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# BIOLOGICAL PERSPECTIVES ON THE COLLAPSE OF THE PASION MAYA

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## Abstract

This paper reviews bioarchaeological research that aimed to test the biological correlates of ecological explanations for the Maya collapse using human skeletal remains from five sites in the Pasión region. Stable isotope ratios of bone collagen and alkaline earth ratios in bone minerals do not support the expectation of increased reliance on maize and declining meat consumption during the final years of Pasión occupation. Moreover, skeletal pathology does not illustrate any increment in anemia, infectious disease, or dental growth disruption that is predicted to have been a consequence of high population density and deteriorating nutrition. Instead, changes in the social distribution of foods during the Terminal Classic supports the mounting evidence that the Pasión collapse was fueled more by sociopolitical transformations than environmental ones.

A common theme in Maya studies concerns the effects of population density and environmental degradation on the long-term survival of ancient Maya civilization. Such ecological models of the ninth-century collapse of southern lowland Maya cities propose a dramatic expansion of the agricultural system in order to feed the rapidly growing Late Classic population. By the eighth century, overcultivation, soil erosion, grass invasion, and deforestation had compromised agricultural productivity. These agronomic pressures are thought to have transformed the diet consumed by the Late Classic Maya. Together with an elevated disease load and compromised hygiene at the hand of the high population density, this dietary change is implicated in a deterioration of the nutritional status and the health of the population. Ultimately, demographic instability brought on by these health changes is argued to have contributed to population loss after A.D. 800 (Culbert 1988; Sanders 1973; Santley 1990; Santley et al. 1986; Webster et al. 1992; Willey and Shimkin 1973).

Early studies of Maya skeletons lent credence to such arguments, especially those by Hooton (1940), Haviland (1967), and Saul (1972, 1973). Finding no biological evidence for foreign invasion as a factor in the Pasión collapse, despite the attention drawn to it by the Harvard projects (e.g., Sabloff and Willey 1967), Frank Saul's pioneering paleopathological study at Altar de Sacrificios focused attention on malnutrition and disease as possible agents of depopulation. Although Saul (1972, 1973) did not affirm that disease was the direct cause of the collapse, he argued that the Maya of Altar de Sacrificios and Seibal were extremely unhealthy and that Classic lowland civilization must have been poised upon a dangerous demographic precipice. Since that time, archaeologists have integrated this disease factor into models that characterize the Maya as a society living in a precarious balance with their environment (Adams 1983; Culbert 1988; Sharer 1977; Webster et al. 1992).

Recent discoveries in the Petexbatun region of the Guatemalan Peten now force us to reexamine our understanding of the collapse and depopulation of this region. As detailed in the other papers of this issue, the Petexbatun region became a focus of politico-military competition during the Late Classic period. For both Dos Pilas and Aguateca, twin capitals of the Petexbatun dynasty, archaeological data demonstrate that warfare was directly implicated in site abandonment. A small Terminal Classic population remained at Dos Pilas after the elite collapse, but Aguateca appears to have remained completely abandoned (Demarest 1996; Inomata 1995; Palka 1995, and other papers in this section). In the Pasión Valley, a large Terminal Classic occupation also persisted at Altar de Sacrificios long after the last monumental construction activity ceased (Willey 1973), but only at Seibal is there evidence for continued elite leadership into the Terminal Classic period (Mathews and Willey 1991; Willey 1990). This new epigraphic and archaeological information hints that politics—not ecology—hold the key to the collapse of the Maya polities living in the Pasión drainage. Whatever the proximate cause of collapse, these new data do not entirely rule out the possibility that environmental pressures might have contributed to political instability.

## A BIOARCHAEOLOGICAL APPROACH

This paper reviews research in paleopathology and paleodietary bone chemistry that aimed to test several expectations for the diet and health of the Pasión Maya that originate in ecological models of collapse. Because Maya skeletal series are typically small and poorly preserved, the problem was approached from a broad regional perspective. The data used in this research come from six sites: Dos Pilas, Aguateca, Seibal, Altar de Sacrificios, Tamarindito, and Itzan. In total, the skeletal remains of 254 individuals were examined, but the sample size is much smaller for each statistical comparison due to the poor preservation of bone in this humid environment (see Wright 1994). The Dos Pilas and Aguateca skeletal remains were excavated by Vanderbilt University's Petexbatun Regional Archaeological Project between 1989 and 1993.



