Isolated carbonate platforms of Belize, Central America: sedimentary facies, late Quaternary history and controlling factors

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Abstract: The closely spaced, isolated carbonate platforms of Glovers Reef, Lighthouse Reef and Turneffe Islands (Belize) differ significantly with regard to geomorphology and distribution of sedimentary facies, especially in platform interiors. Glovers Reef has a deep (18 m) lagoon with 860 more or less randomly distributed patch reefs. The interior of Lighthouse Reef is characterized by a linear trend of hundreds of coalescing patch reefs that separate a deeper (8 m) eastern and a shallower (3 m) western lagoon. Within both Glovers and Lighthouse Reefs, non-skeletal (peloidal) wackestone and packstone are found in shallow (<5 m) water depths. Deeper lagoon parts are characterized by mollusc-foram wackestones. Facies belts are circular in Glovers Reef, as opposed to linear in Lighthouse Reef. The Turneffe Islands platform has up to 8 m deep interior lagoons that are surrounded by large land/mangrove areas. These lagoons have restricted circulation, are devoid of coral patch reefs, and are dominated by organic-rich wackestone.

These differences are largely a consequence of variations in antecedent topography and in exposure to waves and currents from platform to platform. Differences in elevation and relief of the Pleistocene basement are most likely controlled by differential subsidence and latitudinal variation in karstification. Differences in exposure to waves and currents are created as the Turneffe Islands platform is in a leeward position, protected from the open Caribbean Sea by Lighthouse Reef to the east. Variation in Pleistocene elevation caused the platforms to flood successively at different rates during Holocene sea-level rise. However, all reefs investigated kept pace with the rising Holocene sea level. Sediment is now largely bypassing the margins and filling in platform interior lagoons.

These examples indicate how local attributes of antecedent topography and exposure to waves and currents can be at least as important as globally operating factors such as sea-level fluctuations. This observation should be kept in mind when interpreting palaeo-relationships in the geologic record.

The isolated carbonate platforms of Glovers Reef, Lighthouse Reef and the Turneffe Islands are part of the 600 km long reef system offshore from Belize and the eastern Yucatan Peninsula (Fig. 1). This reef system consists of the Belize Barrier Reef, the fringing reefs that can be followed from Reef Point on Ambergris Cay to Cancun, along with a number of isolated carbonate platforms. From north to south these are: Arrowsmith Bank, a drowned platform; the reef-fringed Tertiary-Pleistocene island of Cozumel; and the reef-fringed carbonate platforms Banco Chinchorro, the Turneffe Islands, Lighthouse Reef and Glovers Reef.

A series of NNE-trending tilted fault-blocks characterizes the passive margin of Belize and the eastern Yucatan, forming the basement of the reef system (Dillon & Vedder 1973). Neotectonic activity on the fault-blocks is presumably caused by the nearby lithospheric plate boundary between the North American and Caribbean plates. Deep boreholes on the Turneffe Islands and Glovers Reef penetrated 1030 and 560 m respectively, of Tertiary and younger reefal and shallow-water carbonates, before reaching Late Cretaceous to Eocene age siliciclastics (Fig. 2).

Even though Glovers Reef, Lighthouse Reef and the Turneffe Islands have a common geological framework, including the same Holocene sea-level rise, they are considerably different with regard to geomorphology and sedimentary facies. In this paper, we consider the controlling factors of Holocene reef and platform development, including antecedent topography, exposure to waves and currents, and sea level.

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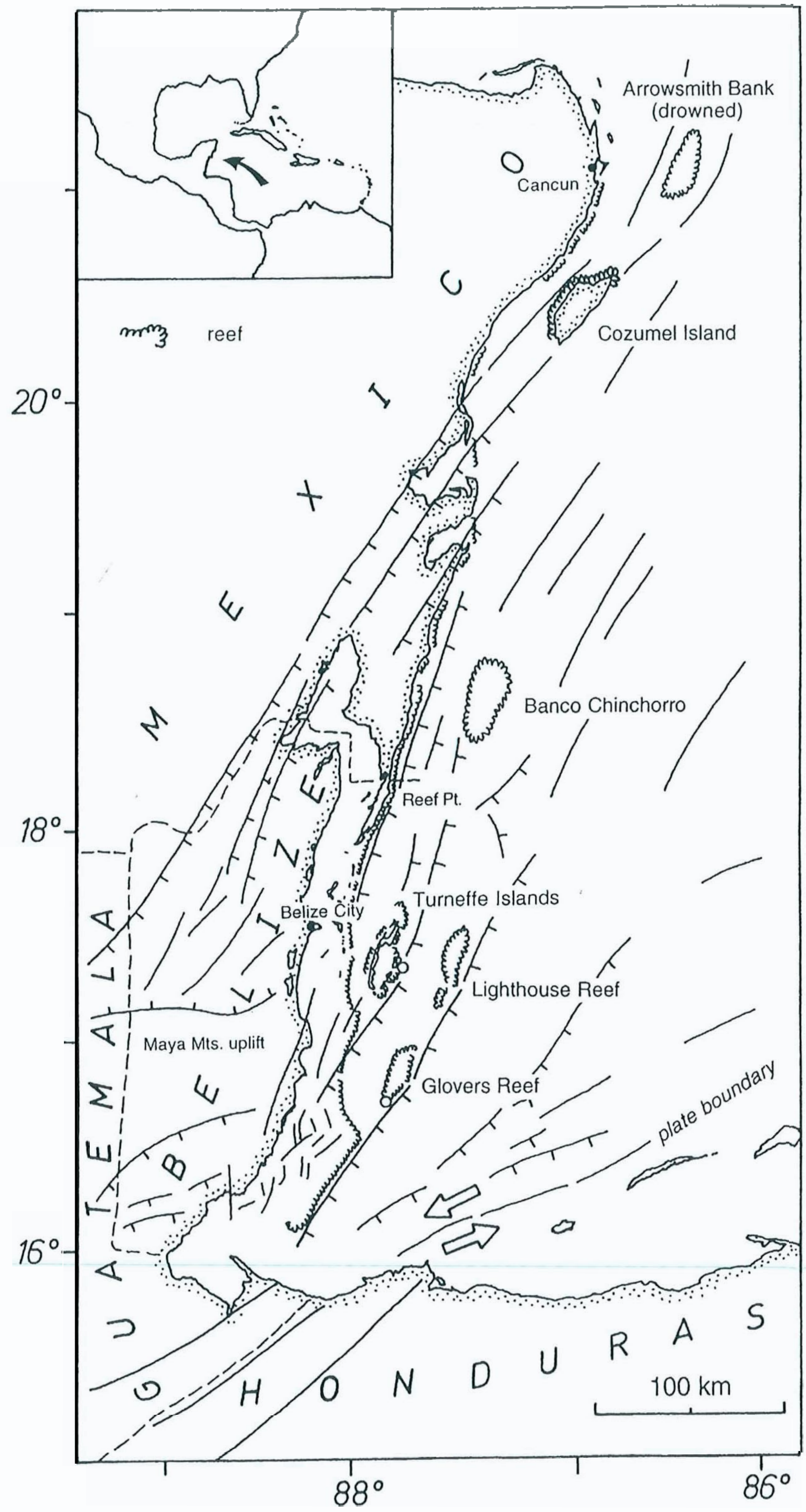

