Dietary Reconstruction and Near Eastern Archaeology

ANDREW SILLEN

"One farmer says to me, 'You cannot live on vegetable foods solely, for it furnishes nothing to make bones with'; and so he religiously devotes a part of his day to supplying his system with the raw material of bones; walking all the while he talks behind his oxen, which, with vegetable-made bones, jerk him and his lumbering plough along in spite of every obstacle. Some things are really necessaries of life in some circles . . ., which in others are luxuries merely, and in others still are entirely unknown."
Henry David Thoreau, Walden, *1854*

While agriculture is a natural and obvious aspect of modern life, it is a relatively recent occurrence. Humans and their direct ancestors hunted and gathered for some three million years before the first plants were cultivated in the Near East only 10,000 years ago. This observation suggests a question to those interested in both the biology and the behavior of prehistoric humans: Why did agriculture happen at all?

This question, more than any other, has dominated scientific discussions of Near Eastern archaeology in this century. In seeking to explain the origin of cereal domestication, archaeologists have focused on the possibility of environmental or demographic disruption, or disequilibrium, that would have encouraged the inhabitants of the region to experiment with new foods, and new methods of obtaining familiar ones (see Katz and Voigt this issue).

Unfortunately, the reconstruction of prehistoric diets is no easy matter. This is partly due to the unpredictability of humans themselves. Like Thoreau's neighbor, people are often arbitrary about the foods they choose to exploit from a given environment: the availability of resources is quite a different matter from what was actually eaten. It is also due to the nature of the archaeological record. Even if no other factors were involved, it is unlikely that the scraps discarded from the table would give an accurate impression of what was actually on the prehistoric menu. But other factors are involved. Food items are differentially preserved at archaeological sites: archaeologists were once misled into believing that early humans relied heavily on meat foods, because bones, the remains of edible animals, survive far better than the remains of plant foods. For example, foods that were not cooked, such as fresh herbs and greens, are unlikely to be represented in the charred vegetable remains recovered. Foods that were cooked or processed near a fire may be represented by accidentally carbonized seeds, but not all seeds recovered from archaeological sites represent food plants. A study of modern villages suggests that many seeds are brought into settlements as fuel, or as fodder for domestic animals. Given the problems introduced by accidents of preservation, reconstructions of human diets based on the seeds and bones recovered from camps and settlements are necessarily very tentative.

The last decade has seen a remarkable development in the study of prehistoric diets. Scientists have learned to exploit various geochemical and biochemical phenomena that produce dietary signals in bones. Techniques are now available that make it possible to study various aspects of diet directly from human bones. Some of these aspects, such as the relative amounts of meat versus vegetable foods, and marine versus terrestrial foods, were previously almost invisible to archaeologists. Such techniques have exciting applications to the study of a variety of archaeological questions, including that of the origins of plant domestication in the Near East. In this article, I will first introduce two of these techniques, strontium-calcium ratios (Sr/Ca) and stable carbon isotope measurements. Following this introduction, I will discuss their application to the study of agricultural origins in the Levant, modern Israel and Jordan.

In the 1950s and early 1960s, a tremendous amount of information had been gathered about the distribution of strontium in food chains. This was in response to concern over radioactive Sr-90, a much-feared byproduct of above-ground nuclear testing. At that time, it was discovered that both Sr-90 and natural, stable strontium (with which archaeometrists are concerned) have a characteristic distribution in food chains when compared to a chemically similar element, calcium. Strontium and calcium are so similar that plants do not discriminate between them: the Sr/Ca of a plant is normally identical to that available to the plant in the form of water and soil nutrients. Mammals, on the other hand, discriminate against strontium in favor of calcium in the digestive absorption of these elements: relatively more calcium than strontium is absorbed into the