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Several burials excavated in 1994 from Tamarindito (Valdés, 1997) also contribute to the enamel hypoplasia database (Wright 1997a). The Petexbatun remains come from a variety of contexts at each site that span the social spectrum. The burials are mostly from domestic groups within the mapped area of each site but also include a few royal interments (Demarest et al. 1991). Human remains from Altar de Sacrificios and Seibal, excavated by Harvard University (Willey 1973, 1990) and previously studied by Saul (1972, 1973), were examined at the Peabody Museum at Harvard. The Altar de Sacrificios remains include burials from both the ceremonial core and surrounding house mounds, while those from Seibal are more evenly derived from domestic contexts across the site. A few Late Classic burials from an outlying low-status domestic group at Itzan (Johnston 1994) were also included in paleopathological comparisons. Preclassic and Early Classic skeletons studied are only from Altar and Seibal, while all sites contribute to the Late Classic series. Terminal Classic skeletons are from Altar, Seibal, and Dos Pilas.

Analysis of the Pasión skeletal remains was structured around five hypotheses that have been framed by proponents of an ecological explanation for the collapse (Abrams and Rue 1988; Culbert 1988; Harrison 1977; Lowe 1985; Pozo-Ledezma 1985; Sanders 1973; Santley et al. 1986; Sharer 1977; Shimkin 1973; Willey and Shimkin 1973; Santley 1990; Webster et al. 1992). The first two hypotheses address dietary changes that are rooted in the agronomic implications of high population density, as follows:

1. Due to declining crop yields at the hand of overcultivation and to increasing food needs of a growing population, farmers shifted to intensive cultivation of high-yielding maize at the expense of other plants, a shift that transformed the diet of individual consumers (see Santley [1990]; Santley et al. [1985]; Wiseman [1985]).
2. Together with increased hunting pressure from the larger population, agricultural expansion destroyed primary forest habitats, thereby limiting the availability of animal protein.

The second set of hypotheses focus on the health implications of this dietary and demographic change, as follows:

3. Increased dietary reliance on few staple crops, especially maize, resulted in widespread malnutrition.
4. Increased population density led to an increment in infectious disease.
5. Malnutrition and infection took the greatest toll on children, affecting mortality and the demographics of Maya society.

The two dietary expectations are tested using stable isotopic ratios in bone collagen and alkaline earth ratios in bone minerals. The three health expectations of the ecological arguments are evaluated with reference to the abundance of skeletal lesions of porotic hyperostosis, periostosis, and enamel hypoplasia. Although insight from the florescence of paleopathology during the last two decades permits a more sensitive interpretation of prehistoric health than was possible when Saul (1972, 1973) conducted his studies, small sample size continues to hinder the use of statistical analysis. Because of the paucity of Preclassic and Early Classic burials, these two periods are considered together here as a single "Early" period in chronological comparisons of skeletal pathology. Poor bone preservation hinders intrasite analysis, thus health expectations are evaluated at the broader regional scale. By contrast, paleodietary trends are examined at each site, using traditional chronological divisions. Detailed discussion of archaeological sampling issues, correlation of chronological divisions, and social heterogeneity among series can be found in Wright (1994:79–86).

## BONE CHEMISTRY AND PALEODIETS

### Stable Isotopes

Stable-isotopic analysis of human bone permits the evaluation of the two dietary shifts that are expected if environmental factors had been instrumental in the collapse. The standardized ratios between the two stable isotopes each of carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) in Maya bone collagen are good measures of the relative amount of maize and meat consumed, respectively. As a C4 plant, maize incorporates relatively more of the heavy isotope $^{13}C$ than do C3 plants like beans, squash, and fruits, and this "heavy" isotopic composition is passed on to the tissues of a consumer. Since maize is the main C4 plant eaten by the ancient Maya, $\delta^{13}C$ can be used as a relative measure of maize consumption. By contrast, $^{15}N$ is enriched during transamination of digested protein, so carnivorous animals, including fish, have heavier $\delta^{15}N$ than herbivorous ones do (Ambrose 1993; Schwarcz and Schoeninger 1991). Thus, $\delta^{15}N$ is a good measure of meat consumption. If maize consumption had increased during the span of the Classic period, we expect heavier $\delta^{13}C$ in later skeletons than in earlier ones. Likewise, if meat consumption declined over time, we expect lighter $\delta^{15}N$ in the skeletons of later occupants of the region.