Fig. 1. Geological–tectonic setting of isolated carbonate platforms of Belize (after Dillon & Vedder *1973;* Purdy 1974*b*; Case & Holcombe *1980)*. Location of deep boreholes on Glovers Reef and the Turneffe Islands are marked by open circles (after Deal *1983)*.

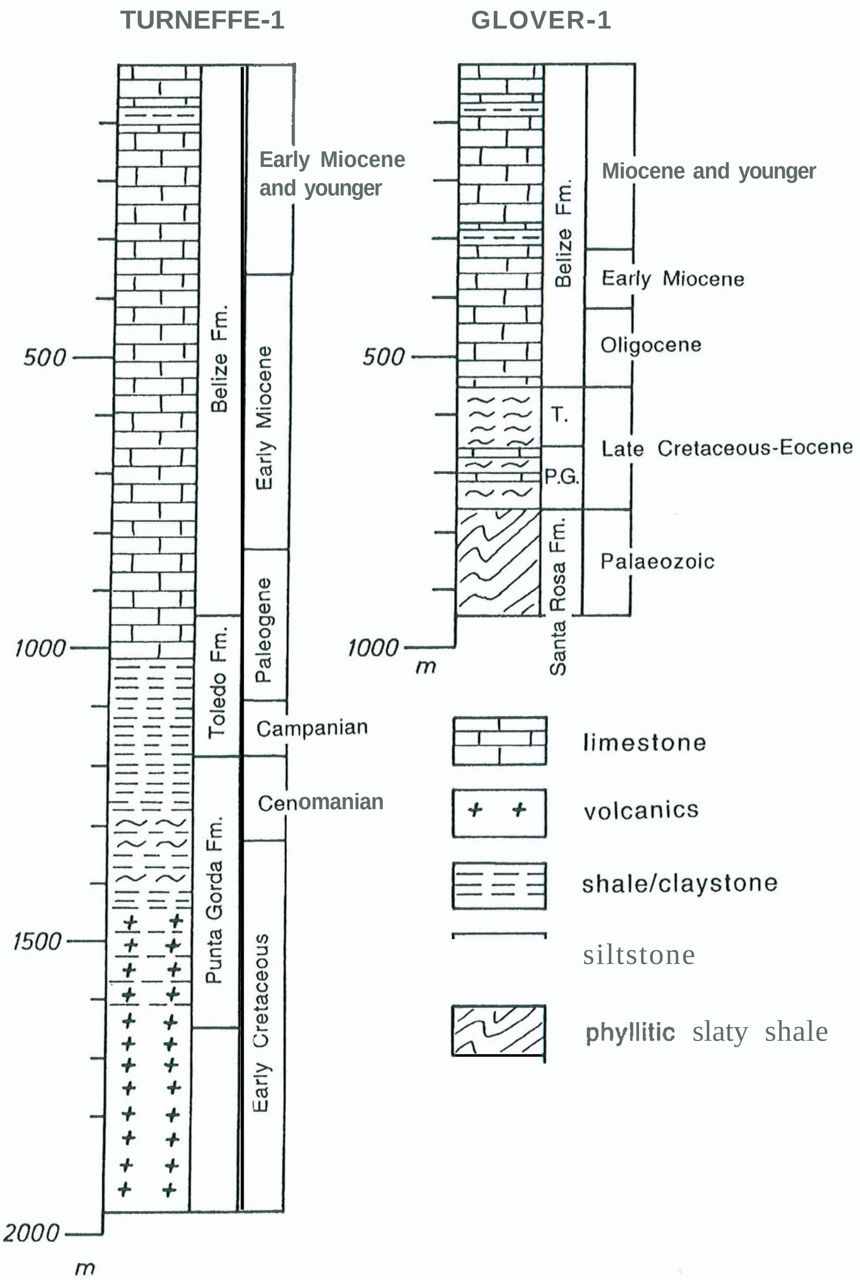

Fig. 2. Description of deep boreholes on Turneffe Islands and Glovers Reef (compiled from unpublished data of Royal Dutch Shell, The Hague).

