Calcareous algae in changing environments

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ABSTRACT
Although calcareous algae are known both in present environments and fossil records, from shelf and upper slope settings, either in warm seas for green algae or at all latitudes for red algae, we still need models to quantify their abundance in space and time. Calcareous algae are an important component of biogenic carbonate production but they are very sensitive to marine acidification and rise in temperature, as illustrated by the effects of ongoing global change. Contributions herein were first presented at the 6th Regional (European) Symposium of the International "Fossil Algae" Association: they include two reviews respectively devoted to the carbonate production of red and green algae, and a suite of investigations covering quantification, facies delineation, and controlling factors spanning the present-day Mediterranean Sea and Eastern Pacific going back to the Jurassic of Romania.

KEY WORDS
Calcareous algae,
Bryopsidales,
Corallinales,
Dasycladales,
Sporolithales,
microfossils,
algal carbonates,
algal lithofacies,
environmental factors,
global change.

RÉSUMÉ
Les algues calcaires dans des environnements en constante évolution.
Bien que les algues calcaires soient reconnues et dans les environnements actuels, et dans le registre fossile, dans des domaines de plate-forme ou du talus supérieur, dans des mers chaudes pour les Chlorophycées ou à toutes les latitudes pour les Rhodophycées, nous ne disposons pas encore de modèles permettant de quantifier leur abondance (paléo-)géographique et stratigraphique. Ces

algues calcaires, qui jouent également un rôle primordial dans la production biogénique de carbonates, sont particulièrement sensibles à l'acidification des océans et aux modifications climatiques, comme cela est illustré de nos jours par le réchauffement climatique dont nous sommes acteurs et témoins. Initialement présentées dans le cadre du 6ème Symposium régional (européen) de l'Association internationale des « Algues fossiles » (IFAA), les publications rassemblées dans ce volume comportent deux articles de synthèse dédiés à la production de carbonates par ces algues, l'un se focalise sur les algues rouges tandis que l'autre traite des seules algues vertes, suivis d'une sélection de contributions couvrant des aspects aussi divers que la quantification proprement dite, la cartographie des environnements, les variables environnementales… documentées par des exemples contemporains pris en Mer Méditerranée ou dans l'Océan Pacifique, mais aussi remontant dans le temps jusqu'à un « morceau choisi » du Jurassique de Roumanie.

MOTS CLÉS
Algues calcaires,
Bryopsidales,
Corallinales,
Dasycladales,
Sporolithales,
microfossiles,
carbonates d'origine
algaire,
lithofaciès à algues
calcaires,
paramètres
environnementaux,
changement planétaire.

This special issue of Geodiversitas compiles scientific contributions originally presented at the 6th Regional – European – Symposium of the IFAA (International "Fossil Algae" Association). The symposium, held in Milan between 1-5 July 2009, was jointly organized by the University of Milano-Bicocca (Department of Geological Sciences and Geotechnologies), and the University of Genova ("Dipartimento per lo Studio del Territorio e delle sue Risorse").

Researchers from fourteen countries (Canada, Croatia, France, Germany, Japan, Iran, Italy, Mexico, Romania, Saudi Arabia, Spain, Switzerland, UK, USA) contributed to this truly international symposium. Among them, some twenty Italian researchers from the universities of Milano-Bicocca, Catania, Ferrara, Genova, Modena e Reggio Emilia, Napoli, and Roma, presented their latest results (Fig. 1).

Participants in a one-day pre-symposium fieldtrip visited Triassic outcrops in the area of Lake Iseo, where the microbial and microbially-induced limestones and cements of two discrete carbonate systems, the Ladinian Esino Limestone and the Norian Dolomia Principale, crop out, each presenting a discrete depositional architecture and tectonic setting (Berra *et al.* 2009). On the post-symposium field trip participants explored a suite of paleoenvironments in the Tertiary Piedmont Basin including the Oligocene Characeae and Tracheophyta of Santa Giustina (Savona), the Oligocene coral and red algae reefal facies of Maddalena (Sassello, Savona), the rhodolith beds of the Burdigalian of Ponzone and the Serravallian of Stazzano (Alessandria) (Quaranta *et al.* 2009).

The abstracts and excursion guides were published in the e-journal *Museologia Scientifica e Naturalistica* (Basso *et al.* 2009). As with previous IFAA symposia, the subjects encompassed many geological and paleontological aspects of calcareous algae and microbialites, including their current distribution and ecology. In addition, participants were invited to present contributions dealing with the production of carbonates by calcareous algae in space and time, as affected or controlled by physical, chemical, geological and biological factors. Calcareous algae are sensitive to the consequences of global change, including marine "acidification" and rise in ocean temperature. However, in assessing the sensitivity of an organism or taxon to the effects of global change, we need reliable data on the composition of present-day marine sediments and the distribution and relative abundance of the producers of biogenic carbonates: these data are required for the establishment of a model predicting the response of benthos on both regional and basinal scales. Therefore, the contribution of specialists on calcareous algae extends well beyond the usual limits conceived to be their discipline, for it involves marine geology, oceanography and climatology.

