Articles

Facies Models 7. Introduction to Carbonate Facies Models

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Introduction

This article is a general introduction to facies models in carbonate sedimentary rocks, within the larger *Facies Models* series. Here I would like to set the stage for these articles by outlining the inherent differences between siliclastic and carbonate sedimentation (Table I).

Table I
Differences between siliclastic and carbonate sediments.

Carbonate Sediments	Siliclastic Sediments
The majority of sediments occur in shallow, tropical environments	Climate is no constraint, sediments occur worldwide and at all depths
The majority of sediments are marine	Sediments are both terrestrial and marine
The grain size of sediments generally reflects the size of organism skeletons and calcified hard parts	The grain size of sediments reflects the hydraulic energy in the environment
The presence of lime mud often indicates the prolific growth of organisms whose calcified portions are mud size crystallites	The presence of mud indicates settling out from suspension
Shallow water lime sand bodies result primarily from localized physiochemical or biological fixation of carbonate	Shallow water sand bodies result from the interaction of currents and waves
Localized buildups of sediments without accompanying change in hydraulic regimen alter the character of surrounding sedimentary environments	Changes in the sedimentary environments are generally brought about by widespread changes in the hydraulic regimen
Sediments are commonly cemented on the sea floor	Sediments remain unconsolidated in the environment of deposition and on the sea floor
Periodic exposures of sediments during deposition results in intensive diagenesis especially cementation and recrystallization	Periodic exposure of sediments during deposition leaves deposits relatively unaltered
The signature of different sedimentary facies is obliterated during low grade metamorphism	The signature of sedimentary facies survives low grade metamorphism

Carbonate Sediments are Born, Not Made

This deceptively simple phrase encapsulates the main theme of the differences between the two sediment types. Siliclastic sediments, made primarily by the disintegration of parent rock, are transported to the environment of deposition and once there the patterns of texture and fabric are impressed upon the sediment by the hydraulic regimen. The signature of siliclastic facies is thus in sedimentary structures and grain size variations. Carbonate sediments, on the other hand, are born in or close to the environment of deposition. Thus, in addition to the purely physical sedimentary parameters used in the analysis of non-carbonate sediments, the composition of the sedimentary particles themselves either precipitated out of seawater (e.g., ooids) or formed by organisms (e.g., corals and clams), is equally important in characterizing the depositional environment.

Variations of Carbonate Producing Organisms with Time

To interpret ancient sedimentary sequences and construct facies models we rely heavily upon observations in modern environments of deposition. This approach works and is seen to work because the basic composition of most sedimentary particles has remained the same through time, a quartz sand grain or an ooid is the same in the Pleistocene, Permian or Precambrian. Because organisms have changed with time it is difficult, at first glance, to compare modern and specific ancient carbonate facies. I think, though, that carbonate secreting organisms in the rock record, when viewed as sediment producers, do have living equivalents in modern oceans, although they may not even be in the same phyla. This is because, despite the numerous groups of organisms with hard parts, there are only two ways in which these hard parts are arranged: 1) as whole, rigid skeletons (foraminifers, snails, corals), and 2) as numerous individual segments held together in life by organic matter (trilobites, clams, fish). Table II lists the more important *carbonate* producing and binding organisms and their fossil equivalents.

Zones of Carbonate Accumulation

Because the precipitation of carbonate is easiest in warm, shallow seawater, most carbonate sedimentation takes place on continental shelves or banks in the tropics. Although the majority of sediments produced in this 'carbonate factory' remain in the source area, some are transported landward and some are transported basinward (Fig. 1). Thus, there are three different zones of accumulation: 1) the subtidal, open shelf and shelf margin, characterized by in place accumulations of lime sands, lime muds and reefs; 2) the shoreline, where sediments are transported from the open shelf onto beaches and tidal flats; and 3) the slope and basin, where shelf-edge sediments are transported seaward, often by mass movements, and redeposited at depth. In the basins, especially in post-Jurassic time, the fallout of calcareous zooplankton and phytoplankton has also contributed significantly to carbonate sediments.

The reader who wishes a detailed account of different carbonate sedimentary facies through time is referred to a recent outstanding documentation by Wilson (1975).

As each of the three zones of accumulation have distinctive sedimentary environments and produce differing sedimentary facies they will form a framework for the subsequent articles on carbonate facies models. The shoreline and slope to basin facies models are most like siliclastic facies models because sediments are transported from one area and deposited in another. Roger Walker (1976) has already alluded to slope to

Table II

The sedimentary aspect of modern carbonate producing and binding organims and their counterparts in the fossil record

