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M.J. SCHOENINGER

ABSTRACT. – The reason that people accepted the responsibility of agriculture is still a subject of controversy. Most explanations include the inherent assumption that a change occurred in the subsistence base. This study investigated the dietary changes that accompanied the development of agriculture in the Middle East. Human and faunal bone samples were taken from three Epipaleolithic period levels at Kebara and el-Wad in the Levant and two Neolithic period sites (Ganj Dareh and Hajji Firuz) in Iran. The proportion of meat to vegetable materials in the diet was estimated by means of trace element analysis for strontium levels in bone. The trace element results from the Levantine sites indicate that human diet changed to include more plant products long before the development of agriculture. The results from the two Iranian sites indicate that the human diet contained relatively high amounts of meat in addition to cultivated plants. Considered together, the results suggest that agriculture did not provide a new food source, but rather, was an economic change which enabled human populations to continue, with increased control and reliability, subsistence systems that had been developed previously.

RÉSUMÉ. – Les raisons qui ont entraîné l'apparition de l'agriculture sont encore controversées, la plupart des explications font appel à un changement dans le mode principal de subsistance. Cette étude s'est attachée à rechercher les changements du régime alimentaire qui ont accompagné le développement de l'agriculture au Proche-Orient. Des échantillons d'ossements humains et animaux ont été prélevés dans trois couches de niveaux épipaléolithiques à Kébara et à el-Wad au Levant et dans deux sites néolithiques en Iran (Ganj Dareh et Hajji Firouz). Le rapport viande/végétaux dans l'alimentation a été estimé grâce au dosage de la quantité de strontium dans les os. Les résultats pour les sites du Levant suggèrent que l'alimentation a changé pour inclure davantage de produits végétaux bien avant le développement de l'agriculture. En ce qui concerne les deux sites iraniens, le régime alimentaire contenait une relativement grande proportion de viande, en plus des plantes cultivées. Si l'on considère l'ensemble des résultats, on peut suggérer que l'agriculture n'a pas fourni des sources nouvelles de nourriture, mais a entraîné un changement d'économie permettant aux populations humaines de continuer à suivre, avec des possibilités de contrôle et de régularité accrues, les systèmes de subsistance adoptés auparavant.

Why did people accept the responsibility of agriculture ? Although at one time its development was referred to as a 'revolution' (1) even the original proponent of such views toned down that emphasis (2). Some still believe that agriculture allowed social organization and cultural development of more complex forms (3). Recently, however, the burdens of agriculture have been noted in addition to its purported benefits (4). It appears that in some cases the agricultural way of life is not necessarily *better* than that of a hunter-gatherer. In fact, it has been suggested that skeletal indicators of dietary insufficiency may actually occur in higher frequency among early agricultural populations in North America than among the hunting-gathering populations that preceded them (5). This does not appear to be true among the early agriculturalists in the Middle East (6), yet even in that area, no clear cut advantage to an agricultural way of life is obvious. Yet, agriculture was developed or adopted throughout the world. Why ?

This study addresses the question in one particular area of the Old World, the Middle East. The focus is on one area because the events leading to the development of agriculture differ between the Old and New World (7) and it is very possible that the reasons for its development differ as well. The Middle East was chosen because of its importance in the history of agricultural development both in the Middle East and in Europe (8). Although a complete answer can not be expected to result from one study, clarifying some of the events surrounding its development should contribute toward a final answer.

Several hypotheses have been proposed as explanations for the development of agriculture. Childe (9) suggested that desiccation, increasing throughout the early part of the Holocene, necessitated the congregation of humans, other animals, and certain cereals, around water holes. This propinquity resulted in the domestication of several kinds of ungulates and cereals as humans became increasingly dependent on them as food sources. An opposite climatic change was reported by Wright (10) who proposed that amelioration of climate at the end of the Pleistocene (11) resulted in the spread of cereals across large portions of the Levant and Zagros area. According to him, agriculture was the result of increasing dependence by humans on this newly available food source. Braidwood (12) has proposed that do-

(1) CHILDE 1942.
(2) CHILDE 1958, 1965.
(3) See RINDOS 1980 for a recent example.
(4) COHEN 1977.
(5) BUIKSTRA 1979; COOK 1979.
(6) ANGEL 1968.
(7) FLANNERY 1973.
(8) CLARK 1980.
(9) CHILDE 1965.
(10) WRIGHT 1977.
(11) BUTZER 1957, 1958.
(12) BRAIDWOOD and BRAIDWOOD 1950; BRAIDWOOD 1952; BRAIDWOOD and HOWE 1960; BRAIDWOOD 1970.

mestication was the logical consequence of humans acquiring knowledge of their surrounding habitat and the resources within it. These hypotheses propose that agriculture is the result of increasing knowledge and dependence on certain plants.

A disequilibrium between human population density and traditional food sources has also been proposed by several people as an incentive for the development of agriculture (13). Arguing that population growth is an inherent factor of human populations, Cohen (14) has maintained that agriculture was practiced when the need arose for a food source capable of supporting large human populations. Binford (15) suggested that population expansion by sedentary, coastal populations created a disequilibrium as the overflow moved into areas previously inhabited by hunting/gathering populations. Agriculture was the result of a need for greater productivity. According to these 'disequilibrium' hypotheses, agriculture provided a new food source. In fact, to a greater or lesser extent all the previously cited hypotheses include the assumption that agriculture involved a shift in subsistence. In other words, agriculture resulted in a change in the provisions or supplies used by human populations.

A model, similar to the disequilibrium hypotheses, but which has a very different emphasis has been proposed by Flannery (16). He suggested that people with a tradition of « broad spectrum » resource utilization increased their use of grains following the inception of the Middle East's present day Mediterranean-type climate which occurred around 11,000 years before the present (17). Agriculture, on the other hand, « may have taken place in the less favorable valleys and wadis and around the periphery of the zone of maximum carrying capacity » (18). According to this line of reasoning, the development of agriculture was a means of continuing in marginal areas, a subsistence activity previously developed in areas prime for cereals. This hypothesis differs from the preceding ones because it suggests that the main alteration in human subsistence occurred before the development of agriculture. Thus, agriculture was a change in economy. In other words, it involved a change in management or regulation of a previously exploited subsistence system.

(13) Following BOSERUP 1965.
(14) COHEN 1977a, 1977b.
(15) BINFORD 1968.
(16) FLANNERY 1969, 1973.
(17) WRIGHT 1977.
(18) FLANNERY 1969 : 80.

This study proposes to test whether or not there was a dietary change at the time that agriculture was developed. If it can be demonstrated that the diets of early agriculturalists included larger amounts of plant materials than did the diets of preagriculturalists, then the economic change hypothesis can be rejected. In other words, agriculture could not be considered as only an economic change. If, on the other hand, such a dietary change cannot be demonstrated then the subsistence change hypotheses would be recommended for rejection. Agriculture could not be viewed as a means of providing a new food supply.

