A. Vecsei

Nutrient control of the global occurrence of isolated carbonate banks

Abstract The growth and origin of the world's isolated carbonate banks are as yet not completely understood. This paper presents a comparison of the areas, depths, and latitudinal distribution of the world's carbonate banks. These are then compared with chemical parameters of seawater in the upper mixed zone of the oceans and at depth. The results allow large-scale inferences to be made on the interacting controls on bank growth and distribution. The data support the hypothesis that nutrient-rich waters commonly control bank depth and size.

Keywords Isolated carbonate banks · Growth · Depth and area · Controls · Nutrients

Introduction

The world's modern isolated carbonate banks, separated from land by deep seaways, are a major part of the oceanic shoals (Milliman 1974; Wilson 1975). Most, if not all, larger isolated banks occur in low latitudes (Vecsei 2000; Fig. 1). The growth and distribution of these banks, at global and regional scales, can be represented by their summit area and depth (Grigg and Epp 1989) and related to current- and climate-influenced properties of the water above the summits (temperature or carbonate ion saturation: Kleypas et al. 1999, nutrient concentration: Hallock and Schlager 1986, salinity: Wilson and Roberts 1992). These parameters are considered to control and limit the benthic associations precipitating the carbonate sediments that form the banks.

A. Vecsei (✉)
Geologisches Institut,
Universität Freiburg,
Albertstraße 23B, 79104 Freiburg, Germany
e-mail: vecsei@rz.uni-leipzig.de
Tel.: +49-341-9732907
Fax: +49-341-9732809

Present address:
A. Vecsei, Institut für Geophysik und Geologie,
Universität Leipzig, Talstraße 35, 04103 Leipzig, Germany

Vertical and lateral biotic accumulation and cementation result in bank growth. Rates of carbonate precipitation are similar in the Indo-Pacific and Atlantic, despite the rather different assemblages of corals and other calcifying benthos in these areas and the much greater coral diversity in the Indo-Pacific (cf. Kinsey 1985).

The nutrients phosphate and nitrate have received much attention as controls on the associations of platform biota and on platform growth. The 'nutrient control hypothesis', based largely on work on the Nicaragua Rise region, showed that the change from low to high nutrients results in a systematic shift in the benthos (e.g., Hallock and Schlager 1986). In the upper ocean of this area, trophic grade, proxied by chlorophyll content, reveals that high nutrients occur only during short periods (Hallock and Elrod 1988). Hallock (2001) suggested that nutrient-poor waters characterized by up to ~0.1 mg chlorophyll-a m^{-3} are oligotrophic in the geologic sense; these favor shallow-water reef corals. Waters with intermediate nutrients (~0.1–0.2 mg chlorophyll m^{-3}) are slightly mesotrophic; here macroalgae, sponges, molluscs, and echinoids dominate, including many bioeroders. This association is characterized by somewhat lower calcification rates with respect to the oligotrophic association. The strong bioerosion prevents net framework accretion, and probably much of the sediment is swept from these banks (Hallock 2001). This promotes bank drowning (submergence below the highly productive euphotic zone). Waters richer in nutrients (>~0.2 mg chlorophyll m^{-3}) are strongly mesotrophic; here macroalgal growth is enhanced. This includes the strongly calcifying green algae, which can form bioherms and result in strong platform growth. Eutrophication (>>~0.2 mg chlorophyll m^{-3}) promotes the growth of heterotrophic organisms, resulting in low calcification. Even short-term upwelling of nutrient-rich water may either suppress or enhance carbonate production (Hallock 2001).

