MAPPING FLOODED CAVES FROM ABOVE: SURFACE KARST INVENTORY OF THE YUCATAN PENINSULA

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Abstract

More than 700 km of flooded cave have been documented along the 200 km of coastline south of Cancún, Yucatán Peninsula, México. Development projections include a 40-fold increase in population in the coming 20 years. Access to the caves is through collapse sinkholes called cenotes, which may serve as surface proxies for the underlying cave systems. Cenote mapping will likely expedite exploration and ultimately contribute to water and waste management. However, all data on cenotes remains limited. Modest efforts began in 2006 to establish a standardized cenote data collection methodology bridging geological, biological, archeological, and land use aspects for use by local persons, explorers, and visiting interested persons. Therefore the methodology needed to be usable by persons with no specific background in karst or the local area. A three-page data collection form is supported by a 10-page orientation guide including instructions for field sketching, and a field picture guide. In 2006-2007, volunteers spent a total of four months collecting data on 80 sites. In 2008 the project will include more volunteers, data entry into a GIS, and initial interpretations of cenote geospatial data with structural and topographic features in this subtle, low relief karst platform. The greatest long term challenge in this effort remains legal issues surrounding information management and ultimately transfer to government decision makers.

Key words: mapping, karst, cenotes, Mexico, hydrology, contaminants, ecology, land use

Introduction

The Yucatan peninsula is the ~150,000 km^2 emergent portion of the Yucatán Platform that divides the Gulf of Mexico from the Caribbean Sea. The aquifer is density stratified, with a lens of freshwater overlying naturally intruding saline water. The aquifer system remains the only natural source of potable water for the whole peninsula, while it is also widely used under government directives as a sink for treated and untreated effluent. Mexican government plans include the establishment of several new urban centers with target populations of 200,000 each along the Caribbean coast, which will result in a nearly contiguous urban strip from ~50 km south of Cancún, to the northern border of the Sian Ka'an Biosphere Reserve. These development plans aim to increase the local population 40-fold in the coming 20 years.

The whole peninsula is highly karstified. However, there is a notable concentration of more than 700 km of explored caves along the 200-km, north-central portion of the Caribbean coast and cave density reaches >4/km^2 in well-explored areas (Beddows, 2004). Collapse sinkholes, locally called cenotes, are abundant throughout the region, and these provide access to the underlying cave networks. Most of these caves explored so far are water-filled, and exploration is therefore by cave diving. The geomorphology and speleogenesis of the flooded caves shows that these develop principally in relation to sea level and the depth of the fresh-saline mixing zone where the phenomenon of mixing corrosion generates waters undersaturated with respect to calcium carbonate *in situ* (Smart et al., 2006; Smith et al., in preparation).

The cenotes overlie the phreatic cave networks, and they form principally by mechanical collapse of the cave roofs during low sea levels when buoyant support is lost. The vast majority of cenotes along the Caribbean coast do not have exposed water pools and remain invisible from the air under the closed forest canopy. Mapping all of them aerially remains a serious challenge. Nonetheless, the cenotes remain excellent surface proxies for the underlying caves which function as the river networks through this large region. Mapping of cenotes will not only expedite direct exploration of the subterranean rivers but may also provide the basis for a quantified ecological signature based on the distinct vegetation often growing in the cenotes. Mapping will equally contribute to water and waste management by generating the ability to test questions of structural and geological controls on speleogenesis at the regional scale . This project aims to establish a georeferenced surface karst inventory of features situated principally within the proposed urban footprints with data generated by a wide range of "stakeholders."

Data Collection Methodology

Beginning in 2006, the efforts began to establish a standardized methodology for collecting data on cenotes, bridging geological, biological, archeological, and land use aspects for use by local persons, explorers, and visiting interested persons. The methodology needed to be used by persons with no specific background in karst or the local area. The surface karst inventory (SKI) package presently consists of:

- Instruction Booklet of ~10 pages: This booklet has a brief introduction to karst in the local context, scientific terms needed for collecting data, instructions on how to collect correct GPS points, and exercises to build field sketching and mapping skills.
- Picture guide of features of interest.
- Data collection sheets which presently fill three pages, mostly with tick-boxes to facilitate easy and rapid data entry (See Table 1).
- Grid paper for sketching the site to scale.
- Data inventory sheets to track the sites visited and the photographs taken.

