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Kings and commoners at Copan: Isotopic evidence for origins and movement in the Classic Maya period

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A B S T R A C T

Eight human interments were excavated in the 1990s beneath the Acropolis at the Classic Maya site of Copan in Honduras, which was the capital of a Maya kingdom from ca. AD 400 to 800. These human remains come from both royal tombs and less elaborate burials dating to the early part of this period and lie deep in the accumulated architectural layers of the Acropolis. We present a brief summary of the context, contents, and external links represented by these interments. Several lines of evidence point to connections between early Copan and Teotihuacan in the Central Highlands of Mexico, and Tikal in the central Maya lowlands of the Petén in Guatemala.

The bioarchaeology of the interred individuals from the Copan Acropolis is summarized in terms of major characteristics and life history. The focus of this study is the isotopic investigation of these individuals, which included both light and heavy isotopes. We have measured carbon and nitrogen in some of the burials along with strontium, carbon, and oxygen in tooth enamel. In addition, we have a substantial database of strontium isotopes from human burials and both ancient and modern fauna at the site that help to characterize the local isotope ratio at Copan. This information is compared with the larger Maya region and the site of Teotihuacan in the Central Highlands of Mexico to examine questions of human migration and interaction in the Classic Maya period. Focus is on the primary burial identified as K'inich Yax K'uk' Mo', the first dynastic ruler of Copan. Epigraphic information on his early years and subsequent events in his life are compared to isotopic data on his place of birth and possible movements. The isotopic evidence suggests that several of the individuals buried in the Acropolis at Copan, including K'inich Yax K'uk' Mo', were not born in the local area, but came to this ancient city from elsewhere.

Introduction

Copan was an important capital of a Classic period Maya state. The site covers an area of some 4 km^2 in the Copan Valley in western Honduras. Construction at Copan began in the first part of the Early Classic period (ca. AD 200–400). In AD 426/427 Copan's royal dynasty was founded by K'inich Yax K'uk' Mo', the first of 16 kings who ruled the city and its polity for about 400 years, until ca. AD 820 at the end of the Late Classic period (Fash, 2001; Andrews and Fash, 2005).

Copan is composed of a civic and ceremonial core, surrounded by elite and commoner residences. Its peak population is estimated at between 20,000 and 30,000 people (Webster et al., 1992). Excavations of deeply buried levels beneath the Acropolis at the center of the site (Fig. 1) have exposed a sequence of Early Classic buildings and burials from the early dynastic era (ca. AD 400–600) that reveal much about the initial development of the city and its kingdom (Bell et al., 2004a).

The evidence presented here was recovered by tunnels excavated by the Copan Acropolis Archaeological Project (PAAC), directed by William Fash, and the Early Copan Acropolis Program (ECAP), directed by Robert Sharer (Andrews and Fash, 2005; Bell et al., 2004b). These projects applied multiple lines of evidence to test and refine a series of research propositions (Fash and Sharer, 1991). Some of these questions addressed interaction between Copan and other Mesoamerican cities. Architectural data reflects links to several Mesoamerican regions: the central Petén, the

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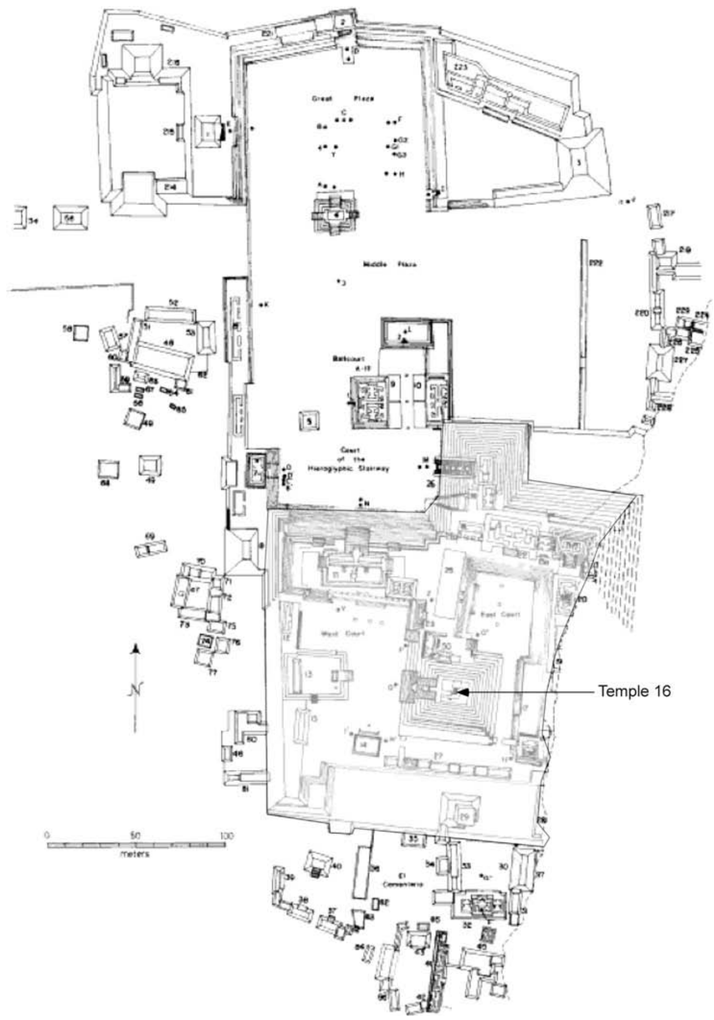

Fig. 1. Plan of the Principal Group at Copan, showing the location of the Acropolis, plazas, and associated architecture. The Acropolis itself is shaded in this drawing. The east side of the Acropolis has been partially destroyed by river cutting and erosion (after Fash, 2001).

Valley of Guatemala and the Valley of Mexico (Fash, 2001; Sharer, 2003a,b, 2004; Sharer et al., 1999, 2005). Pottery and other artifacts from these same regions suggest trade and political ties (Reents-budet et al., 2004; Sharer et al., 2005). Other questions tested the historicity of Maya texts (Sharer, 2004; Sharer et al., 2005). Copan's inscriptions reveal that K'inich Yax K'uk' Mo' was a foreigner who was inaugurated in AD 426 and arrived at Copan in AD 427 (Schele, 1986; Stuart and Schele, 1986). Some evidence associates K'inich Yax K'uk' Mo' with Tikal in the central Maya lowlands (Martin and Grube 2008; Sharer, 2003b, 2004; Stuart, 2004: 219–221), and a recent finding suggests his origins at Caracol in Belize (Stuart, 2007). The research reported here focuses on the continuing isotopic analysis of human remains from Early Classic Copan, and more specifically on strontium and oxygen isotopes, which provide data on ancient migrations and the founder's origins (Buikstra et al., 2004).

We begin by summarizing some results of the PAAC and ECAP excavations. The architectural settings of the burials are briefly described, along with associated evidence for Copan's external connections, to provide the context for the isotopic studies. The isotopic investigations involve both light and heavy isotopes for information on diet and place of origin. Principles and methods for these isotopic analyses are followed by the results and interpretation of the measurements. Our conclusions summarize the results of the study in the larger context of early Copan and Maya civilization.

The early Acropolis structures at Copan

The Acropolis (Fig. 1) was continuously rebuilt over the course of the Classic period, ca. AD 400–800. It was a private royal precinct, the residence of the king, and the seat of power for the ruler and his court (Agurcia, 2004; Fash, 2001; Sharer et al., 2005; Traxler 2003). On the northern edge of the Acropolis William Fash's excavations beneath Str. 10L-26 discovered remains from the dynastic founding era. A round monument, the Motmot Marker, was found in front of the earliest building under Str. 26 (Fash, 2001; Fash et al., 2004; Stuart, 2000, 2004). Its carved surface portrays K'inich Yax K'uk' Mo' and his son, Ruler 2 celebrating the great 9.0.0.0.0 (AD 435) period ending in the Maya calendar (Stuart, 2004).

The Motmot Marker covered a circular masonry chamber, ca. 1 m in diameter, recalling burial practices in Central Mexico (Fash and Fash, 2000; Fash, 2001). The tomb held Burial 37-8, a primary interment of an adult female and a human skull, designated Burial 37-7 (Buikstra et al. 2004; Fash et al., 2004. The chamber was later re-opened for fire rituals and the placement of offerings and two more human skulls, designated Burials 37-9 and 37-10. The tomb was then sealed beneath the Motmot Marker and later constructions (Fash, 2001; Fash et al., 2004).

Three royal tombs and four burials were revealed by ECAP's tunnels amid constructions and monuments from the reigns of

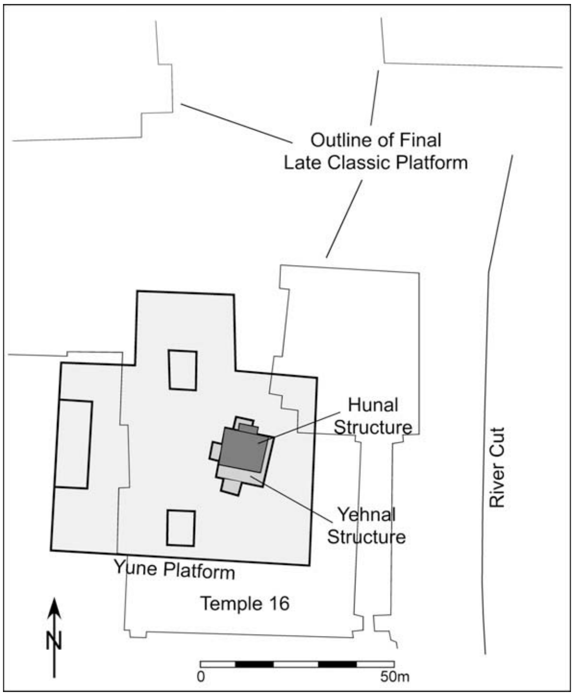

Fig. 2. The Yune platform, which supports the Hunal and Yehnal structures at the base of the Acropolis, buried beneath Temple 16.

Copan's earliest kings (Fig. 2; Sedat and López, 2004). An inscription from an early level records a date equivalent to November 30, 437, only a decade after the dynastic founding (Sharer et al., 2005). The earliest level comprised structures built around a central court. An earthen substructure ("Uranio") on its north side contained Burial 93-1), a presumed dedicatory sacrifice.

On the court's east side was a masonry building ("Hunal"), constructed in the talud-tablero style of Central Mexico (Fig. 2; Sedat and López, 2004; Sharer et al., 2005). This widespread style links Hunal structure with the great Early Classic city of Teotihuacan (Sharer, 2003a), as well as the Maya highlands and the Petén lowlands of Guatemala (Sharer, 2004). The evidence suggests Hunal was K'inich Yax K'uk' Mo's residence (Sharer et al., 2005). A vaulted masonry tomb was constructed beneath its northern room and held the bones of an elderly man on a stone bier (Burial 95-2). Several lines of evidence identify this tomb with Copan's dynastic founder, K'inich Yax K'uk' Mo' (Sharer, 2004; Sharer et al., 2005).

After K'inich Yax K'uk' Mo's death, Ruler 2 expanded the royal compound begun by his father. Hunal was succeeded by a series of superimposed funerary temples. The first of these was built as an orthodox Maya temple (Fig. 2; Sedat and López, 2004; Sharer et al., 2005). A second funerary temple ("Margarita") replaced Yehnal, also rendered in lowland Maya style. Beneath Margarita's floor is a vaulted tomb, which held the bones of an elderly woman (Burial 93-2) and an array of adornments and offerings. Its location, size, and bountiful offerings indicate that this woman was a powerful royal lady. Her name is unknown since no women are mentioned in Copan's texts at this time, but it is likely that she was K'inich Yax K'uk' Mo's queen and the mother of Ruler 2 (Bell, 2001; Sharer et al., 2005).

The Margarita Tomb remained accessible for funerary rituals by a vaulted passageway entered from the north side of a later structure (Mitzil platform) that covered the Margarita temple (Sharer et al., 2005). A presumed sacrificial guardian (Burial 94-1) was interred adjacent to this passageway. A similar unembellished sacrificial interment (Burial 92-1) was found in the construction fill at the base of Teal platform, a slightly later stage of the Acropolis, although the individual apparently had been dismembered prior to burial (Bell et al., 2004a).

At about the time the royal woman was buried in the Margarita Tomb, Allamanda platform was constructed to its west, burying the Margarita substructure. This new platform held the interment of a young male (Burial 95-1). Wearing a warrior's shell goggles, he was covered by matting with his weapons and other offerings (Bell et al., 2004a; Sharer et al., 2005). These trappings indicate high status; he may have been an elite captive sacrificed to guard both Burials 93-2 and 95-2 (the Margarita and Hunal tombs) to the east (Sharer, 2003a).

Soon thereafter the royal Acropolis was expanded to the north, burying a sequence of earlier royal palaces (Sharer et al., 2005; Traxler, 1996, 2003). A tunnel within this Acropolis level revealed a buried courtyard from the time of Copan's eighth ruler, Wil Ohl K'inich (reigned AD 534–551). On its east side was an elaborate temple dedicated with a carved hieroglyphic step that records the name and inauguration of Wil Ohl K'inich (Stuart, 2004). Excavation directly west of his temple discovered the SubJaguar Tomb (Fig. 3) that held a male skeleton on a stone burial platform covered with adornments of jade and shell (Burial 92-3).[1] This is the likely tomb of Copan's eighth king, given its location on the same east–west axis as Wil Ohl K'inich's temple across the court. In addition, the tomb's offering vessels date to about 550, matching the 551 date of Wil Ohl K'inich's death (Bell et al., 2004a; Sharer et al., 2005).

The Acropolis burials

The burials from the early Copan Acropolis excavated by the PAAC and ECAP come from four tomb chambers, the Motmot Tomb (Burial 37-8) including three "trophy" skulls (37-7, 37-9, and 37-10), the Hunal Tomb, (Burial 95-2) the Margarita Tomb (Burial 93-2) including a separate human mandible, and the SubJaguar Tomb (Burial 92-3). Also included are four interments from construction fills, Burials 92-2 (Teal platform), 93-1 (Uranio structure), 94-1 (Mitzil platform), and 95-1 (Allamanda platform).