The depth and size of the banks reflect their carbonate accumulation over time. This paper shows that the summits, at a global scale, show high accumulation where the upper mixed zone of the oceans are poor in
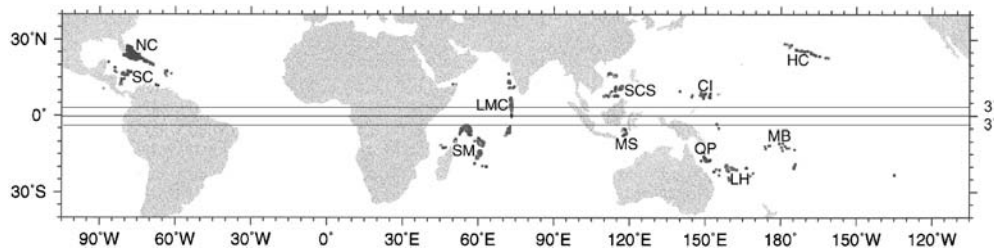
Fig. 1 The world's 197 isolated carbonate banks, excluding most atolls, having more than ca. 170 km² summit area and summit depths less than 200 m. Bank clusters are northern Caribbean (*NC*), southern Caribbean (*SC*), Seychelles-Mascarene Ridge (*SM*), Laccadives-Maldives-Chagos (*LMC*), South China Sea (*SCS*), Makassar Strait (*MS*), Caroline Islands (*CI*), Melanesian Border-land (*MB*), Queensland Plateau (*QP*), Lord Howe Rise to New Caledonia (*LH*), and Hawaii Chain (*HC*). Pixel size increased for graphic representation (after Vecsei 2000)

nutrients, reduced accumulation in waters with slightly higher nutrients, and again high accumulation in waters with elevated nutrients. This pattern corresponds to Hallock's (2001) observations for the Nicaragua Rise area. Also, the biotic associations on the summits of the world's banks, where known (cf. Vecsei 2000), are similar to those on the Nicaragua Rise banks. Thus, it appears justified to crudely correlate the measured nutrients with Hallock's (2001) trophic grades and the chlorophyll proxy. This correlation suggests the oligotrophic associations thrive in waters having <~30 ppm (v.) PO_4^{3-}, the slightly mesotrophic associations live in waters with 30–100 ppm PO_4^{3-}, and the strongly mesotrophic biota thrive in waters with >100 ppm PO_4^{3-}. The nutrients reach much higher values, >170 ppm PO_4^3, below the nutricline. Hallock (2001) has suggested that upwelling from below the nutricline brings nutrients to many summits. Mixing of these nutrient-rich waters with waters from the mixed zone of the upper ocean, containing less nutrients, can result in the trophic conditions that control the biotic associations on many summits.

The actual combination of the diverse controls that results in the distribution of calcifying organisms on the banks, their calcification rates, the amount of diagenetic cementation, and thus in bank growth is poorly known, except in a few regions (Bahamas: Morse et al. 1984; Wilson and Roberts 1992; Nicaragua Rise area: Hallock et al. 1988; Makassar Strait: Roberts et al. 1987). This note explores the controls, particularly of nutrients, on the world's low-latitude isolated banks, with summit areas >~170 km² and depths <200 m, based on the analysis of a database from bathymetric charts (Vecsei 2000). The atolls, having annular reefs that break the water near sea level, are excluded. The Maldive 'atolls' are here considered banks because of the extraordinary size of their summits (cf. Purdy and Bertram 1993). Vecsei (2000) discussed the derivation and accuracy of the bank data. The summits are circumscribed by the marginal slope break, most representative for nearly flat summits. The depths presented here are arithmetic means for these summits.

The summit area and depth of the banks and the properties of the ambient seawater (annual averages of nutrients: Conkright et al. 1994; temperature: Levitus and Boyer 1994; salinity: Levitus et al. 1994), mostly available as discrete values, reveal how the banks have grown. This analysis allows to infer how the properties of the seawater have controlled the banks. In particular, I propose that upwelling of deeper water is an important control on the growth of many banks, which grow in regions where the deeper waters are rich in nutrients. Thus, the validity of the hypothesis of nutrient control can be substantiated at a global scale. The important effects of sea level change are treated elsewhere (Vecsei 2003).

Results and evaluation

Area versus depth

Bank area versus depth data scatter considerably and are uncorrelated (Fig. 2a). Most summits are less than 70 m deep. The few deepest summits are among the smallest (<300 km²). Many summits from the entire size range are deeply submerged. These banks drowned during the rapid sea level rise, following the last glacial maximum ca. 20,000 years ago (cf. Fairbanks 1989).

