Table 1. Absolute and relative (to the Tiziano bed) position (m) and chronology of events at the Bartonian - Priabonian transition.

Event/Marker	Position (m)	Position relative to Tiziano bed (m)	Notation relative to Chron Top	Galeotti et al. (2019)			CK95		PÄ06		W14	
				Age (U-Pb dating) (Ma)	Age (astro-chronol-ogy) (Ma)	Time relative to the Tiziano bed (kyr)*	Age (Ma)	Time relative to the Tiziano bed (kyr)**	Age (Ma)	Time relative to the Tiziano bed (kyr)**	Age (Ma)	Time relative to the Tiziano bed (kyr)**
Subchron C17n.1n base	74.28	10.71	C17n.1n 1.00	37.402	37.380	340	37.473	341	37.520	352	37.385	361
B *G. semiinvoluta*	68.37	4.8	C17n.2n 0.25	37.600	37.578	142	37.665	149	37.719	153	37.593	153
T *C. grandis*	66.47	2.9	C17n.2n 0.49	37.664	37.657	63	37.724	90	37.780	92	37.654	92
TIZIANO BED	63.57	0	C17n.2n 0.86	37.762	**37.710**	0	37.814	0	37.872	0	37.746	0
Bc *C. erbae*	62.96	-0.61	C17n.2n 0.94	37.782	37.740	-20	37.833	-19	37.892	-20	37.766	-20
Br *C. oamaruensis*	62.85	-0.72	C17n.2n 0.95	37.786	37.742	-22	37.837	-23	37.895	-23	37.769	-23
Subchron C17n.2n base	62.48	-0.48	C17n.2n 1.00	37.798	37.772	-30	37.848	-34	37.907	-35	37.781	-35
T *M. crassatus*	57.52	-6.05	C17n.3n 0.39		37.890	-170	37.996	-182	38.036	-164	37.946	-200
T large acarininids	57.32	-6.25	C17n.3n 0.42		37.893	-173	38.001	-187	38.040	-168	37.951	-205
Subchron C17n.3n base	52.62	-10.95	C17n.3n 1.00		38.090	-290	38.113	-299	38.158	-286	38.081	-335

*Time (kyr) relative to the Tiziano bed
**Time (kyr) relative to the Tiziano bed assuming constant linear sedimentation rates within Chrons
CK95 - Cande & Kent (1995); PÄ06 - Pälike et al. (2006); W14 - Westerhold et al. (2014)

nificant variations occur at the Bartonian-Priabonian transition except for a slight gradual increase in $\delta^{13}C$ values starting in the middle part of Subchron C17n.3n (+ 0.6 ‰) and culminating in the lower part of Subchron C17n.2n (+ 1.1 ‰). By contrast, the lower part of the section, from ~ 13 m level to 25 m level, is characterized by major and distinct shifts in both $\delta^{13}C$ and $\delta^{18}O$ records. A coupled negative excursion of $\delta^{13}C$ and $\delta^{18}O$ is documented from the 13 m level to 17 m level, which is interpreted as the Middle Eocene Climatic Optimum (MECO), being constrained within the upper part of Chron C18r and the basal-most part of Subchron C18n.2n (Bohaty et al., 2009; Spofforth et al., 2010). Interestingly, after the climax of the event (~ 40.1 Ma; Bohaty et al., 2009), from ~ 17 m level to ~ 25 m level, the $\delta^{18}O$ record gradually recovers while the $\delta^{13}C$ and $CaCO_3$ profiles are more complex. Two positive excursions in $\delta^{13}C$ of ~ 1.25 ‰ associated with low carbonate content are interrupted by a rapid and transient return to climax conditions (0.3‰) and an increase in carbonate content (Spofforth et al., 2010). This interval is named 'post-MECO' after Luciani et al. (2010) and is lithologically characterized by two sediment packages (ORG1 and ORG2 in Figs. 8, 12) with an elevated organic carbon content (up to 3%). The response of benthic and planktonic foraminifera, and calcareous nannoplankton to the MECO and 'post-MECO' is the focus of a number of papers (Luciani et al., 2010; Toffanin et al., 2011; Boscolo-Galazzo et al., 2013; 2016).