In this study, the diet of pre-agricultural and early agricultural populations is estimated through the analysis of strontium levels in bone from the respective populations. The level of bone strontium is proportional to the amount of strontium in diet (19). Since plants contain relatively more strontium than do animal tissues, a diet consisting largely of plant material should contain more strontium than should a diet that includes a large fraction of animal material (20). If the shift from hunting and gathering to agriculture included an increase in dietary dependence on plant materials, this should be reflected in higher bone strontium levels in the agricultural populations.

METHODS

The empirical and technical aspects of the estimation of diet using strontium levels in bone have been discussed more thoroughly elsewhere (21). Only a summary discussion is included here.

The method relies upon empirical information that was acquired during studies performed in the 1950's. At that time, the interest was in tracing the movement of fission products from nuclear weapons testing through the biosphere (22). The results of these studies indicated that there is a decrease in the amount of strontium from lower to higher trophic levels of terrestrial vertebrates.

Most plants do not discriminate between strontium and calcium and the strontium/calcium ratio in plants usually reflects the strontium/calcium ratio in surface

(19) ALEXANDER *et al.* 1956; COMAR *et al.* 1957; COMAR and WASSERMAN 1964.
(20) See references in SCHOENINGER 1979a.
(21) SCHOENINGER 1979a, 1979b.
(22) COMAR and WASSERMAN 1964; OPHEL 1963.

water (23). During metabolism of ingested materials by animals, however, strontium is discriminated against, in favor of calcium. The majority of strontium is excreted, only a small, though constant, percentage of dietary strontium crosses the gut, enters the blood stream, and is available for incorporation in bone mineral (24). Due to the balance of several mechanisms controlling strontium uptake and exchange, there appears to be no resultant discrimination between strontium and calcium in the formation of bone mineral (25). Therefore, the strontium/calcium ratio in bone mineral is nearly the same as the strontium/calcium ratio in blood. Because the major discrimination against strontium occurs during passage across the gut nearly 99% of the strontium stored in the body is located in bone mineral; less than 1% is stored in the soft tissues (26).

In sum, the amount of strontium available for incorporation by bone mineral is determined by the strontium level in blood. Blood strontium levels are determined by the amount of strontium crossing the gut which, in turn, is reflective of dietary levels of strontium. An herbivore subsisting entirely on plants will incorporate relatively large amounts of strontium in its bone. A complete carnivore, on the other hand, will ingest relatively little strontium because it feeds on flesh that contains very little strontium. It follows, then, that carnivore bone should contain less strontium than should herbivore bone. The first application of the method, involving the analysis of a Pliocene vertebrate fauna from a single quarry in Knox County, Nebraska, produced results which supported this expectation (27). My own analysis of animal bone from a modern fauna collected in one geographically restricted area in Iran produced similar results (Table 1).

Humans should fall somewhere in between the complete carnivore and complete herbivore. The exact position would depend on the relative amounts of meat and vegetable products included in their diet. Analysis of pre-human and human populations has been accomplished with varying degrees of success (28). 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 (29). The controls that were developed for this project are discussed briefly below. A more thorough documentation will appear elsewhere (30).

TABLE 1

Bone Strontium Levels In Modern Iranian Animals *

Fauna	Bone strontium (ppm)
Ovis aries	1,508
Lepus capensis (UMMZ 122382 ©)	652
Sus scrofa	326
Canis aureus (UMMZ 122373)	435
Felis chaus (UMMZ 122370)	181

* Analysis by neutron activation.
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Several things could affect the most simplistic scaling of herbivore, omnivore, carnivore. First of all, there are few, if any, complete carnivores and/or herbivores. Lions have been observed eating the stomach contents of their prey in addition to feeding on the muscle tissue (31). Hyaenas chew, swallow, and digest bones (32) and, thereby raise their dietary levels of strontium. In addition they consume quantities of fruit in the dry season (33). Some foxes « consume a very large quantity of fruit and other vegetation » (34). In fact, foxes, dogs, and pigs are noted omnivores with foxes and dogs tending toward the carnivorous side and pigs tending toward the herbivorous side. Similarly, some variability in diet has been noted for those animals usually considered true herbivores. For example, a superficial review of the literature reveals that deer have been reported as bone chewers (35).

(23) BOWEN and DYMOND 1955; COMAR *et al.* 1957; MENZEL and HEALD 1959.
(24) COMAR and WASSERMAN 1964.
(25) LIKINS *et al.* 1959, 1960, 1961; NEUMAN *et al.* 1963.
(26) SCHROEDER *et al.* 1972.
(27) TOOTS and VOORHIES 1965.
(28) BROWN 1973, 1974; GILBERT 1975; SZPUNAR 1977; WESSEN *et al.* 1977; BOAZ and HAMPEL 1978; LAMBERT *et al.* 1979; ELIAS 1980; SCHOENINGER 1980.
(29) SCHOENINGER 1979a, 1980; SCHOENINGER and PEEBLES in press.
(30) SCHOENINGER in preparation.
(31) Plate 34 in SCHALLER 1972; WALKER 1975.
(32) KRUUK 1972; SUTCLIFFE 1970.
(33) OWENS and OWENS 1978.
(34) BURROWS 1968 : 114.
(35) BROTHWELL 1976; SUTCLIFFE 1973.