Modern Organism	Ancient Counterpart	Sedimentary Aspect
Corals	Archaeocyathids, corals Stromatoporoids, Bryozoa, Rudistid bivalves, Hydrozoans	The large components, often in place, of reefs and mounds.
Bivalves	Bivalves, Brachiopods, Cephalopods, Trilobites and other arthropods	Remain whole or break apart into several pieces to form sand and gravel-size particles
Gastropods Benthic foraminifers	Gastropods, Tintinids, Tentaculitids, Salterellids, Benthic Foraminifers, Brachiopods	Whole skeletons that form sand and gravel-size particles
Codiacean algae - *Halimeda*, sponges	Crinoids and other pelmatozoans, sponges	Spontaneously disintegrate upon death into many sand-size particles
Planktonic foraminifers	Planktonic foraminifers Coccoliths (post Jurassic)	Medium sand-size and smaller particles in basinal deposits
Encrusting foraminifers and coralline algae	Coralline algae, phylloid algae, Renalcids encrusting Foraminifers	Encrust on or inside hard substrates build up thick deposits or fall off upon death to form lime sand particles
Codiacean algae *Penicillus*	Codiacean algae - *Penicillus*-like forms	Spontaneously disintegrate upon death to form lime mud
Blue-green algae	Blue-green algae (especially in Pre-Ordovician)	Trap and bind fine-grained sediments to form mats and stromatolites

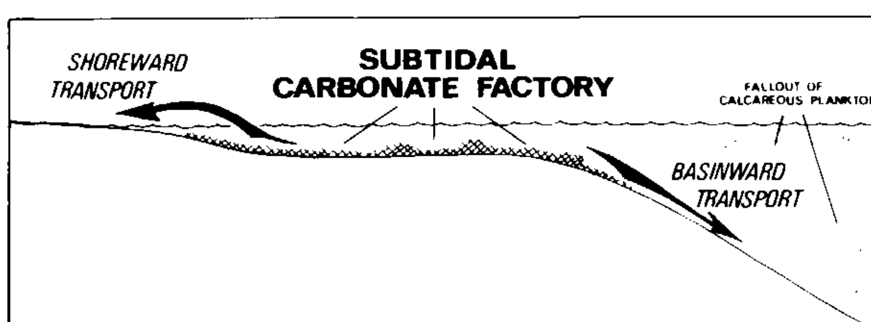

Figure 1
A sketch illustrating the main zones of carbonate accumulation

basin facies in the context of carbonate turbidites and debris flows. At the other end of the spectrum, reefs and reef-like deposits are the most unlike siliclastic facies as they are predominantly accumulations of biologically produced, in place, carbonate.

I have chosen to begin the discussion of carbonate facies models with a description of the nearshore zone of accumulation, reflected in the rock record by shallowing-upward sequences. They are most like the siliclastic models described previously in this series by Walker, are reasonably well understood and more or less independent of variations in carbonate-producing organisms with time.

General References

The reference list on this topic is relatively short because there have recently appeared several excellent texts on carbonate sediments and facies. From these the reader can easily gain access to most of the pertinent literature on any specific aspect.

Bathurst, R. G. C., 1975, Carbonate Sediments and their Diagenesis: Developments in Sedimentology, No. 12, Elsevier, 2nd Ed., 658 p.

This book is the most complete reference on the topic of modern and ancient carbonates. Chapters 1 and 2 detail the petrography and occurrence of modern and ancient carbonate particles. Chapters 3 and 4 summarize several different and well-studied environments of carbonate deposition. The book does not cover ancient sedimentary rock sequences.

Milliman, J. D., 1974, Marine Carbonates: Springer-Verlag, 375 p.

This book is devoted wholly to modern carbonate sediments. The first half of the book is an exhaustive documentation of different carbonate particles, the second half is a discussion of modern environments of carbonate deposition.

Wilson, J. L., 1975, Carbonate Facies in Geologic History: Springer-Verlag, 471 p.

Chapters 1, 2 and 12 of this book are an excellent summary of the principles and stratigraphic aspects of carbonate sedimentation. The bulk of the text is a detailed review of carbonate sedimentary facies at different times in geologic history.

Horowitz, A. S. and P. E. Potter, 1971, Introductory Petrography of Fossils: Springer-Verlag, 302 p.

Chapter 2 is a concise introduction to carbonate sedimentology and the remainder of the book is devoted to the recognition of various skeletal particles in thin section.

Ham, W. E., ed., 1962, Classification of Carbonate Rocks, a Symposium: Amer. Assoc. Petrol. Geol., Memoir 1, Tulsa, Okla., 279 p.

This symposium contains several papers, notably those by W. E. Ham and L. C. Pray, M. W. Leighton and C. Pendexter, R. L. Folk, R. J. Dunham, which, by attempting to classify sedimentary carbonates, outline succinctly the important factors governing carbonate sedimentation.

Ginsburg, R. N. and N. P. James, 1974, Holocene carbonate sediments of Continental Shelves, *in* C. A. Burke and C. L. Drake, eds., The Geology of Continental Margins: Springer-Verlag, p. 137-157.

A short article summarizing the sedimentology of eight different well-studied areas of carbonate sedimentation in the modern ocean.

Ginsburg, R. N., R. M. Lloyd, K. W. Stockman and J. S. McCallum, 1963, Shallow Water Carbonate Sediments: *in* M. N. Hill, ed., The Sea, Vol. 3, p. 554-578.

This article illustrates how the architecture of modern marine carbonate skeletons governs the grain-size of the resultant sediments.

Folk, R. L. and R. Robles, 1964, Carbonate Sands of Isla Perez, Alacran Reef, Yocatan: Jour. Geol., v. 72, p. 255-292.

A classic study illustrating how two different skeletal organisms, corals and the codiacean alga *Halimeda*, break down under different conditions into specific grain sizes.

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