Orbital tuning and radioisotopic dating (^{206}Pb-^{238}U)

Galeotti et al. (2019) complemented the already existing data (calcareous plankton biostratigraphy, magnetostratigraphy, carbon and oxygen isotope, $CaCO_3$ content) with a cyclochronology based on carbon isotope and wt.% $CaCO_3$ records and $^{206}Pb/^{238}U$ dating of zircons from four volcanic tuffs throughout the interval spanning the Bartonian-Priabonian transition. Although small systematic discrepancies exist between orbital and radioisotopic age estimates of the Tiziano bed, the duration of intervals bracketing consecutive crystal tuff layers are in good overall agreement (Table 1). The age model obtained allows calculation of the duration of individual magnetochrons and calibrating biostratigraphic and non- biostratigraphic events at the Bartonian-Priabonian transition. This approach thus provides two very close independent numerical ages for the Tiziano bed, specifically 37.762 ± 0.077 Ma from the zircon $^{206}Pb/^{238}U$ dating and 37.710 ± 0.01 Ma from astrochronology, that represent an additional but strongly suggested (by ICS) requirement when a GSSP is defined.

Selecting the Boundary Level at Alano

The historical review and discussion above indicates that the optimal interval for defining the base of the Priabonian and placing the "golden spike" lies between the Base of Subchron C17n.3n and the Base of Subchron C17n.1n according to correlatability and historical appropriateness criteria (Fig. 3).

The most widespread practice in proposing GSSPs has been and still is to locate the "golden spike" exactly in the lithologic level where a specific, arguably widely correlatable, biostratigraphic or magnetostratigraphic event occurs (Remane et al., 1996). Within this practice, there would be at least three viable options at Alano for defining the base of the Priabonian:

1. the Top of large acarininids and *Morozovelloides* (Base of Zone E14). As discussed above, these two closely spaced biohorizons represent very reliable events with a high correlation potential in the marine domain. These taxa are very distinctive and easy to recognize even in thin section, and are precisely calibrated (Wade et al., 2011; 2012).

2. the Base of *C. oamaruensis* (Base of Zone NP18). This biohorizon has been used for the past three decades to recognize the base of the Priabonian by some workers but, unfortunately, it is not a reliable biostratigraphic datum. However, if we still want to place the base of the Priabonian as close as possible to the Base of *C. oamaruensis* using calcareous nannofossils, the Base of common and continuous *C. erbae* (Base of Zone CNE17) and the Top of *C. grandis* (Base of Subzone CP15a) might be used to approximate this biohorizon;

3. the Base of Chron C17n (Base of Subchron C17n.3n). This magnetic polarity event as part of a rapid series of magnetic reversals embedded in Chron 17 would allow correlations between expanded marine and continental sections well outside the proposed GSSP.

There is a significant practical problem with all these bio- and magnetostratigraphic events, namely that the Alano section is rapidly eroding which means (for posterity) that any GSSP marker will have to be accurately relocated as the section erodes. We are also mindful of the comment of Berggren et al. (1985) that: "*...proper stratigraphic procedure requires that paleontologic criteria, although definitive for regional correlation (i.e. recognition) beyond the stratotype region, should not be part of the definition itself...* (Hedberg, 1976)".

After much discussion of the relative merits of the various stratigraphic levels that might best serve as the boundary, we propose to define the Priabonian GSSP at a lithologic level (tuff layer Tiziano bed) that is easily recognizable in the field and around which the above set of events occurs. This rather unconventional choice of defining the base of a chronostratigraphic unit (Priabonian in this case) at a lithologic level that does not directly coincide with a biostratigraphic and/or magnetostratigraphic event has the clear advantage of making the GSSP easily recognizable in the field as the Tiziano bed stands out clearly relative to the surrounding featureless and rapidly eroding marls.

The high number of closely spaced events that accompany the Tiziano Bed guarantees a high degree of correlatability of the Priabonian GSSP well outside the Alano section where it is formally defined.

