PALEOGENE *HALIMEDA* ALGAL BIOSTRATIGRAPHY FROM MIDDLE ATLAS AND CENTRAL HIGH ATLAS (MOROCCO), PALEOECOLOGY, PALEOGEOGRAPHY AND SOME TAXONOMICAL CONSIDERATIONS

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Abstract *Halimeda*-bearing deposits of the Middle Atlas Mountains and of the southern rim of the central High Atlas, bordering the Neogene Quarzazate Basin, east of Asseghmon (Morocco), were studied with regard to their lithostratigraphy, biostratigraphy, sequence stratigraphy and carbonate microfacies (Herbig, 1991; Trappe, 1992, Kuss and Herbig, 1993 and Dragastan and Herbig, 2007). The deposits were subdivided into lithostratigraphic groups and formations, according to the Hedberg stratigraphic Code. The focus was especially centered on the biostratigraphy of marine strata with a rich *Halimeda* microflora of Paleogene successions, first in the central High Atlas (Dragastan and Herbig, 2007) and now extended in the Middle Atlas. The aim of this study was to compare and to verify the stratigraphical value and range of *Halimeda* species and their associations. The defined eight *Halimeda* Assemblage Zones and one dasycladalean Assemblage Zone with two Subzones from the central High Atlas were very useful to correlate and to differentiate the Paleogene deposits of Bekrit-Timahdit Formation on stages and substages for middle-late Thanetian and Ypresian. Only the Lutetian - Bartonian? interval still remains not so clear in Middle Atlas region. In spite of different rates of diversity between the central High Atlas with 20 *Halimeda* species and only 14 *Halimeda* species in the Middle Atlas, the green siphonous species of the genus *Halimeda* showed their biostratigraphic potential to be used in the same way as dasycladaleans were used as marker or index species. They proved for the first time the value of Assemblage Zones for the Paleogene deposits of the Moroccan Atlas.

Keywords: *Halimeda*, Dasycladales, green algae, Paleogene, biostratigraphy, paleoecology, paleogeography, taxonomy.

INTRODUCTION AND GEOLOGICAL SETTING

Halimeda deposits in the Middle Atlas Mountains (Fig. 1a) and the southern rim of the central High Atlas (Fig. 1b), which border the Neogene Quarzazate basin, east of Asseghmon (Morocco), where studied with regard to lithostratigraphy, biostratiography, sequential stratigraphy and carbonate microfacies (Herbig, 1986, 1991; Trappe, 1992; Kuss and Herbig, 1993; Dragastan and Herbig 2007).

The deposits were subdivided into lithostratigraphic groups and formations according to the Hedberg stratigraphic Code. Interest was especially focused upon the biostratigraphy of marine strata with rich *Halimeda* microflora of the Paleogene succesion, first in the central High Atlas (Dragastan and Herbig, 2007) and now extended in the Middle Atlas to compare and to verify the stratigraphical value and range of *Halimeda* species and their associations.

MOROCCAN PALEOGENE STRATIGRAPHY: AN OVERVIEW

The Subatlas Group was introduced and described by Trappe (1989, 1991), Herbig (1991), Herbig and Trappe (1994). This unit corresponds to a complete transgressive - regressive megacycle formed by carbonate sediments, marls, siltstones, sandstones, phosphatic gypsum or gypsiferous mudstone. The major facies realms with different lithostratigraphy are recognized as follows: Souss Plain, Meskala Range, High Atlas, central High Atlas (Basin of Quarzazate) and Middle Atlas synclines (Fig. 2).
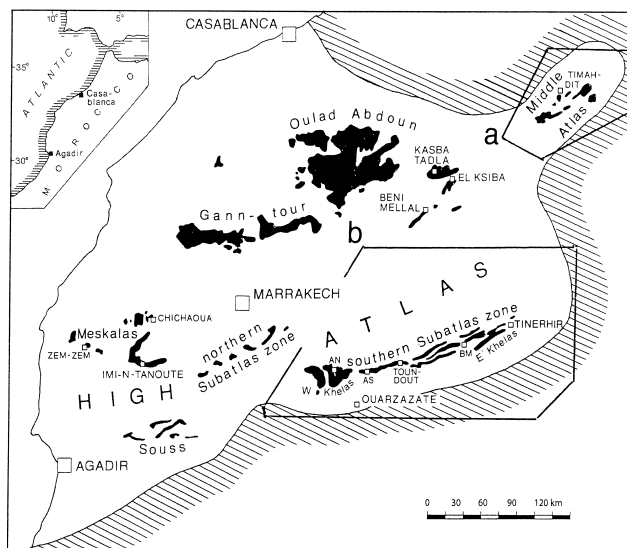
Fig. 1 Areal distribution of the central Moroccan early-late Thanetian to late Lutetian deposits (in black) on algal-shallow ramp and studied regions: **a** Middle Atlas and **b** central High Atlas (after Herbig, 1986, 1991 and Trappe, 1989, 1992).

In the central High Atlas to the upper part of Paleocene was separated the *Asseghmou Formation* (1.0 – 22 m in thickness) consisting predominantly of greenish-gray siltstones and thin dolomitic beds followed by calcareous mudstones, which contain freshwater to brackish gastropods. The stratigraphic range of this unit was restricted to the earliest Thanetian (Herbig, 1991), because *Turritella marocana* Moret was recorded together with other typical Thanetian molluscs. Trappe (1991, 1992) confered to the basal part of this formation a

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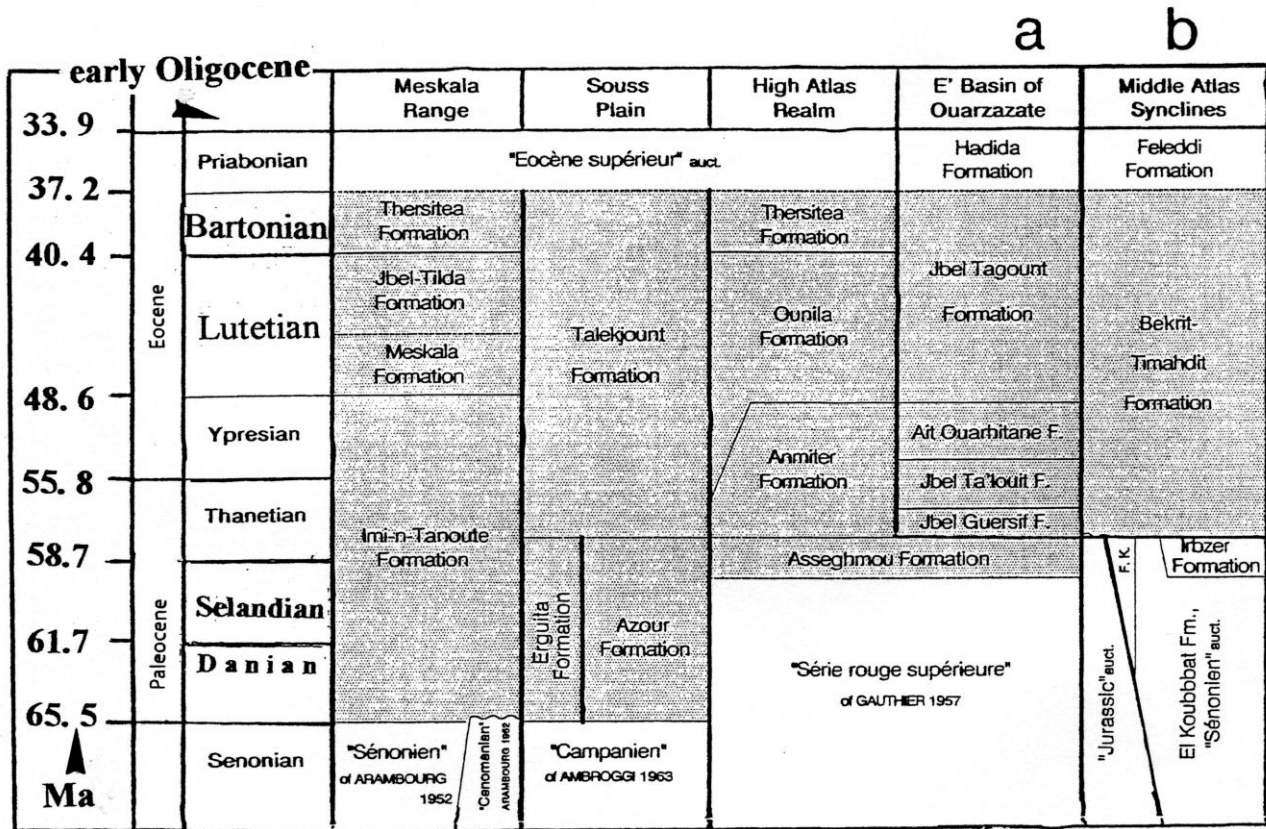
Fig. 2 Subatlas Group (Maastrichtian-Eocene) and the main lithostratigraphic units (Formations) of the Moroccan Altas Mountains: **a** central High Atlas, Basin of Quarzazate and **b** Middle Atlas synclines, here studied (after Herbig and Trappe, 1994, modified).

Danian age. The age of this lithostratigraphic unit remains disputed and a Danian-Thanetian age was accepted (Herbig and Trappe, 1994).

The Jbel Guersif Formation (10-36 m in thickness) is transgressively underlying the Asseghmou Formation. It is represented by variegated white and rose bioclastic limestones, oyster biostromes and fragmented shallow-water fossils, abundant bryozoans, molluscs, echinoids, miliolides and globorotaliids *(Globorotalia pseudomenardii)* and a rich microflora composed by different *Halimeda* species (Dragastan and Herbig, 2007), dasycladalean green algae such as *Acicularia* sp., *Cymopolia elongata* Defrance (Kuss and Herbig, 1993) and lesser red algae (*Sporolithon* sp.). The age of this lithostratigraphic unit is assigned to the upper part of the early and middle Thanetian (Herbig, 1991) and to the middle and late Thanetian (Dragastan and Herbig, 2007).

The Jbel Ta´louit Formation (2-90 m in thickness) points out to a regressive sequence consisting of gray-greenish siltstones with sandstones interlayers, oyster-bearing limestones, micritic or oolithic limestones and calcareous sandstones. In this unit, the *Halimeda* species were not recorded, as well as other dasycladalean green algae, due to the detrital, siltic facies recorded in the intertidal to supratidal (pars) sedimentation, up to mangove habitats with silicified woods (Herbig and Trappe, 1994). The age assigned of this unit is latest Thanetian up to earliest Ypresian (Herbig 1991, Dragastan and Herbig, 2007).

The Ait Ouarhitane Formation (4.5- 52 m in thickness) follows transgressively, it is predominantly represented by yellow bioclastic limestones, rarely gray-greenish marls and siltstones with oyster biostromes, bryalgal bindstones and microbialite-mounds. Between these buildups in the shallow lagoons green and red algae flourished. The microflora of this formation comprises *Halimeda* species, *Ovulites margaritula* (Lamarck), *Acicularia* sp., *Neomeris avellanensis* (Segonzac), *N. plagnensis* Deloffre and crustose coralline algae such as *Sporolithon* sp., *Lithophyllum* sp., *Lithothamnion* sp. and *Ethelia alba* (Pfender). The red algae form together with bryozoan bindstones which correspond to bryalgal facies and build banks and mounds reefs. The age of the unit is Ypresian (Herbig 1991; Herbig and Trappe, 1994), more precisely middle to late Ypresian (Dragastan and Herbig, 2007).

The Jbel Tagount Formation (20-150 m in thickness) is lying conformably on the topmost sequence of the Ait Ouarhitane Formation. The deposits are represented by fine- grained siliciclastics and they show sporadically interlayers with limestones, marls and calcareous sandstones. The age of the unit was assigned to uppermost Ypresian (Herbig, 1991) or to Lutetian-Bartonian (Herbig and Trappe, 1994). The same age was argued using the *Halimeda* species associations (Dragastan and Herbig, 2007).The upper boundary of this formation corresponds to a global regressive phase during the Priabonian, respectively to the Hadida Formation (Fig. 2).

Swezey (2009), in a paper concerning the Cenozoic stratigraphy of the Sahara (Northern Africa), referred also to the Tindauf-Quarzazate Basin of Morocco produced a new characteristic, composite stratigraphic section for this area (Fig. 3). According to this author, the late
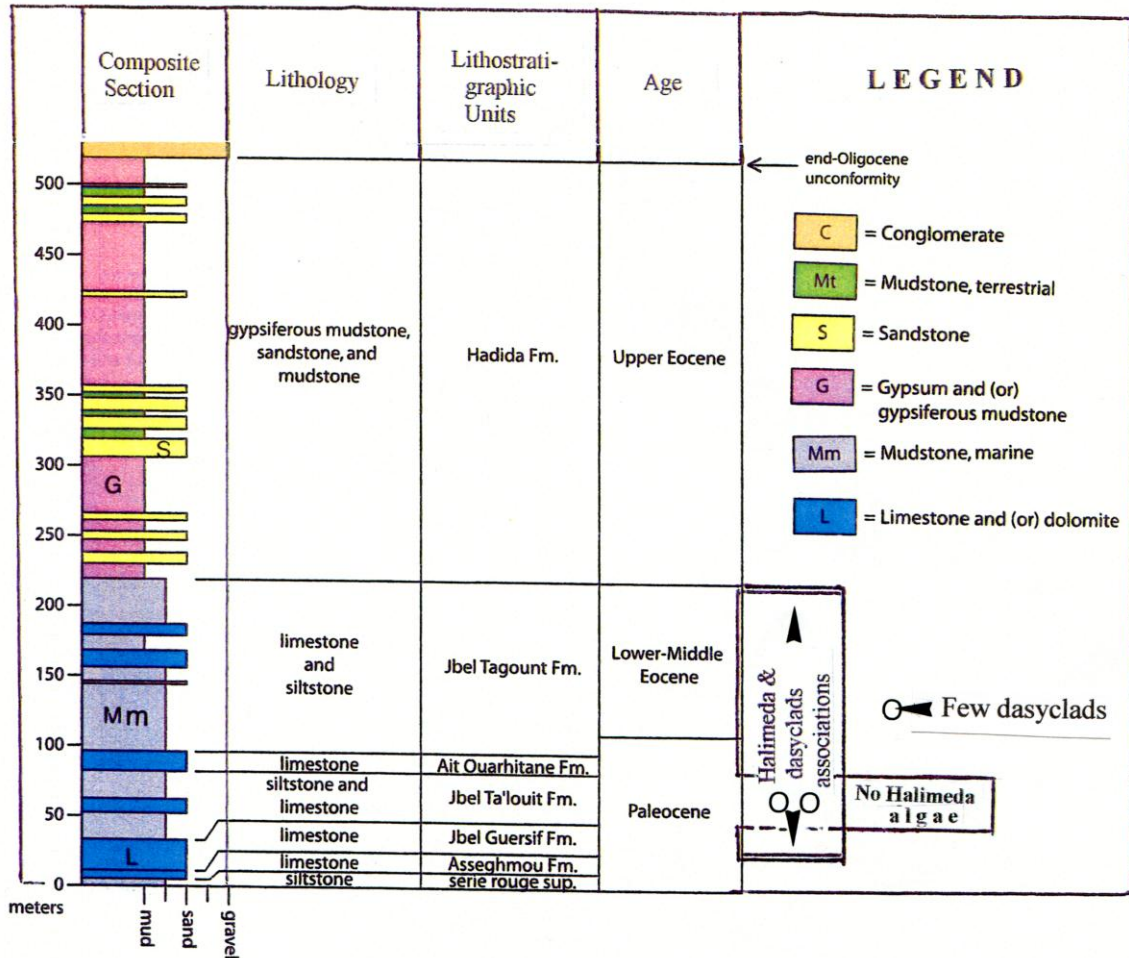
Fig. 3 Composite section of Paleogene deposits of the Quarzazate Basin - Morocco (from Swezey, 2009 modified after Herbig and Trappe, 1994 and El Harfi et al., 2001).

Cretaceous strata, the "Série rouge supérieur" of Gauthier (1957), is overlain by Paleocene - Middle Eocene limestones and siltstones of shallow marine deposits (Asseghmou, Jbel Guersif, Jbel Ta´louit, Ait Quarhitane and Jbel Tagout Formations) and they are overlain by the Upper Eocene gypsiferous, red mudstones corresponding to the Hadida Formation. The Upper Eocene deposits are covered unconformably by detrital Lower-Middle Miocene of the Ait Kandoula Formation. In spite of many cited data, Swezey (2009) introduced a new stratigraphical scale for the High Atlas-Tindouf-Quarzazate section and new ages for the lithostratigraphic units, without taking into account the fossils and the biostratigraphical results previously obtained for this area (Herbig, 1991; Kuss and Herbig, 1993; Herbig and Trappe, 1994, Dragastan and Herbig, 2007). Grosso modo, the author assigned to Paleocene (Danian, Selandian and Thanetian) the followings units: Série rouge supérieur, Asseghmou, Jbel Guersif, Jbel Ta´louit and Ait Ouarhitane Formations. The basal part of Jbel Tagount Formation is latest Thanetian age. This stratigraphical scheme contradicts the paleoalgological data regarding the stock of algae species (Dragastan and Herbig, 2007, Fig. 3) and paleozoological data (foraminifers, molluscs, bryozoans and vertebrates), being essentially based on lithological sequences and facies, as it has no real biostratigraphic base.

The first gypsum-bearing red beds indicate a gradual transition to the sabkha environment of the overlying Hadida Formation, which is considered Upper Eocene (Priabonian) in age. With this facies ended the Eocene deposits in the central High Atlas.

In the Middle Atlas, on the top of the conformably underlying late Cretaceous deposits, the Paleocene formations of the Subatlas Group are preserved in five regions (synclines), west of Boulemane, as follows: Bekrit and Timahdit, with the type locality of *Halimeda nana,* Pia et al. 1932, considered Danian in age, Section MA-8, Bou Angueur, Feleddi and Oudiksou (Fig. 4). Due to intense synsedimentary tectonics bounded by two major oblique sinistrial strike-slip faults, the Northern Middle Atlas Fault (NMAF) and the Middle Atlas Fault (MAF), the group cannot be further subdivided (Herbig and Trappe, 1994).

The Paleocene deposits conformably overlaying the late Cretaceous are the El Koubbat and Irbzer Formations, being isochronous, Danian-Selandian-basal Thanetian in age. These units are covered conformably by the middle-late Thanetian-Lutetian-Bartonian Bekrit-Timahdit Formation (10-255 m in thickness) composed by bioclastic limestones in various colors and phosphatic limestones, middle to late Thanetian-Lutetian and Bartonian in age (Fig. 4).
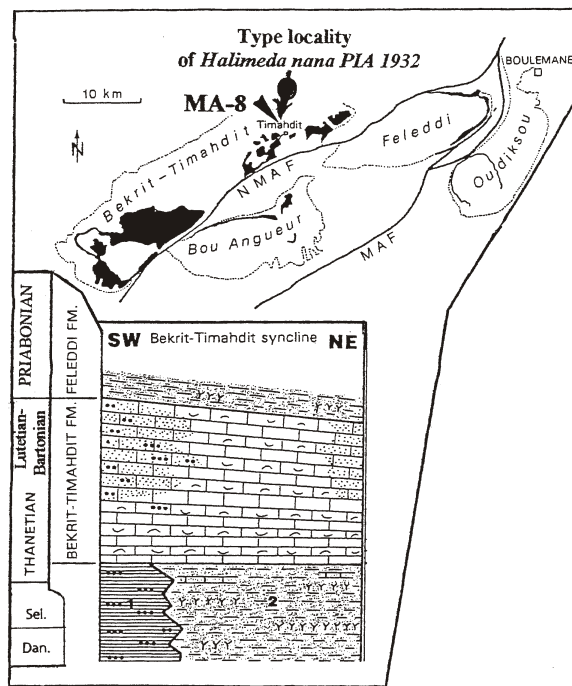
Fig. 4 Regional distribution and stratigraphic subdivisions of the Subatlas Group in the Middle Atlas: Bekrit-Timahdit Formation, (1) El Koubbat Formation, (2) Irbzer Formation and Feleddi Formation, NMAF - Northern Middle Atlas Fault, and MAF - Middle Atlas Fault (after Herbig and Trappe, 1994, modified).

A wide open marine lagoon appeared east of this shoal and comprises the eastern margin of the Bekrit syncline, most of the Timahdit syncline except its eastern margin, and the northern limb of the Bou Angueur syncline. This realm is characterized by the predominance of *Halimeda* thalli segments and coated molluscan shells. East of Timahdit, a complex association of microfossils flourished with different species of *Neomeris* sp*., Acicularia* sp., miliolids, globorotaliids and fauna with echinoids.

The green-calcareous algae from the Bekrit-Timahdit Formation were first described by Pia et al. (1932) and Segonzac et al. (1986). Besides *Halimeda nana* Pia, *Halimeda* sp., *Acicularia* sp., *Neomeris plagnensis* Deloffre, *N.* sp. and *Broeckella* sp., Segonzac et al. (1986) mentioned debris of *Carpenterella* sp*., Digitella* sp. and *Zittelina* sp.

Crustose coralline algae like *Sporolithon* sp. are rare. The foraminifers are represented by miliolids, globorotaliids, rotaliids and nodosariids (Pfender in Pia et al., 1932; Segonzac et al., 1986).

The Bekrit-Timahdit Formation ends to the top of the uppermost marine limestones, overlain by the continental deposits of the Ain Nokra Group. The Group starts with red clays and siltstones of the lower Feleddi Formation, which is Priabonian in age (Kuss and Herbig, 1993).

PALEOGENE *HALIMEDA* ALGAL STRATIGRAPHY

In the majority of the cases, an attempt to use green-siphonous algae (Chlorophycota-Halimedaceae) as markers for the stratigraphy, respectively *Halimeda* species, was not performed yet. This is due to the fact that the Paleogene species of *Halimeda* were not recorded frequently in deposits of different areas, compared to the development of dasycladaleans in the same time interval, although they have been considered by Pia (1927) „Siphonee verticillatae" and both groups of algae belong to green-siphonous calcareous algae. According to some authors (Berger and Kaever, 1992; Parente, 1997; Barattolo, 1998, 2002), the green-dasycladaleans do not exhibit a significant biological collapse in respect to the mass-extinction event at the K/T boundary.

This conclusion can be extended also to the species of genus *Halimeda* studied not so intensively like the dasycladaleans. It is sure that the evaluation of a real biological crisis at the K/T boundary needs more biostratigraphical data from calibrated sections, to record the algal changes of halimedacean assemblages with those of benthic and planktonic foraminiferal assemblages during the Paleogene. A real contribution regarding the late Cretaceous-Paleogene dasycladaleans biostratigraphy was analysed critically by Barattolo (1998, 2002).

The author distinguished three phases: first, the recovery (Danian-Thanetian pars), second, the stabilization starting from the boundary of uppermost Thanetian-lowermost Ypresian and continued from Ypresian-Lutetian; and third, a new crisis is hypothetized starting from the Bartonian.

Dragastan and Herbig (2007) recently compared the Barattolo's model with the evolution and stratigraphical range of *Halimeda* species during the Paleogene, as recorded from the central High Atlas (Morocco). The present study extends the results concerning the *Halimeda* stock of species, also for the Middle Atlas, as the three evolutive phases of dasycladaleans were confirmed by the stock of Paleogene *Halimeda* species from Morocco.

There is a biostratigraphic limitation due to the real stratigraphical range of Recent and fossil species of the genus *Halimeda*. Many species still remain provisional or unknown, due to the lack of sufficient, complete data for the pre-Cenozoic and Cenozoic times (Pia et al., 1932; Elliott, 1957; Segonzac, 1967; Deloffre et al., 1977; Hillis-Colinvaux, 1980, 1986, 2000; Bassoullet et al., 1983; Herbig, 1991; Kuss and Herbig, 1993; Kuss, 1994; Dragastan et al., 2002, 2003; Dragastan and Soliman, 2002; Dragastan and Herbig, 2007; Schlagintweit, 2010; Schlagintweit and Ebli, 1998; Taherpour et al., 2009).

During the middle and late Thanetian and the early to middle Eocene, the species of genus *Halimeda* are well diversified due to the modifications of internal anatomy including the medullar area and mostly in the cortex. The external morphology of the thallus segments does support some modifications along the entire thalus.

The medullary siphons of five Recent sections of genus *Halimeda* were investigated morphological by Verbruggen and Kooistra (2004). These authors considered that each sections in *Rhipsalis*, *Micronesica*, *Pseudo-opuntia* and *Opuntia* provided „a helpful tool" towards accurate identification of species, but also allows, at least tentatively, placement of relatively recent fossil specimens in these sections.

Unfortunately, for the fossil and Recent *Halimeda* species, the characterization of medullary siphons by

morphology is possible at level of shape, disposition in rows, number and diameter. But the segments in the fossil state which preserve the nodes between segments, a structure for retaining their identity such as in the Recent species of *Halimeda*, are rarely found.

Also, the molecular data and taxonomic morphometry regarding the genus *Halimeda* (Verbruggen et al. 2005a, 2005b) confirm our arguments regarding the importance of the internal anatomy (medulla and cortex) and the morphometric data along the thallus segments (Dragastan and Soliman, 2002; Dragastan et al., 2002, 2003).

The studies of the genus *Halimeda* by Gent and Kooistra have shown that „significant morphological differences exist between genetically delineated species and that allocation of specimens to species on the basis of morphometric variables is nearly perfect. Anatomical characters yielded better results than external morphological characters". In addition, the authors consider the segment size, shape and a broad range of anatomical structures as a predictive discriminant for the identification of Recent *Halimeda* species, as we add here more or less for the fossils as well (Dragastan and Soliman, 2002, Dragastan et al. 2002). The difficulties in the fossil *Halimeda* species are induced by the segments which do not represent the entire thallus like in the case of Recent species, having the status of parataxons. For example, an entire thallus of Recent *Halimeda incrassata* is 9.89 cm tall and it is composed of about 93 segments (Freile and Hillis, 1992), but with different shapes or morphae. The thallus contains four morfological types of segments: cylindrical, subcuneate to the basal part and plane, disk-like and reniform, with undulated or deeply lobed margins from the middle to the upper parts of the thallus (Hillis-Colinvaux 1980). More or less, the Recent *Halimeda cylindracea* with a thallus up to 19 cm high mostly has cylindrical segments from the basal part, in the middle becomes compressed lateraly, while to the top of the thallus the segments are also cylindrical. This means that up to 80% the production of the fossil segments in sediments are predominantly cylindrical in shape, as stated by Dragastan et al. (2002), Littler and Littler (2003). In this case, the identification of fossil *Halimeda cylindracea* using only the shape of segments can be recommended for this taxon, but not for other taxa such as *H. incrassata*, without the description of internal morphology of medulla and moreover, without the description of the cortex.

Molecular data were used only to delimit species groups. In exchange the segment's morphological characters proved fairly good predictors for species membership, in case of less morphotypes as shape (not so many segment forms) along the thallus, but not like the anatomical (internal) structures. A good performance of morphometric taxon predictors offers perspectives, not only for the future taxonomic case studies within problematic species complexes, but also for thorough examinations of the rich fossil record of *Halimeda*.

„The biostratigraphic interpretations based on *Halimeda* species, like in the dasycladaleans, generally suffer from not so speedy evolution rate, difficulties in taxonomy of the species discrimination, incomplete inventory, facies print, paleoecology (ecology), and provincialism" sensu Rasser and Fenninger (2002).

Many inadvertences or poor knowledge of stratigraphic range, regional distribution and gaps of real *Halimeda* species, along to the geological time scale, represents an impediment to obtain a real stratigraphic range of taxa and and an appropiate scale (Dragastan et al. 2003).

FACTORS LIMITING THE BIOSTRATIGRAPHIC INTERPRETATIONS

Three limiting factors regarding the *Halimeda* biostratigraphy were distinguished: 1. the variability of facies; 2. paleoecology and ecology in case of Recent counterparts, and 3. provincialism or paleoprovinces. The facies and provincialism are the main limiting factors, leading to the fact that the first and last occurences (appearance - dissapearance) of *Halimeda* species, varies between different localities and regions as well as time interval or range.

From a historical point of view, d'Orbigny (1849-1852) introduced the first the term „la faune chronologique", which corresponds to the total content of fauna or flora from a stage. This was followed by Oppel (1856-1858), by the introduction of the „Zone", a stratigraphic unit composed of "one bed or by a group of beds" without taking into consideration the lithology. A Zone is marked by a „fossil index" confined to its boundaries, giving also the name of the unit. The appearance and disappearance of a species are essential moments during the range and corresponds more or less to a vital range of a taxon. The benthic green algae (dasycladales) and green siphonous algae (Halimedaceae) were traditionally applied to define the Assemblage or Abundance Zones during the middle Triassic-Jurassic and Cretaceous, Paleogene, Miocene, up to the Recent time intervals, mainly in the carbonate platforms, in association with foraminifers. However, an attempt to correlate the dasycladaleans ranges with the benthic foraminfera zonation during Cenozoic (Paleogene) has been presented upon the data of Karst area by Barattollo (1998, 2002). This author distingushed:

1. the oligotypic assemblage with the presence of *Acroporella chiapasis* before the appearance of *Decastroporella tergestina* (Upper Maastrichtian in age) and after;

2. the assemblage with the appearance of *Decastroporella tergestina* and *Drobnella slovenica* before of the appearance of *Cymopolia* assemblage (Lower Danian in age);

3. the occurrence of *Cymopolia* assemblage diversified in the Tethyan realm (Upper Danian-Thanetian pro parte in age). The late Thanetian-Lutetian and Bartonian intervals were not defined with assemblage zones by Barattollo, but the author discussed the „real" or possible stratigraphic ranges of species which belong to genera: *Acicularia*, *Actinoporella*, *Broeckella*, *Dissocladella*, *Ollaria*, *Castellaria*, *Ferganella* and *Trinocladus*.
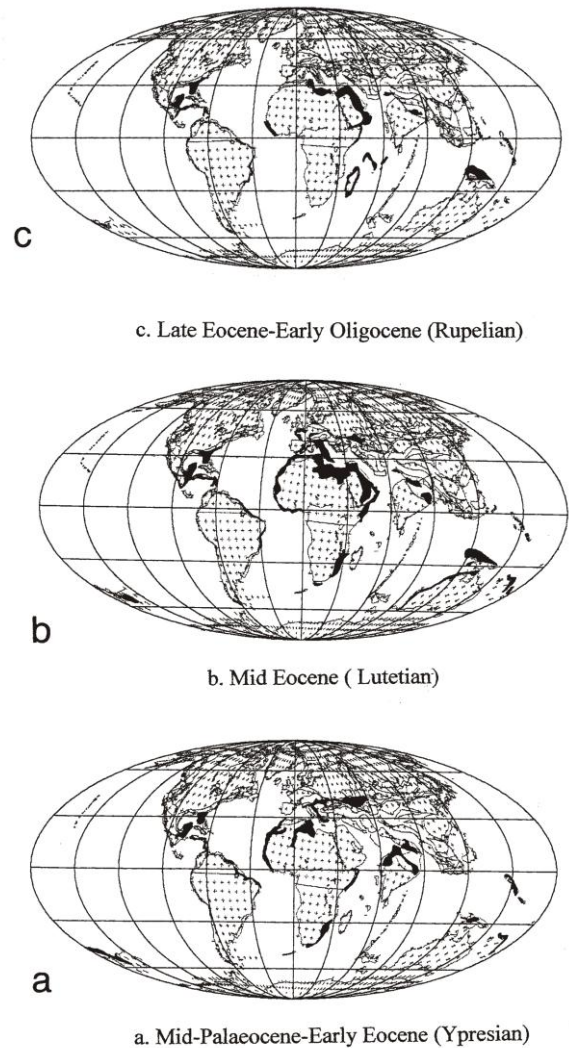
PALEOECOLOGY OF PALEOGENE *HALIMEDA* VERSUS ECOLOGY OF RECENT *HALIMEDA* SPECIES

The sedimentary data is the key evidence for environmental interpretations, facies models, the type of basin, and the shape of the carbonate platform. The structure of constructional reefs can influence the distribution of green algae and subsequently the range of taxa, as well as the ecologic factors. Geological observations such as composition, grain size, sorting, thickness of beds and sedimentary structures permit the identification of sedimentary facies, which reflect the depositional environment. The fossil assemblages in most of the cases confirm the interpretation made on sedimentological evidences. It is also, the case of Paleogene deposits from central High Atlas and from the Middle Atlas (Herbig, 1991; Kuss and Herbig, 1993; Dragastan and Herbig, 2007).