Discussion

Field Sketches – When photos will not do

It is a common temptation to document sites using only digital photographs. However the information on location, scale, and orientation of the field of view are rarely adequately documented, and therefore these photos fail to show the site dimensions, orientation of features within the image, depth profiles, etc.

Most often digital images taken quickly only show the undergrowth vegetation. At a minimum

Table 1 Information sections currently included in the Surface Karst Inventory data collection sheets.

1.1 Name of Inventory person(s):	5.1 Site Type
1.2 Position (Volunteer, resident, tourist, other.):	5.2 Site Usage
	5.3 Floor Covering
2.1 Date of site visit	5.4 Vegetation
2.2 Date form filled out	5.5 Formations – Karst and Cave related
2.3 Your familiarity with the site	5.6 Geology
	5.7 Archaeology
3.1 common name of site (if exists)	5.8 Water
3.2 Directions to site (sketch of how you got there)	5.9 Critters
3.3 General location (nearest settlement)	
3.4 GPS Coordinates	6.1 Dimensions – aerial perspective
3.5 GPS Make, Model, Projection used:	+ SKETCH TO SCALE
	6.2 Dimensions – vertical development
4.1 Landowner name + contact information	+ SKETCH TO SCALE
4.2 Who showed you/told you about the site?	Entrance dimensions and details

this project requires low-resolution, quantitative data of the long and short axis in both the plane and cross-section orientations notably to address questions of fracture and structural controls on cenote collapse formation, and how these factors may relate on a larger scale to regional speleogenesis.

We assume a low level of prior knowledge of the target workers, and so far a significant challenge has been providing instructions on how to draw simple, but adequate plan and cross-section field sketches with key measurements. We believe that providing limited written instructions, but with numerous examples of good field sketches followed by exercises on estimating distances, will result in adequate quality site sketches. Distance estimation exercises and methods include: calibration of paces, calibration of visual estimates inside a room analogous to inside a cave and outdoors (e.g. distance between trees), and use of a knotted string for horizontal measurements, combined with a plumb weight for vertical measurements inside actual sites.

While we are not trying to enforce standardized and codified symbology for the maps, the foundation of good field map and sketching is required, including the listing of symbols and shading marks used, drawing to scale (1 square on the grid paper equals a stated measure such as 1 m), north arrow, and metadata including site name and date.

We think that new data collectors with no prior experience may be trained in less than one day. Figure 1 (a & b) provides examples of sketches generated by volunteers with no prior experience in karst shortly after their involvement in the project. While the more accurate and computer-enhanced surveys generated by experienced cave mapping volunteers provide some advantages (Figure 1c), in all cases the simpler scale sketches equally serve the purpose of documenting the fundamental aspects of the feature, which may be of particular value when significant cenote modification has occurred (Figure 2).

Characteristics of Target Participants

This effort aims ultimately to include the participation of local landowners, staff of nongovernmental organizations, and municipal government agencies, scientifically knowledgeable volunteers recruited for the project, cave explorers and cave divers visiting and living in the area, and university