The Motmot Tomb (Burials 37-7, 8, 9, and 10)

The primary interment within the Motmot Tomb was a young adult female estimated to be 22–29 years of age and between 146 and 168.5 cm in stature (Burial 37-8). The post-cranial remains are quite gracile, suggesting that this individual led an inactive life. The only notable skeletal pathologies are a healed midshaft fracture of the right ulna and perhaps of the proximal right humerus (Buikstra et al., 2004). Three adult human skulls (Burials 37-7, 37-9, and 37-10) and a few neck vertebrae were accompanied by several pottery vessels and other offerings within the Motmot Tomb. Cut marks are present on cervical vertebra 5 of skull 37-10 (Buikstra, 1996; Buikstra et al., 2004: 202). All the skulls appear robust and were therefore probably males.

The Hunal Tomb (Burial 95-2)

This vaulted tomb chamber contains the bones of a single individual placed supine on a stone bier, head to the south, adorned by several large jade objects (Fig. 4). As already noted, several lines of evidence suggest that these are the remains of the dynastic

[1] The SubJaguar Tomb (Burial 92-3) was misnumbered as Burial 92-2 in a previous publication (Bell et al., 2004b), and the burial labeled 92-3 in that publication is actually Burial 92-2.

Fig. 3. Artist's reconstruction of the Acropolis, showing Structure 16 and its sequence of buried temples (upper left) and the SubJaguar Tomb beneath the East Court (center). Note the modern tunnel openings along the eastern side of the Acropolis, into the eroded mound. Christopher A. Klein/National Geographic Stock.

Fig. 4. The primary burial in the Hunal Tomb, probably K'inich Yax K'uk' Mo'.

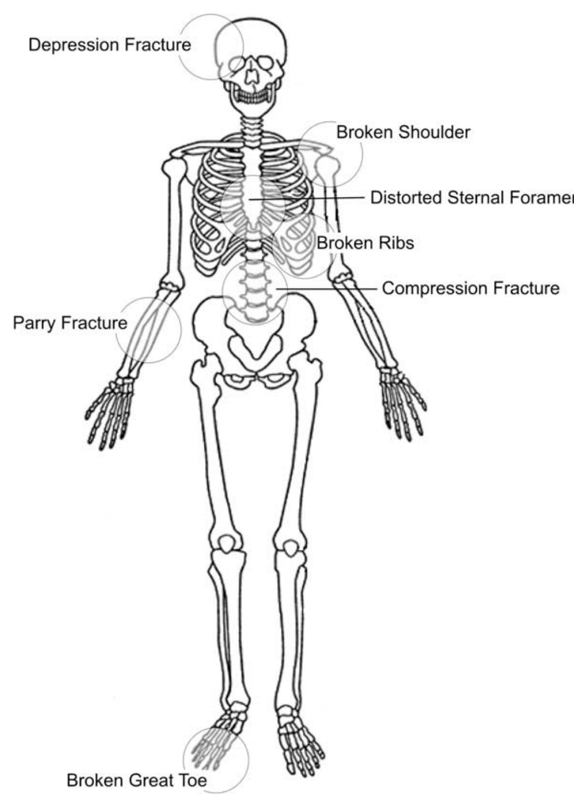

Fig. 5. Location of injuries visible in the skeleton of the Hunal burial.

founder, K'inich Yax K'uk' Mo'. Some bones on the slab had been displaced varying distances from their original positions. This, along with the deposition of cinnabar pigment on many of the bones, suggests that the tomb was re-opened some time after the body was interred. There was also disturbance from masonry collapse, presumably due to earthquakes, and movement of offerings on the tomb floor by water infiltration (Bell et al., 2004a).

The bones are of a robust male, a little over 168 cm tall, who was probably 55 years of age or older when he died (Buikstra et al., 2004). The skull exhibits slight fronto-occipital artificial deformation and the posterior portion was also deformed by pressure, conforming to the "classic" tabular erect pattern (Tiesler Blos, 1998, 1999). The Hunal individual's dentition was decorated both with jadeite inlays and by filing.

The most striking physical evidence of lifestyle for this individual comes from the extensive blunt force trauma that had been absorbed during adulthood, but long before death (Buikstra et al., 2004) (Fig. 5). One remarkable injury involved the left shoulder, possibly from the results of a fall. The superior third of the glenoid fossa and the coracoid process of the scapula had separated from the remainder of the bone and this fracture never healed. The posterior of the right parietal of the skull displays evidence of a healed, depressed fracture approximately 4 by 2.5 cm in diameter, likely the result of a blow to the head. There was also a "parry" or "nightstick" fracture at the midpoint of the right forearm. The fracture was not reduced and the radius showed significant angulation. The broken ulna from this fracture also did not heal, creating a false joint. The sternal foramen is distorted, apparently the result of blunt force injury to the chest. In addition, one or more ribs had broken and healed. The spine exhibits arthritic joints and a compression fracture that may be related to direct injury or secondary results of trauma to other parts of the body. Finally, there is a vertical fracture through the distal phalanx of the right great toe.

The Margarita Tomb (Burial 93-2)

This elaborate tomb contains the remains of an important royal woman, placed supine (head to the south) on a broken stone slab, along with offerings. Most of the bones composing the upper portion of the body remained intact and articulated, despite severe disturbances and masonry collapse that had caused the breakage of the burial slab. The bones on both the northern and southern slab fragments rested in a layer of red pigment composed mostly of cinnabar (Bell et al., 2004a).

The skeletal remains were from a single individual whose pelvic structures include a wide sciatic notch and ischiopubic indicators consistent with a sex diagnosis of female. The left pubic bone is nearly complete, presenting deep "gestation pits" on its dorsal aspect and pubic symphysis morphology consistent with an age-at-death in advance of 50 years (Buikstra and Ubelaker, 1994). This individual was relatively tall, compared to Danforth's Early Classic Maya female 140.6–163.9 cm range (1999: 109). The skull exhibits intentional cranial deformation following a pattern similar to that of the Hunal individual (Buikstra et al., 2004).

The SubJaguar Tomb (Burial 92-3)

An elaborate tomb attributed to the 8th ruler in the Copan dynasty was located within later Early Classic construction episodes and to the north and west of the earlier royal tombs (Sharer et al., 1992, 1999; Traxler, 1994, 2001). The body had been laid supine head to the north on a bier composed of two stone slabs, surfaced with layers of cinnabar and magnetite covered by a woven mat, accompanied by an array of offerings (Bell et al., 2004a). The skeletal remains from the SubJaguar tomb were extremely fragmentary, including the dentition. The skull was quite robust, with a bilateral chin, suggesting that the remains represent a male individual. An age-at-death is estimated to be greater than 35 years of age (Buikstra et al., 2004).

Burial 92-1

This grave was a simple pit dug at the base of Teal platform (Bell et al., 2004). A presumed sacrificial victim, the remains are very fragmentary, except for the dentition, which is well preserved. Sex can be estimated from the maximum femur head diameter of 47 mm as within the male range (Buikstra and Mielke, 1985). An appropriate age-at-death estimate is 18–25 years, probably at the upper end of this range, given the apparent skeletal maturation (Buikstra et al., 2004).

Burial 93-1

These remains were placed in the earthen fill of Uranio structure. The burial was only superficially exposed and then removed in a single block and not excavated further. The remains appear to be those of an adolescent, probably male. Burial 93-1 may have been bundled and its teeth have jadeite inlays in the central incisors, the right upper canine, and the right upper first premolar (Bell et al., 2004; Sedat and López, 2004).

Fig. 6. The skull of Burial 95-1 with the shell goggles and jade earspools.

Burial 94-1

This individual was interred in a seated position as a tightly flexed bundle placed in the fill of Mitzil platform at the entrance to the vaulted passageway leading to the Margarita Tomb. The remains were those of a robust male, at least 30–40 years of age at death (Buikstra et al., 2004), too fragmentary for an estimate of stature.

Burial 95-1

This individual was buried in the fill of Allamanda platform, wrapped in a woven mat. The body was in an extended position, laid on his back but shifted slightly onto the left side, head to the west, with adornments symbolic of a warrior from Central Mexico (Fig. 6). The remains are those of a robust male, apparently over 40 years of age with an estimated stature of 162 cm (Tiesler Blos, 1999). The only observed pathology was an enlarged callus on the right ulna that resulted from a healed parry fracture (Buikstra et al., 2004).

Copan's external connections

The origins of Copan's dynastic founder, along with the broader role of its foreign allies and contacts in the politics and economy of Copan, can be assessed from archaeological and textual evidence. These contacts include Teotihuacan located in the Valley of Mexico, some 1200 km from Copan, and major Maya centers located to the north and west but closer to Copan—Kaminaljuyu in the highlands of Guatemala (185 km), and huge lowland centers like Tikal (270 km), Calakmul (345 km), among others. These and a number of other Maya cities were involved in economic and political interaction with Copan during the Classic era (Marcus, 1992).

There is evidence from architecture, artifacts, and epigraphy that the origins of the Copan founder, K'inich Yax K'uk' Mo', were closely associated with the central Petén region of the Maya lowlands. This evidence points more specifically to close links with Tikal, a major Early Classic power in the Maya lowlands of the Petén (Sharer, 2003b). There are also connections with Central Mexico, dominated in the Early Classic by Teotihuacan (Sharer, 2003a). Yet the available evidence strongly suggests K'inich Yax K'uk' Mo' was ethnically Maya. His only contemporary depiction (on the Motmot Marker discussed) portrays him as a traditional Maya ruler, and both his pre-inaugural and royal names are Mayan. Thus, it is very unlikely that K'inich Yax K'uk' Mo' was actually from Teotihuacan. Stuart (2007) also points to the founder's "Maya-ness" and makes the important distinction between his Maya ethnic identity and his political identity associated with Teotihuacan. It is also significant that most of the connections between K'inich Yax K'uk' Mo' and Teotihuacan seen on Copan's monuments and buildings are retrospective and date to the Late Classic era, at a time when Teotihuacan's power had vanished. Thus, the linking of the founder's political identity with Central Mexico was emphasized far more by Copan's Late Classic kings than by K'inich Yax K'uk' Mo' and his immediate successors. In other words, the founder's association with Teotihuacan's glorious past was created long after his death (Sharer, 2003a, 2004).

In contrast, Copan's three known founding era monuments refer or portray K'inich Yax K'uk' Mo' as a Maya ruler. Only one known building from this period, Hunal, was rendered in a Central Mexican style, and it sat along side many others built in the styles of the Maya highlands and lowlands. Most of the objects displaying links to Teotihuacan were personal and portable objects found in the Hunal and Margarita Tombs, placed along with many other objects with connections to both the Maya highlands and lowlands. Rather than demonstrating an exclusive or dominant connection with Teotihuacan, the archaeological evidence from the founding era reflects multiple external connections, quite similar to the documented Early Classic relationships with Teotihuacan seen at Kaminaljuyu, Tikal, and elsewhere in the Maya lowlands (LaPorte and Fialko, 1990; Martin and Grube, 2008). The most plausible explanation for Central Mexican elements at Copan during the founding era is that they were used by K'inich Yax K'uk' Mo' to bolster his authority and legitimacy as Copan's ruler. At the same time, the founder and his son and successor (Ruler 2) also promoted Maya traditions as seen in their royal monuments, architecture, and funerary practices, to further reinforce the legitimacy of the newly established Copan dynasty (Sharer, 2004).

Although many details of Copan's history will never be known, the evidence suggests that the dynastic founding was instigated by Tikal whose rulers apparently had close connections with Central Mexico (Martin and Grube, 2008; Stuart, 2004). As for motive, an alliance with Copan had considerable political, economic, and ideological advantages. As but one example, Tikal would have acquired substantial new resources by this action. From its southeastern location Copan could monitor trade routes linking Central America with the Maya area, while its secondary center at Quirigua could manage the Motagua jade and obsidian route between the Maya highlands and the Caribbean. Overall, securing Copan would have established Tikal's control over the resources and trade routes of the southeastern area (Sharer, 2003b).

Architecture

The architecture of the Early Classic Acropolis tombs shows connections with both the Maya lowlands and Central Mexico. Two royal tombs, Hunal and Margarita, are within the Early Classic lowland Maya tradition (Krejci and Culbert, 1995). Both have vaulted chambers with single supine interments on stone slabs elevated by stone pedestals (Bell et al., 2004a). The SubJaguar Tomb also represents this lowland Maya tradition, although its burial chamber was covered by lintel stones rather than a corbelled vault. Motmot's round masonry funerary chamber and the seated position of the burial within are both linked to Teotihuacan (Fash et al., 2004).

The styles of the excavated buildings of the earliest Acropolis represent three major architectural traditions (Sharer, 2003b; Traxler, 1996, 2004). Many of the earliest constructions beneath the Acropolis are earthen-cored and plastered substructures with perishable superstructures of adobe or pole and thatch. These derive from a southern Maya tradition with well-documented examples at Kaminaljuyu and Chalchuapa.

Central Mexican-style talud-tablero architecture is represented by only the Hunal structure. Hunal's tableros are undecorated like the tableros found at Early Classic Kaminaljuyu. But Hunal's masonry and plaster construction could well derive from Tikal where similar talud-tablero substructures were well established by this time (LaPorte and Fialko, 1990). So while the style of Hunal offers a clear, symbolic association of power and prestige between Copan and Teotihuacan, this architectural connection also reflects ties to closer centers with talud-tablero architecture, especially Kaminaljuyu and Tikal (Sharer, 2003a).

The Early Classic architectural tradition of the central Maya lowlands is prevalent at Copan and has close links with Tikal. Early Copan masonry substructures have apron moldings with inset corners, are often red-painted, and decorated with polychrome stucco masks or panels. Motmot structure's apron-molded substructure is dated to the reign of the Founder (Fash et al., 2004). Two slightly later examples, Yehnal and its successor Margarita, date from the reign of Ruler 2 (Sharer, 2003b).

Buildings with corbelled masonry vaults reflect another link to the Early Classic Maya lowlands. The initial building on the Hunal substructure was probably vaulted, but its later and larger replacement could have been unvaulted. Other early examples of masonry construction, Yehnal, Margarita, and possibly Motmot, were likely vaulted buildings. After the dynastic founding, masonry became more prevalent and was used to replace earlier earthen buildings, including palace-type structures in the Acropolis. These masonry structures were constructed in the Maya lowland tradition with triple doorways, curtain holders, multiple rooms, and stucco-decorated exteriors (Traxler, 1996, 2003).

