Chapter 7. Calcium Carbonate Production and Contribution to Coastal Sediments

Contributors: Colin D. Woodroffe, Frank R. Hall, John W. Farrell and Peter T. Harris (Lead member)

1. Calcium carbonate production in coastal environments

Biological production of calcium carbonate in the oceans is an important process. Although carbonate is produced in the open ocean (pelagic, see Chapter 5), this chapter concentrates on production in coastal waters (neritic) because this contributes sediment to the coast through skeletal breakdown producing sand and gravel deposits on beaches, across continental shelves, and within reefs. Marine organisms with hard body parts precipitate calcium carbonate as the minerals calcite or aragonite. Corals, molluscs, foraminifera, bryozoans, red algae (for example the algal rims that characterize reef crests on Indo-Pacific reefs) are particularly productive, as well as some species of green algae (especially Halimeda). Upon death, these calcareous organisms break down by physical, chemical, and biological

1.1 Global distribution of carbonate beaches

Beaches are accumulations of sediment on the shoreline. Carbonate organisms, particularly shells that lived in the sand, together with dead shells reworked from shallow marine or adjacent rocky shores, can contribute to beach sediments. Dissolution and re-precipitation of carbonate can cement sediments forming beachrock, or shelly deposits called coquina. On many arid coasts and islands lacking river input of sediment to the coast, biological production of carbonate is the dominant source of sand and gravel. Over geologic time (thousands of years) this biological source of carbonate sediment may have formed beaches that are composed entirely, or nearly entirely of calcium carbonate. Where large rivers discharge sediment to the coast, or along coasts covered in deposits of glacial till deposited during the last ice age, beaches are dominated by sediment derived from terrigenous (derived from continental rocks) sources. Carbonate sediments comprise a smaller proportion of these beach sediments (Pilkey et al., 2011).

Sand blown inland from carbonate beaches forms dunes and these may be extensive and can become lithified into substantial deposits of carbonate eolianite (wind-blown) deposits. Significant deposits of eolianite are found in the Mediterranean, Africa, Australia, and some parts of the Caribbean (for example most of the islands of the Bahamas). The occurrence of carbonate eolianites is therefore a useful proxy for mapping the occurrence of carbonate beaches (Brooke, 2001).

Carbonate beaches may be composed of shells produced by tropical to sub-polar species, so their occurrence is not limited by latitude, although carbonate production on polar shelves has received little attention (Frank et al., 2014). For example, Ritchie and Mather (1984) reported that over 50 beaches in Scotland are composed almost entirely of shelly carbonate sand. There is an increase in carbonate content towards the south along the east coast of Florida (Houston and Dean, 2014). Carbonate beaches, comprising 60-80 per cent carbonate on average, extend for over 6000 km along the temperate southern coast of Australia, derived from organisms that lived in adjacent shallow-marine environments (James et al., 1999; Short, 2006). Calcareous biota have also contributed along much of the western coast of Australia; carbonate contents average 75 per cent, backed by substantial eolianite cliffs composed of similar sediments along this arid coast (Short, 2010). Similar non-tropical carbonate production occurs off the northern coast of New Zealand (Nelson, 1988) and eastern Brazil (Carannante et al., 1988), as well as around the Mediterranean Sea, Gulf of California, north-West Europe, Canada, Japan and around the northern South China Sea (James and Bone, 2011).

On large carbonate banks, biogenic carbonate is supplemented by precipitation of inorganic carbonate, including pellets and grapestone deposits (Scoffin, 1987). Ball (1967) identified marine sand belts, tidal bars, eolian ridges, and platform interior sand blankets comprising carbonate sand bodies present in Florida and the Bahamas. This is also one of the locations where ooids (oolites) form through the concentric precipitation of carbonate on spherical grains. Inorganic precipitation in the Persian Gulf, including the shallow waters of the Trucial Coast, reflects higher water temperature and salinity (Purser, 1973; Brewer and Dyrssen, 1985).

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budgets (Cooper and Pilkey, 2004). Few analyses consider the contribution of biogenic carbonate and none foreshadow the consequences of any reduction in supply of carbonate sand. This is partly because of time lags between production of carbonate and its incorporation into beach deposits, which is poorly constrained in process studies and which is subject to great variability between different coastal settings, ranging from years to centuries (Anderson et al., 2015). In view of uncertainties in rates of sediment supply and transport, probabilistic modeling of shoreline behavior may be a more effective way of simulating possible responses, including potential accretion where sediment supply is sufficient (Cowell et al., 2006).