Within this conceptual frame, we propose to the ICS that the base of the Priabonian is to be defined at the base of a prominent crystal tuff layer named the 'Tiziano bed', positioned at 63.57 m level in the Alano section. This is proposed as the primary marker horizon in the sense of Remane et al. (1996) and although we are aware that in and of itself it has limited and only local correlation potential, it is surrounded by a set of biostratigraphic and non-biostratigraphic events that permit easy correlation out of the GSSP section. Moreover it has the rare advantage of being amenable to direct and precise age-dating by radioisotopic methods (i.e., $^{206}Pb/^{238}U$ zircon dates) which can then be compared with advantage to ages derived from interpolation between magnetic reversal datums on magnetochronologic timescales and astronomical dating using orbital cyclicity expressed in the sedimentary facies at Alano (Galeotti et al., 2019).

The Proposed GSSP of the Priabonian

The main motivation in proposing the base of the Tiziano bed in the Alano section as the base of the Priabonian Stage is that this level is surrounded by a key set of events that have good correlation potential and allow the recognition of the Priabonian Stage out of the section in which it is formally defined. The definition we propose here is historically appropriate and respectful of most of the commonly accepted paleontological events that have, historically, been used to approximate this boundary because:

1. It is in the same region as the historically important Priabona section that gives the stage its name, and in its auxiliary sections; the proposed GSSP lies stratigraphically below the base of the Priabona section and so incorporates it;

2. the double extinction of large acarininids and *Morozovelloides*, which have previously been considered to be within the Bartonian, would remain in the Bartonian;

3. The common and continuous presence of *I. recurvus*, which has widely been considered an intra-Priabonian calcareous nannofossil biohorizon, would remain in the Priabonian;

4. The Base of *N. fabianii*, which is considered an unquestionable Priabonian benthic larger foraminiferal biohorizon, would remain in the Priabonian. However, a limitation of the proposed definition concerns the stratigraphic range of several benthic larger foraminiferal taxa across the Bartonian-Priabonian transition and, specifically, there are some larger benthic foraminifera taxa traditionally considered to be Bartonian which could now lie in the Priabonian (e.g. *Nummulites biedai* and *N. maximus*).

Last but not least, as strongly suggested by the ICS revised guidelines, the Alano section meets a set of non-biostratigraphic requirements such as a solid magnetostratigraphic record, a firm astrochronological tuning based on cycle counting of $\delta^{13}C$ and wt.% $CaCO_3$ records, complete carbon and oxygen isotope profiles, and a precise U-Pb radioisotopic dating of the Tiziano Bed, the crystal tuff layer chosen to define the base of the Priabonian. It is also easily accessible and the GSSP will remain obvious despite being in a relatively rapidly eroding section.

The proposed GSSP of the Priabonian

Name of the boundary: Base of the Priabonian.

Rank of the Boundary: Stage/Age.

Position of the unit: Upper part of the Eocene Series, between the Bartonian (below) and the Rupelian (above) stages.

Type locality of the Global Stratotype Section and Point: Alano section at Alano di Piave, southern part of the Belluno Province, Veneto region, northeastern Italy, Europe.

Geographic location: The Alano section crops out for ~ 500 meters along the banks of the Calcino Creek, between the small villages of Colmirano and Campo, ~ 1 km NE of Alano di Piave village. In correspondence to the section, the Calcino Creek has deeply eroded the Quaternary deposits exposing the marly substratum in banks of 2 up to 6 meters high, along which the succession is cropping out continuously. Latitude: 45°54'51.10"N; Longitude: 11°55'4.87"E (WGS84; Fig. 1).

Map: The area is included on the "Carta Topografica d'Italia" at 1:25:000, Tavoletta Cavaso del Tomba, F° 37, I S.E. A detailed geologic map of the Alano area is reported in Agnini et al. (2011; Fig. 2).

Accessibility: Alano di Piave village is easily reached by the regional roadway SR 348 and provincial roadway SP10. The easiest way to access the section is to pass the small Colmirano village and reach the soccer field indicated in Fig. 1. Departing from the parking area of the soccer field there is an easy walk of some 300-400 m in a plain grass field that leads you to the base of the section (Fig. 1).