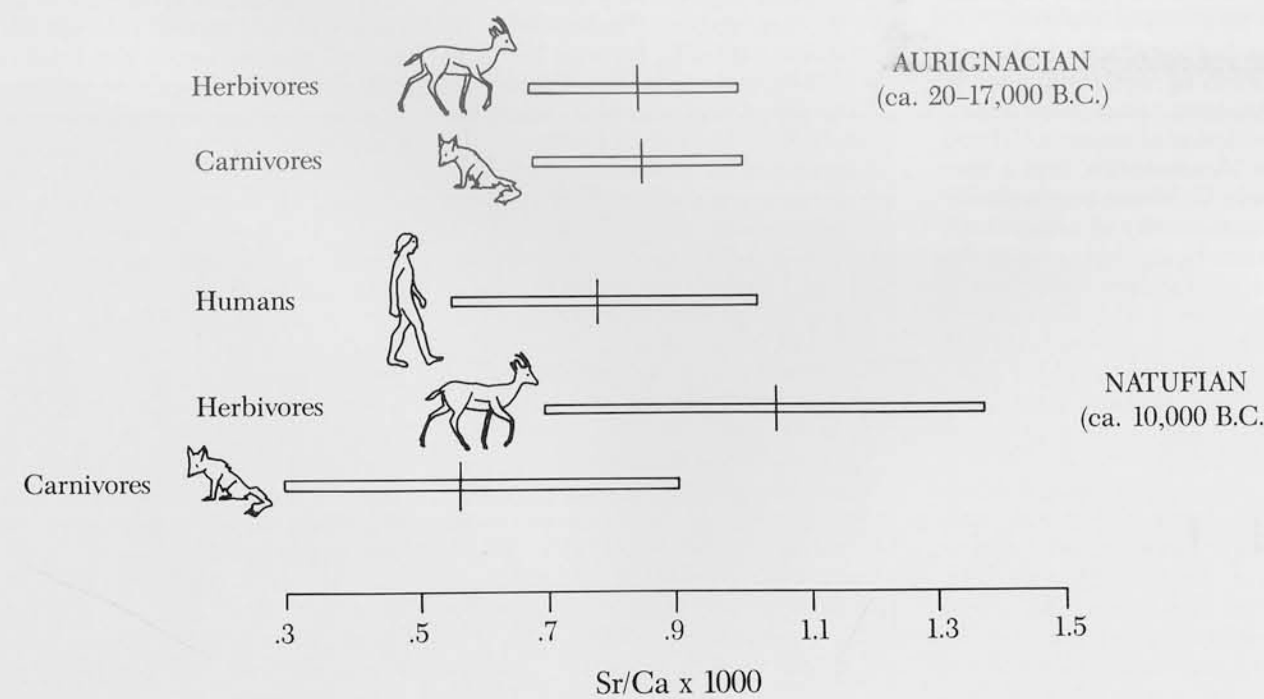
bloodstream and deposited in bone. As a result, the bones of herbivores have lower Sr/Ca than the plants these animals consume. Carnivores, ingesting the flesh of other mammals, repeat the process. Sr/Ca values are thus *reduced* at the higher levels of food chains, and carnivores have the lowest Sr/Ca in a given food chain. What makes this reduction useful is that it can be used to infer the dependence of humans on meat foods: the more meat foods contribute to diet, the lower the skeletal Sr/Ca.

> "it [is] possible to study various aspects of diet directly from human bones."

To test whether archaeological bones retain the biological signal present in living animals, it was necessary to identify and work with an appropriate archaeological site. My early research focused on Hayonim Cave in the western Galilee (Fig. 1), a site excavated by Professor Ofer Bar-Yosef of Hebrew University. What made Hayonim Cave special is that it contained large quantities of bone from both carnivores and herbivores, dated to two different time periods: the Natufian (ca. 10,000 B.C.) and the Aurignacian (ca. 20-17,000 B.C.). This archaeological sample made it possible to search for chemical changes after burial that might obscure the biological signal. I could assume that the diets of the animals hadn't changed through time; if the technique was working, there would be no difference in the Sr/Ca ratio of Natufian and Aurignacian animal bones.

