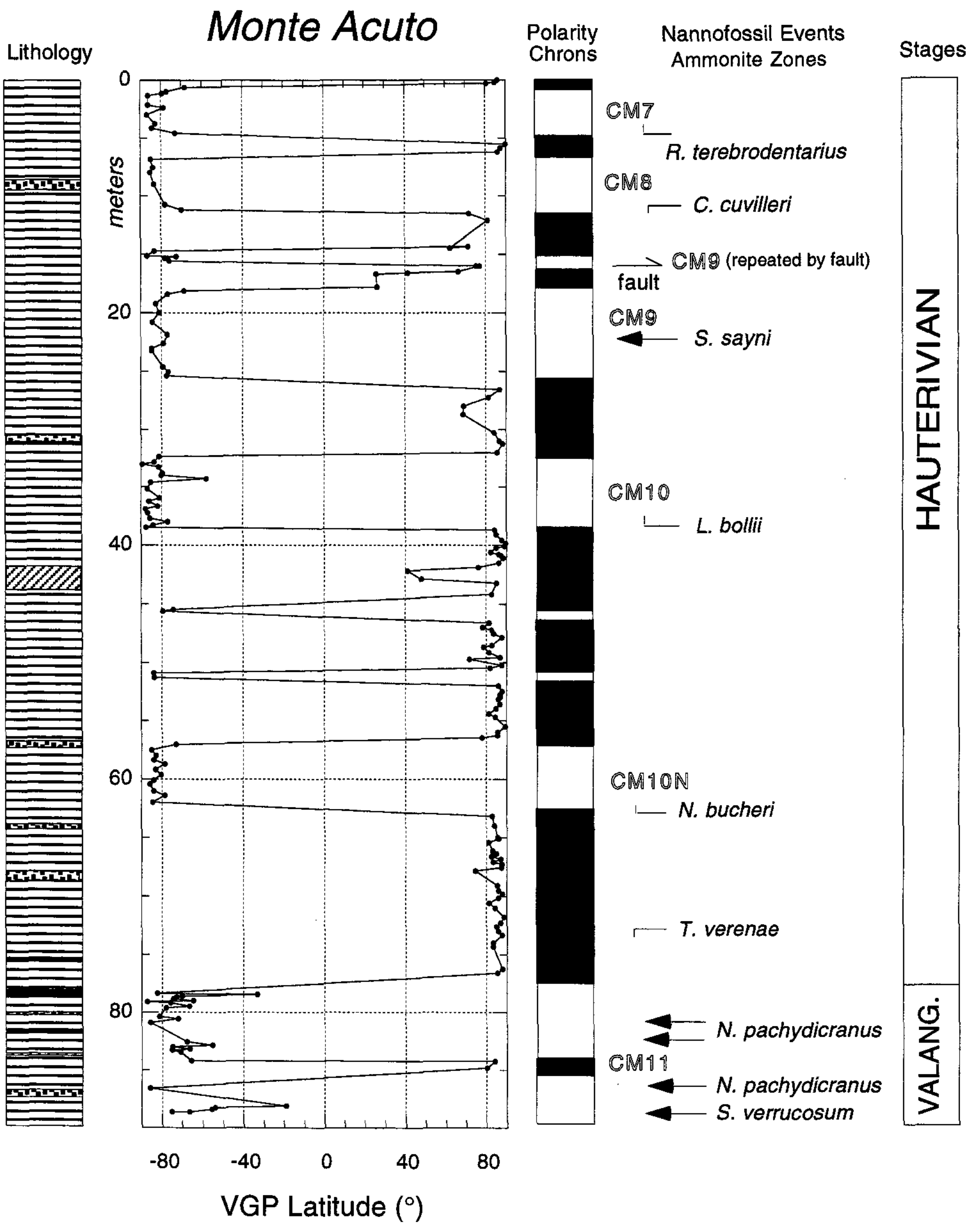

Fig. 10. Virtual geomagnetic polar (VGP) latitude for Monte Acuto section with polarity chron interpretation, positions of nannofossil events and ammonite finds (see Table 2). For key to lithology, see Fig. 2.

specimen of *Subsaynella* sp. indicates the *S. sayni* zone.