The isotopic study was conducted on cortical bone samples from each well-preserved skeleton. Isotopic ratios were measured by mass spectrometry on collagen obtained by demineralizing bone in EDTA. Good collagen preservation was evident for the majority of bone samples. Further details of the sample preparation and diagenetic evaluation can be found in Wright (1994, 1997b). Subsequent infrared spectroscopic study of Dos Pilas bone mineral found the apatite $\delta^{13}C$ to be subtly affected by carbonate diagenesis and unsuitable for paleodietary interpretation (Wright and Schwarcz 1996).

Mean values for collagen $\delta^{13}C$ and $\delta^{15}N$ by time period are indicated for each site in Table 1. Human bone collagen from the

**Table 1.** Stable isotopic composition of human bone from the Pasión region

| | $\delta^{13}C$ | | | $\delta^{15}N$ | | |
|---|---|---|---|---|---|---|
| Site and Period | Mean | S.D. | N | Mean | S.D. | N |
| Altar de Sacrificios | | | | | | |
| Preclassic | −10.4 | .6 | 8 | 8.4 | .7 | 8 |
| Early Classic | −9.1 | .5 | 5 | 8.2 | .6 | 5 |
| Late Classic | −8.3 | 1.0 | 7 | 9.0 | 1.0 | 7 |
| Terminal Classic | −9.0 | .9 | 16 | 8.8 | 1.1 | 16 |
| Seibal | | | | | | |
| Preclassic | −9.6 | 1.0 | 7 | 9.7 | .8 | 7 |
| Late Classic | −9.4 | 1.4 | 11 | 9.9 | .9 | 11 |
| Terminal Classic | −9.4 | 1.2 | 16 | 8.9 | .9 | 16 |
| Dos Pilas | | | | | | |
| Late Classic | −9.0 | 1.0 | 14 | 9.8 | .9 | 15 |
| Terminal Classic | −9.4 | .8 | 4 | 8.8 | 1.2 | 4 |

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Pasión region is slightly heavier in $\delta^{13}C$ than is maize, and the $\delta^{15}N$ of the human bones is rather heavier than that of local herbivores. While these results confirm that maize was an important foodstuff in the Pasión region, they also indicate that meat was a significant source of dietary protein. Given the inland location of Dos Pilas, and the similarity of $\delta^{15}N$ there to the riverine sites, it is likely that $\delta^{15}N$ values throughout the region are mostly due to terrestrial meat consumption, not to fish.

At Altar de Sacrificios, the $\delta^{13}C$ of bone collagen increased gradually from the Preclassic through to the Late Classic period. In the Terminal Classic, $\delta^{13}C$ declined toward the Early Classic value, despite the maintenance of a large community at the site after the elite collapse. Given that no change in $\delta^{15}N$ is evident throughout the sequence, it is possible to attribute these trends to shifts in the relative importance of maize to Altar diets. At Dos Pilas, the few Terminal Classic burials show slightly lighter $\delta^{13}C$ and $\delta^{15}N$ than do Late Classic skeletons, but neither of the differences are statistically significant. This might suggest a decline in maize consumption after the Petexbatun dynasty withdrew to Aguateca, as at Altar, but the evidence is not conclusive.

By contrast, Seibal skeletons do not show any significant chronological change in $\delta^{13}C$. Preclassic, Late Classic, and Terminal Classic residents consumed comparable quantities of maize. Note that Preclassic Seibal occupants were more reliant on maize than were their contemporaries at Altar de Sacrificios (see Table 1). Preclassic and Late Classic Seibal collagen is heavier in $\delta^{15}N$ than is that of Altar, due to greater meat or fish consumption at Seibal. Instead of changes in $\delta^{13}C$, Terminal Classic Seibal collagen is light in $\delta^{15}N$ when compared to the Late Classic period data. However, Late Classic Seibal collagen is the most $^{15}N$-enriched in the region, and the Terminal Classic mean is not so light as to imply a scarcity of animal protein. The heavier $\delta^{15}N$ of Late Classic Seibal may be due to greater consumption of $^{15}N$-enriched fish. Perhaps a decline in fish consumption accounts for this Terminal Classic decline in $\delta^{15}N$.

