**"Carbonate ramp depositional environments"**

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**Abstract:**

Ramps can be devided into homoclinal and distally steepened ramps and can be subdivided into inner-, mid-, and outer-ramp. Carbonate ramps are common in all geological periods, but were dominant when reef-constructing organisms were inhibited or absent. The zone of greatest organic carbonate production shifted from mid- to inner ramp since the late Jurassic. Ramps are known from nearly all tectonic regimes but are favoured in cratonic-interior basins, passive continental margins, and foreland basins. They are characterized by a low-angle slope and therefore respond to sea-level changes with shifting of facies belts in contrast to rimmed shelves that undergo flooding and exposure of platform tops.

**Ramp classification:**

The first concept of a carbonate ramp was given by Ahr (1973) as an contrast to steep-sloped and reef-rimmed shelves. Ramps can be understood as a type of carbonate platforms. Carbonate platforms are succesions formed in shallow water, including rimmed shelves, ramps and isolated buildups. The slope-gradient of ramps are smaller than 1° and have no slope break. Read (1982, 1985) devided ramps into *homoclinal* and *distally steepened*. The distinction of there two types remains problematic unless slope or slope apron deposits are present in the record. Most classifications (Markello and Read, 1981; Aigner, 1984; Calvet and Tucker, 1988; Buxton and Pedley, 1989 and Somerville and Strogen,1992) use the fair weather wave base (FWWB) and the storm wave base (SWB), to subdevide ramp depositional systems. On this basis Wright (1986) and Burchette et al. (1990) define four sedimentary subdivisions (see Figure 1) :

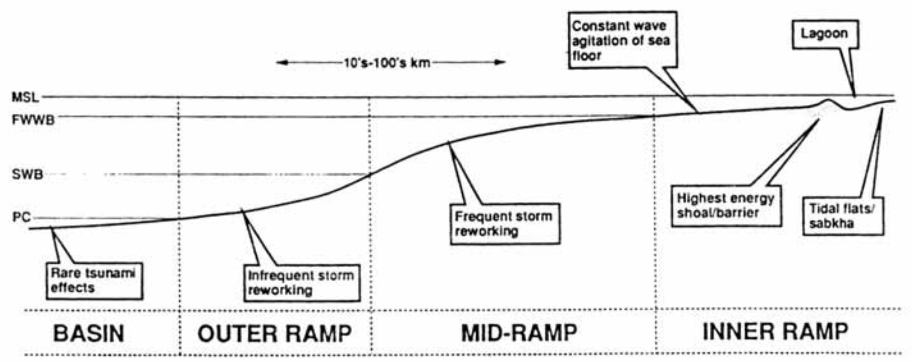



Fig. 1. The main environmental subdivisions of a "homoclinal" carbonate ramp. *MSL* = mean sea level; *FWWB* = fair-weather wave base; *SWB* = storm wave base; *PC* = pycnocline (not always identifiable in the rock record). Water depths corresponding to these boundaries are variable.

Fig.1 (from Burchette and Wright 1992)

*Inner ramp:* zone above FWWB

sand shoals, organic barriers, shoreface deposits

*Mid-ramp:* zone between FWWB an SWB

only affected by storm waves

graded beds, hummocky cross-stratification (HCS), storm related features

*Outer ramp:* zone below SWB up to the basin

sparse, graded, distal tempestites

*Basin:* distallmost part

type of sediment depends on depth and nature of basin (siliceous, limestone,...)

lacks coarse tempestites

In distally steepened ramps a slope break is situated between the outer-ramp and the basin and should be recognized by slumpings and slope apron deposits. Similar to the classification of silicilclastic shelves the classification of carbonate ramps is based on storm, wave or tidal influence used by (Burchete and Wright, 1992; Figure 2).

