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ORIGINAL ARTICLE

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Pleistocene facies of Belize barrier and atoll reefs

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Abstract The knowledge of Pleistocene reef facies of Belize, Central America, is largely limited to outcrops in the northernmost part of the country. Otherwise, Pleistocene limestone, which forms the basement of the modern barrier and atoll reefs, occurs in the subsurface and is to a major extent unstudied. Based on the study of 40 m of core from 25 rotary core holes collected on central and southern Belize barrier and on atoll reefs, five Pleistocene reef facies are distinguished in the present study. They include (1) *Acropora palmata* grainstone, (2) *Acropora cervicornis* grainstone, (3) biogenic grainstone, (4) mollusk packstone, and (5) mollusk-foram wackestone. Facies 1 and 3 occur on marginal reefs, facies 2 is found on marginal and lagoonal reefs, and facies 4 and 5 mark lagoon shoals and lagoons, respectively. Most of the facies have equivalents in the Pleistocene of the wider Caribbean and also in the modern of the study area. Diagenetic features include dissolution, caliche formation, laminated blocky low-magnesium-calcite and dogtooth spars. Age data from Pleistocene corals obtained during earlier studies are discussed, and indicate deposition during marine isotope stage 5, between 140–80 ka BP.

Keywords Belize · Pleistocene · Reef · Carbonates

Introduction

Pleistocene reefs are of great geoscientific significance because they do not only provide insight into questions regarding fossil reef facies, reef paleo-ecology, and diagenesis, but they also help to reconstruct sea-level variation and high-resolution paleo-climatological variation in the Quaternary.

Facies of Pleistocene reefs in the wider Caribbean area were the focus of numerous investigations. Studies focused on the Key Largo Limestone of south Florida (e.g., Multer et al. 2002), the Ironshore Formation of Grand Cayman (Hunter and Jones 1996), the Codrington Formation of Barbuda (Wigley 1977), and Pleistocene reefs of Barbados (Mesolella et al. 1970; Dullo 1987), the Netherlands Antilles (De Buisonjé 1974; Pandolfi et al. 1999), Jamaica (Boss and Liddell 1987), or the Bahamas (e.g., Hattin and Warren 1989). Geister (1980) compared a number of studies on Pleistocene Caribbean reefs up to that time, and identified coral zonations in relation to exposure to waves and currents. Comprehensive facies and diagenesis studies of Pleistocene reefs outside the Caribbean were made by Gvirtzman and Friedman (1977), Dullo (1990); and Strasser et al. (1992) along the Red Sea coast. Crame (1980, 1981) and Pandolfi (1996) studied paleo-ecology and community structure of Pleistocene reefs in Kenya and New Guinea, respectively. Jackson (1992) discussed long-term variation of reef community structure based on Pleistocene reef examples. Several of the above studies indicate striking similarities between Pleistocene and Holocene reefs, like, e.g., in Barbados; however, there are also examples with significant dissimilarities indicating differences between Pleistocene and Holocene environmental conditions. Pleistocene reefs of Florida appear to lack *Acropora palmata*-dominated margins, unlike their modern counterparts. Likewise, oolites are present in the Pleistocene reefs of Florida and Belize, however, they do not occur in the Holocene of these areas. The same holds true for Rodrigues (Indian Ocean) where oolite is found in the Pleistocene but not in the modern (Braithwaite 1994).

Reconstructions of sea-level variation based on Pleistocene reef data were made in various locations including the Huon Peninsula, New Guinea (Chappell 1974), the Bahamas (e.g., Neumann and Moore 1975), Bermuda (e.g., Vacher and Hearty 1989), Barbados (e.g., Bard et al. 1990), the Cook Islands (Gray et al. 1992), Mururoa (Camoin et al. 2001) and Mayotte (Zinke et al. 2003). Numerous studies identified marine isotope stage (MIS) 5e reefs, which form either prominent terraces or the foundations of modern reefs (Thurber et al. 1965, Eniwetok; Dodge et al. 1983, Haiti; Woodroffe et al. 1983, Cayman Islands; Marshall

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and Davies 1984, Great Barrier Reef; Battistini et al. 1986, Guadeloupe; Zhu et al. 1993, Abrolhos; Szabo et al. 1994, Hawaii; Israelson and Wohlfarth 1999, the Seychelles; Fruijtier et al. 2000, south Florida). Recent studies have also identified reefs of the youngest Pleistocene, i.e., MIS 5c and 5a in south Florida and Bermuda (e.g., Ludwig et al. 1996; Toscano and Lundberg 1999; Multer et al. 2002). Intensively discussed topics include the rate of rise of sea level during the last interglacial and the question whether or not the highstand during marine isotope stage 5e was interrupted by a short lowstand period (e.g., McCulloch and Esat 2000). Recent studies have also shown that major modern barrier reefs (Australia, Belize, Florida) are, in geological terms, relatively young features, which were only initiated in the late Pleistocene, i.e., either in the long and warm MIS 11 (Multer et al. 2002; Droxler et al. 2003) or not later than MIS 17, the so-called "Mid-Pleistocene Revolution" when high-amplitude, eccentricity-driven sea-level variation set in (International Consortium for Great Barrier Reef Drilling 2001). A new major challenge is the recovery of study of high-resolution climate proxy data stored in coral skeletons. For example, Pleistocene corals from the Huon Peninsula have yielded high-resolution climate proxy data identifying El Niño variation during marine isotope stage 5e (Tudhope et al. 2001).

The 250-km-long Belize Barrier Reef including the atolls Glovers Reef, Lighthouse Reef, and Turneffe Islands, represents the largest modern reef system in the Atlantic Ocean (Fig. 1). In contrast to the Holocene reefs and carbonates of the area, which were studied quite intensively (see reviews by Purdy and Gischler 2003; Purdy et al. 2003), the Pleistocene reefs of Belize received only very little attention. The reason is that these reefs are to a large part only accessible in the subsurface (Purdy 1974). According to boreholes in the southern Belize shelf lagoon (Ginsburg et al. 1995, pp 147–148) and exploration and seismic data (Purdy et al. 2003), Pleistocene reef deposits in Belize are about 80–150 m thick. Tebbutt (1975) investigated the only Pleistocene reef outcrops in northernmost Belize (around Ambergris Cay) and, from windward to leeward, distinguished reef-crest, backreef, shelf, and mudbank facies (Fig. 1). James and Ginsburg (1979, p 165) reported late Pleistocene to Holocene ages (32.3–2.2 years BP) from fore reef walls of the southern barrier reef and Glovers Reef. Gischler et al. (2000) and Gischler and Hudson (2004) dated a total of 13 Pleistocene corals from drill cores of the Belize atolls, from Ambergris Cay, and the central and southern barrier reef as belonging to MIS 5. Macintyre and Toscano (2004) described facies and diagenesis of Pleistocene limestone based on 7.5-m of core from seven shallow cores on the Twin Cays on the central barrier reef platform (Fig. 1). They distinguished a branched *Porites* and a *Thalassia* (sea grass)/sediment facies. It becomes clear from the foregoing that our knowledge about Pleistocene reef facies in Belize is locally limited to only a few areas. This study provides data from core material collected over a wide area offshore Belize, including the central and southern barrier reef and the offshore atolls.

