Atti Accademia Nazionale dei Lincei

Classe Scienze Fisiche Matematiche Naturali

Rendiconti

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Sequence stratigraphy of Monte Brione (Tertiary of Lake Garda, N. Italy)

Atti della Accademia Nazionale dei Lincei. Classe di Scienze Fisiche, Matematiche e Naturali. Rendiconti, Serie 8, Vol. **82** (1988), n.2, p. 319–339.

Accademia Nazionale dei Lincei

<http://www.bdim.eu/item?id=RLINA_1988_8_82_2_319_0>

Atti della Accademia Nazionale dei Lincei. Classe di Scienze Fisiche, Matematiche e Naturali. Rendiconti, Accademia Nazionale dei Lincei, 1988.

Atti Acc. Lincei Rend. fis.
(8), LXXXII (1988), pp. 319-330

Geologia. — *Sequence stratigraphy of Monte Brione (Tertiary of Lake Garda, N. Italy)* (*). Nota di VALERIA LUCIANI (**), presentata (***) dal Corrisp. A. BOSELLINI.

ABSTRACT. – The Cenozoic succession of Monte Brione is subdivided into two distinct depositional sequences. The lower sequence is Rupelian in age and is clearly recognizable as an unconformity bounded unit in the entire area between Lake Garda and the Adige Valley. The upper sequence, of Chattian to Aquitanian age, is only partially represented as the upper boundary is missing due to erosion. Several facies and unit not previously described, including a prograding carbonate unit with well developed clinoforms (*Linfano Limestone*), have been recognized.

KEY WORDS: Sequence Stratigraphy; Southern Alps; Oligocene-Miocene.

RIASSUNTO. – *Stratigrafia sequenziale di Monte Brione (Terziario del Lago di Garda).* I principali risultati di questo studio riguardano la suddivisione della successione Cenozoica del Monte Brione, una tra le più note delle Alpi Meridionali, in due distinte unità primarie con significato cronostratigrafico (sequenze deposizionali) di età Rupeliana e Cattiano – Aquitaniana, rispettivamente. Vengono inoltre riconosciute varie unità non descritte precedentemente, tra le quali una carbonatica progradante con clinostratificazioni ben sviluppate. Le sequenze deposizionali e le loro unità costituenti sono infine correlate in un assetto stratigrafico dinamico dove le fluttuazioni globali del livello marino hanno un ruolo principale.

INTRODUCTION

Developments in seismic stratigraphy during the 1960's and 1970's led Vail *et al.* (1977) to propose that sediment packages, the so-called *depositional sequences*, bounded by unconformities and their correlative conformities, represent primary units with chronostratigraphic significance. Moreover, Vail *et al.* used stratal geometries and patterns of onlap, downlap, truncation, and basinward shifts of coastal onlap to interpret sea-level rises and falls along various continental margins.

The sequence-stratigraphy depositional models, together with detailed paleon-

(*) This study has been supported by the Italian Consiglio Nazionale delle Ricerche (Grant n. 87.00838.05).
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(***) Nella seduta del 23 aprile 1988.

tological data, also enhance the ability to recognize genetically related sediment packages in outcrop sections. What is presented here is the sequence-stratigraphic analysis of one of the most classic Tertiary succession of the Southern Alps, the Monte Brione section. This mountain is an isolated massif, in the middle of the alluvial plain, just rising north of Lake Garda, between the towns of Torbole and

