

Diet and the Evolution of Modern Human Form in the Middle East

MARGARET J. SCHOENINGER

Department of Cell Biology and Anatomy, John Hopkins University School of Medicine, Baltimore, Maryland 21205 and Department of Earth & Space Sciences, University of California at Los Angeles, Los Angeles, California 90024

KEY WORDS Strontium analysis, Diet, Modern humans

ABSTRACT Fully modern human form, more gracile than the antecedent archaic modern form was evident by 30,000 years ago. One hypothesis to explain this decrease in skeletal robustness is that change occurred in human diet and that this change was associated with a decrease in activity levels required in both individual and group behavior. It is possible to study dietary change directly using trace element analysis of strontium levels in bone. The amount of strontium in bone reflects the amount of strontium in diet. Since plants contain higher levels of strontium than do animal soft tissues, the level of bone strontium will differ between individuals according to the proportion of plant and animal products in their diets. In this study the ratio of strontium:calcium in human bone to strontium:calcium in faunal bone is compared for samples of archaic modern humans (from Mugharet et Tabūn, Mugharet es-Skhūl, and Jebel Qafzeh) and fully modern humans (from Mugharet el-Kebara and Mugharet el-Wad) from Israel. The use of a ratio controls for potentially unequal strontium levels in soils at different sites and for different diagenetic histories between sites. The results of the analysis are internally reliable, reflecting bone strontium levels rather than technique error; therefore, they reflect diet.

It appears that a change occurred in the amount of animal protein in the diet of humans but that this change occurred almost 20,000 years after the first appearance of skeletally modern humans. These results refute the hypothesis that the morphological transformation to modern human form occurred as a result of behavioral changes involved in obtaining previously unused foods. If any decrease in human activity level occurred between archaic modern and fully modern humans, this decrease probably was due to alterations in the means of procuring or processing the same kinds of foods that had been utilized earlier in time.

The general sequence of fossil forms documenting the later course of human evolution has been known for many years. The earliest members of our species appeared about 100,000 years ago, yet these archaic humans, colloquially referred to as Neandertals, are morphologically distinct from fully modern humans. Although the differences are no longer considered major (due in part to the work of Straus and Cave, 1957), the combination of skeletal traits seen in the earliest humans is outside the range of variation and covariation

apparent today. In general, the physical changes that took place in the past 100,000 years involved an overall reduction in skeletal robustness. Neandertals are considerably more robust in both their cranial and post-cranial skeleton than are present-day humans (Trinkaus, 1976, 1977, 1978a, 1978b, 1980; Smith and Ranyard, 1980; Wolpoff, 1980; and others).

Received March 9, 1981, accepted August 18, 1981.

Even though these facts are commonly accepted, the adaptational reasons for the appearance of fully modern human form are still unclear. Most explanations for the difference in skeletal robustness between Neandertals and modern humans have incorporated a decrease in activity requirements through time (Brace, 1964, 1979; Binford, 1968a; Brose and Wolpoff, 1971; Trinkaus, 1976, 1977; Wolpoff, 1980). The specific hypotheses have included: (1) the development of food processing tools and techniques (Brace, 1962, 1979; Binford, 1968b; Brace and Ryan, 1980), (2) the use of more efficient tools (Brose and Wolpoff, 1971; Wolpoff, 1980), and (3) a change in social organization (Binford, 1968a). Although there are studies in progress that may soon provide the information necessary to test the first two hypotheses (note in Jelinek, 1975), ascertaining function and efficiency from tool form is still a problem that has several competing solutions (Bordes and Bourgon, 1951; Bordes, 1962, 1968; Oakley, 1964; Bordes and de Sonneville-Bordes, 1970; Mellars, 1970 and citations therein). Recent microscopic analyses of edge wear (Keeley, 1977; Keeley and Newcomer, 1977; Cahen et al., 1979) and studies on tool combinations (see Binford and Binford, 1966; Binford, 1968b) have not been applied widely enough to determine whether a change occurred in either tool function or tool efficiency before the appearance of modern humans.

In the third hypothesis, Binford suggests (1968a) that a change in social organization occurred as the result of a shift toward dependence on fewer, larger species, and that a significant adaptation to this shift was group hunting. One problem with this argument is that the evidence for such a change in hunting pattern is not very strong for areas outside Europe. In the Middle East, for example, published faunal lists suggest long-standing dependence on varying proportions of three ungulate genera: *Bos*, *Dama*, and *Gazella* (Garrod and Bate, 1937; Hooijer, 1961; Perkins, 1964; Flannery, 1965, 1969; Bouchud, 1969, 1974; Davis, 1977). Therefore, it does not seem likely that in the Middle East there was a change in social organization for the reason that she proposes.

The general explanation of a decrease in activity requirements is still reasonable, however, and this study tests an alternative hypothesis. Although, this investigation is restricted to one area of the world, the Levant, results from future studies on other geographical areas will allow more general conclusions.

It is proposed that the decrease in robustness characterizing modern humans in the Middle East occurred in response to changes in food procurement activities. Changes in these activities would have altered the developmental environment and/or selective forces affecting individuals, thereby resulting in an overall decrease in skeletal robustness. Food procurement activities are an obvious focus for study because they are so important for survival. While the activity of the individual, or group, is the actual focus of our interest, such behavior is impossible to observe directly. Therefore, other aspects of food procurement must be used to gain information about behavior, i.e. the food actually obtained or the tools used in obtaining and processing the food. For the reasons mentioned above, information retrieved from studies of tools has been inconclusive. In this project, the focus is on the food as evidenced by corresponding bone strontium levels.

Generally, the earliest members of our species are considered to have been hunters (Howell, 1965; Binford and Binford, 1966; Binford, 1968a; Brace, 1979; Brace and Ryan, 1980; for an extreme view see Geist, 1981). No one, however, expects that these people subsisted totally on animal products. Stones used for grinding seeds have been recovered from 50,000 year old sites and the use of processed plant products probably began even earlier (Kraybill, 1977). It is accepted, however, that through the course of human evolution, an increase in dependence on plant materials occurred even though the magnitude and timing of this dietary change remain unknown. Since it could be argued that a shift toward an emphasis on procuring plant material would demand lower activity levels per individual, the purpose of this project is to determine if a dietary change occurred concomitantly with the decrease in human skeletal robustness.

To obtain information on diet, I employed the method of trace element analysis for strontium levels in bone. Bone strontium levels reflect the amount of dietary strontium (Alexander et al., 1956; Comar et al., 1957; Comar and Wasserman, 1964). Diets containing meat provide less strontium than do diets containing mostly vegetable materials (see references in Schoeninger, 1979a). This method has been applied to pre-human and human populations with varying degrees of success (Brown, 1974; Gilbert, 1975; Szpunar, 1977; Wessen et al., 1977; Boaz and Hampel, 1978; Elias, 1980; Schoeninger, 1980). It has been demonstrated, however, that with the

application of certain controls, the method provides a means of detecting if and when changes occurred in the amount of meat included in human diets (Schoeninger, 1979a, b, 1980). The controls that were developed for this project are discussed briefly in the Materials and Methods section. A more thorough documentation will appear elsewhere (Schoeninger, 1980 and in preparation).

The method of trace element analysis for bone strontium levels is applied in this project to bone samples from Levantine sites containing humans with non-modern skeletal features and sites containing humans of modern form. The results are compared between sites in order to determine when changes occurred in the dependence on vegetable materials. The results of this analysis are then considered in relation to evidence derived from the archaeological record.

THE LEVANT

Several relatively large series of human skeletons have been discovered in the Levant. The advantages of these skeletal series are: (1) that they are from a relatively restricted area geographically, (2) the directors of the excavations saved other animal material as well as the human skeletons, and (3) the skeletal material was easily accessible since much of it is stored in London, Paris, and Cambridge (Massachusetts). The series used in this project included three sites that have produced archaic modern humans: Mugharet et Tabūn (McCown and Keith, 1939), Mugharet es-Skhūl (McCown and Keith, 1939), and Jebel Qafzeh (Neuville, 1951; Vandermeersch, 1977).

Ever since their discovery, there has been a great deal of controversy concerning the human skeletal remains from these three caves. Initially, investigators believed that the skeletons from Tabūn and Skhūl were contemporaneous (Garrod and Bate, 1937). Partially because of this and because of the morphology of the Tabūn I skeleton, it was concluded that although the individuals at the two caves were similar to modern *Homo sapiens*, they could not be ancestral to them (McCown, 1936; Keith and McCown, 1937; McCown and Keith, 1939). Others decided that some of the remains at Skhūl were hybrids of modern *Homo Sapiens* and Neandertals (Ashley-Montagu, 1940; Dobzhansky, 1944; Hooton, 1946; Weckler, 1954). Another opinion was that "some of the Mt. Carmel inhabitants appear to represent a transitional stage leading from pre-Mousterian *H. sapiens* to a

later differentiation both of the definitive species *H. neanderthalensis* and of *H. sapiens* of the modern type" (Clark, 1964:73).