These relations and their controls may be explained in a similar way to Grigg and Epp's (1989) generalization for the Hawaiian Chain. There, bank depth generally increases with decreasing summit size, and all banks <~150 km² are drowned, possibly because waves eroded them to present depths, of >16 m, during Pliocene or Miocene times (Grigg and Epp 1989). The growth of these eroded banks did not keep pace with the fast Quaternary deglacial rises of sea level. In the shallower banks, growth restarted and has since continued during the decelerated sea level rise of the last deglaciation period.

Area and depth versus latitude

Summit area and depth plotted against latitude each yield two clusters, which are crudely symmetrical around the equator (Fig. 2b, c). The banks reach almost 25°N and 30°S. Area and latitude are uncorrelated. Only a few banks, mainly in the Maldives (Fig. 1), lie around the
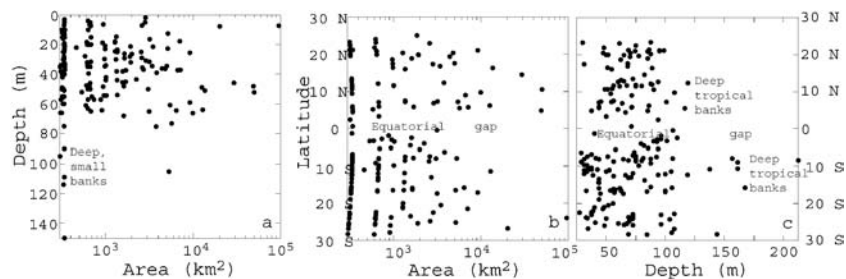
Fig. 2a–c Properties of the world's isolated banks. Most banks are shown at discrete sizes in ~300 km² steps. **a** Many relatively small summits and a few large summits tend to be shallow. The smallest summits are mostly the deepest. All summits are at depths between 0 and 150 m. **b** The banks form two clusters in north and south equator. This results in an 'equatorial gap' between ~3°N and 3°S. The banks in ~3–18°N and S are deeper (respectively reaching ~150 and ~120 m) than those in higher latitudes (reaching ~100 m).

latitudes, only a few banks occur within the 'equatorial gap'. Higher latitude banks tend to be small. **c** The few summits within the equatorial gap are relatively deep (~100 m). Some tropical banks have deeper summits (~120 to 150 m)

The occurrence of most banks in the tropical-subtropical climate zone reflects that their strongly calcifying biota require warm water or high seawater carbonate saturation (cf. Kleypas et al. 1999). The prolonged inhibition of bank growth by upwelling of nutrient-rich, cool, and less carbonate-saturated waters in the Pacific appears to be a main cause of the equatorial gap. Some seamount chains continue across the equator, thus a lack of tectonically suitable substrates is unlikely the only cause for the equatorial gap. The preferential occurrence of deep banks between ~3–18°N and S still needs to be explained.

Nutrients versus depth and area

Phosphate concentration, from Conkright et al.'s (1994) annual averages, can be used to approximate nitrate content, because both nutrients are highly correlated in the oceans. The waters from the upper mixed zone of the oceans, represented by data from 30 m depth, are oligotrophic (<30 ppm PO_4^{3-}) to slightly mesotrophic (30–100 ppm PO_4^{3-}) over most summits (Fig. 3a, b). The majority of summits, encompassing a large range of depths (Fig. 3a) and areas (Fig. 3b), occur in oligotrophic waters. The shallow mesotrophic waters (>30 ppm) cover only summits ≥20 m deep, with one exception (Fig. 3a), and small to medium-sized summits (<~6,000 km²). There are no summits in slightly mesotrophic waters at shallow depth, forming a 'nutrient gap'. The depth of most summits is unrelated to the nutrients measured at shallow depth. Another reason or reasons must be invoked to explain the depth distribution of the deeper banks.

