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Solution pans and linear sand bedforms on the bare-rock limestone shelf of the Campeche Bank, Yucatán Peninsula, Mexico

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ABSTRACT

A high-resolution, near-surface geophysical survey was conducted in 2013 on the Campeche Bank, a carbonate platform offshore of Yucatán, Mexico, to provide a hazard assessment for future scientific drilling into the Chicxulub impact crater. It also provided an opportunity to obtain detailed information on the seafloor morphology and shallow stratigraphy of this understudied region. The seafloor exhibited two morphologies: (1) small-scale (< 2 m) bare-rock karstic features, and (2) thin (< 1 m) linear sand accumulations overlying the bedrock. Solution pans, circular to oblong depressions featured flat bottoms and steep sides, were the dominant karstic features; they are known to form subaerially by the pooling of rainwater and dissolution of carbonate. Observed pans were 10–50 cm deep and generally 1–8 m wide, but occasionally reach 15 m, significantly larger than any solution pan observed on land (maximum 6 m). These features likely grew over the course of many 10's of thousands of years in an arid environment while subaerially exposed during lowered sea levels. Surface sands are organized into linear bedforms oriented NE-SW, 10's to 100's meters wide, and kilometers long. These features are identified as sand ribbons (longitudinal bedforms), and contained asymmetric secondary transverse bedforms that indicate NE-directed flow. This orientation is incompatible with the prevalent westward current direction; we hypothesize that these features are storm-generated.

1. Introduction

Drowned carbonate platforms are found at many of the Earth's continental margins (Schlager, 1981). During sea level low-stands, much of these platforms are subaerially exposed to karstic weathering, subject to the local climatic conditions at those times (Read and Grover, 1977). Subsequent sea level rise will preserved karst features against additional weathering; where the sediment cover is thin, such geomorphology may be exposed at the seafloor and accessible to acoustic surveys (Obrochta et al., 2003). Detailed seafloor mapping over carbonate platforms therefore has the potential to enable investigating ancient karstic morphologies and, by analogy to modern settings, provide an understanding of past climate conditions.

This paper documents such an investigation on the continental shelf of the Yucatán Peninsula, Mexico, also known as the Campeche Bank, a carbonate platform extending into the southern Gulf of Mexico (Fig. 1). Aside from the early research by Logan et al. (1969), the Campeche Bank is understudied, particularly in regards to the detailed geomorphology of the vast regions of seafloor between coral reefs. It is unlikely to be featureless. Subaerially exposed by sea level low-stands, the thin sediment veneer to exposed limestone seafloor is apt to exhibit well-preserved karstic landforms (compare, for example, the morphology of the Florida shelf (Obrochta et al., 2003)).

An opportunity to conduct high-resolution mapping of the Campeche Bank seabed was provided in 2013, when the European Consortium for Ocean Research Drilling (ECORD) funded a hazards assessment survey ahead of scientific drilling by the International Ocean Discovery Program (IODP) into the Chicxulub impact crater, roughly half of which extends beneath the offshore Campeche Bank (Gulick et al., 2013). The hazards assessment sought to ascertain the stability of the seafloor and shallow substrate for jack-up drilling operations. It required high-resolution mapping of the seabed morphology and characterization of the shallow sedimentary stratigraphy of the drill sites. This paper is therefore exploratory in nature, an investigation of opportunity in an interesting region that has received little attention in the scientific

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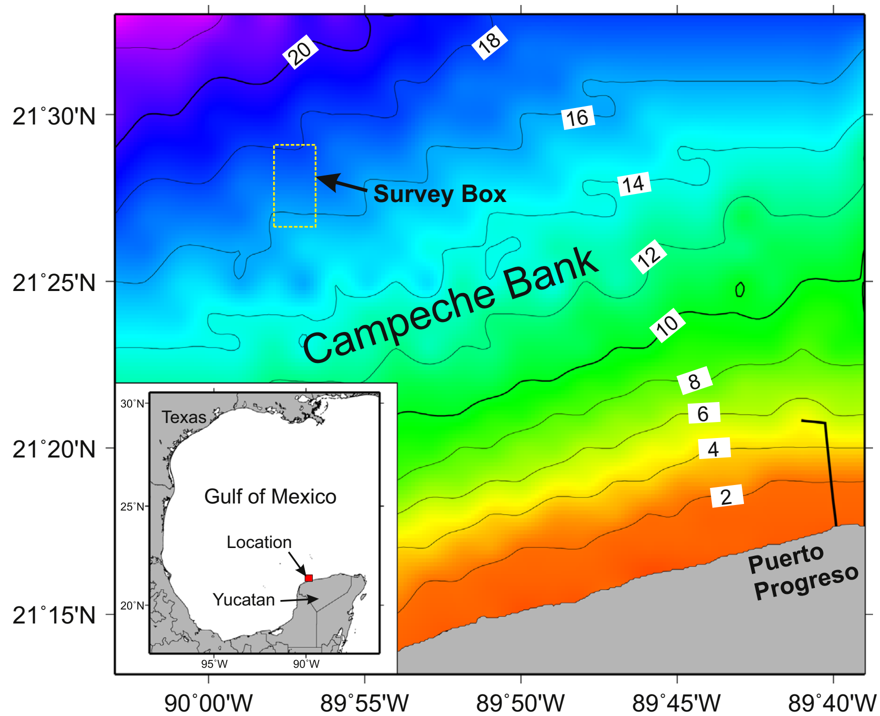