A re-evaluation of the stratigraphy in the caves led to general acceptance that the hominid bearing level at Skhūl (level B) was about 10,000 years younger than the main hominid bearing level at Tabūn (level C) (Howell, 1958, 1959; Higgs and Brothwell, 1961). Garrod (1962) in a reversal of her earlier opinion agreed that the Skhūl deposits were younger than the deposits from Tabūn C although she maintained that the time differential could not have been as great as 10,000 years.

Even after accepting the age difference, some authorities still believed that certain of the skeletal remains were hybrids (Thoma, 1965; Ferembach, 1972) or that there had been replacement of Neandertals by modern humans (Brothwell, 1961). Howell (1951, 1958) concluded that the individuals at Skhūl and Qafzeh were more similar to the modern form than was the Tabūn skeleton but that there was only one taxon represented throughout all of the Middle Eastern sites.

The relative ages of these sites remains controversial (Haas, 1972; Farrand, 1972, 1979; Jelinek, 1975; Bada and Helfman, 1976), but the most likely temporal relationship is that seen in Figure 1. Evidence for this relation comes from: (1) the stratigraphy that was studied during the recent re-excavation of the Tabūn by Jelinek (Jelinek et al., 1973), (2) the sedimentology of Tabūn and Qafzeh (Jelinek et al., 1973; Farrand, 1979), and (3) a study of the artifacts from all three sites by Jelinek (personal communication). The work of Jelinek also indicates that the human adult female from Tabūn came from level D rather than from level C as first believed (Garrod and Bate, 1937), making this individual even older relative to Skhūl than previously suggested (Howell, 1958; Higgs and Brothwell, 1961). Some 40,000 years separate the people who inhabited Tabūn during the deposition of level D from those at Skhūl and Qafzeh.

Although the Tabūn skeleton has been regarded as similar to European Neandertals (McCown and Keith, 1939), both the Skhūl and Qafzeh specimens have been reported to be modern from the neck down (Brace, 1964; Vandermeersch, 1972, 1977; Trinkaus, 1976, 1980; Trinkaus and Howells, 1979; Wolpoff, 1980). Recently, however, Lovejoy and Trinkaus (1980) have stated that the Skhūl IV tibia is Neandertal-like rather than modern in its degree of robustness. In addition, it is agreed among the authors cited above that the

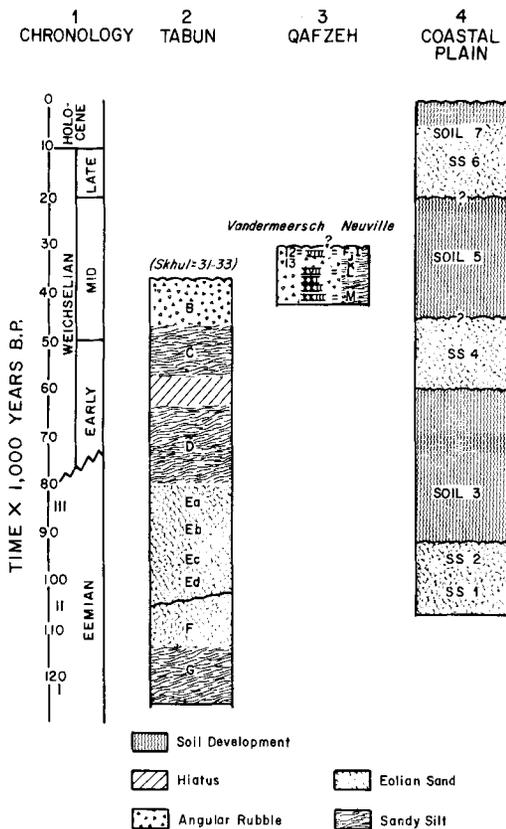


Fig. 1. Relative stratigraphic positions of Mugharet el-Tabun, Mugharet es-Skhul, and Jebel Qafzeh (adapted from Farrand, 1979). The hominid-producing layer at Skhul is shown above the Tabun stratigraphic column. The dates ($31-33 \times 10^3$ years BP) are from amino acid racemization and are similar to C14 dates on Tabun B. Based on artifact similarity, Jelinek (personal communication) believes that Skhul is near in time to the hominid bearing layer at Qafzeh (layer XVII of Vandermeersch, 1977 and layer L of Neuville, 1951). Also, the adult female skeleton from Tabun (Tabun I) probably came from level D rather than C (Jelinek, personal communication). Therefore, Tabun I is 30-40,000 years earlier than the layer that produced the Skhul and Qafzeh hominid sample.

skeletons from Skhul and Qafzeh are more robust than are present-day humans. Therefore, in this project the Skhul and Qafzeh individuals are considered "archaic modern" in the sense suggested by Howells (1974) for the Skhul sample. Bone samples were taken from all human specimens for which fragments were available. Faunal bone samples were taken from all levels within each site where bone was available even though human bone was not discovered in all levels.

Three sample sets were also taken from two sites that have produced skeletons of unquestionably modern humans; for these the adjective "archaic" can be dropped. The earliest samples come from level C at Mugharet el-Kebara (Turville-Petre, 1932). The tool industry found within the level suggests that these skeletons are probably around 15,000 years old (Henry and Servello, 1974). They may be somewhat older (Bar-Yosef, 1970). The humans from this level constitute the earliest sample of fully modern humans that has been recovered in Israel (Arensburg, 1977). A second set of skeletons used in this project came from a more recent level (level B) in the Kebara cave (Turville-Petre, 1932) and a third came from level B at Mugharet el-Wad (Garrod and Bate, 1937). Both level B at Kebara and level B at el-Wad have been dated to about 10,000 years before present (Henry and Servello, 1974). These sites precede the development of agriculture (Neolithic period) and post-date the Upper Paleolithic period in Israel. They have been called Epipaleolithic (Bar-Yosef, 1970), which is similar but not strictly equivalent to the Mesolithic period in Europe (Braidwood and Willey, 1962). As was true for the earlier sites, bone samples were taken from all human specimens and from faunal specimens in all levels. The human skeletons were very fragmentary; therefore, sexing and aging (beyond the general category 'adult') were impossible. Only adults were sampled for trace element analysis.

MATERIALS AND METHODS

The empirical and technical aspects of the estimation of diet using strontium levels in bone have been discussed elsewhere (Schoeninger 1979a,b). In sum the method depends on the fractionation of strontium through the tropic system (Odum, 1951; Bowen and Dymond, 1955; Vose and Koontz, 1955; Comar et al., 1957; Ophel, 1963) and partitioning of strontium within the tissues of individual animals (Comar et al., 1957; Likins et al., 1960, 1961; Neuman et al., 1963; Comar and Wasserman, 1964; Schroeder, et al., 1972). Due to differential strontium uptake by plants versus animals (Vose and Koontz, 1952; Bowen and Dymond, 1955; Comar et al., 1957; Schroeder et al., 1972), complete herbivores should ingest relatively large amounts of strontium. Because less than 1% of the body's strontium is stored in soft tissues (Comar and Wasserman, 1964), complete carnivores should ingest much lower amounts of strontium than do herbivores.

Since 90% of the body's strontium is stored in bone, measurable amounts of strontium should be found in bone of both carnivores and herbivores. It follows that herbivore bone contains a higher concentration of strontium than is found in carnivore bone. The analysis of a Pliocene vertebrate fauna from a single quarry in Knox County, Nebraska by Toots and Voorhies (1965) produced results that supported this expectation. My own analysis of individuals of a modern fauna from one geographically restricted area in Iran produced similar results (see Table. 1).

Table 2 presents the human and other mammal bone samples that were taken for trace element analysis in this project. For the human skeletons, bone samples were taken from bone fragments associated with the skeleton. Because the analytical techniques used in this

project are destructive, human skeletons were not sampled if they were represented by complete bones or skulls alone. For the other mammalian skeletons, bone samples were taken from all levels within each site without regard for bone type.

The use of different bones in this analysis should not affect the final results. Several reports have concluded that the distribution of strontium within and between bones of a single individual varies within the limits of measurement error (Hodges et al., 1950; Turekian and Kulp, 1956; Thurber et al., 1958; Yablonskii, 1971, 1973; Bang and Baud, 1972). My own analysis on samples taken from the skeleton of one rabbit supports the earlier reports (Mean = 233 ppm strontium; SD = 21, V = 9, N = 14). These results are presented in Figure 2.

In addition to the prehistoric samples, tibiae from nineteen modern mink skeletons were analyzed. All of these animals were raised at the Michigan State University mink farm and were fed the same diet throughout life. This analysis was performed in order to estimate the amount of variation in bone strontium levels that could be expected to occur in the absence of dietary differences. The results are presented in Figure 2.

Sample Preparation and Analysis

Samples were prepared for analysis as described in Schoeninger (1980). First, all samples were cleaned. The samples from

TABLE 1. Bone strontium levels in modern Iranian animals¹

Fauna	Bone strontium (ppm)	N
<i>Ovis aries</i>	1508	1
<i>Lepus capensis</i> (UMMZ 122382)*	652	1
<i>Sus scrofa</i>	326	1
<i>Canis aureus</i> (UMMZ 122373)*	435	1
<i>Felis chaus</i> (UMMZ 122370)*	181	1

¹ Analysis by neutron activation.

*University of Michigan Museum of Zoology number.