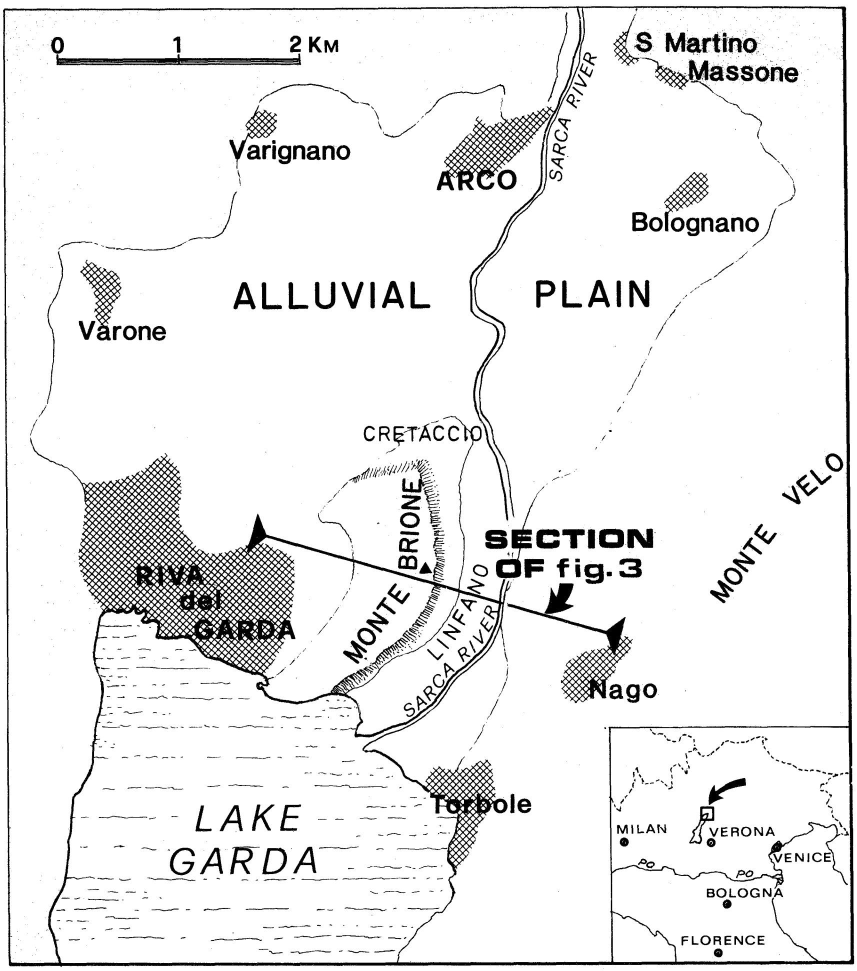

Fig. 1. - Location map of the study area.

Riva del Garda (figs. 1 and 2). Its characteristic, asymmetric profile is structural in origin, as Monte Brione belongs to the western limb of the M. Bondone-M. Baldo anticline.

The main results of this study include (1) the subdivision of the Cenozoic succession into primary units (depositional sequences) with chronostratigraphic