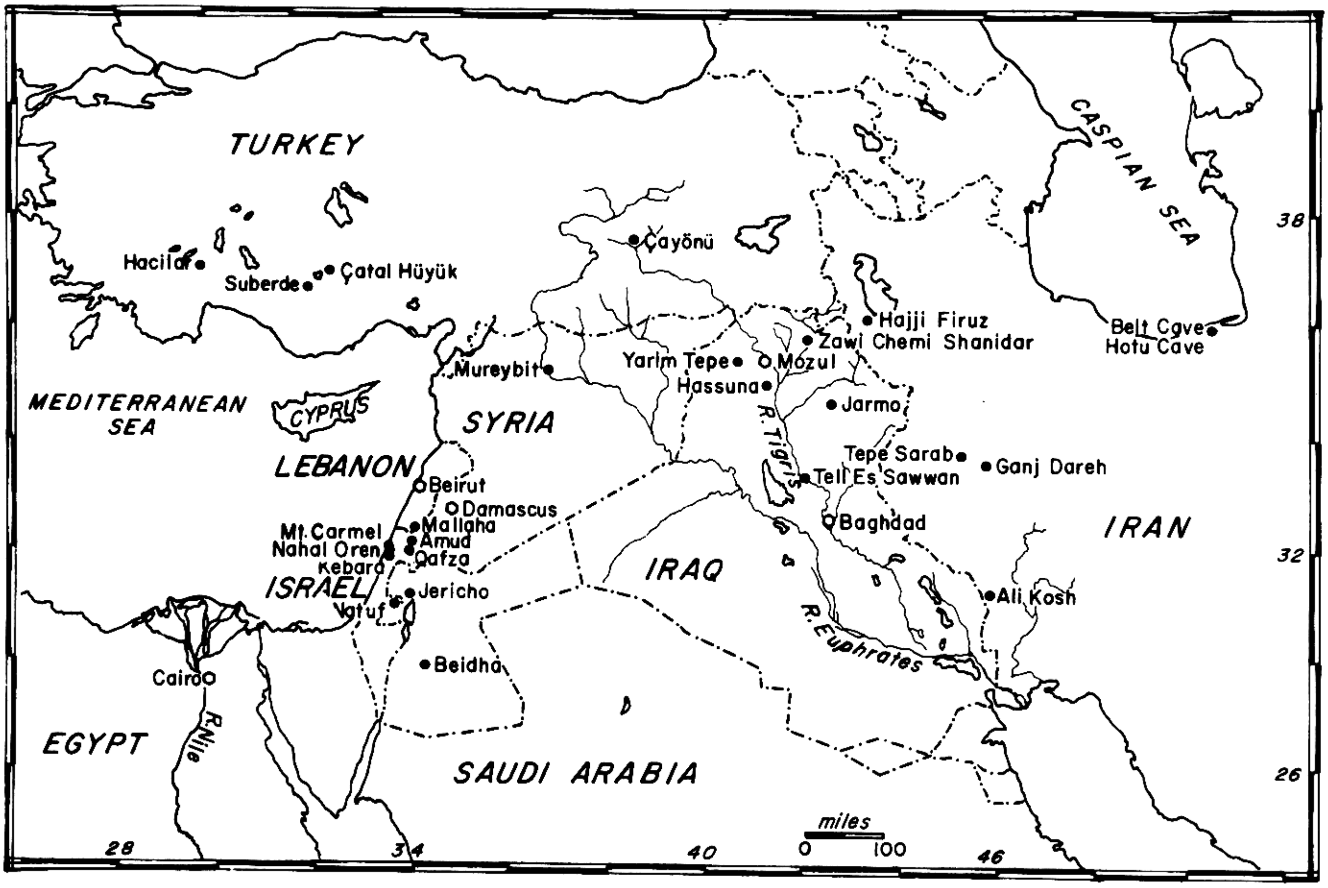

FIG. 1. – Map of archeological sites in the Middle East.
The sites discussed in the text are: Kebara and el-Wad (Mt. Carmel) in the Levant, Ganj Dareh and Hajji Firuz in Iran.

Perhaps more important is a second factor that may affect the most simplistic herbivore to carnivore scale, i.e. differential geographic distribution of strontium (36). Because the sites for the project discussed in this paper came from diverse geographic areas (Fig. 1), some means of normalizing the strontium levels is required. The solution is to compare the human strontium levels with the strontium levels of a selected portion of the fauna from the same site. This relative position, human to fauna, is then compared between sites.

Only herbivores were used for this comparison since they should contain the maximum amount of strontium and thereby represent a maximum possible level of strontium. Also, as discussed previously, 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 (i.e. grass, fruit, bone) in addition to animal flesh. Although deer have been observed chewing bone, the herbivorous animals (deer, gazelle, sheep, goat, cow) have not been noted eating meat which is the one item which would alter the bone strontium levels in a direction opposite from that expected for primary consumers. All herbivores from a site were used because no single genus was represented at all sites. Rather than picking one particular genus at each site, it seemed that the total would be more representative of the trophic level.

It could be argued that using this method, the final results might be a function of the faunal sample chosen,

(36) ODUM 1951, 1957.

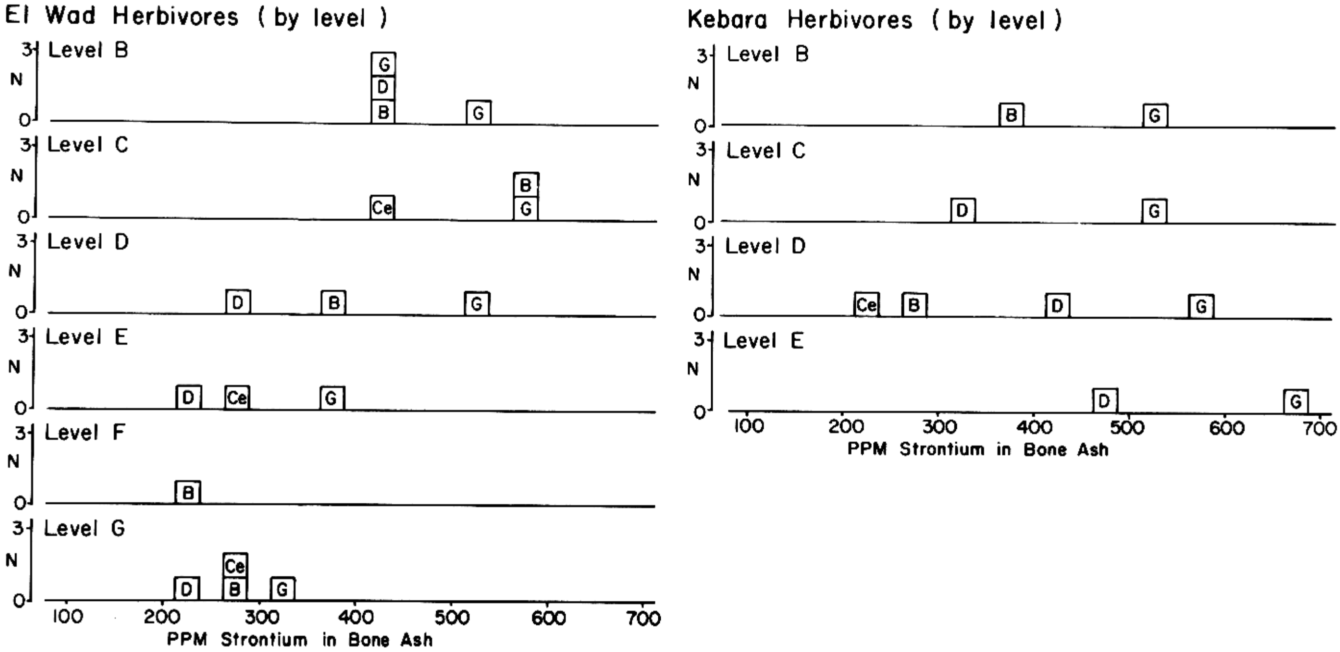

FIG. 2. – Bone strontium levels in the Herbivorous fauna at el-Wad and Kebara.
'B' stands for *Bos*, 'Ce' for *Cervus*, 'D' for *Dama*, and 'G' for *Gazella*. Although the absolute amounts of strontium are different between stratigraphic levels, the relative positions of the genera within any one level are fairly constant.

if there were different strontium levels between genera of herbivores. The bone strontium in several genera of herbivores at different levels in two sites can be seen in Fig. 2. In this figure 'B' refers to *Bos*, 'Ce' to *Cervus*, *'D' to Dama*, 'G' to *Gazella*. Although there are differences between genera, it should be noted that the relative positions remain fairly constant. *Gazella* always has the highest amount of bone strontium. The rest are fairly close to each other with *Bos* generally higher than *Dama* or *Cervus*. Since all of the sample sets that were analyzed contained more than one genus of fauna, it did not seem that choice of fauna would alter the final results. The absolute amounts of bone strontium may differ between site levels but since humans are compared only to the fauna from the same stratigraphic level, any differences would be unimportant.

