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CARBONATE PLATFORMS OF PASSIVE (EXTENSIONAL) CONTINENTAL MARGINS: TYPES, CHARACTERISTICS AND EVOLUTION

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ABSTRACT

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Carbonate platforms of extensional margins may be grouped into several major categories. *Homoclinal ramps* have gentle slopes into deep water, may have skeletal or ooid/pellet sand shoal complexes, that grade without break in slope into deep-ramp nodular limestone, and then into pelagic/hemipelagic basin facies; they generally lack significant slump and sediment gravity flow deposits in the deeper-water facies. *Distally steepened ramps* differ from the above in having a marked increase in slope at the seaward edge of the deep ramp, and abundant slumps, slope breccias and turbidites. However, clasts of shallow platform margin facies are generally absent from breccias. *Rimmed shelves* have linear trends of shelf edge lime sands and reefs, a marked increase in slope into deep water, and foreslope and slope sands, breccias (with clasts of platform margin rocks) and turbidites, grading seaward into basin hemipelagic/pelagic muds. They may be divided into accretionary, bypass and erosional margins. *Isolated platforms* are broad flat-topped shallow platforms surrounded by deeper water (few hundred meters to 4 km deep); many are bypass margins but accretionary and erosional margins also occur. Finally, incipiently to completely *drowned or open platforms* may develop by rapid submergence of ramps, shelves or isolated platforms; shallow platform margin facies are shifted landward and the earlier shallow-water platform is covered with transgressive lags, and deeper-water blankets of hemipelagic or pelagic facies or open marine, whole fossil wackestone.

The carbonate prisms commonly develop above a basal clastic phase. Ramps develop early, and evolve into rimmed shelves. However, with drowning, rimmed shelves may evolve up into ramps. Rimmed shelves may also develop into ramps where miogeoclinal facies prograde into filling marginal basins. Carbonate miogeocline deposition terminates when the shelf becomes a prograding clastic shelf, or where it becomes part of a collisional orogen. The various platform types may be recognized from continental margin sequences ranging from Proterozoic to Holocene in age.

INTRODUCTION

Carbonate rocks are important components of sedimentary prisms formed in passive or extensional continental margins, ranging in age from mid-Proterozoic to Holocene. These passive (or Atlantic-type) continental margins may extend out from cratons into marginal basins located behind magmatic arcs, or they border major ocean basins (Heezen, 1974). The carbonate prisms are commonly tens to hundreds of kilometers wide and up to a few kilometers thick. The miogeoclinal carbonate sequences commonly develop above basal rift volcanics, evaporites, immature rift-clastics or mature miogeoclinal clastics (cf. Bird and Dewey, 1970; Dewey and Bird, 1970). They may subsequently be overlain by prograding shelf clastics or by synorogenic clastics following conversion of the passive margin into a convergent margin associated with collisional orogeny.

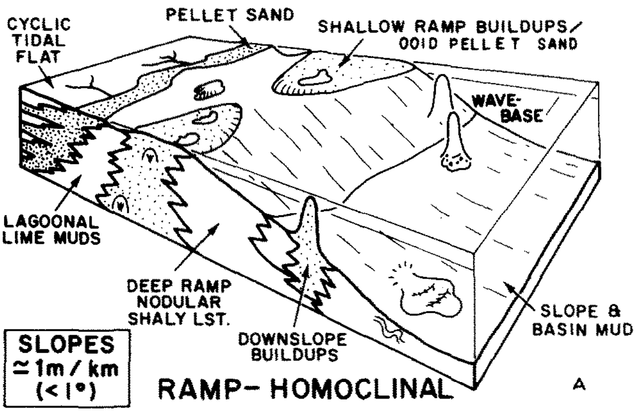
Carbonate platform models are important aids in understanding evolution of the miogeoclinal carbonate facies. However, many of the terms that are commonly used to describe the different models have various meanings to geologists. This lack of uniformity of usage appears to have hampered the application of the models to miogeoclinal sequences, and has greatly inhibited our understanding of the different facies sequences. The classification of platform margins (Table I) is based on that used by Ahr (1973) who recognized differences between shelves and ramps; Ginsburg and James (1974), who outlined characteristics of rimmed and drowned shelves, and Wilson (1975) who provided the first comprehensive model of platform margins. The classification used in this paper (Table I) uses the terms platform, ramp and shelf to describe geomorphic, 2-dimensional features, which appears to be consistent with most prior geological and common English usage. These terms may be used to describe rock bodies when used in conjunction with a rock term (e.g. ramp deposits). Wilson (1975), in contrast, used the terms "platforms", "ramp" and "major offshore bank" to describe rock bodies, and "shelf" to describe a 2-D surface. In this paper, the different types of platforms are defined, the facies associated with each are described briefly, and actual examples are used to illustrate each type. The platform types reflect stages in the evolution of the platform, sealevel or subsidence history, tectonic influences and biological evolution. Because the paper is limited to miogeoclinal platforms on passive margins, many well studied examples of platforms from interior basins, foreland basins, failed rifts (aulacogens), and fault-bounded cratonic basins opening out onto continental shelves, are excluded.