Geomorphology

The carbonate platforms offshore from Belize are truly isolated in that they are surrounded by deep water (Fig. 3). Surface-breaking reef margins enclose lagoons that identify the platforms as atolls (Stoddart 1962). James et *al.* (1976) and James & Ginsburg (1979) described marginal reefs of one of the platforms in detail. Major differences among the three platforms are found in platform interiors, as described below.

Glovers Reef covers 260 km^2 with only 0.2% of land in the form of small, marginal sand–shingle cays. The lagoon is up to 18 m deep, has open circulation, and there are over 850 patch reefs of coral (Wallace & Schafersman 1977) some of which form linear trends. Lighthouse Reef has an area of 200 km^2 with 2990 of land: there are three marginal, small sand–shingle cays and two large mangrove–sand cays in the platform interior. The well circulated lagoon is divided into two halves by a linear

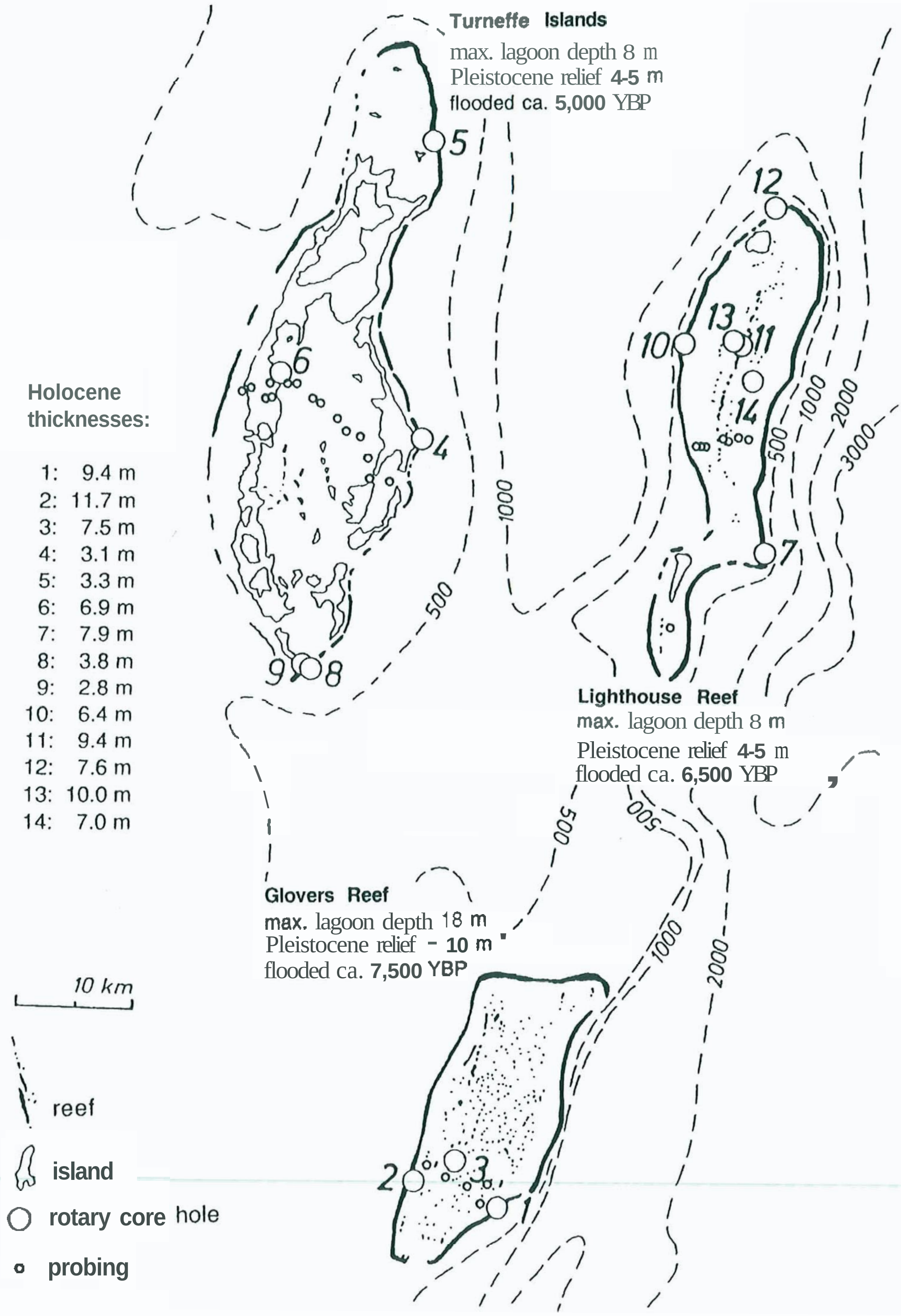

Fig. 3. Maps of isolated carbonate platforms offshore from Belize. Water depth between Turneffe Islands and Belize Barrier Reef is 250 m; that between Glovers Reef and the barrier reef amounts to over 400 m. Localities of rotary core holes are indicated by large circles (after Gischler & Hudson 1998; Gischler & Lomando 1999). Holes 1, 2, 4, 5, 7, 8, 10 and 12 were drilled into marginal reefs, holes 3, 11, 13 and 14 into lagoon patch reefs. Hole 6 was drilled into the lagoon floor, hole 9 on an island. Localities of probing with a 4 m long aluminium rod are indicated by small circles. The results of probing are included in the construction of cross-sections shown in Fig. 6.

trend of coalescing coral patch reefs. The eastern lagoon reaches 8 m in depth whereas the western lagoon is only 3 m deep. The Turneffe Islands platform covers 525 km^2 with 22% of land. The land area comprises numerous small sand cays on the windward margin. Large mangrove cays and mangrove–sand cays enclose two large restricted lagoons that have rare coral patch reefs. Lagoon depths reach a maximum of 8 m. The northernmost part of the platform has open circulation with abundant coral patch reefs.