Methods

Twenty-five drill cores were taken on Belize barrier and atoll reefs with a portable rotary drill and wireline system during four expeditions, which took place between October 1995 and July 2002 (Figs. 1 and 2). Individual cores are as long as 20 m, and the total core length is 275 m (Gischler and Hudson 1998, 2004; Gischler and Lomando 2000). The length of Pleistocene sections—the focus of this study—is 40 m. Recovery in the Pleistocene rocks was close to 100%. Cores were cut and subsequently described; selected parts of the core were polished. Thin-sections and SEM were used to identify aspects of diagenesis. Staining of thin-sections with Feigl's solution, alizarine red S, and titan yellow, as well as X-ray diffractometry (Milliman 1974, pp 21–27) were used in order to identify and quantify aragonite, high-magnesium-calcite, low-magnesium-calcite, and possible dolomite.

Facies

Five Pleistocene facies may be distinguished based on macroscopic inspection of the core material (Fig. 2). These include branched coral grainstones (*Acropora palmata* grainstone, *Acropora cervicornis* grainstone), biogenic grainstone, mollusk grainstone, and mollusk-foram wackestone. These facies are described in the following and briefly compared to facies of the two other studies in Belize, which investigated the Pleistocene (Tebbutt 1975; Macintyre and Toscano 2004).

A. palmata grainstone

This facies occurs in barrier reef cores 2 and 5 and in marginal atoll cores 8 and 12 (Fig. 3c, d). Besides slabs of the elkhorn coral *A. palmata*, fragments of the branched staghorn coral *A. cervicornis*, the massive star coral *Montastraea* sp., the brain coral *Diploria* sp., the hydrocoral *Millepora* sp., and crustose coralline algae are common. Interstices are occupied by biogenic grainstone including smaller coral fragments, pieces of the calcareous alga *Halimeda* sp., crustose coralline algae, benthic and encrusting foraminifera including *Homotrema rubrum*, and mollusk fragments. This facies is equivalent to the Pleistocene reef crest facies in northern Belize (Tebbutt 1975).

A. cervicornis grainstone

This branched coral facies is most common. It occurs in most of the atoll cores (1–11) and in barrier reef cores 1, 10, and 11 (Fig. 3a, b). Fragments of the staghorn coral *A. cervicornis* are surrounded by biogenic grainstone with smaller coral fragments, coralline red algae, gastropod and bivalve shells, foraminifera, *Halimeda*, echinoid spines, and the encrusting foram *Carpenteria* sp. Few larger pieces

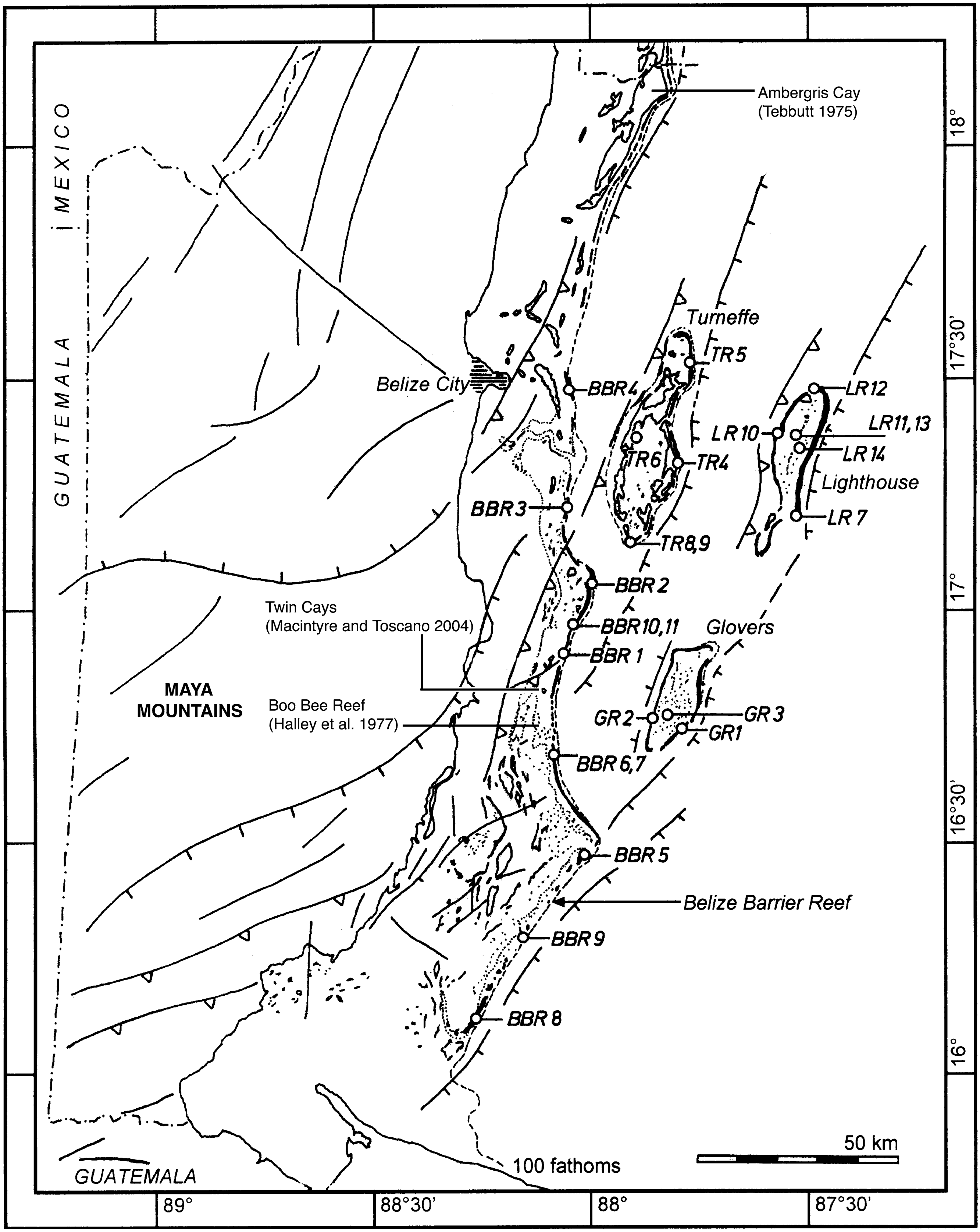


Fig. 1 Location of rotary core holes offshore Belize. The only studies on Pleistocene limestone in Belize were conducted in outcrops around Ambergris Cay (Tebbutt 1975) and in cores from the Twin Cays (Macintyre and Toscano 2004). Some information on Pleistocene limestone facies was also given by Halley et al. (1977) from Boo Bee patch reef