TABLE 2. Samples analyzed in this project

Site	Date of hominid bearing layer (years B. P.)	No. of humans sampled	No. of faunal samples	References
Mugharet el-Wad Level B	10,000	21	4	Garrod and Bate, 1937
Mugharet el-Wad Levels B-G	-	21	18	Garrod and Bate, 1937
Mugharet el-Kebara Level B	10,000	6	2	Turville-Petre, 1932
Mugharet el-Kebara Level C	15,000	9	2	Turville-Petre, 1932
Mugharet el-Kebara Total	-	15	10	Turville-Petre, 1932
Jebel Qafzeh Level XVII=L	30,000-35,000	5	1	Neuville, 1951 Vandermeersch, 1977
Jebel Qafzeh Total	-	5	8	Neuville, 1951 Vandermeersch, 1977
Mugharet es-Skhūl	30,000-35,000	5	2	McCown in Garrod and Bate, 1937
Mugharet et-Tabūn Level D	70,000	1	2	Garrod and Bate, 1937
Mugharet et-Tabūn Levels B-Eb	-	1	10	Garrod and Bate, 1937

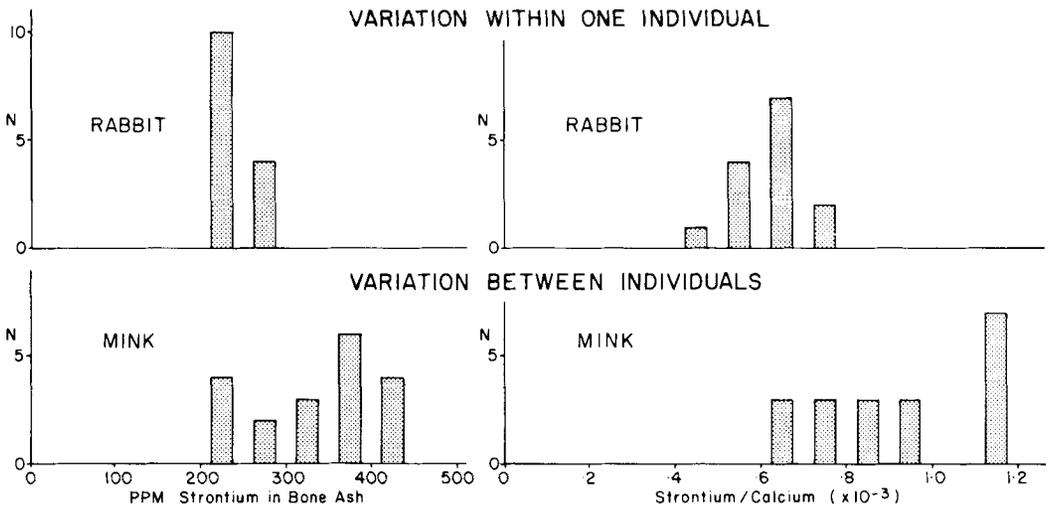


Fig. 2. Variation in bone strontium levels within one individual (rabbit $N = 14$, $\bar{X} = 233$ ppm Sr; $SD = 21$; $V = 9$) compared with the variation among 19 individuals all of whom were fed the same diet (mink, $N = 19$, $\bar{X} = 337$ ppm Sr; $SD = 72$; $V = 22$). These results indicate that the choice of

bone for analysis should not affect the final results. In addition, a coefficient of variation of approximately 20% and a range of 250 ppm strontium is expected in a human population if all individuals ingested roughly the same diet.

Tabūn, Skhūl, and Qafzeh were freed of matrix using an air-abrasive tool. Following this, all samples were cleaned ultrasonically with de-ionized water. This step removed any soil still adhering to the sample and also removed the powder used in the air-abrasive unit.

All samples were analyzed by atomic absorption spectrometry (AAS) and a subset was also analyzed by neutron activation analysis (NAA) as a check for random error in the atomic absorption results (Morrison, 1976). The samples were ground and ashed as described in Schoeninger (1979a, 1980) and then were prepared for AAS following the dissolution procedure suggested by Szpunar (1977; Szpunar et al., 1978). A check for complete dissolution was performed on a subset of the samples. The filter papers used in the final transfer of the sample were ashed and then analyzed by neutron activation in order to ascertain whether any bone was retained on the paper. Only silica and other soil elements remained on the filter paper; therefore, it is assumed that the bone was completely dissolved and passed through the filter paper.

In the sample preparation for AAS both lanthanum and potassium were added in excess in order to offset ionization and interference from phosphate (Perkin-Elmer, 1971). The analysis for strontium was performed using the method of standard addition. Three subsamples were

taken from each dissolved bone sample. No strontium was added to the first subsample (+ 0 ppm Sr). Enough strontium was added to the second subsample to raise its concentration one additional part strontium per million parts liquid (+ 1 ppm Sr). Enough strontium was added to the third subsample to raise its concentration two additional parts strontium (+ 2 ppm Sr.). The use of standard addition was necessary because the addition of lanthanum cannot completely offset interference from the extremely high level of phosphate in bone (Helsby, 1974). Also, since in the method of standard addition, the bone of the unknown sample acts as its own standard, the problem of strontium contamination in commercially prepared reagents is avoided (see Szpunar, 1977). The samples were analyzed on a Perkin Elmer 460 atomic absorption spectrometer using wavelength = 460.7 nm, fuel (acetylene) at 32 psi, support (nitrous oxide) at 35 psi, lamp current at 15 mA, and the burner head centered horizontally and at position #7 in the vertical plane. The final sample dilution was 1:100. The results of the three subsamples of each original bone sample (the first contained + 0 ppm Sr; the second contained + 1 ppm Sr; the third contained + 2 ppm Sr) were plotted in order to calculate the concentration in the original bone sample. Only samples in which the three subsample values were very close to a

straight line were accepted (coefficient of determination = 0.98-1.00). This restriction assured that error in prediction of the bone strontium level from a regression line was minimal (Sokal and Rohlf, 1969; Mueller et al., 1970). The value of the x-intercept was multiplied by the final dilution value (100) and divided by the sample weight (around 0.5 gm). The result of this calculation is the concentration of strontium in the original ashed bone sample. A set of internal standards of cleaned, homogenized cow bone (analyzed twice within each run) had a level of precision of $\pm 6\%$ of the mean. Fourteen rabbit samples, from one individual, produced a range of $\pm 15\%$ of the mean. Based on these two estimates, only samples of prehistoric bone that were analyzed two or more times and that had results within $\pm 10\%$ of their own mean were accepted as reliable.

The analysis for calcium was performed without standard additions since a much greater dilution (1:62,500) could be used in order to avoid problems of phosphate interference. The AAS parameters for calcium analysis were: wavelength = 422.7 nm, fuel (acetylene) at 32 psi, support (nitrous oxide) at 35 psi, lamp at 10 mA, and the burner centered in the horizontal plane and at position #7 in the vertical plane.

A subset of the samples were prepared for analysis of strontium by neutron activation following Schoeninger (1979a). The radioisotope used to calculate the strontium concentration in the samples was strontium-85 ($T = 62.5$ days), which emits gamma rays with an energy of 514 keV. It had been determined previously that the shorter lived isotope Sr-87m produced unreliable results (Schoeninger and Peebles, in preparation). The data reduction was performed using a Gaussian fit program (compare Schoeninger, 1979a) used by the Phoenix Memorial Laboratories at the University of Michigan.

The two analytical techniques produced very similar results (see Fig. 3). Even so, two outliers (open circles in Fig. 3) are immediately apparent. In both cases in the AAS sample preparation, there was a great deal of soil remaining on the filter paper following the final sample transfer (0.02 gm and 0.09 gm in samples that weighed 0.5 gm originally). In all other samples the weight of soil remaining on the filter paper was less than 0.005 gm. The soil was not removed during sample preparation for NAA, therefore, the most likely explanation for the high NAA result in these

two samples is that certain elements in soil (especially zinc and iron) expanded the signal at 511 keV to the point where the Gaussian fit program could not separate the 511/514 couplet effectively. Instead, an incorrectly high level of strontium (at 514 keV) was calculated. If these two samples are eliminated, the rank-order correlation coefficients between the two sets are very high. Spearman's Rho has a value of 0.96, which indicates that the overall pattern of ranks is very similar. Kendall Tau-B, which is based on the relative ordering of pairs of samples, is equal to 0.85, which suggests that the position of one sample relative to other samples is also stable. Based on this confirmation, the set of results produced by AAS was accepted as internally valid. Since the results are accepted as reflecting bone strontium levels rather than measurement error, they can be assumed to reflect dietary intake levels of strontium as long as any diagenetic effect can be controlled.

Diagenesis

In addition to the trace element analysis, x-ray diffraction patterns were made on samples of unashed, ground bone, both human and faunal, from each site. These patterns were used as a check for diagenesis (postmortem chemical change in bone).

Because strontium is a 2+ cation situated well within the crystal lattice in mature bone mineral, it is not subject to facile exchange with ions in solutions surrounding bone (Neuman et al., 1963). Even so, given certain conditions of groundwater and temperature, the dissolution of part of the original bone mineral might be possible. If the remaining bone mineral is intact, the amount of strontium per unit of bone mineral should be unaffected and the strontium/calcium ratio should remain the same.