A third factor which may disrupt the simplistic herbivore to carnivore scale of bone strontium levels is diagenesis. Diagenesis refers to all post-mortem chemical changes in bone. I have argued previously (37) that diagenesis should not be a problem if bone mineral is retained in the sample. Because strontium is a 2+ cation situated well within the crystal lattice, it is not subject to facile exchange with ions in solutions surrounding bone. 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. On the other hand, an addition of carbonate to the bone after burial might result in some alteration of bone strontium levels and/or strontium : calcium ratios (38). X-ray diffraction patterns on unashed, ground bone from two of the sites were identical to fresh bone (39). There appeared to be no inclusion of diagenetic carbonate. Even if some alteration of bone not indicated by X-ray diffraction had occurred, however, all bone from one level within one site should be affected equally. For this reason, the absolute amount of bone strontium may have been changed but the relative position of human bone strontium levels to faunal bone strontium levels

(37) SCHOENINGER 1979b; versus BOAZ and HAMPEL 1978.

(38) DeNIRO pers. comm.
(39) SCHOENINGER 1980.

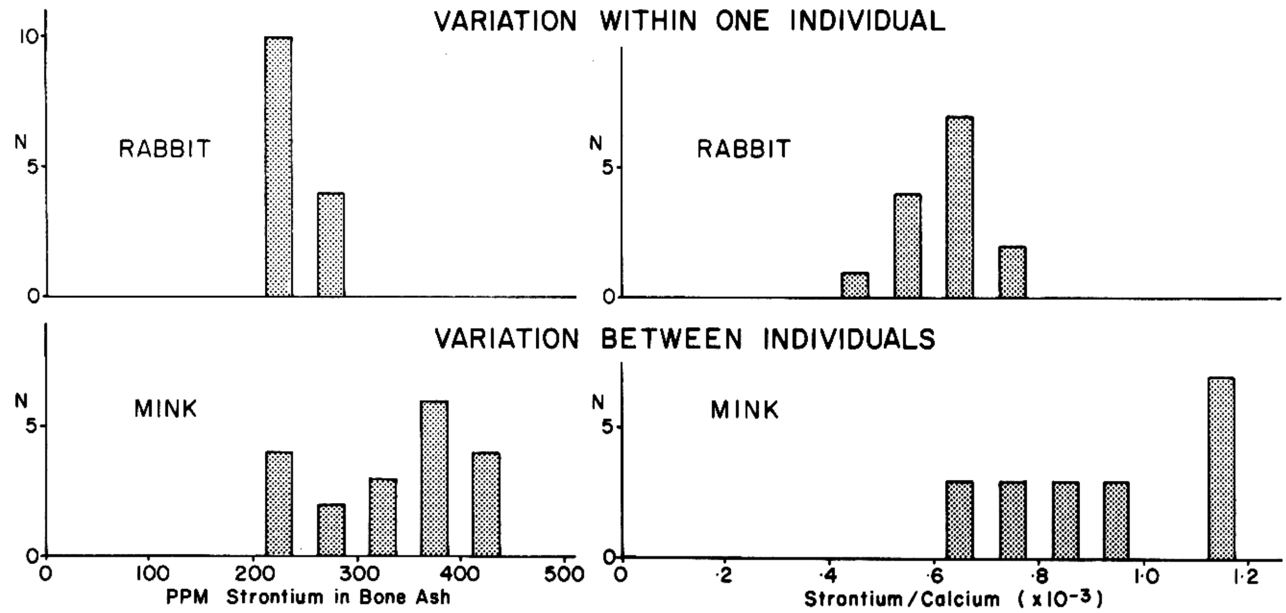

FIG. 3. – Variation in strontium levels in bone samples from one individual.
(rabbit: N = 14; ppm Sr: $\bar{x} = 232$, S.D. = 21, CV = 9, range = 212-280; Sr/Ca: $\bar{x} = .61 \times 10^{-3}$, S.D. = $.09 \times 10^{-3}$; CV = 14, range = $.46 \times 10^{-3} - .79 \times 10^{-3}$). Variation in strontium levels in bone from different individuals all raised on the same diet (mink N = 19, ppm Sr: $\bar{x} = 336$, S.D. = 75, C.V. = 22, range = 224 – 439; Sr/Ca: $\bar{x} = .92 \times 10^{-3}$, S.D. = $.20 \times 10^{-3}$, CV = 21, range = $.60 \times 10^{-3} - 1.17 \times 10^{-3}$).

within one site level should remain the same as it was during the individuals' lives. The amount of bone strontium in humans relative to the amount of bone strontium in the herbivorous fauna should be an indication of human diet even if some diagenetic alteration of bone had occurred.

MATERIALS

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 either from a rib or 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 (40). My own analysis on samples taken from the skeleton of one rabbit supports these earlier reports (Mean = 223 ppm strontium; SD = 21, V = 9, N = 14). These results are presented in Fig. 3.

Three of the sample sets (Kebara C, Kebara B, and el-Wad B) come from sites located in the Levant. Agriculture was not practiced at these sites although the presence of numerous grinding stones and sickle blades with grass sheen at Kebara B and el-Wad B suggests some use of processed plant products (41). Such indicators of plant processing are scarce in Kebara C which is at least 5,000 years older than Kebara B and el-Wad B (Table 2). The human skeletal material from Kebara C represents the earliest skeletal series in the Levant post-dating the Middle Paleolithic period (42). Other than Kebara C the human material from this region is limited to single skeletons from isolated sites.

(40) HODGES *et al.* 1950; TUREKIAN and KULP 1956; THURBER *et al.* 1958; YABLONSKII 1971, 1973; BANG and BAUD 1972.
(41) TURVILLE-PETRE 1932; BAR-YOSEF 1970, 1975.
(42) ARENSBURG 1973, 1977; ARENSBURG and BAR-YOSEF 1973.

TABLE 2
Samples Analyzed in This Project

Site	Date	# of humans sampled	# of faunal samples	Comment	Reference
Hajji Firuz	7,000 years BP	16	6	agricultural settled village domestic sheep & goats	Dyson *et al.*, 1969 Meadow, 1975 Voigt, 1976, 1977
Ganj Dareh	9,000-11,000 years BP	16	8	agricultural ? settled village domestic goats	Smith, 1972, 1978
El-Wad B	10,000 years BP	21	4	hunting/*gathering* mortars and pestles sickle blades	Garrod & Bate, 1937
Kebara B	10,000 years BP	6	2	hunting/*gathering* mortars and pestles sickle blades	Turville-Petre, 1932 Henry & Servello, 1974
Kebara C	15,000 years BP	9	2	*hunting*/gathering microliths	Turville-Petre, 1932

A fourth sample set is from Ganj Dareh which is located in the region of the Zagros mountains in western Iran. The period of site occupation spans the pre-agricultural (level E, 8,000-9,000 years B.C.) and agricultural periods (levels D-A, 7,000-8,000 years B.C.)(43). Very few plant remains have been recovered from the site but in Level D there are large boulder mortars and pestles and first floor cubicles that are too small for living purposes (44). Their presence suggests storage and dependency on plant material. In addition, it appears likely that from the time represented by level D the site was occupied year round (45), although it is still uncertain whether the population was agricultural or not. It is reasonably certain, however, that domesticated goats were present (46). Most of the human bone samples were recovered from level D.