Surface sediments

Sediments of the platform margins are skeletal (coral–red alga–Halimeda) grainstones (Fig. 4). In contrast, major sediment differences occur in the platform interiors: Glovers Reef has a circular facies pattern with mixed peloidal–skeletal wackestones and packstones in shallow lagoon parts and skeletal (mollusc–foram–Halimeda) wackestones in deeper (>5 m) areas. Similar facies are found in Lighthouse Reef, but their distribution is linear. Mixed peloidal–skeletal compositions are found in the western lagoon, whereas mollusc–foram compositions occur in the eastern lagoon. Larger areas are represented by grainstone textures compared to Glovers Reef. Restricted lagoons in the Turneffe Islands platform are covered by Halimeda wackestones, rich in organic matter. Total organic carbon values average 5.6% with maximum values of 15% (Gischler & Lomando 1999).

Nine surface sediment samples from Glovers Reef were radiometrically dated (Table 1). Sediment from the deep forereef is modern. Sediment samples from the deep interior lagoon are not older than 300 years, but sediment from the marginal reef and backreef areas are significantly older with ages approximating 600–700 and 1000 years BP, respectively. These ages are comparable to radiometric ages of beachrock in Belize (Table 1), the material of which is largely derived from marginal reef areas (Gischler & Lomando 1997). These limited data are nonetheless consistent in indicating not only the similarity of measured ages from similar reef environments but also the clear differences between sediment ages from different environments. This is the case even though the dated sediment represents a mixture of ages from younger and older constituent grains.

Subsurface data

The Holocene thickness of marginal reefs is highest on Glovers Reef and lowest on the

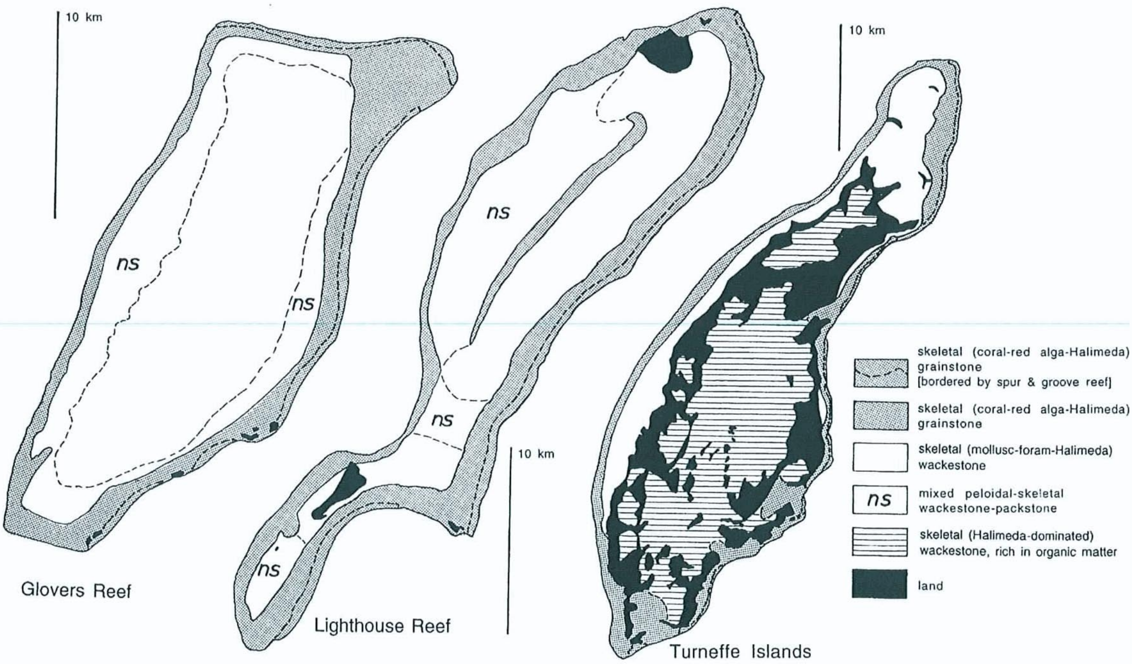

Fig. 4. Sedimentary facies of isolated carbonate platforms (after Gischler 199%Gischler & Lomando 1999). Maps are based on quantitative textural and compositional analysis of 345 surface sediment samples. Note scale differences for each of the platforms.