CARBONATE RAMPS

Carbonate ramps (Fig. 1) are gently sloping (generally less than 1°) platforms on which shallow wave-agitated facies of the nearshore zone pass downslope (without marked break in slope) into deeper-water, low-energy deposits (Ahr, 1973). They differ from rimmed shelves in that continuous reef trends are absent, buildups are

TABLE I

WEBSTERS THIRD NEW INTERNATIONAL DICTIONARY	AHR (1973)	GINSBURG AND JAMES (1974)	WILSON (1975)	THIS PAPER
PLATFORM - (LITERALLY "FLAT FORM"). A HORIZONTAL FLAT SURFACE USUALLY HIGHER THAN THE ADJOINING AREA (AS OF FLOOR OR GROUND) OR A FLAT OR NEARLY FLAT AREA OF THE EARTHS SOLID SURFACE EITHER ABOVE OR BELOW THE SURFACE OF THE SEA THAT STANDS ABOVE ADJACENT AREAS ON AT LEAST ONE SIDE.	CARBONATE PLATFORM - A GENERAL TERM USED BY AHR (1973), WHICH INCLUDES SHELVES AND RAMPS.		CARBONATE PLATFORM: HUGE CARBONATE BODIES BUILT UP WITH A MORE OR LESS HORIZONTAL TOP AND ABRUPT SHELF MARGINS WHERE "HIGH ENERGY" SEDIMENTS OCCUR. THIS 3 DIMENSIONAL USAGE OF PLATFORM (AND RAMP) CONTRASTS WITH COMMON ENGLISH USAGE OF THE TERMS TO REFER TO SURFACES (2 DIMENSIONAL FEATURES).	PLATFORM: THIS TERM IS USED IN THE SENSE OF AHR (1973) TO INCLUDE BOTH SHELVES AND RAMPS (OF AHR, 1973).
SHELF - A THIN, FLAT USUALLY LONG AND NARROW PIECE OF WOOD OR OTHER MATERIAL FASTENED HORIZONTALLY AT A DISTANCE FROM THE FLOOR (AS ON A WALL OR FRAME) TO HOLD OBJECTS; OR SOMETHING RESEMBLING A SHELF IN FORM OR POSITION; OR THE SUBMERGED BORDER OF A CONTINENT OR OF AN ISLAND EXTENDING FROM THE SHORELINE TO THE DEPTH AT WHICH THE SEA-FLOOR BEGINS TO DESCEND STEEPLY TOWARD THE BOTTOM OF THE OCEAN BASIN.	SHELF - NEARLY FLAT PLATFORM WITH A CLEARLY DEFINED SHELF-SLOPE BREAK. MUDDY ROCKS ON THE INNER SHELF PASS DOWNDIP INTO BOUNDSTONES AND GRAINSTONES AT THE SHELF MARGIN. CONTINUOUS REEF TRENDS (RATHER THAN PATCH REEFS) PRESENT.	RIMMED SHELVES - THOSE IN WHICH A CONTINUOUS OR SEMICONTINUOUS RIM OR BARRIER ALONG THE SHELF MARGIN RESTRICTS CIRCULATION AND WAVE ACTION ON THE ADJACENT SHELF LAGOON.	SHELF: AN AREA ON TOP OF A RAMP OR PLATFORM. NOTE THAT WILSON'S USAGE OF THIS TERM REFERS TO A SURFACE (2-DIMENSIONAL) WHEREAS THE OTHER TERMS USED BY WILSON (1975) ARE 3-DIMENSIONAL AND REFER TO CARBONATE BODIES.	RIMMED CARBONATE SHELF: A SHALLOW PLATFORM WHOSE OUTER EDGE HAS A SHALLOW RIM AND IS MARKED BY A PRONOUNCED INCREASE IN SLOPE (COMMONLY FEW DEGREES TO OVER 45°) INTO DEEP WATER. SHELF EDGE DOMINATED BY LIME SANDS, AND REEFS THAT MAY FORM CONTINUOUS TRENDS. ABUNDANT SEDIMENT GRAVITY FLOW DEPOSITS CONTAINING PLATFORM DERIVED MATERIAL (TURBIDITES, MEGABRECCIAS) DOWNSLOPE FROM THE SHELF EDGE. DIVIDED INTO DEPOSITIONAL (ACCRETIONARY) MARGINS, BYPASS MARGINS, EROSIONAL MARGINS.
RAMP - A SLOPING FLOOR OR WALK LEADING FROM ONE LEVEL TO ANOTHER.	RAMP - A SLOPING TOPOGRAPHIC SURFACE ON WHICH FACIES ARE DEPOSITED WHILE SUBJECT TO OPEN OCEAN CONDITIONS FROM THE SURF ZONE TO DEPTH OF HUNDREDS OF FEET. GRAINY FACIES ARE DEPOSITED NEAR THE SURF ZONE AND THE ADJACENT MAIN-LAND, AND PASS DOWNDIP INTO MUDDY SEDIMENTS. CONTINUOUS REEF TRENDS ABSENT.		CARBONATE RAMPS: HUGE CARBONATE BODIES BUILT AWAY FROM POSITIVE AREAS AND DOWN GENTLE REGIONAL PALEOSLOPES. NO STRIKING BREAK IN SLOPE EXISTS, AND FACIES PATTERNS ARE APT TO BE WIDE AND IRREGULAR BELTS WITH THE HIGHEST ENERGY ZONE RELATIVELY CLOSE TO THE SHORE	CARBONATE RAMP: SHALLOW, GENTLY SLOPING PLATFORM (SLOPES TYPICALLY LESS THAN 1°) THAT LACKS A MARKED BREAK IN SLOPE. GRAINSTONES COMMONLY IN UPDIP POSITION, AND MAY ALSO BE ASSOCIATED WITH LOCAL BUILDUPS DOWNDIP. CONTINUOUS REEF TRENDS ABSENT; BUILDUPS TYPICALLY SEPARATE AND DISCRETE; DOWNSLOPE, SEDIMENT-GRAVITY FLOW DEPOSITS CONTAINING CLASTS OF SHALLOW PLATFORM ROCKS ABSENT, EXCEPT ADJACENT TO LOCAL BUILDUPS. DIVIDED INTO HOMOCLINAL AND DISTALLY STEEPENED RAMPS.
			MAJOR OFFSHORE BANKS: COMPLEX CARBONATE BUILDUPS OF GREAT SIZE AND THICKNESS WELL OFFSHORE FROM THE COASTAL RAMPS OR PLATFORMS	ISOLATED PLATFORM: ISOLATED SHALLOW WATER PLATFORMS TENS TO HUNDREDS OF KILOMETERS WIDE, THAT ARE SURROUNDED BY DEEP WATER. COMMONLY STEEP SIDED. MARGINS MAY BE DIVIDED INTO ACCRETIONARY, BYPASS AND EROSIONAL.
		OPEN SHELVES - TYPICAL OF MOST SHELVES BORDERING CONTINENTS IN TODAYS OCEANS. LACK OF AN ELEVATED RIM ALLOWS TIDAL FLUSHING AND SWELL TO EXTEND ACROSS MOST OR ALL OF THE INNER SHELF.		DROWNED (OPEN) PLATFORM: WHERE SUBSIDENCE OR SEALEVEL RISE EXCEEDS UPBUILDING, PLATFORMS (RAMPS, SHELVES, ISOLATED PLATFORMS) MAY BE DROWNED. MARGIN FACIES ASSOCIATED WITH RAMPS, SHELVES OR ISOLATED PLATFORMS MAY DEVELOP ADJACENT TO POSITIVE ELEMENTS (FAULT BLOCKS, EOLIANITE DUNES, ARCHES AND CRATONIC SHORELINES), AT CONSIDERABLE DISTANCE FROM THE EARLIER SEAWARD MARGIN.



