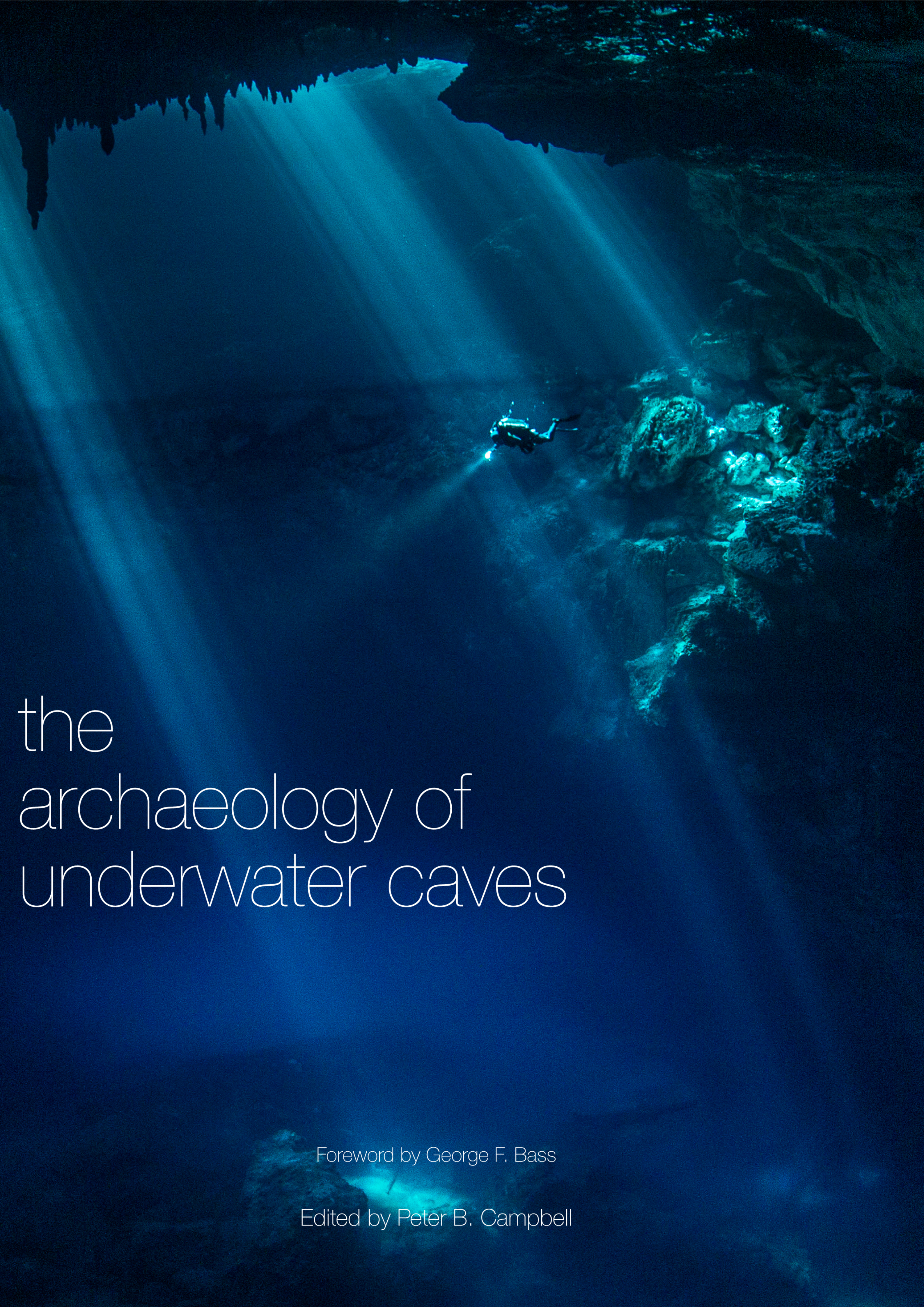

the archaeology of underwater caves

Foreword by George F. Bass

Edited by Peter B. Campbell

THE ARCHAEOLOGY OF UNDERWATER CAVES

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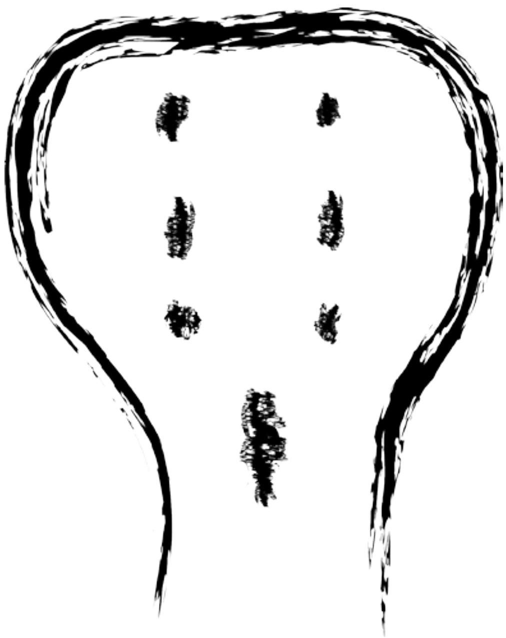

The symbol for a spring from a circa 4,000 year old oracle bone found in China.

HP
Highfield Press

ISBN: 978-0-9926336-7-7

A CIP record for this book is available from the British Library.

Cover: Paul Nicklen, National Geographic Creative
Title page: Chinese symbol drawn after Zhou *et al*. 2011: 1104
Dedication: Image courtesy of Florida Memory, artwork by Penn Tom
Table of Contents: Mayan symbol drawn after von Winning 1985: Figure 91
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Published by the Highfield Press Southampton, 10 Hiltingbury Road, Chandlers Ford,
SO53 5ST, United Kingdom

This book is available from
Oxbow Books Ltd, The Old Music Hall 106-108 Cowley Road Oxford, OX4 1JE
Casemate Academic, 28 Main Street, Oakville, CT USA 06779

Printed in Great Britain by imprint.co.uk.