## Alkaline Earth Elements

These interpretations can be further explored by reference to the relative abundance of the alkaline earth elements barium, strontium, and calcium (Ba, Sr, Ca) in human bone. Although early research heralded bone Sr/Ca as a trophic indicator (Schoeninger 1979; Sillen and Kavanagh 1982), more recent work demonstrates the importance of dietary mineral sources to bone alkaline earth ratios (Burton and Wright 1995). Sr/Ca and Ba/Ca are best interpreted as measures of Ca sources because Sr and Ba occur in bone as accidental substitutions for Ca. Analysis of a broad suite of local foods indicates that the Ba/Ca and Sr/Ca of Maya bone primarily reflect Ca consumed as lime-treated maize. Also, elevated Sr may identify freshwater fish and snail consumption, if these foods contribute enough Ca to the diet. Unlike stable-isotopic ratios, alkaline earth ratios cannot be compared between sites due to baseline differences in soils across the region (Wright 1994, 1998). However, Ba/Ca and Sr/Ca help to refine dietary interpretations at individual sites.

Mechanically and chemically cleaned bone samples were ashed and digested in hot nitric acid. The abundance of 13 elements was measured in this solution by inductively coupled plasma emission spectroscopy (ICP-AES). Bone mineral diagenesis was examined with a variety of approaches, and samples with evident contamination were excluded from paleodietary interpretation. Further details of the analytic methods and diagenetic evaluation can be found in Wright (1994, 1998).

At Altar de Sacrificios, a decline in Ba/Ca ratios tracks the increase in maize consumption indicated by $\delta^{13}C$ from the Preclassic to Late Classic periods. Ba/Ca then rose into the Terminal Classic period as maize consumption declined. This pattern is due to the greater Ba concentration in plant foods that were grown on the alluvial soils at Altar (and not treated with lime), than in lime used for maize preparation, which had to be imported from several miles away. At Seibal, most agricultural soils are derived from weathering of local Cretaceous limestones, so lime-treated and untreated foods would not have been so disparate in elemental compositions. Unlike Altar, Seibal Ba/Ca is stable, but Sr/Ca is statistically enriched in Late Classic Seibal bones. A likely source of this elevated Late Classic Sr/Ca is from consumption of fish from the Pasión River. This finding supports the prior hypothesis that greater fish consumption contributes to the enriched $\delta^{15}N$ signature of Late Classic Seibal collagen (Wright 1994, 1998).

## Dietary Inequality

The stable isotopic and alkaline earth data provide an avenue to evaluate patterns of economic inequality within burial series at each site. Status groups were identified through multivariate analysis of binary variables of burial location, grave form, skeletal position, orientation, and offerings. Principal components analysis suggests that mortuary symbols covaried independently at different sites across the region, with the exception of symbols of rulership that had pan-regional recognition. Thus, burials with similar attributes were identified using complete-linkage cluster analysis for each site individually and within each time period. Paleodietary chemistry was compared among these clusters for each sample (Wright 1994).

Although the samples are too small to be evaluated statistically, several patterns are apparent. At Late Classic Altar de Sacrificios and Dos Pilas, mortuary clusters show some systematic differences in $\delta^{13}C$ and $\delta^{15}N$. At Altar, the two most elite burials are enriched in $^{15}N$, indicating greater meat consumption. Low-status skeletons at Dos Pilas consumed less meat than the occupants of intermediate-status graves, although the two royal burials do not follow this trend. Alkaline earth ratios also differ among burial clusters at Late Classic Dos Pilas indicating differential plant consumption and/or culinary practices.

By contrast, the large Terminal Classic burial series from Altar de Sacrificios and Seibal lacks the superordinate status dimension seen at Late Classic Dos Pilas and Altar. Either social differentiation was reduced in this final occupation, or status competition was no longer acted out in mortuary ritual. Tourtellot's (1990) interpretation of the Bayal burials at Seibal as those of foreign invaders is unlikely given local antecedents for each of the burial attributes he cites (Wright 1994:158–162). Instead, the local funerary pattern is slightly restructured in this final occupation. Terminal Classic diets show no patterning among burial clusters at either site. Instead, $\delta^{13}C$ shows sexual patterning; males consumed more maize than females. This pattern suggests a shift from social inequality in access to food to a less-stratified system in the Terminal Classic where diet may have been more constrained by sex-specific daily activity patterns (Wright 1994, 1997b).