If, however, this dissolution were accompanied by a precipitation of nonbiological (geological) apatite or of carbonate, the strontium/calcium ratio would not necessarily remain the same. In vitro studies of apatite synthesis support the idea that the slower the rate of crystal growth and the larger the final crystal size, the lower the concentration of strontium in the final product (Likins et al., 1960, 1961; Neuman et al., 1963). Geological apatite, a slow growing, large crystal, is reported to have very low concentrations of strontium (Noll, 1934).

The difference between these two forms of apatite is readily apparent in x-ray diffraction patterns. Patterns produced by geological

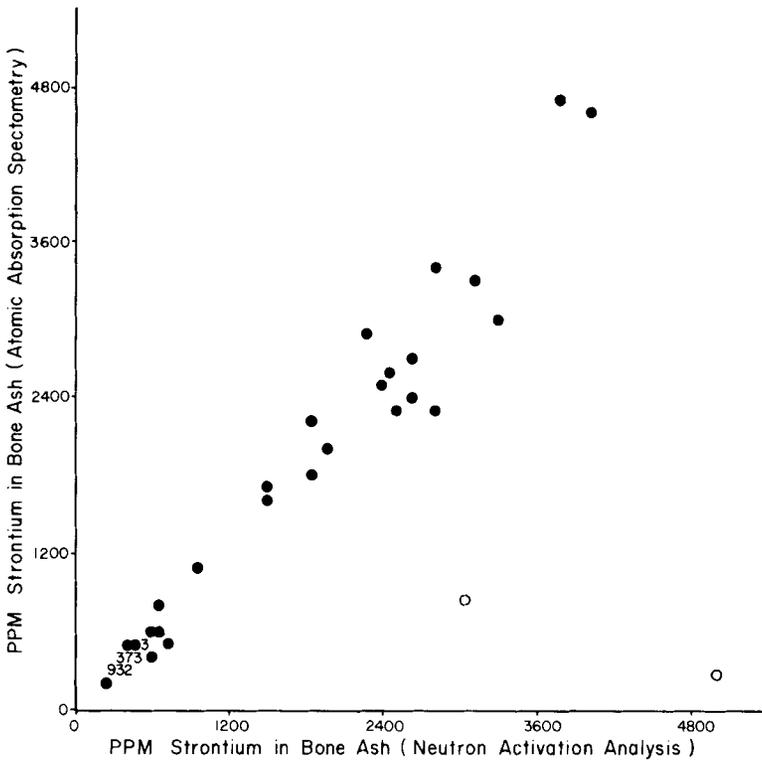


Fig. 3. Comparison of results of 58 bone samples analyzed by both neutron activation analysis and atomic absorption spectrometry. The two outliers (open circles) were heavily contaminated with soil, which disallowed proper separation of energy levels in neutron activation analysis and resulted in incorrect calculation of strontium levels. With these samples eliminated, Spearman's Rho equals 0.96; Kendall Tau-B equals 0.85. This indicates that

the overall pattern and the relative ordering of pairs is very similar. Therefore, random error can be considered minimal in the total sample set analyzed by atomic absorption spectrometry. For this reason, the set of results produced by atomic absorption spectrometry was accepted as internally reliable and reflect bone strontium levels rather than measurement error.

apatite have very high sharp peaks, especially in the area of 32° - 34° 2θ (see Fig. 4, synthetic hydroxyapatite at bottom of the same figure). Biological apatite, on the other hand, produces a more amorphous pattern, one that is similar to synthetic hydroxyapatite of small crystal size (see Posner, 1969 and Fig. 4, modern *Bos.*)

Since alteration of bone was considered to be a possible result of postmortem contact with groundwater, x-ray diffraction patterns were made on human and other animal bone from each of the sites.

RESULTS

The results of both the x-ray diffraction and the atomic absorption spectrometry are presented below. The x-ray diffraction patterns and their significance concerning diagenetic alteration of the bone are discussed first. Then,

the results of the atomic absorption spectrometry are considered both in relation to the diagenetic alteration and to diet.

X-ray diffraction patterns

As discussed above, x-ray diffraction patterns made on powdered bone samples should provide information about post-mortem chemical changes in bone mineral. Bone that has been altered may have a carbonate peak at 29° 2θ and peaks between 32° - 34° 2θ that are sharper than those produced by fresh bone.

All bone (both human and faunal) from one level within one site produced similar x-ray diffraction patterns. Yet, there are some major differences in the patterns from the different sites. In the sites of Skhul, Qafzeh, and especially Tabun, the bone appears to include

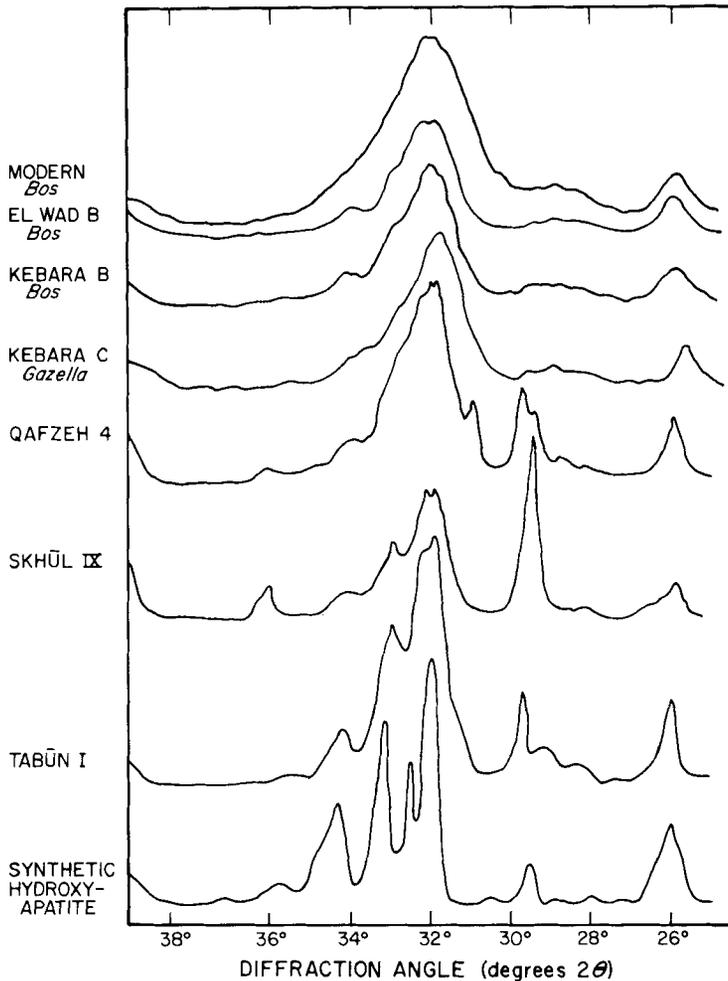


Fig. 4. X-ray diffraction patterns of unashed, ground bone from modern cow bone and from representative samples taken at each site studied in this project. The synthetic hydroxyapatite of large crystal size at the bottom is similar to geological apatite (from Posner, 1969). The patterns indicate that bone from the older sites of Qafzeh, Skhül and especially Tabün has been altered following burial. The sharpness and separation of four peaks in the area of 32° to 34° 2θ indicate that precipitation of geological apatite has occurred. The peak at 29° 2θ indicates that some precipita-

tion of carbonate has also occurred. Due to space limitations, only one pattern from each site is displayed, but, both human and faunal bone from the same level at each site produced the same pattern. For this reason, it can be assumed that both human and faunal bone have been altered equally. Therefore, even though the absolute amount of strontium may have changed, the relative position of human bone strontium to faunal bone strontium should be an indication of human diet.

an amount of geological apatite. The peaks around 32° 2θ are sharper than the more rounded curve that can be seen in the modern cow bone at the top of the figure. The bone from Kebara and el-Wad, on the other hand, produces x-ray diffraction patterns that are much closer to that of modern cow bone. It appears that little dissolution of the biological

apatite has occurred in the bone from Kebara and el-Wad or, perhaps more correctly, little precipitation of geological apatite has taken place.

In addition, the large carbonate peak around 29° 2θ , not present in modern cow bone, suggests that there has been some inclusion of carbonate during fossilization of bone at

Tabūn, Skhūl, and Qafzeh. Large amounts of carbonate are present in the soil at Tabūn and Qafzeh (Jelinek et al., 1973). Its presence at Skhūl is unknown because all the sediments were removed during the original excavation and no modern sedimentology could be done. From the accounts of the excavation of the site and the preparation of the skeletal material (McCown, 1937), however, one could guess that a substantial amount must have been present. This addition of carbonate in the bone samples, whether it is adhering to the apatite surface or is part of the crystal lattice, is another way that the bone has been altered chemically following burial. The more recent bone from Kebara and el-Wad does not include the carbonate peak.