Conservation: Since the end of 2013, the Alano section has been included in the Italian geosite inventory by the Institute for Environmental Protection and Research, ISPRA (Istituto Superiore per la Protezione e la Ricerca Ambientale) (http://sgi1.isprambiente.it/geositiweb/Default.aspx)

GSSP definition: The base of the Tiziano bed, a prominent crystal tuff layer positioned at 63.57 m level in the Alano di Piave section, is the GSSP of the base of the Priabonian Stage. An age of 37.762 ± 0.077 Ma (2σ analytical and systematic uncertainty) Ma has been assigned to this level based on U-Pb radioisotopic data complemented by an age of 37.710 ± 0.01 Ma based on counting astronomical cycles in the carbon isotope record (Galeotti et al., 2019). The Tiziano bed is ~ 6 meters above the Top of large acarininids (57.32 m level) and *Morozovelloides* (57.52 m level) and close to the Base of common and continuous *C. erbae* (62.96 m level or -0.61 m from the Tiziano bed) and Top of *C. grandis* (66.47 m level or + 0.49 m from the Tiziano bed) (Fornaciari et al., 2010; Agnini et al., 2011). The Base of Subchron C17n.3n (52.62 m level) is positioned ~ 11 m below the base of Tiziano bed, whereas the closest polarity inversion, i.e. the Base of Subchron C17n.2n (62.48 m level or -1.09 m from the Tiziano bed), is just below the base the crystal tuff layer (Fig. 3; Table 1).

Identification in the field: The base of the 14-16 cm-thick green to grey tuff layer named the Tiziano bed. Identification in the field and resampling of the section are facilitated by the presence of multiple sandy-silty layers that represent useful marker beds along the section. A metal tag will be applied at the base of the boundary level.

Completeness of the section: The Alano section contains excellent and continuous faunal/floral and magnetic polarity records across the Bartonian to Priabonian transition. All the reference biostratigraphic and magnetostratigraphic events are present. If hiatuses occur, their durations are below the resolution provided by bio-magnetostratigraphic datums. An average sediment accumulation rate of ~ 2.4 cm/kyr (not corrected for compaction) was estimated assuming constant sediment accumulation rates between magnetochron boundaries (Agnini et al., 2011).

Global correlation: The global correlation of the Priabonian GSSP is assured by different events, applicable in marine and continental stratigraphic records over large areas and depositional settings. The Base of Subchron C17n.3n (52.62 m level) is located 10.95 m below the proposed GSSP and serves as a good approximation of the base of the Priabonian in continental and marine settings. The floating chronology available for the Alano section indicates that this event precedes the Priabonian GSSP by 290 kyr (Fig. 3; Galeotti et al., 2019). Though the Base of Chron C17n has surely the highest correlation potential among the polarity reversals across the critical interval, the closest magnetostratigraphic boundary is the Base of Subchron C17n.2n (62.48 m level), which is positioned 1.09 m below the Tiziano Bed preceding the base of the Priabonian by 30 kyr (Fig. 3; Galeotti et al., 2019). Based on precession cycle counting the base of the Tiziano bed lies at ~12% of Subchron C17n.2n.

In Fig. 3 (and Table 1) the age of the Tiziano bed, that is the base of the Priabonian, is compared with biochronologic data based on calcareous plankton, the most powerful correlation tool available in Cenozoic marine sediments. The extinction of the large acarininids and *Morozovelloides* approximates the base of the Priabonian within 170-173 kyr (Fig. 3; Galeotti et al., 2019). The Base of calcareous nannofossil *C. oamaruensis* should be used with extreme caution because this taxon is exceedingly rare at low to middle latitudes (Fornaciari et al., 2010). However, two highly reliable calcareous nannofossil biohorizons, the Base of common and continuous *C. erbae* (62.92 m level; -20 kyr) and the T of *C. grandis* (66.47 m level; +22 kyr) are recorded close to the Tiziano bed (Fig. 3; Table 1). These biohorizons were tested outside the GSSP section to evaluate their reproducibility. The same ranking and spacing was observed when several on-land and oceanic successions were compared (Fornaciari et al., 2010; Agnini et al., 2011). The proposed definition of the GSSP of the Priabonian will serve to overcome the present state of uncertainty in recognizing the Bartonian/Priabonian boundary.