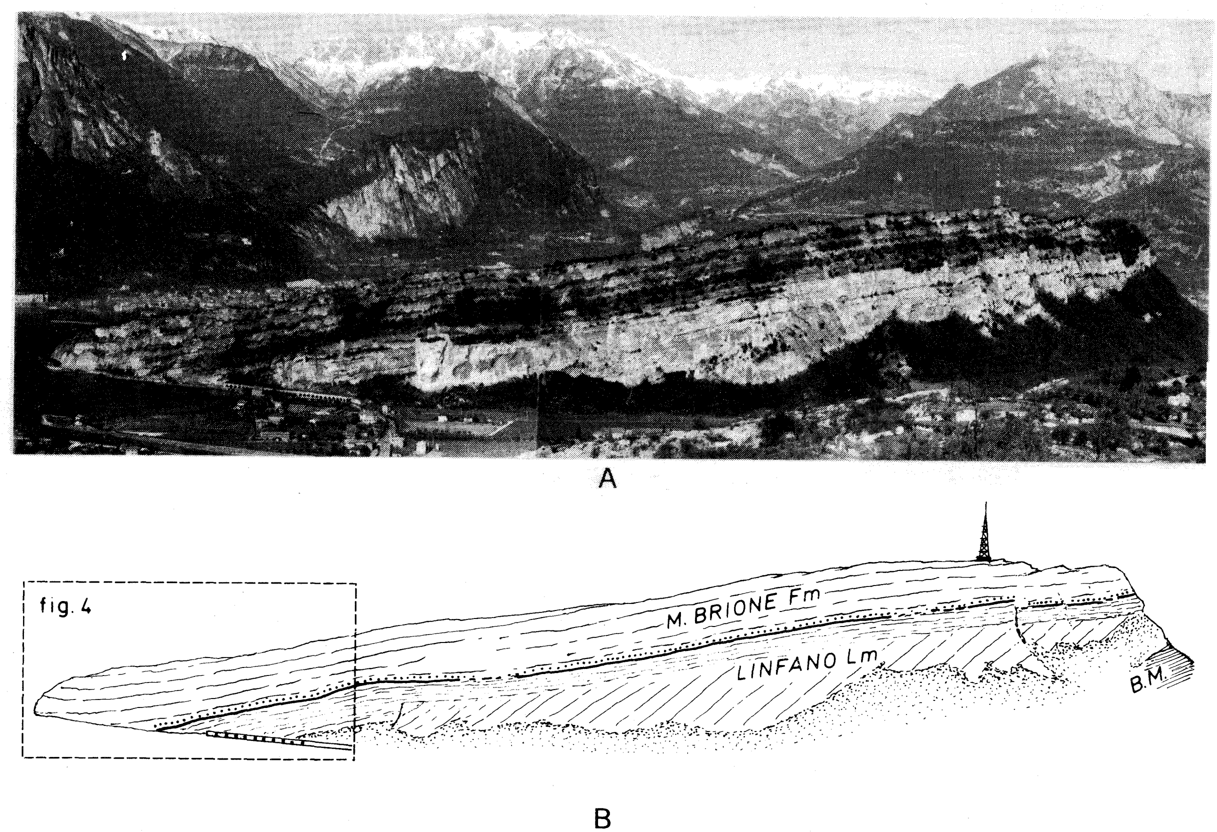

Fig. 2. - The eastern steep cliff of Monte Brione (A) and its general stratigraphy (B). Note clinoforms and toplap relationship in the *Linfano limestone*; the *Bolognano marls* (BM) outcrop on the slope, on the right end of the picture.

significance, (2) recognition of several facies and units not previously described, (3) recognition of a prograding carbonate unit with well-developed clinoforms, and finally, (4) a stratigraphic framework where depositional sequences and their constituent units are dynamically related and global sea-level fluctuations play a primary role.

Previous studies

The first important contributions regarding the Oligocene-Miocene succession of Monte Brione date back to the end of the last century (Lepsius, 1878; Gümbel, 1896; Vaceck, 1899). Since then, however, many authors have reported on the same section; they include Schubert (1900 a and b), Vaceck (1903, 1911), Fabiani (1922, 1930), Venzo (1934), Hagn (1956), Lindenberg (1966), Ulcigrai (1966), Castellarin & Cita (1969a).

As regards the basal marlstone unit which outcrops in the northern end of the cliff, both Late Eocene (Priabonian) (Fabiani 1922, 1930; Venzo, 1943; Hagn, 1956) and Early Oligocene (Gümbel, 1896; Vaceck, 1899, 1903 and 1911; Schubert, 1900 a and b; Lindenberg, 1966; Castellarin & Cita, 1969a) ages have been proposed. The ages of the middle and upper parts of the section have also been widely discussed and interpreted.

The only author who gives an environmental interpretation is Ulcigrai (1966). He discusses the sedimentary environment in a very general way (clear water, warm sea, etc.) and recognizes the occurrence of an Oligocene sedimentary cycle culminanting with the Chattian regression (glauconitic horizon), followed by a Late Oligocene transgression. According to Ulcigrai, both the cycles and the occurrence of glauconitic intervals are related to Oligocene tectonic pulses.

Litho-biostratigraphy

The Monte Brione succession belongs to two distinct depositional sequences (figs. 3 and 5). The lower sequence is Rupelian in age and is clearly recognizable as an unconformity-bounded unit in the entire area between Lake Garda and the Adige Valley. It overlies another well-defined depositional sequence of Priabonian age, represented by the *Nago Limestone* and its basinal equivalent, the *Scaglia cinerea*. The upper sequence, of Chattian to Aquitanian age, is only partially represented as the upper boundary is missing due to erosion.