## SKELETAL PATHOLOGY AND HEALTH

Although diet certainly changed over the span of Pasión occupation, paleodietary data do not indicate that the nutritional quality of the diet may have declined dramatically in the manner predicted by environmental models of the Maya collapse. However, it is important to recall that while these chemical techniques reflect the weighted average of foods consumed, they do not allow us to directly evaluate the adequacy of total food intake. Instead, paleopathological indicators provide an assessment of nutritional status. Chronological trends in three health indicators used to evaluate the remaining three hypotheses are detailed in Table 2.

### Anemia

Porotic hyperostosis, which is caused by childhood anemia, is a key pathological lesion for study of nutritional adequacy. Indeed, Hooton (1940) once speculated that porotic hyperostosis (which he called "osteoporosis symmettrica") might have caused the Maya collapse. Under anemic conditions, the cranial diplöe expands and perforates the thin external table of the juvenile cranium and the orbital roof, giving it a porotic or coralline texture. As the child grows, the bony lesion gradually heals and is reduced to an irregular, sclerotic texture on the surface of the cranium. On adult crania, the presence of healed porotic hyperostosis indicates that an individual had suffered from prolonged anemia during childhood, and that they had survived the illness. Among the Maya, the presence of these cranial lesions has typically been interpreted primarily as a consequence of the use of maize atole as the main food given to recently weaned children, although the potential contribution of blood loss due to intestinal parasitism has also been noted (Saul 1972, 1977). Maize is very low in iron and also contains phytate, which inhibits the intestinal absorption of the little iron consumed.

In the combined Pasión skeletal series, porotic hyperostosis could be scored on the parietals of 81 adult crania. As there were few juvenile crania, the age of anemic onset cannot be identified for this population with any confidence. But, almost all subadult skeletons show fine porosity in the orbit, and most also show vault changes. Of adult crania, some 64% show healed lesions, indicating that they had suffered from an anemic episode during childhood. The sclerotic lesions are symmetrically located near the parietal bosses and along the lambdoid sutures of both parietal and some occipital bones. Although common, Chi-square tests indicate no significant differences in lesion abundance over time. Anemia did not increase in prevalence during the occupation of the Pasión region (Wright 1994). This is a fairly high frequency of lesions when viewed in a global perspective but is not beyond the range observed in other agricultural and urban groups (Wright and White 1996). Moreover, it indicates a high degree of survivorship through a protracted period of childhood anemia.

Table 2. Prevalence of porotic hyperostosis, periostosis, and enamel hypoplasia over time in the Pasión region

| | "Early" | | Late Classic | | Terminal Classic | |
|---|---|---|---|---|---|---|
| Pathology/Location | +[a] | N[b] | + | N | + | N |
| Porotic hyperostosis | | | | | | |
| Parietal | 5 | 9 | 17 | 26 | 27 | 46 |
| Parietal or occipital | 5 | 9 | 18 | 26 | 30 | 46 |
| Periostosis | | | | | | |
| Left femur | 5 | 14 | 9 | 32 | 10 | 26 |
| Left tibia | 9 | 13 | 16 | 27 | 17 | 20 |
| Left fibula | 3 | 7 | 11 | 22 | 9 | 14 |
| Enamel hypoplasia | | | | | | |
| Maxillary central incisor | 5 | 17 | 12 | 31 | 16 | 40 |
| Maxillary canine | 7 | 16 | 21 | 47 | 23 | 44 |
| Mandibular canine | 8 | 15 | 21 | 40 | 30 | 45 |

[a]Number of skeletons affected by lesions.
[b]Number of skeletons that could be scored for that element.

### Infectious Disease

Pasión skeletons often show periosteal reactions, or periostoses, which consist of a layer of new bone deposited over the surface of the original healthy bone. New periosteal bone apposition that was active and ongoing at the time of death has a fine woven texture and can be differentiated from the underlying original cortical bone, while healed lesions are dense and sclerotic. Although periostoses result from a variety of conditions, most cases result from infection. Some diseases show characteristic populational and intraskeletal patterns of periosteal new bone deposition that permit a diagnosis of the infectious agent.

Periosteal reactions could be scored on 127 skeletons from the Pasión region, although many of these were missing several bones. Active periostitis is very rare in the series, but is common on the skeletons of children. Sclerotic healed periosteal reactions are typically located on the diaphysis of long bones and are frequent findings on adult skeletons. These are most abundant on the left tibia, with 66% of left tibial diaphyses affected. Similarly, 53% of fibulae show lesions, as well as 28% of femoral diaphyses. The arm bones and cranium are very rarely affected.