Previous votes: During the Priabonian Working Group meeting held in 2012 in Alano (Italy), the Alano section was elected as a suitable candidate for the Priabonian GSSP with an unanimous decision adopted by the Priabonian Working Group, which also voted in favor of the Tiziano bed, as the formal definition of the Priabonian GSSP (see Appendices 1,2 for details).

The International Subcommision on Paleogene Stratigraphy (ISPS) and the International Commission on Stratigraphy (ICS) approved the Priabonian GSSP proposal on August 28th 2019 and January 17th 2020, respectively. The IUGS Executive unanimously ratified the Eocene Priabonian Stage GSSP on February 17th 2020.

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Appendices

Appendix 1. Composition of the Alano Working Group

	Name	e-mail	Affiliation	Expertise
1	Agnini Claudia	claudia.agnini@unipd.it	University of Padova (Italy)	calcareous nannofossils
2	Alegret Laia	laia@unizar.es	Zaragoza University (Spain)	small benthic foraminifera
3	Arenillas Ignacio	ias@unizar.es	Zaragoza University (Spain)	planktonic foraminifera
4	Backman Jan	backman@geo.su.se	Stockholm University (Sweden)	calcareous nannofossils
5	Balini Marco	marco.balini@unimi.it	University of Milan (Italy)	biostratigraphy
6	Fornaciari Eliana	eliana.fornaciari@unipd.it	University of Padova (Italy)	calcareous nannofossils
7	Galeotti Simone	simone.galeotti@uniurb.it	University of Urbino "Carlo Bo" (Italy)	cyclostratigraphy
8	Giusberti Luca	luca.giusberti@unipd.it	University of Padova (Italy)	Small benthic foraminifera
9	Grandesso Paolo	paolo.grandesso@libero.it	University of Padova (Italy)	stratigraphy
10	Lanci Luca	luca.lanci@uniurb.it	University of Urbino "Carlo Bo" (Italy)	magnetostratigraphy
11	Luciani Valeria	valeria.luciani@unife.it	Ferrara University (Italy)	planktonic foraminifera
12	Mietto Paolo	paolo.mietto@unipd.it	University of Padova (Italy)	stratigraphy
13	Molina Eustoquio†	emolina@unizar.es	Zaragoza University (Spain)	planktonic foraminifera
14	Monechi Simonetta	simonetta.monechi@unifi.it	Univerisity of Florence (Italy)	calcareous nannofossils
15	Muttoni Giovanni	giovanni.muttoni1@unimi.it	University of Milan (Italy)	magnetostratigraphy
16	Pälike Heiko	hpaelike@marum.de	Bremen University (Germany)	cyclostratigraphy
17	Pampaloni Maria Letizia	marialetizia.pampaloni@isprambiente.it	ISPRA Roma (Italy)	biostratigraphy
18	Papazzoni Cesare A.	cesareandrea.papazzoni@unimore.it	University of Modena and Reggio Emilia (Italy)	larger benthic foraminifera
19	Pearson Paul	PearsonP@cardiff.ac.uk	Cardiff University (United Kingdom)	planktonic foraminifera
20	Pichezzi Rita	rita.pichezzi@isprambiente.it	ISPRA Roma (Italy)	biostratigraphy
21	Pignatti Johannes	johannes.pignatti@uniroma1.it	University of Rome "La Sapienza" (Italy)	larger benthic foraminifera
22	Premoli Silva Isabella	isabella.premoli@unimi.it	University of Milan (Italy)	planktonic foraminifera
23	Raffi Isabella	raffi@unich.it	"Gabriele d'Annunzio" University of Chieti-Pescara (Italy)	calcareous nannofossils
24	Rio Domenico	domenico.rio@unipd.it	University of Padova (Italy)	calcareous nannofossils
25	Rook Lorenzo	lorenzo.rook@unifi.it	Univerisity of Florence (Italy)	vertebrate paleontology
26	Stefani Cristina	cristina.stefani@unipd.it	University of Padova (Italy)	sedimentology
27	Wade Bridget	b.wade@ucl.ac.uk	University College London (United Kingdom)	planktonic foraminifera