The fifth sample set is from Hajji Firuz, a site near the Zagros mountains in N.W. Iran (47). The site has been dated by carbon-14 to between 5,500-5,200 years B.C. (48). The people who occupied Hajji Firuz appear to have depended on both domesticated plants and animals (49).

(43) SMITH 1978.
(44) SMITH, 1972.
(45) SMITH 1978.
(46) SMITH 1978.
(47) DYSON 1969; DYSON *et al.* 1969.
(48) VOIGT 1976.
(49) MEADOW 1975; VOIGT 1977.

In sum, this study includes bone samples from human populations that were hunter-gatherers with an emphasis on hunting (Kebara C); hunter-gatherers who were processing plant materials (Kebara B, el-Wad B); sedentary, probably agricultural, villagers who were storing plant materials and who had domesticated goats (Ganj Dareh, level D-A), and an agricultural village which had domestic goats, sheep, and pigs (Hajji Firuz). The time covered by these sites begins about 15,000 years B.P. (Kebara C)(50) and ends about 7,000 years B.P. (51).

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. These results are presented in Fig. 3.

SAMPLE PREPARATION AND ANALYSIS

Samples were prepared for analysis as described in a previous publication (52). First, all samples were cleaned

(50) Kebara C, HENRY and SERVELLO 1974.
(51) Hajji Firuz, DYSON 1972.
(52) SCHOENINGER 1980.

ultrasonically with deionized water. This step removed any soil adhering to the sample.

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. This precaution was taken because there is no nationally recognized standard that includes strontium levels in bone and there is no other way to check for random errors in technique (53). The samples were ground and ashed as described in Schoeninger (54) and then were prepared for AAS following the dissolution procedure suggested by Szpunar (55). 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 (56). 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 (57). 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 (58). 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 proved to contain a concentration of strontium that was within the linear range of the atomic absorption spectrometer (59) except in the case of the prehistoric bone samples from Iran. In the case of these samples a dilution of 1:1000 was necessary in order to produce a concentration of strontium in the sample that was within the linear range of the atomic absorption spectrometer.

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 strontium 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 (60). The value of the x-intercept was multiplied by the final dilution value (100 or 1,000) and divided by the sample weight (around 0.5 g). 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 ± 5% of the mean. Fourteen rabbit samples, from one invididual, produced a range of ± 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 ± 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 was prepared for analysis of strontium by neutron activation following Schoeninger (61). 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

(53) MORRISON 1976.
(54) SCHOENINGER 1979a, 1980.
(55) SZPUNAR 1977; SZPUNAR *et al.* 1978.
(56) PERKIN-ELMER 1971.
(57) HELSBY 1974.
(58) See SZPUNAR 1977.
(59) See CHRISTIAN and FELDMAN 1970; PERKIN-ELMER 1971, for a discussion of the linear range in atomic absorption spectrometry.
(60) SOKOL and ROHLF 1969; MUELLER *et al.* 1970.
(61) SCHOENINGER 1979a.

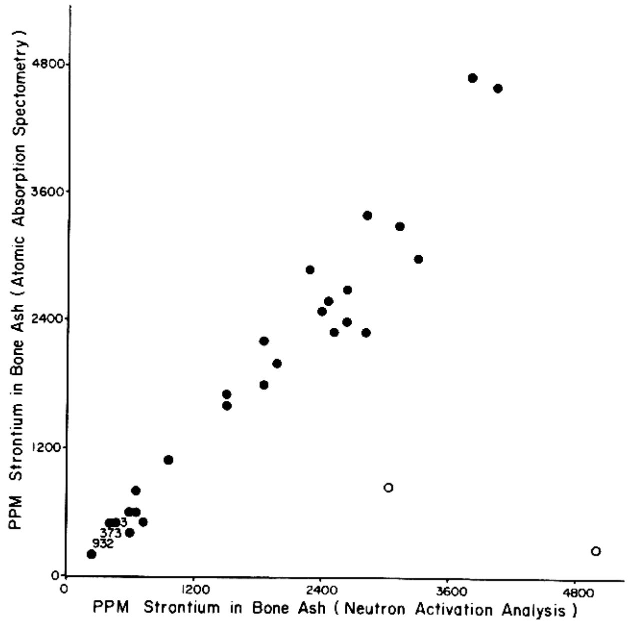

FIG. 4. – Comparison of results of 50 bone samples analyzed by both neutron activation analysis and atomic absorption spectrometry. The two outliers (open circles) were heavily contaminated with soil which disallowed proper separation of energy levels in neutron activation analysis and resulted in incorrect 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.

shorter lived isotope strontium-87 m produced unreliable results (62). The data reduction was performed using a Gaussian, fit program (63) used by the Phoenix Memorial Laboratories at the University of Michigan.

The two analytical techniques produced very similar results (Fig. 4). Even so, two outliers (open circles in Fig. 4) are immediately apparent. In both cases, there was a great deal of soil remaining on the filter paper following the final sample transfer (0.02 g and 0.09 g in samples that weighed 0.5 g originally) in the AAS sample preparation. In all other samples the weight of soil remaining on the filter paper was less than 0.005 g. The soil was not removed during sample preparation for NAA, therefore, the most likely explanation for the high NAA results 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.

RESULTS

The results of the trace element analysis by atomic absorption spectrometry are presented in Fig. 5 and 6. The levels of strontium in the ashed bone samples can be seen to the left. To the right are the strontium : calcium ratios for the same samples. The stippled bars represent the human bone samples, the open squares with letters in them represent the genera of herbivorous mammals. In these figures, 'B' stands for *Bos*, 'D' for *Dama*, 'G' for *Gazella*, 'Ca' for *Capra*, 'Ce' for *Cervus*, and 'O' stands for *Ovis*.

It is apparent that the samples from the two sites in Iran have bone strontium levels that are an order of magnitude higher than those from the Levant samples. I am not aware of any reports documenting strontium levels in bone on the order of 0.1-0.3 percent of bone ash before the ones presented here. A summary of published strontium levels (64) reports bone levels between 0.01-0.03 percent of bone ash. There is no reason, however, to attribute to error these very high levels of bone strontium in the Iranian samples. These samples were analyzed at three different dilutions (1:100, 1:500, 1:1000). Although only the results from the 1:1000 dilution can be accepted as correct since this was the only dilution that produced absorbance values within the linear range of the atomic absorption spectrometer, all three dilutions produced results of the same order of magnitude. Perhaps more significant is the fact that the neutron activation results from the same samples are also of the same order of magnitude (Table 3).

