| Subject | Geology |
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| **Paper No and Title** | **Sedimentology and Petroleum Geology** |
| **Module No and Title** | Geometry of Carbonate Platform |
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## Table of Content



## 1. Learning outcomes

After studying this module, you shall be able to:

- Know about how different types of carbonate platform develop.
- Learn about controlling factors, roll of tectonics and different stages of carbonate platform development.
- Know about the geometry of the carbonate platform and their response to relative sea level changes.

## 2. Introduction

Carbonate sediments are largely biogenic commonly deposited in shallow illuminated aquatic environments. Carbonate sediments are born as precipitates or organic skeletons within the depositional environment (James and Jones, 2016). Biogenic control dominated Phanerozoic carbonate sedimentation. In the Proterozoic, situation was not probably much different, although microbiota substituted for skeletal organisms. Archaean carbonates are mostly fragmentary and clastic, precursors of which are largely uncertain. Passive margin basins, particularly the matured ones (Shanmugam and Moiola, 1988) are favorable for carbonate deposition while carbonate deposition is almost negligible in active margins and foreland basins owing to preponderance of terrigenous influx. Intracratonic platforms, intracratonic rift basins, epicontinental seas also encourage carbonate deposition when terrigenous influx is curtailed and stopped. Thick and extensive carbonate sequences are mostly interpreted as marine deposits though carbonate deposition can also take place in lakes and lagoons, even in terrestrial realm. Carbonates favour deposition in lacustrine condition where the lakes are fed by internal drainage (James and Jones, 2016). However, as mentioned above carbonate deposition mostly favored within shallow marine settings wherever there is paucity of terrigenous influx and high rates of organic productivity (around 300 N and S latitudes. Carbonate sediments are formed in clear near-surface ocean waters where sunlight is available. These sediments are often accreted in-situ and get cemented during diagenesis. Biogenic growth of carbonates often give rise to steep slopes. A Carbonate platform is a thick carbonate deposit deposited in a shallow water condition (Tucker and Wright, 1990). Carbonate platform development can be traced back up to Middle Proterozoic Era. Their record in Archean and Paleoproterozoic Era is poor may be because of different tectonic behavior of earth's crust (Grotzinger, 1986). Details of carbonate platform geometry are discussed below.

## 3. Carbonate Platform

Carbonate platforms are classified depending on their large-scale (10's Km) geometry and slope. The broad categories of carbonate platform are Ramp, Rimmed Shelf, Epeiric platform, Isolated platform and Drowned platform (Fig. 1). The study of carbonate platform is important as they can serve as rich hydrocarbon source and reservoirs. A carbonate platform can change its type with time. Thus, their formation and evolution from one type to another is of special interests for research. The different carbonate platforms have different geometry, facies, porosity and permeability, which result into the differences in the distribution of the reservoirs.