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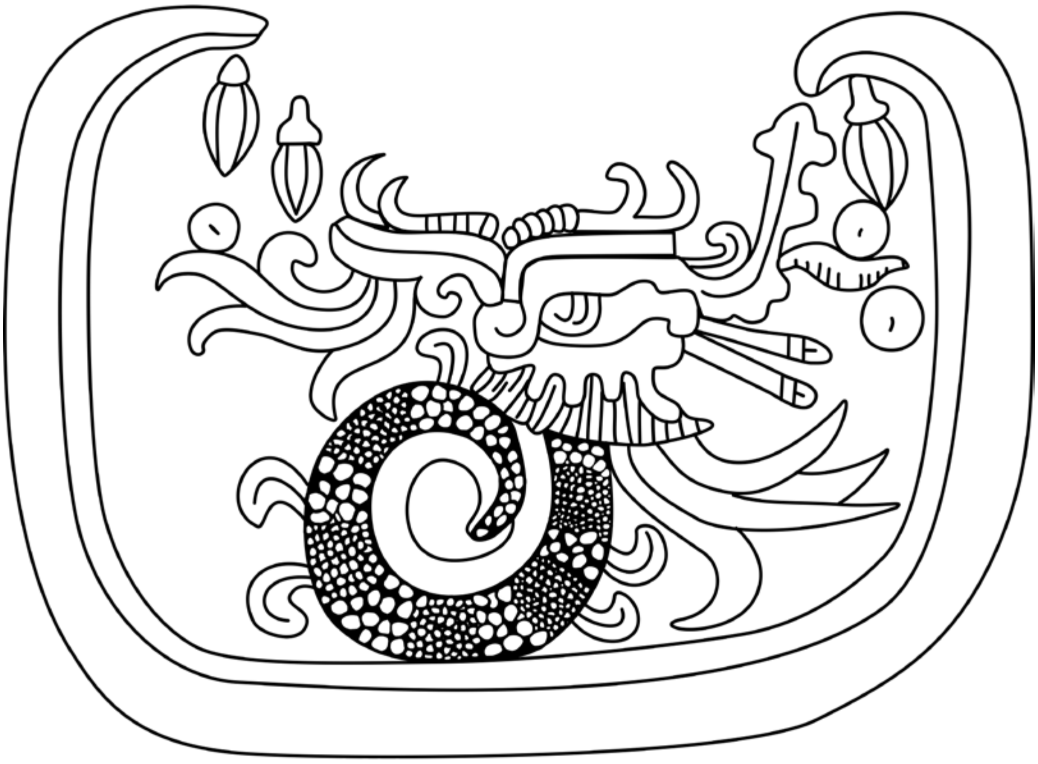

Portion of a painted Mayan capstone depicting a serpent from which the rain god Chac emerged. The capstone from the Temple of Owls at Chichen Itza and it dates to approximately 870-890 AD.

Figure 6.1. A view of Hoyo Negro looking up and to the north from the bottom near the south wall tunnel. This photo was produced by time exposure using the painting-with-light method (Roberto Chávez Arce).

Chapter 6

Hoyo Negro: Tapping the Paleoanthropological and Paleoecological Potential of a Deeply Submerged, Underground Chamber on the Yucatan Peninsula, Mexico

James C. Chatters, Dominique Rissolo, Joaquin Arroyo-Cabrales, Thomas W. Stafford, Jr., Brian M. Kemp, Alejandro Alvarez, Alberto Nava Blank, Patricia A. Beddows, Eduard Reinhardt, Shawn Kovacs, Shawn Collins, Shanti Morell Hart, Roberto Chávez Arce, Susan Bird, Franco Attolini Smithers, and Pilar Luna Erreguerena

Introduction

The karst systems of the Yucatan Peninsula, most of them submerged, have long held the potential for Pleistocene aged fossil deposits. Since the late 1980s, cave diving explorers have been mapping these systems and, in the course of their work, discovering the remains of animals and humans. Although most of the human remains have been from the Maya occupation of the region, a few discoveries of pre-Maya humans are thought, but not confirmed, to date to the Late Pleistocene or early Holocene (González González *et al*. 2006; 2013), but archaeological assemblages dating to this early period have not yet been reported for the peninsula. The region's potential has remained largely untapped.

A major step toward realizing the paleoanthropological and paleontological potential of the Yucatan's submerged caves came in 2007 with the discovery of Hoyo Negro. Under study by an international team of archaeologists, paleontologists, paleoecologists, and cave geochemists from Mexico, the United States and Canada and led by the Instituto Nacional de Antropología e Historia (INAH), Hoyo Negro contains a remarkable time capsule of the terminal Pleistocene climate and plant, animal, and human life of the Yucatan Peninsula.

Geology and Pleistocene Prehistory of the Yucatan

The Yucatan Peninsula is a broad, level-lying platform with off-lapping sequences. The central Paleocene-Eocene limestone grades outwards to early Pleistocene coastal margins (Servicio Geologico Mexicano 2007). The whole peninsula is karstified, but the eastern margin is literally riddled with coastal-karst cave systems (ORSS 2013; Smart *et al*. 2002). The caves of Yucatan have long been known to contain fossils of Pleistocene megafauna (Arroyo-Cabrales and Alvarez 2003). Because of the extreme permeability of the karst system, the water table gradient is so shallow that groundwater levels in this region closely track sea level. The upper tiers of caves closest to the ground surface formed subaqueously during past high sea level stands and were drained during the Late Pleistocene when sea levels lowered by as much as 110 m (360 ft) in response to changes in the mass of glacial ice. At lower sea levels, the shallow tunnels were air filled above the water table and accessible to terrestrial animals and humans.

With lower water levels and reduced evaporation from a cooler sea surface, the now humid, tropical climate was at times much cooler and drier (Bush *et al*. 2009; Leyden *et al*. 1993). No deposit of Pleistocene sediment has yet been found in the extreme low elevation landscape of Quintana Roo, but a long record from Lake Petén Itzá, 500 km (310 miles) to the south-west in the climatically similar Petén region of Guatemala provides a record of full-glacial to early Holocene environments. Pollen and sediment composition indicate mesic climate and a temperate pine-oak forest from 23,000 to 18,000 years ago, aridity and a thorn scrub/savanna from 18,000 to 10,300 years ago, with a slightly wetter interval between 14,700 and 12,800 years ago, and more mesic tropical forest after 10,300 years ago (Hodell *et al*. 2008).

Although people of a distinctly different cultural tradition were already well established in South America (Dillehay 2000), the earliest cultural tradition that has been documented in southern Mexico and Central America was the Clovis, which arrived shortly after 13,000 years ago (Ranere 2006). Sites and isolated projectile points of this tradition, which arrived as a demic expansion rather than acculturation of already established societies, have been documented in Panama, Costa Rica, Belize, and Guatemala, (Ranere 2006) and in western Mexico, where Clovis points have recently been found in association with a gomphothere kill (Sanchez *et al*. 2014). However, no conclusively dated Pleistocene-aged archaeological site has yet been found in the Yucatan Peninsula.

Cave Exploration in the Region

Over the past thirty years, international teams of cave divers have been mapping over 300 km (186 miles) of largely drowned tunnel systems along the eastern side of the Yucatan Peninsula, inadvertently revealing the well preserved remains of extinct megafauna and pre-Maya humans (e.g. Fiorelli 2004: 65-75; Motyča *et al*. 2013: 71-75). Examples of extinct horse, camelid, sloth, gomphothere, glyptodont (Arroyo-Cabrales and Alvarez 2003; González González *et al*. 2006) and possibly Florida cave bear have been reported. Nine human skeletons found more than 22 meters (72 ft) below modern sea level (mbsl) near Tulum, are purported to be over 10,000 years old (González González *et al*. 2006; 2013), but dating has been problematic due to the poor preservation of collagen. Researchers report a radiocarbon age of 11,670 ±60 ^{14}C yBP (13,800-13,400) on bone from the fragmentary skeleton of a young adult female (Naharon I) found near Cenote Cristal (González González *et al*. 2006), but it is unclear what bone fraction was used for age determination and no corroborative dating has been conducted. Taylor (2009), who conducted the analysis, asserts that the dated material was not identifiable as human protein. Apatite dates are reported for two other skeletons (González González *et al*. 2013), but again, the osseous fraction used is not reported. The antiquity of these early Yucatan inhabitants remains in question, but their discovery has made it clear that the caves of this region may contain a remarkable record of Mexico's and Central America's Late Pleistocene human and animal inhabitants.