Fig. 1. — A group of attendees at the Milano-Bicocca University.

We dedicate this special issue to all aspects of quantifying species abundance and the subsequent elaborations of it in paleophycology. The need is particularly pressing for the quantification of carbonate production by calcareous algae, a heterogeneous group of important and sometimes dominant organisms in present-day marine benthic environments. Only they can furnish evidence for the primary production of algal $CaCO_3$ in the past. As the following contributions demonstrate, quantification is the only way to clarify the role of calcareous algae in the global carbon budget, a basic tool for the interdisciplinary fields that global change research demands. In addition to the question of quantification, all contributions focus on the conditions fostering the development and evolution of algal facies and the factors controlling the relative importance of major carbonate producers.

The first two articles are reviews of red algae and green algae as carbonate producers. Basso (2012) provides a synthesis of the features of algal calcification in existing Rhodophyta, their role as framework builders and sediment producers. Basso synthesizes published data on carbonate production by coralline algae and concludes that coralline algal distribution appears to have been greatly underestimated in modern benthic environments because of a lack of adequate surveys. Basso (2012) recommends that the identification and delimitation of marine habitats dominated by calcareous red algae and all approaches to the quantification of living and fossil calcareous algae in the several environmental and paleoenvironmental settings should be intensified because this information is crucial to the establishment of a valid global carbon budget. Furthermore this information will help predict carbonate budget changes in response to alterations of the marine environments as temperatures rise and marine acidification continues.

In most red algae calcification is intracellular and consists of magnesian calcite. By contrast,

the calcification process is extracellular (eventually intercellular) in most green algae and consists of aragonite, an unstable polymorph of $CaCO_3$, which is precipitated. Aragonite is rarely observed in ancient rocks and, well aware of this fact, Granier (2012) presents a review of the effective contribution of green algae to carbonate sedimentation over Phanerozoic times. This synthesis provides a better understanding of both the modern and fossil records; Granier investigates some unexplored fields (e.g., porosity genesis, green algal bioherms, interpreted paleobathymetry ranges) and he also suggests additional fields for future investigations in calcareous green algal research.

The remaining contributions are ordered from the present-day examples to the most ancient paleoenvironments, spanning the present-day Mediterranean and eastern Pacific to the Jurassic of Romania.

Coralline carbonate production in the present-day Mediterranean has been quantified in two soft-substrate benthic environments of the Tyrrhenian Sea, using a combination of seafloor-mapping by acoustic survey techniques and petrographic analyses of voucher sediment samples. Using these methods, Bracchi & Basso (2012) identify a Coralline Algal facies (CA) and a Carbonate matrix facies (CM) in the Pontian Archipelago, covering 62 km^2 between 30 and 100 m of water depth. Corallines contribute about 80% and 15% of the total carbonate in the CA and CM facies respectively, with a production rate of the mean 7% live coralline cover ranging between 8 and 32 g per m^2 per year. Similarly, Savini *et al.* (2012) calculate a total coralline cover of about 14 km^2 off the Cilento peninsula, between 42 and 52 m of water depth, with an accumulation of coralline algal carbonate of about 20 kg m^2. The live maërl facies produces about 90 g m^{-2} yr^{-1} of coralline algal carbonate. The authors also provide information on maërl-bed characterization by acoustic survey and suggest that submarine terraces are a preferential maërl location because the terraces divert bottom currents that prevent smothering by fine sediment. Quantitative acoustic mapping is reported by Halfar *et al.* (2012) in the Gulf of California, where a series of well-developed rhodolith-dominated communities occur. The carbonate factory of Punta Chivato, off the eastern Baja California Peninsula, is characterized by wave-dominated rhodolith beds producing more than 60% of the total biogenic carbonate, mostly confined to the 15 m depth contour. Nutrients play a significant role in decreasing the light penetration by stimulating phytoplankton growth. Decreased light penetration results in a compressed benthic zonation and shallow euphotic zone which in turn controls the depth distribution of the rhodolith beds at Punta Chivato.

Aguirre *et al.* (2012) describe the rhodolith beds and bryozoan-coralline algal-bivalve buildups occurring in the Lower Pliocene deposits of the Carboneras Basin (Spain). The development of rhodolith beds in transgressive deposits was promoted by moderate energy and low sedimentation rates, although rhodoliths continued to accumulate during the highstand, beyond the influx of siliciclastics that reduced carbonate production in the rest of the basin. The outer-shelf bioconstructions differ from the present-day *coralligène de plateau* in the secondary role played by corallines as builders and in the very low relief, hardly protruding from the seafloor.