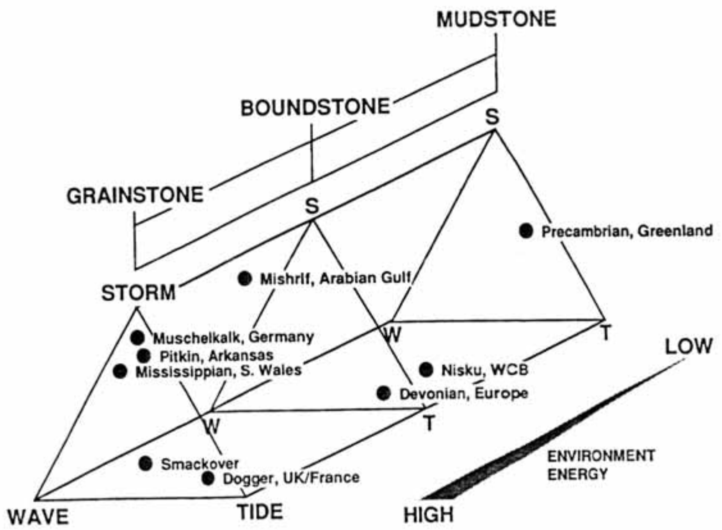



Fig. 2. Ternary diagram showing suggested classification for carbonate ramps based on the degree of storm, wave, or tidal influence which they exhibit in the mid- and inner-ramp zones. An additional axis accommodates the various lithologies which dominate ramp sediments and seem to reflect the level of environmental energy (see arrow). Several representative ramps have been entered. See text for source references on the characteristics of individual ramps.

Fig. 2 (from Burchette and Wright 1992)

Most ramps in the geological history are storm-dominated and show low tidal influence (Burchette and Wright, 1992). This fact may reflect the dominance of storm events in low latitudes where most ramps form. In storm-dominated ramps the inner ramp exhibits linear sand ridges and the mid-ramp tempestites, HCS and swaley cross-stratification (SCS). Tidal-dominated ramps are rare in the geological history and are characterized by ribbons, sand waves and sheets.

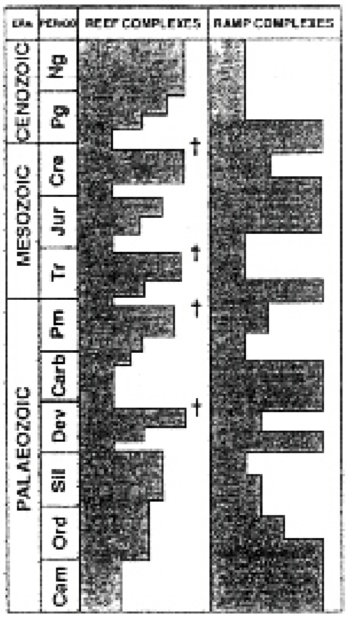
**Ramp facies:**

„Ramp facies reflect the protracted offshore energy gradients which are a consequence of gradual water-depth change.“ (Burchette and Wright 1992). Individual ramp depositional zones differ strongly in their facies compositions. Inner-ramp deposits consist mostly of oolitic or bioclastic components. These components build shoals, barriers, and back-barrier sediments and shoreface sediment bodies that migrate or prograde fast. Lagoonal sections, if they exist, may exhibit a variety of mud-, wacke-, or packstone sediments. Shallow water depth may be reflected by biostromal biotas. Mid-ramp deposits form below the FWWB and therefore reflect storm deposition in the sediments. During fairweather intervals sediment is forming by suspension fall-out (terrigenous mud or lime) and becomes bioturbated. Storm event features may be HCS, SCS or graded tempestites consisting of grainstone or packstone bioclasts. The origin of the carbonate in the mid-ramp zone is still enigmatic. In most of the ancient ramps the volume of carbonate sediment in the mid-ramp exceeds the volume in the inner ramp zone. A reverse situation is observed in other carbonate depositional systems. This fact may reflect the carbonate generation of higher volume in offshore areas. Argillaceous carbonate and terrigenous mud, fallen out of suspension, dominates the outer-ramp zone and is affected only by the heaviest storms.