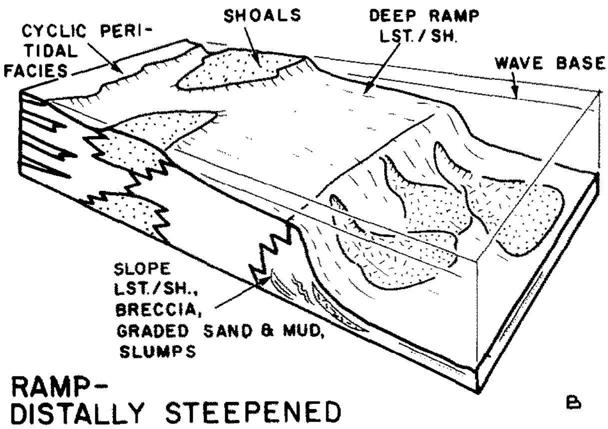


Fig. 1. A. Block diagram of homoclinal carbonate ramp. B. Block diagram of distally steepened ramp.

typically separate and discrete, and sediment gravity flow deposits containing clasts of cemented, shallow-water facies generally are absent from deeper water facies. Ramps may be characterized by nearshore skeletal shoal complexes or by ooid-pellet shoal complexes. In this paper, ramps are further subdivided on the basis of slope into *homoclinal ramps* and *distally steepened ramps*.

Homoclinal ramps (Fig. 1A): These have relatively uniform slopes (1 to a few meters/km) into the basin and generally lack significant sediment gravity flow deposits and slumps in deep-water facies. Major facies include:

(1) Coastal clastics, cyclic lagoonal and tidal flat carbonates, coals/evaporites. These pass seaward into nearshore ooid/peloid sands (2A) or skeletal sheets and buildups (2B).

(2A) Nearshore zone of shallow, high-energy, oolitic and peloid sands (associated with wave-agitated shoals and tidal deltas); may be associated with local islands; pass seaward into thin skeletal sands/muds; or

(2B) Skeletal sheets and discrete, shallow ramp buildups; may be reefal locally, although most are banks that lack rigid frames. Interbank sediments are cherty wackestone/mudstone.

(3) Deeper-ramp argillaceous lime wackestone/mudstone, containing open marine, diverse biotas, whole fossils, nodular bedding (related to early synsedimentary patchy cementation, compaction and pressure solution), local storm-generated upward-fining sequences and burrows; may also have downslope buildups that are discrete, biohermal to biostromal, and heavily cemented.

(4) Slope and basinal, deep-water pelagic muds or periplatform muds (composed of fines carried in from the shallow ramp) and shale interbeds. May contain minor slumps, intraformational truncation surfaces, minor lime conglomerates of slope facies, and turbidites.

Homoclinal ramps are relatively rare in the Holocene, which probably reflects the maturity of modern continental margins. However, homoclinal ramps appear to be common during the initial development of carbonate miogeoclines (cf. Wilson, 1975). The Jurassic Smackover of the U.S. Gulf Coast is an excellent example of a continental margin ramp (Ahr, 1973). Nearshore facies are shaly anhydrite, quartz sand and peloid ooid packstone (Buckner Formation); these pass seaward into a 30 to 80 km wide and 100 m thick belt of ooid and pellet grainstone and oncolitic packstone; reefs are rare; deeper-ramp beds are argillaceous, peloidal skeletal wackestone/mudstone and these pass into basinal pelagic muds 300 to 600 m thick (Wilson, 1975, pp. 293–296; Ahr, 1973). The early phase of the Jurassic–Cretaceous sequence, eastern Canadian continental shelf also has ramp characteristics (Eliuk, 1978), as does the Cambrian, lower Shady Dolomite, southern Appalachians (Pfeil and Read, 1980). Other examples of ramp facies from miogeoclines probably include the Upper Ordovician and Silurian-Devonian of the Western U.S.A. (Dunham, 1977; Matti and McKee, 1977; Nichols and Silbering, 1977). Because of the low slopes on ramps, subsidence or sealevel changes may result in pronounced cyclicity in ramp facies, as in the Upper Cambrian of the western U.S.A. (Lohmann, 1976).

Distally steepened ramp (Fig. 1B): These have some characteristics of ramps (agitated shoal water to subwave-base facies transition occurs well back on platform), and some characteristics of shelves (slope facies contain abundant slumps, megabreccias and slope breccias, and allochthonous lime sands. However, they differ from shelves in that the major break in slope does not occur at the transition from wave-agitated lime sand to subwave-base muds, but many kilometers seaward of this zone. Consequently, because the shoal water facies occur some distance back from the break in slope, deep-water megabreccias at the foot of the slope lack clasts of shallow-platform facies such as shallow-water sands and reefal carbonates. Instead they contain reworked sands and muds from the deep ramp and slope.

Facies belts on the shallow ramp resemble facies belts 1 and 2 of the homoclinal ramp, discussed previously.