Hoyo Negro

In 2007 Alex Alvarez, Alberto Nava, and Franco Attolini of the Proyecto Espeleológico de Tulum, mapping the Outland Cave of the Sac Actun system, discovered Hoyo Negro, an immense underground collapsed chamber (Attolini 2010). At the bottom they found the bones of many animals, including a human skull, and the femur and pelvis of a gomphothere. Formed by a massive collapse at the confluence of three extensive tunnels, Hoyo Negro is a bell-shaped void 37 m (121 ft) in diameter at its rim and widening to 62 m (203 ft) at the floor (Figures 6.2 and 6.3). Just 12 m (39 ft) below sea level at its rim, 18 m (59 ft) below ground, the pit drops to -36 m (118 ft) at its north end and -55 m (180 ft) along the south wall. Overhanging walls on all sides eliminate any means for ingress or egress, making it a perfect natural trap. Access tunnels are broad and high. The eastern tunnel, which we have mapped in the greatest detail, ranges from 3 to 60 m (10-197 ft) wide and is typically over 3 m (10 ft) high. North-west and south-west tunnels are narrower. Surveys identify Oasis Cenote, 600 m (1970 ft) away by the east tunnel in a nearly straight line, as the nearest Pleistocene point of access to Hoyo Negro (Figure 6.3). A narrow karst window, named Ich Balam opens in the roof of the east tunnel within 60 m (197 ft) of the Hoyo Negro rim, but the drop from it to the apex of its debris cone is ten meters (33 ft) and our radiocarbon dating of a bat midden below the cone indicates it was no more than a crack before 8,000 to 9,000 years ago. The direction of groundwater flow is west to east, from Hoyo Negro toward Ich Balam, making it highly unlikely that animals in the pit arrived as floating carcasses from this entrance. Thus we conclude that animals walked to the trap in complete darkness from one or more of three distant entrances.

Hoyo Negro, which is nine kilometers (5.6 miles) from the Caribbean coast and was within one kilometer (0.6 miles) of that distance throughout the Pleistocene, contains layered fresh and salt water, with the halocline lying at 20 mbsl (66 ft). The fresh water lens is slightly acidic (pH 6.85), the saltwater slightly basic (pH 7.16). Temperature is a uniform 25° C (77° F). Roof-collapse boulders riddled by dissolution are strewn across the pit floor, supporting a thin scattering of stalagmites formed by sparse drips from the nearly flat ceiling. Flowstone is confined to areas inside the rim and depths under 41 mbsl (135 ft). Under the overhang, the otherwise empty floor is dotted with small middens of bat droppings, animal bones, and branches of burned and unburned wood. There is little other sediment. Snow-white cones of calcite raft sediment thinly coat much of the surface in the central portion of the floor, inside the pit rim. Concentrations of small, bush-like $CaCO_3$ formations of the type known as frostwork and cave coral occur in small areas beneath lines of thin stalactites. Charcoal is ubiquitous. Bones on the cave floor are exceptionally well preserved; most, including skulls, are complete and unbroken. Most are bare; only the most-shallow specimens in the pit have a thin coating of calcite. None of the bones in the bottom of the chamber show any signs of carnivore consumption. Where bones and bat middens are superimposed, in all cases the bones at least partially underlie the midden. Bones of tapir and gomphothere have been found in the upper passages of the cave system, but in all cases these have a thick calcite coating. They are also dispersed in a manner indicative of consumption by carnivores or scavenging by carrion eaters.

The south pit wall exhibits distinct horizontal banding that has no apparent relationship to cave-limestone stratigraphy. Below 40 to 47 mbsl (131-154 ft) to the cave floor at 55 m (180 ft), the rock is the grayish-white of bare limestone; above 40 mbsl (131 ft) it appears white from a thin coating of calcite. Between lies an iron-rich orange band that can be traced across the edges of boulders in the cave center, even staining the surfaces of the frostwork and cave coral. Our observations of cave hydrology indicate this band probably precipitated from seasonal infusions of meteoric water through overlying soils, forming a temporary, discolored surface layer during the rainy season. It figures prominently in our understanding of cave history.

Field Investigations

We began the study of Hoyo Negro in December 2011, working closely with the divers who had discovered it. Work through the early months of 2014 focused on site