Appendix 2. Results of the ballots* of the working group

1) Is the Alano section the best candidate for defining the Priabonian GSSP? *Alano meeting (June 9-10, 2012). Please corfirm your vote.*	Alano voting members	ABSENT	TOTAL voters	IN FAVOR	AGAINST	NULL	ABSTAIN
	27	3	24	23	0	0	1
voter percentage (%)	88.9						
results (%)				95.8	0.0	0.0	4.2
2) Is the Tiziano bed the best definition for the Priabonian GSSP? *Alano meeting (June 9-10, 2012). Please corfirm your vote.*							
	27	3	24	19	4	0	1
voter percentage (%)	88.9						
results (%)				79.2	16.7	0.0	4.2
3) Is the Alano section the best candidate for defining the Priabonian GSSP? *Present ballot (to vote by July 10, 2015)*	Alano voting members	NOT VOTING	TOTAL voters	IN FAVOR	AGAINST	NULL	ABSTAIN
	27	2	25	25	0	0	0
voter percentage (%)	92.6						
results (%)				100.0	0.0	0.0	0.0
4) Is the Tiziano bed the best definition for the Priabonian GSSP? *Present ballot (to vote by July 10, 2015)*							
	27	2	25	20	4	0	1
voter percentage (%)	92.6						
results (%)				80.0	16.0	0.0	4.0

*The ballot was repeated in 2015 to give all the members of the working group the chance to vote, in fact in 2012 not all the members were present in Alano di Piave during the meeting.