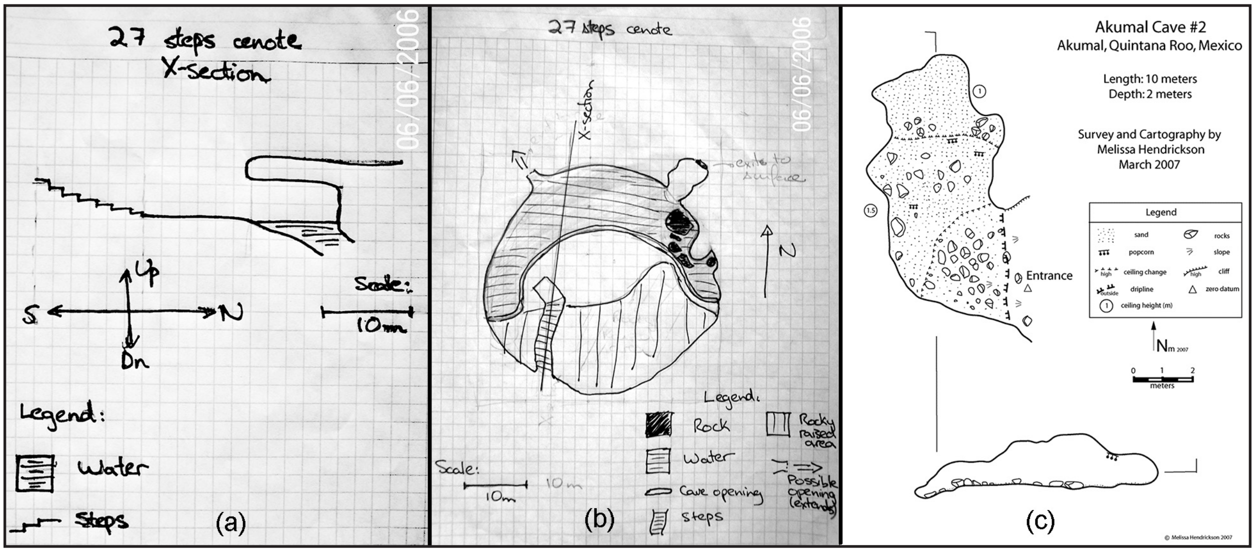

Figure 1 *Examples of cenote field sketches in cross section (a) and plan form (b) generated by volunteers with no previous knowledge of karst, and comparison with that generated by an experienced cave surveyor (c)*

Figure 2 *Recent example of cenote enlargement using heavy machinery. The landowner created an open water pool to attract paying snorkelers. (Photo by Robbie Schmittner)*

and high-school groups on field trips.

Of the five volunteers who have so far employed the existing methodology, the ability to speak Spanish and explain the goals of the work to the local persons and landowners has proven most valuable in generating leads and access to new and previously unidentified cenotes. Even without the ability to speak Spanish, there remains a large number of known and publicly accessible sites that have never been documented, which would keep a willing volunteer occupied.

With the number of cenotes being modified, it is also becoming increasingly obvious that return site visits perhaps every two years will prove valuable in documenting changes to the surface karst features, notably in relation to tourism and waste disposal activities.

Future of the Surface Karst Inventory

In 2006-07, three volunteers spent a total of four months dedicated to collecting data on 80 sites, with a smaller number of contributions coming from two of the local cave divers. In 2008, the goals include

- upgrading the data collection sheets with the input of the dedicated volunteers of this project,
- additional data collection by more volunteers,
- entry of all data collected to date into a GIS framework which includes the significant geopolitical features of coastline and proposed urban footprints,
- initial attempts at interpretations of cenote geospatial data with structural and topographic features in this subtle, low-relief karst platform.

Effort so far has been concentrated in the area of the village of Akumal located 105 km south of Cancún, slated to be the city of Akumal with a population of 200,000 by 2036. Akumal and the neighboring village of Puerto Aventuras, also slated to become urbanized, are likely to remain the focal points of efforts in 2008, in part because of the local support available through the Centro Ecologico Akumal (www.ceakumal.org). Other significant collaborations include financial support from the Quintana Roo Speleological Society, and data sharing with Amigos de Sian Ka'an. Most recently, the establishment of the GIS aspects are beginning through coordination with Aaron Addison of Washington University in St. Louis. The greatest long term challenge in this effort remains the legal issues surrounding information management and ultimately transfer to government decision makers, and these will remain to be addressed beyond 2008.

Acknowledgments

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