5. Polaveno

The Polaveno section [30] is located near Lago d'Iseo (Fig. 1). The magnetostratigraphy and nannofossil biostratigraphy are already published for the upper part of the section in the CM3–CM11 interval [8]; however, the sampling was not continued below polarity zone M11 due to very weak magnetization intensities coinciding with the carbon isotope $d^{13}C$ anomaly [9]. Although very weak magnetization intensities precluded resolution of magnetization components within part of polarity zone M11, magnetiza-

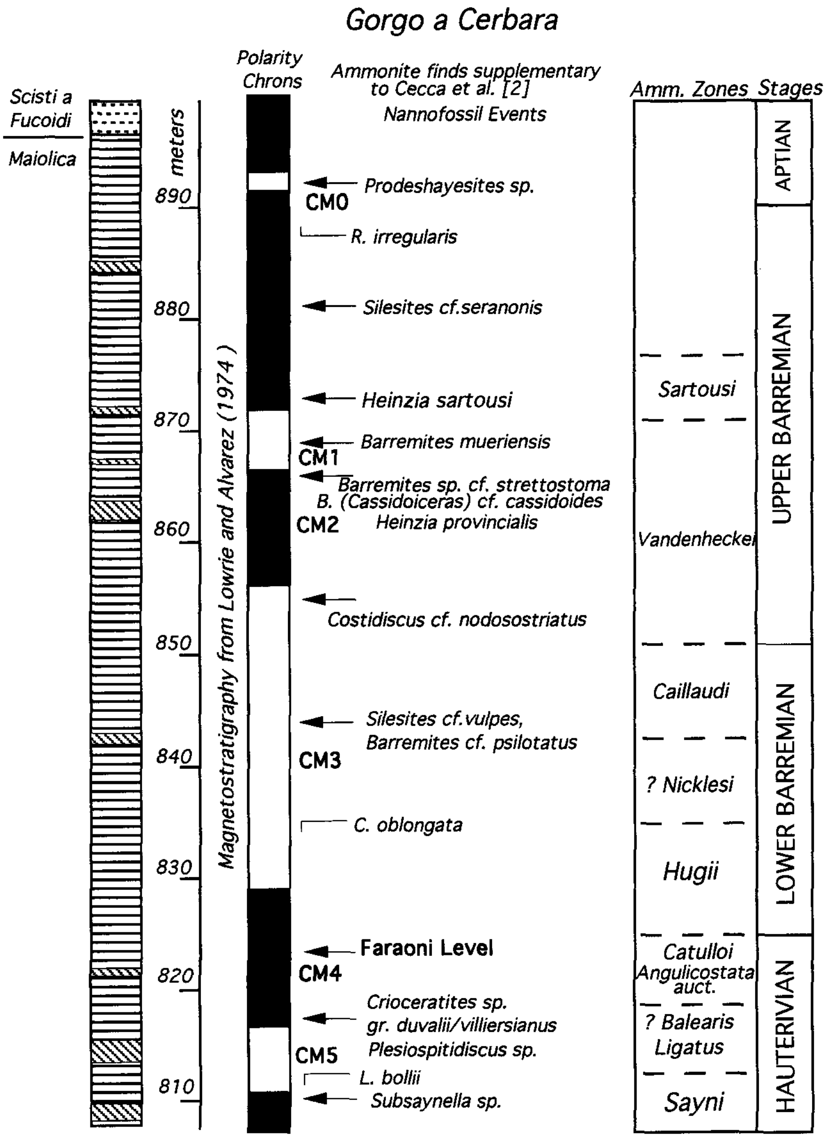

Fig. 11. Ammonite finds at Gorgo a Cerbara additional to those previously published [2], and the revised correlation of ammonite zones to polarity chrons.

tion components could be resolved further down section (Fig. 12). Although no ammonites have been found at Polaveno, nannofossils and calpionellids provide a biostratigraphy which is consistent with previous correlations of nannofossil/calpionellid events to polarity chrons (Table 2, Fig. 6).