While royal buildings during the founder's reign included all three traditions, those dating to Ruler 2's reign increasingly emphasized lowland Maya architecture. At the same time the only known example of the talud-tablero style from the founding era was replaced by a succession of funerary temples constructed in the lowland Maya Early Classic style (Sharer, 2003b; Sharer et al., 1999).

Artifacts

The offerings from the Early Classic Acropolis burials furnish evidence of wide spread external connections during the dynastic founding era. Yet, instead of being public displays, like architecture or carved monuments, these artifacts include personal symbols of power and authority removed from circulation by their placement in burials and tombs (Sharer, 2003a).

In contrast to the solitary interments in the Hunal, Margarita, and SubJaguar Tombs, the "trophy" skulls and animal remains buried in the Motmot Tomb recall similar grave goods from Early Classic Kaminaljuyu and Tikal. A comparable number of pottery vessels were placed in the Hunal, Margarita, and SubJaguar Tombs, many more than in the very limited confines of the Motmot chamber. But the Hunal, SubJaguar, and Motmot Tombs have far fewer offerings of jade than Margarita. While the vessels in the Motmot Tomb are generally of local traditions (Fash, 2001), those in the three royal tombs signal diverse external connections.

Warrior paraphernalia accompanied several Early Classic Acropolis burials and shows clear associations with the warfare traditions of Central Mexico (Bell et al. 2004a). The composite shell headdress in the Hunal Tomb reinforces the occupant's status as a warrior with links to Teotihuacan, like the Founder's Late Classic portrait on Copan Altar Q. It also associates the founder with Tikal, where ruler Yax Nuun Ayiin is portrayed on Tikal Stela 31 wearing a similar shell-platelet headdress (Sharer, 2003b). A similar shell-platelet artifact was found on the floor of the SubJaguar Tomb, tentatively identified as the burial of Copan's eighth ruler, Wil Ohl K'inich (Bell et al., 2004a). Burial 95-1 likely represents a warrior burial adorned with mosaic jade-and-hematite earflares, shells, and jade, including examples of Teotihuacan military gear such as cut shell "goggles" (Fig. 6), and a bundle of atlatl darts with obsidian points (Bell et al., 2004a).

Twenty pottery vessels and four lids from the Hunal Tomb were sampled for Instrumental Neutron Activation Analysis (Reents-Budet et al., 2004). While 3 were indeterminate, the results indicate that 10 vessels and 2 lids had local origins, 3 vessels came from Central Mexico, 3 vessels came from the Petén (2 with lids), 1 vessel came from the Maya highlands, and 2 came from Quirigua, a site founded by K'inich Yax K'uk' Mo' as a subordinate center within the Copan polity (Looper, 2003). Most of the other items from this tomb conform to artifacts commonly associated with Early Classic Maya royal tombs (Krejci and Culbert, 1995). An inscribed shell pendant was decorated with a Maya-style jade mosaic. The pendant is of a type found at both Kaminaljuyu and Teotihuacan, made from *Patella mexicana*, a species imported from the Pacific coast region (Sharer, 2003a).

The greatest array of artifacts comes from the Margarita Tomb (Bell et al., 2004a). Neutron Activation Analysis (Reents-Budet et al., 2004) of 28 vessels reveals 15 were of local manufacture, 6 were imports, and 7 were indeterminate. Of the imports, 4 vessels were identified with Central Mexico, 1 with the Maya lowlands and 1 with the Maya highlands. One of the indeterminate vessels combines Maya and Teotihuacan attributes in both its form and imagery (Fig. 7) in referring to K'inich Yax K'uk' Mo' (Reents-Budet et al., 2004: 179). The non-pottery items from the Margarita Tomb also represent connections with Central Mexico, the Maya highlands, the Maya lowlands, and the surrounding southeastern region (Bell et al., 2004).

Instrumental Neutron Activation Analysis of 27 vessels from the SubJaguar Tomb indicates a much more localized pattern for their origins, with 17 vessels from the Quirigua area, an important part of the Copan kingdom, 5 vessels from greater Copan, and 5 of indeterminate origin (Reents-Budet et al., 2004). A large carved shell collar from the tomb also represents a local southeastern tradition (Traxler, 1994). Otherwise the offerings from this tomb are consistent with other Early Classic Maya royal burials (Krejci and Culbert, 1995).

These external links focus on the movement of people, ideas, objects, and materials (B. Fash, 2001; Fash and Fash, 2001; Stuart, 2000). We will discuss the isotopic evidence for movement of some of Copan's ancient inhabitants in the next section of this study, after we consider the evidence from Maya texts and iconography for the origins of Copan's dynastic founder.

Fig. 7. A tripod vessel from the Margarita Tomb showing talud-tablero architecture and a goggle-eye figure at the entrance to the structure.

Evidence from epigraphy and iconography

Stuart (2007) cites a reference on Copan Stela 63 which links the name of K'inich Yax K'uk' Mo' with the *Uxwitza*' ("Three Hills Water") title, found at the site of Caracol, Belize. From this he suggests that K'inich Yax K'uk' Mo' was an elite lord from Caracol, located southeast of Tikal. This conclusion seems fully justified. The only question this new finding raises is the lack of archaeological evidence for Caracol connections during the founding period at Copan. On the other hand, the evidence from archaeology and architecture, along with several indirect epigraphic indications, continue to associate K'inich Yax K'uk' Mo' with Tikal. As a solution to this apparent contradiction we postulate that Copan's dynastic founder was indeed a Caracol lord by birth, but given the likelihood that Tikal's kings were Caracol's overlords at the time, the young K'uk' Mo' Ajaw (the founder's pre-inaugural name on Copan Altar Q) was raised at Tikal as a member of Tikal's royal court. By this scenario, he was later dispatched by his Tikal overlords to take power at Copan.

Of course the evidence that associates K'inich Yax K'uk' Mo' with Tikal and suggests that he was an agent for Tikal's expansion into the southeastern Maya area is largely circumstantial. But it is strengthened from several independent sources. The verb used on Altar Q to record the founder's arrival in Copan (*hul-li*) is used to refer to the establishment of new dynasties (Martin and Grube, 2008: 29) and may imply conquest (Stuart, 2000). Possible support for the founder's ties to Tikal comes from two text references to an individual named K'uk' Mo' on the headless carved-stone statue known as the Hombre de Tikal (Martin and Grube, 2008: 32–33; Sharer, 2003b). The Hombre de Tikal text refers to events in AD 403 and 406, about 20 years before the 426/427 dynastic founding at Copan.

Several other proposed references to K'inich Yax K'uk' Mo' date before his AD 426/427 assumption of rule at Copan. The earliest of these is a possible portrait on a carved peccary skull (Stuart, 2004: 221). This object's date is unknown, but it appears to retrospectively depict a meeting between two elite figures at 8.17.0.0.0 (AD 376). Schele et al. (1993) proposed that the secondary figure in the scene is K'inich Yax K'uk' Mo'. But since this event took place some 50 years before the Copan founding date, it seems unlikely this individual could be the future dynastic Founder.

A retrospective reference on Copan Stela 15 associates K'inich Yax K'uk' Mo' with a more feasible date, 8.19.0.0.0 (AD 416), only a decade prior to the dynastic founding. In another clause on Stela 15 the Copan ruler Balam Nehn is referred to as the 7th successor of "the Sun Lord of the West" (Schele et al., 1993). This is one of several references to K'inich Yax K'uk' Mo' as "Lord of the West," which also links him with Tikal where this title was often used by its kings (Martin and Grube, 2008). Copan and Tikal are also linked in their early inscriptions by mutual references to an important location, known as the "Bent Kawak" place and what may be an early ruler, nicknamed "Foliated Jaguar" (Stuart, 2004: 219–220).

The best-known retrospective reference to K'inich Yax K'uk' Mo' was carved some 350 years after the founding on Copan Altar Q (Schele, 1986; Schele et al., 1993; Stuart, 2004; Stuart and Schele, 1986). Commissioned by Copan's 16th ruler, Altar Q depicts the founder as a warrior in the Central Mexican tradition, bearing a shield on his right forearm and goggles over his eyes. Altar Q's text records that on 8.19.10.10.17 (September 6, 426) "K'uk' Mo' Ajaw took the K'awiil Scepter (at) Tree Root House." In so doing, K'uk' Mo' Ajaw (compare to the K'uk' Mo' in the Hombre de Tikal text) became a Maya king. Then 3 days later, "He came from the Tree

Root House…" his status as a Maya king reflected in his new name, K'inich Yax K'uk' Mo' ("Great Sun, First Quetzal Macaw"). The next event is on 8.19.11.10.13 (February 8, 427) when as "Lord of the West" K'inich Yax K'uk' Mo' arrived at Copan. That is, some 5 months after becoming king, K'inich Yax K'uk' Mo' came to Copan from elsewhere. Although there is nothing in the Altar Q text to identify the location of the Tree Root House where Copan's dynastic founder was inaugurated—most scholars associate it with either Tikal or Teotihuacan.

Isotopic analyses

Artifacts, architecture, and inscriptions are things. They provide indirect evidence of human interaction and influence in the past. The problem with these indirect indications of contact, of course, is that artifacts and styles can move independently of the people that made them, through exchange or theft. Direct evidence of human mobility has been rare but is now possible through the application of isotopic analysis (e.g., Ericson, 1985; Krueger, 1985).

The application of these principles to the remains from Copan is the focus of the following pages. The purpose of these analyses is to identify non-local individuals among the human and faunal materials that are analyzed in order to know more about mobility and migration in the Maya period. The discussion is organized to present the principles, methods and results of the use of first oxygen isotopes and then strontium isotopes. We describe known variation in these isotopes across Mesoamerica in order to compare the results from Copan to the larger region of the Maya area and highland Mexico. A brief section considers the application of the two isotope measures in combination to examine questions of mobility and changes in residence among the individuals buried at Copan. Finally our conclusions assemble some of the information this study has produced and address their significance.

Oxygen isotopes

Oxygen isotope ratios in prehistoric tissues can provide information on human mobility (Schwarcz et al., 1991). Oxygen isotopes are measured as a ratio between ^{18}O and ^{16}O compared with a standard, and the ratio ($\delta^{18}O$) is expressed in permil (‰). Polar and inland rain is isotopically lighter than tropical and coastal rain. Clouds that form over tropical seas gradually lose heavier $H_2{}^{18}O$ through rainfall as they move over land masses and toward higher latitudes, disproportionately retaining the lighter $H_2{}^{16}O$ to fall later in rain. The $\delta^{18}O$ of drinking water declines with increasing latitude, distance from the coast (or source of evaporated water), and elevation (Luz and Kolodny, 1989; Rozanski et al., 1993; Schwarcz et al., 1991; Longinelli, 1984). Skeletal tissues thus record the $\delta^{18}O$ of body water as they form and remodel, and reflect the average $\delta^{18}O$ of all water sources imbibed (Longinelli, 1984; Bryant et al. 1994). Tooth enamel forms in childhood and does not change during life, thus providing a signal of the water sources at the place of birth (Hillson, 2005).

The hydroxyapatite in skeletal tissues contains oxygen, both in phosphate groups (PO_4) and in carbonates (CO_3). Both phosphate and carbonate oxygen have been used in studies of human provenience. Phosphate-oxygen ratios ($\delta^{18}O_p$) are typically reported relative to the VSMOW (Vienna Standard Mean Ocean Water) standard; carbonate oxygen ratios ($\delta^{18}O_c$) are reported relative to the PBD (Pee Dee Belemnite) carbonate standard. Laboratory procedures for the preparation and analysis of samples for oxygen isotope analysis are published elsewhere (Schwarcz et al., 1991; Buikstra et al., 2004).

Phosphate and carbonate generally produce comparable results (Bryant et al., 1994; Sponheimer and Lee-Thorp, 1999; Zazzo et al., 2004). Although the formulations for conversion are complex, phosphate oxygen values can be converted to approximate carbonate values by subtracting −21.0 (Iacumin et al., 1996). A recent study has raised some questions about this correlation and suggests that preparation and analytical methods may have some effect on results (Metcalfe et al., 2009). Samples of poorly preserved ancient human bone from coastal Guatemala showed no correlation between $\delta^{18}O_p$ and $\delta^{18}O_c$. A study of well-preserved ancient human bone from the Sudan did provide the expected correlation. The study suggests that the $\delta^{18}O_c$ values were affected by post-mortem alteration and laboratory procedures, while the $\delta^{18}O_p$ values were not. Earlier studies on carbonates from bone in the Maya lowlands have also shown considerable diagenetic change (Wright and Schwarcz, 1996); tooth enamel is a more reliable sample tissue for this environment.

In practice, there are a number of problems with the application of oxygen isotopes to questions of human migration. The $\delta^{18}O$ of human tissues may differ from that of rain falling in the same landscape. Several different variables appear to affect the final values in the human skeleton. Rainwater $\delta^{18}O$ is seasonally variable, both in temperate latitudes and in tropical areas with marked dry and wet seasons. In the tropics, seasonal fluctuation in $\delta^{18}O$ is determined more directly by seasonal variation in the amount of rainfall (Rozanski et al., 1993). Rainfall levels also vary from year to year. This annual variability is undoubtedly a major contributor to the broad variability of $\delta^{18}O$ values seen at a given site. Though they occur on longer-term cycles than the lives of most individuals, even skeletons buried within a single chronological period can be expected to vary somewhat due to climate fluctuation (Wright, submitted for publication).

There are also reservoir effects. Water in lakes, ponds, and storage vessels can have higher $\delta^{18}O$ values due to evaporation of the lighter isotope. And through-flowing rivers can have $\delta^{18}O$ that differ from local rainfall values. even beverage-preparation techniques can affect mean dietary $\delta^{18}O$ (Knudson, 2009).