These two kinds of post-mortem chemical changes, addition of carbonate and geological apatite, would be expected to alter both the absolute amount of strontium in bone mineral and the strontium/calcium ratio and there is evidence that this has occurred. The results of the trace element analysis of the fauna from different levels at Tabūn indicate that the more recent bone (level B) has higher amounts of strontium than the bone from the earlier levels (see Table 3). The same is true for the earlier levels at el-Wad (C through G) (see Table 4). It is possible that the environmental levels of strontium have increased through time. Diagenesis, however, appears to be a more probable explanation, since the direction of change is what would be expected if diagenesis were the cause. Precipitation of geological apatite should result in an overall decrease in the absolute amount of strontium in the strontium/calcium ratio. Other reports on fossil and modern bone indicate that diagenesis does not necessarily occur (Jaffe and Sherwood, 1951; Kochenov and Zonov'ev, 1960; Wyckoff and Doberenz, 1968; Parker and Toots, 1980) and, in fact, no trend is obvious in the fauna from Kebara (see Table 5).

The results discussed above do not mean that the bone strontium levels in these samples cannot be used to estimate diet, only that some correction factor must be applied. As noted previously in this project, the human and other animal bone from any particular level within one site produced the same kind of pattern. This similarity strongly suggests that all bone has undergone the same diagenetic processes. Since the human and animal bone have undergone the same changes, the bone strontium levels in humans relative to fauna should remain the same even though the absolute

TABLE 3. Bone strontium levels in the fauna from Tabūn Cave

Layer	Fauna		
	<i>Gazella</i>	<i>Dama</i>	<i>Bos</i>
B	530	370	—
C	—	—	390
D	380	—	330
Ea	330	330	—
Eb	260	260	260

TABLE 4. Bone strontium levels in the fauna from El-Wad Cave

Layer	Fauna			
	<i>Gazella</i>	<i>Dama</i>	<i>Bos</i>	<i>Cervus</i>
B	505	—	—	—
C	447	400	402	—
D	552	—	518	418
E	529	273	382	—
F	360	203	—	295
G	—	—	229	—
	305	218	253	281

TABLE 5. Bone strontium levels in the fauna from Kebara Cave

Layer	Fauna			
	<i>Gazella</i>	<i>Dama</i>	<i>Bos</i>	<i>Cervus</i>
B	542	—	394	—
C	549	321	—	—
D	565	434	272	242
E	667	490	—	—

amount of strontium may have changed. Therefore, the ratio of strontium:calcium in human to strontium:calcium in other animal bone can be compared between sites in order to determine differences in diet. As the ratio approaches 1.0, an increase in the amount of vegetable products in the diet is indicated.

In order to compute this ratio, an average was taken of the bone strontium levels of all the herbivores from the same level that produced the human sample within each site. An average of all herbivores was used because no single genus was represented at all sites. The average was assumed to be more representative of the trophic level than would the choice of a different genus at each site.

Only herbivores were used for this comparison since their bone should contain a maximum amount of strontium. Also, they should be somewhat more stable as a standard than should carnivores since the latter seem to include an unpredictable amount of other dietary items. Lions have been observed eating

the stomach contents of their prey in addition to feeding on the muscle tissue (Schaller, 1972; Walker, 1975). Hyaenas chew, swallow, and digest bones (Sutcliffe, 1970; Kruuk, 1972) and, thereby raise their dietary levels of strontium. In addition, they consume quantities of fruit in the dry season (Owens and Owens, 1978). Some foxes "consume a very large quantity of fruit and other vegetation" (Burrows, 1968:114). Perhaps more important, however, carnivores are relatively rare as archeological remains. Those that are present are usually the smaller canids (foxes and dogs), which were probably scavengers of human rubbish and, therefore, their bone strontium levels would be suspect.

The results of the bone strontium levels analyzed by atomic absorption spectrometry are presented in Figure 5. Plots of strontium content in bone ash (left) and strontium:calcium ratios (right) are shown. Comparing each of these distributions with the range of variation in the modern mink sample (indicated by the bar at the top of the figure), it is obvious that the range of values within each sample of humans from the three earliest sites (Tabūn, Skhūl, and Qafzeh), is no larger than that of the mink results. In fact, the combined sample of human and fauna at these three sites displays a range no larger than the mink sample alone. This does not imply that the humans and fauna were eating the same diet, only that the humans and fauna cannot be separated on the basis of range of variation alone.

The argument for dietary difference between the human and faunal samples at each site must be made on the basis of pattern. In the distributions from these three sites, the bone strontium levels and the strontium:calcium levels of the humans are separate from those of the fauna. In addition, humans always have lower bone strontium levels and lower strontium:calcium ratios than those of the faunal samples. The direction of the difference is as expected for humans who included meat in their diet. Even though the sample sizes are small, it is unlikely that sampling error can account for this pattern at three separate sites.

The distribution of results from the sample taken from Level C at Kebara is shown in the same figure. The ranges of these two distributions are much larger than those for the sample of mink. In addition, the values for the human and fauna overlap for the first time. This is a different pattern from that produced in the samples from Tabūn, Skhūl, and Qafzeh. The overlap indicates that by 15,000 years ago some of the humans had diets containing levels

of strontium that were higher than had been ingested in the earlier time periods. Even though the ranges overlap, however, the mean for the human sample (ppm strontium mean = 208; strontium:calcium ratio mean = 0.74×10^{-3}) is much lower than that of the faunal sample (ppm strontium mean = 435; strontium:calcium ratio mean = 1.13×10^{-3}). In fact, the position of the human mean relative to the faunal mean in the Kebara C sample is similar to that in the samples from Tabūn, Skhūl, and Qafzeh.

A very different pattern, however, is apparent in the samples from the two latest sites. There is complete overlap of the human and faunal bone strontium levels in the samples from Kebara B and el-Wad (10,000 years ago). This overlap might be due to dietary emphasis on grass heads (seeds) that contain higher amounts of strontium than do grass stems and leaves (Schroeder et al., 1972). In addition, the means for the human samples are much closer to the means of the faunal samples than was true in the samples from the earlier time period. This can be seen clearly in Figure 6.

DISCUSSION AND CONCLUSIONS

The results of the trace element analysis suggest that a change in diet did not occur through the time period in which archaic modern individuals lived in Israel. The patterns of the bone strontium levels for human versus fauna from Tabūn, Skhūl, and Qafzeh are identical. There is a separation between the human and herbivorous mammal samples in both the bone strontium levels and strontium:calcium ratios. The strontium:calcium ratio of the human samples is about 60% of the strontium:calcium ratio of the herbivorous mammal samples at the three sites (see Fig. 6). Based on the results of this analysis, nothing other than a constant proportion of meat versus vegetable material can be shown in the diets of humans throughout the time represented by these sites (70,000–35,000 years BP). It is possible that different foods were being collected even though there was no net change in the meat:vegetable proportions. The composition of the fauna, recovered from the three sites, however, suggests that there was no change in the kinds of fauna being exploited other than changing from one genus of large bodied herbivore to another (Garrod and Bate, 1937; Bouchud, 1974).

It now seems that if changes occurred in the food procurement activities during this time, those changes were unrelated to the kind of

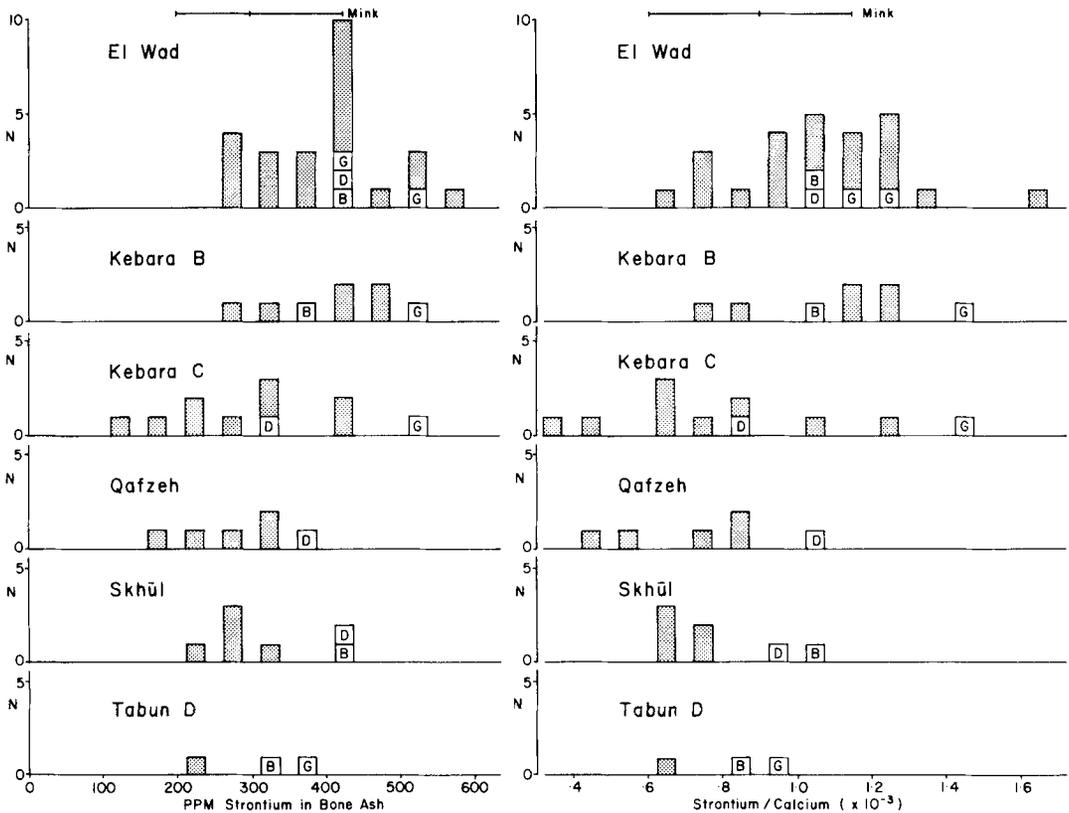


Fig. 5. Results of atomic absorption spectrometry on human and other mammal bone from six prehistoric levels in the Levant. B = *Bos*; G = *Gazella*; D = *Dama*. The pattern at the sites containing archaic modern humans (Tabun, Skhul, and Qafzeh) is different than the one at the levels containing fully modern humans (Kebara C and B, and el-Wad). In the former, the fauna are separate from the humans; the direction indicates the inclusion of meat in the human diet.