The results of this first study can be seen in Figure 2. I found that

1
Hayonim Cave, in the western Galilee, contained bones from both the Natufian (ca. 10,000-8,500 B.C.) and Aurignacian (ca. 20,000-17,000 B.C.) periods. (Photo courtesy of Prof. Ofer Bar-Yosef, Hebrew University)



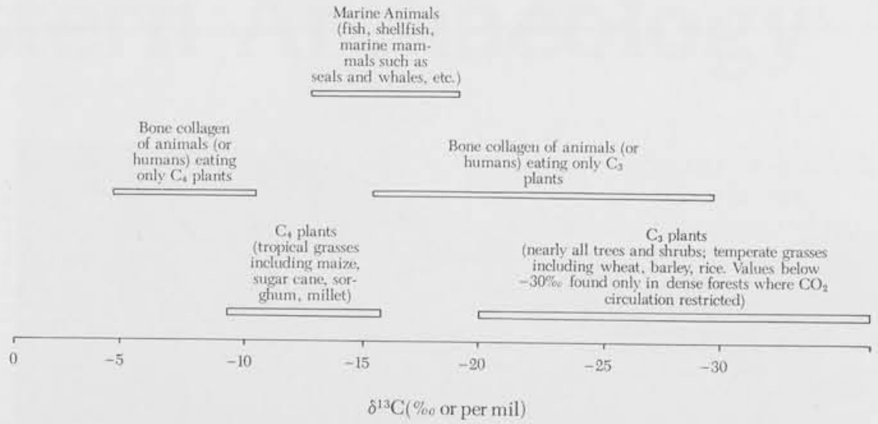
2
Herbivore, carnivore, and human Sr/Ca from the Natufian and Aurignacian levels of Hayonim Cave. (Drawn by Gil Stein)

although a clear difference existed between herbivores and carnivores within the younger Natufian level, there was no difference at all between the herbivores and carnivores from the older Aurignacian deposits. The unavoidable conclusion was that chemical change after interment could obscure the meaningful biological signal. This bittersweet result had two important implications. First, Sr/Ca could be used to study periods up to about 15,000 B.C. in Near Eastern caves, and therefore would be useful in the study of any dietary changes that might be associated with the beginnings of farming. Second, it would be necessary to use rather stringent faunal controls at each site to ensure that the technique was actually working.

A second complication in the use of strontium/calcium ratios has since been discovered. Marine foods have exceptionally high Sr/Ca, so that at coastal sites it may be impossible to make inferences based on a simple plant-versus-meat dichotomy. Fortunately, a parallel research line was developing in the 1970s, based on the stable isotopes of carbon. These isotopes make it possible to independently signal the presence of marine foods in diet, as well as the presence of certain types of plants (see box on Isotopic Analysis).

Carbon isotopes have revolutionized the study of food production in North America, since they signal the introduction of maize, a C_4 food native to Mesoamerica, into a predominantly C_3 biome (ecologically defined community of organisms). They cannot be similarly used in the Levant, since the first domesticates in the region are part of the local C_3 biome. On the other hand, carbon isotopes complement Sr/Ca studies by signalling the presence of marine foods that might otherwise complicate the Sr/Ca.

The application of carbon isotopes to Near Eastern specimens has had to await the development of new procedures for dealing with skeletons older than about 5000 years. Isotopic studies of skeletons usually employ the carbon in bone collagen, a protein that contributes approximately 30 percent to the weight of fresh bone. Unfortunately, this isn't possible for most Near Eastern archaeological sites, since the collagen doesn't survive for more than a few thousand years. While carbon in bone mineral (the remaining 70 percent of fresh bone weight) may survive longer, it is highly subject to contamination in the ground. Recent research by Harold Kruger of Geochron Laboratories in Cambridge, Massachusetts, and Julie Lee Thorp at the University of Cape Town has focused on separating contaminant minerals from the original bone so that the biological signal can be unambiguously seen. We are just beginning to see some preliminary



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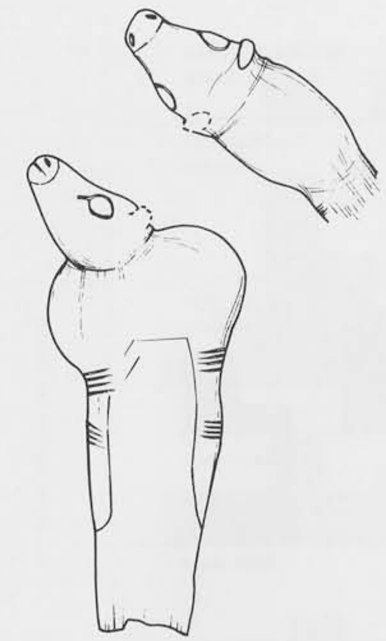
Summary of carbon isotopes from a variety of marine and terrestrial foods. A clear distinction exists between the isotopic values of C_3 and C_4 plants, and between C_3 plants and marine animals. (Drawn by Gil Stein)