Moreover, considerable variability may be expected among the teeth of a single individual (Fricke and O'Neil, 1996; Weidemann et al., 1999; Wright and Schwarcz, 1998), or indeed within a single tooth. Since most permanent teeth form over the span of 2–4 years, seasonal fluctuations in $\delta^{18}O$ may well be visible in dental $\delta^{18}O$ values, if measurements are sufficiently precise. Cultural practices, such as long-term water storage, cooking, diet, and breastfeeding can influence the $\delta^{18}O$ of human skeletal tissues (White et al., 2007; Wright, submitted for publication). In sum, the use of oxygen isotopes in human migration studies is still experimental.

In Mesoamerica, stable oxygen isotope ratios have been measured in bone phosphate for skeletal remains from Teotihuacan, Monte Alban, Kaminaljuyu, Altun Ha, and elsewhere (e.g., White et al., 1998, 2000). Oxygen isotopes in enamel carbonate are now available from skeletons from Calakmul, Kaminaljuyú, Copan and elsewhere (Price et al. 2007; Wright and Schwarcz 1999; Wright submitted for publication, unpublished data). Values in carbonate are generally negative and range from 0‰ to $-10‰_{PDB}$ in humans in Mesoamerica; values in phosphate are positive and range between 10‰ and $20‰_{VSMOW}$. Again conversion requires the addition or subtraction of a value of approximately 21.0 for carbonate to phosphate, and vice versa.

Oxygen isotopes in Mesoamerica

Regional variability in oxygen ratios for Mesoamerica has not yet been adequately mapped, but the limited data do help to constrain the origins of the Copan skeletons. As oxygen isotope ratios are determined by large-scale patterns in rainfall and can be affected by climate change, we expect broad areas to share similar ratios. Table 1 and Fig. 8 present the current data on phosphate and carbonate oxygen isotope variation across Mesoamerica (after White et al., 2007: Fig. 2). Sites with phosphate data are shown with a black circle on the map; carbonate values are shown with a negative sign and/or an open circle.

Sites on the Belize coast have the highest phosphate oxygen isotope ratios measured to date in Mesoamerica, around 25‰. As the prevailing weather systems come from the Caribbean, southern highland sites such as Kaminaljuyu show lower $\delta^{18}O$. Values for enamel from Kaminaljuyu are somewhat lower than for the Petén and the Belize Lowlands. The isotope ratios in the Highlands of Mexico are lower, due to loss of heavy $H_2{}^{18}O$ through rain as clouds move inland. These values are, however, very similar to measurements along the Pacific Coast at Balberta, Guatemala. Values in the central Mexican highlands at Teotihuacan and Cholula (14–16‰) are slightly higher than in Michoacan and at Monte Alban (12–14‰) to the west and south.

Table 1
Carbonate oxygen isotope ratios in tooth enamel from selected sites in Mesoamerica. Kaminaljuyu data from Wright and Schwarcz (1998). Site locations shown in Fig. 8. The Tikal mean includes 2 teeth for some individuals and several samples per tooth.

Site	*n*	$\delta^{18}O$
Calakmul	12	−1.2
Campeche, Local	54	−2.9
Chapantongo	3	−5.6
Copan, Commoners	10	−4.1
Kaminaljuyu	14	−4.2
Maltrata	3	−3.9
Palenque	3	−3.9
Palmarejo Valley	5	−3.7
Teotihuacan	3	−5.3
Tikal	150	−3.8
Tzintzantzun	3	−5.4

In general there appears to be very little systematic variation among the carbonate values. Variation within one site may be as great as variation between sites. Note that sample sizes are frequently small and therefore mean values are less than reliable. Nevertheless, carbonate ratios show a similar pattern to phosphate with lower values in the higher elevations and higher values in lowlands and coastal regions. It is likely that the colder waters of the Pacific will mean somewhat lower values on the west coast of Mexico and Guatemala as well. In general, carbonate values lower than ca. −4.5‰ seem to reflect higher elevations across Mesoamerica, although this statement is based on very little data. Phosphate values exhibit a generally similar pattern with lower values (generally less than 18‰) seen in the highlands (with the exception of the Pacific Coast of Guatemala).

It is important to note that the phosphate data are primarily bone samples, which record a long term average (years), while the carbonate data are from tooth enamel, which samples an earlier phase of life and a shorter period of time (months). Thus, the broader variability of enamel carbonate data is to be expected, since it captures variability introduced by breastfed and weaned diets, as well as seasonal and annual fluctuations that are more homogenized among the bone phosphate data. Given the broad variability of stable oxygen isotope ratios in human remains from Mesoamerica, and the many factors that can affect oxygen in drinking water and human tissues, it is difficult to use oxygen isotopes to predict a place of origin for a migrant skeleton. However, when considering variability among oxygen isotope ratios among skeletons from a given site, it may be possible to identify some migrant individuals as those with outlying values.

Oxygen isotope results

For Copan we have measured $\delta^{18}O$ values in enamel carbonate of first molars for five skeletons, the Margarita premolar, and in the third molars for all the skeletons from the Acropolis (Table 2).

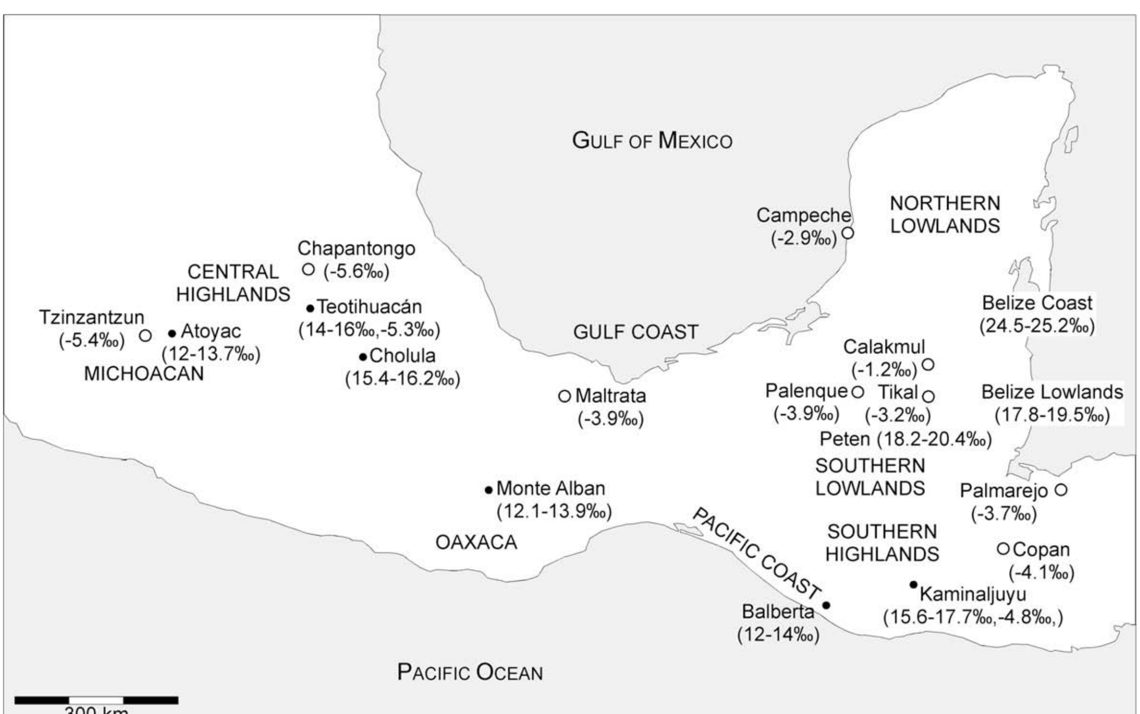

Fig. 8. Oxygen isotope ratios of human bone and enamel from sites and areas in Mesoamerica. Phosphate sites are shown with a black circle on the map; carbonate values are shown with a negative sign and/or an open circle. Names of major regions are shown. Phosphate data from White et al. (2004, 2000, 1998). Carbonate data from Wright and Schwarcz (1999), Buikstra et al. (2004), Price et al. (2007), and unpublished.

Table 2
Oxygen isotope ratios in enamel carbonate from Early Classic Copan (Wright, submitted for publication).

Burial #	Structure/tomb	Tooth	Sample	$\delta^{18}O$
92-1	Teal	LRM1	Midcoronal	−3.25
92-1	Teal	LRM3	Whole	−3.99
92-3	SubJaguar	URI1	Midcoronal	−0.99
92-3	SubJaguar	URM1	Midcoronal	−1.16
92-3	SubJaguar	LLM3	Whole	−5.96
93-1	Uranio	L_I2	Midcoronal	−2.97
93-2	Margarita	LLP3	Whole	−4.52
93-2	Margarita	LRM3	Whole	−5.01
94-1	Mitzil	URI1	Midcoronal	−5.05
94-1	Mitzil	LRM1	Midcoronal	−5.15
94-1	Mitzil	LLM3	Whole	−5.77
95-1	Allamanda	LLM1	Midcoronal	−2.21
95-1	Allamanda	LLM3	Whole	−2.66
95-2	Hunal	LLI2	Whole	−3.17
95-2	Hunal	LLM1	Midcoronal	−3.39
95-2	Hunal	URM3	Whole	−4.02
37-7	Motmot	U_I2	Midcoronal	−1.66
37-7	Motmot	L_M3	Whole	−3.44
37-8	Motmot	ULM3	Whole	−1.63
37-9	Motmot	U_M3	Whole	−4.35
37-10	Motmot	L_I2	Midcoronal	−4.52
37-10	Motmot	L_M3	Whole	−4.96

M3s and six I2 enamel crowns were sampled to obtain a section of mid-coronal enamel, approximately 2×2 mm, which was homogenized. The finely ground enamel was soaked for 1 h in pH 4.5 1 M acetic acid to remove diagenetic carbonates. More information on the method can be found in Wright (submitted for publication). In addition, we have measured carbonate oxygen isotope ratios on 10 M1 and 1 M2 tooth enamel samples from commoner graves at Copan (Table 3).

The commoner samples came from the Copan Valley grave lots excavated by the Proyecto Arqueológico Copan or PAC II (Sanders, 1986, 1990). Samples were taken from the human remains described in Whittington (1989) with some revision of the age estimates by Miller. Whittington selected burials that he deemed as "low status" (Whittington, 1989:34) when the type of site in which an individual was interred belonged to the two smaller categories in the classifications made by the Harvard Project and PAC I. The underlying assumption is that individuals buried within these low status complexes resided there during life and were thus by definition lower status individuals. More information on these commoner burials can be found in Table 3.

The Acropolis data exhibit pronounced inter-tooth variation in $\delta^{18}O$ in tooth enamel. For five of the skeletons, the first molar samples are about 0.7‰ higher than the third molars, likely due to nursing during infancy (Wright and Schwarcz, 1998). Along with these differences, the overall picture is one of great variability both within and among the teeth. This variability likely reflects the multiple sources of fractionation involved in oxygen isotopes travel from drinking water to the skeleton as discussed earlier (cf., Weidemann et al., 1999; Wright, submitted for publication).

Fig. 9 shows phosphate and carbonate oxygen isotope values for a variety of sites and areas in Mesoamerica. Copan data from the Acropolis and commoner graves are also indicated on this graph. The carbonate $\delta^{18}O$ values from the mid-corona portion of the M1 samples (I2 when no M1) plus an M3 from 37-9 were used in this plot. The reasonably tight cluster of eight commoner burials between −3.8‰ and −4.8‰ suggest a local signal for the Copan Valley. This range of values resembles ratios observed at Kaminaljuyu (Wright and Schwarcz, 1999) as well as a number of lowland Maya centers (Palenque, Palmarejo, Campeche) and the Veracruz site of Maltrata. The two exceptions to the cluster (244 and 224) are very deviant and possibly migrants to the Copan Valley from some distance. The presence of 20% migrant individuals among the commoner graves suggests a high rate of migration to the Copan Valley and emphasizes the need for more research on such burials.

Among the Acropolis burials, the oxygen isotope data from the early childhood enamel in the first molars and incisors suggests that Burials 37-9, 37-10 (Motmot crania), and 93-2 (the Margarita individual), closely match the commoner cluster. Perhaps these individuals are indigenous to the Copan region. Burials 94-1 (Mitzil) and 37-8 (the Motmot individual) at the two extremes of the Acropolis range, raise attention and their $\delta^{18}O$ value suggest a more distant origin. The values for the Mitzil could fit with the Central Highlands of Mexico among other places. The female (37-8) Motmot isotope ratio falls close to the range of the Peten sites.

There are six individuals (in addition to Motmot) that exhibit values higher than the commoner cluster. These individuals are Burials 95-2, 92-2, 93-1, 95-1 37-7, and SubJaguar. Their ratios most closely match the Central Maya Lowlands, while exhibiting quite a range. Hunal (Burial 95-2) is the closest to the commoner cluster at Copan in terms of his early childhood oxygen isotope ratio.

There is pronounced variation between the early childhood teeth (Incisor, M1) and the adolescence age M3 observed in Table 3.

Table 3
Laboratory for Archaeological Chemistry oxygen and strontium isotope data for commoner burials from Copan. The OP and Burial numbers identify the sample by Operation and Burial number at Copan. All burials belong to the Coner Phase, except 244 and 249 which are Early Coner.