**Organic influence on ramps:**

Figure 3 indicates that periods of reef complexes and ramp complexes alternated through geological time. Organisms function as sediment producers and form energy barriers. They have changed through time in both roles as sediment producers and in location and character of the buildups. Ramps were dominant when reef-constructing organisms were inhibited or absent. Major extinctions, climate , or changes in features of the ocean (salinity, sea-level, currents,…) could be made responsible for this. High oolite production in shallow water characterises the ramp-dominated intervals. The lacking reef-constructers in the shallow water decreases the carbonate production and so the platform is not able to develop shelf morphologies. As a consequence the rate of carbonate sediment production is more evenly distributed. Computer simulations demonstrated that models with a uniform sediment production across ramps form more „homoclinal“ morphologies and models with higher production in the inner ramp form steeper slopes, flat-topped platform morphologies or rimmed shelves (Elrick and Read, 1991; Read et al., 1991).
Stromatolites were mound builders across ramps in the Precambrian and early Paleozoic. Reef-mounds formed by stromatoporoids and corals are dominant in Silurian times (e.g. Heckel, 1974: Wilson, 1975). During the mid- and late Paleozoic bryozoans, crinoids and stromatoporoids were the sediment producers in the mid-ramp. The zone of greatest organic carbonate production shifted from mid- to inner ramp since the late Jurassic because of the evolution of different sediment producers (e.g. molluscs, rudists, benthic foraminifers, corals, ...). Since the Cretaceous the evolution of pelagic

calcareous foraminifera lead to carbonate production in the basins adjacent to ramps. From late Palaeogene and Neogene on see-grass banks formed part of the sediment producers in the inner-ramp.




Bar chart showing the major ramp-dominated periods compared with the time-distribution of reefs (after Heckel, 1974; James, 1984) and other rimmed shelves. Note that ramps are the dominant platform types following major organic extinctions (crosses). Extinctions were clearly a factor in determining the relative importance of ramp depositional systems, although other possible causes (see text) should not be overlooked.

Fig. 3 (from Burchette and Wright 1992)

**Tectonic settings:**

Optimal tectonic settings for a ramp development must be continuosly subsidence, slight gradients, and a relatively shallow water depth. Ramps are known from the following regimes with subsidence: extensional basins, passive continental margins, compressional basins, cratonic interior basins and salt-withdrawal basins. Cratonic interior basins, foreland basins, and passive margins are favoured. Ramps tend to form preferentially where rapid carbonate production is hindered e.g. by clastic input, cool climate, or hypersalinity. If subsidence is too high ramp evolution is generally of short duration, the ramp itself is small (see e.g. Ebdon et al. 1990).

*Extensional basins:* (see Figure 4 A)

Most of the ramps in extensional settings only develop in quiescent phases because in active basins subsidence rates are high, producing a marked topography. The development is restricted on the post-rift stage when the relief is infilled or reduced and subsidence is low.