During Cenozoic, carbonate platform areas started with moderate values in the mid Paleocene to Early Eocene-Ypresian (Fig. 5a), being developed to the north-western part, to the northern part of the African continent and in the eastern area of the Mediterranean sea (Kiessling et al., 2003). The peak was achieved during the Mid Eocene-Lutetian, when the carbonate platforms covered large areas of the African-Arabian continent and also the circum Mediterranean region, including Italy, France and the southern part of England (Fig. 5b). In exchange, the carbonate platform areas declined drastically during Late Eocene to Early Oligocene-Rupelian (Fig. 5c), when only a small part is present to the north-eastern part of Africa and a large area of the eastern part of the Arabian peninsula.

Beginning with the mid Paleocene-early and middle Eocene, the quantitative contribution of benthic calcareous green algae (halimedaceans and dasycladaceans) and foraminifers to carbonate production is large, whereas reefal debris or constructions were rare in the African-Arabian continent. The latitudinal extent of early Paleogene platforms, including green calcareous algae, was extraordinarily wide, reaching more than 45° latitude on both hemispheres (Kiessling et al. 2003).

The deposits of the Bekrit-Timahdit Formation from the Middle Atlas were accumulated along a funnel-shaped gulf, widening and deepening towards the west, and being linked with Neo-Tethyan Atlantic Ocean. The Paleogene basin is considered a carbonate ramp (non rimmed platform) considering the facies patterns, divided into three zones: 1. an inner zone (mudstones with dolomite and wackestones with terrigenous inputs), 2. a median zone (packstones, grainstones with small patch-reefs) and 3. an outer ramp zone (rudstones, float-stones, oolithic shoal with rare patch-reefs). The distribution of *Halimeda* species along the carbonate ramp was reconstructed after the Paleogene sections of Timahdit (MA-8, MA-8a, MA-9, MA-4, MA-7, MA-10) and Bekrit (MA-16, MA-24, MA-18, MA-17, MA-14, MA-15) areas. The carbonate ramp of Bekrit area had approximately 18 km in length. Most of the Paleogene *Halimeda* species of Bekrit area are distributed in the lagoon, some also similar to the Recent, others in the

c. Late Eocene-Early Oligocene (Rupelian)

b. Mid Eocene (Lutetian)

a. Mid-Palaeocene-Early Eocene (Ypresian)

**Fig. 5 a-b-c** Global distribution of Paleogene carbonate platforms (in black, after Kissling et al., 2003).

restricted inner ramp (*Halimeda incrassata, H. cylindracea, H. nana, H. praeminima* n.sp.) or in the open, middle ramp lagoon (*Atlasinium erikfluegeli* - Precodiaceae, *H. lacunosa, H. copiosa,*and *H. tuna*). The species *Halimeda gracilis* covered the limit between the inner and the middle ramp (Fig. 6).

The restricted inner ramp was separated from the middle ramp open lagoon by the occurrence of a series of patch-reefs built by corals and bryalgal organisms. The outer ramp, oriented seaward to the Atlantic Ocean, was the place where the species *Halimeda opuntia* covered rock surfaces and *H. simulans* disposed from the "boundary" between the middle and the outer carbonate ramp, and it had a large distribution area. The species *Atlasinium erikfluegeli, Halimeda fragilis, H. lacunosa, H. copiosa, H. tuna, H. incrassata, H. cylindracea, H. praeminima* n.sp. *and H. nana* were recorded also in the outer ramp zone, the latter group representing ubiquistic species, present in all paleoenvironmental zones from the inner to the outer ones.

In the outer zone of the carbonate ramp of Bekrit area, some scleractinian reefs together with sponges covered by crusts of red algae and microbialites occurred, but not so frequently. In the Timahdit area, the carbonate ramp
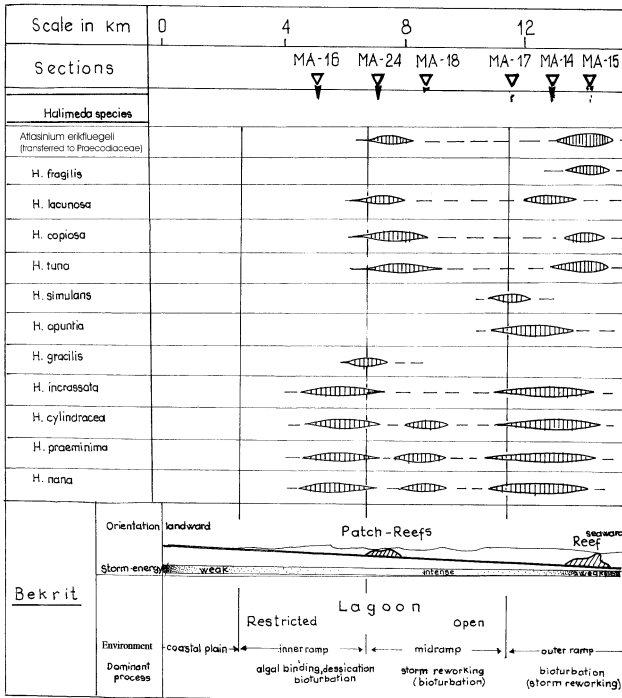
Fig. 6 The distribution of Paleogene *Halimeda* species on the carbonate ramp of the Bekrit area (Middle Atlas).
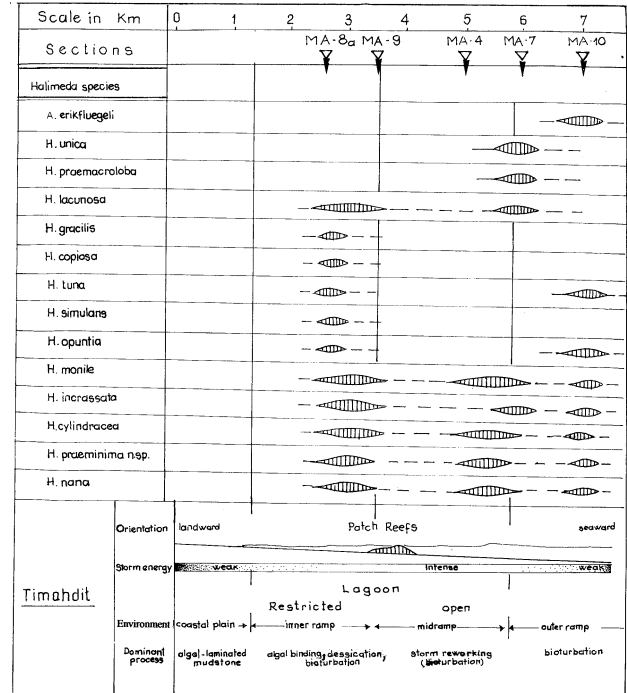
Fig. 7 The distribution of Paleogene *Halimeda* species on the carbonate ramp of the Timahdit area (Middle Atlas).

had approximately 10 km in length and the distribution of Paleogene *Halimeda* species is different, because the inner ramp zone was not so clearly separated from the coastal plain, and the distribution of species occurs mostly in the distal area of the inner ramp.

In the distal inner carbonate ramp, the distribution of the following species of the *Halimeda* stock were frequently encountered: *Halimeda lacunosa, H. gracilis, H. copiosa, H. tuna, H. simulans* and *H. opuntia*. The other species like *Halimeda monile, H. incrassata, H. cylindracea, H. praeminima* n. sp. and *H. nana* have also the same distribution, being prolific and predominantly as specimens (Fig. 7). The inner ramp zone was separated from the middle ramp by scleractinian, bryalgal and algal patch-reefs disposed more or less in the proximal part of the middle ramp zone. In the middle ramp area, the distribution of *Halimeda* species was to the distal part of this zone and only these species covered the area: *H. monile, H. incrassata, H. cylindracea, H. praeminima* n.sp. and *H. nana* (Fig. 7). The other species like *Halimeda unica, H. praemacroloba* and *H. lacunosa* are distributed preferentially in the distal part of middle ramp zone.

In the outer ramp zone, no reef was found and the following species are distributed more or less equally, but not being dominant as specimens in this area: *Atlasinium erikfluegeli* (in Dragastan, 2008, former *Halimeda erikfluegeli*), *H. tuna, H. opuntia, H. monile, H. incrassata, H. cylindracea* and very rare *H. praeminima* n. sp. and *H. nana*.

Comparing the two basin ramp areas, in the Bekrit were identified 12 species (3 fossil and 9 fossil and Recent species) and in the Timahdit 14 species (5 fossil and 9 fossil and Recent species), which is not so different

for the ramp areas by number of species. But if we compare both areas, in the Bekrit area are missing the species *Halimeda unica, H. praemacroloba* and *H. monile* and the distribution of species is different, as the taxa *H. lacunosa, H. copiosa* and *H. tuna* in the Bekrit area occur in the middle ramp.
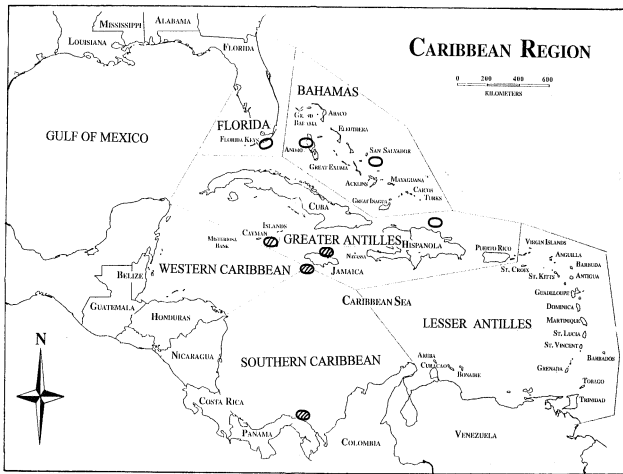
In the Timahdit area, the following species have a different distribution: *Halimeda gracilis, H. copiosa, H. tuna, H. simulans* and *H. opuntia* occurred only in the inner ramp zone, different in comparison with the distribution of the same species in the Bekrit area, here mainly occurring in the proximal part of the middle ramp, crossing up to the outer ramp.

The rest of species, like *Halimeda incrassata, H. cylindracea, H. praeminima* n. sp. and *H. nana* from Bekrit and Timahdit areas occur in the same zone, to the distal part of the inner ramp, in the middle ramp and in the outer ramp zones.

In the Timahdit the species *Atlasinium erikfluegeli,* also a green alga of the Family Preacodiaceae Dragastan (2008), was found in the outer ramp zone, and in the Bekrit area, in the proximal part of the middle ramp zone, and continued to occur also in the outer ramp zone.

The distribution of *Halimeda* species during the Paleogene deposits of High Atlas and Middle Atlas has some characteristic features influenced by the basin. The basin is a carbonate ramp and in some respect, it is not so easy to separate or to divide the zones and the distribution of species. Therefore, it is only tentative to obtain a base to compare the fossils with the distribution of the Recent *Halimeda* species from the Atlantic Ocean, the Pacific Ocean and the Mediterranean sea.

The environmental models regarding the distribution of Recent *Halimeda* species were established by Goreau
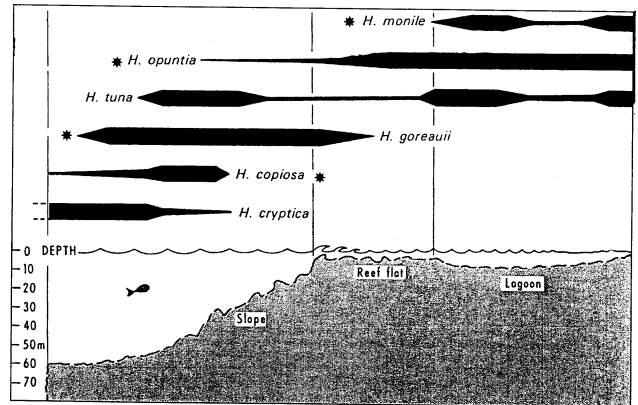
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Fig. 8 Recent reefs areas of the Caribbean Region (after Littler and Littler, 2000).

Fig. 9 Depth distribution and relative abundance of some *Halimeda* species in the Jamaican reefs, with *, the species also found in fossil state (after Goreau and Goreau, 1973).

and Goreau (1973) for the Jamaican reefs, by Hillis-Colinvaux (1980, 1986) for the Glory Be reefs from the northern part of Jamaica, by Johns and Moore (1988) for the Cayman Island from the Greater Antilles, and by Dragastan (unpublished data), for the fringing reefs of Punta Galeta-Panama, in the Southern Antilles (Fig. 8).

All these reefs areas cover different environmental zones: lagoon, reef crest, upper fore-reef terrace, lower fore-reef terrace and deep reef, in Cayman Island (Greater Antilles) or lagoon, reef-flat rubble and reef pools, reef crest, fore-reef and deeper fore-reef, in Punta Galeta of the Southern Antilles, both reefs from the Caribbean Sea (Atlantic Ocean). The zonation of Caribbean reefs of the Atlantic Ocean differs more or less from the reefs of the Indo-Pacific Ocean, and from the Great Barrier Reef area, or from the atolls of the Pacific Ocean.

If the carbonate ramps from the Paleogene of central High Atlas and Middle Atlas had only three depositional or environmental zones, with a typical *Halimeda* species distributions, some species in the frame of inner ramp, others in the middle ramp and more of the species occurring in frame of the outer ramp (Figs. 6-7). Few Paleogene *Halimeda* species showed a transitional distribution from the mid ramp to the outer ramp, like Recent and fossil taxa *H. monile* and *H. incrassata, H. unica, H. praemacroloba* and *H. lacunosa.* The distribution models for Recent *Halimeda* species from the Caribbean area (Atlantic Ocean) in the frame of the reefs have more or less three environmental zones.

The model of Goreau and Goreau (1973) for the Jamaican reefs recognized three zones: lagoon, inward, after the reef flat and the reef slope, seaward (Fig. 9). In the lagoon only one species, *Halimeda monile* has a relative abundance, while in the reef flat to the distal part occurs *H. goreauii*, a species having a relative counterpart in the Paleogene species, *H. praegoreauii.* Two species, *Halimeda opuntia* and *H. tuna* crossed all the three zones (lagoon, reef flat and slope), with different rates of abundance. Only one species *Halimeda copiosa* was abundant in the reef slope zone.

Another Jamaican reef profile, the Glory Be, is a compilation of data from Hillis-Colinvaux (personal data), Colinvaux and Graham (1964), Goreau and Goreau (1973) and Hillis-Colinvaux (1980). The reef was divided
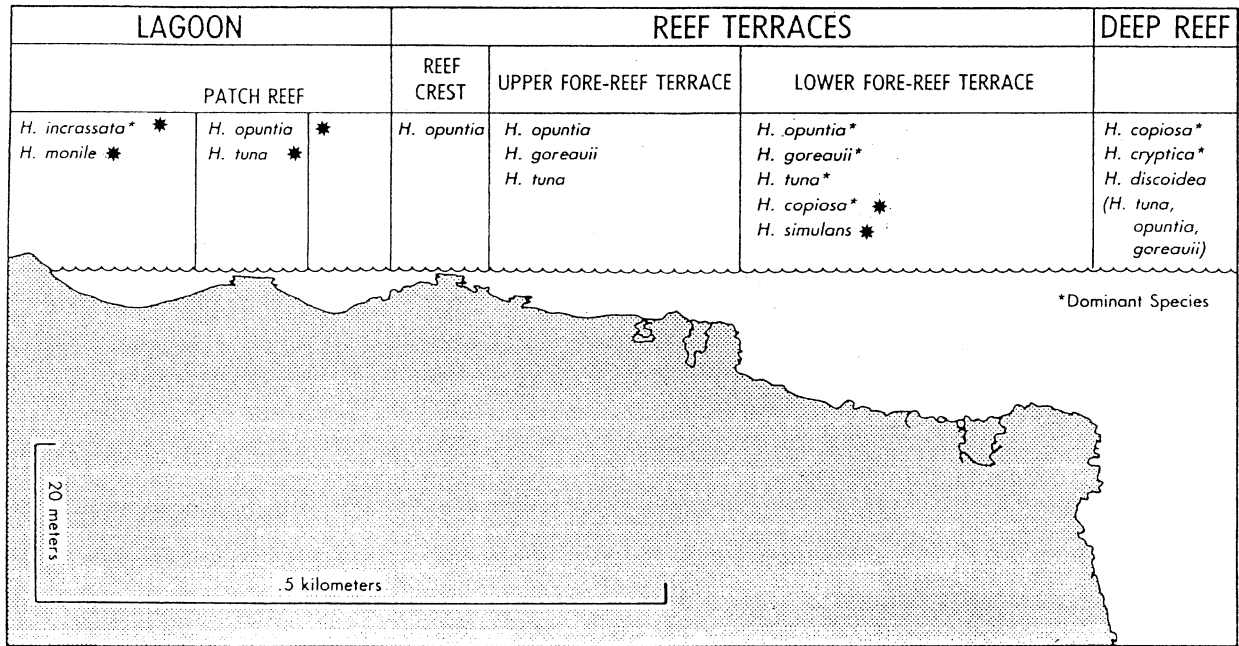
also in three environmental zones: back reef, which corresponds to the lagoon, the reef framework-reef crest, comparable with the reef-flat, and the reef framework to seaward slope, corresponding to the slope (Fig. 10). The species *Halimeda incrassata* (i), *H. simulans* (s), *H. opuntia* (o), *H. goreauii* (g) and *H. tuna* (t) were distributed in all three zones. In the back reef zone occurs only the species *Halimeda monile* (m) and in the reef framework-seaward slope zone occur the species *H. copiosa* (co) and *H. discoidea* (d). The species *Halimeda gracilis* (gr) covered the reef framework-reef crest and reef framework to seaward slope zones. The distribution of *Halimeda* species along the Glory Be reef contains a high number of taxa which are useful to compare with some Recent and fossils *Halimeda* found in the Paleogene of central High Atlas and in the Middle Atlas.
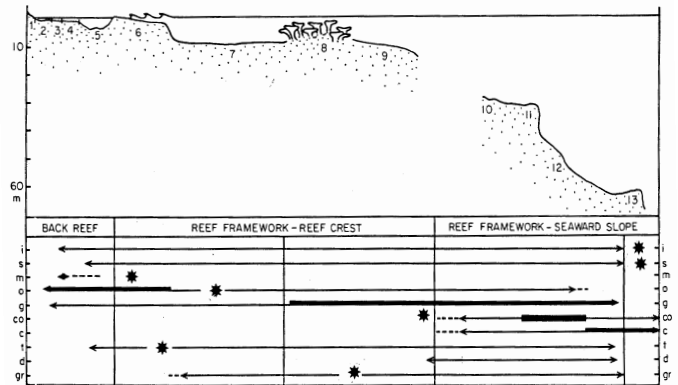
Fig. 10 Profile of the Jamaican Glory Be reef and the distribution of *Halimeda* species (after Hillis-Colinvaux, 1980). With * are indicated Recent and fossil species.

Also, another area is in the Greater Antilles, with the fringing reefs of Cayman Islands, where the distribution of *Halimeda* species was studied by Johns and Moore (1988). The fringing reef is a carbonate ramp which is approximatively 10 km long (Fig.11). The fringing reef carbonate ramp was divided in four environmental zones: the lagoon with patch-reefs, and the reef terraces with three subzones: 1. reef crest; 2. upper fore-reef terrace, and 3. lower fore-reef terrace and the deep reef or slope of the reef. In these interpretations, each zone or subzone is characterized by assemblages of *Halimeda* species as follows: in the proximal part of the lagoon the
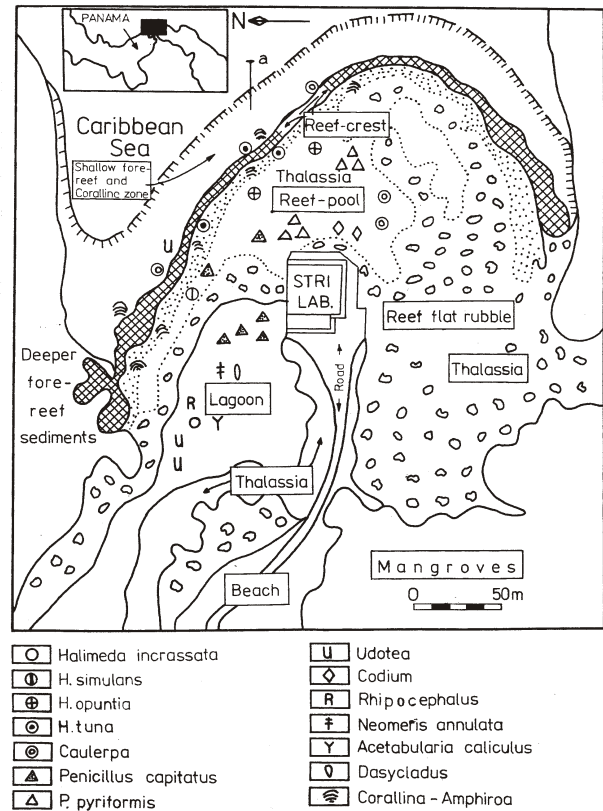
LAGOON			REEF TERRACES			DEEP REEF
	PATCH REEF		REEF CREST	UPPER FORE-REEF TERRACE	LOWER FORE-REEF TERRACE	
H. incrassata* ✱ H. monile ✱	H. opuntia ✱ H. tuna ✱	✱	H. opuntia	H. opuntia H. goreauii H. tuna	H. opuntia* H. goreauii* H. tuna* H. copiosa* ✱ H. simulans ✱	H. copiosa* H. cryptica* H. discoidea (H. tuna, opuntia, goreauii)

*Dominant Species

20 meters

.5 kilometers

Fig. 11 The distribution of *Halimeda* species on the fringing reef of the Cayman Island (after Johns and Moore, 1988). With * are indicated Recent and fossil species.

assemblage is represented by *Halimeda incrassata* and *H. monile*, in the distal part of the lagoon and on or in the surrounding area of the patch reef lived *H. opuntia* and *H. tuna*. In the subzone of reef crest *H. opuntia* is dominant. In the upper fore-reef terrace, the assemblage contains *Halimeda opuntia, H. goreauii* and *H. tuna* (Fig.11). In the distal subzone of the lower fore-reef terrace, the assemblage is represented by *Halimeda opuntia, H. goreauii, H. tuna, H. copiosa* and *H. simulans*. In the slope of the reef ramp, the assemblage is represented by *Halimeda copiosa, H. cryptica, H. discoidea, H. tuna, H. opuntia* and *H. goreauii*. The advantage of this reef interpretation is the occurrence of *Halimeda* assemblage species per zones and subzones, easy to compare the Recent assemblages with those of the Paleogene in the Moroccan Atlas.

The Southern Caribbean (Antilles) area includes a very important fringing reef occurring on a carbonate ramp at Punta Galeta, Panama (Fig.12). On the reef is located the famous Marine Station of the Smithsonian Tropical Institute (STRI). There, the reef ramp is predominantly built-up by the scleractinian coral *Acropora palmata* with branched colonies up to 1.0m high (Fig. 13). The ramp reef contains the beach, the reef flat rubble, with two subzones: the lagoon and the reef pools followed by the reef crest, by fore-reef and the slope with deeper reef sediments. In the lagoon subzone, from reef flat rubble, the assemblages of *Halimeda* species is represented by *H. incrassata, H. monile*, together with *Udotea* sp., *Penicillus capitatus* and with dasycladaleans dominance, *Acetabulria* sp., *dasycladus* sp. and *Neomeris annulata*. In the distal subzone, within the reef-pools of the reef flat rubble zone, the assemblage of algae contains *Halimeda simulans, H. opuntia, H. tuna, Caulerpa racemosa (Caulerpaceae)*, the Udoteacean *Penicillus capitatus*, and near to the reef crest zone, the red algae *Corallina* and *Amphiroa*. The reef

crest and the fore-reef zones are dominated by corallinacean red algae building rodolithes. In exchange, in the fore-reef and in the slope zones occur *Halimeda tuna, Caulerpa,* rodolithes and algal debris. The abundance of specimens per *Halimeda* species was

O	Halimeda incrassata	U	Udotea
⊕	H. simulans	◇	Codium
⊕	H. opuntia	R	Rhipocephalus
◎	H. tuna	✝	Neomeris annulata
◉	Caulerpa	Y	Acetabularia caliculus
△	Penicillus capitatus	Q	Dasycladus
△	P. pyriformis	🐚	Corallina – Amphiroa

Fig. 12 Zonation of the reef flat of Punta Galeta and the distribution of the principal groups of algae (reinterpreted after Meyer and Birkeland, 1974). A profile crossing the reef ramp was divided in environmental zones by Lighty et al. (1982).
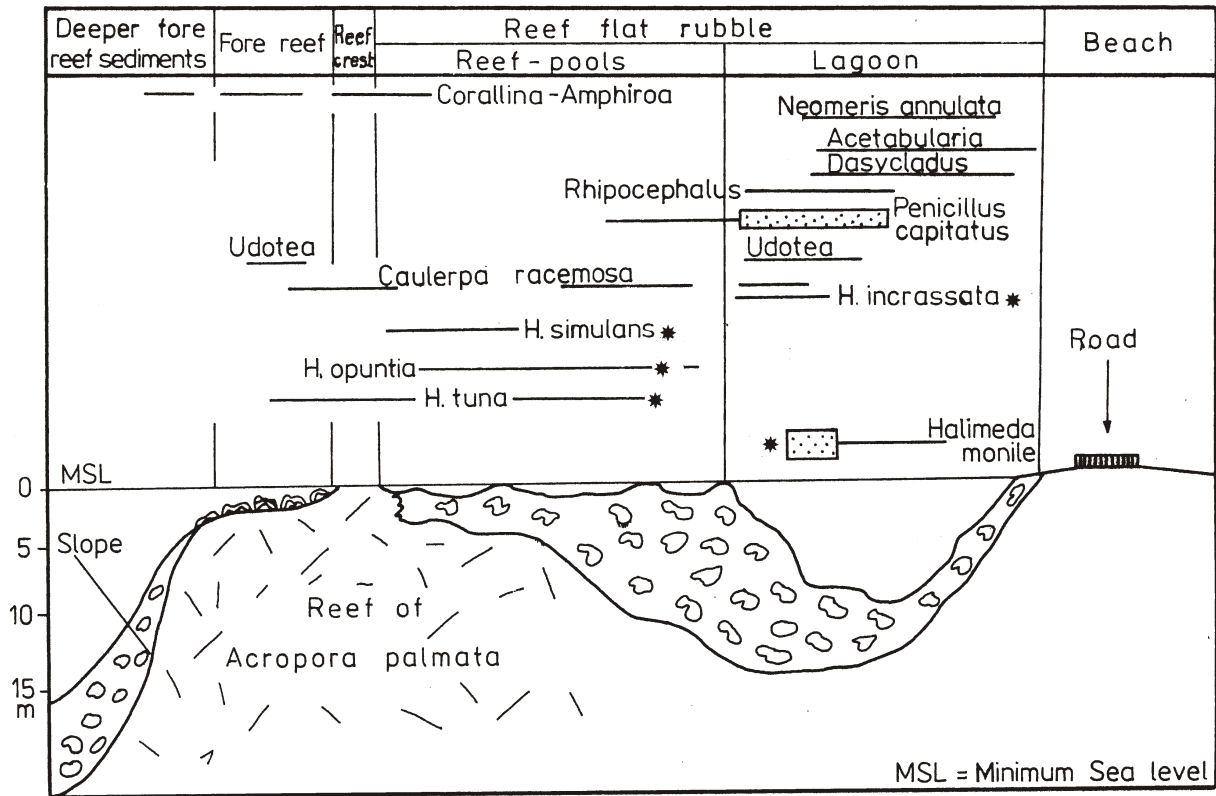
Fig. 13 Profile crossing the reef flat of Punta Galeta and distribution of principal groups of calcareous algae (inspired after Lighty et al., 1982). With * are indicated Recent and fossil species.

calculated for each zones and subzones for the Punta Galeta reef, a reef occurring on the western shore of the Atlantic Ocean. In the lagoon, *Halimeda incrassata* reaches up to 40 specimens/m^2, *H. opuntia*, 50 specimens, *H. tuna*, a variable abundance between 30 up to 50 specimens, *H. monile* also variable, between 10 up to 30 specimens, and a caulerpacean alga, *Caulerpa racemosa*, a less participation of about 5 specimens. In the subzone of the reef pool, the following data were obtained: *Halimeda incrassata*, with a variable abundance of specimens between 10-20 up to 50 thalli, *H. simulans* less around 10 specimens, *H. opuntia*, maximum 50 specimens, *H. tuna,* also 50 specimens, *H. copiosa* only 2 specimens, and *Caulerpa racemosa*, a variable participation between 2 up to 10 specimens (Fig. 14). In the reef crest zone, the halimedaceans are rarely found, *Halimeda opuntia* with only 5 specimens, *H. tuna* with the same participation like *H. opuntia*, and *H. copiosa*, with 20 specimens. The caulerpaceans are missing in this zone. In the shallow fore-reef and along the slope, mostly as debris thalli, the assemblage with *Halimeda opuntia* has 10 specimens, *H. tuna* has a maximum participation up to 50 specimens, *H. copiosa* up to 10 specimens, and *Caulerpa racemosa* up to 10 specimens.