The presence of lesions is highly correlated in the two sides of the body, and these bilateral cases are usually highly symmetrical in form. As first suggested by Saul (1972), many of these could have been cause by a form of endemic treponematosis. Infection by the spirochetal bacterium *Treponema* produces widespread bilaterally symmetrical subperiosteal inflammation of the tibiae, fibulae, and distal femora (Hackett 1976). Several Pasión skeletons show marked anterior tibial periostosis that resembles the sabreshin deformity which is pathognomic of treponematosis. Several skeletons with tibio-fibular periostosis also show periosteal reactions on the metacarpals or metatarsals. This "dactylitis" is a common sequela of advanced treponematosis. Caries sicca, which are lesions characteristic of venereal syphilis (a more virulent form of treponematosis), are absent from Pasión crania. Instead, this lesion pattern strongly resembles that of yaws, an endemic form of treponematosis that is contracted in childhood by contact with skin lesions. The subsequent bony changes are gradual and progressive over the life span of an individual, but the infection has little effect on longevity and is not as debilitating as the visible bone changes might suggest (Powell 1991). The presence of several examples of these pathognomic lesions in the small Pasión skeletal series implies that the majority of the population may well have been exposed to *Treponema* (Wright 1994).

Other localized periosteal reactions on Pasión skeletons might have been caused by cutaneous leishmaniasis, although other infectious agents and trauma cannot be ruled out. *Leishmania mexicana* is carried by sand flies that normally prey on Peten rodents.

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The protozoal infection produces a small granulomatous cutaneous lesion, known locally as "chiclero ulcer." Underlying bone can be secondarily affected by bacterial infection. Chiclero ulcers often heal within a year, even when they have not been treated medically (Costa et al. 1990; Reeder and Palmer 1981). A number of discrete and sclerotic periostoses on Pasión tibiae might have been caused by leishmaniasis, as the disease is known to have been present pre-Hispanically (Wright 1994).

Environmental models of collapse predict an increase in infectious disease over the long occupation span of the region. Instead, Pasión periostoses demonstrate chronological stability in the manifestation of infectious disease. If indeed the majority of periostitis can be attributed to yaws and to leishmaniasis, two diseases that do not increase significantly with malnutrition or sanitation, then these conditions might mask any changes in acute infectious disease. Regardless, the skeletal data give no indication of health decline (Wright 1994).

### Dental Development

The final expectation of ecological explanations of the collapse is the most difficult to evaluate because the Pasión skeletal series are inadequate for paleodemographic reconstruction. One indirect approach is to study early childhood health, a key determinant of demographic structure. Enamel hypoplasias provide a good measure of overall childhood morbidity. Caused by a variety of infections in conjunction with dietary deficiency, these dental defects are formed when metabolic stress disrupts the normal growth of the tooth, leaving a ring of deficient enamel. Enamel hypoplasias constitute a permanent record of childhood health experience, and their location on the tooth indicates the age at which the growth disruption occurred (Goodman and Rose 1990; Saul 1972). Enamel hypoplasias were scored in the dentitions of 160 adult skeletons from the Pasión region. The location of each defect relative to the cervical border of the enamel was used to estimate the age of peak stress experience. Chronological tendencies in childhood health were evaluated for each tooth position by comparing the proportion of teeth affected by hypoplasia in each period for the region as a whole (Wright 1994, 1997a).

Hypoplasias are abundant on those teeth known to be most susceptible to growth disruption, especially the mandibular canine (59% of individuals affected), the maxillary central incisor (48%), and the maxillary canine (38%). For these teeth, contingency-table analysis finds no significant chronological differences, indicating stability in the total level of childhood illness suffered by those children who survived to adulthood. But, the proportion of several posterior teeth affected is significantly different between the Late and Terminal Classic periods. Because these teeth only register more severe stress episodes during narrow age spans, these shifts do not indicate a change in the total level of illness suffered, but rather hint at a shift in the timing of peak stress. Together with a decline of 2–3 months in the mean age of canine hypoplasias, these subtle patterns suggest that Terminal Classic children may have experienced stress at a slightly younger age than had their Late Classic ancestors (Wright 1994, 1997a). Although many factors can contribute to early childhood morbidity, the duration and frequency of breastfeeding can influence the pattern of childhood illness, because infants receive an immunologic boost from maternal breastmilk. Mothers often respond to food shortage by prolonging lactation (Dow 1977; Pérez-Escamilla 1993), so conversely, this shift to earlier peak stress may imply an improvement in the Terminal Classic nutritional environment. However, it is difficult to infer a direct link between this shift and the slight dietary changes revealed in adult bone chemistry.