Facies belts seaward of the nearshore, shoal complex include:

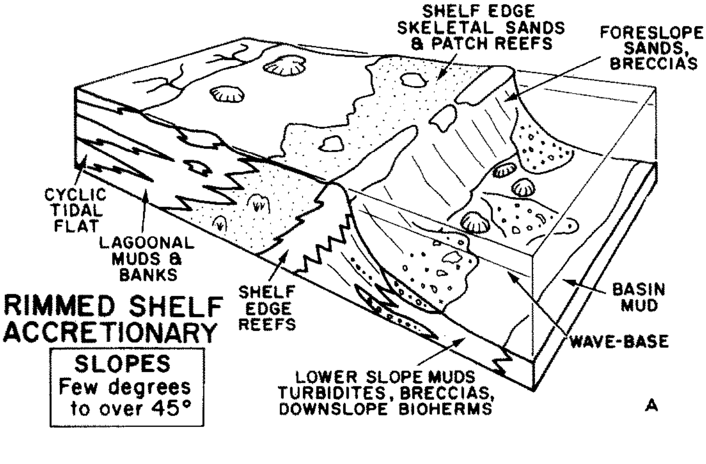
(3) Deep ramp, sub-wave base, nodular, burrowed lime wackestone mudstone (with open marine biota), argillaceous; in distal parts may also have slumps, breccias and allochthonous lime sands,

(4) Slope and basin margin facies of even-bedded, gray to black lime mudstone and lesser wackestone; may be argillaceous or shaly; laminated, unburrowed; abundant intraformational truncation surfaces, slumps and breccias of slope facies (units up to 10 m thick), lesser breccias with slope clasts and shoal-water clasts (of lithified lime sand); breccias commonly channel-form or sheet-like; some interbedded allochthonous lime sand beds (turbidites and contourites). Facies reflect relatively high (few degrees) slopes into the basin.

Examples include the Upper Cambrian–Lower Ordovician sequences of the western U.S.A., described by Cook and Taylor (1977), Cook (1979) and Brady and Rowell (1976). This ramp-type might be developed where a shelf is drowned to form a ramp (for example: the Holocene Yucatan platform, Ahr, 1973; and the Middle Cambrian Marjum-Pole Canyon Sequence, western U.S.A.; Brady and Rowell, 1976). The earlier rimmed shelf surface would then largely lie below wave base and muddy carbonates would mantle the slope at angles promoting downslope sediment gravity transport. The ramp-type also might develop where the distal ramp facies are developing over a zone of flexuring and rapid downwarping.

RIMMED CARBONATE SHELVES

Rimmed carbonate shelves (Ginsburg and James, 1974) are shallow platforms whose outer wave-agitated edge is marked by a pronounced increase in slope (commonly a few degrees to 60° or more) into deep water (Fig. 2). They have a



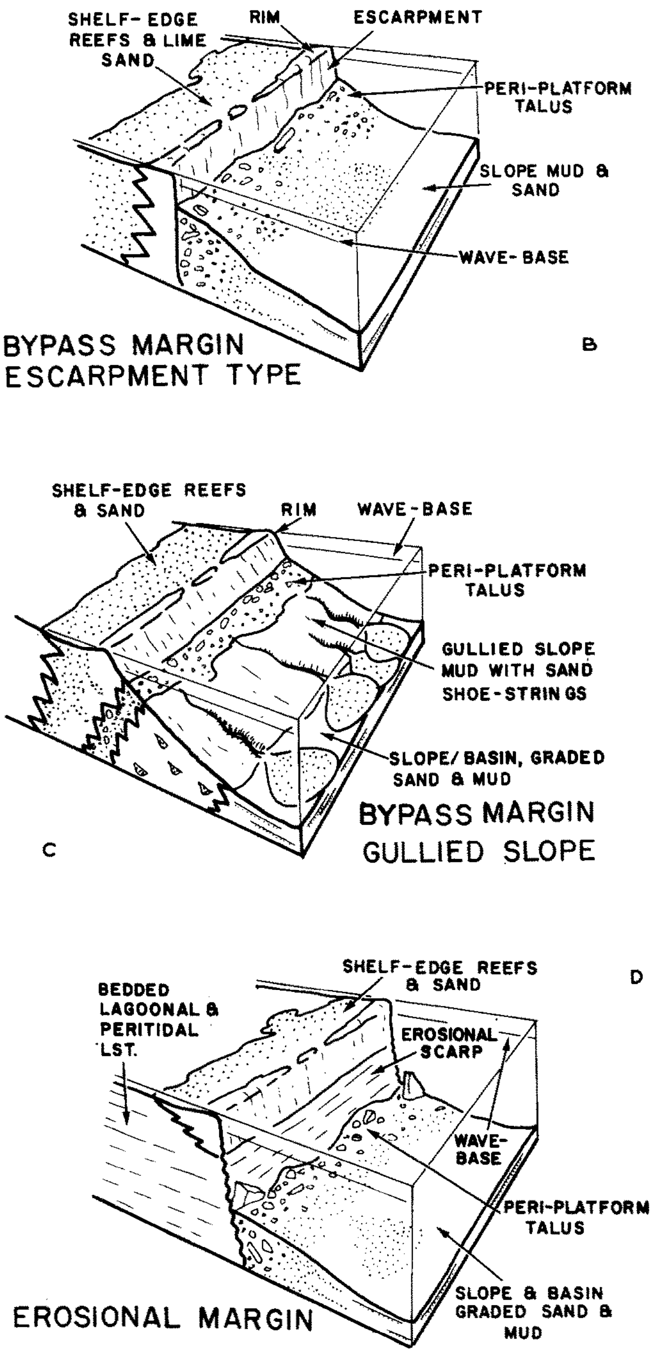


Fig. 2. A. Block diagram of rimmed carbonate shelf, accretionary type. B. Block diagram of rimmed shelf, with bypass margin of escarpment type. C. Block diagram of rimmed shelf, with bypass margin of gullied slope type. D. Block diagram of rimmed shelf; erosional margin.

semi-continuous to continuous rim or barrier along the shelf margin which restricts circulation and wave action to form a low-energy lagoon to landward (Ginsburg and James, 1974). On Holocene shelves, the rims may consist of Pleistocene reefal or eolianite limestone, Holocene reefal carbonate, or skeletal and ooid sands.