Isotopic Analysis of Carbon

The element carbon has three naturally occurring isotopes, ^{12}C, ^{13}C, and ^{14}C, two of which, ^{12}C and ^{13}C, are stable. (Radioactive ^{14}C decays naturally, forming the basis of radiocarbon dating.) Dietary reconstruction is possible because the ratio of ^{13}C to ^{12}C changes in the environment in certain very predictable ways. Since ^{12}C is a slightly lighter atom than ^{13}C, it tends to react faster in most chemical reactions, notably photosynthesis. Therefore, plants use relatively more ^{12}C than ^{13}C when they fix atmospheric carbon dioxide. This process is called fractionation. Plants that fix atmospheric carbon dioxide initially into a three-carbon molecule (the Calvin, or C_3 photosynthetic pathway) fractionate the isotopes of carbon more than do those using a four-carbon molecule (the Hatch-Slack, or C_4 pathway). As a result, the two groups of plants have different ^{13}C-^{12}C ratios, measured as $\delta^{13}C$ values ($\delta^{13}C$=[$^{13}C/^{12}C$ of sample / $^{13}C/^{12}C$ standard -1] × 1000). The ranges do not overlap (Fig. 3). Tropical and savanna grasses follow the C_4 pathway, while trees, most shrubs, and temperate grasses follow the C_3 pathway. Because less significant fractionation occurs in mammals, differences in the carbon isotope ratios of the plants at the base of the food-web are carried through into animal tissues; hence the relative contribution of these different plants to animal diets can be determined. Carbon isotopes also distinguish between marine and terrestrial foods in areas where the terrestrial plants are C_3, since most marine organisms tend to have C_4-like values.

The carbon isotopic system represents a neat complementary twist on the Sr/Ca system: plants do not discriminate between strontium and calcium, but mammalian digestive tracts do. In contrast, carbon isotopes are severely fractionated at the level of plants, and relatively less so by mammals. As a result, archaeometrists can examine different aspects of diet with the two different techniques. Sr/Ca can tell the proportionate amount of meat versus vegetable foods, but not which kind of vegetable foods. Isotopic analyses make it possible to identify specific categories of plants, and the presence of marine foods.



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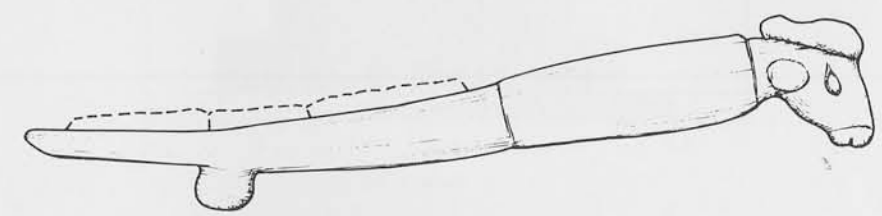
Side and top views of a fragment of a bone sickle haft from el Wad Cave on Mount Carmel. This Natufian carving represents a young gazelle. Length: ca. 12 cm. (After Emmanuel Anati, Palestine before the Hebrews *1962; drawn by Denise Hoffman)*

results with this new procedure on Near Eastern specimens.

In the Near East the period between the Upper Paleolithic and Neolithic, dating from approximately 17,000 to 8,500 B.C., is called the Epipaleolithic. During Epipaleolithic times, cultural and demographic changes took place that apparently laid the foundation for the subsequent development of farming during the Neolithic. The last food-collecting peoples who lived in the Levant are known as the Natufians. They lived between 10,000 and 8,500 B.C. along the eastern Mediterranean coastal plain, in the Galilee, and along the Jordan river valley. They harvested wild stands of cereals and had developed a special tool kit that included flint sickle blades for this purpose (Figs. 4, 5). Earlier food-collectors in the region, the Kebarans, may also have eaten cereal foods, since their campsites have produced grinding tools. The Natufians differed, however, not only in their use of sickles, but also in the construction of pits for food storage and in their form of settlement: many sites, both caves and open villages, contain circular houses, and bear evidence of year-round occupation. In one sense the Natufians did not differ from their predecessors: they still hunted wild gazelle and deer, as shown by the large numbers of bones of these animals at their habitations.