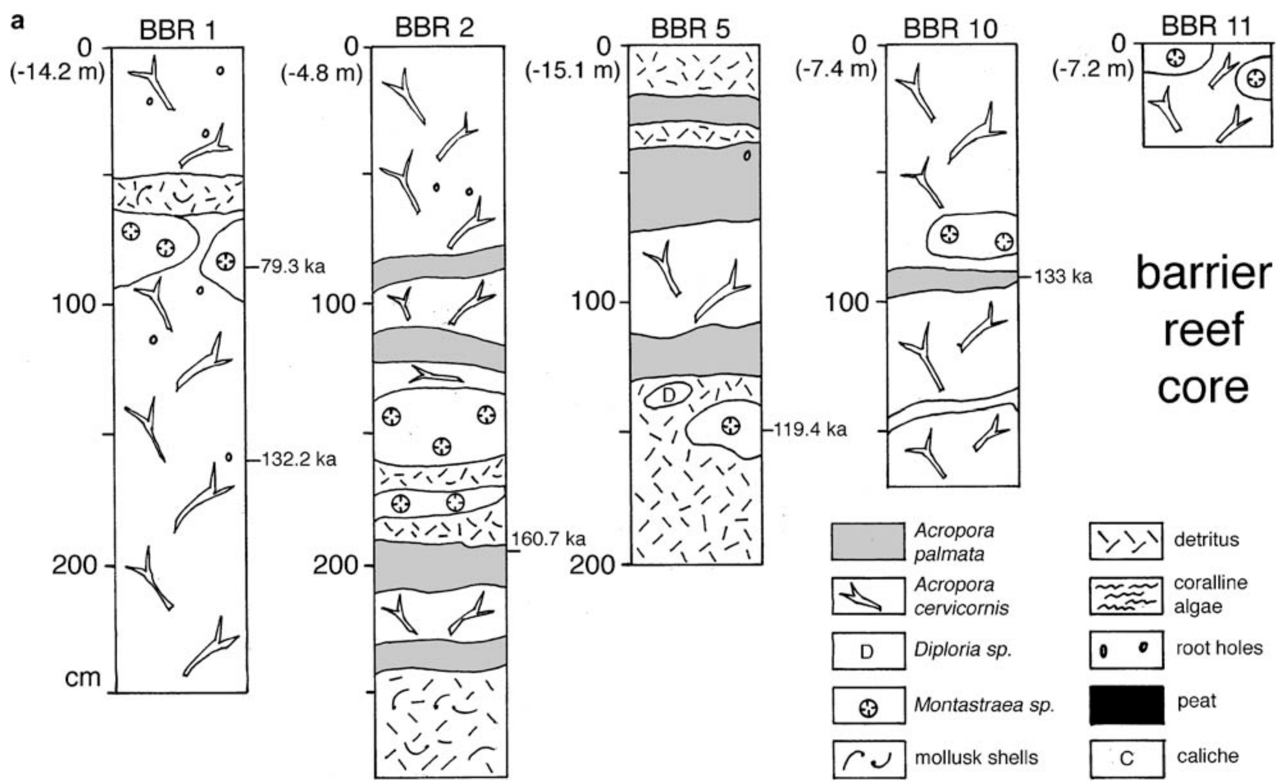


Fig. 2 Core logs. Depth of Pleistocene top below sea level is written in parentheses. Atoll core 6 and barrier reef core 4 are not shown because only loose *Montastraea* coral pieces were obtained. **a** Cores from Belize Barrier Reef. **b** Belize atoll lagoon cores. **c–d** Belize marginal atoll reef cores

of *Montastraea* sp. and the massive starlet coral *Siderastrea siderea* occur. Tebbutt (1975) found the equivalent back reef facies in northern Belize, where it occurs directly leeward of the reef crest facies. This study shows that the facies occurs both in the marginal back reef and on lagoon patch reefs.

Biogenic grainstone

This facies occurs only in the marginal atoll core 5 and is dominated by high amounts of fragments of red coralline algae and coral (Fig. 4a). Mollusk shell pieces and echinoid spines are also found. Biogenic grainstone is very well cemented. No comparable facies were described by Tebbutt (1975). Based on the location of atoll core 5, the facies is interpreted as belonging to the back reef area.

Mollusk packstone

This facies is found only in atoll patch reef core 14 (Fig. 4b). Large mollusk fragments, largely bivalves, occur together with *Halimeda*, red algae, and foraminifera. The rock has relatively high porosity as compared to other Pleistocene facies. The relatively high porosity may be explained by both a high primary porosity in between larger mollusk shells and weaker cementation in the lagoonal setting. The facies may be compared to the inner shelf facies of Tebbutt (1975), which was interpreted as being characteristic of seagrass and carbonate sand areas.

Mollusk-foram wackestone

This fine-grained type is found in atoll interior cores 3, 11, and 13 (Fig. 4c, d). The rock appears chalky and is characterized by large mollusk shells in a matrix of fine-grained carbonate, which contains smaller mollusk fragments, foraminifera, red algae, *Halimeda*, and peloids. In core 3, larger pieces of branched corals (*A. cervicornis*, *Porites* sp.) and the rose coral *Manicina areolata* occur in addition to large mollusk shells. This facies is probably quite similar to the tentative mudbank facies of Tebbutt (1975), the mudstone of Halley et al. (1977), and the *Thalassia*/sediment facies described by Macintyre and Toscano (2004).

Diagenesis

Large parts of the Pleistocene limestone in Belize were diagenetically altered within the meteoric realm. Features characteristic of the meteoric realm include dissolution, caliche formation, laminated crusts, and root holes, recrystallization of grains and marine cement, and precipitation of meteoric cements. Prominent features are observed in the