CP	CV	OP	Burial	Group	Type	Phase	Sex	Age	Context	Sample	$\delta^{18}O$	$^{87}Sr/^{86}Sr$
235	–	4	46	9M-14	Core 1	Coner	F	Early 30s	Flexed, partly disturbed, no associated architecture	ULM1	−4.49	0.70704
246	30	9	5	9M-22 Plaza B	Core 2	Coner	F	Young 30s	Flexed, head E, n wall of Structure 191	LRM1	−4.61	0.70656
233	–	3	2	10I-11	Noncore 1	Coner	M	Early 30s	1 vessel	ULM1	−4.10	0.70656
224	34	18	11	9M-25	Core, 1	Coner	M	Mid-20s	Flexed, head W, below stucco feature, 2 vessels, 3 deer bones, S side of Structure 212.	ULM1	−1.06	0.70810
244	30	9	3	9M-22 Plaza B	Core 2	E Coner	M	Early 30s	Extended, head N, offering of 2 bowls	ULM1	−7.79	0.70674
249	30	9	8	9M-22 Plaza B	Core 2	E Coner	I	10–12 years	Flexed, head S, E wall of Structure 191	ULM1	−4.56	0.70605
94	34	18	9	9M-24	Core 1	Coner	M	Late 20s-Early 30s	Flexed, head S, 1 vessel, SE corner Structure 213.	ULM2	−4.76	0.70655
196	–	24	8	4N-5	Noncore 1	Coner	F	Late 30s	Flexed, head S?, large cut stones over body, 1 vessel, 1 worked bone and animal bones in fill	ULM1	−4.37	0.70787
19	34	18	3	9M-24	Core 1	Coner	I	12–13 years	Flexed, partly disturbed, head E, 1 vessel	ULM1	−3.81	0.70728
208	34	18	13	9M-27	Core 1	Coner	M	Mid-30s	Flexed, Head E, Structure 212 in terrace under room wall.	ULM1	−3.98	0.70662

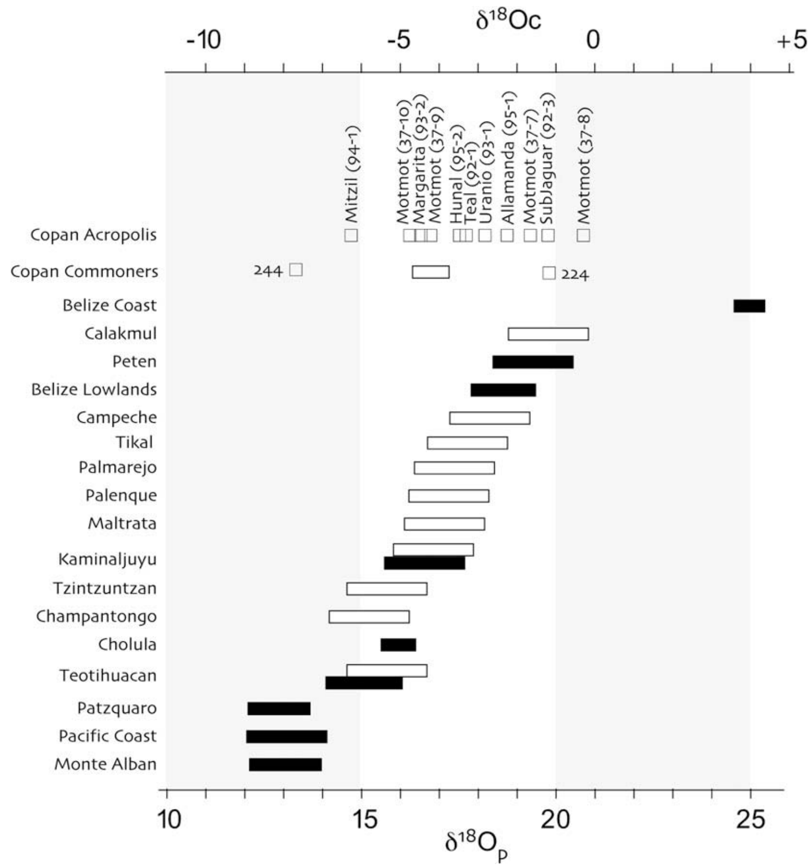

Fig. 9. Oxygen isotope ratios of human bone and enamel (original after White et al. (2007)). Black bars are phosphate data, width is range of values: white bars are carbonate data, width is arbitrary 2‰ to indicate variation. Copan commoners fall into a cluster with two outliers (Burials 244 and 244). The Copan Acropolis individuals are shown at the top of the graph as individuals; values are from mid-corona enamel or whole tooth. Mitzil and Motmot (37-8) are distinct from the wide range that characterizes the rest of the samples.

The SubJaguar interment has a dramatically higher M1 δ^{18}O value than M3. The female interred in the Motmot Tomb shows a relatively high δ^{18}O ratio in M3, that is consistent with values for Tikal and the Central Petén, as well as for Seibal. Oxygen isotopes in the M1 suggest that the Burial 95-1 was born at substantial distance from Copan, perhaps a Yucatecan or Petén origin. He appears to have moved closer to Copan in adolescence based on the M3. His M3 value is slightly lower, consistent with the expected drop due to weaning and adolescence spent in the same location as early childhood.

The problem here, however, is the great variation between teeth in these individuals, compared to the subtle variation seen geographically. For the Acropolis burials alone, δ^{18}O values range over 8‰, basically the range for all of Mesoamerica if we ignore the particularly high value from the Belize coast. Values exhibit quite a range within the same dentition depending on the tooth that is sampled. The suggested place of origin for an individual will thus vary substantially, depending on the specific tooth that is sampled, if biological processes such as nursing and long-term climate changes are not kept in mind. Rather than applying these data to identify a source of origin, they more readily serve to identify outliers that are probably not local, or individuals who may have had access to distinct sources of water within the local environment. The variability also underscores the fact that there is still a great deal we do not understand about this isotopic system. Such variation does not inspire confidence in the results of oxygen isotope analysis as a simple tool for provenience studies. We will return to this issue in the comparison of results from strontium and oxygen isotopes below.

Strontium isotopes

For humans, strontium isotope ratios are measured in bones and teeth as tracers of the geology of the areas where individuals grew up and where they died, respectively. This isotope ratio varies among different kinds of rock. Strontium moves into the skeleton from rock through the food chain and is incorporated in bone and teeth. The enamel in teeth forms during early childhood and undergoes relatively little subsequent change. Thus a strontium isotope ratio in the tooth enamel from human skeletal remains that are different from the local geology document a change in residence. Details of this method are readily available in a number of publications (e.g., Bentley, 2006; Price et al., 2000, 2002, 2008).

The isotope geology of Mesoamerica

In order to provide a brief background on the strontium isotope environments of Mesoamerica relevant to studies of migration at Copan, we discuss the general geology of major regions of archaeological relevance: the Maya area of the Yucatan, Guatemala, and Honduras and the Central Highlands of Mexico.

The limestone shelf of the Petén and the Yucatan peninsula dominates the geology of the Maya area. The oldest limestones, of Cretaceous age, are found in the southernmost part of the peninsula. The limestone becomes younger as one proceeds northwards through Eocene carbonates in the southern lowlands and Miocene carbonates in the northern peninsula to the youngest Quaternary rocks on the northern periphery and along the coasts. These rocks are predominately calcium carbonate, high in strontium deposited from the ocean at the time of formation of the rock. Because of an age-dependent trend in marine carbonates, their Sr isotopic characteristics can be directly inferred from the well-defined Cretaceous-to-Quaternary seawater $^{87}Sr/^{86}Sr$ ratios (e.g., Hess et al., 1986). Thus, the $^{87}Sr/^{86}Sr$ ratios increase northwards from approximately 0.707 in the southern Cretaceous carbonates to 0.709 in the latest Quaternary deposits of the northern coasts (Hodell et al., 2004).

The carbonate-dominated lowlands are bounded to the south by the young volcanic rocks of the Guatemalan highlands. The highlands have much lower $^{87}Sr/^{86}Sr$ ratios, approximating 0.704–0.706, which are characteristic of young Cordilleran volcanic rocks throughout Mesoamerica (Torres-Alvarado et al., 2000). The southern Pacific slopes of the volcanic highlands are likewise derived from these rocks and have similar isotope ratios.

Thus in the Maya area there is a north–south trend arising from characteristically low (0.704–0.706) igneous rocks in the south and higher ratios in the northern sedimentary rocks (0.707–0.709). Moreover within the northern region there is an age-related trend from the relatively older rocks in the southern part of this area (0.707) to the youngest rocks in the north (0.709). The highest ratios in Mesoamerica are likely to be those of the Maya Mountains of Belize and in the metamorphic highlands where there are small pockets of relatively ancient rocks with $^{87}Sr/^{86}Sr$ ratios in the range of 0.711–0.712 (Hodell et al., 2004).

The geology of the Central Highlands of Mexico is complex, a mixture of recent volcanic uplands and older marine sedimentary deposits, along with a variety of metamorphic rocks. Two major ranges, the Sierra Madre Occidental and the Sierra Madre Oriental, dominate the mountains of Central Mexico. The eastern ranges are predominantly Paleozoic sediments of marine origin and are likely to have $^{87}Sr/^{86}Sr$ ratios close to those of Paleozoic seawater (0.708). The western ranges are predominantly young volcanic rocks of rhyolitic and andesitic composition and, thus, have somewhat lower $^{87}Sr/^{86}Sr$ ratios (avg. 0.7058, Torres-Alvarado et al., 2000).

Fig. 10 presents our $^{87}Sr/^{86}Sr$ data from Mesoamerica, with the isotopic average for each site from where we have samples. The composite data come from samples of dental enamel from archaeological human remains as well as modern local fauna. These samples might include immigrants among the local individuals, thus potentially expanding the range for that site and skewing the mean from the true local value. The median/inter-quartile statistics are chosen because the data are not normally distributed, especially when skewed by possible immigrants. For large urban sites (e.g., Tikal, Kaminaljuyu, Teotihuacan) that undoubtedly do contain immigrants among the sample set, the variation exceeds ±0.0010 (Price et al., 2000), approaching that for all of Mesoamerica itself (±0.0017). For these sites, the mean, if possible, is determined from local fauna. When humans are included site means are approximately that expected from the local geology, but nonetheless have a greater uncertainty due to the bias of such immigrants or foreign trophies (Teotihuacan and Kaminaljuyu), to more complex local geology (Copan), or to consumption of non-local items high in Sr such as salt (Tikal) (Wright, 2005). Even including such large sites, our data correspond quite closely to the $^{87}Sr/^{86}Sr$ values published by Hodell et al. (2004) from the rocks, soils, and waters of these regions.

The inter-quartile ranges within most regions are quite small (<0.001) while differences between regions are normally much larger. For these regions the "provenience postulate" that 'differences between regions exceed differences within regions' (Weigand et al., 1977) is no longer a postulate but confirmed, implying that such isotopic measurements of individual teeth can now be used to identify geographic origins among these regions without the need for further, extensive baseline studies of samples from suspected places of origin. It should be noted that many of these regions are not only geologically different, but are also highly culturally relevant for studies of mobility. While there might be isotopic equivalence within a single region, the northern Yucatan, the central Petén, and the Guatemalan highlands, for example,

Fig. 10. Strontium isotope ratios measured across Mesoamerica by the Laboratory for Archaeological Chemistry. Selected additional measurements from Hodell et al. (2004) and Krueger (1985) are also indicated on the map.

are isotopically distinct. It should also be noted that not every region is distinct from every other, e.g., the Gulf Coast is not isotopically distinct from the central Maya area and the method would likely provide equivocal results in trying to distinguish them. Finally, it is important to note in the case of Copan that we have virtually no information from Central America to the south and east of western Honduras. There may well be geological terrains in that region that are comparable to the highlands of Mexico and Guatemala, as well as other strontium isotope ratio values that could be of interest. This is clearly an area requiring further investigation in terms of baseline $^{87}Sr/^{86}Sr$ values.

As a further caveat, it must be recognized that the $^{87}Sr/^{86}Sr$ of calcified tissues reflects that of human diet, which can be complex. The consumption of imported resources such as sea salt (Wright, 2005), or materials used in food preparation (e.g., lime for the processing of maize; Burton and Wright, 1995), or even the selective use of specific geologic terrains for agricultural fields can bias dietary, and hence bioavailable, $^{87}Sr/^{86}Sr$ values away from the expected regional geologic ratio. In addition, the effects of marine foods on the isotope ratios of coastal populations have to be determined. Nonetheless, we generally observe excellent correspondence among our biological $^{87}Sr/^{86}Sr$ ratios, those obtained from geological samples (e.g., Hodell et al., 2004), and ratios anticipated from knowledge of the local geology.

Strontium isotope results

There are several sources of information on strontium isotopes around Copan and in the larger realm of Mesoamerica. An early study of Copan fauna by Hal Krueger (1985) provided some initial numbers. Measurement of strontium isotope ratios in water, bedrock, soils, and plants in the Maya region by Hodell et al. (2004) provided more detailed information on geographic variation. The Laboratory for Archaeological Chemistry in Madison has been involved in the development of baseline data for Mesoamerica for many years (Price et al. 2008). Over the last several years we have conducted detailed studies of both modern and archaeological fauna as well as a number of human burials from the site of Copan.

In fact, the earliest archaeological applications of strontium isotopes in Mesoamerica involved materials from Copan. Harold Krueger used a number of archaeological faunal samples from Copan as part of an experimental study of variation in strontium isotopes (1985). Krueger's data are presented in Table 4 and provide very interesting information because of the variation that is present. As Krueger noted, the values were generally around 0.7060 with two exceptions, the puma and one of the deer, which exhibit much higher values around 0.7090. The data clearly indicate that these two animals were not native to the Copan area and likely came from some distance, either to the north in the Yucatan or perhaps to the east from somewhere in Central America. These data from Krueger provide an initial starting point for determining the local strontium isotope ratio for the area around the site of Copan.

Hodell et al. (2004) measured $^{87}Sr/^{86}Sr$ in 216 water, rock, soil, and plant samples across much of Guatemala, northern Yucatan, and in the vicinity of Copan as well. In general they document the presence of increasing values from south to north in the Maya Lowlands—values from approximately 0.707 to 0.709. The Maya Highlands, which are largely volcanic, exhibit expected lower values ranging around 0.705. The ratios measured for the Copan area are presented in Table 5 and correspond well with the data from Krueger. Values for water and plant samples in the mixed metamorphic geology of the Copan area range between 0.7062 and 0.7068.

The Laboratory for Archaeological Chemistry has also measured modern species from Copan and its surroundings (Table 6). These bone samples for the most part were taken from various places within 5 km of Copan from different geological formations as indicated on geological maps of the area. The samples with known locations come from mice and rabbits. In addition we have one armadillo and two cow bones from the site area that have been measured. With the exception of one of the cows (clearly from volcanic regions, likely in the highlands, with a value of 0.704), the remaining values are surprisingly homogeneous and likely provide a good range for the expected local signal at Copan, ranging from 0.7063 to 0.7074. These data also suggest that the two peccaries measured by Krueger may have wandered some distance from Copan before they came to the site as they do not fall in our expected range.

