Novel Application of 3D Documentation Techniques at a Submerged Late Pleistocene Cave Site in Quintana Roo, Mexico

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***Abstract*— The submerged cave site of Hoyo Negro, located along the east coast of the Yucatan Peninsula, contains a diverse fossil assemblage of extinct megafauna as well as a nearly complete human skeleton. The remote nature of the site, and its limited access for researchers, requires the use of specialized documentation techniques in order to fully record the site and all its elements in three dimensions. The Proyecto Arqueologico Subacuatico Hoyo Negro of the Instituto Nacional de Antropologia e Historia (INAH) of Mexico in cooperation with the Center of Interdisciplinary Science for Art, Architecture, and Archaeology (CISA3) at the University of California, San Diego is developing advanced protocols for structure-from-motion documentation and visualization of underwater cultural heritage sites.**

***Index Terms*— Underwater, Late Pleistocene, Mexico, structure-from-motion.**

I. Introduction

The cenotes and underwater cave systems of the Yucatan Peninsula are emerging as one of the most promising frontiers for Late Pleistocene and Paleoamerican studies. Following the end of the last glacial maximum, rising sea levels flooded the region's maze of underground passageways and preserved a diverse Late Pleistocene fossil assemblage. A relatively well preserved female human skeleton (HN5/48; named "Naia") found in spatial association with the remains of now-extinct fauna in the submerged subterranean pit of Hoyo Negro presents a unique opportunity for interdisciplinary Paleoamerican and paleoenvironmental research in Quintana Roo, Mexico. At 13,000-12,000 years BP, the young woman's skeleton represents the oldest nearly complete individual yet found in the Americas.

Investigations have thus far revealed a range of associated features and deposits, which make possible a multi-proxy approach to identifying and reconstructing the processes that have formed and transformed the site over millennia. Recent and ongoing studies involve osteological and taphonomic analyses; absolute dating of human and geological samples; human DNA analyses; and a consideration of site hydrogeology and sedimentological facies. Additionally, innovative recording and imaging techniques are enabling researchers to analyze deposits and their contexts with minimal impact to the site.

II. Recent Research

Recent efforts have focused on detailed survey and mapping of the site (and associated submerged passageways and entrances) as well as detailed recording and initial sampling of cave deposits. In 2012, analyses of samples (taken in situ) from the human skeleton and a gomphothere resulted in significant findings [1]. Direct radiocarbon dating of human tooth enamel (via AMS) combined with uranium-thorium dating of calcite formations on the human bones produced an age range of 13,000-12,000 calendar years ago. Analyses identified intact human mitochondrial DNA as belonging to D1 – a Beringian-derived subhaplogroup.

One of the enduring mysteries of the First Americans is why, in terms of cranio-facial morphology, they look so different from modern Native Americans. This has led to the idea that perhaps the ancestors of modern Native Americans migrated into the New World from regions other than Siberia. Indeed, Naia shares much in common with the few Paleoamerican crania known to science. However, her Siberian/Beringian-derived mtDNA is shared by modern

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Native Americans. This link between a Paleoamerican (for whom we have a complete skull) and modern Native Americans suggests that the morphological differences we see between the two groups are the result of evolutionary changes that occurred within the Americas.

III. Current Image Acquisition and Processing for Structure-from-Motion Photogrammetry

The location and integrity of the remains, with respect to individual deposits and the cave's overall morphology, are essential to reconstructing the natural and cultural processes that resulted in the formation of this unique site as well as provide essential temporal information. The deep and remote nature of the site requires the use of specialized documentation techniques in order to fully record the site and all its elements in three dimensions. Structure-from-motion (SfM), as a means by which 3D reconstructions can be generated from 2D photographs, has been widely adopted as an accessible and empowering technique for rapid documentation and visualization of archaeological sites, features, and objects. However, its application in underwater environments presents certain physical and methodological challenges. For Hoyo Negro, these include total darkness, complex bathymetry, and extremely limited bottom-time (in addition to the distortion issues inherent to underwater photography).

The implementation of different image acquisition methodologies at different scales (site, feature, and object) has resulted in geometrically accurate and complementary models of cave features as well as individual skeletal elements. These 3D digital (and printable) models have proven critical to current and ongoing morphometric and taphonomic analyses (figs. 1 and 2), as many of the bones have not been removed from the cave. These data will not only serve as documentation of the site, but will enable project researchers from across disciplines to evaluate and annotate the imagery remotely while guiding subsequent sampling and recovery activities.

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Reference

[1] J.C. Chatters et al., "Late Pleistocene human skeleton and mtDNA link Paleoamericans and modern Native Americans," Science, vol. 344, no. 6185, pp. 750-754, May 2014.

Fig. 1. Susan Bird prepares cranium HN5/48 (Naia) for image capture. (Photo by Paul Nicklen; courtesy of National Geographic).

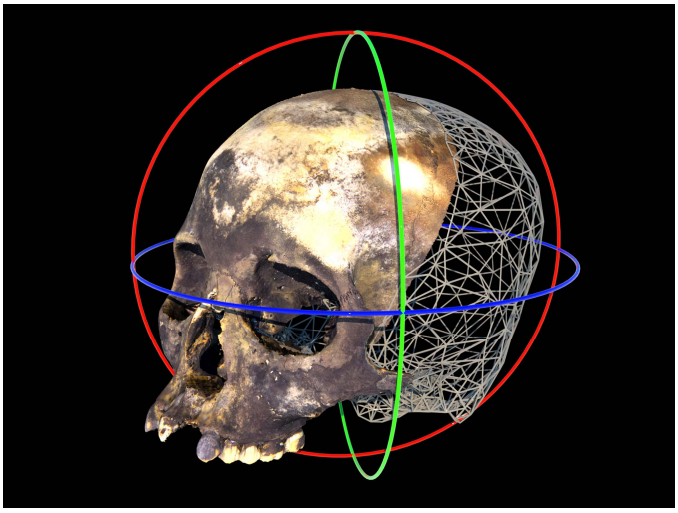

Fig. 2. Structure-from-motion model of cranium HN5/48 (Naia) created by Corey Jaskolski.