The pattern is different at Kebara C (15,000 years BP) but it is not until Kebara B and el-Wad (10,000 years BP) that a significant difference is obvious. In the latter two sample sets there is complete overlap of the faunal range of bone strontium levels by the human bone strontium levels. Inclusion of much higher amounts of plant material at this time relative to earlier periods is indicated.

food actually obtained. Rather, there may have been acceptance of alternative means of procuring or preparing the same kinds of food that had been used previously. As mentioned above, the artifact studies that might provide information on this possibility have not yet been completed, but we know that there were changes in artifact morphology (Garrod and Bate, 1937) and technology (Jelinek, 1977) during this time period. What these changes mean in terms of tool function and in human behavior may be uncertain at present (Jelinek, 1975), but future work will probably help clarify this enigma.

In addition, it appears that no major dietary change occurred concomitantly with the decrease in skeletal robustness. Between the time represented at Skhul and Qafzeh (30,000–35,000 years BP) and the time represented at Kebara C (around 15,000 BP) there was a decrease in robustness but no change can be demonstrated in the average human diet. In Kebara C the strontium:calcium ratio of the mean of the human sample is around 60% of the strontium:calcium ratio of the mean of the herbivorous fauna (see Fig. 6), just as it is at Tabun, Skhul, and Qafzeh. The pattern of the distributions from Kebara C, however, is

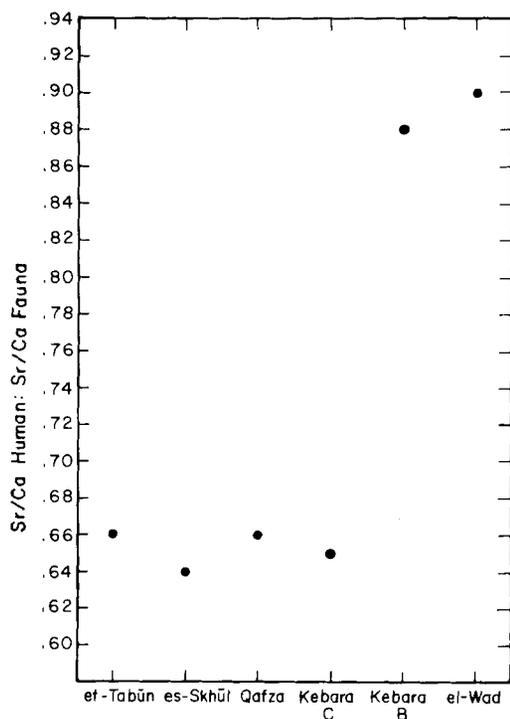


Fig. 6. Plot of the mean of human bone strontium:calcium divided by the mean of bone strontium:calcium levels of herbivorous fauna at each site. The sites which have produced archaic modern humans included far more meat in their diets (indicated by the low strontium level in human versus fauna) than did the fully modern humans from the most recent sites (Kebara B and el-Wad). Yet Kebara C, which was also inhabited by fully modern humans, is more similar to Tabūn, Skhūl and Qafzeh than to Kebara B and el-Wad. This indicates that the dietary change occurred some 15,000–20,000 years after the advent of modern *Homo sapiens*.

different from those at the earlier sites and there is, therefore, some indication that a change, though slight, had taken place.

The distributions of strontium and strontium:calcium ratios from the two late phase Epipaleolithic sites (Kebara B and el-Wad) which date to around 10,000 years BP, compared with all the earlier sites, however, suggest that a major dietary change occurred between early and late phases of the Epipaleolithic. The strontium:calcium ratios of the human samples are over 90% that of the strontium:calcium ratios in their respective faunal samples (Fig. 6). The large increase in this ratio between the early Epipaleolithic level site

(Kebara C) and the two late Epipaleolithic level sites (Kebara B and el-Wad) suggests that the major dietary shift occurred some 15,000 years after the major morphological shift had been completed.

Archeological evidence supports this interpretation. Although the first semi-permanent circular houses (Lechevallier, 1977) and some stone blades with grass sheen (Bar Yosef, 1970) have been found at Epipaleolithic period sites equivalent to Kebara C, neither of these are common. Major changes, however, appear to have occurred by the later Epipaleolithic period, when sites contain large numbers of mortars and pestles, in addition to sickle hafts and sickle blades with grass sheen along their edges (Henry, 1973). From the abundance of these remains relative to their numbers in earlier levels, it seems that there was a greater emphasis on the processing of plant material in the later versus the earlier portion of the period. In addition, the evidence for permanent houses and the possibility of at least one permanent settlement (Ein Mallaha, Perrot, 1966) in the later Epipaleolithic period indicate that people were living a more sedentary life later in the period.

Both the results of the trace element analysis and the archeological record, therefore, indicate that the change in subsistence activities related to dietary components occurred long after the change in skeletal robustness from archaic to modern *Homo sapiens*. In fact, the shift toward greater dependence on plant products, occurred some 15,000 years after the first appearance of fully modern *Homo sapiens*.

It seems, therefore, that if the reduction in human robustness was related to alterations in food procurement activities, these activity changes were unrelated to modifications in the food base. Rather, the alterations may have been in the means of procuring or preparing the same kinds of food that had been utilized earlier in time. For example, it is possible that more efficient means of organizing people to do tasks might have been developed and accepted (see Klein, 1979 for a similar suggestion applied to South Africa). Hunting large bodied, gregarious herbivores (e.g. *Gazella* or *Bos*) with numerous hunters should require less activity per individual than would be necessary for a solitary hunter or for a few individuals stalking the same animals. Based on the results of this study, it seems that investigation of tool function and efficiency plus

increased attention to indicators of social organization must be initiated before the reasons for the reduction in human skeletal robustness between Neandertals and ourselves can be understood.

ACKNOWLEDGMENTS

I wish to thank Dominic Dziewiatkowski, John Jones, Ward Rigot, Robert Owen, Jim Mackin, P.L. Fan, and Donald Peacor (University of Michigan) for use of their laboratory facilities and equipment. Bone samples were obtained thanks to the generosity of Christopher Stringer and Andrew Currant [British Museum (Natural History)], Bernard Vandermeersch (Université de Paris VI), Jean Louis Heim (Institut de Paléontologie Humaine, Paris), and Erik Trinkaus (Harvard University). Richard Aulerich (Michigan State University) supplied the sample of mink. L. Hoffman-Geertz supplied the rabbit. I also thank C. Loring Brace, William Farrand, Stanley Garn, Christopher Peebles, Henry Wright, Milford Wolpoff (University of Michigan), Aaron Posner, Adele Boskey, Foster Betts (Hospital for Special Surgery in New York City), and Erik Trinkaus (Harvard University) for discussions during the planning of and throughout this project. Comments by Mark Burchette, C. Loring Brace, Philip Gingerich, Ken Rose, Pat Shipman, Mark Teaford, Erik Trinkaus, and Alan Walker have improved the manuscript. Support for the project was supplied by Research Grant No. 539 from the Phoenix Laboratories of the University of Michigan and the Horace H. Rackham School for Graduate Studies (University of Michigan). Tony Sims (Johns Hopkins University) and Gen Kurtin (UCLA) typed the manuscript. Teryl Schessler drew Figures 1, 4, and 6.