6. Correlation of ammonite zones and stage boundaries to polarity chrons

The new correlations of ammonite zones to polarity chrons (Fig. 6) in the CM0–CM11 interval lead to revision of the correlation of polarity chrons to

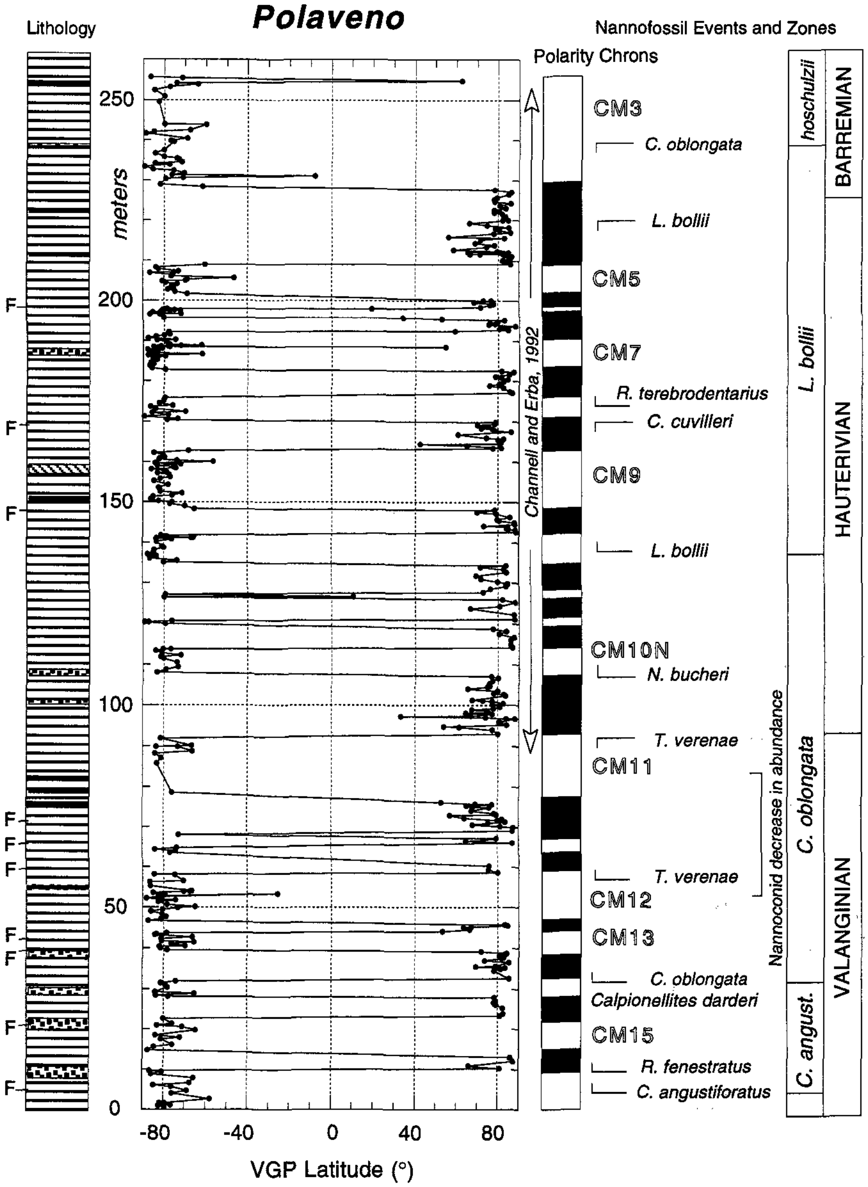

Fig. 12. Virtual geomagnetic polar (VGP) latitude for Polaveno section with positions of nannofossil and calpionellid events (see Table 2). Data for CM3–CM11 interval from [8]. For key to lithology, see Fig. 2.

Table 2

Nannofossil events	Reversed polarity chrons	Polaveno (m)	Monte Acuto (m)	Bosso (m)	Laghetto (m)	Alpetto (m)
Base nannoconid crisis						36.02
	Top CM0					23.48
	Base CM0					4.62
FAD *R. irregularis*					above top	2.95
	Top CM1				12.88	
	Base CM1					
	Top CM2					
	Base CM2					
	Top CM3					
	End CM3					
	Begin CM3	227.98		8.75		
LAD *C. oblongata*		222.62		above top	below base	
	End CM5	208.78		22.86		
LAD *L. bollii*		204.87		16.26		
	Begin CM5	200.90		28.30		
	End CM6	198.18		30.67		
	Begin CM6	195.81		32.85		
	End CM7	192.35	0.45	35.52		
	Begin CM7	182.69	5.07	43.61		
FAD *R. terebrodentarius*		173.22	3.80	39.77		
	End CM8	176.55	6.52	47.60		
	Begin CM8	170.16	11.35	53.23		
LAD *C. cuvillieri*		167.54	11.50	54.15		
	End CM9	163.15	17.96	60.68		
	Begin CM9	148.30	25.98			
	End CM10	142.20	32.17			
FAD *L. bollii*		135.60	38.30			
	Begin CM10	134.78	38.57			
	End CM10Nn-1	127.50	44.85			
	Beg CM10Nn-1	126.20	46.15			
	End CM10Nn-2	120.94	50.74			
	Beg CM10Nn-2	119.40	51.67			
	End CM10N	114.05	56.77			
FAD *N. bucheri*		108.00	61.40			
	Begin CM10N	107.53	62.57			
	End CM11	92.75	77.47			
LAD *T. verenae*		91.00	70.15			
	Begin CM11	77.33				
	End CM12	58.35				
FAD *T. verenae*		56.54				
	Begin CM12	46.27				
	End CM13	43.91				
	Begin CM13	39.36				
FAD *Calpionellites darderi*		32.78				
FAD *C. oblongata*		32.58				
	End CM14	32.23				
	Begin CM14	28.00				
	End CM15	23.04				
	Begin CM15	13.36				
	End CM16	9.97				
FAD *R. fenestratus*		9.00				
FAD *C.angustiforatus*		5.00				