The first known domesticated cereals in the Levant have been recovered from Nahal Oren on the coastal plain and Jericho in the Judaean desert; both are assigned to the Pre-Pottery Neolithic A (PPNA) period, dating between ca. 8,500 and 7,500 B.C. Rare seeds document the presence of domesticated strains



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Bone sickle haft (handle?) from the Natufian occupation at Kebara Cave. The dashed lines indicate the way in which flint sickle blades would have been set into a groove on the haft. Length: ca. 38 cm. (After Henry Hodges, Technology in the Ancient World *1970, and David Oates and Joan Oates,* The Rise of Civilization *1976; drawn by Denise Hoffman)*

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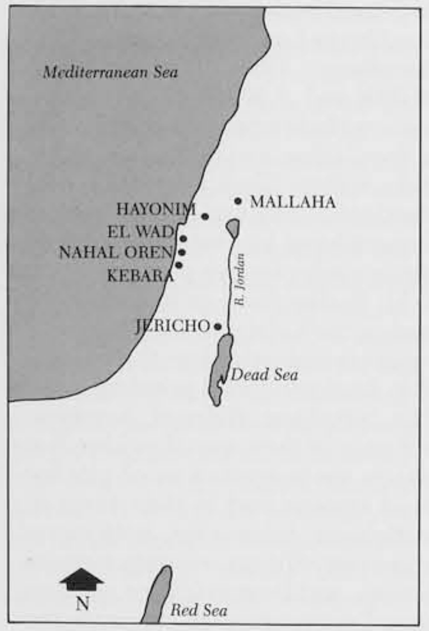
El Wad Cave, on the left, is a coastal Natufian site on Mount Carmel. (Photo courtesy of Prof. Ofer Bar-Yosef)



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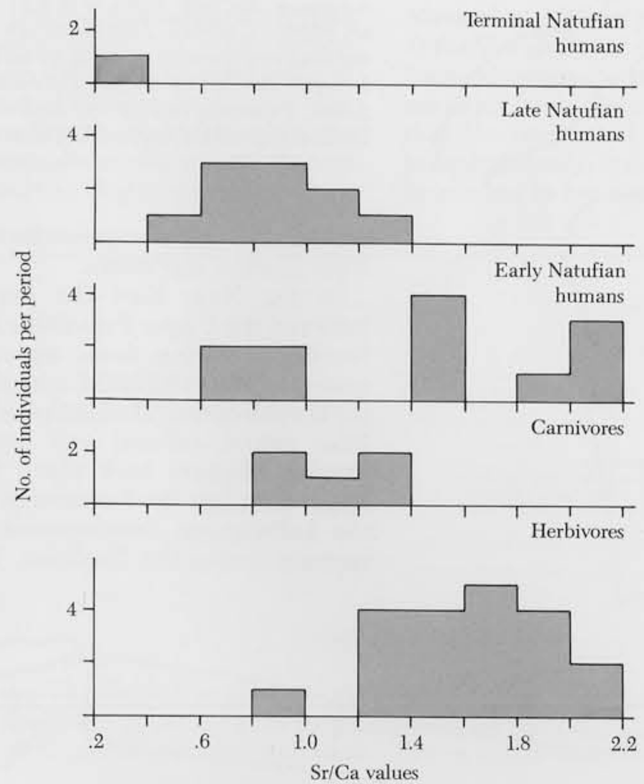
Map showing locations of archaeological sites mentioned in the text. (Drawn by Gil Stein)