Plates

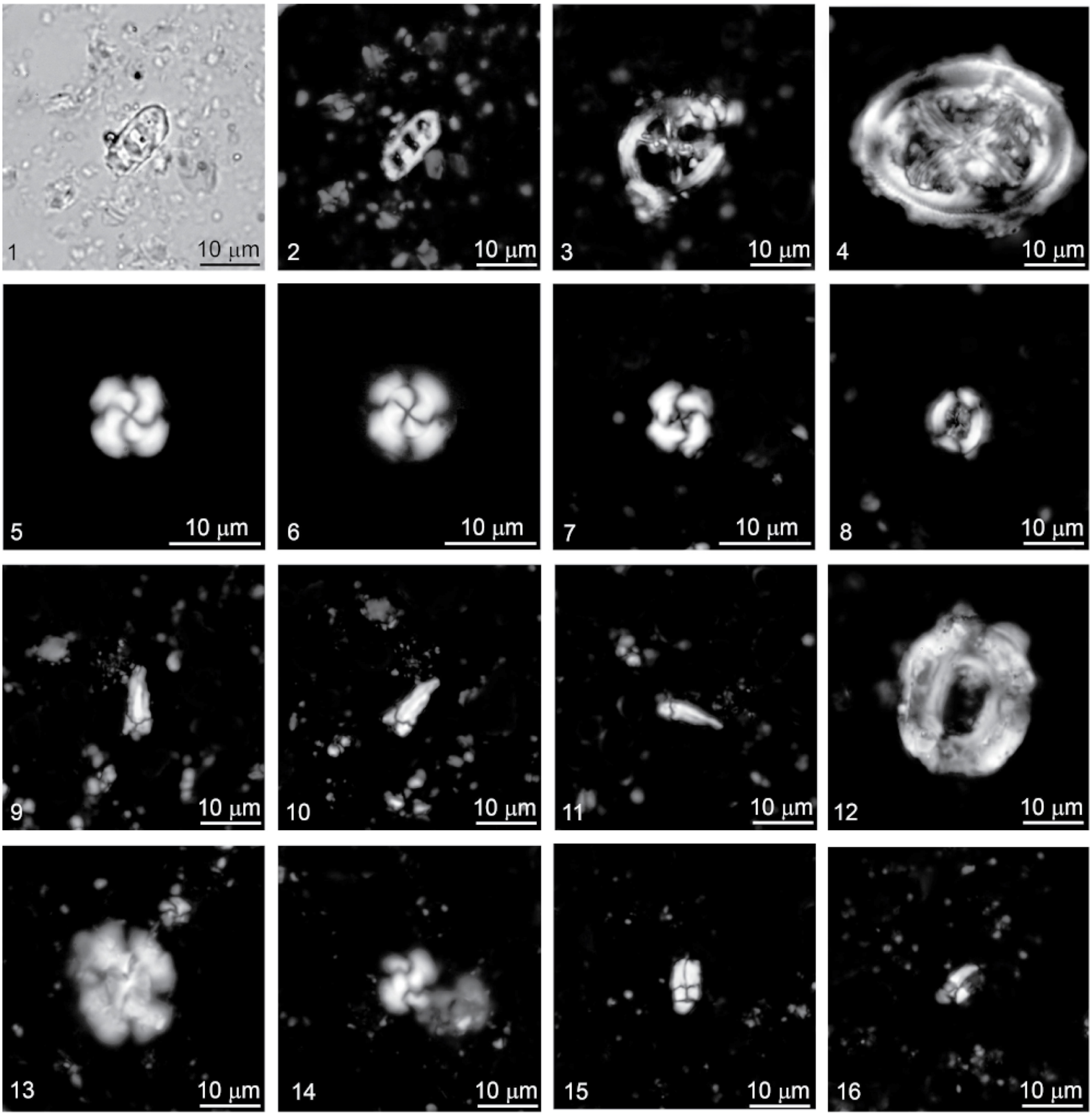

Plate I. (after Agnini et al., 2011). Microphotographs of selected calcareous nannofossil taxa from the Bartonian-Priabonian Alano section (northern Italy). 1, 2 — Isthmolithus recurvus. Sample COL 4645c (1. parallel light; 2. crossed nicols). 3 — Chiasmolithus oamaurensis. Sample COL 5225c. Crossed nicols. 4 — Chiasmolithus grandis. Sample COL 40a. Crossed nicols. 5, 6 — Cribrocentrum erbae (5. sample COL 3521c, crossed nicols; 6. sample 171B-1052B-10H-2w, 130 cm, crossed nicols). 7 — Cribrocentrum reticulatum. Sample COL 10b. Crossed nicols. 8 — Chiasmolithus solitus. Sample COL 40a. Crossed nicols. 9–11 — Sphenolithus obtusus. Sample COL 1285b (9. crossed nicols 0°; 10. crossed nicols 45°; 11. crossed nicols 20°). 12 — Reticulofenestra umbilicus. Sample COL 40a. Crossed nicols. 13 — Dictyococcites bisectus. Sample COL 40a. Crossed nicols. 14 — Dictyococcites hesslandii. Sample COL 40a. Crossed nicols. 15, 16 — Sphenolithus furcatolithoides. Sample COL 0 (15. crossed nicols 0°; 16. crossed nicols 45°).