For Polaveno, meter levels for CM3–CM10N interval from [8] adjusted for new base of section.

stage boundaries. The recent ammonite finds in the Maiolica limestones at Alpetto and Gorgo a Cerbara close to the Barremian/Aptian stage boundary indicate that this stage boundary lies close to CM0. The FAD of the nannofossil *R. irregularis* was proposed over twenty years ago for identification of the Barremian/Aptian boundary [12,13]. However, recent studies of the Rio Argos section (Spain) and Route d'Angles section (France) revealed that *R. irregularis* occurs in the uppermost part of the *M. sarasini* ammonite zone [2] and consequently predates the Barremian/Aptian boundary. As the FAD of *R. irregularis* lies just below the older boundary of CM0, this polarity reversal has been considered as a suitable means of defining the stage boundary. Recent timescales [14,31,32] place the stage boundary either within CM0, or slightly older, in CM1n.

The Hauterivian/Barremian boundary has been placed within CM3 [31] or in the CM5–CM7 interval [14] based on the tradition [12,13] of placing this boundary between two nannofossil events: the LAD of *L. bollii* and the LAD of *C. oblongata*. The presence of the *P. catulloi* ammonite subzone within CM4 at Bosso (Fig. 9) and other significant ammonite finds in neighbouring sections confirms the conclusion [2] that the Hauterivian/Barremian boundary lies in the late part of CM4.

The presence of the *S. sayni* ammonite zone in CM9 at Monte Acuto (Fig. 10) and at the young end of CM6n at Gorgo a Cerbara (Fig. 11) indicates that the boundary between the Lower and Upper Hauterivian is older than CM9, and that the *S. sayni* zone has greater duration (> 2 Myr) than the ammonite zones immediately above it (Fig. 6).

The Valanginian/Hauterivian boundary has usually been placed in CM10N [14,31,32] on the basis of the tradition [12,13] of placing this stage boundary between two nannofossil events, the LAD of *T. verenae* and the FAD of *L. bollii*. The base of the Monte Acuto section is in the upper part of the *S. verrucosum* ammonite zone, and the level 7.5 m above base (80.5 m) at the top of polarity zone M11 is within the *N. pachydicranus* zone, the uppermost ammonite zone of the Valanginian (Fig. 6). At 79.7 m, the presence of a specimen with characteristics of *N. (T.) flucticulus* (Thieuloy) indicates proximity to the Valanginian/Hauterivian boundary. The younger boundary of CM11 is at 77.5 m, and we therefore place the Valanginian/Hauterivian boundary at the CM11/CM11n boundary.

The magnetobiostratigraphy of the Valanginian hypostratotype section at Angles, France has been studied [33]. The pattern of polarity zones cannot be convincingly correlated to the GPTS, and therefore the correlation of ammonite zones to the GPTS remains unclear in this section.

Magnetic polarity stratigraphy is central to the construction of Mesozoic–Cenozoic timescales because the GPTS is the preferred means of correlation and interpolation among diverse chronostratigraphic elements. Over the last ten years, microfossil correlations to the Early Cretaceous GPTS have been established in Italian pelagic limestone sections. In this paper, we focus on Valanginian to Aptian Maiolica limestone sections in which diagnostic ammonites have been found. The magnetic stratigraphy in these sections allows the ammonite zones, which define stage boundaries, to be correlated to polarity chrons and hence to microfossil (nannofossil) events.

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