Bioarchaeology of the Stillwater Marsh

Prehistoric Human Adaptation in the Western Great Basin

Clark Spencer Larsen Robert L. Kelly

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BIOARCHAEOLOGY OF THE STILLWATER MARSH: PREHISTORIC HUMAN ADAPTATION IN THE WESTERN GREAT BASIN

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ABSTRACT

This monograph reports on the recovery and study of human remains from the Stillwater Marsh in the western American Great Basin (west-central Nevada). Analysis of these remains provides new details on health, lifeway, and population history of prehistoric native populations inhabiting the region. These results inform our understanding of how earlier societies used resources drawn from both lacustrine and uplands landscapes in this challenging setting.

Between 1982 and 1986, record high winter precipitation resulted in massive flooding of several Great Basin wetlands, including the Stillwater Marsh, located in the Carson Sink in western Nevada. As the floodwaters receded in 1985 and 1986, dozens of archaeological sites and hundreds of human skeletal remains were uncovered. Soon thereafter, the Nevada State Museum salvaged the disturbed remains representing, according to Brooks et al. (1988), 416 burials or individuals. Wind and wave erosion, however, continued to disturb burials in the region.

In 1987, archaeological crews under our direction surveyed the most heavily impacted marsh shoreline in order to document scattered skeletal remains and burials in danger of destruction. This monograph reports on eight burials excavated in 1987, 557 isolated human cranial and postcranial elements, and 122 isolated teeth collected during the course of this shoreline survey. These remains represent a minimum of 85 people, including 50 adults and 35 juveniles. This monograph also presents various analyses of the combined samples of human remains collected by the Nevada State Museum and by us. These analyses include assessments of dental health, evidence for iron deficiency anemia, the use of serum albumin and mitochondrial DNA as population markers, dental hypoplasia, bone chemistry, osteoarthritis, and long-bone (femur and humerus) cross-sectional geometry. Results are used to test competing reconstructions of the prehistoric use of wetland resources and to characterize the human condition generally in this region of the Desert West. One reconstruction argues that wetland resources could consistently provide sufficient food for a hunter-gatherer population and would therefore have been used by a sedentary population. An alternative reconstruction argues that temporal fluctuations in wetland resources relative to resources available in other valleys or in the nearby uplands would have resulted in a residentially mobile lifeway, even where the wetlands could provide the necessary amount of food.

The importance of the skeletal sample lies largely in its size: There is no comparable skeletal population in the Great Basin that has been analyzed to date. Some of the analyses reported here are the first of their type to be conducted on prehistoric Great Basin peoples.

Only six of the burials of the entire Stillwater series have been radiocarbon dated. These dates range from ca. 2300 to 300 B.P., with four of the dates falling within the Underdown phase (1250–650 B.P.), the predominant period represented by projectile point types found in, and radiocarbon dates on, the archaeological sites exposed by high water. Consequently, the human remains here are treated as if they were a single population. The dates available do not indicate any obvious temporal trends, but better controls are needed to ascertain whether such trends exist.

Overall, the Stillwater skeletal remains are extraordinarily robust. They reflect a population that was generally healthy, but people who lived physically demanding lives.

The frequency of dental caries is very low in the series. High rates of occlusal surface wear, a function of the introduction of grit to the diet through seed grinding on metates and the preparation of food in a sandy environment, may have contributed to low caries prevalence. However, given that most foods consumed were noncariogenic, it is likely that the low prevalence of caries in this sample is related to diet and not attrition.

The burials also show a low frequency of cribra orbitalia and porotic hyperostosis suggesting low rates of iron deficiency anemia.

A long-running debate in Great Basin archaeology concerns the origin and timing of the migration of Numic-speaking peoples into this region of the Desert West. Linguistic data suggest an entry of these peoples sometime between 1000 and 700 B.P. Study of serum albumin revealed similarities between the Stillwater population and modern Uto-Aztecan or Yuman speakers. The most common allele among the indigenous peoples of North America is Al^{A}. However, within some populations, including Numic speakers, another allele—Al^{Me}—occurs at low frequencies. This allele is present in four of the analyzed samples, a frequency nearly as high as that known for any living population. Because these burials were not dated, it is not known if individuals with this allele occur in early or late burials, or throughout the sequence. Thus, the timing of the Numic migration into the Great Basin based on this analysis is inconclusive. The analysis of mitochondrial DNA reveals a very low frequency of the 9-basepair deletion, a deletion observed in some prehistoric and extant Native American populations. The study suggests that the Stillwater population is probably not ancestral to any group that has a much higher deletion frequency (e.g., California Penutian, Zuni, Yuman,

Washo, or Southern Uto-Aztecan language groups). This finding is in part consistent with Smith et al. (this volume), who were able to exclude California Penutian and Washo as descendants. However, it also suggests that the Yuman and Southern Uto-Aztecan groups are probably not direct descendants of the Stillwater population. Several possibilities remain as to the identification of ancestral–descendant relationships in this region.

Dental hypoplasias are nonspecific growth arrest markers in teeth; as such, they provide evidence on periodicity and intensity of stress in a population. These features may be a product of either dietary or disease-related stress during tooth development. The low rate of nonspecific infections in the population suggests that dietary stress may have been a major cause of dental hypoplasias. Many diseases do not leave impressions on skeletal tissues, which limits understanding of specific causes of hypoplasias. Regardless, dental hypoplasias within the Stillwater sample suggest that this population underwent less frequent and less intense physiological stress than Georgia coastal hunter-gatherers or agriculturalists. The stress events occurred at 3–4 years of age.

Data on carbon and nitrogen isotopes were collected from human bone collagen, archaeological faunal remains, and modern plant specimens in order to reconstruct diet. The data show significant variation in diet compared to boreal forest hunter-gatherers and southwestern U.S. agriculturalists. However, this variation does not exhibit patterning by bone element, age group, or sex. The control specimens indicate that the diet could have been derived from the marsh, with variation representing either periodic movement out of the Stillwater Marsh and the use of other resources or changes in the range of resources available within the marsh itself. Significantly, the data suggest that piñon seeds, an important element of diet elsewhere in the Great Basin, may not have been a large part of the Stillwater diet.

Although data from dental hypoplasias and bone chemistry indicate a comparatively healthy population that ate a range of food items, the prevalence of osteoarthritis and the nature of long-bone cross sections indicate a physically demanding lifestyle. Osteoarthritis was found to have afflicted 75 percent of Stillwater individuals, with highest frequencies on lumbar vertebrae, cervical vertebrae, and the elbow. Controlling for age, there are several differences between males and females. Overall, osteoarthritis is less prevalent among females than males with the exception of lumbar vertebrae. This suggests that women carried heavy loads daily, perhaps children (as well as food, water, firewood, and other burdens), while foraging. Males have significantly higher frequencies of osteoarthritis in the hip and ankle, and possibly in the shoulder. Based on this and especially the observed differences between male and female femur cross-sectional geometry, it appears that males did more walking and more strenuous walking than females.

Comparisons of the Stillwater population to Georgia coastal hunter-gatherers and agriculturalists, as well as southwestern Anasazi agriculturalists, show a tendency for the femora of hunter-gatherer males to exhibit higher bending and torsional strength than males in agricultural populations. The shape of the female femur, on the other hand, shows no change with the mode of subsistence, but instead correlates with the overall terrain inhabited by the different populations.

Finally, the Stillwater adults show a relatively low amount of cortical bone in the cross sections analyzed. Although the relatively old age distribution for the series may account for recorded bone loss, periodic suboptimal nutrition likely played an important role.

This study casts light on current reconstructions of prehistoric lifeways in the Carson Sink. It does not provide evidence of a sedentary lifestyle, but instead points to considerable mobility and heavy workloads for both males and females. Males may have been more mobile than females, which appears to be reflected in Great Basin ethnographic data, and cross-culturally as well, where males generally walk longer daily distances in hunting forays than women do in plant-gathering trips. Moreover, analysis of cross-sectional geometry of the femur reveals that travel over difficult terrain (uplands) was an important feature of the Stillwater adaptation, especially for males.

On the other hand, the study suggests that the diet could have been comprised of only those resources found in the marsh. In particular, piñon may have been a less important element of the diet than is commonly assumed from ethnographic data. This suggests a "tethering" of the prehistoric population to the marsh wetlands, but with forays into the uplands.

All burial excavations and subsequent skeletal analyses were conducted with permission from the Fallon Paiute-Shoshone Tribe under a Memorandum of Understanding between the U.S. Fish and Wildlife Service and the Tribe. All remains discussed in this monograph have been reinterred in a subterranean crypt on U.S. Fish and Wildlife Service land. With appropriate permissions from the Tribe and the U.S. Fish and Wildlife Service, these remains could be made accessible to other researchers.

INTRODUCTION

The North American Great Basin has been the focus of archaeological study beginning in the decades following initial contact of native populations by Euroamericans in the early 19th century. The very rich archaeological record of this vast region of the western United States has been instrumental in elucidating key aspects of prehistoric hunter-gatherer lifeways, especially with regard to subsistence economies, settlement patterning, mobility, and other factors relating to cultural and social behavior among desert-dwelling foragers. In other regions of the Americas, human remains discovered in archaeological contexts have provided a plethora of information relating to these topics. Unfortunately, very few skeletons representing earlier societies in the Great Basin have been recovered from archaeological sites. Moreover, most human skeletons that have been found are either isolated individuals, too fragmentary, or too poorly documented to be useful for study.

Flooding of the Stillwater Marsh and Carson Sink between 1982 and 1986 revealed a remarkable assemblage of human bones and teeth in prehistoric archaeological sites, mostly owing to the ground surface erosional damage from wave action, ice, and other natural processes following the retreat of floodwaters. The Nevada State Museum launched an aggressive archaeological recovery campaign in Churchill County to assess the damage to cultural and biological resources, rescue materials in danger of being lost to the ongoing forces of nature and increased vandalism, and report on the results of their investigations. The U.S. Fish and Wildlife Service negotiated a Memorandum of Understanding with the Fallon Paiute-Shoshone Tribe. The key attributes of the memorandum were that all human remains recovered would be available for reburial, and that scientific analyses would be permitted under the following conditions: (1) destructive analyses would be performed on already broken elements only, (2) all analyses were to be conducted by qualified personnel, (3) no specimen would be removed from the Nevada State Museum or state of Nevada unless the analysis could not be performed within the Museum or state, and (4) a researcher would acquire permission from the Tribe and the Fish and Wildlife Service for any analyses not specifically mentioned in the memorandum's appendix.

Soon after the recovery of skeletal specimens—numbering in the hundreds from more than 30 archaeological sites—Sheilagh T. Brooks and her associates began a detailed inventory and preliminary analysis. Thereafter, R. L. Kelly entered into discussions with the curatorial staff at the Nevada State Museum and the U.S. Fish and Wildlife Service regarding the possibility of completing additional human skeletal analyses that would tie in with his long-term study of prehistoric hunter-gatherer adaptation in the Carson Sink. Following from these discussions, in addition to surveying the major shorelines in the Stillwater Marsh in the summer of 1987, C. S. Larsen and co-workers began a skeletal analysis of the Stillwater human remains relating to dietary reconstruction, population history, and behavioral patterning. In this monograph, we present the results of that analysis.

ACKNOWLEDGMENTS

This volume is a contribution to the Carson-Stillwater Archaeological Project.

It is highly unlikely that the research presented in this monograph would have come about had it not been for Charlie and Hazel Gomes alerting state and federal officials to the fact that archaeological sites, including numerous human remains, were being exposed on a daily basis following the recession of lake waters in the Carson Sink in 1985. We extend our thanks to them for their concern for these important cultural and biological resources as well as for their very kind assistance given us during the 1987 field season. Katherine Russell, director of the 1987 Human Skeletal Field Survey, Joseph Craig, field assistant, and crew members David Bjorstad, Ed Boston, Kate Boston, Phil Carr, Joe Czerwinski, Nancy Harris, John Hayes, Hong Huynh, Joanna Lambert, and Catherine Walter persevered under a very hot desert sun in locating and recovering human re-

mains. We are indebted to these individuals for completing the fieldwork. The culinary talents of Lin Poyer were much appreciated after long days on survey. Her support in this and other ways made the stay in the rustic setting of the "town" of Stillwater tenable.

Thanks are also extended to the staff at the Stillwater Wildlife Management Area (U.S. Department of the Interior, Fish and Wildlife Service), refuge manager Ron Anglin, maintenance crew Delvan Lee, Ernie Lantto, and Eugene Duffney, and especially to Anan Raymond for his help and advice throughout the fieldwork and during the following analysis.

Data collection and analysis were facilitated by various people. C.S.L. especially thanks Christine E. Larsen, who willingly agreed to spend part of her honeymoon in the late spring of 1987 measuring bones and teeth in the Nevada State Museum Annex outside Carson City. Her cooperation in this regard was well above and beyond spousal duties. Thanks are extended to Thomas C. Barcia and the members of the Research and Development Committee at the Veterans Administration Hospital in Reno for approving use of the computed tomography (CT) scanner for biomechanical analysis of Stillwater long bones in 1988. Thanks are also given to the radiology staff at the hospital for providing technical assistance in collecting CT data. Joanna Lambert gave invaluable help in use of a sometimes recalcitrant mainframe computer at Northern Illinois University in analyses of skeletal and dental metric data. Peter Peregrine advised us on statistical analyses of osteoarthritis data.

Bone samples for serum protein and DNA analysis were provided by Amy Dansie and Anan Raymond. Frederika Kaestle thanks especially Joseph Lorenz and Phillip Morin for their valuable advice and good humor in the laboratory and Robert Bettinger and David Smith for their advice in the preparation of Chapter 5.

Several people helped in preparing bone samples for stable isotope analysis and in the mass spectrometry of these samples. For these efforts, we thank John Blitz, Al Hengge, Urszula Iwaniec, Matthew Murray, Renee Robinson, Mark Schurr, and Isabel Treichel. Special thanks are extended to Urszula Iwaniec, who put enormous effort into determining replicable methods for analyzing plant samples for nitrogen isotope analysis. Collections of modern plant specimens in the Carson Sink used in the isotopic analysis were made by Elizabeth Budy, Anan Raymond, and Robert Kelly. Pam Fitzer and Jim Stoltman read the Chapter 7 manuscript and provided helpful comments. Phil DiBlasi drew figure 1-1 and Earl Lee drafted figure 3-1.

Most of the fieldwork and laboratory analyses of human remains were made possible through funding from the National Science Foundation (grant award BNS-8704094 to R.L.K., with separate subcontracts to Larsen, Ruff, and Schoeninger). Much of the osteological research was completed while Larsen was on the faculty at Northern Illinois University. A grant from the Northern Illinois University Graduate School for Larsen's travel and support for a graduate field assistant were of tremendous help. In addition to funding from the National Science Foundation, the University of Wisconsin Alumni Research Foundation provided support to Schoeninger for the stable isotope analysis. Funding for the DNA analysis also came from the National Science Foundation (grant award GER-9255683 to F. A. Kaestle). Additional support from the National Institutes of Health (grant award RR05090 to D. G. Smith) for DNA and serum protein analyses is also gratefully acknowledged.

A number of individuals in Nevada deserve special mention for their contributions to the bioarchaeological research. Paramount among the supporters of this endeavor are the members of the Fallon Paiute-Shoshone Tribe, especially then Tribal Chairman, Richard Hicks. The trust and understanding between archaeologists and the Tribe was central to the success of the project. While collecting data at the Nevada State Museum Annex, the hotel managements and staffs of the Ormsby House and the Mother Lode did their best to see that Clark and Christine Larsen's stay in Carson City was comfortable and productive during the research trips to Nevada in 1987 and 1988. Our data collection was made easier owing to the careful work of Michelle Haldeman, Sheilagh Brooks, Amy Dansie, and Don Tuohy at the Nevada State

Museum in identifying skeletons and cataloging and organizing the human remains prior to our study of them.

Drafts of this monograph were written while Larsen was on the faculty at Purdue University. The manuscript was finished at the University of North Carolina. During this phase, we received invaluable help from six reviewers. Our gratitude for their careful reading and critical commentary is extended to Pat Bridges, Alan Goodman, Brian Hemphill, Steve Simms, Anan Raymond, and Cliff Creger.

The Stillwater skeletal series is a unique human osteological assemblage well deserving of the scientific attention that it received prior to its reinterment in 1989. By any measure, this mortuary record of prehistoric hunter-gatherers offers an extremely rich fund of information on the biology and culture of past societies that occupied the region. In this collaborative effort, we thank all of our colleagues who generously gave of their time, expertise, and good humor throughout the course of the research and the preparation of this monograph.

CHAPTER 1. HUNTER-GATHERER LIFEWAYS IN THE CARSON DESERT: A CONTEXT FOR BIOARCHAEOLOGY

Robert L. Kelly

INTRODUCTION

The Great Basin of the western United States usually brings to mind an image of vast dune fields, sagebrush, and arid, rocky mountain ranges. Although this image is an accurate characterization of the region, the Great Basin also contains a number of extensive wetlands (fig. 1-1). Along the base of the Sierra Nevada are Pyramid, Winnemucca (now dry), and Walker Lakes. A short distance to the east are the Humboldt and Carson Sinks, and in the central Great Basin, the Ruby Valley wetlands. To the north are Surprise Valley, Fort Rock Basin, Warner Valley, Lake Abert, and Malheur Lake (Harney Basin). In the eastern Great Basin are the Great Salt Lake, Utah Lake, and Sevier Lake, with wetlands located on their peripheries.

Archaeologists have debated for years how native populations used these wetland habitats prehistorically, but the debate gained renewed vigor when flooding from record high winter precipitation exposed hundreds of archaeological sites in several of these wetlands containing, in some places, shallow pithouses, storage pits, and human burials (see Janetski and Madsen, 1990). Contributing to this debate is the timely publication of ethnographic material from several of these wetlands (Fowler, 1989, 1990a, 1990b, 1992; Janetski, 1991).

The current study examines the prehistoric use of one wetland, the Stillwater Marsh in the Carson Sink in western Nevada, from a bioarchaeological perspective; a later volume will examine this wetland from an archaeological perspective (Kelly, MS.). We have two general objectives in this monograph (see also the next chapter for specific goals). First, in addition to providing primary descriptive data on human remains from the region, we use bioarchaeological analyses to determine the overall constraints or conditions under which the prehistoric population lived in relation to the assessment of quality of life in the region. Second, we will ask what, if anything, the skeletal data tell us about the nature of mobility in this prehistoric population. In this chapter, we present the environmental, ethnographic, archaeological, and theoretical background to the bioarchaeological analyses.

CARSON SINK ENVIRONMENT

Encompassing nearly 2800 km^2, the Carson Desert is a large area of sand dunes, alkali flats, and slightly alkaline marshes located in west-central Nevada, about 100 km east of Reno. At 1180 m (3870 ft) above sea level, the Carson Desert is one of the lowest points in the west-central Great Basin. It forms the sink of the Carson River and, frequently in the past, for the Humboldt River as well (fig. 1-2). On rare occasions, the Walker River may also have flowed into the region.

Today, the northern half of the Carson Desert is dominated by an extensive alkali flat with less than 2 m of topographic variation over its entire extent. A large shallow body of water reaching 30 km in diameter—North Carson Lake—occasionally occupied the northwestern corner of Carson Sink in the past, and does so today sporadically. South Carson Lake, in the southeastern corner, was a more permanent feature, although it no longer exists.

The southern half of the desert is covered by low, partially stabilized east–west trending longitudinal and barchan dunes that are interspersed with alkali flats. Vegetation here is predominantly greasewood (*Sarcobatus* sp.), four-wing saltbush (*Atriplex canescens*), and shad scale (*Atriplex confertifolia*), with lesser amounts of budsage, winterfat (*Ceratoides lanata*), and wolfberry (*Lycium cooperi*). Some areas, especially those near the wetlands, probably had extensive grassy meadows consisting of economically important grasses such as Indian rice grass (*Oryzopsis hymenoides*), wildrye (*Elymus* sp.), and needle and thread (*Stipa comata*). These grass seeds were gathered by hand stripping (or beaten with a woven paddle into a basket), ground, and stored. Experiments show that

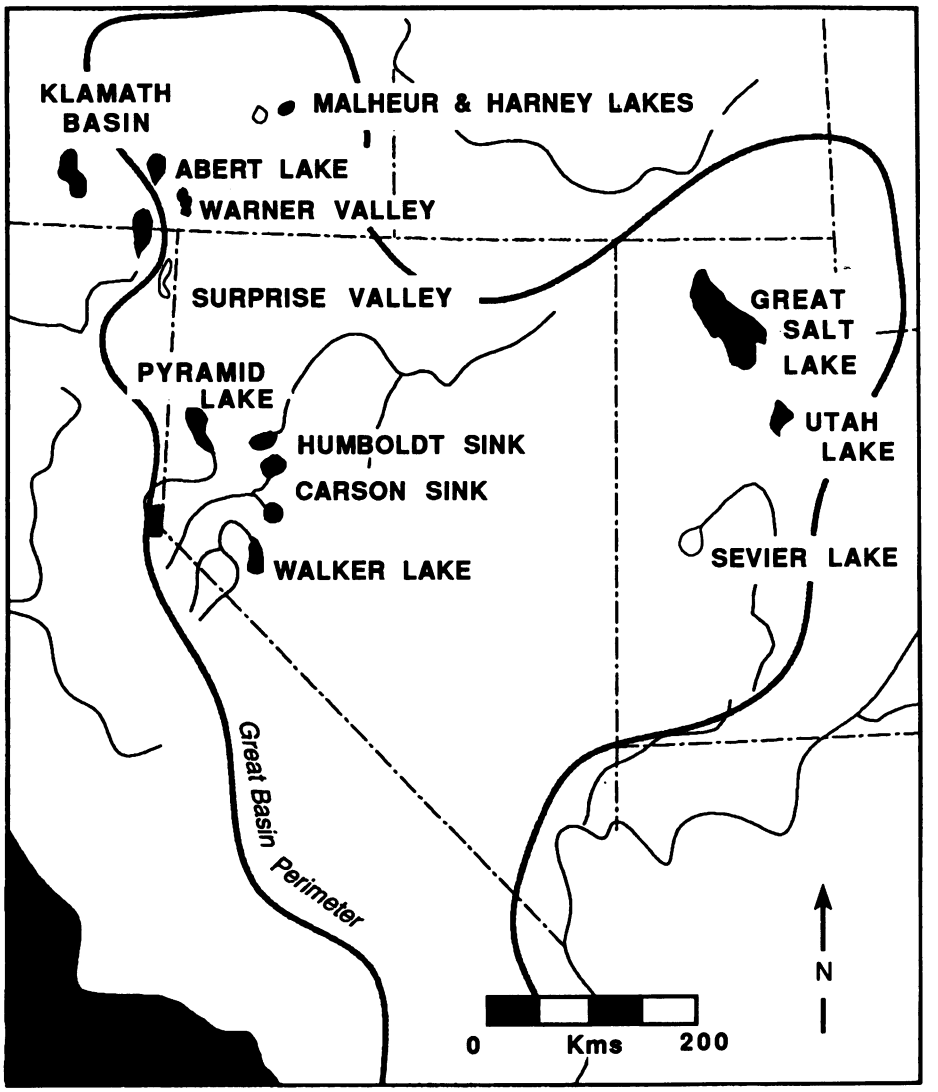

Fig. 1-1. Map of the Great Basin showing wetlands including the Carson Sink.

grass seeds can be gathered at varying return rates but, for the most part, collection efforts provide relatively low returns. Grass seed yield is also highly variable from year to year because of variation in winter and spring precipitation (Kelly, 1985).

The most significant feature in the Carson Sink is the Stillwater Marsh, which encompasses about 375 km^2 of the eastern Carson Sink (fig. 1-3). Water enters the Carson Desert predominantly as runoff from the Sierra snowpack via the Carson River. In the past, the Carson River spilled into South Carson Lake. From there, water ran into the Stillwater Slough and drained to the north into the Stillwater Marsh. However, because the Carson River enters the Carson Desert through an enormous, flat delta, in some years the Carson River shifts its course, running to the north after entering the Carson Desert and draining directly into the northern Carson Sink. Furthermore, there is considerable variation in the annual and seasonal discharge of the Carson River that could produce fluctuations in the water level of the marsh and hence in the kinds of resources

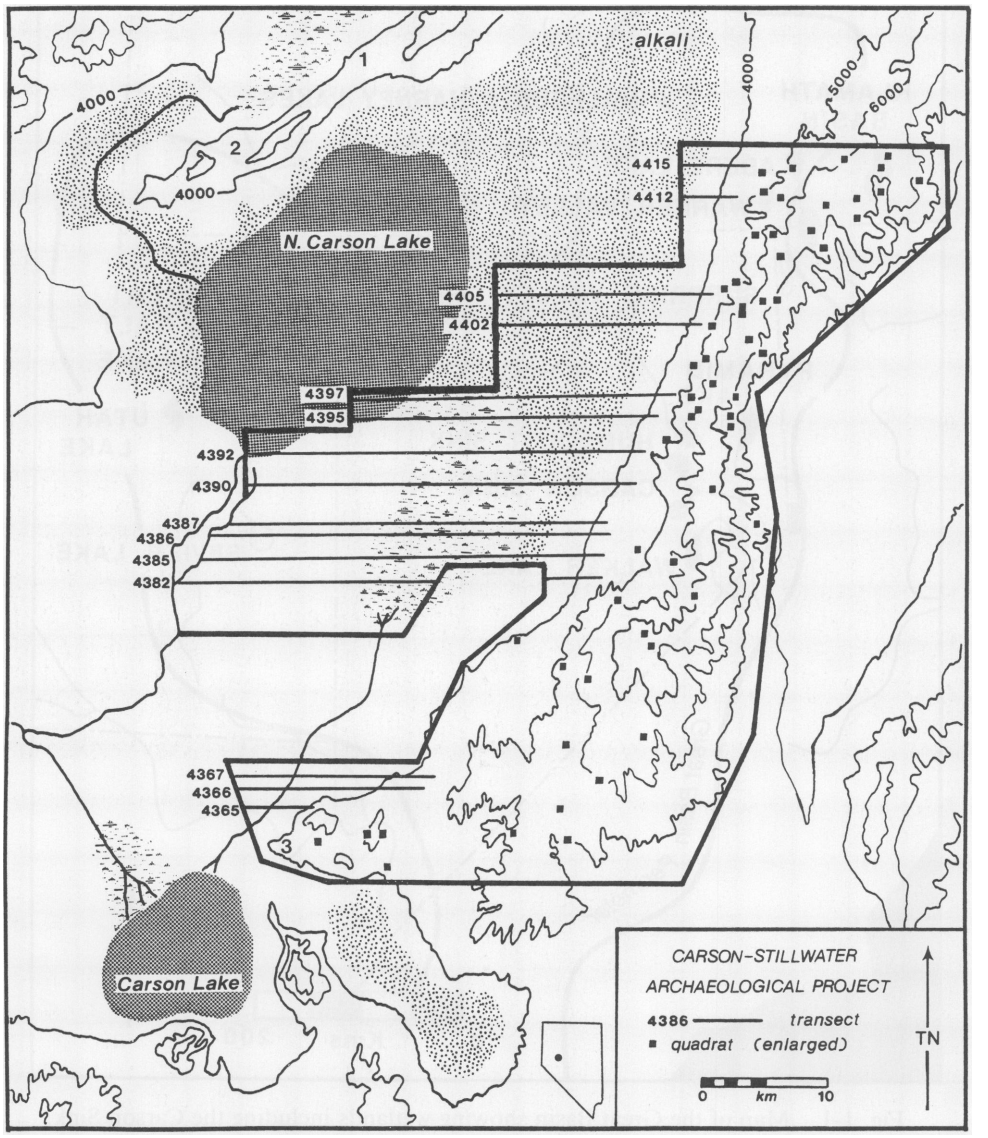

Fig. 1-2. Map of the Carson Sink showing primary archaeological localities mentioned in text and CSAP survey region (**1** = Lovelock Cave; **2** = Humboldt Cave; **3** = Hidden Cave; Stillwater Marsh in Center).

present. Thus, it is likely that the Stillwater Marsh has fluctuated in both size and resource productivity. Whether such fluctuations had an impact on prehistoric inhabitants of the region remains to be determined. Raven and Elston (1989) argued that the marsh could have provided sufficient food resources during most years.

A variety of plant and animal resources were available to prehistoric inhabitants of this region (table 1-1). Ethnographic information, much of it available only recently, demonstrates the potential diversity of food resources for prehistoric inhabitants of the Carson Sink. Only a brief summary can be presented here (see Wheat, 1967; Fowler, 1989, 1992). The Stillwater Marsh contains a number of economically useful plants, such

Fig. 1-3. View of the Stillwater Marsh from the Stillwater Mountains, facing northwest (photograph taken in June 1986).

as bulrush (*Scirpus* sp.), cattail (*Typha* sp.), pickleweed, nutgrass, spikerush (*Eleocharis palustris*), and sedge. The seeds and roots of many of these plants were probably used for food. Archaeological and experimental data indicate that bulrush seeds, which are ready for harvest in the late summer, may have been especially important.

The marsh is also host to more than 160 species of waterbirds, the most abundant of which are mallards (*Anas platyrhychos*), pintail (*Anas acuta*), cinnamon teal (*Anas cyanoptera*), redhead (*Aythya americana*), canvasbacks (*Aythya valisineria*), and, especially, coots (*Fulica americana*). Waterbirds were hunted with nets and decoys. Nearly all the species of waterfowl are migratory, producing resource blooms in the early spring (March–April) and fall (August–November). Some species remain in the marsh year-round. The fall population of ducks can vary from 35,000 to 300,000; the spring migratory population is about half as large (see Fowler, 1992). Annual variations occur as a result of changes in water depth, which affect the availability of food and nesting material.

The marsh supports three fish species: the Tahoe sucker (*Catostomus tahoensis*), the Lahontan redside (*Richardsomius egregius*), and the tui chub (*Gila bicolor*), which is the most abundant. The tui chub is a small fish, rarely exceeding 300–350 mm in length. Remains of these fish found in human coprolites from Hidden and Lovelock Caves suggest that, in general, fish 7–17 cm in length were taken (Thomas, 1985; Raymond and Sobel, 1990). Experimental studies indicate that these fish can be harvested at fairly high return rates using either fine-mesh nets or baskets (Raymond and Sobel, 1990).

Freshwater shellfish (*Anondonta* sp.) are also found in the marsh. With one exception, archaeological documentation of marsh sites suggests that these mussels were probably unimportant in diet. Such shellfish are also rarely mentioned in ethnographic accounts.

TABLE 1-1
Carson Sink Food Resources[a]

Food resource	Part eaten	Season[b] or month available
Wetlands		
Tule bulrush (*Scirpus acutus*)	Shoots, seeds	S, F
Nutgrass (*Scirpus maritimus*)	Seeds	F
American bulrush (*Scirpus americanus*)	Seeds	S, F
Common cattail (*Typha latifolia*)	Pollen	Sp, S
Common cattail (*Typha latifolia*)	Shoots, seeds	S, F
Cattail (*Typha domingensis*)	Shoots, seeds	S, F
Cattail (*Typha latifolia*)	Roots	F
Bulrush (*Scirpus* sp.)	Roots	F
Spikerush (*Eleocharis palustris*)	Seeds	S, F
Sago pondweed (*Potamogeton pectinatus*)	Tubers	S
Sago pondweed (*Potamogeton* sp.)	Seeds	S
Chufa fatsedge (*Cyperus esculentus*)	Tubers	Sp
Water plantain (*Alisma geyeri*)	Stems	Sp, S
Seepweed (*Suaeda depressa*)	Seeds	Sept.
Red sage (*Kochia americana*)	Seeds	
Pickleweed (*Allenrolfea occidentalis*)	Seeds	S, F
Saltgrass (*Distichlis stricta*)	Seeds	S, F
Rodents		Sp, S, F, W
Jackrabbits		Sp, S, F, W
Waterbirds		Sp, S, F, W
Tui chub		Sp, S, F, W
Lowlands		
Carved seed (*Glyptopleura marginata*)	Leaves	Sp
Prince's plume (*Stanleya pinnata*)	Leaves	Sp
Onion (*Allium anceps*)	Corms, leaves	Sp
Nevada onion (*Allium nevadense*)	Corms, leaves	Sp
Cymopterus (*Cymopterus globosus*)	Roots	Sp
Smoky mariposa lily (*Calochortus leichtlinii*)	Bulbs	Sp
Sago lily (*Calochortus nuttalli*)	Bulbs	Sp
Broomrape (*Orobanche fasciculata, O. corymbosa*)	Stalk	S
Thistle (*Cirsium* sp.)	Stalk	S
Prickly pear (*Opuntia polyacantha*)	Buds	Sp
Great Basin wildrye (*Elymus cinereus*)	Seeds	S
Sunflower (*Helianthus annuus*)	Seeds	Sept.
Tansy mustard (*Descurainia pinnata*)	Seeds	July
Saltbush (*Atriplex argentea*)	Seeds	Aug.–Sept.
White-stem blazing star (*Mentzelia albicaulis*)	Seeds	July–Aug.
Indian ricegrass (*Oryzopsis hymenoides*)	Seeds	July–Aug.
Curly dock (*Rumex crispus*)	Seeds	S
Foxtail barley (*Horideum jubatum*)	Seeds	S
Big sagebrush (*Artemesia tridentata*)	Seeds	S
Four-wing saltbush (*Atriplex confertifolia*)	Seeds	S, F
Shadscale (*Atriplex canescens*)	Seeds	S, F
Witchgrass (*Panicum capillare*)	Seeds	
Wheatgrass (*Agrophyron* sp.)	Seeds	S
Bluegrass (*Poa* sp.)	Seeds	Sp, S
Muhly (*Muhlenbergia* spp.)	Seeds	S
Gooseleaf globemallow (*Sphaeralcea grossalariafolia*)	Seeds	S
Silver buffalo berry (*Sheperdia argentea*)	Berries	S
Wolf berry (*Lycium andersonii*)	Berries	S

TABLE 1-1—(*Continued*)

Food resource	Part eaten	Season[b] or month available
Cooper wolfberry (*Lycium cooperi*)	Berries	Sp
Wild rose (*Rosa woodsii*)	Hips	S, F
Stillwater Mountains		
Nevada desert parsley (*Lomatium nevadense*)	Roots	June
Yampa (*Perideridia bolanderi*)	Roots	S
Spring berry (*Claytonia umbellata*)	Roots	Sp
Bitteroot (*Lewisia redivivia*)	Roots	Sp
Sego lily (*Calochortus leichtlinii*)	Bulbs	May–June
Arrowleaf balsamroot (*Balsamorhiza sagittata*)	Seeds, roots	June
Hairy balsamroot (*Balsamorhiza hirsuta*)	Seeds, roots	June
Onion (*Allium parvum*)	Leaves	Sp
Onion (*Allium biseptum, A. platycaule*)	Leaves, roots	Sp
Wolly wyethia (*Wyethia mollis*)	Seeds	July
Piñon (*Pinus monophylla*)	Seeds	Aug.–Sept.
Great Basin wildrye (*Elymus cinerus*)	Seeds	S
Prairie sunflower (*Helianthus petiolaris*)	Seeds	S, F
Blue elderberry (*Sambuscus caerulea*)	Berries	F
Service berry (*Amelanchier alnifolia*)	Berries	S, F
Chokecherry (*Prunus virginiana*)	Berries	Sept.
Wild rose (*Rosa woodsii*)	Hips	F
Current (*Ribes aureum*)	Berries	S, F
Sagebrush gooseberry (*Ribes velutinum*)	Berries	S, F
Silver buffalo berry (*Shepherdia argentea*)	Berries	S
Bighorn sheep		Sp, S, F, W
Rodents		Sp, S, F

[a] Based on Fowler (1989).
[b] Sp = spring; S = summer; F = fall; W = winter.

Various small mammals, including muskrat (*Ondrata zibethicus*) and various rodents, also inhabit the marsh and surrounding foothills and uplands. Two of the more important small mammals were probably jackrabbits (*Lepus californicus*), which live in the greasewood and sagebrush zones of the valley floor and alluvial fans, and ground squirrels (*Citellus* sp., *Spermophilis* sp.), which were hunted in the early spring (Wheat, 1967). However, rodents and other small game could be caught from late winter through the fall using a variety of traps and snares.

To the east, the Carson Sink is bordered by the Stillwater Mountains. The highest point, Job Peak, is only 2650 m (8785 ft) above sea level. The Stillwater Mountains are rugged, consisting of a single long fault block with steep sides. There are few springs in the mountains, and no significant creeks are present. Two ecological zones are found in the mountains: the piñon-juniper zone and an unwooded sagebrush (*Artemesia* sp.) zone. Juniper (*Juniperus osteosperma*) and piñon (*Pinus monophylla*) are confined chiefly to the northern Stillwater Mountains, although there are a few stands around Job Peak. Many varieties of economically important grasses, such as ricegrass (*Oryzopsis hymenoides*) and wildrye (*Elymus* sp.), are found in the Stillwater Mountains and foothills.

Perhaps the most critical plant resource here is piñon pine seeds. Ethnographic and archaeological data from elsewhere in the Great Basin point to the importance of piñon (e.g., Thomas, 1988; Bettinger, 1989). Piñon seeds are nutritious (containing from 4880 to 6600 kcal/kg), high in fat and protein, and can be gathered at fairly high return rates. Ethnographic accounts indicate that the seeds were gathered during a 2- to 3-week period in the late summer or early autumn. Once parched, the seeds can be stored for up to 2 years.

However, recent evidence suggests that pi-

ñon may not have been present in the Stillwater Mountains until relatively recently. A packrat midden in the Stillwater Mountains contains no piñon macrofossils until after 1250 B.P., a pollen core from the Stillwater Marsh shows an increase in pine pollen only after 1500 B.P., and there is no evidence of piñon in soil samples from Mustang Shelter (26CH1082) in the northern Stillwater Mountains older than 1300 B.P. (Peter Wiegand, personal commun., 1993). Piñon, therefore, may be a relatively recent immigrant to the Stillwater plant community.

The Stillwater Mountains were also home to a variety of large and small game. Rodents such as wood rats and ground squirrels could be trapped in the Stillwater Mountains. In the lower elevations, as well as on the valley floor, there were probably herds of antelope (*Antilocapra americana*) present. The major faunal resource of the mountains, however, was probably bighorn sheep (*Ovis canadensis nelsoni*), several herds of which live there today. Bighorn sheep were usually hunted in the fall, although "a shortage of food [drove] the people to hunt mountain sheep any time of the year" (Fowler, 1989: 19). Ethnographic accounts describe a variety of techniques for hunting bighorn through individual encounter forays, communal hunts, and the use of blinds at strategic points (e.g., springs).

MOBILITY IN CARSON SINK ETHNOGRAPHY

Ethnographic data indicate that residential movements and lengthy logistical forays were a recurrent feature of late 19th century life of the Toedökadö ("Tule-eaters" or "Cattail-eaters") Northern Paiute in the Carson Sink. Fowler (1989, 1992) presented a wealth of information on native populations of the region based on interviews and other sources. We briefly review the relevant ethnographic data here.

One of the earliest ethnographic accounts came from Zenas Leonard of the Walker-Bonneville party who passed through the Humboldt Sink in September and October of 1833 (Leonard, 1904). Leonard estimated that there were from 800 to 900 people living in the Humboldt Sink, although others of the expedition gave more conservative figures. Leonard described a people making extensive use of wetland resources:

> They subsist upon grass-seed, frogs, fish, etc. Fish, however, are very scarce—their manner of catching which, is somewhat novel and singular. They take the leg-bone of a sandhill crane, which is generally about 18 inches long, this is fastened to the end of a pole—they then, by means of a raft made of rushes, which are very plenty, float along the surface of these lakes, and spear the fish .... They also have a kind of hook by which they sometimes are very successful, but it does not afford them as much sport as the spear. This hook is formed of a small bone .... Their habitations are formed of a round hole dug in the ground, over which sticks are placed giving it the shape of a potatoe [sic] hole—this is covered with grass and earth—the door at one side and the fire at the other (Leonard, 1904: 166–167).

Leonard noted that the women gathered "flies" from the lake's beach in warm weather. The flies were dried in the sun in willow baskets and laid away for winter storage. Leonard suggested that these flies, along with grass seeds and rabbits, were principal winter foods, but he did not directly observe native life during the winter. The houses Leonard described, especially if they were covered with grass and earth, suggest a low level of residential mobility. However, no other observer described such houses for the Humboldt Sink, and there is some doubt as to the accuracy of Leonard's diary.

In October 1841, John Bidwell of the Bidwell-Bartleson party traveled down the Humboldt River and across the Carson Sink to the Walker River. At the Humboldt Sink, Bidwell noted that "Indians were numerous" and that they had collected great heaps of "dry cane grass . . . to procure sugar from the heavy dew [probably a sweet insect secretion] with which it was covered" (Bidwell, 1964: 32). Bidwell also noted the presence of many people in the Carson Sink, but provided no further commentary. Later, when Bidwell met up with Bartleson on the Walker River, Bartleson recounted how the Paiute camped near South Carson Lake had supplied him with fish and pine nuts. The closest groves of piñon pine to South Carson Lake are in the Stillwater Mountains, from 30 to 50 km away.

In June 1859, Captain James H. Simpson

came upon South Carson Lake as he was blazing a new trail across the central Great Basin to California. He noted the presence of many shorebirds and ducks at the lake, as well as fish:

> The alluvial bottom about Carson Lake is quite extensive and rich, as the luxuriant growth of rushes shows .... Curlew, pelican, and ducks, and other aquatic birds frequent the locality, and the lake is filled with fish. A number of Piutes, some two dozen, live near our camp, and I notice they have piles of fish lying about drying, principally chubs and mullet. They catch them with a seine. Their habitations consist of flimsy sheds, made of rushes, which screen them from the sun and wind .... The duck decoys they use on the lake to attract the live ducks are perfect in form and fabric (Simpson, 1876: 85).

The houses described in this account suggest high residential mobility, because they could be manufactured rather easily and perhaps even moved. Later in the same month, Simpson (1876: 106) encountered several families collecting grass seed some 75 km east of South Carson Lake who had apparently come from the lake. Therefore, while some people were still using the wetland resources of the Carson Sink, other families had traveled far away (although we do not know if seed collection was their purpose in traveling).

Two years later, in the summer of 1861, William Wright (Dan DeQuille) traveled through the Carson Sink and Stillwater Mountains (DeQuille, 1963). While traveling along the south and east shores of South Carson Lake, DeQuille noted the presence of numerous camps, both individual houses and "towns." His description of Paiute houses accords well with Simpson's observations:

> After passing a few scattering huts we traveled about one mile when we passed a small town of some half dozen *noobees* or shanties and saw, some distance ahead, a larger village .... Their habitations are merely shades to protect them from the sun. They are made by planting willow brush and reeds in the ground, in a semi-circular form, a southern wall for a shade. There is no roof. Some of these walls are portable, being woven of reed and flag in the shape of a large mat. The women build all the homes. They generally build at the distance of half a mile from the lake, on account of the swarms of mosquitos found near the water (DeQuille, 1963: 30–31).

Wright encountered many families in several villages along the lake and marshes, who were fishing and gathering plant food, eggs, rabbits, and waterbirds.

Riding into the mountains 24 km from the marsh, Wright encountered Paiute women harvesting "bunchgrass" (wildrye?) seed (DeQuille, 1963: 53). Baskets and recently abandoned houses were located nearby. Wright then rode into the mountains where he encountered a Paiute man and his sons (Wright does not tell us what they were doing). He later encountered "a party of seven Paiute men, coming up the cañon with packs on their backs, and bows and arrows in their hands [who] had been hunting in a range of mountains to the eastward [possibly the Clan Alpine Range]" and who were returning to their families in the Carson Sink. They had been traveling by night, across Dixie Valley, and "carried small water bottles . . . and were loaded with a species of mountain rat, smoked and dried, packed in oblong hampers made of twisted ropes of grass" (DeQuille, 1963: 71).

Still later, in the piñon-juniper zone north of Silver Hill Canyon, Wright encountered "women, with their conical baskets on their heads, gathering the harvest of grass seed, while children were playing near by in the shade of the pines" (DeQuille, 1963: 83). Entire families were clearly living in the mountains (DeQuille, 1963: 104–105).

Because Wright's journey lasted only part of the summer, he presented us with a snapshot of what people were doing over a fairly large area. Some people were at the lake fishing and gathering foods, others were in the mountains gathering grass seeds, and some men were off hunting. That some people were away from the marsh could have resulted from tension within the lowland camps, but it could also reflect different subsistence decisions made on the basis of family needs and capacities. Perhaps some families left members in the marsh while others went into the hills. It is likely that the wetlands could support those who were in the mountains; for some reason, however, some individuals chose not to stay there.

Other ethnographic data point to even greater mobility. In April or May, the Lahontan cutthroat trout (*Salmo clarki*) and cui-

ui (*Chasmistes cujus*) migrate up the Truckee and Walker Rivers, 55 km to the west and 90 km to the south, respectively, from the Carson Sink. These large fish do not occur in the Carson or Humboldt River drainages, and some Toedökadö families traveled to the Truckee and Walker Rivers for the harvest (Park, 1938; Wheat, 1967; Fowler and Bath, 1981). Paiute camped along the Walker River during the winter, where men fished and occasionally hunted deer and rabbits; women prepared seeds that had been stored from the previous summer and fall. However, some families camped in the mountains; men went down to the Walker River periodically to fish, taking their catches back to their families in the hills (Fowler, 1989: 101). Likewise, the Carson Sink Paiute also occasionally wintered in the mountains (Wheat, 1967).

In March, the Toedökadö congregated on the marshes in groups of 15 to 30 individuals to hunt migratory waterfowl and to gather cattail shoots and duck eggs. Men sometimes traveled to the Humboldt or Truckee Rivers to fish. Roots were also gathered in the spring. If an antelope drive were to be held, it was usually held in early spring (Fowler, 1989: 14).

In the summer, the Walker River winter villages broke up into family groups who spread across the desert collecting roots and, especially, grass seeds. One Paiute informant recalled that the "men helped move the camp to the grounds where seeds are gathered and then returned to the river to fish. They carry the fresh fish to the camps where the women are" (Fowler, 1989: 101).

In the fall, inhabitants of the Carson Sink sometimes traveled to the Desatoya Mountains (located 80 km to the east), the Shoshone Range (95 km to the east), or the Clan Alpine Mountains (65 km to the east) in order to gather piñon pine nuts (Stewart, 1939). Those who lived at Pyramid Lake occasionally traveled to the Carson Sink in order to hunt.

Throughout the summer and fall, Great Basin peoples spent much of their time storing resources for the winter. This was not an easy task, for no single resource could be reliably stored in bulk for the winter. Piñon nuts were an important stored resource, but they were not always available and had to be supplemented with grass seeds, grasshoppers, service berries, yampa, caterpillars, sunflower seeds, roots, fly larvae, dried fish, and dried rabbit meat. In the western Great Basin, dried fish—especially the larger species—and grass seeds were important stored resources (Fowler, 1989: 11), and these may have played the critical role that piñon did for inhabitants of the central Great Basin.

Collectively, the ethnographic data point to considerable residential and logistical mobility of inhabitants of the western Great Basin, although settlement systems appear to have been tethered to wetland areas with individuals moving between these systems. However, the ethnographic data could very well record a lifeway that had been substantially altered from the precontact situation by the presence of Euroamericans (see Kelly, 1985, MS.; Fowler, 1992: 95). We therefore turn to the archaeology of the Carson Sink.

CARSON SINK ARCHAEOLOGY

Although it has fluctuated in size and location, there has probably been a marsh or lake in the Carson Sink throughout the late Holocene (Raven and Elston, 1989). Based on an evaluation of the resource base of the Stillwater Marsh, Raven and Elston suggested that prehistoric foragers in the Carson Sink did not have to routinely leave the marsh (Raven and Elston, 1989: 138–146). Plant life provides one measure of resource diversity. For example, at the turn of the century (before irrigation reduced water flow to the marsh), there were more than 400 ha of cattail in Stillwater Marsh, along with several hundred hectares each of tule and hardstem bulrush (Kelly, 1985: 16). Raven and Elston suggested that fall was the only season during which the piñon crop may have provided a better return than marsh resources, if, for example, plant productivity in the marsh were low. That is, wetlands in the Carson Sink afforded sufficient food to feed a foraging band during most years. This required minimal residential movements within the Marsh itself with logistical forays into the mountains or other regions. The model proposed by Raven and Elston argues that prehistoric foragers should have pursued a sedentary settlement strategy in the Carson Sink.

Several aspects of the region's archaeology, however, are inconsistent with a sedentary occupation. Until recently, the archaeology of the Carson and Humboldt Sinks was known primarily from a series of cave and rockshelter sites (fig. 1-2). These sites include Lovelock Cave, one of the first systematic and large-scale excavations of an archaeological site in the Great Basin (Loud and Harrington, 1929; Heizer and Napton, 1970), Humboldt Cave (Heizer and Krieger, 1956), and Hidden Cave (Thomas, 1985). There is little evidence that these caves ever served as habitation sites. In this regard, thousands of artifacts were recovered from them, but indicators of habitation—such as hearths, debitage, and food remains—are virtually nonexistent (Heizer and Krieger, 1956: 5; Heizer and Napton, 1970: 43). Two of the sites, Humboldt and Hidden Caves, have very restricted openings and are dark and dusty, unsuited for long-term habitation (Thomas, 1985). Instead, these three caves functioned as cache locations and perhaps secondarily as diurnal shelters (Kelly, 1985; Thomas, 1985). Over 40 cache pits were recorded at Lovelock Cave, 31 in Humboldt Cave, and 22 in Hidden Cave.

A few examples give a sense of the variety of material cached in these caves. In Lovelock Cave, Pit 9 contained 126 dried tui chub. In Pit 12, wrapped in a bundle of rush matting and cached beneath a false bottom were 11 duck decoys, two bundles of snares with attached trigger pins, a rush bag of feathers, another bundle of feathers wrapped in matting, and a bundle of feathers bound with cordage. In another cache was a basket-maker's tool kit, including a chert flake, two bone awls, one bone awl blank, and a bundle of willow splints, all in a folded fox skin pouch and wrapped in a Canada goose skin. In Humboldt Cave, Cache 6 contained 100 pieces of dried chubs. Cache 10 contained three hafted stone knives, two hafted spear or knife blades, three chert arrowpoints, a wooden bunt point, a mass of pitch with tule strands, a buckskin wrapping, and *Apocynum* cordage. One duck decoy, complete except for the head, and four decoy fragments were also found in the deposits. Six "sickles" of mountain sheep horn were also found, three in Cache 20, two in Cache 11, and two in the deposits. At Hidden Cave, many of the caches had been emptied prehistorically, yet concentrations of projectile points and worked wood and bone suggest that they were cached there (Thomas, 1985). Very few pieces of groundstone tools were cached at any of the caves. Human coprolites may also have been cached at Hidden and Lovelock Caves. Ethnographic evidence from Baja California indicates that undigested bulrush seeds could have been retrieved from dried coprolites (see Thomas, 1985: 380–383).

TABLE 1-2
Carson Sink Archaeological Phase Names and Temporal Ranges[a]

Phase name	Time range
Yankee Blade	650–100 B.P.
Underdown	1250–650 B.P.
Reveille	3250–1250 B.P.
Devil's Gate	5000–3250 B.P.

[a] Adapted from Thomas (1981, 1985).

Using Thomas's (1981) chronological phase names (table 1-2), Hidden Cave was used predominantly during the Devil's Gate Phase and to a lesser extent during the Reveille Phase. Lovelock Cave was used predominantly during the Reveille Phase, although an apparent cessation of use may be a function of historic guano mining of the upper deposits. Alternatively, a major roof collapse about 1500 B.P. may have simply made the shelter less attractive (Heizer and Napton, 1970; Kelly, MS.). There are no radiocarbon dates from Humboldt Cave; however, based on projectile point styles, the cave appears to have been used during the Underdown Phase. The presence of a cache with European goods indicates use of the cave into the historic period.

Many of the artifacts cached in the caves (fish hooks, duck decoys, nets) clearly indicate the use of wetland resources, as do the contents of coprolites in Hidden and Lovelock Caves, which contained various amounts of bulrush seeds, the bones of tui chub, cattail pollen, and some piñon nut hulls (perhaps stored from the previous fall harvest). Bulrush seeds are collected in the early fall, whereas cattail pollen is collected in the midsummer. Growth rings on the tui chub ver-

tebrae indicate a predominantly spring collection (Thomas, 1985: 386).

In summary, the caves appear to have served primarily as caching facilities and perhaps secondarily as daytime resting places (Thomas, 1985). They were used by people who exploited the nearby wetland resources. However, Kelly (1985) asked why materials were cached in the caves if nearby marshes were used sedentarily. In other words, why store materials so far from where they would have been used daily? One possible reason is that the marshes were not used sedentarily, but were only one stop in a seasonal round. The marshes were possibly used more intensively in some years than in others or when the piñon crop failed or large game diminished in abundance.

The archaeological data from cave sites, however, could be misleading. The abundance of material occurs because the caves are excellent preservational environments. The caves may record a frequent behavioral pattern, but they may also record an extremely rare pattern. The cave archaeology clearly needed to be complemented with regional data. Therefore, in 1980–1981 a survey was undertaken of the Carson Sink and Stillwater Mountains as part of the American Museum of Natural History's reexcavation of Hidden Cave. This survey encompassed 1600 km^2 of the Carson Sink and Stillwater Mountains (fig. 1-2) and recorded 161 archaeological sites. Sites were originally sorted into archaeological phases based on projectile point frequencies to discern temporal change in the use of the sink (Kelly, 1985, 1988, 1990). However, this procedure had no statistical validity because so few points were found in the sites (see also discussion in Thomas, 1988: 400–401). A subsequent reanalysis of these sites focuses on geographic differences in the distribution of stone tools and debitage. The reanalysis takes differential exposure, the effects of amateur collection, lithic raw material, and survey biases into account. We only summarize the analysis here. A detailed discussion will be published later (Kelly, MS.).

The analysis divides the survey region into five geographic areas, including (1) the Stillwater Marsh, (2) a dune region between the marsh and the Carson River to the west, (3) the valley south of the marsh and immediately west of Hidden Cave, (4) the piñon-juniper zone of the Stillwater Mountains, and (5) the unwooded zone of the Stillwater Mountains. The artifacts and debitage found in these areas differ in several significant ways, suggesting key differences in mobility strategies used by prehistoric native populations inhabiting the Carson Sink.

In the dune area west of Stillwater Marsh, there is significantly greater evidence of bipolar knapping and tool recycling or scavenging, and there are more groundstone tools but significantly fewer bifacial tools, scrapers, and utilized simple flake tools. There is also considerable evidence of bipolar knapping in the southern part of the valley, but this is accompanied by evidence of simple, casual flake tool production. In the marsh, where there are significantly higher amounts of imported obsidian and poor-quality toolstone (e.g., locally available siltstones and silicified tufts), there is evidence of simple flake production (rather than bipolar core reduction) and many utilized flake fragments. There is also a significantly higher frequency of groundstone tools on the valley floor than in the mountains (the reverse pattern of some other regions, e.g., Monitor Valley [Thomas, 1988]).

In contrast to the valley floor in general, there is considerably more evidence for the use of bifacial tools and virtually no evidence of bipolar reduction in the Stillwater Mountains. In the unwooded area of these mountains, there is more evidence of simple flake tool production and use than in the wooded area. There are more bifacial tool fragments in the piñon-juniper area than in the unwooded area, and there are significantly more isolated projectile point fragments in the unwooded area.

Using current arguments that relate mobility to stone tool production and use (Kelly, 1988, 1992), these patterns point to differences in the way the five geographic regions were used by native populations. The piñon-juniper zone may have been used through both residential and logistical mobility, although the high frequencies of bifacial tools suggest either logistical or high residential mobility, especially in light of the abundance of raw material in the mountains. In either case, the dearth of groundstone in this zone suggests that piñon seed harvesting was probably not the objective of these forays. The

unwooded area of the mountains was probably used almost exclusively through logistical mobility. The unwooded area was possibly used for hunting and seed collection, but given the lack of grinding equipment, little processing of seeds likely took place here.

On the valley floor, sites in the dune area west of the marsh contain the best evidence that inhabitants lived under strong constraints on their lithic resources. This is probably because the dune area is the farthest from local stone tool raw material. However, because a round trip to the local stone tool resource areas could easily be made within a day, some inhabitants while in the dunes decided that such an investment was not worth the effort—they preferred instead to reduce small scraps of stone and scavenge old tools. This scenario suggests a shorter residential occupation than is indicated by the archaeological record in the Stillwater Marsh itself.

But even in the marsh, residential occupations may not have been year-round and sedentary. Although there are biface fragments in the marsh sites, there is little evidence of biface tool manufacture or repair there. Bifacial tools were being heavily used but not replenished. This would probably not be the case for sites that were occupied year-round.

New light was shed on the archaeology of the marsh as floodwaters receded in 1986, exposing several dozen sites containing shallow pithouses (fig. 1-4), storage pits, and the human remains that are the subject of this monograph (see Tuohy et al., 1987; Raven and Elston, 1988, 1989; Raven, 1990). Some of the pithouses are very shallow, and the only two that have been fully excavated (26CH1062) may only be the remnants of open-sided windbreaks (Kelly, MS.). However, soil cores and trenching suggest that there are deeper houses elsewhere in the marsh (Raven and Elston, 1988). The sites contain surprisingly few stone tools, although they have high tool/debitage ratios. Flakes and tools tend to be very small, utilized intensively, often derived from bipolar knapping, and fashioned predominantly from poor quality, locally available materials in the foothills (Raven and Elston, 1988). All of these characteristics indicate long-term occupations—an interpretation similar to that inferred from the survey data—but not occupations long enough to warrant consistent raw material replenishing or extensive tool production.

The exposed sites provide some information on subsistence practices in the region. Faunal remains of muskrats and other aquatic mammals indicate that they were hunted for food. A few remains of bighorn sheep indicate their use as well. Carnivores such as dogs and minks were apparently used as food and for their pelts. The remains of fish, especially tui chub, are abundant, as are the remains of many species of water birds, especially coots and shallow-water ducks. Carbonized plant remains include the seeds of bulrush and lesser amounts of cattail seeds. The bones of lagomorphs are rare and remains of ricegrass and, importantly, piñon are absent.

The seasons when these marsh sites were occupied are difficult to ascertain. The presence of egg shell indicates a spring–early summer occupation, whereas the use of cattail and bulrush seeds suggest a late summer–early fall occupation. Efforts to determine seasonality from tui chub growth rings have been inconclusive.

Projectile points and radiocarbon dates suggest that most of the occupation in the marsh may date to the Underdown phase. Table 1-3 includes radiocarbon ages from several sites in the marsh; table 2-2 (see next chapter) contains calibrated radiocarbon ages for six burials. Four of the burials and four of the sites fall within the Underdown Phase. One site has a late Reveille Phase occupation while a sixth, 26CH1052, contains a late Devil's Gate/early Reveille as well as an Underdown Phase occupation. Survey data collected by Kelly (1985, MS.) and Raven (1990) suggest that Desert Series points, which are indicative of a Yankee Blade Phase occupation, are relatively rare in the marsh and are more common in the dunes west of the marsh. In making a comparison between allegedly Reveille and Underdown Phase sites in the marsh, Raymond and Parks (1990) assumed that sites with Elko series points date to the Reveille Phase. However, the number of points from most sites in their sample are too small to permit temporal categorization of the sites with any degree of statistical assurance (see Thomas, 1990). Additionally, Elko series points may have been scavenged from

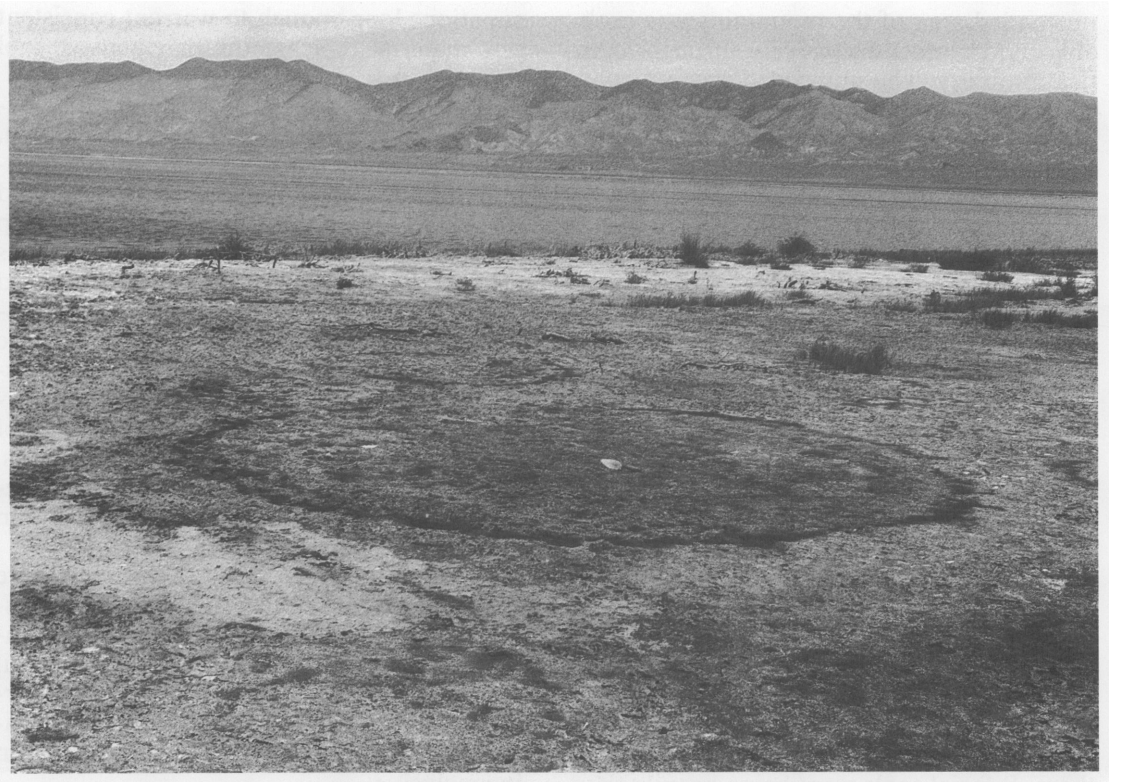

Fig. 1-4. Probable house feature exposed by flooding in the Stillwater Marsh, facing east; Stillwater Mountains in background (photograph taken July 1986; note trowel for scale).

early sites by Underdown occupants. There were a number of Elko series points found at site 26CH1062, for example, but the three radiocarbon dates from this site associated with cultural material place the site squarely within the Underdown Phase (see table 1-3). Three of Raymond and Parks' sites are also dated using radiocarbon dates from burials in or near the site. However, the associations between the burials and archaeological remains are problematic.

In conclusion, the archaeological data provide no definitive picture of mobility in the Carson Sink during the last 5000 years. The data suggest, however, that different mobility strategies may have been used by the prehistoric inhabitants of this region. Evidence from the cave sites may suggest that prior to approximately 1250 B.P. the Carson Sink may have served as one of several localities on a seasonal round. Sites from the Stillwater Marsh may indicate that after 1250 B.P., and perhaps until 650 B.P., residential mobility was lower, perhaps resulting from use of the marsh as a source of stored food. Relative to other Great Basin valley and range systems, however, the Stillwater Mountains may have been used more frequently through logistical mobility, and piñon may have been less intensively exploited than in other valleys, perhaps because it was not present in any appreciable abundance until relatively late. The marsh may always have served as a hub of residential movements prior to 1250 B.P. and as a hub for logistical movements from 1250 to 650 B.P. This pattern may have continued after 650 B.P., with perhaps only a shift in marsh location shifting the location of settlements on the valley floor, or the lifeway may have undergone an as yet undocumented transition.