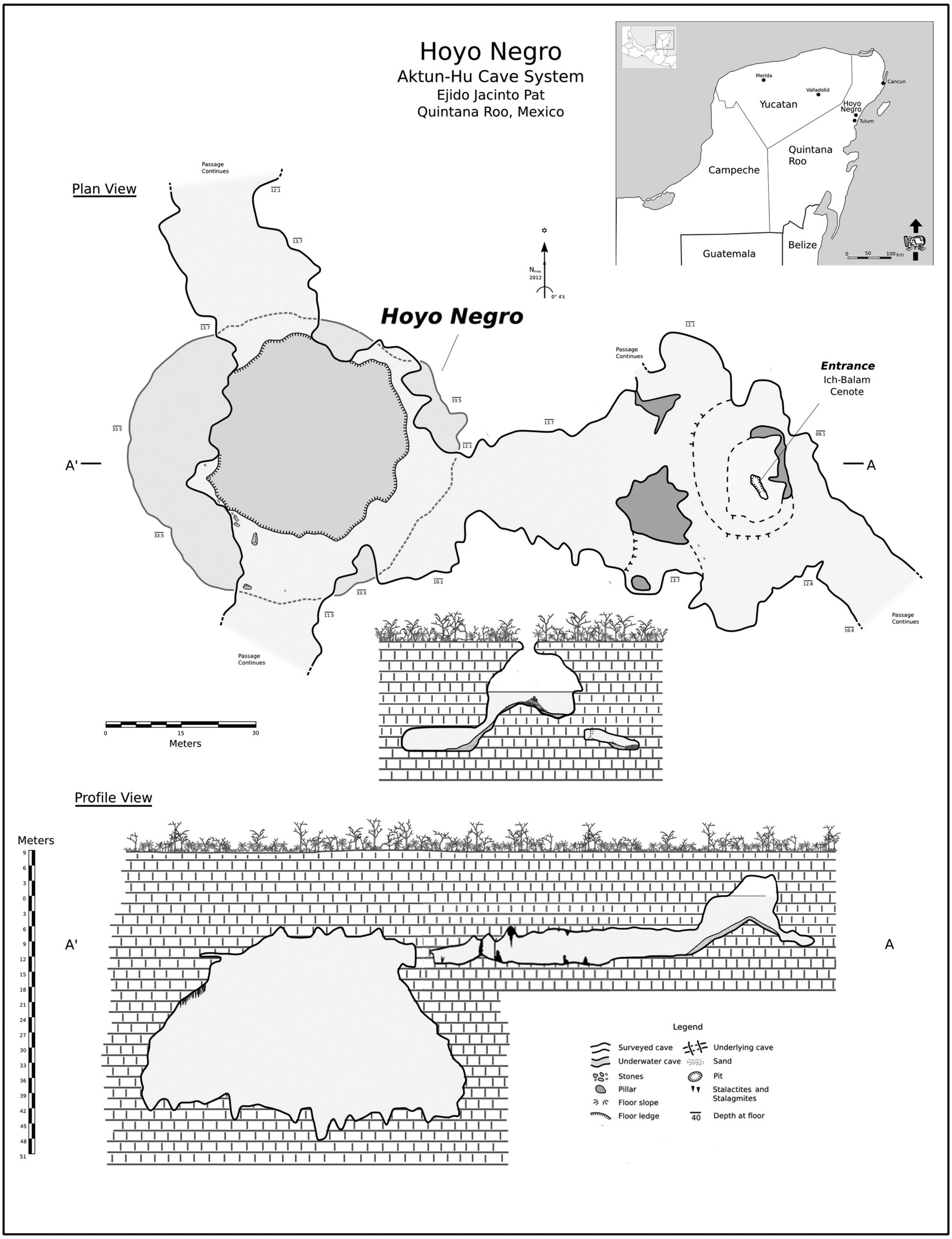

Figure 6.2. Plan and profile of Hoyo Negro (Authors).

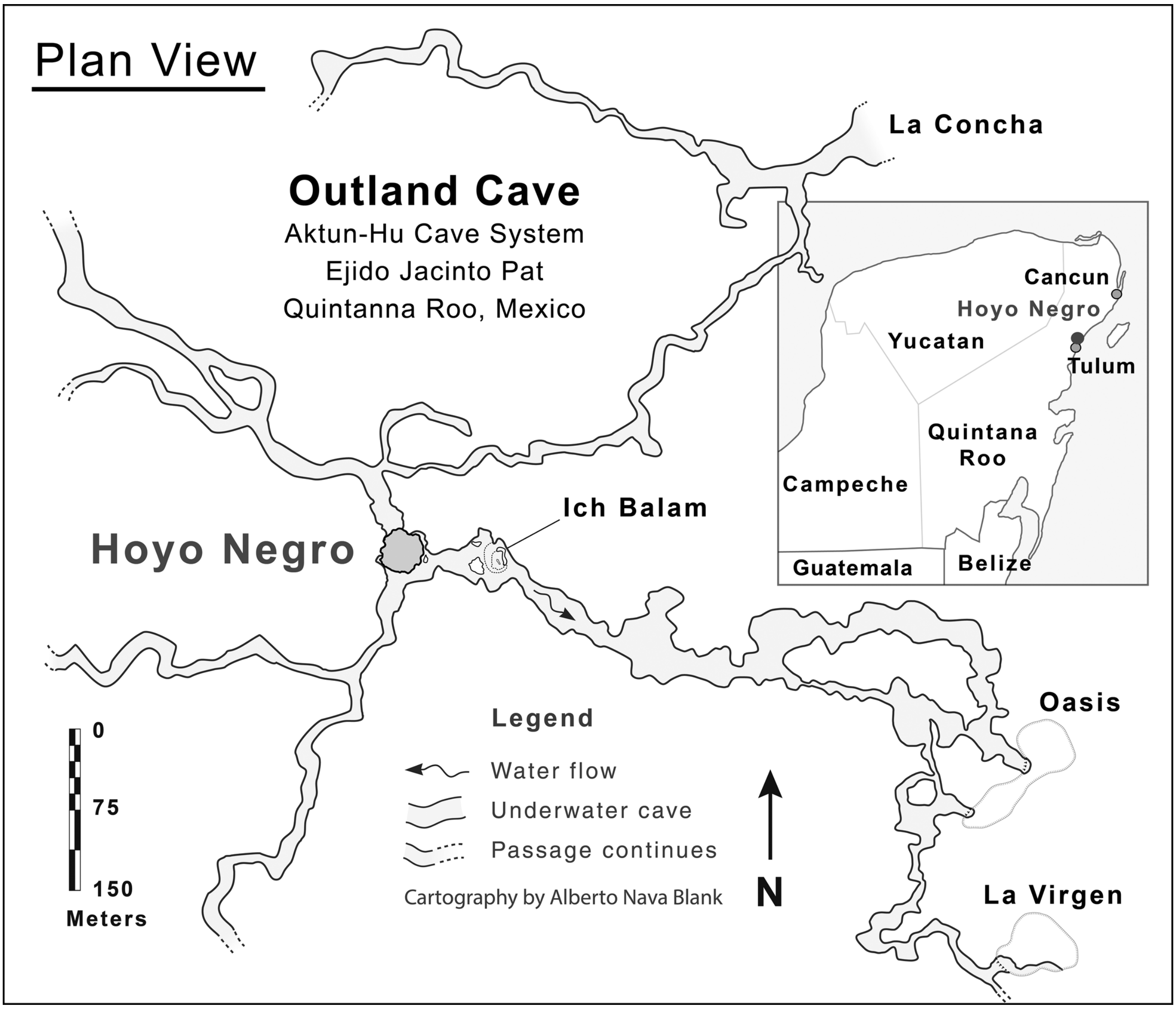

Figure 6.3. Map of Outland Cave, a portion of the Sac Actun system (Authors).

mapping, documenting the paleontological record, with an emphasis on establishing taxonomic identification, assemblage formation, and chronology. Respecting the ethics of the cave diving community and due in part to the difficulties of working more than 40 mbsl (131 ft) below sea level, we have attempted to conduct these investigations without disturbing the deposit. This included work on the human skeleton. Aside from collecting small samples of bone, tooth, plant materials, and cores of sediment, we have left the site exactly as it was found. Identifications are, therefore, provisional assessments made from scaled photographs. Divers collected data and materials following detailed, collaboratively developed procedures after repeated training. Products of this effort included samples for radiocarbon and uranium-thorium dating, paleobotanical analysis, geochemical analysis of mineral coatings, and a 3-dimensional model of the human skull and mandible.

Beginning in fall 2011 and culminating in early 2014, it became increasingly apparent that despite official closure of the site to tourist diving, unauthorized divers were entering the site. These unwanted visitors began to displace some bones, including the human skull and the skull of one bear. In 2011 we sequestered the skull within the cave, replacing it with a stand-in to avoid drawing attention to the act and triggering a search for the missing piece. By 2014, after observing that three additional human bones had been broken by these people, we developed protocols for collecting the skull and broken elements in order to preserve them. Working from measurements made from photographs and a 3-D print of the human skull based on a structure-from-motion model (created by Corey Jaskolski and Vid Petrovic), we produced sealable boxes with silicone beds for the skull and mandible as well as padded sealable recovery boxes for the other elements. These were recovered and underwent conservation at the INAH restoration laboratory in Campeche City. They now reside under tight security at the National Museum of Anthropology in Mexico City.