(62) SCHOENINGER and PEEBLES in preparation.
(63) Compare SCHOENINGER 1979a.
(64) UNDERWOOD 1977.

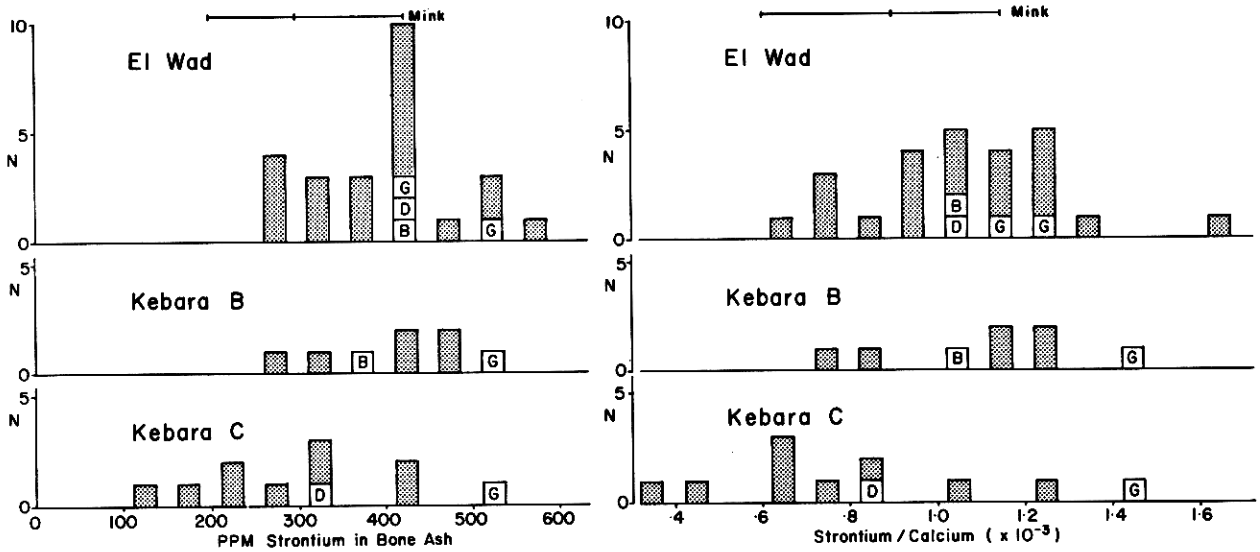

FIG. 5. – Parts per million strontium and strontium:calcium in human and faunal bone samples from Kebara C, Kebara B and el-Wad B. Summary statistics are presented in Tables 4 and 5.

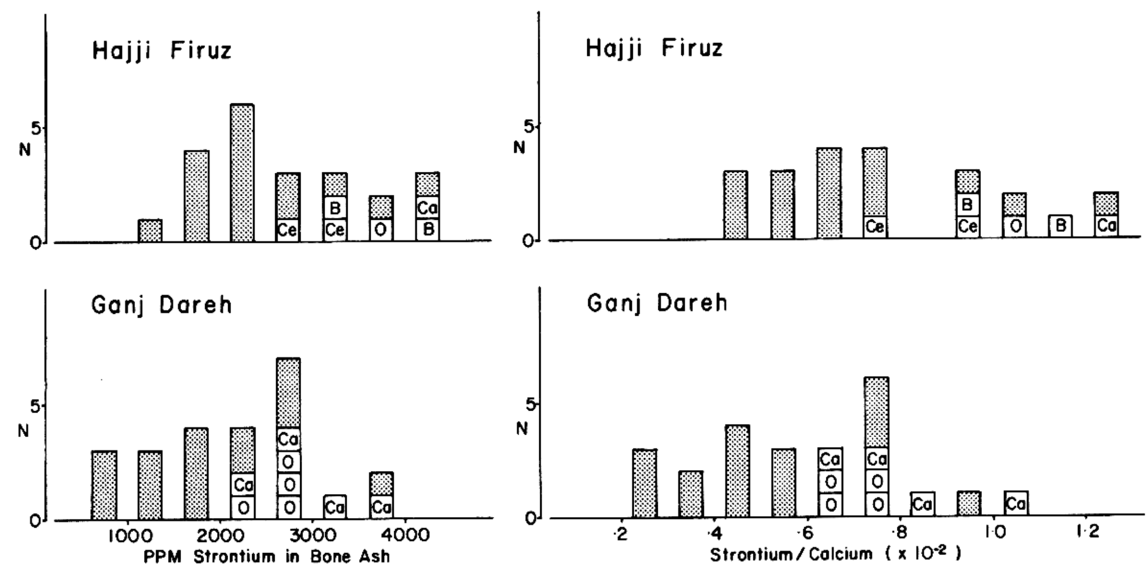

FIG. 6. – Parts per million strontium and strontium:calcium in human and faunal bone samples from Ganj Dareh and Hajji Firuz. Summary statistics are presented in Tables 4 and 5.

TABLE 3

Comparison of bone strontium levels produced by AAS and NAA from Ganj Dareh and Hajji Firuz

Sample #	Site	Specimen #	Bone Sr Levels (ppm) AAS	NAA
1206	Ganj Dareh	22004	2022	1985
1209	Ganj Dareh	62013	1718	1530
1210	Ganj Dareh	41020	1631	1473
1214	Ganj Dareh	41028	762	675
1216	Ganj Dareh	42030	1079	942
1222	Hajji Firuz	F11-B3-2	2578	2398
1223	Hajji Firuz	F11-B3-1	2489	2383
1224	Hajji Firuz	F10-B1	2205	1843
1225	Hajji Firuz	J9B1	3304	3101

The difference in the order of magnitude between the Iranian and Israeli samples makes it difficult to compare them. If, however, the bone strontium levels in the samples from Iran and Israel are assumed to be the same except that the levels from Iran are K times larger than those from Israel, then the samples can be compared graphically by plotting the natural logarithm (ln) (65) of parts per million strontium and of the strontium : calcium ratios (Fig. 7). By plotting the ln of the original values, the variability in each of the samples should be comparable to all the others and to the mink sample. This should be true even though the original values from the Iranian samples would be expected to vary more, merely because the absolute values are an order of magnitude higher than those from Israel or of the mink. This argument is based on one originally put forth by Simpson *et al.* (66) in their discussion of 'relative variation'.

An argument could be made against the assumption that the samples from Iran are merely K times larger than those from Israel. As mentioned previously, there have been no accounts of bone strontium levels of the magnitude of the ones reported here. It is possible that strontium at these levels is not treated metabolically by hydroxyapatite (bone mineral) in the same manner as strontium at much lower levels. If, however, the bone levels of strontium can be assumed to be reflecting dietary levels to some extent, then the bone strontium levels should still be meaningful for the project discussed here.

(65) Following LEWONTIN 1966.

(66) SIMPSON *et al.* 1966.

DISCUSSION

The patterns in the graphs of results are not the same at all sites. Here, pattern refers to the position of the human samples relative to the herbivorous mammals from the same site level. Since absolute strontium levels cannot be compared between sites, it is the pattern of results, human to fauna, which indicates diet in the human population at each site.