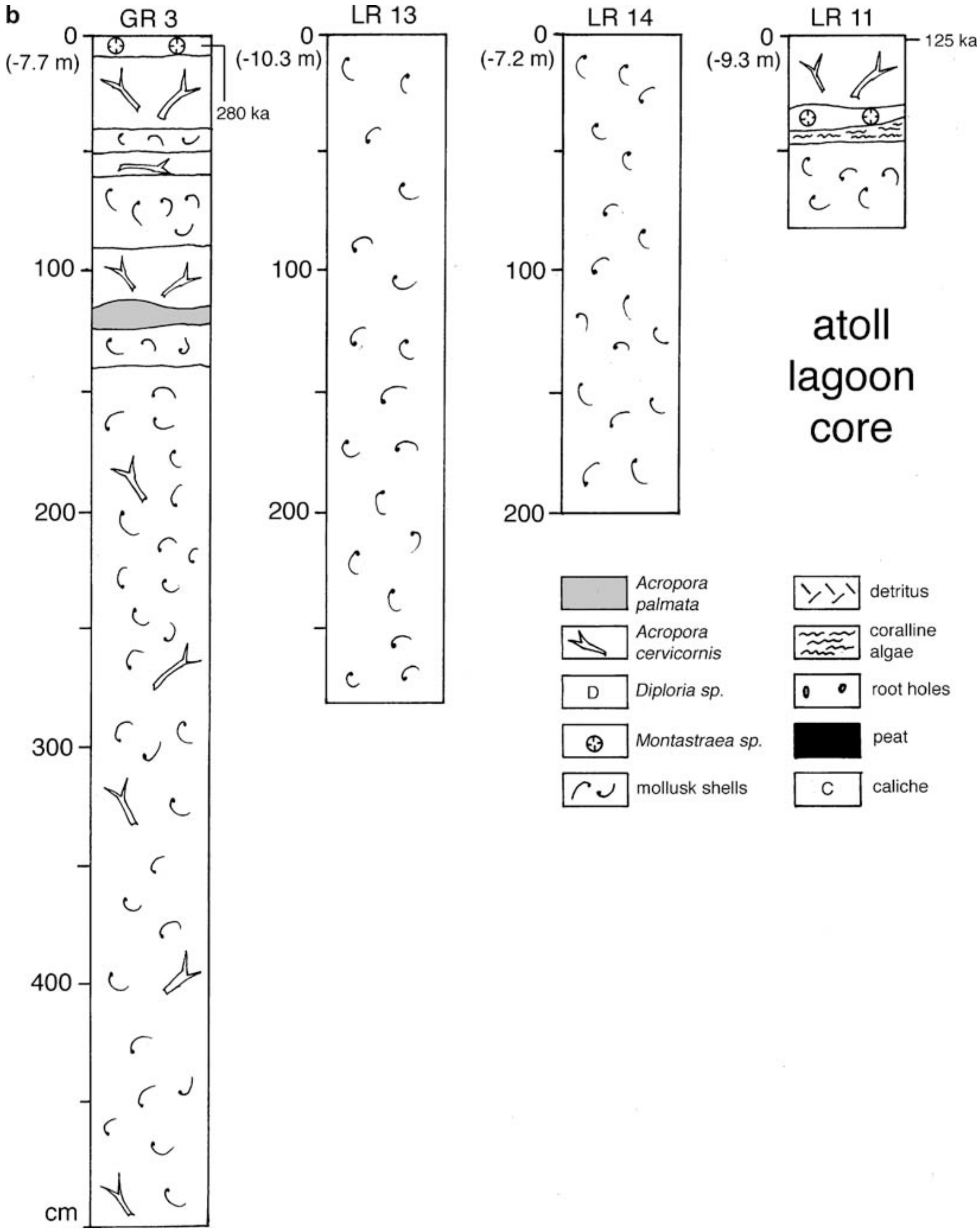


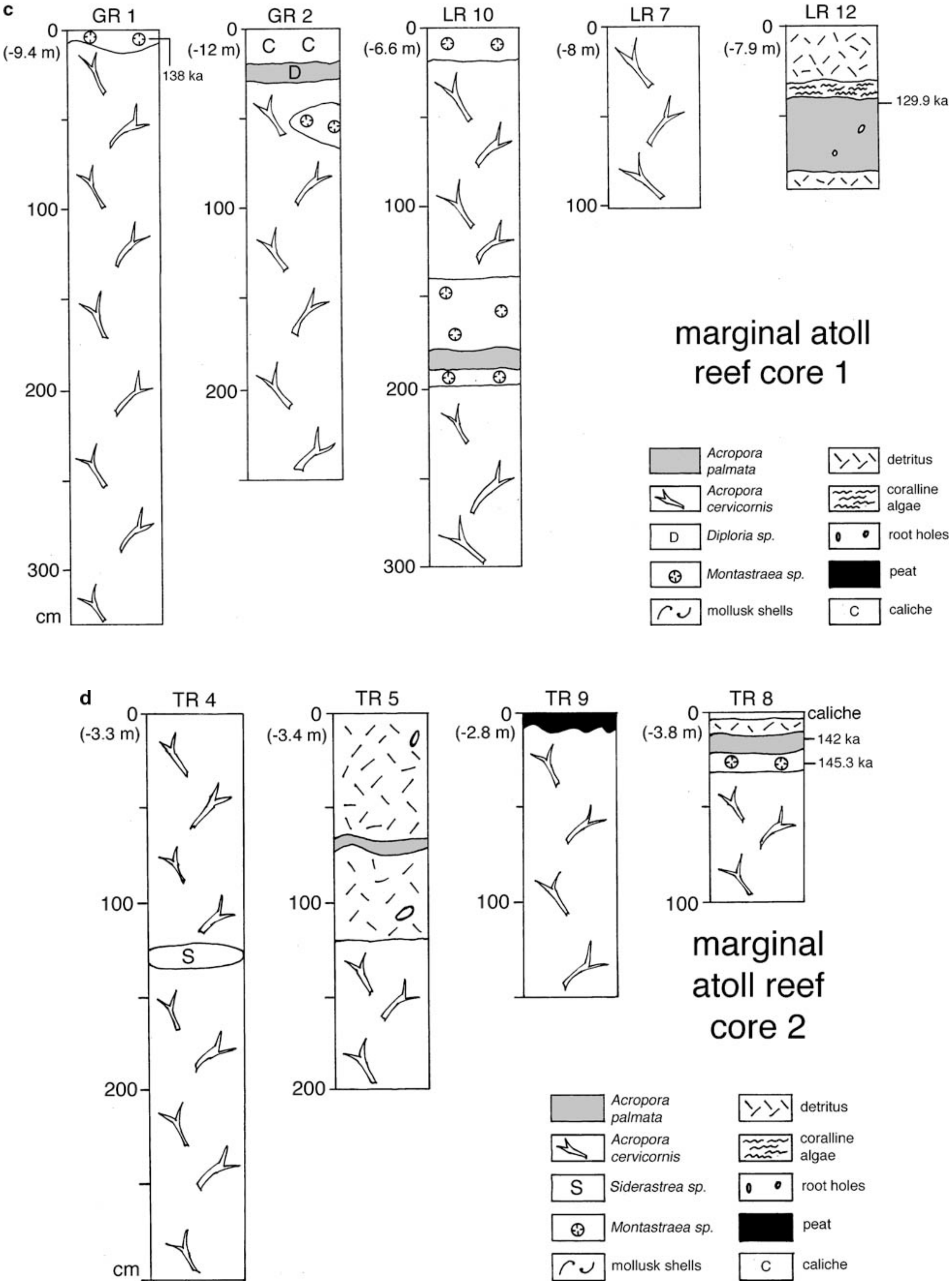
Fig. 2 Continued

macroscopic scale near the Pleistocene-Holocene boundary (Fig. 5).

Mineralogy of Pleistocene facies is predominated by low-magnesium-calcite over aragonite and high-magnesium-calcite. X-ray diffraction of 40 bulk rock samples along atoll and barrier reef cores revealed average relative percentages of 86.5% low-magnesium-calcite, 1.8% high-magnesium-calcite, and 11.7% aragonite. In most cases, there is an increasing trend in low-magnesium-calcite downcore. X-ray diffraction analyses of Pleistocene corals identified two groups of either >80 or <10% relative aragonite content (Gischler et al. 2000; Gischler and Hudson 2004).