Paleontology

Hoyo Negro's nonhuman paleontological assemblage thus far includes 27 individuals from 12 terrestrial mammal species plus numerous skeletons of catfish and bats (Table

6.1). Seven are from the sabertooth (*Smilodon* cf. *fatalis*; Figure 6.4), gomphothere (*Cuveronius cf tropicus*) Shasta ground sloth (*Nothrotheriops shastensis*), and an as-yet-undescribed new species of Megalonychid ground sloth, all of which are thought to have become extinct at the end of the Pleistocene (Graham 2001; Grayson and Meltzer 2002; Faith and Surovell 2009). Six individuals of a form of tremarctine bear that is larger than the spectacled bear (*Tremarctos ornatus*) and has different tooth morphology than the extinct Florida cave bear (*T. floridanus*) is also present. Most of these animals occur as scattered, yet largely complete skeletons.

The Shasta ground sloth had not previously been found south of the Valley of Mexico (McDonald 2002). Two other species, the bobcat and coyote, were historically absent from the tropical jungles of the region.[1] With the possible exception of the peccary, coati, puma and tapir, which still occupy the region (Hall and Kelson 1959) the fauna of the cave is more consistent with that expected in the last full glacial pine-oak forest or thorn scrub/savanna of the deglaciation than in the tropical jungle that now occupies Quintana Roo. All but the tapir would also be at home in the cooler, more xeric environments. Many of the species, including bobcat and coyote, were also found in Pleistocene strata of Cueva Loltún, Yucatan State (Arroyo-Cabrales and Alvarez 2003; Morales-Mejía *et al*. 2009). The Hoyo Negro assemblage is a Pleistocene fauna. The dog, if that is what it ultimately proves to be, would be an important discovery as it probably dates to the Late Pleistocene.

Animal bones are strongly patterned both horizontally and vertically, forming an oval ring around the pit's south half, below the southern and eastern tunnels and a broad shelf that connects them. Only one skeleton, however, a sabertooth, lies directly beneath the rim from which it could have fallen. All others are deep behind the overhang or located toward the pit center. Depths taken for the uppermost element from each animal show that except for those in the east end of the oval, where the cave wall is entirely undercut from floor to rim, all came to rest on wall projections or sloping boulders at minimum depths between 40 and 43 mbsl (131-141 ft), 28 to 31 m (92-102 ft) below the pit rim (Figure 6.5). Some portions of the same skeletons lie as much as eight meters (26 ft) below, on the pit floor. Except for one complete, articulated Shasta ground sloth, all skeletons are scattered, often in articulated limb or vertebral units, in a manner indicative of decomposition while floating in water (Haglund and Sorg 2002). Forelimbs and scattered ribs of two sloths, for example, hang on the pit's south wall, their associated pelvic units lying on the floor more than five m (16 ft) below and up to 15 m (49 ft) laterally removed. Hind legs of two pumas are wedged in crevices far above the rest of their skeletons. This scatter pattern is also true of the aforementioned sabertooth as well as four animals that exhibit perimortem bone and tooth breakage probably due to falls into the pit. We have observed no evidence of carnivore gnawing on any elements, eliminating predation or scavenging as agents of dispersal.

Order	**Family**	**Genus/Species**	**Common Name**	**MNI**
Artiodactyla	Tayassuidae	*Pecari tajacu*	collared peccary	2
Carnivora	Canidae	*Canis latrans*	coyote	2
		cf Canis familiaris	domestic dog ?	1
	Felidae	*cf. Lynx rufus*	bobcat	2
		Puma concolor	cougar	3
		Smilodon cf. fatalis	sabertooth	2
	Procyonidae	*Nasua narica*	white-nose coati	1
	Ursidae	*cf Tremarctos sp*.	tremarctine bear	6
Primates	Hominidae	*Homo sapiens*	human	1
Perissodactyla	Tapiridae	*Tapirus bairdii*	tapir	2
Proboscidea	Gomphotheridae	*Cuvieronius cf tropicus.*	gomphothere	2
Xenarthra	Nothrotheriidae	*Nothrotheriops shastensis*	Shasta ground sloth	2
	Megalonychidae	Unnamed	ground sloth	1

Table 6.1. Large mammal species documented on the floor and walls of Hoyo Negro.

[1] Although coyote has recently been seen on the Yucatan Peninsula (Sosa-Escalante et al. 1997).

Figure 6.4. Sabertooth (*Smilodon fatalis*) and peccary (*Tayassu pecari*) skulls found at the 41 mbsl depth of Hoyo Negro. Both exhibit the iron staining common on most bones found in the cave (Roberto Chávez Arce).

All animals, we conclude, accessed the pit from the south-western or south-eastern tunnel. They fell to their deaths into water, some breaking their bones on shallow boulders during the fall, after which their bodies floated to the edges of the shallow, temporary pool as they decomposed. Their bones are often stained a dark, orange brown, teeth a bright orange, and combine with the iron-rich stain and dense concentrations of charcoal to form a distinct "bathtub ring" on the cave wall between 40 and 43 mbsl (131-141 ft), indicating that the pool was a frequently recurring feature of Hoyo Negro.

Paleobotany

The paleobotanical record of Hoyo Negro consists of plant macrofossils, including charcoal, wood, plant fiber, and seeds from bat guano deposits, as well as pollen incorporated into guano and calcite raft sediments. We have not yet initiated studies of pollen or of wood, charcoal, or fiber fragments, but preliminary identification of seeds collected from bat guano piles indicates they are from tropical fruit-bearing trees, including *Byrsonima sp., Coccoloba sp., Manilkara sp.,* and *Thevetia peruviana,* which are still common in forests of the northern Yucatan Peninsula. The apices of the guano deposits from which these seeds were obtained radiocarbon date between 9,000 and 11,100 cal BP, which is consistent with palynological evidence for tropical forest development in nearby upland Guatemala (Hodell *et al.* 2008). Coming from the top of the guano piles, however, these dates hint that tropical fruit species were present in the area above Hoyo Negro much earlier and could have been among the foods available to the area's first human inhabitants.

The Human Skeleton

The human skeleton, referred to as Naia from the ancient Greek Naiads, or water nymphs, by the research team, lies scattered across boulders just west of the pit center, beside and commingled with the bones of an adult gomphothere (*Cuvieronius* cf. *tropicus*). We have been able to locate almost all major skeletal elements, including the complete skull, both scapulae, all major arm bones, the complete pelvis, both femora, one tibia, one fibula, 19 ribs, and nine vertebrae. The deeply dissolution-fretted limestone crevices hide many smaller elements.