Table 1. *Radiometric ages of sediment samples from Glovers Reef*

Sample environment	Depth (m)	Conventional age (years BP)	2-sigma range
Sediment sample			
G 150, windward reef	0.5	920 ± 70	AD 1315–1515
G 101, leeward reef	1	850 ± 60	AD 1405–1565
G 124, windward back reef	2	1380 ± 40	AD 960–1085
G 135, leeward back reef	6	1400 ± 50	AD 905–1085
G 17, windward fore reef	27	260 ± 60	'modern'
G 1, leeward fore reef	40	220 ± 60	'modern'
G 116, deep lagoon	11	420 ± 50	AD 1805–1950
G lag 1, deep lagoon	17	470 ± 40	AD 1720–1950
G lag 2, deep lagoon	17	510 ± 40	AD 1695–1950
Beachrock from cays on windward platform margins			
Glovers Reef, Long Cay	sea level	1.550 ± 60	AD 710–990
Glovers Reef, Middle Cay	sea level	1.230 ± 60	AD 1045–1290
Glovers Reef, Southwest Cay	sea level	1.320 ± 60	AD 980–1220
Lighthouse Reef, Halfmoon Cay	sea level	1.910 ± 70	AD 345–650

Dates of beachrock from Glovers and Lighthouse Reefs from Gischler & Lomando (1997). Conventional ages are adjusted for reservoir correction. The 2-sigma range has 95% probability. (Dating was performed by BETA ANALYTIC INC., Miami)

Turneffe Islands (Figs 3, 5, 6). Radiometric dating of corals and peats from rotary drill cores shows that Glovers Reef was the first platform to be flooded by the rising Holocene sea, about 7500 years BP. The Turneffe Islands platform was flooded last, a little less than 6000 years BP (Table 2; Fig. 7). Pleistocene relief is highest on Glovers Reef (*c.* 10 m) compared to Lighthouse Reef and Turneffe Islands (c. 4–5 m) (Fig. 6). Probing in lagoon interiors has shown that Holocene sediment thicknesses rarely exceed 4 m (Gischler & Hudson 1998).

The Holocene reef facies is represented either by coral boundstone, grain to rudstone, or unconsolidated sand and rubble. Holocene reefs are generally situated on Pleistocene reef limestone, with the exception of the patch reef of hole 13 that developed on a topographic low (Fig. 6). Radiometric dates from diagenetically unaltered corals of the Pleistocene in Belize suggest that the foundations of Holocene reefs were deposited during the last interglacial highstand of sea level (oxygen isotope stage 5e) (Gischler *et al.* 2000).

Discussion: controlling factors of late Quaternary development

Antecedent topography

The importance of antecedent topography for Holocene reef development and sedimentation on the Belize shelf was demonstrated by Purdy (1974*a*, *b*). He showed that Holocene reefs are situated on Pleistocene highs whereas unconsolidated sediment accumulated in topographic lows of the Pleistocene. Pleistocene relief was created during sea-level lowstands by karstification which was directed in its expression by underlying structure. Halley *et al.* (1977) and Shinn *et al.* (1982) showed that Holocene reefs in the central Belize shelf area are located on Pleistocene reefs. This possibility was also considered earlier by Purdy (1974b). Choi & Holmes (1982) and Choi & Ginsburg (1982) interpreted Holocene reefs in the southern shelf to superpose clastics, based on seismic data. The importance of underlying structure for the development of Quaternary reefs offshore from Belize was again stressed by Lara (1993) for the southern shelf and Lomando *et al.* (1995) for the isolated carbonate platforms.

Results of drilling show that Pleistocene elevation is different among the three platform margins (Figs 3, 5, 6). The decrease of Pleistocene elevation from Lighthouse Reef to Glovers Reef, which are situated on the same fault-block trend, might be caused by a southward tilt. Dill (1977) showed that giant Pleistocene stalactites in the 125 m deep sinkhole in the eastern lagoon of Lighthouse Reef (south of our hole 14), are tilted 10–15° towards the north. Differential subsidence along and among the offshore fault-blocks is also indicated by the results of radiometric dating of uppermost-Pleistocene sections. Pleistocene deposits on the northern barrier reef and the platforms differ by as much as 10 m in elevation, but have the same age (Gischler *et al.* 2000).