8
Sr/Ca of human skeletons from Mallaha. (Drawn by Gil Stein)

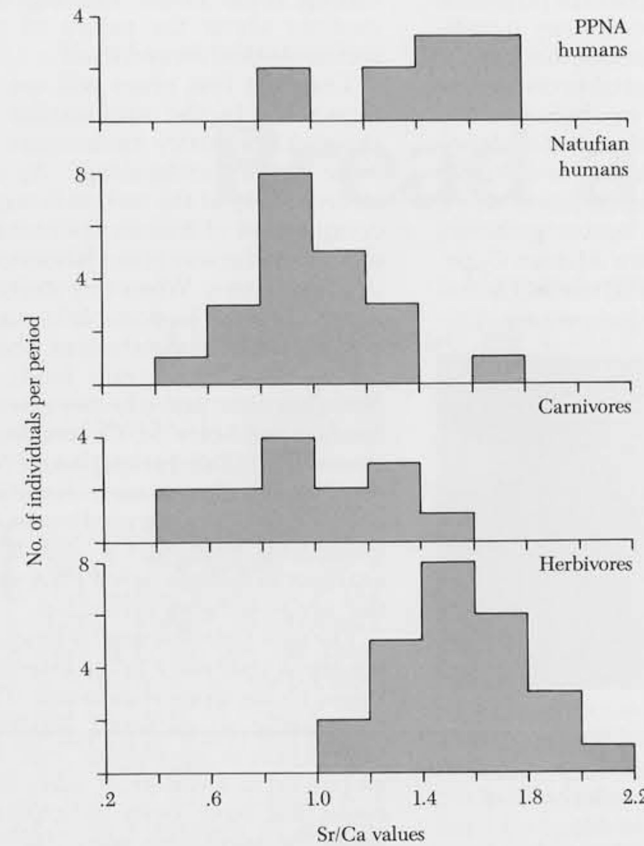
of wheat, barley and lentil, together with wild plants including cereals. There is, however, no archaeological evidence for a change in the pattern of animal exploitation. PPNA people continued to hunt gazelle and deer, much as had the Natufians and the Kebarans before them. It is not until ca. 7500 B.C., at sites assigned to the Pre-Pottery Neolithic B (PPNB) horizon, that there is a clear shift in the faunal remains from available game to domestic sheep and goat (see Stein in this issue).

Natufian archaeological sites in the Levant provide a case study of how dietary reconstruction based on archaeological evidence may provide a picture of somewhat less than photographic clarity. In the early 1970s, C. Vita Finzi and Eric Higgs conducted a 'site-catchment survey' of the region: an attempt to reconstruct the subsistence resources utilized by prehistoric groups through a detailed environmental reconnaissance of the immediate regions in which they lived. On the basis of their analyses, Vita Finzi and Higgs grouped Nahal Oren, el Wad (Fig. 6), and Kebara because these were coastal habitations and therefore less likely to be dependent upon cereals, versus Hayonim Cave and Mallaha, inland sites closer to the wild habitat zone of the cereals and therefore presumably more dependent upon them (Fig. 7). This classification doesn't quite fit with the evidence of the tool-kits, however, since the sickle blades so closely associated with cereal gathering are healthily represented in both the Nahal Oren and el Wad assemblages.

In 1981, I began an extensive series of Sr/Ca analyses from coastal and inland Natufian sites. Would Sr/Ca and $\delta^{13}C$ studies support site-catchment analyses? The data on the Sr/Ca of Natufian humans and fauna from Hayonim Cave were presented in Figure 2. As previously mentioned, the values fell midway between those of herbivores and carnivores. Indeed, the human values are nearly identical to the midpoint between these two classes of fauna. Surprisingly, a similar pattern was observed for the coastal sites of El Wad and Kebara.

These results suggested that the dietary variability hypothesized by the 'site-catchment' analysis was not supported. That is, the diets of the inland Hayonim Cave Natufians appear to be indistinguishable from those at the sites of El Wad and Kebara on the margin of the coastal plain. But one complication remains: could marine foods be causing a 'false positive' result? One possibility is that coastal individuals ate less cereal foods but more marine foods than inland dwellers, resulting in similar Sr/Ca despite different diets. To answer this, the carbon isotopes would be useful. Results so far suggest that marine foods were insignificant in the diets of both coastal and inland Natufians: carbon isotopic measurements of the El Wad and Hayonim Cave humans examined so far fall squarely in the very negative C_3 range. This result still requires confirmation.