A broad sciatic notch and preauricular sulchus in the os coxae mark this individual as a female. The near-complete

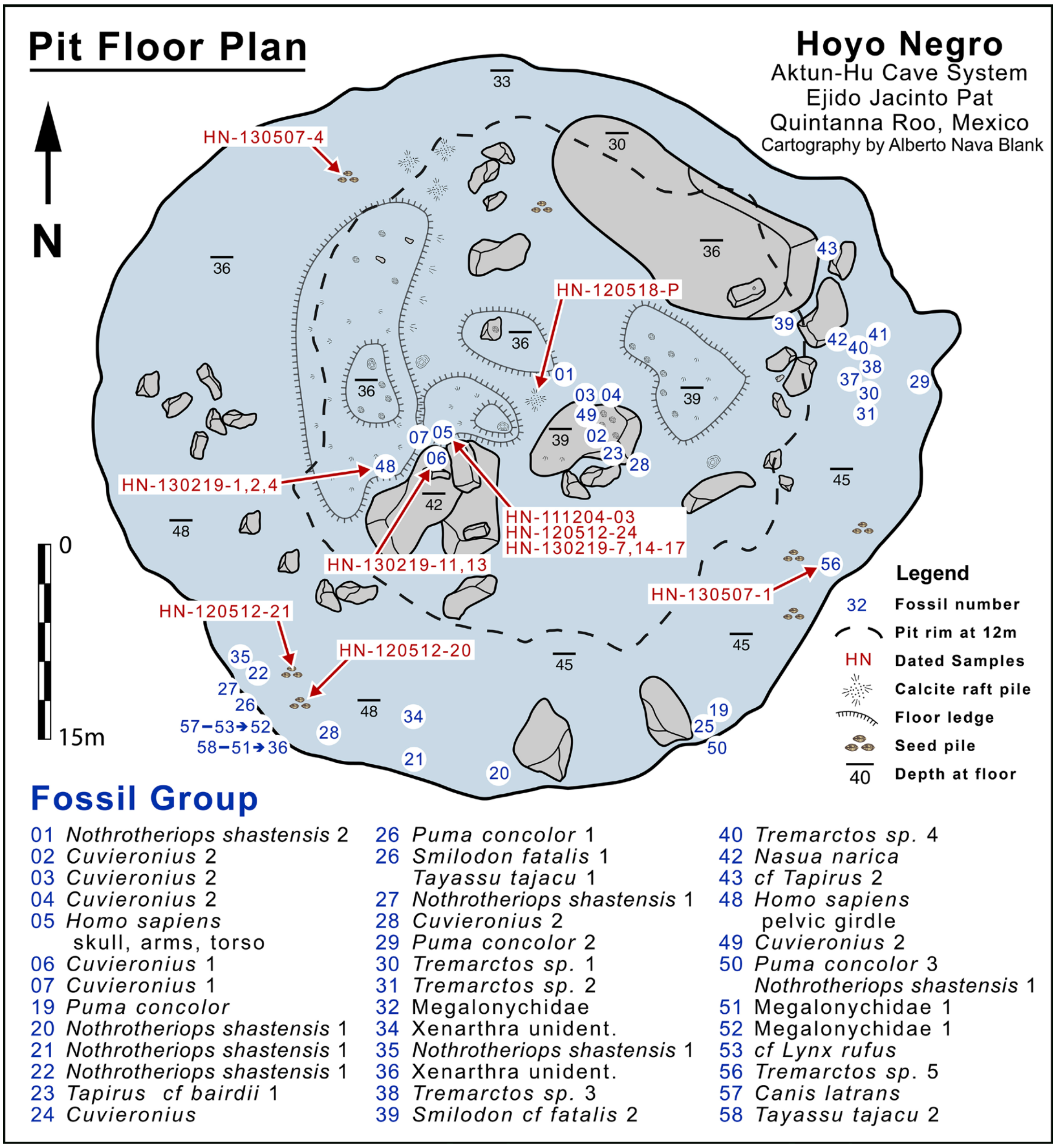

Figure 6.5. Floor plan of Hoyo Negro, showing the locations of animals and the human on the floor and walls. They are distributed over an oval area along the deeper, southern half of the pit. Numbers in boxes and preceded by HN mark samples taken for radiocarbon and uranium-thorium dating (Authors).

Figure 6.6. Cranium of Naia, the 15-16 year-old human female from Hoyo Negro, shown after recovery and conservation (J. C. Chatters).

eruption and 75% completion of the roots of the third molars and complex of epiphyseal unions indicate this girl died between 15 and 16 years of age (Chatters *et al*. 2014). Length of the mature femur, determined using a metric rule placed beside and in the same plane as the element (38.2 cm or 1.25 ft), indicates an approximate stature of 148.6±3.8 cm (4.86 ft) (based on Genoves 1967). Longbones are notably gracile. Her neurocranium is long and high (Figure 6.6), with a pronounced forehead and sharply angled occipital. The upper face is short, narrow, and small relative to the neurocranium, and lacks the everted zygomatics characteristic of later Native Americans. The palate is long and parabolic, with shoveled (but not double shoveled) central incisors, third molars approximately equal in size to the second, and a strongly developed Carabelli cusp on the upper first molar. CT scans indicate the lower first molars, as well as the second and third, are two-rooted and the upper premolars are all two-rooted. Prominent enamel extensions are observable on all first and second molars. She exhibits moderate alveolar prognathism. In general, cranial characteristics and the complex of dental traits are comparable to those seen in Paleoamerican females (Powell 1993; Steele and Powell 1994), including Peñon (Jiménez López *et al*. 2006), Buhl (Green *et al*. 1998), and Wilson-Leonard (Steele 1998), and in Upper Paleolithic humans across Eurasia (Lahr 1996).

The characteristics and spatial distribution of human bones are similar to those of other skeletons in Hoyo Negro. Elements are intact except for what appear to be perimortem fractures of both pubic bones and post-discovery fractures of one zygomatic, both nasal bones, and a scapula, humerus and clavicle. It appears this young woman fell face down onto a hard surface. Her elements are scattered in four semi-articulated groups across a span of five meters (16 ft) at between 41.6 and 41.9 mbsl (136-137.5 ft), the pelvis and legs in one area, torso, partially articulated arms, and skull in another. Again, the pattern indicates decomposition while floating in water. The fact that all larger elements are within 30 cm (11.8 in) by depth indicates water level was just above 41.5 mbsl (136 ft) at the time of decomposition, the middle of the range in which the Pleistocene fauna occurs. This includes an adult gomphothere, bones of which are commingled with the girl's, with two of her ribs and one vertebra lying beneath ribs and a patella of the larger animal. This raised the tantalizing prospect that the young woman was a contemporary of the diverse Pleistocene fauna found at the same depth.