THEORETICAL BACKGROUND

Low regional productivity and spatiotemporal variance in food resources have long

TABLE 1-3
Selected Radiocarbon Dates from Stillwater Marsh

Lab no.	Site	Date[a] B.P.	Date[b]	Date range[c]	Context
24791	1048	870 ± 70	A.D. 1195	A.D. 1019–1287	IMR214, fea. 16[d]
24792	1048	800 ± 90	A.D. 1253	A.D. 1028–1391	IMR215, fea. 12[d]
25140	1052	3190 ± 70	1436 B.C.	1614–1270 B.C.	Charcoal, IMR105, stratum 2[d]
25141	1052	2680 ± 160	818 B.C.	1257–399 B.C.	Charcoal, IMR307C, fea. 6[d]
25142	1052	2690 ± 70	822 B.C.	989–776 B.C.	Shell, IMR307S, fea. 6[d]
33255	1052	2150 ± 90	181 B.C.	394 B.C.–A.D. 60	Scattered carbon, fea. 3
24793	1052	3290 ± 90	1525 B.C.	1749–1395 B.C.	IMR102/103, fea. 8, stratum 8[d]
24794	1052	1040 ± 60	A.D. 1011	A.D. 888–1159	IMR107/108, organic layer w[d]
24795	1055	1860 ± 70	A.D. 141	A.D. 11–342	IMR61/64, stratum 7, marsh[d]
33003	1062	1390 ± 80	A.D. 657	A.D. 541–786	Scattered carbon, fea. 7
23853	1062	1100 ± 120	A.D. 973	A.D. 671–1214	Single carbon piece, fea. 4
25041	1062	830 ± 80	A.D. 1225	A.D. 1025–1300	Scattered carbon, fea. 23
24884	1062	2940 ± 70	1125 B.C.	1382–920 B.C.	Buried soil horizon, noncultural
24796	1068	1320 ± 100	A.D. 680	A.D. 551–962	IMR407, fea. 19[d]
24797	1173	1350 ± 70	A.D. 668	A.D. 599–862	IMR157, fea. 6[d]

[a] All dates from Beta Analytic, Inc. (uncorrected).
[b] Dates calibrated using the University of Washington CALIB program (release 3.03, method A; Stuiver and Reimer, 1993).
[c] Corrected range (±2 SD).
[d] Submitted by Intermountain Research (Raven and Elston, 1989).

been thought a key to understanding the nomadic lifestyle and low population density of many prehistoric Great Basin peoples. From ethnographic and archaeological data, wetlands appeared to stand out from the general Great Basin pattern, with relatively high population densities and low mobility. This association seemed to make sense given the concentration of a diversity of apparently productive resources in these places. But archaeology is not that easy, and archaeologists have debated both reconstructions of prehistoric wetland subsistence and settlement as well as the cause of that prehistoric behavior. Reconstructions and theoretical perspectives have informed and molded one another. We herein consider the nature of theoretical frameworks that have informed debate.

Archaeologists have often thought of societies as being either mobile or sedentary (Kelly, 1992). In fact, there are several dimensions to mobility, including intra- or interseasonal movement of the residential base camp (residential mobility), movement of individuals away from and back to camps on specific foraging trips (logistical mobility), and movement of a group's yearly range (long-term mobility) (Binford, 1980; Eder, 1984; Rafferty, 1985). In the earlier perspective, sedentism was viewed as "a process akin to a settlement system's batteries running down: people move less and less until they are not moving at all" (Kelly, 1992: 49). Ethnographic studies, however, suggest that as people become less mobile as groups, they frequently become more mobile as individuals (Hitchcock, 1982; Eder; 1984; Kelly, 1992). Residential mobility is replaced by logistical mobility. For the sake of clarity, we define sedentism narrowly as the process "whereby human groups reduce their [residential] mobility to the point where they remain *residentially* stationary year-round" (Hitchcock, 1987: 374; emphasis added) and sedentary settlements as places where at least part of the population remains for at least one annual cycle (cf. Rice *in* Rafferty, 1985: 115).

Two general hypotheses—the Pull and Push hypotheses—have been used to explain sedentism (Price and Brown, 1985). In the Pull hypothesis, hunter-gatherers reduce their residential mobility because of superabundant and reliable resources. In this construction, people establish sedentary settlements whenever the opportunity to do so arises, no matter what the surrounding environment is like.

According to the Pull hypothesis, resource abundance is both a necessary *and sufficient* condition for sedentism.

The Push hypothesis argues just the opposite: Sedentism occurs when people are forced to restrict mobility primarily because of high population density. Here, people must make use of lower-ranked and possibly more risky resources. They therefore trade higher processing and individual travel costs and increased risk for the cost of group residential movement. Moreover, resource abundance is a necessary, but not sufficient condition for sedentism.

The Pull hypothesis predicts that a sedentary lifeway should entail (1) the exclusive use of local resources, (2) an adequate and reliable diet, and (3) low levels of individual mobility. By contrast, the Push hypothesis predicts that a sedentary lifeway should entail (1) the use of resources other than those found locally and, consequently, higher rates of logistical mobility (for at least some individuals who undertake logistical forays for food and information on resources elsewhere), (2) a barely adequate diet, and (3) periodic resource failure.

The debate over the nature and cause of sedentary settlement has been played out in Great Basin archaeology as well as in the discipline of archaeology in general, with the debate in the Great Basin focusing on two key areas: (1) whether wetlands supported sedentary populations in the past, and (2) whether wetlands provided high- or low-quality resources.

Robert Heizer was one of the first archaeologists to comment on the potential of Great Basin wetlands to support sedentary foraging populations (Heizer, 1967; Heizer and Napton, 1970). Based on excavations at Lovelock Cave and 26CH15 in the Humboldt Sink (north of the Carson Sink), Heizer proposed the concept of *limnosedentism,* a lifeway based on the exploitation of rich wetland resources that consisted of sedentary or semi-sedentary occupation of lakeside villages composed of shallow pit structures. This lifeway involved the use of duck decoys, reed rafts or canoes, aquatic plants for food and tools, cattail and bulrush seeds, fish, and aquatic mammals. Although Heizer argued that the productivity of wetlands made a sedentary lifeway possible, he did not demonstrate the Humboldt Sink's productivity or year-round sedentism (Janetski, 1986; but see Livingston, 1986).

David Madsen advocated a similar position while researching Fremont materials in Utah, on the opposite side of the Great Basin from the Carson Sink (Madsen and Lindsay, 1977; Madsen, 1979, 1982). During the Fremont Phase (ca. A.D. 500–1200), people lived in pithouse villages, with some being quite large. Some Fremont villagers grew maize, but others did not. Excavating the Backhoe Village site near the Sevier River, Madsen found virtually no evidence of maize consumption; however, cattail pollen was found in abundance on house floors. Based on measures of the productivity of cattail, Madsen (1982: 207) concluded that wetlands ecosystems "were sufficiently sizeable and productive to support large, stable populations throughout the year." Following Heizer, Madsen advocated the Pull hypothesis of sedentism.

On the side of the Push hypothesis were researchers who, relying on only a few measures of resource procurement costs (e.g., that of cattail seeds), saw the marshes as less productive and reliable than those in surrounding areas (e.g., Kelly, 1985). Thomas (1985) used ethnographic data on the Carson Sink to argue for a *limnomobile* lifeway, one that was tethered to wetland resources, but that also made use of resources distant from the Carson Sink as well (see Chapter 2). Kelly (1985) argued that the Stillwater Marsh would have been used primarily as one stop on a seasonal round, or as a backup to piñon and large game, with, however, a post-1250 B.P. increase in the intensity of resource use related to the influx of Numic-speaking peoples into the Basin and/or an environmentally related reduction in large game density.

Both the Push and Pull perspectives on marsh resource use were based on stereotypical images of wetland environments as well as on limited data on the actual costs of using wetland foods. As a group, wetlands cannot be easily characterized as a type; they differ in the abundance and diversity of foods present as well as in how variable those foods are from year to year. A simple dichotomy between limnosedentism and limnomobile life-

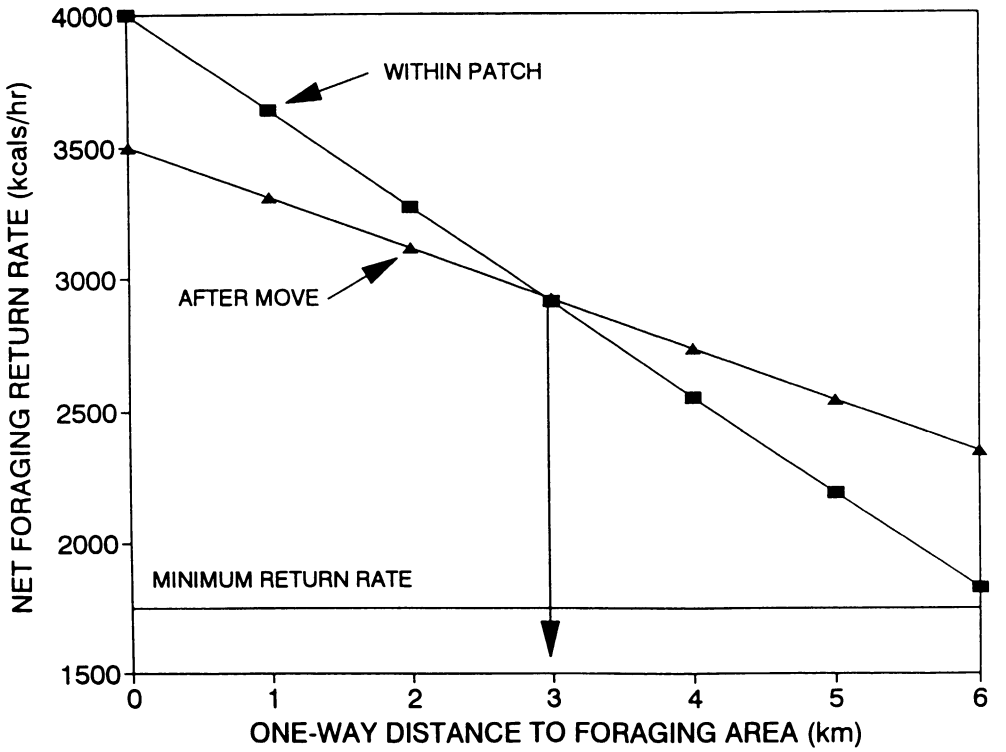

Fig. 1-5. The relationship between return rates within a camp and those anticipated after moving on the day of a move.

ways, between a characterization of marshes as good or bad places to live, and between the Pull and Push hypotheses of sedentism has been succeeded by more informed models that anticipate variability in the use of wetlands.

In fact, although not originally framed as such, the Pull and Push hypotheses, as well as the limnosedentism and limnomobile models, share a theoretical framework by placing costs and benefits of remaining stationary versus moving in the foreground. This framework is compatible with models derived from foraging theory that focus on the relationship between individual foraging and group movement (see Kelly, 1983, 1990, 1995). Imagine the simple case of a forager who collects a homogeneously distributed resource at a postencounter rate of 4000 kcal/hr. Assume that the forager's family requires about 14,000 kcal/day, that the forager walks at a pace of 3 km/hr at a relatively low caloric cost of 300 kcal/hr, and that the cost of walking increases by 30% when returning home with food (Jones and Madsen, 1989). Assume also that foraging activities, including the time to travel to foraging areas as well as the time to harvest and process the food resource, are confined to 8 hr/day. The overall daily return rate is

$$\frac{4000\,(8 - 2T) - (300T + 390T)}{8} \quad (1)$$

Where T is the time spent traveling out from camp. As figure 1-5 shows, the net return rate of the current camp decreases farther from camp as the forager spends more time and energy traveling to and from the foraging area and less time collecting and processing the resource. At about 6 km, the forager cannot bring home enough food for his or her family. Would the forager remain at the current camp until eating everything within that 6 km radius?

To answer this question, we can compute the return rate if the group were to move to a new foraging area after exploiting the resources within a given radius of the site. This

new camp will be located twice the current foraging radius from the current camp (assuming no other factors affect movement and a homogeneous distribution of food). Allowing an hour for camp breakdown and setup, the postmove return rate of the individual forager is

$$\frac{4000\ (7 - 2T) - 300\ (2T)}{8} \qquad (2)$$

Note that at a return rate of just under 3000 kcal/hr (achieved at a foraging distance of about 3 km) that the after-move return rate is higher than the within-patch return rate. After having eaten everything within about 3 km of camp, foragers would do better (maintain the highest possible return rate) to move their families to the center of a new foraging area (6 km away).

There are many other variables that affect this relationship—the distribution of food, variance in return rates, the terrain to be traversed in moving, the time it takes to breakdown and set up camp, and other factors (see Kelly, 1995). In general, however, the higher the cost of moving a family relative to the benefit of remaining in the current camp, the longer a family of foragers will remain in their current residential camp. Decisions about whether to move or stay—or, within the framework of a longer period, to become sedentary or remain residentially mobile—can only be understood in a regional perspective. To predict how a marsh was used prehistorically, we need to consider the benefit of remaining in a marsh during a given season versus the cost of moving logistically and residentially to another area.

We are preceded in this effort at modeling Stillwater Marsh mobility by Christopher Raven's approach (Raven and Elston, 1989; Raven, 1990). Raven modeled the valley floor environment using soil and hydrological information to reconstruct the prehistoric distribution of food resources. Contrary to Kelly's (1985) assertion, it is clear that the Stillwater Marsh could have provided a diversity of high return rate resources for most seasons of most years. From the reconstructed food base, Raven predicted changes in mobility within the valley floor, arguing that sites should, in general, be placed centrally to women's foraging targets (plants and small game), with men foraging farther afield for large game. In his model, residences are located in different parts of the valley to take advantage of spatial and seasonal differences in food resources. Additionally, depletion of foods around a camp through women's foraging would result in different levels of residential mobility within a given season. Raven suggested that only in the fall might it have been worthwhile to move camp into the mountains to procure piñon. An archaeological survey of the valley floor, covering some of the same area as the 1980–1981 survey, provided some support for Raven's model (Raven, 1990).

Conducted as part of a cultural resource management program, Raven only considered resources on the valley floor rather than in the larger region. To expand upon his research, a model incorporating resources in the Stillwater Mountains is needed. We herein briefly describe our efforts at such a model; a complete discussion will be presented elsewhere (Kelly, MS.). Here we give only an idea of the approach being taken by modeling the foraging choices of a group residing in the marsh in the fall. We chose this season because we have the best experimental foraging data for it and because one of these fall resources, piñon, figures importantly in the bone chemistry analysis (Schoeninger, this volume).

The question that this model addresses is simple: If foragers are in the marsh, would they obtain the highest foraging rates by remaining in the marsh, by exploiting distant resources alone, while others remain in the marsh, or by moving the entire family to the distant resources? Modeling these situations involves many permutations, so we examine only the simplest case here.

The model uses experimentally acquired information on resource harvesting rates (Simms, 1987), limitations on the amount of a resource that can be transported with a burden basket by an individual (Simms, 1987; Metcalfe and Barlow, 1992). It takes into account the actual distances between the marsh and the modern piñon-juniper zone and limitations on how much time a forager would have to spend in the mountains to gather a basketful of a resource. Using modified versions of Equation 1, we can determine the

net daily return from using resources in the marsh at a particular season, the return from collecting resources (logistically) at a distance from the marsh—piñon or bighorn sheep, for example—and the return from moving the entire family residentially to those distant resources.

Table 1-4 shows the predictions for resources in the Stillwater Mountains and the marsh for both good and bad years, that is, when return rates are high or low. Figure 1-6 shows the relationship between returns from foraging for a variety of resources from a residential base in the marsh versus returns from foraging for upland resources logistically. In this figure, we assume all marsh resources are providing their highest rates of return. The highest return in this case may come from remaining in the marsh and focusing on waterfowl and fish, with some individuals foraying into the Stillwater Mountains for bighorn sheep, but probably not piñon.

Figure 1-7 shows the same diagram, but using the lowest rates of return for marsh resources. In this case, the highest return might come from logistical acquisition of bighorn sheep and piñon (further analysis suggests residential movement to the mountains). If it were also a bad year in the mountains, it might be better to remain in the marsh, taking resources there and sending forays into the mountains for bighorns, rodents, or piñon depending on their individual return rates.

The situation is far more complex, of course, because different resources fluctuate on different scales. Additionally, we have only been able to include the Stillwater Mountains; however, if ethnographic data are used as a guide, resources from the Clan Alpine Mountains and areas farther east might also be included, as should the fishery resources of the Walker and Truckee Rivers. The important point is that predictions need to be based both on the wetland resources and their regional matrix.

When working out predictions for other seasons, it appears that in most years a residential occupation of the marsh was most likely, with logistical parties sent up to the mountains for hunting. Changes in the availability of marsh resources, especially fish, could make the uplands more attractive. Piñon is not expected to form an important part of the diet unless the marsh is substantially reduced in quality and there are significant reductions in game.

TABLE 1-4
Return Rates of Resources Resulting from Different Mobility Choices in the Carson Sink

	Valley		Mountain	
Resource	Resid.	Logist.	Resid.	Logist.
Cattail pollen	4508	—	—	—
	1589	—	—	—
Waterfowl	1436	—	—	—
	1105	—	—	—
Tui Chub, winter	3430	—	—	—
	1242	—	—	—
Tui Chub, spring	1416	—	—	—
	522	—	—	—
Tui Chub, summer/fall	3912	—	—	—
	986	—	—	—
Tui Chub, storage	1602	1136	—	—
	696	612	—	—
Small mammals	1081	1161	2436	1161
	162	331	423	331
Seeds and roots	1081	981	1194	886
	91	43	303	43
Piñon	—	—	1365	1418
	—	—	798	995
Bighorn	—	—	4507	2624
	—	—	144	166
Waterfowl, dried	—	708	—	—
	—	617	—	—

CONCLUSIONS

Our brief summary of ethnographic and archaeological data suggests that the Stillwater Marsh may have served as a hub of settlement systems for the last 5000 years. At times, settlement may have been more tightly tied to the marshes than at others, perhaps especially during the Underdown Phase, although this is still not clear from the archaeological data. It appears that residential mobility and significant logistical mobility, beyond the foraging patch of the marsh, were employed to gather food resources most efficiently, although possibly in different mixes at different times. The question still remains: Although the marshes may have permitted a completely sedentary lifeway in some years, perhaps more so during some climatic periods than others, did prehistoric peoples avail

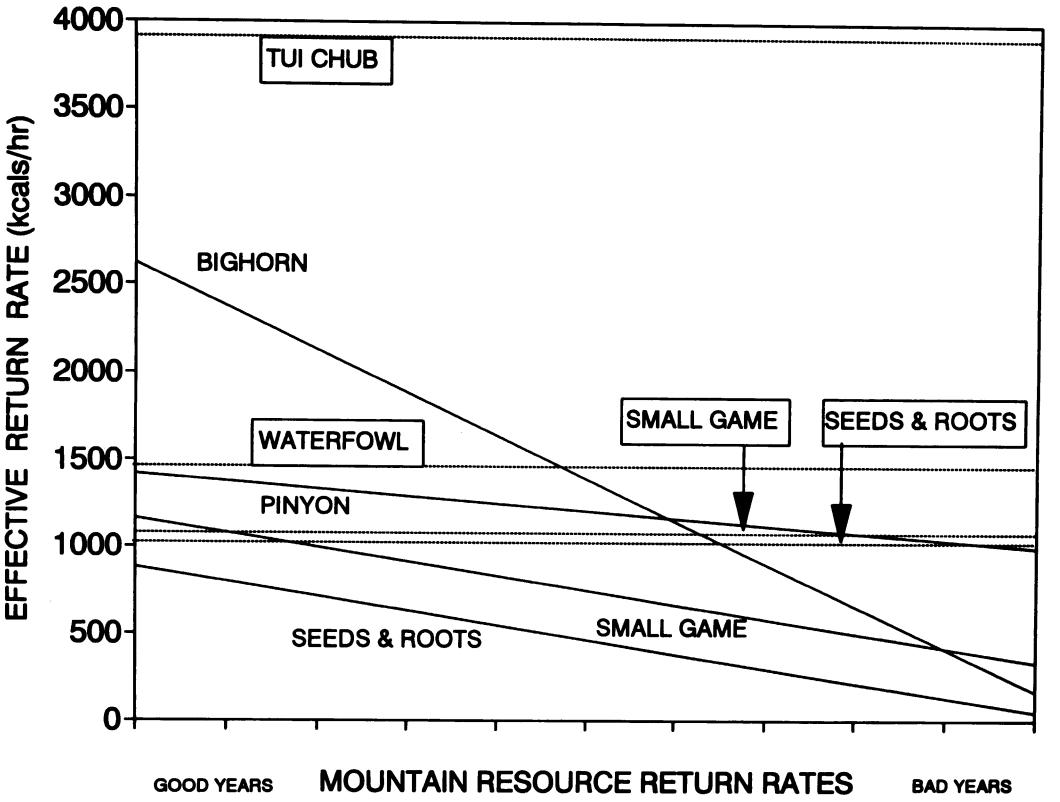

Fig. 1-6. The relationship between return rates of a residential occupation in the marsh versus moving logistically for a variety of resources in the mountains during a time of high return rates in the marsh. Marsh resources indicated by boxed text.

themselves of this opportunity? At present, one reading of the archaeological record suggests they did not. People probably continued to move as a group *and* as individuals. Based on ethnographic data, men may have traveled more than women, as they transported fish to women gathering seeds, as they traveled from winter villages in the mountains to fish, or as they traveled from lowland villages to hunt bighorn sheep in the mountains, among other pursuits.

One of the difficulties in drawing conclusions from archaeological or bioarchaeological data is that both represent conglomerates of events, the products of a lifetime (in the case of bioarchaeological data) or multiple lifetimes (in the case of archaeological data) of possibly diverse subsistence-settlement regimes. The wetlands of the western Great Basin, perhaps especially in the Carson Sink, are susceptible to fluctuations in water supply (at times considerable), and consequently undoubtedly oscillated. Although marshes may have provided sufficient resources each year, these resources would have changed in kind and abundance from year to year or during longer periods. A rapid increase in water level may increase the fish population, for example, but reduce the density of bulrush and cattail (which in turn could affect migratory waterfowl and mammals).

One response to these shifts could have been to shift the foods extracted from the marsh. Another response, however, could have been to move from the marsh to another wetland or river or into the nearby mountains if the differences between the wetland resources and those resources available elsewhere were great enough. Still another response could be to leave families on the marsh and make heavier use of the uplands through logistical mobility. In any case, we could ex-

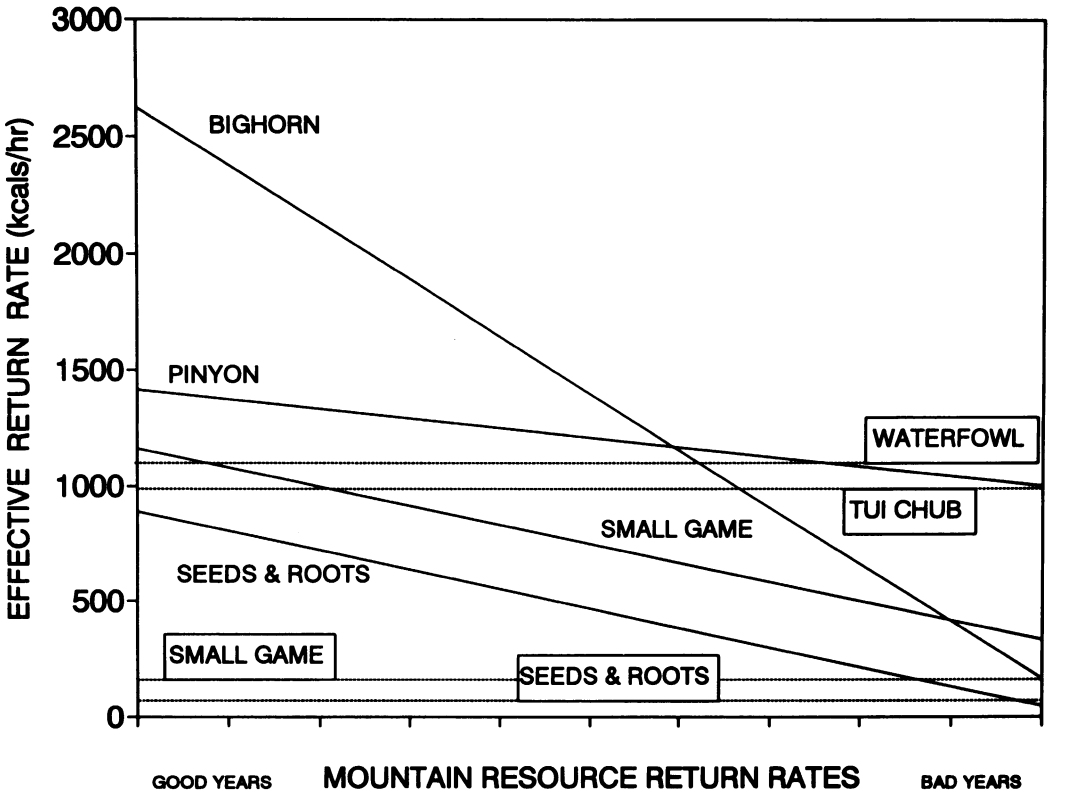

Fig. 1-7. The relationship between return rates of a residential occupation in the marsh versus moving logistically for a variety of resources in the mountains during a time of low return rates in the marsh. Marsh resources indicated by boxed text.

pect people's diets to differ considerably from year to year, or from decade to decade, and for residential, logistical, and long-term mobility to be used in response to changing regional resource configurations.

Lack of evidence for intensive residential use of the piñon-juniper zone in the Stillwater Mountains and the lack of groundstone artifacts suggest that piñon may not have been heavily used by prehistoric peoples in the Carson Sink. The reason for this may be that the wetland resources provided sufficient stored resources, as well as a possible source of winter food resources (especially fish), which made piñon less attractive—especially given its distance from the marsh—than it was in areas of the Great Basin without wetlands. On the other hand, piñon may very well have been absent from the region for much of the prehistoric sequence.

This monograph addresses these issues as well as other related aspects of human adaptation in and occupation of the western Great Basin; however, it does not claim to resolve all questions raised in this chapter. In Chapter 2, Larsen discusses the general characteristics of the Stillwater human remains. He gives overviews of the biocultural context for the region and of the bioarchaeological project that began in 1987. In Chapter 3, Larsen, Russell, and Hutchinson describe the human remains encountered by the Human Skeletal Field Survey. These remains include all isolated bones and teeth as well as burials excavated or otherwise identified during our 1987 survey of the Stillwater Marsh. Chapter 4, by Smith, Bettinger, and Rolfs, presents the analysis of serum albumins extracted from human bone samples from the Stillwater series. In Chapter 5, Kaestle presents data on DNA extracted from human remains from various sites. The findings

from Chapters 4 and 5 provide important contextual information on population history in this region of the Great Basin. Chapter 6 includes a discussion by Hutchinson and Larsen of physiological stress, primarily via the investigation of dental enamel defects (hypoplasias). Chapter 7 is a discussion of dietary reconstruction completed by Schoeninger based on stable carbon and nitrogen isotopes from human bone collagen samples. Chapter 8, by Larsen, Ruff, and Kelly, is a study of biomechanical variation and activity based on the analysis of degenerative changes in articular joints (osteoarthritis) and long bone morphology (cross-sectional geometric properties). Lastly, in Chapter 9, Larsen and Kelly summarize the project findings, evaluate strengths and weaknesses of the database, and assess the role of bioarchaeology in contributing to an understanding of the adaptation of prehistoric hunter-gatherers in the Carson Desert.

CHAPTER 2. PREHISTORIC HUMAN BIOLOGY OF THE CARSON DESERT: A BIOARCHAEOLOGICAL INVESTIGATION OF A HUNTER-GATHERER LIFEWAY

Clark Spencer Larsen

BACKGROUND

Following the retreat of floodwaters in the Stillwater Marsh and the Carson Sink in the summer and fall of 1985, perhaps the most striking characteristic of the newly visible desert landscape was the plethora of exposed human skeletal remains. Occasional instances of exposed human remains in the region had long been reported, but the archaeological community was ill-prepared for the extent of mortuary activity by prehistoric native populations. Many of these newly exposed remains were isolated bones and teeth; many, however, were from original burial contexts (Tuohy and Dansie, 1986a; Fagin and Raymond, 1987; Brooks et al., 1988, 1990; Raymond and Parks, 1990). Although an abundance of archaeological features and related materials—including, but not limited to, trash and cache pits, artifacts, animal bones, and pithouse sites—were observed, it was the alarming nature of the exposed human remains, potentially numbering in the hundreds, that occasioned a Fallon, Nevada, resident and amateur archaeologist, Mr. Charlie Gomes, to alert state and federal authorities to the magnitude of destruction of valuable cultural resources.[1] In the ensuing months, under contract from the United States Fish and Wildlife Service (Regional Office, Portland, Oregon), personnel from the Nevada State Museum (NSM) documented many previously unknown archaeological sites and collected exposed and partially exposed artifacts and human remains.

[1] Exposure of archaeological sites from rising and subsequent receding of water levels in lakes in other Great Basin settings—eastern Oregon (Malheur Lake) and northern Utah (Great Salt Lake)—have recently yielded other significant samples of prehistoric human skeletal remains. Investigations of human remains from various sites will provide important information on populations occupying these other regions of the Great Basin (Simms et al., 1991; Loveland and Gregg, 1991; Hemphill, 1994).

Under the direction of Donald R. Tuohy and Amy Dansie, primarily during October 1985 and in a follow-up operation in June 1986, heroic efforts by the NSM staff and volunteer amateur archaeologists resulted in the recovery of hundreds of human skeletal and dental remains from exposed sites on high-ground (peninsula and island) localities in the Stillwater National Wildlife Management Area. The area of investigation was primarily south and west of Nutgrass Dike in and immediately surrounding North Nutgrass, South Nutgrass, Goose Lake, Pintail Bay, Swan Check, Tule Lake, and Swan Lake (Tuohy and Dansie, 1986a, 1986b; Tuohy et al., 1987). Although the region was generally hard-hit by the effects of flooding, exposure of sites was most extensive on the downstream third of the Stillwater Marsh (Raymond and Parks, 1990). By July 1985, 51 previously unknown sites had been documented in this region, 33 of which contained human remains (Brooks et al., 1988; Raymond and Parks, 1990). A description of these sites, including the human remains and their context, has been presented by Tuohy et al. (1987). An analysis of the human remains from the various Stillwater localities was subsequently provided by Brooks et al. (1988). According to them, 144 relatively complete skeletons, in addition to 272 incomplete skeletons, are present in the series. Some of the latter materials included single skeletal elements. Brooks's study serves as a guide to the collection of human remains from the region.

The fortuitous exposure of the Stillwater Marsh archaeological sites by the erosional effects of wind, water, and ice has presented an unprecedented opportunity to examine prehistoric aboriginal use of the marshes specifically and human adaptation in the far western Great Basin generally. With the availability of preliminary results from the excavation of human burials and collection of other exposed archaeological materials by the NSM, it became abundantly clear that

prehistoric populations in the Carson Desert had utilized a considerably wider variety of resources in their subsistence economy than had been previously known (Tuohy and Dansie, 1986a, 1986b; Tuohy et al., 1987; Raven and Elston, 1989; Raven, 1990; Kelly, this volume). Prior to the discovery of these materials, understanding of prehistoric utilization of resources in the region was mostly speculative (see Pendleton et al., 1982; Kelly, 1985; Thomas, 1985; Raven, 1990). The study of faunal remains from Stillwater Marsh archaeological sites (e.g., Schmitt and Sharp, 1990) and the analysis of the role of various edible plants in the region (reviewed in Raven and Elston, 1989), combined with information provided by the analysis of the newly excavated human remains from the Stillwater Marsh, offered a remarkable data source on the human ecology of this region.

BIOCULTURAL CONTEXT

One of the most important developments in anthropological archaeology in recent years is the comprehensive approach to the study of subsistence economy, diet, and related aspects of lifeway. In particular, human remains offer information for nutritional inference, dietary reconstruction, activity patterns, demographic analysis, and paleopathology (Ford, 1979; Wing and Brown, 1979; Huss-Ashmore et al., 1982; Gilbert and Mielke, 1985; Larsen, 1987; Saunders and Katzenberg, 1992). In this regard, skeletal and dental tissues are remarkably sensitive to the environment, providing what Stanley M. Garn (1976: 454) has referred to as "a rich storehouse of individual historical events." A cumulative history of these events, including dietary stress, nutritional quality, disease history, population size and mobility, physical exercise, and habitual activity associated with workload, are left as indelible marks on the hard tissues, thus providing a range of biocultural inferences about the past (Larsen, 1987; Iscan and Kennedy, 1989; Bush and Zvelebil, 1991). Growing numbers of bioarchaeological regional studies from New World contexts in various settings have contributed to increased understanding of now-extinct lifeways and adaptive success (e.g., Ubelaker, 1981, 1984; Larsen, 1982, 1990; Cook, 1984; Buikstra et al., 1987; Hodges, 1989).

The Great Basin has played a pivotal role in elucidating prehistoric lifeways in general, and especially patterns of subsistence and settlement among earlier foraging societies (e.g., Jennings, 1978; Thomas, 1973, 1985, 1988; Bettinger, 1977, 1989; Kelly, 1985; Simms, 1987; Zeier and Elston, 1992; and see discussion in Upham, 1994). Because of the paucity of human remains from this region, very little attention has been paid to prehistoric human biology generally or the special role of human remains in ecologically oriented studies in archaeology. Aside from the recently excavated Stillwater Marsh human remains, two of the largest skeletal series from the western Great Basin include remains from the nearby Humboldt Sink and Lovelock Cave. The stratigraphic, temporal, and other controls for these materials are very poorly known and archaeologically undocumented. Because native populations in the western Great Basin rarely buried their dead in designated cemeteries, virtually all human remains from the region occur in isolated contexts (e.g., rock crevices, shelters, and caves). Therefore, with the exception of relatively few sites, there are usually few individuals from the same archaeological locality. At least 75% of the several hundred individuals excavated from the vast region of the western Great Basin are accidental discoveries made, in many instances, by amateur collectors who donated the materials to museums without providing appropriate contextual information (table 2-1). Considerably less than half of the human skeletal remains are from known contexts (see Kobori, 1981; Tuohy, 1983; Larsen, 1985b).

Although human skeletal remains have been excavated from the western Great Basin since the late 19th century (see summaries in Kobori, 1981; Pendleton et al., 1982), these materials offer limited information for elucidating past lifeways in the region because of their poorly known cultural context. The Carson Sink, Stillwater Marsh, and Carson Lake—the three dominant features of the Carson Desert—as well as the immediate area of the western Great Basin are no exceptions to this problem. Kobori (1981) and Larsen

TABLE 2-1
Human Remains from Western Great Basin[a]

Site[b]	Burials[c]
Hidden Cave	5
Spirit Cave	4
Fish Cave	2
Burial Crevices	5
Burial Shelter	2
Grimes Point	2
Sand Hill	1
The Island	2
Pelican Island	1
Big Indian Lake	1
Crypt Cave	5
Fallon	2
Mongoose Cave	3
Blazing Star Cave	11
Chimney Cave	1
Nicolarsen	9
Lovelock Cave	52
Leonard Rockshelter	1
26CH12	3
26CH13	3
26CH14	1
26CH15	10+
26CH28	1
26CH86	1
Nixon	5
26Las86	1
Glendale	1
Pitt Ranch	2
Humboldt Cave	2
Humboldt Lake (various sites)	10
Humboldt Sink (various sites)	36
Bishop	1
North Winnemucca Lake	6
Deep Springs Valley	1
Winnemucca Cave	3
Paul Bunyan's Corral	1
Bull's Head Canyon	1
26Do12	7
Rose Spring	4
Karlo	40+
Honey Lake Valley	2
Ezra's Retreat	2
$10,000 Cave	1
26Wa7	1
26Wa275	1
26Wa292	1
26Wa315	3
26Wa349C	1
26Wa349D	2
26Wa525	10
26Wa1014	1
26Wa1016	4
26Wa1018	8
26Wa1021	6
26Wa1072	1
26Wa1201	1
Falcon Island	3
Painted Pestle Cave	1
Bitsy Shelter	1
Camelback Tufa Dome	1
Paradigm Lost Cave	1
Desiccation Cave	2
Mixion Cave	3
Guano Sack Shelter	1
Pancakes Cave	3
Thea Heye Cave	10+
Mule Ears Cave	1
Square Cave	1
Warrior Point	1
Hanging Rock Cave	1
Hell's Kitchen	3
Muller	2
Pancho's House	1
Pancho's Cut Bank	2
Willow Beach	1
Mule Springs	1
Overton Burial Hill	5
26Hu8	4
NSM122	2
Walker River	2
Hawthorne	1
Tule Springs	1
Yerington	1
Sand Hill	1
Pahrump Valley	2
Good Springs	1
Gold Butte Ranch	1
Marble Bluff	5
Duck Flat	1
Pyramid Lake	2
Connally Ranch	1
26Ny94	1
Bell Cave	1
Carlin	1
The Needles	1
Hathaway Beach	1
Chimney Cave	5
Ophir	1
Fort McDermit	1

TABLE 2-1—(*Continued*)

[a] Compiled from Stark (1983), Tuohy (1983), Larsen (1985a, 1985b, 1985c, unpubl.), and Hattori et al. (1987); does not include the Stillwater Marsh series.

[b] The first 11 sites in this list are located in the Carson Sink.

[c] Number of individuals/burials (N = 350+).

(1985a, 1985b) have reviewed the pre-1985 database of human remains from this region.

As part of an archaeological research program involving the excavation of Hidden Cave and study of prehistoric lacustrine adaptation in the Carson Sink by Thomas et al. (see Thomas, 1985; Kelly, 1985), I examined the available human remains from this area to provide a preliminary biocultural profile of the precontact human populations that occupied the region (Larsen, 1985a, 1985b, 1985c). Based on a meager sample of mostly incomplete skeletons (N = 18), which were excavated from Hidden Cave and other localities in the Carson Desert during a period of about 50 years, I provided a few cursory details regarding the nature of human biological adaptation in the region (Larsen, 1985b). Specifically, I suggested that these Great Basin populations enjoyed generally good health, had adequate diets, and experienced extremely high levels of mechanical demand. However, because of the limited database, I emphasized that larger, better documented skeletal samples were required for developing a more comprehensive understanding of biocultural aspects of human adaptation in the region.

This historical context underscores the tremendous importance of the skeletons excavated in the Stillwater Marsh following the retreat of floodwaters in 1985. For the *first* time, a large sample of human remains from localities of known archaeological and cultural context became available, thereby presenting a remarkable opportunity to view in some detail the human biological component of past societies in the region. With this series of human remains, it is possible to address key questions on the general nature of regional prehistoric human biology as well as the specific issues of adaptation, subsistence technology, and lifeway in this desert setting.

Among these questions, the study of the Stillwater series is key to addressing broader anthropological questions on the adaptive efficiency or "affluence" of hunter-gatherers in general. In a popular archaeology textbook published in the mid-1960s, Braidwood characterized the hunter-gatherer lifeway as "a savage's existence, and a very tough one . . . following animals just to kill them to eat, or moving from one berry patch to another" (Braidwood, 1967: 113). In contrast, after the epic "Man the Hunter" conference in 1966, data emerged that suggested hunter-gatherer lifeways were far from "nasty, brutish, and short." Contrary to the Hobbesian portrayal of foragers, the consensus emerged in the anthropological community that far from being nutritionally deprived and subject to excessive workloads, foragers had adequate nutrition and were not subject to overbearing amounts of work; in fact, life overall was leisurely (see Sahlins, 1972).

Stimulated by the "Man the Hunter" conference and especially by Richard Lee's provocative findings based on his field research among the Ju/'hoansi (!Kung) Bushmen (Lee, 1979), ecologically oriented field programs conducted by anthropologists among extant foragers were initiated in many diverse settings (e.g., Australasia, the Arctic, the Subarctic, Africa, South America) that addressed the affluence of hunter-gatherers (see discussion by Hill and Hurtado, 1989). Far from confirming the ubiquity of an easy lifestyle, these investigations showed that by virtually any measure—food selection, nutritional quality, gender-based work patterns, subsistence strategy and food procurement, workload, disease stress, and demographic profiles—hunter-gatherers are *highly* variable (Kelly, 1995). In this monograph we hope to demonstrate that the contributions of bioarchaeology and paleopathology to these areas of inquiry are important, particularly as they relate to earlier human populations. Many of these measures can be examined by study of the Great Basin skeletal remains.

It is important to note that the mortuary landscape in the Stillwater Marsh is unique relative to many other human death assemblages that are typically encountered by archaeologists; that is, the human remains from Stillwater Marsh were not excavated from a single, identifiable cemetery unit containing a group or groups of skeletons. Rather, the human remains were excavated from isolated graves scattered throughout the marsh region, thus indicating lack of formal disposal areas. Some of the archaeological sites contain a relatively large number of skeletons. For example, Brooks and co-workers (1988) list some 58 individuals of varying completeness from site 26CH1043. The human re-

TABLE 2-2
AMS Radiocarbon Dates from Six Stillwater Marsh Burials[a]

Lab no.[b]	Specimen	Date[c] (B.P.)	Date[d]	Date range[e]
UCR 2336	1044-2	1140 ± 80	A.D. 893	A.D. 688–1029
UCR 2337	1050-3	290 ± 80	A.D. 1644	A.D. 1443–1954
UCR 2338	1070-4	660 ± 30	A.D. 1302	A.D. 1287–1396
UCR 2339	1159-4	1080 ± 50	A.D. 984	A.D. 883–1029
Beta 33554	1159-200	2265 ± 70	270 B.C.	408–130 B.C.
Beta 33555	L72-200	820 ± 70	A.D. 1229	A.D. 1036–1298

[a] Dates calibrated using the University of Washington CALIB program (release 3.03, method A; Stuiver and Reimer, 1993).

[b] UCR 2336, UCR 2337, UCR 2338, and UCR 2339 from Brooks and Brooks, 1990: 72; Beta 33554 and Beta 33555 provided by Beta Analytic, Inc.

[c] Uncorrected.

[d] Corrected.

[e] Corrected range (±2 SD).

mains recovered by the Human Skeletal Field Survey (HSFS) at this site in 1987 (see Appendix A) are likely from many of those same individuals because of the fragmentary and disturbed nature of many of the remains. Despite the presence of many individuals, archaeological survey of the site revealed no clear concentration of burials in a context that would characterize a planned cemetery. Although human burials occurred on a frequent basis in this region, they were from a wide area. The archaeological survey of the region by Christopher Raven and associates in 1989 has provided additional confirmation for this finding (Raven, 1990; Schmitt, 1990).

Thus, the study of this and other mortuary localities from an area measuring approximately 16 km^2 (about 4 mi^2) shows no evidence for continuous use of a single burial area during a restricted period. Instead, a general region was used for interment over an indeterminate time. Therefore, the biocultural analysis of these remains is beset by several problems unique to this area. Because the remains are not from a cemetery unit, there is an increased probability that they may not be representative of the population from which they were drawn. Moreover, it is especially difficult to provide a time range from earliest to latest deaths in the assemblage—temporally and culturally diagnostic artifacts (e.g., projectile points) that represent virtually every period of prehistoric era (pre-1829) and historic era occupations in the region have been found by archaeologists working in the area (Tuohy and Dansie, 1986a; Russell, 1987; Tuohy et al., 1987; Raven, 1990). Surface collection of one site by Raven, who noted that "several thousands of years of projectile point manufacture (represented by specimens of the Large Side-notched, Gatecliff, Rosegate, and Desert series) are reflected in the minimal assemblage (22 pieces) of a 10 m diameter site" illustrates the temporal confusion in the regions (Raven, 1990: 121). However, Tuohy and Dansie (1986a) pointed out that most artifacts that they collected from the Stillwater Marsh are from the Reveille (3250–1250 B.P.) and Underdown (1250–650 B.P.) Phases, suggesting that the prehistoric use of the region was primarily focused on this 2600-year period (Tuohy and Dansie, 1986a; Raymond and Parks, 1990; see also Raven, 1990).[2] Moreover, these workers indicated that a relatively higher frequency of temporally diagnostic artifacts are from the Underdown Phase. This suggests that the greater proportion of burials are also from this period.

Unfortunately, very few burials contain directly associated, diagnostic artifacts. Artifacts were found in relatively few instances in clear association with burials excavated by the NSM. Finally, six burials have been radiocarbon dated by accelerator mass spec-

[2] Dates for archaeological phases in the Carson Desert follow Thomas's chronology (1985: 363–373; see Chapter 1).

trometry, including four burials excavated by the NSM and two burials excavated by the HSFS (table 2-2). These few dates are consistent with the temporal pattern revealed by analysis of diagnostic artifacts: one date is from the Reveille Phase, four dates are from the Underdown Phase, and one date is from the Yankee Blade Phase, the final prehistoric period (650–100 B.P.) in the region.

Because the Stillwater human remains are from many sites that encompass hundreds (if not thousands) of years of occupation, the strong possibility remains that they are not representative of the populations from which they are drawn. However, Brooks et al. (1988) noted homogeneity in skeletal measurements and discrete traits in the series, which they argued reflects little biological change throughout the course of occupation of this region of the Great Basin. Their findings suggest that the series can be regarded as a cohesive skeletal sample that is amenable to broadscale comparisons with other archaeological human death assemblages. Thus, despite the intractable nature of the temporal and cultural associations of the Stillwater human remains, they are treated herein as a single unit to facilitate the analysis of and comparisons with other skeletal series. Unknown sampling biases of the series, however, may influence at least some of the results discussed in this monograph (see also Wood et al., 1992). Moreover, the lack of adequate temporal controls in the Stillwater skeletal series prohibits characterization of patterns of diachronic variation.

THE PROJECT

During Kelly's examination of the effects of flooding and erosion of archaeological sites in the Carson Desert in the summer of 1986, he noted that degradation of these sites had been somewhat arrested. Nevertheless, erosion was continuing, and burials and other evidence of the prehistoric occupation of the region were being lost at an alarming rate. Recognizing the obvious relevance of these materials to his research program in the Carson Desert–Stillwater Mountains region as well as to my own interests in prehistoric human biology of the western Great Basin, a collaboration was initiated on the prehistoric human ecology in the region.

The objectives of fieldwork involving the osteological component of the Stillwater sites were to record previously unknown sites, excavate human burials in danger of erosion or other disturbance, and retrieve exposed human skeletal materials that lacked clear burial associations (isolated surface remains). During the summer of 1987, a pedestrian survey was completed by the HSFS of the Carson-Stillwater Archaeological Project (CSAP). This survey involved identifying and recording archaeological sites and collecting human remains while walking along the shorelines of the Stillwater Marsh (fig. 2-1).

The areal focus of the survey was on the northern and eastern portions of the Stillwater Marsh, because they appeared to exhibit the most severe effects of wind, water, and ice erosion. The survey perimeter was identified as being bound on the north by the northern tip of Pintail Bay, on the west by a point located 0.5 km east of the junction of Willow Dike Road and Center Road, on the south by Division Road at the southern tip of Goose Lake, and on the east by Nutgrass Road. This area encompasses approximately 16 km^2.

From the outset, it was clear that a study of the human remains collected by the HSFS could not be undertaken without combining our database with data derived from human remains excavated in 1985 and 1986 by the NSM (described in Tuohy et al., 1987; Brooks et al., 1988). Therefore, during 1987 and 1988 I collected skeletal and dental data on the 1985–1986 NSM human remains at the NSM Annex laboratory facility in Carson City. Specifically, data collected in 1987 included a full inventory of skeletal remains, observations on pathology (periosteal reactions, cribra orbitalia/porotic hyperostosis, dental caries, fracture and other trauma, degenerative articular joint pathology [osteoarthritis]), dental wear (gross occlusal; anterior dentition occlusal surface grooves), and standard anthropometric measurements (cranial, dental, postcranial). Because age and sex are important factors when interpreting these data, we estimated age and determined sex for human remains using standard morphological criteria (reviewed in Ubelaker, 1989; White, 1991). Research completed in 1988 included computed tomography scanning of selected humeri and femora at the Veterans Admin-

Fig. 2-1. View of the Stillwater Marsh landscape (photograph taken in July 1987).

istration Hospital in Reno, Nevada, observations on additional dental pathology (enamel hypoplasias), and study of the human remains excavated or surface collected by the HSFS in 1987. Additionally, human bone fragments were selected from the NSM collection for analysis of stable isotopes (carbon and nitrogen) and other specialized analyses, including serum albumin identification.

The study of human remains excavated in 1985 and 1986 by the NSM was part of an ongoing, long-term investigation of Great Basin human osteology by Sheilagh T. Brooks and her associates. To avoid redundancy with their efforts in the analysis of the Stillwater Marsh human remains, we have attempted to report only on data that are relevant to the present monograph. Although Brooks et al. (1988) have provided descriptions of the NSM skeletal series, including skeletal inventory, age at death, sex, cranial and postcranial measurements, observations on pathology, dental wear and other related oral pathology (e.g., abscesses, periodontal disease), and skeletal (cranial and postcranial) discrete traits (see Tuohy et al., 1987; Brooks et al., 1988), we collected additional data from these materials while we examined the then-unanalyzed CSAP component of the collection. Furthermore, we have independently estimated ages on all human remains and identified sex on adult remains recovered by the NSM following standard procedures outlined in Ubelaker (1989).

The present monograph does not include the human remains encountered by Raven et al. during their 1989 survey of the Stillwater Wildlife Management Area (Raven, 1990). With the exception of a single burial found eroding out of a sand dune in the western part of the area, all human remains were encountered by Raven and co-workers in the Stillwater marsh and lake region, thus following the same pattern as reported by the NSM and by us. Schmitt (1990) indicated that the human remains observed in 1989 represent a minimum of nine individuals (two juveniles and seven adults). Four individuals (all adults) in varying stages of preservation were encountered at a single site (26CH1661); the other individuals were from different sites. These remains are largely fragmentary and out of their original context. At least two individuals, however, contained skeletal elements in their original burial positions. Although the Intermountain Research survey (Raven, 1990) produced very few human remains, the project established, along with the findings of NSM and HSFS, that prehistoric mortuary activity was largely restricted to the

marsh/lake region of the eastern half of the Stillwater Wildlife Management Area. We note, however, that erosion following the retreat of lakewaters in 1985 was largely restricted to the downstream region of the marsh. It is therefore possible that mortuary activity was present in areas yielding few human remains.

Despite the above-cited caveats of the Stillwater skeletal series, these remains offer an extraordinary opportunity to contribute to an otherwise sparse bioarchaeological record for this region of western North America. In conjunction with the general objectives outlined by Kelly in the preceding chapter on regional and theoretical archaeological questions, the osteological research outlined in this monograph addresses five goals: (1) to provide a description of human remains excavated by the HSFS, (2) to assess the quality of life in the human populations that occupied the Stillwater Marsh, (3) to improve documentation and understanding of population history, (4) to characterize diet in this region and, (5) to identify physical activity patterns in these prehistoric hunter-gatherers in an effort to understand mobility patterns and workload in this region. For a comprehensive review of other aspects of biological anthropology of the prehistoric human remains from the Stillwater Marsh, the reader is referred to the report by Brooks et al. (1988).

CHAPTER 3. THE HUMAN SKELETAL FIELD SURVEY

Clark Spencer Larsen, Katherine F. Russell, and Dale L. Hutchinson

INTRODUCTION AND SURVEY SUMMARY

During the course of the Stillwater Marsh survey, the HSFS located some 35 previously unreported archaeological sites; 5 of these sites contained human remains (table 3-1). In this chapter, we report on the human remains encountered, collected, or otherwise documented by field crews under the supervision of Russell, field director of the survey, during the 6-week period from June 25 to August 9, 1987. We collected these materials on approximately 55 km of eroded shorelines and included human remains encountered on both previously documented sites (by the NSM) as well as the new sites listed in table 3-1. The site locations yielding human remains in the survey are shown in figure 3-1. All of the human remains encountered by the survey are summarized in Appendix A.

Most of the human remains documented by the HSFS were isolated surface finds, whose original positions had been altered because of a combination of erosional forces, primarily water and wind. The positions of these human remains were recorded as to previously identified localities; if remains were not identified prior to our survey, new locality designations were assigned. The specific locality numbers were assigned using the Nevada State Museum temporary numbering system (e.g., locality 1 or L1). Most localities have since been renumbered following the Smithsonian Institution format (e.g., 26CH1043). The site localities are discussed in this monograph in relation to the Smithsonian Trinomial System (STS) numbers (see table 3-2) except in instances where the STS numbers have not been designated for respective localities.

At sites encountered by the HSFS, all isolated human skeletal and dental elements were picked up by crew personnel and subsequently described, cleaned, and numbered by Russell at the CSAP field laboratory in Stillwater, Nevada. Following this initial processing, the remains were taken to the Nevada State Museum Annex in Carson City for temporary curation. In 1988, Larsen and Hutchinson reexamined these materials at the NSM Annex laboratory, verified the original identifications made in the field, revised field identifications where necessary, and provided additional osteological documentation (e.g., sex, age, pathology, measurements).

During the 1987 fieldwork by the HSFS, several burials were encountered in original depositional context that showed varying states of surface exposure. These states of exposure ranged from less than 10% percent to more than 75% of individual skeletons. Immediately following the discovery of an undisturbed burial eroding out of the ground, Kelly notified Anan Raymond, the then-staff archaeologist at the U.S. Fish and Wildlife Service offices (USFWS) in Fallon, Nevada. In keeping with the agreement between the USFWS, the Nevada State Historic Preservation Office, and the Fallon Paiute-Shoshone Tribe (document titled "Memorandum of Understanding on Human Remains"), permission was granted to the HSFS by the USFWS (in consultation with the Tribe) to archaeologically document and remove skeletal individuals that either showed more than 50% exposure or were otherwise threatened at the time of discovery. Burials encountered by the HSFS showing more than 50% exposure or evidence of potential further deterioration from natural forces, vandalism, or other forms of disturbance were recorded and excavated, and the remains were subsequently processed at the field laboratory in Stillwater, Nevada. Before the end of the field season, the remains were taken to the NSM Annex in Carson City for further study. Burials showing less than 50% exposure and judged unthreatened were recorded, but not excavated, by the HSFS. Regardless of whether a newly discovered burial was excavated by the HSFS, it is listed in our descriptions (see Burials). Human remains from the burials excavated by the HSFS were examined in May and June of 1988 by Larsen and Hutchinson, and a description of the remains and their archaeological contexts are presented (see Burials). Only the skeletal re-

TABLE 3-1
HSFS Documented Stillwater Marsh Archaeological Sites

Site	Archaeological remains
L100	Groundstone, flakes, features[a]
L101	Groundstone, flakes, animal bone, shell, features, human remains
L102	Human remains
L103	Flakes, biface fragment, projectile point (corner-notched, convex base, type?), burned rock, animal bone
L104	Flakes, possible midden
L105	Flakes, groundstone
L106	Flakes, groundstone (metate, mano)
L107	Flakes, projectile point ("residual" concave base point)
L108	Groundstone, flakes, human remains
L109	Flakes, mano, metate
L110	Flakes, groundstone, metate, projectile point (type?), blue glass bead, features
L111	Flakes, groundstone, human remains
L112	Flakes, hammerstone
L113	Flakes, shell
L114	Flakes, groundstone, hammerstone
L115	Groundstone, shell, animal bone
L116	Flakes, groundstone, animal bone
L117	Flakes, feature
L118	Flakes, rocks, features
L119	Flakes, rocks, features
L120	Flakes, groundstone, dog cranium, human remains
L121	Flakes, groundstone
L122	Flakes, groundstone
L123	Flakes, groundstone, biface fragment, historic ceramics, cans, bottles
L124	Flakes, obsidian, groundstone, mano, animal bone
L125	Flakes
L126	Flakes, obsidian, groundstone, shell, nearby large, circular feature
L127	Flakes, obsidian, slate, groundstone, animal bone, large features
L128	Flakes, biface, projectile point (Elko corner-notched)
L129	Flakes, groundstone, mano fragment, features
L130	Flakes, groundstone, metate, features
L131	Flakes, groundstone, mano, possible bone fragments
L132	Flakes, groundstone, 2 mano fragments, projectile point (Elko corner-notched)
L133	Flakes, groundstone, animal bone, features
L134	Flakes, groundstone, animal bone, features

[a] Features refer to visible pit outlines.

mains excavated by the HSFS were measured or otherwise included in analyses discussed in this monograph.

In total, the HSFS found 16 burials in their original context. Of these burials, eight (representing 10 individuals) were completely exposed and removed; eight were left in situ. Excluding burial remains exposed by the HSFS, 557 disturbed cranial and postcranial elements (in varying states of preservation) and 122 disturbed teeth (represented by roots only, crowns only, or root/crown elements) were recorded and collected. Among these materials are disturbed remains from burials that were partially exposed by erosion, but were not excavated. The remains excavated in disturbed contexts represent a rough minimum of 85 individuals, including approximately 50 adults and 35 preadults. We estimate that about 100 individuals in total were encountered during the course of HSFS fieldwork in the summer of 1987. Of these remains, skeletal elements that were undisturbed prior to excavation by us were in excellent condition. However, disturbed materials showed various states of deterioration, depending on the time that they had been exposed. Exposed skeletal materials exhibited a characteristic cracking and flaking of bone cortex (fig. 3-2).

Standard osteometric and odontometric observations were made for all human remains excavated by the HSFS. These observations include cranial measurements for nine partial or nearly complete adult crania and mandibles (table 3-3), postcranial measurements for 80 bones representing 16 partial or nearly complete preadult and adult individuals (table 3-4), and dental measurements for 21 individuals represented by 48 deciduous and 117 permanent teeth (tables 3-5, 3-6) using instrumentation and methods outlined by Larsen (1982). Based on external diaphyseal dimensions of available adult long bones (femora, tibiae, humeri), postcranial indices were calculated (table 3-7). Maximum lengths of adult femora and tibiae were used to calculate stature estimates (table 3-7). Finally, listed with dental measurements in tables 3-5 and 3-6 are observations on gross occlusal surface wear for deciduous and permanent teeth, respectively, following wear stages presented by Smith (1984). Because of

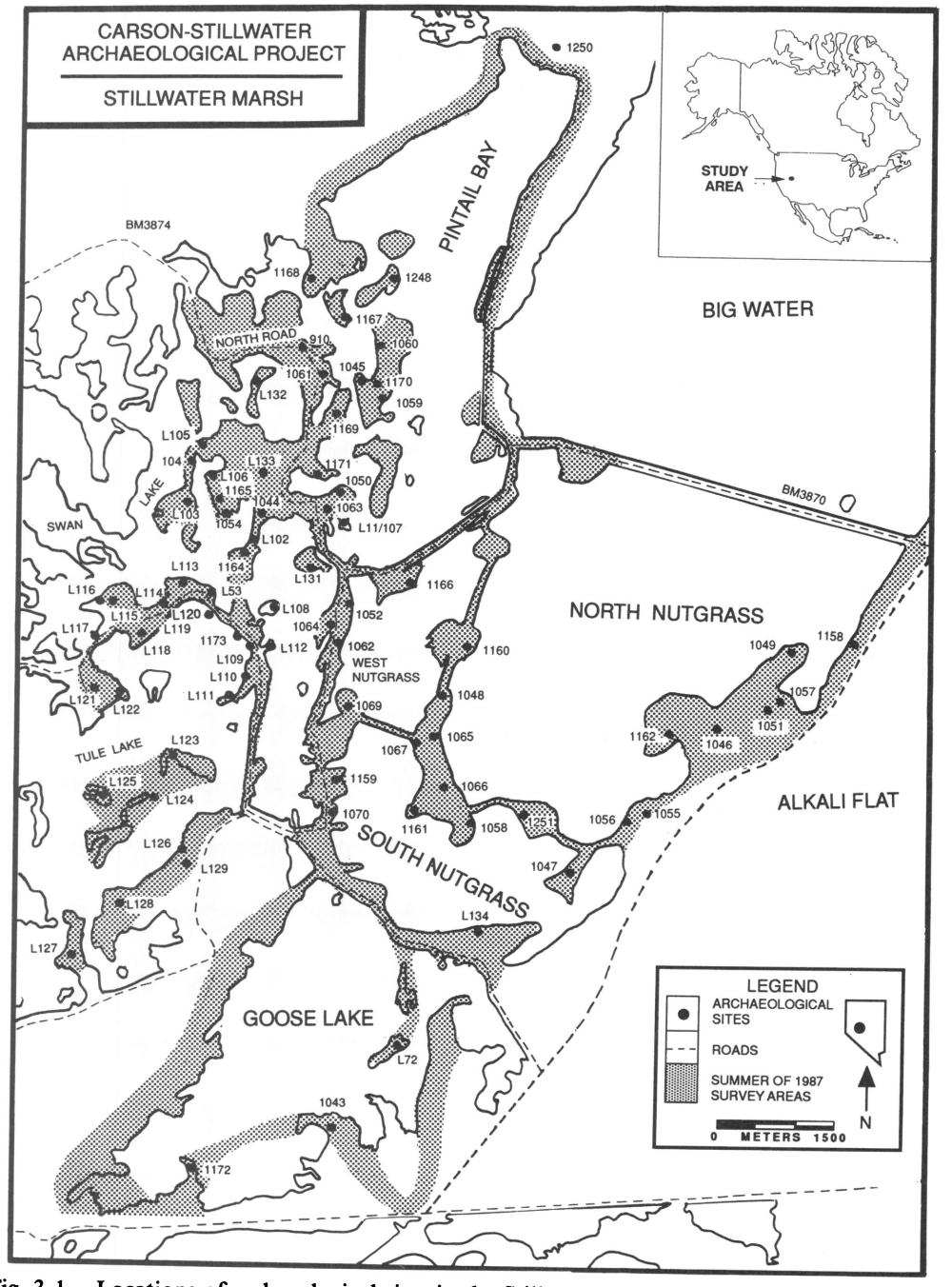

Fig. 3-1. Locations of archaeological sites in the Stillwater Marsh (HSFS documentation only).

the limited size of the anthropometric data set (e.g., cranial and postcranial measurements), we have not attempted to summarize data in a statistical format, except where it seemed appropriate. Summary statistics for the NSM series, which comprises the bulk of the Stillwater Marsh series, are presented in Brooks et al. (1988).

TABLE 3-2
Nevada State Museum Site Locality Numbers and Corresponding Smithsonian Trinomial System Numbers

Smithsonian[a]	Nevada[b]
26CH910	L20
26CH1043	L1
26CH1044	L2
26CH1045	L3
26CH1046	L4
26CH1047	L5
26CH1048	L6
26CH1049	L7
26CH1050	L8
26CH1051	L9
26CH1052	L10
26CH1054	L12
26CH1055	L13
26CH1056	L14
26CH1057	L15
26CH1058	L16
26CH1059	L17
26CH1060	L18
26CH1061	L19
26CH1062	L21
26CH1063	L22
26CH1064	L23
26CH1065	L24
26CH1066	L25
26CH1067	L26
26CH1068	L27
26CH1069	L28
26CH1070	L29
26CH1071	L30
26CH1158	L51
26CH1159	L52
26CH1160	L54
26CH1161	L55
26CH1162	L56
26CH1163	L58
26CH1164	L59
26CH1165	L60
26CH1167	L63
26CH1168	L64
26CH1169	L65
26CH1170	L66
26CH1171	L67
26CH1172	L73
26CH1173	L101
26CH1247	L57
26CH1248	L62
26CH1249	L68
26CH1250	L69
26CH1251	L74
na[c]	L11
na	L53
na	L72
na	L100
na	L102
na	L108
na	L111
na	L120
na	L133

TABLE 3-2—(*Continued*)

[a] Smithsonian trinomial system number.
[b] Nevada State Museum locality number.
[c] Not available.