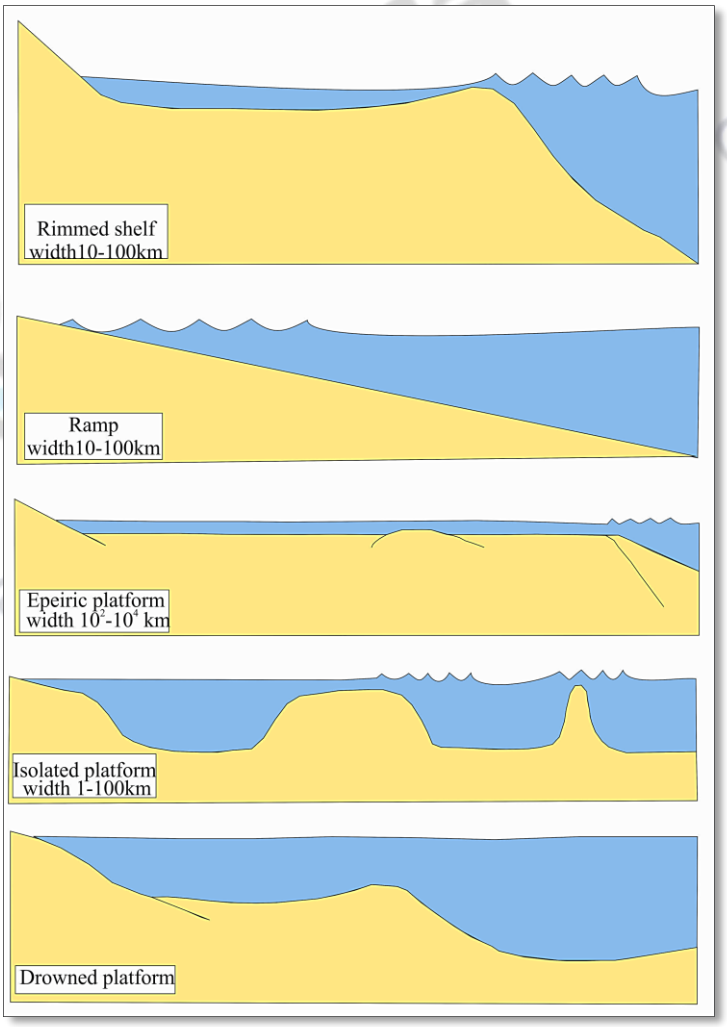



**Fig. 1** Schematic diagram of different types of carbonate platforms (modified after Tucker and Wright, 1990).

## 4. Carbonate Ramps

A carbonate ramp is defined as a carbonate system with a very low gradient/depositional slope (commonly <10) from a shallow water shoreline or lagoon to basin floor (Burchette and Wright, 1992). It has no major break in slope in contrast to the rimmed shelf or isolated platform. The landward facies of a carbonate ramp is dominated by grainstone or packstone while the sediments become muddy towards sea. The shoreward part of a low gradient ramp is dominated by wave action and the energy level increases toward the land part. Thus, an agitated environment is shifted far landward and a beach forms there. Biogenic buildups may grow at those parts where the wave base meets the ramp surface within the photic zone.

The carbonate ramp initially has been subdivided into three zones viz. back ramp, shallow ramp and deep ramp, based on the location of two critical interfaces i.e. fair weather wave base (FWWB) and storm wave base (SWB) (Read, 1981). Later Burchette and Wright, (1992) proposed a four zones subdivisions. They are Inner ramp (the zone above FWWB), Mid ramp (the zone between FWWB and SWB), Outer ramp (the zone below SWB) and the Basin (Fig.2).

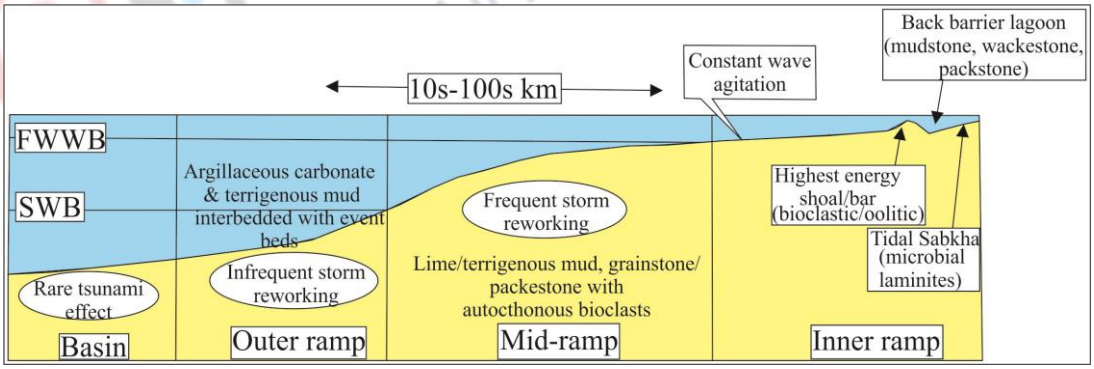



**Fig. 2** Subdivision of a carbonate ramp based on FWWB and SWB; modified after Burchette and Wright, 1992.

Morphologically and hydrodynamically, carbonate ramps are almost similar to siliciclastic shelf systems. Read (1982, 1985) redefined the concept of carbonate ramp by introduction of two categories of ramp-

*a)* ***Homoclinal ramp-*** have relatively uniform slope; passes into basins without sediment gravity flow deposits or slumps; change of slope is gradual (Fig. 3a).

*b)* ***Distally steepened ramp-*** have a slope break in outer/deep ramp (Fig. 3b); the slope can be created due to tectonics; sediment gravity flow deposits like slumps, debris flow or turbidites are common at the base of slope. These deposits are not laterally continuous compare to carbonate slope deposits of rimmed platform.

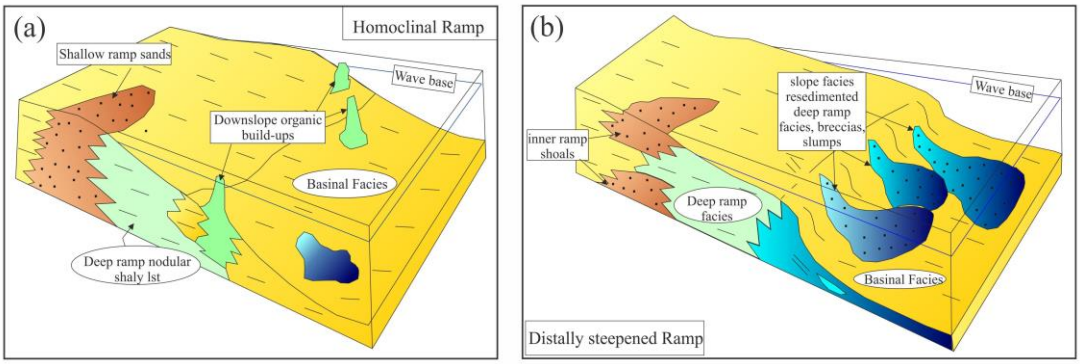



**Fig. 3** Homoclinal Ramp (a) and Distally steepened ramp (b) (modified after Tucker & Wright, 1992).

The creation, development and lifespan of a ramp setting are the result of a wide range of interacting controls. These include the tectonic settings, sediment productivity and dynamics of the system and sea level history. As a whole, sediment productivity, sediment dispersal, climatic fluctuations and tectonics are the major factors, which actually control the ramp geometry and the sediment character.