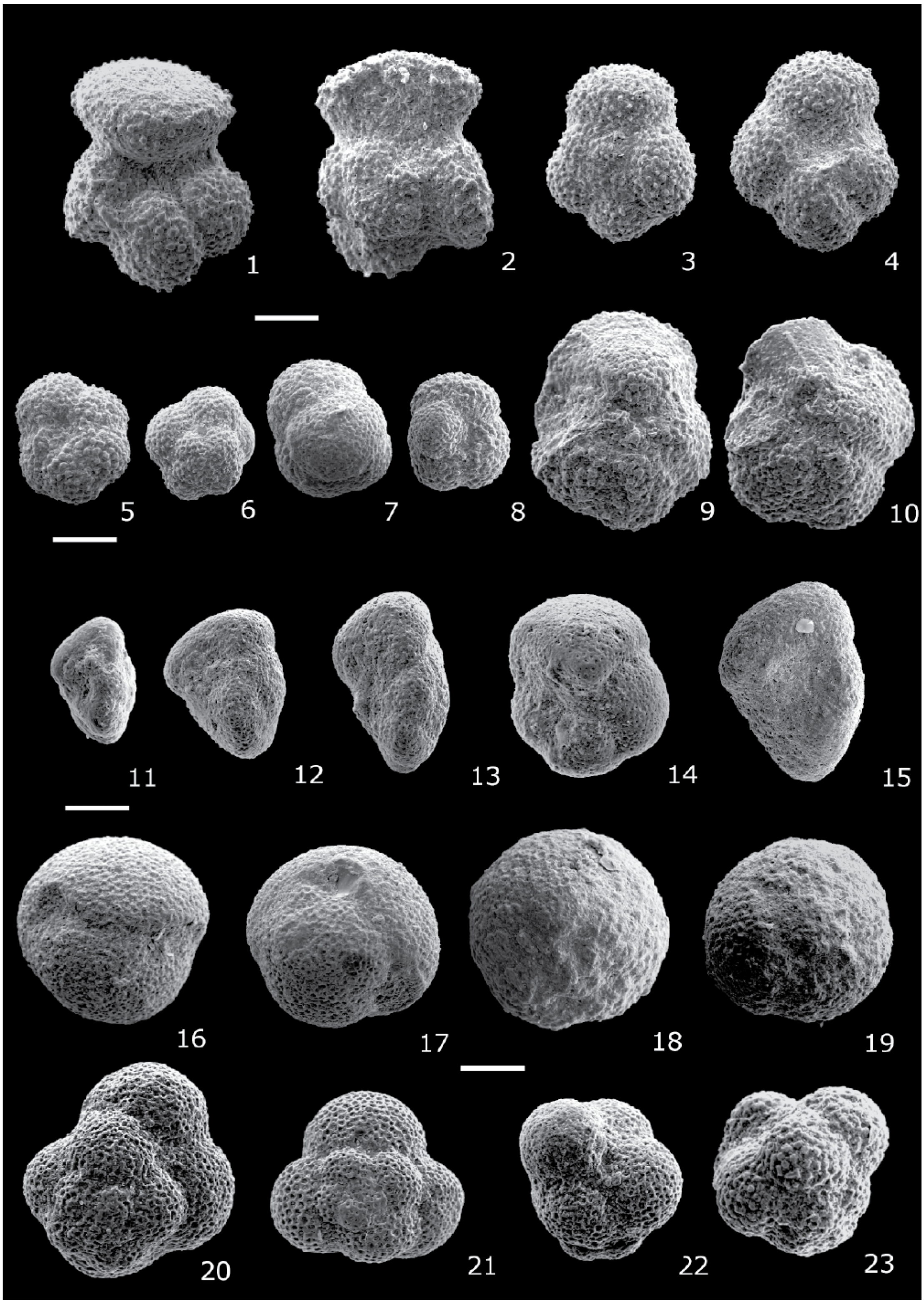

Plate II. (after Agnini et al., 2011)1–23: Planktonic foraminiferal scanning electron micrograph (SEM) images of selected zonal markers from the Bartonian-Priabonian Alano section (northern Italy). large acarininids: 1, 2—Acarinina topilensis. Sample COL 345 b (1. ventral view; 2. spiral view). 3, 4 — Acarinina rohri (3. sample COL 40a, spiral view; 4. sample COL 600a, spiral view). Small acarininids: 5, 6 — Acarinina medizzai. Sample COL 2799c (5. ventral view; 6. spiral view). 7, 8 — Acarinina echinata. Sample COL 4845c (7. ventral view; 8. ventral view). 9 — Morozovelloides coronatus. Sample COL 2496c, ventral view. 10 — Morozovelloides crassatus. Sample COL 732c, ventral view. 11–15 — Turborotalia cocoaensis (11, 12, 13— sample COL 520a [horizon of lowest occurrence of the species], profi le; 14. sample COL 600 a, ventral view; 15— sample COL 1285b, profile). 16, 17 — Globigerinatheka semiinvoluta. Sample COL 4605c. 18, 19 — Orbulinoides beckmanni. Sample COL 440a. 20–23 — Guembelitroides nuttalli (20. sample COL 240a, spiral side; 21. sample COL 3701c, spiral side; 22. sample COL 492c, ventral side; 23 — sample COL 3281c, lateral side). Scale bar = 100 µm.