We have also measured a series of ancient human remains from Copan. In addition to the individuals in the tombs and burials beneath the Acropolis, we have data from other individuals. The burials within the Acropolis itself are likely to be special personages, either sacrificial victims or elite. The likelihood that these individuals had different diets or came from distant places might result in strontium isotope ratios different from the normal population at Copan. For this reason, we measured enamel samples from 10 commoner graves from the adjacent valley to verify the local human isotope signal (Table 3). Most of these individuals, with three exceptions, fall within the local range as determined by the fauna and confirm these values are the Copan signal. These exceptions are discussed below.

Finally, we come to the burials from beneath the Acropolis that have been described in some detail above. We have measured strontium isotopes on both tooth enamel and bone on most of

Table 4
$^{87}Sr/^{86}Sr$ data on archaeological fauna at Copan (Krueger 1985).

Sample #	Species	$^{87}Sr/^{86}Sr$
CAB-1	Deer	0.70663
CAB-2	Deer	0.70904
CAB-3	Deer	0.70612
CAB-18	Peccary	0.70554
CAB-19	Peccary	0.70576
CAB-34	Puma	0.70895
CAB-36	Paca	0.70632

Table 5
Hodell et al. (2004) data from the Copan area.

Location	Material	$^{87}Sr/^{86}Sr$
Town of Copan	Water	0.70633
Town of Copan	Plant	0.70622
Town of Copan	Plant	0.70639
Rio Copan	Water	0.70681
Rio Copan	Water	0.70644

Table 6
Laboratory for Archaeological Chemistry modern faunal data from Copan.

Location	Species	$^{87}Sr/^{86}Sr$
Santa Rita	Rabbit	0.70698
El Jaral	Rabbit	0.70687
Hacienda Grande	Rabbit	0.70690
Llanetillo	Rabbit	0.70644
Copan Cemetery	Rabbit	0.70630
Carrizalito	Field mouse	0.70722
Cerron	Field mouse	0.70681
Copan ruins	Field mouse	0.70700
Copan unknown	Armadillo	0.70637
Copan WDM	Cow	0.70735
Copan WDM	Cow	0.70424

these individuals. We have measured more than one tooth on several of these individuals. The detailed data for the Acropolis remains are provided in Table 7.

All of the strontium isotope data from Copan are compiled in Fig. 11. This chart requires some discussion and interpretation. These values are arranged by category—water, plants, fauna, commoners, and Acropolis burials—and ranked by the highest strontium isotope value within the categories. The white bars are water, plant, or bone samples; the black bars are tooth enamel. The water, plant, and most of the fauna fall clearly within the range that defines Copan, from 0.7069 to 0.7073. There are three values below the range (a modern cow and two archaeological peccaries) and two above (an archaeological puma and deer). These five animals did not come from the Copan region originally. These data suggest that sources of animal protein and secondary animal products were often brought substantial distances to Copan.

The commoner burials from Copan also show a good bit of variation. There is one distinctively low value and two very high values. The higher values are almost certainly from the Maya lowlands to the north. The lower value may be from the Maya Highlands or perhaps a closer locality to Copan that we have not registered. It is important to note that 3 of the 10 commoner individuals we measured seem to be migrants to Copan. This high percentage suggests that immigration may have been an important mechanism in the growth of Copan Valley populations.

The values from the Acropolis burials are numerous and we have several measurements from some individuals. Adjacent bars denote samples from the same individual. More than one black bar (enamel) from the same individual indicates different teeth that were sampled and these are recorded in Table 7. Initially, it is important to note that all six bone values measured from the Acropolis tombs are within the local Copan range. This value likely

Table 7
Samples and strontium isotope data from the Acropolis burials.

LAC#	Burial	Bone/tooth	$^{87}Sr/^{86}Sr$
F97	Hunal 95-2	Left proximal tibia	0.70637
F96	Hunal 95-2	Left proximal fibula	0.70632
F438	Hunal 95-2	Left proximal fibula	0.70633
F439	Hunal 95-2	Left proximal fibula	0.70635
F17	Hunal 95-2	LLM1	0.70844
F18	Hunal 95-2	URM3	0.70736
F445	Hunal Tomb Lower Lt.	I2	0.70788
F95	Margarita 93-2	Left medial tibia	0.70634
F440	Margarita 93-2	Left medial tibia	0.70643
F446	Margarita 93-2	LLP3	0.70717
F16	Margarita 93-2	LRM3	0.70684
F6	Allamanda 95-1	LLM1	0.70908
F7	Allamanda 95-1	LLM3	0.70715
F442	Allamanda 95-1	Right proximal ulna	0.70633
F443	Mitzil 94-1	Long bone	0.70630
F8	Mitzil 94-1	URI1	0.70711
F9	Mitzil 94-1	LRM1	0.70686
F10	Mitzil 94-1	LLM3	0.70685
F441	Teal 92-1	Right radius Diaphysis	0.70640
F11	Teal 92-1	LRM1	0.70688
F12	Teal 92-1	LRM3	0.70687
F13	SubJaguar 92-3	URI1	0.70681
F14	SubJaguar 92-3	URM1	0.70688
F15	SubJaguar 92-3	LLM3	0.70682
F444	SubJaguar 92-3	Rib	0.70683
F1771	Uranio 93-1	I2	0.70723
F1775	Ent. 37-7	M3	0.70707
F1776	Ent. 37-7	I2	0.70796
F1772	Motmot 37-8	I2	0.70797
F1765	Ent. 37-9	M3	0.70683
F1766	Ent. 37-9	I2	0.70682
F1768	Ent. 37-10	M3	0.70656
F1769	Ent. 37-10	I2	0.70644
F19	Ent. 37-10	ULM3	0.70763

reflects the fact that any foreign individuals must have been living in the Copan region long enough for bone values to equilibrate to local signal. Individuals had probably been in the area of the site for some time. This is particularly relevant for the remains from the Hunal Tomb and Burial 95-1.

Many of the individuals buried in the Acropolis appear to be native to the Copan region. This is true for two of the sacrificial skulls found in the Motmot Tomb (37-9 and 37-10), for Burials 94-1 and 92-1, and for the individual in the SubJaguar tomb (Burial 92-3). In addition, the isolated mandible found in the first chamber of the Margarita Tomb and the Uranio individual are also of local origin.

The remaining four individuals have isotopic evidence of non-local origin. Skull 37-7, from the Motmot Tomb, has two different values on tooth enamel. The molar value of 0.70707 falls within the Copan range, while the higher value of the second incisor (0.70796) clearly marks an outsider. A very similar pattern is seen on the Motmot individual (Burial 37-8). The second incisor ratio (0.70797) is virtually identical to 37-7 and the third molar value is lower (0.70763) although not within the local Copan range.

Some information on tooth formation is essential at this point. Calcification of the enamel in the permanent I2 begins at 3–4 months of age in the mandible and 10–12 months in the maxilla. Crowns are completed by 4–5 years of age. M1 enamel calcification begins at birth and is completed by ages 3–5. M3 begins 7–9 years of age and is completed by 12–16 years of age (ElNesr and Avery, 1994; Mincer et al., 1993; Smith, 1991).

It is tempting to suggest that these two individuals (Motmot 37-7 and 37-8) came from the same place of origin, given the similarity of their I2 enamel ratio, and moved to Copan before or during the time of M3 formation, between approximately 7 and 16 years of age. If one individual was slightly older at the time of migration, their M3 may have already included some of the isotopic ratio from their place of origin and never fully calibrated to the Copan value.

The two remaining individuals exhibit the highest strontium isotope ratios in their tooth enamel seen in our study of human remains from Copan and are of non-local birth: the Hunal burial (Burial 95-2, probably K'inich Yax K'uk' Mo') and Burial 95-1 (Allamanda). Three samples were measured from Burial 95-1. The bone sample and M3 enamel fall within the local Copan range; the M1 enamel value is 0.70908, one of the highest we have recorded from all of Mesoamerica. Despite his distinctive goggles, his childhood $^{87}Sr/^{86}Sr$ value is not from the Valley of Mexico, where the volcanic terrain dictates low strontium isotope ratios around 0.705. The very high value for Burial 95-1 M1 points to the northern part of the Yucatan peninsula as the only area of Mesoamerica where such strontium isotope ratios in this range are normally encountered. The M3 is between the bone and M1 in value and suggests that this individual may also have moved during childhood.

Four samples were taken from the Hunal individual (Burial 95-2, probably K'inich Yax K'uk' Mo') for analysis. These include a bone sample from the left proximal tibia and three enamel samples from the LLM1, I2, and URM3. These values show some differences. The bone value (0.70635) falls at the lower end of the local Copan range, documenting the presence of this individual at Copan during the later years of his life. The enamel values are highest for the M1 (0.70844) and lowest for the M3 (0.70736). The I2 value is 0.70788. The highest value for the M1 corresponds closely to ratios we have measured at Tikal and the surrounding northern Petén. It is not unlikely that the Hunal individual came from that region.

The shift in ratios among the three teeth suggests some movement during the childhood years, but only the M3 value approaches the Copan range. This value, however, could also be found in other parts of the Maya region, particularly the southern Maya lowlands. In this case of shifting values in the tooth enamel, it is may be helpful to recall the reference to K'inich Yax K'uk' Mo' as a Caracol lord discovered by Stuart (2007) in the text on Copan

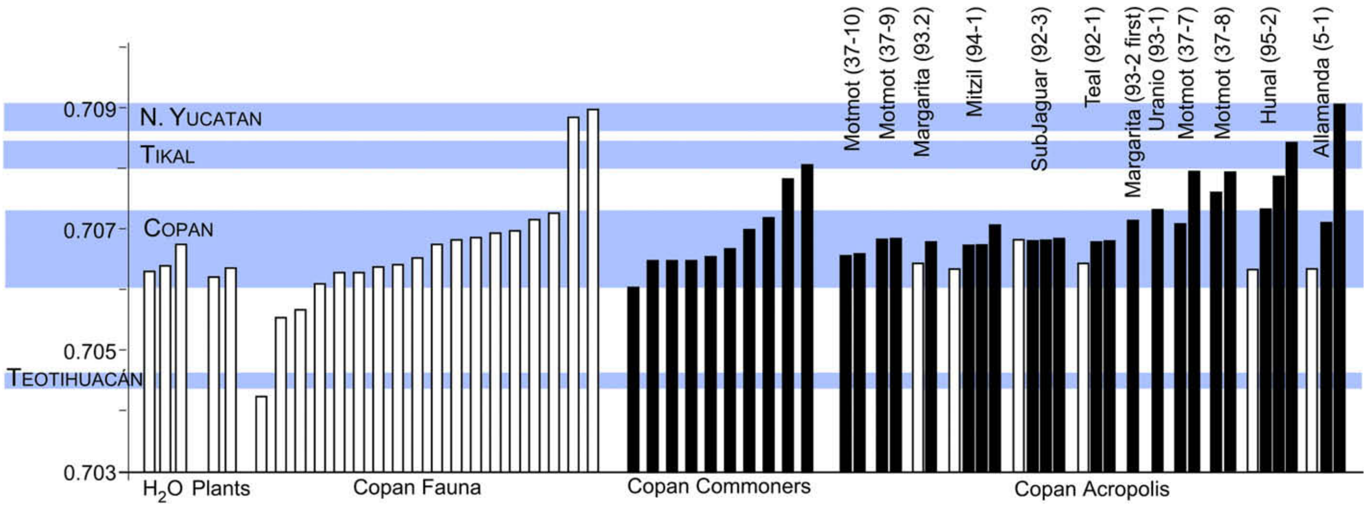

Fig. 11. Strontium isotope ratios from Copan. The horizontal bars mark the approximate range of local values for the sites of Tikal, Copan, and Teotihuacan. Values are arranged in rank order for each category of fauna and burials. The white bars are water, plant, or bone samples; the black bars are tooth enamel.

Stela 63. This could mean that K'uk' Mo' may have spent some time at Caracol during his childhood, prior to his later years when, as we have suggested, he may have become a member of the royal court of Tikal before his journey to Copan to found a new dynasty. The strontium isotope ratio we have measured for the Caracol area ranges between 0.7075 and 0.7080. The measured $^{87}Sr/^{86}Sr$ value on the I2 of the Hunal individual (0.70788) could come from a large region in the southern and central Maya lowlands, but does not rule out a place like Caracol, among a number of others.

None of the values from the Hunal individual are close to the range for Teotihuacan ca. 0.704–0.707. This individual did not spend his childhood or later years of life in Central Mexico. It is not impossible that he may have visited Teotihuacan for a relatively brief period in his life, but that visit did not register isotopically.

Strontium and oxygen combined

Two different isotope systems that contain information on the geography of Mesoamerica have been used to study the human remains from Copan. Combining these two isotopic dimensions may provide even more insight into the question of place of origin. The data used for this analysis are provided in Table 8 and include the strontium and mid-coronal enamel oxygen isotope ratios for 19 individuals from Copan, 9 from the Acropolis burials and 10 from commoner graves.

Table 8
Strontium and oxygen isotope ratios for 20 M1 enamel samples from Copan.

Burial	$^{87}Sr/^{86}Sr$	^{18}O
Hunal (95-2)	0.70844	−3.4
Margarita (93-2)	0.70717	−4.5
Motmot (37-8)	0.70763	−1.6
Allamanda (95-1)	0.70909	−2.2
Mitzil (94-1)	0.70686	−5.2
Teal (92-1)	0.70688	−3.3
SubJaguar (92-3)	0.70688	−1.2
Motmot (37-9)	0.70682	−4.51
Motmot (37-10)	0.70644	−5.21
235	0.70704	−4.49
246	0.70656	−4.61
233	0.70656	−4.10
224	0.70810	−1.06
244	0.70674	−7.79
249	0.70604	−4.56
94	0.70655	−4.76
196	0.70787	−4.37
19	0.70728	−3.81
208	0.70662	−3.98

The scatterplot of these ratios, strontium against carbonate oxygen (Fig. 12), provides a starting point for discussion. At the outset it is important to remember that the oxygen isotope ratios are less robust than strontium in documenting residential change. For this reason, more emphasis is placed on the strontium results. There is a clear correlation present among the data points ($r = 0.52$, df = 17, significant at 0.05), indicating a positive relationship between strontium and oxygen isotope ratios in tooth enamel. This relationship reflects the fact that both strontium and oxygen values are higher in lowlands and lower in highlands and more inland areas in the Maya region.