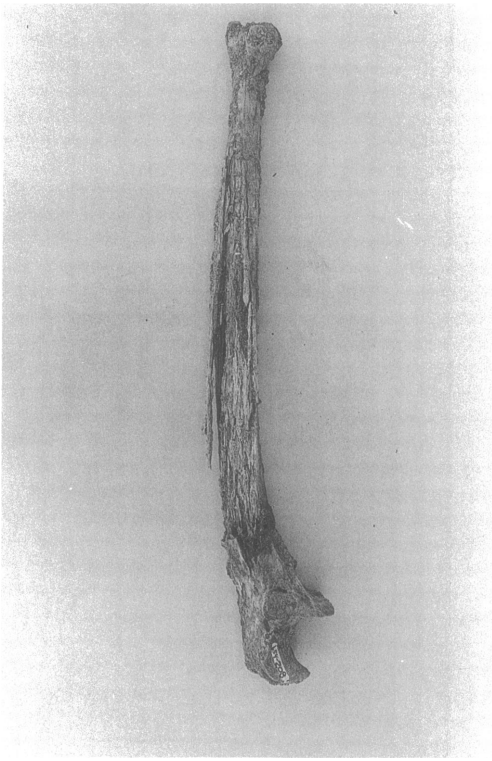

Fig. 3-2. Cracking and flaking of exposed human bone. This specimen (1160-200), an adult ulna, shows modifications that are typical of bones that have been subjected to long-term surface exposure in the Stillwater Marsh.

TABLE 3-3
HSFS Cranial Measurements

Measurement	Burial/specimen								
	910-201	1070-1/1	1159-200	1160-203	1160-212	L72-200	1173-200	L102-200	L111-200
Face—masticatory complex									
Mass. origin lt.	—	—	—	—	—	36.7	36.4	—	—
Zyg. arch th.	—	—	—	—	—	21.4	31.8	—	21.7
Cheek ht.	—	—	—	—	—	24.9	25.5	—	21.2
Biorbital br.	—	—	—	—	—	(94.5)[b]	—	—	82.7
Orbital br.	—	—	—	—	—	39.1	—	—	34.0
Orbital ht.	—	—	—	—	—	33.5	—	—	—
Temporalis lt.	—	—	164.0	—	—	130.4	—	—	—
Temporalis ht.	—	—	—	—	—	94.1	—	—	—
Bizygomatic br.	—	—	—	—	—	(132)	—	—	—
Minimum frontal br.	—	—	—	—	—	94.0	95.9	—	84.0
Frontal chord	—	—	115.2	—	—	109.2	108.9	—	—
Frontal arc	—	—	131	—	—	127	122	—	—
Mandible									
Bicondylar br.	—	—	(124.0)	—	22.7	—	—	—	93.2
Condylar br.	—	15.8	24.1	—	—	21.5	—	—	16.8
Bigonial br.	98.8	—	96.5	—	—	—	—	—	—
Asc. ramus ht. cor.	—	49.3	70.2	—	—	—	59.3	—	51.5
Asc. ramus ht. con.	—	44.5	66.7	—	65.8	—	59.1	—	42.5
Asc. ramus br.	37.5	30.2	35.4	—	38.4	37.4	36.7	—	—
Symphysis ht.	32.3	—	—	—	30.0	—	30.3	—	28.7
Symphysis thick.	18.6	11.9	—	—	15.9	—	15.0	—	17.1
Mand lt.	—	81	—	—	—	—	—	—	—
Vault									
Parietal chord	—	—	103.5	114.6	—	107.4	111.5	—	107.6
Occipital chord	—	—	—	—	—	93.0	—	—	—
Lambda-inion chord	—	—	75.3	60.1	—	62.7	—	69.4	—
Inion-opisthion chord	—	—	—	—	—	40.1	—	—	—
Biasterionic chord	—	—	104.0	—	—	112.5	—	—	—
Parietal arc	—	—	115	127	—	—	126	—	121
Occipital arc	—	—	—	—	—	124	—	—	—
Lambda-inion arc	—	—	81	—	—	72	—	79	—
Inion-opisthion arc	—	—	—	—	—	39	—	—	—
Biasterionic arc	—	—	126	—	—	130	—	—	—
Bregma-inion	—	—	152	155	—	142	—	—	—
Bregma-opisthion	—	—	—	—	—	144	—	—	—
Lambda-basion	—	—	—	—	—	131.0	—	—	—
Nasion-lambda	—	—	178	—	—	171	—	—	—
Nasion-opisthion	—	—	—	—	—	134	—	—	—
Cranial ht.	—	—	—	—	—	132	—	—	—
Maximum lt.	—	—	186	—	—	176	176	—	—
Maximum br.	—	—	(139)	—	—	138	—	—	—
Biauricular br.	—	—	—	—	—	127	—	—	—

[a] Measurements taken following procedures outlined by Larsen (1982); measurements in mm.
[b] Parentheses denote measurement estimate.

TABLE 3-4
HSFS Postcranial Measurements

Measurement[a]	Burial/specimen															
	910-201	910-208	910-211	1062-201	1062-214	1064-200	1065-205	1159-200	L72-200	1173-200	1173-202	1173-204	1173-210	L108-200	L111-200	L120-200
Left femur																
Head diam.	–	–	–	–	–	–	40.8	43.5	40.5	–	–	–	–	–	–	–
Vertical diam., neck	–	–	–	–	–	26.4	28.6	30.1	26.4	–	–	–	–	–	–	–
Horiz. diam., neck	–	–	–	–	–	21.9	21.6	23.7	22.8	–	–	–	–	–	–	–
Maximum length	–	–	126	–	–	327	430	447	412	(390)[b]	–	(315)	–	–	–	–
A-P diam., midsh.	–	–	9.5	–	–	21.3	24.2	28.6	25.6	24.7	–	–	–	–	–	–
M-L diam., midsh.	–	–	11.5	–	–	21.1	26.3	27.5	24.7	24.7	–	–	–	–	–	–
Circum. midsh.	–	–	34	–	–	69	80	90	78	79	–	–	–	–	–	–
A-P diam., subtr.	–	–	10.5	–	–	20.1	24.3	25.5	21.3	20.6	–	–	–	–	–	–
M-L diam., subtr.	–	–	14.3	–	–	27.2	26.0	35.8	30.4	32.4	–	–	–	–	–	–
Bicondylar br.	–	–	–	–	–	–	–	74.5	71.1	–	–	–	–	–	–	–
Right femur																
Head diam.	–	–	–	–	–	–	–	44.0	39.9	–	–	–	–	–	–	–
Vertical diam., neck	–	–	–	–	–	25.7	–	31.2	25.5	–	–	–	–	–	–	–
Horiz. diam., neck	–	–	–	–	–	21.6	–	27.1	23.3	–	–	–	–	–	–	–
Maximum length	–	–	(126)	–	–	320	–	–	412	(390)	–	(315)	–	–	–	(430)
A-P diam., midsh.	–	–	9.9	–	–	22.4	–	–	24.9	25.5	–	–	–	–	–	–
M-L diam., midsh.	–	–	10.8	–	–	21.7	–	–	23.8	24.1	–	–	–	–	–	–
Circum., midsh.	–	–	34	–	–	68	–	–	77	78	–	–	–	–	–	–
A-P diam., subtr.	–	–	10.9	–	–	21.1	–	–	22.3	20.1	–	–	–	–	–	–
M-L diam., subtr.	–	–	14.5	–	–	27.0	–	–	30.2	32.0	–	–	–	–	–	31.0
Bicondylar br.	–	–	–	–	–	–	–	–	71.8	–	–	–	–	–	–	–
Left tibia																
Maximum length	358	–	–	–	–	278	–	(354)	349	(345)	–	–	–	–	–	–
A-P diam., midsh.	28.5	–	–	–	–	23.2	–	–	26.5	26.8	–	–	–	–	–	–
M-L diam., midsh.	21.5	–	–	–	–	18.3	–	–	18.6	18.5	–	–	–	–	–	–
Circum., midsh.	81	–	–	–	–	66	–	–	71	76	–	–	–	–	–	–

TABLE 3-4—(*Continued*)

Measurement[a]	Burial/specimen															
	910-201	910-208	910-211	1062-201	1062-214	1064-200	1065-205	1159-200	L72-200	1173-200	1173-202	1173-204	1173-210	L108-200	L111-200	L120-200
Right tibia																
Maximum length	–	(115)	105	–	–	274	–	–	349	345	–	–	(345)	–	–	(360)
A-P diam., midsh.	–	13.2	10.9	–	–	23.7	–	–	27.1	26.3	–	–	–	–	–	–
M-L diam., midsh.	–	9.8	9.6	–	–	18.0	–	–	19.2	18.5	–	–	–	–	–	–
Circum., midsh.	–	37	36	–	–	66	–	–	72	73	–	–	–	–	–	–
Left fibula																
Maximum length	–	–	102	–	–	268	–	–	339	–	–	–	–	–	–	–
Right fibula																
Maximum length	–	–	–	–	–	270	–	–	344	–	–	–	–	–	–	–
Left clavicle																
Maximum length	–	–	62	–	–	114	–	(155)	152	–	129	–	–	55	–	–
Right clavicle																
Maximum length	–	–	–	–	–	114	–	(155)	152	–	–	–	–	56	–	–
Left ulna																
Maximum length	–	–	–	–	–	193	–	288	254	(246)	–	–	–	–	–	–
Right ulna																
Maximum length	–	–	–	–	–	197	–	(288)	258	246	–	–	–	86	–	–
Left radius																
Maximum length	–	–	(75)	(278)	–	176	–	(266)	232	(222)	–	–	–	–	(160)	–
Head diam.	–	–	–	25.4	–	–	–	22.9	20.8	–	–	–	–	–	–	–
Interos. crest max.	–	–	6.9	17.4	–	12.7	–	16.9	13.4	13.1	–	–	–	6.9	10.6	–
Interos. crest min.	–	–	5.5	12.4	–	8.8	–	12.0	10.2	9.0	–	–	–	5.5	7.5	–
Right radius																
Maximum length	–	–	–	–	–	175	–	(266)	234	(222)	–	–	–	75	(160)	–
Head diam.	–	–	–	–	–	–	–	23.4	20.9	19.8	–	–	–	–	–	–

TABLE 3-4—(*Continued*)

Measurement[a]	Burial/specimen															
	910-201	910-208	910-211	1062-201	1062-214	1064-200	1065-205	1159-200	L72-200	1173-200	1173-202	1173-204	1173-210	L108-200	L111-200	L120-200
Interos. crest max.	—	—	—	—	—	12.9	—	15.8	15.1	13.6	—	—	—	6.8	—	—
Interos. crest min.	—	—	—	—	—	9.2	—	12.7	10.1	9.1	—	—	—	5.3	—	—
Left humerus																
Maximum length	—	—	—	—	62	230	—	324	—	—	—	—	—	—	(185)	—
Maximum diam., midsh.	—	—	—	—	5.9	16.6	—	22.8	20.9	—	—	—	—	—	14.2	—
Minimum diam., midsh.	—	—	—	—	5.5	12.9	—	16.7	13.2	—	—	—	—	—	10.7	—
Circum., midsh.	—	—	—	—	—	48	—	65	59	—	—	—	—	—	41	—
Head diam.	—	—	—	—	—	—	—	41.4	37.5	—	—	—	—	—	—	—
Biepicondylar br.	—	—	—	—	—	43.5	—	59.0	54.2	—	—	—	—	—	—	—
Right humerus																
Maximum length	—	—	—	—	—	234	—	—	305	(265)	—	—	—	94	—	—
Maximum diam., midsh.	—	—	—	—	—	16.1	—	23.8	20.7	20.0	—	—	—	9.5	—	—
Minimum diam., midsh.	—	—	—	—	—	14.0	—	16.4	13.0	13.7	—	—	—	8.0	—	—
Circum., midsh.	—	—	—	—	—	50	—	72	59	58	—	—	—	29	—	—
Head diam.	—	—	—	—	—	—	—	42.1	39.8	—	—	—	—	—	—	—
Biepicondylar br.	—	—	—	—	—	43.5	—	59.6	54.1	—	—	—	—	—	—	—
Left ilium																
Maximum length	—	—	55.4	—	—	(111.0)	—	—	—	—	—	—	—	52.0	—	—
Right ilium																
Maximum length	—	—	54.0	—	—	—	—	—	—	—	—	—	—	54.0	—	—

[a] Measurements taken following procedures outlined by Larsen (1982); measurements in mm.
[b] Parentheses denote measurement estimates.

BURIALS

Eight burials were excavated by the HSFS. These burials are described below (see table 3-8). (Bone numbers are indicated by site number without state and county abbreviations [26CH] followed by bone number.)

1058-211: The skull, feet, and associated bone fragments of this individual were partially or completely exposed at the time of discovery. This individual was interred in an extremely shallow, oval-shaped pit 69 cm long, 45 cm wide, and 6 cm in maximum depth. The pit outline, although visible, was poorly defined. (Pit depths for this and other burials reflect the depth at the time of archaeological excavation. Because the pits were exposed by flooding, they were all deeper by an unknown amount at the time of burial.) The soil matrix in the burial pit was only slightly darker than the surrounding, undisturbed matrix. A soil sample of pit fill immediately adjacent to the individual was collected during the exposure of the skeleton. One rib fragment was submitted for carbon and nitrogen isotopic analysis (see Schoeninger, this volume).

The legs of this fully articulated individual were resting in a tightly flexed posture on their left sides; the axial skeleton was mostly prone, but tilted slightly to the left side (fig. 3-3). The skull faced south, and the top of the cranium (bregma) was oriented toward the northeast. There were no artifacts excavated with this individual, but mussel shell fragments, several small fragments of unidentifiable animal bones, and nonartifactual stones were included in the burial matrix. During the initial process of clearing the surface area around the burial, the top of a cranium of a second individual, an older adolescent or adult, was encountered immediately to the west (1058-215). Because this second individual was not threatened by further erosion or other apparent destructive processes, it was not excavated. The bones of 1058-211 are in generally very good condition, but some are slightly to moderately crushed, including the cranium and many of the major long bones.

Dental development shows the following characteristics: (1) erupted and slightly worn maxillary and mandibular permanent first molars, (2) all other permanent teeth unerupted, (3) permanent maxillary and mandibular first and second incisors with half to three-fourths of roots formed, (4) permanent maxillary right third molar crown initial formation, and (5) the deciduous canines, first molars, and second molars (maxillary and mandibular) with moderate wear. Stage of dental development indicates that the individual was approximately 7.5 years old at death (Ubelaker, 1989). Because of the young age of the individual, sex identification is not possible.

The following skeletal elements are present: nearly complete cranium and mandible; partial dentition (permanent maxillary left first incisor through first molar, right first incisor through first molar, right third molar, mandibular left first incisor through second molar, right first incisor through second molar; deciduous maxillary left first incisor through second molar, right second incisor through second molar, mandibular left canine through second molar, right canine through second molar). The postcranial skeleton is represented by the following elements: partial left ilium, left ischium, partial left and right pubes, left and right clavicles, scapulae, radii, ulnae, femora, tibiae, left fibula, left and right calcanea, tali, left navicular, left first, second, and third cuneiforms, metatarsal diaphyses (8), most ribs, and partial cervical and thoracic vertebrae.

The only skeletal pathology observed included very slight cribra orbitalia. Dental pathology is limited to the presence of hypoplasias on the permanent maxillary right first incisor and permanent mandibular right first incisor.

910-211: The skull and major long bones of this individual were discovered resting on the ground surface in a clear burial context. However, when first encountered by the HSFS, the positions of cranial bones, both arms, and the right leg had been substantially altered from water action. The pit outline was impossible to identify because very little of the pit fill was preserved. Therefore, it was not possible to record dimensions for the burial pit outline. The remaining pit fill measured only 2 to 3 cm in depth and was darker than the surrounding, undisturbed matrix outside of the burial feature. Beneath the

TABLE 3-5
HSFS Deciduous Dentition Measurements and Wear

		Burial/specimen								
Observation[a]		1048-210	1058-211	1060-200	910-202	910-211	1062-209	1070-1/1	L108-200	L111-200
Mandible, left										
dI1	B	–	–	–	–	–	–	–	3.8	–
	W	–	–	–	–	–	–	–	1	–
dI2	B	–	–	–	–	–	–	–	3.9	–
	W	–	–	–	–	–	–	–	1	–
dC	L	–	6.4	–	–	–	–	–	–	–
	B	–	5.5	–	–	–	–	–	–	–
	W	–	4	–	–	–	–	–	–	–
dM1	L	–	8.9	8.1	–	–	–	8.7	–	–
	B	–	7.6	7.2	–	–	–	7.4	–	–
	W	4	4	2	–	–	–	4	–	–
dM2	L	10.9	11.1	–	–	–	–	9.8	–	–
	B	8.8	9.7	–	–	–	–	–	–	–
	W	3	4	2	–	–	–	4	–	7
Mandible, right										
dI1	B	–	–	–	–	–	–	–	3.7	–
	W	–	–	–	–	–	–	–	1	–
dI2	B	–	–	–	–	–	–	–	–	–
	W	–	–	–	–	–	–	–	–	–
dC	L	–	6.7	6.5	–	–	–	–	5.9	–
	B	–	5.5	5.4	–	–	–	–	4.8	–
	W	–	2	2	–	–	–	–	1	–
dM1	L	–	9.3	8.6	–	–	9.0	–	–	–
	B	–	7.4	7.4	–	–	7.5	–	–	–
	W	4	5	2	–	–	2	–	–	–
dM2	L	–	11.7	–	–	–	10.9	–	–	–
	B	8.8	9.5	–	–	–	9.0	–	–	–
	W	3	4	2	–	–	2	–	–	7
Maxilla, left										
dI1	B	–	5.3	–	5.6	–	–	–	–	–
	W	–	2	–	1	–	–	–	–	–
dI2	B	–	4.9	4.6	–	–	–	–	–	–
	W	–	2	3	–	–	–	–	–	–
dC	L	–	7.4	7.2	–	–	–	–	–	–
	B	–	6.4	6.2	–	–	–	–	–	–
	W	–	2	2	–	–	–	–	–	–
dM1	L	–	8.0	7.2	–	–	–	–	–	–
	B	–	9.1	8.9	–	–	–	–	–	–
	W	–	4	2	–	–	–	–	–	–
dM2	L	–	9.7	9.4	–	–	–	–	8.7	–
	B	–	10.7	10.6	–	–	–	–	9.5	10.2
	W	–	4	2	–	–	–	–	1	7
Maxilla, right										
dI1	B	–	–	–	–	4.7	–	–	–	–
	W	–	–	–	–	2	–	–	–	–
dI2	B	–	4.8	–	5.4	4.8	–	–	–	–
	W	–	2	–	1	2	–	–	–	–
dC	L	–	7.4	–	7.5	–	–	–	–	–
	B	–	6.1	–	6.3	–	–	–	–	–
	W	–	–	–	1	–	–	–	–	5

TABLE 3-5—(*Continued*)

Observation[a]		Burial/specimen								
		1048-210	1058-211	1060-200	910-202	910-211	1062-209	1070-1/1	L108-200	L111-200
dM1	L	–	8.0	–	–	–	–	–	–	–
	B	–	9.2	–	–	8.5	–	–	–	–
	W	–	5	–	–	1	–	–	–	–
dM2	L	–	9.7	–	–	–	–	–	–	–
	B	–	10.5	–	–	–	–	–	–	–
	W	–	4	–	–	–	–	–	–	7

[a] L = length and B = Breadth (measurements in mm taken following procedures outlined by Larsen [1982]); W = wear stage (observations following Smith [1984]): for incisors/canines, 1 = unworn to polish or small facets with no dentin exposure; 2 = hairline of dentin exposure; 3 = dentin line of distinct thickness; 4 = moderate dentin exposure; 5 = large dentin area with enamel rim complete; 6 = large dentin area with enamel rim lost on one side; 7 = enamel rim lost completely; 8 = severe loss of crown height; for premolars, 1 = unworn to polish or small facets with no dentin exposure; 2 = modern cusp removal involving blunting of cusps; 3 = full cusp removal and/or moderate dentin patches; 4 = at least one large dentin exposure on one cusp; 5 = two large dentin exposures with possible slight coalescence; 6 = coalescence of dentin exposures, but enamel rim still complete; 7 = full dentin exposure, with loss of enamel rim on at least one side; 8 = severe loss of crown height; for molars, 1 = unworn to polish or small facets with no dentin exposure; 2 = moderate cusp removal with blunting of cusps; 3 = full cusp removal and/or some dentin exposure that is pinpoint to moderate; 4 = several large dentin exposures that are still discrete; 5 = two dentinal areas coalesced; 6 = three dentinal areas coalesced or four dentinal areas coalesced with enamel island; 7 = dentin exposed on entire occlusal surface; 8 = severe loss of crown height).

burial pit, probable midden matrix was encountered. Thus, this burial may have been intrusive into an earlier midden deposit. A soil sample of pit fill was collected during excavation, and a charcoal sample from pit fill was collected for radiocarbon assay. In addition, a rib fragment was submitted for carbon and nitrogen isotopic analysis (see Schoeninger, this volume).

The head of this partially articulated individual was oriented toward the northwest. The skeleton was in an extended position, mostly prone, and the left leg was crossed under the right leg (fig. 3-4). There were no associated grave objects encountered in this burial, but stone fragments were included in the burial matrix and stone flakes were located immediately to the northwest of the cranium. The latter were probably part of the associated midden deposit in the site. The remains of this individual are in fair to good condition.

Dental development shows the following characteristics: (1) permanent maxillary right first molar with initial crown formation, (2) deciduous maxillary right first and second incisors in occlusion with very slight occlusal wear, (3) unerupted maxillary right canine, (4) maxillary right first molar not quite in functional occlusion, and (5) unerupted maxillary right second molar. This stage of development corresponds with age 1.5 years (Ubelaker, 1989). The young age of the individual precludes identification of sex.

The skeletal elements present in this individual include a right zygoma fragment, right maxilla (with permanent maxillary right first molar), left and right ilia, ischia, pubes, left clavicle, partial left scapula, right radius missing proximal one-third, left and right femora, left tibia, left fibula, left and right calcanea, tali, right navicular, unidentified tarsals (2), metatarsals (5 diaphyses, including 1 first), terminal foot phalanges (3), left lunate, metacarpals (5 diaphyses, including 1 first), proximal hand phalanges (3), intermediate hand phalanges (2), left and right rib fragments, thoracic vertebrae (4 neural arch segments), and miscellaneous vertebrae (23 bodies, 5 body fragments, 14 neural arch halves, 10 neural arch fragments, 2 fragments).

1064-200: This burial was first identified when a scatter of disarticulated bone in association with a pit outline was encountered by the HSFS. Some bones in articulation, including vertebrae and tops of other skeletal elements, were observed in this exposure.

TABLE 3-6
HSFS Permanent Dentition Measurements and Wear

Observations[a]		1043-201	1048-201	1048-218	1058-211	910-201	910-203	1062-205	1064-200	1064-206	1070-1/1	1159-200	1160-212	L72-200	1173-200	L111-200
Mandible, left																
I1	B	–	–	–	6.0	–	–	–	–	–	–	–	–	–	5.3	–
	W	–	–	–	1	7	–	–	–	–	–	6	7	–	5	–
I2	B	–	–	–	–	–	–	6.3	–	–	–	–	–	–	5.8	–
	W	–	–	–	–	7	–	3	–	–	–	6	7	–	4	–
C	L	–	–	–	–	–	–	–	–	–	–	–	–	–	–	6.8
	B	–	–	–	–	–	–	–	–	–	–	–	–	–	–	6.7
	W	–	–	–	–	7	–	–	–	–	–	6	7	–	–	2
PM3	L	–	–	–	–	–	–	–	–	–	–	–	–	–	6.9	6.8
	B	–	–	–	–	–	–	–	–	–	–	–	–	–	7.2	7.1
	W	–	–	–	–	7	–	–	–	–	–	6	7	–	4	–
PM4	L	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	B	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	W	–	–	–	–	7	–	–	–	–	–	–	7	–	–	–
M1	L	–	–	–	11.9	–	–	–	–	–	12.5	–	–	–	10.6	11.6
	B	–	–	–	11.2	–	–	–	–	–	10.8	–	–	–	10.6	10.8
	W	–	–	–	2	7	–	–	–	–	2	–	7	–	7	3
M2	L	–	–	–	–	–	–	–	–	–	–	–	–	–	11.1	10.6
	B	–	–	–	–	–	–	–	–	–	–	–	–	–	9.9	9.8
	W	–	–	–	–	6	–	–	–	–	–	–	7	–	5	2
M3	L	–	–	–	–	–	–	–	–	–	–	–	–	–	10.3	–
	B	–	–	–	–	–	–	–	–	–	–	–	–	–	9.3	–
	W	–	–	–	–	–	–	–	–	–	–	–	6	–	2	–
Mandible, right																
I1	B	–	–	–	6.4	–	–	–	–	–	–	–	–	–	5.5	–
	W	–	–	–	1	–	–	–	–	–	–	6	7	–	5	–
I2	B	–	–	–	6.1	–	–	–	–	–	–	–	–	–	5.7	–
	W	–	–	–	1	7	8	–	–	–	–	6	7	–	4	–
C	L	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	B	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	W	–	–	–	–	7	8	–	–	–	–	6	7	–	–	–
PM3	L	–	–	–	–	–	–	–	–	–	–	–	–	–	6.8	–
	B	–	–	–	–	–	–	–	–	–	–	–	–	–	7.1	–
	W	–	–	–	–	7	8	–	–	–	–	6	7	7	4	–
PM4	L	–	–	–	–	–	–	–	–	–	–	–	–	–	6.5	–
	B	–	–	–	–	–	–	–	–	–	–	–	–	–	7.1	–
	W	–	–	–	–	7	–	–	–	–	–	–	7	7	4	–
M1	L	–	–	–	12.1	–	–	–	–	–	–	–	–	–	10.6	11.6
	B	–	–	–	11.4	–	–	–	–	–	–	–	–	–	10.6	11.1
	W	–	–	–	2	7	–	–	–	–	–	–	7	7	6	4
M2	L	11.7	–	–	–	–	–	–	–	–	–	–	–	–	10.6	9.9
	B	–	–	–	–	–	–	–	–	–	–	–	–	–	9.8	9.8
	W	6	–	–	–	6	–	–	–	–	6	–	7	7	4	2
M3	L	10.4	–	–	–	–	–	–	–	–	–	–	–	–	10.1	–
	B	10.2	–	–	–	–	–	–	–	–	–	–	–	9.6	9.2	–
	W	3	–	–	–	–	–	–	–	–	–	–	6	6	2	–
Maxilla, left																
I1	B	–	–	–	–	–	–	7.6	–	–	–	–	–	–	6.8	6.9
	W	–	–	–	–	–	–	2	–	–	–	6	–	–	4	2
I2	B	–	–	–	–	–	–	–	–	–	–	–	–	–	6.7	6.4
	W	–	–	–	–	–	–	–	–	–	–	6	–	–	4	2
C	L	–	–	–	–	–	–	–	8.5	–	–	–	–	–	–	–

TABLE 3-6—(*Continued*)

Observations[a]		1043-201	1048-201	1048-218	1058-211	910-201	910-203	1062-205	1064-200	1064-206	1070-1/1	1159-200	1160-212	L72-200	1173-200	L111-200
	B	—	—	—	—	—	—	—	8.2	—	—	—	—	—	—	—
	W	—	—	—	—	—	—	—	1	—	—	6	—	—	—	—
PM3	L	—	—	—	—	—	—	—	—	—	—	—	—	—	6.2	7.7
	B	—	—	—	—	—	—	—	—	—	—	—	—	—	—	9.6
	W	—	—	—	—	—	—	—	—	—	—	6	—	—	7	1
PM4	L	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	B	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	W	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
M1	L	—	—	10.3	—	—	—	—	—	—	—	—	—	—	10.4	10.0
	B	—	—	12.1	—	—	—	—	—	—	—	—	—	—	—	11.6
	W	—	—	2	—	—	—	—	—	—	—	—	—	—	6	3
M2	L	—	—	—	—	—	—	—	—	—	—	—	—	—	—	9.1
	B	—	—	—	—	—	—	—	—	—	—	—	—	—	10.1	10.8
	W	—	—	—	—	—	—	—	—	—	—	—	—	—	5	1
M3	L	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	B	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	W	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Maxilla, right																
I1	B	—	—	7.7	—	—	—	—	—	—	—	—	—	—	6.2	7.0
	W	—	—	—	—	—	—	—	—	—	—	6	—	—	4	2
I2	B	—	—	—	—	—	—	—	—	—	—	—	—	—	6.3	6.1
	W	—	—	—	—	—	—	2	—	—	—	6	—	—	4	2
C	L	—	8.3	—	—	—	—	—	—	—	—	—	—	—	—	—
	B	—	8.7	—	—	—	—	—	—	—	—	—	—	—	—	—
	W	—	2	—	—	—	—	—	—	—	—	6	—	—	—	—
PM3	L	6.6	7.4	—	—	—	—	—	—	—	—	—	—	—	—	7.4
	B	9.7	9.7	—	—	—	—	—	—	—	—	—	—	—	—	9.0
	W	2	3	—	—	—	—	—	—	—	—	6	—	—	—	2
PM3	L	6.2	6.8	—	—	—	—	—	—	—	—	—	—	—	7.3	—
	B	9.1	—	—	—	—	—	—	—	—	—	—	—	—	9.4	—
	W	2	3	—	—	—	—	—	—	—	—	—	—	7	4	—
M1	L	9.9	—	11.4	—	—	—	—	—	—	—	—	—	—	10.1	10.2
	B	—	—	12.3	—	—	—	—	—	—	—	—	—	—	11.3	11.7
	W	5	5	2	—	—	—	—	—	—	—	—	—	7	6	3
M2	L	—	—	—	—	—	—	—	—	—	—	—	—	—	9.5	9.0
	B	—	—	—	—	—	—	—	—	—	—	—	—	—	10.9	10.6
	W	—	4	—	—	—	—	—	—	—	—	—	—	7	4	2
M3	L	—	—	—	—	—	—	—	—	—	—	—	—	—	7.8	—
	B	—	—	—	—	—	—	—	—	—	—	—	—	—	8.9	—
	W	—	—	—	—	—	—	—	—	—	—	—	—	—	2	—

[a] L = length and B = breadth (measurements in mm taken following procedures outlined by Larsen [1982]); W = wear stage (observations following Smith [1984]): for incisors/canines, 1 = unworn to polish or small facets with no dentin exposure; 2 = hairline of dentin exposure; 3 = dentin line of distinct thickness; 4 = moderate dentin exposure; 5 = large dentin area with enamel rim complete; 6 = large dentin area with enamel rim lost on one side; 7 = enamel rim lost completely; 8 = severe loss of crown height; for premolars, 1 = unworn to polish or small facets with no dentin exposure; 2 = modern cusp removal involving blunting of cusps; 3 = full cusp removal and/or moderate dentin patches; 4 = at least one large dentin exposure on one cusp; 5 = two large dentin exposures with possible slight coalescence; 6 = coalescence of dentin exposures, but enamel rim still complete; 7 = full dentin exposure, with loss of enamel rim on at least one side; 8 = severe loss of crown height: for molars, 1 = unworn to polish or small facets with no dentin exposure; 2 = moderate cusp removal with blunting of cusps; 3 = full cusp removal and/or some dentin exposure that is pinpoint to moderate; 4 = several large dentin exposures that are still discrete; 5 = two dentinal areas coalesced; 6 = three dentinal areas coalesced or four dentinal areas coalesced with enamel island; 7 = dentin exposed on entire occlusal surface; 8 = severe loss of crown height).

TABLE 3-7
HSFS Postcranial Indices and Stature Estimates

Specimen/ burial	Index value[a]	Stature estimate[b]
910-201	75.4 (L. tibia midshaft)	–
	22.6 (L. tibia robusticity)	
1065-205	93.5 (L. femur platymeric)	161.0 ± 3.8 (L. femur)
	108.7 (L. femur midshaft)	
	18.6 (L. femur robusticity)	
1159-200	71.2 (L. femur platymeric)	165.5 ± 3.8 (L. femur)
	96.2 (L. femur midshaft)	160.1 ± 3.5 (L. tibia)
	20.1 (L. femur robusticity)	
	73.2 (L. humerus midshaft)	
	20.1 (L. humerus robusticity)	
	68.9 (R. humerus midshaft)	
L72-200	70.1 (L. femur platymeric)	156.5 ± 3.8 (L. femur)
	96.5 (L. femur midshaft)	156.5 ± 3.8 (R. femur)
	18.9 (L. femur robusticity)	158.7 ± 3.5 (L. tibia)
	73.8 (R. femur platymeric)	158.7 ± 3.5 (R. tibia)
	95.6 (R. femur midshaft)	
	18.7 (R. femur robusticity)	
	70.2 (L. tibia midshaft)	
	20.3 (L. tibia robusticity)	
	70.9 (R. tibia midshaft)	
	20.6 (R. tibia robusticity)	
	63.2 (L. humerus midshaft)	
	62.8 (R. humerus midshaft)	
	19.3 (R. humerus robusticity)	
1173-200	63.6 (L. femur platymeric)	150.8 ± 3.8 (L. femur)
	100.0 (L. femur midshaft)	150.8 ± 3.8 (R. femur)
	20.3 (L. femur robusticity)	157.6 ± 3.5 (L. tibia)
	62.8 (R. femur platymeric)	157.6 ± 3.5 (R. tibia)
	94.5 (R. femur midshaft)	
	20.0 (R. femur robusticity)	
	69.0 (L. tibia midshaft)	
	22.0 (L. tibia robusticity)	
	70.3 (R. tibia midshaft)	
	21.2 (R. tibia robusticity)	
	68.5 (R. humerus midshaft)	
	21.9 (R. humerus robusticity)	
1173-210	–	161.4 ± 2.8 (R. tibia)
L120-200	–	161.1 ± 3.8 (R. femur)
		161.7 ± 3.5 (R. tibia)

[a] Indices calculated by following formulas: femur platymeric = (subtr. a-p diam. × 100)/subtr. m-l diam.; femur midshaft = (midsh. m-l diam. × 100)/midsh. a-p diam.; femur robusticity = (midsh. circum. × 100)/max. length; tibia midshaft = (midsh. m-l diam. × 100)/midsh. a-p diam.; tibia robusticity = (midsh. circum. × 100)/max. length; humerus midshaft = (midsh. min. diam. × 100)/midsh. max. diam.; and humerus robusticity = (midsh. circum. × 100)/max. length.

[b] Stature estimates calculated by formulas for femur and tibia provided by Genovés (1967); estimates are in centimeters.

Unlike some burial pits, the pit outline associated with this burial was very clearly defined. This oval-shaped pit was approximately 79 cm long and 49 cm wide. The pit fill continued for approximately 3 cm below the skeleton and contained considerably darker fill than the surrounding nonburial matrix. Unintentional burial pit inclusions

TABLE 3-8
HSFS Burial Summary

Burial	Age	Sex[a]	Position	Context	Pathology
1058-211	7.5 years	I	Flexed	Primary	Cribra orbitalia
910-211	1.5 years	I	Extended	Primary	None
1064-200	9 years	I	Flexed	Primary	None
1064-201A	Adult	I	?	Primary/secondary	None
1064-201B	Preadult	I	?	Primary	None
1159-200	45–50 years	F	Flexed	Primary	Premortem tooth loss; infection; osteoarthritis; Schmorl's; compression fracture vertebra
L72-200	30–40 years	F	Flexed	Primary	Osteoporosis?; osteoarthritis; compression fracture vertebra
1173-200	25–30 years	F	Flexed	Primary	None
L108-200	9 months	I	Flexed	Primary	None
L111-200	10.5 years	I	?	Secondary	Cribra orbitalia

[a] I = Indeterminate; F = female.

consisted of clay, nonartifactual stones, shell, red ochre, and charcoal. The matrix outside of the pit appeared to be midden; it contained charcoal and human and nonhuman bone fragments. Both soil and charcoal samples were collected from the burial pit fill. Additionally, a rib fragment was submitted for carbon and nitrogen isotopic analysis (see Schoeninger, this volume).

This individual is a tightly flexed skeleton, resting on the left side (fig. 3-5). The skull was missing, but had it been present, it would have been directed northward. The orientation of the skeleton was almost on a direct north–south axis. No artifact associations were identified with this individual. The bones of this skeleton are in good condition, but there is some bone fragmentation near the ground surface.

Because the dentition of this individual is represented by only a single tooth, it is difficult to estimate age at death. However, the tooth present—a maxillary permanent left canine—shows about three-fourths of root length present, indicating an age of about 9 years (Ubelaker, 1989). In the absence of a complete dentition, age can be estimated at 9 to 11 years on the basis on long bone length (Ubelaker, 1989).

The following skeletal elements are present for this individual: left ilium, left and right ischia, pubes, clavicles, scapulae, humeri, ra-

Fig. 3-3. Burial 1058-211. The tip of the range pin points north.

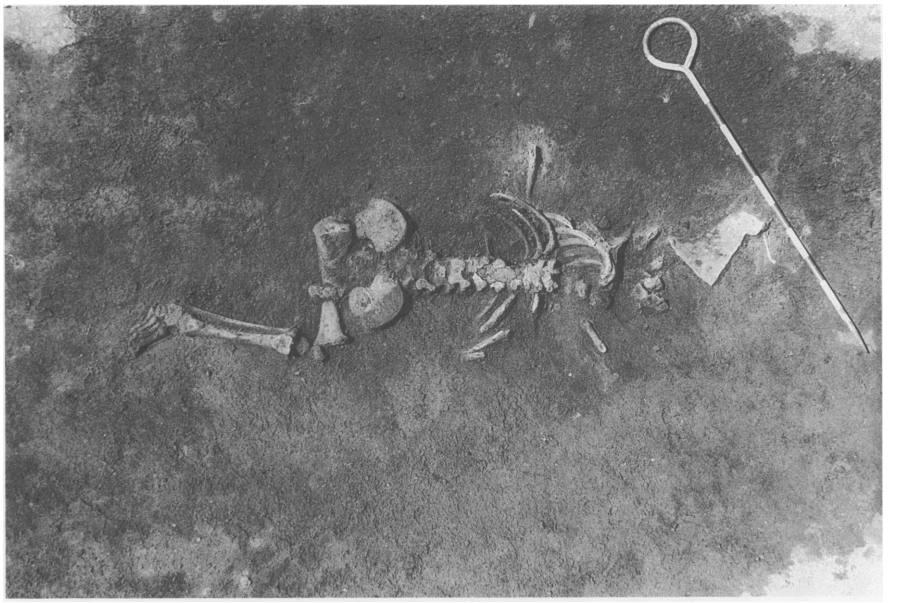

Fig. 3-4. Burial 910-211. The tip of the range pin points north.

dii, ulnae, femora, patellae, tibiae, fibulae, calcanea, tali, left navicular, right cuboid, left and right first cuneiforms, second cuneiforms, third cuneiforms, all metatarsals, proximal foot phalanges (3), left and right scaphoids, lunates, left triquetral, pisiform, right greater multangular, right lesser multangular, left and right capitates, hamates, left metatarsals (first, second, third, fourth), right metatarsals (second, third, fourth, fifth), proximal hand phalanges (4 right), intermediate hand phalanges (2 right), left and right first ribs, rib fragments (21), manubrium, sternun (4 segments, 3 of which are fused), cervical vertebrae (all except first), thoracic vertebrae (all), lumbar vertebrae (all), sacral vertebrae (all; S2 and S3 fused dorsally), and coccyx (all).

No apparent pathological conditions were observed in this individual.

Other Remains Associated with 1064-200

The remains of at least two other individuals were encountered within and immediately outside of the 1064-200 burial pit. The remains of these individuals are listed below:

1064-201A: Skeletal elements present for this individual include fragments of anterior mandibular corpus (2), right patella, articulated left foot (calcaneus, talus, navicular, cuboid, first cuneiform, second cuneiform, third cuneiform, 5 metatarsals, 5 proximal phalanges, 3 intermediate phalanges, 5 terminal phalanges, sesamoid bone), articulated partial right hand (scaphoid, lunate, hamate, 5 metacarpals, 5 proximal phalanges, 4 intermediate phalanges, 3 terminal phalanges), and rib fragments (8). The articulated hand and foot were found inside the burial pit to the north and east, respectively, of the legs of 1064-200. The other skeletal elements of 1064-201A were located outside of the pit to the east of 1064-200. Although purely conjectural, it appears that 1064-200 may have been intrusive into an earlier burial, the individual associated with 1064-201A. If so, the only remaining undisturbed component of 1064-201A included a hand and a foot. All other remains were disturbed in the process of placing 1064-200 in the burial pit. All disturbed remains of individual 1064-201A, with the exception of rib fragments, patella, and partial mandible, were subsequently lost, perhaps due to the flooding of the Carson Sink.

A rib fragment from this individual was submitted for carbon and nitrogen isotopic analysis (see Schoeninger, this volume).

Fig. 3-5. Burial 1064-200. The tip of the range pin points north.

The presence of complete closure of all epiphyses indicates that the individual was an adult. However, given the incompleteness of the skeleton, neither a more precise estimate of age nor an indication of sex are possible.

1064-201B: This individual is represented by a partial foot (including 5 metatarsals, 4 proximal phalanges, 2 intermediate phalanges, and 2 terminal phalanges) located to the immediate west of 1064-200, outside of the burial pit. It may be that the remainder of the individual had been lost because of flooding and subsequent erosion in the Carson Sink.

The lack of closure of epiphyses on the foot bones indicates that this individual was a juvenile. A more precise estimate of age or determination of sex are not possible.

No obvious pathologies were noted in either 1064-201A or 1064201B.

1159-200: The discovery of this burial was made when a fragmentary femur diaphysis, tibia diaphysis, vertebral, and rib fragments were observed on the ground surface by the HSFS. No clear pit outline was discernible. The burial pit fill disappeared immediately below the skeletal remains. The pit fill matrix included some clay and a few fragments of shell on the surface. A sample of burial pit fill was collected. An additional soil sample and a rib fragment were collected, frozen in dry ice, and sent to D. G. Smith for serum albumin analysis (see Smith et al., this volume). A sample of charcoal from pit fill was collected and a rib fragment was designated for radiocarbon assay. The rib fragment yielded an uncorrected radiocarbon date of 2265 ± 70 B.P. (Beta-33554). Lastly, a rib fragment was submitted for carbon and nitrogen isotopic analysis (see Schoeninger, this volume).

The skeleton is very tightly flexed on the right side. The left knee is located directly beneath the skull, and the right knee rests on top of the skull (fig. 3-6). The top of the cranium is oriented toward the northeast. One possible artifact association is a small nonartifactual avian (Ardeid) bone found in the cranial region. Other nonassociated materials included an additional animal bone and the aforementioned shell. Skeletal elements are in very good condition, except for some fragmentation of bones exposed on the ground surface prior to discovery.

The presence of fully erupted and extremely worn permanent maxillary and mandibular incisors, canines, and premolars indicates that this individual was a fully mature adult at the time of death. The morphologies

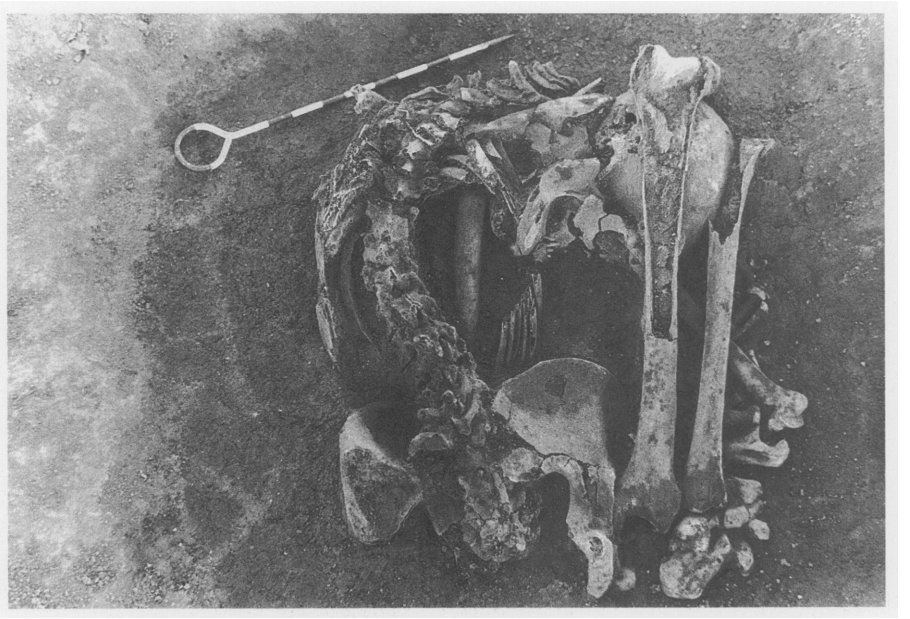

Fig. 3-6. Burial 1159-200. The tip of the range pin points north.

of both the symphyseal face of the pubes and auricular surfaces of the ilia are consistent with an individual who was at least 45 years old at death. The pubic symphyseal faces possess marked rims, uniform lipping of the dorsal margins, and irregular lipping of the ventral margins (i.e., 45–50 years old; see Todd, 1920). The auricular surfaces show replacement by relatively dense bone, lack of billowing and striations, lack of transverse orientation, and irregular margins (i.e., 45–49 years old; see Lovejoy et al., 1985).

The presence of a wide sciatic notch and parturition scars associated with a preauricular sulcus indicates that this individual was female.

Skeletal elements that are present with this individual include a nearly complete cranium and mandible, permanent maxillary and mandibular left and right first incisors through third premolars, left and right innominates, clavicles, humeri, radii, ulnae, femora, patellae, tibiae, fibulae, calcanea, tali, navicular, cuboids, first cuneiforms, second cuneiforms, left third cuneiform, left and right metatarsals (all), 7 proximal phalanges, 2 intermediate phalanges, 3 terminal phalanges, 2 sesamoid bones, left and right scaphoids, lunates, triquetrals, pisiforms, greater multangulars, lesser multangulars, capitates, hamates, metacarpals (all), 9 proximal phalanges, 8 intermediate phalanges, 8 terminal phalanges, right first rib, 49 rib fragments, cervical vertebrae (all), thoracic vertebrae (all), lumbar vertebrae (all), sacrum (first segment only).

Pathological conditions observed in this individual included (1) premortem loss of permanent maxillary and mandibular left and right fourth premolars through third molars; (2) hypoplastic maxillary left first incisor; (3) periosteal inflammation of anterior crest of right tibia (probable infection); (4) severe proliferative marginal lipping on distal left and right ulnae and all vertebrae bodies and intervertebral articulations, as well as slight proliferative marginal lipping on proximal left and right ulnae, distal left radius, and left triquetral (osteoarthritis); (5) Schmorl's depression on body of second cervical vertebra; and (6) compression fracture of body of a thoracic vertebra (fig. 3-7). These pathological conditions are consistent with the older age at death of the individual.

L72-200: This individual was encountered as a surface exposure of the skull and left clavicle. There was no apparent pit outline associated with this individual at any point during the excavation. Therefore, no burial pit dimensions were recorded. It appeared

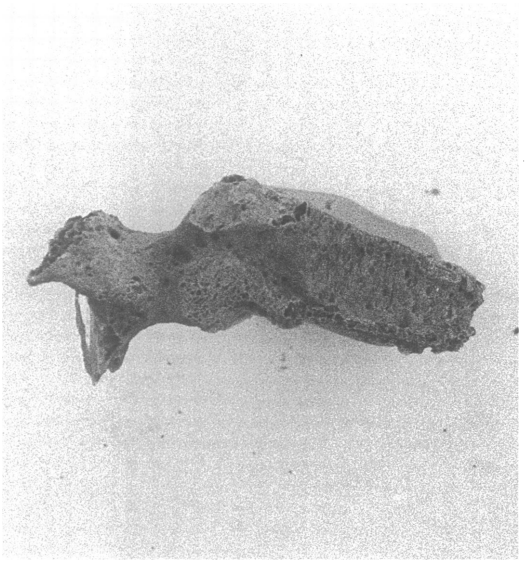

Fig. 3-7. Vertebral compression fracture (skeleton 1159-200).

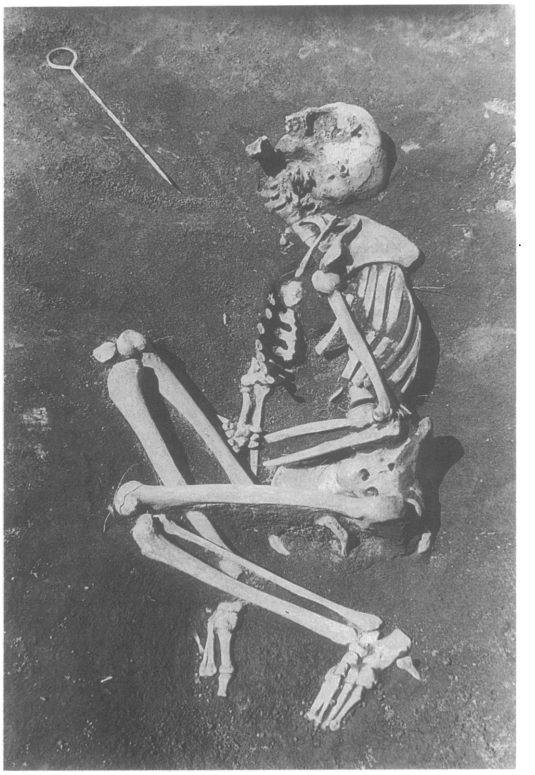

Fig. 3-8. Burial L72-200. The tip of the range pin points north.

that the entire surrounding matrix—well beyond the limits of the burial—was comprised of dark soil with shell, stone, clay, and animal bone inclusions. It is likely, therefore, that the individual was interred in a midden deposit. The soil immediately surrounding the skeleton was clearly darker than the midden. A soil sample of the burial fill was collected. A second soil sample and rib fragment were collected, frozen, and shipped to D. G. Smith for serum albumin study (see Smith et al., this volume). A charcoal sample and rib fragment were collected for a radiocarbon assay. A radiocarbon assay on the rib fragment produced an uncorrected date of 820 ± 70 B.P. (Beta-33555). Additionally, a rib fragment was submitted for carbon and nitrogen isotopic analysis (see Schoeninger, this volume).

The top of the cranium of L72-200 is oriented toward the west. However, the skull and cervical vertebrae were disturbed and moved from the original burial posture (probably from water activity during the flooding and subsequent erosion of the Carson Sink) (fig. 3-8). Prior to disturbance, the top of the cranium was likely oriented toward the southwest. With the exception of the skull, cervical vertebrae, and a metatarsal, all bones were undisturbed prior to excavation. The individual was in a flexed position, on the right side. With the exception of the left side of the skull, all bones are in excellent condition.

All teeth of this individual are fully erupted and exhibit marked occlusal surface dental wear. Therefore, this individual was a mature adult. There are faint remnants of the ridge and furrow system remaining on the pubic symphyseal faces, but also some development of a rim. Based on this morphology, the individual was in the late 20s to early 30s at the time of death (Todd, 1920). This age is consistent with the presence of lines of recent epiphyseal union on a number of skeletal elements (e.g., proximal tibiae, distal ulnae and radii, heads of femora and humeri). However, an extreme degree of tooth wear and advanced state of ectocranial suture closure are consistent with an age of 40 years or perhaps older. We suggest an age of 30 to 40 years at death for this individual.

The presence of a wide sciatic notch, preauricular sulcus with parturition scars, well-developed subpubic concavity, ventral

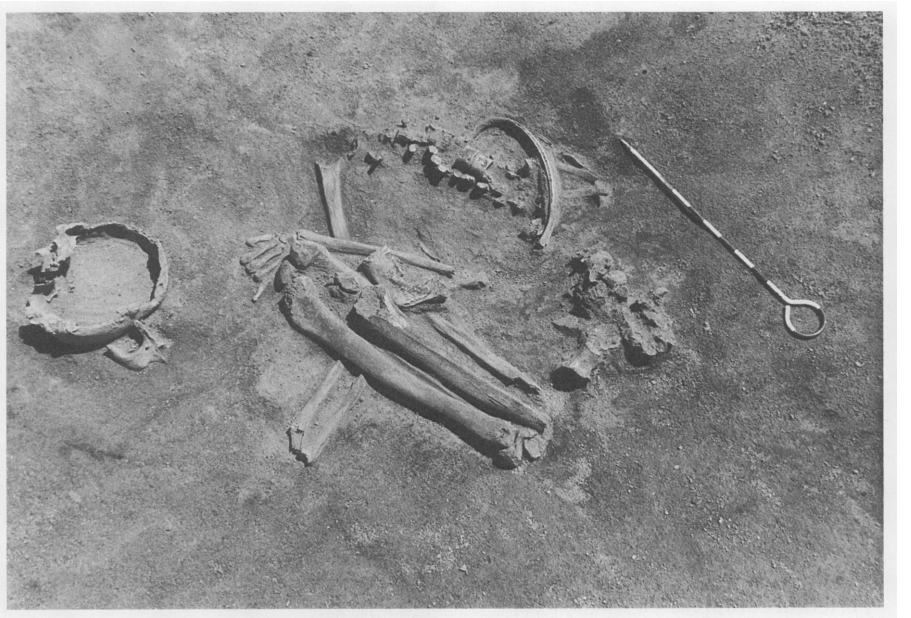

Fig. 3-9. Burial 1173-200. The tip of the range pin points north.

arc, wide subpubic angle, gracile face, poorly developed nuchal area, and small mastoid processes indicates that this individual was likely female (Phenice, 1969; Ubelaker, 1989).

Skeletal elements present for this burial include a nearly complete cranium (missing only the left zygoma and left maxilla), right half of mandible, right permanent mandibular third premolar through third molar, right permanent maxillary fourth premolar through third molar (all other teeth missing represent postmortem loss), hyoid, left and right innominates, clavicles, scapulae, humeri, radius, ulnae, femora, patella, tibiae, fibulae, calcanea, tali, naviculars, cuboids, first cuneiforms, second cuneiforms, third cuneiforms, metatarsals (all), 8 proximal phalanges, 2 intermediate phalanges, 7 terminal phalanges, 7 sesamoids bones, left and right scaphoids, lunates, left triquetral, pisiforms, greater multangulars, lesser multangulars, capitates, hamates, metacarpals (all), 7 proximal phalanges, 5 intermediate phalanges, 4 terminal phalanges, 9 left ribs, 8 right ribs, 13 rib fragments, manubrium/sternum, cervical vertebrae (all), thoracic vertebrae (all), lumbar vertebrae (all), sacrum (complete), and coccyx.

Pathological conditions included (1) fractured and healed coccyx; (2) markedly porous metaphyses of all major long bones (osteoporosis?); (3) scapular bodies very thin, virtually transparent (osteoporosis?); (4) all vertebrae are very light and possess multiple perforations on bodies (osteoporosis?); (5) moderate degree of proliferative marginal lipping on body of fourth lumbar vertebra (osteoarthritis); (6) moderate to extreme degree of marginal lipping on all cervical vertebrae (osteoarthritis); and (7) compression fracture involving fourth and fifth cervical vertebrae.

1173-200: This burial was initially encountered in a site that contained a wealth of artifactual materials, including groundstone, obsidian and chert flakes, shell, animal bone, human bone, and soil discolorations representing features. Several adult cranial fragments and a left femur were associated with one surface discoloration. Although these skeletal elements were clearly disturbed and out of any original burial context, they were thought to have been part of a burial feature with, perhaps, additional bones in original context. Upon further excavation, the remains of a tightly flexed individual on the right side were exposed within the confines of a distinct burial pit (fig. 3-9). The pit outline was oval-shaped and measured 89 cm

long and 68 cm wide. Pit fill continued several centimeters below the skeleton. The cranium of the burial was displaced some 40 cm to the west of its original location. Had the cranium been in original context, it would have been oriented toward the north. The vertebral column is on a north–south axis. The bones are in generally fair to good condition, although there is some fragmentation from water activity and surface exposure. No artifactual inclusions were encountered with this skeleton. The pit fill was considerably darker than the surrounding matrix and contained small rocks. A soil sample was taken of the pit fill. One rib fragment was submitted for carbon and nitrogen isotopic analysis (see Schoeninger, this volume).

The dental development of this individual shows complete eruption of the permanent teeth, thus indicating full adulthood. There is no endocranial suture closure and only limited ectocranial suture closure. This degree of suture closure combined with moderate occlusal surface wear of the teeth and no proliferative marginal lipping indicate an age at death of 25–30 years.

The individual possesses a wide sciatic notch and gracile cranial and postcranial bones. This suggests that the individual is likely a female.

The skeleton is represented by the following skeletal and dental elements: most of right side of cranial vault, right face with zygoma, maxilla, and nasal, fragments of left temporal and occipital, nearly complete mandible; dentition, including permanent maxillary left first incisor, second incisor, third premolar, first molar, second molar, right first incisor, second incisor, third premolar through third molar, mandibular left first incisor, second incisor, third premolar, first molar through third molar, right first incisor, second incisor, third premolar through third molar; postcrania, including right ilium fragment (at the sciatic notch), partial right scapula, right humerus diaphysis, left radius missing proximal end, right radius missing distal end, left and right ulnae, left and right femora (right missing proximal end), patellae, left and right tibiae (left missing distal end), fibula diaphyses, right talus, left scaphoid, greater multangular, lesser multangular, metacarpals (all), 3 proximal phalanges, 1 intermediate phalanx, 30 rib fragments (including 1 first), fragments of most thoracic vertebrae and sacrum.

Pathological conditions observed in this individual include small, carious lesions on the occlusal surfaces of the maxillary and mandibular right third molars. This is the only instance of dental caries in the HSFS skeletal series. Additionally, the maxillary left second incisor is hypoplastic.

Both left and right ulnae exhibit extremely well-developed supinator crests.

L108-200: This individual was first encountered as a concentration of juvenile cranial fragments that likely represented a partially disturbed cranium in original context. Preparation of the burial for excavation revealed a poorly defined, oval-shaped burial pit outline of 62 cm long by 34 cm wide by a few centimeters deep. The pit fill was somewhat darker than the surrounding, nonburial matrix, and included clay, snail shells, and a bird(?) bone. The bone was excavated in direct context with the individual and may have represented an intentional inclusion, although it is not modified. A soil sample of burial pit fill was collected during exposure of the skeleton. One rib fragment was submitted for carbon and nitrogen isotopic analysis (see Schoeninger, this volume).

Upon complete excavation and exposure of the skeletal remains, it became clear that much of the appendicular skeleton was disturbed or missing (fig. 3-10). Leg bones were not present in the assemblage. Foot bones excavated from the top of the pelvis suggest, however, that the legs had been tightly flexed prior to their disturbance and loss. The right arm was tightly flexed; the left arm was loosely flexed. The skull was disturbed, but in its original position, and was oriented toward the southwest. With the exception of the bones exposed prior to discovery of the burial, the skeletal elements were in good condition.

Dental development in this individual shows the following characteristics: (1) permanent maxillary and mandibular left and right first molars are in the initial stage of formation; (2) deciduous mandibular first incisors are not quite in functional occlusion; (3) all other deciduous teeth (maxillary first incisors, mandibular and maxillary second incisors, canines, first molars, second molars) are completely unerupted; (4) root of the de-

Fig. 3-10. Burial L108-200. The tip of the arrow points north.

ciduous mandibular left second incisor is half-formed; (5) deciduous mandibular right canine crown is completely formed (but no root formation); and (6) deciduous maxillary left second molar crown is half-formed. This stage of development suggests that the individual was approximately 9 months old at death (Ubelaker, 1989). The young age of this individual prevents identification of sex.

Skeletal and dental elements present include a partial, fragmentary cranium (maxilla, left second occipital, basilar occipital, occipital squama, partial right temporal, sphenoid fragments, partial left frontal, 14 left and right parietal fragments), complete mandible (in 4 pieces), partial mixed dentition (permanent maxillary and mandibular left and right first molars, deciduous maxillary left first incisor through second molar, right canine, first molar, second molar, mandibular left and right first and second incisors, right canine, left and right first and second molars), left and right ilia, ischia, pubes, clavicles, scapulae, humeri, radii, ulnae, partial calcanea, 7 metatarsal diaphyses (including 1 first), 3 metacarpal diaphyses (including 1 first), foot or hand bones (7 middle phalanges, 3 terminal phalanges, miscellaneous unidentifiable fragments), 10 left ribs (including first), 7 right ribs (including first), rib fragments (20), first cervical vertebra (half arch), second cervical vertebra (half arch), third through seventh cervical vertebrae (7 + ½ arches), thoracic vertebrae (6 arches), lumbar vertebrae (3 arches), sacral vertebrae (5 bodies), and miscellaneous vertebrae fragments (19 body, 20+ ½ arches).

No pathological conditions were observed in this individual.

L111-200: This burial was indicated by the presence on the ground surface of several completely exposed cranial fragments, a facial skeleton, and a partially exposed long bone. The individual was located in a small, round pit (measuring approximately 40 by 40 cm) on the extreme western end of a much larger pit that measured approximately 150 cm long (east to west) by 80 cm wide (north to south). The larger pit contains charcoal and has the appearance of an aboriginal feature. The smaller pit containing human remains may have been intrusive into the larger pit. However, there was no clear outline separating the two pits. Both pits appeared to be very shallow (less than 15 cm deep). Soil and charcoal samples from the smaller (burial) pit were collected.

The skeletal elements show no articulations; many of the bones are broken (e.g., cranium), and the skeleton is only partially complete (fig. 3-11). These observations indicate that the individual excavated from the smaller pit represents a secondary deposit, having been disturbed and redeposited during the prehistoric occupation of the region. Artifacts encountered with this burial include an obsidian flake, a ground stone (mano) fragment, a chert projectile point (missing the base), and biface fragments. Some or all of these materials may have been intentional inclusions with this burial. However, the disturbed nature of the skeleton and the presence of a larger, nonburial feature prevent us from determining intentional placement of burial objects. It is noteworthy that the larger pit, although not fully investigated, appeared

Fig. 3-11. Burial L111-200. View of human remains when encountered by the Human Skeletal Field Survey (top); same view following excavation (middle); superior view following excavation (bottom). The tip of the range pin points north in all views.

to contain no artifacts, only the aforementioned charcoal.

The estimated age at death of this individual is based on dental development and wear. In particular, the following characteristics of the dentition were observed: (1) deciduous maxillary right canine, left and right second molars, and mandibular left and right second molars are fully erupted and show advanced wear on the occlusal surfaces (a great deal of secondary dentine is exposed on these teeth); (2) permanent maxillary left and right first and second incisors, third premolars, first and second molars, mandibular left canine, third premolar, and left and right first molars are fully erupted; (3) root length is complete, but apices open, in the permanent maxillary first and second incisors; (4) root length is three-fourths complete in the mandibular left canine and left second molar; (5) root length is half-formed on the permanent maxillary left and right second molars; and (6) there is slight to moderate occlusal surface wear on the permanent mandibular left and right first molars. This stage of development and degree of occlusal surface wear suggest that the individual was 10.5 years of age at death (Ubelaker, 1989).

The young age of this individual prevents identification of sex.

Specific skeletal and dental elements present include fragments of frontal, occipital squama, left and right temporals, parietals, sphenoid (one side only, left or right), left and right maxillae, complete mandible, dentition (deciduous maxillary right canine, mandibular and maxillary left and right first molars; permanent maxillary left and right first and second incisors, third premolars, first and second molars, mandibular left canine, third premolar, left and right first and second molars); and partial postcranium (partial left scapula, left humerus missing proximal one-fifth, left and right radii missing proximal and distal ends, 2 proximal hand phalanges).

The eye orbits exhibit slight cribra orbitalia, and two permanent teeth exhibit hy-

poplasias (permanent maxillary left first and second incisors and permanent mandibular left canine).

DISCUSSION AND CONCLUSIONS

To understand the osteological data presented here, the reader should refer to the analysis of human remains collected by the Nevada State Museum in 1985 and 1986. This study—completed by Sheilagh Brooks and her associates—focuses on age and sex determination, anthropometry, discrete cranial and postcranial traits, and skeletal pathology. Among other pathological characteristics in the NSM series, Brooks et al. reported a high frequency of osteoarthritic skeletal changes, especially polishing of the articular joint surfaces (eburnation). Later in the present monograph, we discuss our findings on osteoarthritis and the light they shed on the lifestyle of these Great Basin populations.