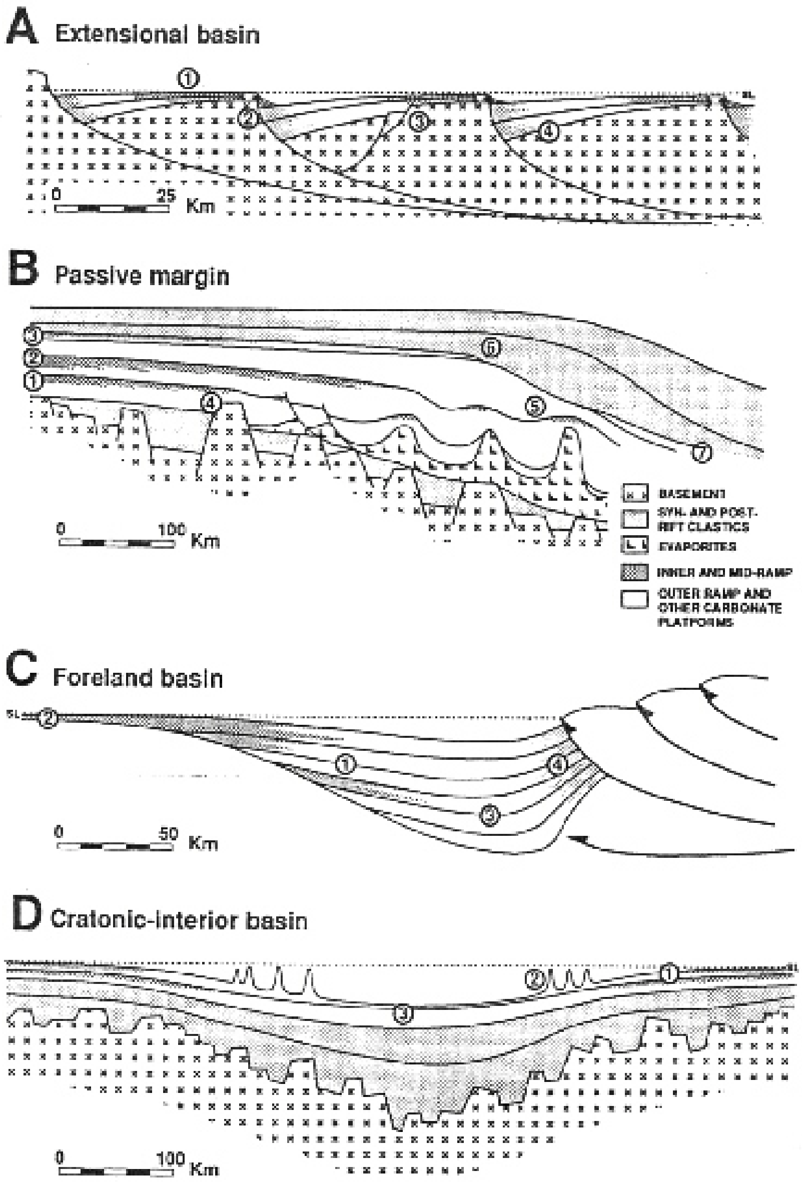



Fig. 4 (from Burchette and Wright 1992)

*Passive continental margins:* (see Figure 4 B)

When the transition from rift stage to a passive continental margins is completed and the rift relief is removed or infilled the resulting tectonic settings favour the development of carbonate ramps. These margins represent great areas with gradual slopes. The dimension reaches hundreds of kilometres across and thousands of kilometres along strike. Remanent topographic highs can develop into locations for shoals or isolated buildups in the mid- or outer-ramp zone. The ramp-stage may be followed by a rimmed shelf stadium.

*Compressional basins:* (see Figure 4 C)

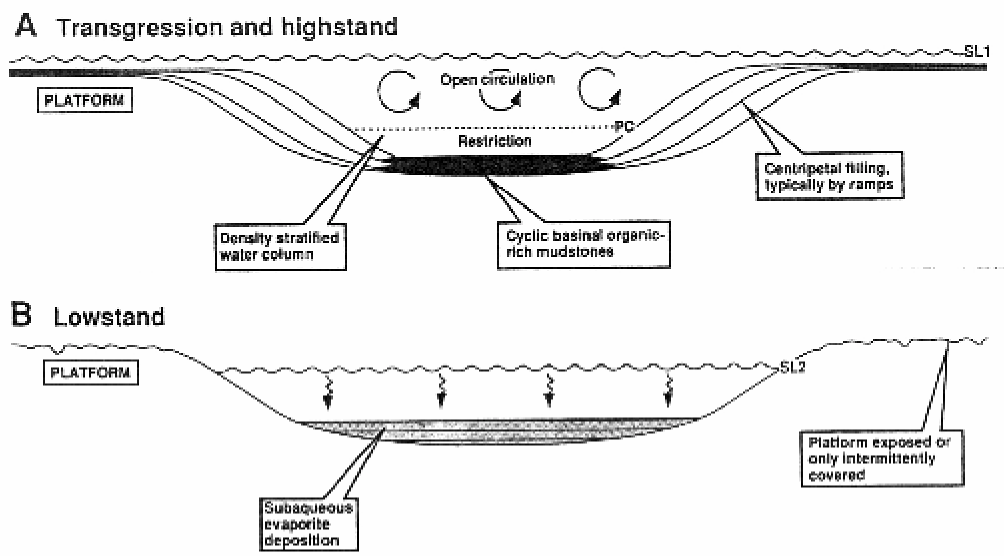
Ramps in marine foreland basins are located along the peripheral „bulge“ where gradients are lowest and subsidence is flexural. The growth can be modified by reactivated extensional topographies and can reach a hundred kilometres across. Ramps attached to such a developing „bulge“ may be affected by drowning and uplift. This can be observed by complex karsted unconformities in the geological record.

*Cratonic-interior basins:* (see Figure 4 D)

The broad and persistent depressions of cratonic-interior basins favour the formation of carbonate ramps with sometimes over 1000 kilometres across and several kilometres of sediment thickness (Allen and Allen 1990). Especially in arid climate such basins may become evaporitic.

*Intrashelf basins:* (see Figure 5)

Intrashelf basins are shallow (<200 m), short-lived and a few hundreds kilometres across. They develop within major carbonate platforms commonly along passive continental margins. It's one of the few situations where real ramps have a lagoon behind the oolitic sand-belt. The basins posses only an indirect connection to the platform top or a re-entrant with the open sea environment. In the case of a sea-level lowstand the basin may become evaporitic because of isolation. In times of sea-level highstand the sedimentation crosses to organic-rich material.