Chronology of the Site

To date we have established only the ages of Naia and the associated gomphothere using a combination of uranium-thorium and radiocarbon dating (Chatters *et al*. 2014). Dentin of teeth from both individuals and a rib from Naia, sampled in 2011 and 2012, were found to be virtually devoid of protein or remnant amino acids, so analyses were conducted on bioapatite of the tooth enamel. Enamel from Naia's upper left third molar, pretreated independently at Stafford Laboratories and Pennsylvania State University and measured at the Keck Carbon Cycle AMS facility of the University of California, Irvine, produced statistically identical results of 10,970±25 RCY BP (12,976-12,655 cal BP at 95.4%, SR 6205) and 10,985±25 RCY BP (13,065-12,670 cal BP, PSU 5193) (Chatters *et al*. 2014, table S3). The near-identity of these ages despite differences in pretreatment strongly indicates that this is probably the correct age for the specimen. However, radiocarbon analysis of apatite from a fragment of rib produced a much older date of 16,164±78 RCY BP (19,741-19,246 cal BP) indicating the potential for contamination of the enamel by old carbonate (Hedges *et al*. 1995) to have produced an artificially early age. The gomphthere enamel produced much older ages of 36,250±370 (SR 8260) and 33,190±370 RCY BP (PSU 5493) or between 36,400 and 41,600 cal BP. Again, contamination was a potential problem.

The upper limiting age of Naia and the gomphothere was established by conducting uranium-thorium analyses of bush-like calcite "florets" that we believe formed on the bones from drip water mist after the bones had come to rest on the cave floor and before the 42 m (138 ft) level of the cave had become inundated by rising sea level. Bone beneath the florets, when exposed, was stained a dark brown from what we have determined to be iron compounds. We have observed that bone, when it lay permanently in contact with another bone, stone, or crystallizing material, retained a bright white color. Bone beneath the florets was stained brown, indicating it had been periodically submerged for some time before the florets began forming. Many of the florets are also stained, indicating they, too, were periodically inundated after formation. Nine measurements on florets from a human scapula, mandible and rib formed between 12,100 and 9,600 years ago; five from the gomphothere pelvis ranged from 19,000 to 11,500 years (Chatters *et al*. 2014: table S3). The youngest date on the florets from human bone indicates sea level curtailed formation of the crystals shortly after 9,600 years ago.

Bat middens provided a check on this assertion. They consist primarily of fecal matter and large seeds from tropical forest trees, produced by bat colonies roosting in dissolution pockets of the cave ceiling and overhanging pit walls. Bats can maintain access to these roosts as long as their entrances remain above water, so the age of the detritus at the top of a midden pile should mark the flooding of a roost as the water table rose with sea level during the last deglaciation. We sampled two subaqueously deposited midden piles (M1 and M2) on the south-west end of the floor, which lie beneath roosts situated well below the pit rim. Ages of seeds from the middens' apices predate sea level reaching those elevations. A third midden (M3) near the center of the floor was found beneath a cone of calcite rafts at 42 mbsl (138 ft), the same elevation as the florets sampled from the human and gomphothere. That midden lacked ostracods and raft debris, indicating it was subaerially deposited. It was deposited shortly before the water level rose above the 42 m (138 ft) mark, making it a means for corroborating the U/Th results. M1 dates to 10,197-9914 cal BP and M3 to 9764-9583 cal BP, providing an additional *terminus post quem* for the human skeleton and confirming the rise of sea level past the elevation of the skeleton at around 9,600 cal BP.

This sequence of ages enables us to construct the following chronology for Hoyo Negro. Between at least 37,000 and 9,600 cal BP, the pit periodically held a temporary pool of water, probably during the stormiest rainy seasons. The surface of that pool probably most often stood between 40 and 43 mbsl (131-141 ft). The pit episodically trapped large animals, which would fall nearly 30 m (98 ft) to their deaths. Their bloated bodies floated to the pool margins, where they slowly decomposed, scattering bones as they went. At about 13,000 years ago, when the young woman arrived, water stood above 41.5 mbsl (136 ft). She lay there, periodically being inundated by seasonal floods long enough for her bones to darken from minerals and humic acids in the water. Water then dropped shortly before 12,000 years ago, allowing subaerial $CaCO_3$ florets to form and bat droppings to accumulate just above the water level. Water then rose rapidly at around 10,000 years ago, again submerging the skeleton and florets, and quickly raising the water level above 20 mbsl (66 ft). The evidence for a temporary fresh water pool between 55 mbsl (180 ft), the cave floor, and 40 mbsl (131 ft) is contrary to expectations if the deeper layers of limestone behave like the surface strata and allowed the water table to track sea level. If that were true, the water level should have stood closer to 60 mbsl (197 ft) at the time the young woman died, not 42 mbsl (138 ft). This would seem to belie the bioapatite date on the woman's tooth, but the evidence for the temporary pool's existence - iron staining, charcoal accumulation, and skeleton accumulation - is strong enough that we are convinced of its existence.

Collectively, the U/Th series for florets developed on the human bones, terminal ages of bat middens, and evidence for sea level rise, support the bioapatite age for the woman. Hers is, therefore, verifiably one of the oldest human skeletons yet found in North America. If the age on her enamel is accurate, which probability states it should be, she is the first complete individual to date within the time of the Clovis expansion (Waters and Stafford 2007).

Genetic Heritage of the Human

To determine if the young woman was of Asian or other derivation, we extracted aDNA from the root of the third molar used for the bioapatite ^{14}C date, duplicating the effort at Washington State University and University of Texas at Austin and conducting mtDNA sequencing at the University of Illinois at Urbana-Champaign. Results place Naia in mitochondrial sublineage D1 (Chatters *et al*. 2014). This sublineage, although uncommon, is found throughout the Americas and therefore is considered to be one of the founding haplogroups carried into the Americas by the initial migrants out of Beringia.

Conclusion

Work in Hoyo Negro is far from finished. We have initial identifications on the many animals found on the cave floor and determined the ages of just two of the 28 we currently know of. The girl, Naia, who has Paleoamerican physical characteristics, dates between 12,000 and 13,000 cal BP and probably closer to the older end of that span. Ancient DNA analysis has demonstrated that her people were of a Beringian lineage. If indeed she is coeval with Clovis, and since Clovis is the earliest known culture in Central America, this finding may prove that Clovis people did not, as Stanford and Bradley (2012) suggest, develop out of the Spanish Solutrean. The animals that lie with her near the cave floor include numerous extinct and extant species, including two that might be new to science. They began falling into the cave, perhaps lured by the scent of the temporary pool, at least as long as 37,000 years ago. We can say only that the rest of the animals died before the pool ceased to form around 10,000 years ago. Some or none might be contemporary with Naia.

Much remains to be done in Hoyo Negro. We continue to map the cave passages, seeking a closer, Pleistocene entrance that would account for so many animals this far underground. We are taking detailed photographs of the cave floor with the intent of producing a scaled map of the paleontological deposits and 3-D model of the most important areas. Coring of more calcite raft deposits and bat guano heaps and sampling of calcite and mineral deposits on the pit walls will allow us to refine the climatic history of the region through stable isotope, palynological, and macrobotanical analyses. Additional radiocarbon and uranium-thorium dating will hopefully allow us to determine, in detail, the chronology of animal deaths and thus, along with paleobotanical data, develop a paleoecological image of the eastern Yucatan Peninsula during the last deglaciation. This site is almost without equal. It is a time capsule of the terminal Pleistocene in an area for which that interval remains a mystery. We are eager to reveal that capsule's secrets.