## 5. Carbonate Rimmed Shelves

If reefs/carbonate sand bodies grow along the shelf margin and baffle wave energy, a rimmed shelf can form (Tucker and Wright, 1990). Reef is a vertically accreted organic build up and is wave resistant elongated ridge like structure. Reefs are the zone of maximum agitation and considered as important carbonate factory as they act as the source of most of carbonate sediments. The shelf margin is most turbulent part as waves touch the sea floor at the margin. The depth adjacent to shelf margin is shallow and thus organic productivity is highest at this zone especially if the ocean

water is well circulated through upwelling. The broken shell fragments from the reef can be transported to both the land ward side and ocean ward side. Rimmed shelves can be subdivided into (a) Fore reef (wind ward part of the reef) or reef slope and proximal and distal talus, (b) the reef core and reef crest and (c) the back reef zone (lee ward side of the reef) of the reef flat and reef sand. The reef sands are mostly of skeletal origin derived from reef building organisms. Reef is the key element in a carbonate depositional system being the major repository and source of clastic carbonate sediments and regulating the hydraulic regime around it. A reef when vertically accreted turns wave resistant and ultimately forms a Rimmed shelf. Two important changes in the environmental setting are effected (1) a low energy environment develops on the leeward side and (2) the depositional surfaces adjacent to its windward side turn steeper inducing mass failure of sediments.

Reefs can be of three types based on geomorphic associations (i) fringing reef (ii) circular reef and (iii) barrier reef.

(i) **Fringing reef**- directly adjacent to the landmass.

(ii) **Circular reef**- an encircled reef body enclosing a low energy lagoon (Atoll) within open Ocean.

(iii) **Barrier reef**- creates a lagoon between itself and the landmass.

On the basis of geometry, reefs can again be subdivided into:

(i) **Bioherm**- if the geometry of organic build up is lensoid with a convex-up surface and

(ii) **Biostrome**- if the organic build up is bed-parallel.

Genetically reef can be classified as

(i) **Stratified reef**- if a thick vertical organic build-up grows as a stalk of multiple units, none of the individual units ever becomes wave-resistant; the peripheral surface is transacted by successive time planes and

(ii) **Ecologic reef**- if the reef forms as a single, unitary body growing up continuously till it turned wave-resistant. Here the peripheral surface represents a single time plane.

Behind the reef/rimmed shelf, tide dominated lagoon is formed. Here the wave action is curtailed by the presence of reef in front and thus only tidal currents become stronger. Hence, the condition is relatively calm, quite, occasionally affected by major storm events and hypersaline during dry season due to poor circulation. The inner margin of the rimmed shelf may be tide dominated forming tidal flats if the tidal range is high or a beach-barrier tidal delta coastline can form if wave dominates over tide. Because of constant wave, pounding on the reef wall of the windward/ ocean ward side of a rimmed shelf steep gradient develops and as a result apron like mass flow deposits forms on this side. At the base of slope, scree deposits dominate. Debris flow and turbidites are also common. In the case of rimmed carbonate shelf, the reefs act as a line source for the different types of mass flow deposits.

### 5.1 Carbonate rimmed Shelf Types

The rimmed shelf can be classified into different types (McIlreath & James, 1984, Read, 1982, 1985).

(i) ***Accretionary-rimmed shelf margins*** can form at the period of high carbonate productivity during stable or slowly rising sea level. The shallow shelf-margin reefs and sand bodies migrate laterally over fore-reef and slope deposits. Little vertical aggradation takes place. As carbonate productivity is high, slope deposits progrades with an interdigitation of shallow water rimmed shelf, resedimented slope and deeper water basinal facies (Fig. 4).

(ii) ***Bypass rimmed shelf margins*** develop due to rapid vertical accretion where shelf-margin sedimentation keeps pace with rising sea level but little sediment is deposited on the shelf slope. Sediment shed off the shelf edge is deposited at the toe of the shelf slope or in the basin (Fig. 5).

(iii) ***Erosional rimmed shelf margins*** develop in the strong tidal or ocean currents dominating areas; cliffs and escarpments characterize the shelf slope. At the toe of the shelf slope, mass flow deposits accumulate in form of fan or apron (Fig. 6).