The waters from −125 m around the slopes and a few deep summits of many banks vary from oligotrophic to eutrophic (Fig. 3c, d). The summit depths and areas are uncorrelated to nutrient concentration (R <0.1). Significantly, however, summits of a partial depth and area range are excluded from nutrient-rich waters. Shallow
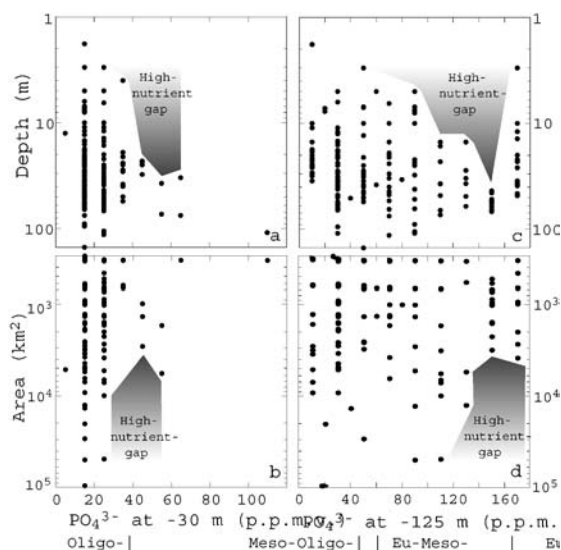

Fig. 3a–d The depth and area of the world's isolated banks greatly scatter with respect to nutrient concentration (PO_4^{3-}, from Conkright et al. 1994). **a** Most summits, shallow and deep, occur in oligotrophic upper mixed zone waters at −30 m. Shallow banks are absent from a slightly mesotrophic 'high-nutrient gap'. **b** Oligotrophic upper zone waters contain most banks, and these cover the entire range of sizes. Nutrient-rich waters contain only a few banks, whose size does not exceed ~6,000 km². **c** Shallow banks form a 'gap' where the waters at −125 m depth are mesotrophic, the gap deepens where waters become eutrophic. The summits are shallow again where deep waters are strongly eutrophic (~170 ppm. PO_4^{3-}). **d** The nutrient-rich waters at 125 m depth exclude the largest banks with summits exceeding 4,000 km²

summits are lacking, forming a 'high-nutrient gap', where these deeper waters are mesotrophic and eutrophic (~50–160 ppm at 125 m; Fig. 3c). This gap increases from −10 to −40 m depth with increasing nutrients. An analogous gap excludes banks larger than 4,000 km² where the deep waters are eutrophic (Fig. 3d). The largest summits of these banks are around an order of magnitude smaller than the summits of banks surrounded by nutrient-poor deeper water. The summits deeper than ~70 m are concentrated where the deep waters are mesotrophic (~40–90 ppm at −125 m).

The greater summit depth and smaller size of many banks, which grow in regions where the waters of the upper ocean and particularly at depth are mesotrophic and eutrophic, support the hypothesis that high nutrients adversely affect benthic calcification and bank growth. The nutrients further increase with depth in most regions (Conkright et al. 1994). At the high-nutrient (~170 ppm) end of the range, strong fertilization of green algae by upwelling from ~125 m and below can explain the strong aggradation and shallowness of some banks (Makassar Strait, Laccadives). This fertilization has not resulted in larger summits.

Temperature and salinity

Temperature controls the carbonate-producing benthos of the banks directly (cf. Lees and Buller 1972; Lees 1975), or indirectly through the preference of the calcifying benthos for carbonate-oversaturated seawater (Kleypas et al. 1999). The temperature, from Levitus and Boyer's 1994 annual averages, is >20 °C even in ~100 m depth around all banks studied, except in the Seychelles-Chagos area in the Indian Ocean where it is 15–20 °C. The main carbonate-producers thrive at these temperatures. The relative shallowness of banks subject to particularly intense upwelling (e.g., Makassar Strait, Roberts et al. 1987) also argues against major temperature control. Salinity is normal around the banks from the sea surface to below 100 m (cf. Levitus et al. 1994). These observations indicate that temperature and salinity are subordinate to nutrients as controls on most low-latitude banks, except of temperature control at the latitudinal extremes. I have therefore not studied the effects of temperature and salinity further.