Dissolution, root holes, caliche, laminated crusts

Dissolution and root holes are observed in nearly all samples. Dissolution affected carbonate components, matrix, and cements as seen in thin-sections (Figs. 6 and 7a–d). There appear to be no systematic differences in degrees of dissolution between aragonite, high-magnesium-calcite, and low-magnesium-calcite particles. Root holes of up to 1 cm diameter surrounded by brownish, dense, and layered calcium carbonate occur in almost all cores (Fig. 3d). Caliche features are also common (Fig. 5). The thickest caliche horizon may be observed in leeward margin atoll core 2 at the Pleistocene-Holocene boundary (Fig. 5a). It is



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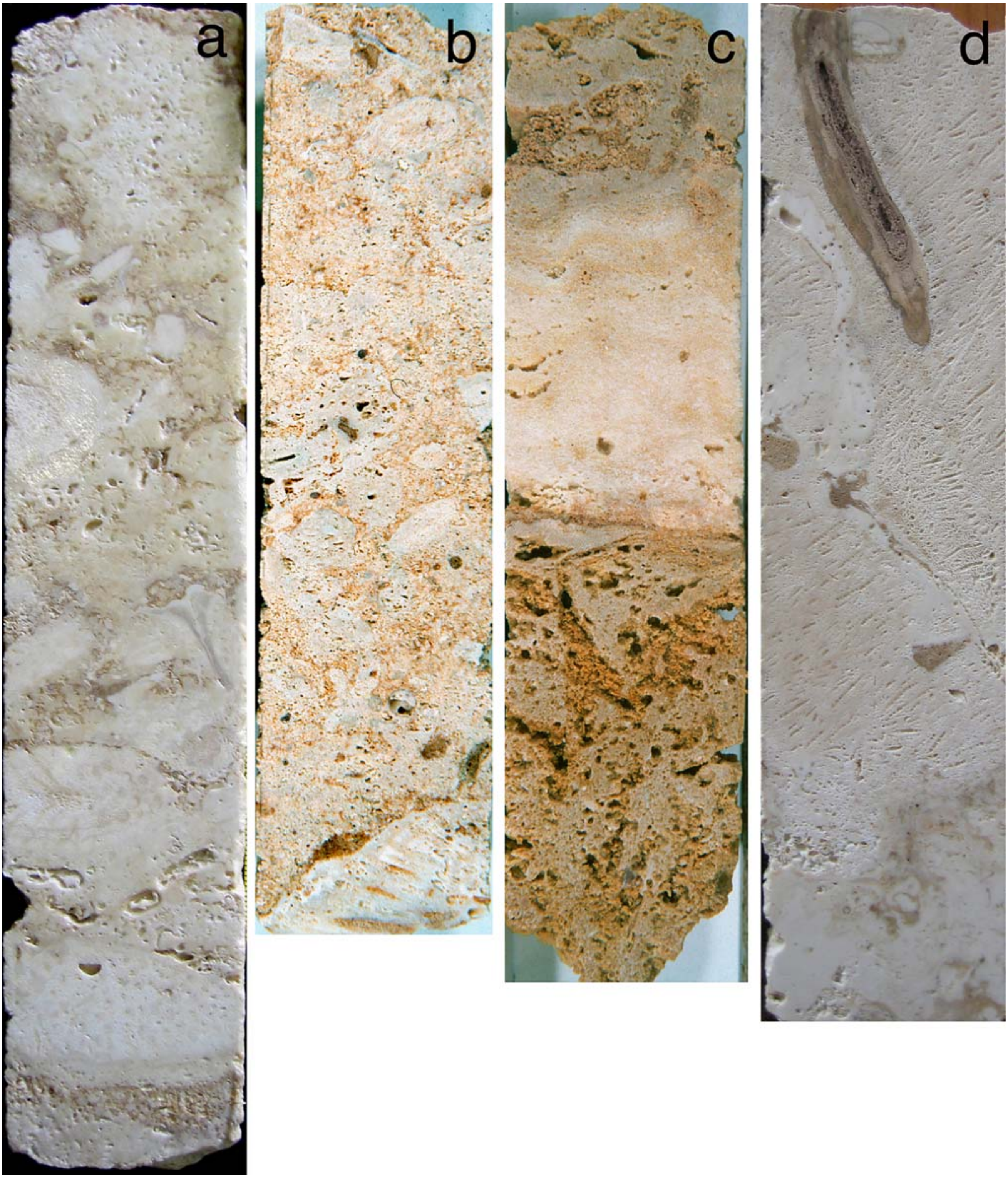


Fig. 3 Pleistocene facies. **a** Branched *A. cervicornis* facies. Core LR7, −8 m. **b** *A. cervicornis* facies. Core BBR 5, −16 m **c** *A. palmata* facies with biogenic detritus. Core BBR 2, −5 m. **d** *A. palmata* facies. Note root hole in coral. Coralline algae occur near base of sample. Core LR12, base of core. Diameter of core is 5 cm

Fig. 4 Pleistocene facies. **a** Biogenic grainstone with abundant coralline algal fragments. Core TR5, − 5 m. **b** Mollusk packstone facies. Core LR14, − 8 m. **c** Mollusk-foram wackestone facies. Core LR13, − 11 m. **d** Mollusk-foram wackestone facies. Core LR13, − 12 m. Diameter of core is 5 cm

colored brown and contains the typical characteristics such as mottled textures, shrinkage cracks, and brecciation (Fig. 7c, d). Laminated crusts of microcrystalline carbonate may be seen in a number of cores near the Pleistocene-Holocene boundary (Figs. 5b, c and 7c).

Meteoric cements, recrystallization

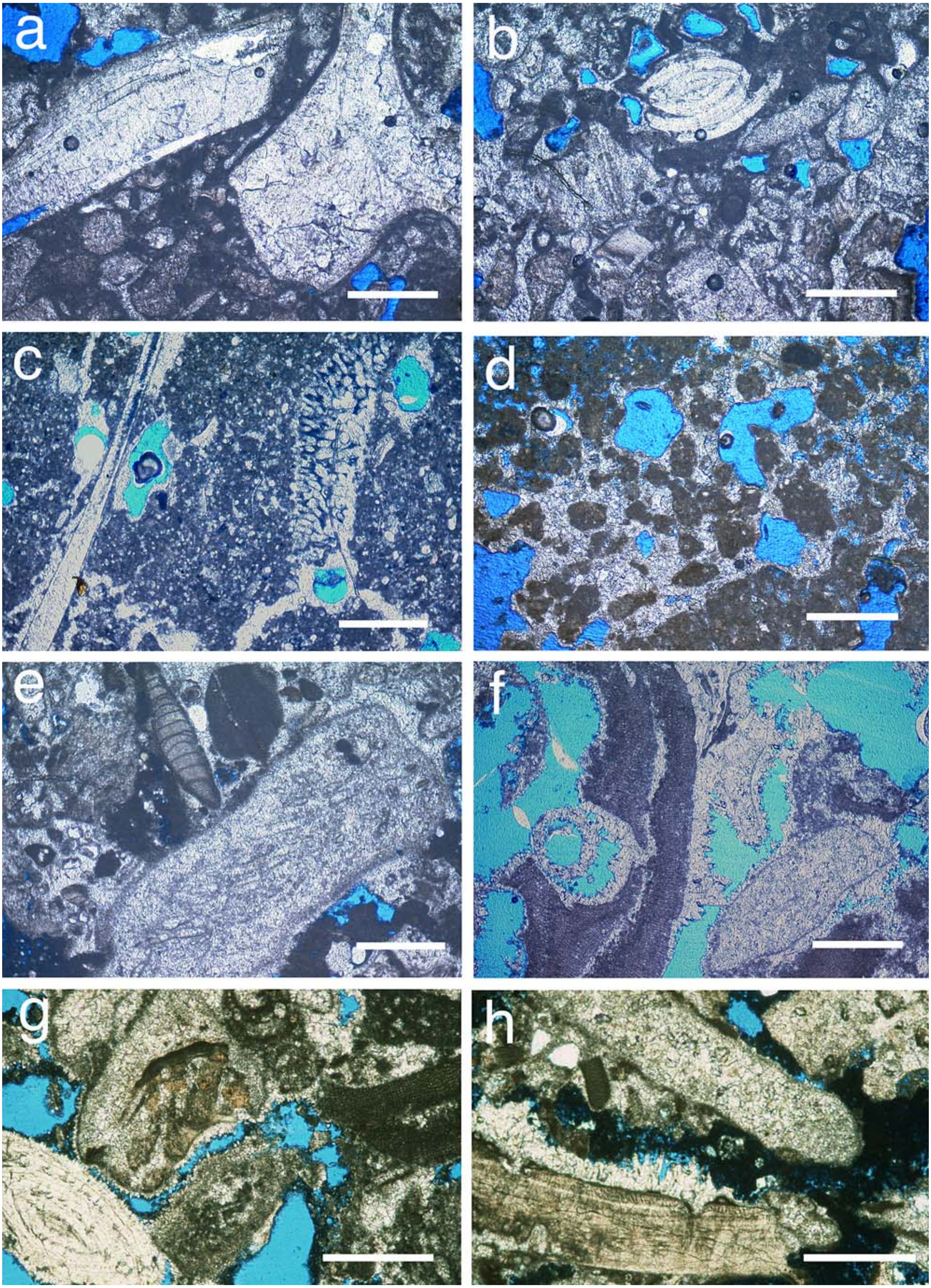
Meteoric cements include blocky low-magnesium-calcite spar with crystals usually ranging from 100–150 μm in size (Figs. 6b, d, e and 7b, c). This cement fills or lines dissolution cavities and it may be found in interparticle and intraparticle porosity like coral skeletons. Dogtooth (scalenohedral) spar is less common and also fills and lines dissolution holes (Fig. 6f–h). Two kinds of recrystallization may be observed. First, large blocky spar described above is observed to replace primary mollusk shell or coral skeleton textures or parts of particles (Figs. 6a–c, e, f, h and 7a, c). Second, small blocky spar ("microspar") with crystal sizes of only 30–50 μm, replaces components, matrix, and older cement (Fig. 7e, f). This feature was observed only at the base of windward atoll cores 1, 5, and 7. The resulting rock appears grey at first glance as opposed to the typical buff color of both Pleistocene and Holocene limestone in the core. Like with dissolution, no systematic differences were detected with regard to recrystallization of aragonite, high-magnesium-calcite, or low-magnesium-calcite particles.