An attempt to count the abundance of Udoteaceans and dasycladacean specimens was undertaken in the same reef area as follows: in the lagoon, *Udotea abbottiorum* has up to 10 specimens, *Penicullus capitatus* up to 30 specimens, *Neomeris annulata* and *dasycladus vermicularis*, both only with 1 specimen, and *Acetabularia caliculus* up to 2 specimens (Fig.15).

Taxa	Shallow Fore reef	Reef crest	Reef flat rubble Reef-pool	Lagoon
Halimeda incrassata			10 50 20	40
H. simulans			10	
H opuntia	10	5	50 50 40	50
H. tuna	50	5	50	30 50
H. monile				30 10 10
H. copiosa	10	20	2	
Caulerpa racemosa	10		10 2	5

Fig. 14 The distribution and abundance of halimedacean and Caulerpacean specimens in the Punta Galeta reef (after Dragastan, unpublished data).

Taxa	Shallow Fore reef	Reef crest	Reef flat rubble / Reef-pool	Lagoon
Udotea looensis	10		5	
U. dixonii	5			
U. abbottiorum			5	10
Penicillus pyriformis			10 / 20	
P. capitatus			10	30
Rhipocephalus phoenix				1
Neomeris annulata				1
Acetabularia caliculus				2
Dasycladus vermicularis				1

Fig. 15 The distribution and abundance of Udoteaceans and dasycladaleans specimens in the Punta Galeta reef (after Dragastan, unpublished data).

In the reef pool subzone, Udoteaceans are predominant, as follows: *Udotea looensis* with only 5 specimens, *U. abbottiorum* also with 5 specimens, *Penicillus pyriformis* with a variable participation between 10 up to 20 specimens, and *P. capitatus* with maximum of 10 specimens. In the reef crest zone was found only algal debris. In the fore-reef zone and along the upper slope were found only Udoteacean species, *Udotea looensis* with 10 specimens and *U. dixonii* with up to 5 specimens.

After this synthetic review of halimedacean and other green algae distribution and abundance in the Recent reefs of the Caribbean area and western part of the Atlantic Ocean, we can conclude that a comparison with some *Halimeda* species distribution in the Paleogene of the Moroccan Atlas is possible.

A study concerning the distribution of algae and the zonation of coralline algae pavement at Zulajanska, in the Adriatic Sea (Senes, 1967), as part of the Mediterranean, corresponds also to a carbonate ramp (Fig. 16). The carbonate ramp was covered by algal crusts of *Corallina* and *Amphiroa*, which can be an equivalent of the inner ramp zone or of the lagoon, where occurred different species of *Amphiroa*, *Corallina*, *Melobesia*, *Lithothamnion*, *Udotea petiolata*, *Halimeda tuna* and dasycladaceans, *dasycladus vermicularis* and *Acetabularia acetabulum*. The *Lithophyllum-Lithothamnion* zone corresponds to a mid carbonate zone with a transition to the slope. In this zone of transition to the slope, the *Lithophyllum* and *Lithothamnion* species became predominant. Within this zone occurred Halimedanceans, with two species, *Halimeda tuna* and *H.*
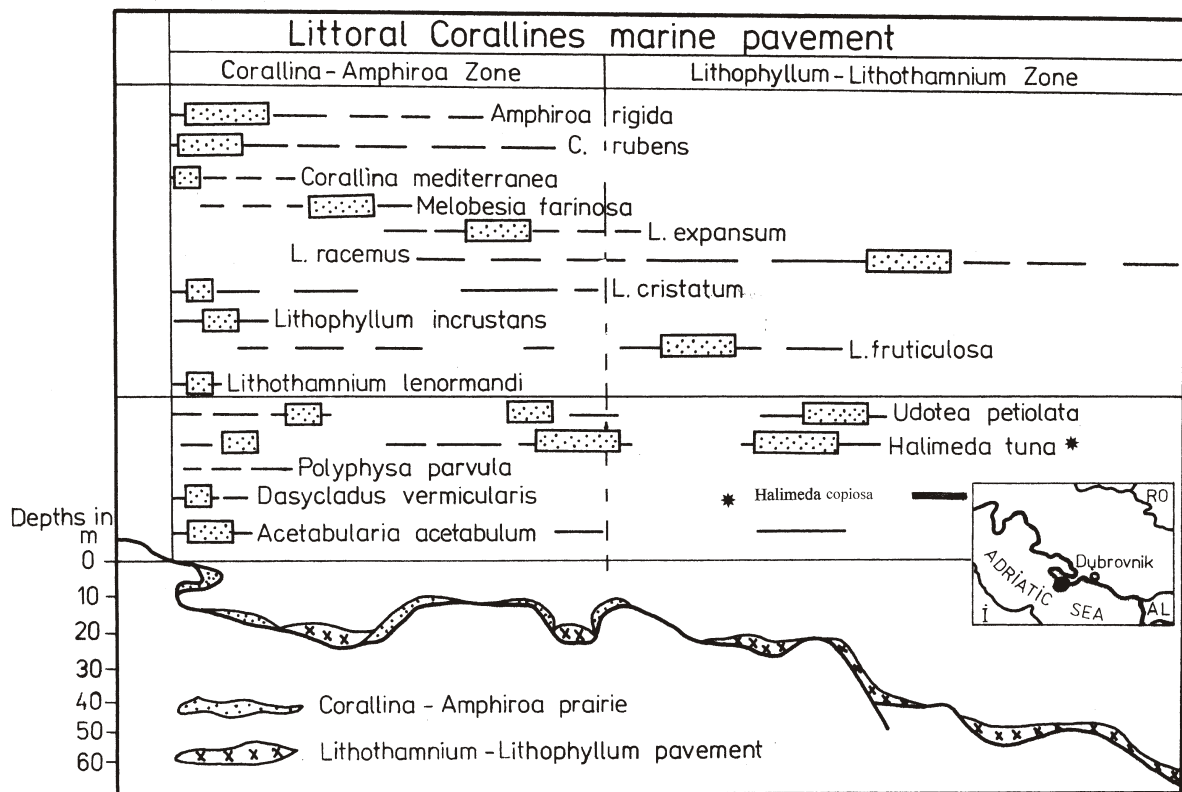

Fig. 16 Distribution of algae and their abundance on the carbonate ramp of Zulajanska from Adriatic sea (reinterpreted after Senes, 1967). With * are indicated Recent and fossil species.

copiosa, Udoteaceans with a single species, *Udotea petiolata*, and also a single dasycladalean species, *Acetabularia acetabulum*.

The occurrence of green algae with a few number of species, like *Halimeda tuna, H. cuneata, Udotea, Acetabularia* and *dasycladus* represent a relict stock of species or descendents of taxa during Pliocene and upper Miocene interval, as large reef areas covered the shores of the Mediterranean Sea.

Although other sedimentary basins show different environmental zones for the reefs along the Great Barrier, respectively along the One Tree platform reef, occurring east of Gladstone, and the Enewetak Atoll, both from the Pacific Ocean (Fig. 17), they still remain important because they contain a large part of the *Halimeda* stock of species. These areas include assemblages which are comparable with some Recent and fossil *Halimeda* species from the Paleogene of the Moroccan Atlas.
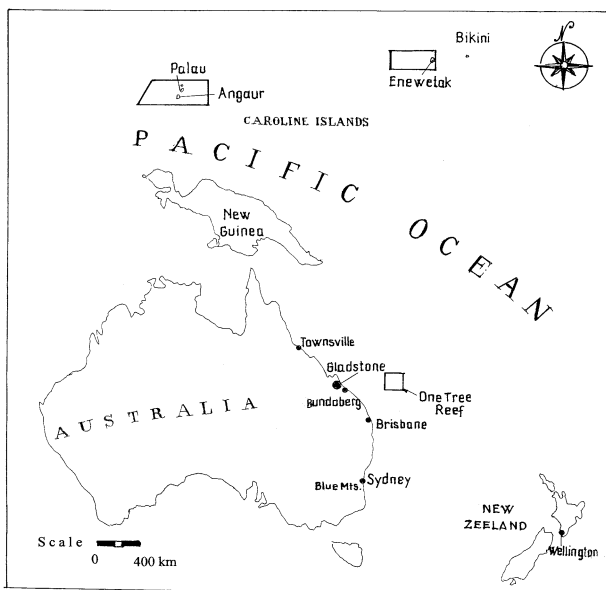

Fig. 17 The Pacific Ocean and the position of studied One Tree reef and the Enewetak atoll (after Mc Knight, 1982, World Atlas - Pacific area).

The One Tree platform reef occurs 200 km west of the Gladstone locality (Australia), and it belongs to the Great Barrier reefs. The reef carbonate platform has the following environmental zones:

1. the lagoon, inward of the barrier, lacking algae, but only with algal debris accumulated on the reef-terraces and on the Pleistocene cliff (Fig. 18 a-b);

2. the lagoon with patch- reefs, where *Halimeda cylindracea* and *H. opuntia* occur frequently, together with rare *Caulerpa serrulata*, cyanophycean *Oscillatoria* sp., building algal crusts and rodolithes generated by *Lithophyllum molluccense*;

3. the reef flat colonized by *Halimeda opuntia* and *H. discoidea* and rare *Caulerpa racemosa* and *Bryopsis* sp.;

4. the rubble crest and algal rim zones, containing *Caulerpa racemosa*, the red alga *Porolithon,* one of the highly important builders of the rim, together with cyanophyceans and many endolithic boring structures;

5. the reef slope, mostly covered and built by the red algae *Paragoniolithon* sp. and *Porolithon* sp.

The Enewetak atoll delivered more data and studies as a result of atom bomb tests. Their craters represent interesting sites for marine phycology and botany (Hillis-Colinvaux, 1980, 1986). The atoll consists of approximatively 40 islets forming an elliptical ring reef surrounding a large, deep lagoon (Fig. 19 a-b). The algal ridge was built predominantly by red algae such as *Neogoniolithon, Porolithon* and *Lithophyllum.* Fourteen species of *Halimeda* are described from Enewetak atoll: *Halimeda incrassata, H. cylindracea, H. stuposa, H. opuntia, H. copiosa, H. distorta, H. minima, H. gigas, H. gracilis, H. lacunalis* f. *lata, H. macrophysa, H. taenicola, H. micronesica* and *H. fragilis* (Hillis-Colinvaux, 1980). The environmental zones of the atoll are different in terms of disposition and dimensions, in and out of the ring of islets:

1. the fore-reef and groove, reef crest, back-reef zones contain: *Halimeda copiosa, H. opuntia, H. gracilis, H. fragilis, H. lacunalis* f. *lacunalis* and *H. distorta.*;

2. the bomb crater, full of thalli of *Halimeda incrassata* as a colonizer and

3. the shallow lagoon with patch reefs, with the predominant species *Halimeda cylindracea*, followed by *H. incrassata, H. micronesica, H. gigas, H. distorta, Udotea* sp. and also the calcareous alga *Tydemania expeditionis*.

This overview dealing with different reef areas of the Atlantic and Pacific Oceans and with the distribution of Recent *Halimeda* species in the frame of environmental
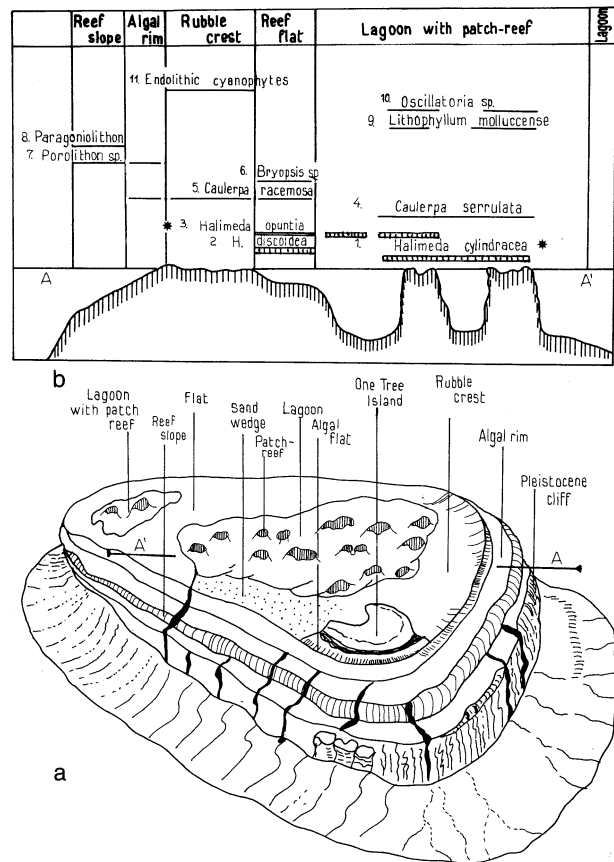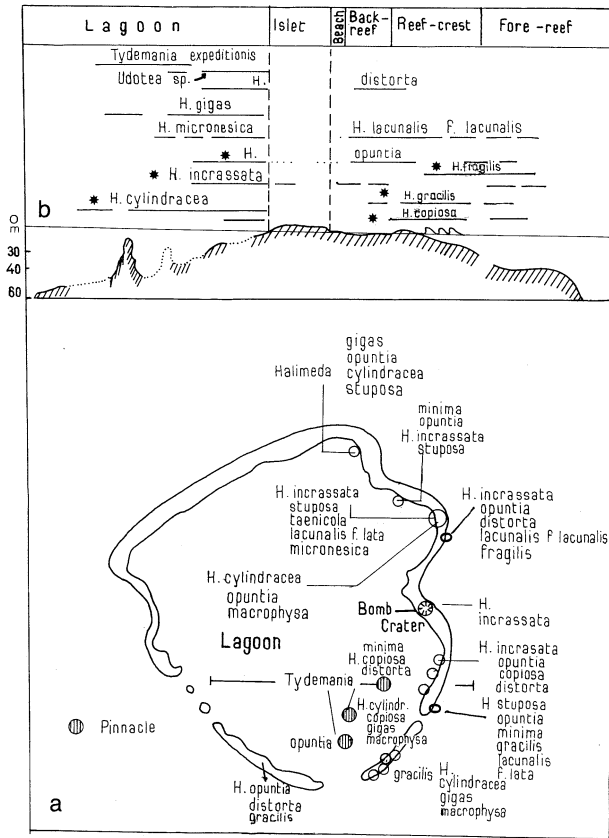

Fig. 18 a-b One Tree platform reef (Great Barrier reef, east of Gladstone) and the distribution of major algal species (after Borowitzka and Larkum, 1986). With * are indicated Recent and fossil species.

Fig. 19 a The Enewetak atoll and distribution of *Halimeda* species and other algal groups (after Hillis-Colinvaux, 1980, 1986), **b** profile of Enewetak atoll (after Orme et al., 1978). With * are indicated Recent and fossil species.

zones can be used as an attempt to understand if some species of the Moroccan Paleogene could have had the same conditions of life, and if they lived in the same environmental zones.

During the Paleogene in Morocco, the deposits accumulated on the calcareous ramp can be subdivided in three zones (inner, mid and outer), and they can be compared to the Caribbean reefs which have three environmental and depositional zones: lagoon (equivalent of inner ramp), reef-flat or terrace (equivalent to the mid ramp) and reef slope or slope (equivalent of the outer ramp).

The Recent and fossil *Halimeda* species of the Moroccan Atlas are represented by *Halimeda copiosa, H. opuntia, H. incrassata, H. monile, H. simulans, H. tuna, H. fragilis* and *H. gracilis*. Another Recent and fossil species is *Halimeda cylindracea* found in the Paleogene of the Moroccan Atlas. The Recent species representatives are typical for the reefs of the Great Barrier and of other reefs from the Pacific Ocean.

In the Paleogene of the Moroccan Atlas, the inner ramp or lagoon contained: *Halimeda copiosa, H. tuna, H. simulans, H. opuntia, H. monile, H. incrassata* and *H. cylindracea*. In the mid ramp or reef terrace zone, only four species were identified: *Halimeda monile, H. copiosa, H. tuna, H.opuntia*, and in the outer ramp or reef slope were found: *H. tuna, H.opuntia, H. monile, H. incrassata* and *H. cylindracea*. (Figs. 5-6).

Comparing the distribution of Recent *Halimeda* species with the same species distribution found in the Paleogene of the Moroccan Atlas, three species (*Halimeda opuntia, H. tuna* and *H. incrassata*) preserved the same distribution crossing all three environmental and depositional zones, such as in the Recent time, in spite of the time span evolution from 59 Ma (Thanetian) up to 41 Ma (Lutetian-Bartonian boundary). The species *Halimeda copiosa* in the Paleogene was found in the inner ramp and mid ramp zones, while today it lives in the reef-flat and in the reef slope zones, meaning it left the lagoon or inner ramp, remained in the reef-flat or mid ramp and migrated during geological time to the slope reef zone.

The Recent species *Halimeda cylindracea* of the Pacific Ocean was found only in the lagoon environmental zone, but the same species during the Paleogene covered all three zones, showing that during geological time this species migrated to the east, to the Indian-Pacific areas and lived predominantly in the lagoon zone.

Halimeda monile and *H. simulans* occupied different zones during the Paleogene and they are not comparable with the distribution of Recent species. *Halimeda monile* lives in the lagoon and *H. simulans* lives only in the reef-flat, and it does not correspond to environmental zones during the geological past.

A comparison can be done between the Upper Miocene reefs of SE Spain and those of the Mediterranean region (Messinian Upper Evaporite sensu Dabrio et al. 1981; Esteban, 1996), corresponding to the fringing reefs on the shore and island reefs archipelagos (Fig. 20). Unfortunately, based only on petrographic quantitative investigation regarding reef-slope facies (rich and poor) and *Halimeda* clasts, without species discrimination, it is difficult to compare Miocene data to the results of Paleogene *Halimeda* facies from Morocco.

In the Miocene reefs of SE Spain, Esteban (1996) distinguished the reef-core with *Porites* corals as a dominant component and a proximal reef-slope facies divided in two subfacies: the *Halimeda*-poor to the
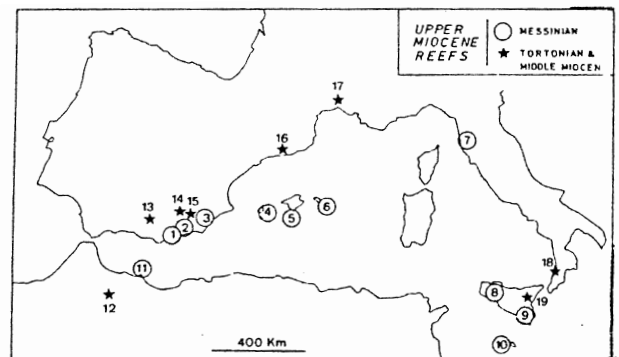
Fig. 20 Distribution of Upper Miocene reefs in the Mediterranean sea (modified after Esteban, 1979): 1. Almeira, 2. Murcia, 3. Alicante,4. Ibiza, 5. Mallorca, 6. Menorca, 7. Livorno, 8. Western Sicily, 9. Southeastern Sicily, 10. Malta, 11. Melilla,12. Taza, 13. Granada, 14. Almanyora River, 15. Murcia (Fortuna), 16. Barcelona, 17. Languedoc, 18. Calabria , 19. Central-Northeastern Sicily.

Halimeda-rich facies, and the distal slope facies. It is possible that the Miocene fringing reefs of the Mediterranean area grew more or less on the carbonate ramp platforms, occurring on or near the shores.

According to the cited data, the fossil halimedaceans are recorded from restricted lagoon on the inner ramp (*Halimeda*-poor) up to the open lagoon with patch-reefs represented by coralgal and bryalgal facies possible corresponding to the middle ramp (*Halimeda*-poor) and to the outer ramp to the open sea (*Halimeda*-rich).

A synthetic stratigraphic range for different *Halimeda* species was published by Dragastan et al. (2002) from the late Miocene up to the Recent times (Fig. 21).

Halimeda species	Late Miocene	Pliocene	Pleistocene	Recent
H. discoidea	▰	▰	▰	▰
H. gracilis	▰			▰
H. cylindracea	▰			▰
H. monile	▰			▰
H. bikinensis	▰		▰	▰
H. incrassata	▰			▰
H. tuna	▰		▰	▰
H. tuna f. platydisca	▰	▰		▰
H. fragilis		▰		▰
H. simulans		▰		▰
H. cf. bikinensis		▰		▰
H. opuntia		▰		▰
H. opuntia f. triloba			▰	▰
H. micronesica			▰	▰
H. opuntia f. opuntia			▰	▰

Fig. 21 Stratigraphic range of *Halimeda* species during late Miocene- Pliocene- Pleistocene and Recent, black bar -main stock phyletic lineages of the " fossil species", dark gray bar, common species and light gray bar, rarely encountered (after Dragastan et al. 2002).

For the upper Miocene reefs, *Halimeda* occurs primarily in the proximal reef-slope and it is concentrated in beds that make up about 20 % of the proximal slope deposits, being the dominant biotic component in the *Halimeda*-rich subfacies. In situ accumulation of *Halimeda* is difficult to prove, because its segments disarticulated upon death, and they could be easily transported in suspension (Moore et al., 1976).

It is also noted that the limited associations of *Halimeda* with other organisms, such as microflora and fauna (green algae, bivalves, gastropods, bryozoans or echinoids) in the Paleogene Bekrit-Timahdit Formation suggest (as far as for the upper Miocene reeefs) a spatial isolation of *Halimeda* from other organisms accompanied by a temporal separation, repetitive changes in the water quality, from restricted to normal, and a cyclic sedimentation, all consistent with the sea level changes and episodic upwelling intervals (Herbig, 1991; Kuss and Herbig, 1993).

Different factors have been invoked to explain the *Halimeda* distribution on the Paleogene carbonate ramp. One factor is the temperature, both fossil and Recent *Halimeda* species being restricted to tropical and subtropical conditions. Some Recent and fossil species like *Halimeda incrassata* and *H. opuntia* responded to seasonal warming and grew more rapidly than other species, such as *H. tuna* and *H. copiosa*.

The nutrients are another factor for *Halimeda* species' proliferation, produced in nutrient-rich waters, whereas the scleractinian corals can better compete in the nutrient-poor waters. Maybe this contradiction is the answer to the question: why in the Paleogene Bekrit-Timahdit Formation from Middle Atlas, the coral patch-reefs are so rarely recorded while the rate of *Halimeda* productivity was so high in the area, but not so diversified at the species level, as in the central High Atlas. Some species of *Halimeda* concentrated in the areas where the amount of nutrient influx was produced, mainly in the frame of upwelling currents.

The most efficient reef builders were recorded first in the Danian, up to early Eocene, within reef mounds, and afterwards starting with the Middle Eocene, within framework reefs. During the Moroccan Paleogene the reefs were sparse as builders. Salinity is another factor, the majority of *Halimeda* species are today more or less stenohaline, and they grow in normal marine, euhaline waters, but for short intervals they support salinity variations between 18-30 ‰.

Bathymetry and light are two important factors for the *Halimeda* species. *Halimeda* grows from very shallow depth under low tide and reaches over 150 m depths in the modern environments, a major role being played by different substrates. A bathymetric zonation for some Recent *Halimeda* species has depth intervals:

1. 0-30 m depth is preferable for Recent *Halimeda tuna, H. opuntia, H. copiosa, H. macroloba, H. monile* and *H. incrassata*. It is possible also for the fossils *Halimeda nana* and *H. praeminima* n. sp. lived in this bathymetric interval;

2. 30-50 m depth is the interval preferred by *Halimeda cylindracea, H. simulans*, also *H. tuna* and *H. opuntia*;

3. over 50 m (100 m) depths live the Recent species *Halimeda opuntia, H. tuna, H. copiosa* and *H. fragilis.* Other species like *Halimeda copiosa, H. gracilis* and *H. lacrimosa* live at 152 m and even over, corresponding to the maximum depths for this stock of green algae (Fig. 22).

It is difficult to compare *Halimeda* Paleogene species with Recent species in terms of bathymetry, because the fossil species are desarticulated in segments. The Recent *Halimeda* species prefer a typical substrate, for example *Halimeda incrassata* prefers unconsolidated sandy-muds, while *H. opuntia* prefers rock surfaces and *H. tuna* prefers broken corals or rocks (Fig. 22).

The proliferation of *Halimeda* is optimal in the euphotic zone, where the light is intense, but it can occur also in the upper dysphotic, with not so intense light. A high rate of sedimentation and a rapidly shifting substrate has a great influence for colonies and growth rates of different *Halimeda* species.
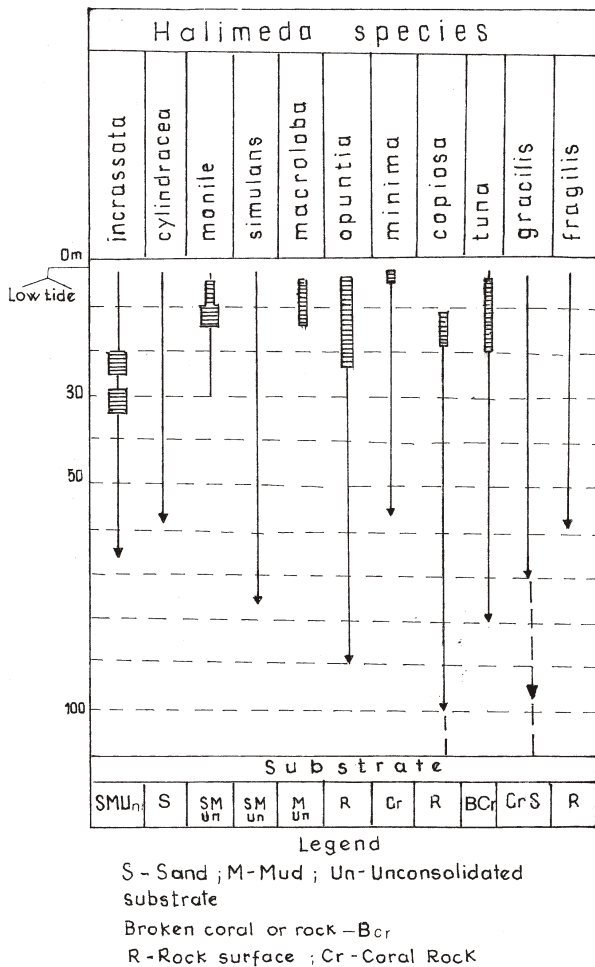
Fig. 22 The substrate and bathymetric distribution of some Recent *Halimeda* species (compilation after Hillis-Colinvaux, 1980, Blair and Norris, 1988, Littler et al. 1989 and Littler and Littler, 2000, 2003).

The Paleogene *Halimeda* microflora of the Moroccan Atlas is more diverse, this fact contrasting with the occurrence of a few coral-scleractinian reefs, of few patch-reef buildups on the carbonate ramp platforms. Such a basin is not much favourable to fulfill the conditions to build real reefs. The deposits with *Halimeda* produced coarse, cemented packstone and grainstone with sparse or without scleractinian corals, but including molluscs, gastropods and benthic foraminifers.

The rocks are comparable with the Recent *Halimeda* banks or bioherms with epibenthic community, without reefs in the Nicaragua Rise, in SW Caribbean (Hine et al.,1988). The accumulation of entire and of broken thalli segments of *Halimeda*, more or less in a horizontal plane or rarely in disorder, documented the occurences of *Halimeda* algal buildups as bank bioherms in the Paleogene of Morocco.

In the Bekrit-Timahdit Formation of the Middle Atlas, a relationship between rich *Halimeda* bioherms or banks and the sparse occurrence of scleractinian reefs could have been possible. The packstone and grainstone with *Halimeda* bioherms or banks indicate a high concentration of *Halimeda* segments, along with dasycladaleans, foraminifers and rare debris of bivalves, bryozoans and gastropods.

A comparison between Recent and fossil *Halimeda* from the Paleogene of the Moroccan Atlas and the Recent *Halimeda* of banks described in the northern part of the Great Barrier reefs (Marshall and Davies, 1988) is possible.

The *Halimeda* segments from Bou Angueur area reached 71% during the Thanetian, and 60-82 % participation of segments during the Ypresian, in Timahdit area. These values are similar to the Recent lagoonal *Halimeda* segments of the Caribbean Sea and they are more appropiate to the Funafuti reef from Pacific Ocean, with a *Halimeda* participation up to 77%. In the Florida Keys, the bioclasts of *Halimeda* are dominant nearshore and commonly comprised between 30-40% of the carbonate sands in the inner shelf, and 30-50% of *Halimeda* segments and coral debris sands in the outer shelf (Enos, 1977; Lidz and Hallock, 2000).

Provincialism could be another factor which can influence the distribution of the *Halimeda* species. The provincialism of *Halimeda* species is related first to facies and to the paleogeography of the sedimentary area during the Paleogene interval, influenced directly by the direction of the thermohaline line crossing the Neo-Tethys Ocean. *Halimeda* species are stenobiontic, requiring a stable and uniform environment, in the same time they are eurytopic, with a narrow range of tolerance for variations of particular environmental factors.

In the Middle Atlas and central High Atlas, the terrigenous inputs from the coastal plains up to the inner and middle carbonate ramp and the phosphatic facies in the outer ramp, as recorded in the westernmost outcrops, contributed to the decrease in producing calcareous skeletons and indirectly to the impoverishment of the halimedacean and dasycladalean flora, but only in this part of the basin (Herbig, 1991; Kuss and Herbig, 1993).

The fossil flora and fauna were altered in various limits by transportation.