Discussion

Interacting controls

These results suggest several interacting controls on the vertical and lateral growth and distribution of the world's isolated carbonate banks. The banks grow where the benthos produces abundant carbonate, particularly if the loose sediment is stabilized in situ by early cementation. Water temperature or carbonate saturation control the growth of the calcifying biota, particularly reef corals (Kleypas et al. 1999) and green algae (Hillis 1997). The same parameters control the amount of early cementation (Given and Wilkinson, 1985). Temperature or carbonate saturation restrict substantial bank growth to the shallow photic waters of the tropical–subtropical climate zone.

Within the low latitudes, the great scatter of bank area versus depth suggests that several controls have interacted during the evolution of the banks. The great scatter of depth and area plotted against the nutrients from both the upper mixed zone and ~125 m depth support this suggestion. The evaluations presented here confirm that both depth and nutrients need to be favorable for high carbonate production and accumulation on banks. The huge Great Bahama Bank exemplifies strong growth under such favorable shallow depth and low nutrients (cf. Eberli and Ginsburg 1989; Wilson and Roberts 1992).

The most deeply drowned banks are among those with the smallest summits. Area limitation apparently acts through wave erosion, which primarily affects small banks (e.g., Hawaiian Chain: Grigg and Epp 1989).

Nutrient control and upwelling

Elevated nutrients in the upper zone of the oceans and, more importantly, nutrient-rich waters at ~−125 m and below coincide with greater bank depth and smaller summits, reflecting decreased bank growth. The relations between the areas and depths of the banks and the biotic associations producing the carbonate on the banks are strong circumstantial evidence for the respective nutrient regimes proposed, although the absolute values need to be better constrained. The complete exclusion of a partial range of shallow summit depths and large sizes implies that nutrients are an important control on bank distribution and growth on a global scale. The upwelling of mesotrophic to eutrophic deep waters with 100–160 ppm PO_4^{3-} can suppress calcification, primarily by inhibiting the growth of reef corals, but these waters are not rich enough in nutrients to induce strong green-algal production. Modern reefs in the equatorial upwelling zone indeed produce little carbonate (Kinsey 1985).

The coincidence of high nutrients at ~125 m depth with the reduced growth of shallow banks implies that upwelling is common along many of the world's bank slopes. The occurrence of the high-nutrient gap where the deep waters are eutrophic implies that these are diluted during upwelling by mixing with waters having lower nutrient concentrations. The high nutrients represented in Fig. 3, however, include only those resulting from regional-scale upwelling, e.g., in the Pacific zone of equatorial convergence, the Arabian Sea and Indonesia.

Many growth-restricted banks occur outside these upwelling regions. For instance, PO_4^{3-} hardly increases from surface to ~100 m in parts of the Nicaragua Rise and other areas where nutrient control is probable (Hallock et al. 1988). Boehlert and Genin (1987), Roden (1987), and Hay (1995) reviewed the hydrodynamic theory and numerical simulations of upwelling processes along banks and other shallow oceanic structures. Significant upwelling is induced by leeward whorls and Ekman currents, and specially along larger banks by the Bernoulli effect and the Coriolis force on latitudinal currents. Such local upwelling has as yet been demonstrated only along a few bank slopes (e.g., southern Caribbean: Hallock and Elrod 1988, Galapagos Islands: Feldman et al. 1984, Cobb Seamount: Lueck and Mudge 1997). Local upwelling is probably a common mechanism for nutrient advection to bank summits. Thus control by upwelling nutrients, both at regional and local scales, must be much more

widespread and important than suggested by regional upwelling represented in Fig. 3.

Timing of bank growth

The successions of carbonate sediments below bank summits are known from only a few banks. Quaternary and older carbonate sediments are some hundredss to thousands of meters thick in banks from the Caribbean (Great Bahama Bank: Schlager and Ginsburg 1981; Aurell et al. 1995; Eberli and Ginsburg 1989; Saba Bank: Despretz et al. 1985) and Indian Ocean (Maldives atolls: Aubert and Droxler 1996; Seychelles Bank: Plummer et al. 1998; Saya de Malha Bank: Meyerhoff and Kamen-Kaye 1981; Sherbakov et al. 1990). This suggests that many summits have reached their present-day depth and size during their Quaternary and earlier evolution.