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Larry E. Murphy began his underwater archaeology career with the Florida Underwater Archaeology Research Section in 1973 working on maritime sites and the Warm Mineral Springs Archaeological Research Project. A diving instructor since 1972, he began cave diving in 1974 and was an active exploratory cave diver through the 1970s. Murphy joined the

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Alberto Nava Blank is visiting scholar at the University of California/CISA3 who holds a Masters degree in Computer Science from Simon Bolivar University in Venezuela. He is a cave explorer and cartographer working in the underwater caves of the Yucatan Peninsula. Part of the team that discovered Hoyo Negro he has been a co-director of studies at the site since 2010.

Lee A. Newsom is an Associate Professor with the Department of Anthropology and a member scientist of the Institutes of Energy and the Environment at The Pennsylvania State University. Her research emphasizes Environmental Archaeology in theory and practice, drawing especially on insights from paleoethnobotany, island biogeographic theory and human niche construction to consider issues involving biotic resources and human social organization, plant and animal domestication, the evolution and transformation of Caribbean garden systems, and the so-called "Columbian Exchange", i.e. the global biotic interchange that had its inception in 1492. Her (2004) co-authored book with Elizabeth Wing, *On Land and Sea: Native American Uses of Biological Resource in the West Indies*, concerns Environmental Archaeology in the Caribbean. In 2002 Newsom was named a MacArthur Fellow and she has since used that award to foster a variety of projects and initiatives in the region.

Elsa Nuzzo has a Ph.D. in classical archaeology. After obtaining her degree, Elsa received a postdoctoral specialization at the Scuola Archeologica Italiana, Athens. Her research topics range from architecture to marble sculpture in the Roman age. She has attended as a curator to the set-up of Museo Archeologico dei Campi Flegrei a Baia (Bacoli, Italy).

John A. Peterson is currently Assistant Vice President for Graduate Studies, Research, and Sponsored Programs at the University of Guam and a Vice President and expert member, ICOMOS Committee for Archaeological Heritage Management. He is conducting landscape and historical ecology studies in the Philippines and in the Western Pacific region. He has worked in the American Southwest, Northern Mexico, Congo-Brazzaville, People's Republic of China, Ecuador, Hawaii, Guam, Palau, Saipan, and the Philippines. The Marigondon Project is his first underwater project and was undertaken to assess landscape changes and opportunities for Paleolithic settlement in the Philippines.

Eduard Reinhardt is a Professor at McMaster University in the School of Geography and Earth Sciences with a research focus on coastal geoarchaeology and cave paleohydrology. He uses microfossil (foraminifera and testate amoebae), geochemical (O, C and Sr isotopes, trace elements) and sedimentological proxies to reconstruct environmental change.

Sandra Ricci is a biologist working at the ISCR (Ministry of Cultural Heritage and Activities and Tourism -Rome) since 1981 where she directs the Marine Biology Area. Her research focuses on marine bioerosion due to endolithic and epilithic marine organisms characterizing submerged archaeological artefacts in the Mediterranean Sea.

Dominique Rissolo is an archaeologist with expertise in site formation in the cave context. His research interests include cave and cenote use by ancient Maya and Paleoamericans as well as Pre-Columbian coastal human ecology on the Yucatan Peninsula. Rissolo is the special projects coordinator for the Center of Interdisciplinary Science for Art, Architecture, and Archaeology (CISA3) at the University of California, San Diego.

Carmen Rocha is currently a Ph.D student in the Metallurgy and Materials Engineering Department at The University of Texas at El Paso (UTEP). She works as a Research Assistant student under the supervision of Dr. David Roberson developing novel plastics for the 3D printing industry at the W.M. Keck Center for 3D innovation at the University of Texas at El Paso.

Rosario Santanastasio is a geologist who graduated from University of Naples "Federico II." Currently he is a research freelancer with the Superintendency of Archaeology in Campania and University of Naples "Federico II" relating to the geoarchaeology of the Gulf of Naples and Pozzuoli. He has authored various publications on the subject of erosion affecting coastal archaeological sites, both terrestrially and underwater. He is the head of Marenostrum Archeoclub of Italy. Currently, he is the director of the geology and geoarchaeology Elleesseitalia society performing survey in coastal areas.

Eugène Warmenbol is professor at the Université libre de Bruxelles, teaching "Bronze and Iron Age Archaeology of North-Western Europe." Early in his career he excavated in Egypt and Syria, and he is presently involved in several projects in Belgium and France. One of them aims the full publication of the numerous underwater finds from the cave of Han-sur-Lesse, from Prehistory to Roman times, and their study in a wide European context.

The sea encroaches on a painted panel of horses in Cosquer Cave, France, that dates to over 18,000 years ago.

The Archaeology of Underwater Caves is an exploration of karst and marine caves around the world. Caves have drawn explorers since early forays by John Leland, King Henry VIII's antiquary, at Bath in 1545, Helisäus Rößlin at Niederbronn-les-Bains in 1593, and the discovery of Capri's Blue Grotto in 1606. Caves were at the forefront of modern underwater exploration such as at Wookey Hole (1935-1946) and Jacques Cousteau's team in 1946, as well as featured in popular books like Cousteau's *Silent World*, Sheck Exley's *Caverns Measureless to Man*, and Dan Lenihan's *Submerged.* In 1966, George Bass, the father of nautical archaeology, wrote that underwater caves had "so far defied thoughts of proper excavation... [but] technical advances may be able to untangle the jumbled context at a future date." In the foreword Bass announces, "that 'future date' has arrived."

Underwater caves provide insight into areas critical for understanding the past, such as drowned landscapes and religion since the Paleolithic. Karst systems provide a window into ritual cave use. The Roman Servius wrote, "There is no spring that is not holy." Indeed, Solomon was anointed king of Israel at the Gihon Spring, Jason and the Argonauts cast *Argo*'s anchor into the Artacie Spring, Buddha was born at the Lumbini Spring, and the angel Gabriel created the Zamzam Spring for the infant Ishmael at Mecca. Archaeology in these underwater cave systems can provide unparalleled perspective on ancient cultures. Alfred M. Tozzer described Chichén Itzá's Sacred Cenote by saying, "There is perhaps no other single collection in New World archaeology that has offered so comprehensive a view of the aesthetic life of an ancient people." Elsewhere, the most sensitive organic remains – brain tissue dating to 7,000 and 10,000 years ago – are preserved in underwater caves.

The volume draws on the last sixty years of research in springs, cenotes, flooded caverns, sea caves, and cave lakes with chapters written by original excavators. Authors address topics including early humans, sea level and climate change, ritual and religion, and art from many different cultures. The sites span the globe and include famous caves such as France's Cosquer Cave, Mexico's Hoyo Negro, and Italy's Blue Grotto.

Many readers will find *The Archaeology of Underwater Caves* fascinating, from divers exploring underwater passages to historians searching written passages, from archaeologists who dive in to anthropologists who study communities on the surface, and those interested in human origins to those seeking an understanding of religion. As each chapter explores, underwater caves are rare sites providing incredible perspective on ancient cultures.

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ISBN 978-0-9926336-7-7

3D model of the Poseidon statue found in the Blue Grotto on Capri.