With regard to skeletons encountered by the HSFS, in addition to the human remains lacking clear burial association (see Appendix A), remains representing at least 10 skeletal individuals from eight burials were excavated by the HSFS in the summer of 1987 (table 3-8). Seven burials contained a single individual each, and one burial contained a single primary individual in addition to the very incomplete remains of two other individuals. Six of the individuals are juveniles, the remaining four are adults. Three of these adults are females; one is of indeterminate sex. With the exception of a single individual representing a secondary deposit (L111-200), all individuals were primary interments. Only one of these individuals was in a nonflexed position. The two older adult females (1159-200, L72-200) exhibited a range of pathological conditions, including fractures, infections, and various bony manifestations of osteoarthritis (proliferative marginal lipping, Schmorl's nodes). Osteoarthritis is a disorder related to excessive mechanical loading of articular joints, largely reflecting physically demanding activities (Jurmain, 1977; Merbs, 1983; DeRousseau, 1988; and others). The combined presence of osteoarthritis, Schmorl's nodes (also representative of excessive mechanical stress), and vertebral compression fractures in these two females indicates that they led very mechanically demanding lives. These observations, particularly regarding extensive osteoarthritis, are consistent with observations of the other human remains from the Stillwater Marsh that were excavated by the NSM (see Chapter 8; Tuohy and Haldeman, 1986; Tuohy et al., 1987; Brooks et al., 1988).

Notably absent in all skeletal materials examined are instances of dental pathology. Only one individual displayed carious lesions (incipient lesions on each of the upper and lower right third molars), reflecting the very low carbohydrate diet of these Great Basin populations. This represents a prevalence of 1.7% (2/117) and 0.0% (0/48) for the permanent and deciduous teeth, respectively. These prevalence values are comparable to those derived from the study of other dental remains from the Carson Sink region in particular as well as the western Great Basin (Larsen, 1985a, 1985b, unpubl. data; Tuohy and Haldeman, 1986; Tuohy et al., 1987; Brooks et al., 1988) and other North American contexts (see summary in Larsen et al., 1991). Moreover, few teeth exhibited evidence of gross dental defects (hypoplasias) arising from metabolic disruption.

The dentitions examined, however, show very marked occlusal surface attrition that is presumably related to consistency of dietary items or to materials incorporated into the food because of use of grinding stone implements. With regard to subsistence technology, the use of grinding stones for preparation of plant foods for consumption undoubtedly resulted in additions of stone particles into the foods consumed by the Stillwater native populations. In addition to the use of grinding stones as a source of incorporation of grit in foods, Brooks et al. (1988) suggested that debris or grit may have been incorporated into food during stone-boiling of food. This process involves cooking of food by placement of fire-heated rocks directly into baskets containing water and food. Thus, grit particles contained on these rocks could become incorporated into the food. Indeed, the inclusion of grit particles and other hard objects in food (e.g., bone fragments, plant fibers) has been demonstrated in the study of human coprolites from a number of Great Basin ar-

chaeological sites (e.g., Fry, 1970). In coprolite samples from Hogup Cave, for example, several specimens contained minute obsidian and chalcedony chips. Fry (1970: 249) speculated that these materials were ingested during the process of touch-up sharpening of stone tools with teeth, a practice that has been observed ethnographically in other areas of the world.

The characteristics of dental wear in this sample are illustrated by observations of several dentitions. For example, individual 1173-200, a 25–30-year-old female, shows dentin exposure on the entire occlusal surface of the first molars, coalescence of dentin exposure on the second molars, and moderate cusp removal on the third molars. This observation indicates that wear on teeth began at an early age—certainly during adolescence or by early adulthood in the permanent dentition (see also Brooks et al., 1988). Moreover, the marked wear gradient between teeth suggests very rapid wear in these populations. In older adults, this rapid wear rate led to significant loss of dental hard tissue. For example, in 1159-200, a 45–50-year-old female, all teeth remaining show complete dentin exposure, but with a faint enamel rim preserved. The extreme degree and rate of dental wear is also documented in other human remains from the Carson Sink region (e.g., Larsen, 1985a, 1985b, unpubl. data).

Prevalence of dental caries in the Stillwater series is low (2.8%, or 27/960 permanent and deciduous teeth combined; NSM + HSFS). The very harsh attritional environment in this setting may explain, in part, the low caries prevalence (Brooks et al., 1988; cf. Powell, 1985; Maat and Van der Velde, 1987). However, Meiklejohn et al. (1992) presented data based on a series of Mesolithic dentitions from Portugal that strongly suggest the dynamics of caries and attrition are independent. They argued, therefore, that the relationship between caries and attrition should not be generalized; instead, patterns of caries frequency and attrition must be interpreted separately. In the present instance, most (if not all) foods consumed by western Great Basin populations were likely noncariogenic. We argue, therefore, that the low prevalence of caries is related to dietary and not attritional factors. In this regard, the low percentage is well within the range of values (<7%) reported for hunting and gathering populations worldwide (see Turner [1979] and discussion by Larsen et al. [1991]).

The marked degree of occlusal wear could have obliterated enamel defects in the series (see discussion in Simpson et al., 1990). The very low prevalence of hypoplasias in the minimally worn, younger individuals suggests that wear is not an important factor in interpreting low hypoplasia frequencies (see also Tuohy and Haldeman, 1986; Tuohy et al., 1987). Nevertheless, the juveniles examined may not be representative of the population from which they were derived.

There are no instances of occlusal surface grooves on anterior teeth that reflect their use for preparation of plant materials for construction purposes or sinew for bows (see Larsen, 1985c). The lack of these features likely reflects the very small sample of dentitions collected by the HSFS and not the absence of them in the Stillwater series in general. This interpretation is supported by the presence of occlusal surface grooves in anterior teeth from Stillwater Marsh older adult (>35 years old) dentitions that were collected by the NSM (see Tuohy and Haldeman, 1986; Tuohy et al., 1987; Brooks et al., 1988). Our study of these (NSM) specimens showed the presence of occlusal surface grooves in the anterior dentitions of three females and six males. All anterior teeth in the affected individuals were markedly worn, with the occlusal surfaces showing a great deal of secondary dentin exposure. Basket construction is an activity associated with females in historic times. Therefore, the possibility remains that the predominance of anterior grooves in Stillwater males may reflect male-based activities such as preparation of sinew for bows or fish line (see Brooks et al., 1988). However, these dental samples are small, thus preventing us from conclusively linking specific activities and dental modifications (see also Larsen, 1985c). Interestingly, grooves that reflect task-related activities are found only in archaeological hunter-gatherer populations, most notably in California, British Columbia, and Greenland (see review in Milner and Larsen, 1991), as well as in northern Syria (Molleson, 1994), in addition to the aforementioned examples from the western

Great Basin (Larsen, 1985c; Brookes et al., 1988).

Two juveniles in the HSFS sample (1058-211, L111-200) exhibited slight to moderate cribra orbitalia. Cribra orbitalia is a hard tissue pathology characterized by porous, sievelike lesions found in the roof areas of eye orbits. It usually appears bilaterally in archaeological human remains (e.g., Stuart-Macadam, 1991). These pathological alterations represent childhood stress episodes related to any condition that causes iron-deficiency anemia (Huss-Ashmore et al., 1982; Kent, 1986; Larsen, 1987; Hirata, 1990; various authors in Stuart-Macadam and Kent, 1992). Because native New World populations lack hemolytic anemias (e.g., sickle-cell anemia), the condition is probably related to single or multiple variables, such as parasitic infection from water contamination, consumption of iron-poor foods, poor hygiene in general, consumption of foods that inhibit bioavailability of iron (e.g., maize), or a variety of other factors that promote iron deficiency (see Stuart-Macadam, 1989).

In reference to other prehistoric human populations in the U.S. Desert West, Kent (1986) has proposed that high prevalences of cribra orbitalia and porotic hyperostosis (pathology sharing the same etiology with cribra orbitalia, but found on the extra-orbital cranial vault bones) of Anasazi populations are related to a cycle of chronic infections (viral, bacterial, and parasitic) associated with lack of sanitation accompanying sedentary aggregations of human populations (see also discussion in Stodder, 1990). Although the Carson Sink populations certainly did not follow a lifeway that was as sedentary as that of the Anasazi or other populations of the American Southwest, Kelly (1985) suggested that these populations focused on marsh resources such that they may have been semisedentary for at least part of the year. Potentially, therefore, there were opportunities for exposure to contaminated water sources, thereby providing conditions that were conducive to chronic infections and, hence, iron-deficiency anemia.

However, iron-deficiency anemia was likely not a common stressor in these Carson Sink native populations because only three other individuals that we observed in the entire Stillwater series exhibited associated pathology. These individuals included a 12- to 13-year-old (1046-2a) with cribra orbitalia, a 1- to 2-year-old (1050-30) with porotic hyperostosis, and a 40+-year-old female (1070-4) with an unusually porous cranial vault that may represent porotic hyperostosis (see also Brooks et al., 1988). However, the latter individual does not possess skeletal lesions that are typical of porotic hyperostosis that has been observed by most researchers. The porosity observed in this individual may be related to the advanced stages of osteoporosis observed in much of the postcranial skeleton (Larsen, personal obs.).

In conclusion, there is a remarkably low prevalence of skeletal manifestations of iron-deficiency anemia in the Stillwater series. This finding is consistent with observations of skeletons of prehistoric desert-dwelling hunter-gatherers from other regions of the world (e.g., Australia: Webb, 1989, 1995), especially in areas of low population density (see discussion in Stuart-Macadam, 1992). These findings from the Stillwater Marsh, however, are in striking contrast with various Southwestern skeletal series where fully half of crania examined show evidence of iron-deficiency anemia (see discussions in Walker, 1985; Martin et al., 1991; Stodder, 1994).

In contrast to findings by Brooks et al. (1988: 11), who reported that "swollen or porous long bone shafts are common in the Stillwater series," our study of the remains collected by the HSFS revealed a very low frequency of periosteal reactions or inflammation. Only one individual, an older adult female (1159-200), exhibited evidence of periosteal remodeling. Interpreting periosteal reactions in archaeological skeletal series is difficult in that two primary causes are associated with them, including trauma and/or infection (Larsen, 1987; Grauer, 1993; Lambert, 1993). There is a tendency toward relatively high frequencies of periosteal reactions in sedentary, agricultural populations compared with hunter-gatherer groups. Foraging populations may exhibit relatively low prevalences of periosteal reactions in that their exposure to conditions conducive to infectious agents may be reduced in comparison with agriculturalists. However, other economic transitions not involving agriculture

have been documented. For example, Lambert (1993) found an increase in periosteal reactions in the Santa Barbara Channel area of southern California when comparing earlier populations involved in a generalized maritime hunting-gathering adaptation with later populations that were more focused on fishing. The mechanisms for an increase in infectious pathology parallel developments in adoption of agricultural lifeways in that the later fishing-oriented populations were more sedentary and densely settled than were their antecedents in the region. Although tentative, our findings confirm these various studies regarding population size and settlement pattern in relation to skeletal infection (see also various studies in Cohen and Armelagos, 1984; Hutchinson and Larsen, this volume).

CHAPTER 4. SERUM ALBUMIN PHENOTYPES AT STILLWATER: IMPLICATIONS FOR POPULATION HISTORY IN THE GREAT BASIN

David Glenn Smith, Robert L. Bettinger, and Becky K. Rolfs

INTRODUCTION

Albumin, a noncollagenous protein, is one of several serum proteins with rare forms that are specific to particular ethnic groups, language stocks, or language families in the New World. In addition to the common gene Al^{A}, there are two widely distributed genetic variants that also code for albumin, namely albumin Naskapi (Al^{Na}) and albumin Mexico (Al^{Me}). Both variants exhibit gene frequencies between 0.01 and 0.10 in certain Amerindian groups. Insofar as we know, Al^{Na} is found in Algonkian-speaking and Athapascan-speaking American Indian groups, but in no other demonstrably unrelated groups except in rare cases through admixture. In addition to the overwhelming linguistic evidence, the occurrence of Al^{Na} in the Navaho and Apache in the American Southwest establishes unequivocally their Athapascan ancestry.

The other distinctive North American albumin variant, Al^{Me}, is known to occur only among some Uto-Aztecan (especially southern Uto-Aztecan) and Yuman speakers, but not among speakers of any other language group except, again, in rare cases through admixture (Schell and Blumberg, 1988). Because many tribal groups have not yet been screened for albumin variants, the distribution of Al^{Na} and/or Al^{Me} could be more extensive than what is described here. Neither Al^{Na} nor Al^{Me} is found in South America, where several albumin variants occur whose distributions are more limited than those of Al^{Na} and Al^{Me}. A third albumin variant, albumin Platero (Al^{Pl}), has recently been discovered in a full-blooded Kumiai Indian from Platero, Baja, California, but little is known about the distribution or linguistic associations of this variant (Smith et al., MS. b).

The distribution of albumin variants is not always consistent with other evidence of New World culture history and thus provides data for generating alternative hypotheses to accepted interpretations. For example, the fact that both Algonkian and Athapascan speakers share the otherwise rare allele Al^{Na} is contrary to Greenberg's (1987) hypothesis, which suggested that those stocks represent entirely different phases of New World migration. Similarly, the presence of Al^{Me} in Uto-Aztecan- and Yuman-speaking groups suggests they share a recent common ancestor, a hypothesis that is not supported by linguistic evidence. If the presence of either variant in both groups in which it occurs does not result from sharing a common recent ancestor, extensive admixture between the two groups prior to their diversification might be responsible. Alternatively, one or both variants might be very ancient and have since become extinct in all other groups. Neither variant has been proven to occur in any Asian population, and both are therefore presumed to be of New World origin.

Because about 1% of the protein in human bone originates from serum, it is feasible to identify albumin variants in prehistoric populations and to infer population movements that figure prominently in competing cultural-historical hypotheses. The route of migration into the American Southwest followed by the Southern Athapascans, for example, might be identified by the presence of Al^{Na} in human bone retrieved from archaeological sites along that route of migration.

Similarly, the prehistoric distribution of albumin variants in Great Basin skeletal remains should shed considerable light on ancient population movements in this region of the Desert West. At the time of contact in the 19th century, the Great Basin was occupied by members of the Numic branch of the Uto-Aztecan language family (Madsen and Rhode, 1994). The Numic branch is broken into three subbranches—Western, Central, and Southern Numic—within each of which are two languages, Mono and Northern Paiute, Shoshoni and Panamint, and Ute and Kawaiisu, respectively. It has long been assumed that the Great Basin Numic speakers

originated in southern California and spread to the north and east to form the protohistoric linguistic distribution no more than 1000 years ago and, if lexicostatistical estimates are correct, more likely 500 to 700 years ago (see Aikens and Witherspoon, 1986). Genetic markers provide one approach to testing this hypothesis.

The distribution of Al^{Me} is helpful in this case because Al^{Me} appears to characterize speakers of Hokan and Uto-Aztecan, the language stocks most commonly identified with the earliest continuous occupation of the Great Basin (cf. Taylor, 1961; Goss, 1977). However, Al^{Me} is evidently absent in speakers belonging to a third language stock, Penutian, whose ancestors are occasionally thought to have previously occupied the northern half of the Great Basin (Pettigrew, 1980; Hattori, 1982; see also Aikens and Witherspoon, 1986).

Unfortunately, genetic markers for serum proteins extracted from human bone have not been used to address cultural-historical issues because biological anthropologists have only recently been able to extract serum protein in quantity from skeletal remains (e.g., Tuross, 1991). Moreover, methods for characterizing genetic markers in very dilute protein solutions were not available. It is now technically possible to extract sufficient soluble protein from archaeological human bone to characterize the electrophoretically defined phenotypes of several proteins, including albumin.

In a recent study (Smith et al., MS. a), albumin phenotypes were resolved for skeletal samples representing 83 individual burials from Windover Pond, a submerged archaeological site in Florida that dated between 8000 and 7000 B.P. All samples were monomorphic for the common gene Al^{A}, an outcome consistent with the absence of albumin polymorphism in ethnographic Native American populations in the southeastern United States (Smith et al., MS. b).

Success in resolving albumin phenotypes for the Windover Pond population was initially attributed to thermally stable, anaerobic conditions that were unusually favorable for protein preservation and the practice of freezing and shipping bone sample to Davis, California, immediately after excavation. As the study progressed, however, it became clear that the extremely sensitive techniques used for staining albumin after protein electrophoresis accounted for analytical success. For example, albumin phenotypes were resolved for protein extracted from several skeletal samples excavated from the Windover site that had been stored at room temperature for several years (Smith et al., MS. a). As we demonstrate here, our results confirm the importance of these techniques in a skeletal population from western Nevada.

MATERIALS AND METHODS

Electrophoretic analysis was conducted to resolve phenotypes for serum albumin extracted from prehistoric human bone excavated from archaeological sites in the Stillwater Marsh. The skeletons and the sites in which they occur range in age from ca. 5000 to 300 B.P., but most date between 3000 and 500 B.P., with a median age of ca. 1500 B.P. (Tuohy et al., 1987; Raven and Elston, 1988; see Chapters 1 and 2). The study was undertaken specifically to ascertain the presence or absence of the variant albumin Mexico, Al^{Me}, a genetic marker for Yuman/Uto-Aztecan ancestry. In order to gauge the feasibility of the project, in 1987 we asked R. Kelly to send us bone samples from two different burials obtained from the HSFS excavations in the Stillwater Marsh region. Following the Windover (Florida) practice, both samples were frozen immediately upon disinterment; they remained frozen until after arrival at the University of California–Davis laboratory. When subsequently processed, each sample produced a clear electrophoretic band that indicated homozygosity for the common albumin gene (Al^{A}). Successful resolution of albumin phenotypes for these two individuals suggested that it would be useful to study a larger sample of skeletal remains from the Stillwater archaeological sites. Accordingly, additional Stillwater skeletal samples were secured from the Nevada State Museum.

Bone fragments (predominantly ribs) ranging from 4.1 to 11.5 g and representing 25 individual burials from 17 different Stillwater localities were shipped to our laboratory facility from the Nevada State Museum, where they had been stored at room temper-

TABLE 4-1
Bone Samples and Albumin Phenotypes from Stillwater Marsh

Sample	Specimen	Sex[a]	Age	Bone	Albumin phenotype
1	1043-5	M	40+	Rib	A/A
2	1043-37	I	13	Rib	A/mex
3	1043-61	F	30	Rib	A/A
4	1044-1	F	27	Rib	A/A
5	1044-2	M	40+	Rib	A/A
6	1045-1	F	35	Rib	A/A
7	1046-2A	I	12	Rib	A/A
8	1046-2B	I	12	Rib	A/A
9	1046-9	M	37	Rib	A/mex
10	1047-1	M	21	Tibia	A/A
11	1050-3	M	40+	Rib	A/A
12	1054-1	M	27	Rib	A/A
13	1055-1	M	27	Rib	A/A
14	1058-12A	F	22	Rib	A/A
15	1062-1	M	40+	Rib	A/A
16	1063-19,20	M	40+	Rib	A/A
17	1064-1,18	F	30	Rib	A/mex
18	1070-3	F	40+	Rib	A/A
19	1070-4	F	40+	Rib	A/A
20	1158-1	M	40	Long bone	A/mex
21	1159-4	M	35	Rib	A/A
22	1159-6	M	27	Rib	A/A
23	1159-7	M	17	Rib	A/A
24[b]	1159-200	F	45+	Rib	A/A
25	L53-B-1	F	35+	Vertebra	A/A
26	1160-2	F	45	Vertebra	A/A
27[b]	L72-200	F	37	Rib	A/A

[a] I = Indeterminate; F = female; M = male.
[b] Identifies first two samples analyzed.

ature for from several months to 3 years. The fragments were washed, dried, and then pulverized to powder form with a ceramic mortar and pestle. The powder was then deproteinized in a buffered saline solution, which was then desalted and concentrated by reverse dialysis. Concentrates were subsequently subjected to isoelectric focusing, transferred to nitrocellulose membranes, and then stained specifically for albumin using an enzyme-linked double antibody assay.[1]

[1] Details of the protocol for extraction and analysis of albumin are as follows: The bone powder was suspended in a 5% (wt/vol) solution of Tris-buffered saline (TBS, pH 7.4) (Gurtler et al., 1981) and stirred magnetically overnight to deproteinize the bone powder. After centrifugation, the supernatant was removed and the wet bone powder was resuspended in a 20% (wt/vol) solution of TBS and stirred magnetically, as before, for 12–18 hours. After centrifugation, the supernatants from the first and second deproteinizing washes in TBS were combined and then simultaneously desalted and concentrated to an approximately 0.5 ml volume by dializing PVP K30 against the supernatants at room temperature.

After thin-layer polyacrylamide IEF (using pH 5–6 ampholytes), the samples were immobilized on a sheet of TBS-saturated (0.45 μm) nitrocellulose paper (NCP) following the method of Kamboh and Ferrell (1986). The NCP was blocked for 1.5 hours with a 5% (wt/vol) solution of nonfat dry milk in TBS, rinsed, and then incubated successively with a 0.1% solution (in TBS) of goat anti-human serum albumin and a 0.02% solution (in TBS) of rabbit anti-goat immunoglobulin conjugated with alkaline phosphatase. After a 2–4-hour rinse in TBS, the NCP was stained for alkaline phosphatase (Boyer, 1961) to reveal the albumin bands.

RESULTS

Of 27 individuals comprising our prehistoric skeletal sample from the Stillwater Marsh, 19 were initially judged to be monomorphic for Al^{A} (table 4-1). Eight samples either suspected of being heterozygous or whose albumin phenotypes were initially unresolvable were rerun together with three control samples, one each heterozygous for Al^{Me}, Al^{Na}, and Al^{Pl} (fig. 4-1, table 4-1). Two of these eight samples were judged to be monomorphic for Al^{A}, four were heterozygous Al^{A}/Al^{Me}, and two were still not satisfactorily resolvable and were presumed to be homozygous for Al^{A}.

DISCUSSION AND CONCLUSIONS

The frequency of Al^{Me} in the prehistoric population represented by the Stillwater skeletal remains is approximately 0.07 [4/(27 × 2)], about as high as that known for any living population. This is all the more remarkable given that the skeletons are certainly not fully contemporaneous. In this regard, these remains represent a series of small samples drawn at unknown intervals from a larger population over a span of centuries, if not millennia. Moreover, each of the four samples that was heterozygous for Al^{Me} originated from a different site location within the Carson Sink. This suggests that the frequency of Al^{Me} was relatively homogeneous throughout the Carson Sink during the period involved.

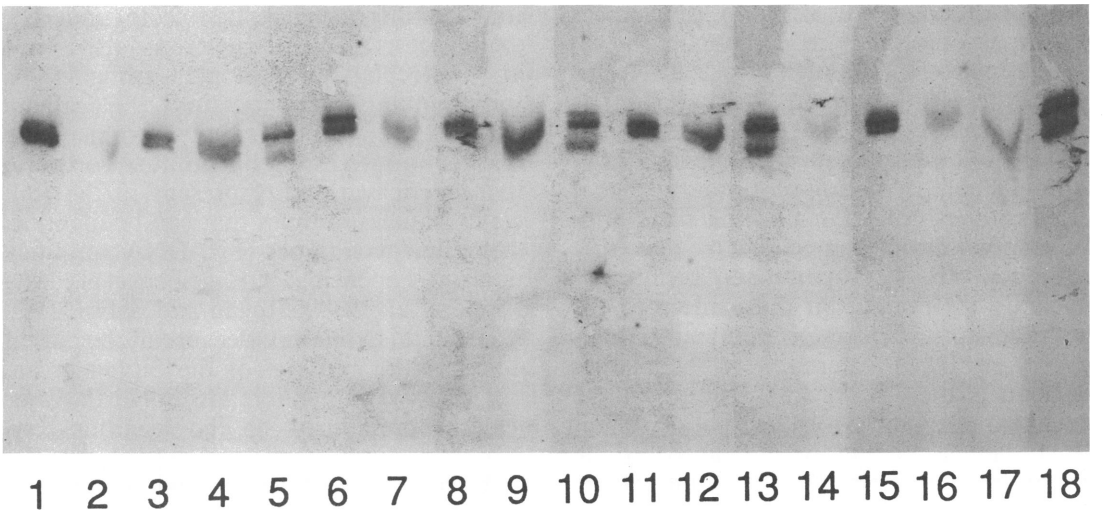

Fig. 4-1. Serum albumin phenotypes of the Stillwater series. Control serum samples include sample numbers 1 (Al^{A}/Al^{A}); 3, 8, 11, and 15 (Al^{A}/Al^{Me}); 5, 10, 13, and 18 (Al^{A}/Al^{Pi}); and 6 (Al^{A}/Al^{Na}). Samples extracted from bone include 2 (unresolvable), 4 (Al^{A}/Al^{Me}), 7 (Al^{A}/Al^{Me}), 9 (Al^{A}/Al^{A}), 12 (unresolvable), 14 (Al^{A}/Al^{Me}), 16 (Al^{A}/Al^{Me}), and 17 (Al^{A}/Al^{A}).

However, the sample studied here is small; thus, sampling error could be responsible for so high a frequency of Al^{Me}.

Al^{Me} has not been found among the Washoe or the Northern Paiute who occupied the west-central Great Basin in historic times (Smith et al., MS. b). This observation is consistent with the idea that Northern Paiute first occupied the Carson Sink region only recently (Lamb, 1958; Bettinger and Baumhoff, 1982; and see various authors in Madsen and Rhode, 1994). The Stillwater population might be ancestral to other Numic speakers that carry Al^{Me} or to non-Numic (e.g., Northern Hokan) groups whose albumin phenotypes have not been studied. The absence of Al^{Me} in modern Washoe further suggests that if the ancestral occupants of the Great Basin were Hokan speakers, they were of a branch other than that which eventually developed into Washoe. Unfortunately, Yuman and Washoe are the only Hokan-speaking groups that have been studied for albumin polymorphism (Smith et al., MS. b). Furthermore, the presence of Al^{Me} suggests that the population represented by the Stillwater skeletal remains probably was not ancestral to groups that today speak languages of the Penutian stock (e.g., Maidu), none of whom are known to carry Al^{Me}. Jointly, the absence of Al^{Na} and the presence of Al^{Me} preclude either an Athapascan or an Algonkian ancestry for the populations represented by human remains from the Stillwater Marsh. This finding is compatible with virtually all widely accepted reconstructions of Great Basin linguistic prehistory (Fowler, 1972).

The highest modern frequencies of Al^{Me} occur in the delta (e.g., Cocopa) and river (e.g., Mohave, Maricopa, and Quechan) Yuman groups and Southern Uto-Aztecan groups (e.g., Pima) (see Schell and Blumberg, 1988). By contrast, Al^{Me} appears to be absent in the neighboring Northern Uto-Aztecan Hopi, although it is found in lower frequency among the upland Yumans (e.g., Yavapai and Hualapai), some Baja Yumans (e.g., Pai-Pai), and some Numic speakers such as Ute (Johnston et al., 1969) and Northern Shoshone (Smith et al., MS. b). These preliminary results suggest that the most likely affiliation for the Stillwater human remains is with Yuman or Southern Uto-Aztecan groups. Given the postulated recent date of migration of Numic speakers into the Great Basin, it seems unlikely that an incoming group with as high a frequency of Al^{Me} as found in the Stillwater population could have evolved into the historic occupants of the Carson Sink region. However, sampling effects could be respon-

sible for differences in very low frequencies of traits among closely related populations of Numic speakers. Although absent in Northern Paiute, Al^{Me} occurs in Ute and Shoshonean tribes (Smith et al., MS. b) and either tribe could descend from the Stillwater population. The distribution of Al^{A} and Al^{Me} that we recently estimated in a sample of 12 Shoshone Indians from near Schurz, Nevada (Al^{Me} frequency = 0.042) was not statistically significantly different from that estimated for the prehistoric Stillwater population (chi-square: $p > 0.05$). Alternatively, the historic residents of the Carson Sink region could be descendants of the Stillwater population if Al^{Me} became extinct in that region within the last millennium because of random genetic drift. Results of the present study simply cannot exclude the Numic speakers as descendants of the ancient Stillwater population.

We close by noting that technical advances make it increasingly possible to undertake studies of human paleogenetics—also known as "molecular archaeology"—using prehistoric human skeletal remains (cf. Rogan and Salvo, 1990). Albumin polymorphism represents an interesting but minute portion of the genetic variability present in the Stillwater skeletal samples that can be identified using new techniques (e.g., DNA amplification and sequencing: cf. Hagelberg et al., 1989; Pääbo et al., 1989; Rogan and Salvo, 1990; Kaestle, this volume). Because of the current demands for reburial of the Stillwater and other native human remains in North America, the pressure is on the scientific community to apply these new and developing techniques to address old, but nonetheless important, issues relating to population origins and history. We hope that studies of this type will demonstrate the value of these materials for understanding peoples of the past.

CHAPTER 5. MITOCHONDRIAL DNA EVIDENCE FOR THE IDENTITY OF THE DESCENDANTS OF THE PREHISTORIC STILLWATER MARSH POPULATION[1]

Frederika A. Kaestle

INTRODUCTION

The study of genetic material from ancient tissues, including human bone from archaeological settings, has facilitated our understanding of past population biology and history in ways unenvisioned just a decade ago. With the development of polymerase chain reaction (PCR) technology for the recovery and analysis of deoxyribonucleic acid (DNA), it has become possible to amplify millions of copies of DNA segments from single strands (see Herrmann and Hummel, 1993; Hagelberg, 1994). For the study of ancient human populations and for anthropology generally, this breakthrough provides possibilities for addressing long-standing issues and debates.

Recent studies have shown that certain mitochondrial DNA (mtDNA) mutations characterize at least three, and more likely four, distinct founding matrilines to which almost all Native Americans belong (Schurr et al., 1990; Torroni et al., 1992; Wallace and Torroni, 1992; Horai et al., 1993; Hagelberg, 1994). The frequencies of these matrilines vary significantly among modern Native American groups (Torroni et al., 1993; Lorenz and Smith, 1994) and, presumably, in ancient groups. This variability should be useful for identifying ancestor–descendant relationships (e.g., Hagelberg and Clegg, 1993). A 9-basepair (bp) deletion located between the genes for cytochrome oxidase II and lysine transfer RNA in mtDNA characterizes one of the surviving founding Native American matrilines, commonly known as lineage B (Torroni et al., 1993). The only report on the frequency of this deletion was in a large archaeological population of Native Americans from the late prehistoric (ca. A.D. 1300) Norris Farms #36 site, Illinois (Stone and Stoneking, 1993). Stone and Stoneking (1993) found that the 9-bp deletion was present in 10% (5 of 50) of the skeletons. They concluded that the frequencies of this and the other three matrilines in the Norris Farms group were "more similar to the Amerind (Paleoindian-derived) populations than to the Na-Dene (Athapascan) populations," in which the 9-bp deletion is completely absent (Stone and Stoneking, 1993: 468). However, they could not associate the archaeological group with any modern population because the frequency distribution of the founding matrilines among modern Native American tribes was not well known at the time of their analysis.

The present study uses the frequency of the 9-bp deletion to identify the descendants of an even older archaeologically defined group, namely from the Stillwater Marsh. For several reasons, the Stillwater skeletal sample lends itself to this form of analysis. First, bone residues from a significant number of individuals (N = 27) were available for analysis. Second, ^{14}C dating had been performed on six of the samples, which provided an estimate of the period represented—a corrected range of 270 B.C. to A.D. 1644 (see table 2-2). Third, the heterogeneous temporal and geographic distribution of sites where the 27 samples were excavated decreases the likelihood that stochastic changes in gene frequencies, such as those from genetic subdivision followed by genetic drift, could influence any inference regarding ancestor–descendant relationships. Examination of this particular population might answer a long-standing archaeological question concerning Great Basin cultural history: Who were the inhabitants of the Great Basin before the expansion of the ethnographic inhabitants (Numic speakers) into the region? Because most of the ancient samples pre-date 1000 B.P., which is the proposed date of the Numic spread, their affiliation with a modern Native American group should provide clues to the

[1] An earlier version of Chapter 5 was presented at the 1994 annual meeting of the American Association of Physical Anthropologists held in Denver, Colorado. It received the Aleš Hrdlička Award.

identity of the pre-Numic inhabitants of the Great Basin.

MATERIALS AND METHODS

Ancient DNA samples were extracted from bone residues that remained from a previous study of albumin phenotypes (Smith et al., this volume). These bone samples had been ground into a powder, deproteinized, and frozen at −20°C. For the present study, the bone residues were deproteinized again and phenol-chloroform was extracted. The mtDNA fragments of interest were amplified from concentrated extract using PCR, and those with the deletion (109 bp long) and without the deletion (118 bp long) were visualized under ultraviolet light after electrophoresis on polyacrylamide or agarose gels.[2]

In parallel with the Stillwater samples, DNA was extracted from five archaeological skeletal samples from Sacramento County, California, dating to between 2000 and 1500 B.P. (Bouey and Waechter, personal commun., 1993). These samples were excavated from site CA-SAC-133 (Slough House) and donated for analysis by the Far Western Anthropological Research Group. The fragment containing the site of the 9-bp deletion was amplified from these ancient DNA extracts using the procedures described above. Because the 9-bp deletion is absent in all of the researchers currently working in our laboratory facilities at the University of California, Davis, its detection in at least one ancient sample lends confidence to the assumptions that (1) the protocols employed can accurately detect the presence or absence of the 9-bp deletion in ancient samples, and (2) the ancient samples were not contaminated during extraction and amplification. However, these ancient Sacramento County samples were not subjected to the same albumin extraction protocols as were used for Stillwater bone residues. Therefore, the successful amplification of the deletion in one or more of the California samples cannot eliminate the possibility that the Stillwater samples were contaminated during the albumin extraction process.

To further test for contamination of the samples with modern DNA during the albumin extraction, a sexing technique described by Sullivan et al. (1993) that takes advantage of the presence of a 6-bp deletion in intron 1 of the amelogenin gene on the X chromosome, but not on the Y, was used. This technique, which is described in the analysis protocol,[2] uses PCR primers that amplify a 106-bp fragment when the X chromosome is used as template for PCR. Because the Y chromosome does not contain

[2] Details for protocol of extraction and identification of mtDNA are as follows: 100 μl of serum, one to three hair follicles, or 0.25 g of bone residue were incubated overnight at 37°C with proteinase K. Samples were phenol-extracted, phenol-chloroform (1:1)-extracted, and then chisam (24:1, chloroform : isoamylalcohol)-extracted. Modern samples were ethanol-precipitated and resuspended in autoclaved ddH_2O, whereas archaeological samples were concentrated with Centricon® 100 microconcentrators to about 50 μl, washed twice with autoclaved Tris-EDTA (TE, pH 8.0), and then reconcentrated to 50 μl. The fragment of the mtDNA region V containing the 9-bp deletion site was amplified using the polymerase chain reaction (PCR) with nested primers (external = 5'CCGGGGGTATACTACGG3' and 5'TTTCACTGTAAAGAGGTGTTGG3', internal = 5'ATGCTAAGTTAGCTTTACAG3' and 5'ACAGTTTCATGCCCATCGTC3'; Wrishnick et al., 1987). A single pair of primers (5'CCCTGGGCTCTGTAAAGAATAGTG3' and 5'ATCAGAGCTTAAACTGGGAAGCTG3'; Sullivan et al., 1993) was used to amplify a segment of intron 1 of the amelogenin gene on the sex chromosomes. Reactions were performed in 50–100-μl volumes with 5–10 μl of DNA extract or 1–5 μl external amplification product. Bovine serum albumin at a final concentration of 0.8 mg/ml was added to all archaeological DNA sample reactions, and 1% Triton® X-100 was added to the buffer used for all amelogenin amplifications. Amelogenin PCR reactions were performed with a hot start (Morin et al., 1994) using the same buffer in both portions of the reaction mix. Reactions were subjected to 35–40 cycles of 1 minute at 94°C, 1 minute at 50°C (55°C for amelogenin), and 1 minute at 72°C, with an initial denaturing of 3 minutes at 94°C and a terminal extension of 5 minutes at 72°C. Fifteen to 25 μl of the PCR products amplified using the region V internal primers were electrophoretically separated on a 4% agarose gel and stained using ethidium bromide to ascertain the presence or absence of the 9-bp deletion under ultraviolet light. Ten microliters of amelogenin product were electrophoretically separated on an 8% polyacrylamide gel and stained using ethidium bromide to visualize DNA bands under ultraviolet light.

the 6-bp deletion, a 112-bp fragment is amplified when it is used as template. Because a female possesses two copies of the X chromosome, both containing the 6-bp deletion, PCR products of only one length (106 bp) are amplified from female DNA. A sample from a male, containing both X and Y chromosomes, produces fragments of both the 106-bp and the 112-bp lengths when amplified. Thus, sex of the sample can be identified by electrophoresis on a polyacrylamide gel: samples with two bands are male; those with only one band are female. Because the Stillwater bones were handled extensively during the albumin extraction process by only a single individual, a male, contamination from this extraction process should result in the majority of samples testing male. However, if the amplified product is indeed representative of the ancient DNA sample, the genetic sex should usually agree with the osteologically determined sex for the sample (see table 4-1).

Most of the modern DNA samples studied were extracted from sera collected for various clinical tests or studies and have been described in earlier studies (Schurr et al., 1990; Torroni et al., 1992; Lorenz and Smith, 1994), although some of the California samples were obtained from hair follicles. When available, genealogical records or interviews with the subjects were used to eliminate samples that were not matrilineal members of the tribe they represented (Lorenz and Smith, 1994). In instances where the sample size of known phenotypes for some groups was small, analysis of additional modern samples was done by the author to increase the sample size.

The modern samples were sorted into both language groups and geographic regions for estimating and comparing frequencies of the 9-bp deletion. Language groups were compiled from three sources (Shipley, 1978; Jorgensen, 1980; Greenberg, 1987; but see Goddard and Campbell, 1994) and consist of eight subsets of three larger groups: Penutian, Hokan, and Uto-Aztecan (see table 5-1 and fig. 5-1). The samples were also sorted into the following three geographic regions: California, the Great Basin, and the Southwest (see table 5-1). These geographic regions follow Driver's (1961) geographic division of North America, with his "Baja California" and "Oasis" collapsed into the "Southwest." Comparisons of distributions of samples with and without the 9-bp deletion among all language groups and geographic regions and between pairs of language groups and geographic regions (see table 5-5) were made using the chi-square statistic with correction for continuity (Pagano and Gauvreau, 1992). Comparisons were not limited to those among language groups because the correlation between language or dialect and Mendelian populations is not always high (Campbell, 1986; Weiss and Woolford, 1986; Ruvolo, 1987; Goddard and Campbell, 1994; Lorenz and Smith, 1994). Moreover, there is evidence of considerable gene flow among unrelated language groups in the southwestern United States, but marked variation in frequency of the 9-bp deletion among geographic regions of North America (Lorenz and Smith, 1994).

The Athapascans were eliminated from consideration as descendants of the prehistoric Carson Stillwater population. They are not compared with the groups described above, because archaeological evidence suggests that they did not migrate into the southwestern United States until after 1000 B.P. and perhaps as late as 500 B.P. (Jorgensen, 1980; Greenberg et al., 1986). This probably postdates most of the Stillwater archaeological material. Additionally, Smith et al. (this volume) eliminated the Athapascans as probable descendants of the ancient Stillwater group because the Athapascans lack the albumin allele Al^{Me}, which is found at a high frequency in the ancient Stillwater group, and because the Athapascans carry the albumin allele Al^{Na}, which is absent in the ancient Stillwater group.

RESULTS

The PCR product containing the 9-bp deletion was reliably amplified using DNA extracted from 23 of the 27 ancient samples. Samples 14, 17, 25, and 26 (see table 4-1) did not amplify reliably. Therefore, they were excluded from the analysis. Of the reliably amplified samples, only one of these, specimen 1046-9 (sample 9, NSM catalog number 9-11-31 [b]), an adult male, possessed the 9-bp deletion. This represents a 9-bp deletion frequency of about 4% for the Stillwater series

TABLE 5-1
Amerind Samples Analyzed by Language Group, Subgroup, Tribe, and Geographic Region[a]

Group	Subgroup	Number	Region
Penutian	California Penutian	4 Costanoan (Ohlone)	California
		1 Miwok	California
		1 Wintun	California
		8 Yokut	California
	Zuni	20 Zuni	Southwest
Hokan	Northern Hokan	2 Karok	California
		1 Achumawi	California
		3 Pomo	California
	Yuman	5 Walapai	California
		5 Havasupai	Southwest
		5 Yavapai	Southwest
		8 Paipai	Southwest
		14 Quechan	Southwest
		3 Mojave	Southwest
		16 Kumiai	California
		3 Cocopa	Southwest
		3 Kiliwa	Southwest
		13 Cochimi	Southwest
	Washo	30 Washo	Great Basin
	Salinan-Seri	4 Salinan	California
		6 Chumash	California
Uto-Aztecan	Northern Uto-Aztecan (Shoshonean)	29 Paiute	Great Basin
		23 Shoshone	Great Basin
		1 Kawaiisu	California
		4 Tubatulabal	California
		4 Kitanemuk	California
		2 Gabrieleño	California
		2 Luiseño	California
		1 Cahuilla	California
		4 Hopi	Southwest
	Southern Uto-Aztecan (Sonoran)	38 Pima	Southwest

[a] Most samples tabulated are from Lorenz and Smith (1994); Pima samples are from Schurr et al. (1990) and Torroni et al. (1992); additional samples were also analyzed and included.

(see fig. 5-2). It is unlikely that this low frequency is from contamination that arose during the extraction or amplification process; that is, negative controls were run during both processes and extreme precautions were taken to avoid contamination (frequent changing of gloves, working in a hood, wearing a face mask, and autoclaving and ultraviolet-irradiating reagents). Moreover, the deletion was identified in four of five archaeological DNA samples from the Slough House site in Sacramento County, California, that were extracted and amplified in parallel with the Stillwater samples. This suggests that the protocols employed in this study allowed detection of the 9-bp deletion when it was present, and that contamination by modern DNA in the laboratory did not occur.

Finally, of five samples from which the amelogenin gene was successfully amplified (samples 8, 15, 16, 17, and 25 in table 4-1), there was no case of an osteologically determined female that tested genetically male. That no Y chromosomes were detected in archaeological female skeletons (samples 17 and 25) supports the conclusion that contamination did not occur during the processing of the bone for the Smith et al. (this volume) study of the albumin polymorphism. One individual (sample 15) was osteologically determined to be male but genetically determined to be female. However, given the po-

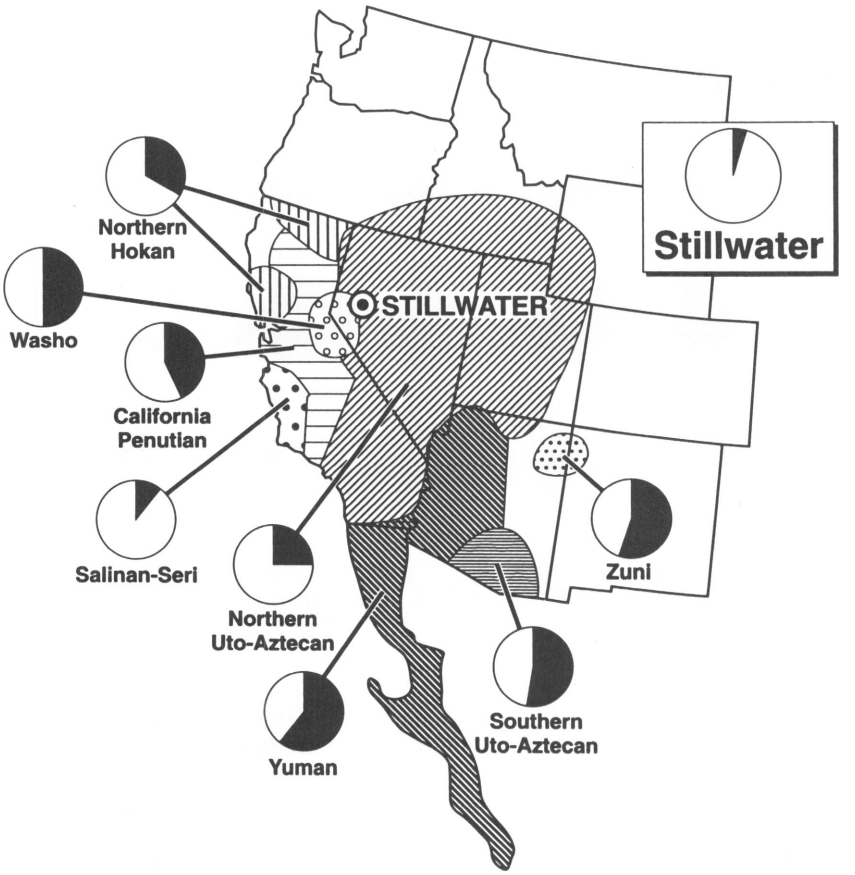

Fig. 5-1. Geographic distribution of modern language groups and their 9-bp deletion frequencies (represented by the dark portion of the pie charts).

tential for error in skeletal sexing, that only one female (F.A.K.) was present during the analysis, and that she took extreme precautions to avoid contamination, this single discrepancy is regarded as minor. Lastly, sample 8 was genetically determined to be female (osteological sex was indeterminate because of juvenile status), and sample 16 was genetically determined to be male (osteological sex was also male).

Estimates of the frequency of the 9-bp deletion in modern language groups varied from 0.11 in the Salinan-Seri to 0.60 in the Yuman (table 5-2, fig. 5-1). Estimates of the frequency of the 9-bp deletion in modern geographic groups were 0.30 in the Great Basin, 0.38 in California, and 0.58 in the Southwest (table 5-3). These estimates are similar to those reported by Lorenz and Smith (1994) because most of the samples employed for the estimates were reported in that study.

DISCUSSION AND CONCLUSIONS

It seems unlikely that the Stillwater population is ancestral to any modern language or geographic group with a very high frequency of the deletion. However, this inference assumes that the frequencies of the 9-bp deletion in modern tribal groups are the same as those in their ancestors. As mentioned above, the Norris Farms archaeological population revealed a deletion frequency of 10%. More recent studies (Lorenz and Smith, 1994) have shown that modern inhabitants of this and nearby regions—speakers of what Green-

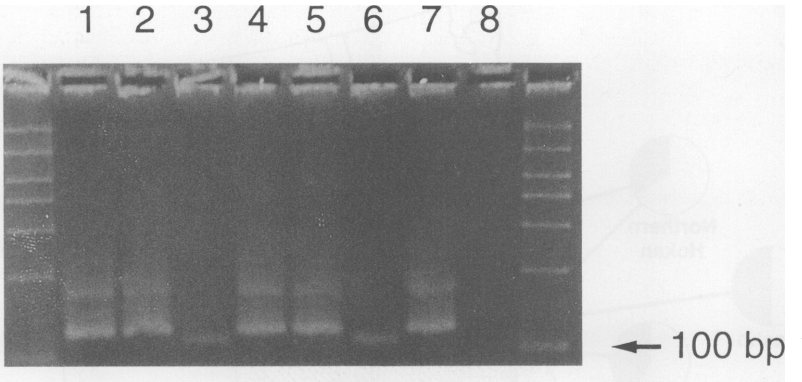

Fig. 5-2. PCR product for Stillwater skeletal samples (lanes 1–5), modern controls positive for the 9-bp deletion (lane 6) and negative for the 9-bp deletion (lane 7), and a negative amplification control (lane 8). Lanes 1 and 8 are flanked on either side by a size marker. Note that the Stillwater skeletal sample in lane 3 possesses the 9-bp deletion (see also table 5-2).

berg (1987) called Almosan-Keresiouan languages (but see Goddard and Campbell, 1994)—have a similar frequency for the deletion, about 8%. The frequency of the 9-bp deletion in the Norris Farms population is statistically significantly different from that of all modern Amerind groups other than Almosan-Keresiouan (chi-square: $p \leq 0.025$), with the exception of Northern Uto-Aztecan (see table 5-4). This outcome is consistent with the hypothesis that the Norris Farms population is ancestral to the extant population in that area, and suggests that the frequency of the 9-bp deletion has remained sufficiently stable, at least in the midwestern United States, to assess ancestor–descendant relationships.

The frequencies of the 9-bp deletion in the California Penutian, Zuni, Yuman, Washo, and Southern Uto-Aztecan language groups, as well as in all three geographic groups (see table 5-5), were significantly higher than that of the ancient Stillwater population (chi-square: $p \leq 0.025$). Thus, it can be concluded that unless sampling error or increases in the frequency of the 9-bp deletion over time in these groups has profoundly influenced the results of the present study, these groups can be eliminated from consideration as possible descendants of the ancient Stillwater popu-

TABLE 5-2
Nine-Basepair Deletion Frequencies in Modern Language Groups[a]

Language group	Subgroup	Sample size (N)	Number with deletion	Frequency
Penutian	California Penutian	14	6	0.43
	Zuni	20	11	0.55
Hokan	Northern Hokan	6	2	0.33
	Yuman	75	45	0.60
	Washo	30	15	0.50
	Salinan-Seri	9	1	0.11
Uto-Aztecan	Northern Uto-Aztecan	70	18	0.26
	Southern Uto-Aztecan	38	20	0.53

[a] Most samples tabulated are from Lorenz and Smith (1994); Pima samples are from Schurr et al. (1990) and Torroni et al. (1992); additional samples were also analyzed and included.

TABLE 5-3
Nine-Basepair Deletion Frequencies in Modern Geographic Regions[a]

Region	Sample size (N)	Number with deletion	Frequency
California	60	23	0.38
Great Basin	82	25	0.30
Southwest	121	70	0.58

[a] Most samples tabulated are from Lorenz and Smith (1994); Pima samples are from Schurr et al. (1990) and Torroni et al. (1992); additional samples were also analyzed and included.

TABLE 5-4
Homogeneity Test of Frequencies of Samples with and without the 9-bp Deletion between Norris Farms Population and Each Modern Language Group[a]

Modern language group	Number with deletion	Number without deletion	Chi-square (1 df)[b]
Almosan-Keresiouan	23	168	0.022
Penutian	33	88	5.13[c]
Hokan	52	46	24.18[d]
Kiowa-Tanoan	11	11	11.87[e]
Northern Uto-Aztecan	18	52	3.33
Southern Uto-Aztecan	20	18	17.23[d]

[a] Most samples tabulated are from Lorenz and Smith (1994); Pima samples are from Schurr et al. (1990) and Torroni et al. (1992); additional samples were also analyzed and included.

[b] Yates' correction (Pagano and Gavreau, 1992) employed to correct for small sample size.

[c] $p \leq 0.025$.

[d] $p \leq 0.0001$.

[e] $p \leq 0.001$.

TABLE 5-5
Homogeneity Test of Frequencies of Samples with and without the 9-bp Deletion between Stillwater Sample and Each Modern Language Group and Geographic Region[a]

	Number with deletion	Number without deletion	Chi-square (1 df)[b]
Modern Language Group			
California Penutian	6	8	6.34[c]
Zuni	11	9	11.25[d]
Northern Hokan	2	4	1.77
Yuman	45	30	19.73[e]
Washo	15	15	3.04[d]
Salinan-Seri	1	8	0.02
Northern Uto-Aztecan	18	52	3.62
Southern Uto-Aztecan	20	18	12.66[d]
Modern Geographic Region			
Great Basin	25	57	5.90[c]
California	23	37	7.88[c]
Southwest	70	51	19.89[e]

[a] Most samples tabulated are from Lorenz and Smith (1994); Pima samples are from Schurr et al. (1990) and Torroni et al. (1992); additional samples were also analyzed and included.

[b] Yates' correction (Pagano and Gavreau, 1992) employed to correct for small sample size.

[c] $p \leq 0.025$.

[d] $p \leq 0.001$.

[e] $p \leq 0.0001$.

lation. Smith et al. (this volume) also eliminated the California Penutian and Washo as possible descendants of the ancient Stillwater population because they lacked Al^{Me}. However, they suggested that the Yuman and/or Southern Uto-Aztecan groups are more likely to be affiliated with the ancient Stillwater group because both exhibit high frequencies of Al^{Me}. The present study does not appear to support their conclusion.

Frequencies of the 9-bp deletion in modern Native Americans and in the ancient Stillwater group suggest several inferences about ancestor–descendant relationships. First, the Stillwater skeletal population might be ancestral to the Northern Uto-Aztecan–speaking people because both share similar frequencies of the 9-bp deletion and the latter now inhabit territory previously occupied by the former. Thus, as for the Norris Farms skeletal population, genetic comparisons with extant populations provide no evidence of a population replacement. This is interesting because the Northern Uto-Aztecan language group is supposed to have *replaced* the ancient Stillwater population (Lamb, 1958; Bettinger and Baumhoff, 1982; Young and Bettinger, 1992). An explanation consistent with this inference is that the Numic expansion took place much earlier than is commonly believed, an hypothesis that has some supporters (Taylor, 1961; Hopkins, 1965; Crapo and Spykerman, 1979; Aikens and Witherspoon, 1986; Shaull, 1986). Therefore, according to this explanation, members of the ancient Stillwater population included in this study were Numic immigrants.

Alternatively, the Numic expansion might have involved the replacement of one Northern Uto-Aztecan group with another Northern Uto-Aztecan group, thereby rendering the replacement genetically invisible, or might not have involved replacement of any indigenous population at all; that is, the Numic groups might have developed in situ (see Swanson, 1962; Goss, 1977; Miller, 1986). However, the results from the Smith et al. study (this volume) and other studies of albumin phenotypes in modern Northern Uto-Aztecan tribes (Johnston et al., 1969; Smith et al., MS. b) suggest that the frequency of Al^{Me}

in modern Northern Uto-Aztecans is much lower than that among the ancient Stillwater people, thus decreasing the likelihood that they are closely related to the modern Northern Uto-Aztecan groups.

Second, speakers of Salinan-Seri and/or the Northern Hokan languages, whose albumin phenotypes have not been studied, could be descendants of the ancient Stillwater population. It is significant that historical narratives of the Northern Paiute, who currently inhabit the Stillwater area, identify the Achumawi/Atsugewi (members of the Northern Hokan language group) as the descendants of the pre-Numic inhabitants of the Great Basin (Stewart, 1939; Heizer, 1970).

Third, the direct descendants of the Stillwater population might be extinct, in which case the ancient group's resemblance to any modern group of Native Americans would be due to chance. If this explanation for the outcome of this study were correct, it should be possible to demonstrate that the frequencies of other genetic markers in modern Northern Uto-Aztecan, Northern Hokan, and Salinan-Seri groups differ from those of the ancient Stillwater population. Thus, this inference would be favored if the genetic characteristics of the ancient Stillwater population were found to differ from those of all living groups.

The above conclusions are based on several assumptions. First, the ancient samples are assumed not to have been contaminated. Careful precautions were taken to prevent contamination, and subsequent diagnostic tests failed to reveal evidence of any such contamination. Second, the ancient samples are assumed to represent one genetic group, despite the fact that they span a period of about 2000 years (Tuohy et al., 1987; Raven and Elston, 1988; Larsen, this volume). Third, the frequencies of the 9-bp deletion in modern populations are assumed to be reliable estimates of historic (and prehistoric) frequencies of the deletion in the ancestors of those populations. Although this assumption appears to hold true during recent prehistory for groups in the vicinity of the Norris Farms archaeological site, and perhaps more generally for groups speaking Almosan-Keresiouan languages, its applicability to populations in the southwestern United States that lived much earlier is problematic (Lorenz and Smith, 1994). Fourth, although some modern language groups whose deletion phenotype frequencies were compared with those of the ancient Stillwater population were represented by fewer than 20 members, and one, the crucial Northern Hokan sample, numbered only 6 members, the assumption was made that sampling error did not influence any inference drawn above. Additional samples will be acquired from the appropriate groups to confirm the conclusions described above. Finally, contemporary language or geographic groups are assumed to correlate sufficiently well with genetic groups such that the evolution of group composition has not rendered comparison of ancestral and descendant groups meaningless. This assumption may not be realistic because studies of distribution frequencies of the 9-bp deletion have revealed evidence of considerable admixture among unrelated groups in the southwestern United States (Lorenz and Smith, 1994). One valuable prospect of studies of ancient DNA is that some day we may be able to assess the validity of this assumption of ethnic continuity through time.

The present study is a preliminary exploration of possible ancestor–descendant relationships between the ancient Stillwater population and modern groups. It has provided several alternative hypotheses that can be tested using analyses of restriction fragment length polymorphism (RFLP) and sequence analyses of the mtDNA D-loop, a hypervariable region. Both of these methods have been shown to be informative when applied to modern Native American groups (Torroni et al., 1993). Additional studies now underway should produce a more precise characterization of both the ancient Stillwater group and the modern Native American groups under consideration, thereby allowing more reliable conclusions regarding ancestor–descendant relationships in the Great Basin.

CHAPTER 6. PHYSIOLOGICAL STRESS IN THE PREHISTORIC STILLWATER MARSH: EVIDENCE OF ENAMEL DEFECTS

Dale L. Hutchinson and Clark Spencer Larsen

INTRODUCTION

The study of stress has taken on increasing importance in the reconstruction of adaptation in both living and past human populations (Goodman et al., 1988). In this regard, stress has become central to developing a more comprehensive understanding of well-being and health in earlier human populations. Stress in this context has been defined as "the physiological disruption of an organism resulting from environmental perturbation" (Huss-Ashmore et al., 1982: 396). It is a product of three key factors, namely (1) environmental constraints, (2) cultural systems, and (3) host resistance (Goodman et al., 1984). The degree of stress experienced by human populations is related to both the severity of specific environmental stressors and the degree of host resistance (Huss-Ashmore et al., 1982). In normal circumstances, cultural systems influence these factors through their role as adaptive mechanisms.

The population examined for this analysis occupied, at least on a seasonal basis, an extensive marsh biome. Kelly (1985) has indicated that a special property of marshes as subsistence resource areas is their reliability in providing at least some foods throughout the year, although food availability may fluctuate (see Chapters 1 and 2). We suspect that stresses resulting from seasonal resource shortages were relatively infrequent, with the exception being years with either very low or very high amounts of precipitation. Because of the orographic effect of the Sierra Nevada mountain range located 100 km to the west, very little rain or snow falls on the Carson Desert (Raven and Elston, 1989). Therefore, most of the water is derived from the flow of the Carson and Humboldt Rivers, water courses that are dependent on the amount of winter snowfall and subsequent spring and summer snowmelt. The marshes potentially offer a wealth of plant and animal dietary resources. However, these resources vary considerably. For example, in years of very low snowfall in the Sierra Nevada Mountains, marsh shrinkage results in a loss of habitat for many animal species and a reduction in availability of economically important plants. Likewise, in years of unusually high snowfall, such as during the winter of 1982–1983, the resulting runoff can lead to inundation of the marshes and loss of resources. Raven and Elston (1989) noted, however, that flooding on the scale necessary for creation of large lakes and inundation most likely occurs once every century. Thus, it is unlikely that loss of dietary resources from high water is a major factor in explaining potential physiological stress in local populations.

This discussion reports on and assesses the degree of physiological stress in prehistoric human populations occupying the Stillwater Marsh to characterize health status and quality of life. Study of archaeological skeletal samples has provided a number of stress indicators in bones and teeth (Larsen, 1987; Goodman et al., 1988). Although many of these indicators reflect specific metabolic insults, others are reflective of more generalized stress. For the present study, we utilize enamel hypoplasias, an indicator of stress that reflects growth disruption occurring during the years of dental development. Hypoplasias are macroscopically visible, surface dental defects in enamel that result from disturbance of enamel formation during the initial stage of matrix deposition or production; they are represented as deficient enamel on an area or areas of the tooth crown (Hillson, 1986; Goodman and Rose, 1990). This deficiency can be manifested by circumferential pitting, linear furrowing (fig. 6-1), or, in extreme instances, lack of enamel (Sarnat and Schour, 1941; Bhaskar, 1986).

Various studies in both living and archaeological populations have demonstrated that increased exposure to environmental insults leads to elevated prevalence of enamel defects (Goodman and Rose, 1990; Santos, 1991; various authors in Goodman and Ca-

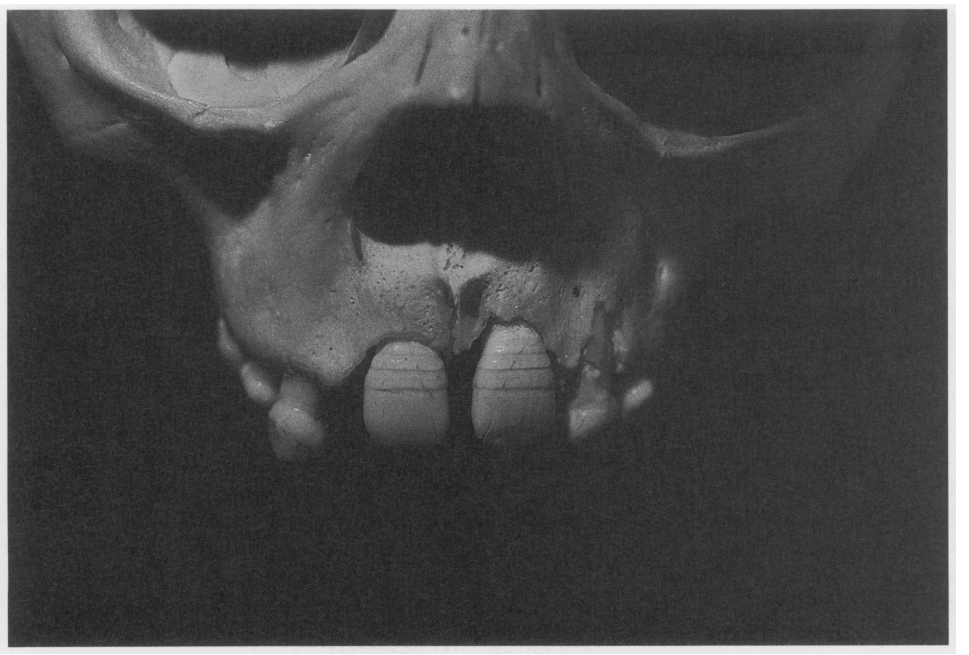

Fig. 6-1. Linear enamel hypoplasias on incompletely erupted permanent maxillary central incisors (anatomical specimen; not from Stillwater).

passo, 1992). Because enamel does not remodel once it is formed, nor is it lost except from excessive wear or pathological processes (e.g., caries), hypoplasias are permanent features of the tooth crown surface throughout the life of the individual. Therefore, hypoplastic dental defects represent an indelible record or "memory" of stress events during the years of dental development (Goodman et al., 1980; Hillson, 1986; Larsen, 1987; Goodman and Rose, 1990, 1991).

Because enamel is deposited in consecutive layers from the incisal/occlusal surface to the cervical region of the tooth, some investigators have suggested that hypoplasia widths provide reasonable quantification of duration of a stress event or series of events (Sarnat and Schour, 1941, 1942; Blakey and Armelagos, 1985; Hutchinson and Larsen, 1988, 1990; Simpson et al., 1990; Walker, MS.). In a standard textbook on oral pathology, Guita (1984) indicated that hypoplasia width bears a direct relationship to the length of the period of stress. Suckling et al. (1986; Suckling, 1989) argued, however, that severity of stress events plays a vital role in determining the width of hypoplastic lesions on tooth crowns. In research based on laboratory animals (sheep), they found that

> . . . a range of hypoplastic defects was produced in which the amount of missing enamel was related to the severity of the systemic reaction . . . [w]ith insults of increasing severity, fewer ameloblasts retained the capacity for complete or partial recovery of their normal activities. Thus, in sheep, hypoplastic lesions follow damage to the secretory cells by an insult of short duration, the extent and appearance of the affected enamel being determined by severity of the insult (Suckling et al., 1986: 432).

Thus, hypoplasia widths likely reflect either duration or severity (or both) of a stress episode occurring during the period of growth of the dental structures. Such chronological information makes the study of teeth especially valuable in assessment of health status and measurement of stress in earlier human populations.