Discussion

Comparison with other studies on Pleistocene Caribbean reefs

The *A. palmata* and *A. cervicornis* grainstones as well as the biogenic grainstone represent marginal facies just like the reef crest and back reef facies described by Tebbutt (1975) from the Pleistocene outcrops of northern Belize (Fig. 1). These facies also have equivalents in the Holocene of Belize (James et al. 1976; Gischler and Lomando 1999). In the wider Caribbean, *A. palmata*-dominated Pleistocene reef margins with *A. cervicornis* in the back reef areas were also described, e.g., from Barbados (Mesolella et al. 1970), the Netherlands Antilles (De Buisonjé 1974), or the youngest Pleistocene (MIS 5c, a) reefs of south Florida (Multer et al. 2002). The occurrence of the branched *A. cervicornis* grainstone facies in atoll interiors (core 3) also has Holocene counterparts as seen in the lagoon of Glovers Reef (Wallace and Schafersman 1977). The occurrence of *A. cervicornis* in the Lighthouse Reef lagoon (core 11) has no modern counterpart because patch reefs are dominated by *Montastraea* sp. and *A. palmata* (Gischler and Lomando 1999). In the northern Belize Pleistocene, Tebbutt (1975) reports on the occurrence of *A. cervicornis* in the outer shelf and patch reefs facies. Pleistocene *A. cervicornis*-dominated patch reefs facies can be observed only rarely in

Fig. 5 Caliche-type deposits near Pleistocene-Holocene boundary. **a** Core GR2, Pleistocene-Holocene boundary is marked by 18 cm-thick caliche horizon. Brain coral *below caliche* is Pleistocene; brain coral *on top of caliche* is 7.37 ka BP. **b** Barrier reef core 2. Brown laminated crust near Pleistocene-Holocene boundary. **c** Near base of barrier reef core 4: laminated crust near the Pleistocene-Holocene boundary. Diameter of core is 5 cm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the wider Caribbean. An example includes the Key Largo Limestone of Florida (Multer et al. 2002). In the Pleistocene patch reefs of the Ironshore Fm. of Grand Cayman, *A. cervicornis* is virtually absent (Hunter and Jones 1996). Be that as it may, several studies have shown that the replacement of *A. cervicornis* by other taxa may proceed rather rapidly and frequently such as on the Belize barrier reef and in offshore atoll reef lagoons (McClanahan et al. 1999). The study by Davis (1982) on the Dry Tortugas, Florida, has shown that *A. cervicornis* was probably replaced several times during the late nineteenth and most of the twentieth centuries. The mollusk packstone recovered from atoll interior core 14 may be compared to Tebbutt's (1975) inner shelf facies, which is rich in large bivalve shells. The facies was probably deposited on a shallower bank, which in the Holocene became the foundation of a lagoonal coral patch reef. Similar facies are again found in the Pleistocene Key Largo Limestone of Florida, especially in Florida Bay (Multer et al. 2002). The mollusk-foram wackestone recovered from atoll interior cores 3, 11, and 13 again has a modern counterpart in Belize (Gischler and Lomando 1999). It is presumably similar to the Pleistocene mudbank facies of Tebbutt (1975), the mudstone of Halley et al. (1977), and the Pleistocene fine-grained facies described by Macintyre and Toscano (2004). The Key Largo Limestone of Florida, further afield, also includes this low depositional energy, lagoonal facies type, especially in the lower Florida Keys and in Florida Bay (Multer et al. 2002). The spatial occurrence of Pleistocene facies in Belize is shown schematically in Fig. 8.

Two controversial topics refer to the abundance of fragments of the coral *A. palmata* and chips of the calcareous alga *Halimeda*. The presence and absence of *A. palmata* has often been used as an indicator of marginal reefs. For example, in the Key Largo Limestone of Florida, the absence of this coral triggered a longstanding debate regarding the origin of this Pleistocene shelf margin (Stanley 1966; Hoffmeister and Multer 1968; Harrison and Coniglio 1985; Multer et al. 2002). Multer et al. (2002) showed that *A. palmata* is absent to missing in MIS 5e and older sequences where a ramp-type morphology of the margin existed. Shelf margin reefs with *A. palmata* presumably only came into existence within the latest Pleistocene MIS 5c and MIS 5a. The reasons behind this change are still enigmatic. In this study, *A. palmata* was not observed to be very abundant; however, this was probably the consequence of the fact that only 1–2 cores were taken at each location and that the *A. palmata* zone is rather narrow. On Ambergris Cay, northern Belize, modern and Pleistocene *A. palmata* zones appear to be directly superimposed (Tebbutt 1975). At several locations studied here, Holocene and Pleistocene *A. palmata* zones are apparently not located on top of each other. Marginal cores on the atolls and the barrier reef were taken on the modern reef crest proper, which is characterized by abundant *A. palmata* rubble right behind the live *A. palmata* zone.