The fossil *Halimeda* community may be objectively investigated statistically to discriminate the dominant or primary species with over 10 % participation, less dominant or secondary around 5 %, and poor under 5 %. Waterhouse (1976) used two characteristic species „Kennarten", corresponding to the index species and „Trennarten", corresponding to the discriminant species. The Thanetian association of *Halimeda* species of central High Atlas (Dragastan and Herbig, 2007) was investigated statistically for dominance analysing the percentage participation of taxa. In this way, it was possible to separate „Kennarten" or dominant (abundant) species, such as *Halimeda incrassata* (24%), *H. cylindracea* (20%) and *H. nana* (17 %), while „Trennarten"species were identified as *H. marcconradi*, *H. unica*, *H. monile*, *H. praetaenicola*, all under 10% participation (Fig. 23). The category of species poor or minor in terms of participation (under 4% or up to 4%) are: *Atlasinium erikfluegeli* (green alga, Praecodiaceae), *Halimeda lacunosa*, *H. barbata* and *H. opuntia*. The same quantitative method has been applied for the Ypresian and Lutetian-Bartonian *Halimeda* associations. During the mid and late Ypresian, the „Kennarten" or dominant species are *Halimeda tuna* (31%) and *H.*
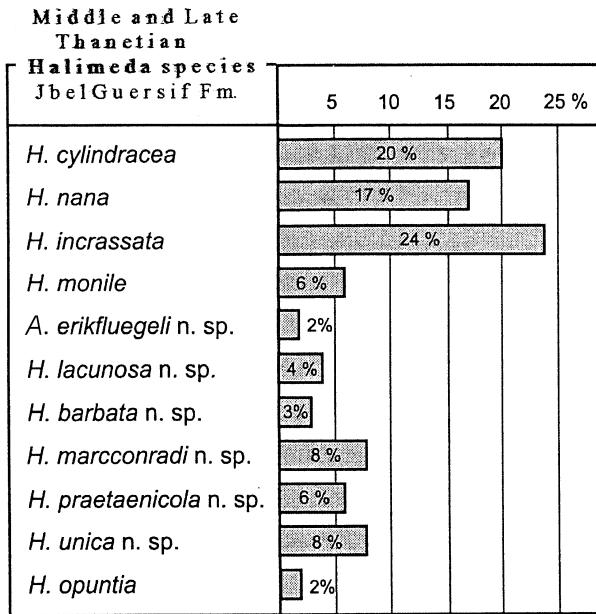
Middle and Late Thanetian Halimeda species JbelGuersif Fm.

	5	10	15	20	25 %
H. cylindracea			20 %		
H. nana		17 %			
H. incrassata			24 %		
H. monile	6 %				
A. erikfluegeli n. sp.	2%				
H. lacunosa n. sp.	4 %				
H. barbata n. sp.	3%				
H. marcconradi n. sp.	8 %				
H. praetaenicola n. sp.	6 %				
H. unica n. sp.	8 %				
H. opuntia	2%				

Fig. 23 The percentage participation of *Halimeda* species during Thanetian of the central High Atlas (after Dragastan and Herbig, 2007).

opuntia (21%). The rest of *Halimeda* species have variable dominance trends, between 1% and 9%: *H. opuntia* f. *triloba*, *H. tuna* f. *platydisca* (1%), *H. incrassata*, *H. gracilis*, *H. copiosa* (4%), *H. cylindracea*,
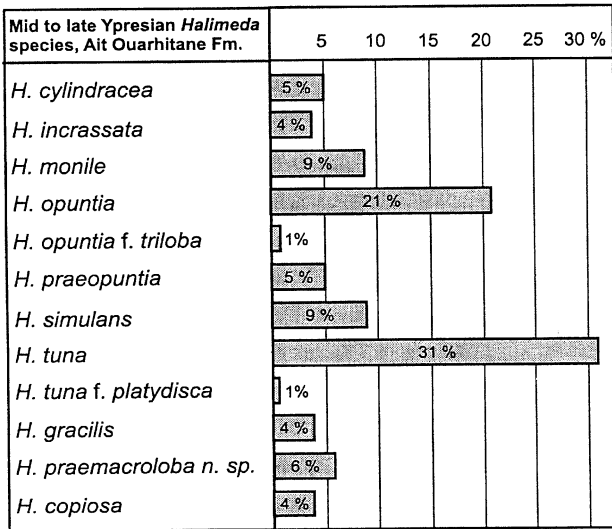
Mid to late Ypresian Halimeda species, Ait Ouarhitane Fm.

	5	10	15	20	25	30 %
H. cylindracea	5%					
H. incrassata	4 %					
H. monile	9 %					
H. opuntia			21 %			
H. opuntia f. triloba	1%					
H. praeopuntia	5 %					
H. simulans	9 %					
H. tuna				31 %		
H. tuna f. platydisca	1%					
H. gracilis	4 %					
H. praemacroloba n. sp.	6 %					
H. copiosa	4 %					

Fig. 24 The percentage participation of *Halimeda* species during mid to late Ypresian of the central High Atlas (after Dragastan and Herbig, 2007).

H. praeopuntia (5%), *H. praemacroloba* (6 %), *H. monile* and *H. simulans* (9%). All these taxa with small percent participation represent assemblage species (Fig. 24).

During the Lutetian- Bartonian inerval, the *Halimeda* species had also two dominant species: *H. tuna* (40%) and *H. opuntia* (18%), similar in percentages of the same species found during the Ypresian, but they can not be used as index or characteristic species for Lutetian-Bartonian interval. The other *Halimeda* species from the same stratigraphic interval have the following quantitative participation in associations: *Halimeda simulans* (10%), *H. praecuneata* (9%), *H. cylindracea* (6%), *H. tuna* f. *platydisca* (6%), *H. fragilis* (4%), *H.*

praegoreauii, H. monile, H. gracilis and *H. scabra,* all last three species only 1% (Fig. 25).

Lutetian- - Bartonian Halimeda species, Jbel Tagount Fm.

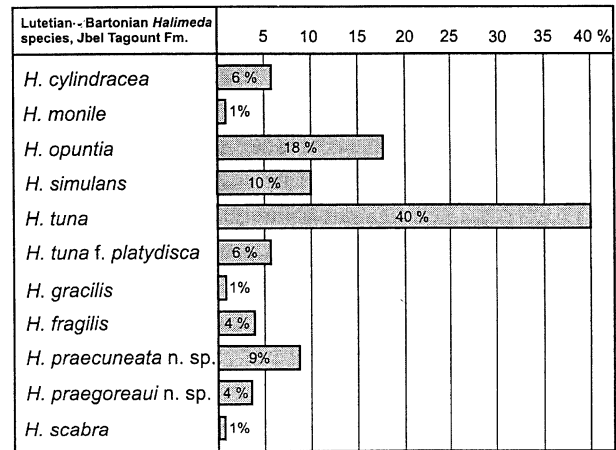|	5	10	15	20	25	30	35	40 %
H. cylindracea	6 %							
H. monile	1%							
H. opuntia			18 %					
H. simulans	10 %							
H. tuna								40 %
H. tuna f. platydisca	6 %							
H. gracilis	1%							
H. fragilis	4 %							
H. praecuneata n. sp.	9%							
H. praegoreaui n. sp.	4 %							
H. scabra	1%							

Fig. 25 The percentage participation of *Halimeda* species during Lutetian-Bartonian of the central High Atlas (after Dragastan and Herbig, 2007).

Boucot (1975) considered that the distribution of benthic assemblages in various floral or faunal provinces have a spatial and temporal boundaries frame which can be classified in realms. Fossil communities are recognized on the basis of species distribution with regard to lithofacies, salinity, water depth, temperature and associated biota other than halimedaceans (red algae, foraminifers, bivalves, gastropods, bryozoan, echinoids in the case of the Moroccan Atlas, see Herbig, 1991, 1997). The paleoalgal provinces can be incorporated in realms defined by paleobiological factors. In the case of the Moroccan Atlas, the large distribution of *Halimeda* species in direct relations with the carbonate ramp, and with the distribution of reefs, can be included in a regional, global model of carbonate platforms, such as that proposed by Kiessling et al. (2003). In the Recent time only two coral reef provinces are recognizable, the Indian-Pacific and the Antlantic (Wells, 1969). The halimedaceans and dasycladaceans are restricted to only one province: the tropical to subtropical areas with the water temperature of 25°C (including the majority of *Halimeda* species) and subsequently the areas with a water temperature of about 15°-20°C, such as the Mediterranean, where only two species, *Halimeda copiosa* and *H. tuna* live.

An answer for a *Halimeda* paleoprovince in the North African-Arabian area including the Mediterranean basin could be related to the global distribution of carbonate platforms which covered this region (Kiessling et al., 2003).

During the middle Paleocene-early Eocene (Ypresian), the shelf was represented mostly along the west to north-west, and along the north and central African margin, including some Mediterranean areas. During the Lutetian, more was covered over smaller sized areas in the north-west and east Africa, but more to the eastern part of the Arabian peninsula (Syria, Iraq, Iran) and Mediterranean area, including Turkey, Serbia, Sicily, Italy, France, Spain, Belgium and up to the south of England. In exchange, starting with late the Eocene (Priabonian), these platforms declined drastically, as no

carbonate platform developed in the western and northern Africa. They survived only in east Africa and in the Arabian peninsula, thus influencing the scarcity of *Halimeda* species associations during the late Eocene in the Morrocan Atlas and in the Mediterranean area.

The quantitative contribution of benthic organisms, such as calcareous algae, especially halimedaceans, dasycladaceans and foraminifers, to carbonate production is substantial, whereas the reefal constructions (bindstone, patch-reefs, reefs) are rare or moderate in the Moroccan Atlas carbonate ramps.

The Thanetian (late Paleocene) *Halimeda* species assemblage from the central High Atlas contains a total of 10 species, including 6 fossil species, possible an endemic character for the west and north African area: *Halimeda nana, H. marcconradi, Atlasinium erikfluegeli* (Praecodiaceae Family, in Dragastan, 2008), *H. praetaenicola, H. lacunosa, H. unica*. It includes also other 4 fossil *Halimeda* species (including Recent representatives): *H. cylindracea, H. opuntia, H. incrassata* and *H. monile* (Fig. 26).

Comparing the stocks of *Halimeda* species from both regions, the number of fossil species is different (10 species in central High Atlas and 7 species in Middle Atlas). Both regions had 7 common *Halimeda* species, a

Fig. 27 Paleogene stratigraphic range of *Halimeda* species of the Middle Atlas (MA).
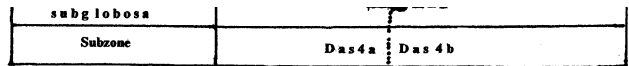
Fig.27

new species, *Halimeda praeminima* only in the Middle Atlas, and 3 *Halimeda* species missing in the Thanetian of the Middle Atlas: *H. praetaenicola, H. barbata* and *H.marcconradi*. The 4 fossil *Halimeda* species with Recent representatives from Morocco have a pantropical distribution (*H. incrassata, H. opuntia*), while others (*H. monile*) occur in the western Atlantic. *Halimeda cylindracea* occurs in the central to the eastern part of the Indian Ocean and also in the western Pacific (Hillis-Colinvaux, 1980; Littler and Littler, 2003). During the Ypresian (early Eocene), the *Halimeda* species assemblage from the central High Atlas contains 11 species: only 2 fossil species, *H. praemacroloba* and *H. praeopuntia*, and 9 fossil species with Recent representatives, *H. cylindracea, H. opuntia, H. incrassata, H. monile, H. copiosa, H. simulans, H. tuna, H. gracilis* and *H. fragilis* (Fig. 26). In the Lutetian-Bartonian? interval (middle Eocene), 10 *Halimeda* species were recorded: *H. cylindracea, H. opuntia, H.incrassata, H. monile, H. simulans, H. tuna, H. gracilis, H. fragilis, H. praecuneata, H. scabra* and *H. praegoreauii*. In the Middle Atlas, during the Ypresian-Lutetian (early to middle Eocene), the *Halimeda* species assemblage contains 11 species: 2 fossil species, *H. praemacroloba, H. praeminima* n. sp. and 9 species with Recent representatives: *H. fragilis, H. copiosa, H. tuna, H. simulans, H. opuntia, H. gracilis, H.*
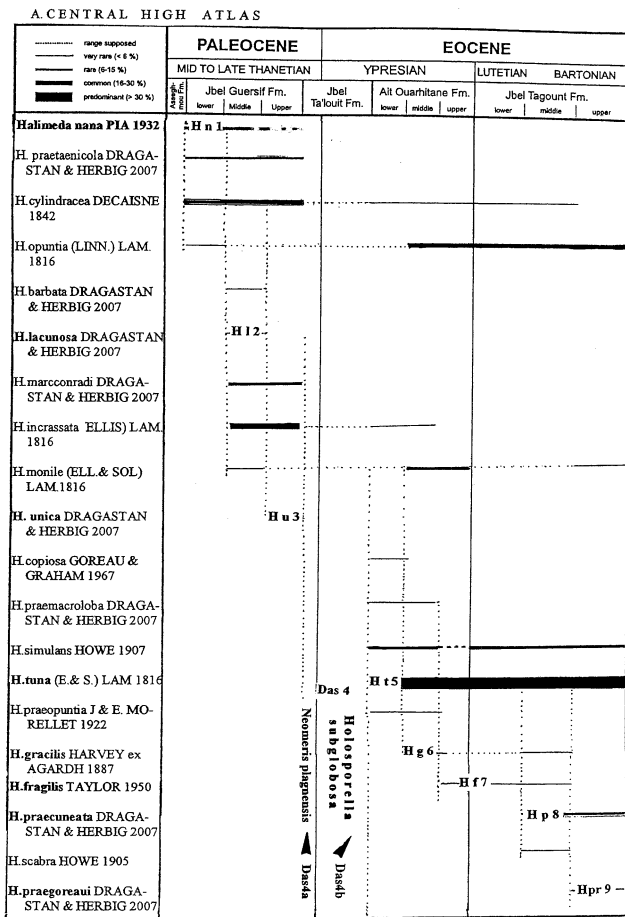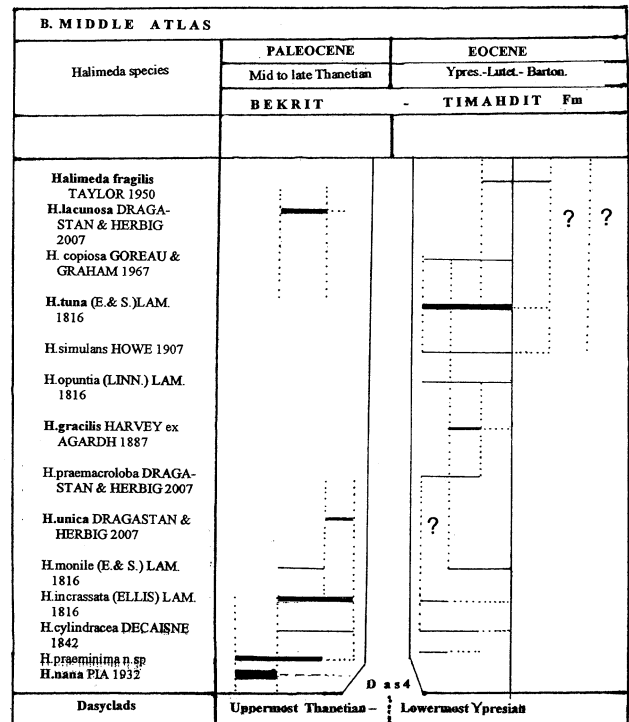

Fig. 26 Paleogene stratigraphic range of *Halimeda* species of the central High Atlas.

In the Middle Atlas during the Thanetian, the *Halimeda* species assemblages contain a total of only 7 species, including 4 species known only as fossils: *H. lacunosa, H. unica, H. praeminima* n.sp. and *H. nana*. Only 3 *Halimeda* species are have recent representatives: *H. lacunosa, H. monile, H. incrassata* and *H. cylindracea.* (Fig. 27).

monile, H. incrassata and *H. cylindracea* (Fig. 27). The maximum number of species is recorded for the Ypresian (early Eocene) interval, as no confident Lutetian (middle Eocene) assemblage was recorded in this region.

The total number of Lutetian *Halimeda* species counts 10 taxa, characteristic only for the central High Atlas, but not for the Middle Atlas. Starting with the Lutetian, the *Halimeda* species association is poor and reduced in diversity in the Middle Atlas, due to the non-carbonatic deposition and to the change of basin type. No *Halimeda* species was identified during the late Eocene (Priabonian) in the central High Atlas and in the Middle Atlas, as a large evaporitic basin developed, with the deposition of gypsum, sandstone and terrestrial mudstone, under dry climate conditions.

Considering the data on fossil and Recent *Halimeda* species, we state that starting with the Paleogene, a large paleoprovince was configured in the area of NW and NE African-Arabian and Circum-Mediterranean basin. It is a supposition that this palaeoprovince represents an endemic centre for many *Halimeda* species, such as *H. nana, H. praeminima, A. erikfluegeli, H. praeopuntia* and also for fossils and Recent species.

A major problem remains the spreading of fossil and Recent species, especially the Paleogene spreading, one towards the Atlantic Ocean and another, towards the Indian and Pacific Oceans. A paleoprovince can be defined considering the species diversity. When the diversity is high or relevant, it can be related to the stability of environmental, climatic conditions during a time interval, and in carbonate platforms. Such is the case of Paleogene *Halimeda* from north African-Arabian and circum-Mediterranean province. Silva (1992) showed that the species diversity defined by biogeographers corresponds to the total number of species occurring in a given area. By contrary, the ecologists consider usually the number of species to be only one element of species diversity (richness), the second element is the equitability or the evenness, in the representation of the component species by groups or families.

In the central High Atlas area during the Paleogene – middle Eocene (Thanetian-Bartonian), the *Halimeda* species have been represented by 21 taxa, including *H. praeminima* n. sp. From this stock of taxa, 10 are new fossil species and can be considered endemic, and 14 taxa are fossil and non-endemic species with Recent representatives. A cause for the endemism of certain Paleogene species in the area of African – Arabian – Mediterranean (AfArMed) province was the special basin type with carbonate ramps, influencing the spreading of species only on the margins of the province, like a spot of insular colonization (Silva, 1992).

In the Middle Atlas the *Halimeda* stock of species is less diverse including, only 14 species in the Timahdit area, and 12 species in the Bekrit area. The *Halimeda* association is represented by one new species (*H. praeminima* n. sp.), 5 fossil species (*A. erikfluegeli*, transferred to the *Atlasinium* nov. gen. of the Preacodiaceae Family, introduced by Dragastan (2008), (*H. unica, H. praemacroloba, H. lacunosa, H. nana*) and 8 fossils species with Recent representatives (*H. gracilis, H. copiosa, H. tuna, H. simulans, H. opuntia, H. monile, H. incrassata* and *H. cylindracea*). In our estimation were not considered the Paleogene dasycladaleans from published sources, more diverse in the Egypt-Libya-Tunis area (Kuss and Herbig, 1993, Dragastan and Soliman, 2002) and less diverse in the Moroccan Atlas (Dragastan and Herbig, 2007).

A great diversity is shown by microfloras in the area of the basin with transtional features from warm to cool temperate coasts, as the *Halimeda* stock of species shows in the area of the Moroccan Atlas. Herbig (1991) and Kuss and Herbig (1993) showed that the reasons for impoverished floras in the case of dasycladaleans and halimedaceans seem to be a combination of several factors. These factors point to a large embayment basin connected to the Atlantic Ocean, possible extrabasinal barriers, missing migration routes and the occurrence of upwelling and transitional currents, from warm to cool temperate. The participation ratio (%) of green algae, between halimedaceans and dasycladaleans (H/D) from different areas, as counted segments in thin sections of the Middle Atlas during the Thanetian, similar with the Bou Angueur section MA-6, the participation ratio for *Halimeda* entire segments (Hes) is of 48 % and for *Halimeda* debris segments (Hds) is of 52%. The ratio between *Halimeda* segments and dasycladaleans thalli (H/D) is 71 % against 29 %. Such data indicated a maximum dominance during the Thanetian of the halimedaceans against the dasycladaleans represented by less thalli debris (Fig. 28). In the same area but during the Ypresian, in section Timahdit MA-8a, the type locality of *Halimeda nana* described by Pia (1932), the participation ratio for *Halimeda* entire segments (Hes) is of 44% and
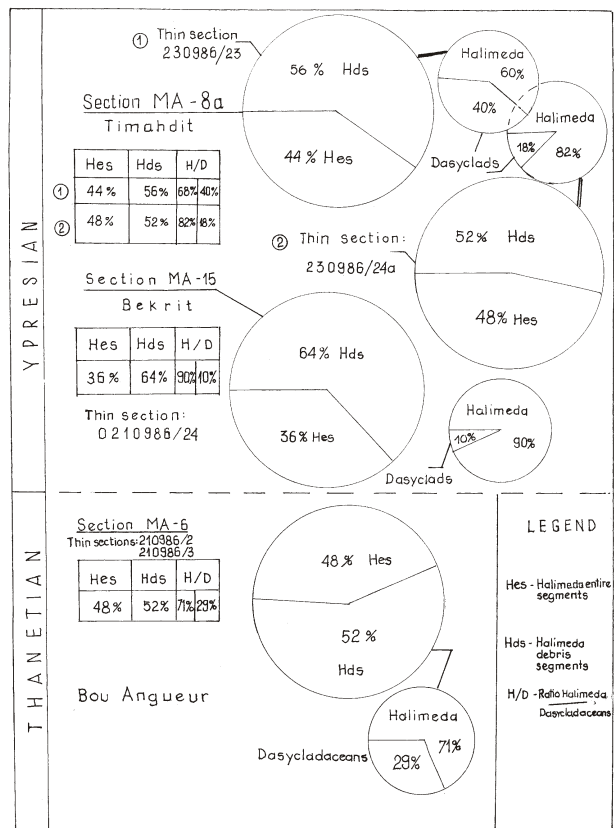

Fig. 28 The ratio participation between *Halimeda* entire and debris segments and dasycladaleans thalli (H/D) during Thanetian and Ypresian of the Middle Atlas area.

for *Halimeda* debris segments (Hds) is of 56 %. In the thin section 230986/23, the H/D ratio is 60% per *Halimeda* and 40% per dasycladaleans.

In the thin section 230986/24a, the Hds/Hes participation ratio was for *Halimeda* debris segments (Hds) up 52 % and for *H.* entire segments (Hes) is up 48 % and H/D ratio is 82 % for *Halimeda* and for dasycladaleans only 18 %, the last having no dominance. Also during the Ypresian in the Bekrit area, in section MA-15, in the thin section 0210986/24, the participation of *Halimeda* debris segments is up to 64% and for *Halimeda* entire segments is only up 36 %. The ratio between *Halimeda* segments and dasycladaleans is of 90% per 10%.

In conclusion, during Thanetian, the total number of *Halimeda* segments (debris and entire) from Bou Angueur, Section MA-6 (thin sections 210986/2-3) and the ratio of participation H/D - (halimedaceans/dasycladaleans) is of 71% / 29%, corresponds to the end of recovery phase sensu Barattolo (2002). During this phase, starts the diversification of the halimedaceans taxa.

The halimedaceans had a maximum of dominance participation during this time interval, in comparison with the dasycladaleans now in regress with only 21%.

During the Ypresian in the north-east of Middle Atlas at Timahdit-Section MA-8, the halimedaceans had a maximal variable participation between 60% up to 82% and the dasycladaleans had less participation, between a large variability from 18% up to 40%. This corresponds to the stabilization phase, with a decrease of number of genera and with the encrease of species per genus, sensu Barattolo (2002). In the south-west area, at Bekrit, in section MA-15, the halimedaceans reach the maximum of participation for the entire Middle Atlas region up to 90%, and in the same time recorded a drastical decline of dasycladaleans, with only 10% of participation.

In the Timahdit-Bekrit area, during the Ypresian, the *Halimeda* segments dominated regionally against the dasycladaleans which recorded a reduced participation. In spite of the dominance of the *Halimeda* segments and to the poor representation of dasycladaleans, the evolution of green algae during the Ypresian certifies the stabilization phase established by Barattolo (2002), only for dasycladaleans. In the Middle Atlas, during the Lutetian-Bartonian interval, the regress of green algae implied that the halimedaceans were drastically reduced, represented only by 1 species, together with rare dasycladaleans debris thalli not identifiable as a species. This fact indicated that the crisis phase of Barattolo (2002) began in north and in north-east of the African – Arabian – Circum - Mediterranean province to the end of the Lutetian and continued during the Bartonian-Priabonian. In the Middle Atlas, the carbonate ramp had an inner zone corresponding to a restricted lagoon with terrigenous imput, pedogenetic dolomite interlayers and a non active subsidence, with shallow water conditions not favourable to build real reefs. On the mid and outer ramp areas occurred patch-reefs, built by scleractinian and red algae corresponding to the coralgal facies or by bryozoans and algae, corresponding to the bryalgal facies interbedded with oyster-banks (Herbig, 1991; Geyer and Herbig, 1988).

Sea level change is an essential factor which influenced the evolution of the species by limiting the development of areas of carbonate ramps or platforms, while it is the most effective barrier for the distribution of marine organisms in a sedimentary basin. The Paleogene deposits of the Moroccan Atlas have a variable thickness between 150 m to maximum 250 m (Herbig, 1991). The *Halimeda* assemblages in these deposits were succesively controlled in diversity and richness by transgressive and regressive phases. Herbig (1991) showed, using the global sea-level curve of Haq et al. (1987) and Falkowski et al. (2004), that during the Paleocene, two transgressive phases can be recognized, one along the Selandian-Thanetian boundary and a second, during the late Thanetian or along the boundary between the Paleocene-
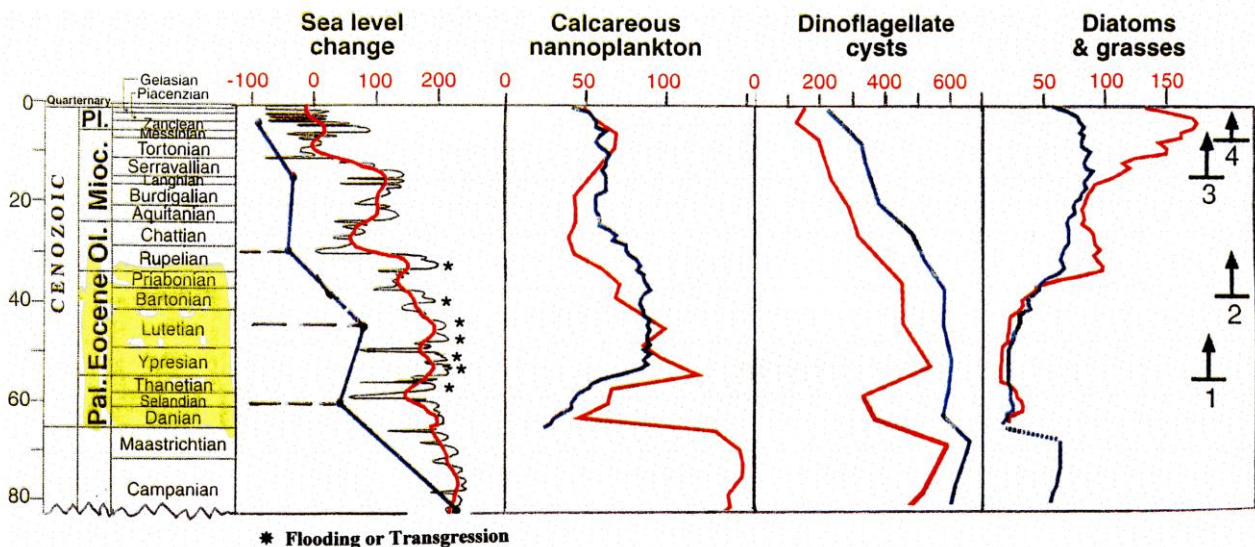
Fig. 29 Sea level change curve and the planktonic evolution of calcareous nannoplankton, dinoflagellate cysts, diatoms and calcareous benthos represented by green-algae (* flooding or transgressions) halimedaceans and dasycladaleans, adapted from Falkowski et al. (2004).

Eocene (Thanetian – Ypresian, Fig. 29). The Falkowski et al. (2004) curve shows the evolution of the main marine phytoplankton groups, such as the calcareous nannoplankton, dinoflagellates, diatoms and of the terrestrial grass, to which we add the main transgressive phases (*) connected to the evolution of benthos, respectively the green algae, such as the halimedaceans and dasycladaleans.

During the transgressive phases of the Selandian-Thanetian boundary and of the late Thanetian, the halimedaceans and the dasycladaleans flourished and proliferated on the Moroccan carbonate ramps of the Atlas areas. This time, the transgressive evolution can be included in the recovery phases separated only for the dasycladaleans. Another transgressive phase can be supposed as intra-Ypresian, up to the Ypresian-Lutetian boundary, the halimedaceans and the dasycladaleans pointing to a stabilization phase (Fig. 29).

The crisis phase in the proliferation of halimedaceans began in the late Lutetian and continued during the Bartonian and Priabonian times. In this time interval, transgressive phases occurred, but they are not so important for the Atlas area, where the carbonate ramps were dislocated by marine mudstone and evaporite deposits, like gypsum and dolomite. Swezey (2009) presented a synthetic succession for the central High Atlas, with a lithology which included limestone deposits during the Danian-Thanetian interval, followed by marine mudstone during the Ypresian-Bartonian interval, and evaporite deposits during the Priabonian. Swezey (2009) considered a sea level above present level, with a variable curve under 200 m during the Danian-Selandian interval, and above 200 m during the Thanetian-middle Ypresian. After this interval, the sea level curve remains under 200

m during the late Ypresian-Bartonian, recording the begining of a regressive tendency up to the end of the Priabonian (Fig. 30). To understand the relations between the transgressive – regressive phases and the abundance of halimedaceans or generally of the green algae, it is important to corellate the evolution of algae with climate. The climate was hot, humid, during the Paleocene times, warm and humid during the Ypresian-Bartonian interval, and finally arid, with gypsum and gypsiferous mudstone, during the Priabonian. Meantime, the flourishing phases of the benthic green siphonous algae (halimedaceans and dasycladaleans) can be correlated with the diversity and evolution of the phytoplankton (nannoplankton, dinoflagellates, and diatoms).