LITERATURE CITED

- Alexander, GV, Nusbaum, RE, and MacDonald, NS, (1956) The relative retention of strontium and calcium in bone tissue. *J. Biol. Chem.* 218:911-919.
- Arensburg, B (1977) New Upper Palaeolithic human remains from Israel. *Eretz-Israel* 13:208-215.
- Ashley-Montagu, MF (1940) Review of: McCown, T.D. and A. Keith 1939: The Stone Age of Mount Carmel, Vol. 2. The fossil humans remains from the Levallois-Mousterian. *Am. Anthropol.* 42:518-522.
- Bada, J, and Helfman, P (1976) Application of amino acid racemization in paleoanthropology and archaeology. *Union Internationale des Sciences Préhistorique et Protohistoriques, IXe Congress, Nice, Colloque I*:39-62.
- Bang, S, and Baud, CA (1972) Topographic distribution of Sr and its incorporation into bone mineral substance in vivo. In G Shinoda (ed): *Proceedings of the International Conference on X-ray Optics and Microanalysis, Sixth Annual.* Tokyo: University of Tokyo Press, pp. 841-845.
- Bar-Yosef, O (1970) *The Epipalaeolithic Cultures of Palestine.* Doctoral Dissertation. Hebrew University, Jerusalem.
- Binford, SR (1968a) Early Upper Pleistocene adaptations in the Levant. *Am. Anthropol.* 70:707-717.
- Binford, SR (1968b) Variability and change in the Near Eastern Mousterian of Levallois facies. In SR Binford and LR Binford (eds): *New Perspectives in Archeology.* Chicago: Aldine Publishing Co., pp. 49-60.
- Binford, LR, and Binford, SR (1966) A preliminary analysis of functional variability in the Mousterian of Levallois facies. *Am. Anthropol.* 68:238-295.
- Boaz, NT, and Hampel, J (1978) Strontium content of fossil tooth enamel and diet in early hominids. *J. Paleont.* 52: 928-933.
- Bordes, F (1962) Sur la chronologie du Paléolithique au Moyen Orient. *Quaternaria* 5:57-69.
- Bordes, F (1968) *The Old Stone Age.* New York: McGraw-Hill.
- Bordes, F, and Bourgon, M (1951) Le complexe Moustérien: Moustériens, Levalloisien et Tayacien. *L'Anthropologie* 55:1-23.
- Bordes, F, and de Sonneville-Bordes, D (1970) The significance of variability in Palaeolithic assemblages. *World Arch.* 2:61-73.
- Bouchud, J (1969) Etude préliminaire de la faune du Djebel Qafzeh près de Nazareth (Israel). Paris: INQUA, VII^e Congrès, pp. 455-458.
- Bouchud, J (1974) Etude préliminaire de la faune provenant de la grotte du Djebel Qafzeh, près de Nazareth, Israel. *Paleorient* 2:87-102.
- Bowen, HJM, and Dymond, JA (1955) Sr and Ba in soils and plants. *Proc. R. Soc. Lond. (Biol.)* 144:355-368.
- Brace, CL (1962) Refocusing on the Neanderthal problem. *Am. Anthropol.* 64:729-741.
- Brace, CL (1964) The fate of the "classic" Neanderthals: a consideration of hominid catastrophism. *Curr. Anthropol.* 7:204-214.
- Brace, CL (1979) Krapina. "Classic" Neanderthals and the evolution of the European face. *J. Hum. Evol.* 8:527-550.
- Brace, CL and Ryan, AS (1980) Sexual dimorphism and human tooth size differences. *J. Hum. Evol.* 9:417-435.
- Braidwood, RJ, and Willey, GR (1962) *Courses Toward Urban Life.* Chicago: University of Chicago Press.
- Brose, DS, and Wolpoff, MH (1971) Early Upper Paleolithic man and late Middle Paleolithic tools. *Am. Anthropol.* 73:1156-1194.
- Brothwell, DR (1961) The people of Mount Carmel: a reconsideration of their position in human evolution. *Proc. Prehist. Soc.* 27:155-159.
- Brown, AB (1974) Bone Strontium as a dietary indicator in human skeletal populations. *Contrib. Geol.* 13:47-48.
- Burrows, R (1968) *Wild Fox.* New York: Taplinger Pub. Co.
- Cahen, D, Keeley, LH, and Van Noten, FL (1979) Stone tools, toolkits, human behavior in prehistory. *Curr. Anthropol.* 20:661-683.
- Clark, WELG (1964) *The Fossil Evidence for Human Evolution.* Chicago: University of Chicago Press.
- Comar, CL, Russell, RS, and Wasserman, RH (1957) Strontium-calcium movement from soil to man. *Science*, 126:485-492.
- Comar, CL, and Wasserman, RH (1964) Strontium: In CL Comar and F Bronner (ed): *Mineral Metabolism.* New York: Academic Press, Vol. 2, part A, pp. 523-572.
- Davis, S (1977) The ungulate remains from Kebara Cave. *Eretz Israel* 13:150-163.
- Dobzhansky, T (1944) On species and races of living and fos-

- sil man. *Am. J. Phys. Anthrop.* 2:251-265.
- Elias, M (1980) The feasibility of dental Sr analysis for diet-assessment of human populations. *Am. J. Phys. Anthropol.* 53:1-4.
- Farrand, WR (1972) Geological correlation of prehistoric sites in the Levant. In F Bordes (ed): *The Origin of Homo Sapiens*. Paris: UNESCO, pp. 227-235.
- Farrand, WR (1979) Chronology and paleoenvironment of Levantine prehistoric sites as seen from sediment studies. *J. Arch. Sci.* 6:369-392.
- Ferembach, D (1972) *L'ancêtre de l'homme du paléolithique supérieur était-il Néandertalien?* Paris, UNESCO pp. 73-80.
- Flannery, KV (1965) The ecology of early food production in Mesopotamia. *Science* 147:1247-1256.
- Flannery, KV (1969) Origins and ecological effects of early domestication in Iran and the Near East. In PJ Ucko and GW Dimbleby (ed): *The Domestication and Exploitation of Plants and Animals*. Chicago: Aldine, pp. 73-100.
- Garrod, DAE (1962) The Middle Palaeolithic of the Near East and the problem of Mount Carmel man. *J. R. Anthropol. Inst.* 92:232-259.
- Garrod, DAE, and Bate, DMA (1937) *The stone age of Mount Carmel I: Excavation at the Wadi el-Mughara*. Oxford: Oxford University Press.
- Geist, V (1981) Neanderthal the hunter. *Natural History* 90: 26-36.
- Gilbert RI (1975) Trace Element Analyses of Three Skeletal Amerindian Populations at Dickson Mounds. Doctoral Dissertation, University of Massachusetts, Amherst.
- Haas, G (1972) The microfauna of the Djebel Qafzeh cave. *Paleovertebrata*, 5:261-270.
- Helsby, CA (1974) Determination of strontium in human tooth enamel by atomic absorption spectrometry. *Anal. Chim. Acta* 69:259-265.
- Henry, D (1973) *The Natufian of Palestine: Its Material Culture and Ecology*. Doctoral Dissertation. Southern Methodist University, Dallas.
- Henry, DA, and Servello, AF (1974) Compendium of C-14 determinations derived from Near Eastern prehistoric sites. *Paleorient* 2:19-44.
- Higgs, ES, and Brothwell, DR (1961) North Africa and Mount Carmel: Recent developments. *Man* 61:138-139.
- Hodges, RM, MacDonald, NS, Nusbaum, R, Stearns, R, Ezmilian, F, Spain, P, and MacArthur, C (1950) The strontium content of human bones. *J. Biol. Chem.* 185:519-524.
- Hooijer, DA (1961) The fossil vertebrates of Ksâr 'Akil a paleolithic rock shelter in Lebanon. *Zool. Verh.* 49:1-67.
- Hooton, EA (1946) *Up from the Ape*. New York: Macmillan.
- Howell, FC (1951) The place of the Neanderthal man in human evolution. *Am. J. Phys. Anthropol.* 9:379-416.
- Howell, FC (1958) Upper Pleistocene men of the southwest Asian Mousterien. In GHR von Koenigswald (ed): *Hundert Jahre Neanderthaler 1856-1956*. Köln-Graz: Bohlen Verlag, pp. 185-198.
- Howell, FC (1959) Upper Pleistocene stratigraphy and early man in the Levant. *Proc. Am. Philos. Soc.* 103:1-65.
- Howell, FC (1965) *Early Man*. New York: Time-Life Books.
- Howells, WS (1974) Neanderthals: names, hypotheses, and scientific method. *Am. Anthropol.* 76:24-38.
- Jaffe, EB, and Sherwood, AM (1951) Physical and chemical comparison of modern and fossil tooth and bone material. U.S. Geol. Survey Dept., TEM 149.
- Jelinek, AJ (1975) A preliminary report on some Lower and Middle Paleolithic industries from the Tabūn Cave, Mount Carmel (Israel). In F Wendorf and A Marks (eds): *Problems in Prehistory: North Africa and the Levant*. Dallas: Southern Methodist University Press, pp. 297-313.
- Jelinek, AJ (1977) A preliminary study of flakes from the Tabūn Cave, Mount Carmel. *Eretz Israel*, 13:89-96.
- Jelinek, AJ, Farrand, WR, Haas, G, Horowitz, A, and Goldberg, P (1973) New excavations at the Tabūn Cave, Mount Carmel, Israel, 1967-1972: A preliminary report. *Paleorient* 1:151-183.
- Keeley, LH (1977) The functions of palaeolithic flint tools. *Sci. Am.* 237:108-126.
- Keeley, LH, and Newcomer, MH (1977) Microwear analysis of experimental stone tools: a test case. *J. Arch. Sci.* 4:29-62.
- Keith, A, and McCown, TD (1937) Mount Carmel man. His bearing on the ancestry of modern races. *Am. Sch. Prehist. Res.* 13:5-16.
- Klein, RG (1979) Stone age exploitation of animals in Southern Africa. *Am. Sci.* 67:151-160.
- Kochenov, AV and Zonov'ev, VV (1960) Distribution of rare earth elements in phosphatic remains of fish from the Maikop deposits. *Geochemistry* 8:860-873.
- Kraybill, N (1977) Pre-agricultural tools for the preparation of foods in the old world. In CA Reed (ed): *Origins of Agriculture*. The Hague: Mouton, pp. 485-521.
- Kruuk, H (1972) *The Spotted Hyaena*. Chicago: The University of Chicago Press.
- Lechevallier, M (1977) Les debuts de l'architecture domestique en Palestine. *Eretz-Israel* 13:253-259.
- Likins, RC, McCann, HG, Posner, AS, and Scott, DB (1960) Comparative fixation of calcium and strontium by synthetic hydroxyapatite. *J. Biol. Chem.* 235:2152-2156.
- Likins, RC, Posner, AS, Paretzkin, B, and Frost, AP (1961) Effect of crystal growth on the comparative fixation of Sr⁸⁶ and Ca⁴⁵ by calcified tissues. *J. Biol. Chem.* 236:2804-2806.
- Lovejoy, CO, and Trinkaus, E (1980) Strength and robusticity of the Neanderthal tibia. *Am. J. Phys. Anthropol.* 53:465-470.
- McCown, TD (1936) Mount Carmel Man. *Bull. Am. Sch. Prehist. Res.* 12:131-140.
- McCown, TD (1937) Mugharet es Skhūl, description-excavation. In DAE Garrod and DMA Bate (eds): *The Stone Age of Mount Carmel I: Excavations at the Wadi el Mughara*. Oxford: Oxford University Press, pp. 91-107.
- McCown, TD, and Keith, A (1939) *The Stone Age of Mount Carmel*. Vol. 2: *The Fossil Human Remains From the Levallois-Mousterian*. Oxford: Clarendon.
- Mellars, P (1970) Some comments on the notion of functional variability in stone-tool assemblages. *World Arch.* 2:74-89.
- Morrison, GH (1976) Interpretation of accuracy of trace element results for biological materials. *Natl. Bur. Stand. Spec. Pub.* 422:65-78.
- Mueller, J., Schuessler, KF, and Costner, HL (1970) *Statistical Reasoning in Sociology*. Second ed. Boston: Houghton Mifflin Co.
- Neuman, WF, Bjornstedt, R, and Mulryan, BJ (1963) Synthetic apatite crystals. II. Aging and strontium incorporation. *Arch. Biochem. Biophys.* 101:215-224.
- Neuville, R (1951) Le paléolithique et le mésolithique de désert de Judée. *Arch. Inst. Paléont. Hum.* 24.
- Noll, W (1934) *Geochemie des Strontiums*. Chem. Erde 8:507-600.
- Oakley, KP (1964) *Frameworks for Dating Fossil Man*. Chicago: Aldine Publishing Co.
- Odum, HT (1951) The stability of the world Sr cycle. *Science* 114:407-411.
- Ophel, IL (1963) The fate of radiostromium in a freshwater community. In V Schultz and AW Klement (eds): *Radioecology*. London: Chapman and Hall, pp. 213-216.
- Owens, MJ and Owens, DD (1978) Feeding ecology and its influence on social organization in brown hyenas (*Hyaena*