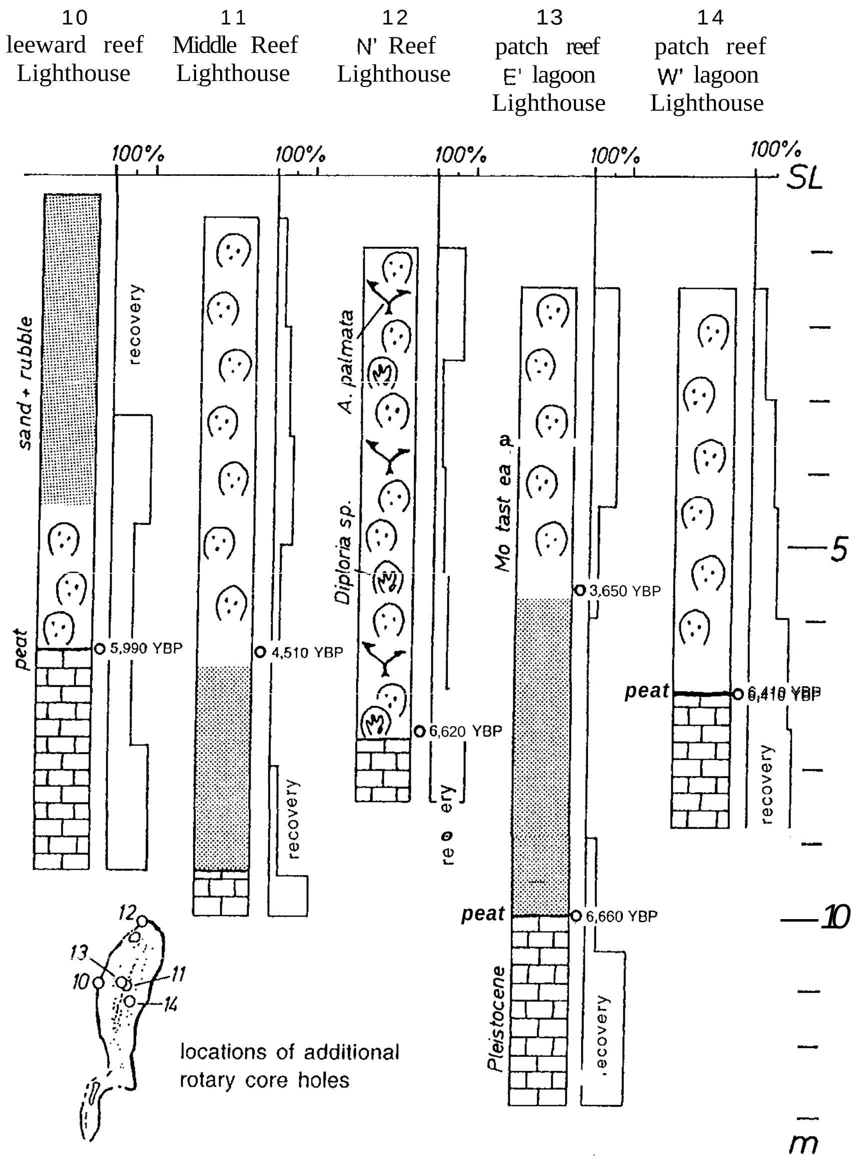

Fig. 5. Description of rotary cores on Lighthouse Reef (core hole numbers 10–14) that were drilled in addition to those described in Gischler & Hudson (1998) (core hole numbers 1–9). For complete data on radiometric dates see Table 2.

The differences in Pleistocene relief between the northern two platforms and Glovers Reef might be a consequence of an increase in the intensity of Pleistocene karstification. Data on precipitation on the isolated platforms proper are not available, but the precipitation rates on the relatively flat relief of the mainland adjacent to the two northern platforms amount to *1500* mm per year at the most (Purdy 1974*b*). In contrast, the annual rainfall on the mainland adjacent to Glovers Reef exceeds *4500* mm per year (Purdy 1974*b*) reflecting the *1160* m elevation of the Maya Mountains.

Following the model of Purdy (1974*a*,*b*), we interpret linear morphological features on the platforms as an expression of underlying structure. These are the NNE-trending lagoonal patch reefs in Lighthouse and Glovers Reef that parallel the fault-block system (Fig. *1*). Northwest-trending features such as the island chain in the main lagoon of the Turneffe Islands (Fig. 3, west of borehole *4*) may also be an expression of structural control in the form of underlying wrench faults (Lomando *et al. 1995*).

Sea level

The response of all the platform reefs to rising sea level was to keep up (*sensu* Neumann & Macintyre *1985;* Davies & Montaggioni *1985).*