The observation that the effects of area, depth, and nutrients together explain many aspects of modern bank distribution suggests that similar factors have been acting not only during the last deglaciation, but for a long period of bank growth, perhaps during much of Quaternary time and before. Indeed Larson et al. (1995) and Wilson et al. (1998) suggested that equatorial upwelling probably resulted in the drowning of Pacific atolls during Cretaceous times.

Conclusions

The empirical analysis of the growth parameters of the world's isolated carbonate banks and comparison with the chemistry of the waters surrounding their summits and slopes, suggest that nutrients, summit size acting through wave erosion, and possibly other factors have interacted as controls on bank growth and distribution.

The nutrient-control hypothesis, stating that seawater of diverse trophic grades enhances or suppresses benthic calcification and thus bank growth, has been previously based on studies of a few regions. The evaluations presented here support the hypothesis at a global scale. The depth and areal distribution of many bank summits with respect to nutrients at depth indicate that commonly the nutrient-rich waters upwell along the bank slopes.

The specific combination of the effects of the diverse controls on the individual banks is as yet largely unknown. Future studies should examine in detail the global, regional, and local controls on the growth and distribution of the banks and other carbonate platforms.

References

Aubert O, Droxler AW (1996) Seismic stratigraphy and depositional signatures of the Maldive carbonate system (Indian Ocean). Mar Petrol Geol 13:503–536

Aurell M, McNeill DF, Guyomard T, Kindler P (1995) Pleistocene shallowing-upward sequences in New Providence, Bahamas: Signature of high-frequency sea-level fluctuations in shallow carbonate platforms. J Sediment Res B65:170–182

Boehlert GW, Genin A (1987) A review of the effects of seamounts in biological processes. In: Keating BH, Fryer P, Batiza R, Boehlert GW (eds) Seamounts, Islands, and Atolls. Am Geophys Union, Geophysical Monograph 43, pp 319–334

Conkright ME, Levitus S, Boyer TP (1994) World ocean atlas 1994 Volume 1: Nutrients. NOAA Atlas NESDIS 1. Nat Oceanic Atmospheric Administration, Washington

Despretz J-M, Daly TE, Robinson E (1985) Saba Bank petroleum geology, NE Caribbean. Oil Gas J 83:112–118

Eberli GP, Ginsburg RN (1989) Cenozoic progradation of NW Great Bahama Bank—a record of lateral platform growth and sea-level fluctuations. In: Crevello JL, Wilson JL, Sarg JF, Read JF (eds) Controls on carbonate platform and basin development. Soc Econ Paleont Mineral Spec Publ 44:339–351

Fairbanks RG (1989) A 17,000-year glacio-eustatic sea-level record: Influence of glacial melting rates on the Younger Dryas event and deep-ocean circulation. Nature 342:637–642

Feldman G, Clark D, Halpern D (1984) Satellite color observations of the phytoplankton distribution in the eastern equatorial Pacific during the 1982–1983 El Nino. Science 226:1069–1071

Given RK, Wikinson BH (1985) Kinetic control of morphology, composition, and mineralogy of abiotic sedimentary carbonates. J Sediment Petrol 55:109–119

Grigg RW, Epp D (1989) Critical depth for the survival of coral islands: effects on the Hawaiian archipelago. Science 243:638–641

Hallock P, Hine AC, Vargo GA, Elrod JA, Jaap WC (1988) Platforms of the Nicaraguan Rise: Examples of the sensitivity of carbonate sedimentation to excess trophic resources. Geology 16:1104–1107

Hallock P (2001) Coral reefs, carbonate sediments, nutrients, and global change. In: Stanley GD Jr (ed) The history and sedimentology of ancient reef systems. Topics in geobiology 17. Kluwer/Plenum, New York, pp 387–427

Hallock P, Elrod JA (1988) Oceanic chlorophyll around carbonate platforms in the western Caribbean; observations from CZCS data: Proc 6th Int Coral Reef Symp 2:449–454

Hallock P, Schlager W (1986) Nutrient excess and the demise of coral reefs and carbonate platforms. Palaios 1:389–398