MATERIALS AND METHODS

All available partial and complete dentitions excavated in the years 1985, 1986, and 1987 by the NSM and HSFS from the Still-

water Marsh, Nevada, were evaluated for suitability in this study. Only tooth crowns with intact labial/buccal surfaces were utilized for observation. Because tooth crown height reduction from occlusal wear results in elimination of enamel defects, teeth showing marked occlusal wear were removed from the sample. How much wear will affect the expression of enamel defects for any given tooth? Various workers have found a differential distribution of enamel defects within each tooth type (e.g., Cook, 1981; Milner, 1983; Goodman and Armelagos, 1985a, 1985b; Goodman, 1989; Condon and Rose, 1992). For example, Goodman's (1989) examination of hypoplasia distribution by crown location (incisal/occlusal one-third, middle one-third, cervical one-third) revealed that the incisal/occlusal one-third has the lowest frequency of defects (usually less than 25%), whereas the middle one-third has the highest frequency of defects (about 50%). Our analysis of defect distribution in the Stillwater series and other studies (e.g., Hutchinson and Larsen, 1988, 1990; Condon and Rose, 1992) confirm Goodman's observations. Therefore, to be included in our analysis of the Stillwater sample, dental elements must preserve at minimum the middle and cervical thirds of crown. We think that the data reported here closely approximate the true surface enamel defect profile of this population.

Because of the relatively greater susceptibility of anterior teeth to enamel disruption (Goodman and Rose, 1990), most workers have found that permanent incisors and canines offer the most information on enamel defects (see Goodman and Armelagos, 1985a, 1985b; Hutchinson and Larsen, 1988; Goodman and Rose, 1990; Condon and Rose, 1992). These findings also indicate that it is essential that data be reported for specific tooth type. Data reported by occurrence per individual or pooling of tooth types are not sufficient by themselves. Because of the greater amount of information for the anterior dentition, we limit the sample universe for this study to the 12 teeth comprising the anterior permanent dentition—maxillary and mandibular first incisors, second incisors, and canines. All data are reported by tooth type.

In total, 136 permanent teeth representing 39 individuals were judged suitable for inclusion in this study (table 6-1). Prior to observation, all available permanent maxillary and mandibular first incisors, second incisors, and canines were cleaned with acetone to remove debris that could obscure enamel defects. Hypoplasias were subsequently identified on the labial surfaces of teeth. Most dental defects were horizontal grooves, referred to as type 4 enamel developmental defects (FDI, 1982), although some were pits (type 3 defects). Our identification of hypoplasias was aided by use of a stereozoom, binocular microscope at a fixed power of approximately 10×. Unusually narrow hypoplasias were eliminated from the study because of the likelihood that they may not be true hypoplasias (cf. Goodman and Rose, 1990). Following identification of individual defects, the superior and inferior margins of individual hypoplasias were measured relative to the cementoenamel junction at the midsagittal plane of each tooth using a reticle with a fixed 0.1-mm measurement scale mounted in the eyepiece of the microscope. In an earlier investigation, we found that this method offers a more reliable estimate of hypoplasia width than the use of sliding calipers (see Hutchinson and Larsen, 1988, 1990; Larsen and Hutchinson, 1992).

In addition to recording the prevalence of hypoplasias in the Stillwater series, two measures of hypoplastic enamel were obtained following procedures developed for a previous study (Hutchinson and Larsen, 1988, 1990; Larsen and Hutchinson, 1992). First, the *area* of enamel hypoplasia was estimated for the defects. This measurement represents the total of hypoplastic enamel widths within half-year age intervals. For example, if two hypoplastic bands are present within a half-year interval, the widths from the superior to inferior margins are summed. This sum represents the area of hypoplastic activity covered on the tooth surface. Second, each hypoplastic *event* was measured. This is a measurement of the total width of continuous hypoplastic enamel, regardless of age boundary.

Age of hypoplasia occurrence for each tooth affected was determined within half-year intervals utilizing the developmental chronology of Massler et al. (1941) and modified for

TABLE 6-1
Data Used in Stillwater Hypoplasia Analysis

Specimen	Tooth[a]	Wear[b]	Event[c]	Age[d]	Area[e]
1043-1	^{1}C	3	0	0	0
1043-1	I^{1}	3	0	0	0
1043-5	$_{1}$I	4	0	0	0
1043-5	$_{2}$I	3	0	0	0
1043-5	$_{1}$C	4	0	0	0
1043-5	^{1}I	4	0	0	0
1043-5	^{2}I	3	0	0	0
1043-5	^{1}C	4	0	0	0
1043-7	I_1	3	0	0	0
1043-7	I_2	3	0	0	0
1043-7	C_1	3	0.8	2.5	0.7
1043-7	C^{1}	3	0	3.0	0.1
1043-7	C_1	3	0.6	3.0	0.6
1043-7	^{1}I	3	0.1	4.0	0.1
1043-7	^{1}I	3	0.1	4.0	0.1
1043-7	^{1}I	3	0.3	3.0	0.3
1043-7	^{2}I	3	0	0	0
1043-7	^{1}C	3	0	0	0
1043-37	I_2	3	0	0	0
1043-37	C_1	3	0	0	0
1043-37	^{1}I	3	0	0	0
1043-37	^{1}C	3	0	0	0
1044-1	$_{1}$I	3	0	0	0
1044-1	$_{2}$I	3	0.3	3.0	0.2
1044-1	$_{2}$I	3	0	3.5	0.1
1044-1	$_{1}$C	3	0.9	3.5	0.1
1044-1	$_{1}$C	3	0	4.0	0.7
1044-1	$_{1}$C	3	0	4.5	0.1
1044-1	$_{1}$C	3	0.8	5.0	0.4
1044-1	$_{1}$C	3	0	5.5	0.4
1044-1	^{1}I	3	0	0	0
1044-1	I^{2}	3	0	4.0	0.4
1044-1	I^{2}	3	1.0	3.5	0.6
1044-1	C^{1}	3	1.0	3.5	0.5
1044-1	C^{1}	3	0	4.0	0.5
1044-2	^{1}I	3	0	0	0
1044-2	^{2}I	3	0.1	4.0	0.1
1044-2	^{2}I	3	0.1	4.0	0.1
1044-2	^{1}C	3	0.1	5.0	0.1
1045-1	I_2	3	0.3	3.0	0.3
1045-1	C_1	3	0.3	4.0	0.3
1045-1	C_1	3	0.4	4.5	0.4
1045-1	^{2}I	3	0.2	5.5	0.2
1045-1	^{1}C	3	0.2	4.0	0.2
1046-2A	$_{1}$I	3	0	0	0
1046-2A	$_{2}$I	3	0.5	3.0	0.5
1046-2A	$_{1}$C	2	0.6	3.5	0.6
1046-2A	$_{1}$C	2	0.3	4.0	0.3
1046-2A	$_{1}$C	2	0.3	5.0	0.2
1046-2A	$_{1}$C	2	0	5.5	0.1

TABLE 6-1—(*Continued*)

Specimen	Tooth[a]	Wear[b]	Event[c]	Age[d]	Area[e]
1046-2A	^{2}I	3	0.2	3.0	0.2
1046-2A	^{2}I	3	0.7	3.5	0.7
1046-2A	^{2}I	3	0.2	4.0	0.2
1046-2A	^{1}C	3	0.2	3.5	0.2
1046-2A	^{1}C	3	0.1	4.5	0.1
1046-2A	^{1}C	3	0.2	5.0	0.2
1046-2B	$_{1}$I	3	0	0	0
1046-2B	$_{2}$I	3	0.2	2.0	0.2
1046-2B	$_{1}$C	3	0.5	4.0	0.5
1046-2B	$_{1}$C	3	0.1	4.5	0.1
1046-2B	$_{1}$C	3	0.1	5.0	0.1
1046-2B	^{1}I	3	0.6	2.0	0.6
1046-2B	^{1}I	3	0	1.5	0.2
1046-2B	^{1}I	3	0.5	1.0	0.3
1046-2B	^{2}I	3	0.1	3.0	0.1
1046-2B	^{2}I	3	0.1	3.5	0.1
1046-2B	^{1}C	3	0.2	2.0	0.2
1046-2B	^{1}C	3	0.2	3.5	0.2
1046-9	$_{1}$I	4	0	0	0
1046-9	$_{2}$I	4	0	0	0
1046-9	$_{1}$C	4	0	0	0
1046-9	^{1}I	4	0.6	2.5	0.6
1046-9	^{1}I	4	0.8	3.0	0.8
1046-9	^{2}I	3	0.1	3.0	0.1
1046-9	^{2}I	3	0.2	3.5	0.2
1046-9B	^{1}C	3	0	0	0
1047-1	^{1}C	3	0.7	0.5	0.4
1047-1	^{1}C	3	0	1.0	0.3
1047-1	^{1}C	3	0.7	3.5	0.5
1047-1	^{1}C	3	0	4.0	0.2
1047-1	I^{2}	3	0	0	0
1049-3	^{1}I	3	0	0	0
1049-3	^{1}C	3	0	0	0
1050-1	$_{1}$I	3	0	0	0
1050-1	$_{2}$I	3	0	0	0
1050-1	$_{1}$C	3	0.3	4.5	0.2
1050-1	$_{1}$C	3	0	5.0	0.1
1050-1	C^{1}	3	1.3	3.0	0.7
1050-1	C^{1}	3	0	3.5	0.6
1050-1	C^{1}	3	0.8	4.0	0.6
1050-1	C^{1}	3	0	4.5	0.2
1050-2	^{1}I	3	0	0	0
1050-2	^{2}I	3	0	0	0
1050-2	C^{1}	3	0	0	0
1054-1	$_{1}$I	3	0	0	0
1054-1	$_{1}$C	3	0.1	3.0	0.1
1054-1	$_{1}$C	3	0.2	3.0	0.2
1054-1	$_{1}$C	3	0.2	3.5	0.2
1054-1	$_{1}$C	3	0.2	4.0	0.2
1054-1	^{1}I	3	0.2	2.5	0.2
1054-1	^{1}I	3	0.2	3.0	0.2

TABLE 6-1—(*Continued*)

Specimen	Tooth[a]	Wear[b]	Event[c]	Age[d]	Area[e]
1054-1	^{1}I	3	0.2	3.5	0.2
1054-1	^{2}I	3	0	0	0
1054-1	^{1}C	3	0.2	3.5	0.2
1054-1	^{1}C	3	0.2	4.0	0.1
1054-1	^{1}C	3	0	4.5	0.1
1055-1	$_{2}$I	3	0	0	0
1055-1	$_{1}$C	3	0	0	0
1055-1	I_{1}	3	0	0	0
1055-1	^{1}C	3	0	0	0
1055-1	I^{1}	3	0	0	0
1056-1	$_{2}$I	3	0	0	0
1056-1	$_{1}$C	3	0	0	0
1058-1	$_{2}$I	3	1.7	2.0	1.0
1058-1	$_{2}$I	3	0	2.5	0.7
1058-1	$_{1}$C	3	0	0	0
1058-1	I_{1}	3	0.3	1.5	0.3
1058-1	I_{1}	3	0.3	2.0	0.3
1058-1	I^{1}	3	1.3	2.5	1.2
1058-1	I^{1}	3	0	3.0	0.1
1058-1	I^{2}	4	0	0	0
1058-1	C^{1}	3	0.3	2.5	0.1
1058-1	C^{1}	3	0	3.0	0.2
1058-1	C^{1}	3	0.4	3.0	0.4
1058-1	C^{1}	3	0.4	3.5	0.4
1058-211	I_{1}	2	0.1	1.5	0.1
1058-211	I_{2}	2	0	0	0
1058-211	I^{1}	2	0.2	2.0	0.2
1058-211	I^{1}	2	0.2	2.5	0.2
910-1-8A	^{2}I	4	0	0	0
910-1-8A	^{1}C	4	0	0	0
910-1-8A	I^{1}	3	0	0	0
910-23	^{2}I	3	0.3	3.0	0.3
910-23	I^{1}	3	0.3	2.5	0.3
910-23	I^{1}	3	0.2	3.5	0.2
910-23	C^{1}	3	0	0	0
910-201	$_{1}$C	3	0	5.0	0.2
910-201	$_{1}$C	3	0.6	5.5	0.4
1062-1	^{1}I	3	0.3	3.0	0.3
1062-1	^{2}I	3	0	0	0
1062-1	^{1}C	3	0	0	0
1062-205	C_{1}	3	0	0	0
1062-205	^{1}I	3	0	0	0
1063-19,20	$_{1}$I	4	0	0	0
1063-19,20	$_{2}$I	4	0	0	0
1063-19,20	$_{1}$C	4	0	0	0
1063-19,20	^{1}I	3	0	0	0
1063-19,20	^{2}I	3	0.3	3.5	0.3
1063-19,20	^{1}C	3	0	0	0
1068-6	C^{1}	3	0.5	5.0	0.5
1070-3	$_{1}$I	4	0	0	0
1070-3	$_{2}$I	4	0	0	0

TABLE 6-1—(*Continued*)

Specimen	Tooth[a]	Wear[b]	Event[c]	Age[d]	Area[e]
1070-3	$_{1}$C	4	0	0	0
1070-3	^{1}I	3	0	0	0
1070-3	^{2}I	3	0	0	0
1070-3	^{1}C	3	0	0	0
1159-4	$_{2}$I	4	0	0	0
1159-4	$_{1}$C	3	0.2	4.0	0.1
1159-4	$_{1}$C	3	0	4.5	0.1
1159-4	$_{1}$C	3	0.2	4.5	0.2
1159-7	$_{1}$I	3	0	0	0
1159-7	$_{1}$C	3	0	0	0
1159-7	C^{1}	3	0	0	0
1159-200	^{1}I	3	0.1	3.0	0.1
L53-B-1	$_{2}$I	4	0	0	0
L53-B-1	$_{1}$C	3	0	0	0
L53-B-1	^{1}I	3	0	0	0
L53-B-1	^{1}C	3	0	0	0
L53-B-1	I^{1}	3	0	0	0
L53-B-1	I^{2}	3	0	0	0
1160-1-1	^{1}I	3	1.6	3.0	1.6
1160-1-1	^{2}I	3	0	0	0
1160-1-1	^{1}C	3	0	0	0
1160-18	^{1}I	4	0	0	0
1160-18	^{2}I	3	0	0	0
1160-18	^{1}C	3	0	0	0
1160-62-2	$_{1}$I	3	0	0	0
1160-62-2	$_{2}$I	3	0	0	0
1160-62-2	$_{1}$C	3	0.5	3.0	0.5
1160-62-2	$_{1}$C	3	0	3.0	0.1
1160-62-2	$_{1}$C	3	1.0	3.5	0.9
1160-62-2	$_{1}$C	3	0	4.0	0.3
1160-62-2	$_{1}$C	3	1.0	4.5	0.7
1160-64-1	^{2}I	6	0	0	0
1160-64-1	^{1}C	6	0	0	0
1160-64-1	C^{1}	3	0.2	3.5	0.2
1249-1	C_{1}	3	0.4	5.5	0.3
1249-1	C_{1}	3	0	6.0	0.1
1173-200	I_{1}	3	0	0	0
1173-200	I_{2}	3	0	0	0
1173-200	^{1}I	3	0	0	0
1173-200	^{2}I	3	0.1	4.0	0.1
1173-200	^{1}C	3	0	0	0
L111-200	$_{1}$C	2	0.3	4.0	0.3
L111-200	$_{1}$C	2	0.5	4.5	0.4
L111-200	$_{1}$C	2	0	5.0	0.1
L111-200	^{1}I	2	0.3	2.0	0.3
L111-200	^{1}I	2	0.2	2.5	0.2
L111-200	^{1}I	2	0.1	3.0	0.1
L111-200	^{1}I	2	0.1	3.0	0.1
L111-200	^{1}I	2	0.1	3.0	0.1
L111-200	^{1}I	2	1.0	3.5	0.9
L111-200	^{1}I	2	0	4.0	0.1

TABLE 6-1—(*Continued*)

Specimen	Tooth[a]	Wear[b]	Event[c]	Age[d]	Area[e]
L111-200	^{2}I	2	0.3	3.5	0.3
L111-200	^{2}I	2	0.4	4.0	0.4

[a] I^1 = maxillary right central incisor; I^2 = maxillary right lateral incisor; C^1 = maxillary right canine; ^{1}I = maxillary left central incisor; ^{2}I = maxillary left lateral incisor; ^{1}C = maxillary left canine; I_1 = mandibular right central incisor; I_2 = mandibular right lateral incisor; C_1 = mandibular right canine; $_{1}$I = mandibular left central incisor; $_{2}$I = mandibular left lateral incisor; $_{1}$C = mandibular left canine.

[b] 1 = unworn; 2 = slight wear; 3 = worn; 4 = significant enamel exposure; 5 = heavy wear; 6 = extreme wear.

[c] Width of a discrete hypoplasia, regardless of age boundary.

[d] Age category of hypoplasia occurrence; the number refers to the low end of the age range of the age category (e.g., 3.0 refers to the 3.0–3.5 age category).

[e] Width of hypoplasia or hypoplasias contained within a half-year age group.

use in hypoplasia research by Swärdstedt (1966) and Goodman et al. (1980; see also Goodman, 1989; Goodman and Rose, 1990, 1991; Santos, 1991; Blakey et al., 1994). This approach involves dividing the tooth crown into a series of increments corresponding to half-year development intervals and then relating the hypoplastic event to a specific developmental age. The method assumes a constant velocity of enamel development until data are provided that indicate otherwise (Goodman and Rose, 1991). Importantly, this chronological estimation for defects is indicative of developmental *dental* age of the tooth relative to a single standard. There most certainly is a range of developmental variability in human populations that is likely related to many different circumstances, including genetic factors and degree of metabolic stress (Goodman, 1989). However, use of the Massler et al. (1941) standard is warranted because of general agreement with other standards and the availability of data on all teeth, deciduous and permanent (Goodman and Rose, 1990).

Additionally, this approach has been applied to a number of archaeological populations using the same standard of determination of age at stress. Thus, a literature exists whereby various workers have reported on

TABLE 6-2
Enamel Hypoplasias in Stillwater Dentitions

Tooth type	N[a]	Prevalence (%)	Area (mm)	Width (mm)
Mandible				
I1	16	13	0.23	0.23
I2	19	26	0.43	0.60
C	23	52	0.32	0.44
Maxilla				
I1	26	42	0.36	0.40
I2	23	43	0.26	0.28
C	29	38	0.30	0.42

[a] n = number of teeth examined per tooth type.

hypoplasia age patterns using the same dental developmental standard. This method also has the benefit of examination of the varying ages at which a particular tooth type is subject to hypoplasia (see Suckling et al., 1983; Goodman and Armelagos, 1985a, 1985b). Still, it is important to add the proviso that other factors, principally tooth size (especially crown height), can influence the position of the enamel defect on the tooth crown, and therefore the determination of age at stress (Hodges and Wilkinson, 1990).

To avoid duplication of hypoplastic events through the use of paired teeth, only teeth from the left side of the dentition were examined. In the case of a missing tooth, the antimere was substituted when available. Results in this study are reported by individual tooth types because of the apparent differential susceptibility and timing of hypoplastic defects within the tooth row (see Goodman and Armelagos, 1985a, 1985b). To compare the results of age at stress with other samples, we have not applied a size correction (cf. Hodges and Wilkinson, 1990).

RESULTS

Two-thirds of individuals in this study possessed at least one hypoplastic defect (minimum of one tooth with one hypoplasia). The frequency (percent), areas, and event widths of these developmental defects in incisors and canines are presented in table 6-2 and figures 6-2, 6-3, and 6-4. These data show that the mandibular canine exhibits the highest percentage of affected teeth (52%), where-

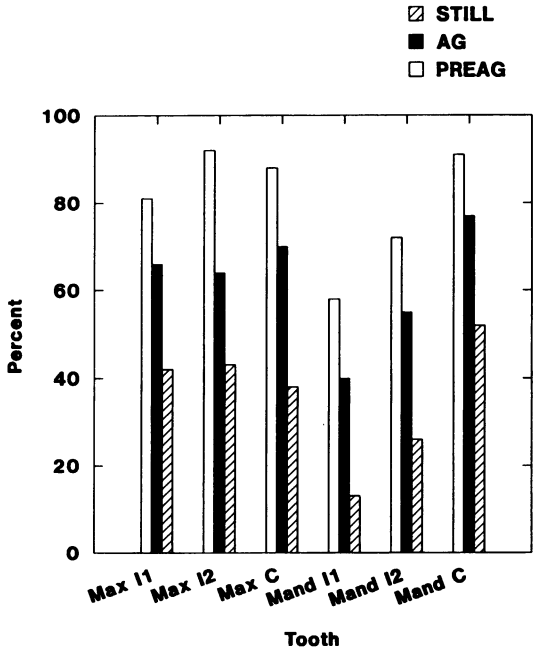

Fig. 6-2. Hypoplasia frequency (% per tooth type) of Stillwater (STILL) individuals compared with Georgia coastal hunter-gatherers (PREAG) and agriculturalists (AG).

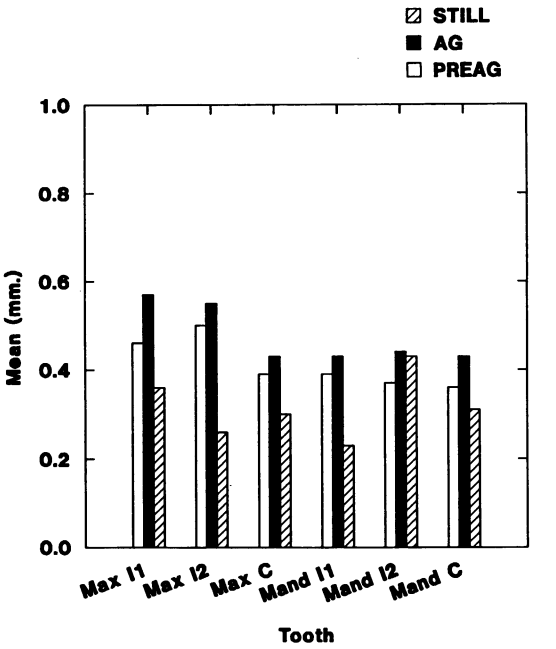

Fig. 6-3. Hypoplasia areas (mm) in Stillwater (STILL) individuals compared with Georgia coastal hunter-gatherers (PREAG) and agriculturalists (AG).

as the mandibular first incisor exhibits the lowest percentage (13%). Measurement of hypoplasias reveals that the mandibular first incisor has the smallest area (0.23 mm) and the mandibular second incisor has the largest area (0.43 mm). Similarly, hypoplasia width is smallest in the mandibular first incisor (0.23 mm) and largest in the mandibular second incisor (0.6 mm).

To evaluate the relative degree of physiological stress, we compared hypoplasia prevalence for the Stillwater series with two prehistoric dental series from the Georgia coast region that were analyzed by the same methods (see Hutchinson and Larsen 1988, 1990). The Georgia coastal samples included a series of dentitions representing human populations dependent on a foraging lifeway (pre-A.D. 1150), and a second series of dentitions representing a population dependent, at least in part, on maize agriculture (A.D. 1150–1450). The latter sample is from the Irene Mound site, the largest Mississippian period locality on the Georgia coast (Caldwell and McCann, 1941; Larsen, 1982, 1984; Powell,

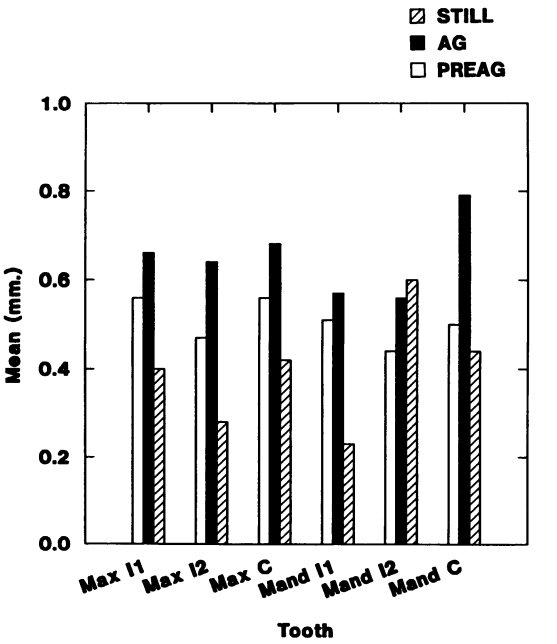

Fig. 6-4. Hypoplasia event widths (mm) in Stillwater (STILL) individuals compared with Georgia coastal hunter-gatherers (PREAG) and agriculturalists (AG).

TABLE 6-3
Hypoplasias in Preagricultural and Agricultural Georgia Coastal[a] and Stillwater Dentitions

Tooth	Prevalence (%)			Area (mm)			Width (mm)		
	Preagri-culture	Agri-culture	Still-water	Preagri-culture	Agri-culture	Still-water	Preagri-culture	Agri-culture	Still-water
Mandible									
I1	58	40	13	0.39	0.43	0.23	0.51	0.57	0.23
I2	72	55	26	0.37	0.44	0.43	0.44	0.56	0.60
C	91	77	52	0.36	0.43	0.32	0.50	0.79	0.44
Maxilla									
I1	81	66	42	0.48	0.57	0.36	0.56	0.70	0.40
I2	92	64	43	0.50	0.55	0.26	0.47	0.64	0.28
C	88	70	38	0.39	0.43	0.30	0.56	0.68	0.42

[a] Data from Hutchinson and Larsen (1990).

1990). In earlier studies, we demonstrated that the Georgia coastal prehistoric agriculturalists experienced generally higher stress levels than the preagriculturalists, in part from reduced quality of nutrition and elevated nonspecific and specific disease loads (Larsen, 1982, 1990; Powell, 1990). Although the prehistoric populations occupying the Georgia coast followed markedly different lifeways than those occupying the western Great Basin, they nevertheless offer a basis for comparing levels of physiological disruption. Ide-

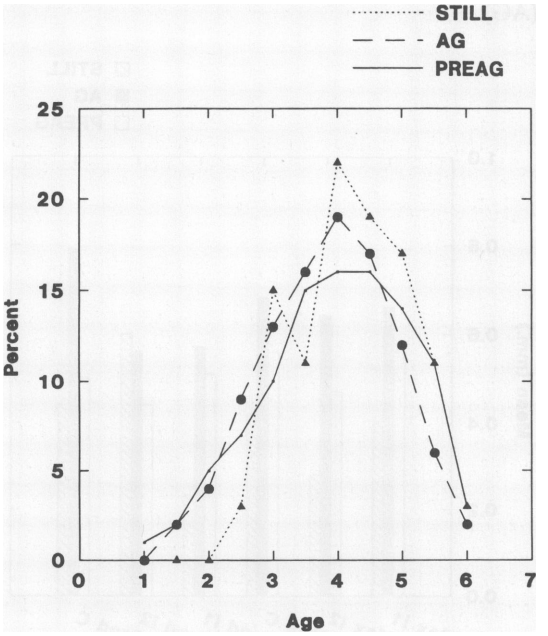

Fig. 6-5. Stillwater (STILL) hypoplasia frequencies (% per half-year age group—1.0–1.5, 1.5–2.0, 2.0–2.5, 2.5–3.0, 3.0–3.5, 3.5–4.0, 4.0–4.5, 4.5–5.0, 5.0–5.5, 5.5–6.0) compared with Georgia coastal hunter-gatherers (PREAG) and agriculturalists (AG): mandibular canine.

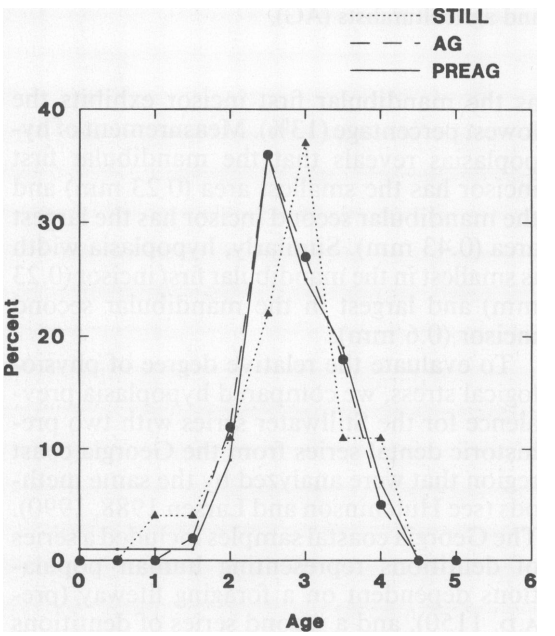

Fig. 6-6. Stillwater (STILL) hypoplasia frequencies (% per half-year age group—1.0–1.5, 1.5–2.0, 2.0–2.5, 2.5–3.0, 3.0–3.5, 3.5–4.0, 4.0–4.5, 4.5–5.0, 5.0–5.5, 5.5–6.0) compared with Georgia coastal hunter-gatherers (PREAG) and agriculturalists (AG): maxillary central incisor.

TABLE 6-4
Individuals Affected by Hypoplasia in Selected Archaeological and Fossil Hominid Populations[a]

Source	Period/diet	Frequency (%)
This study	Hunter–gatherer	64
Cassidy, 1984	Archaic	86–94
	Mississippian	73–91
Goodman, 1989	Late Woodland	45
	Late Woodland/Mississippian	60
	Mississippian	80
Milner, 1982	Mississippian	90
Patterson, 1984	Initial agricultural	67
	Agricultural	79
Perzigian et al., 1984	Late Archaic	20
	Mississippian	60
Murray, 1989	Historic	96
Powell, 1988	Mississippian	54
Powell, 1989	Mississippian	90
Sciulli, 1978	Mixed economy	30
	Agricultural	52
Schulz and McHenry, 1975	Hunter-gatherer	16
Mack and Coppa, 1992	Hunter-gatherer (Oman)	99
Yamamoto, 1992	Historic (Edo)	65
Hall and Browman, 1992	Historic (England)	42
Lanphear, 1990	Historic	70–73
Blakey et al., 1994	Historic	89
Molnar and Molnar, 1985	Mousterian (Old World)	72
Ogilvie et al., 1989	Mousterian (Old World)	57

[a] All data are from sites in North America unless otherwise indicated.

ally, samples from other western U.S. burial populations would represent a more meaningful comparison (e.g., Martin et al., 1991). However, no other western U.S. series has been studied using these techniques, especially regarding comparisons of enamel widths.

Comparison of the Stillwater series with the two prehistoric Georgia coastal samples shows clear differences between them in virtually all comparisons (table 6-3). First, hypoplasia prevalence for each of the six teeth shows lower values for the Stillwater series relative to the two Georgia coastal samples. Second, comparison of measurements for both area and event indicates that virtually all Stillwater tooth types have narrower widths than Georgia coastal tooth types. One tooth only, the mandibular second incisor, has a greater event width in the Stillwater sample than in the Georgia coastal sample.

The developmental distribution of the hypoplasias in the Stillwater and Georgia coastal series are illustrated for the mandibular canine and maxillary first incisor in figures 6-5 and 6-6, respectively. These data show that like the Georgia coastal hunter-gatherers and agriculturalists, hypoplasias peak between 3 and 4 years of age.

DISCUSSION AND CONCLUSIONS

Comparisons between the Stillwater series and other archaeological samples (see table 6-4) indicate that physiological stress was not rampant (cf. Murray, 1989; Mack and Coppa, 1992; Blakey et al., 1994) or infrequent (cf. Schulz and McHenry, 1975; Ubelaker, 1992). Moreover, when compared with the Georgia coastal samples, which represent a variety of subsistence economies that ranged from exclusively hunting and gathering early in prehistory to partial agricultural dependence late in prehistory, the Stillwater series shows relatively lower hypoplasia prevalence. Overall, however, the Stillwater prevalence (64%) is moderately high and even exceeds some of the Mississippian Period samples from the eastern United States that likely represent

populations that experienced relatively elevated stress levels. Thus, although physiological stress was not severe in the Stillwater Marsh populations, it was nevertheless present. However, some of the variability that we observed in hypoplasia prevalence may result from how data were collected. The Stillwater data were collected with the use of a low-power microscope, whereas most other investigators rely on observation procedures not involving magnification. Nevertheless, we have no reason to think that the use of low-power magnification explains the range of values presented in table 6-4.

Many direct associations have been made between hypoplastic defects and nutritional disorders, disease, or other factors that predispose individuals to physiological perturbation, such as low birthweight and socioeconomic status (see Pindborg, 1982; Goodman et al., 1984, 1987, 1991; Goodman, 1989; Goodman and Rose, 1991; Rose et al., 1985; Hillson, 1986; Hutchinson and Larsen, 1990; Seow, 1992; Lukacs and Joshi, 1992; Goodman et al., 1992). Laboratory studies have shown that hypoplasia can be induced by alloxan diabetes (Kreshover and Clough, 1953a), fever (Kreshover and Clough, 1953b), and parasitic infection (Suckling et al., 1983, 1986; Suckling and Thurley, 1984), among other factors. We have argued elsewhere that both malnutrition and disease in combination likely lead to hypoplasia (see Hutchinson and Larsen, 1988, 1990). Malnutrition and infectious disease are generally characterized by a synergistic relationship (Scrimshaw et al., 1968). That is, poor nutrition, especially protein deficiency, will lower an individual's resistance to infection and depress the cell-mediated immune response (Mims, 1982; Hoffman-Goetz, 1986). Infectious disease interferes with nutrition by altering absorption in the digestive system and increasing the physiological need for nutrients, especially protein. Consequently, when an organism is placed under stress, it will either slow or cease growth while nutrients are used to combat stress (Acheson, 1960).

Most attempts to link specific diseases or dietary insufficiencies with enamel defects in archaeological human populations have been only marginally successful (see Goodman and Rose, 1990; Santos, 1991). Consequently, researchers generally follow the conservative approach taken by Kreshover (1960) in recognizing that hypoplasias are nonspecific or general indicators of metabolic stress that result from nutritional deficiencies or disease (or both).

Enamel is highly sensitive to disruptions during its development (Hillson, 1986). Disruptions that could have affected the developing dental hard tissues in the Stillwater series include either genetic disorders (e.g., Witkop, 1970) or environmentally based disruptions. Regarding the latter, trauma (e.g., Skinner and Hung, 1989), stresses associated with birth (e.g., Sweeney et al., 1971), infectious diseases (e.g., Sarnat and Schour, 1941, 1942; Pindborg, 1970), and malnutrition (e.g., Molnar and Ward, 1975; Goodman et al., 1991) have been linked to hypoplasia. For most human populations, it is unlikely that many of these defects are caused by localized trauma, because in most instances trauma is readily identifiable in skeletal remains (Cook, 1980; Goodman, 1989; Goodman and Rose, 1990). Ogilvie et al. (1989) have pointed out that genetic problems with a selective disadvantage would have been removed from the gene pool. Thus, it is unlikely that trauma or genetic disorders are primary factors in explaining hypoplasia at Stillwater.

Many infectious diseases have been tied to hypoplasias (Pindborg, 1982). In the Great Basin in general, however, skeletal pathologies that reflect infectious conditions are infrequent (e.g., Stark and Brooks, 1985; Larsen, unpubl. data). Most osseous infections observed for this region are localized bone infections that likely did not lead to systemic perturbation and defective enamel development. Moreover, specific infections linked to hypoplasia (e.g., mycobacterial infections such as tuberculosis [Kreshover, 1944]) may not have existed in these populations prior to European contact in the 19th century. However, this is speculative because a tuberculosis-like disease was present in other areas of North America prior to European contact (e.g., Powell, 1990).

Consistent with these observations for the Great Basin generally is a low prevalence of nonspecific infectious lesions (called periosteal reactions) on the tibiae in the Stillwater series. Examination of data presented in table

6-5 shows that of the available Stillwater tibiae, only 15.5% (13/84) exhibit periosteal reactions (left tibiae = 11.9% [5/42]; right tibiae = 19.1% [8/42]). This sample is represented by a minimum of 61 skeletal individuals, of which 10 (16.4%) have at least one periosteal reaction. These prevalences—based on either number of skeletal elements or individuals affected—are either lower than or similar to other North American hunter-gatherer skeletal series studied in the American Midwest (e.g., Cassidy, 1984; Cook, 1984), Southeast (e.g., Rose et al., 1984), South America (e.g., Ubelaker, 1984), Australia (Webb, 1989, 1995), or Japan (Suzuki, 1991). Moreover, the prevalence in the Stillwater sample is generally lower than late prehistoric agriculturalists studied from other mortuary contexts throughout North America (e.g., Lallo et al., 1978; Cassidy, 1984; Cook, 1984; Rose et al., 1984; Milner and Smith, 1990; Stodder, 1990, 1994; Martin et al., 1991; Milner, 1991; but see Larsen, 1982; Larsen and Harn, 1994).

The specific cause of these infections in the Stillwater sites is unclear. One individual (1159-6), an adult male, shows widespread infection that includes virtually all of the major long bones. Most or all of the diaphyses of the left and right tibiae, fibulae, and right femur show extensive remodeling. The other elements affected (right clavicle, left ulna, right radius, right femur) show localized patches of periosteal reactions. All other infectious lesions observed in the Stillwater skeletal remains are localized and are largely limited to single skeletal elements of affected individuals (see table 6-5). Only three other individuals in the series (each of which is represented by single bones) had evidence for infection, including an adult left ulna (1043-60-16), an adult left femur (1049-4,6), and an adult right fibula (1160-61). Like most of the other infections, they are localized periosteal reactions. Thus, systemic infection is limited to a single individual in the entire series. Given the presence of mostly localized infections in the Stillwater skeletons, it seems likely that most infections in the Stillwater series resulted from pathogens (e.g., *Staphylococcus aureus*) introduced to skeletal tissues via wounds in the surrounding soft tissue (cf. Steinbock, 1976; Webb, 1989). Therefore, it is unlikely that these infections contributed to systemic insult leading to enamel defects.

Recent studies have found a causal link between enamel hypoplasias and protein–energy malnutrition. For example, Goodman et al. (1991) compared two groups from Tezonteopan, State of Puebla, Mexico, where one group received supplemental diets and the other received nonsupplemental diets. The latter group had a relatively higher prevalence of enamel defects. This finding suggests that even mild to moderate undernutrition is linked to the formation of enamel defects.

Given that infectious disease was likely not an important causal factor in enamel hypoplasias in the prehistoric Stillwater populations, it is probable that nutritional deficiencies were more common sources of metabolic insult, especially in situations involving periodic food shortages. In the desert setting of the Carson Sink, the availability of edible plants and animals is closely tied to precipitation levels (measured in rainfall), which average less than 10 cm/yr (Houghton et al., 1985; also see Raven and Elston, 1989). Thus, most water feeding the Stillwater Marsh and lakes is from snowmelt from the Sierra Nevada Mountains to the west. Regardless of the source of water in the region, it can fluctuate widely. For example, in years involving high snowfall in the Sierra Nevada Mountains, the spring and summer thaws can result in huge increases in available water in the Carson Desert (as per the 1984 winter). On the other hand, severe shortages of snowfall and rainfall can limit the availability of plant and animal resources. In the Stillwater Marsh, in particular, severe water shortages from low snowfall in the Sierra Nevada Mountains result in shrinkage of local lakes and drying of the marshes. Drought reduces numbers of waterbirds and other fauna as well as edible plants that comprise important food sources for human populations in the region.

Kelly and Hattori (1985) examined historical sources regarding changes in water supply and flow in the Carson Desert. They found that there has been tremendous change in water distribution and abundance recently as well as throughout the Holocene. The relative availability of water and its impact on plant and animal resources are underscored by the late Margaret Wheat's remark that "In the

TABLE 6-5
Periosteal Reactions of Tibiae from the Stillwater Series

Specimen (N = 61)	Sex	Age	L. tibia[a] (n = 42)	R. tibia[a] (n = 42)	Other elements with periosteal reaction
1043-ind. 2	?	Juvenile	0	–	
1043-ind. 5	M	40+	–	0	
1043-21	F?	Adult	–	1	None
1043-ind. 37	?	13	0	0	
1043-60-7	F	Adult	–	1	R. fibula
1043-61	F	30+	0	–	
1043-misc.	?	Adult	0	–	
1044-1	F	27	1	1	None
1044-2	M	40+	0	0	
1044-ind. 2	M	35+	0	–	
1045-205	?	Adult	1	–	None
1046-2A	?	12	0	0	
1046-2,4	?	Adult	–	0	
1046-9	M	37	0	0	
1046-201,202	F	Adult	0	–	
1047-1	M	21	0	0	
1048-240	?	1	0	–	
1050-3	M	40+	1	1	L. ulna
1051-ind. 6	F	25	0	0	
1051-ind. 7	M	Adult	0	–	
1051-7	?	Adult	–	0	
1051-9	F	Adult	0	–	
1051-205	?	3	0	–	
1054-1	M	27	0	0	
1056-1	F	35	0	0	
1058-5	?	Adult	–	0	
1058-12A	F	22	0	–	
1058-211	?	8	0	–	
1060-1	F	Adult	1	–	None
1060-202	?	Adult	–	0	
910-ind. 3	F	27	–	0	
910-18	?	2	0	0	
910-102	?	1	–	0	
910-201	?	35	0	–	
910-208	?	2	–	0	
910-211	?	1.5	0	–	
1062-1	M	40+	0	1	L. fibula
1063-19,20	M	40+	–	0	
1064-1,18	F	30	–	0	
1064-200	?	12	0	0	
1065-4-1	F	Adult	–	0	
1065-14-1	F	Adult	–	0	
1065-20-1	?	15	0	0	
1070-2,40	?	8	0	0	
1070-3	F	40+	0	0	
1070-4	F	40+	0	0	
1158-1	M?	40	0	–	
1159-4	M	35	0	0	
1159-6	M	27	1	1	R. clavicle, l. ulna, r. radius, l. femur, r. femur, l. fibula, r. fibula
1159-7	M	17	0	0	
1159-200	F	45+	0	1	None

TABLE 6-5—(*Continued*)

Specimen (N = 61)	Sex	Age	L. tibia[a] (n = 42)	R. tibia[a] (n = 42)	Other elements with periosteal reaction
L53-2-2	F?	Adult	–	0	
L53/–	?	Adult	–	0	
1160-1A	M	25	–	1	None
1160-36	?	Adult	0	–	
1160-55	?	Adult	0	–	
L72-200	F	37	0	0	
1173-200	F	27	0	0	
1173-210	M	Adult	–	0	
L120-200	F	21	–	0	
SP-B	?	8	0	–	

[a] 0 = bone present, no periosteal reaction; 1 = bone present, with periosteal reaction; – = bone missing.

Great Basin the marshes . . . were intermittent affairs, always at the mercy of dry cycles and shifting dunes and channels. In a half a dozen years a marsh could change into a dust bowl" (1967: 3; cited *in* Thomas, 1985: 20). Therefore, we suggest that for this hunter-gatherer population, hypoplasia was most likely caused by periodic nutritional deprivations that resulted from occasional food shortages resulting from reduced water availability.

It is possible that other diseases such as parasitic infections may be partially responsible for Stillwater developmental insults, including enamel defects. Parasites have been identified in coprolites excavated from Lovelock Cave in the nearby Humboldt Sink as well as from other areas of the Great Basin (Fry, 1970; Reinhard, 1990, 1992). Some of these parasites have lethal effects (e.g., thorny-headed worm, *Acanthocephala*; Moore et al., 1969), whereas others are relatively harmless (e.g., pinworm, *Enterobius vermicularis*; Fry, 1970). It is unclear, however, what (if any) the link might be between identified parasites and hypoplasia. Moreover, Reinhard (1990) indicated that, unlike the eastern Great Basin, at least one parasitic infection (helminthiasis) was probably uncommon in this region. Other parasites, however, were certainly present.

Comparison of the Stillwater dental series with Georgia coastal populations representing different subsistence (hunting-gathering and agriculture) economies shows that relative to the prehistoric southeastern U.S. populations, Stillwater teeth had narrower hypoplasia widths. Assuming that hypoplasia width reflects severity of stress, stress episodes in the Stillwater population were likely minor affairs.

A nutritional interpretation for hypoplasia prevalence patterns in the Stillwater series is consistent with other findings based on cross-sectional geometric properties of long bones. That is, bone areas, including cortical area and percent cortical area, which are frequently used to assess nutritional status in human populations (see Garn et al., 1964), are on the low end for other skeletal samples studied in North America. We interpret this finding as reflecting nutritional deprivation (Larsen et al., 1991; see Chap. 8).

The chronological distribution of enamel defects (3–4 years of age) is similar to the Georgia coastal populations as well as to most other archaeological populations reported in the literature (table 6-6). That is, most populations show a peak frequency of enamel hypoplasias during the 2–4-year period. This pattern of peak age distribution of developmental stress is substantially later than the peak age observed in a clinically based, urban population from the American Midwest (Sarnat and Schour, 1941; also see discussion by Goodman, 1988; Goodman and Rose, 1990: table 15). These differences between archaeological and clinical dental series suggest that the occurrence of hypoplasias at Stillwater, like other archaeological samples, represents a pattern of stress largely influenced by extrinsic factors related to environmental influences. In particular, we have argued that the occurrence of hypoplasia in this series is like-

TABLE 6-6
Comparative Ages of Hypoplasia in Permanent Teeth, Selected Archaeological and Fossil Hominid Populations

Source	Period	Age range (years)	Peak age (years)
This study	Prehistoric	0.0–6.0	3.0–4.0
Berryman, 1981	Mississippian	0.0–12.5	0.5–5.5
Corruccini et al., 1985	Historic	0.0–6.5	3.0–4.0
Goodman et al., 1980	LW/MALW[a]	0.0–6.0	3.0–3.5
	Middle Mississippian	0.0–5.5	2.5–3.0
McManamon et al., 1986	Late Woodland	0.0–6.0	2.5–5.5
Powell, 1988	Mississippian	1.5–6.0	2.5–4.5
Powell, 1989	Mississippian	1.0–6.0	3.0–4.0
Rose et al., 1978	Middle Woodland	0.5–4.0	Even
	MALW[b]	2.0–4.5	2.0–2.5
	Mississippian	1.0–3.5	1.8–3.3
Murray, 1989	Historic	1.0–6.0	2.0–4.0
Stodder, 1990	Protohistoric	0.5–6.5	3.0–5.0
Schulz and McHenry, 1975	Prehistoric	1.0–7.0	4.0–5.0
Walker, n.d.	Prehistoric	1.0–6.5	2.0–5.0
	Historic	2.5–6.0	3.0–5.0
Martin et al., 1991	Anasazi	0.0–6.5	3.0–3.5
Hodges, 1989	Formative	0.0–7.0	3.0–3.5
	Classic	0.5–7.0	2.5–3.0
	Postclassic	0.0–6.5	3.0–3.5
Swärdstedt, 1966	Medieval	—	2.0–4.0
Grauer, 1989	Medieval	—	3.0–4.5
Hillson, 1979	Predynastic–Christian	0.8–7.0	2.0–5.0
Blakey et al., 1994	Historic	0.0–6.0	1.5–4.5
Ogilvie et al., 1989	Mousterian	0.0–7.0, 10.0–13.0	2.0–5.0, 11.0–12.0

[a] Late Woodland/Mississippian acculturated Late Woodland.
[b] Mississippian acculturated Late Woodland.

ly tied to nutritional factors associated with the early years of childhood. Although conjectural, a paramount nutritional factor affecting young children is the trauma associated with the shift from maternal dependence to postweaning diet and adult foods. Nonmaternal food sources are generally less sanitary and are potentially poorer in nutritional quality, thereby leading to diarrhea, reduction in host resistance, and metabolic and growth disruptions (see Acheson, 1960; Eveleth and Tanner, 1976; Lowery, 1986). Moreover, this period of the growing juvenile is especially precarious in that the shift involving the loss of mother's milk results in reduced bioavailability of specific nutrients, a decrease in immunity resulting from reduced immunoglobulin levels, and loss of immunities transferred from mother to the nursing infant (see review in Larsen, 1987).

Despite the likelihood that weaning has a negative impact on health and may explain increases in hypoplastic activity during early childhood, the association remains unclear. In this regard, Corruccini et al. have pointed out that "a direct correlation between age of weaning and of hypoplasia concentration has only been presumed, never firmly established in a single population" (Corruccini et al., 1985: 706). Indeed, other factors associated with this harsh, desert setting of the western Great Basin may also be responsible (e.g., food shortages during drought years). Additionally, Goodman and Armelagos (1985a, 1985b) showed that gross dental defects are most prevalent in the midcrown regions of anterior teeth, reflecting the great sensitivity to growth disruption. Thus, there is evidence suggesting an inherent bias that is independent of environmental factors. This suggests

that additional research on enamel defects is required before drawing conclusions regarding weaning (see also Blakey et al., 1994).

Interestingly, frequency of hypoplasias in the Stillwater series is considerably lower than in dental series studied from the southwestern United States. In this regard, Martin et al. (1991) reported very high prevalence values for anterior permanent teeth, ranging from 51.4% (mandibular second incisor) to 93.9% (maxillary first incisor) at Black Mesa (compare with table 6-3). They ascribed these high prevalence rates to living in marginal and unpredictable settings characterized by low productivity in general, possibly having been exacerbated by population increase or slight climatic changes. These findings, then, contrast sharply with findings that we present from the western Great Basin.

In summary, the analysis of hypoplasias in the Stillwater dental series indicates that the population experienced moderate levels of physiological stress in comparison with archaeological populations reported from other regions of North America and elsewhere. Although dental defects in prehistoric Stillwater hunter-gatherers may have been caused by a variety of circumstances—including trauma, genetic disorders, disease, and malnutrition—most hypoplasias were likely caused by nutritional problems related to periodic food shortages, perhaps during seasons of reduced precipitation in this highly variable desert setting. The chronological distribution of hypoplasias shows a peak occurrence during the third to fourth years of life, a finding consistent with nutritional stresses associated with weaning or other factors. Thus, although there are many causative factors related to hypoplasia, we have identified dietary ones as most likely for this population.

CHAPTER 7. DIETARY RECONSTRUCTION IN THE PREHISTORIC CARSON DESERT: STABLE CARBON AND NITROGEN ISOTOPIC ANALYSIS[1]

Margaret J. Schoeninger

INTRODUCTION

There has been a long history of interest in the foodways among Great Basin native populations, primarily from archaeological and ethnographic contexts. Studies of plant and animal remains as well as coprolites (e.g., Heizer, 1967) recovered from archaeological sites have provided important insight into the kinds of foods eaten in the vicinity of the Carson Sink; however, the proportions of food types and changes in those proportions over time have not been adequately characterized. Preliminary archaeological analyses based on faunal and botanical remains and on inferences drawn from ethnographic observations have been completed for the Stillwater Marsh region (see Raven and Elston, 1989; Fowler, 1990a, 1990b, 1992), but far more research is needed to understand foodways.

The basic subsistence strategy of Stillwater peoples was hunting and gathering. These populations likely utilized marsh resources, but the extent of their dependence on them continues to be debated (see Thomas, 1985; Kelly, 1985, this volume; Larsen, this volume). Kelly (1985) has argued that throughout time the archaeological evidence suggests that these populations experienced a shift toward greater sedentism that resulted in an increased use of marsh resources. Kelly has sought alternative ways to test his archaeologically based hypothesis; however, because few of the human skeletal samples have been radiocarbon-dated, a change in diet over time based on the study of human remains alone cannot be assessed. On the other hand, basic information about human diet in the region would be useful in determining the likelihood that people could have extracted all of their diet items from the marsh region, from the surrounding uplands, or from a combination of both.

The primary goal of the present research is to obtain baseline information on human diet in the region by using stable isotope analysis of human bone, animal bone, and plant material. This is an alternative method of investigation that complements those based on other sources (i.e., coprolites, animal and plant remains). Isotopic studies for plant and animal communities have shown that diagnostic signatures of nitrogen and carbon stable isotope ratios ($^{15}N/^{14}N$ and $^{13}C/^{12}C$, respectively) sometimes occur. The bimodal distribution of stable carbon isotope ratios within terrestrial plants—reflecting photosynthetic pathways of plants, C_3 or C_4—is the most familiar. In this regard, C_3 plants typically have very negative ratios, and C_4 plants have less negative ratios. Thus, consumers of these plants should reflect this pattern. This pattern has been extremely valuable in identifying the introduction and intensification of maize (a C_4 plant) agriculture in the New World. Similarly, there is also a bimodal distribution of stable nitrogen isotope ratios within marine and terrestrial organisms that has been used widely to discriminate among potential food sources (for a review of this literature, see Schoeninger and Moore, 1992).

Other diagnostic signatures reported from unique situations are more relevant for this study. For example, the nitrogen isotopic ratio of marine and freshwater blue-green algae is different from that of deep ocean sources of nitrogen and from most terrestrial plants because the algae fix atmospheric nitrogen (Wada, 1980; Capone and Carpenter, 1982). Therefore, the isotope ratios in humans who consume fish that feed on these algae are significantly different from those who consume deep-ocean fish or terrestrial foods (Schoeninger et al., 1983; Schoeninger and DeNiro, 1984; Keegan and DeNiro, 1988; Schoeninger, 1991). In contrast, very high nitrogen isotope ratios have been measured in bone

[1] An earlier version of Chapter 7 was presented at the 1994 annual meetings of the Society for American Archaeology held in Anaheim, California.

collagen of pastoralists from some desertic areas of Africa (Heaton et al., 1986; Ambrose and DeNiro, 1986) and fishing peoples dependent on lakes that do not support nitrogen-fixing algae (Katzenberg, 1989; Pratt, MS.). In these cases, the nitrogen isotope ratios in human bone collagen have been used to identify various subsistence strategies, including shallow-water fishing, deep-water fishing, hunting, or pastoralism.

Similar situations have been reported for carbon stable isotope ratios. Mangrove swamps have carbon isotope signatures that differ from the oceans they adjoin (Rodelli et al., 1984). Salt grass marshes can contain plants with a carbon isotope signature similar to those normally found in C_4 plants (Craft et al., 1988; Peterson et al., 1980) because the marsh plants use atmospheric CO_2 more efficiently than their neighboring terrestrial C_3 plants. Although data are not available on freshwater marshes, it seems possible that carbon or nitrogen cycling in the Carson Desert marsh could differ from that in the surrounding desert, which could result in diagnostic carbon and/or nitrogen isotopic ratios in marsh plants and animals. The present study was undertaken in part to investigate this possibility.

MATERIALS AND METHODS

Samples were taken from 39 human skeletons, seven plants, and 20 animal skeletons for carbon and nitrogen stable isotope analysis (table 7-1). As indicated in table 7-1B, the human skeletons were largely recovered as individual burials throughout the marsh region. All of the faunal samples were recovered from archaeological sites and may represent food remains. As discussed elsewhere in this monograph, preliminary work on the faunal remains from the Carson Desert indicates that a variety of waterbirds, fish, and other animals were used by native populations. Several of these remains were collected for analysis in the present study (table 7-1A).

It is likely that a wide variety of plants was also used by native populations in the Carson Desert, but floral remains have been sparse in the recovered archaeological record in this region. For this reason, ethnographic data were used to identify potential plant foods. Piñon, which grows in the Stillwater Mountains bordering the Stillwater Marsh, was clearly an important resource for many Great Basin peoples. Many other small-seeded grasses (e.g., Indian ricegrass and wildrye), sedges (e.g., cattail and bulrush), and shrubs (e.g., shadscale and seepweed) found in the Carson Desert are mentioned as foods in the ethnographic record of the area (Fowler, 1990a, 1990b, 1992). These plants are likely to have been important dietary plants prehistorically. A recent study (Raven and Elston, 1989) ranked several of these plants based on their relative caloric yield and period of availability. Based on this comparison, bulrush (*Scirpus acutus*) was ranked very high (see table 7-2) because of its high caloric return and long period of availability. In contrast, even though high in protein, Indian ricegrass (*Oryzopsis hymenoides*) was ranked relatively low because it is available for only a short period and its caloric return is significantly lower than that of bulrush. Cattail pollen was ranked high because its caloric return rate is the highest of all plants in the region, even though it is available only through spring and summer. Shadscale (*Atriplex confertifolia*), four-wing saltbush (*Atriplex canesens*), nutgrass (*Scirpus paludosis*), and seepweed (*Suaeda depressa*) were also ranked among the top 10 plants. Seepweed is an annual, whereas another species in the same genus, *Suaeda torreyana* (desert blite), a perennial shrub, was not ranked because it has not been mentioned in the ethnographic literature (Raven and Elston, 1989). Because carbonized seeds have been recovered archaeologically, however, Raven and Elston (1989) thought that it may have been an important plant food. A sample of *Suaeda,* not identified to species, was analyzed in this study.

Several modern representatives of these plants were collected in the Stillwater Marsh and Carson River region by Robert Kelly, Elizabeth Budy, and Anan Raymond. The plants were analyzed in the author's laboratory as described below. With the exception of *Suaeda,* all have been identified to species. For plant samples that were not available for isotopic assay, the photosynthetic pathway (C_3, C_4, or CAM) was determined from the literature whenever possible (see table 7-2).

TABLE 7-1A
Stable Isotope Data from Carson Sink: Animals and Plants

Species	Common name	Sample	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)
Lepus sp.	Hare	Bone	−12.7	5.7
—	Artiodactyl	Bone	−18.1	10.2
—	Canid	Bone	—	—
—	Canid	Bone	−17.5	12.0
—	Canid	Bone	−17.4	9.1
Gila bicolor	Tui chub	Bone	—	—
G. bicolor	Tui chub	Bone	—	—
G. bicolor	Tui chub	Bone	—	—
G. bicolor	Tui chub	Bone	−22.1	5.5
—	Mustelid	Bone	−17.1	9.3
—	Mustelid	Bone	−20.9	8.8
—	Badger	Femur	—	—
—	Badger	Femur	−17.3	13.5
Ovis canadensis	Sheep	Bone	−19.1	7.8
O. canadensis	Sheep	Bone	−18.6	8.4
—	Goose	Bone	−19.5	5.6
Fulica sp.	Coot	Bone	−22.9	7.2
Anas sp.	Duck	Bone	−18.8	6.6
—	Duck	Bone	−20.8	5.4
Aythya sp.	Duck	Bone	−11.2	6.1
Elymus sp.	Wildrye	Chafe	−23.4	6.4
Pinus monophylla	Piñon	Seed	−21.2	1.0
Scirpus paludosus	Nutgrass	Seed	−25.6	4.3
S. acutus	Bulrush	Seed	−25.8	6.3
Suaeda sp.	Desert-blite	Seed	−27.3	11.4
Oryzopsis sp.	Ricegrass	Seed	−23.3	2.6
Typha latifolia	Cattail	Chafe	−26.2	12.1

Nitrogen isotope data were not available for plants not analyzed by the author.

The samples were prepared in the author's laboratories at Harvard University or the University of Wisconsin. Handling of the samples depended on their composition. Bone samples were cleaned mechanically in double-distilled water, broken into 1-mm-square pieces, and placed in 1% hydrochloric acid (HCl) for approximately 10 days or until they were completely demineralized as described previously (Schoeninger et al., 1989). Following demineralization, samples were rinsed to neutrality in double-distilled water, soaked in 0.125 M sodium hydroxide (NaOH) for 10 hours to remove humic acid contamination, and again rinsed to neutrality. The samples were freeze-dried and then weighed to determine the amount of organic material (largely bone collagen) remaining in the sample as a means of screening samples acceptable for analysis.

Previous studies have demonstrated that significant shifts occur in the nitrogen and carbon stable isotope ratios as a result of kinetic isotope effects when proteins have been markedly degraded (DeNiro et al., 1985; Bada et al., 1989). Nitrogen ratios can increase by a factor of three when less than 1% of the original organic material is retained in bone; however, carbon is less affected. In the present study, all samples with less than 3% organic material of the original sample weight were discarded. Only the organic component of the human and faunal samples was analyzed. For the acceptable samples, approximately 3 mg were loaded into quartz tubes in preparation for combustion.

Plant samples were rinsed in double-distilled water, dried in a warm oven, and ground to ensure homogeneity. Approximately 7 mg was loaded into each quartz tube in preparation for combustion and analyses of carbon isotope ratios. Diatomaceous earth was add-

TABLE 7-1B
Stable Isotope Data from Carson Sink: Human

Specimen	Site	Sample	Age	Sex	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)
1-1[a]	L53	Rib	35+	F	−18.1	9.7
200	L72	Rib	35–40	F	−16.8	9.6
200	L108	Rib	0.5–1	?	−17.9	14.2
1/8-2[a]	910	Rib	40+	F	−18.2	10.6
208	910	Rib	2	?	−17.8	12.8
211	910	Rib	1.5	?	−17.8	8.7
16-1	910	Rib	30–40	F	−16.7	11.1
5-2-b[a]	1043	Rib	40+	M	−16.0	12.0
61-1[a]	1043	Rib	30+	F	−16.5	10.6
1-2[a]	1044	Rib	25–30	F	−16.3	13.6
2-3[a]	1044	Rib	40+	M	−16.5	11.2
1-2-15[b]	1045	Rib	30–40	F	−18.5	10.5
9-11[a]	1046	Rib	35–40	M	−16.1	12.6
222	1046	Rib	Adult	?	−16.5	11.6
1-1-5a	1047	Vertebra	18–25	M	−16.7	10.8
13-1-4a	1047	Humerus	40+	F?	−16.8	10.4
3-5[a]	1050	Rib	40+	M	−18.6	9.8
1-3[a]	1054	Rib	25–30	M	−17.8	11.2
1-4[a]	1055	Rib	25–30	M	−18.5	10.4
1-15	1056	Rib	30–40	F	−15.9	11.2
12-11[a]	1058	Rib	20–25	F	−16.5	11.6
211	1058	Rib	7.5	?	−17.7	16.7
1-4a	1060	Radius	Adult	F?	−17.3	12.1
1-2[a]	1062	Rib	40+	M	−16.9	11.2
20-2-16(b)	1063	Rib	40+	M	−18.9	10.8
200	1064	Rib	10–15	?	−16.0	11.7
201A	1064	Rib	Adult	?	−15.1	13.4
1-2-14(c)	1064	Femur	25–35	F	−16.8	11.3
20-1	1065	Rib	13–17	?	−18.2	11.9
4-3[a]	1070	Rib	40+	F	−18.0	10.2
3-3[a]	1070	Rib	40+	F	−18.7	10.3
1-1[a]	1158	Rib	35–40	M	−18.9	9.5
7-16[a]	1159	Rib	16–19	M	−16.8	12.6
4-1[a]	1159	Rib	30–40	M	−17.1	10.3
200	1159	Rib	45+	F	−16.8	11.7
6-1-29(b)	1159	Rib	25–30	M	−16.7	10.9
1-1	1163	Rib	18–25	M	−16.6	11.2
207	1173	Rib	Adult	?	−14.4	14.4
200	1173	Rib	25–30	F	−16.4	10.9

ed to the plant samples to provide excess silica during the combustion phase, thereby enhancing stability of the quartz-sample tubes. A separate aliquot of the plant sample was prepared to nitrogen gas via the Kjeldahl method (Bradstreet, 1965) for nitrogen stable isotope analysis. Whenever possible, the portion of the plant sample analyzed was limited to the part thought to have been eaten by humans.