BIOSTRATIGRAPHIC ZONATION OF PALEOGENE *HALIMEDA*

Biostratigraphic units, or biozones, are bodies of strata characterized by fossil content or assemblages (Salvador, 1994). A biozone is based on the stratigraphic and geographic distribution of a single taxon when is index or marker, and on an assemblage of relative abundance of taxa (Acme Zone). An attempt to correlate the dasycladalean ranges or zones with foraminifers zonation on carbonate platforms at the K/T boundary has been proposed by Barattolo (1998, 2002).

In the present study we propose a biostratigraphic zonation scheme for the Paleogene using green siphonous algae, the halimedaceans from two areas of Morocco: the central High Atlas and the Middle Atlas, from the Timahdit. Because the *Halimeda* stock of species and the dasycladaleans taxa from Morocco represent benthic organisms and the correlation with other groups such as foraminifers, molluscs, bryozoans and other calcareous algae was rarely undertaken or not performed yet, the biozones proposed here have the value of Assemblage Zones.

In this case, the main principle used to define the boundaries was the first occurence or appearance of a taxon, to establish only the lower boundary of the zone. Additionally, it is possible to use the abundance of a single species (Acme Zone) or a notable change in abundance. The Paleogene *Halimeda* biostratigraphic scheme (Fig. 26) was based on the data set of the central High Atlas (Herbig, 1991; Kuss and Herbig, 1993; Dragastan and Herbig, 2007), respectively from the Jbel Guersif Formation (mid to late Thanetian), Jbel Taʹlouit Formation (uppermost Thanetian-lowermost Ypresian), Ait Quarhitane Formation (Ypresian) and Jbel Tagount Formation (Lutetian-Bartonian?).

The Paleogene biostratigraphical data sets obtained from the central High Atlas have been compared with the *Halimeda* stock of species from the Middle Atlas, to calibrate and to correlate the areas, to establish the age of the Bekrit-Timahdit Formation, an unit which was formaly assigned to the Thanetian-Lutetian and possibly to the Bartonian interval (Herbig, 1987, 1991; Trappe, 1992; and Kuss and Herbig, 1993).

In the central High Atlas, during the Thanetian interval, 11 species of *Halimeda* have been identified. The new species *H. praeminima* was described from the
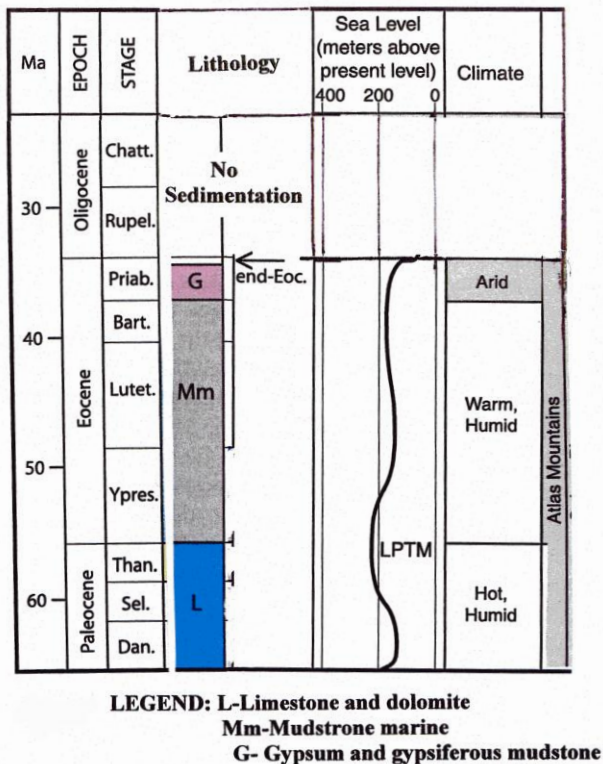

Fig. 30 Paleocene-Eocene-Oligocene lithology of central High Atlas in relation with sea level change and climate, reinterpreted from Swezey (2009).

Middle Atlas, but it was recorded in the central High Atlas.

In the Thanetian (Dragastan and Herbig, 2007), three groups of taxa were identified : 1. a single fossil species, first described from the Danian by Pia (*Halimeda nana*); 2. two Recent species (*H. incrassata, H. cylindracea* - rare) and; 3. seven fossil species (*H. praeminima* n.sp., *Atlasinium erikfluegeli, H. lacunosa, H. barbata, H. marcconradi, H. praetaenicola* and *H. unica*).

The high number of *Halimeda* species during Thanetian indicates the starting of diversification of the group and it corresponds to the Barattolo's (2002) recovery phase of dasycladaleans. During the Ypresian, the *Halimeda* number of species is also 12, including *H. cylindracea, H. opuntia, H. incrassata, H. monile, H. copiosa, H. praemacroloba, H. simulans, H. tuna, H. tuna* f. *platydisca, H. praeopuntia, H.opuntia* f. *triloba* and *H. gracilis*. The Ypresian time corresponds to the stabilization phase, it is also the maximal diversification of halimedacean spectrum of species. In the same area, during the Lutetian, the number of halimedaceans species decreases, with *Halimeda cylindracea, H. monile, H. tuna* f. *platydisca, H. gracilis, H. fragilis, H. scabra*, and *H. praegoreaui*, all under 6%, very rare as a participation. Only *Halimeda tuna* has a maximal participation over 30%, followed by *H. opuntia* with up 30% and *H. praecuneata* with up 15%. Besides the maximal participation of 2 species, *Halimeda tuna* and *H. opuntia*, the rest of halimedaceans species were in regress. Totally, during the Lutetian time interval, the number indicates the beginning of the crisis phase which corresponds to the Lutetian dasycladaleans crisis. During the Lutetian, the percentage of new originating species is low and the ratio between fossil and Recent taxa is also favourable to the latter. The crisis was accentuated during the Bartonian, when the halimedaceans species count only 2-5 species in this time interval, such as *Halimeda scabra, H. praegoreaui, H. tuna, H. fragilis* and *H. opuntia* scarce and represented by thalli debris.

The abundance of *Halimeda* species in the central High Atlas, with 21 species, and only with 14 species in the Timahdit-Berkit Formation of the Middle Atlas, was probably restricted due to the morphology of the basin, with a narrow carbonate ramp, to the sea level changes, and to the connections with the Atlantic Ocean.

The halimedacean taxa recorded along the Permian-Triassic boundary *Saxonia pygmaea* Gebhardt et Schneider 1993 and „*Halimeda*" *soltanensis* Poncet 1989 should be accepted as morphospecies, as they represent parts or morphs of Halimedaceae, as all types of thallus segments are unknown, opposite to the modern taxa. The Mesozoic stock of taxa such as the Triassic – Cretaceous *Halimeda,* the Carnian *Collarecodium oenipontanum* Bradner and Resch 1980 and other new Triassic genera described by Senowbari-Daryan and Zamparelli (2005), some species of *Arabicodium*, etc., considered by these authors as halimedaceans (now transferred to Family Boueineae), must be restudied, as well as some of the species around the K/T boundary. The oldest halimedacean taxon described is *Saxonia pygmaea* Gebhardt et Schneider 1993, described from the Lower

Permian of the Döhlen Basin (Germany), in a lacustrine facies with clasts of reworked marine, dasycladalean algae (*Mizzia* sp., Pl. 1, Fig. 4 in Gebhardt and Schneider, 1993), as well as *Saxonia pygmaea*. To validate the species *Saxonia pygmaea*, we elect as lectotype only the specimen figured in Plate 2, Figure 2 of the original paper of Gebhardt and Schneider (1993), thus becoming *Saxonia pygmaea* (Gebhardt and Schneider 1993) Dragastan et al., this paper.

If the Paleogene halimedacean taxa are well known and studied, during the Oligocene occur many unknown *Halimeda* species. During the Miocene, some time intervals with *Halimeda* species are well known, but other still remain unstudied (Dragastan et al., 2003). The Pliocene-Pleistocene *Halimeda* species were studied from drillings crossing the Bahamas carbonate platform (Dragastan, 2007).

The modern studies regarding the fossil *Halimeda* species of Miocene, Pliocene and Pleistocene age of Palau-Angaur, in the Pacific Ocean and of the Key Largo (Miami Formation), Florida, in the Atlantic Ocean, expanded the knowledge about the *Halimeda* assemblages and about the stratigraphic range of fossils, from late Cretaceous to the Recent times (Dragastan et al., 2002, 2003, Fig. 31 in this paper).

A first attempt to use the *Halimeda* species for Paleogene biostratigraphic zonation is based mainly upon the data obtained of the Moroccan Atlas region.

For another time interval, a wide distribution of *Halimeda* species was described by Manckewicz (1988) in the Miocene deposits of the Circum-Mediterranean
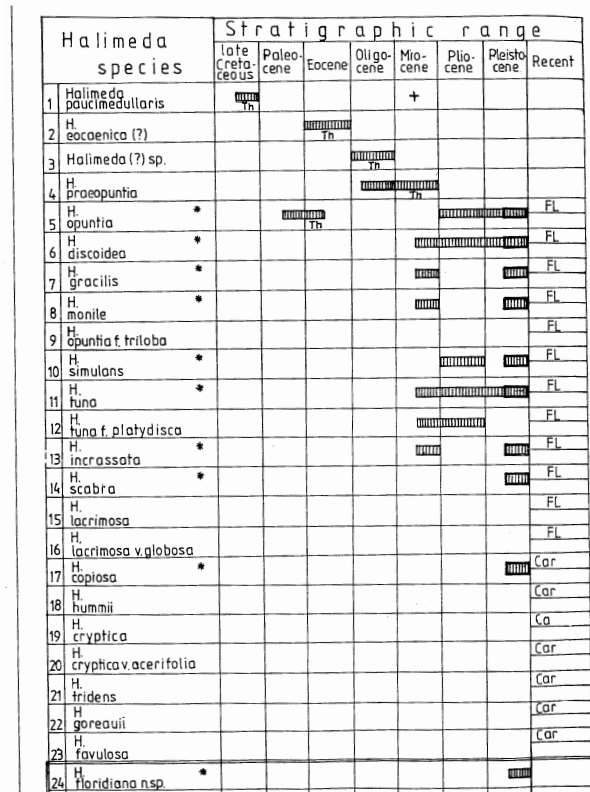
Halimeda species	Stratigraphic range							
	late Creta-ceous	Paleo-cene	Eocene	Oligo-cene	Mio-cene	Plio-cene	Pleisto-cene	Recent
1 Halimeda paucimedullaris	Th				+			
2 H. eocaenica (?)			Th					
3 Halimeda (?) sp.				Th				
4 H. praeopuntia				Th				
5 H. opuntia	*		Th					FL
6 H. discoidea	*							FL
7 H. gracilis	*							FL
8 H. monile	*							FL
9 H. opuntia f. triloba								FL
10 H. simulans	*							FL
11 H. tuna	*							FL
12 H. tuna f. platydisca								FL
13 H. incrassata	*							FL
14 H. scabra	*							FL
15 H. lacrimosa								FL
16 H. lacrimosa v. globosa								FL
17 H. copiosa	*							Car
18 H. hummii								Car
19 H. cryptica								Ca
20 H. cryptica v. acerifolia								Car
21 H. tridens								Car
22 H. goreauii								Car
23 H. favulosa								Car
24 H. floridana n.sp.	*							

Fig. 31 Stratigraphic range of *Halimeda* species of the late Cretaceous till Pleistocene and Recent (from Dragastan et al. 2003).

area. This wide distribution was coupled to the repetitive changes (from normal to restrictive conditions) suggesting the possibility that *Halimeda* beds in different complex succesions might be correlative.

From a biostratigraphic point of view, during the Paleogene of the Moroccan Atlas were distinguished different kinds of *Halimeda* taxa groups:

1. Taxa with short stratigraphic range, some endemic taxa or taxa developed between transgressive and regressive phases, such as in the central High Atlas and in the Middle Atlas;

2. Long stratigraphic range taxa, crossing some stages and also epochs;

3. Taxa with local, or shorter stratigraphic range, controlled by the depositional system, such as terrigenous or evaporitic sediments, by the environmental influences, and by climate change;

The species with long stratigraphic range crossing the stages and epochs are: *Halimeda cylindracea, H. incrassata, H. opuntia, H. tuna and H. tuna* f. *platydisca*, these taxa survived to Recent times.

The species with short stratigraphic range, some endemic, were favoured by local cicumstances, such as a special gulf basin with a low rate of subsidence: *Halimeda nana, H. praeminima* n. sp., *H. lacunosa, H. unica, H. praecuneata, H. praegoreauii, H. monile* and *H. fragilis,* some species survided to Recent times.

In the Middle Atlas, the inventory of Paleogene *Halimeda* species found mostly in the Timahdit area, is represented by 6 fossils species, and 8 fossils species with Recent representatives. In the Bekrit area, the assemblage is composed only by 4 fossils species, 2 fossils and Recent species, and 6 Recent species. In the Bou Angueur and Boulemane areas, occur less *Halimeda* species when compared to the Timahdit-Bekrit area, only 3 species (*Halimeda praeminima* n. sp., *H. nana, Atlasinium erikfluegeli*) and only 2 species with Recent representatives (*H. cylindracea, H. incrassata*) in the first area, and 2 fossils species (*H. praeminima* n.sp., *H. nana*) and 4 species with Recent representatives (*H. cylindracea, H. incrassata*, *H. tuna and H. gracilis*) in the second area.
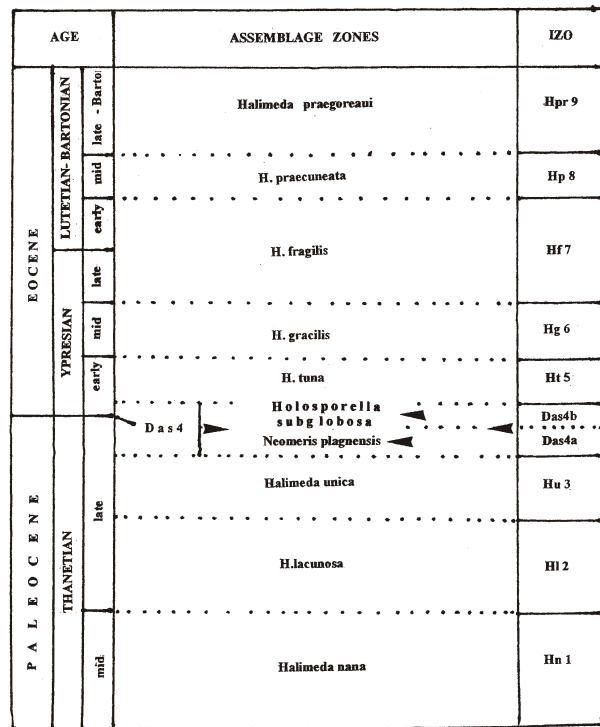
For the Moroccan Paleogene deposits of the Atlas region, the following *Halimeda* biozones are proposed.

Thanetian

The biostratigraphic interval for the middle Thanetian, lowermost part, is defined by *Halimeda nana* Assemblage Zone (Hn 1). The zone can be recognized and established by the first occurence of the species *Halimeda nana* Pia (Pl. 2, Figs. 1-7, Pl. 3, Figs. 1-9), which corresponds to the lower limit or to the biohorizon of this stratigraphic unit (Fig. 32).

During the Middle Thanetian, middle part, the *Halimeda nana* displays large cylindrical segments becoming more frequent (Pl. 2, Figs. 1-7). The maximum dominance of *Halimeda nana* thalli was recorded during the Middle Thanetian, at its uppermost part (Pl. 4, Figs.1-6, Pl. 5, Figs. 1-4) and the extinction of this species was recorded in the *Halimeda unica* Assemblage Zone (Hu2) during the Late Thanetian, upper part (Pl.7, Fig. 4). The assemblage of this *Nana* zone includes also the species *Atlasinium erikfluegeli* (Dragastan and Herbig,

AGE			ASSEMBLAGE ZONES	IZO
EOCENE LUTETIAN-BARTONIAN		late - Bart(o)	Halimeda praegoreaui	Hpr 9
		mid	H. praecuneata	Hp 8
		early		
	YPRESIAN	late	H. fragilis	Hf 7
		mid	H. gracilis	Hg 6
		early	H. tuna	Ht 5
			Holosporella subglobosa	Das4b
		Das 4	Neomeris plagnensis	Das4a
PALEOCENE	THANETIAN	late	Halimeda unica	Hu 3
			H. lacunosa	Hl 2
		mid	Halimeda nana	Hn 1

Fig. 32 Paleogene biostratigraphic scale using the *Halimeda* Assemblage Zones for the Moroccan Atlas areas (central High Atlas and Middle Atlas).

2007) Dragastan 2008 (in this paper Pl. 9, Figs. 1-2), *Halimeda praeminima* n. sp. (Pl.1, Figs. 4, 7, 11-12, 15-18), *H. praetaenicola* Dragastan and Herbig. The assemblage is oligotypic, dominated only by the *Halimeda nana* marker species. In the type locality of Timahdit section, this species reached an abundance over 40% from the total of Thanetian *Halimeda* species. An infrequent presence in the assemblage are dasycladaleans, *Neomeris craniphora* (Morrellet) Pia, *Acicularia* sp., *Neomeris* sp. and the foraminifers (globorotaliids and miliolids).

The Late Thanetian included two biozones, the first (lower part) with *Halimeda lacunosa* Dragastan and Herbig, and a second (upper part) with *H. unica* Dragastan and Herbig (Fig. 10, Fig. 3).

The *Halimeda lacunosa* Assemblage Zone (Hl 2) contains *H. lacunosa*, rare *Atlasinium erikfluegeli, H. nana* (Pl. 4, Figs. 1-2), *H. incrassata* (Pl. 8, Figs. 1-2, 4-5, 10) and rare *H. cylindracea* (Pl. 6, Fig. 1). The new stock of *Halimeda* species here are *H. barbata* Dragastan and Herbig, and *H. monile* (Ellis and Solander) Lamouroux. The dasycladaleans are represented by rare *Neomeris plagnensis* Deloffre, *Neomeris defrancei* (Morrellet and Morrellet, 1922) Deloffre 1970, *Acicularia* sp. and also rare foraminifers, especially miliolids and globorotaliids.

The *Halimeda unica* Assemblage Zone (Hu 3) for the Late Thanetian, upper part, begins with the first appearance of this index species (Pl. 10, Fig. 3). The assemblage of this zone included a part of the *Halimeda* species from the previous zone, and additionally, the species *Halimeda incrassata* (Ellis) Lamouroux (Pl. 8, Figs. 7-8), *H. monile* (Ellis and Solander) Lamouroux , *H. nana* Pia, very rare (the extinction level of this species, Pl. 7, Fig. 4) and *H. marcconradi* Dragastan and Herbig. In the central High Atlas, *Halimeda incrassata* is

abundant during the Late Thanetian, with a maximum of participation up to 24 %. In the frame of this biozone, the dasycladaleans are presents by *Acicularia* sp., *Broeckella belgica* Morrellet and Morrellet, *Dissocladella deserta* Elliott, *Cymopolia paronai* Raineri, *Orioporella* aff. *villattae* Segonzac, *Carpenterella* sp., sparse Udoteaceans *Ovulites arabica* (Pfender) Massieux, *Ovulites* sp. and globorotaliid foraminifers.

Thanetian-Ypresian boundary
In both regions of the Moroccan Atlas, this boundary is difficult to define by means of lithostratigraphic units alone. In the central High Atlas, the Jbel Taʼlouit Formation crossed this boundary, and in the Middle Atlas, this boundary can be traced in the middle part of undifferentiated unit Bekrit-Timahdit Formation.

The Jbel Taʼlouit Formation corresponds to a regressive cycle, represented by greenish-grey, red siltstones and some sandstones, interlayered with marine limestone rich in algae, as a short transgressive pulse during the latest Thanetian to earliest Ypresian.

The limestones across this boundary is rich in green algae, mostly dasycladaleans and rare halimedaceans. The dasycladaleans species are important to define this boundary and this biozone (D a s 4), which spanned the interval latest Thanetian to earliest Ypresian. In the Late Thanetian, the uppermost part is marked by an important subzone (Subzone D a s 4 a) with abundant thalli of *Neomeris plagnenis* Deloffre (Pl. 8, Fig. 8, inside of the *Halimeda* thallus), *Acicularia eocaenica* Morrellet (Pl. 4, Figs. 1a, 2a) and *Ovulites* sp.

Another subzone (Subzone D a s 4 b) was identified in the Early Ypresian, its lowermost part starting with the first occurence of the dasyclad species *Holosporella subglobosa* (Dragastan and Soliman, 2002) Dragastan nov. comb., and *Acicularia* sp. aff. *eocaenica* with many thalli and with unidentifiable dasycladalean debris, also abundant in the limestones of this time interval (Fig. 32).

Dragastan and Soliman (2002) described and published *Niloporella subglobosa* n. gen., n. sp., in the limestones deposits of Late Ypresian age from Egypt, in the same time with the work of Granier and Hofmann (2002), a guide of algae from the Collection of Julius Pia, including a revision, a description, and an update of synonymy of *Holosporella siamensis* Pia 1930 emend., which has a large stratigraphic range, Triassic-Jurassic (Liassic-Kimmeridgian). Considering the emendation by Granier and Hofmann (2002) of *Holosporella* Pia, the genus *Niloporella* is a junior synonym of *Holosporella* Pia, thus the species becomes *Holosporella subglobosa* (Dragastan and Soliman 2002) Dragastan.

The halimedaceans in this limestones occur as well, but only as bioclasts not identifiable at species level. In the Bekrit-Timahdit Formation, the middle sequence with packstones-grainstones and some wackestones interlayers contains also few dasycladaleans similar to those recorded in the central High Atlas, together with *Halimeda* fragments.

The Thanetian-Ypresian boundary can be traced in the Atlas only using the dasycladalean species. Some other inconvenients regarding the difficulties of this boundary

remain: the very short time of deposition for the marine limestone facies, the terrigenous influx, the hostile environmental conditions which hindered the algae development, and the short transition time from the transgressive to the regressive phase.

Early Ypresian
This substage is marked by *Halimeda tuna* Assemblage Zone (Ht 5), disposed in the basal part of Ait Quarhitane Formation in the central High Atlas. The lower limit of this zone can be traced by the first appearance of *Halimeda tuna* (Ellis and Solander) Lamouroux (Pl. 9, Fig. 6). This marker species indicates the uppermost part of the Early Ypresian, its uppermost part age, and it reached 31% in abundance from the total of the Ypresian microflora, only in the central High Atlas. The assemblage zone contains the species *Halimeda praemacroloba* Dragastan and Herbig (Pl.10, Fig. 2), *H. simulans* Howe (Pl.10, Fig. 6), *H. praeopuntia* J.and E. Morrellet, *H. opuntia* (Linnaeus) Lamarck (Pl. 9, Fig. 5), rare *H. incrassata* (J. Ellis) Lamouroux (Pl. 8, Figs. 3, 9) and *H. cylindracea* Decaisne (Pl. 7, Figs. 1, 3).

The dasycladalean species were dominated by *Neomeris avellanensis* (Segonzac) Deloffre and Génot, *Cymopolia elongata* (Defrance) Munier-Chalmas, *Acicularia* sp., *Belzungia sp.* and rare *Neomeris sp.* as bioclasts, *Holosporella* sp. and the predominant Udoteacean *Ovulites margaritula* (Lamarck) Lam.

Middle Ypresian
This time interval is represented as marker species by *Halimeda gracilis* Harvey ex Agardh- *(Hg 6)* or *H. gracilis* Assemblage Zone (Pl. 10, Fig. 5). The first appearance of this species marks the lower limit of the zone. In association with the index species, appear a part of the species mentioned for the previous *Halimeda tuna* Assemblage Zone, but missing *Halimeda praemacroloba, H. simulans* and *H. praeopuntia*. New taxa appeared in the frame of the assemblage, such as *Halimeda copiosa* Goreau and Graham (Pl. 10, Fig. 7) and rare *H. monile* (Ellis and Solander) Lamouroux (Pl. 10, Fig. 4). The dasycladaleans are represented by *Acicularia* sp., *Neomeris* sp. and *Carpenterella* sp.

Late Ypresian-Early Lutetian
This time interval contains a distinctive assemblage zone based on index species *Halimeda fragilis* Taylor (Hf 7). This assemblage crossed the Ypresian-Lutetian boundary, and the index species has its first appearance during the Late Ypresian and continues also into the Early Lutetian, in the Jbel Tagount Formation from the central High Atlas. Some dasyclads occurs, such as *Carpenterella* sp., *Cymopolia* aff. *elongata* (Defrance), *Neomeris* cf. *limbata* (Defrance) and *Terquemella* sp. In the Middle Atlas, the index species was not recorded, but were recorded only rare, broken segments of not identifiable halimedacean debris. It is not excluded that, at this level of the Bekrit-Timahdit Formation, was a break in sedimentation or a phase with intraformationally reworked stormy sedimentation. The species association contains rare

Halimeda simulans Howe (Pl. 10, Fig. 6) and *H. tuna* (Ellis and Solander) Lamouroux (Pl. 9, Fig. 7).

The dasycladaleans are also represented by *Neomeris fragilis* (Defrance) Munier-Chalmas, *N. bipartita* Génot, *Zittelina* sp., rarely *Acicularia sp.* and the Udoteacean *Ovulites margaritula* (Lamarck).

Middle Lutetian

This substage is characterized by the *Halimeda praecuneata* Assemblage Zone (Hp 8) species, found also in the Jbel Tagount Formation from the central High Atlas (Pl. 28, Figs. 1-3 in Dragastan and Herbig, 2007). This zone was not recorded to the terminal part of the Bekrit-Timahdit Formation of the Middle Atlas. The lower limit of the zone corresponds to first appearance of the index species. The assemblage contains also *Halimeda tuna* (Ellis and Solander) Lamouroux, *H. gracilis* Harvey ex Agardh, *H. opuntia* (Linnaeus) Lamarck, *H. tuna* f. *platydisca* (Decaisne) Barton and rarely *H. scabra* Howe. Some dasycladalean species appear at this level, such as *Acicularia* aff. *heberti* Morrellet, *Cymopolia* sp., *Neomeris radiata* Morrellet, *Zittelina elegans* Morrellet and the Udoteacean species *Ovulites elongata* Lamarck.

Late Lutetian-Bartonian?

This stratigraphic interval is marked by the *Halimeda praegoreauii* Assemblage Zone (Hpr 9). The lower limit is indicated by the first appearance of the index species. The assemblage zone contains also the species *Halimeda opuntia* (Linnaeus) Lamarck (Pl. 12, Fig. 1 in Dragastan and Herbig, 2007), *H. monile* (Ellis and Solander) Lamouroux, *H. simulans* Howe and *H. tuna* (Ellis and Solander) Lamouroux (Pl. 17, Figs. 9-10, Dragastan and Herbig, 2007). The dasyclads represented in this zone are *Acicularia acuminata* Génot, *Neomeris* sp. and *Zittelina* cf. *simplex* (Morrellet) Pia.

Although the *Halimeda* species are not so diverse to the upper and terminal part of the Jbel Tagount Formation from the central High Atlas, in this region was possible to separate the zone at this level, in spite that this time interval can correspond to the begining of the crisis of halimedaceans and dasycladaleans green-calcareous algae.

As a conclusion, the *Halimeda* species of the middle-late Thanetian-Ypresian-Lutetian-Bartonian? deposits of the Moroccan Atlas (central High Atlas and Middle Atlas), provided the biostratigraphical value of some index species making possible to recognize 8 assemblage zones based (Fig. 32) on halimedaceans (*Halimeda nana*, *H. lacunosa*, *H. unica*, *H. praecuneata*, *H. praegoreauii* known only as a fossil species and *H. tuna*, *H. gracilis*, *H. fragilis* as species with Recent representatives) and one assemblage zone based on dasycladaleans (DAS 4) with two subzones: a first with *Neomeris plagnensis* (DAS 4a) and a second with *Holosporella subglobsa* (DAS 4b).

The sections of Paleogene deposits from the central High Atlas have been well calibrated lithostratgraphically by microfacies, microfossils and macrofauna (Herbig 1991) and the richness in *Halimeda* thalli, in thin beds or in event strata allowed to introduce for first time a biostratigraphic scale using the assemblage zones for

Paleogene stages or substages. The defined *Halimeda* assemblage biozones of the central High Atlas were useful to correlate and to differentiate the Paleogene deposits of the Bekrit-Timahdit Formation of the Middle Atlas, at level of stages and substages for middle-late Thanetian and Ypresian – Lutetian (pro-parte). The Lutetian- Bartonian? interval still remains rather unclear in this region. In spite of different rates of diversity between the central High Atlas, with 20 *Halimeda* species, and with only 14 *Halimeda* species in the Middle Atlas, the green siphonous species of genus *Halimeda* showed the potential for index species proving for the first time the biostratigraphic value of assemblage zones for the Paleogene deposits of the Moroccan Atlas.

The paleogeography of the carbonate shelf, the abundance and the diversity of *Halimeda* species associations during the Middle Thanetian-Lutetian-Bartonian? of the Moroccan Atlas, the presence of *Halimeda* facies in various Paleogene intervals and occurrences (Tunis, Libya, Egypt, Syria, Iran, Oman, Irak) certify the idea of a paleoprovince with halimedaceans and dasycladaleans in the North African-Arabian area. This area includes a Circum-Mediterranean subprovince during Thanetian – Bartonian times, in the area of Spain, France, Italy, Serbia and Turkey (Eskişekir region), accepting that the genus *Anatoliacodium* described by Erdem and Radoicic (2009) from the uppermost Thanetian-Ypresian is a junior synonym of genus *Halimeda* Lamouroux 1812, with its new species *A. xinanmui* and *A. merici*. The diagnosis for the new genus shows no difference from genus *Halimeda*, therefore, the two new species defined should be transferred to this taxon. In the same paper, Fig. 8.4-6 assigned to *Halimeda*? sp. correspond to *Halimeda tuna* (Ellis and Solander 1786) Lamouroux 1816.

Cuvillier (1930) showed that Juliette Pfender did not publish all the algae of the „Egyptian Nummuliticum" (Pfender, 1940). In the same context, the paper published by Pfender and Massieux (1966) revised the material of Pfender from the Cuvillier collection.