Hay WW (1995) Paleoceanography of marine organic-carbon-rich sediments. In: Huc AY (ed) Paleogeography, paleoclimate, and source rocks: Am Assoc Petrol Geol, Stud Geol 40:21–59

Hillis L (1997) Coralgal reefs from a calcareous green algal perspective, and a first carbonate budget: Proc 8th Int Coral Reef Symp Panama 1:761–766

Kinsey DW (1985) Metabolism, calcification and carbonate production. I Systems level studies. Proc 5th Coral Reef Symp Tahiti 1:505–526

Kleypas JA, Buddemeier RW, Archer D, Gattuso J-P, Langdon C, Opdyke BN (1999) Geochemical consequences of increased carbon dioxide on coral reefs. Science 284:118–120

Larson R, Rebe E, Nakanishi M, Bergersen DD, Lincoln JM (1995) Stratigraphy, vertical subsidence and paleolatitude histories of Leg 144 guyots. In: Haggerty JA, Premoli Silva I, Rack F, McNutt M (eds) Proc ODP Sci Res 144:915–934

Lees A (1975) Possible influence of salinity and temperature on modern shelf carbonate sedimentation. Mar Geol 19:159–198

Lees A, Buller AT (1972) Modern temperate-water and warm-water shelf carbonate sediments contrasted. Mar Geol 13:M67–M73

Levitus S, Boyer TP (1994) World ocean atlas 1994 Volume 4: Temperature. NOAA Atlas NESDIS 4. Nat Oceanic Atmospheric Administration, Washington

Levitus S, Burgett R, Boyer TP (1994) World ocean atlas 1994 Volume 3: Salinity. NOAA Atlas NESDIS 3. Nat Oceanic Atmospheric Administration, Washington

Lueck RG, Mudge TD (1997) Topographically induced mixing around a shallow seamount. Science 276:1831–1833

Meyerhoff AA, Kamen-Kaye M (1981) Petroleum prospects of Saya de Malha and Nazareth Banks, Indian Ocean. Am Assoc Petrol Geol Bull 65:1344–1347

Milliman JD (1974) Marine Carbonates. Springer-Verlag, Berlin

Morse JW, Millero FJ, Thurmond V, Brown E, Ostlund HG (1984) The carbonate chemistry of Great Bahama Bank waters: after 18 years another look. J Geophys Res 89:3604–3614

Plummer PS, Joseph PR, Samson PJ (1998) Depositional environments and oil potential of Jurassic/Cretaceous source rocks within the Seychelles microcontinent. Mar Petrol Geol 15:385–401

Purdy EG, Bertram GT (1993) Carbonate concepts from the Maldives, Indian Ocean: Am Assoc Petrol Geol, Stud Geolgy 34:56 pp + 12 plates

Roberts HH, Phipps CV, Effendi LL (1987) *Halimeda* bioherms of the eastern Java Sea. Geology 15:371–374

Roden GI (1987) Effect of seamounts and seamount chains on ocean circulation and thermohaline structure. In: Keating BH, Fryer P, Batiza R, Boehlert GW (eds) Seamounts, Islands, and Atolls. Am Geophys Union, Geophys Monogr 43:335–354

Schlager W, Ginsburg RN (1981) Bahama carbonate platforms—the deep and the past. Mar Geol 44:1–24

Sherbakov VS, Kara VI, Pilipenko AI (1990) Cenozoic structure and evolution of the central part of the Mascarene Plateau, Indian Ocean. Geotectonics 24:174–181

Vecsei A (2000) Database on isolated low-latitude carbonate banks. Facies 43:205–222

Vecsei A (2003) Systematic yet enigmatic depth distribution of the world's modern warm-water carbonate platforms: the 'depth window'. Terra Nova (in press)

Wilson JL (1975) Carbonate Facies in geologic history. Springer, Berlin Heidelberg New York

Wilson PA, Jenkyns HC, Elderfield H, Larson RL (1998) The paradox of drowned carbonate platforms and the origin of Cretaceous Pacific guyots. Nature 392:889–894

Wilson PA, Roberts HH (1992) Carbonate-periplatform sedimentation by density flows: A mechanisms for rapid off-bank and vertical transport of shallow-water fines. Geology 20:713–716