In the following section, the various lithostratigraphic units of the succession will be briefly described and biostratigraphically defined.

Nago limestone

The *Nago Limestone* (Castellarin & Cita, 1969 a and b) constitutes the outcropping substratum of the Monte Brione succession. It is a shallow-water carbonate unit,

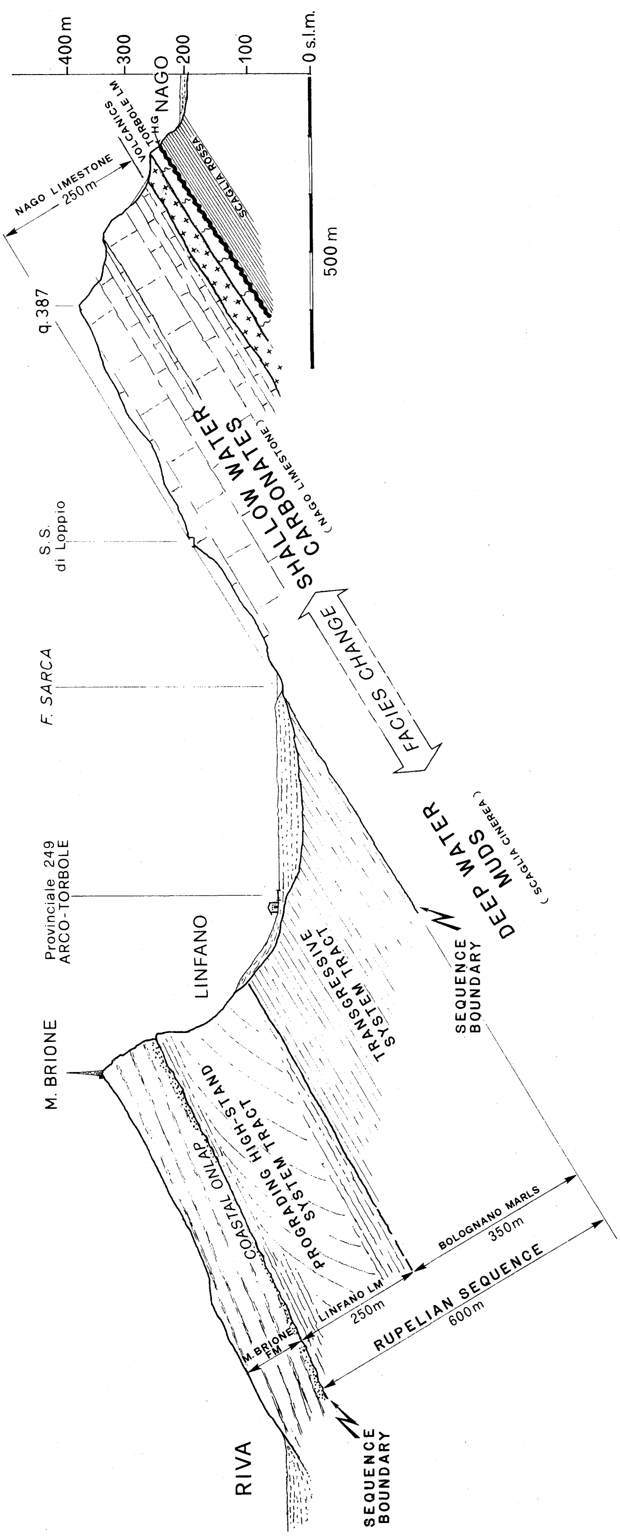

Fig. 3. - Cross-section of Monte Brione and its sequence stratigraphy. For location of the profile see fig. 1.

150-200 m thick, of late Middle Eocene p.p. - Late Eocene (Priabonian) age.

The lower limit is regionally defined by a basalt flow of Late Lutetian ("Biarritzian") age, which was exposed and eroded before the deposition of the *Nago Limestone*. In the study area, the *Nago Limestone* also has a sharp upper boundary. Locally, a paleoerosional surface is still recognizable (Castellarin & Cita, 1969 b), in general, the shallow-water limestones are abruptly overlain by a thick succession of marls, rich in planktonic Foraminifera (*Bolognano marls* of Gümbel, 1896).