- brunnea*, Thunberg) of the Central Kalahari desert. *East African Wildlife J.* 16:113-135.
- Parker, RB, and Toots, H (1980) Trace elements in bones as paleobiological indicators. In AK Behrensmeier and AP Hill (eds): *Fossils in the Making*. Chicago: University of Chicago Press, pp. 197-207.
- Perkin-Elmer (1971) *Analytical methods for atomic absorption spectrophotometry*. Norwalk, Connecticut.
- Perkins, D Jr (1964) Prehistoric fauna from Shanidar, Iraq. *Science* 144:1565-1566.
- Perrot, J (1966) The gisement Natoufien de Mallaha (Eynan), Israel. *L'Anthropologie* 70:437-484.
- Posner, AS (1969) Crystal chemistry of bone mineral. *Physiol. Rev.* 49:760-792.
- Schaller, G (1972) *The Serengeti Lion*. Chicago: The University Press.
- Schoeninger, MJ (1979a) Dietary Reconstruction at Chalcatzingo, a Formative Period Site in Morelos, Mexico. Museum of Anthropology, The University of Michigan, Technical Reports, No. 9.
- Schoeninger, MJ (1979b) Diet and status at Chalcatzingo: some empirical and technical aspects of strontium analysis. *Am. J. Phys. Anthropol.* 51:295-310.
- Schoeninger, MJ (1980) Changes in human subsistence activities from the Middle Paleolithic to the Neolithic Period in the Middle East. Doctoral Dissertation. University of Michigan, Ann Arbor.
- Schroeder, HA, Tipton, IH, and Nason, AP (1972) Trace metals in man; strontium and barium. *J. Chronic. Dis.* 25:491-517.
- Smith, FH, and Ranyard, RG (1980) Evolution of the Supra-orbital region in Upper Pleistocene hominids from south-central Europe. *Am. J. Phys. Anthropol.* 52:281.
- Sokal, RR, and Rohlf, FJ (1969) *Biometry*. San Francisco: W.H. Freeman.
- Straus, WL Jr, and Cave, AJE (1957) Pathology and the posture of Neanderthal man. *Q. Rev. Biol.* 32:348-363.
- Sutcliffe, AJ (1970) Spotted hyaena: crusher, gnawer, digester, and collector of bones. *Nature* 227:1110-1113.
- Szpunar, C (1977) Atomic absorption analysis of archaeological remains: human ribs from woodland mortuary sites. Doctoral Dissertation, Northwestern University, Evanston, Illinois.
- Szpunar, CB, Lambert, JB, and Buikstra, JE (1978) Analysis of bone by atomic absorption. *Am. J. Phys. Anthropol.* 48:199-202.
- Thoma, A (1965) La définition des Néandertaliens et la position des hommes fossils de Palestine. *L'Anthropologie* 69: 519-534.
- Thurber, DL, Kulp, JL, Hodges, E, Gast, PW, and Wampler, JM (1958) Common strontium content of the human skeleton. *Science* 128:256-257.
- Toots, H, and Voorhies, MR (1965) Strontium in fossil bones and the reconstruction of food chains. *Science* 149:854-855.
- Trinkaus, E (1976) The evolution of the hominid femoral diaphysis during the Upper Pleistocene in Europe and the Near East. *Z. Morphol. Anthropol.* 67:291-319.
- Trinkaus, E (1977) A functional interpretation of the axillary border of the Neandertal scapula. *J. Hum. Evol.* 6: 231-234.
- Trinkaus, E (1978a) Dental remains from the Shanidar adult Neanderthals. *J. Hum. Evol.* 7:369-382.
- Trinkaus, E (1978b) Les métatarsiens et les phalanges du pied de Néandertaliens du Spy. *Bull. K. Belg. Inst. Nat. Wet.* 51:1-18.
- Trinkaus, E (1980) New light on the very ancient Near East. *Symbols, Summer 1980*:2, 3, 11.
- Trinkaus, E, and Howells, WW (1979) The Neanderthals. *Sci. Am.* 241:118-133.
- Turekian, KK, and Kulp, JL (1956) Strontium content of human bones. *Science* 124:405-407.
- Turville-Petre, F (1932) Excavations in the Mugharet el-Kebarah. *J.R. Anthropol. Inst. Gr. Br. Ir.* 62:271-276.
- Vandermeersch, B. (1972) Récentes découvertes de squelettes humains à Qafzeh (Israël): essai d'interprétation. In F. Bordes (ed): *The Origin of Homo Sapiens*. Paris: UNESCO, pp. 49-54.
- Vandermeersch, B (1977) *Les Hommes fossiles de Qafzeh (Israël)*. Thèse de Doctorat d'état Ès-Sciences Naturelles. L'Université Pierre et Marie Curie, Paris VI.
- Vose, PB, and Koontz, HV (1955) The uptake of strontium by pasture plants and its possible significance in relation to the fall-out of strontium-90. *Nature* 183:1447-1448.
- Walker, EP (1975) *Mammals of the World*, 3rd ed. Baltimore: Johns Hopkins University Press.
- Weckler, JE (1954) The relationships between Neanderthal man and *Homo sapiens*. *Am. Anthropol.* 56:1003-1025.
- Wessen, G, Ruddy, F, Gustafson, C, and Irwin, H (1977) Characterization of archaeological bone by neutron activation analysis. *Archaeometry* 19:200-205.
- Wolpoff, M (1980) *Paleo-Anthropology*. New York: Alfred A. Knopf.
- Wyckoff, RWG, and Doberenz, AR (1968) The strontium content of fossil teeth and bones. *Geochim. Cosmochim. Acta* 32:109-115.
- Yablonskii, MF (1971) Use of differences in bone mineral content for identification of corpses. *Sb. Nauch. Tr. Vitebsk. Gos. Med. Inst.* 14:368-374.
- Yablonskii, MF (1973) Identificational significance of major and trace elements of human long tubular bones. *Sud-Med. Ekspert.* 16:16-18.