The scatterplot shows a cluster of points at its center surrounded by a number of outliers that are presumably non-local individuals. Most of these non-local individuals were excavated from the Early Classic Acropolis, but two of them (224 and 244) are among the commoner graves. These two individuals lie at the extreme ends of the range of oxygen isotopes. In terms of $^{87}Sr/^{86}Sr$, 224 is outside but 244 falls in the middle of the local range. In this case it is difficult to understand the very low oxygen value for 244 who appears to be a local inhabitant.

In terms of the Acropolis individuals, the Motmot Tomb skulls 37-9 and 37-10 appear to be local, as does the Margarita female who falls almost in the center of the distribution. Burial 92-1 also has a local $^{87}Sr/^{86}Sr$ signal and oxygen ratio close to the center. The remaining individuals are clearly outliers.

The oxygen data confirm the non-local status of these skeletons, especially that of Hunal, the Motmot female, and Burial 95-1. However, $\delta^{18}O$ values conflict with an apparent local status as shown by $^{87}Sr/^{86}Sr$ for the SubJaguar skeleton (Burial 92-3). When compared to his M3 values, the divergently heavy $\delta^{18}O$ ratios of this individual's M1 and I1 seems far too large to be explained by either seasonality or local climate change at Copan and suggest a childhood spent elsewhere, and a move to Copan at an age between 4 and 9 years. He may have come from somewhere in the southeastern Maya area where $^{87}Sr/^{86}Sr$ is comparable to that at Copan, but where $\delta^{18}O$ is substantially higher. It is difficult to determine where that might be given the limited data available for $\delta^{18}O$ variability, in particular to the east and south of Copan, where Sr isotope ratios may be similar to those at Copan. Given the unusually high proportion of SubJaguar Tomb pottery vessels identified by INAA analysis as coming from Quirigua, it could be that this individual was originally from this subordinate site

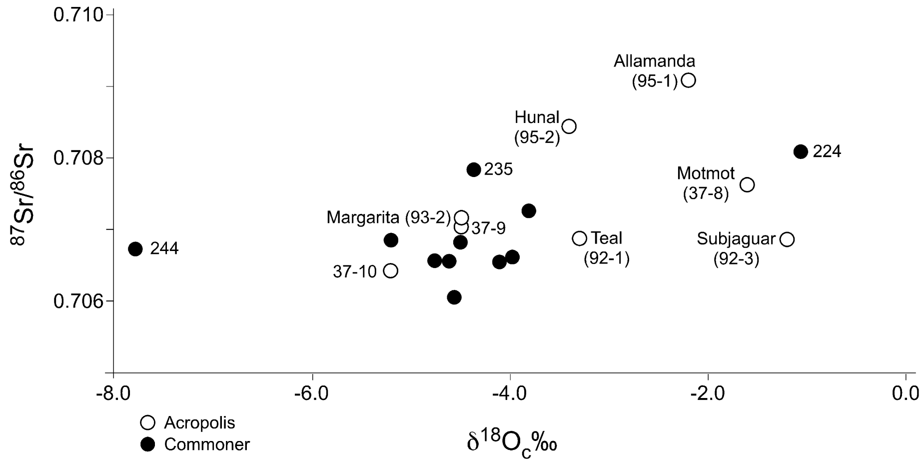

Fig. 12. Scatterplot of strontium and oxygen isotope ratios for Acropolis burials.

located north of Copan in the lower Motagua Valley. On the whole, there is a reasonable correspondence between the strontium and oxygen isotope ratios, but there are several problematic individuals that raise questions about the utility of oxygen isotopes.

Conclusions

The PAAC and ECAP excavations beneath the Copan Acropolis posed a number of major questions concerning the Early Classic Maya. At the time this research began (1980s) there was substantial disagreement about the historicity and meaning of ancient Maya texts. At Copan, for example, a number of Late Classic (ca. AD 650–800) retrospective texts referred to a dynastic founder who took the royal K'awiil scepter in AD 426 and apparently arrived at Copan in AD 427 (Schele, 1986; Martin and Grube, 2008; Stuart, 2000). While some scholars argued that Maya accounts of founders and early kings were records of actual people and events, many others believed these retrospective accounts were mythical—created by later kings to enhance their royal ancestry and inflate their prestige and authority. Tunnels deep within the Early Classic Acropolis documented the founding of Copan and the growth of a Classic Maya polity capital. These excavations have clearly shown that individuals mentioned in retrospective texts were in fact real personages and that reported events did occur when described (Sharer et al., 2005).

The construction of the Acropolis was focused on raising a series of huge platforms through repeated construction of royal palaces, tombs, memorial temples for dead ancestors, and other ritual structures (Carrelli, 2004). One critical indicator of the presence of state-level societies is the construction and scale of royal palaces. In addition, since the size of royal architecture reflects the amount of labor and materials harnessed by Copan's rulers to construct their royal compound, a major increase in such investments is another indication of the existence of state systems. Construction of Copan's initial palaces began with the founding of the center and documents the presence of the state and its early rulers, the first kings of Copan (Traxler, 2003). Some of the individuals buried in the Acropolis were members of the Copan royal house. Others were apparently sacrificial offerings. Their burials document the prominence, wealth, and power of the ruling elite at the onset of the Classic period, their strong ties to rulers of distant centers, and the ancestral power of the original founder of the dynasty, K'inich Yax K'uk' Mo'.

The origins and external relationships of these rulers is a reflection of the organization of Maya civilization and the interaction between Copan and other Mesoamerican cities. For these reasons, questions about the origins of Copan's rulers and other individuals buried at the site are of great importance. We believe that the isotopic data, particularly the strontium ratios, provide convincing evidence for the non-local birth of a number of individuals at Copan, including the Hunal burial (putative K'inich Yax K'uk' Mo'). While it is impossible to specify exactly where these individuals came from in the Maya region, we can rule out a number of areas and make some general suggestions for place of origin.

Several lines of evidence can be used in some cases to argue for a place of origin, artifacts and epigraphy providing independent indicators of external relationships. At the same time, bodies can be moved, replaced, and reburied in the Maya region, as elsewhere. Isotopes in enamel provide the direct evidence of place of origin and patterns of movement during life from the skeletal remains of the interred individual.

For example, the $^{87}Sr/^{86}Sr$ data indicates that the individual interred in the SubJaguar Tomb was born and raised in the Copan region. However, these data are at variance with the $\delta^{18}O$ values from this burial, likely that of Wil Ohl K'inich, Copan's 8th ruler. The INAA evidence shows an unusually high proportion of pottery in the SubJaguar tomb originated from the nearby site of Quirigua. Thus, one possible explanation for the differences in the isotope values is that the $\delta^{18}O$ data reflects this individual's origins at Quirigua, and that the offering vessels in his tomb commemorated this link with his homeland. On the other hand, the most parsimonious hypothesis for the identification of the woman buried in the Margarita Tomb is that she was the royal wife of K'inich Yax K'uk' Mo', a woman of local origins, who belonged to Copan's original royal house (Sharer et al., 1999). While INAA results indicate that about half the vessels in the Margarita Tomb are non-local in origin, the strontium isotope analyses from samples of the burial itself indicate that this woman was born and raised in the Copan region.

As for the Hunal Tomb, the evidence is very strong that this tomb contains the burial of Copan's dynastic founder, K'inich Yax K'uk' Mo'. There are a number of indications that during his lifetime this man had connections to both the Central Petén (Tikal) and Central México (Teotihuacan) (Sharer, 2003a,b; Stuart, 2000). Neutron activation analyses show that a number of vessels in the Hunal Tomb are derived from both of these regions. The clues from the human remains in the Hunal Tomb provide especially important support for the hypothesis that these are the remains of K'inich Yax K'uk' Mo' and reinforce a strong connection to the Central Petén seen in the archaeological and epigraphic record, including the text on Copan Stela 63 that refers to the founder as a Caracol lord (Stuart, 2007).

In particular, the strontium isotope analyses of the Hunal bones indicate this man was not native to Copan, and suggest he spent his childhood and young adult years in the Central Petén. This information matches historical accounts that K'inich Yax K'uk' Mo' was inaugurated king in 426 and came to Copan 427 from elsewhere to become its dynastic founder. Our hypothesis based on both the archaeological and epigraphic data postulates that K'uk' Mo' Ajaw, as he was known before becoming king, was originally an elite lord from Caracol. He spent his young adult years in the Central Petén, most likely as a member of the Tikal royal court, before coming to Copan as a Maya king to found a dynasty that would rule this southeastern kingdom for some 400 years. Interestingly, the age of the Hunal occupant at death, between 55 and 70 years, is in line with the expected age of K'inich Yax K'uk' Mo' if he was already an established leader at Tikal at least 20 years before his arrival at Copan. In addition, if the founder was a warrior (as many later references imply), the Hunal bones certainly have the kind of serious fractures and injuries that likely resulted from combat, all of which had healed before death.

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References

Agurcia, Ricardo F., 2004. Rosalila, temple of the Sun King. In: Bell, E.E., Canuto, M.A., Sharer, R.J. (Eds.), understanding Early Classic Copan. University of Pennsylvania Museum, Philadelphia, pp. 101–111.

Andrews, E. Wyllys, Fash, William L., 2005. Copán The History of an Ancient Maya Kingdom. School for American Research Press, Santa Fe.

Bell, Ellen E., 2001. The Engendering of a Dynasty. In: Ardren, T.A. (Ed.), Ancient MayaWomen. Walnut creek CA, Altamira, pp. 89–104.

Bell, E.E., Sharer, R.J., Traxler, L.P., Sedat, D.W., Carelli, C.W., Grant, L.A., 2004a. Tombs and burials in the Early Classic Acropolis at Copan. In: Bell, E.E., Canuto, M.A., Sharer, R.J. (Eds.), Understanding Early Classic Copan. University of Pennsylvania Museum, Philadelphia, pp. 131–157.

Bell, Ellen E., Canuto, Marcello A., Sharer, Robert J. (Eds.), 2004b. Understanding Early Classic Copan. Philadelphia, Penn Museum.

Bentley, R.A., 2006. Strontium isotopes from the Earth to the archaeological skeleton: a review. Journal of Archaeological Method and Theory 13, 135–187.

Bryant, Daniel J., Boaz, Luz, Froelich, Philip N., 1994. Oxygen isotopic composition of fossil horse tooth phosphate as a record of continental paleoclimate. Palaeogeography, Palaeoclimatology, Palaeoecology 107, 303–316.

Buikstra, Jane E., 1996. Estudio Piloto de Enterraientos de la Acrópolis. Apéndice II. In: Sharer R.J. (Ed.), Programa de Investigación de la Acrópolis Temprana (PIAT), Proyecto Arqueológico Acrópolis Copan, Informe Preliminar de la Temporada del 1996. Manuscript on file at the Instituto Hondureño de Antropología e Historia, Tegucigalpa and Copan.

Buikstra, Jane E., Mielke, J.H., 1985. Demography, diet, and health. In: Gilbert, R.I., Mielke, J.H. (Eds.), The Analysis of Prehistoric Diets. Academic Press, New York, pp. 359–422.

Buikstra, Jane E., Ubelaker, Douglas H. (Eds.), 1994. Standards for Data Collection from Human Skeletal Remains. Arkansas Archaeological Survey Research Series 44. Arkansas Archaeological Survey, Fayetteville.

Buikstra, Jane E., Price, T. Douglas, Wright, Lori E., Burton, James H., 2004. Tombs from the Copan Acropolis: a life history approach. In: Bell, Ellen E., Canuto, Marcello A., Sharer, Robert J. (Eds.), Understanding Early Classic Copan. University of Pennsylvania Museum, Philadelphia, pp. 185–205.

Burton, J.H., Wright, L.E., 1995. Nonlinearity in the relationship between bone Sr/Ca ratios and dietary ratios: paleodietary implications. American Journal of Physical Anthropology 96, 273–282.

Carrelli, Christine W., 2004. Measures of power: the energetics of royal construction at Early Classic Copan. In: Bell, Ellen E., Canuto, Marcello A., Sharer, Robert J. (Eds.), Understanding Early Classic Copan. University of Pennsylvania Museum, Philadelphia, pp. 113–127.

Danforth, Marie Elaine, 1999. Coming up short: stature and nutrition among the Ancient Maya of the Southern Lowlands. In: White, C.D. (Ed.), Reconstructing Ancient Maya Diet. University of Utah Press, Salt Lake City, pp. 103–117.

ElNesr, N.M., Avery, J.K., 1994. Tooth eruption and shedding. In: Avery, J.K. (Ed.), Oral Development and Histology. Thieme Medical Publishers, New York, pp. 110–129 (Chapter 7).

Ericson, J.E., 1985. Strontium isotope characterization in the study of prehistoric human ecology. Journal of Human Evolution 14, 503–514.

Fash, William L., 2001. Scribes, Warriors, and Kings: The City of Copan and the Ancient Maya. Thames and Hudson, New York (Revised edition).

Fash, William, L., Sharer, R. J., 1991. Sociopolitical developments and methodological issues at Copan, Honduras: a conjunctive perspective. Latin American Antiquity 2, 166–187.

Fash, William.L., Fash, Barbara W., 2000. Teotihuacan and the Maya: a Classic heritage. In: Carrasco, D., Jones, L., Sessions, S. (Eds.), Mesoamerica's Classic Heritage: From Teotihuacan to the Aztecs. University of Colorado Press, Bounder, pp. 433–464.

Fash, W.L., Fash, B.W., Davis-Salazar, K.L., 2004. Setting the stage: origins of the hieroglyphic stairway plaza on the great period ending. In: Bell, E.E., Canuto, M.A., Sharer, R.J. (Eds.), Understanding Early Classic Copan. University of Pennsylvania Museum of Archaeology and Anthropology, Philadelphia, pp. 65–83.

Fricke, Henry C., O'Neil, James R., 1996. Inter- and intra-tooth variation in the oxygen isotope composition of mammalian tooth enamel phosphate: implications for palaeoclimatological and palaeobiological research. Palaeogeography, Palaeoclimatology, Palaeoecology 126, 91–99.