In the type section, the *Nago Limestone* is represented by two major TU sequences (fig. 3), starting at the base with thin and irregularly bedded gray marls and marly limestones containing macroforaminifera (*Nummulites*, *Discocyclina*, *Operculina*), rare planktonic Foraminifera and algal fragments, upwards the rock becomes richer in red algae (Melobesiae) and macroforaminifera (*Nummulites, Pellatispira, Spiroclypeus* etc.), and the bedding is more massive and regular. Finally, the top of the sequence is represented by a massive (8-10 m) limestone, rich in corals (growth position), spongae, and thick-walled gastropods. The TU cycles of the *Nago Limestone* are the response of repeated attempts of basinward progradation by small coralalgal shoals localized at the margin of a shallow-water platform extending eastward (see Luciani 1987, fig. 2).

Bolognano marls

This unit, recognized and named by Gümbel (1896), outcrops around the Riva-Arco plain and on the northern slope of Monte Brione, a locality called "Cretaccio" due to the characteristic argillaceous composition of the ground. The *Bolognano marls* (from 48% to 25% $CaCO_3$), quarried near Varignano, are bioturbated and without a well defined bedding. In the Monte Brione section, their thickness is on the order of 350 m (fig. 3).

The writer was able to collect several samples, one at the very base of the Monte Brione succession, the others 50-60 m higher stratigraphically, almost at the base of the overlying carbonate unit (*Linfano limestone*). The lowest sample bears a Lower Oligocene foraminiferal association characterized by the absence of the typical Late Eocene taxa (hantkeninids, *Turborotalia cerroazulensis* group, *Globigerinatheka* group) and by the occurrence of *'Globigerina' tapuriensis*, a species appearing just before the Eocene/Oligocene boundary and quite common in the Lower Oligocene. Pseudohastigerinids are represented by *P. naguewichiensis*, *P. barbadoensis* and small-sized *P. micra*. This association is referred to Zone P18 (Blow, 1979) which corresponds to the lower part of the *C. chipolensis/P. micra* Zone of Bolli and Saunders (1985). The highest samples bear an assemblage similar to the preceding one, but are characterized by the absence of pseudohastigerinids. Since this event is used in most biozonations (Stainforth *et al.*, 1975; Blow, 1979; Bolli and Saunders, 1985 etc.) to identify the lowest portion of the Oligocene, it is possible that the uppermost part of the *Bolognano marls* belongs to the top of Zone P19 or to the base of the Zone P20 (*'Globigerina' ampliapertura* Zone of Bolli and Saunders, 1985). According to the stratigraphic distribution of low-latitude planktonic Foraminifera, the upper part of the *C. chipolensis/P. micra* Zone (corresponding to Zone P19 of Blow, 1979) should be characterized by the occurence of *'Globigerina' sellii*, but typical specimens of *'G'. sellii* have not been found in the highest samples of the *Bolognano marls*. This fact could therefore throw some doubts on the precise stratigraphic assignement of the highest samples. It is worth pointing out, however, that the late appearance of this species is reported in several Mediterranean sections (Bizon & Bizon, 1972; Nocchi *et al.* in press). The Oligocene age of the *Bolognano marls* has already been suggested by a number of authors including Gümbel (1896), Vaceck (1899, 1903, 1911), Schubert (1900 a and b), Lindenberg (1966) and Castellarin & Cita (1969 a).

As previously described, the *Bolognano marls* abruptly and unconformably overlie the shallow-water *Nago Limestone* (fig. 3) to the east of the Sarca river, from Nago to Bolognano. Westward, instead, the Lower Oligocene marls are part of a continuous basinal succession of Late Cretaceous-Oligocene age (Castellarin, 1972; Luciani & Lucchi Garavello, 1986). It is worth noting, however, that several carbonates turbidites (some very coarse) occur at the top of the Eocene in the Varignano section (see fig. 2 in Luciani & Lucchi Garavello, 1986).