Fig. 1. Location of survey area, overlain on regional bathymetry (derived from ETOPO5 (http://www.ngdc.noaa.gov/mgg/global/etopo5.html). Depth contours are in meters. The dock at Puerto Progreso, Mexico, is indicated by heavy line in the lower right of the image; it is ~20 nm from the survey box. Inset shows location of map on the northwest coast of the Yucatán Peninsula, in the Gulf of Mexico.

literature. In particular, the observations provide two avenues of research: fossil karstic geomorphology and modern sedimentary bedforms. Karstic morphology is abundant on the bare-rock exposures at the seafloor, formed in a subaerial environment when the shelf was exposed by lowered sea levels. Such morphology may illuminate surface hydrologic processes and environmental conditions across the peninsula during global glacial conditions. Unconsolidated sediments (carbonate sands) are also distributed throughout the survey area. The bedform morphology of these sediments can provide information on modern hydrodynamic conditions.

1.1. Setting

The Campeche Bank is a broad shelf, covering ~57,000 km^2 and extending ~100–300 km from the shoreline to the shelf break at ~200–300 m water depth with an overall gradient of ~0.0002–0.001 (Logan et al., 1969). Most of the shelf seafloor is composed of indurated, karstic limestone of probable Pleistocene age (Logan et al., 1969). Sedimentary cover from the shoreline to the ~60 m isobath is identified as the Progreso Blanket (Logan et al., 1969), and ranges in thickness from 0 m to around 1 m. With no major drainage systems on the Peninsula, there is very little terrigenous sediment, particularly to the north and east. What deposits do exist in these regions are composed primarily of medium- to fine-grained skeletal carbonate sand, presumably formed by the breakup of skeletal material along the bottom due to wave-current action (Logan et al., 1969). Reef complexes fringe the Campeche bank near the 60 m isobaths (Kornicker and Boyd, 1964; Logan et al., 1969; Blanchon and Perry, 2004), and additional reefs are mapped within the shallower regions of the Progreso Blanket (Zarco-Perelló et al., 2013). Nevertheless, the inner shelf is not a protected, lagoonal setting; rather, it is open to the passage of waves and currents and, like the west Florida shelf, the Campeche Bank is considered to be an “open, deeply submerged inclined shelf”, as well as a “high energy” environment (Logan et al., 1969). The Yucatán shelf is typically subjected to westerly currents (Zavala-Hidalgo et al., 2003), and it is frequented by hurricanes and tropical storms (Boose et al., 2003) that can mobilize sand in large quantities.

2. Methods

The ECORD survey on the Campeche Bank was conducted through a partnership between the University of Texas Institute for Geophysics (UTIG), the Universidad Nacional Autónoma de México (UNAM), and Seafloor Geotec LLC (SGL). The survey included a broad spectrum of data collection: multibeam bathymetry, side-scan backscatter, CHIRP and boomer acoustic reflection, cone penetrometer, and sediment samples which were analyzed for grain size distribution. It was conducted aboard the UNAM R/V *Justo Sierra* from 16 April to 23 April, 2013, over a study area within the Chicxulub impact crater that encompasses three potential IODP drilling sites. The planned study area covered an area ~10.58 km^2, located ~32 km northwest of Puerto Progreso, Mexico in ~16–18 m water depth (Fig. 1). This region is within the sedimentological environment identified as the Progreso Blanket (Logan et al., 1969), and east of the Sissal Reefs mapped by Zarco-Perelló et al. (2013). Survey speeds were typically 4–5 kts for all instrumentation. Primary navigation for the R/V *Justo Sierra* multibeam echosounder was by the Seatex Seapath 200 positioning system. Navigation for all other instrumentation was derived by differential GPS with a base station located in Puerto Progreso.

2.1. Multibeam echosounder

The R/V *Justo Sierra* is fitted with a hull-mounted Kongsberg EM3002 multibeam echosounder system with data acquisition using the Kongsberg SIS software. The operating frequency of the system is 280–310 kHz. Track density (~70 m) was sufficient to provide >100% coverage in the area of interest. The raw