The first attempt to quantify the coralline algal carbonate in a fossil rhodolith bed is reported by Basso *et al.* (2012), for a Serravallian outcrop of Alessandria, in the Tertiary Piedmont Basin, Italy. After reviewing the definition of rhodolith beds in the biologic and geological literature, the authors report a carbonate production spanning 55 to 136 g m^{-2} yr^{-1}, based on image analysis of 33 sites within the 7-m thick outcrop, and they provide comparisons with the carbonate production and rhodolith growth-rate in a Brazilian present-day analogue.

Environmental factors controlling the abundance and composition of rhodalgal assemblages along the depositional profile on the Attard carbonate ramp (Upper Oligocene of Malta) are discussed by Quaranta *et al.* (2012). The succession of tropical red algal assemblages follow an inner/middle ramp (depth) gradient, possibly complicated by episodes of downslope transport. Rhodolith structure in the inner ramp reflects high-energy conditions, locally mitigated by the presumed occurrence of seagrasses. Availability of nutrients and a rising Mg/Ca ratio are thought to control the abundance of coralline algae in the Oligocene factories.

The uncommon association of rudist and rhodalgal lithofacies in the Late Cretaceous carbonate factories of north-western Sardinia is discussed by Simone *et al.* (2012). The authors describe the substitution of chlorozoan assemblages by rhodalgal/foramol ones in the Late Turonian carbonate system of the Nurra Region, in a tectonically-controlled setting. In the uppermost Turonian-early Campanian times, rudists became the major carbonate producer, confining red algae to the deepest areas. The demise of the chlorozoan factory was induced by the Early-Middle Turonian hyper-greenhouse conditions. The relatively cool and mesotrophic/eutrophic conditions presumed to become dominant in the Santonian Nurra carbonate system fostered the development of the rudist-bearing rhodalgal facies.

Takayanagi *et al.* (2012) report that the inception of a shallow-water carbonate factory on 24 submerged seamounts of variable age in the northwestern Pacific is primarily controlled by the substrate availability on newly formed volcanic edifices, disregarding paleoclimate. By contrast, the change in carbonate facies of shallow-water factories, from molluscs (including rudists) and non-skeletal grain-dominated carbonates of Cretaceous to scleractinian corals and a coralline algal-dominated carbonates of the Oligocene to the Quaternary, is explained by increased seawater Mg/Ca ratios, decreased temperatures and carbonate saturation states combined with local variable nutrient supply.

The simplistic textbook view of the Dasycladales is that they are characteristic of the lagoonal environments. This environmental limitation is contradicted by the modern examples as well as by fossil cases such as the one dealt with by Bucur & Săsăran (2012): these authors describe large and heavily calcified dasyclads from reefal areas. These dasyclads preferred the hard substrates of the reef to the muddy soft sediments of the lagoon.

To conclude this introductory chapter we take the opportunity to briefly assess today's state of paleophycology. Comparing the status of our discipline in terms of researchers per country or at the level of the groups investigated (red, green, blue-green) reveals a great heterogeneity. The study of coralline algae is still a vivid field of research: this geologically young algal group (the oldest coralline record dates back to the Early Cretaceous times and they have kept expanding since then) is bridging biological and sedimentological interests (Basso 2012). The Italian community is very active in this field as this volume testifies. We worry however that the balance is moving towards "pure" sedimentologic studies because the number of people involved in systematics is dramatically decreasing (due to retirement without replacement). The situation is even worse with respect to the study of the green algae. For instance, the "French" (French-speaking) group studying fossil algae (known as the "Groupe français d'étude des algues fossiles") has drastically been reduced from more than ten people in 1979 to one - "the Last of the Mohicans" - in 2012. There are several parameters that should be taken into consideration to explain this fact. One commonly assumes we already know all about the green algae, an assumption which easily proves to be wrong (Granier 2012). As a matter of fact paleophycology is one of the many fields of paleontology that suffers a lack of institutional support because they merely imply a naturalistic approach to geology. We said our community of paleophycologists is presently not expanding unlike the Coralline algae during the Late Cretaceous and then the Cenozoic: however we still hope it will survive the crisis and renew as the Dasycladales have done a couple of times in geologic history. Therefore let us end with an optimistic view because the 10th International Symposium on Fossil Algae, which was recently (12-18 September 2011) held in Cluj Napoca, was quite successful (with 54 participants from 16 countries), because the 11th International Symposium is scheduled for 2015 in Japan, and because the 7th Regional Symposium will be organized next year (2013) in Schladming, Austria.

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