Pfender and Massieux (1966) did not typify the newly defined species collected from the Lower Lutetian of the Gebel Galala el-Baharia (south of Suez Channel). Pfender (1940), based on transversal and oblique-transversal sections, introduced a new species, *Gymnocodium nummuliticum* (Fig. 3.1-4, in Pfender and Massieux, 1966), comparing it with the Upper Permian species *G. bellerophontis* Rothpletz and *G. solidum* Pia, without defining a holotype. Although there is no clear description of the new taxon *Gymnocodium nummuliticum*, recently, Erdem and Radoicic (2009) transferred this taxon to *Anatoliacodium* nov. gen, becoming *A. nummuliticum* (Pfender et Massieux, 1966) nov. comb. emend. Erdem et Radoicic. (2009). As *Anatoliacodium* is a junior synonym with *Halimeda*, and the chosen lectotype related to this emendation (Pl. 5, Fig. 1, in Pfender and Massieux, 1966) is based on a transversal section of a flattened, commonly dichotomous segment (with two clear medullar zones), this emendation does not reflect the diagnosis introduced by these authors. This is why we consider that *Gymnocodium nummuliticum* should be transferred to *Julpfenderella* nov. gen. Dragastan, Herbig et Popa, therefore becoming

Julpfenderella nummulitica (Pfender et Massieux, 1966) nov. comb. emend. Dragastan, Herbig et Popa with the designation of a lectotype in Pl. 4, Fig. 7, in Pfender and Massieux (1966).

Regarding the reproductive structures, some species of fossil *Halimeda* preserved the long, fertile siphon transformed in pedunculate gametangium, starting from the medullar siphons and continued to cross the cortex up to the margin such as in *H. lacunosa* (Pl. 7, Figs. 2-3, Pl. 9, Fig. 2), *H. praetaenicola* and in *H. monile* (Pl. 14, Figs. 1, 3, all in Dragastan and Herbig, 2007). Not all gametagia have to be reproductive, some stop inside of the medulla or to the margin of the cortex, but in many cases, it is possible to preserve the place of the gametagium under a trace, such as spheroidal or various shaped cavities (Pl. 8, Fig. 3, in Dragastan and Herbig 2007). Sometimes, in the case of *Halimeda* thalli, the gametogenesis is interrupted, ending with immature, sterile gametagia (Meinesz, 1980).

Génot (1987) produced an important contribution to the knowledge of taxonomy and validation of many Paleogene green algae of the NW Europe, respectively from the Paris Basin, Bretagne, Cotentin, Mons Basin, Landes and Hampshire (England). This contribution was based on material of the Morrellet Collection, including the stratigraphic ranges for many taxa of the Thanetian-Bartonian interval, within such a large subprovince (Fig. 33).

We consider this North African-Arabian-Circum-Mediterranean paleoprovince different of that defined during the late Cretaceous, as the latter started during the Paleogene and continued with interruptions during the Oligocene, the Miocene and in small, restrictive areas, during the Pliocene-Pleistocene into Recent, when in the Mediterranean lived only 2 species of *Halimeda* (*Halimeda tuna* and *H. copiosa*).
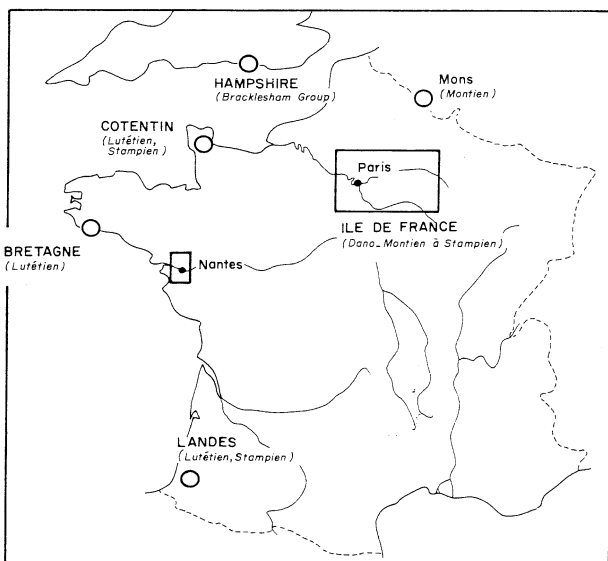
Fig. 33 The distribution of the main basins with Paleogene green algae of North-West Europe (from Génot, 1987).

HALIMEDA PALEOGENE PALAEOGEOGRAPHY VERSUS THE OCEANIC CONVEYOR BELT

In the central High Atlas, the Paleogene *Halimeda* stock of species includes 20 species of which 10 species have Recent counterparts, and only 10 fossil species (Dragastan and Herbig, 2007). In the Middle Atlas, this stock includes 14 species, of which 9 species have Recent counterparts, and only 5 fossils species: *Atlasinium erikfluegeli* (Dragastan and Herbig 2007) Dragastan 2008, *Halimeda lacunosa* Dragastan and Herbig, *H. nana* Pia, *H. unica* Dragastan and Herbig and *H. praeminima* n.sp. The stock of Paleogene *Halimeda* is very diversified, as it contains a total of 34 species, 20 found in the central High Atlas, and 14 found in the Middle Atlas. The richness and diversification of the *Halimeda* group of species started during the Thanetian stage as a recovery phase, continued with a maximum phase during the Ypresian and recorded a less diversity phase starting with the Lutetian and continued into the Bartonian. After an extinction phase during the Priabonian, no *Halimeda* species were later recorded.

This evolution of *Halimeda* species crossing different phases recorded in the Paleogene deposits of the Moroccan Atlas was directly influenced by:

1. the various extention of carbonate platforms in the western, northern and eastern parts of the African continent, including also the Arabian Peninsula;
2. the basin type (carbonate ramp), which is not so favourable for *Halimeda* as it misses a real lagoon area;
3. the circulation of currents in the Neo-Tethys Ocean, different to the Recent oceanic currents;
4. the plate tectonics during the Paleogene, which modified the configuration of carbonate basins and finally modifying the distribution of *Halimeda* species within a large paleobiogeographical province.

The paleogeographic distribution of Paleogene *Halimeda* microflora within the West-North- East African-Arabian area, with species recorded between middle Thanetian – earliest Lutetian (in Morocco, Libya, Egypt, Iran, Iraq and Syria). The migration of the new stock of *Halimeda* species in the North-West (France, Belgium and England, in Génot, 1987) began during the Ypresian – Lutetian – up to Stampian (Oligocene) times.

In the Eastern part of Europe (Serbia and Turkey) the species migration continued during the late Thanetian (Illerdian) – Ypresian (Cusian) times. This circum-Mediterranean area can be considered as a subprovince generated after the collision of African-Arabian plate with Eurasian plate during the Lutetian time (Swezey, 2009). The *Halimeda* microflora suffered a significant regress after the Late Lutetian, followed by an extinction during the Bartonian. A new evolutive phase began during the Oligocene (Stampian), with the species *Halimeda praeopuntia* Morrellet 1922, cited by Génot (1987) in the Landes Basin.
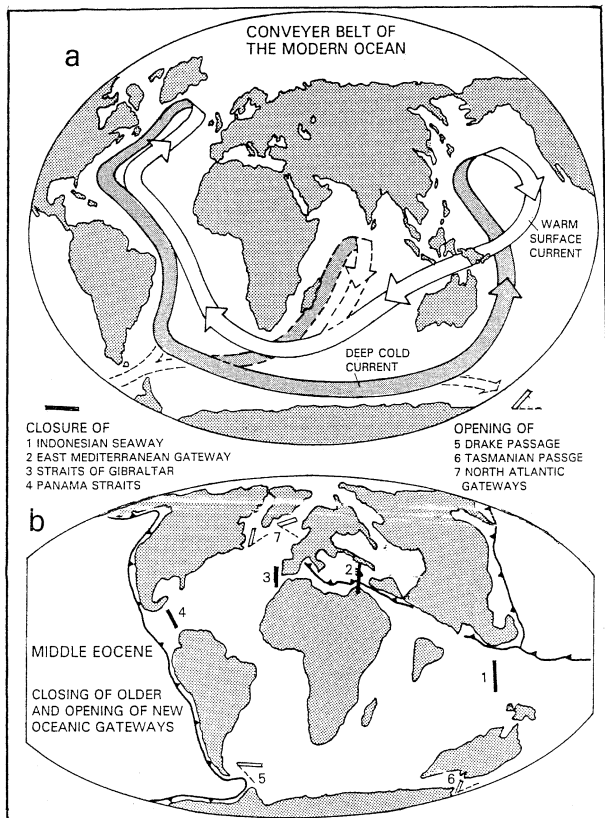
Within this major paleoprovince, a fundamental influence was the conveyor belt of the Neo-Tethys,

having similar paths and intensities for exchanging masses of water between three large oceanic basins. This process is similar to the Recent conveyor belt (Broecker, 1989) generated by two water masses, a warm flow from the northern Pacific (surface currents through the Indo-Australian passage, around South Africa and northward into the Caribbean area, with the Gulf Stream continued up to the North Atlantic, and a deep, cold flow, from Greenland, around the eastern American coast, into the Pacific (Fig. 34 a).

This water mass mechanism crossing the Atlantic, Indian and Pacific oceans has a strongly influence on thermohaline circulation and implicitly over the dispersal and distribution of green algae, especially on *Halimeda* microflora.

However, the shape of the ocean basins and the location of swells, ridges, island chains can close the oceanic gateways around the Cretaceous-Cenozoic boundary and continued during the Paleogene. The warm climate of the late Cretaceous continued during the Paleocene, when a new peak of temperature was reached. Also, during the Paleocene-Eocene interval, the carbonate deposition, with high rates of sediments into the carbonate platforms, influenced the *Halimeda* stock of species. All these changes (paleogeographic and climatic) influenced the oceanic thermohaline, with a trend since the middle and upper Eocene of lower eustasy and climate cooling (Einsele, 2000). The Neo-Tethyan regional spliting included the closure of the Indonesian seaway, of the Gibraltar and of eastern Mediterranean

gateway, and of the Panama strait (Fig. 34 b, Eisele, 2000). The closure of several regional gateways in Neo-Tethys involved a drastic reorganization of the carbonate platform basins and the circulation of thermohaline with a profound, direct influence in the dispersal, diversification and distribution of *Halimeda* microflora.

The general transition from early Cenozoic carbonate strata to late Cenozoic siliciclastic strata coincides with the general northward movement of the African Plate, with a long term eustatic fall since the Late Cretaceous, and with a global climate transition, from a warm mode between the Late Cretaceous-Early Eocene, to a Late Eocene-Quaternary cool mode (Swezey, 2009).

Paleocene (Danian-Thanetian, Fig. 35 a) and Eocene carbonate (Ypresian and partly Lutetian, Fig. 35, b-c) and phosphate deposits (Lutetian and Priabonian, Figs. 35 c-d) suggest a warm and humid climate.
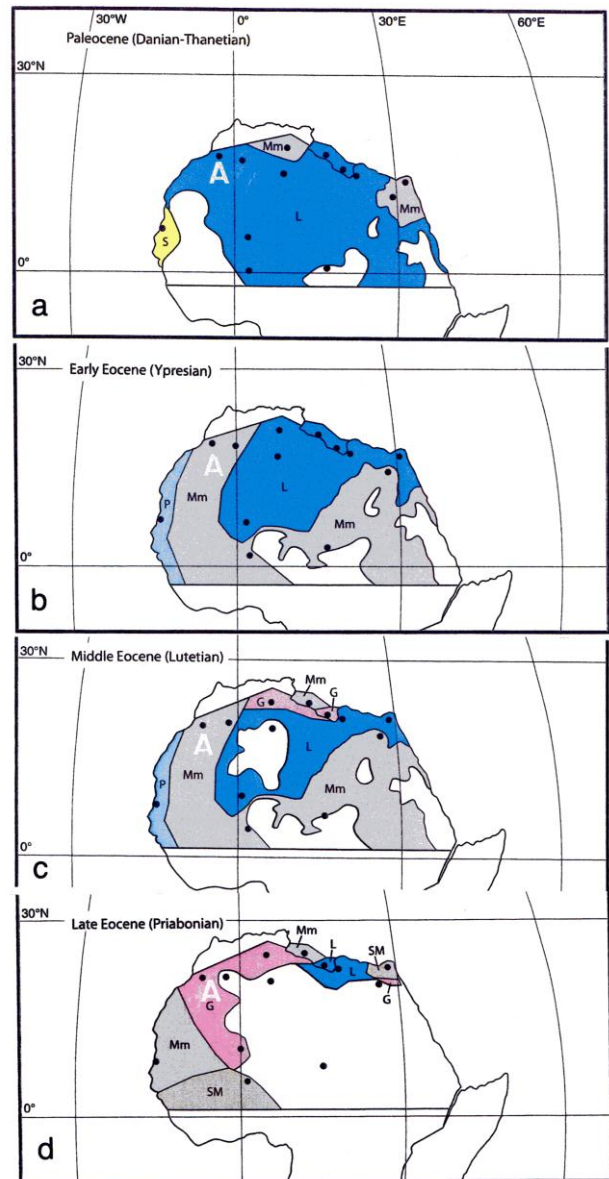
Fig. 35 Paleogeographic lithological setting of North African area : **a** during Danian – Thanetian. **b** during Ypresian. **c** during Lutetian and **d** during Priabonian, A, position of Atlas Mts. (after Swezey, 2009). SM - sandstone and mudstone, S – sandstone, Mm – marine mudstone, L – limestone or dolomite, G – gypsum or gypsiferous mudstone, P – phosphatic mudstone and limestone.

Fig. 34 a Conveyer belt of the Recent Ocean showing the exchange between te warm surface water and colder deep weater (after Broecker, 1989; from Einsele, 2000) and **b** Eocene oceans and post-Eocene closure or opening of oceanic gateways which led to a drastic reorganization of thermohaline circulation (modified after Seibold and Berger, 1996; from Einsele, 2000).

A circum-equatorial Neo-Tethys Ocean, controlled by a strong free water current system, allowed a large exchange between all oceanic basins with an optimal thermohaline. This process played a significant role in the proliferation of *Halimeda* species within the African-Arabian-circum-Mediterranean province, well established during the Thanetian-Lutetian time interval. The *Halimeda* paleoprovince had a centre of radiation in the Atlas region, the spreading of species occurred to the east, in Egypt and in the Arabian Peninsula (Iraq, Iran, Syria), mostly during the Paleocene and Early Eocene (Ypresian). The migration of *Halimeda* species along the northern shores of the Mediterranean area during the Thanetian, in Turkey, Serbia or in former Yougoslavia, and thereafter in France, Belgium and in southern England (Hampshire), during the Lutetian. Morrellet and Morrellet (1922, 1940) described from Late Lutetian deposits the species *Halimeda* sp. (Middle Lutetian), *H. eocaenica* Morrellet and Morrellet 1940 and *H. praemonilis* Morrellet and Morrellet 1940. The Morrellet Collection with *Halimeda* species was validated with the designation of lectotypes by Génot (1987), in his thesis including good illustrations. No *Halimeda* species were found in the Paris Basin or in France in Thanetian-Ypresian-Early Lutetian deposits. This fact is related to the extentional to compresional tectonic processes, responsible for changing carbonate platform basins and thermohaline circulation, or even closing the circulation in the Mediterranean, when this basin was closed westwards and eastwards during the Eocene. Génot concluded that the Lutetian-Rupelian *Halimeda* species associations are less diversified than the dasycladalean associations. The type localities of many species in France such as Cotentin and Landes, were parts of the areas included in the NW spreading of *Halimeda* species up to Hampshire (England). To the end of the Eocene, about 35-40Ma (Bartonian-Middle Priabonian), began a change in the dynamics of the conveyor belt, the deep-water cooling from low latitude to high latitude and with deeper water masses, imposing a restriction of the circulation for the circum-equatorial ocean (Einsele, 2000). During and after the Lutetian, the *Halimeda* microflora recorded a regressive phase (corresponding to a reduced number of species) and since the Bartonian, the number of species gradually decreased and a crisis took place till the disappearance. This extinction is related to a new phase of climate cooling at the Priabonian-Rupelian boundary, during the transition to a more accentuated global ice-house, marking the Antarctic glaciation. Most of the tectonic activity during the Paleocene was extensional, while during the Eocene the activity was compressional. The African Plate and possibly the Arabian Plate moved northwards and counterclock during the Late Eocene, to a 6-8°N latitude, south of its position today.

PALAEOALGOLOGY, DESCRIPTIONS AND TAXONOMICAL CONSIDERATIONS

New species of *Halimeda* are described, recorded frequently in the Middle-Late Thanetian deposits of the Middle and the High Atlas and a redescription of *Halimeda nana* Pia 1932, a marker or index species for Middle Thanetian, is given. Also from the Early Jurassic of Morocco is described *Toulaina* nov. genus and nov. species under the name of *Toulaina liassica* (Le Maitre 1937) Dragastan, Herbig and Popa nov. comb., which initially was described by Le Maitre as *Boueina hochstetteri* (Toula 1884) var. *liassica* Le Maitre 1937.

Phylum Chlorophycota ENGLER 1903
Class Siphonophyceae HAECKEL 1894
Order Siphonales KIRCHNER 1878
Family Halimedaceae LINK 1832
Genus *Halimeda* LAMOUROUX 1812
***Halimeda praeminima* n. sp.**
Fig. 36, a-s, Fig. 37, g, Fig. 40, d

Derivatio nominis: "*praeminima*", a species close, but not similar to the Recent *Halimeda minima* (Taylor) Hillis-Colinvaux 1968.

Holotype: Fig. 36 a, Collection Hans-Georg Herbig (HGH), Universität zu Köln, Institut für Geologie und Mineralogie, Middle Thanetian, Middle Atlas.

Additional material: Fig. 36 b, c, d, s, Fig. 37, g, Fig. 40, d, Collection Hans-Georg Herbig, Universität zu Köln, Institut für Geologie und Mineralogie, Middle Thanetian, Middle Atlas.

Description: Thalli segments cylindrical, small, crossed by a narrow medullar zone with 3 up to 4 vertical and parallel medullar siphons. The cortex is thin, crossed by two utricle series. The primary utricle are tubular, not so long, slightly growing in diameter distally. The primary utricles support the secondary, tiny, short, more inflated distally and dichotomously branched utricles.

Dimensions in mm: D-outer diameter, 0.20-0.60, md-medulla diameter, 0.10-0.30, msd-medulla siphon diameter, 0.010-0.015, cth-cortex thickness, 0.060-0.10, pudp-primary utricle proximal diameter, 0.010- 0.015, pudd-primary utricle distal diameter, 0.020-0.025, pul-primary utricle lenght, 0.058-0.062, sud-secondary utricle diameter,0.010-0.15, sul-secondary utricle length, 0.030-0.035.

Remarks: *Halimeda praeminima* n. sp. has small thalli segments, as it can be compared with the Recent species *H. minima* (Taylor) Hillis-Colinvaux. The Recent species is also small and it includes segments of different shapes, ribbed, trilobed to the lower half of the thallus and flattened, cylindrical, or only cylindrical, to the upper part of the thallus (Hillis-Colinvaux, 1980). The new fossil species differs from the Recent species by a single type of cylindrical segments and by the reduced number of cortical utricles, of only two. The Recent species presents a cortex with two, up to four utricle series. Also, the new species can be compared with *Halimeda praemonilis* Morrellet and 1940 of the Cotentin region (late Lutetian) and with *H. eocaenica* Morrellet 1940 of Cotentin and Paris Basin (late Lutetian), but also with the same species described by Elliott (1957) under *H. praemonilis* Morrellet of Iraq (Paleocene), corresponding to *H. nana* Pia 1932. Génot (1987) revalidated them by
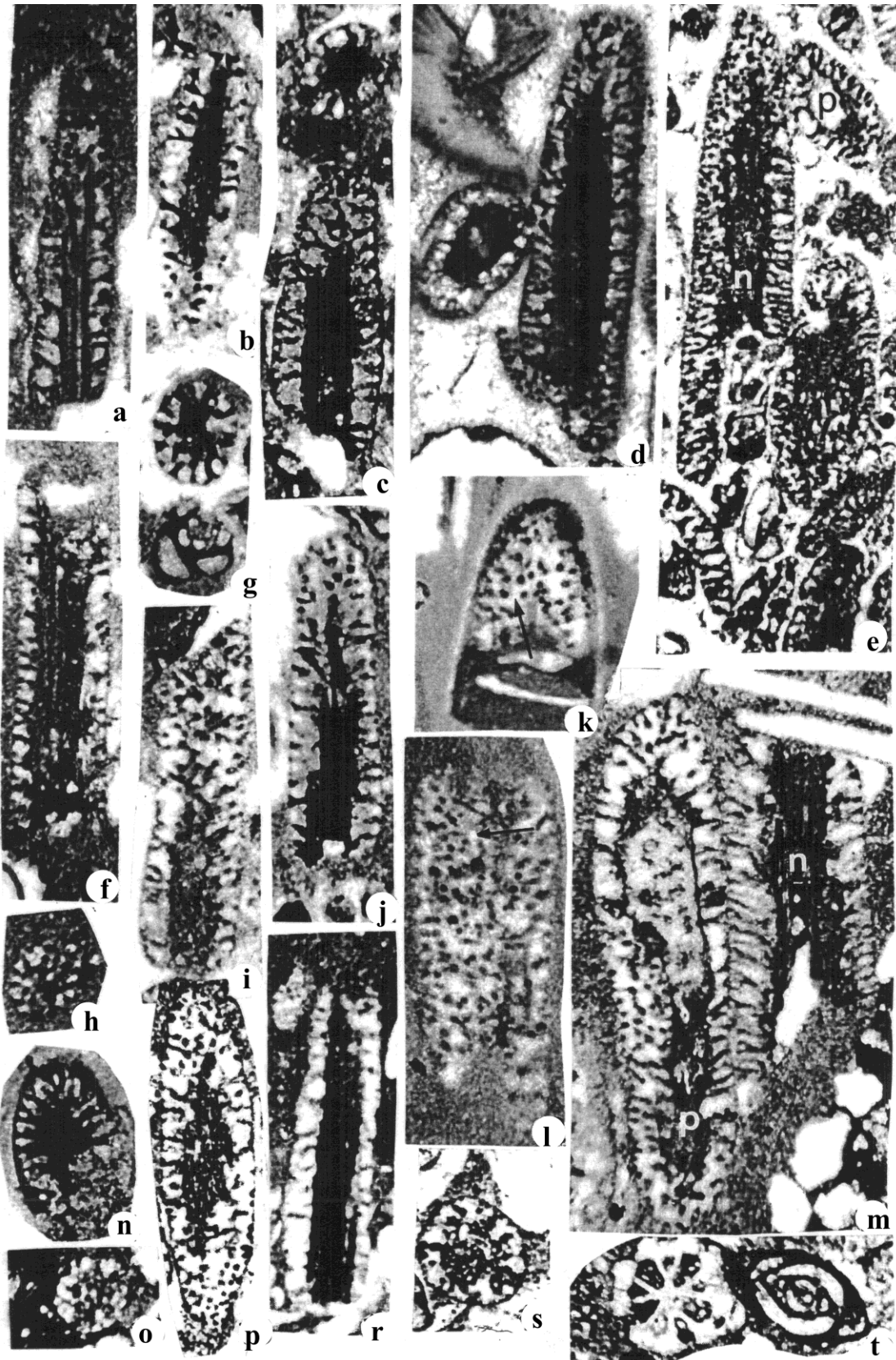
Fig. 36 a *Halimeda praeminima* n. sp., Holotype, oblique-longitudinal-axial section showing few medullar siphons and typical primary and very short secondar utricles, Section MA-10, Ypresian, Middle Atlas,Timahdit. **b-d, f, i, j, p, r** *H. praeminima* n.sp., Additional material, longitudinal and oblique longitudinal sections crossing very small thalli, Section MA-7 and Section MA-10, Thanetian (d, p-r), Section MA-10, Ypresian (b-c, f, i, j). **e, m** *H. praeminima* n.sp.(p) and *H.nana* (n), longitudinal sections showing the differences between two taxa, Additional material, Section MA-8 a,Ypresian (e), Section MA-10,Thanetian (m). **k, l** *H. praeminima* n.sp., tangential sections showing the secondary utricles disposed 4 or 5, more or less in a polygonal manner (see arrows), Additional material, Section MA-10,Thanetian (k, l). **g, f, n, s** *H. praeminima* n.sp., transverse and oblique transverse sections, Additional material, Section MA-7, Thanetian (g, o, s), Section MA-10,Ypresian, (h, n). **g, t** Miliolides and cellariform bryozoan, Section MA-7, Thanetian (g, t). **a-t** Middle Atlas, Timahdit, Collection Hans-Georg Herbig, all Figures x 30.

Fig. 37 a-f *Halimeda nana* Pia 1932, longitudinal and oblique longitudinal sections with medium, large medullar area and primary, secondary and tertiary utricles, Section MA-7, Thanetian (a-c), Section MA-10, Thanetian (d-f). **g** *H. nana* Pia 1932, oblique transverse section (n) and *H. praeminima* n. sp. (p), oblique-longitudinal sections, Section MA-8 and Section MA-10, Thanetian. **a-g** Middle Atlas, Timahdit, Collection Hans-Georg Herbig, all Figures x 30.

choosing lectotypes for both species from the Morrellet Collection.

Halimeda praemonilis is described as a species with cylindrical thallus segments, crossed by 5-10 medullar siphons, oriented parallely to the axis of the thallus, but without a clear description of number of utricles (after the author with a "grande nombre d´utricules"). Segonzac et al. (1986) described *Halimeda praemonilis* Morrellet (Pl. 1, Fig. 6) with three or four utricle series from the Ypresian deposits of Camplong (French Pyrenées).

In spite of the numerous illustrations of Génot (1987), the redescription of shape and of number of utricle series is missing, but in the figures it is possible to recognize only two utricle series. The specimens figured by Elliott (1957) as *Halimeda praemonilis* are considered by Génot questionable, and in his opinion, they do not belong to this species. We consider also this species valid, as surely it has an Ypresian - late Lutetian stratigraphic range, thus not characteristic for the Paleocene. The new species is comparable with *Halimeda nana* Pia 1932, but it differs of *H. nana* by a smaller diameter thallus, by a reduced number of medullary siphons and by having a cortex crossed by a constant number of utricle series (only two).

Halimeda eocaenica Morrellet 1940 figured and revalidated by Génot (1987) in Plate 44, Figs. 9-15, late Lutetian in age (Cotentin, Paris Basin), has trilobate, flattened segments crossed by 10-12 medullary siphons and a cortex with three utricle series: primary, short and conical, large inflatted distally; secondary, cylindro-conical, dichotomously branched; and tertiary, very short, cylindrical, dichotomously branched. This species can be compared with the Recent and fossil *Halimeda opuntia*, which has the same shape of segments and three utricle series (Dragastan and Herbig, 2007) and rarely three to five utricles (Littler and Littler, 2003). Another species revalidated by Génot (1987) is the Stampian *Halimeda praeopuntia* Morrellet 1922 (Plate 45, Figs. 1-11), which has disc-like, ribbed segments, crossed by large medullary siphons and cortex with three utricle series: primary, conical; secondary, cylindro-conical; and tertiary, with the same shape, long and fine. Also, it can be compared with the fossil and Recent *Halimeda tuna* (Ellis and Solander, 1786) Lamouroux 1816. The species described by Morrellet and Morrellet (1922, 1940) and revalidated by Génot (1987) has a clear morphology of segments, and it is dominant during the Lutetian-Bartonian interval.

Halimeda nana Pia, 1932
(in Pia, Pfender and Termier, 1932)
Fig. 36, e(n), m(n), Fig. 37 a-g, Fig. 38a-i,
Fig. 39a-f, Fig. 40a-d

Halimeda nana n. sp. Pia 1932 in Pia, Pfender and Termier 1932, p.17, Pl. 2, Fig. 4;
Halimeda nana Pia in Elliott 1955a, p.126, p.128, Pl.1, Fig. 3; Bassoullet et al. 1983, p. 488, Pl.7, Figs. 5-6, Segonzac, Peybernes and Rahhali 1986, p. 502, Pl.1, Figs.1-2, 4, 5-8; Tragelehn 1996, Pl. 48, Fig.1; Kuss and Herbig 1993, p.277, Pl. 5, Figs.1-5, Pl. 8, Figs. 4-5, Dragastan and Herbig 2007, p.17, Pl. 3, figs.1-9, Pl. 5, Figs. 5-6;

Halimeda sp. 2 Segonzac, Peybernes and Rahhali 1986, p. 503, Pl.1, Fig. 4.

Paratypes: Fig. 36 e(n), m(n), Fig. 37 a-g, Fig. 38 a-i, Fig. 39 a-f, Fig. 40a-d(n), Collection Hans-Georg Herbig, Middle-Thanetian, *Halimeda nana* Assemblage Zone, central High Atlas and Middle Atlas (Timahdit type locality).

Description: Thallus segments cylindrical, small in diameter (0.50-0.87-1.0mm, Fig. 37b, d), in some cases with small lobes or protuberances, but no branches (Fig. 39 a-f, Fig. 40b-c). The segments crossed by a narrow medullar area. The medullar siphons with a very slight, undulated tajectory, occurring more or less parallely in 5-7, rarely 8 rows, depending of age and position of the segments along the thallus. The number of siphons along the thallus: only 5 in the upper thallus segments, and 7 in the lower and middle thallus segments. In transversal sections, the medullar area is circular and has 5-8, small, circular siphons distributed more or less in concentric rows, from the outer to the central part (Fig. 38 g, Fig. 39 e). To the medulla-cortex boundary, gametangian places or cavities can occur, subrhomboidal in shape (Fig. 38 e). The cortex is not so thick and it is crossed in the majority of segments by three utricle series (Fig. 37 a, d, f, Fig. 38, e, h). The primary utricles cylindrical, not so long, distally slightly inflated or smaller club-shaped (Fig. 39 b). The secondary utricles cylindrical, not longer than the primary utricles, dichotomously branched (Fig. 37 a, d; Fig. 38 c, h). Tiny tertiary utricles, very short and large, opened distally (Fig. 37 a, Fig. 38 e, h).

Dimensions in mm: D-0.50-1.0, md-0.15-0.38, msd-0.016-0.035, cth- 0.080-0.10, pudp-
0.010-0.016, pul-0.060-0.080, sud- 0.012-0.020, sul-0.025-0.032, tud-0.005- 0.007, tul-0.010.