The abundance of the alga *Halimeda* in various Pleistocene Caribbean reefs was used by Pandolfi et al. (1999) to distinguish between low-*Halimeda* fringing oceanic and high-*Halimeda* barrier or bank barrier reefs. This interpretation should be modified based on observations in Florida and Belize, which do not fit this model. *Halimeda* is present in Pleistocene Belize core material; however, it is much more abundant in the Holocene of the same area. In the Florida Key Largo Limestone, *Halimeda* is abundant in the late Pleistocene MIS 5 deposits; although, it is strikingly rare in the older Pleistocene sequences of the same formation. Finally, modern Caribbean settings with high abundances of *Halimeda* are apparently not barrier or bank barrier reefs, but restricted lagoons like, e.g., in Turneffe Islands (Gischler and Lomando 1999) or in the Marquesas Keys (Hudson 1985).

◀ **Fig. 6** Thin-section photographs of Pleistocene facies. *Scale bar* is 0.5 mm. **a** Recrystallized mollusk shells in a packstone matrix. Note dissolution holes. Core GR1, −10 m. **b** Biogenic packstone-grainstone with blocky cement and dissolution features. Core GR1, −10 m. **c** Partly recrystallized mollusk and *Halimeda* fragments in a packstone matrix. Core GR3, −10 m. **d** Foraminfera and other biogenic grains cemented by blocky spar. Note dissolution features. Core GR3, −10 m. **e** Fragments of coralline algae, forams, and *Halimeda* (recrystallized) cemented by blocky spar. Core TR5, −4 m. **f** Coralline algal fragment and recrystallized particle with micrite envelope cemented by dogtooth spar. Note dissolution. Core TR5, −6 m. **g** Fragments of forams, coralline algae and *Halimeda* with blocky spar and small scalenohedral spar. Core TR5, −6 m. **h** Texturally intact and recrystallized bivalve shell with dogtooth spar. Core LR7, −8 m

Pleistocene age data from Belize

A total of 13 Pleistocene corals were dated using the U/Th-method during earlier studies on the atolls and northern Belize (Gischler et al. 2000) and on the barrier reef (Gischler and Hudson 2004). These data are the only existing Pleistocene ages from Belize.

Atoll and northern Belize data

From the seven dates from the atolls and northern Belize, two were reliable and five were only moderately reliable because of elevated ratios of $^{234}U/^{238}U$. The majority of age dates from the atolls and northern Belize indicate a deposition during MIS 5e, ca. 120–140 ka BP. One date from an atoll lagoon patch reef remained enigmatic with an age of 280 ka BP, which would put the sample into MIS 8 with a much-too-low sea level. Diagenetic loss of uranium probably shifted the date to an older age. Missing deposits of MIS 5 and 7 under Holocene atoll lagoonal deposits, however, were also reported by Buigues (1997) from, for example, Mururoa Atoll in the Pacific.

Macintyre and Toscano (2004) considered the Pleistocene dates of Gischler et al. (2000) from Belize atolls and Ambergris Cay as being "problematic and unreliable". Whereas dating of Pleistocene corals, which potentially experienced meteoric diagenesis, is always problematic, the statement that our dates were unreliable is clearly unacceptable. Using the elevation of up to 9 m below

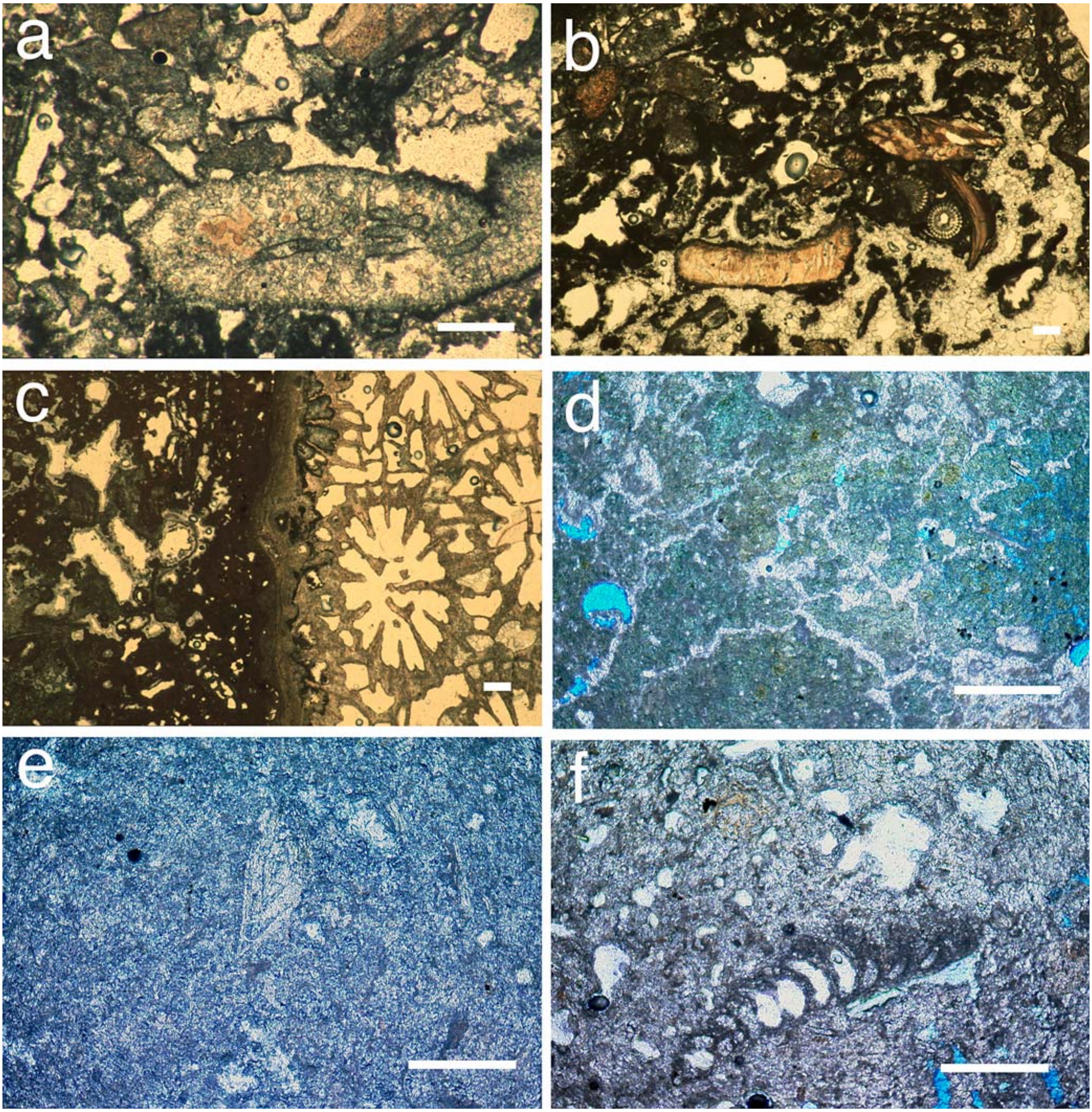

Fig. 7 Thin-section photographs of Pleistocene facies. *Scale bar* is 0.5 mm. **a** Recrystallized *Halimeda* and other particles with meniscus-type cementation. Core BBR 1, −16.5 m. **b** Mollusk, echinoderm, and other fragments. Note that holes are lined by blocky spar. Core BBR 5, −16 m. **c** Recrystallized *Montastraea* coral (*right*) and caliche with dissolution holes lined by blocky spar (*left*). Core BBR 2, −5 m. **d** Caliche with mottled texture and cracking. Core GR2, −12 m. **e–f** Almost entirely recrystallized limestone, Base of core GR1