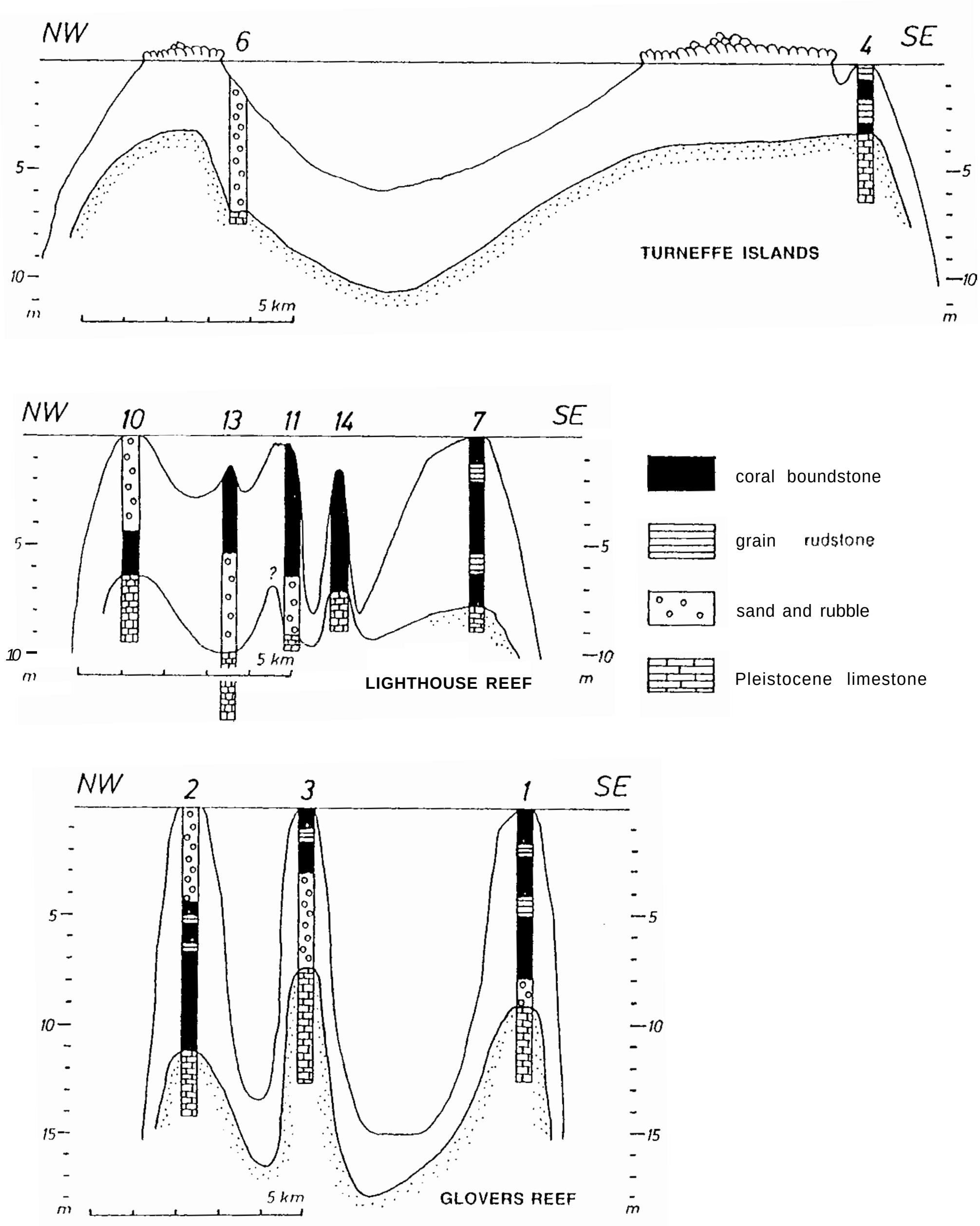

Fig. 6. *Cross-sections through isolated carbonate platforms based on rotary core drilling, probing with 4 m long aluminium rod in unconsolidated sediment in platform interiors, and lagoon bathymetries. Locations of probing are shown on Fig. 3. Holocene sediment thicknesses obtained from probing are projected on sections that are drawn from borehole to boreholc. Question mark indicates that Pleistocene elevation under Holocene patch reef is probably higher than observed in the hole, as we drilled near the reef margin.*

All radiometric dates plot close to the Belize sea-level curve (Macintyre *et* al. 1995) or within a **3** m envelope around it. This is remarkable in that the three platforms were flooded more or less successively (Fig. 7) and had to keep pace with different rates of sea-level rise.

The relatively old ages of marginal reef sediment (Table 1) in combination with radiometric dates from core material (Fig. 7) suggest that the margin of Glovers Reef 'caught up' with sea level early because of lack of accommodation space. In general, the margins of the Belize isolated platforms can be interpreted as areas that are largely bypassed by sediment filling in interior lagoons (Gischler & Lomando 1999).

Exposure to waves and currents

The three platforms are situated within the trade wind belt with winds from the northeast and east

Table 2. Radiometric dates from rotary cores through isolated platforms offshore from Belize

Sample (hole no., depth below sea level)	Conventional age ± std dev. (years BP)	2-sigma range
Turneffe Islands		
8, 3.8 m	5,850 ± 50	4825–4575 BC
Lighthouse Reef		
10, 6.5 m	5,990 ± 60	5030–4765 BC
11, 6.5 m	4,510 ± 60	2890–2560 BC
12, 7.5 m	6,620 ± 60	5275–5015 BC
13, 5.5 m	3,650 ± 70	1765–1420 BC
13, 10.0 m	6,660 ± 50	5605–5450 BC
14, 7.0 m	6,410 ± 50	5435–5255 BC

These data are additional to those published in Gischler & Hudson (1998)

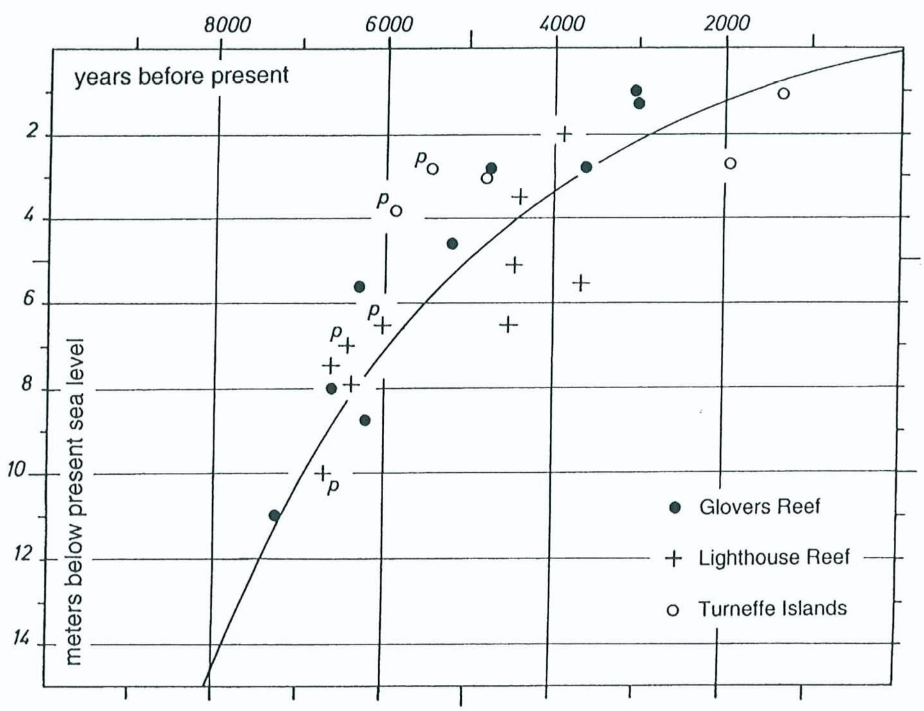

Fig. 7. Radiometric dates from core material (coral and peat) plotted on minimum western Atlantic and Belize sea-level curve of Macintyre *et al.* (1995). Data from Gischler & Hudson (1998) and Table 2. Peat samples are marked by **'p'**.

predominating. Mean wave approach is 75° (Burke 1982). Glovers Reef, Lighthouse Reef and the northernmost part of Turneffe Islands are open to the Caribbean Sea (Fig. 8). The part of Turneffe Islands that has extensive mangrove areas receives only modified and impeded wave forces as it is protected by Lighthouse Reef to the east. This configuration suggests that extensive mangrove growth is only possible in rather protected areas. The same is true for the Belize shelf. The central barrier reef that is protected by the isolated platforms to the east (zone **3**) has the highest abundance of mangrove islands (Fig. 8).