2.2 Potential impacts of sea-level rise on reef islands

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The impacts of future sea-level rise on individual atolls remain unclear (Donner, 2012). Healthy reef systems may be capable of keeping pace with rates of sea-level rise. There is evidence that reefs have coped with much more rapid rates of rise during postglacial melt of major ice sheets than are occurring now or anticipated this century. Reefs have responded by keeping up, catching up, or in cases of very rapid rise giving up, often to backstep and occupy more landward locations (Neumann and Macintyre, 1985; Woodroffe and Webster, 2014). Geologic evidence suggests that healthy coral reefs have exhibited accretion rates in the Holocene of 3 to 9 mm $year^{-1}$ (e.g., Perry and Smithers, 2011), comparable to projected rates of sea-level rise for the 21st century. However, reef growth is likely to lag behind sea-level rise in many cases resulting in larger waves occurring over the reef flat and affecting the shoreline (Storlazzi et al., 2011; Grady et al., 2013). It is unclear whether these larger waves, and the increased wave run-up that is likely, will erode reef-that are connected to deep-water, oceanic environments (Andersson and Mckenzie, 2012). The seawater chemistry within a reef system can be significantly different from that in the open ocean, perhaps partially offsetting the more extreme effects (Andersson et al., 2013; Andersson and Gledhill, 2013). Corals have the ability to modulate pH at the site of calcification (Trotter et al. 2011; Venn et al. 2011; Falter et al., 2013). Internal pH in both tropical and temperate coral is generally 0.4 to 1.0 units higher than in the ambient seawater, whereas foraminifera exhibit no elevation in internal pH (McCulloch et al., 2012).

Changes in the severity of storms will affect coral reefs; storms erode some island shorelines, but also provide inputs of broken coral to extend other islands (Maragos et al., 1973; Woodroffe, 2008). Alterations in ultra-violet radiation may also have an impact, as UV has been linked to coral bleaching. Furthermore, if reefs are not in a of 0.2 m year^{-1}, and a 10 per cent discount rate [similar to an interest rate] over a 25-year period). In the Maldives, mining of coral for construction has had severe impacts (Brown and Dunne, 1988), resulting in the need for an artificial substitute breakwater around Malé at a construction cost of around 12,000,000 dollars (Moberg and Folke, 1999).

4. Conclusions, Synthesis and Knowledge Gaps

There has been relatively little study of rates of carbonate production, and further research is needed on the supply of biogenic sand and gravel to coastal ecosystems. Most beaches have some calcareous biogenic material within them; carbonate is an important component of the shoreline behind coral-reef systems, with reef islands on atolls entirely composed of skeletal carbonate.

The sediment budgets of these systems need to be better understood; direct observations and monitoring of key variables, such as rates of calcification, would be very useful. Not only is little known about the variability in carbonate production in shallow-marine systems, but their response to changing climate and oceanographic drivers is also poorly understood. In the case of reef systems, bleaching as a result of elevated sea temperatures and reduced calcification as a consequence of ocean acidification seem likely to reduce coral cover and production of skeletal material. Longer-term implications for the sustainability of reefs and supply of sediment to

Ford, M., (2012). Shoreline changes on an urban atoll in the central Pacific Ocean: Majuro Atoll, Marshall Islands. Journal of Coastal Research 28, 11-22.

Ford, M., (2013). Shoreline changes interpreted from multi-temporal aerial photographs and high resolution satellite images: Wotje Atoll, Marshall Islands. Remote Sensing of Environment 135, 130-140.

Frank, T.D., James, N.P., Bone, Y., Malcolm, I., Bobak, L.E., (2014). Late Quaternary carbonate deposition at the bottom of the world. Sedimentary Geology, 306, 1-16.

Fujita K., Osawa, Y., Kayanne, H., Ide, Y., Yamano, H. (2009). Distribution and sediment production of large benthic foraminifers on reef flats of the Majuro Atoll, Marshall Islands. Coral Reefs 28, 29-45.

Glynn, P.W., (1996). Coral reef bleaching: facts, hypotheses and implications. Global Change Biology 2, 495-509.

Gourlay, M.R., Hacker, J.L.F. (1991). Raine Island: coastal processes and sedimentology. CH40/91, Department of Civil Engineering, University of Queensland, Brisbane.

Grady, A.E., Reidenbach, M.A., Moore, L.J., Storlazzi, C.D., Elias, E., (2013). The influence of sea level rise and changes in fringing reef morphology on gradients in alongshore sediment transport. Geophysical Research Letters 40, 3096-3101.

Hamylton, S.M., East, H., (2012). A geospatial appraisal of ecological and geomorphic change on Diego Garcia Atoll, Chagos Islands (British Indian Ocean Territory). Remote Sensing 4, 3444-3461.