Ramps in intrashelf basins. (A) During flooding and highstand. Ramps prograde centripetally from the basin margins during highstand. Basin may become density-stratified with the development of cyclic suboxic or anoxic basin centre sediments. These commonly correspond with parasequence-scale cycles in the shallow ramp. (B) During lowstand. Sea-level draw-down may lead to isolation of the basin and lowstand deposition of subaqueous evaporite sediments. The surrounding platform may be exposed and karsted. *SL1* and *SL2*: relative sea-level stands.

Fig. 5 (from Burchette and Wright 1992)

*Salt-withdrawal basins:*

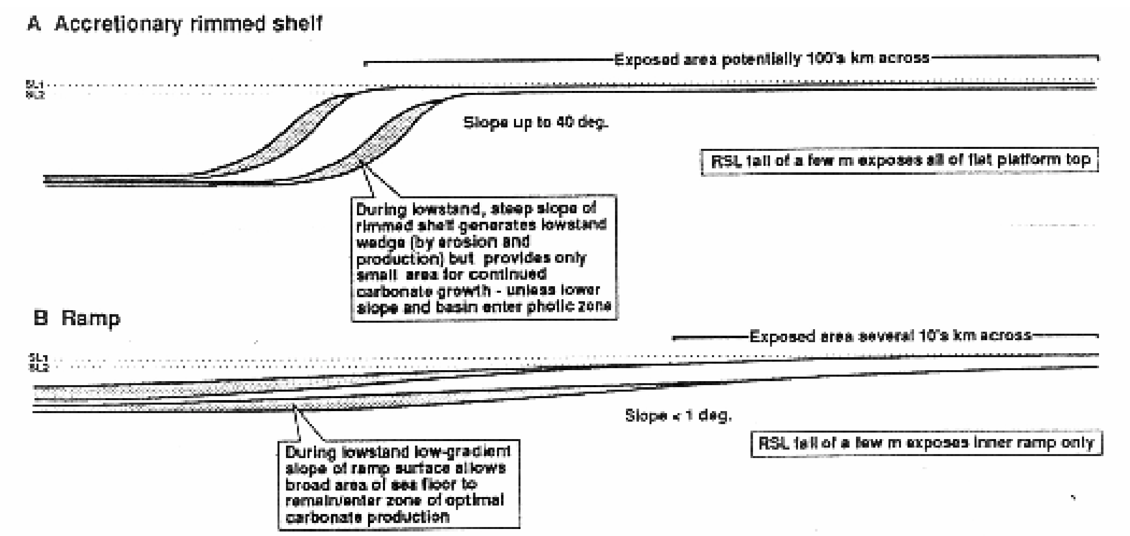
This type of basins are rare and a few tens of kilometres across. They form as peripheral sinks of salt diapirs or on flanks of simultaneous diapiric uplifts. Salt-withdrawal basins can develop within major carbonate platforms in foreland basins, cratonic interior basins or at passive margins. In such settings only small basins (<20 km) with low-energy ramps can develop.

**Response to sea level changes:**

Figure 6 indicates that a sea-level fall of a few metres would expose the complete interior of a rimmed shelf. The carbonate production on flat-topped carbonate platforms is high during highstand intervals because most of the platform is flooded and therefore situated in an environment where carbonates can be produced. In lowstand times the carbonate production is restricted to the slope. A sea-level fall of 1 – 2 m would have no effect on a homoclinal carbonate ramp and furthermore no effect on the carbonate production. A sea-level fall of about 10 m would expose the complete interior of a rimmed shelf, but only 20 – 50 km of the inner- and mid-ramp section. In the latter case a major part of the mid- and outer ramp zone would slide into a better position for carbonate production. A major fall of about 100 m would expose a whole ramp. Distally steepened ramps will behave like ramps during minor relative sea-level falls and like rimmed shelves during major falls.
Exposure and flooding surfaces on ramps are diachronous in contrast to flat-topped rimmed shelves caused by the geometry and the absence of a slope break (see Figure 6).