All samples for combustion were treated identically. Excess elemental copper, cupric oxide, and silver were added to each quartz-sample tube. The quartz-sample tubes were sealed under vacuum, placed in a muffle furnace at 900°C for 2 hours, and permitted to cool to room temperature. The combustion products were purified and distilled cryogenically. The purified carbon dioxide (CO_2) was analyzed on a Finnegan MAT Delta E gas isotope ratio mass spectrometer in Professor John Haye's laboratory at Indiana University

TABLE 7-2
Seasonality, Ecological Context, and Carbon-Stable Isotope Signature of Modern Carson Desert Animals and Plants[a]

Rank	Resource (species)	Availability[b]	Locale	Carbon-stable isotope signature	Reference[c]
1	Rabbit (*Lepus* sp.)	Sp, S, F, W	Various	C_4	1
2	Cattail pollen (*Typha latifolia*)	Sp (S)	Marsh	C_3	1
3	Rodents (various)	Sp, S, F, W	Various		
4	Birds (*Fulica* sp. and *Anas* sp.)	Sp, S, F, W	Marsh	C_3, C_4	1
5	Fish (*Gila bicolor*)	Sp, S, F, W	Marsh	C_3	1
6	Shadscale (*Atriplex confertifolia*)	S, F	Uplands and islands	Prob. C_4[d]	5
7	Four-wing saltbush (*Atriplex canesens*)	S, F	Uplands	Prob. C_4[d]	5
8	Bulrush seeds (*Scirpus acutus*)	S, F	Marsh	C_3	1
9	Nutgrass (*Scirpus paludosis*)	S, F	Marsh	C_3	1
10	Seepweed (*Suaeda depressa*)	S, F	Uplands and islands	?[e]	
11	Torrey quailbush (*Atriplex torryi*)	S, F	Uplands	Prob. C_4[d]	5
12	Bluegrass (*Poa* spp.)	Sp	Uplands	C_3	2
13	Basin wildrye (*Elymus cinereus E. condensatus*)	S, F	Uplands and floodplain	C_3	2
14	Indian ricegrass (*Oryzopsis hymenoides*)	Sp	Uplands	C_3	1, 2
15	Creeping wildrye (*Elymus triticoides*)	S, F	Uplands	C_3	1, 2
16	Western wheatgrass (*Agropyron smithii*)	S, F	Uplands	C_3	2
17	Slender wheatgrass (*Agropyron trachycaulum*)	S, F	Uplands	C_3	2
18	Cattail seeds (*Typha latifolia*)	S, F	Marsh	C_3	1
19	Sand dropseed (*Sporobolus cruptandrus*)	S	Uplands	Prob. C_4[f]	2
20	Alkali sacaton (*Sporobolus airoides*)	Sp (S)	Uplands	Prob. C_4[f]	2
21	Forbs (*Mentzelia dispersa, Sophia sonnei, Descurainia californica*)	Sp (S)	Various	?	
22	Spikerush (*Eleocharis* sp.)	S, F	Marsh	C_3	4
23	Cattail roots (*Typha latifolia*)	S, F	Marsh	C_3	1
24	Bulrush roots (*Scirpus acutus*)	S, F	Marsh	C_3	1
25	Saltgrass (*Distichlis stricta*)	S	Uplands	C_4	4
26	Iodinebush (*Allenrolfea occidentalis*	S, F	Uplands and marsh	?	
27	Needle-and-thread (*Stipa comata*)	Sp	Uplands	C_3	4
28	Squirreltail (*Sitanion hystrix*)	Sp	Uplands	Prob. C_3[g]	2

[a] The rank of species, season of availability, and locale are based on Raven and Elston (1989).

[b] Sp = spring; S = summer; F = Fall; W = winter; (S) = probable summer.

[c] 1 = this study; 2 = Waller and Lewis (1979); 3 = Troughton et al. (1974); 4 = Bender (1971); 5 = Downton (1975).

[d] This genus includes both C_3 and C_4 species; the species included in the table display Kranz-type leaf anatomy associated with C_4 photosynthesis.

[e] The *Suaeda* sp. analyzed in this study is C_3; *Suaeda torreyana*, desert blite, is reported to be C_4 by Troughton et al. (1974).

[f] Of 138 species studied in this species' subfamily, all are C_4 with one exception.

[g] Of 206 species studied in this species' subfamily, all are C_3.

(the same type of mass spectrometer used in the author's laboratory at the University of Wisconsin). The purified nitrogen gas (N_2) was analyzed on a VG Isogas 602E isotope ratio mass spectrometer in Professor James McCarthy's laboratory at Harvard University or on a Finnegan MAT 251 isotope ratio mass spectrometer in the author's laboratory at the University of Wisconsin.

Isotope ratios are presented as delta (δ) values in per mil (‰) notation. The standard used for comparison in the calculation of the carbon δ value is the PeeDee Belemite carbonate (PDB):

$$\delta^{13}C = \left(\frac{^{13}C/^{12}C_{sample}}{^{13}C/^{12}C_{standard\ (PBD)}} - 1 \right) \times 1000\ (‰).$$

The standard used for comparison in the calculation of the nitrogen δ value is Ambient Inhalable Reservoir (AIR):

$$\delta^{15}N = \left(\frac{^{15}N/^{14}N_{sample}}{^{15}N/^{14}N_{standard\ (AIR)}} - 1 \right) \times 1000\ (‰).$$

A homogenized proline sample was analyzed at Harvard University and a homogenized glycine sample was analyzed in the author's laboratory at the University of Wisconsin as internal laboratory combustion standards. Repeated analyses of both standards yielded a replicability of less than $\pm 0.2‰$ in $\delta^{13}C$ and of $\pm 0.3‰$ in $\delta^{15}N$. As a check on interlaboratory and intralaboratory precision, 11 samples (including bone and plant samples) were analyzed in duplicate for carbon. These samples had $\delta^{13}C$ values within 0.6‰ of each other with an average difference of 0.2‰. Seven samples (including bone and plant samples) were analyzed in duplicate for nitrogen. These samples had $\delta^{15}N$ values within 0.5‰ of each other with an average difference of 0.3‰. In cases of replicate analyses of samples, only the average is reported.

RESULTS

The results for the isotopic analyses are shown in table 7-1 and figure 7-1. All of the plant samples analyzed in this study have $\delta^{13}C$ values between $-27‰$ and $-21‰$, well within the range of C_3 plants (O'Leary, 1988). Prehistoric members of these species would have had $\delta^{13}C$ values approximately 1‰ to 2‰ less negative than today's plants (i.e., $-25‰$ to $-19‰$) because atmospheric carbon dioxide would have been around $-6‰$ to $-5‰$ compared with $-7.5‰$ today (Keeling, 1961; Bada et al., 1990; Marino and McElroy, 1991). Although no C_4 plants were analyzed by the author, C_4 plants are among those ranked by Raven and Elston and have been identified elsewhere (see table 7-2). The $\delta^{15}N$ values in the plant samples fall between 1.0‰ (piñon) and 12.1‰ (cattail). The former is close to zero, as is expected in nitrogen-fixing plants; such metabolism has been reported previously for species of the genus *Pinus* (Virginia and Delwiche, 1982). The latter value is at the high end of expected nitrogen values in terrestrial plants (Wada et al., 1975). In combination, the carbon and nitrogen data argue against any diagnostic isotope signals in the Carson Desert.

Among the faunal samples, the $\delta^{13}C$ values fall into two clusters. With the exception of two animals, all $\delta^{13}C$ values fall between $-22.9‰$ and $-17.1‰$. The exceptions include a hare ($-12.7‰$) and a duck ($-11.2‰$). The high values for hares and ducks indicate that C_4 plants provided a significant portion of their diet. The $\delta^{15}N$ values range from 5.4‰ (a duck) to 12.0‰ (a canid) and also fall within two clusters. Animals that are mainly herbivorous (ducks, rabbits, and sheep) cluster between 5.4‰ and 8.4‰, with one outlier at 10.5‰. The outlier is an artiodactyl not identified to genus or species. Animals that are omnivorous or carnivorous (canids and mustelids) cluster between 9.9‰ and 12.0‰.

For the human samples, the range of the $\delta^{13}C$ values is $-18.9‰$ to $-14.4‰$, with an average of $-17.1‰$. The range of the $\delta^{15}N$ values is 8.7‰ to 16.7‰, with an average of 11.4‰ and a standard deviation of 1.5‰. One outlier, a juvenile (7.5 years old) from site 1058, had a $\delta^{15}N$ value of 16.7‰. Removal of this particular sample does not alter the average or the standard deviation. Nevertheless, this sample is not included in the figures presented here. No explanation can be given for the incongruous value. The range of variation among animals on monotonous diets is less than 2‰ in both carbon and nitrogen (DeNiro and Schoeninger, 1983), whereas in this study, the range of variation in isotope values among the human samples is 4.5‰ in carbon and 5.7‰ in nitrogen. This range suggests that there was a variety of diets that supplied sustenance to people of the Carson Desert. Some of the people could have eaten only plants and animals that had a C_3 signature; others must have eaten a significant amount of food with a C_4 signature. Between these extremes lie several subsistence strategy combinations. A similar variety of foods is suggested by the nitrogen isotope findings.

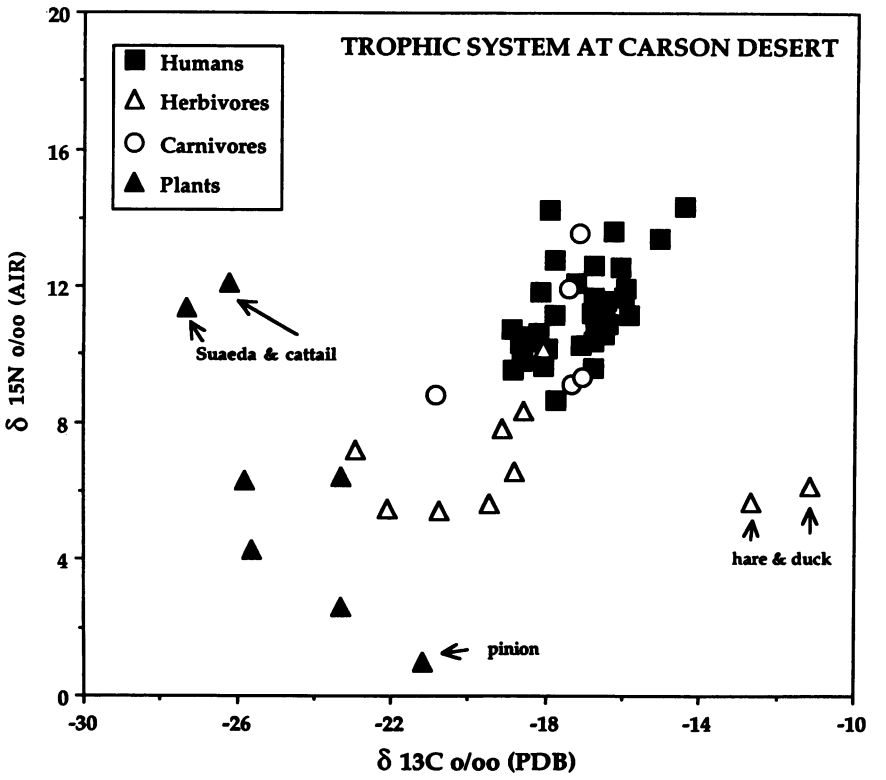

Fig. 7-1. $\delta^{13}C$ values plotted against the $\delta^{15}N$ values for all the samples analyzed from the Carson Desert. Each point represents an individual sample. These data indicate that two plants have very positive $\delta^{15}N$ values and that all plants analyzed are C_3. Even so, two of the herbivorous animals have $\delta^{13}C$ values indicating that they fed on C_4 plants. The carnivorous animals are 3–4‰ more positive in $\delta^{15}N$ values than the herbivorous animals upon which they feed. Because humans fall within the distribution of carnivorous animals, this suggests that most of their nitrogen and carbon came from herbivorous fauna rather than from plants. Furthermore, some of the humans have less negative $\delta^{13}C$ values, indicating that they ate C_4 plants or animals with a C_4 signature.

DISCUSSION

One important finding that stands out in the analysis of carbon and nitrogen stable isotope values is the lack of obvious patterning within the group of humans analyzed in this study, especially with regard to skeletal element type, age at death, sex, or site. Although the sample sizes for any one skeletal element are small (see table 7-1), no isotope value patterns are present by bone type. This supports findings reported previously of minimal variation (less than 0.5‰) in both carbon and nitrogen across skeletal elements (DeNiro and Schoeninger, 1983). Similarly, the samplings of different age groups are not complete enough to be certain, but there appears to be a lack of age-associated variation as reported previously for carbon isotope ratios from another geographic area (Lovell et al., 1986; but also see Katzenberg et al., 1993). The three samples from individuals 2 years old and younger fall within the range of the remainder, as do three older juveniles with ages less than 18 years (see table 7-1). With regard to the younger group of juveniles, this may reflect the limitations of small sample size, or there may be no elevation in $\delta^{15}N$ values in nursing versus weaned individuals, as has been observed in at least one other study (see Tuross and Fogel, 1994).

The sample of identifiable males and females, on the other hand, is large enough to conclude that there is no difference between

the sexes in the isotopic ratios or in the general categories of foods eaten. In a comparison of 16 females and 13 males, the averages of both the $\delta^{15}N$ and $\delta^{13}C$ values fall within 0.1‰ of each other (11.0‰ versus 11.00‰ and −17.2‰ versus −17.1‰, respectively). The ranges are also virtually identical. The female nitrogen isotopic values range from 9.6‰ to 13.6‰ (with one outlier; the second most positive value is 12.1‰); the males range from 9.5‰ to 12.6‰. The carbon isotopic values show the same similarity in ranges—the female samples are −18.7‰ to −15.9‰; the male samples are −18.9‰ to −16.0‰. The same finding has been reported in several other studies (reviewed in Schwarcz and Schoeninger, 1991).

The more general question addressed by this study, however, is whether the resources in the Carson Desert region could have supported the human population or if supplementation with foods from outside the area was necessary. The first suggestion that external foods were used is that the human carbon isotope signals indicate that some people ate a significant amount of food with a C_4 signal, even though none of the plants analyzed are C_4. At first glance, this suggests that nonlocal foods were used. Significantly, however, two of the faunal samples have $\delta^{13}C$ values (hare = −12.7‰; duck = −11.2‰), indicating that up to 70% of their diet was a C_4 plant (or plants) or a CAM plant with a C_4 signature. This estimate is based on the assumption that a value in collagen of −21‰ represents a 100% C_3 diet, that a value in collagen of −7‰ represents a 100% C_4 diet, and that there is a linear relation between diet composition and the $\delta^{13}C$ values (see discussions in Schwarcz and Schoeninger [1991] and Tieszen [1991]). The duck may be a migratory animal whose collagen carbon value represents food eaten some distance from the Carson Desert. The rabbit may have been killed some distance away from the marsh area. However, birds and rabbits are available in the region throughout the year, which argues against traveling out of the region to obtain them. Furthermore, even though none of the plants analyzed in this study is C_4, several of the plants listed by Raven and Elston (1989) are probably C_4 based on a survey of the literature (see references in table 7-2). Three of these plants—shadscale, desert blite (substituting for seepweed), and four-wing saltbush—are in the family Chenopodiaceae, which includes both C_3 and C_4 species. Shadscale and four-wing saltbush have been identified as C_4 based on leaf anatomy (Downton, 1975), although no isotopic analyses have been reported and samples were not available for this study. Desert blite has been identified isotopically and anatomically as C_4, although the *Suaeda* sample analyzed in this study is C_3. Note that two of the plants (shadscale and four-wing saltbush) that Raven and Elston (1989) ranked among the top 10 plants are probably C_4.

The season of availability is also important when considering whether people had to move out of the marsh region to obtain food. Several of the important plants produce seeds in the fall and/or summer (shadscale, four-wing saltbush, Torrey quailbush, sand dropseed, and saltgrass); these have been identified as C_4 in the literature (see table 7-2). Other plants (i.e., bulrush and nutgrass) are C_3. Some combination of plant foods would provide the mix of C_3 and C_4 signals measured in a large portion of the human samples. All of the higher-ranked spring plants are C_3 (bluegrass and Indian ricegrass), although one lower-ranked plant (alkali sacaton) is probably C_4. Bone collagen (human and fauna) records a dietary average, however. Therefore, a lower amount of C_4 plants in spring could still result in the isotope signatures observed here. It is assumed that a mix of plant foods was stored for use throughout the winter months; meat should have been available throughout the entire year.

The range of variation in plant $\delta^{15}N$ values is also informative. The cattail and *Suaeda* spp. have very positive values (12.1‰ and 11.4‰, respectively), and several other plants have values around 6‰. Large ranges of variation have also been observed in other environments such as South Africa (Vogel et al., 1990) and Isle Royale located in Lake Superior, Michigan (Bada, Schimmelmann, Peterson, and Schoeninger, unpubl. data). Because there is no reason to suspect variation in the plants' metabolic processes, the data suggest that there is variation in the isotopic ratio of the nitrogen available to the plant. Kuhlbusch et al. (1991) reported that

up to 50% of organically bound nitrogen is lost as nitrogen gas (N_2) during biomass burning. The remaining nitrogen would presumably be enriched in the heavier isotope because the lighter isotope would be lost first. Such a mechanism—that is, fire followed by plant uptake of soil with enriched organically bound nitrogen—could account for the very positive nitrogen isotope values observed in some of the plants analyzed in the present study; however, it is not known whether a fire had occurred in the area where these particular plants were collected.

In any case, the relatively positive $\delta^{15}N$ values in human bone collagen (9‰ and higher) suggest that piñon provided little to diet because the piñon $\delta^{15}N$ value is close to zero. The nuts from species available near the Carson Desert (*Pinus monophylla*) are high in fat (23%) and carbohydrates (54%), but also contain a significant amount of protein (10%) relative to other plants (Lanner, 1981). If piñon had provided a major portion of the diet to prehistoric occupants of the Carson Desert, the human bone collagen nitrogen isotope values should be lower than those measured. In contrast, the samples of cattail and *Suaeda* spp. analyzed in this study have very positive $\delta^{15}N$ values. The *Suaeda* spp. was analyzed in duplicate (11.5‰ and 11.3‰; two separate preparations and analyses) because the value is unexpectedly high for a terrestrial plant, although it is certainly within the range reported elsewhere (Wada, 1980). Because both plants are considered by Raven and Elston (1989) to have been highly valued foods, they may be the source of the high $\delta^{14}N$ values in some of the human bone collagen samples if they had such high nitrogen isotope values prehistorically. Raven and Elston (1989) reported that *Suaeda* spp. can provide up to 1000 calories per hour. Cattail was highly prized for its nutritious pollen, which was prepared into cakes (Fowler, 1990a).

There is a group of individuals, however, with less negative $\delta^{13}C$ values (−16‰ to −14‰) and also very positive $\delta^{15}N$ values. When compared with other hunter-gatherers and with maize agriculturalists from the North American continental interior (see fig. 7-2), the positive $\delta^{15}N$ values in some individuals are striking. In figure 7-2, the samples from Ontario (replotted from Schwarcz et al., 1985) are Archaic Period hunter-gatherers; the other two groups represent a subsample of maize-based agriculturalists from Pecos Pueblo (Spielmann et al., 1990) and part-time maize horticulturalists from the Panhandle region of Texas who ate cactus and bison as the remainder of their diet (Habicht-Mauche et al., 1994). This comparison demonstrates that the C_4 component in the diet of people from the Carson Desert was much lower than that of maize agriculturalists or of part-time horticulturists in the southern Great Plains, but higher than the Archaic hunter-gatherers from Ontario.

Many of the Carson Desert humans overlap in $\delta^{15}N$ values with those from Ontario and are significantly more positive than the other two groups. The positive values among the Ontario samples are from ingestion of fish with $\delta^{15}N$ values of about 9‰ or 10‰ (Katzenberg, 1989). In contrast, in other areas of the upper Midwest located some distance from the Great Lakes, the $\delta^{15}N$ values in human bone collagen are similar to those at Pecos Pueblo (Pratt, MS.). Only one of four fish samples from the Carson Desert retained enough organic material for analysis. This sample yielded a $\delta^{15}N$ value of 5.5‰, which is much lower than the Great Lakes fish. This suggests that fish were not the major protein source for people in the Carson Desert with the positive nitrogen isotope values. Because the nitrogen isotope ratios for the literature citing C_4 plants are unknown, diet items that could produce this combination for positive nitrogen isotope values with less negative carbon isotope values remain unidentified, but some of the presumed C_4 plants may have had positive $\delta^{15}N$ values. Two surveys of plants in northern California revealed that annual herbaceous plants had the highest amount of the heavier isotope (Virginia and Delwiche, 1982) and that *Suaeda torreyana* varied from 5.8‰ to 13‰ in two different areas (Shearer et al., 1983).

Another possibility is that most of the carbon and nitrogen that was used in the synthesis of their tissue proteins came from the animals that they ate (as previously suggested by Krueger and Sullivan, 1984). If rabbits and those ducks with C_4 signatures were used

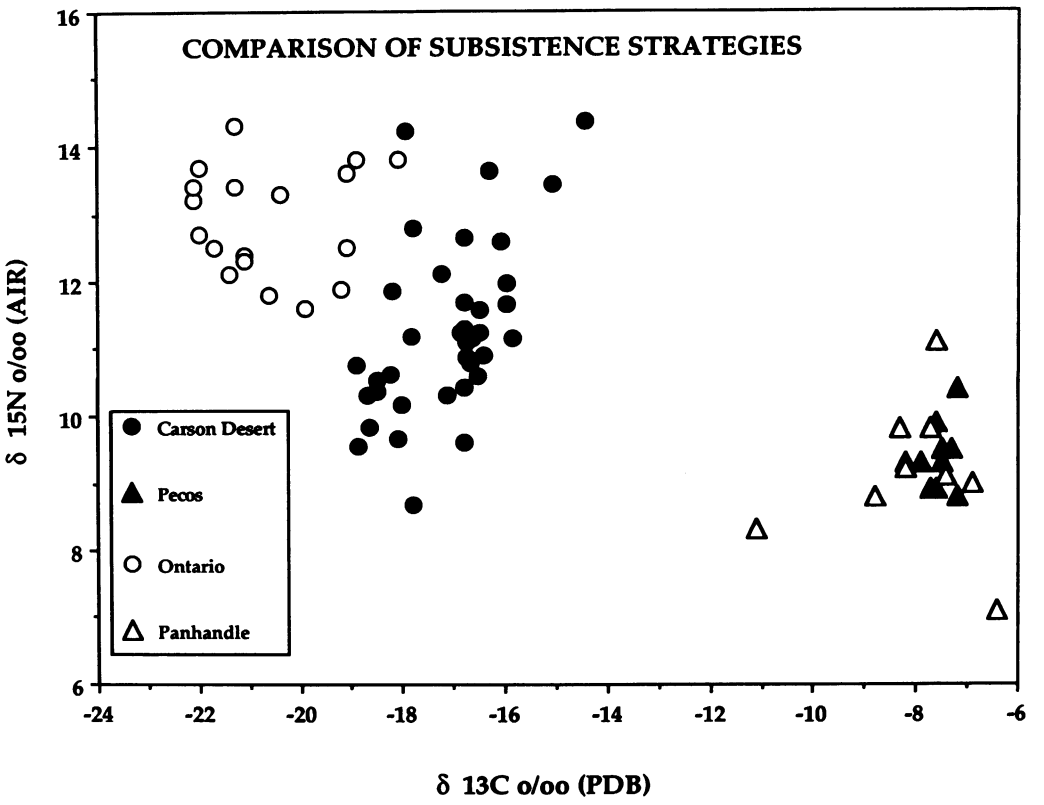

Fig. 7-2. $\delta^{13}C$ values plotted against $\delta^{15}N$ values of human bone collagen from several different archaeological human populations compared with data from the Carson Desert. The data demonstrate less negative $\delta^{13}C$ values in the Carson Desert people compared with Archaic period hunter-gatherers from Ontario (data replotted from Schwarcz et al., 1985). Furthermore, the values show positive $\delta^{15}N$ values in some of the Carson Desert people compared with part-time and full-time maize agriculturalists from the southwestern portion of North America (data replotted from Spielmann et al., 1990, and Habicht-Mauche et al., 1994).

selectively, this would account for the relatively high $\delta^{13}C$ values of some of the people. People clearly would not select food on the basis of carbon isotope values; more likely, the values represent season of capture.

CONCLUSIONS

This study seeks to provide baseline information about foods used by people of the Carson Desert in prehistoric times. Although there is no partitioning according to site, sex, or age group, the range of isotope values (almost 6‰ in nitrogen and more than 4‰ in carbon) indicates that these people ate a variety of foods. Although a change in diet over time has been proposed as an explanation for settlement change (see Kelly, 1985), the general lack of temporal control for individuals used in this study does not permit direct assessment of this possibility. All six individuals for which radiocarbon dates are available cluster at the low nitrogen isotope range and show no apparent temporal pattern. Indirect evidence, however, suggests that people had distinctly different diets at various times throughout the occupation of the area. Raven and Elston (1989) discussed temporal cycles in fish abundance and viral diseases among ducks and rabbits that would have affected the availability of these animals. If these occurred on 5-yr or 10-yr cycles, there

would be people with distinctly different bone collagen isotope ratios such as those observed in this study. For example, a person who ate many rabbits ($\delta^{13}C$ value of $-11‰$) during childhood and adolescence, when most bone collagen is formed, would have a bone collagen $\delta^{13}C$ value substantially different from his or her offspring if fish ($-22‰$) were substituted for rabbit in the offspring's diet. Similarly, if people ate plants from a region that had a major fire several years earlier, they would have relatively high bone collagen $\delta^{15}N$ values.

In general, the isotopic data indicate that the diet of most of these people depended on plants and animals similar to those considered in this study. These data do not refute a model suggesting that people remained yearround in the vicinity of the marsh. The more negative human bone collagen $\delta^{13}C$ values ($-19‰$ to $-17‰$) can be accounted for by a combination of plants and animals from the immediate marsh region. These data support archaeological reports that most identifiable quids found nearby are bulrush and cattail (Thomas, 1985), both of which are C_3 plants. Such use reflects ethnographic observations that stalks of these two plants were chewed like celery in the spring (Fowler, 1990a, 1990b). The samples of *Suaeda* sp. and cattail analyzed in this study would also contribute a very positive $\delta^{15}N$ signature. People with less positive $\delta^{15}N$ values and the range of carbon values probably ate various combinations of plants from uplands surrounding the marsh. Piñon, a nonlocal plant analyzed in this study, was probably not a very important food source. The subset of people with very positive $\delta^{15}N$ values and less negative $\delta^{13}C$ values is the only one not readily explained by the food items considered here. Perhaps these people ate food items from uplands regions. Skeletal structural analyses and osteoarthritis data suggest that these people undertook travel over difficult terrain (see the following chapter). Further analyses of plants and fauna from the immediate and surrounding areas should clarify this problem. Finally, additional work on metabolism of specific nutrients is necessary for understanding the origin of the most positive nitrogen isotope ratios in human bone collagen.

CHAPTER 8. STRUCTURAL ANALYSIS OF THE STILLWATER POSTCRANIAL HUMAN REMAINS: BEHAVIORAL IMPLICATIONS OF ARTICULAR JOINT PATHOLOGY AND LONG BONE DIAPHYSEAL MORPHOLOGY[1]

Clark Spencer Larsen, Christopher B. Ruff, and Robert L. Kelly

INTRODUCTION

A central issue in bioarchaeology is the reconstruction of behavioral aspects of lifeways in past societies, including physical activity patterns and levels of mechanical demand (Larsen, 1987; Bridges, 1990). Physical activity and its influence on the morphology of the human skeleton have been investigated with regard to several themes in Native Americans, such as prehistoric subsistence transitions (e.g., Ruff et al., 1984; Bridges, 1989a; Hodges, 1989), effects of European contact (e.g., Ruff and Larsen, 1990; Larsen and Ruff, 1994), and use of weapons (e.g., Angel, 1966; Ortner, 1968; Pickering, 1984; Bridges, 1990). Moreover, these patterns advance understanding of the evolution of robusticity in *Homo sapiens* in general (Ruff et al., 1993).

With regard to Great Basin prehistoric populations, a debate has centered on the relative degree of mobility of human groups and the degree of importance of dietary resources extracted from marsh versus uplands settings (see, for example, Kelly, 1985; Thomas, 1985; and various papers in Janetski and Madsen, 1990). Thomas (1985) summarized the two primary competing hypotheses regarding these specific aspects of hunter-gatherer lifeways in the Carson Desert. As described in Chapter 1, the *limnosedentary hypothesis* indicates that populations in this region were sedentary, and that most resources were obtained from lacustrine contexts. On the other hand, the *limnomobile hypothesis* indicates that these populations, although partially reliant on marsh resources, spent significant time collecting and transporting uplands foods, sometimes over considerable distances. The latter hypothesis argues that populations were highly mobile, with seasonal reliance on both upland and marsh flora and fauna. Variations of these models have emerged during the course of the debate. For example, based on assessment of available dietary resources and analysis of the archaeological record of human habitation in the Carson Desert, Raven concluded that "[f]or more than five millennia, human foragers appear to have *centered their subsistence activities on the procurement of marsh resources* . . ." (Raven, 1990: 135; emphasis ours). In sharp contrast to this assessment of the prehistoric dietary record, Kelly (1985) argued that marsh resources provided a backup for resources available in the nearby uplands and became more important in the past 1500 years, possibly in response to climatic change. As shown below, hypotheses related to land-use patterns and subsistence strategies can be directly tested by the study of human remains. In the context of this debate, this chapter highlights the importance of human skeletal pathological and morphological variation in this region in particular and in foragers in general (see Kelly, this volume).

The principal objective of this study is to provide an understanding of behavior patterns associated with a highly challenging lifeway. In order to do so, we utilize two complementary approaches to the study of mechanical adaptation in order to shed light on patterns of physical activity, resource acquisition, and settlement in the prehistoric Stillwater populations. These approaches include the analysis of degenerative articular joint pathology known as osteoarthritis (Part I) and long bone diaphyseal morphology (Part II). Regarding the former, Brooks et al. (1988, 1990) have documented the high frequency of articular degeneration in adults in the Stillwater series. They have noted that osteoarthritis in this series is likely related to activity patterns. Moreover, they suggest that presence of the extreme expression of osteoar-

[1] An earlier version of Chapter 8 was presented at the 1991 annual meeting of the American Association of Physical Anthropologists held in Milwaukee, Wisconsin.

thritis whereby some articular surfaces are polished from loss of cartilage and bone-on-bone contact (called eburnation) may be related to the ingestion of mycotoxins introduced via the consumption of seeds stored in damp, cold conditions. These toxins are produced by spores of some parasitic fungi (e.g., *Fusarium*). Apparently, consumption of these mycotoxins destroyed cartilage, which resulted in eburnated joints in an area of Siberia where wheat was stored in cold, damp settings (see Brooks et al., 1990: 104).

We herein provide a systematic analysis of osteoarthritis prevalence, especially in relation to understanding adaptation to the very demanding setting of the Carson Desert and nearby uplands. Moreover, we think that the analysis of long bone diaphyseal morphology, particularly through the study of cross-sectional geometric properties, will help clarify behavioral characteristics left unclear by the analysis of osteoarthritis patterns alone.

PART I. ARTICULAR JOINT PATHOLOGY

Osteoarthritis (also known as degenerative joint disease, osteoarthrosis, deforming arthropathy, and other synonyms) is among the most frequently documented skeletal pathologies in archaeological human skeletal remains. Given its ubiquitous presence in these materials, osteoarthritis has received extensive attention by biological anthropologists and paleopathologists (Jurmain, 1977; Merbs, 1983; Larsen, 1987; Ruff, 1992; Bridges, 1992). The cause of osteoarthritis is highly controversial (Pugh, 1982). Various contributing factors have been identified in its etiology (Jurmain, 1977; DeRousseau, 1988; Moskowitz, 1989); however, the excessive and repetitive mechanical loading of articular joints stands foremost in explanations of the characteristic bone remodeling (Jurmain, 1977, 1990; Duncan, 1979; Larsen, 1982; Merbs, 1983; Radin, 1983; Moskowitz, 1987; DeRousseau, 1988; Hough and Sokoloff, 1989; Miles, 1989; Pascale and Grana, 1989; Walker and Hollimon, 1989).

The prevalence of osteoarthritis has been shown to vary considerably between and within human groups, both in contemporary and in archaeological settings, largely because of the range of variation in activities and associated mechanical stresses (summarized in Jurmain, 1977; Merbs, 1983; Larsen, 1987; Bridges, 1992; Ruff, 1992). Our survey of an extensive literature indicates that human populations engaging in physically demanding activities should possess relatively high prevalences of osteoarthritis and associated degenerative skeletal changes. Indeed, studies documenting osteoarthritis patterning and prevalence have demonstrated this to be the case in anthropological contexts worldwide, such as in Eskimos (e.g., Ortner, 1968; Jurmain, 1977, 1980, 1990; Merbs, 1983), Amerindians (e.g., Anderson, 1976; Jurmain, 1977, 1980, 1990; Larsen, 1982, 1984; Bridges, 1989b, 1990, 1991), and Australian Aborigines (e.g., Webb, 1989, 1995). Although it is difficult to identify specific behaviors from osteoarthritis prevalence alone (see discussion in Bridges, 1990), the disorder offers important data for understanding the cumulative effects of mechanical demand during adulthood as well as general characteristics of adaptation and lifeway (e.g., hunter-gatherers vs. agriculturalists: Jurmain, 1977, 1990; Larsen, 1982, 1984; Pickering, 1984; Bridges, 1989b, 1991; Larsen and Ruff, 1994).

Materials and Methods

Skeletal elements comprising articular joints from 34 adults (showing complete or nearly complete epiphyseal union) drawn from the entire Stillwater Marsh series (combined NSM and HSFS samples) were used in the analysis. Sixteen other partial or nearly complete skeletons are also present in the combined series, but they were either too young (N = 14) or too fragmentary (N = 2) for inclusion in the study. An abundance of isolated skeletal elements or concentrations of several bones with intact articular surfaces and margins were collected from various sites examined by NSM and HSFS field crews (see Chapter 3). However, we concluded that these materials would not contribute substantially to the analysis, and they were therefore not included in the investigation. A case-by-case description of degenerative articular modifications in many of these materials has been provided by Brooks et al. (1988).

Osteoarthritis results from a physiological

TABLE 8-1
Articular Surfaces and Margins of Major Adult Joints Observed for Presence or Absence of Osteoarthritis[a]

Articular joint	Skeletal component observation
Cervical	Intervertebral body; superior and inferior articular processes
Thoracic	Intervertebral body; superior and inferior articular processes
Lumbar	Intervertebral body; superior and inferior articular processes
Sacrum	Superior intervertebral body of first sacral vertebra
Shoulder	Proximal humerus (head); scapula (glenoid)
Elbow	Distal humerus (trochlea, capitulum); proximal radius (head, radial tuberosity); proximal ulna (semilunar notch, radial notch, coronoid process)
Wrist	Distal ulna (head, styloid process); distal radius (lunate-scaphoid articular surfaces); carpals; metacarpals (proximal)
Hand	Metacarpals (heads); proximal, intermediate, and terminal phalanges
Hip	Femur (head); innominate (ilium auricular and acetabulum)
Knee	Femur (lateral and medial condyles); patella (condylar surfaces); tibia (lateral and medial condyles)
Ankle	Tibia (talar articular surfaces); tarsals; metatarsals (proximal)
Foot	Metatarsals (heads); proximal, intermediate, and terminal phalanges

[a] Adapted from Larsen (1982).

imbalance between mechanical stress of articular joints—comprised of cartilage, bone, and other tissues—and the ability of those tissues to withstand that stress (Radin, 1983; Maquet, 1983). Importantly, osteoarthritis is not a *disease*; instead, it is a *disorder* that represents a group of conditions whereby the common manifestation is joint deterioration by largely mechanical means (Radin, 1982). Also important is the fact that etiologically osteoarthritis is complex and multifactorial. However, few would disagree with Jurmain (1977: 363) in his observation that "The most convincing etiological argument relates directly to the kind and amount of environmental (mechanical) stress typical of the varying life styles of . . . populations sampled." Finally, osteoarthritis involves deterioration of both the skeletal tissues and articular cartilage (Hough and Sokoloff, 1989). In dealing with archaeological populations, however, it is usually only possible to examine the skeletal manifestations of this disorder.

We follow DeRousseau's (1988: 7) definition of osteoarthritis as including all degenerative articular joint changes. For the present study, examination of bone articular surfaces and margins representing the major weight-bearing and nonweight-bearing articular regions was made. These articular regions include the intervertebral joints (cervical, thoracic, lumbar, sacral), shoulder, elbow, wrist, hand, hip, knee, ankle, and foot (see table 8-1 for a listing of specific component skeletal elements of articular joints). The skeletal manifestations of the disorder in intervertebral (disc) joints are not arthritic per se because, unlike the other joints, they are not diarthrodial. However, given the similarity of degenerative skeletal changes of intervertebral with other joints, it is appropriate to include them in the study of osteoarthritis in general (see Ortner and Putschar, 1985).

Osteoarthritis in the Stillwater series is exhibited in a range of degrees, from very slight to severe. For purposes of the present investigation, we have identified and recorded osteoarthritis as simply present or absent for the 12 articular regions. Although these regions contain more than 12 corresponding articular joints (e.g., the hand, foot, and vertebral joints have multiple articulations), we have assigned presence of osteoarthritis for an articular joint even if only one joint surface for a multisurface joint is affected. During data collection, presence of osteoarthritis was recorded if there was evidence of any one or a combination of the following skeletal modifications: (1) proliferation of bone on joint margins (also called marginal or osteophytic lipping); (2) loss of bone on joint surfaces from resorptive activity; and (3) loss of

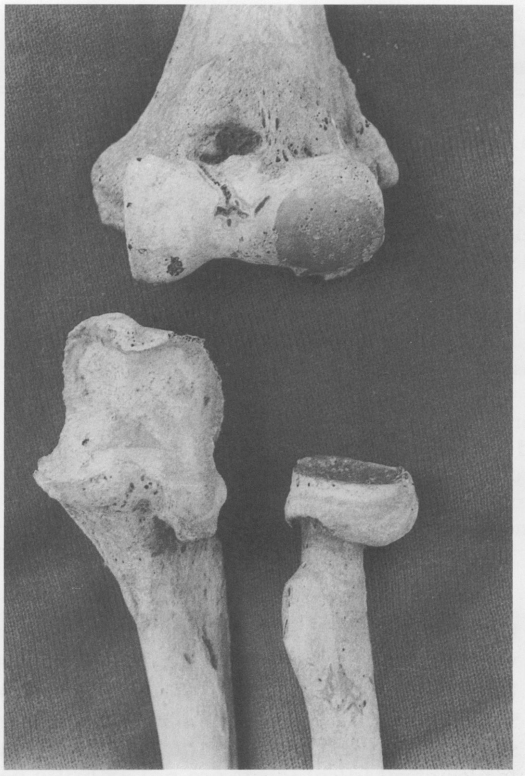

Fig. 8-1. Pathological skeletal modifications associated with osteoarthritis in left elbow (humerus, radius, and ulna) of individual 1047-13. Note the presence of both lipping on the joint margins and loss of bone on joint surfaces, including polishing (eburnation).

bone because of mechanical attrition or polishing that resulted from direct bone-on-bone articulation following degeneration of cartilage (also called eburnation) (fig. 8-1; and see examples figured in Brooks et al., 1990). Marginal lipping usually precedes eburnation (Steinbock, 1976; Merbs, 1983). During data collection, we observed that occasionally only one component skeletal element of an articular joint was affected. In at least one instance, the scapular glenoid fossa was affected but not the humeral head or acromioclavicular joint. However, from a strictly functional/mechanical perspective, a more important consideration is the joint affected and not a specific skeletal element.

Because of the progressive nature of osteoarthritis, we examined the prevalence of osteoarthritis by 5-year age categories. Age at death was estimated on the basis of one or more of the following criteria (depending on completeness of the skeleton): dental attrition, suture closure, epiphyseal union, and pubic symphyseal and auricular surface morphology (Ubelaker, 1989). Because of skeletal incompleteness, it was not possible to estimate age at death for three adults (individuals 1043-8, 1057-1, or 1060-1). We therefore assigned the mean age at death for the sample (33 years) to these individuals. A number of older adults could only be determined to be 40 years old or older (called 40+). We have included these individuals in the 35.1–40-year-old age class. (Inclusion in the 40.1–45-year-old category does not alter results of the statistical analysis. Thus, we report here only on the analysis with inclusion of individuals in the 40+ cohort in the 35.1–40-year-old age group.)

Many workers have shown differences in prevalence of osteoarthritis by sex, particularly in relation to role-based work behaviors (e.g., Pickering, 1979, 1984; Fahlström, 1981; and see discussions by Pfeiffer, 1977; Larsen, 1982, 1987; Merbs, 1983; Webb, 1989; McCafferty et al., 1992; Waldron, 1992). Therefore, we also examined osteoarthritis pattern by comparison of prevalence in males and females in the series. Sex was determined on the basis of pelvic morphology and degree of skeletal (both cranial and postcranial) robusticity (Ubelaker, 1989; White, 1991). It was not possible to determine sex for individuals 1043-8 or 1057-1, who were therefore excluded from sex comparisons.

To provide additional perspective on the degree to which the Stillwater population is affected by osteoarthritis, we provide comparative data from a series of human remains from the southeastern U.S. Atlantic coast examined by Larsen (1982). These materials are representative of hunter-gatherers (pre-A.D. 1150) and later agriculturalists (A.D. 1150–1450) who occupied the Georgia coast prior to European contact (Larsen, 1982; Griffin and Larsen, 1989). As noted above, many archaeological skeletal series have been examined for osteoarthritis by numerous investigators. However, these workers have used different methods in data collection. The consistency in method of osteoarthritis data

TABLE 8-2
Observations of Stillwater Postcrania for Osteoarthritis Analysis

Specimen	Sex	Age	Bone	Pathology[a]
1043-5	M	40+	Cervical	P, L
			Thoracic	P, L, T11–12 fracture[b]
			L., r. scapulae	P
			R. proximal ulna	P
			R. distal ulna	P
1043-8	?	33	Cervical	P
1043-ind. 4	F	40	L. proximal humerus	P
			L. distal femur	P, L
1043-61	F	30+	Lumbar	P
1044-1	F	27	—	—
1044-2	M	40+	Cervical	P
			Thoracic	P, T10–12 Schmorl's
			Lumbar	P, Schmorl's
			Sacrum	P
			L., r. proximal humeri	P
			L., r. distal humeri	P, E
			L., r. proximal radii	P, E
			L., r. proximal ulnae	P
			L., r. distal radii	P
			L., r. distal ulna	P
			L., r. carpals	P
			L., r. metacarpals	P, E
			L., r. hand phalanges	P, E
			L., r. proximal femora	P
			L., r. distal femora	P, L
			L., r. patellae	P
			L., r. proximal tibiae	P
			L., r. distal tibiae	P
			L., r. tarsals	P
			L., r. metatarsals	P
			L., r. foot phalanges	P
1044-ind. 2	M	35+	Cervical	P
			Sacrum	P
			L. scapula	P
			L. proximal ulna	P
1045-1	F	35	Lumbar	P
			L. proximal radius	P
			L. proximal ulna	P
1046-9	M	37	Lumbar	P
			L., r. proximal humeri	P
1047-1	M	21	—	—
1047-13	F	40+	L., r. proximal humeri	P
			L., r. distal humeri	P, E
			L., r. proximal radii	P, E
			L., r. distal radii	P
			L., r. proximal ulnae	P
			L., r. distal ulnae	P
1050-3	M	40+	Cervical	P
			Thoracic	P
			Lumbar	P
			Sacrum	P
			L., r. scapulae	P, L
			L., r. distal humeri	P, L

TABLE 8-2—(*Continued*)

Specimen	Sex	Age	Bone	Pathology[a]
			L., r. proximal ulnae	P
			L., r. carpals	P
			L., r. metacarpals	P
			L., r. hand phalanges	P
			L., r. distal femora	L
			L., r. tarsals	P
			L., r. metatarsals	P
			L., r. foot phalanges	P
1051-ind. 6	F	25	—	—
1054-1	M	27	—	—
1055-1	M	27	Cervical	P, L
1056-1	F	35	L., r. scapulae	P
1057-1	?	33	Lumbar	P
1058-1	M	25	—	—
1058-12A	F	22	—	—
1060-1	F	33	L. proximal ulna	P
			L. distal femur	P, L
			L., r. patellae	P
			L. proximal tibia	P
910-ind. 3	F	27	—	—
1062-1	M	40+	Cervical	P
			Thoracic	P
			Lumbar	P
			Sacrum	P
			R. proximal humerus (no involvement of l. prox. humerus)	E
			R. proximal radius	P
			L., r. proximal ulnae	P
			R. distal radius	P
			L., r. distal ulnae	P
			L., r. proximal femora	P
			L., r. distal femora	P, E
			L., r. proximal tibiae	P, E
			L., r. distal tibiae	P
			L., r. distal fibulae	P
1063-19,20	M	40+	Cervical	P
			Thoracic	P
			Lumbar	P
			Sacrum	P
			L., r. scapulae	P
			L. proximal humerus	P
			L. distal humerus	P
			L. proximal radius	P
			L. proximal ulna	P
			L. distal radius	P
			L. distal ulna	P
			L., r. proximal femora	P
			L., r. distal femora	P
			R. proximal tibia	P
			R. distal tibia	P
1064-1,18	F	30	Lumbar	P
1070-3	F	40+	Cervical	P
			Thoracic	P

TABLE 8-2—(*Continued*)

Specimen	Sex	Age	Bone	Pathology[a]
			Lumbar	P
			Sacrum	P
			L., r. proximal radii	P
			L., r. proximal ulnae	P
			L., r. proximal tibiae	P
1070-4	F	40+	Cervical	P
			Thoracic	P
			Lumbar	P, fracture
			Sacrum	P
			L., r. scapulae	P, L
			L., r. proximal ulnae	L
			L., r. distal radii	P
			L., r. metacarpals	P
			L., r. distal femora	P, L, E
			L. patella	P
			L., r. proximal tibiae	P
			L., r. dist. metatarsals	P
			L., r. foot phalanges	P
1159-4	M	35	Cervical	P
			Thoracic	P, T11–12 fracture
			L., r. proximal ulnae	P
			L., r. ilia auricular	P
1159-6	M	27	L. scapula (no involvement of r. scapula)	L
			L. proximal humerus (no involvement of r. prox. humerus)	L
			L. proximal radius (no involvement of r. prox. radius)	L
			L., r. distal tibiae	P
1159-200	F	45+	Cervical	P, C2 Schmorl's
			Thoracic	P, T5(?) Schmorl's
			Lumbar	P
			Sacrum	P
			L., r. proximal ulnae	P
			L. distal radius	P
			L., r. distal ulnae	P
			L. carpal	P
L53-B-1	F	35+	Lumbar	P
			Sacrum	P
1160-2	F	45	Lumbar	P
			L., r. ilium auricular	P
1249-1	M	21	Lumbar	P
L72-200	F	37	Cervical	P, C4–5 fracture[b]
			Lumbar	P
1173-200	F	27	—	—

[a] P = proliferation of bone on joint margins (also called marginal or osteophytic lipping); L = loss of bone on joint surfaces from resorptive activity; E = eburnation (loss of bone from mechanical attrition or polishing resulting from direct bone on bone articulation).

[b] Fracture refers to compression fracture of anterior vertebral body.

collection in the Stillwater and Georgia coastal series offers a more precise basis for comparison.

Results

Summaries of sex, age at death, bones affected by osteoarthritis, and the manifestations of the disorder for each of the 34 Stillwater individuals are presented in table 8-2. Our findings indicate that most of the pathology is proliferative; that is, most degenerative changes consist of marginal lipping. Some individuals, however, show resorptive loss of bone on joint surfaces, eburnation, and, with regard to some vertebral bodies, Schmorl's nodes and compression fractures. The latter two conditions are discussed more fully later in this chapter (see Discussion).

In cases involving paired skeletal elements (e.g., elbow, hip, knee), we have noted degenerative changes in some individuals that occur on only one side of the skeleton (table 8-2). Some individuals examined are missing one side of paired joints (e.g., 1043-ind.4). For these materials, assessment of unilateral/bilateral degenerative involvement was not possible. However, in individuals where both sides are present, we found a pattern of general bilateral involvement of articular joints. That is, if present, degenerative changes usually occur on both sides of paired joints. Indeed, only two individuals showed involvement of a single side when both sides were available for observation. In particular, 1062-1, an adult male, showed degenerative changes (eburnation) on the right humerus head, but not on the left humerus head. Individual 1159-6, a young adult male, exhibited degenerative changes on the left shoulder and left elbow joints, but not on these joints on the right side. Because unilateral osteoarthritic involvement was limited to these two individuals, we have combined left and right sides for analysis (i.e., if one or both sides of nonvertebral joints exhibit degenerative changes, the articular joint is noted as being involved).

The distribution of arthritic and nonarthritic articular joints in the Stillwater series is presented in table 8-3. Analysis of these data indicates that most individuals (all joints combined per skeleton) in the study population are affected by the disorder (table 8-4). For the total sample (indeterminate sex, females, and males combined), more than three-fourths of the skeletal series (76.5%) are affected by osteoarthritis. All individuals greater than 30 years of age at death (N = 21) exhibit at least some manifestation of osteoarthritis. The findings also revealed that more males are arthritic than females (78.6% vs. 72.2%), although differences between the sexes do not reach statistical significance (chi-square: $p > 0.05$) for any of the age group comparisons.

Table 8-5 and figure 8-2 show the frequency of osteoarthritis for each of the articular joints. For the total sample, the lowest prevalence occurs for the hand (13.0%), the highest prevalence for the lumbar vertebrae (66.7%). In addition to the lumbar vertebrae, other articular joints with frequencies of 50% or higher include the cervical vertebra (52.0%) and elbow (50.0%). In males, the percentages range from a low of 18.2% for the hand to a high of 61.5% for cervical, shoulder, and elbow joints. In addition to these joints, the lumbar vertebrae show greater than 50.0% prevalence (54.5%). In females, the frequency of osteoarthritis by articular joint ranges from 0.0% (ankle) to 75.0% (lumbar vertebrae). It is clear from these findings that females have a lower prevalence of osteoarthritis than males. However, the lumbar joint exceeds 50% osteoarthritis prevalence for females, and it is the only joint of the 12 examined that exceeds the male prevalence. Two comparisons show significantly higher frequency of osteoarthritis in males than females, including the hip (chi-square: $p \leq 0.03$) and ankle (chi-square: $p \leq 0.02$) joints. In addition, the greater frequency in male versus female shoulder joints approaches statistical significance (chi-square: $p = 0.11$).

Because osteoarthritis is a progressive disorder—that is, older individuals should be more afflicted than younger individuals—it is possible that the male–female comparisons may simply represent differences in age composition between male and female samples. The mean age at death for males is 32.5 years, whereas that for females is 34.1 years. If age were the sole explanation for the sex difference in osteoarthritis, then the slightly higher age at death for females would suggest that

TABLE 8-3
Articular Joints Affected by Osteoarthritis[a]

Individual	Joint[b]											
	C	T	L	S	Sho	Elb	Wri	Han	Hip	Kne	Ank	Foot
1043-5	1	1	–	–	1	1	1	0	–	–	0	0
1043-8	1	–	–	–	–	–	–	0	–	–	0	–
1043-ind. 4	–	–	–	–	1	0	–	–	0	1	–	–
1043-61	–	0	1	0	–	0	0	–	0	0	0	–
1044-1	0	0	0	0	0	0	0	0	0	0	0	0
1044-2	1	1	1	1	1	1	1	1	1	1	1	1
1044-ind. 2	1	0	0	1	1	1	–	–	–	0	0	0
1045-1	0	0	1	0	0	1	0	0	0	0	0	0
1046-9	0	0	1	0	1	0	0	0	0	0	0	0
1047-1	0	0	–	–	0	0	0	–	0	0	0	0
1047-13	0	–	–	–	–	1	1	0	–	–	–	–
1050-3	1	1	1	1	1	1	1	1	0	1	1	1
1051-ind. 6	–	–	–	–	0	0	0	–	0	0	0	–
1054-1	0	0	0	0	0	0	0	0	0	0	0	0
1055-1	1	0	0	0	0	0	0	0	–	0	–	–
1056-1	–	0	–	–	1	–	–	–	0	0	0	0
1057-1	0	0	1	–	–	–	–	–	–	–	–	–
1058-1	0	–	–	–	–	–	–	–	–	–	–	–
1058-12A	0	0	0	–	0	0	–	0	0	–	0	–
1060-1	–	–	–	–	–	1	0	0	0	1	0	–
910-ind. 3	0	–	0	–	0	0	–	–	0	0	0	–
1062-1	1	1	1	1	1	1	1	0	1	1	1	0
1063-19,20	1	1	1	1	1	1	1	0	1	1	1	–
1064-1,18	0	0	1	0	0	0	0	–	0	0	0	–
1070-3	1	1	1	1	0	1	0	0	0	1	0	0
1070-4	1	1	1	1	1	1	1	1	0	1	0	1
1159-4	1	1	0	0	0	1	0	0	1	0	0	0
1159-6	0	0	0	0	1	1	0	0	0	0	1	0
1159-200	1	1	1	1	0	1	1	0	0	0	0	0
L53-B-1	–	0	1	1	0	–	0	0	0	–	–	–
1160-2	–	0	1	0	–	–	–	–	1	0	–	–
1249-1	–	0	1	0	0	0	0	0	0	0	–	–
L72-200	1	0	1	0	0	0	0	0	0	0	0	0
1173-200	–	0	–	–	–	0	0	0	–	0	0	0

[a] Compiled from table 7-2.

[b] C = cervical, T = thoracic, L = lumbar, S = sacrum, Sho = shoulder, Elb = elbow, Wri = wrist, Han = hand, Hip = hip, Kne = knee, Ank = ankle, Foot = foot; 0 = osteoarthritis absent, 1 = osteoarthritis present, – = missing data (joint not present for observation).

they should have a higher prevalence of the disorder. Because females clearly do not have a higher prevalence of osteoarthritis than males, these differences cannot be attributed to age at death.

Comparison of articular joints by 5-year age category provides evidence that the prevalence of osteoarthritis is greater in males than in females for most cohorts (table 8-6). None of the comparisons reaches statistical significance, a factor that is most likely related to the very limited sample sizes. However, four comparisons that show greater prevalence in males than in females approach statistical significance: shoulder (35.1–40-year-old group), hip (35.1–40), ankle (25.1–30), and ankle (35.1–40).

To increase the sample sizes for age comparison of males and females, we combined the 5-year age classes into two groups, including "young" adults (20.1–35) and "old" adults (35.1+) (table 8-7). The tendency for

TABLE 8-4
Age Comparisons of Individuals Affected by Osteoarthritis[a]

Age group	Total (33.4)[b]		Males (32.5)		Females (34.1)	
	N[c]	%[d]	N	%	N	%
20.1–25	5	20.0	3	33.3	2	0.0
25.1–30	8	50.0	3	66.7	5	40.0
30.1–35	8	100.0	2	100.0	4	100.0
35.1–40	11	100.0	6	100.0	5	100.0
40.1–45	2	100.0	0	—	2	100.0
Total	34	76.5	14	78.6	18	72.2

[a] No significant differences between males and females (chi-square: $p > 0.05$ for each age class).

[b] Mean age at death was 33.4 years for individuals in the study (includes both those affected and unaffected by osteoarthritis).

[c] Number of individuals observed for presence/absence of osteoarthritis; presence of pathology denoted by at least one articular joint affected.

[d] Percentage of individuals affected by osteoarthritis.

males to exceed females in osteoarthritis prevalence is evident, especially in the cervical (20.1–35 group), shoulder (35.1+ group), hip (35.1+ group), and ankle (35.1+ group) joints.

TABLE 8-5
Osteoarthritis Summary Statistics[a]

Joint	Total		Males		Females	
	N[b]	%[c]	N	%	N	%
Cervical	25	52.0	13	61.5	10	40.0
Thoracic	27	33.3	13	46.2	13	23.1
Lumbar	24	66.7	11	54.5	12	75.0
Sacrum	21	42.9	11	45.5	10	40.0
Shoulder	26	42.3	13	61.5	13	23.1
Elbow	28	50.0	13	61.5	15	40.0
Wrist	25	32.0	12	41.7	13	23.1
Hand	23	13.0	11	18.2	11	9.1
Hip	26	19.2	10	40.0	16	6.3
Knee	27	29.6	12	33.3	15	26.7
Ankle	26	19.2	11	45.5	14	0.0
Foot	18	16.7	10	20.0	8	12.5

[a] Two male/female comparisons were significant (chi-square): hip ($p \leq 0.03$) and ankle ($p \leq 0.02$). One male/female comparison approached significance; shoulder ($p = 0.11$).

[b] Number of articular joints observed for presence or absence of osteoarthritis.

[c] Percentage of articular joints affected by osteoarthritis.

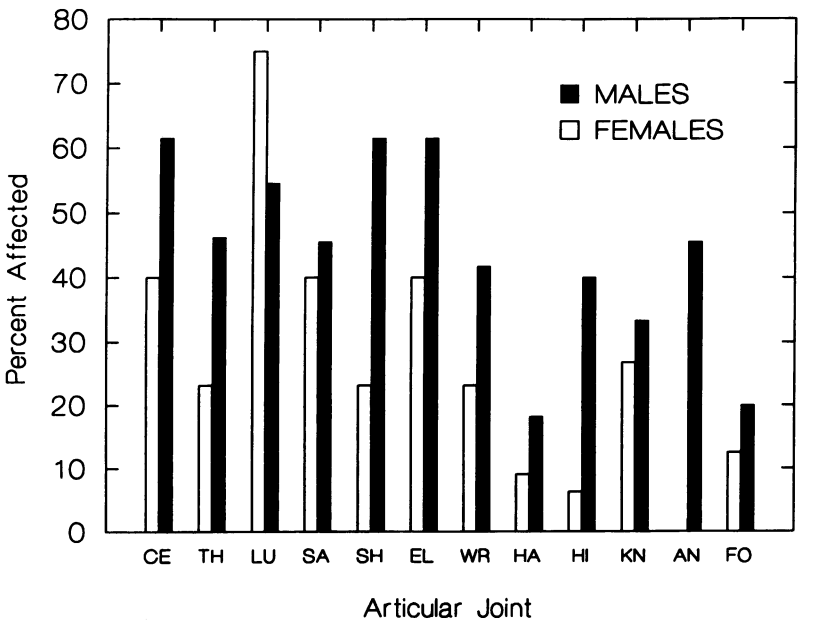

Fig. 8-2. Stillwater male and female osteoarthritis prevalence by articular joint (CE = cervical, TH = thoracic, LU = lumbar, SA = sacrum, SH = shoulder, EL = elbow, WR = wrist, HA = hand, HI = hip, KN = knee, AN = ankle, FO = foot).

TABLE 8-6
Osteoarthritis Summary Statistics (by 5-Year Age Groups)[a]

Joint/age group	Total[b]		Males		Females	
	N[c]	%[d]	N	%	N	%
Cervical						
20.1–25	3	0.0	2	0.0	1	0.0
25.1–30	6	16.7	3	33.3	3	0.0
30.1–35	5	60.0	2	100.0	1	0.0
35.1–40	10	80.0	6	83.3	4	75.0
40.1–45	1	100.0	0	—	1	100.0
Thoracic						
20.1–25	3	0.0	2	0.0	1	0.0
25.1–30	7	0.0	3	0.0	4	0.0
30.1–35	6	16.7	2	50.0	3	0.0
35.1–40	9	77.8	6	83.3	3	66.7
40.1–45	2	50.0	0	—	2	50.0
Lumbar						
20.1–25	2	50.0	1	100.0	1	0.0
25.1–30	7	28.6	3	0.0	4	50.0
30.1–35	5	60.0	2	0.0	2	100.0
35.1–40	8	100.0	5	100.0	3	100.0
40.1–45	1	100.0	0	—	2	100.0
Sacrum						
20.1–25	1	0.0	1	0.0	0	—
25.1–30	6	0.0	3	0.0	3	0.0
30.1–35	4	50.0	2	50.0	2	50.0
35.1–40	8	75.0	5	80.0	3	66.7
40.1–45	2	50.0	0	—	2	50.0
Shoulder						
20.1–25	4	0.0	2	0.0	2	0.0
25.1–30	6	16.7	3	33.3	3	0.0
30.1–35	5	40.0	2	50.0	3	33.0
35.1–40	10	80.0	6	100.0	4	50.0
40.1–45	1	0.0	0	—	1	0.0
Elbow						
20.1–25	4	0.0	2	0.0	2	0.0
25.1–30	8	12.5	3	33.3	5	0.0
30.1–35	4	100.0	2	100.0	2	100.0
35.1–40	11	72.7	6	83.3	5	60.0
40.1–45	1	100.0	0	—	1	100.0
Wrist						
20.1–25	3	0.0	2	0.0	1	0.0
25.1–30	7	0.0	3	0.0	4	0.0
30.1–35	4	0.0	1	0.0	3	0.0
35.1–40	10	70.0	6	83.3	4	50.0
40.1–45	1	100.0	0	—	1	100.0
Hand						
20.1–25	2	0.0	1	0.0	1	0.0
25.1–30	5	0.0	3	0.0	2	0.0
30.1–35	5	0.0	1	0.0	3	0.0
35.1–40	10	30.0	6	33.3	4	25.0
40.1–45	1	0.0	0	—	1	0.0
Hip						
20.1–25	4	0.0	2	0.0	2	0.0
25.1–30	6	0.0	2	0.0	4	0.0
30.1–35	5	20.0	1	100.0	4	0.0
35.1–40	9	33.3	5	60.0	4	0.0
40.1–45	2	50.0	0	—	2	50.0
Knee						
20.1–25	3	0.0	2	0.0	1	0.0
25.1–30	8	0.0	3	0.0	5	0.0
30.1–35	5	20.0	2	0.0	3	33.3
35.1–40	9	77.8	5	80.0	4	75.0
40.1–45	2	0.0	0	—	2	0.0
Ankle						
20.1–25	3	0.0	1	0.0	2	0.0
25.1–30	7	14.3	2	50.0	5	0.0
30.1–35	6	0.0	2	0.0	3	0.0
35.1–40	9	44.4	6	66.7	3	0.0
40.1–45	1	0.0	0	—	1	0.0
Foot						
20.1–25	1	0.0	1	0.0	0	—
25.1–30	4	0.0	2	0.0	2	0.0
30.1–35	4	0.0	2	0.0	2	0.0
35.1–40	8	37.5	5	40.0	3	33.3
40.1–45	1	0.0	0	—	1	0.0

[a] No comparisons were significant (chi-square: $p > 0.05$); five comparisons (lumbar, 30.1–35; shoulder, 35.1–40; hip, 35.1–40; ankle, 25.1–30; ankle, 35.1–40) approached significant levels ($p \leq 0.25$).

[b] Totals include males, females, and indeterminate sex combined.

[c] Number of articular joints observed for presence or absence of osteoarthritis.

[d] Percentage of articular joints affected by osteoarthritis.

Our initial impressions of high prevalence of osteoarthritis in the Stillwater series is borne out by comparisons with two other skeletal series from the southeastern United States. In table 8-8 and figure 8-3, we show comparisons of Stillwater, Georgia coastal preagriculturalists, and Georgia coastal agriculturalists for adult males and females. In an earlier study, Larsen (1982) demonstrated that there was a temporal decline in osteoarthritis prevalence, which he related to a

TABLE 8-7
Sex Comparisons of Osteoarthritis Prevalence in Young and Old Adults[a]

Joint/age group	Males		Females	
	N[b]	%[c]	N	%
Cervical				
20.1–35	7	42.9	5	0.0
35.1+	6	83.3	5	80.0
Thoracic				
20.1–35	7	14.3	8	0.0
35.1+	6	83.3	5	60.0
Lumbar				
20.1–35	6	16.7	7	57.1
35.1+	5	100.0	5	100.0
Sacrum				
20.1–35	6	16.7	5	20.0
35.1+	5	80.0	5	60.0
Shoulder				
20.1–35	7	28.6	8	12.5
35.1+	6	100.0	5	40.0
Elbow				
20.1–35	7	42.9	9	22.2
35.1+	6	83.3	6	66.7
Wrist				
20.1–35	6	0.0	8	0.0
35.1+	6	83.3	5	60.0
Hand				
20.1–35	5	0.0	6	0.0
35.1+	6	33.3	5	20.0
Hip				
20.1–35	5	20.0	10	0.0
35.1+	5	60.0	6	16.7
Knee				
20.1–35	7	0.0	9	11.1
35.1+	5	80.0	6	50.0
Ankle				
20.1–35	5	20.0	10	0.0
35.1+	6	66.7	4	0.0
Foot				
20.1–35	5	0.0	4	0.0
35.1+	5	40.0	4	25.0

[a] Young adults = 20.1–35 years; old adults = 35+ years. No comparisons were significant (chi-square: $p > 0.05$); four comparisons (cervical, 20.1–35; shoulder, 35.1+; hip, 35.1+; ankle, 35.1+) approached significant levels ($p \leq 0.25$).