Although in all of the distributions there is an overlap of the faunal samples by the human samples, the bulk of the human samples and their spread is not the same between sites. For example, the ranges of the Kebara C distributions are much larger than those for the sample of modern mink. In addition, the coefficients of variation in the Kebara C sample are higher than those of the mink sample. The larger variation in the Kebara C sample suggests that individuals with different diets are represented in the sample. Another point is that although the human and faunal ranges overlap, the mean for the human sample is much lower than that of the faunal sample.

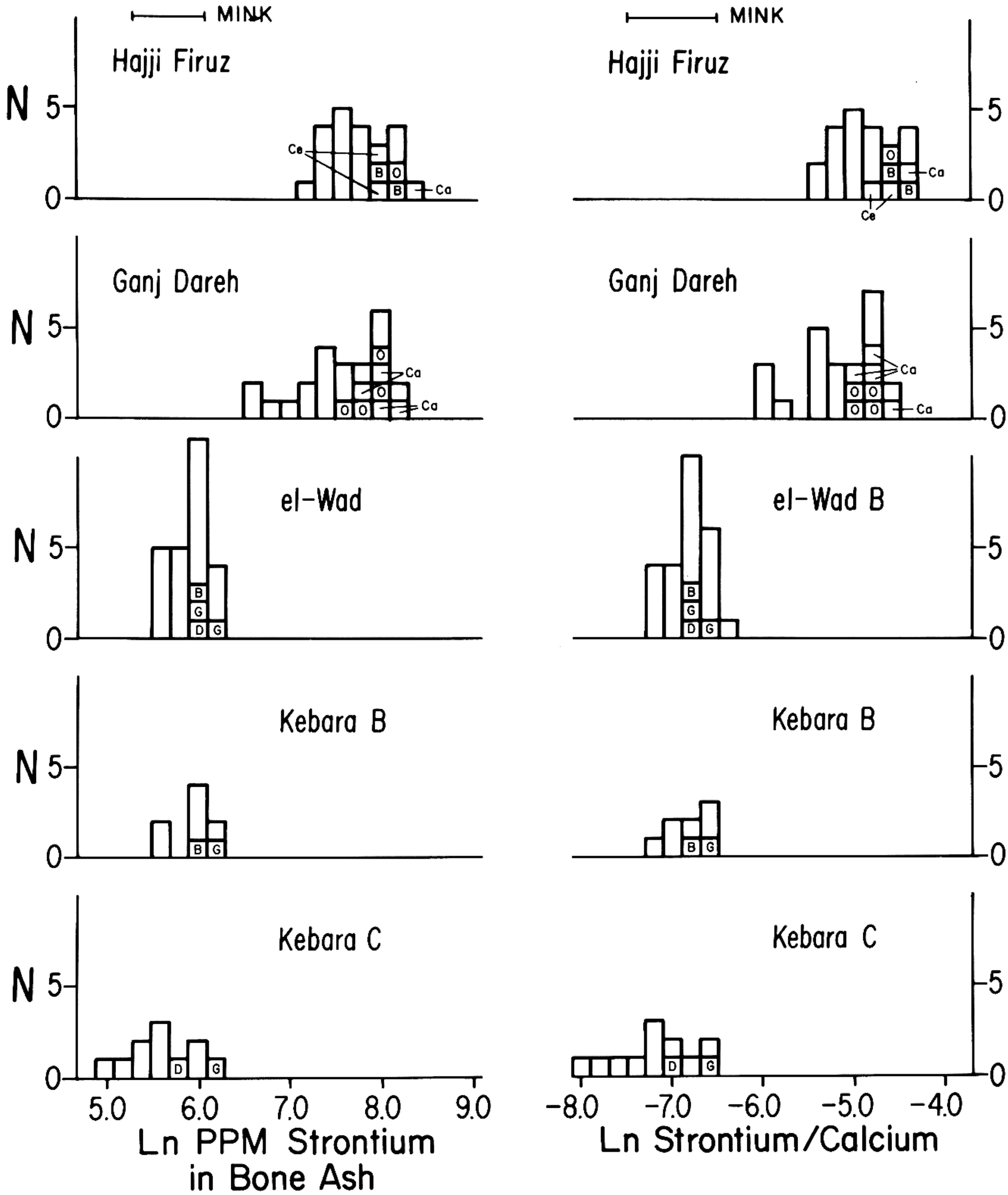

FIG. 7. – Natural Logarithm (Ln) of bone strontium levels and strontium:calcium ratios from Kebara C, Kebara B, el-Wad B, Ganj Dareh, and Hajji Firuz.

TABLE 4
Summary Statistics Discussed in Text

			Strontium (PPM in bone ash)				Strontium (Ln PPM in bone ash)			
Site	*Sample*	*N*	$\bar{X}$	*S.D.*	*C.V.*	*Range*	$\bar{X}$	*S.D.*	*C.V.*	*Range*
Mink	.....	19	336	75	22	224-439	5.79	.23	4	5.41-6.08
Hajji Firuz	Humans	16	2,328	697	30	1,467-4,051	7.71	.28	4	7.29-8.31
	Fauna	6	3,612	516	14	2,882-4,277	8.19	.14	2	7.97-8.36
Ganj Dareh	Humans	16	1,859	834	45	762-3,539	7.43	.47	6	6.64-8.17
	Fauna	8	2,863	495	17	2,276-3,820	7.95	.17	2	7.73-8.25
El-Wad	Humans	21	394	84	21	257-560	5.96	.22	4	5.58-6.33
	Fauna	4	438	49	11	400-505	6.08	.11	2	5.99-6.22
Kebara B	Humans	6	399	82	21	284-473	5.97	.22	4	5.65-6.16
	Fauna	2	468	..	..	394-542	6.14	...	.	5.98-6.29
Kebara C	Humans	9	280	95	34	146-437	5.58	.35	6	4.98-6.08
	Fauna	2	435	..	..	321-549	6.04	...	.	5.77-6.31

TABLE 5
Summary Statistics Discussed in Text

			$Sr/Ca \times 10^{-3}$ (in bone ash)				Ln Sr/Ca (in bone ash)			
Site	*Sample*	*N*	$\overline{X}$	*S.D.*	*C.V.*	*Range*	$\overline{X}$	*S.D.*	*C.V.*	*Range*
Mink	.....	19	.92	.20	21	.60-1.17	− 7.01	−.22	3	−6.75-7.41
Hajji Firuz	Humans	16	6.70	2.30	34	4.30-12.80	− 5.05	−.29	6	−4.36-5.43
	Fauna	6	10.00	1.70	17	7.80-12.20	− 4.61	−.17	4	−4.40-4.85
Ganj Dareh	Humans	16	5.00	2.10	42	2.30-9.40	− 5.38	−.43	8	−4.66-6.07
	Fauna	8	7.60	1.30	17	6.30-10.20	− 4.89	−.16	3	−4.59-5.07
El-Wad	Humans	21	1.04	.24	23	.67-1.63	− 6.89	−.23	3	−6.42-7.30
	Fauna	4	1.12	.11	10	1.02-1.27	− 6.79	−.09	1	−6.67-6.89
Kebara B	Humans	6	1.05	.21	20	.83-1.24	− 6.88	−.22	3	−6.69-7.21
	Fauna	2	1.19	...	..	1.00-1.39	− 6.74	..	.	−6.58-6.91
Kebara C	Humans	9	.74	.27	36	.35-1.23	− 7.27	−.38	5	−6.70-7.96
	Fauna	2	1.12	...	...	.86-1.39	− 6.82	- ..	.	−6.58-7.06