## CONCLUSIONS

Neither the paleodietary nor the paleopathological data gleaned from Pasión skeletons fulfill the expectations of an environmental model for the collapse in this region. Maize was an important Pasión crop, but $\delta^{13}C$ trends do not support the assertion that maize reliance increased dramatically or was a key factor leading to a deterioration of health. Likewise, nitrogen isotopic data confirm that animal protein remained available for human consumption into the Terminal Classic period. Moreover, paleopathological studies document no tendency toward a decline in the health of surviving children over the span of the Classic period. Porotic hyperostosis, periostosis, and enamel hypoplasias are no more abundant in the skeletons of Late and Terminal Classic Pasión adults than they were during earlier periods. Since this level of disease did not impede the growth of the large Late Classic population, there is little reason to argue that disease was a critical element in the Terminal Classic depopulation.

By contrast, the partitioning of stable isotopic and alkaline earth ratios in bone hint that changes in the social distribution of resources may have accompanied the Late to Terminal Classic transition in the Pasión. Together with the mounting evidence for political conflict and warfare as a proximate cause of the abandonment of several cities, the results of this study provide little support for the argument that nutrition played a determining role in the collapse, at least for this region. Neither do they support a model of foreign invasion. Future research, especially at Maya sites where skeletal series are large, would profit from detailed scrutiny of social inequality in diet and health during the later Classic period, which may allow a more sensitive reconstruction of the role of nutritional disparity in ancient Maya social history.


## RESUMEN

Aquí se resumen los resultados de un programa de investigación bioarqueológica en seis sitios de la región del Río de la Pasión. El estudio fue diseñado para evaluar los correlativos biológicos de los modelos ecológicos que proponen que el colapso maya fue un resultado del deterioro ambiental y de la sobrepoblación, por medio del análisis de los restos óseos humanos. Los modelos predicen que el consumo del maíz incrementó durante la ocupación maya y que el consumo de la carne de animal disminuyó a finales del periódo clásico. A causa de estos cambios nutritivos y demográficos, los modelos predicen un aumento en los niveles de la anemia, de las enfermedades infecciosas y un empeoramiento de la salud juvenil.

Se utilizó el análisis químico de los huesos para examinar la dieta prehistórica de la región. Los cambios cronológicos documentados en los radios de los isótopos estables del carbono y del nitrógeno en el colágeno óseo y el contenido de los elementos alcalinotérreos en el mineral óseo no apoyan las expectativas dietéticas de los modelos ecológicos. Aunque el $\delta^{13}C$ declinó en la última ocupación de Altar de Sacrificios, y el $\delta^{15}N$ declinó en la fase Bayal de Seibal, estas tendencias cronológicas no ocurren


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de manera consistente a través de la región. En Seibal el consumo del maíz fue estable, mientras el consumo de la carne fue estable en Altar. Los niveles de $\delta^{15}N$ medidas no indican una crítica escasez de proteína animal. Además, el estudio osteopatólogica no documentó ningún empeoramiento en las condiciones de la salud que se esperaría como una consecuencia de la alta densidad de la población y del deterioro nutricional. En los esqueletos no se documentó un incremento en la abundancia de la hiperostosis porótica, la periostitis, o las hipoplasias del esmalte en los esqueletos adultos a través de la larga ocupación de la región.

Aunque los resultados bioarqueológicos no confirman las expectativas de los modelos ecológicos del colapso, sí hubieron cambios biológicos a través del tiempo. Durante el clásico tardío el análisis isotópico documenta diferencias sociales en el consumo de varios elementos, pero éstas son ausentes en las muestras del clásico terminal cuando los hombres comían más maíz que las mujeres. En lugar de un deterioro ambiental estos cambios en la distribución social de los alimentos proporcionan evidencia de que el colapso de la región del Río de la Pasión fue empujado más por transformaciones sociopolíticas que por cambios ambientales.

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