Hamylton, S., (2014). Will coral islands maintain their growth over the next century? A deterministic model of sediment availability at Lady Elliot Island, Great Barrier Reef. PLoS ONE-1.23 Td [(R)6(e)1(m)4(o)0.001(m)4(o)1 Tf l003 Tc 0.001 Tw 0.2

Hatziolos, M.E. (2007). Coral reefs under rapid climate change and ocean acidification. Science 318, 1737–1742.

Houston, J.R., Dean, R.G. (2014). Shoreline change on the east coast of Florida. Journal of Coastal Research 30, 647–660.

Hopley, D., Smithers, S.G. and Parnell, K., (2007). Geomorphology of the Great Barrier Reef: development, diversity and change. Cambridge University Press.

James, N.P., Collins, L.B., Bone, Y., Hallock, P., (1999). Subtropical carbonates in a temperate realm: modern sediments on the southwest Australian shelf. Journal of Sedimentary Research 69, 1297–1321.

James, N.P., Bone, Y., (2011). Neritic carbonate sediments in a temperate realm. Springer, Dordrecht.

Kroeker, K.J., Kordas, R.L., Crim, R.N., Singh, G.G. (2010). Meta-analysis reveals negative yet variable effects of ocean acidification on marine organisms. Ecology Letters 13, 1419–1434.

Leon, J.X., Woodroffe, C.D., (2013). Morphological characterisation of reef types in Torres Strait and an assessment of their carbonate production, Marine Geology 338, 64–75.

Maragos, J.E., Baines, G.B.K. and Beveridge, P.J. (1973). Tropical cyclone creates a new land formation on Funafuti atoll. Science 181: 1161–1164.

Mazaris, A.D., Matsinos, G., Pantis, J.D. (2009). Evaluating the impacts of coastal squeeze on sea turtle nesting. Ocean & Coastal Management 52, 139–145.

McCulloch, M., Falter, J.L., Trotter, J., Montagna, P., (2012). Coral resilience to ocean acidification and global warming through pH-up regulation. Nature Climate Change 2, 1–5.

McGranahan, G., Balk, D., Anderson, B., (2007). The rising tide: assessing the risks of climate change and human settlements in low elevation costal zones. Environment and Urbanization 19, 17–37.

McKenzie, E., Woodruff, A., McClennen, C., (2006). 'Economic assessment of the true costs of aggregate mining in Majuro Atoll, Republic of the Marshall Islands'. SOPAC Technical Report 383, p. 74.

Milliman, J.D., and Droxler, A.W. (1995). Calcium carbonate sedimentation in the global ocean: Linkages between the neritic and pelagic environments. Oceanography 8(3):92–94, http://dx.doi.org/10.5670/oceanog.1995.04.

Mimura, N., (1999). Vulnerability of island countries in the South Pacific to sea level rise and climate change. Climate Research 12, 137–143.

Moberg, F. Folke, C., (1999). Ecological goods and services of coral reef ecosystems. Ecological Economics 29, 215–233.

Montaggioni, L.F., Braithwaite, C.J.R., (2009). Quaternary Coral Reef Systems: history, development processes and controlling factors. Elsevier, Amsterdam.

Nelson, C.S., (1988). An introductory perspective on non-

Neumann, A.C., Macintyre, I., (1985). Reef response to sea level rise: keep-up, catch-up or give-up. Proceedings of the 5th International Coral Reef Congress 3, 105-110.

Nicholls, R.J., Wong P.P., Burkett V.R., Codignotto J.O., Hay J.E., McLean R.F., Short, A.D., (2006). Australian beach systems, nature and distribution. Journal of Coastal Research 22, 11-27.

Short, A.D., (2010). Sediment transport around Australia - sources, mechanisms, rates and barrier forms. Journal of Coastal Research 26, 395-402.

Smithers, S.G., Harvey, N., Hopley, D. and Woodroffe, C.D., (2007). Vulnerability of geomorphological features in the Great Barrier Reef to climate change. In Johnson J.E., Marshall, P.A. (Editors) in Climate Change and the Great Barrier Reef. Great Barrier Reef Marine Park Authority and Australian Greenhouse Office, Australia, pp. 667-716.

Spalding, M.D. and Grenfell, A.M., (1997). New estimates of global and regional coral reef areas. Coral Reefs 16, 225-230.

reef island over the past 3000 years indicated by component-specific radiocarbon dating, Geophysical Research Letters, 34, L03602, doi:10.1029/2006GL028875.

Woodroffe, C.D., Webster, J.M., (2014). Coral reefs and sea-level change. Marine Geology doi 10.1016/j.margeo.2013.12.006.

Yates, M.L., Le Cozannet, G., Garcin, M., Salai, E., Walker, P., (2013). Multidecadal atoll shoreline change on Manihi and Manuae, French Polynesia. Journal of Coastal Research 29 870-882.