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Letter

Seismic stratigraphy of the Blue Hole (Lighthouse Reef, Belize), a late Holocene climate and storm archive

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ABSTRACT

Five seismic units may be identified in the ~8 m thick Holocene sediment package at the bottom of the Blue Hole, a 120 m deep sinkhole located in the atoll lagoon of Lighthouse Reef, Belize. These units may be correlated with the succession of an existing 5.85-m-long sediment core that reaches back to 1.385 kyrs BP. The identification of seismic units is based on the fact that uniform, fine-grained background sediments show weak reflections while alternating background and coarser-grained event (storm) beds exhibit strong reflections in the seismic profiles. The main source of sediments is the marginal atoll reef and adjacent lagoon area to the east and north. Northeasterly winds and storms transport sediment into the Blue Hole, as seen in the eastward increase in sediment thickness, i.e., the eastward shallowing of the Blue Hole. Previous assumptions of much thicker Holocene sediment packages in the Blue Hole could not be confirmed. So far, close to 6-m-long cores were retrieved from the Blue Hole but the base of the sedimentary succession remains to be recovered. The nature of the basal sediments is unknown but mid-Holocene and possibly older, Pleistocene sinkhole deposits can be expected. The number of event beds identified in the Blue Hole ($n = 37$) during a 1.385 kyr-long period and the number of cyclones listed in historical databases suggest that only strong hurricanes (categories 4 and 5) left event beds in the Blue Hole sedimentary succession. Storm beds are numerous during 1.3–0.9 kyrs BP and 0.8–0.5 kyrs BP.

1. Introduction

The Blue Hole of Belize is among the few examples of large, circular and cylindrical submarine reefal karst cavities (Sachet, 1962; Backshall et al., 1979; Hine and Steinmetz, 1984; Shinn et al., 1996). Still, the Belize Blue Hole is virtually unique, in that undisturbed, annually-layered muddy sediments with intercalated event layers (sands, silts) that may serve as a high-resolution climate and storm archive in the late Holocene, are found at the bottom (Gischler et al., 2008). The only other continuous, high-resolution Holocene climate archives in the Belize region include stalactites in mainland caves that reach back 2 kyrs BP (Kennett et al., 2012). The total extent of the Blue Hole record is not known because the previously recovered cores did not reach the Pleistocene–Holocene boundary (Gischler et al., 2008). This core-length limitation refers to the fact that penetration depths of portable electrical vibracorers to be used from small boats usually do not exceed 6–8 m. Larger drill rigs that could potentially drill tens of meters of core may only be brought into the Blue Hole across the very shallow Lighthouse lagoon with great difficulties and hazards for the environment. To establish the sedimentary architecture, we designed a seismic study to investigate the nature and structure of the base of the Blue Hole and to estimate the total thickness of the sediment package that can potentially be used as a high-resolution late Quaternary climate and storm archive.

2. Setting

The Belize Blue Hole is located in the eastern lagoon of Lighthouse Reef, Belize, which is part of the Belize barrier and atoll reef system (Gischler and Hudson, 1998, 2004). The Blue Hole is a 125 m deep and 320 m wide Pleistocene sinkhole (Fig. 1). It is surrounded almost completely by coalesced coral patch reefs. Two channels through the surrounding reefs are located in the north and east and connect the Blue Hole with the atoll lagoon. The lagoon floor is about 5 m deep. Inside the patch reef ring, there is a ca. 30° coarse sediment slope that transitions to the vertical wall of the Blue Hole at 10 m of depth. Below 90 m of depth, the water in the Blue Hole is anoxic (Dill, 1977). New temperature and conductivity profiles show three negative steps at 9–17 m, around 60 m, and from 80–100 m (Fig. 1). Water sampling revealed that the two samples below 100 m of depth smelled strongly of H_2S. Both water samples from below 100 m of depth have high concentrations of HCO_3^-, which is probably a consequence of sulfate reduction (Table 1).

The cylindrical shape of the hole presumably results from the collapse of the roof of a karst cave (Dill, 1977), which left a circular ridge