Linfano limestone

This unit, which is well-exposed on the eastern vertical cliff of Monte Brione (locality Linfano), overlies the *Bolognano marls*, but the actual contact has never been observed. The upper boundary is representend by a prominent unconformity, mantled by the Chattian glauconitic sandstone of the basal *Monte Brione formation*. Its age is therefore referred to the Lower Oligocene. The *Linfano limestone* is a wedge-shaped carbonate body, largely clinostratified and thickening southward from about 100 to about 250 m. It is represented by several facies showing a shallowing up trend; starting from the base, they include:

(a) strongly bioturbated, wavy-bedded to meganodular biocalcarenites (packsstones and grainstones with *Lithothamnium*, *Archaeolithothamnium*, *Lithoporella*, echinoderms and bryozoa fragments, *Rotalia*, *Asterigerina*, *Nodosariidae*, *Textulariidae*) subdivided by marly interbeds. Macroforaminifers (*Nummulites* cf. *vascus*, *Operculina complanata*, *Heterostegina depressa*, *Lepidocyclina*, *Gypsina*) may occur in the coarser calcarenite beds. This basal, nodular facies presents a slight clinostratification and outcrops at the northern end of Monte Brione; it has a thickness of about 50 m and overlies the *Bolognano marls*.

(b) SW-clinostratified (12°-15°) algal biocalcarenites (packstone/grainstone), rich in *Lithothamnium* fragments with echinoderms and bryozoa fragments and benthic foraminifers) organized in few metres thick sequences, very coarse and massive at the base, becoming more marly upward.

(c) Metre-thick, horizontally bedded grainstone, rich in rhodolites, algal fragments, microbenthonic (*Rotalia*, *Textulariidae* and large foraminifers (*Num-*

mulites, Lepidocyclina, Gypsina). This facies, about 15-20 m thick, is geometrically discordant (toplap) with respect to the underlying clinostratified sediments. Coarse bioclastic breccias (storm layers) occur commonly at the base of the thicker beds. A small terrigenous component (1-2% quartz and muscovite) occurs throughout. A 50 cm marlstone separates these grainstones from the top unit, a 7 m thick massive biocalcarenite, strongly bioturbated and glauconitic.

It is worth pointing out that the geometric discordance between the toplap facies and the underlying clinostratified calcarenite had been already observed by Vaceck (1903).

Monte Brione formation

It represents the cap of the Monte Brione succession. Its maximum outcropping thickness (106 m) occurs at the southern end of the mountain, along the Torbole-Riva road (fig. 4). It thins slightly northward, due to the onlap relationships with respect to the underlying *Linfano limestone*.

The *Monte Brione formation* is a mixed siliciclastic-carbonate association characterized by a foraminiferal assemblage, strongly resembling in this respect the Chattian-Lower Aquitanian megasequence of Massari *et al.* (1986). It consists of 5-6 m thick silstone-carbonate units (groups of strata) which alternate with more argillaceous intervals (fig. 4). Three of these units occur below the Oligocene/Miocene boundary. Scattered pelecypod valves, rare ehinoids and bryozoa occur throughout the section, which is strongly bioturbated.