*lowstand-sections:*
The determining factors are duration of lowstand, type of inner ramp sediments, rate and magnitude of sea-level fall, and the remaining space for sediments. The reaction to a minor sea-level fall means that in a homoclinal ramp the facies belts shift basinwards and a small part of the inner ramp is exposed. Thick grainstone bodies can develop through seaward progradation of the shoreline. A major sea-level fall (e.g. 3-rd order) means that the sea-level has fallen below the level of fair-weather wave base of the previous highstand. Under such conditions inner-ramp grainstones rest on outer-ramp mudstones. This process seperates the inner-ramp sediments completely from those of the previous highstand sytstem tract. The whole inner-ramp becomes exposed and karstified. Sometimes evaporites develop.
*transgressive-sections:*
A longer relative sea-level rise on high-energy ramps would develop stacked sequences (beach, barrier-island, or barrier-shoal carbonate grainstone and associated shoreface and transitional sediments). Rapid transgression may leave little record of the shoreface. On low-energy ramps the sections are formed of pack- and wackestone with local high-energy grainstones. By drowning the inner-ramp sand-bodies may be covered by phosphatic mudstones, black shales and glauconitic or chamositic ironstones (Burchette, 1992) or reworked by storms. In most cases the flooding surfaces are well recognizable. The forming of isolated buildups is favoured in transgressive phases because of the reduced sediment input to the offshore environment.
*highstand-sections:*
The facies belts prograde seawards and the sediments become grainier and more oolitic in comparison to transgressive phases. Highstand sediments are often characterized by thick grainstone-bodies. Lagoonal facies possess a greater proportion of the ramp section. The accommodation space formed in the transgressive phase can be filled, that is the reason why the potential for slope steepening and

clinoforming is greater during highstand. Stacked upward-shallowing sequences occur in highstand sections.




Schematic profiles of (A) a rimmed shelf, and (B) a ramp showing the effects of minor changes in relative sea level. Note how even a small relative sea-level fall may expose the whole surface of a flat-topped rimmed shelf and restrict lowstand carbonate sedimentation to a narrow rim along the old platform slope unless the lower slope and basin floor enter the photic zone. On a ramp, facies belts will shift basinward over the ramp surface without significant interruption producing a "lowstand prograding wedge". Stippled areas represent notional lowstand deposits.

Fig. 6 (from Burchette and Wright 1992)

**<u>Reservoirs in ramp succesions:</u>**

Ramps can host several types of petrolium reservoirs because they offer many opportunities for structural and stratigraphic traps. Organic buildups demonstrate locations for such reservoirs. In early Palaeozoic times mud-textured buildups restricted to the outer ramp zone were dominant but the situation changed from the late Ordovician on. The evolution of framebuilding organisms (stromatoporoids, corals,...) increased the abilitiy to form more primary reservoirs in shallow and deeper water. If the buildups in mid- or outer-ramp facies are sealed by highstand mud-textured sediments or onlapping basinal facies they form ideal traps. In the case of being situated in an intermediate position it is easy for the hydrocarbons to migrate upwards. These reservoirs in ramps may seldom reach a dimension larger than 100 – 200 m, but forming larger bodies they may become giant oil and gas fields (e.g. Swan Hills and Leduc in West Canadian Basin) (Burchette and Wright, 1992). Furthermore, grainstones, consisting of oolitic or bioclastic material, situated in grainstone-dominated ramps build reservoirs. The shoreline carbonate sandbodies and shoal complexes form the reservoir facies which are mostly thin or layered but often have a wide lateral distribution. Bodies hosting the reservoirs are barriers, bars, and shoreline beaches sealed by carbonate or terrigenous mudstones.

**Examples:**

Precambrian: Wonoka Fm.; Adelaide Geosyncline S.Australia → early post-rift
Cambrian: Nebida Fm.; S.W. Sardinia → ?passive margin
Ordovician: Whiterock Series; W.Utah → passive margin modified by fault reactivation
Silurian: Washington Land Group; N.Greenland → passive margin
Devonian: Nisku Fm.; West Canada Basin, Alberta → cratonic-interior basin
Carboniferous: Pitkin Limestone and Fayettville Shale; Ozarka Mountains, northern Arkansas → foreland basin
Permian: Un-named; E.Finnmark, Barents Shelf, Norway → late synrift/early post-rift
Triassic: El Brull-Capafona Units; Catalan Basin, E.Spain → Extensional
Jurassic: Hanifa Fm.; Southern Arabian Gulf → intrashelf basin on passive margin
Cretaceous: Mishrif Fm.; Southern Arabian Gulf → cratonic-interior basin at passive margin
Tertiary: Darai Limestone; S.W.Papua New Guinea → foreland basin ca. 700 km wide
Quaternary: Shark Bay; Western Australia → passive margin
(examples from Burchette and Wright, 1992)