[b] Number of articular joints observed for presence or absence of osteoarthritis.

[c] Percentage of articular joints affected by osteoarthritis.

TABLE 8-8
Comparison of Osteoarthritis Frequency in Stillwater and Georgia Coastal Populations

Joint	Still[a]		GA-Preag		GA-Ag	
	N[b]	%[c]	N	%	N	%
Males						
Cervical	13	61.5	20	40.0	53	11.3
Thoracic	13	46.2	16	12.5	51	11.8
Lumbar	11	54.5	13	69.2	47	27.7
Sacrum	11	45.5	10	0.0	33	0.0
Shoulder	13	61.5	38	10.5	120	1.7
Elbow	13	61.5	51	13.7	114	6.1
Wrist	12	41.7	39	2.6	106	0.9
Hand	11	18.2	28	0.0	100	2.0
Hip	10	40.0	51	0.0	110	9.1
Knee	12	33.3	59	18.6	111	12.6
Ankle	11	45.5	49	4.1	109	9.2
Foot	10	20.0	26	0.0	93	1.1
Females						
Cervical	10	40.0	29	17.2	73	1.4
Thoracic	13	23.1	30	6.7	72	1.4
Lumbar	12	75.0	28	32.1	64	12.5
Sacrum	10	40.0	23	4.3	47	6.4
Shoulder	13	23.1	83	2.4	144	0.7
Elbow	15	40.0	94	9.6	167	0.0
Wrist	13	23.1	77	2.6	140	0.0
Hand	11	9.1	50	0.0	129	0.8
Hip	16	6.3	93	4.3	148	0.0
Knee	15	26.7	94	15.0	147	3.4
Ankle	14	0.0	88	4.5	139	0.0
Foot	8	12.5	48	0.0	120	0.0

[a] Still = Stillwater; GA-Preag = Georgia coast, preagricultural (from Larsen, 1982; Griffin and Larsen, 1989); GA-Ag = Georgia coast, agricultural (from Larsen, 1990; Griffin and Larsen, 1989).

[b] Number of articular joints observed for presence or absence of osteoarthritis.

[c] Percentage of articular joints affected by osteoarthritis.

decline in workload and increased sedentism that accompanied the shift from a lifeway based on hunting, gathering, and fishing to one based at least in part on maize agriculture. The Stillwater hunter-gatherers have a markedly higher prevalence of osteoarthritis than either the Georgia coastal hunter-gatherers or agriculturalists. When compared to southeastern U.S. hunter-gatherer samples, the Stillwater series exhibits considerably higher frequencies in every comparison except the male lumbar vertebra and the female ankle (table 8-8). However, these exceptions to the general pattern are not statistically sig-

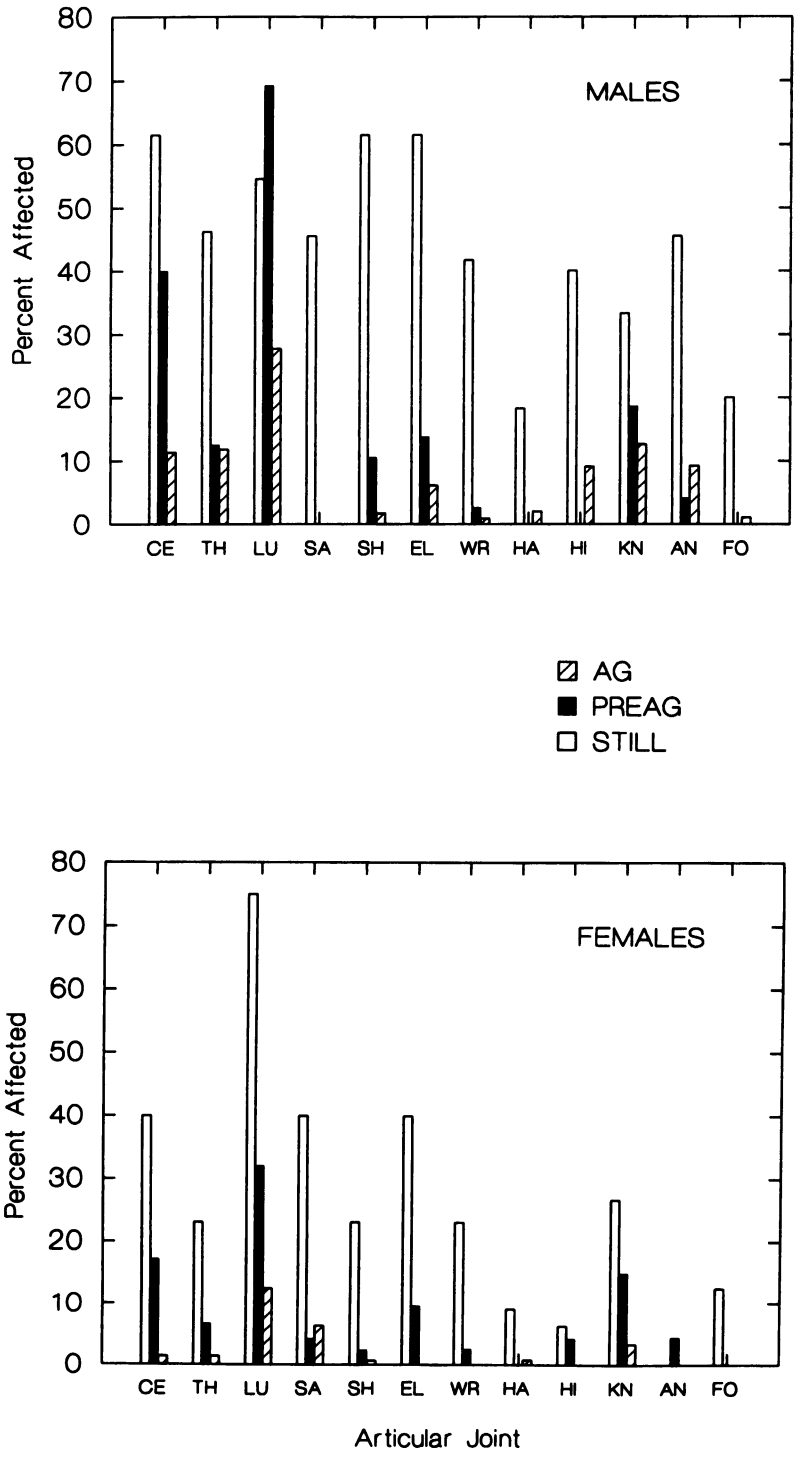

Fig. 8-3. Male and female comparisons of Stillwater (STILL), Georgia coastal preagriculturalists (PREAG), and Georgia coastal agriculturalists (AG) osteoarthritis prevalence (CE = cervical, TH = thoracic, LU = lumbar, SA = sacrum, SH = shoulder, EL = elbow, WR = wrist, HA = hand, HI = hip, KN = knee, AN = ankle, FO = foot).

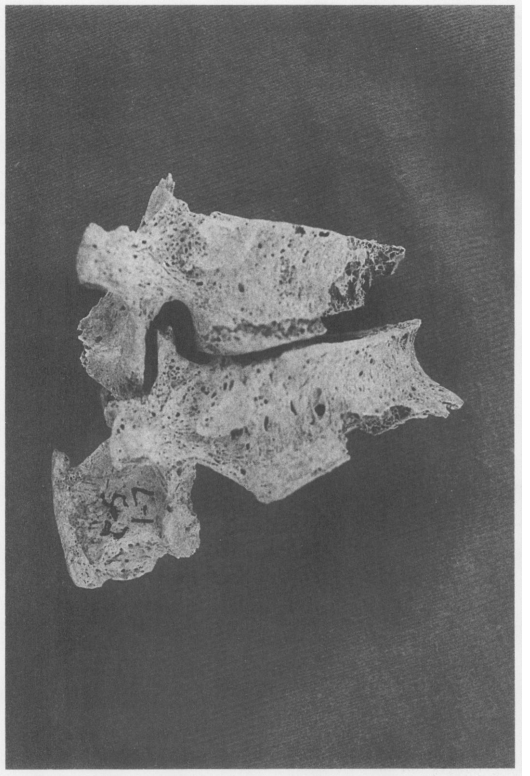

Fig. 8-4. Compression fractures of vertebral bodies (1047-5). Note the wedge-shaped appearance caused by the greater anterior than posterior compression of the bodies.

nificant (chi-square: $p > 0.05$) and may simply reflect an unknown sampling bias.

Discussion

Our analysis of patterning of osteoarthritis suggests that mechanical factors are likely more important than systemic factors in the etiology of the disorder in the Stillwater series. For example, very few hands are affected, particularly with regard to metacarpal–phalangeal articulations of all five digits. In clinical settings, these joints of hands are usually involved in nonmechanical, systemic arthritises, such as rheumatoid arthritis (see discussions in Cockburn et al., 1979; Merbs, 1983).

Our findings strongly suggest that this population led a rigorous and demanding lifeway. The vertebral column is subjected to very pronounced vertical mechanical loads, and a number of individuals exhibited, in addition to extensive marginal lipping, pathological modifications that reflect these demands. For example, several individuals exhibited anterior compression fractures of vertebral bodies, which resulted in marked reductions of height (fig. 8-4). The vertebral compression fractures were mostly restricted to the lower thoracic and lumbar vertebrae (N = 3). One individual exhibited severe compression of the fourth and fifth cervical vertebral bodies that was probably related to a severe neck injury. All compression fractures observed in this series are associated with older adults (35+ years). In addition to this indicator of trauma, several individuals show depressions known as Schmorl's nodes in the intervertebral surfaces of the vertebral bodies. These depressions are likely the skeletal manifestations of herniated intervertebral disks, frequently arising from excessive mechanical loading of the back (see Merbs, 1983, 1989).

There is much variation in sexual dimorphism in osteoarthritis in human remains from archaeological settings (see review in Bridges, 1992). In at least one archaeological study, female prevalence of osteoarthritis exceeded male prevalence (McCafferty et al., 1992), but this is extremely rare. Some researchers have shown few differences between males and females in at least some joints. For example, Pickering (1984) reported no significant differences in the arms and legs in prehistoric Illinois samples he studied. However, most researchers show that males tend to have more osteoarthritis than females; some of these differences are highly significant (e.g., Jurmain, 1977; Pfeiffer, 1977; Merbs, 1983). The Stillwater series exhibits a pattern of sexual dimorphism in which males are generally more affected than females. Although nearly all joints examined indicate that males exceed females in osteoarthritis prevalence, three articular joints show either statistically significant or near statistically significant differences, including the shoulder, hip, and ankle. In virtually all hunter-gatherer societies, males are responsible for hunting and females are responsible for gathering (e.g., Lee, 1979; Hill and Hurtado, 1989). The pattern of greater osteoarthritic involvement of shoulder, hip, and ankle in males relative to females likely reflects

sex differences in degree of mechanical stress in relation to resource procurement in general and hunting activity in particular. In this context, excessive use of the shoulder may arise from thrusting activity, perhaps in spear-throwing. However, if the activity responsible for shoulder use was due to thrusting, it is unlikely that it arose entirely from spear-throwing or use of the atlatl because of the presence of *bilateral* involvement of osteoarthritis in the Stillwater remains.

On the other hand, osteoarthritic involvement of the hip and possibly the ankle may represent mechanical demands associated with running and walking. The relatively higher prevalence of osteoarthritis in males for these articular joints suggests that it was acquired through a lifetime of activity in difficult terrain, such as in the nearby uplands surrounding the Stillwater Marsh.

Perhaps the most outstanding aspect regarding the presence of degenerative articular changes in the Stillwater series is its very high prevalence compared with archaeological samples studied by others (cf. Anderson, 1976; Jurmain, 1977, 1980, 1990; Merbs, 1983; Pickering, 1984; Bennike, 1985; Frankenberg et al., 1988) and by us (Larsen, 1982; Griffin and Larsen, 1989). The high frequencies in the Great Basin sample may be somewhat misleading, however, owing to differences in scoring and data collection procedures followed by different researchers (see also Bridges, 1992). However, the ubiquitous nature of osteoarthritis in the Stillwater remains argues for high prevalence in the populations represented. Comparisons of Stillwater and Georgia coastal hunter-gatherers and agriculturalists reveal a much higher prevalence of osteoarthritis in the Stillwater series, which we conclude reflects greater mechanical loadings on articular joints of these representative Great Basin populations. Insight into the behavior context for understanding these high prevalence levels is provided in the ethnographic literature. Brooks et al. (1988) summarized various activities recounted by Steward (1938) and Wheat (1967) in their descriptive and photographic documentation of Great Basin activities undertaken by native populations. Among other habitual activities that could lead to articular joint deterioration, they report on carrying heavy loads, cutting animal hides, seed grinding and pounding with stone mortars and pestles, stone tool production, and use of the bow and arrow.

Stark and Brooks (1985) summarized the results of their paleopathology survey of a series of 259 skeletal individuals recovered from a variety of contexts in Nevada (excluding human remains from the Stillwater Marsh). Incidence of degenerative joint pathology was considerably less in their study than what we report for the Stillwater series. For example, only 4% of their Pyramid Lake group, 5% of their Humboldt Sink group, and 17% of their southern Nevada group had at least one vertebral body exhibiting proliferative marginal lipping (Stark and Brooks, 1985: 68). As they correctly pointed out, their findings are largely inconclusive because of insufficient sample sizes and poor archaeological and geographical contexts from which many of the remains were collected. Unfortunately, therefore, comparisons made between the present study and summary statistics reported by Stark and Brooks (1985) are not meaningful.

In summary, the high prevalence of osteoarthritis in the Stillwater series portrays a population involved in very heavy, repetitive physical activities that resulted in frequent and severe expressions of the disorder. This high prevalence is not consistent with the low prevalence or distribution of osteoarthritis in other sedentary populations. High prevalence does not tell us, however, the relative amounts of time spent in marsh versus uplands settings. Nonetheless, based on the extremely high frequency of osteoarthritis in this sample, we speculate that although the individuals were at least part-time inhabitants of the Stillwater Marsh, they likely devoted appreciable time and effort to activities in the uplands surrounding the region. We note that the high prevalence of osteoarthritis by itself does not indicate that individuals were spending significant time in the nearby mountains. Nevertheless, these findings are consistent with such a scenario, especially in light of results presented in Part II of this chapter.

Analysis of these data by sex suggests that the lower prevalence in females may indicate that they were subject to less mechanical de-

mand than males, perhaps as a result of greater sedentary behavior or at least less participation in activities thought to cause osteoarthritis. It is conceivable that females spent more time in the marsh setting than did males. On the other hand, the higher frequency of osteoarthritis in female lumbar vertebrae compared to males may reflect specific behaviors affecting the lower back, such as carrying children (as well as other burdens such as firewood, food, and collecting equipment) while foraging, or the demands of food-processing, such as seed grinding.

PART II. LONG BONE DIAPHYSEAL MORPHOLOGY

At first glance, the skeletal robusticity of the Stillwater postcranial remains is striking, both in terms of development of muscle attachment sites on individual bones and overall size (standard osteometric data are provided in Brooks et al., 1988). This is certainly one of the most robust modern *Homo sapiens* human skeletal series that we have observed, particularly among North American native populations. These observations, along with the extraordinary osteoarthritis prevalence documented above, strongly suggest that lifeways in this region of the Great Basin were mechanically demanding. To investigate the functional and behavioral meaning of this assessment in greater depth, we use a biomechanical/structural approach to the study of long bone morphology. In particular, we apply beam theory as developed by civil and mechanical engineers for structural analysis of building materials (Nordin and Frankel, 1980; Lanyon and Rubin, 1985). That is, in engineering terminology, long bones can be modeled as hollow beams, and the strength of these beams can be measured. Although it has been known for a century or more that bone tissue remodels in response to mechanical forces (Wolff, 1892), the biomechanical approach was first applied to animals relatively recently and to bioanthropological issues only within the last several decades (e.g., Jungers and Minns, 1979). Recent developments in use of automated means of analysis and noninvasive imaging techniques (e.g., computed tomography [CT] scanning) have greatly expedited the study of large skeletal samples, thus improving understanding of long bone morphological variation in relation to mechanical environment. This has been central to the development of more precise means of understanding variation in robusticity in modern humans as well as ancestral hominids (see Ruff et al., 1993).

By applying beam analysis to archaeological human remains, function and behavior have been delineated by summarizing complex shapes of long bone diaphyses viewed in cross section into a series of readily interpretable properties (Hayes and Gerhart, 1985; Bridges, 1989a; Ruff, 1989). These properties—called cross-sectional geometric properties—are used to measure the strength or resistance of bone to the two primary forces that long bones are subject to in life, namely bending and torsion (twisting). These forces are from the combined actions of gravity and muscles on bone. They vary according to a number of factors—principally body weight, body proportions, sex, habitual postures, and activity level and types (see discussion in Ruff, 1992). The resistance of bone to mechanical factors is reflected by the pattern of distribution of skeletal tissue as it remodels during the years of growth and development and adulthood.

Materials and Methods

Twenty-four femora and 27 humeri (including seven bilateral pairs) representing an approximately equal number of adult males and females from the Stillwater Marsh were selected by us at the NSM Annex (table 8-9). Right and left humeri of bilateral pairs were averaged for this analysis. Thus, a total of 20 individuals with humeri were included in the study. Fourteen individuals had a matched femur/humerus (or humeri in the case of matched pairs); 10 femora and 6 humeri were not matched with a corresponding upper or lower limb bone from the same individual. Only complete long bones with intact ends and unweathered surfaces were used in the study. After specimens were selected for analysis, each of the long bones was oriented in standard anteroposterior and mediolateral planes following procedures we have used with other North American skeletal samples (Ruff and Larsen, 1990). Following orienta-

TABLE 8-9
Stillwater Marsh Femora and Humeri Used in Cross-Sectional Geometric Properties Analysis[a]

Specimen	NSM No.	Bone	Side	Age	Sex
1043-ind. 3	9-1	Femur	Left	Adult	Male
1043-ind. 4	57-1	Femur	Right	35–45	Female
1043-ind. 4	60-4A	Femur	Left	35–45	Female
1043-61	61-1-9	Femur	Right	30+	Female
1044-1	1-2-18	Femur	Right	25–30	Female
1044-2	2-3-19	Femur	Left	40+	Male
1045-1	1-2-9	Femur	Left	30–40	Female
1046-9	9-11-20	Femur	Left	35–40	Male
1049-6	6-1	Femur	Right	Adult	Male
1050-3	3-5-19	Femur	Right	40+	Male
1051-ind. 6	10-2	Femur	Left	20–30	Female
1051-ind. 9	1-1	Femur	Left	Adult	Male
1054-1	1-3-14	Femur	Right	25–30	Male
1056-1	1-1	Femur	Right	30–40	Female
1060-1	1-3	Femur	Left	Adult	Female
910-ind. 3	7-1	Femur	Right	25–30	Female
1062-1	1-2-19	Femur	Left	40+	Male
1064-1,18	1-2-13	Femur	Right	25-35	Female
1070-3	3-3-20	Femur	Right	40+	Female
1070-4	4-3-20	Femur	Left	40+	Female
1159-4	4-1-21	Femur	Left	30–40	Male
1159-7	52-1-19	Femur	Right	16–19	Male
1159-9	52-9-1	Femur	Right	Adult	Male
1160-2	2-10-8	Femur	Left	40–50	Female
1043-61	36-1	Humerus	Right	30+	Female
1044-1	1-2-10	Humerus	Right	25–30	Female
1044-1	1-2-11	Humerus	Left	25–30	Female
1044-2	2-3-10	Humerus	Right	40+	Male
1045-1	1-2-6	Humerus	Left	30–40	Female
1046-9	9-11-13	Humerus	Left	35–40	Male
1046-39	39-1	Humerus	Right	Adult	Male(?)
1047-10	10-1	Humerus	Right	18–25	Male
1050-3	3-5-11	Humerus	Right	40+	Male
1050-3	3-5-12	Humerus	Left	40+	Male
1051-ind. 6	10-9	Humerus	Right	20–30	Female
1054-1	1-3-11	Humerus	Left	25–30	Male
1055-1	2-6	Humerus	Right	25–30	Male
1058-12	12-6	Humerus	Right	20–25	Female
910-ind. 3	12-1	Humerus	Right	25–30	Female
1062-1	1-2-11	Humerus	Right	40+	Male
1062-1	1-2-12	Humerus	Left	40+	Male
1063-19,20	20-2-10	Humerus	Left	40+	Male
1064-1,18	1-2-8	Humerus	Right	25–35	Female
1064-1,18	1-2-9	Humerus	Left	25–35	Female
1068-62	62-1	Humerus	Right	Adult	Male(?)
1070-3	3-3-12	Humerus	Right	40+	Female
1070-3	3-3-13	Humerus	Left	40+	Female
1070-4	4-3-12	Humerus	Right	40+	Female
1070-4	4-3-13	Humerus	Left	40+	Female
1159-6	6-1-12	Humerus	Right	25–30	Male
1159-6	6-1-13	Humerus	Left	25–30	Male

[a] Right and left humeri of bilateral pairs were averaged for the cross-sectional analysis (individuals 1044-1, 1050-3, 1062-1, 1064-1,18, 1070-3, 1070-4, 1159-6).

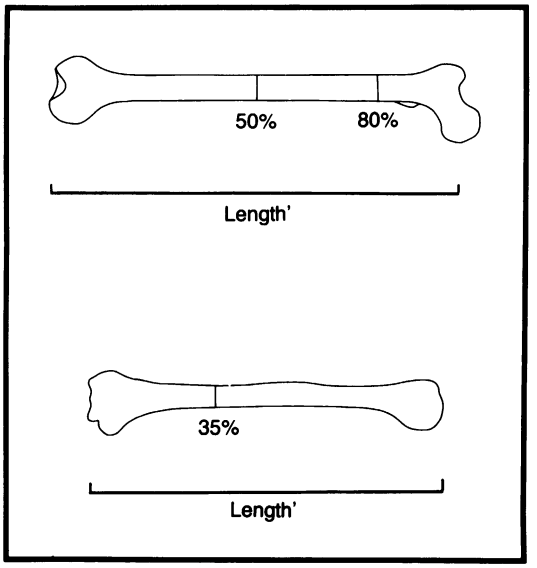

Fig. 8-5. Locations of femoral (top) and humeral (bottom) sections included in the study (from Ruff and Larsen, 1990).

tion, the positions of three sections were marked on the bone diaphyses relative to their distal ends: (1) femur midshaft (50% section), (2) femur subtrochanteric (80% section), and (3) humerus mid-distal (35% section) (fig. 8-5). The section positions represent percentages of *length'* (also called biomechanical length) of long bones (Ruff and Hayes, 1983). For the femur, length' (herein referred to as length) is the average distance from the two distal surfaces of the medial and lateral condyles to the superior margin of the neck, and, unlike the traditional measurement of length (cf. Bass, 1987: 212–213), does not include the head of the femur. For the humerus, length is the distance from the proximal surface of the humeral head to the distal edge of the lateral lip of the trochlea. This measurement closely approximates the traditional length distance of the humerus (cf. Bass, 1987: 147).

After orientation and location of the section positions on individual long bones, all specimens were transported to the Veterans Administration Medical Center in Reno, Nevada, where they were scanned at the predetermined sections using a GE 9800 CT scanner. Section scanning was completed following established procedures for human long bones (Ruff and Leo, 1986; Ruff, 1989). Hardcopy images of the CT scans were produced and transported to the Johns Hopkins University School of Medicine for study and analysis (fig. 8-6). In each of the cross-section profiles from CT scans, the two surfaces—inner (endosteal) and outer (periosteal)—from these images were manually traced on a digitizer screen using an electronic stylus, with boundary-point coordinates input to a microcomputer and section properties calculated by a modified version of the program SLICE (Nagurka and Hayes, 1980).

Cross-sectional properties include *areas* and *second moments of area.* The former include the *amount* of bone tissue in a cross section, cortical area (CA), as well as medullary area (MA), total subperiosteal area (TA), and percent cortical area [PCCA, defined as (CA/TA) × 100]. Second moments of area reflect the *distribution* of bone tissue in a cross section (relative to a central point or axis). These include second moments of area in the anteroposterior plane (I_x) and in the mediolateral plane (I_y), maximum and minimum second moments of area (I_{max}, I_{min}), and polar second moment of area (J). The I and J values represent respective measurements of bending and torsional strength, the two primary mechanical loading modes to which femora and humeri are subject in vivo. J also represents an overall average bending strength in each section. Low values of second moments of area reflect in part an areal distribution of bone that is close to the central (or "neutral") axis of the cross section. Conversely, high values of second moments of area reflect a distribution of bone relatively far from the central axis. According to beam theory, the higher the value of second moments of area, the greater the strength and, hence, ability of the bone to resist mechanical forces.

To standardize for body size differences between sexes and to facilitate comparisons with other archaeological skeletal samples, we have divided areas by bone length^2 and second moments of area by bone length^4 (Ruff, 1984). Only length-standardized properties are presented here. Although variation in material properties (e.g., density) could contribute to variation in bone strength, the approach adopted here assumes a greater functional and mechanical importance of bone

geometry. This assumption appears to be supported by experimental research documenting the direct effects of alteration in mechanical loadings on bone structure (e.g., Woo et al., 1981; Ruff, 1989).

As in our osteoarthritis analysis, we make comparisons between the Stillwater series and other prehistoric North American samples to elucidate Stillwater long bone morphology in regional context. Other samples used in the comparisons include hunter-gatherers from the Georgia coast (various sites; Ruff and Larsen, 1990; Larsen and Ruff, 1991), as well as populations incorporating agriculture to varying degrees in New Mexico (Pecos Pueblo site: Ruff, 1991), Great Plains (various Precoalescent and Coalescent Period sites: Ruff, 1994), and the Georgia coast (Irene Mound site: Ruff and Larsen, 1990; Larsen and Ruff, 1991). All of these populations have been analyzed using identical procedures.

In addition to dietary differences between these populations, each of the comparative samples is representative of populations living in very different topographic settings, ranging from desert/mountainous (Great Basin and New Mexico), to hilly (Great Plains), to coastal (Georgia). This variation in topography represents an approximate continuum from rugged to flat landscapes. Therefore, in addition to subsistence factors, each population was subject to different mechanical demands in relation to locomotion substrate (e.g., walking or running on flat surfaces versus rough surfaces). To our knowledge, the present study is the first such broad-based comparison of North American samples representing different topographic and subsistence contexts.

Results

Summary statistics of cross-sectional geometric properties for the Stillwater series males and females are presented in tables 8-10 (femur) and 8-11 (humerus). Comparisons of these properties with other North American samples for the respective femoral midshaft (50%), femoral subtrochanteric (80%), and humeral mid-distal (35%) sections are presented in tables 8-12, 8-13, and 8-14. Cross-sectional areas and polar second moment of area are presented graphically in figures 8-7

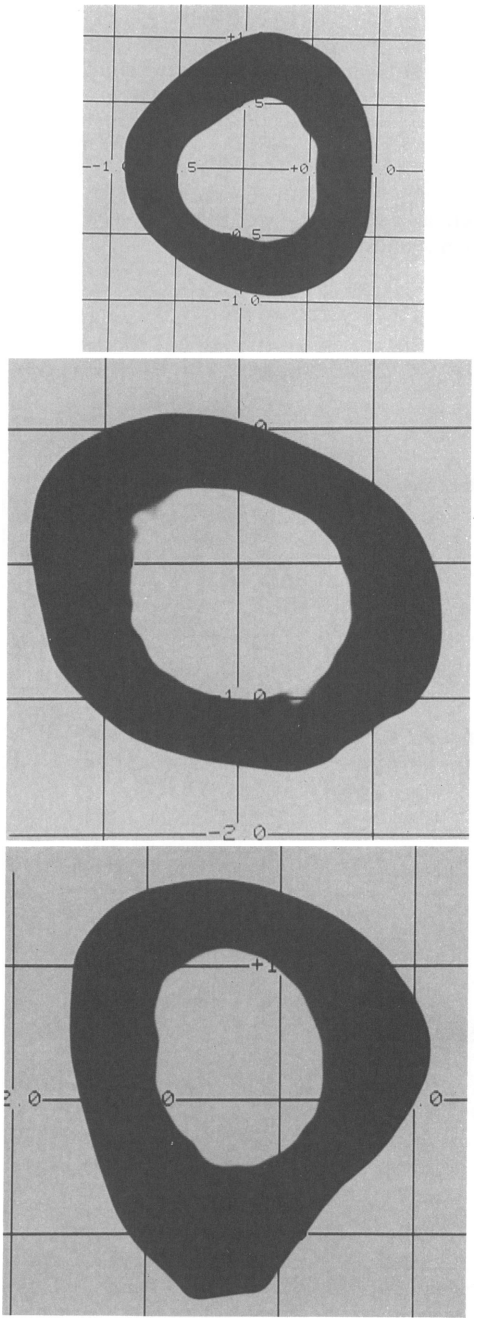

Fig. 8-6. Examples of hard-copy images of CT scans from Stillwater femora and humeri (male, 35–40 years, skeleton 1046-9): humerus, 35% section (top); femur, 80% section (middle); femur, 50% section (bottom). All sections are illustrated to the same scale. Grid lines are 1.0 cm for the femur sections and 0.5 cm for the humerus section.

TABLE 8-10
Summary Statistics for Stillwater Cross-Sectional Geometric Properties: Femur Midshaft and Subtrochanteric

Property[a]	Min.	Max.	Mean	S.E.
Males (N = 12)				
Femur length'	366	457	420	8.81
Femur midshaft				
CA	162.3	276.3	216.5	8.43
MA	66.1	181.0	110.3	8.96
TA	256.7	380.6	326.9	9.02
I_x	51.2	130.1	84.8	5.60
I_y	49.3	91.7	70.1	3.88
I_{max}	54.8	130.1	87.5	5.17
I_{min}	45.7	91.3	67.4	3.96
J	100.5	221.5	154.9	8.50
Subtrochanteric				
CA	187.6	294.9	222.2	8.33
MA	98.2	239.7	147.1	11.13
TA	304.0	434.5	369.3	11.37
I_x	73.0	127.1	93.68	4.55
I_y	63.9	151.2	98.4	7.02
I_{max}	82.2	171.0	123.7	6.64
I_{min}	42.0	107.4	68.4	4.68
J	142.2	278.3	192.1	10.47
Females (N = 12)				
Femur length'	365	414	394	4.26
Femur midshaft				
CA	152.4	224.4	195.8	6.26
MA	82.9	165.9	112.2	7.53
TA	260.8	344.7	308.0	6.81
I_x	47.6	87.2	65.3	3.09
I_y	49.5	85.1	66.7	3.22
I_{max}	54.8	87.9	71.6	2.73
I_{min}	44.6	76.2	60.4	2.92
J	99.5	164.1	132.0	5.39
Subtrochanteric				
CA	180.2	223.3	198.1	4.43
MA	96.9	204.6	154.3	10.48
TA	291.1	395.7	352.4	8.58
I_x	54.6	108.3	78.8	4.03
I_y	54.4	121.7	89.5	17.5
I_{max}	83.9	129.5	112.1	4.23
I_{min}	42.4	66.0	56.2	2.00
J	126.3	195.5	168.3	5.72

[a] Femur length' (in mm) is the distance from the condyles to the superior margin of the neck; the femur midshaft and subtrochanteric regions refer to 50% and 80%, respectively, of length' measured from the distal end; area indices over bone length^2 (CA, MA, TA) are multiplied by 10^5; and second moment of area indices over bone length^4 (I_{max}, I_{min}, I_x, I_y, J) are multiplied by 10^8. CA = cortical area; MA = medullary area; TA = total subperiosteal area; I_x = second moment of area about mediolateral axis (anteroposterior bending strength); I_y = second moment of area about anteroposterior axis (mediolateral bending strength); I_{max} = maximum second moment of area (bending strength); I_{min} = minimum second moment of area (bending strength); J = polar second moment of area.

Area indices (CA, MA, TA) provide relative measures of the amount of cortical bone in a cross section and the relative size of the section and medullary cavity: I (bending strength) and J (torsional strength) reflect the distribution of bone about a neutral point or axis (see Ruff, 1992).

TABLE 8-11
Summary Statistics for Stillwater Cross-Sectional Geometric Properties: Humerus Mid-Distal[a]

Property[a]	Min.	Max.	Mean	S.E.
Males (n = 11)				
Femur length'	293	350	317	5.78
CA	130.6	247.9	187.9	11.74
MA	53.4	219.6	110.2	12.91
TA	256.0	350.2	298.2	9.0
I_x	49.8	82.2	64.4	3.78
I_y	39.8	78.4	59.3	4.10
I_{max}	53.1	89.4	69.2	3.92
I_{min}	39.5	74.1	54.5	3.66
J	95.9	157.8	123.7	7.27
Females (n = 9)				
Femur length'	278	310	294	4.18
CA	122.9	189.6	161.1	7.18
MA	55.4	156.4	98.5	11.27
TA	219.3	295.5	259.5	8.29
I_x	38.8	57.5	49.1	2.39
I_y	29.6	56.1	44.6	2.69
I_{max}	28.5	63.0	51.3	3.59
I_{min}	29.0	53.6	41.2	2.42
J	57.5	112.0	92.4	5.77

[a] The humerus mid-distal region refers to 35% of length' measured from distal end. See footnote to table 8-10 for explanation of properties.

and 8-8, respectively. These comparisons reveal a number of important findings. Regarding Stillwater bone areas, CA and PCCA in all three sections are on the low end of the range for both males and females for the various populations analyzed. In sharp contrast to these values, TA is on the upper end of the range for these samples. This apparent external robusticity is confirmed by the high values of second moments of area in the Stillwater series (e.g., J: fig. 8-8). Indeed, in the

TABLE 8-12
Comparisons of Stillwater and Other Amerindian Cross-Sectional Geometric Properties: Femur Midshaft[a]

Property	Skeletal series[b]					
	Still	GA-Preag	GA-Ag	Pecos	Precoal	Coal
Males						
N	12	8	11	59	25	33
Mean age (years)	34.2	25.5	23.8	37.0	37.3	35.0
Femur length'	420.4	424.9	411.2	405.2	427.4	432.2
	(8.8)	(7.9)	(3.7)	(2.0)	(4.8)	(3.9)
CA	206.1	233.6	234.5	219.0	226.3	216.3
	(5.6)	(14.0)	(7.4)	(3.0)	(7.8)	(4.2)
TA	317.4	315.8	296.3	304.0	311.9	307.6
	(5.9)	(12.5)	(7.7)	(2.8)	(9.9)	(6.0)
PCCA[c]	66.5	73.8	79.1	72.1	72.7	70.6
	(2.3)	(3.1)	(1.2)	(0.8)	(1.5)	(1.0)
J	154.9	154.1	138.9	139.8	148.8	142.6
	(8.4)	(12.6)	(7.5)	(2.9)	(10.9)	(4.9)
I_x/I_y	1.22	1.28	1.08	1.12	1.11	1.18
	(0.07)	(0.05)	(0.05)	(0.03)	(0.04)	(0.03)
Females						
N	12	12	9	60	20	25
Mean age (years)	34.8	30.3	26.1	37.0	34.2	35.4
Femur length'	393.8	415.2	376.4	371.4	399.6	394.6
	(4.3)	(6.0)	(5.0)	(2.3)	(4.5)	(3.2)
CA	195.8	190.2	186.4	212.2	196.4	196.9
	(6.3)	(10.3)	(7.8)	(3.9)	(4.9)	(5.4)
TA	308.0	283.5	256.9	299.9	272.3	286.3
	(6.8)	(5.9)	(10.1)	(3.9)	(5.9)	(5.2)
PCCA[c]	63.8	67.0	72.6	71.1	72.2	68.7
	(2.0)	(3.2)	(1.5)	(1.2)	(1.0)	(1.3)
J	132.0	115.4	99.8	133.5	112.1	121.4
	(5.4)	(5.9)	(3.5)	(3.5)	(5.0)	(4.7)
I_x/I_y	1.00	1.16	1.03	1.05	0.98	1.09
	(0.05)	(0.06)	(0.05)	(0.02)	(0.04)	(0.04)
Sexual dimorphism[c]						
Femur length'	6.8	2.3	9.2	9.1	7.0	9.5
CA	5.3	22.8	25.8	3.2	15.2	9.8
J	17.3	33.5	39.2	4.7	32.7	17.5
I_x/I_y	22.0	10.3	4.8	6.7	13.3	8.3

[a] See footnote to table 8-10 for explanation of properties. Values in parentheses are S.E. Still = Stillwater; GA-Preag = Georgia coast, preagricultural (from Ruff and Larsen, 1990); GA-Ag = Georgia coast, agricultural (from Ruff and Larsen, 1990); Pecos = Pecos Pueblo (from Ruff, 1991); Precoal = Precoalescent, Great Plains (from Ruff, 1994); Coal = Coalescent, Great Plains (from Ruff, 1994).

[b] PCCA was computed by the formula (CA/TA) × 100.

[c] Sexual dimorphism was computed by the formula [(male mean − female mean)/female mean] × 100.

male femoral midshaft, CA and PCCA are the lowest of all populations in the comparative sample, whereas total subperiosteal area and polar second moment of area are the highest. In sum, these values reflect a relatively low amount of bone in the Stillwater sample; however, the bone material that is present is distributed relatively far from the center of the axis of the cross section, resulting in relatively high bending and torsional strengths.

Among males of all populations compared

TABLE 8-13
Comparisons of Stillwater and Other Amerindian Cross-Sectional Geometric Properties: Femur Subtrochanteric[a]

Property	Skeletal series			
	Still	GA-Preag	GA-Ag	Pecos
Males				
N	12	8	11	59
CA	222.2	225.0	220.8	213.1
	(8.3)	(10.4)	(7.1)	(3.2)
TA	369.3	348.6	304.3	350.7
	(11.4)	(15.7)	(9.0)	(4.1)
PCCA	60.5	64.8	72.7	60.8
	(2.1)	(2.2)	(1.7)	(0.6)
J	192.1	183.7	144.1	175.6
	(10.5)	(16.2)	(8.3)	(4.3)
Females				
N	12	12	9	60
CA	195.8	191.5	190.4	205.6
	(6.3)	(10.8)	(5.7)	(3.7)
TA	308.0	311.7	279.0	340.9
	(6.8)	(6.9)	(9.2)	(5.5)
PCCA	56.7	61.7	68.4	60.8
	(2.1)	(3.5)	(1.4)	(1.1)
J	132.0	139.6	121.0	164.8
	(5.4)	(6.6)	(7.8)	(4.6)
Sexual dimorphism				
J	45.5	31.6	19.1	6.5

[a] See footnotes to tables 8-10 and 8-12 for explanations of properties and skeletal series. *Note:* Data were not available from Precoalescent and Coalescent sites.

TABLE 8-14
Comparisons of Stillwater and Other Amerindian Cross-Sectional Geometric Properties: Humerus Mid-Distal[a]

Property	Skeletal series		
	Still	GA-Preag	GA-Ag
Males			
N	11	15	15
Mean age (years)	33.8	29.6	26.8
Femur length'	317.3	318.3	312.5
	(5.8)	(5.1)	(2.6)
CA	187.9	215.0	201.2
	(11.7)	(11.2)	(6.9)
TA	298.2	298.2	272.1
	(9.0)	11.8	(6.7)
PCCA	63.3	72.4	74.2
	(3.6)	(2.8)	(2.5)
J	123.7	135.0	111.6
	(7.3)	(10.1)	(5.1)
I_x/I_y	1.11	0.98	1.01
	(0.06)	(0.03)	(0.03)
Females			
N	9	12	14
Mean age (years)	32.1	29.8	29.0
Femur length'	294.1	305.8	290.2
CA	(4.2)	(7.8)	(2.8)
	161.0	179.4	173.2
	(7.2)	(10.8)	(7.7)
TA	259.5	251.9	244.9
	(8.3)	(10.7)	(7.0)
PCCA	62.6	71.2	70.9
	(3.4)	(3.1)	(2.8)
J	92.5	94.6	89.2
	(5.8)	(7.8)	(5.1)
I_x/I_y	1.11	1.13	1.06
	(0.04)	(0.04)	(0.03)
Sexual dimorphism			
CA	16.7	19.8	16.2
J	33.7	42.7	25.1
I_x/I_y	0.0	−13.3	−4.7

[a] See footnotes to tables 8-10 and 8-12 for explanations of properties and skeletal series. *Note:* Data were not available from Pecos, Precoalescent, and Coalescent sites.

here, variation in J of the femoral midshaft closely parallels subsistence strategy; that is, hunter-gatherers are highest and agriculturalists are lowest. This trend follows a rationale of reduction in lower limb loading in agriculturalists, who are generally less mobile than hunter-gatherers (see below and discussion in Ruff, 1987). However, among females, there appears to be no apparent relationship between subsistence strategy and J. Instead, female values of J seem to correspond to degree of ruggedness of terrain, with Great Basin and Southwestern (Pecos) populations showing the highest values, Georgia coastal populations the lowest, and Plains populations intermediate between the other two regions.

"Shape" of long bone diaphyses is expressed as a ratio of I_x to I_y, which measures relative anteroposterior to mediolateral bending strength. Ruff (1987) found a consistent decline in this index in his comparison of femoral midshaft sections from populations representing respective prehistoric hunter-gatherers, agriculturalists, and Western industrial populations. He interpreted these findings as reflecting a general decline in mobility (e.g., long-distance travel). This conclusion is based on the premise that great-

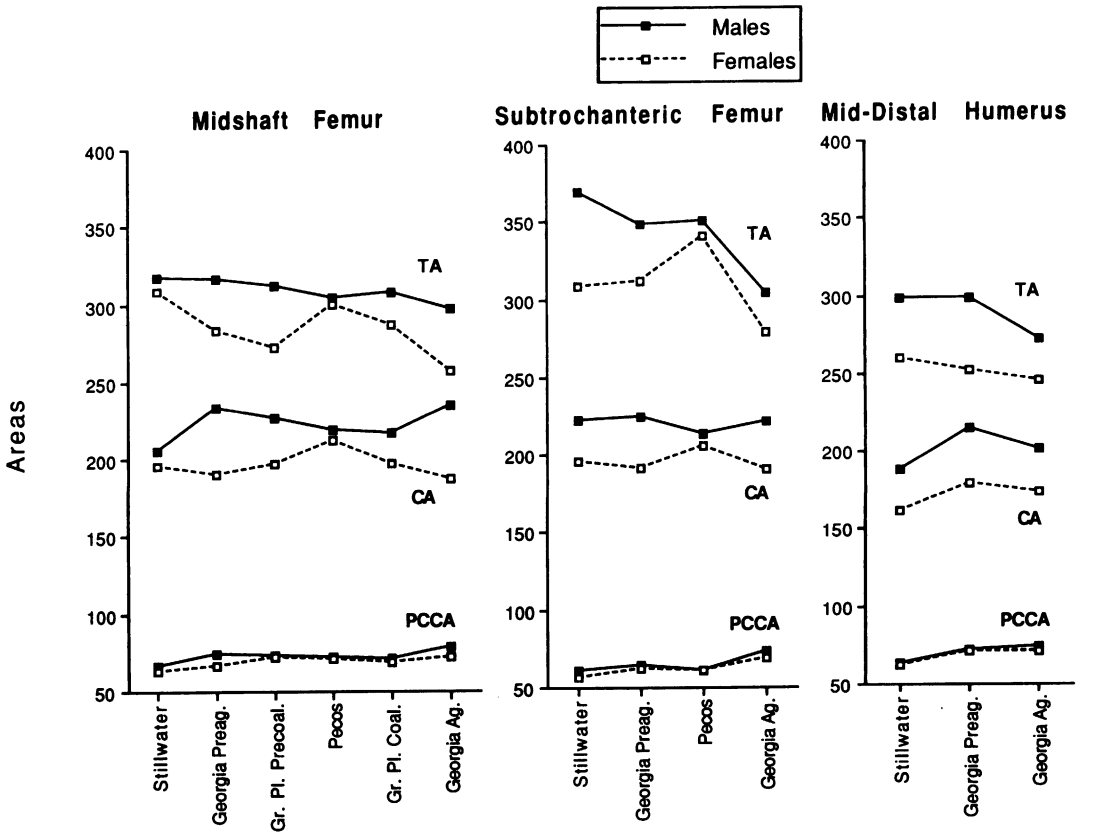

Fig. 8-7. Comparisons of cross-sectional areas—total subperiosteal area (TA), cortical area (CA), and percentage cortical area (PCCA)—for the three sections. Note that for each of the three charts the hunter-gatherers are at the left (with Stillwater to the far left) and agriculturalists are at the right. Areas are standardized over bone length^2 (and multiplied by 10^5).

er or lesser values away from 1.0—a value which represents circularity—reflect greater strength in the anteroposterior or mediolateral planes, respectively. Ruff (1987) suggested that greater relative anteroposterior strength represents a measure of degree of mobility—the further the values are above 1.0, the greater the degree of mobility.

In the present investigation, males show a consistent pattern of decline in I_x/I_y (greater circularity) in comparisons of the continuum from hunter-gatherers to agriculturalists. This is in agreement with results based on the aforementioned observations of second moments of area (table 8-11; fig. 8-9). We note, too, that the pattern of decline in I_x/I_y parallels the simple external breadth ratio of anterior–posterior to medial–lateral dimensions of the femur midshaft. In this regard, various researchers have noted the trend for recent human populations to have rounder diaphyses of lower limb bones than earlier (hunter-gatherer) populations (e.g., Buxton, 1938; Brothwell, 1981; Larsen, 1982; Ruff, 1992).

Finally, the comparison of values of sexual dimorphism for the midshaft femoral I_x/I_y shape ratio reveals that the Stillwater hunter-gatherers are highly dimorphic (table 8-11; fig. 8-10). This has been shown to be a striking characteristic of hunter-gatherers in general, which is probably the result of a sexual division of labor (Ruff, 1987). However, in the humerus, the ratio of I_x/I_y in the mid-distal section shows no discernible pattern of variation in comparisons of the Stillwater hunter-gatherers with Georgia coastal hunter-gatherers or agriculturalists, either within

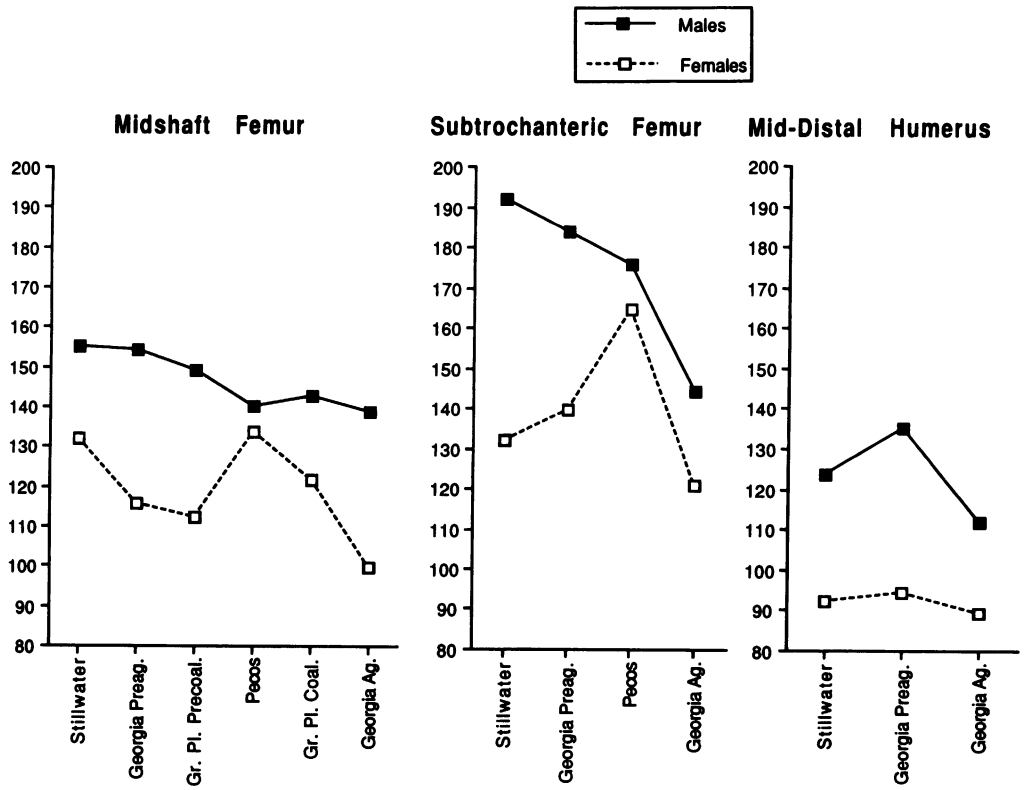

Fig. 8-8. Comparisons of polar second moment of area (J) for the three sections. Note that for each of the three charts the hunter-gatherers are at the left (with Stillwater to the far left) and agriculturalists are at the right. Values are standardized over bone length^{4} (and multiplied by 10^{8}).

sex group, between sex groups, by subsistence strategy, or by topography (table 8-13; fig. 8-11).

Discussion

Comparisons of cross-sectional geometric properties in various archaeological samples show a consistent pattern of elevated bone strength in the Stillwater series, which we interpret to reflect markedly high bending and torsional loading modes in these hunter-gatherers. Interpretation of the low CA and PCCA values is more problematic. In humans, the rate of bone loss after age 40 on the endosteal surface of long bones exceeds the rate of bone gain on the subperiosteal surface, thus resulting in overall bone loss continuing through the remaining years of adult life (Garn et al., 1964). The presence of individuals who were more than 40 years of age at death in the Stillwater sample would certainly indicate that age-related bone loss may be an important consideration in interpreting these relatively low CA and PCCA values. However, the mean age at death for the various North American comparative samples used in this study (see table 8-12) suggests that although age may influence the findings presented here, age alone is likely not too important. That is, mean age at death of three of the samples examined—Pecos Pueblo, Precoalescent Great Plains, and Coalescent Great Plains—is in fact *greater* than the Stillwater series. Therefore, we think that although age may contribute to these low values, it is highly unlikely that it is the most important variable in explaining the differences that we observe.

Apart from age, the most important factor that influences amount of bone in humans is nutritional quality. Human populations undergoing nutritional deprivation show gen-

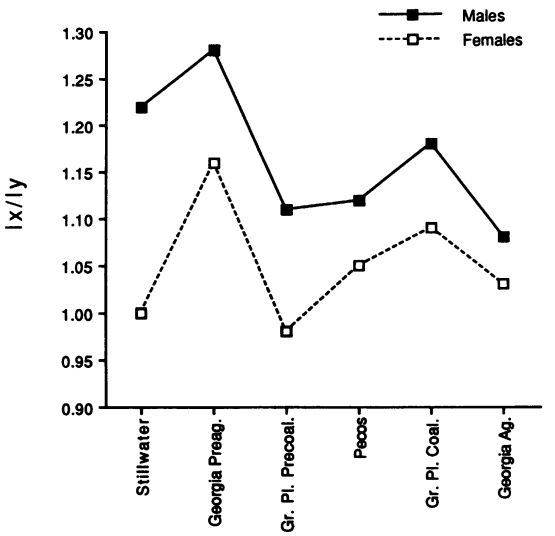

Fig. 8-9. Comparisons of femoral midshaft (50% section) cross-sectional "shape" (I_x/I_y). Note that the hunter-gatherers are at the left (with Stillwater to the far left) and agriculturalists are at the right.

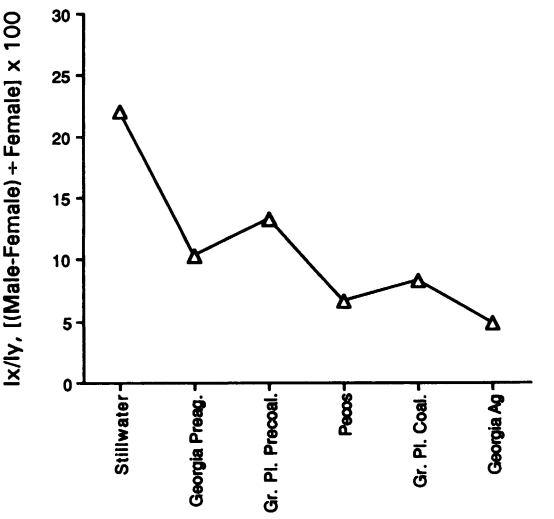

Fig. 8-10. Comparisons of sexual dimorphism in relative anterior–posterior to medial–lateral bending strength (I_x/I_y) of the femoral midshaft (50% section). Note that the hunter-gatherers are at the left (with Stillwater to the far left) and agriculturalists are at the right.

erally low values of CA and PCCA. In populations experiencing protein–calorie malnutrition particularly, the growth spurt associated with adolescence is significantly delayed, resulting ultimately in reduced amounts of adult cortical bone (see Garn et al., 1964; Garn, 1966). Therefore, without age as a factor in interpretation of CA and PCCA values in the Stillwater series, we suggest that suboptimal nutrition may be an important factor. We point out, however, that based on extant data on dietary reconstruction from this region, it is not possible to identify specific factors related to nutritional deprivation. We speculate that periods of reduced availability of some plants and animals during drought years (see Hutchinson and Larsen, this volume) or during winter months in the Carson Desert led to episodic undernutrition (see Raven and Elston, 1989). Much more archaeological research in the area of dietary reconstruction is clearly needed for this region. Moreover, a fuller appreciation of the dietary and nutritional challenges facing desert-adapted hunter-gatherers generally is a prerequisite before drawing conclusions in this particular western North American setting (see also Webb, 1995).

A functional interpretation for the distribution of bone tissue in cross section is supported by the finding of consistently greater differences in the femur midshaft robusticity compared to the humerus mid-distal robusticity in the Stillwater series relative to other archaeological series. Especially noteworthy

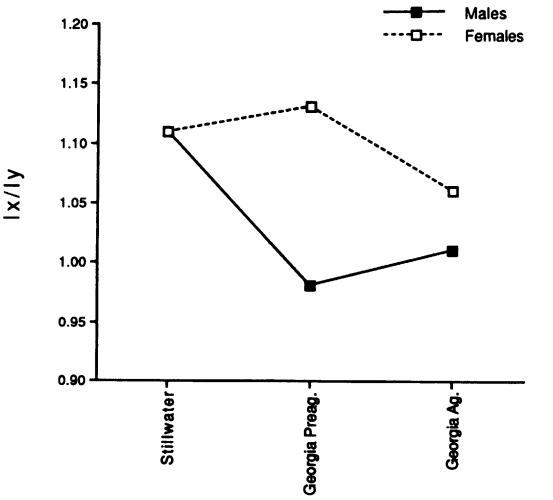

Fig. 8-11. Comparisons of humeral mid-distal (35% section) cross-sectional "shape" (I_x/I_y).

is the presence of both low robusticity and low values of CA and PCCA in the Stillwater humeri. In other words, the presence of high robusticity in only the femur indicates a localized effect, that is, a functional interpretation; the low CA and PCCA values for *both* the femur and humerus are more likely related to systemic factors, which we argue are likely related to relatively low nutritional quality in the Stillwater population. Importantly, the study of cross-sectional geometric properties indicates that not only are long bones large and robust, but the *distribution* of bone reflecting degree of mobility (femur midshaft, I_x/I_y) in males is among the highest of skeletal series studied (see table 8-12). This underscores the fact that the long bones (the femora especially) are not just large in comparison with other archaeological series; rather, the shapes are modified such that they reflect highly mobile behaviors (e.g., long-distance travel).

In the aforementioned study of prehistoric hunter-gatherers, agriculturalists, and industrial populations, Ruff (1987) reported that the degree of sexual dimorphism (in the femoral midshaft mobility index, I_x/I_y) declined dramatically, with hunter-gatherers showing the greatest dimorphism and industrial populations very little sex difference in the ratio. The reduction in sexual dimorphism was largely produced by a reduction in the I_x/I_y index in males. The findings discussed here indicate that the prehistoric hunter-gatherers from the Carson Desert were engaged in gender-specific activities involving different mechanical loads on the lower limbs on a more frequent basis than in virtually every other archaeological (or living) population studied. The very large sex dichotomy in this index indicates that Stillwater women were probably more sedentary, whereas Stillwater men were more wide-ranging. These findings suggest that the two hypotheses by anthropologists for mobility pattern—limnosedentary and limnomobile—may be oversimplifications. That is, underlying these hypotheses is the presumption that males and females were engaged in similar, if not identical, mobility patterns. This is clearly not the case for the Carson Desert populations we examined.

The cross-sectional geometric data cannot be accounted for by the nature of foraging in the marsh alone. In the first place, if movement were restricted to the marsh, it should affect men and women equally. Second, although foraging in the marsh would have required traversing difficult muddy sections that must have required strenuous activity, this activity differs from that which creates the patterning observed in the femora here. This study of structural morphology, then, appears to support a reconstruction of a mobile lifeway for men and women, but with males being more mobile than females. This is consistent with the model utilized by Raven to predict site location and contents on the valley floor (see Kelly, this volume). This pattern of sexual dimorphism related to mobility holds for many hunter-gatherers, but the Stillwater case appears to reflect an extreme example, at least compared to those populations for whom we have similar data.

Interestingly, although limited to comparisons between three skeletal series—Stillwater, Georgia coast preagricultural, and Georgia coast agricultural—there is no clear-cut dimorphism pattern in the I_x/I_y index in the mid-distal humerus. Because use of the upper limb is not related to terrain, we suggest that this ratio more likely reflects specific activities, such as hunting style, food-processing techniques, carrying activity, and so forth, that are unique to the manner in which individual populations use their upper limbs within specific settings.

The findings presented here indicate that the Stillwater hunter-gatherers engaged in frequent long-distance travel and had a generally high level of mobility. We can take this one step farther and infer that their settlement pattern was likely very mobile. Although these populations occupied the marsh biome for at least part of the year, the biomechanical data presented in this chapter strongly suggest that travel over difficult terrain (uplands) involving long distances was an important feature of their overall adaptation, especially for males. These findings are consistent with ethnographic accounts by early 19th-century explorers who noted that native groups traveled 75 to 100 km to collect and transport dietary resources, such as seeds and pine nuts collected from uplands (see

Thomas, 1985). Equally long distances were traversed to fish on a seasonal basis in river drainages to the west and south.

CONCLUSIONS

The general severity of the mechanical environment of the Great Basin is attested to by the presence of frequent and severe osteoarthritis and pronounced bone strength as reflected in cross-sectional geometric properties in Stillwater adults. The Stillwater series can be characterized as markedly robust, despite relatively low amounts of cortical bone. The population is highly dimorphic in femur strength, which we have argued represents a strong male–female dichotomy in activity patterns, particularly in the types of behaviors that affect the morphology of the lower limb. These findings reflect greater mobility in males than in females, which is almost certainly related to hunting activities of males both within marsh and uplands contexts and plant-collecting activities of females. Far from leading a leisurely existence, these populations likely followed a highly physically demanding lifeway that involved frequent travel over very rugged terrain. Thus, although prehistoric Stillwater marsh and lake habitats may have provided for the "best foraging game in town" (sensu Raven and Elston, 1989: 2), the populations living there pursued a lifestyle involving highly rigorous settings, including the nearby uplands. This is not to say that Stillwater prehistoric populations utilized uplands resources to the exclusion of or even more than marsh resources. Indeed, the presence of midden and archaeological material culture indicates at least part-time exploitation of marsh resource patches. Our findings indicate, however, that although these populations likely utilized these resources, subsistence strategies were not focused entirely on the marsh.

The structural analysis indicates that these populations were subjected to severe mechanical demands, which is consistent with a mechanical explanation for the high prevalence of osteoarthritis. Brooks et al. (1990) suggested that mycotoxins introduced via consumption of spores produced by parasites in stored grains may have been a factor in explaining eburnation of articular joints. Although mycotoxins may have been a predisposing or contributing factor to osteoarthritis in this region, we think that the very severe mechanical environment is of far greater significance in interpreting osteoarthritis prevalence and pattern in the Stillwater Marsh skeletal series.

We argue, therefore, that the bioarchaeological record based on the detailed study of osteoarthritis and long bone structural morphology indicates a pattern of settlement consistent with predictions established in Chapter 1. We expected that although the marsh may have served as a settlement hub, variation in the resources available from year to year in the marsh (relative to fluctuations in nonwetland resources) would change the cost: benefit ratio of remaining in the marsh versus moving to either another wetland area or into the uplands, and in so doing encourage residential or logistical movements out of the Carson Sink. Data presented in this chapter appear to be consistent with this prediction. Although prehistoric populations could have focused on the marshes, our findings suggest that individuals (and especially males) frequented upland or other wetland environments. Prehistoric Stillwater Marsh native groups, at least during the timespan covered by these remains, may have spent considerable time in subsistence activities that required traveling out of the Stillwater Marsh.

CHAPTER 9. SUMMARY AND CONCLUSIONS

Clark Spencer Larsen and Robert L. Kelly

Although the sudden and widespread destruction of archaeological resources in the Stillwater Marsh occasioned by the flooding of the Carson Sink was shocking, the exposure of hundreds of human skeletal and dental remains nevertheless led to an impressive body of data on human adaptation in the western Great Basin. We emphasize that prior to the discovery and study of the Stillwater skeletal series, a very small percentage of human remains collected in this vast region of the Desert West had yielded meaningful information about human biology and its larger role in anthropological inquiry relating to the study of hunter-gatherers. Within a few years involving the study of this series, a fund of information has now become available using bioarchaeological approaches (see also Brooks et al., 1988).

We do not pretend to have exhausted the potential avenues of skeletal research for this region (see Brooks et al., [1988] for descriptions and other analyses). Nevertheless, we think that the areas addressed in this monograph shed light on key issues regarding human ecology in this region. In relation to the general objectives and specific goals outlined in Chapters 1 and 2, what have we learned about the prehistoric occupants of this region of the Great Basin for the study of their skeletal remains? First, the populations that occupied this region are morphologically robust. The high degree of robusticity that we have observed in the skeletons is almost certainly related to a very physically demanding lifestyle. From analyses of cross-sectional geometric properties, it is possible to measure strength of limb bones, femora, and humeri. Indeed, these findings confirm the high degree of robusticity relative to other post-Pleistocene *Homo sapiens* populations, especially in North America (cf. Ruff et al., 1993). Moreover, the Stillwater adults show a remarkably high prevalence of osteoarthritis, a disorder related to wear and tear on the skeleton occurring over an individual's lifetime of high activity levels.

Second, despite the pronounced skeletal robusticity, there is some evidence for bone loss in the study of long bone cross sections. The underlying cause of bone loss is unknown, but we suggest that periodic food shortages and nutritional deprivation may have been factors.

Third, analysis of physiological stress via the study of nonspecific enamel defects (dental hypoplasias) reveals moderate levels of metabolic insult during the years of growth and development of the dentition. Hypoplasias are caused by either disease or nutritional problems. We have found that evidence of nonspecific infectious disease is minimal in the human remains from the Stillwater series. Therefore, we think that the enamel defects in the Stillwater series arose primarily from nutritional problems. Because hypoplasias form only during the years of growth and development of teeth, it is not possible to discuss nutritional deficits for adults based on the study of enamel defects. However, we speculate that nutritional deficits may have had a relatively greater impact on juveniles than adults. Juveniles had on average smaller teeth than adults, possibly reflecting their inability to successfully mitigate stressful circumstances leading to physiological perturbation (Guagliardo, 1982; Simpson et al., 1990; and see Appendix B).

Fourth, documentation of porotic hyperostosis and cribra orbitalia, the primary skeletal indicators of iron-deficiency anemia, reveals very low prevalences of these pathologies in the Stillwater skeletal series. It is therefore likely that these populations suffered only minimally from iron-deficiency anemia, at least to the extent that it affected the skeleton.