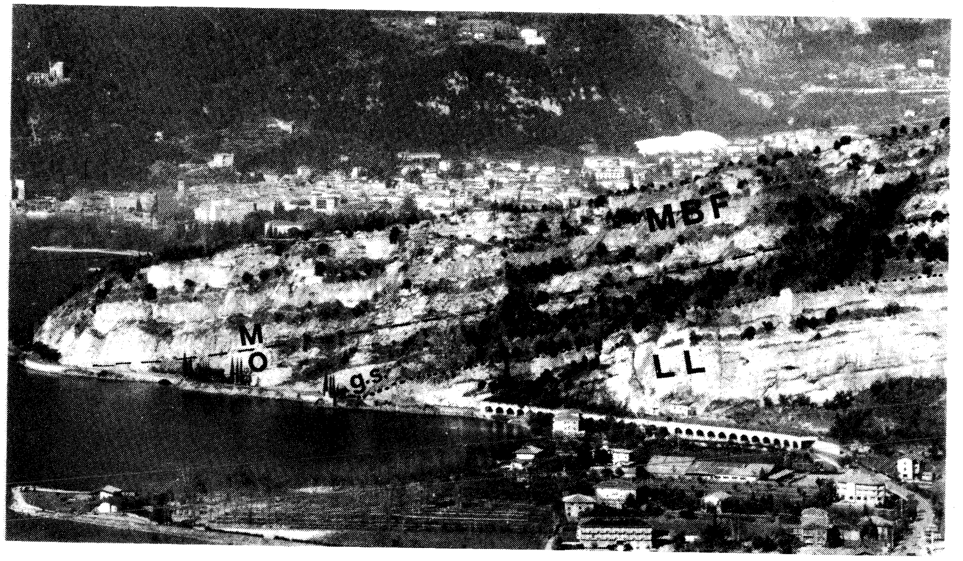

Fig. 4. – The *Monte Brione formation* (MBF), outcropping on the road between the towns of Torbole and Riva del Garda. The Oligo/Miocene boundary occurs 43 m above the glauconitic sandstone (g.s.) which overlies unconformably the *Linfano limestone* (LL).

A dark-grey glauconitic sandstone (glauconite, quartz, feldspar), 1.5 m thick, occurs at the base of the formation and constitutes a major key-bed in the Monte Brione stratigraphy as it separates the *Monte Brione formation* from the underlying *Linfano limestone.*

A rich macrofauna (*Flabellipecten*, *Clamys*, *Turritella*, *Echinolampas*, *Euspatangus* etc.) has been observed in the glauconitic sandstone (Fabiani 1922, Venzo 1934).

As regards the environmental conditions, the *Monte Brione formation* was deposited on a moderately deep offshore shelf, with a relatively slow sedimentation rate, where alternating sea-level fluctuations dictated the characteristic carbonate-marly unit cyclicity.

The age of the *Monte Brione formation* has long been questioned and is generally based on macrofossil (especially pelecypods) content: either entirely Miocene or partly Oligocene and Miocene (Fabiani, 1922; Venzo, 1934; Hagn, 1956).

Hagn (1956) described a foraminiferal assemblage (largely benthic) occurring 16 m above the glauconitic sandstone and, taking into account the occurrence of *Clavulinoides szaboi* and *Karreriella hantkeniana*, assigned a Late Oligocene (Chattian) age to that horizon. The finding of abundant planktonic Foraminifera, especially in the marly interbeds of the lower and middle parts of the formation, now makes it possible to define the age of the *Monte Brione formation* which spans from the top of the Zone P22 to the Zone N5 (Blow, 1979). The Oligocene/Miocene boundary occurs 43 m above the glauconitic sandstone, and is placed, according to Iaccarino and Salvatorini (1982) and Iaccarino (1985), at the first occurrence of *Globoquadrina dehiscens dehiscens*. This event is immediately preceded (1.5 m below) by the relatively abundant and sudden occurrence of the genus *Globigerinoides* (already present in the lower 10 m, with rare specimens of *G. quadrilobatus primordius*). Diffusion and diversification of this genus is considered a further event of the planktonic Foraminifera biostratigraphy which can help to locate the Oligocene/Miocene boundary (Stainforth *et al.* 1975; Bolli and Saunders, 1985). However, a detailed biostratigraphic analysis of the succession will be dealt with in a separate paper.

SEQUENCE STRATIGRAPHY

As described above, the sedimentary succession of Monte Brione belongs to two distinct depositional sequences, of Rupelian and Chattian-Aquitanian age respectively (figs. 3 and 5), which overlie another well-defined sequence of late Middle Eocene pp. – Priabonian age, the *Nago Limestone*.