Comparison of margins of shelves and well studied isolated platforms suggest that rimmed shelf margins and their slopes may be classified into: (1) depositional or accretionary; (2) bypass; and (3) erosional margins; they may have reef-dominated or lime sand-dominated rims (McIlreath and James, 1979).

Depositional or accretionary margins (Fig. 2A): These show both up-building and out-building, they generally lack high marginal escarpments, and shelf edge and foreslope/slope facies may intertongue (rather than abut). Major facies belts include:

(1) Coastal siliciclastics, coals, evaporites, tidal flat carbonates, and subtidal lagoonal wackestone/mudstone and local shelf mounds; sequences commonly cyclic, upward shallowing.

(2) Outer shelf skeletal or oolitic sands, cross-bedded; patch reefs and reef-fringed banks; lime sands muddier to landward; interbedded or grade seaward into (3).

(3) Shelf-edge reefal carbonates, skeletal sands, and reef-derived rudites; abundant synsedimentary marine cement; reefs commonly zoned with respect to depth (James, 1979).

(4) Periplatform or foreslope lime sands, breccias and some hemipelagic lime mud beds. Typically clinoform bedded. Lime sands become muddier with depth. Breccias have abundant clasts of reef and cemented lime sand of platform margin/foreslope. Exotic blocks, slumps, pull-aparts, downslope mounds.

(5) Lower slope/basin margin turbidites, shale and sheet and channel-form breccias (sediment-gravity flows). Polymictic breccias have clasts of reef limestone, cemented shelf edge and foreslope sands, and clasts of dark, fine-grained slope facies; oligomictic breccias mainly composed of slope facies.

(6) Deep-water pelagic and hemipelagic lime muds, distal turbidites and shale.

The accretionary rimmed shelves commonly will have prograding (offlap) relations between reef, foreslope, slope and basin facies (Fig. 2A).

An ancient example of an accretionary rimmed shelf may be the Cambrian "Upper" Shady Dolomite, southern Appalachians (Pfeil and Read, 1980). The Mesozoic carbonates of the continental shelf, eastern Canada also may be rimmed shelf deposits (Eliuk, 1978). An example of a rimmed shelf with relatively gentle slopes (2°) and little forereef talus is the Cretaceous Stuart City shelf, U.S. Gulf Coast (Wilson, 1975). The shelf morphology is indicated by the marked break in slope at the shelf edge, and the linear trends of "reefs" and shelf margin skeletal sands.

Bypass margins: These occur in areas of rapid upbuilding where shallow-water sedimentation keeps pace with relative sealevel rise. Bypassing may be associated with a marginal escarpment (Fig. 2B) and/or a gullied bypass slope (Fig. 2C)

(McIlreath and James, 1979; Schlager and Chermak, 1979). The platform to basin transition is similar to those described under "Isolated platforms." Shelf-edge reefal carbonates pass downslope (below a few tens of meters) into a steep marginal escarpment, fringed by periplatform sands and talus. This may pass out into gullied, hemipelagic bypass slope or fine outward into turbidite lime sands and hemipelagic muds.

The Proterozoic Rocknest Formation of the Wopmay Orogen, Canada (Hoffman, 1973) is an example of a rimmed continental shelf, that may be of the escarpment bypass type. McIlreath (1977) describes an example of a reef-dominated bypass margin, the Cambrian Cathedral Formation, western Canada. Here the bypass margin is a vertical escarpment 200 m high, composed of calcareous algal reefs. The periplatform talus is dominated by clasts of calcareous algal boundstone. An example of a lime sand dominated bypass margin is represented by the Cambrian "boundary limestone" in which a wedge (100 m thick, 3 km wide) of skeletal-peloid grainstone, wackestone and hemipelagic mud, grading out into distal wedge hemipelagic lime mudstone and rare thin allochthonous lime sands, accumulated at the foot of the Cathedral escarpment following cessation of reef growth (McIlreath, 1977). Other bypass margins probably include the Mesozoic of northwest Africa (Todd and Mitchum, 1977).

Erosional margins (Fig. 2D): These may be characterized by lateral erosion of the escarpment to reveal bedded cyclic peritidal facies, and there may be erosional truncation of earlier slope deposits (cf. Mullins and Neuman, 1979; Ryan, 1980). These margins also may be characterized by sediment bypassing.

Intrashelf basins on rimmed shelves: Many rimmed shelves have inshore basins or intrashelf basins lying behind the shallow carbonate rim. Water depths generally are a few tens of meters, and the basin floors may lie below fair weather wave-base but above storm wave base.

The basins commonly are bounded to landward by coastal siliclastics, and have fills of shale, quartz sand and lime silts, intraformational conglomerates and shell lags, arranged in storm-generated, upward-coarsening and upward-fining sequences (Markello and Read, 1981) or fills of euxinic limestone and shale (Murris, 1980). The intrashelf basins pass onto the shallow carbonate platform through a gently sloping carbonate ramp. They commonly develop during relative sealevel rise. Examples include the Cambrian of western Canada (Aitken, 1978), Cambrian of the southern Appalachians, U.S.A. (Markello and Read, 1981), Mesozoic of eastern Canada (Eliuk, 1978) and the Middle East (Murris, 1980), and perhaps Holocene shelves such as the Sahul, Queensland and Belize shelves (Ginsburg and James, 1974).