If Natufian diets do not vary on the basis of the hypothesized catchment differences, is it possible that they changed through time? At Mallaha I examined Early, Late, and Terminal Natufian individuals separately (Fig. 8). Here a clear pattern emerged of variable but relatively high values for the Early

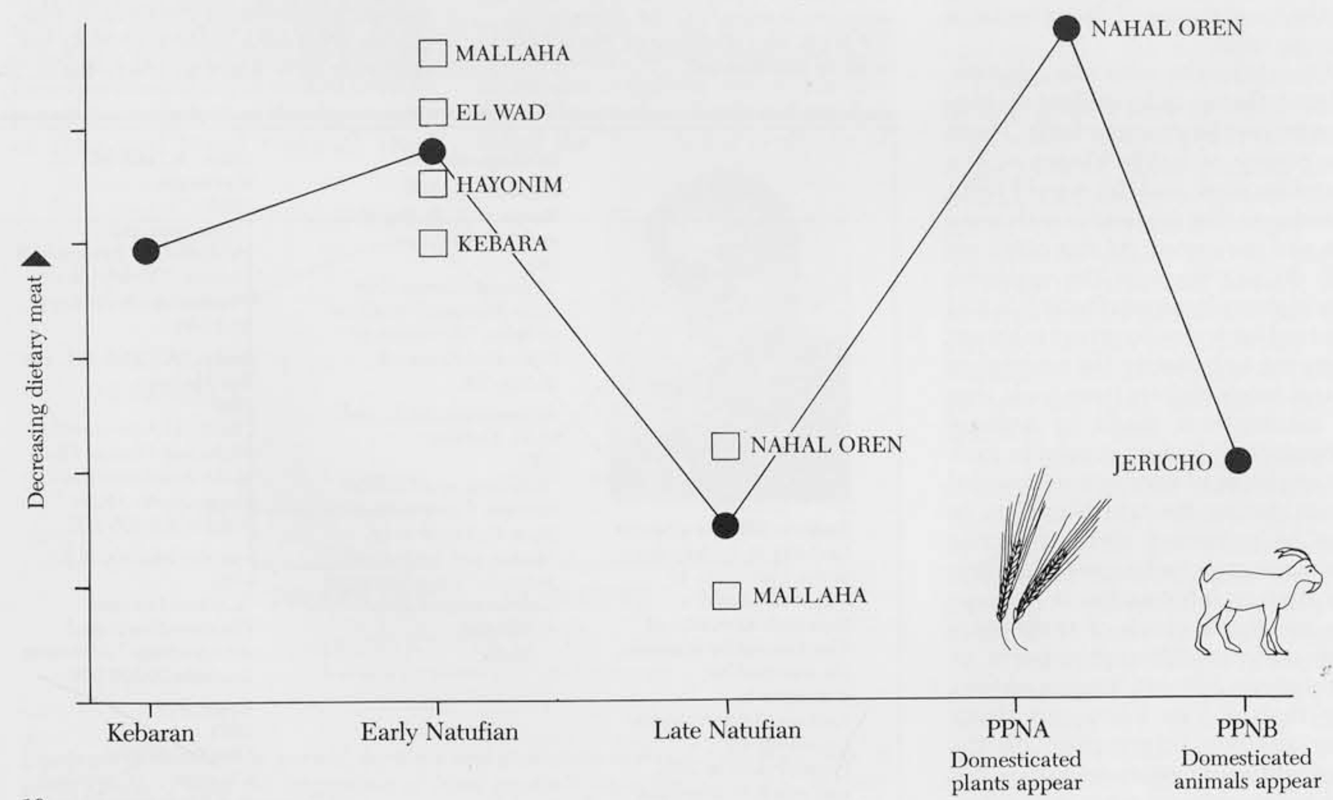


9
Sr/Ca of human skeletons from Nahal Oren. (Drawn by Gil Stein)

Natufian when compared to the Late Natufian. Early Natufian individuals, as at Hayonim, El Wad, and Kebara, had Sr/Ca values midway between that of herbivores and carnivores, while the Late Natufian individuals had values considerably shifted toward the carnivore side of the scale. A similar phenomenon was seen at the coastal site of Nahal Oren, where both late Natufian and PPNA skeletons were available. Here, as at Mallaha, it is apparent that the late Natufians depended rather heavily on meat foods.

The evidence from both Nahal Oren and Mallaha suggests a *decrease* in dietary cereal and/or vegetable foods in the late Natufian; however, this phenomenon may have been rather short-lived. At Nahal Oren, a return to higher Sr/Ca values was seen in the PPNA human skeletons (Fig. 9).