Fifth, analysis of dental remains reveals very little evidence of dental decay (dental caries), indicating low consumption of cariogenic carbohydrates. Extreme tooth wear—especially on occlusal surfaces—may have helped to limit decay processes of the dental hard tissues. However, given the lack of foods that promote dental caries, this latter interpretation seems remote. Other dental prob-

lems affecting oral health were present in the series. In this regard, excessive dental wear in adults led to pulp exposures and premortem tooth loss, especially in older adults.

Taken as a whole, we think that the health of these populations was relatively good, at least in comparison with other skeletal samples in North America or elsewhere. Although some skeletal indicators suggest occasional nutritional problems (e.g., hypoplasia, bone loss), dietary reconstructions based on analysis of stable carbon and nitrogen isotopes reveal a highly mixed diet, especially in comparison with boreal forest hunter-gatherers and southwestern U.S. agriculturalists. This variability likely contributed to the overall robust health of the populations that occupied the Carson Sink. Dietary variability could have resulted either from using resources obtained outside the Carson Sink or from fluctuations in resources available in the marsh. It is also possible that some resources not included in the control samples, such as shadscale and four-wing saltbush, could be responsible for some of the variation. Analysis of control specimens (modern plants and animals) indicates that diet could have been derived mostly from the marsh setting, although this remains conjectural. Contrary to most ethnographic reconstructions for this area, stable isotope analysis suggests that piñon seeds did not contribute significantly to diet. The bone chemistry does not refute a model in which the marsh forms a substantial hub of the prehistoric settlement system. On the other hand, study of cross-sectional geometric properties—especially on the shape of the femoral midshaft—reveals that these populations were highly mobile, at least for males. Moreover, adults likely perambulated over difficult terrain (e.g., nearby uplands) on a frequent basis.

It is not possible to say why males, and to a lesser extent females, were walking in difficult uplands settings. However, it seems likely that movements in these mechanically challenging environments were related to the quest for food. Ethnographic data from the Great Basin indicate walking was more frequent and more strenuous in men than in women, at least in the historic period. Walking was undertaken to hunt, fish, and to provision women during plant-gathering expeditions. We conclude, then, that dietary items were likely extracted from both marsh and uplands contexts, although the uplands may have been used primarily through logistical mobility by men. Given that the bone chemistry data suggest piñon was not a significant dietary item, the bone cross-section data possibly indicate long-distance hunting by men.

Finally, the timing of entry of Numic-speaking groups into the region is important in discussions of Great Basin prehistory. Study of albumin protein in a sample of Stillwater skeletons reveals the presence of the allele Al^{Me} in four individuals. The presence of this allele in living Numic speakers makes this population a candidate for being direct ancestors of Numic speakers. However, because Al^{Me} is presently absent in Numic speakers closest to the Carson Sink, it is also possible that another group, whose albumin phenotypes have not been studied, descend from the Stillwater population. In that case, although no radiocarbon dates are currently available for the individuals in the Stillwater skeletal sample with Al^{Me}, we hypothesize that if such dates become available, they should predate the alleged migration of Numic speakers into the Great Basin.

The DNA analysis reveals a very low frequency of the 9-bp deletion—a deletion observed in some Native American populations. The study indicates that the Stillwater population is probably not ancestral to any group with a much higher deletion frequency (e.g., California Penutian, Zuni, Yuman, Washo, and Southern Uto-Aztecan language groups). This finding is partially consistent with the findings of Smith et al. (this volume), who were able to exclude California Penutian and Washo as descendants. Moreover, neither the albumin nor the DNA study was able to exclude living Numic groups as descendants of the Stillwater population. Inferences based on the DNA analysis went beyond those based on albumin phenotypes by excluding both Yuman and Southern Uto-Aztecan as likely descendants of the Stillwater population. Several possibilities remain as to the identification of ancestral–descendant relationships in this region.

We conclude with a few comments on the implications of these bioarchaeological analyses for an understanding of the sedentari-

zation process. Ethnographically, the sedentarization process often is associated with increased mobility of individuals rather than residential groups (e.g., Eder, 1984); furthermore, this increased mobility falls primarily upon men (e.g., Hitchcock, 1982). However, a comparison of the Stillwater sample to sedentary agriculturalists indicates that the Stillwater males were more mobile and walked longer distances. The increased mobility of males in ethnographic cases of sedentism, therefore, is possibly a function of the historic context of sedentism (cash economies, ecological degradation, and government-enforced sedentism) and not an inherent property of the sedentarization process, or it may be a short-lived response, characteristic only of the early stages of sedentism.

We now have greater insight into the degree of mobility in these groups. Regardless of how the data are framed, it is clear that these populations were not engaged in a primarily sedentary lifestyle, certainly not the kind of lifestyle envisioned by earlier formulations of the limnosedentism model. Rather, study of human remains points to a lifestyle involving very physically demanding and mobile behaviors in this setting of the Great Basin. We speculate that these findings correspond more accurately with the limnomobile, rather than limnosedentary, model.

It is important that we devote time in studies of specific foraging populations or cases (prehistoric or living) to discover and test sources of variation among all foragers. We know the environmental context of the prehistoric foragers in the Carson Sink; now we know something about how they used and responded to that environment. However, our conclusion that the prehistoric inhabitants of Carson Sink are best characterized by the limnomobile model tells us relatively little if our goal is to understand behavioral variation.

Viewed in a much larger geographic perspective, the Stillwater Marsh is a dense "patch" of diverse food resources surrounded by a vast area of relatively lower food diversity and density (more so if piñon were absent prehistorically). Foraging models suggest that in such cases, where the travel time between foraging patches is high, that residence time of a particular patch would also be high (see Kelly, 1995). The archaeological and ethnographic data that point to wetlands in the western Great Basin as settlement "hubs" bear out this prediction. But foraging models would also predict that when returns from the wetlands dropped below those expected from another patch (given the cost of traveling to that patch, be it the piñon–juniper zone or another wetland such as Walker Lake), then people can be expected to move. The bioarchaeological analyses also indicate that the Stillwater population as a whole moved considerably. Less clear is whether this is a function of foraging in the marsh or of movement between foraging patches. If related to foraging, then the population has traded residential mobility for increased logistical mobility of men and an increased work effort on the part of women (in particular, an increase in the work effort that required walking). This would be evidence that sedentism—or any reduction in residential mobility—does not save time or energy as much as it redistributes it. On the other hand, if population movement related to movement between foraging patches, then changes in the way in which the Stillwater Marsh was used over time may partially result from changes in the way key resources fluctuated during short periods (i.e., on a yearly scale) and whether those fluctuations were in sync with those in other potential foraging areas, such as other wetland basins.

Finally, and more generally, the bioarchaeological analyses point to the limitations of these models in particular and approaches that contrast normative characterizations in general. In Chapter 2, we noted that hunter-gatherer lifeways have often been characterized as either "nasty, brutish, and short" or as the opposite extreme, affluent. In one interpretation, foragers lead physically demanding lives and are nutritionally deprived; in the other, foragers lead lives of leisure, with more than adequate nutrition.

The characterization of foragers as "the original affluent society" has come under increasing attack recently, but the important point is not whether the Hobbesian or original affluent society portrayal of foraging society is correct, but rather that there is variability among hunting and gathering societies

in terms of diet and workload, as well as in other areas of life (Kelly, 1995). The comparison between the Georgia coastal and the Stillwater hunter-gatherers demonstrates this point. The prevalence of malnutrition, as evidenced by dental hypoplasias, was lower and less intense for the Stillwater than for the Georgia coastal samples. Evidence of periosteal reactions was also lower for the Stillwater sample when compared with other hunter-gatherer populations. The bone chemistry data showed that the Stillwater population probably had a more variable diet (certainly when viewed from the level of the population) than southern boreal forest hunter-gatherers. On the other hand, the Stillwater population led a more physically demanding lifeway than Georgia coastal hunter-gatherers, as evidenced by long bone cross-section analyses. The level of physical demands for females seems more strongly related to the type of terrain the society lived within, rather than the mode of subsistence. These data demonstrate that there is variability among foragers in terms of diet, workload, disease, and the frequency of malnutrition. Thus, it has become clear that we should begin to focus on sources of variation rather than debate which model best characterizes *all* hunter-gatherers.

The discovery of the extensive Stillwater skeletal series and its follow-up study have presented an important opportunity to address issues regarding hunter-gatherer adaptation. Although several points remain inconclusive, arguably the study of human remains has taken us closer to more clearly grasping an understanding of human ecology in this fascinating North American setting and consequently toward understanding variation in the hunting and gathering lifestyle.

APPENDIX A. REMAINS DOCUMENTED BY THE HUMAN SKELETAL FIELD SURVEY, 1987

Clark Spencer Larsen and Katherine F. Russell

Listed in this appendix are all human remains documented by the Human Skeletal Field Survey (HSFS) during the 1987 fieldwork in the Stillwater Marsh. Other skeletal specimens (*excluding* human remains discovered and collected by the Nevada State Museum in earlier field seasons, 1985 and 1986 [see Tuohy and Dansie, 1986a, 1986b; Tuohy and Haldeman, 1986; Tuohy et al., 1987; Brooks et al., 1988] and by Intermountain Research in 1989 [Schmitt, 1990]) are listed as well, including surface collections by Raymond and others. A number of specimens excavated by Kelly in his surface collection and test excavation of site 26CH1062 are also listed. The information presented includes the site number (without the "26CH" prefix), the reference number assigned by the HSFS, and a brief description of specimens collected or observed. Sites assigned numbers by the Nevada State Museum—L11, L72, L102, L108, L120, and L133—do not as yet have site numbers in the Smithsonian Trinomial System (e.g., 26CH1062).

TABLE A-1
HSFS Human Remains from Stillwater Marsh

Site	Ref. no	Description
1043	200	Adult parietal fragment
	201	Right one-half of adult (20–30 years) maxilla with permanent canine (root only), third premolar, fourth premolar, first molar; very gracile bone suggesting female; age based on occlusal surface tooth wear
	202	Preadult (5–15 years) thoracic vertebra, rib fragment, proximal hand phalanx (second through fifth), terminal foot phalanx (first); age based on general size of skeletal specimens
	203	Adult sacrum (3 segments; first, second, and third)
	204	Adult long bone fragments (9), including a tibia diaphysis fragment, probably from a single individual
	205	Adult rib fragments (6) probably from a single individual
	206	Adult sternum; likely female (very small bone)
	208	Adult cranial vault fragments (4) from one individual
	209	Nearly complete adult right humerus; likely female (small size of bone)
	210	Adult bones: rib fragment, intermediate hand phalanx, left first metatarsal, right second metatarsal, left second cuneiform, terminal foot phalanx
	211	Preadult (5–10 years) femoral head epiphysis; age based on size and development of bone
	212	Preadult (less than 2 years) basilar portion of occipital; age based on size and development of bone
	213	Partially exposed burial left in situ except for remains visible at the time of discovery by the HSFS crew, including adult lower arm and hand bones (left ulna and radius missing proximal and distal ends; 3 metacarpal diaphyses, 4 proximal hand phalanges, 4 intermediate hand phalanges)
	214	Adult fifth metatarsal fragment
	215	Rib fragment
	216	Adult intermediate hand phalanx
	217	Fragmentary right clavicle
	218	Left femur fragment
1044	200	Adult thoracic vertebra spinous process and body fragments from a single individual
	201	Adult ilium fragments from a single individual
	202	Adult left hamate
	203	Adult right ulna with eroded proximal end; missing distal end
	204	Adult terminal first foot phalanx

TABLE A-1—(*Continued*)

Site	Ref. no	Description
	205	Possible adult thoracic vertebra
	207	Adult thoracic vertebrae (2); adult lumbar vertebra; proliferative marginal lipping (osteoarthritis)
	212	Adult long bone fragment
1045	200	Adult right fifth metacarpal
	201	Adult right humerus
	202	Adult right innominate missing pubis; female (possesses wide sciatic notch and preauricular parturition pits)
	203	Adult (22–26 years) right innominate; age based on pubic symphyseal face morphology (Todd, 1920)
	204	Adult left scapula
	205	Adult left tibia; well-healed periosteal inflammation (probable infection) on anterior crest
	206	Adult left patella; slight proliferative marginal lipping
	207	Adult pubis fragment
	208	Adult left first rib
1046	1/1b	Collected by Larsen, Kelly, and Raymond—adult right femur missing distal end; likely female (small size of bone)
	200	Adult occipital squamous
	201	Adult left femur missing proximal and distal ends (same individual as 1046-202)
	202	Adult left tibia missing proximal and distal ends (same individual as 1046-201)
	203	Adult sternum
	204	Preadult (less than 2 years) parietal fragments (age based on size of bone) from a single individual)
	205	Adult (18–25 years) left innominate including most of ischium and pubis; female (wide sciatic notch); age based on morphology of auricular surface of innominate (Lovejoy et al., 1985)
	206	Adult left clavicle
	207	Adult cervical vertebra (third through sixth)
	208	Adult proximal right femur; male (very robust bone)
	209	Preadult (probably adolescent) metatarsal diaphysis (age based on size of bone)
	210	Adult right talus
	211	Adult left second metatarsal
	212	Adult right rib
	213	Adult rib fragment
	214	Left adult mandible corpus with sockets for permanent fourth premolar through third molar; very eroded
	215	Probable adult fibula diaphysis fragments from a single individual
	216	Adult right cuboid
	217	Adult cervical vertebra (third through sixth)
	218	Preadult femur head epiphysis fragment
	219	Adult left rib
	220	Adult thoracic vertebra
	221	Adult first rib
	222	Adult rib fragments probably from a single individual (submitted for carbon and nitrogen isotopic analysis [see Schoeninger, this volume])
	223	Adult lumbar or sacral vertebrae fragments probably from a single individual
	225	Adult right rib
	226	Preadult rib and right ulna; age based on size of bones
	227	Adult rib fragment
	229	Adult metacarpal or metatarsal diaphysis
	230	Adult right talus
	231	Preadult (adolescent) distal left tibia epiphysis; age based on size of bone
	232	Adult rib fragment
	233	Adult right rib
	234	Adult femur diaphysis fragment
	235	Rib fragments probably from a single individual
	236	Adult fibula missing distal end; likely male (very robust bone)

TABLE A-1—(*Continued*)

Site	Ref. no	Description
	237	Adult right hand scaphoid; proximal foot phalanx (second through fifth); intermediate foot phalanx (second through fifth); terminal foot phalanx (first); terminal foot phalanx (second through fifth)
	238	Adult ulna and radius diaphysis fragments probably from a single individual
	239	Two adult vertebrae (thoracic, lumbar)
1047A	200	Partial adult foot, including third, fourth, and fifth left metatarsals
	201	Adult scapula fragments at vertebral border from a single bone
	202	Adult right mandibular corpus and ascending ramus
	203	Adult burial recorded but not excavated by HSFS
	204	Adult proximal foot phalanx (second through fifth)
	205	Adult rib fragment
1047D	206	Adult burial recorded but not excavated by HSFS; femur head from the individual excavated
1048	206	Preadult (less than 5 years) occipital squamous; age based on size and development of bone
	201	Adult (20–30 years) right one-half of mandible with permanent third premolar root, and first, second, and third molars; age based on occlusal tooth wear
	202	Nonhuman vertebra
	203	Cranial fragment
	204	Fragments (23) of most of 1 adult cranial vault, including left and right parietals, temporals, and occipital; female (small size of bone)
	205	Adult long bone fragments (19), mostly femur, probably from a single individual
	206	Adult left humerus missing proximal end; male (robust bone)
	207	Adult left radius; proliferative marginal lipping on both proximal and distal ends (osteoarthritis)
	208	Partial preadult (10± years) cranial vault, including frontal with fragments of nasals, and right zygoma, sphenoid, and parietal; age based on size and development of bones
	209	Adult left mandibular ascending ramus fragment
	210	Preadult (3± years) mandible with deciduous left and right first and second molars; age based on dental development (Ubelaker, 1989) and occlusal surface wear
	211	Adult right maxilla/zygoma fragment with roots and partial crowns of permanent second incisor through second molar
	212	Adult right maxilla with fragmentary permanent canine, third premolar, first molar, second molar
	213	Adult left scapula fragment at vertebral border; adult femur or tibia diaphysis fragments (2)
	214	Adult rib fragment
	215	Preadult (less than 2 years) rib fragment; age based on size of bone
	216	Nonhuman bone fragment
	217	Nonhuman bone fragment
	218	Adult (23–28 years) half maxilla with permanent right canine through second molar; age based on occlusal surface tooth wear
	219	Partial preadult cranial vault, including mostly temporals, occipital, and parietals; age based on size and development of bones and lack of suture closure
	220	Adult long bone fragments (13); adult rib fragment
	222	Metatarsal or metacarpal diaphysis
	223	Adult left mandibular corpus fragment; right mandibular corpus with roots of permanent canine, third premolar, first molar, and partial ascending ramus
	224	Adult mandible with all teeth and both ascending rami missing; female (very gracile bone)
	225	Adult distal fibula fragment
	226	Adult ribs (2)
	227	Adult left patella; proliferative marginal lipping (osteoarthritis)
	228	Adult lumbar vertebra (neural arch only)
	229	Adult right scapula fragment at vertebral border
	230	Adult long bone fragments (12)
	231	Preadult (1.5 years) left humerus; age based on length of long bone (Ubelaker, 1989)
	232	Permanent maxillary second incisor
	234	Preadult (0.5 years) right femur; age based on length of long bone (Ubelaker, 1989)
	235	Adult left femur
	236	Partial adult lumbar vertebra

TABLE A-1—(*Continued*)

Site	Ref. no	Description
	237	Adult humerus fragments (2)
	238	Adult right mandibular ascending ramus; very weathered
	239	Preadult (less than 2 years) parietal fragment; age based on size of bone
	240	Preadult (0.5–2 years) tibia; age based on length of long bone (Ubelaker, 1989); bone missing proximal one-third
	241	Partial adult cranial vault, including frontal and left and right parietals
	242	Adult terminal foot phalanx
	243	Partial adult right mandible with permanent canine, third premolar, and fourth premolar
1049	200	Adult cervical vertebra (third through sixth)
	201	Adult right radius
1050	200	Adult lumbar vertebrae (2); extensive proliferative marginal lipping (osteoarthritis)
	201	Adult terminal hand phalanx; adult intermediate foot phalanx; bones likely from single individual
1051	200	Adult rib fragments; adult long bone fragment (probable femoral diaphysis); fragment of permanent mandibular right second molar; preadult (less than 2 years) parietal fragment; age based on size of bone
	201	Nonhuman bone fragment
	202	Preadult (less than 5 years) proximal right femur; age based on size and development of bone
	203	Adult right talus
	204	Adult rib fragments (7) probably from a single individual
	205	Preadult (2.5–3.5 years) left tibia; age based on long bone length (Ubelaker, 1989)
	206	Adult cervical vertebra fragment; adult cervical (first); adult thoracic vertebra; adult lumbar vertebra
	209	Preadult (adolescent) left scapula, including acromion, glenoid, partial body; age based on size of bones; remainder of burial left in situ by HSFS
	210	Adult left femur missing distal end; Harris lines exposed on distal end (fig. A-1)
	211	Adult rib fragments (6) probably from a single individual
	212	Adult manubrium/sternum; female (bone very gracile)

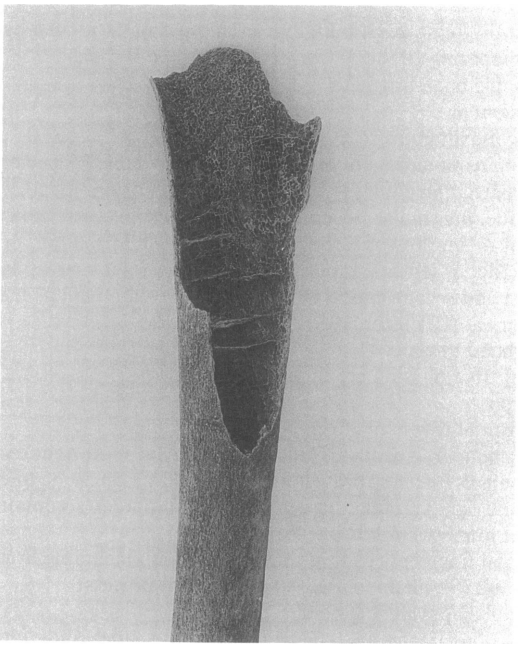

Fig. A-1. Harris lines visible in cross section of distal adult femur (skeleton 1051–210).

TABLE A-1—(*Continued*)

Site	Ref. no	Description
	213	Adult thoracic vertebra
	214	Preadult cervical vertebra (second); age based on size and development of bones
	215	Adult right first cuneiform
	216	Adult left pubis missing part of symphyseal face; likely male (no subpubic concavity, ventral arch, or subpubic ridge [Phenice, 1969])
	217	Long bone fragments (2) probably from a single individual
	218	Preadult (less than 5 years) frontal fragment (orbit with supraorbital); age based on size of bone
1052	200	Adult cranial fragments (2); bones calcined, thus indicating probable cremation burial
	201	Adult cranial fragments (4); bones calcined; may be from same individual as 1052-200
L11	200	Preadult (less than 5 years) right parietal; shows perfect articulation with 1063-200 (left parietal); age based on size of bone; these two specimens are likely from a single individual
1055	200	Adult ribs (5)
	201	Cranial fragments (2) from a single individual
	202	Adult rib
1058	200	Adult lumbar vertebra; slight proliferative marginal lipping (osteoarthritis)
	201	Adult right femur
	202	Adult left radius (proximal one-fourth only); likely male (very robust bone)
	203	Adult cervical vertebra (third through sixth)
	204	Adult right humerus (proximal one-half only)
	205	Adult occipital squamous
	206	Partial adult right scapula at vertebral border
	207	Adult left tibia fragment (distal end)
	208	Adult long bone fragments, including fibula diaphysis, tibia diaphysis, humerus trochlea, unidentifiable bone fragments (4)
	209	Preadult (less than 2 years) parietal fragments (4); age based on size of bone
	210	Adult frontal fragment
	211	Burial exposed and excavated by HSFS (see Burials)
	212	Adult cervical vertebra fragments (5 of second) from a single individual
	213	Adult right mandibular corpus with sockets for permanent third premolar through third molar; permanent second molar alveolar region fully resorbed, indicating premortem loss of tooth
	214	Adult left patella
	215	Adolescent or young adult burial recorded but not excavated by HSFS; discovered in the process of preparing 1058-211 for excavation (see Burials)
	216	Unidentifiable bone fragment
	217	Cranial fragment
	221	Permanent maxillary third molar root
1060	200	Partial remains of an in situ burial excavated by USFWS personnel; context not examined by HSFS—partial preadult (3 years) skull and dentition: maxilla with deciduous left second incisor, canine, first molar, second molar, right canine, first molar, second molar, permanent left and right molar crowns (crowns show complete formation, no root development); mandible with deciduous left first molar, second molar, right canine, first molar, second molar, permanent first and second molar crowns (same development as mandible); age based on dental development (Ubelaker, 1989)
	201	Terminal hand phalanx
	202	Adult right tibia missing proximal epiphysis
	203	Rib fragment
	204	Preadult frontal fragments from a single individual
1061	200	Adult long bone fragments (5); adult left clavicle; adult right second metacarpal; adult proximal hand phalanx (second through fifth); adult left scapula fragments (glenoid and vertebral border); adult right scapula fragments (vertebral border/acromion)
	201	Adult right humerus (distal one-half only)
	202	Adult cranial fragments from a single individual, including frontal (2), left temporal, miscellaneous vault (9); likely female (small mastoid process)
	203	Adult femur diaphysis fragment
	204	Adult long bone fragments (10) probably from a single individual
910	200	Adult rib fragments (4) probably from a single individual; adult metacarpal or metatarsal diaphysis

TABLE A-1—(*Continued*)

Site	Ref. no	Description
	201	Adult (30–40 years) mandible with permanent dentition complete except postmortem loss of right first incisor and agenesis of left and right third molars (age based on tooth wear); partial adult right tibia (diaphysis fragments only); adult left tibia; adult lumbar vertebra (all of these specimens may be from the same individual); mandibular left canine is hypoplastic
	202	Preadult (1 year) partial cranial vault, including left and right parietals, superior frontal, left temporal; dentition includes deciduous maxillary left first incisor, right second incisor and canine; age based on dental development (Ubelaker, 1989)
	203	Adult (greater than 40 years) one-half of right mandible with permanent second incisor, canine and third premolar, but missing first incisor, and fourth premolar through third molar; age based on occlusal surface tooth wear
	204	Adult rib fragments (7) probably from a single individual
	205	Partial adult left scapula, including glenoid, vertebral border, and part of body
	206	Adult vertebrae fragments, including a cervical vertebra body and a thoracic neural arch, from a single individual
	207	Adult long bone fragments (3); adult femur diaphysis fragments (2); adult ulna diaphysis fragment
	208	Scattered remains of a single preadult (2± years), including partial cranium (left temporal, occipital fragment with condyles and portion of squamous), left proximal ulna diaphysis, right tibia missing proximal end, rib fragments (7); age based on length of long bones (Ubelaker, 1989) (rib fragment submitted for carbon and nitrogen isotopic analysis [see Schoeninger, this volume])
	209	Partial adult face, including right nasal bone and maxilla with fragmentary molar roots; very weathered
	210	Adult long bone fragments (9)
	211	Burial excavated by HSFS (see Chapter 3)
	212	Preadult (less than 5 years) right temporal; age based on size of bone
	213	Adult long bone fragments (3)
	214	Preadult (less than 5 years) left zygoma; age based on size of bone
	215	Preadult (less than 10 years) rib fragment; age based on size of bone
1062	—	Burial reported to but not excavated by HSFS (had been discovered by NSM and covered with plastic sheeting)
	200	Adult cranial fragments representing a single individual (most facial and vault elements represented); likely male (very large external occipital protuberance)
	201	Adult left radius; likely male (large size of bone); proliferative marginal lipping on distal end (osteoarthritis)
	202	Permanent mandibular premolar root
	203	Long bone fragments
	204	Adult terminal foot phalanx (first)
	205	Permanent teeth, including maxillary left first incisor and right second incisor, mandibular right second incisor; teeth likely from the same individual
	206	Excavated by Kelly crew in excavation of unit N212.5, E198.5, level 3—adult left tibia distal articular area
	207	Excavated by Kelly crew in excavation of unit N212.5 E200, level 2—fragments of deciduous mandibular left first molar
	208	Excavated by Kelly crew in excavation of unit N213 E200, level 2—deciduous maxillary left second incisor
	209	Partial right one-half of preadult (2–3 years) mandible with first and second deciduous molars; age based on dental development (Ubelaker, 1989)
	210	Excavated by Kelly crew in excavation of unit N201 E223, level 1—tooth root (probably permanent maxillary first incisor)
	211	Excavated by Kelly crew in excavation of unit N199 E200, level 1—permanent molar root fragment
	212	Excavated by Kelly crew in excavation of unit N201.5 E201.5, level 1—adult left cuboid
	213	Excavated by Kelly crew in excavation of unit N211 E195.5, level 1—adult left second metatarsal
	214	Excavated by Kelly crew in excavation of unit N203 E201.5, no level—preadult (prenatal) left humerus; age based on long bone length (Ubelaker, 1989)

TABLE A-1—(*Continued*)

Site	Ref. no	Description
	215	Excavated by Kelly crew in excavation of unit N211 E200.5, feature 3, level 12—molar enamel fragments
	216	Excavated by Kelly crew in excavation of unit N211.5 E198.5, level 2—preadult hyoid; age based on size of bone
	217	Excavated by Kelly crew in excavation of unit N202 E201.5, level 1—adult sesamoid bones (2)
	218	Excavated by Kelly crew in excavation, no unit, surface—adult cranial fragment
	219	Excavated by Kelly crew in excavation, no unit, surface—partial adult (greater than 35 years) mandible with permanent left first incisor through left third molar; age based on marked occlusal surface wear
1063	200	Preadult (less than 5 years) left parietal; age based on size of bone; bone shows perfect articulation with L11-200 (right parietal), thus indicating that the two skeletal elements are likely from a single individual
	201	Adult ulna or radius diaphysis fragment
	202	Preadult rib fragment; age based on size of bone
	203	Preadult rib fragment; age based on size of bone
	204	Adult fibula diaphysis fragment
	205	Adult left temporal fragment
	206	Adult femur diaphysis fragment
	207	Adult tibia or femur diaphysis fragment
	208	Adult tibia diaphysis fragment
	209	Long bone fragment
	210	Adult cranial fragment
	212	Adult temporal squamous fragment
	213	Long bone fragment
	214	Long bone fragment
	215	Long bone fragment
1064	200	Burial excavated by HSFS (see Chapter 3)
	201A	Human remains in association with 1064-200 (see Burials)
	201B	Human remains in association with 1064-200 (see Burials)
	202	Partial preadult innominate (ischium only); bone is relatively large, but no apparent evidence of beginning fusion with other innominate bones
	203	Adult frontal fragment (glabella area)
	204	Rib fragment
	205	Adult humerus fragment (distal end)
	206	Adult mandible fragment with right permanent second molar
1065	200	Right rib
	201	Preadult (adolescent) left scapula; age based on size and development of bone
	202	Adult left humerus (distal end)
	203	Adult right rib
	204	Adult tibia diaphysis fragment
	205	Adult left femur; likely female (small size of bone)
	206	Adult femur diaphysis
	207	Long bone fragments (2) probably from a single individual
	208	Preadult (5–8 years) right femur; age based on length of long bone (Ubelaker, 1989); very weathered
	209	Adult thoracic vertebrae (2) (third through sixth)
	210	Preadult cranial fragments (2) from a single individual; age based on size of bone
	211	Adult left rib fragment
1066	200	Adult right tibia (distal end)
	201	Adult rib fragments (2) from a single individual
1069	200	Adult cervical vertebra (third through sixth)
	201	Adult left rib fragment
	202	Adult thoracic vertebrae (2) (second through eleventh)
	202	Adult left rib fragment
	203	Adult burial recorded but not excavated by HSFS
	204	Probable adult manubrium

TABLE A-1—(*Continued*)

Site	Ref. no	Description
	205	Long bone fragment
	206	Adult cervical vertebra (third through sixth)
	207	Adult proximal hand phalanx
1070	1/1	Collected by Larsen, Kelly, and Raymond—preadult (7 years) one-half left mandible with deciduous first and second molars and permanent first molar; age based on dental development (Ubelaker, 1989) and presence of slight occlusal wear on permanent first molar
	200	Adult right patella; adult left greater multangular; patella shows proliferative marginal lipping (osteoarthritis)
1071	200	Preadult occipital fragment; age based on size of bone
1158	200	Preadult thoracic vertebra; age based on size of bone
1159	200	Burial excavated by HSFS (see Chapter 3)
	201	Long bone fragments (4)
L53	—	Collected by Raymond near site L53—adult right tibia
1160	200	Partial preadult (adolescent) cranial vault, including left and right parietals and occipital; age based on size and development of bones; no suture closure
	201	Adult cervical vertebra (third through sixth)
	202	Adult rib fragment
	203	Partial preadult (5–10 years) cranial vault, including left and right parietals and occipital squamous; age based on size and development of bones; no suture closure; lambdoidal extrasutural bones
	204	Preadult (5–10 years) frontal; age based on size of bone
	205	Adult thoracic vertebra; proliferative marginal lipping (osteoarthritis)
	206	Adult second cuneiform fragment
	207	Adult ribs (3, including a first rib)
	208	Adult left ulna; very weathered
	209	Adult femur head
	210	Preadult (10± years) thoracic vertebra; age based on size of bone
	211	Adult sternum
	212	Adult (greater than 40 years) mandible missing right ascending ramus; dentition includes all permanent mandibular teeth, left and right first incisors through third molars; age based on extreme degree of occlusal surface wear
	213	Adult lumbar vertebra
1168	200	Adult right fibula
1169	200	Adult bones from a single individual; rib fragments (2); left radius (distal one-half only); nearly complete right scapula; nearly complete right fibula; radius shows proliferative marginal lipping (osteoarthritis)
	201	Preadult (prenatal) left ilium; age based on length of bone (Ubelaker, 1989)
1249	1/1	Collected by Raymond—partial adult (18–25 years) skeleton, including skull (left side incomplete; partial mandible), dentition (permanent maxillary left fourth premolar, first molar, second molar, right canine, first molar, second molar, mandibular right canine through right third molar; maxillary third molars missing due to agenesis; all other missing teeth appear to be postmortem loss), postcrania (right ischium, right ilium, right clavicle, left and right scapulae, right humerus, left and right radii, left and right ulnae, right femur, right fibula, left third metacarpal, left fifth metacarpal, proximal hand phalanx, right ribs [7], rib fragments [3], thoracic vertebrae [3, first through ninth], lumbar vertebra [2 incomplete], partial sacrum); likely male based on extreme degree of robusticity, narrow sciatic notch; proliferative marginal lipping on fifth lumbar vertebra (osteoarthritis); age based on moderate occlusal surface wear on teeth
L72	200	Burial excavated by HSFS (see Chapter 3)
1173	200	Burial excavated by HSFS (see Chapter 3)
	201	Preadult ilium fragment; age based on size of bone
	202	Adult left clavicle; likely female, bone small
	203	Adult right patella fragments from one bone
	204	Preadult (8–11 years) postcrania from a single individual: left radius (proximal end); left femur missing ends; right femur missing distal one-third; age based on length of long bones (Ubelaker, 1989)

TABLE A-1—(*Continued*)

Site	Ref. no	Description
	205	Adult right temporal fragments from one bone
	206	Adult left calcaneus fragment
	207	Adult rib fragment (submitted for carbon and nitrogen isotopic analysis [see Schoeninger, this volume])
	208	Adult ilium fragments from one bone
	209	Partial adult left scapula
	210	Adult right tibia missing distal end; likely male (large size of bone); recent line of epiphyseal fusion on proximal end
	211	Unidentifiable bone fragment
	212	Adult ilium fragment
	213	Adult femur head fragment
	214	Adult left tibia fragment (proximal diaphysis)
L102	200	Partial adult cranial vault, including left and right parietals and occipital squamous; associated fragments include left temporal, parietal
L108	200	Burial excavated by HSFS (see Chapter 3)
L111	200	Burial excavated by HSFS (see Chapter 3)
L120	200	Adult (18–25 years) postcrania from a single individual: right innominate missing pubis, right femur missing distal end, right tibia missing both ends; female (wide sciatic notch, parturition pits associated with well-defined preauricular sulcus); age based on incomplete fusion of iliac crest epiphysis
L133	200	Adult rib fragment

APPENDIX B. STILLWATER HUMAN TOOTH SIZE

Clark Spencer Larsen and Joanna E. Lambert

More than 25 years ago, C. Loring Brace (1967) remarked on the paucity of systematically collected data on human biological dimensions in the anthropological literature, even for something as readily measurable as human teeth. Since that time, the importance of tooth-size variation in relation to broader questions in human adaptation and evolution has become fully realized (Kieser, 1990), as is evidenced by the appearance of a spate of reports from many different archaeological contexts in the Old World (e.g., Brace, 1980; Brace and Hinton, 1981; Lukacs, 1985; Calcagno, 1989; Brace et al., 1991; Calcagno and Gibson, 1991; Lukacs and Hemphill, 1991) and in the New World (e.g., Brace and Mahler, 1971; Ubelaker, 1971; Sciulli, 1979; Hinton et al., 1980; Larsen, 1982; Iscan, 1989; Simpson et al., 1990; Dickel, 1991). These studies provide essential data on geographic, cultural, and temporal variation from the earliest representatives of the Hominidae through the appearance and evolution of modern *Homo sapiens*. Despite the increased availability of dental metric data, many regions of the world have gone unstudied, including the Great Basin of western North America.

Tuohy et al. (1987) and Brooks et al. (1988) provide summary statistics on cranial and postcranial measurements, indices, stature, and cranial, postcranial, and dental discrete traits in the NSM Stillwater skeletal series. To augment these observations, we herein report summary statistics on tooth size from dentitions recovered from the Stillwater archaeological sites by the NSM and HSFS. As discussed by Brooks et al. (1988) and by us elsewhere in this monograph, the degree of tooth wear in the Stillwater series is extreme. Our observations of the Stillwater dentitions reveal that occlusal surface wear commences within the first year of occlusal eruption of permanent and deciduous teeth. In many mature and older adults in the series, the severity of tooth wear has precluded the measurement of many teeth. In total, 89 individuals in the series are represented by dentitions (as defined by the presence of at least one tooth). Excessive wear on all available teeth in 20 of these individuals prevented their measurement, thus leaving us with 69 measurable dental individuals (listed in table B-1). All Stillwater dentitions are incomplete because of the combined effects of premortem tooth loss and especially ex-

TABLE B-1
Individuals Used in Preparing Tooth-Size Summary Statistics

Specimen[a]	Sex	Age	Comment
1043-5	M	40+	Most teeth too worn for measurement
1043-7	F	23	Most teeth present
1043-ind. 37	?	13	Maxilla only
1043-201	F	25	Extensive postmortem loss
1044-1	F	27	Most teeth present
1044-2	M	40+	Most teeth too worn for measurement
1045-1	F	35	Most teeth present
1046-2A	?	12	Mixed (permanent + deciduous) dentition
1046-2B	?	12	Most teeth present (permanent)
1046-9	M	37	Most teeth present, but nearly half are too worn for measurement
1047-1	M	22	Most teeth present
1048-7	?	9	One deciduous tooth only
1048-201	?	25	Few permanent teeth
1048-210	?	3	Several deciduous teeth
1048-218	?	25	Partial maxillary dentition
1050-ind. 1	?	2	Partial mandibular deciduous dentition
1050-ind. 2	?	1.5	Few deciduous teeth
1050-1-2	M	30	Nearly complete mandibular dentition; most maxillary teeth missing postmortem
1050-2	F	40	Extensive postmortem loss; maxillary teeth present only
1050-12-2	?	21	One maxillary molar
1051-ind. 3	?	7	Several maxillary deciduous teeth only
1052-1	F	25	Extensive postmortem loss; maxillary teeth present only
1054-1	M	27	Most teeth present
1055-1,2	M	27	Most teeth present
1058-1	M	23	Most teeth present
1058-4	F	18	Extensive postmortem loss; maxillary teeth present only
1058-12A	F	22	Extensive postmortem loss; partial mandibular dentition
1058-211	?	7.5	Deciduous teeth only; nearly complete dentition
1060-A-1	M	25	Extensive postmortem loss; few maxillary teeth only
1060-200	?	3	Deciduous teeth only; partial dentition
910-18	?	2	Deciduous teeth only; nearly complete dentition
910-23	F	40+	Most teeth too worn for measurement; extensive postmortem loss
910-26	?	2	Few deciduous teeth
910-202	?	1	One deciduous tooth
910-211	?	1.5	Few deciduous teeth only
1062-1	M	40+	Most teeth too worn for measurement; extensive postmortem loss
1062-205	?	Adult	Extensive postmortem loss
1062-209	?	2	Two deciduous teeth only
1063-4	?	6	Two deciduous teeth only
1063-5-2	?	13	Partial permanent mandibular dentition
1063-5-3	?	Adult	One permanent mandibular molar
1063-9-1	?	25	Three permanent mandibular molars
1063-20-2	F	40+	Most teeth too worn for measurement
1064-1,18	F	30	Extensive postmortem loss
1064-6	?	10	Two deciduous teeth only
1064-11	?	Adult	One permanent tooth
1064-17	?	9	One permanent tooth
1064-ind. 4	?	20	Few mandibular teeth
1064-11-1,17-1	?	10	Partial deciduous dentition
1064-200	?	12	One permanent tooth
1065-20-1	?	15	Incomplete permanent dentition
1068-6	F	25	Extensive postmortem loss; maxillary teeth only
1068-22-1	M	40+	Most teeth too worn for measurement; extensive postmortem loss

TABLE B-1—(*Continued*)

Specimen[a]	Sex	Age	Comment
1070-3	F	40+	Most teeth too worn for measurement
1070-4	F	40+	Most teeth too worn for measurement
1070-1/1	?	7	Deciduous teeth only
1159-4	M	35	Extensive postmortem loss; mandibular teeth only
1159-7	M	18	Half dentition (maxillary and mandibular)
L53-B-1	F	35+	Most teeth too worn for measurement
1160-ind. 1A	M	25	Some postmortem loss
1160-1-1	F	22	Maxillary dentition only (nearly complete)
1160-64	F	17	Extensive postmortem loss; half dentition (maxillary and mandibular)
1163-1	M	22	Extensive postmortem loss
1249-1-1	M	22	Extensive postmortem loss
L72-200	F	37	One mandibular tooth only
1173-200	F	27	Nearly complete
L108-200	?	9 mo	Few deciduous teeth only
L111-200	?	11	One deciduous tooth; partial permanent dentition
SP-A	M	40	Extensive postmortem loss

[a] Specimen includes the presence of at least one measurable tooth.

cessive wear in older adults. Postmortem tooth loss resulting from disturbances to skeletons following the 1985 flooding also contributed to the incomplete record of dental measurements.

Two dental dimensions were recorded as representative of tooth size for available deciduous and permanent teeth. These measurements include length (or mesiodistal diameter) and breadth (or labiolingual diameter for the anterior dentition and buccolingual diameter for the posterior dentition). Lengths were taken at the region of maximum distance at the midpoints of the interproximal contact points between teeth in their normal positions; breadths were taken perpendicular to the lengths (see Larsen, 1982). Both measurements were made with sliding calipers and were recorded to the nearest 0.1 mm. Tooth breadth represents a somewhat better measure of tooth size because, unlike tooth length, it is unaffected by occlusal surface or interproximal wear, except with regard to extreme circumstances. Because original tooth length of incisor teeth is lost soon after wear of their occlusal surfaces begins, we have not included these dimensions in the data analysis.

Summary statistics for lengths and breadths of the permanent teeth are presented in table B-2. In human populations exhibiting marked or unknown sexual dimorphism (male/female tooth size difference), sex identification must be made in interpretation of tooth size variation (cf. Frayer and Wolpoff, 1985; Kieser, 1990; Brace et al., 1991). Therefore, for the adult sample, we have also computed summary statistics in instances where sex could be identified (based on postcranial or cranial characteristics). These data and percentage sexual dimorphism for each of the tooth types are presented in table B-3. Comparisons of the Stillwater dentitions with other Holocene samples (e.g., Frayer, 1978; Brace and Ryan, 1980; Larsen, 1982; Frayer and Wolpoff, 1985; Calcagno, 1989) reveal that percentage sexual dimorphism values in the Great Basin are similar to other samples for virtually all dimensions, and certainly provide additional evidence for males having larger tooth size than females (see review in Kieser, 1990). However, unlike values reported by most other researchers for the canine, percentage sexual dimorphism is not greater than for other teeth (excepting the mandibular right canine length). Indeed, length of the Stillwater mandibular left canine is 4.0% *less* in males than in females (table B-3). Importantly, however, sample sizes in the Stillwater series are small, thus adding a potential sampling bias in dental measurements.

In contrast to the growth of individual bones of the skeleton, tooth crowns are fully complete well before adulthood has been reached. In addition, once a tooth crown is formed, it does not (unlike skeletal tissues) remodel or alter its form, except with regard to pathological processes (e.g., dental caries) or wear. Similar to skeletal tissues, however, the final determination of tooth size is influenced by several factors during the period of development, including genetic constitution, body size, sex, and environment (Kieser, 1990). With regard to environmental factors, a number of workers have shown that tooth size has a significant environmental component. Estimates of the environmental contribution to tooth size vary widely (e.g., Osborne et al., 1958; Goodman, 1965; Potter et al., 1968, 1976; Goose, 1971; Alvesalo and Tigerstedt, 1974; Garn et al., 1979; Corruccini

TABLE B-2
Stillwater Permanent Dentition: Combined Adult and Juvenile Tooth-Size Summary Statistics

Observation[a]		Mean	N	Min.	Max.	SD
Left mandible						
I1	B	5.8	9	5.2	6.2	0.34
I2	B	6.3	11	5.8	7.1	0.40
C	L	7.1	10	6.8	7.7	0.31
	B	7.8	11	6.7	8.8	0.67
PM3	L	6.9	13	6.2	7.6	0.39
	B	7.6	15	6.7	8.4	0.49
PM4	L	6.8	14	5.7	8.4	0.73
	B	8.1	17	7.3	9.1	0.52
M1	L	11.6	20	10.2	12.5	0.58
	B	10.9	18	9.4	11.8	0.61
M2	L	10.9	19	9.6	12.1	0.68
	B	10.5	15	9.8	11.5	0.54
M3	L	10.9	17	9.3	12.5	0.86
	B	10.4	16	9.1	11.3	0.86
Right mandible						
I1	B	5.0	8	5.4	6.6	0.46
I2	B	6.2	11	5.6	6.8	0.39
C	L	7.2	10	6.3	7.8	0.42
	B	7.8	10	7.0	8.6	0.56
PM3	L	6.8	15	6.1	7.8	0.50
	B	7.7	14	6.8	8.6	0.58
PM4	L	6.9	15	6.2	7.5	0.43
	B	7.9	16	6.3	9.0	0.67
M1	L	11.4	21	10.2	12.3	0.61
	B	10.9	23	9.9	11.6	0.47
M2	L	10.9	21	9.3	12.8	0.77
	B	10.5	21	9.3	11.6	0.63
M3	L	10.9	18	8.8	12.9	0.99
	B	10.3	20	9.2	12.1	0.76
Left maxilla						
I1	B	7.4	16	6.8	8.3	0.42
I2	B	6.9	15	5.9	7.2	0.40
C	L	7.9	18	6.2	8.8	0.67
	B	8.3	19	7.6	9.3	0.37
PM3	L	6.9	14	6.0	7.7	0.51
	B	9.5	13	8.9	10.8	0.45
PM4	L	6.6	11	5.2	7.6	0.65
	B	9.2	11	8.3	10.2	0.60
M1	L	10.1	23	9.1	11.4	0.53
	B	11.7	21	10.5	12.7	0.47
M2	L	9.9	19	9.0	11.0	0.65
	B	11.7	20	10.1	12.9	0.69
M3	L	9.0	15	6.0	10.8	1.30
	B	10.8	15	9.4	13.0	0.88
Right maxilla						
I1	B	7.4	14	6.2	8.3	0.57
I2	B	6.6	13	6.0	7.4	0.48
C	L	7.9	14	6.7	9.0	0.77
	B	8.3	17	7.5	9.0	0.46
PM3	L	6.9	15	6.5	7.4	0.31
	B	9.3	17	8.4	10.7	0.48
PM4	L	6.5	16	5.0	7.4	0.61
	B	9.2	15	8.3	10.3	0.56
M1	L	10.4	20	9.6	11.4	0.47
	B	11.8	20	11.2	12.3	0.32
M2	L	9.8	20	8.8	10.7	0.58
	B	11.7	19	10.6	12.6	0.54
M3	L	9.0	13	7.8	10.7	0.71
	B	10.4	13	8.9	11.8	0.67

[a] L = length, B = breadth (in mm; taken following procedures outlined in Larsen, 1982).

and Potter, 1981). Nevertheless, the consensus is that environment plays a significant role in the determination of tooth size. For example, Townsend and Brown (1978) have indicated that more than one-third (36%) of the total variance in tooth-crown size results from purely environmental causes. Although environment has an effect on crown dimensions, its precise role is not fully understood (Kieser, 1990).

The period of dental development of crowns of the permanent dentition (from several months before birth to 12 years; see Smith, 1991), is arguably the period associated with the greatest physiological stress in the maturing individual, at least for most human populations (Gordon et al., 1963). From this perspective, just as individuals who develop in a stress-free environment are more likely to reach their genetic growth potential in body size and stature, tooth size should also reflect disturbances occurring during growth and development. Thus, individuals who are relatively less stressed should exhibit larger teeth than individuals who are more stressed. In theory, then, individuals who are less able to mitigate the biological effects of stressors should have smaller teeth than those who more successfully cope with environmental perturbations. Archaeological death assemblages should represent an excellent test case for this hypothesis. In particular, individuals comprising the skeletal assemblage include a range of ages from birth (or before) through adulthood. Younger individuals are in the assemblage largely because they were less successful in coping with environmental insults than older individuals. Thus, juveniles should have smaller teeth than adults, especially in a stressed setting.

Two studies of Native American dental samples have provided findings that are consistent with this hypothesis. Guagliardo (1982) compared ju-

TABLE B-3
Stillwater Permanent Dentition: Adult Male and Female Tooth-Size Comparisons, with Percentage Sexual Dimorphism

Observation[a]		Male Mean	Male N	Male SD	Female Mean	Female N	Female SD	Sexual dimorphism[b]
Left mandible								
I1	B	6.0	3	0.29	5.8	3	0.45	+3.3
I2	B	6.4	5	0.27	6.3	4	0.58	+1.6
C	L	7.2	6	0.30	7.5	2	0.07	−4.0
	B	8.1	6	0.47	7.8	2	0.50	+3.7
PM3	L	7.0	6	0.36	7.0	5	0.40	0.0
	B	7.8	7	0.37	7.6	6	0.51	+2.6
PM4	L	7.1	7	0.69	6.4	4	0.86	+9.9
	B	8.3	9	0.62	7.9	5	0.21	+4.8
M1	L	11.6	7	0.29	11.1	5	0.84	+4.3
	B	11.4	6	0.58	10.6	5	0.73	+7.0
M2	L	10.9	9	0.49	10.6	5	1.02	+2.8
	B	10.8	8	0.49	10.4	5	0.64	+3.7
M3	L	11.3	10	0.84	10.3	6	0.61	+8.8
	B	10.7	9	0.52	9.9	6	0.58	+7.5
Right mandible								
I1	B	5.9	4	0.53	6.0	2	0.64	+1.7
I2	B	6.4	4	0.29	6.0	3	0.58	+6.2
C	L	7.4	7	0.29	6.7	3	0.38	+9.5
	B	8.0	6	0.41	7.4	4	0.62	+7.5
PM3	L	6.9	8	0.44	6.8	6	0.61	0.0
	B	7.9	7	0.31	7.6	6	0.61	+2.6
PM4	L	7.1	8	0.29	6.7	6	0.51	+5.7
	B	8.1	9	0.54	7.7	6	0.84	+4.9
M1	L	11.4	9	0.54	11.0	5	0.79	+3.5
	B	11.1	10	0.40	10.5	6	0.54	+5.4
M2	L	11.0	10	0.39	10.5	5	1.37	+4.5
	B	10.7	10	0.40	10.2	6	0.92	+4.7
M3	L	11.3	9	0.87	10.3	7	1.02	+8.8
	B	10.5	10	0.69	9.8	8	0.58	+6.7
Left maxilla								
I1	B	7.8	5	0.38	7.1	5	0.25	+9.0
I2	B	7.0	5	0.16	6.5	6	0.43	+7.1
C	L	8.0	6	1.02	7.8	8	0.37	+2.5
	B	8.4	7	0.23	8.2	8	0.53	+2.4
PM3	L	6.9	5	0.60	6.9	7	0.44	0.0
	B	9.3	5	0.25	9.7	6	0.53	−4.1
PM4	L	6.7	7	0.52	6.2	4	0.80	+7.5
	B	9.2	7	0.64	9.3	4	0.61	−1.1
M1	L	9.9	9	0.44	10.2	8	0.77	−2.9
	B	11.7	9	0.43	11.7	6	0.69	0.0
M2	L	9.8	9	0.62	10.1	6	0.83	−3.0
	B	12.0	9	0.47	11.4	7	0.92	+5.0
M3	L	9.4	5	0.89	8.5	9	1.32	+9.6
	B	10.9	5	0.56	10.5	9	0.70	+3.7
Right maxilla								
I1	B	7.7	5	0.50	7.2	3	0.95	+6.5
I2	B	6.8	5	0.30	6.7	4	0.68	+1.5
C	L	8.1	7	0.81	7.6	6	0.74	+6.2
	B	8.3	10	0.42	8.1	6	0.52	+2.4
PM3	L	6.8	6	0.28	6.9	6	0.27	−1.4
	B	9.1	7	0.39	9.5	7	0.59	−4.2
PM4	L	6.4	7	0.73	6.4	7	0.59	0.0
	B	9.2	7	0.64	9.2	7	0.57	0.0
M1	L	10.2	5	0.47	10.4	8	0.39	−1.9
	B	11.7	6	0.24	11.8	7	0.32	−0.8
M2	L	9.7	7	0.52	9.6	8	0.52	+1.0
	B	11.9	7	0.44	11.6	7	0.52	+2.5
M3	L	9.3	7	0.71	8.6	6	0.49	+7.5
	B	10.5	7	0.69	10.1	6	0.64	+4.0

[a] L = length, B = breadth (in mm; taken following procedures outlined in Larsen, 1982).

[b] Negative values were computed by the formula $-(1 - \bar{X}_M/\bar{X}_F)(100)$; positive values were computed by the formula $+(1 - \bar{X}_M/\bar{X}_F)(100)$. $\bar{X}_M$ = male mean value; $\bar{X}_F$ = female mean value.

venile with adult tooth size from late prehistoric sites in Tennessee (Averbuch site) and South Dakota (Larson site), and Simpson et al. (1990) compared juveniles and adults from a 17th century Spanish mission in coastal Georgia (Santa Catalina de Guale). Both investigations examined dentitions of populations that had been exposed to high levels of chronic stress arising from a combination of poor nutrition, disease, warfare, and other circumstances. Both studies showed that adult tooth size is larger than that in juveniles, thus providing evidence that chronic stress plays an important role in expression of final tooth size in the maturing individual (see Simpson et al., 1990).

We have indicated elsewhere in this volume that stress, including occasional periods of food shortages, likely occurred in the Great Basin populations. Therefore, in similar fashion to the aforementioned populations from the Plains and Southeast, juvenile and adult dentitions should show hypothesized size differences.

Table B-4 shows a comparison of juveniles (≤ 16 years) and adult (> 16 years) permanent tooth size. We have eliminated crown lengths from the analysis because of the greater likelihood of age-related changes in size because of interproximal attrition (Wolpoff, 1971). We also chose not to include the third molar—maxillary or mandibular—because of the high variability in size of this tooth relative to other teeth in human populations. As was the case when evaluating sex differences in tooth size,

TABLE B-4
Stillwater Permanent Dentition: Juvenile-Adult Tooth-Size Comparisons (Breadths)

Observation[a]	Juvenile Mean	N	SD	Adult Mean	N	SD	Difference (%)[b]
Left mandible							
I1	5.6	3	0.40	5.9	6	0.37	+5.1
I2	6.0	2	0.21	6.3	9	0.41	+4.8
C	7.2	3	0.87	8.0	8	0.47	+10.0
PM3	6.9	2	0.28	7.7	13	0.43	+10.4[c]
PM4	7.9	3	0.35	8.1	14	0.55	+2.5
M1	10.8	7	0.36	11.0	11	0.74	+1.8
M2	10.1	3	0.42	10.6	15	0.53	+4.7
Right mandible							
I1	6.2	2	0.35	5.8	6	0.50	−6.5
I2	6.0	3	0.32	6.3	8	0.41	+4.8
C	—	—	—	7.8	10	0.56	—
PM3	6.8	1	—	7.8	13	0.51	+12.8
PM4	7.4	1	—	8.0	15	0.68	+7.5
M1	10.9	6	0.36	10.9	17	0.52	0.0
M2	10.2	4	0.33	10.5	17	0.67	+2.9
Left maxilla							
I1	7.2	5	0.22	7.5	11	0.47	+4.0
I2	6.6	4	0.42	6.7	11	0.40	+1.5
C	8.2	4	0.13	8.3	15	0.42	+1.2
PM3	9.3	2	0.42	9.5	11	0.46	+2.1
PM4	—	—	—	9.3	11	0.6	—
M1	11.8	6	0.33	11.7	15	0.53	−0.8
M2	11.3	4	0.46	11.7	16	0.72	+3.4
Right maxilla							
I1	7.3	5	0.42	7.5	9	0.64	+2.7
I2	6.2	4	0.23	6.8	9	0.47	+8.8[c]
C	—	—	—	8.3	17	0.45	—
PM3	9.2	2	0.28	9.4	15	0.51	+2.1
PM4	9.2	1	—	9.2	14	0.58	0.0
M1	11.8	7	0.49	11.8	13	0.28	0.0
M2	11.2	4	0.49	11.8	15	0.50	+5.1[c]

[a] L = length, B = breadth (in mm; taken following procedures outlined in Larsen, 1982).

[b] Negative values were computed by the formula $-(1 - \bar{X}_A/\bar{X}_J)(100)$; positive values were computed by the formula $+(1 - \bar{X}_J/\bar{X}_A)(100)$. $\bar{X}_J$ = juvenile mean value; $\bar{X}_A$ = adult mean value.

[c] $p \leq 0.05$ (Student's t-test).

TABLE B-5
Stillwater Deciduous Dentition: Tooth-Size Summary Statistics

Observation[a]		Mean	N	Min.	Max.	SD
Left mandible						
dI1	B	3.9	3	3.8	4.0	0.10
dI2	B	4.1	2	3.9	4.2	0.21
dC	L	6.5	2	6.4	6.5	0.07
	B	5.7	2	5.5	5.8	0.21
dM1	L	8.7	7	8.1	9.3	0.37
	B	7.3	7	7.0	7.8	0.30
dM2	L	10.8	6	9.8	11.3	0.54
	B	9.4	5	8.8	10.2	0.55
Right mandible						
dI1	B	3.9	2	3.7	4.1	0.28
dI2	B	4.5	2	4.3	4.7	0.28
dC	L	6.4	5	5.9	6.7	0.30
	B	5.4	5	4.8	5.7	0.37
dM1	L	8.7	8	8.2	9.3	0.35
	B	7.4	8	7.0	7.8	0.26
dM2	L	11.0	4	10.0	11.7	0.79
	B	9.1	5	8.8	9.5	0.27
Left maxilla						
dI1	B	5.4	3	5.3	5.6	0.17
dI2	B	4.8	3	4.6	5.0	0.21
dC	L	7.4	2	7.3	7.4	0.07
	B	6.2	2	6.0	6.4	0.28
dM1	L	7.4	5	6.7	8.0	0.61
	B	8.5	5	7.4	9.1	0.67
dM2	L	9.2	5	8.7	9.7	0.45
	B	10.1	7	9.4	10.7	0.51
Right maxilla						
dI1	B	5.1	2	4.7	5.5	0.57
dI2	B	5.1	4	4.8	5.4	0.30
dC	L	7.5	4	7.2	7.8	0.25
	B	6.2	4	6.0	6.3	0.13
dM1	L	7.8	4	7.2	8.4	0.52
	B	8.5	5	7.0	9.2	0.77
dM2	L	9.3	3	8.9	9.7	0.40
	B	10.5	3	10.4	10.5	0.06

[a] L = length, B = breadth (measurements in mm; taken following procedures outlined in Larsen, 1982).

this component of tooth size analysis is clearly hampered by the limitations inherent in small samples. Regardless of this restriction, however, the comparisons of juvenile and adult teeth yield results that are similar to those presented by Guagliardo (1982) and by Simpson et al. (1990). That is, most comparisons show larger teeth in adults than in juveniles, and in three of the comparisons where adult breadths are larger than juvenile breadths, these differences are statistically significant (mandibular left canine, maxillary right lateral incisor, maxillary right second molar; $p \leq 0.05$, Student's t-test). Only two teeth reveal measurements that are greater in juveniles than in adults (mandibular right first incisor, maxillary left first molar; neither are statistically significant), three

teeth show no differences between the two subgroups (mandibular right first molar, maxillary right fourth premolar, maxillary right first molar), and the lack of measurable teeth in several of the tooth types prevents comparisons in some instances (mandibular right canine, maxillary left fourth premolar, maxillary right canine).

We suggest, therefore, that the differences in permanent tooth size between juveniles and adults provides compelling evidence that supports the hypothesis for the presence of stress factors that influenced growth and development of the dental hard tissues in this population. As pointed out elsewhere (Hutchinson and Larsen, this volume), it is unlikely that infectious diseases contributed to the variation in tooth size reported here. Far more likely is the presence of periodic food shortages that are characteristic of this hunting and gathering lifeway.

Whatever the cause of juvenile–adult tooth size difference, the study of age-associated variation in this series reveals that the cumulative effects of physiological disruption during the years of tooth growth leave a heritage of subsequent growth retardation—namely, smaller teeth. Sampling factors probably contributed to some of the size differences that we have observed here. However, similar to other studies that have examined this variability (e.g., Simpson et al., 1990), the most parsimonious hypothesis is related to developmentally based factors.

Finally, we present summary statistics for deciduous tooth size in the Stillwater series in table B-5. The very limited sample size, coupled with the difficulty of providing sex for juvenile skeletons, prohibits meaningful analysis of these data. We offer these data as baseline information for future studies of dental variation in Great Basin or other Amerindian populations.

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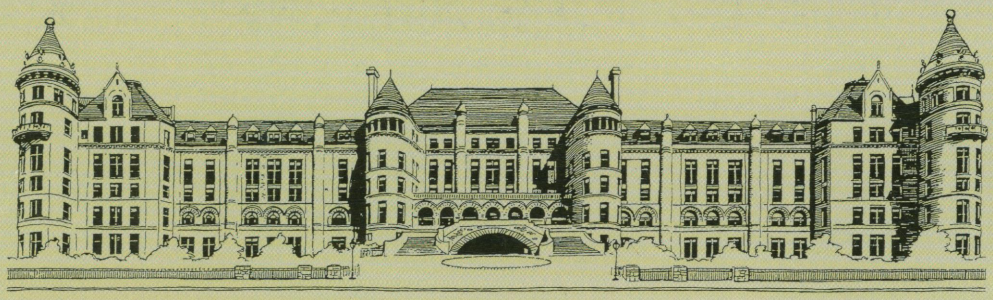

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"[The monograph] presents information on an area that is little known in terms of bioarchaeology." —- Patricia S. Bridges

"... an important contribution to Great Basin archaeology and in general, anthropology." — Steven R. Simms

The American Great Basin has been the focus of archaeological and ethnographic research beginning only decades after initial contact of native groups by Euroamericans in the first half of the 19th century. This rich record has been instrumental in elucidating key aspects of foraging lifeways, especially with regard to subsistence economy, settlement patterning, and mobility. Until recent years, the paucity of human remains has prevented a wider biological consideration of human adaptation in this vast region of the Desert West. Flooding of the Stillwater Marsh and surrounding area of the Carson Desert in the mid-1980s revealed an unprecedented assemblage of skeletal remains in archaeological sites, forming the basis of research presented by Larsen, Kelly, and their collaborators in this monograph.

Bioarchaeology of the Stillwater Marsh describes human remains and presents paleopathological analyses which inform our understanding of health status and adaptive efficiency in this setting. Questions regarding the degree of mobility and landscape use of the Stillwater Marsh and surrounding uplands are addressed via study of osteoarthritis and a novel means of assessing physical activity and behavioral patterns involving structural and biomechanical analysis of limb bones. Generally, these analyses indicate a healthy, but highly active and mobile (especially males) population. Analysis of stable isotopes of carbon and nitrogen are consistent with ethnographic observations that Great Basin native populations utilized a wide range of foods drawn from both marsh and uplands contexts. Unlike many other areas of the Great Basin where piñon was a key dietary staple, chemical analysis indicates that this food may have had only marginal significance in native foodways in this region. New information on serum albumin and mitochondrial DNA leaves open questions regarding the identification of ancestral-descendant relationships and population history. These analyses suggest, however, that Yuman and Southern Uto-Aztecan groups are probably not direct descendants of the prehistoric Stillwater populations.

Clark Spencer Larsen is a biological anthropologist with interests in the history of the human condition and biocultural adaptation. Much of his research has entailed the study of human remains from archaeological settings throughout North America, especially the American Southeast and Great Basin. His publications include *In the Wake of Contact: Biological Responses to Conquest* (edited with George R. Milner) and *The Archaeology of Mission Santa Catalina de Guale: 2 Biocultural Interpretations of a Population in Transition*. He is a member of the anthropology faculty at the University of North Carolina, Chapel Hill.

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