ISOLATED PLATFORMS (BAHAMA TYPE)

These consist of isolated shallow-water platforms tens to hundreds of kilometers wide, located offshore from shallow, continental shelves, and surrounded by deep water, commonly several hundred meters and even exceeding 4 km deep (Fig. 3). Platforms may have gently sloping margins (ramp-like profiles) (Matti and McKee, 1977) or more steeply sloping margins resembling those of rimmed shelves (Mullins and Neumann, 1979). Those with steeper profiles may have a marginal escarpment (up to 60° or more, and few hundred meters to 4 km high), grading down into a more gently sloping (1° to 15°) deep-water sediment wedge that passes out into relatively flat lying basin plain deposits (slopes less than 1 m/km) (Mullins and Neumann, 1979). Marginal facies of isolated platforms are influenced by the windward or leeward location of the margin, whether the margin is ocean facing or faces a protected seaway or narrow basin, or is influenced by deep oceanic currents (Mullins and Neumann, 1979). Also, the deep-water facies may be eroded by deep channels parallel to the platform margins (Schlager and Chermak, 1979). Schlager and Ginsburg (1980) recognize accretionary margins, bypass margins and erosional margins. In their mature stages, many isolated platform margins appear to be bypass margins.

Facies belts of low-relief, gently sloping, isolated platforms resemble those of ramps, discussed previously (cf. Matti and McKee, 1977). Facies belts of isolated platforms with steeper profiles (Mullins and Neumann, 1979; Schlager and Chermak, 1979) are:

(1) Platform and platform rim: Reefal carbonates, skeletal and oolitic sands, cemented islands; the platform may be covered by bedded, cyclic, pelletal sands and muds (locally peritidal) and evaporites; or by skeletal sands. Siliciclastics absent.

(2) Marginal escarpment: variably developed; upper parts expose back-reef, reef and fore-reef sediments; in lower parts of deeper escarpments (below 1 km) escarpment exposes bedded lagoonal and tidal flat carbonates probably as a result of mechanical defacement (Ryan, 1980).

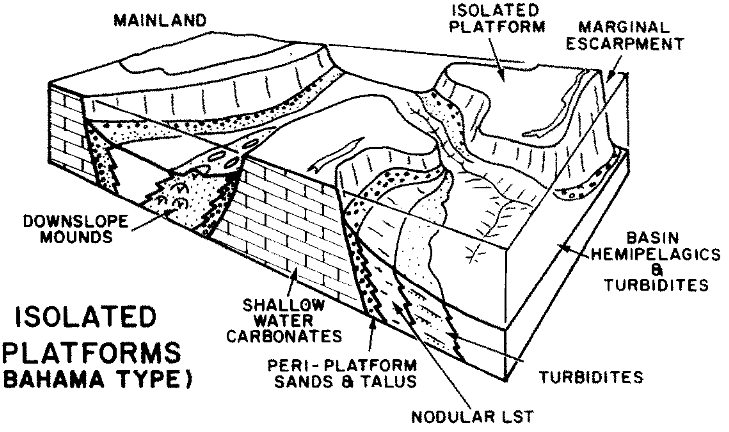


Fig. 3. Block diagram of isolated platform.

(3) Talus slope or periplatform sands: muddy lime sands (mixed shallow-water sediment and pelagics) and talus blocks. Commonly 1 to 3 km wide. The talus slope deposits may pass downslope into basinal facies on high-relief windward margins, or into 4A, 4B or 4C.

(4A) Gullied bypass slope: composed of pelagic lime mud and shoestring lime sands and rubble (gully-fills). May be nodular bedded (reflecting patchy submarine cementation and reworking). Hardgrounds and erosional cliffs present.

(4B) Winnowed slope: sands composed of planktonics, rock fragments and lesser shallow-water sediment, abundant hardgrounds. May prograde out onto and unconformably overlie basin facies; or pass downslope into lower slope lithoherms; or into lower slope, nodular pelagic limestone (cf. 4A).or

(4C) Slump and gravity flow deposits.

(5A) Lower slope or basin margin: alternating proximal, graded turbidites and carbonate mud. Some massive lime sands, debris flows and slumps.

(5B) Lithoherm belt: individual mounds up to 70 m thick; hardgrounds, sand waves (reflect presence of Gulf Stream; probably atypical).

(6) Basin or basin interior: alternating graded distal turbidites and carbonate mud.

Commonly, marginal escarpments and bypassing of the upper slope are associated. Material accumulates at the foot of the escarpment by rock fall, sliding or creep. The coarse debris may then be carried as erosive sediment gravity flows down gullies, bypassing the muddy upper slope, to accumulate on the lower slope and basin margin as turbidites and minor debris flows, together with pelagic and hemipelagic limestone (cf. Schlager and Chermak, 1979).

Besides the Bahamas (Mullins and Neumann, 1979; Schlager and Chermak, 1979) examples of isolated platforms include the Golden Lane and El Doctor platforms of Cretaceous age, Mexico (Enos, 1974, 1977), probably some Triassic platforms in the Dolomites, Italy (Bosellini and Rossi, 1974; Wilson, 1975), and the Devonian Tor Limestone, western U.S.A. (Matti and McKee, 1977). The isolated platforms appear to develop above horsts on faulted, rapidly subsiding platforms of extensional continental margins (Mullins and Lynts, 1977). Less commonly they are localized over linear submarine ridges of unknown origin on the outer continental shelf (Matti and McKee, 1977).

DROWNED PLATFORMS

Where subsidence or sealevel rise exceeds upbuilding, ramps, rimmed shelves and isolated platforms may undergo incipient to complete drowning (Kendall and Schlager, 1981; Schlager, 1981) (Fig. 4). The problem of drowning a carbonate platform, where upbuilding potential is generally greater than tectonic subsidence/sealevel rise, is discussed in detail in Schlager (1981). Where incipient drowning occurs, the platforms may become submerged to depths of several tens of