Comparing the Monte Brione succession with the eustatic curve proposed by Haq *et al.* (1987), a close relationship between sea-level fluctuations and lithostratigraphy appears quite evident (fig. 5). The lower boundary of the Rupelian sequence corresponds to the 36 m.y. lowstand. During this lowstand, the top of the Nago shallow-water limestone was probably exposed as suggested by its paleoero-

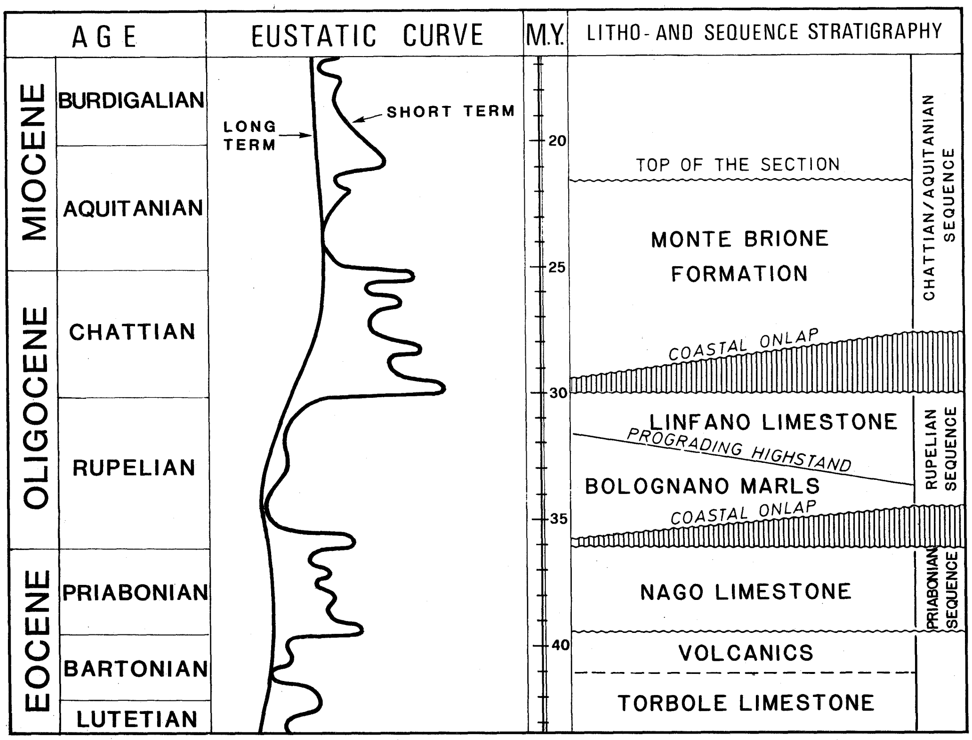

Fig. 5. - Chrono-, litho-, and sequence stratigraphy of the Monte Brione succession. Eustatic curve is from Haq *et al.* (1987).

sional top (Castellarin & Cita, 1969b) and by the coarse calciturbidites occurring in the basinal section of Varignano (Luciani & Lucchi Garavello, 1986). The overlying Lower Oligocene *Bolognano marls* represent the transgressive system tract. They were deposited both in the Sarca basin, in stratigraphic continuity with the underlying *Scaglia cinerea*, and on the flanks and on top of the M. Baldo-M. Bondone positive structure (Luciani, 1987), where a prominent unconformity must be expected.

The *Bolognano marls* are, in turn, overlain by the prograding highstand deposits of the *Linfano limestone* of Middle-Late Rupelian age. The *Linfano limestone*, a southwest prograding biocalcarenite system, is preserved only at Monte Brione; its source area must have been on the "carapace" of the M. Baldo-M. Bondone high. The toplap relationships of the *Linfano limestone* suggest that progradation occurred during a relative stillstand of sea-level.

The pronounced lowstand occurring at the Rupelian-Chattian boundary (30 m.y.) coincides with a major feature in the Monte Brione landscape, i.e. a well-defined unconformity evidenced by the basal glauconitic sandstone of the *Monte Brione formation*. This formation represents the Chattian-Aquitanian depositional sequence and corresponds to the 2nd order supercycle TB 1 of Haq *et al.* (1987). As this supercycle consists of five 3rd order cycles, a strong suggestion exists that the facies organization of the *Monte Brione formation*, where five major silty carbonate units alternate with thinner marls (fig. 4), is also the result of smaller scale sea-level fluctuations.

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