Hess, J., Bender, M.L., Schilling, J.-G., 1986. Evolution of the ratio of strontium-87 to strontium-86 in seawater from Cretaceous to present. Science 231, 979–984.

Hillson, Simon, 2005. Teeth. Cambridge University Press, Cambridge.

Hodell, David A., Quinn, R.L., Brenner, M., Kamenov, G., 2004. Spatial variation of strontium isotopes ($^{87}Sr/^{86}Sr$) in the Maya region: a tool for tracking ancient human migration. Journal of Archaeological Science 31, 585–600.

Iacumin, P., Bocherens, H., Mariotti, A., Longinelli, A., 1996. Oxygen isotope analyses of co-existing carbonate and phosphate in biogenic apatite: a way to monitor diagenetic alteration of bone phosphate? Earth and Planetary Science and Letters 142, 1–6.

Knudson, K.J., 2009. Oxygen isotope analysis in a land of environmental extremes: the complexities of isotopic work in the Andes. International Journal of Osteoarchaeology 19, 171–191.

Krejci, E., Culbert, T.P., 1995. Preclassic and Classic burials and caches in the Maya lowlands. In: Grube, N. (Ed.), The Emergence of Classic Maya Civilization. Anton Saurwein, Möckmühl, pp. 103–116.

Krueger, H.W. 1985. Sr isotopes and Sr/Ca in Bone. In: Poster Paper presented at Biomineralization Conference. Airlie House, Warrenton, Va. April 14–17.

LaPorte, J.P., Fialko, V., 1990. New perspectives on old problems: dynastic references for the Early Classic at Tikal. In: Clancy, F., Harrison, P. (Eds.), Vision and Revision in Maya Studies. University of New Mexico Press, Albuquerque, pp. 33–66.

Longinelli, A., 1984. Oxygen isotopes in mammal bone phosphate: a new tool for paleohydrological and paleoclimatological research? Geochemica et Cosmochimica Acta 48, 385–390.

Looper, Mathew G., 2003. Lightening Warrior: Maya Art and Kingship at Quirigua. University of Texas Press, Austin.

Luz, Boaz, Kolodny, Yehoshua, 1989. Oxygen isotope variation in bone phosphate. Applied Geochemistry 4, 317–323.

Marcus, Joyce, 1992. Dynamic cycles of Mesoamerican states. National Geographic Research and Exploration 8, 392–411.

Martin, Simon, Grube, Nikolai, 2008. Chronicle of the Maya Kings and Queens, second ed. Thames and Hudson, London.

Metcalfe, Jessica Z., Longstaffe, Fred J., White, Christine D., 2009. Method-dependent variations in stable isotope results for structural carbonate in bone bioapatite. Journal of Archaeological Science 36, 110–121.

Mincer, H.H., Harris, E.F., Berryman, H.E., 1993. The A.B.F.O. study of third molar development and its use as an estimator of chronological age. Journal of Forensic Sciences 38 (2).

Price, T. Douglas, Linda, Manzanilla, Middleton, William H., 2000. Immigration and the ancient city of Teotihuacan in Mexico: a study using strontium isotope ratios in human bone and teeth. Journal of Archaeological Science 27, 903–913.

Price, T. Douglas, Burton, James H., Alex Bentley, R., 2002. The characterization of biologically available strontium isotope ratios for the study of prehistoric migration. Archaeometry 44, 117–135.

Price, T. Douglas, James, Burton, Wright, L.E., White, C.D., Longstaffe, F., 2007. Victims of Sacrifice. Isotopic evidence for place of origin. In: Tiesler, Vera, Cucina, Andrea (Eds.), New Perspectives on Human Sacrifice and Ritual Body Treatments in Ancient Maya Society. Springer Publishers, London, pp. 263–292.

Price, T. Douglas, James, Burton, Fullagar, Paul D., Wright, Lori E., Buikstra, Jane E., Tiesler, Vera, 2008. Strontium isotopes and human mobility in ancient Mesoamerica. Latin American Antiquity 19, 167–180.

Reents-Budet, Dorie, Bell, Ellen E., Traxler, Loa P., Bishop, Ronald L., 2004. Early Classic ceramic offerings at Copan: a comparison of the Hunal, Margarita, and SubJaguar tombs. In: Bell, Ellen E., Canuto, Marcello A., Sharer, Robert J. (Eds.),

Understanding Early Classic Copan. University of Pennsylvania Museum, Philadelphia, pp. 159–190.
Rozanski, K., Araguás-Araguás, L., Gonfiantini, R., 1993. Isotopic patterns in modern global precipitation. In: Swart, P.K., Lohmann, K.C., McKenzie, J.A., Savin, S. (Eds.), Geophysical Monograph. Climate Change in Continental Isotopic Records. American Geophysical Union, Washington, pp. 1–36.
Sanders, William T. (Ed.), 1986. Excavaciones en el area urbana de Copán, Tomo I. Tegucigalpa: Secretaría de Cultura y Turismo y Instituto Hondureño de Antropología e Historia.
Sanders, William T. (Ed.), 1990. Excavaciones en el area urbana de Copán, Tomo II. Tegucigalpa: Secretaría de Cultura y Turismo y Instituto Hondureño de Antropología e Historia.
Schele, Linda. 1986. The Founders of Lineages at Copan and Other Maya Sites. Copan Note 8. Copan Mosaics Project and the Instituto Hondureño de Antropología e Historia. Austin, Texas.
Schele, Linda, Nikolai, Grube, Federico Fahsen. 1993. The Tikal-Copan Connection: The Copan Evidence. Copan Note 122. Copan Acropolis Archaeological Project and the Instituto Hondureño de Antropología e Historia. Austin, Texas.
Schwarcz, Henry P., Gibbs, Linda, Knyf, Martin, 1991. Oxygen isotope analysis as an indicator of place of origin. In: Susan, Pfeiffer, Williamson, Ron F. (Eds.), Snake Hill: An Investigation of a Military Cemetery from the War of 1812. Dundurn Press, Toronto, pp. 263–268.
Sedat, David W., López, Fernando, 2004. Initial stages in the formation of the Copan Acropolis. In: Bell, Ellen E., Canuto, Marcello A., Sharer, Robert J. (Eds.), Understanding Early Classic Copan. University of Pennsylvania Museum, Philadelphia, pp. 85–99.
Sharer, Robert J., 2003a. Founding events and Teotihuacan connections at Copan, Honduras. In: Braswell, G.F. (Ed.), Teotihuacan and the Maya: Reinterpreting Early Classic Interaction. University of Texas Press, Austin, pp. 143–165.
Sharer, Robert J., 2003b. Tikal and the Copán dynastic founding. In: Sabloff, J.A. (Ed.), Changing Perspectives on Tikal and the Development of Ancient Maya Civilization. School of American Research, Santa Fe, pp. 319–353.
Sharer, Robert J., 2004. External interaction at Early Classic Copan. In: Bell, Ellen E., Canuto, Marcello A., Sharer, Robert J. (Eds.), Understanding Early Classic Copan. University of Pennsylvania Museum, Philadelphia, pp. 297–318.
Sharer, Robert J., Miller, Julia C., Traxler, Loa P., 1992. Evolution of Classic period architecture in the Early Acropolis, Copan: a progress report. Ancient Mesoamerica 3, 145–159.
Sharer, Robert J., Traxler, Loa P., Sedat, David W., Bell, Ellen E., Canuto, Marcello A., Powell, Christopher, 1999. Early Classic architecture beneath the Copan Acropolis: a research update. Ancient Mesoamerica 10, 3–23.
Sharer, Robert J., Sedat, David W., Traxler, Loa P., Miller, Julia C., Bell, Ellen E., 2005. Early Classic royal power at Copan: the origins and development of the Acropolis. In: Andrews, W.L., Fash, E.W. (Eds.), Copan: The History of an Ancient Maya Kingdom. School of American Research, Santa Fe, pp. 139–199.
Smith, B., 1991. Standards of Human Tooth Formation and Dental Age Assessment. Advances in Dental Anthropology.. Wiley-Liss, New York.
Sponheimer, M., Lee-Thorp, J.A., 1999. Oxygen isotopes in enamel carbonate and their ecological significance. Journal of Archaeological Science 26, 723–728.
Stuart, David, 2000. The arrival of strangers: Teotihuacan and Tollan in Classic Maya History. In: Carrasco, D., Jones, L., Sessions, S. (Eds.), Mesoamerica's Classic Heritage. University of Colorado Press, Boulder, pp. 465–513.
Stuart, David, 2004. The beginnings of the Copan dynasty. A review of the hieroglyphic and historical evidence. In: Bell, Ellen E., Canuto, Marcello A., Sharer, Robert J. (Eds.), Understanding Early Classic Copan. University of Pennsylvania Museum, Philadelphia, pp. 215–248.
Stuart, David. 2007. The Origins of Copan's Founder. Posted on Maya Decipherment: A Weblog on the Ancient Maya Script. <http://decipherment.wordpress.com/>.
Stuart, David, Schele, Linda, 1986. Yax-K'uk-Mo' the founder of the Lineage of Copan. Copan Note 6. Austin TX: Copan Acropolis Archaeological Project, Instituto Hondureõ de Antropología e Historia.
Tiesler Blos, Vera, 1998. La costumbre de la deformacîon cefálica entre los antiguos Mayas: Aspectos morfológicos y culturales. Instituto Nacional de Antropología e Historia, Mexico City.
Tiesler Blos, Vera., 1999. Rasgos Bioculturales Entre los Antiguos Mayas: Aspectos Culturales y Sociales. Doctoral Thesis in Anthropology, UNAM.
Torres-Alvarado, Ignacio, Verma, Surendra P., Carrasco-Nuñez, Gerardo, 2000. Compilation of radiogenic isotope data in Mexico and their implications. Proceedings of Indian Academy of Sciences (Earth and Planetary Sciences) 109, 67–78.
Traxler, Loa P., 1994. A new discovery at Copan. Expedition 35 (3), 57–62.
Traxler, Loa P., 1996. Los grupos de patios tempranos de la Acrópolis de Copán. Yaxkin 14, 35–54.
Traxler, Loa, P., 2001. The Royal Court of Early Classic Copan. In: Inomata, T., Houston, S.D. (Eds.), Royal Courts of the Ancient Maya, vol. 2. Westview Press, Boulder, pp. 46–73.
Traxler, Loa P., 2003. At court in Copan: palace groups of the Early Classic. In: Christie, J. (Ed.), Maya Palaces and Elite Residences. University of Texas Press, Austin, pp. 46–68.
Traxler, Loa P., 2004. Redesigning Copan: early architecture of the polity center. In: Bell, Ellen E., Canuto, Marcello A., Sharer, Robert J. (Eds.), Understanding Early Classic Copan. University of Pennsylvania Museum, Philadelphia, pp. 53–64.
Webster, D., Sanders, W.T., van Rossum, P., 1992. A simulation of Copan population history and its implications. Ancient Mesoamerica 3, 185–197.
Weidemann, Felicitas B., Bocherens, Hervé, Mariotti, André, von den Driesch, Angela, Gisela, Grupe, 1999. Methodological and archaeological implications of intra-tooth isotopic variation ($\delta^{13}C$, $\delta^{18}O$) in herbivores from Ain Ghazal (Jordan, Neolithic). Journal of Archaeological Science 26, 697–704.
Weigand, P.C., Harbottle, G., Sayre, E.V., 1977. Turquoise sources and source analysis: Mesoamerica and the southwestern USA. In: Earle, T.K., Ericson, J.E. (Eds.), Exchange Systems in Prehistory. Academic Press, New York, pp. 15–34.
White, Christine D., Spence, Michael W., Stuart-Williams, Hilary Le Q., Schwarcz, Henry P., 1998. Oxygen isotopes and the identification of geographical origins: the Valley of Oaxaca versus the Valley of Mexico. Journal of Archaeological Science 25, 643–655.
White, Christine D., Spence, Michael W., Longstaffe, Fred J., Law, Kimberley R., 2000. Testing the nature of Teotihuacan imperialism at Kaminaljuyu using phosphate oxygen-isotope ratios. Journal of Anthropological Research 56, 535–558.
White, Christine D., Spence, Michael W., Longstaffe, Fred J., 2004. Demography and ethnic continuity in the Tlailotlacan enclave of Teotihuacan: the evidence from stable oxygen isotopes. Journal of Anthropological Archaeology 23, 385–403.
White, Christine D., Price, T. Douglas, Longstaffe, Fred J., 2007. Residential histories of the human sacrifices at the Moon Pyramid, Teotihuacan: evidence from oxygen and strontium isotopes. Ancient Mesoamerica 18, 159–172.
Whittington, Stephen L., 1989. Characteristics of Demography and Disease in Low-Status Maya from Classic Period Copan, Honduras. Ph.D. Dissertation, The Pennsylvania State University. University Park, PA.
Wright, Lori E., 2005. Identifying immigrants to Tikal, Guatemala: defining local variability in strontium isotope ratios of human tooth enamel. Journal of Archaeological Science 32, 555–566.
Wright, L.E., submitted for publication. An isotope study of childhood diet and mobility at Copan, Honduras. In: Lozada, M.C., O'Donnabhain, B. (Eds.), The Dead Tell Tales: Jane Buikstra and Narratives of the Past. Cotsen Institute of Archaeology, UCLA.
Wright, L.E., Schwarcz, H.P., 1996. Infrared and isotopic evidence for diagenesis of bone apatite at Dos Pilas, Guatemala: paleodietary implications. Journal of Archaeological Science 23, 933–944.
Wright, L.E., Schwarcz, H.P., 1998. Stable carbon and oxygen isotopes in human tooth enamel: identifying breastfeeding and weaning in prehistory. American Journal of Physical Anthropology 106, 1–18.
Wright, Lori E., Schwarcz, Henry P., 1999. Correspondence between stable carbon, oxygen, and nitrogen isotopes in human tooth enamel and dentine: infant diets and weaning at Kaminaljuyú. Journal of Archaeological Science 26, 1159–1170.
Zazzo, Antoine, Lécuyer, Christophe, Mariotti, André, 2004. Experimentally-controlled carbon and oxygen isotope exchange between bioapatites and water under inorganic and microbially-mediated conditions. Geochimica Et Cosmochimica Acta 68, 1–12.