Remarks: This is a redescription of *Halimeda nana* Pia 1932, including the thallus segments with lobes or protuberances, not branched, with the inner structure including places or cavities of gametangia, born to the medulla-cortex boundary. Dragastan and Herbig (2007) showed for the first time the occurrence of large cavities within the cortex, in the place of utricles, where the gametangia were born, remaining only the traces or cavities where the first originate and continue or not, outwards of the thallus segments. The Recent *Halimeda* stock of species is known as having the gametangia born in the medullary siphons or in the primary and secondary cortical utricles, transformed in filaments to care the gametangia, from the inner side to the outer side of the thallus segments (Hillis-Colinvaux, 1980, p. 203 Fig. 64). The print of gametangia positions remains as empty cavities with different shapes, in the fossil state showing the traces or the places (position) where ephemeral gametangia were produced. Not all gametangia were ejected outwards from the medullar area or from the cortex, and many did not reach the surface of thallus segments.

The type locality of *Halimeda nana* Pia 1932 is Timahdit, Middle Atlas (Morocco), a locality originally considered to be Danian in age. According to Kuss and Herbig (1993), the species is restricted to the early-middle Thanetian, to the southern rim of the central High Atlas, while in NE Egypt, the species is late Thanetian-Ypresian in age. Dragastan and Herbig (2007) considered
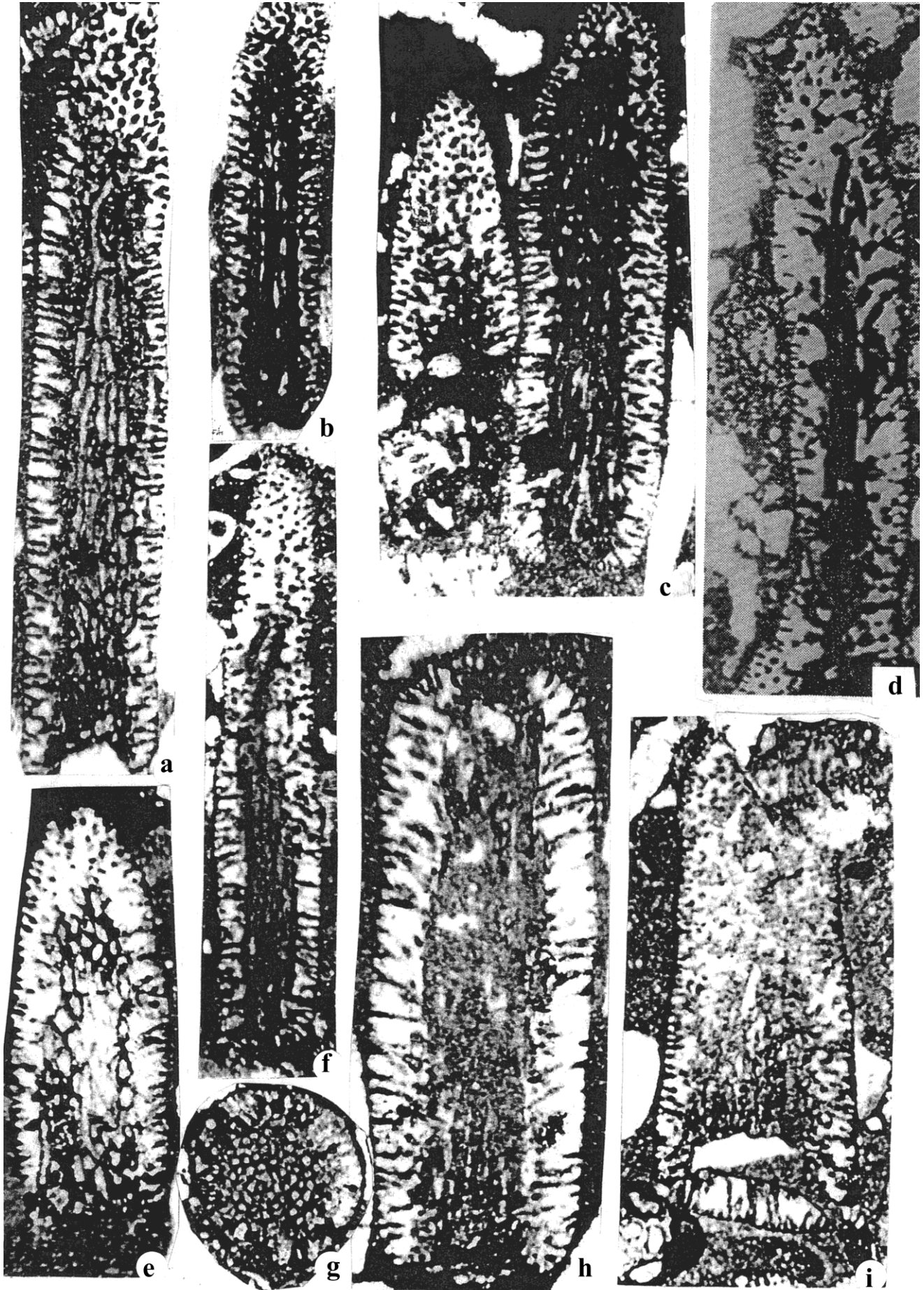
Fig. 38 a-f, h, i *Halimeda nana* Pia 1932, axial longitudinal and oblique longitudinal sections, Section MA-7, Thanetian (a-f, h-i, e, with gametangial cavities). **j** *H.nana* Pia 1932, transverse section, Section MA-8, Thanetian (g). **a-i** Middle Atlas, Timahdit, Collection Hans-Georg Herbig, all Figures x 30.

Fig. 39 a *Halimeda nana* Pia 1932, oblique-longitudinal section and *Acicularia eocaenica* Morellet 1922 (a), oblique-transverse sections, Section MA-8 a, Late Thanetian. **b** *H.nana* Pia 1932, broken thallus in a oblique-longitudinal section and oblique transverse section and a (a), *Acicularia eocoenica* Morellet 1922, Section MA-7, Late Thanetian. **c, e** *H. nana* Pia 1932, cylindrical simple or branched segments from broken thalli, oblique-transverse and transverse sections, Sections MA-10, LateThanetian. **d, f** *H.nana* Pia 1932, oblique-transverse sections in broken branched thalli segments, Section MA-10, Late Thanetian. **a-f** Middle Atlas, Timahdit, Collection Hans-Georg Herbig, all Figures x 30.
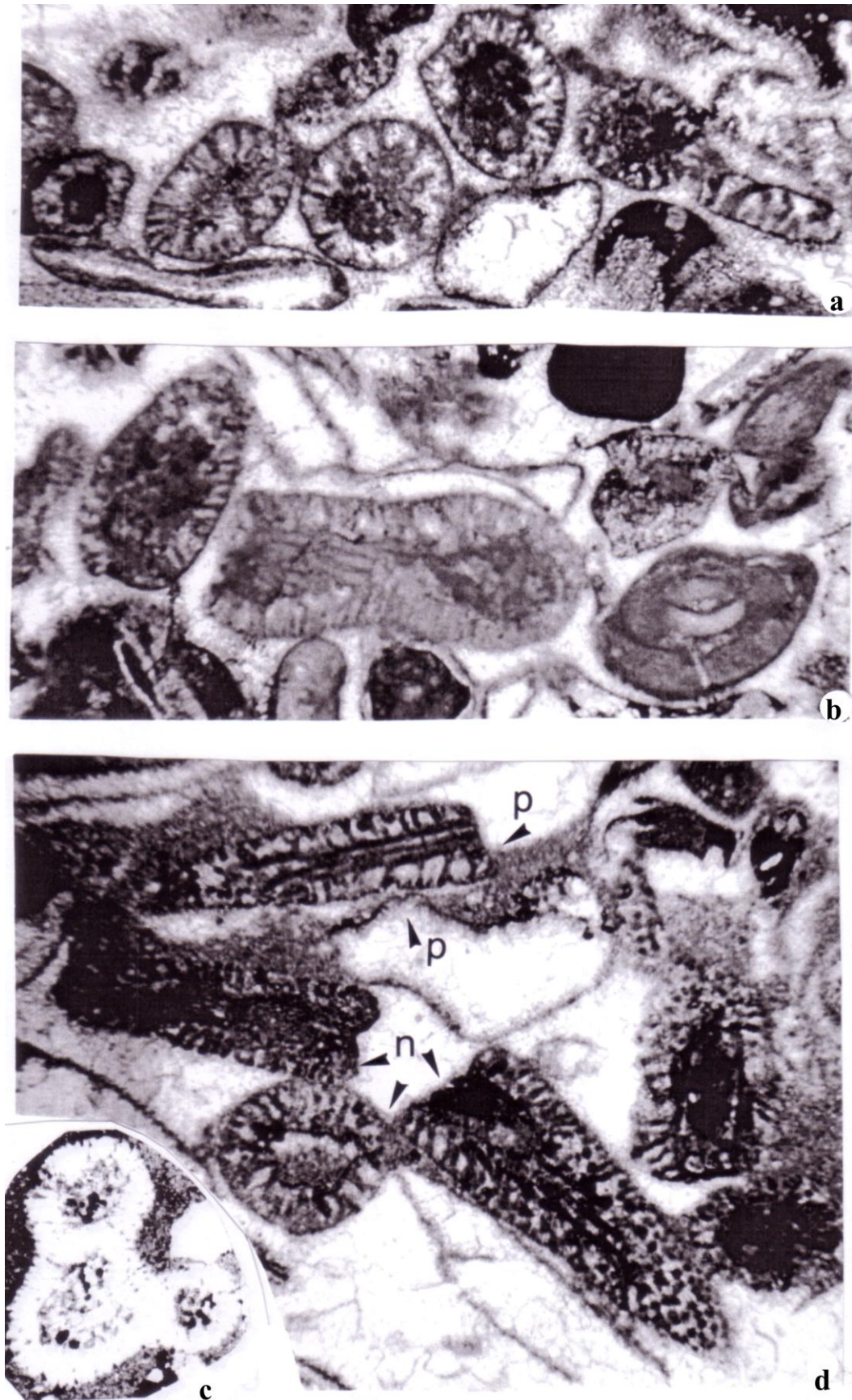
Fig. 40 a *Halimeda nana* Pia 1932, transverse sections in cylindrical thalli showing medullar siphons and cortex crossed by
primary and secondary utricles, Section MA-10, Late Thanetian. **b** *H.nana* Pia 1932, transverse sections in branched and non-
branched thalli segments and miliolide, Section MA-10, Late Thanetian. **c** *H.nana* Pia 1932, transverse section in a branched
thallus segments, Section MA-7, Late Thanetian. **d** *H.praeminima* n.sp.(p), oblique-longitudinal section and *H.nana* Pia 1932 (n),
oblique-longitudinal and transverse sections (n) showing differences between two taxa, Section MA-10, Late Thanetian.
a-d Middle Atlas, Timahdit, Collection Hans-Georg Herbig, all Figures x 30.
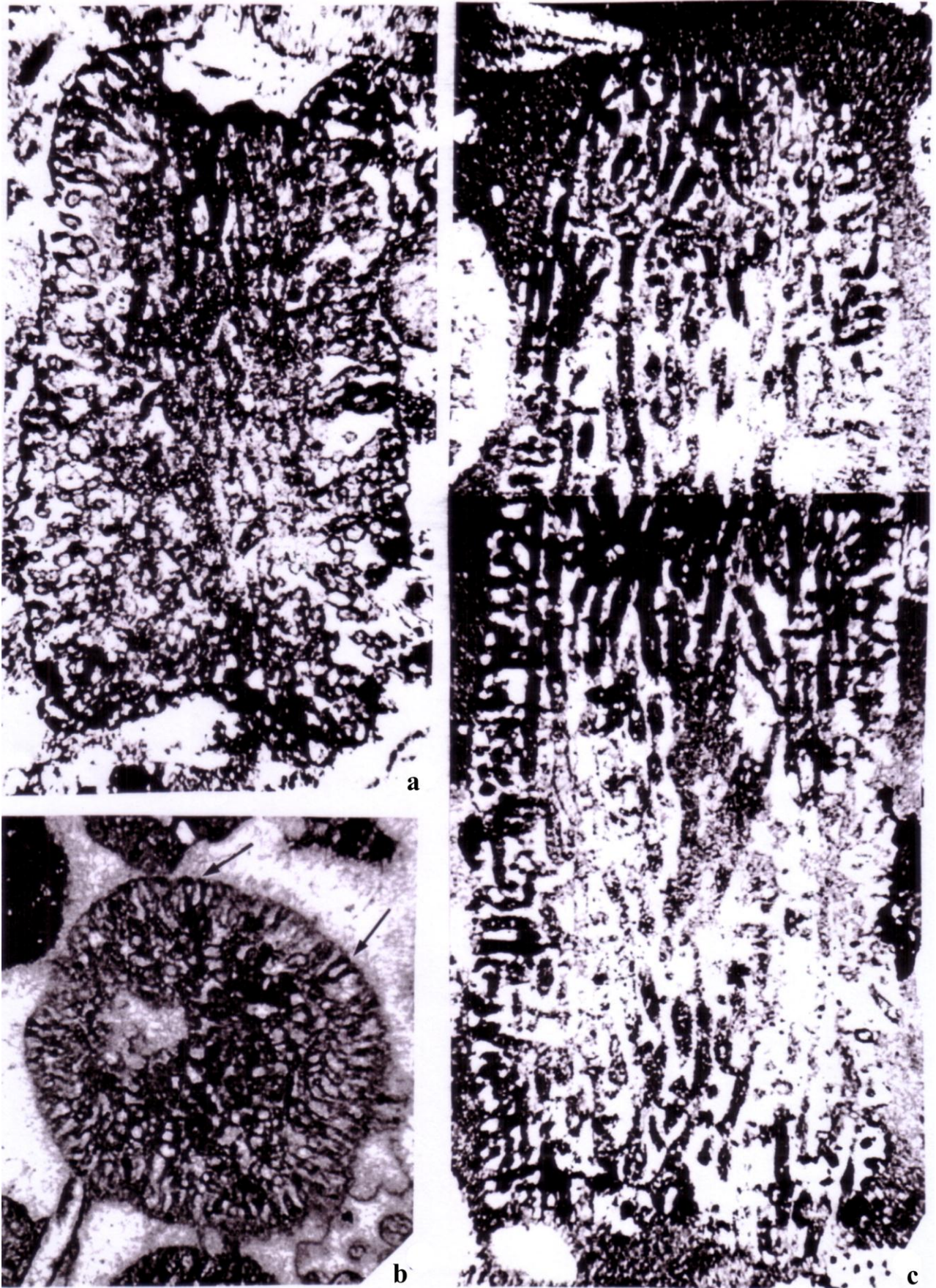
Fig. 41 a, c *Halimeda cylindracea* Decaisne 1842, a, c, axial-longitudinal sections, thalli with large medullar area and cortex crossed by typical *Cylindracea* primary, secondary, tertiary and fourth utricle series, Section MA-7, Late Thanetian (a) and Section MA-17, Lowermost Ypresian (c). **b** transverse section in a cylindrical thallus segment with cortex crossed by four utricle series (arrow), Section MA-10, Lowermost Ypresian. **a-c** Middle Atlas, Timahdit (a-b) and Bekrit (c), Collection Hans-Georg Herbig, all Figures x 35.
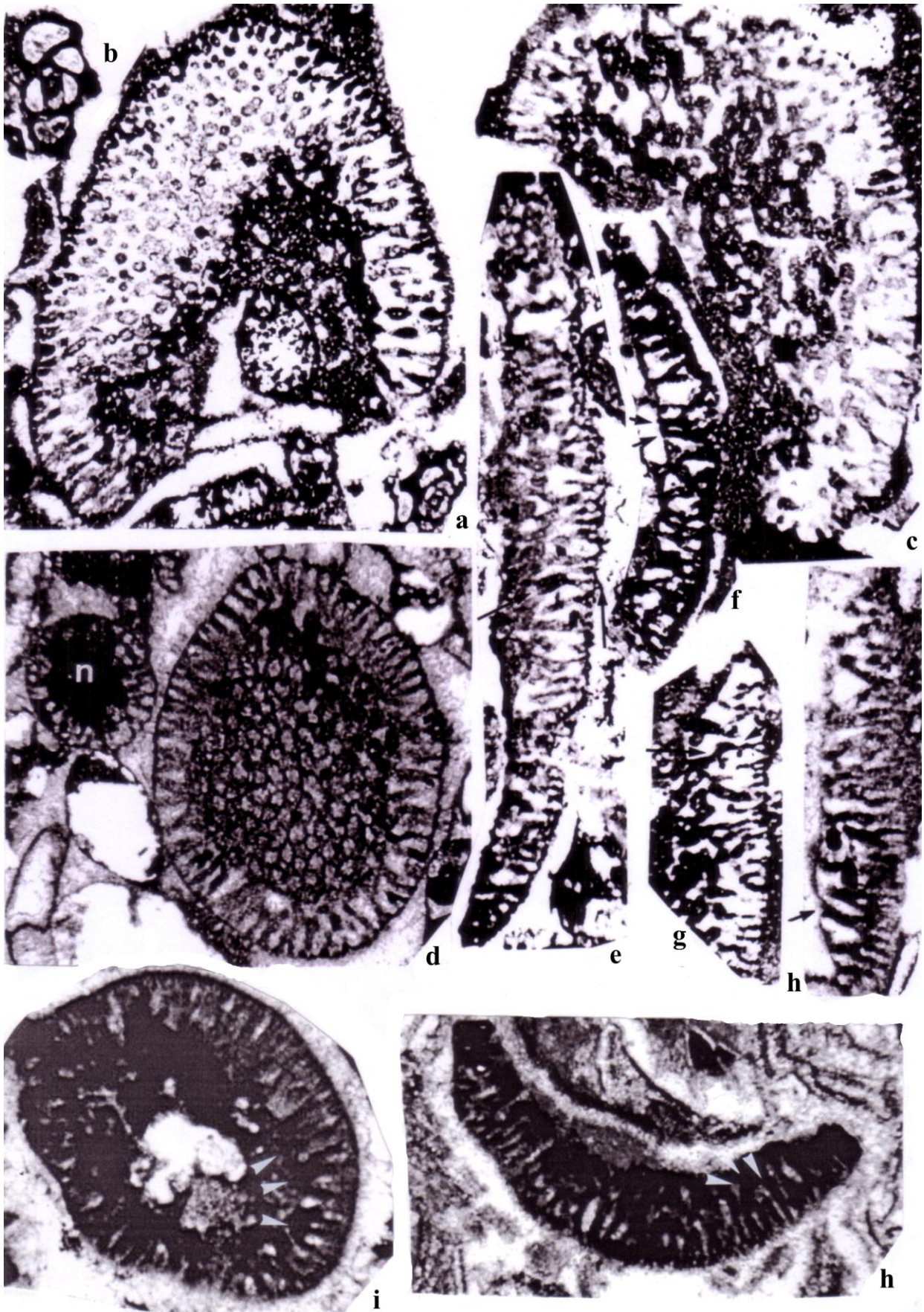
Fig. 42 – a, c-d, e-j *Halimeda cylindracea* Decaisne 1842, a, c, e-j, cylindrical broken thalli showing partially medullary area and four utricles series (clearly seen in e-j, arrows), Sections, MA-8, Early Ypresian (a, c), MA-10, Late Ypresian-Early Lutetian, (e-h, j), MA-10, Late Thanetian, d, transverse section and *H. nana* Pia (n), Late Thanetian (d). **b.** Miliolide, Section MA-7, Early Ypresian. **i.** *Halimeda cylindracea* Decaisne 1842, transverse section in a broken segment, Section MA-15, Late Ypresian-Early Lutetian. **a-j.** Middle Atlas, Timahdit, a-h, j, and Bekrit, i, Collection Hans-Georg Herbig, all Figures x 30.
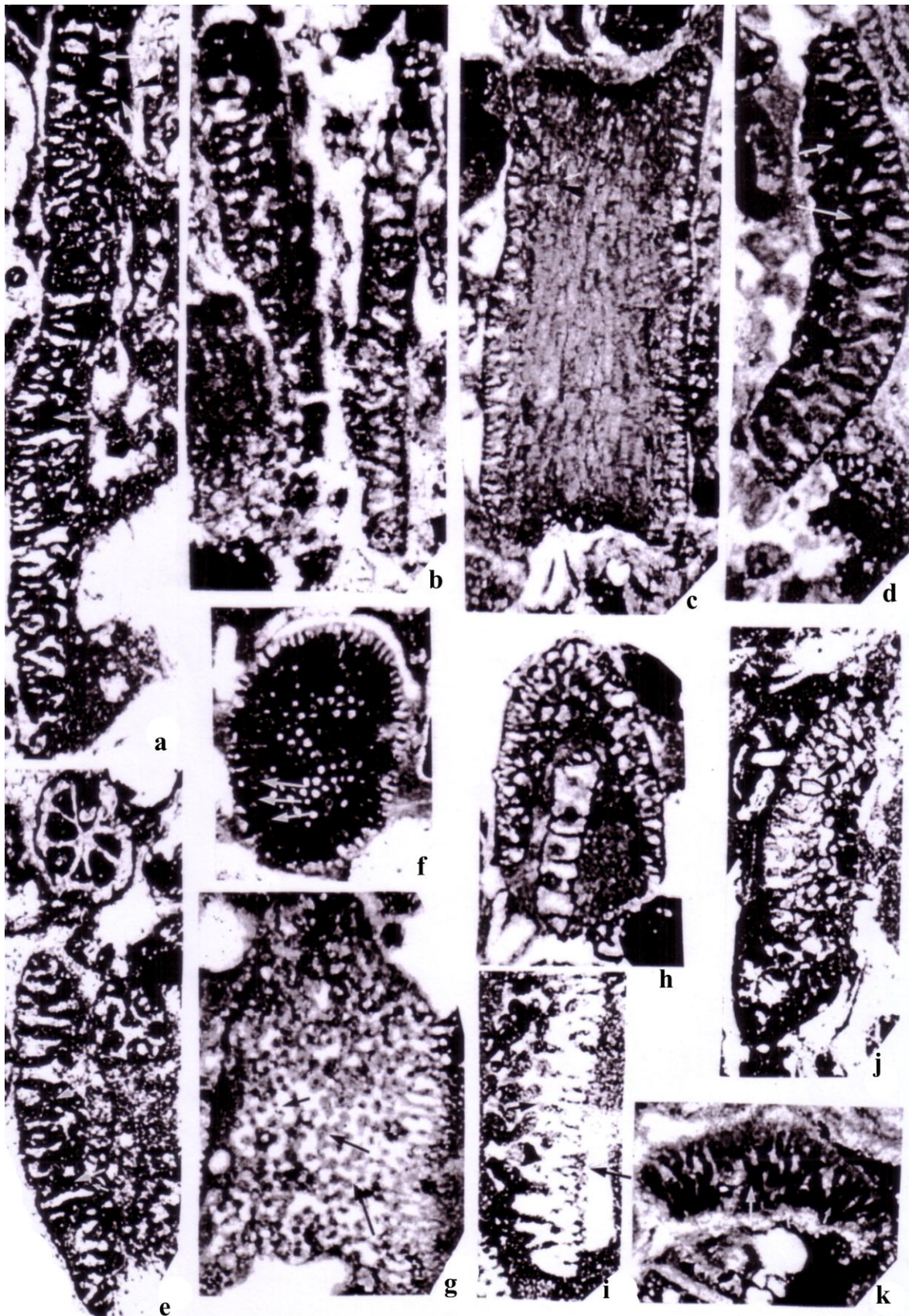
Fig. 43 – a-e, i-k *Halimeda incrassata* (J.Ellis) Lamouroux 1816, Entire and broken cylindrical thalli cuted after different planes, showing large medullar area and cortex with 3 or 4 utricle series (arrows) with primary cylindro-conical, secondary subglobose, tertiary short, conical as well fourth, Sections: MA-8, Late Thanetian (a-b, d-e, j), MA-7 and MA-9, Ypresian (c, i), MA-16, Ypresian (k). **f** *Halimeda incrassata* (J.Ellis) Lamouroux 1816, transverse section showing the typical multisiphons in the medullar area and the cortex with primary (arrows), secondary and tertiary utricle series, Section MA-8, Ypresian. **g** *Halimeda incrassata* (J.Ellis) Lamouroux 1816, tangential section showing the characteristic disposition of last utricle series (black arrows) at exterior, Section MA-9, Late Thanetian. **h** *Halimeda incrassata* (J. Ellis) Lamouroux 1816, oblique-longitudinal section with empty medullar area and inside *Neomeris plagnensis* Deloffre 1970, Section MA-8, Late Thanetian. **a-k** Middle Atlas, Timahdit (a-j) and Bekrit (k), Collection Hans-Georg Herbig, all Figures x 30.

Fig. 44 – **a-b** *Atlasinium erikfluegeli* (Dragastan and Herbig 2007) Dragastan 2008, from Family *Praecodiaceae* Dragastan 2008, longitudinal (a) and transverse (b) sections showing the medullar area and the cortex crossed only by primary utricles, Section MA-10, Thanetian (b) and Lower to Middle Ypresian (a). **c-e** *Halimeda opuntia* (Linneaus) Lamouroux 1816, (c, e) transverse sections in flat disk like segments and (d) oblique-longitudinal section crossing a disk like segment, Sections MA-10, Ypresian (c, e) and MA-15, Late Ypresian- Lower Lutetian (d). **f-g** *Halimeda tuna* (Ellis & Solander) Lamouroux 1816, transverse sections in a disk like segments Sections, MA-8, Early Ypresian (f) and MA-10, Late Ypresian- Lower Lutetian (g). **h** *Halimeda lacunosa* Dragastan and Herbig 2007, in cortex appear some sparse „round cavities" between utricles (see arrows) possible traces of gametangial cavities or between the medulla and cortex, Section MA-7, Late Thanetian. **a-h** Middle Atlas, Timahdit, (a-c, e-h) and Bekrit (d), Collection Hans-Georg Herbig, all Figures x 30.

Fig. 45 – **a** *Halimeda lacunosa* Dragastan and Herbig 2007, oblique-longitudinal section with clear „round holes", possible gametangial cavities, in the cortex (arrows) and a nodule of rhodo-serpulides (r) Section MA-9, Middle Thanetian. **b** *Halimeda praemacroloba* Dragastan and Herbig 2007, broken thallus cuted after an oblique-longitudinal plane, Section MA-7, Middle to LateYpresian. **c** *Halimeda unica* Dragastan and Herbig 2007, transverse section, Section MA-7, Late Thanetian. **d** *Halimeda monile* (J. Ellis & Solander) Lamouroux 1816, oblique- transverse section, Section MA-8 a, Late Ypresian. **e** *Halimeda gracilis* Harvey ex Agardh 1887, longitudinal section, Section MA-8 a, Middle to Late Ypresian. **f** *Halimeda simulans* Howe 1907, oblique-longitudinal section, Section MA-8 a, Late Ypresian-Lower Lutetian. **g** *Halimeda copiosa* Goreau & Goreau 1967, transverse section, Section MA-8, Middle Ypresian **a-g** Middle Atlas, Timahdit, Collection Hans-Georg Herbig, all Figures x 30.

this species Late Thanetian in age, in the same region. In this paper was defined the *Halimeda nana* Assemblage Zone, as a marker (index) species for the middle Thanetian in both regions of the Atlas (Middle and central High Atlas), considering the first occurence of the species.

Bassoullet et al. (1983) considered *Halimeda nana* a small species, with a branching thallus and with internal structure insufficiently known. The specimen attributed by Pia to the species *Halimeda nana* are strongly recrystallized and, in these conditions, their medullary zone cannot be observed. In spite of these remarks, Segonzac et al. (1986) did a revision based also on the specimens from the type locality, considered by these authors as lower Eocene in age. They provided the first biometric data, a good description of the medullar area and of the cortex crossed by three utricle series. The *Halimeda nana* had no branching segments, but the dimensions of these branches correspond to lobes or protuberances, and not to a real branch.

Stratigraphic range: The *Halimeda nana* Assemblage Zone is a marker for the middle Thanetian (lowermost part), taking into account the first occurence level. The maximum dominance of species was reached during the middle Thanetian (uppermost part), and the extinction of this species occurred in the *Halimeda unica* Assemblage Zone during the late Thanetian.

Occurrences: Morocco (Atlas Mountains) and the northern and southern parts of Irak, Iran and Egypt.

Genus *Julpfenderella* nov. gen Dragastan, Herbig et Popa

Derivatio nominis: in honour of Juliette Pfender, who described for the first time the algae of the Lower Lutetian of Egypt.

Diagnosis: thallus made of cylindrical segments, occasionally compressed – cylindrical to subcuneate, commonly dicho- or trichotomous branched. Segments crossed by a central, cylindrical medullar zone, with medullar siphons parallel. Cortex crossed by primary, long siphons (utricles), cylindro-conical, dichomously branched, continued with short, secondary siphons (utricles), conical or sub-conical, simple, unbranched (Pl. 4, Figs. 4-5, 7, in Pfender and Massieux, 1966).

Basionym: *Gymnocodium nummuliticum* Pfender et Massieux, 1966.

Discussion: *Julpfenderella* nov. gen can be compared with Recent and fossil species of the genus *Halimeda* Lamouroux 1832, such as *H. cylindracea*, *H. monile*, *H. gracilis*, and *H. lacunalis*. It is different of the genus *Halimeda* due to the reduced number of medullar siphons and with a cortex crossed by primary siphons, and with simple, unbranched secondary siphons.

Julpfenderella nummulitica
(Pfender et Massieux, 1966) nov. comb. emend.
Dragastan, Herbig et Popa

1966 *Gymnocodium nummuliticum* nov. sp. Pfender and Massieux 1966, p. 120, Figs. 1-4, Pl. 4, Figs. 1-5, 7, Pl. 5, Fig. 1;

2009 *Anatoliacodium nummuliticum* comb. nov. - Erdem and Radoicic, p. 313, Figs. 6.1-8, Figs. 7.1-4.

Basionym: *Gymnocodium nummuliticum* nov. sp. Pfender and Massieux 1966,

Repository: Geological laboratory, Sorbonne University, Paris, France.

Stratum typicum: Lower Lutetian;

Locus typicum: Gebel Galala el-Baharia, south of the Suez Channel, Egypt.

Type series: Cuvillier Collection, studied by Pfender and Massieux (1966).

Lectotype: Pl. 4, Fig. 7, in Pfender and Massieux (1966).