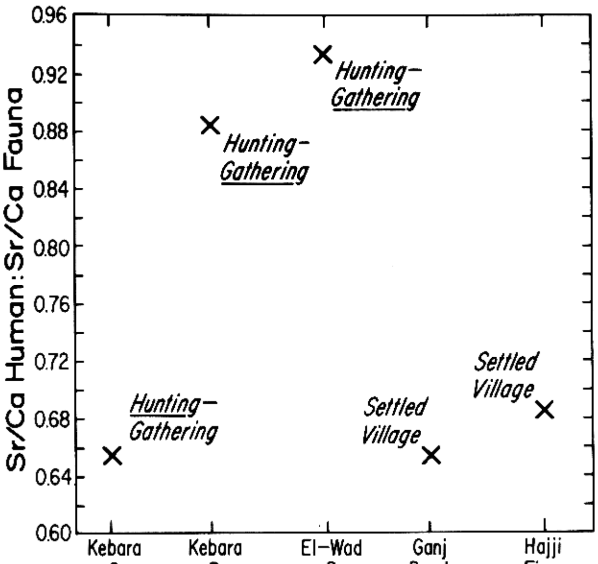

FIG. 8. – Sr/Ca human bone strontium levels: Sr/Ca faunal bone strontium levels at the five sites discussed in the text.
By comparing the human bone strontium level with the levels in the herbivorous fauna, it appears that there was an increase in use of plant materials among the Kebara B and el-Wad B population relative to the preceding Kebara C population. This can be attributed to the use of cereals that began to spread across large areas of the Levant about the time represented by these site levels. It appears that the populations at Ganj Dareh and Hajji Firuz utilized far less plant material. This supports the archeological interpretation that in the Zagros area there was a greater emphasis on herding than was true in the Levant.

The results from the two late phase Epipaleolithic period sites (Natufian period) of Kebara B and el-Wad are similar to each other and somewhat different from that of Kebara C. First of all, the ranges in both are lower than those in the Kebara C sample. The coefficients of variation of the human samples from both Natufian period sites, however, are very close to those of the mink sample. The value of this statistic suggests that all of the humans had diets similar to each other. Further, the coefficients of variation for these Natufian period sites (Kebara B and el-Wad) are lower than those in the sample from Kebara C.

Another interesting point is that the means for the human samples from Kebara B and el-Wad are much closer to the means of the faunal samples than was true in the samples from Kebara C.

The results from the two Iranian sites produce patterns that are more similar to the early site of Kebara C than they are to the patterns from Kebara B and el-Wad B. The ranges in both Iranian sample sets are larger than that in the set of mink samples. The coefficients of variation are also larger than in the mink sample set and in the samples from Kebara B and el-Wad. The values of both these statistics suggest that there was a variety in diet between individuals in these sites. In addition, the means for the human sample relative to the means for the faunal samples are much lower than was true for the Kebara B and el-Wad B sample sets. In all these aspects the Iranian samples are most similar to the samples from Kebara C, the early hunting/gathering population (Fig. 8; Tables 4, 5).

CONCLUSIONS

This project examined human dietary changes around the time that agriculture was developed and spread throughout the Middle East. The Middle East was chosen because of its recognized importance for the development of agriculture in large portions of the Old World. Although the reasons that European populations accepted the responsibility of agriculture may have been different that the reasons for its initial development, still, it is important to learn about that initial development.

Several hypotheses have been proposed as explanations for the initial development of agriculture. These have ranged from attributing climate as a prime mover (67), to absolute increase in human population density (68) and apparent increase in human population density (69) to a more diffuse sort of development based on increasing knowledge of the possible food sources in the environment (70). Most of these hypotheses include a shift in human diet at the time agriculture was established (71).

Flannery's (72) hypothesis, and to some extent Braidwood's as well, proposes that the change in human subsistence occurred prior to the development of agriculture. According to this hypothesis, agriculture was an economic change rather than a subsistence change.

(67) CHILDE 1965; WRIGHT 1977.
(68) COHEN 1977.
(69) BINFORD 1968; FLANNERY 1969.
(70) BRAIDWOOD and HOWE 1960.
(71) CHILDE 1965; BINFORD 1968; COHEN 1977; WRIGHT 1977.
(72) FLANNERY 1969.

The results of this project recommend rejection of the hypotheses that include a change in subsistence with the introduction of agriculture. Within the Levant, the non-agricultural populations at Kebara B and el-Wad B were including a large proportion of plant material in their diets. This represents increased use in plant material when compared with the earlier human population of Kebara C. Such a shift is an example of a subsistence change in the absence of agriculture.

The Iranian sites, on the other hand, provide an example of agriculture without concomitant subsistence change. The site of Hajji Firuz supported an agricultural population (73), yet, the people's diet didn't include appreciably more plant material than did the unquestioned hunter-gatherer population at Kebara C. In addition, no significant change is evident between Ganj Dareh and Hajji Firuz even though it is possible that Ganj Dareh was non-agricultural. This is not to suggest that the results indicate that people who inhabited these two Iranian sites were hunter-gatherers like the people at Kebara C. It is far more likely that the bone strontium levels and the strontium/calcium ratios are reflecting the traditional emphasis on goats and sheep that was present in the Zagros area (74). Domestic goats have been reported from Ganj Dareh (75) and both domestic goats and domestic sheep were present at Hajji Firuz (76). In any case, both the Levant and Iranian sequences suggest that agriculture in the Middle East did not result in a change in subsistence. Rather, it involved a change in economy, a change in the management of previously developed subsistence systems. In the Levant the previous subsistence system was heavily dependent on grains. In Iran, goats and sheep were far more important.

To go back to the original question, why did people accept the responsibility of agriculture ? The results reported here suggest that it was not undertaken in order to provide a new food source. It seems more likely that agriculture provided a means of continuing, with greater control, an already proven, highly productive subsistence system. As Harlan (77) has demonstrated, in the natural habitat areas in the Middle East, grains grow as thickly as in any planned agricultural plot. With increased control grains could be made to grow in areas other than the natural habitat (78). In the Middle East, this appears to have been the major advantage to the acceptance of agriculture.

(73) VOIGT 1977.
(74) PERROT 1977.
(75) SMITH 1978.
(76) MEADOW 1975; VOIGT 1977.
(77) HARLAN and ZOHARTY 1966.

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(78) As suggested by FLANNERY 1969; 1973.

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