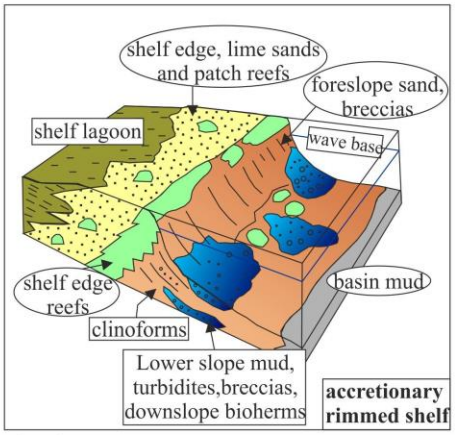



Fig. 4

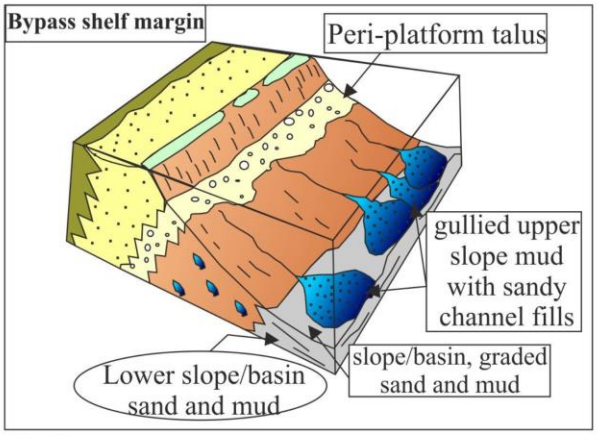



Fig. 5

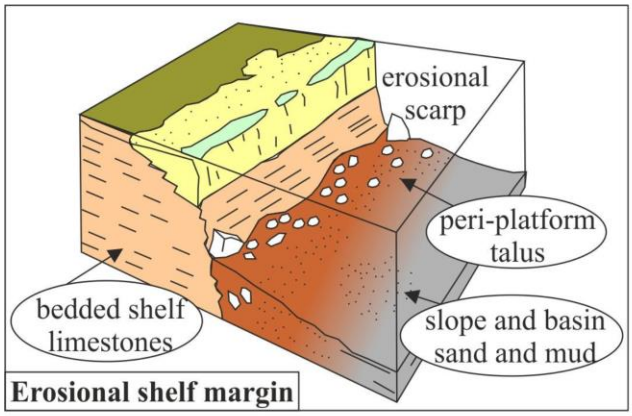



Fig. 6

Most of the carbonate-rimmed shelves have been reported from the Phanerozoic carbonate deposits. During Precambrian Eon the reef, building skeletal organisms were absent. Possibly reef building stromatolites acted as a substitution of Phanerozoic skeletal reefs particularly during the Proterozoic.

Two types of carbonate platforms Rimmed Shelf and Ramp are most common in geological rock record. They have some major differences mentioned below.

| Rimmed Shelf | Ramp Shelf |
|---|---|
| Generally tide dominated | Generally wave dominated |
| Tidal flat forms on landward side | Beach form on landward side |
| Energy level decreases landward | Energy level increases landward |
| Biopopulation restricted | Biopopulation has greater diversity |
| Lamination retained | Lamination erased out |
| Sedimentation rate high | Sedimentation rate low |
| Deposition substrate irregular | Deposition substrate relatively flat |
| Lateral facies disposition irregular | Facies belts parallel to the shoreline |
| Facies transitions rapid and sharp | Facies contact gradational |

## 6. Epeiric Platforms

Epeiric carbonate platforms are extensive cratonic areas covered by shallow sea (water depth <10m) (Fig. 1), almost non-existent in present days. Shallow subtidal and intertidal flat dominate in this type of carbonate platform. Tidal range is also very small. Overall, very quiet, low energy environments prevail in epeiric platform. Fair weather wave base is very shallow (<5m) and thus the platform is dominantly affected by storms.

## 7. Isolated Platform

Shallow water carbonates surrounded by deep-water carbonate is referred to as Isolated platform (Fig. 1). Most of them have steeper side and slopes towards deep water. Reefs or sand bodies can grow at the marginal part. If the carbonate production rate is high, then rimmed isolated platform with a central deep lagoon (Atoll) can develop. Platform interior is dominated by quiet water sandy mud, sandy islands and tidal flats.

## 8. Drowned Platform

Any type of above discussed carbonate platform can be subjected to development of drowned carbonate platforms if the relative sea level rises rapidly (Fig. 1). Deep-water facies deposited over shallow water facies. If the platform is drowned below the photic zone, then fine-grained pelagic carbonates with shaley partings dominate the platform. Hardgrounds may occur. If the sea level rise is not sufficient and depth of the platform is still within photic zone, then it is known as incipiently drowned platform.

During drowning, reefs may keep up the rising sea level by higher rate of carbonate production. Patch reefs may form on drowned ramp setting. If the reef growth resumes landward with rapid rise of sea level, backstepping of a rimmed shelf takes place.

## 9. Change of Platform type from one to another

Platform types may change from one to another, either through natural processes or due to change in tectonics and sea level.

- A rimmed shelf may change to ramp due to reef growth.
- A shelf can develop within a ramp setting due to subsidence.
- An epeiric platform may evolve into ramp, shelves or basins due to tectonic activity.
- Any of the above discussed carbonate platform may become drowned or incipiently drowned platform due to rapid rise in sea level.