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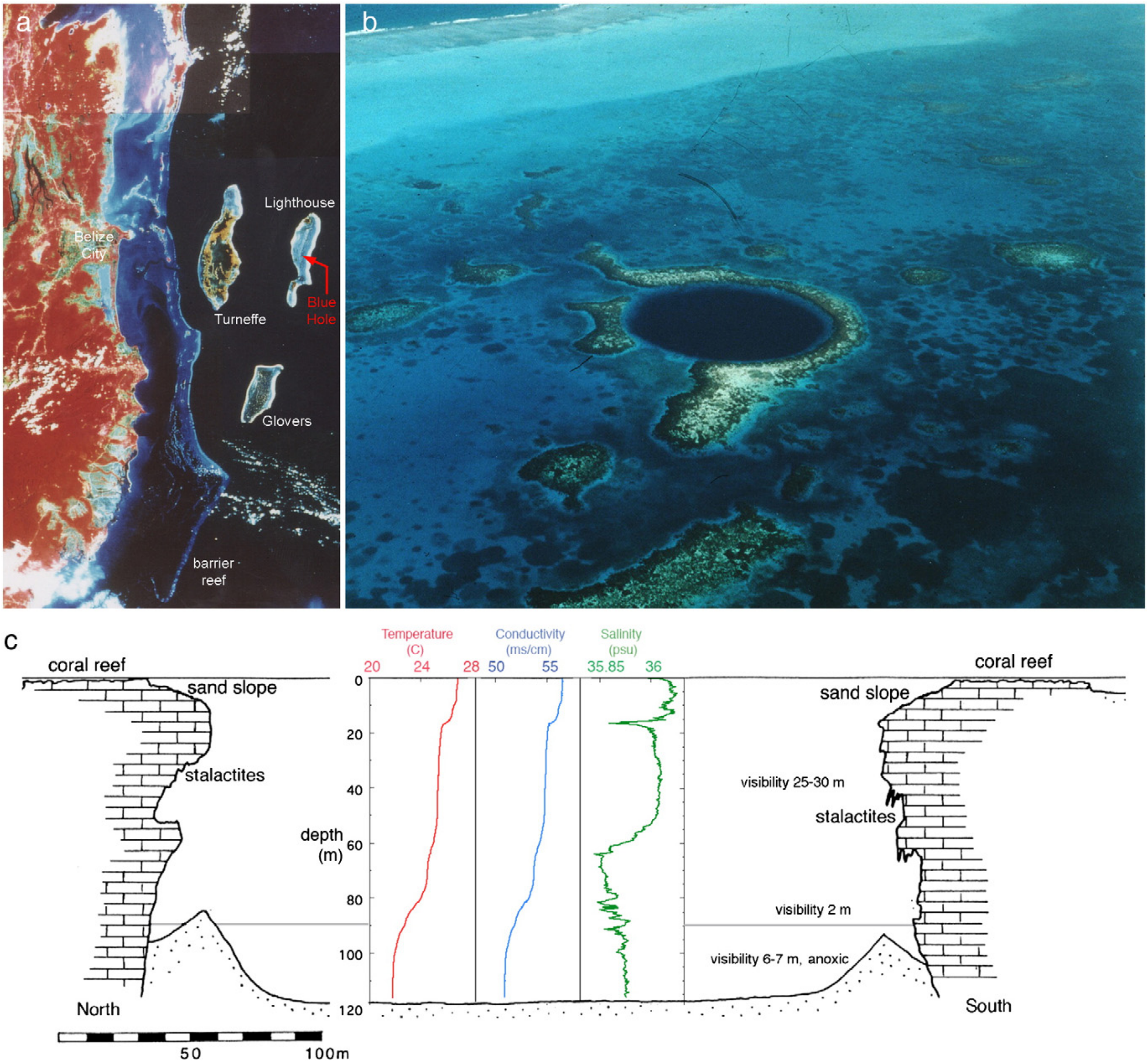

Fig. 1. (a) Location of the Blue Hole (Lighthouse Reef) in the Belize reef system (false color satellite image). (b) Aerial view of the Blue Hole in the Lighthouse Reef lagoon, looking east. Photo by J.C. Smith. Note the proximity to the eastern reef margin of the atoll. (c) Temperature and conductivity profiles in cross-section through the Blue Hole (modified from Dill, 1977). Note that there are three negative jumps; most prominent jump from 80–100 m.

of debris at the bottom. Impressive evidence for the karst origin are 2–3 m long stalactites in ~50 m of water depth, which have formed subaerially under overhangs during Pleistocene sea-level lowstands (Dill et al., 1998). Jones and Dill (2002) obtained three preliminary U-series dates of 153, 66–60, and 15 kyrs BP from the inner part of a stalactite, suggesting formation of the Blue Hole during three consecutive glacial sea-level lowstands. Vibracoring the bottom of the Blue Hole has recovered undisturbed sediment that was used as a high-resolution climate and storm archive (Fig. 2). Two main sediment types can be discerned in an almost 6 m long core (Gischler et al., 2008). Laminated annually-layered, fine-grained carbonates (muds, fine silts) represent the background sedimentation. Lamination is a result of regularly changing amounts of organic matter in the sediment. Coarser-grained and massive beds of sands and silts reflect strong hurricanes sweeping lagoonal sediments into the blue hole. The age model is based on varve counting and six radiocarbon ages of the organic residue (Fig. 2). The average background sedimentation rate amounts to 2.32 mm/yr.

The climate of the study area is sub-tropical with trade winds blowing from the east for most of the year. Sea surface temperature in the Lighthouse Reef lagoon fluctuates annually from 23–29 °C; sea surface

Table 1
Results of water analyses made at ALA Aachen, Germany. Concentrations are in mg/L. Note elevated bicarbonate concentrations in samples from 104 m and 114 m. The same samples smelled intensively of H_2S.

Sample	HCO_3-	$Cl-$	S^{2-}	SO_4^{2-}	Na^+	K^+	Mg^{2+}	Ca^{2+}
0	133	21,100	0.02	3210	10,300	529	1750	452
15	138	20,800	0.02	3520	10,200	537	1690	455
30	133	21,000	0.02	2980	10,200	532	1690	441
45	133	21,000	0.02	3090	10,100	538	1670	442
60	133	21,000	0.02	3110	10,100	518	1650	446
70	133	20,700	0.02	3040	10,200	525	1690	444
80	128	21,000	0.02	2940	10,100	521	1650	446
90	138	24,000	0.02	2990	11,500	469	1690	458
104	143	20,700	0.02	2960	10,300	525	1650	456
114	143	20,700	0.02	3010	10,100	516	1660	466