The pattern of dietary Sr/Ca change in the region is summarized in Figure 10. The results group Hayonim Cave, El Wad, Kebara, and the early Natufian skeletons from Mallaha: all specimens that



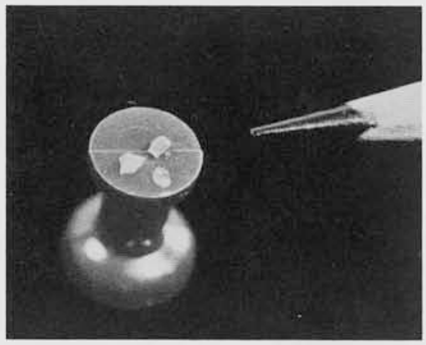
10
Graph showing the changing proportion of meat to vegetable food in the diet of groups in the Levant during the Epipaleolithic and Neolithic periods. Open squares indicate the values for specific sites; filled circles indicate the mean values of meat consumption for all sites in a given period. (Drawn by Gil Stein)

date from the early part of the Natufian. The two skeletal samples from Nahal Oren and Mallaha that date from the later part of the Natufian both indicate a reduction in cereal/vegetable foods. With cereal domestication in the PPNA, cereal/vegetable use recovers to the Early Natufian levels.

One important conclusion we can draw is that no evidence exists for nutritional stress in the period preceding domestication—in fact, meat protein may, if anything, have increased during this period! While this result was, to say the least, unanticipated, there is perhaps an explanation. Archaeologists have long discussed the origins of farming in terms of disequilibria, but have not considered the possibility that the dietary disruption was limited to the foods that were ultimately domesticated. Perhaps there was a disruption in the supply of cereal and/or other vegetable foods in the late stages of the Natufian, and the domestication of this resource was an effort to maintain the supply in the face of a shortage. The subsequent domestication in the PPNA then resulted in the re-establishment of the importance of these foods in human diets.

One difficulty with this interpretation is that no independent archaeological evidence exists for it. There are plenty of sickle blades at late Natufian sites, and this would seem to indicate that grasses/cereals were cut and harvested. At this point we still do not know if the apparent discrepancy between the Sr/Ca and the tool kit is due to errors inherent in trying to quantify the amount of cereal foods in diets from tools, due to assumptions made by archaeologists who had no reason to look for evidence of a reduction in cereal foods during the late Natufian, or due to unknown defects in the archaeometric techniques. Conflicting dietary information is perhaps the inevitable result of techniques that address different aspects of subsistence. Site catchments surveys like that of Vita Finzi and Higgs may provide information on the *availability* of certain resources, but not necessarily on what was eaten. Similarly, tools like the Natufian sickle blades may tell us about what was *harvested*, or even *prepared*, but again, a long chain of inference must be used to make any quantitative statements about diet.

Similar uncomfortable discrepancies are turning up between the conventional and chemical evidence for maize-eating in the New World, and seasonal dependence upon marine foods by hunter/gatherers of the southwestern African Cape. As may be expected, the Sr/Ca and carbon isotope techniques are stimulating some rather exciting discussions about the nature of the archaeological record itself.



11
How much bone is required for elemental analyses? Using modern instruments, it is possible to work with tiny samples. In this photograph, a typical sample, weighing only 4 mg, is shown sitting on the head of a thumbtack. By using such samples, the damage to the gross morphology of the whole bone is minimized.

The next few years will see an expansion in the application of skeletal chemistry techniques to Near Eastern archaeology. An extensive study of the carbon isotopic composition of human skeletons is already underway in our laboratory in Cape Town. When this study is complete it will be possible to make a more definitive statement about the question of marine foods in Natufian diets, and whether marine foods complicate Sr/Ca measurements. The observation that PPNA diets are similar to early Natufian ones also needs to be confirmed by expanding both Sr/Ca and $\delta^{13}C$ analyses to include new PPNA sites that are now being excavated.

The new paleodietary techniques are also a testimony to the essential role of archaeological museums. The data being so gathered illustrate that museum specimens can be employed in a variety of ways that could not have been anticipated when the specimens were discovered. Far from the quaint notion of forgotten specimens in a dusty attic, museum collections continually supply us with new information as we discover new ways to study them.

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