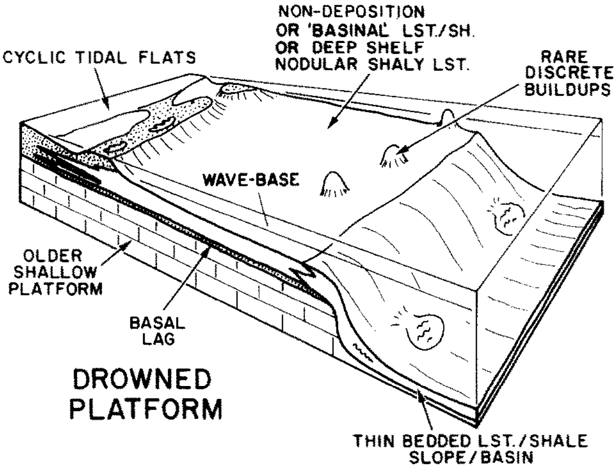


Fig. 4. Block diagram of drowned platform.

meters. They become sites of deposition of open shelf, subwave-base, carbonates (or shale and limestone) that gradually build to sealevel to form a thick (tens to few hundred meters) sequence of subtidal "ribbon carbonate" (Read, 1980); on high-energy, swell-dominated platforms, deposition of skeletal sand blankets may occur (L.B. Collins, pers. commun.). Kendall and Schlager (1981) suggest that incipiently drowned platforms remain in the euphotic zone, although many sequences in the Appalachians that appear to result from incipient drowning lack algae. It seems likely that the outer parts of pericratonic platforms might become submerged below the euphotic zone, but still receive large amounts of shallow-water sediment (from the shallow platform), as well as contributions from subphotic, resident assemblages, so that these do not become completely drowned. However, where the platforms sink deeply below the photic zone, the platforms become sites of deposition of basinal hemipelagic/pelagic facies that overlie earlier, shallow-water platform facies. Condensed sequences with numerous hardgrounds may develop, or in areas of non-deposition, submarine unconformities or chemical sediments (iron, manganese, phosphorite, or sulphide crusts) may develop.

Drowning causes a major, landward shift in the shallow platform facies. New belts of platform margin facies associated with ramp, shelf, and isolated platforms, may be developed adjacent to positive elements (e.g., fault blocks, eolianite dunes, arches and cratonic shorelines) at considerable distance from the earlier platform margin. Vertical transition from shallow platform to deeper water facies of the drowned phase may be abrupt or gradational. It may be marked by basal lime sands and gravels that result from migration of a high-energy transgressive environment over the platform. Where drowning followed a period of sealevel lowering, transgressive sands may rest unconformably on limestones with soil fabrics, caliches or vadose features as in many Pleistocene–Holocene sequences. Where drowning followed shallowing to tide levels, basal lime sands/gravels will rest on tidal flat carbonates with only minor evidence of subaerial weathering (e.g., Cambro-Ordovician cycles, Appalachians). Following drowning, upbuilding and progradation may tend to return the shelf or isolated platform to the original rimmed state; or in a ramp, it may result in progradation of shallow ramp facies over deep-ramp and basinal facies.

Incipiently to completely drowned continental shelves, termed open shelves (Ginsburg and James, 1974) are common in the Holocene, reflecting the rapid postglacial rise in sealevel, and include the Yucatan, West Florida and Sahul shelves. Ancient drowned platform sequences may include the Pole Canyon to Lincoln Peak transition, Middle Cambrian, western U.S. (Brady and Koepnick, 1979), the unconformable Ordovician Hansen Creek Formation to Silurian Roberts Mountains Formation transition and the transition from the Devonian Tor Limestone to the overlying beds, western U.S.A. (Matti and McKee, 1977), Patterson Member (Cambrian of Appalachians; Pfeil and Read, 1980), the Georgetown limestone, Cretaceous shelf of the U.S. Gulf Coast (Wilson, 1975), the drowned Jurassic platforms of Tethys (Bernoulli and Jenkyns, 1974), and the "Thick Cathedral" to "Thin Stephen" Formation transition, Canadian Rockies (McIlreath, 1977).

BIOLOGICAL EVOLUTION AND PLATFORM MARGINS

Summaries of the geological history of biotas associated with development of organic buildups (Fig. 5) are given in Heckel (1974) and James (1979). Proterozoic platforms margins were constructed by cryptalgal bioherms, and platform margin sands are mainly intraclastic because of the lack of skeletal organisms. Cambrian shelf edge reefs are mainly *Epiphyton-Renalcis* boundstones constructed by blue-green (?) calcareous algae. These were succeeded in the Lower Ordovician by sponge-algal bioherm biotas. Later Paleozoic buildup formers include tabulate corals, stromatoporoids, bryozoa, calcareous algae, sponges and associated echinoderms. Corals and stromatoporoids are important in the Mesozoic but give way in the late Mesozoic to rudist clams. Cenozoic platform margins are dominated by scleractinian corals and red algae.

It would seem that rimmed shelves would be more likely to develop during periods when reef builders (skeletal metazoa capable of secreting large, robust, branching, hemispherical or tabular skeletons) were abundant. These were present during the Middle Ordovician (but capable of producing relatively small reefs), the Silurian-Devonian, Late Triassic, Late Jurassic, Upper Cretaceous, Oligocene, Miocene(?) and Plio-Pleistocene (James, 1979); during the Precambrian and Cambrian, blue-green and skeletal algae appear to have been able to construct reefs (Hoffman, 1973; McIlreath, 1977). On ramps, organic communities function mainly as grain and mud producers, and as bafflers, trappers and binders that are associ-

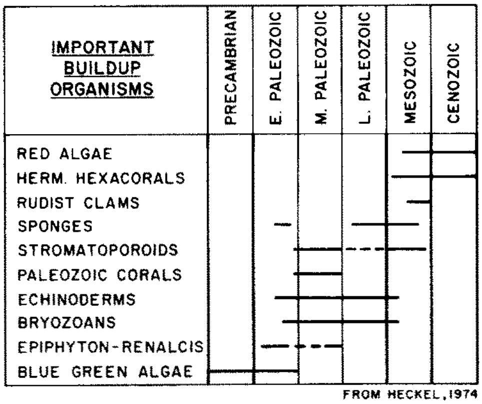


Fig. 5. Geological distribution of major buildup-forming organisms.

ated with carbonate bank deposition. Ramps may have been more likely to develop in areas, or at times, of tectonic or climatic crises in which reef-formers were poorly represented. Ramps would be expected to be dominant in temperate climatic zones. However, the role of submarine cementation cannot be downplayed in developing and maintaining steep margins of platforms.