**References:**

Ahr, W.M., 1973. The carbonate ramp-an alternative to the shelf model. Trans., Gulf Coast Assoc. Geol. Soc., 23: 221-225.

Aigner. T., 1984. Dynamic stratigraphy of epicontinental carbonates, Upper Muschelkalk (M. Triassic), South-German Basin. Neues Jahrb. Geol. Paläontol., Abh., 169: 127-159.

Allen, P.A. and Allen, J.R., 1990. Basin Analysis, Principles and Applications. Blackwell, Oxford, 451 pp.

Burchette, T.P., 1992. Sedimentology and sequence stratigraphic significance of sedimentary ironstones in a carbonate-siliciclastic ramp succession, Lower Limestone Shale Group (early Mississippian), southwest Britain. Sedimentology (in press).

Burchette, T.P., Wright, V.P. and Faulkner, T.J., 1990. Oolitic sandbody depositional models and geometries, Mississippian of southwest Britain: implications for petroleum exploration in carbonate ramp settings. Sedimet. Geol., 68: 87-115.

Burchette, T.P. and Wright, V.P., 1992. Carbonate ramp depositional systems. Sediment. Geol., 79 . 3-57.

Buxton, M.W.N. and Pedley, M.H., 1989. A standardized model for Tethyan carbonate ramps. J. Geol. Soc. London, 146: 746-748.

Calvet, F. and Tucker, M.E., 1988. Outer ramp carbonate cycles in the Upper Muschelkalk, Catalan Basin, N.E. Spain. Sediment. Geol., 57: 185-198.

Ebdon, C.C. et al., 1990. The Dinantian stratigraphy of the east Midlands: a seismostratigraphic approach. J. Geol. Soc. London, 147: 519-536.

Elrick, M. and Read, J.F., 1991. Cyclic-ramp-to-basin carbonate deposits, Lower Mississippian, Wyoming and Montana: a combined field and computer modelling study. J. Sedimet. Petrol., 61: 1194-1224.

Heckel, P.H., 1974. Carbonate buildups in the geological record: a review. In: L.F. Laporte (Editor), Reefs in Time and Space. Soc.Econ. Paleontol. Mineral., Spec. Publ., 18: 90-154.

James, N.P., 1984. Reefs. In: R.G. Walker (Editor), Facies Models. Geosci. Can., Repr. Ser., 1: 229-244.

Markello, J.R. and Read, J.F., 1981. Carbonate ramp to deeper shale shelf transitions of an Upper Cambrian intrashelf basin, Nolichucky Formation, southwest Virginia Appalachians. Sedimentology, 28: 573-597.

Read, J.F., 1982. Carbonate platforms of passive (extensional) continental margins: types, characteristics and evolution. Tectonophysics, 81: 195-212.

Read, J.F., 1985. Carbonate platform facies models.Bull. Am. Assoc. Pet. Geol., 69: 1-21.

Read, J.F., Osleger, D. and Elrick, M., 1991.Two-dimensional modeling of carbonate ramp sequences and component cycles. In: E.K. Franseen, W.L. Watney, C.G.St.C. Kendall andf W. Ross (Editors),Sedimentary Modeling: Computer Simulations and Methods for Improved Parameter definition. Kansas Geol. Surv., Bull., 233: 473-488.

Somerville, I.D. and Strogen, P., 1992. Ramp sedimentation in the Dinantian limestone of the Shannon Trough, Co. Limerick, Ireland. In: B.W. Sellwood (Editor), Ramps and Reefs. Sediment. Geol., 79: 59-75.

Wilson, J.L., 1975. Carbonate Facies in Geologic History. Springer-Verlag, New York, N.Y., 471 pp.

Wright, V.P., 1986. Facies sequences on a carbonate ramp: the Carboniferous Limestone of South Wales. Sedimentology, 33: 221-241.