## 10. Carbonate platforms vs. change in relative sea level

Shallow water carbonate deposits and their facies patterns are primarily controlled by the rate and type of carbonate sedimentation, tectonics (subsidence/upliftment) and eustatic sea level which ultimate control the relative sea level (Fig. 7). These three factors act together though locally one factor can be more important than the other. The facies anatomy of carbonate shelves and platforms reflect the combined effect of these three parameters. A narrow shelf is developed where rate of tectonic subsidence is higher than the rate of sedimentation (Fig. 7). On the other hand, if

rate of sedimentation is high or tectonic subsidence is low, wide shelf is generated (Fig. 7). Regression in response to sedimentation (greater than relative sea level rise) or eustatic sea level drop can generate unconformities (Fig. 7) on the carbonate platforms which are almost similar to the key bounding surfaces used to designate siliciclastic 'Sequences'. Apart from these unconformities, another type of unconformity surface can develop within the carbonate platform during maximum sea level rise known as "*Drowning unconformity*" (Schlagar, 1999). The concept of 'drowning' in carbonate sequence stratigraphy refers to a situation where rapid transgression follows the high stand leading to the drowning of carbonate platforms (Fig. 7) and thus change from carbonate to clastic systems.

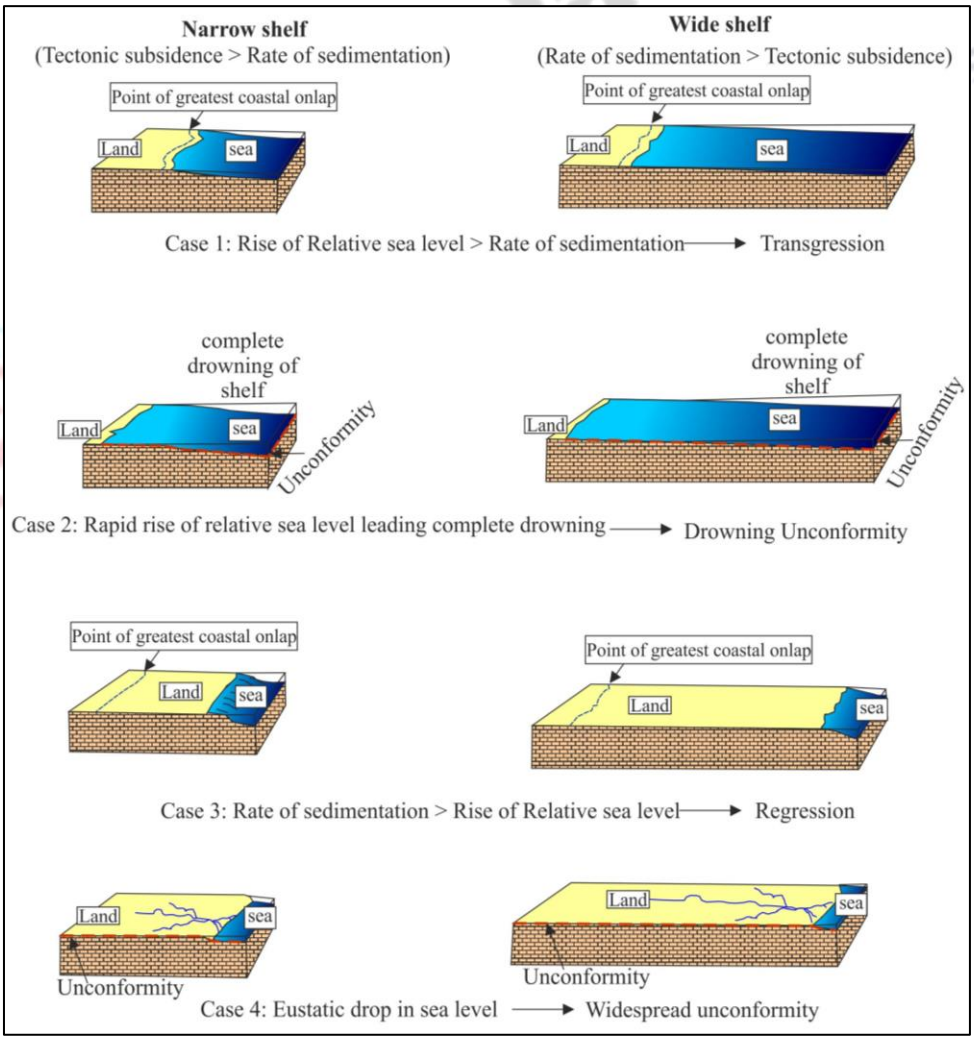



**Fig. 7** Interrelationship between rate of sedimentation, rate of relative sea level rise/fall and tectonics (modified after Kendall & Schlagar, 1981).

## 11. Response of carbonate platform during sea level change

Response of the carbonate system is not simply a function of relative rise in sea level rather the difference between the rate of rise and the growth potential of a platform.