Syntypes: Pl. 4, Figs. 1-2, 4-5, Pl. 5, Fig. 1, in Pfender and Massieux (1966).

Diagnosis: the same as in genus diagnosis (see above), to which the following characters are added: the occurrence of filaments bearing gametes or gametangial cavities, disposed intra-cortically, to the boundary between the primary and secondary siphons (pag. 315, Fig. 7.2, in Erdem and Radoicic, 2009), or extracortically (pag. 315, Fig. 7.1, in Erdem and Radoicic, 2009), as a character more or less similar to the Recent *Halimeda* species.

Description: The thallus is represented by cylindrical segments, sometimes compressed or cuneate, commonly dicho- or trichotomously branched. The segments are crossed by cylindrical, medullar zones, with 6-7, parallel medullar siphons (p. 120, Fig. 3.1, in Pfender and Massieux, 1966). The cortical zone is thin, crossed by primary siphons (utricles), long, cylindrical-conical, increasing distally in diameter, dichotomously branched. The secondary siphons are short, simple, conical, unbranched (Pl. 4, Figs. 1, 4-5, 7, in Pfender and Massieux, 1966). In longitudinal section, the segment appear cylindrical (Pl. 4, Fig. 7, in Pfender and Massieux, 1966), with a clear medullar zone and a thin cortex. In transversal or in oblique-transversal sections (Pl. 4, Figs. 1-2, 4, in Pfender and Massieux, 1966), they have a circular shape, with a cylindrical, medullar zone, dicho- or trichotomously branched, especially in the cuneate shaped segments (Pl. 5, Fig. 1 in Pfender and Massieux, 1966, and at pag. 314, Fig. 6.1, pag. 315, Fig. 7.4 in Erdem and Radoicic, 2009). The traces of gametangial cavities occurring intracortically (pag. 315, Fig. 7.2, in Erdem and Radoicic, 2009) or extracortially (pag. 315, Fig. 7.1, in Erdem and Radoicic, 2009), can be more or less similar to Recent and fossil *Halimeda* species.

Genus *Tunisella* nov. gen.
Dragastan, Herbig et Popa

Derivatio nominis: from Tunisia, the country from which Poncet (1989) described this taxon.

Diagnosis: Thallus represented by discoidal, conical segments, narrow to the base, subcuneate (Pl. 1, Fig. 1, in Poncet, 1989), discoidal and flattened to the upper part of the thallus (Pl. 1, Fig. 3, in Poncet, 1989). Segments crossed by a moderate to large, medullar zone, with cylindrical, sinuous, mingled siphons, thin cortex, crossed by primary, subcylindrical siphons, with an increased

distal diameter, followed by short, cylindrical, dichotomously branched secondary siphons. Tertiary siphons (trichotomous, Pl. 1, Fig. 1 in Poncet, 1989) small, short, spheroidal, more or less swelling-like.

Basionym: *Halimeda soltanensis* Poncet 1989

Remarks: The following characters are typical: segment morphology, moderate to large medullar and thin cortical zones, with three types of siphons, tertiary siphons spheroidal or swelling-like.

Tunisella soltanensis (Poncet 1989) nov. comb. emend. Dragastan, Herbig et Popa

1989 *Halimeda soltanensis* Poncet, p. 41, Pl. 1, Figs. 1-5.
Repository: SNEA(P), Pau.
Stratum typicum: Upper Permian.
Locus typicus: Bir Soltane (Djebel Tebaga, Southern Tunis).
Lectotype: Pl. 1, Fig. 1, in Poncet (1989).
Syntypes: Pl. 1, Figs. 2-5, in Poncet (1989).
Diagnosis: the same as in genus diagnosis (see above).
Remarks: the thallus is represented by discoidal, subcuneate segments, crossed by a large medullar zone, with sinuous, mingled medullar siphons and a thin cortex. The cortex includes subcylindrical primary siphons, increasing distally in diameter, with cylindrical, dichotomously branched secondary siphons. The significant character is given by the shape of the segments and the occurrence of the globular-spheroidal tertiary siphons. Initially, the species from cores of Bir Soltane drillings, was considered to belong to Family Udoteaceae. Although the illustrations of the original paper (Poncet, 1989) do not show clearly the medullar siphons distribution, they still show rare siphons density. The structure of the inner cortex can be regarded as having three cortical siphons, of which the trichotomous branched (?) tertiary siphons (trichotomous sensu Poncet, 1989) are clear globular-spheroidal in shape. In this case, the morphae system is necessary to be used in the case of old (Permian-Jurassic) Halimedaceae species, as the shape and structure of segments is unknown along the thallus, opposite to the Recent *Halimeda* species.

On the other hand, the genus *Calabricodium* Senowbari-Daryan et Zamparelli 2005, Norian-Rhaetian in age, with cylindrical but distinctly annulate (segmented) thalli, crossed by a large medullar siphons and a thin cortical zone with very small siphons, belongs to the Family Halimedaceae.

Family Boueinaeae Shuysky 1987

Shuysky and Schirschova (1987) introduced a new tribe, the *Boueneae* Tribe (spelling of original paper), which included at the time two genera: *Boueina* Toula 1844 (Upper Triassic – Cretaceous) and *Funiculus* Shuysky and Schirschova 1987 (Middle Devonian – Eiffelian). The *Boueineae* Tribe Shuysky and Schirschova 1987 is proposed here to be transferred to Family level, the Family *Boueinaeae* Shuysky 1987. The original diagnosis of the tribe includes the following characters: „massive thallus subcylindrical, with sligthly irregular outline. The medullar zone is represented by

numerous branched filaments (siphons). The cortical filaments are simple, dichotomously ramified, and they have similar diameter to the medlullar filaments. The medullar and cortical zones are difficult to separate".

Emended diagnosis: cylindrical or sub-cylindrical thallus, branched, not articulated (not segmented), crossed by medullar, calcified filaments which are ramified dichotomously. The cortex of the cylindrical thalli includes filaments (siphons) with various orders of ramification (second to fourth orders of ramification). Sometimes, special inner structures occur, containing a central medullar siphon followed by radial-medullar siphons and a cortex with two subzones, a. with intercortical siphons, distributed between the radial-medullar siphons and b. the outer cortical siphons (such as in genus *Toulaina* nov. genus).

The family includes the following genera: *Boueina* Toula 1884, *Toulaina* nov. genus and *Funiculus* Shuysky and Schirschova 1987. However, we follow the hypothesis of De Castro et al. (2008) regarding the cylindrical, inarticulate (not segmented), branched thalli. The inarticulate character, marking the main difference with regard to *Halimeda* (having articulate thalli, made up by large calcified segments), is difficult to identify in fossil state due to preservational and taphonomic reasons. This material is located in Museum of Natural History (Vienna) and will be studied by Prof. Filippo Barattolo from University of Naples (personal communication). Recently, De Castro et al. (2008) discussed the rank of the Aptian taxon *Boueina hochstetteri moncharmonti* occurring near Salerno, Southern Italy. This taxon was erected by De Castro in 1963 as a subspecies of *Boueina hochstetteri* Toula 1884 emend. Steinmann 1901, based on the morphological differences and dimensions of thallus. The subspecies was raised to the specific rank as *B. moncharmontiae* (De Castro 1963) De Castro, Cimmino and Barattolo, for which a lectotype was designated in 2008. The authors considered the other species, such as *Boueina pygmaea* Pia 1936, quite similar to *B. moncharmontiae* (De Castro) and for the genus *Boueina* was hypothesized a thallus habit with branches, but non-articulate (without segments), this remaining the main difference from the genus *Halimeda* (with segments, articulate).

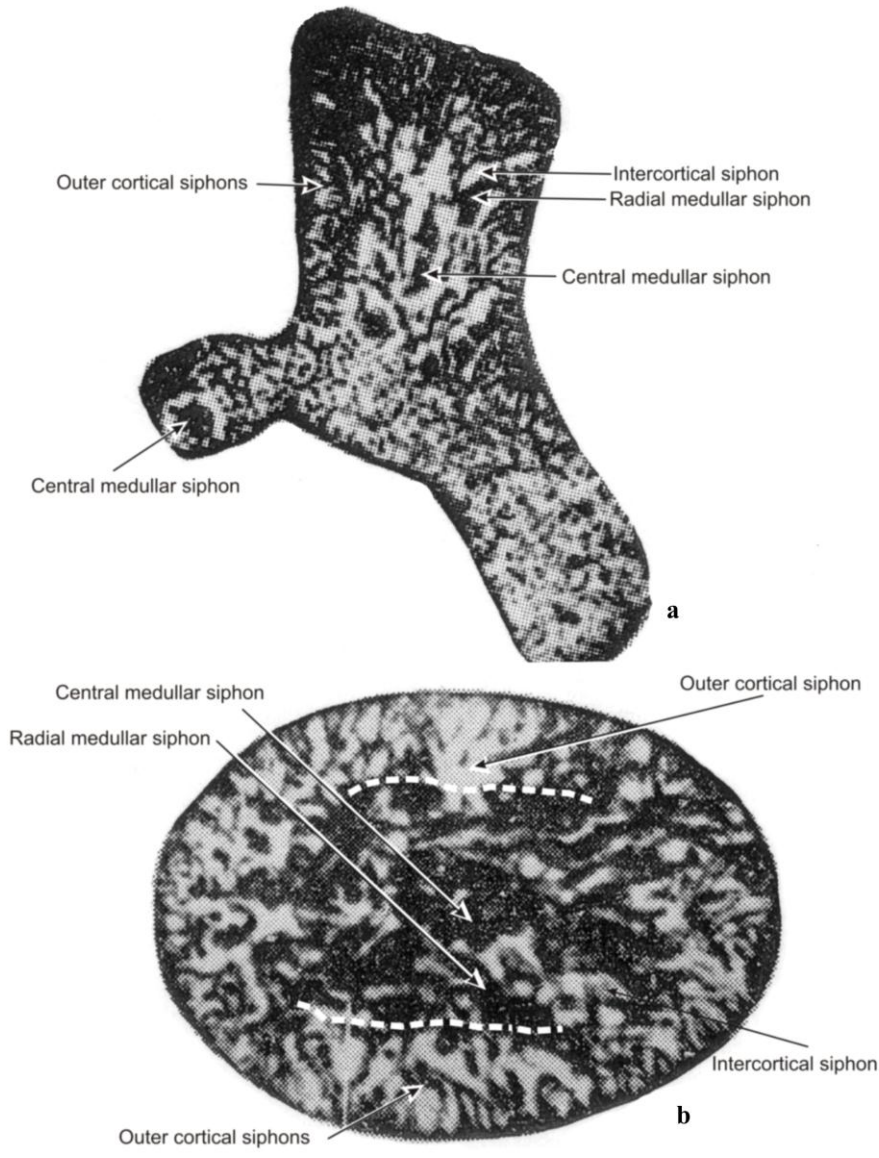### Genus *Toulaina* nov. gen. Dragastan, Herbig and Popa

Diagnosis: A fossil green alga with branched thallus, non-articulate, without segments or articles, crossed by a central medullar siphon from which medullar siphons start radially. Between the radial medullar siphons occur the inner intercortical siphons, dichotomously branched. The outer zone is crossed by outer cortical siphons, polychotomously branched.

Type species: *Boueina hochstetteri* Toula 1884 var. *liassica* Le Maitre 1937.

Toulaina liassica (Le Maitre 1937) nov. comb. Dragastan, Herbig and Popa
Fig. 46 a-b

Fig. 46 – a-b *Toulaina liassica* (Le Maitre 1937) Dragastan, Herbig and Popa, original figures from Le Maitre, 1937 in Johnson 1964 (Pl. 25, Fig.1), *Lectotype*, oblique-longitudinal section and **b** *Syntype*, transverse section, Liassic, locality between Itto-Fezzou and Ait-Aui, Morocco, x 30.

Lectotype: Fig. 46 a, from the original of Le Maitre (1937), in Johnson (1964), Liassic, locality between Itto-Fezzou and Ait-Ani, Morocco, excluded Pl. 12, Figs. 5-6 (Johnson, 1964), which are possible Calcisponges or Scleractinian corals.

Syntype: Fig. 46 b, from the original of Le Maitre 1937, (in Johnson, 1964), Liassic, the same locality, Morocco.

Observation: The Fig. 3 from Le Maitre (1937, in Johnson, 1964), is in reality a more enlarged part of the thallus from Fig. 1, now the Lectotype. Until now, in spite of our investigations, no repository was found for the thin sections of the original material of Le Maitre (1937).

Remarks: The new taxon can be compared with species of genus *Boueina* Toula 1883, but also with several *Halimeda* species, the occurrence of medullar area and of the cortex representing the common character. The new taxon differs from genus *Halimeda* because the thallus is non-articulate, and it has a different inner structure, similar to genus *Halimeda*, but not identical. The genus *Toulaina* has an inner structure different from both genera *Boueina* and *Halimeda*.

Description: Thallus cylindrical, branched, non-articulate, crossed by a central medullar siphon (Fig. 46 a), continued with 6 (?) radially medullar siphons. In the transverse section (Fig. 46 b), between radial medullar siphons occur in the intercortical siphons, dichotomously branched, followed by an outer cortical zone crossed by polytochomously branched siphons. In the tangential section, the outer cortical polytomic siphons are disposed 2 by 2 in a polygonal pattern (Fig. 47 c, lectotype more enlarged, part of the thallus, see the left side of the photo where occurs a small branch).
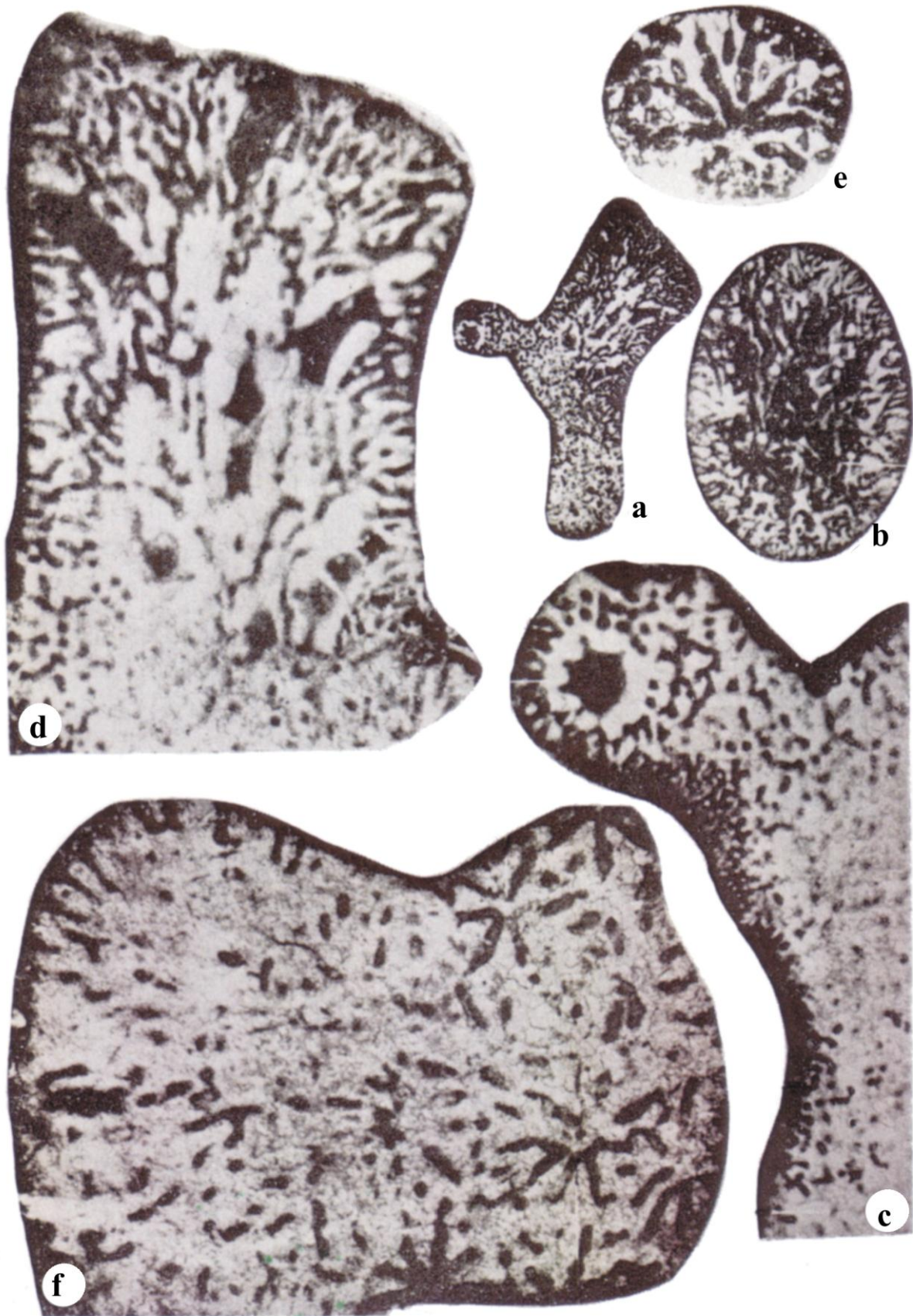
Fig. 47 – This figure is redrawn from Plate 25, Fig. 6 of Johnson (1964) from the original of Le Maitre (1937) **a-d** *Toulaina liassica* (Le Maitre 1937) Dragastan, Herbig and Popa, Fig. 1, *Lectotype,* oblique-longitudinal and tangential section, original in Johnson 1964 (Pl. 25, Fig. 3); **b** *Syntype*, transverse section, original in Johnson 1964 (Pl. 25, Fig. 4); **c** A part of the lectotype, more enlarged with central medullar siphon and the polygonal disposition of polychotomously branched siphons from the outer cortical zone. **d** Cylindrical part of the lectotype, more enlarged, original in Johnson (Pl. 25, Fig. 1); **e-f** Non algae organisms, possible different sections in Calcisponges or in the Scleractinian corals, in Johnson 1964 (Pl. 25, Figs. 2, 5). Liassic, Morocco, a x 10, b: x 20, c-d, e-f: x 3.

Dimensions in mm: in Le Maitre (1937), from Johnson (1964), Outer diameter (D) - 1.50-5.0 and diameter of radially medullar siphons (rdms) - 0.050.

Stratigraphic range: Lower Jurassic, Middle and Upper Domerian, Morocco (after Dorothée Le Maitre, 1937).

Problematical genera and species with different taxonomical assignments: Several genera and species were described from the Triassic limestone of the Dolomitic Alps and from Calabria (Southern Italy) by Brandner and Resch (1980) and by Senowbari-Daryan and Zamparelli (2005), initialy considered as halimedacean, are now transferred to Family Boueineae. In the same Family Boueineae we include the genera *Collareocodium* Brandner et Resch 1980, with 2 species (*C. oenipontanum*, Carnian, *C. cornuiformis*, Ladinian), *Egericodium*, *Madonicodium*, *Alpinocodium*, defined initially as halimedaceans by Senowbari-Daryan and Zamparelli (2005). The reason for this new nomenclatural assignement is represented by the following characters: branched thalli, dicho- trichotomous, multibranched thalli, but not segmented (not articulate), the inner structures of the medullar and cortical zones are different of those of the Halimedaceae.

Bucur (1994) described a new species, attributed to *Permocalculus*? *halimedaformis* from the Late Barremian – Lower Aptian, of the Miniş Valley Limestone Formation, recorded in association with *Palorbitolina lenticularis* (Blumenbach). The descriptions and the illustrations (Pl. 6, Figs. 1-6), the thallus is articulated with cylindrical segments, crossed by medullar siphons, and a cortex interpreted in this paper as crossed by primary, secondary and tertiary siphons (utricles). The cotex shows ovoidal-spheroidal empty cavities, representing the position of gametangia. The inner structural characters of the thallus make possible the transfer of this species, already assigned by it author (Bucur, 1994) to Family Gymnocodiaceae, to genus *Halimeda* Lamouroux 1812, Family Halimedaceae.

The genus *Brandneria* Senowbari-Daryan, Zühlke, Bechstädt et Flügel 1993, with 2 species, *B. dolomitica*, Anisian in age, and *B. calabrica*, Norian-Rhaetian in age. These species have a thallus with a basal part and a distal, club shaped part, dichotomously branched, composed by a thick medullar zone and a very thin cortical zone. These characters permit the inclusion of *Brandneria* to the Family Pseudoudoteaceae Dragastan et al. 1997, Tribe Brandneriaeae Dragastan 2002 (see the reconstruction of the thallus in Dragastan, 2002, Figs. 9-10).

According to De Castro et al. (2008), genus *Boueina* Toula 1883 has a different thallus, non-articulate, cylindical and branched, different from genus *Halimeda* with a thallus including articles or segments (articulate). Le Maitre (1937), in spite of her idea that the thallus presenting branches or ramifications, suggested that it is not necessary to separte two genera, *Boueina* and *Halimeda*. Pia showed that no differences are identified. Both genera have the same inner structure, with a medullar area and a cortex, with a proper inner structure, with specific variations.

The genera belong to different families, Halimedaceae and Boueinaeae. The *Boueina* stock of species already published (Johnson, 1969, Pl. 29, Figs. 4-5; Bassoullet et al., 1983), including *B. hochstetteri* Toula 1884, *B. globosa* Dragastan, Bucur and Demeter 1978, *B. pygmaea* Pia 1936 (in Kuss, 1994), *B. hochstetteri*, *B. pygmaea* (Pl. 3, Figs. 1-5, 8-11), Taherpour et al., 2009, p. 84, Fig. 4, g-i), *B.* cf. *hochstetteri* have to be revised together with new redescriptions. Not all species can be taken into synonymy to some *Halimeda* species. Taherpour et al. (2009), showed unfortunately only the transversal sections, such as in their Fig. 4g, difficult to decide in favour of genus *Halimeda* or genus *Toulaina*. The Fig. 4h can be *Boueina* and Fig. 4i. can be *Halimeda*.

The difficulties of this separation between the two families with different species include also the identification of the real habit (non-articulate thalli) for *Boueinaeae* taxa, because in many cases, the thallus is broken, and the non-articulate habit is not easy to identify. The same difficulties arise also for the controversial genus *Arabicodium* and the species assigned to this genus (in Johnson, 1969, Pl. 30).

The genus *Juraella* described by Bernier (1984) was assigned to the family Udoteaceaee. Bucur (1994) assigned *Juraella* to *Gymnocodiaceae* and Taherpour et al. (2009) to Bryopsidales. The assignment to the *Gymnocodiaceae* was preferred due to the sporangia occurrence in the terminal cortical area (Elliott, 1955b). Moreover, Roux and Deloffre (1990) showed that the conceptacles of different *Gymnocodium* species occur in medullary or cortical positions with ovoidal or fusiform shapes, depending on the section. In fact, these structures were distal, sphaerical, as empty cavities, continuing the proximal siphon, as figured in Fig. 4b of Taherpour et al. (2009). The same disposition of sphaerical cavities was found in *Pseudopalaeoporella lummatonensis* Elliott 1961 from the Eifelian, a taxon disputed between *Halimedaceae* and *Gymnocodiaceae* (Hubmann and Fenninger, 1997).

Dragastan and Herbig (2007) described different taxa, such as *Halimeda lacunosa* Dragastan and Herbig, with cortical or intracortical-gametangial cavities (p. 45, Pl.7, Figs.1-3). *Halimeda praetaenicola* Dragastan et Herbig 2007 shows a long fertile siphon, as pedunculate filament bearing a gametangium as a swelling (p. 47, Pl. 9, Fig. 2). Also, *Halimeda monile* (J. Ellis and Solander) Lamouroux 1816 shows round gametangial cavities located on secondary and tertiary utricles (p. 54, Pl. 14, Figs.1, 3), all these facts proved that also in the fossil state, *Halimeda* preserved such traces of gamentagial cavities, in the place where they were born or where the place of reproductive organs occurred, remaining inside the thallus without being able to germinate. Our opinion is that genera like *Juraella*, and also *Pseudopalaeoporella*, which showed such traces or cavities, can be ascribed with more confidence to family *Halimedaceae* (Chlorophyta) and with less confidence to family *Gymnocodiaceae* (Rhodophyta).

In another paper Erdem and Radoicic (2009) introduced the new genus *Anatoliacodium* which was compared with genus *Halimeda*. Unfortunately, the

diagnosis and the description of the new taxon is the same with genus *Halimeda*, and we consider that the new genus is a junior synonym of genus *Halimeda*. The species *Anatoliacodium xinanmui* nov. sp. must be transferred to genus *Halimeda* Lamouroux 1812, being very close to *H. incrassata* (J. Ellis) Lamouroux 1816. Also *Anatoliacodium merici* nov. sp. has affinities with *Halimeda barbata* Dragastan et Herbig 2007. In the same paper, *Halimeda* ? sp. (Fig. 8, 4-6) is a real *Halimeda tuna* (J. Ellis and Solander) Lamouroux 1816.

The *Gosavisiphon* nov. gen. introduced by Schlagintweit 2010, instead of *Halimeda paucimedullaris* Schlagintweit and Ebli 1998, is a special algal structure with only a thallus plate, non-segmented, and non-branching (in their authors view), crossed by a central, simple siphon, comparable with the medullar structures. In the author's view, the cortication comprises a basal part (conical primary-club-shaped distally siphon, our view), and an erect part (with secondary inflated distally, dichotomously branched siphons). The thallus presented by only one? plate or blade, or a basal prostrate layer, in the opinion of the author. This character is not visible in all cases, and may imply a rhizoidal anchor, partially comparable with the genus *Udotea*, composed by three parts: 1. uncalcified rhizoidal mass; 2. corticated stalk; and 3. fan-shaped terminal blade (Littler and Littler, 1990), but the presence of a system with a narrow medulla and cortex with primary and secondary siphons is close also to the genus *Halimeda*. It differs from this genus by the non-segmented or non articulate thallus. It can be also compared with genus *Boueina*, which had a non articulate (without segments) thallus, but branched, a status recently demonstrated by De Castro et al. (2008). Unfortunately, the description of genus *Gosavisiphon* is not so clear with regard to the morphology of the thallus and of the inner structure (p. 43). However, the author, in only one figure (Fig. 14, p. 48) wished to elucidate the real morphology of this green alga. The thallus comprises three parts: 1. a rhizoidal mass with only primary siphons, prostrate; 2. the erect, flatenned, blade crossed by cortical, primary, secondary and tertiary siphons, bilaterally disposed on both sides of the medulla siphon, which seems like a narrow central channel; and 3. another small blade or blades, laterally disposed, with a central, multisiphonal medullar area, and a cortex crossed by primary, secondary and tertiary siphons.

All these characters support the idea that the genus *Gosavisiphon* belongs to a taxon of family Halimedaceae, with a thallus which preserved a rhizoidal prostrate mass and an erect part composed of a main blade or segment, which successively sustains lateraly other small blades - segments. The inner structure, with a central medulla, and uni- or bilaterally disposed cortex crossed by different branched cortical siphons, are the arguments in favour of this affiliation. The blade can be assimilated with segments and there is no connection of this genus with any phylloid algae.

Family Praecodiaceae Dragastan 2008

To this family are included Palaeozoic taxa (*Botrys compacta*, *Botryella spinosa* and *Uva suspecta*, Devonian in age, see Dragastan, 2008, pag. 86, Fig. 4.1-3).

Dragastan (2008) introduced the genus *Lupertosinnium* nov. gen, based on the type species *L. bariensis*. This species is actually a dasycladalean, according to Dr. T. Grgasović of the Croatian Geological Institute (pers. comm.), therefore we consider this taxon as invalid. Dragastan (2008) described and assigned an other species belonging to this invalid genus, as *Lupertosinnium banatensis* Dragastan 2008. Considering this nomenclatural issue, we transfer this species to genus *Bucurium* nov. gen., as *Bucurium banatensis* (Dragastan 2008) nov. comb. emend. Dragastan, Herbig et Popa.

Genus *Bucurium* nov. gen.

Derivatio nominis: Genus dedicated to Prof. Ioan I. Bucur, Babeş-Bolyai University, Cluj-Napoca, who illustrated for the first time this taxon as ?*Halimeda* sp.

Diagnosis: Calcareous broken, cylindrical branched thalli, crossed by narrow, axial, medullar zone, and cortex only with primary siphons (utricles), cylindrical, up to claviform and ovoidal in shape, and slightly recumbend upwards.

Basionym: *Lupertosinnium banatensis* nov. sp. Dragastan 2008.

Remarks: The thallus morphology and its inner structure with a central medulla and a cortex only with primary siphons, are characteristic for this taxon and for this family. This genus has affinities with the Recent genera *Codium* and *Pseudocodium*. Dragastan (2008) recommended not to use the *Codium* suffix for the genera not belonging to the Families Codiaceae and Pseudocodiaceae. For the Family Praecodiaceae Dragastan 2008 we recommend to use the suffix „*ium*", as in the Recent genus *Codium*.

Bucurium banatensis (Dragastan 2008) nov. comb. emend. Dragastan, Herbig et Popa

1994 *Halimeda*? sp. Bucur, p. 17, Pl. 3, Fig. 6-7;
2008 *Lupertosinnium banatensis* Dragastan, p. 89, Pl. 1, Fig. 6.

Repository: I. I. Bucur Collection, Sample 1242, Babeş-Bolyai University, Cluj-Napoca.

Stratum typicum: Late Barremian – Early Aptian.

Locus typicus: Doman, Reşiţa-Moldova Nouă zone, South Carpathians.

Lectotype: Pl. 3, Fig. 6 in Bucur 1994 (reproduced in Pl. 1, Fig. 6 in Dragastan, 2008).

Diagnosis: The same as in the genus diagnosis to which the specific characters are added: cylindrical thalli, crossed by a narrow medullar zone and a cortex with only primary, claviform – ovoidal siphons.

Description: as in Dragastan (2008, p. 89)**:** Cylindrical, broken thallus, crossed by a cylindrical medullar zone. The medullar zone is represented by 4-6 tubular siphons, medium-long, dichotomously branched and parallel. The connection between the medullar siphons and the cortical siphons is strongly acute and angular. Only primary cortical siphons occur, they have an oval-ellipsoidal shape, and they are arranged in a regular manner.

Remarks: Bucur (1994) assigned this taxon to *Halimeda*? sp., considering a long, cylindrical specimen

having a *Halimeda*-like inner structure. But the occurrence of only primary, cortical siphons points only to a comparison with the Recent genus *Codium* Stockhaus.

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