present sea level, these authors also explained that our dated Pleistocene corals would best correlate to MIS 5c and 5a, ca. 100–80 ka BP when sea-level presumably was several meters lower, and not to MIS 5e, ca. 125 ka BP when sea level was several meters higher as compared to today. This conclusion is again unacceptable because reliable and moderately reliable dates indicate deposition during MIS 5e (140–120 ka BP). Also, dissolution of Pleistocene limestone during Pleistocene sea-level lowstands and differential subsidence was identified to account for the north-to-south decrease of the Pleistocene elevation in Belize (Purdy 1974; Purdy et al. 2003; Gischler and Hudson 2004). Another problem of Macintyre and Toscano's (2004) re-interpretation are controversial Caribbean MIS 5a sea-level data between −18 to +1 m (see discussion, e.g., in Toscano and Lundberg 1999).

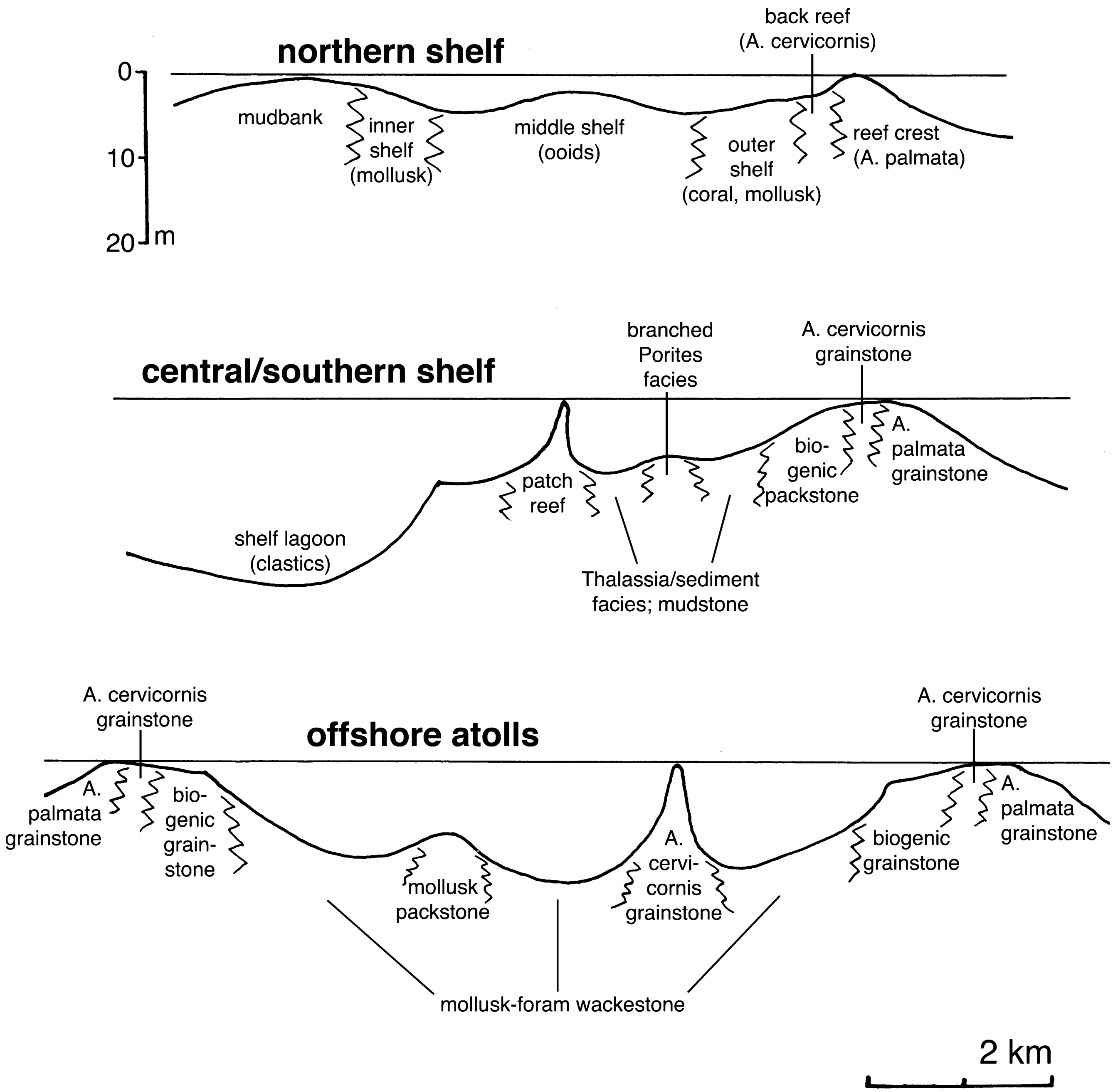

Fig. 8 Spatial occurrence of Pleistocene reef facies in Belize (schematically, not to scale). Northern Belize section after Tebbutt (1975). Occurrence of branched *Porites* facies and *Thalassia*/sediment facies on barrier reef section after Macintyre and Toscano (2004). Occurrence of mudstone facies and patch reef (antecedent high with coral) on barrier reef section after Halley et al. (1977). Information on occurrence of Pleistocene terrigenous clastics in southern shelf lagoon from Purdy (1974)

Barrier reef data

All Pleistocene age dates from the Belize Barrier Reef (Gischler and Hudson 2004) were unreliable because of the influence of meteoric diagenesis including aragonite dissolution and loss of uranium. Even so, the obtained ages may still be used as maximum ages for the corals investigated. These dates range from 160–80 ka BP and indicate deposition during isotope stage 5. Based on these barrier reef dates, deposition during sea-level highstands of MIS 5c and 5a is worth discussing. As mentioned above, studies in south Florida have shown that some Holocene reefs overlie latest Pleistocene reefs of MIS 5c and 5a (Toscano and Lundberg 1999; Multer et al. 2002). These youngest Pleistocene reefs form wedge-shaped deposits between seaward-dipping MIS 5e and Holocene reefs (Multer et al. 2002) as well as outlier reefs (Lidz et al. 1991) at the shelf margin.

Conclusions

– Five Pleistocene facies are delineated from cores taken on Belize barrier and atolls reefs. These are *A. palmata* and *A. cervicornis* grainstone, biogenic grainstone, mollusk packstone, and mollusk-foram wackestone.
– These facies include marginal and lagoonal facies, which have equivalents in the Pleistocene of the Caribbean and the Holocene of Belize.
– Meteoric diagenesis is widespread in Pleistocene limestone of Belize; however, some aragonitic corals are preserved, and may be used for age dating.
– U/Th dates of these Pleistocene corals indicate deposition between 140–80 ka BP, during marine isotope stage 5.

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