### 11.1 Relative rise in Sea level

Relative rise in sea level (due to either tectonic subsidence or eustatic rise) can have the following three types of effects on carbonate sedimentation in rimmed shelf margin-

***Type A- Drowning (Rise of sea level > rim, interior):*** Complete failure of both rim and platform interior to keep pace with the rapidly rising sea level. Therefore, the platform is drowned. Shallow water carbonates are submerged below photic zone, carbonate production is terminated and truly deep-water conditions are established.

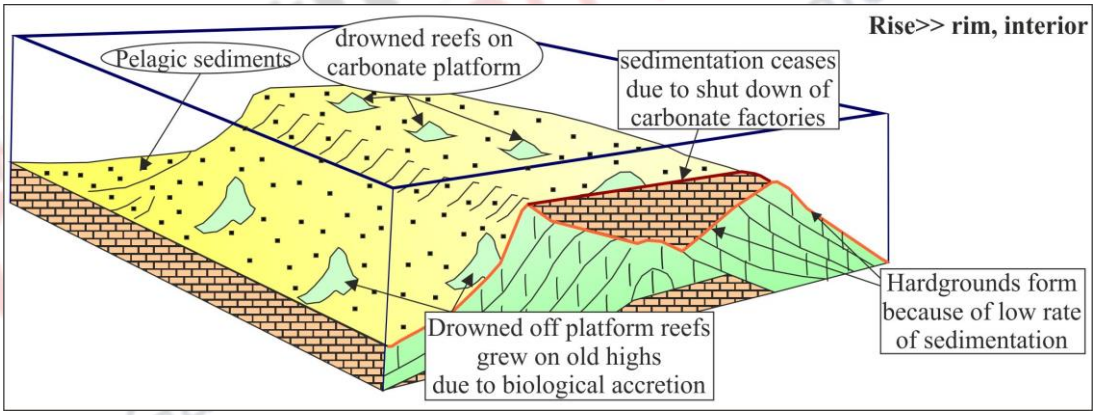



**Fig. 8** Drowning of a carbonate platform due to rapidly rising sea level; modified after Kendall and Schlager, 1981.

***Type B- Catch up/ survival of rim and patches:*** It is an intermediate situation between complete failure and complete success of a carbonate platform development. During startup phase, both the rim and interior can fail to match sea level rise (incipient drowning) while platform top resides within photic zone i.e. rise> rim> interior (Fig. 9a). This is quickly followed by rim> rise> interior (9b). Now the platform rim (normally a reef) catches up with rise. The platform interior is turned into deep lagoon, which acts as

sediment trap. A third phase may follow when the interior lagoon fills up and a flat platform is re-established. However, in many cases, the lagoon does not fill up if the raised rim has existed for a long time.

***Type C- Keep up/ upbuilding and outbuilding (Rim, interior> rise of sea level):*** Growth potential of both the rim and platform interior match or exceed the rate of rise; no deep lagoons are developed and platform maintains flattop (Fig. 10) within few meters of sea level and tends to prograde basinward. These rims may consist of reefs or stacked carbonate sand shoals that record little or no apparent change in water depth during deposition.

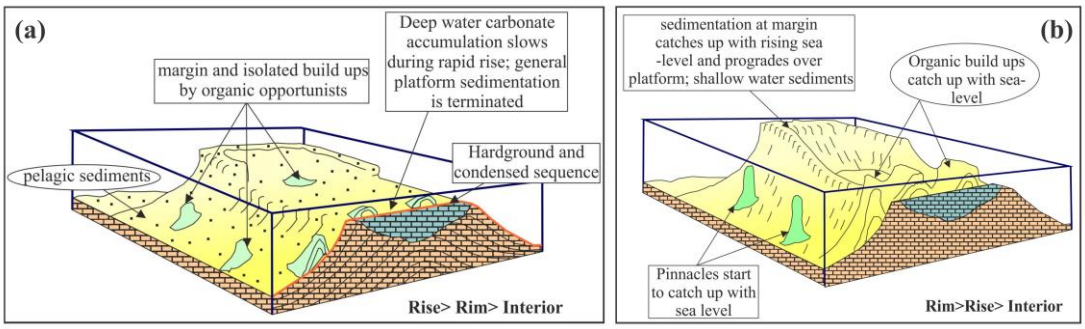



**Fig. 9** (a) After drowning of a platform, at the startup phase, both the rim and interior fail to match sea level rise but platform top resides within photic zone; (b) Later the platform rim catches up with rise and the platform interior is turned into deep lagoon, which acts as sediment trap; modified after Kendall and Schlagar, 1981.