EVOLUTION OF CARBONATE PLATFORMS

Carbonate platforms of extensional margins commonly develop over a basal sequence of rift volcanics, immature clastics and evaporites, or more mature shelf clastics (Fig. 6). Ramps develop initially, upon the gently sloping surface of the clastic continental shelf. They evolve into rimmed carbonate shelves later, as a result of high carbonate production on the developing shelf edge, and sediment starving of off-shelf environments (Fig. 7). The reverse development (rimmed shelf into a ramp) commonly occurs where the earlier rimmed shelf is drowned. A shallow to deep-ramp transition forms some distance back from the drowned shelf edge, and this ramp may then evolve into a rimmed shelf, bordered to seaward by a broad, open (drowned) shelf. Less commonly, rimmed shelves may evolve into ramps where the miogeocline is prograding out into a filling marginal basin (especially just prior to collision) (Fig. 7) or where the shelf is buried by prograding clasties. Initial ramps or rimmed shelves also may evolve into isolated platforms, during rifting. The earlier, extensive platform carbonates are faulted to form horsts and grabens and undergo rapid submergence, with carbonate upbuilding being localized on the highs, while the grabens become sites of drowning and deep water sedimentation.

Incipient to complete drowning of platforms occurs where sumbergence (related to subsidence or sealevel rise) outstrips upbuilding by biological production of carbonate sediment. Eustatic sealevel changes, which give rise to various orders of

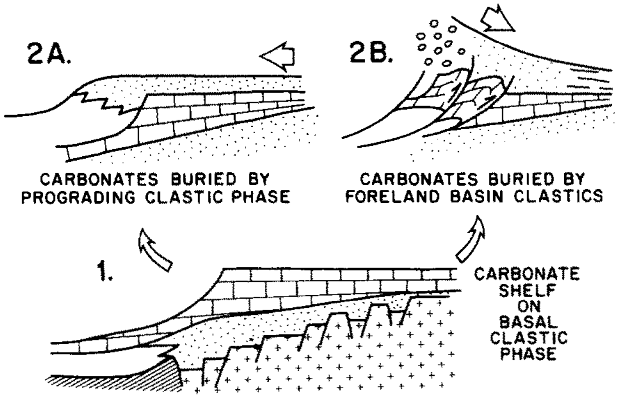


Fig. 6. Geological evolution of carbonate platforms.

cycles, have a major influence on the sequences developed on platforms (Vail et al., 1977). Emergence of platforms may result from tectonic uplift, or more commonly, eustatic lowering of sealevel, and may be accompanied by erosion and subaerial diagenesis. Eustatic lowering may relate to rates of spreading or to glacio-eustatic

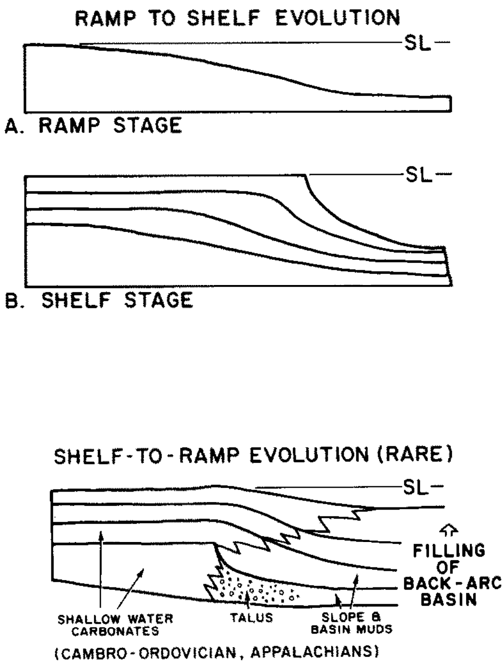


Fig. 7. A. Evolution of a ramp up into a rimmed shelf. B. Development of a rimmed shelf into a ramp with filling of marginal basin.

effects. However, some ancient shelves lack the numerous disconformities that typify Late Cenozoic platforms, and developed by periodic, small scale submergence and shoaling to sealevel; much of the diagenesis on these appears to have occurred under marine conditions or during burial. Submarine "disconformities" may develop in miogeoclines where the shelf is drowned to become a site of non-deposition (Kendall and Schlager, 1981; Schlager, 1981).

Carbonate sedimentation may be arrested at any stage by progradation of continental shelf clastics (due to rejuvenation of clastic source terrains, or climatic change related to global cooling or plate motion) (Fig. 6). Carbonate deposition may also be terminated following continent-continent or continent-arc collision, when the platform may be uplifted to form an unconformity, the shelf edge is subjected to erosion, folding and thrusting, and large volumes synorogenic clastics are shed into foreland basins developed on the foundered platform (Fig. 6).

CONCLUSIONS

Carbonate sediment prisms associated with passive or extensional continental margins may be understood using several facies models, defined by areal geometry, bathymetric profile of the platform-to-basin transition, and water depth. These models include ramp, rimmed shelf, drowned platform and isolated platform types, each of which has distinctive geometry, and facies associations. Ramps may be subdivided into homoclinal and distally steepened types; rimmed shelf and isolated platform margins may include accretionary, bypass and erosional types. Platforms that have undergone long-term submergence include incipiently drowned and completely drowned types.

Distinctive evolutionary sequences exist between the various platform types. These reflect degree of maturity of the platform, degree of equilibrium with regard to sealevel, and tectonic influences. Biological evolution also has played a role in the types of organisms involved in carbonate deposition on the platform. Finally, miogeoclines also may show a large-scale evolution from an early non-carbonate phase to a carbonate phase. This may be followed by a progradational, shelf clastic phase or culminate with collisional orogeny when the miogeocline is buried beneath synorogenic clastic sediments.

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