An alternative interpretation for the extensive Turneffe Islands mangrove development relates this mangrove development to the fact that this platform was flooded last during the lowest rate of Holocene sea-level rise (Fig. 7). If this were the case one would also have to presume a lower Pleistocene elevation and an earlier date of flooding of the open, northernmost part of the platform. The subsurface data,

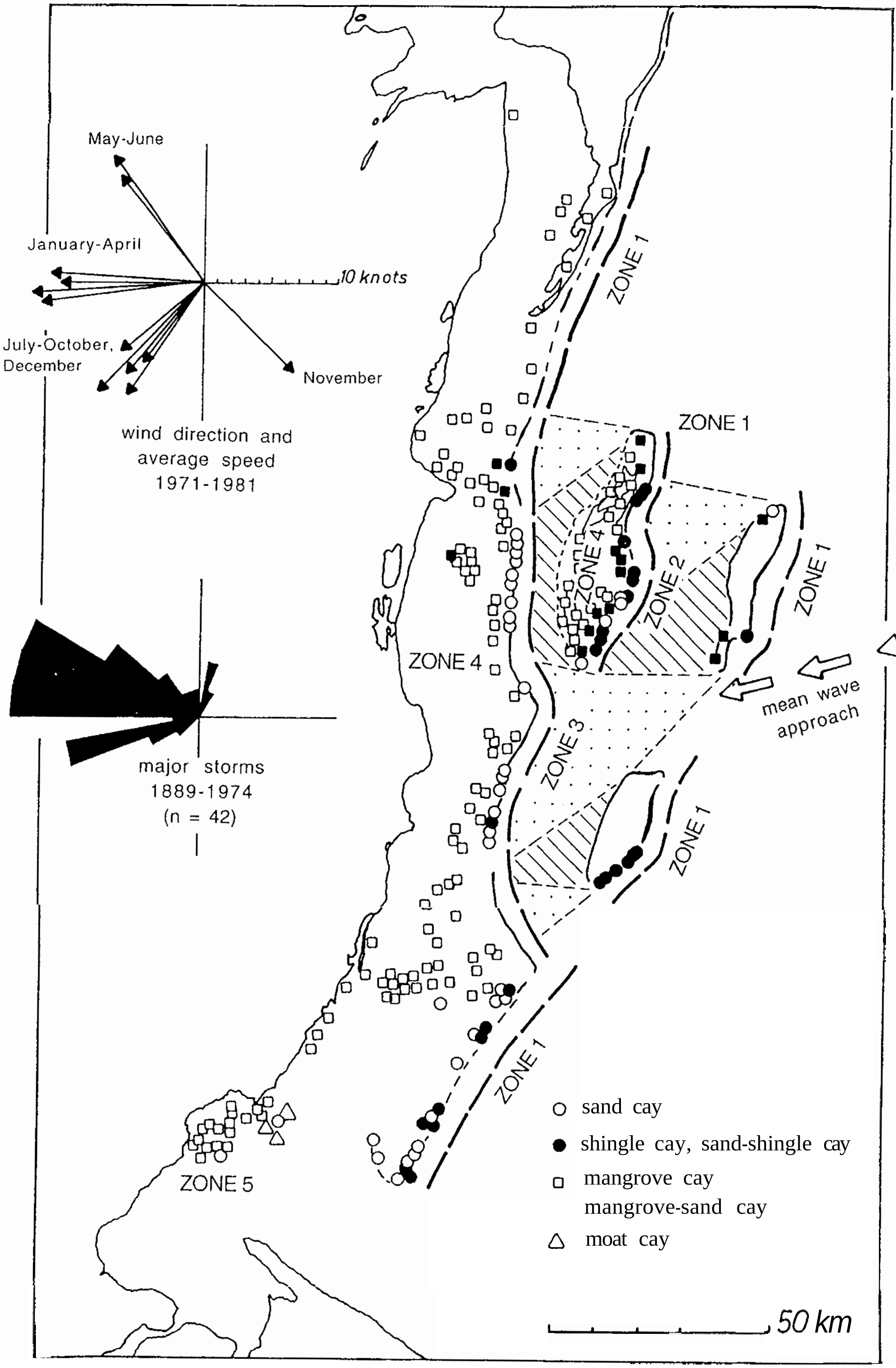

Fig. 8. Wave-sheltered positions of Turneffe Islands due to position of Lighthouse Reef and sheltered areas of central barrier reef by isolated platforms (after Burke 1982; Gischler & Hudson 1998). Stippled areas: modified wave force; hatched areas: maximum impedance of wave force. Wave energy zones and resulting island types after Stoddart (1962,1965). Zone 1, maximum and submaximurn wave energy; zone 2, high wave energy; zone 3, medium wave energy; zone 4, low wave energy; zone 5, moderate wave energy.

especially relating to borehole 5, argue against this interpretation.

Conclusions

Locally operating factors such as antecedent topography and exposure to waves and currents can be used to explain the variation in geomorphology and facies among the closely spaced, isolated carbonate platforms of offshore Belize. Holocene sea-level rise was of importance in creating the accommodation space for reef and platform development. However, this factor by itself does not explain the described differences of geomorphology and facies from platform to platform. The implication of this modern example suggests the potential influence of local controlling factors in ancient examples that might not always be easy to recognize.

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