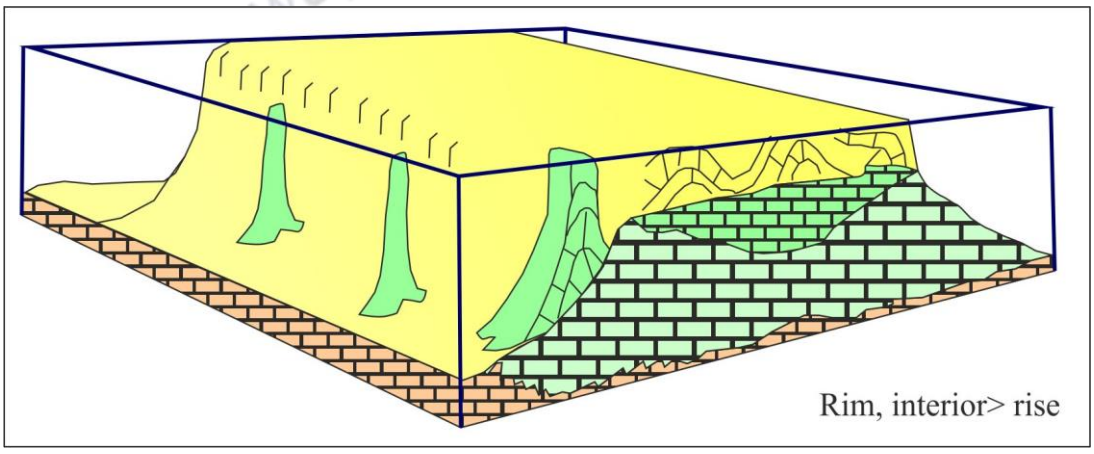



**Fig. 10** Growth potential of carbonate shelf exceeds the rate of rising sea level and carbonates cover whole shelf on reaching sea level at Keep up stage; (modified after Kendall and Schlagar, 1981).

### 11.2 Relative fall in sea level

Relative fall in sea level (either due to tectonic upliftment or drop in eustatic sea level) will expose shallow, flat carbonate platforms and thereby generate widespread unconformity as drop in sea-level usually terminates carbonate production at the shelf margin (Fig. 11). Carbonate platforms and reefs are poorly equipped to shift their depositional loci during the period of sea level fall. The steep platform flanks and other carbonate facies belt are unable to migrate gradually keeping pace with the retreating sea. The little sediments, which get deposited during sea retreat, are quickly removed by beach erosion and subsequent terrestrial weathering. The delta and aeolian clastics that bypass the shelf get deposited in open marine basins (Fig. 11).

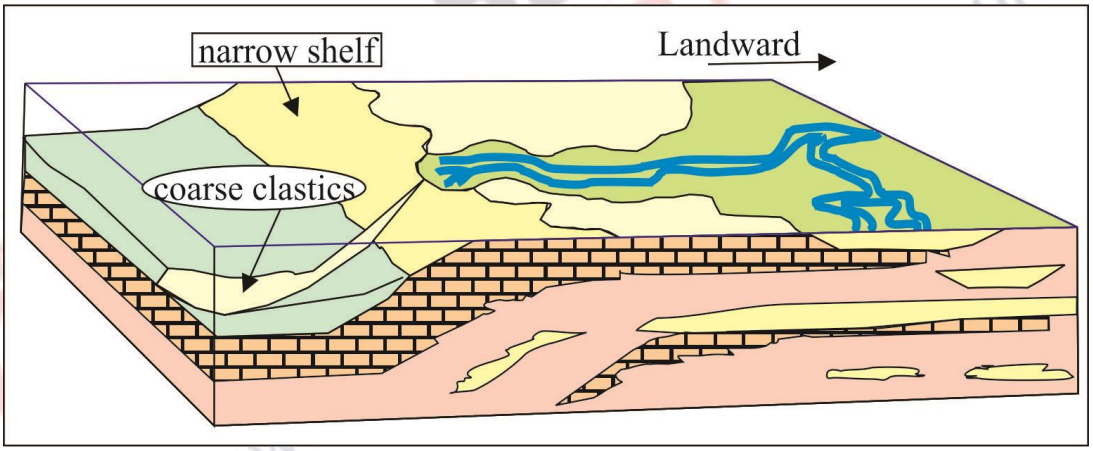
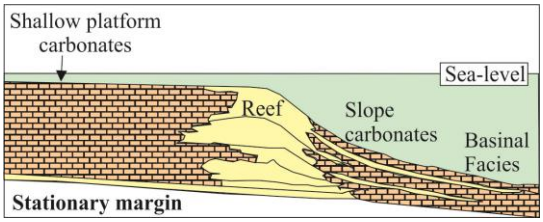



**Fig. 11** During rapid sea-level fall, delta encroaches from land onto carbonates and coarse clastics may bypass a narrow shelf and onlap it to the seaward side; modified after Kendall and Schlagar, 1981.

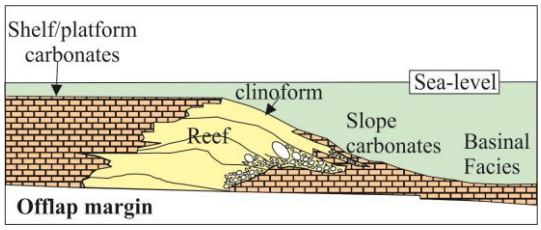
## 12. Sea level changes and response of carbonate platforms

**Rimmed platform /shelf margin** respond to sea level changes in different ways. James & Mountjoy (1983) classified five different types of rimmed shelf margins in response to sea-level change.

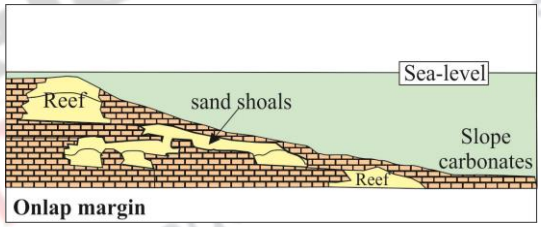
(a) **Stationary**- Sea level at stand still condition; vertical accretion takes place, as the position of the rimmed shelf margin does not change much through time.



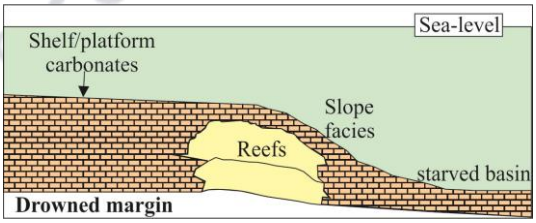

(b) **Offlap**- Sea-level is not rising fast; due to an overproduction of carbonate at the shelf edge the rimmed shelf margin prograde basinwards.



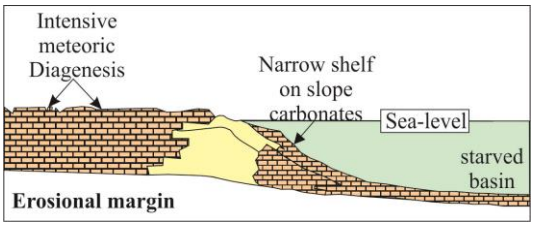

(c) **Onlap**- when sea level rises, coastal onlap occurs either gradually or in backstepping fashion (if relative sea level rises in stages).




(d) **Drowned**- When the sea-level rise is really too fast for carbonate sedimentation to keep pace, then the shelf and slope are drowned.




(e) **Emergent**- if sea level falls below the shelf-break and the shelf is subject to subaerial exposure.




## 13. Summary

Carbonate deposition take places in different types of platform. The term carbonate platform used as a very general and loose term for a thick sequence of mostly shallow water origin. Carbonate platform develops in a whole range of geotectonic settings but preferred along passive continental margins, in intracratonic basins to

failed rifts, and back arc basins to foreland basins. Various types of carbonate platform have been recognized. They are namely carbonate r*amp platform, rimmed shelf, epeiric platform, isolated platform* and *drowned platform.* Amongst them, the ramp and the rimmed platforms are most important and common in nature. The carbonate platforms always respond to relative sea level fluctuations. If the relative sea level fall is maximum and the platform gets exposed an unconformity can form. During maximum rise of sea level if the platform drowns then also unconformity can form, known as drowning unconformity. The carbonate deposition is also affected by sea level changes within a platform.



**Frequently Asked Questions-**

**Q1. What is a Carbonate platform? What are the major differences between a Rimmed platform and a Ramp platform?**

**Q2. Compare facies distribution pattern on a Carbonate homoclinal ramp and a distally steepened ramp?**

**Q3. Discuss the different stages of carbonate deposition within a rimmed shelf?**

**Q4. How do sea level fluctuations affect carbonate sedimentation within a carbonate platform?**

**Q5. How can a ramp platform change into a rimmed platform?**

**Q6. How does geometry of carbonate platform changes with relative sea level fall and rise?**

**Multiple Choice Questions-**

**1.** Carbonate deposition takes place within

(a) $30^0$ N & S
(b) $15^0$ N
(c) Polar region

**Ans:** a

**2.** Drowning Unconformity develops

(a) Relative sea level rise > sedimentation rate
(b) Sedimentation rate > relative sea level rise
(c) Rapid rise in sea level

**Ans:** c

**3.** Accretionary rimmed shelf margins can form during

(a) High carbonate productivity and stable or slowly rising sea level
(b) Shelf-margin sedimentation keeps pace with rising sea level
(c) Strong tidal or ocean currents dominating areas

**Ans:** a

**4.** Onlap takes place within a rimmed shelf margin

(a) During rise of sea level
(b) During sea level fall
(c) Due to carbonate overproduction

**Ans:** a

**5.** Stromatolites are main contributor of carbonate sediments in

(a) Archean
(b) Phanerozoic
(c) Proterozoic

**Ans:** c

**6.** Slope of a carbonate ramp is

(a) $<1^0$
(b) 4° to 10°
(c) 30°

**Ans:** a

**7.** Lagoon is associated with

(a) Distally steepened ramp
(b) Isolated platform
(c) Rimmed shelf margin

**Ans:** c

**Suggested Readings:**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