J. Ethnobiol. 1 (1): 84-94 May 1981

DIETARY MINERAL ECOLOGY OF THE HOPI

HARRIET V. KUHNLEIN
University of British Columbia, Division of Human Nutrition, Vancouver, B.C., Canada V6T 1W5

ABSTRACT.—The Hopi are considered one of America's oldest Native Indian groups who continue to live on traditional lands. In modern times, they have relinquished many of their earlier cultural practices, including those related to agriculture and diet. Foods consumed have changed from the earlier pattern of corn, beans, and squash, augmented with wild plants and animals to a contemporary diet which contains a variety of foods imported to the reservation. A survey of 420 Hopi women and children showed that less than 25% consume one item of indigenous food each day and that the variety of traditional foods consumed has decreased dramatically from that described in the early anthropological literature. The changing diet presupposed changes in nutritional status. Mineral analysis of traditional Hopi foods reveals high levels of all nutritionally essential elements. Additionally, Hopi cultural practices reinforced the use of unusual mineral-rich plant foods and salts which were of nutritional importance when the diet was limited to animal foods. Seventeenth century and contemporary Hopi deciduous teeth were analyzed for several minerals. While calcium and phosphorus were similar in both groups, the earlier group had significantly higher levels of strontium and the latter group had higher levels of zinc, copper and lead.

INTRODUCTION

The Hopi are considered one of America's oldest Native Indian groups who continue to live on traditional lands. Hopi villages on the mesas of northeastern Arizona (Fig. 1) have been continuously inhabited since A.D. 1150-1417, and although the Spanish and Anglo-American acquisition of Indian lands considerably reduced the Hopi food land base in the late nineteenth and twentieth centuries, cultivation of the corn-bean-squash foods continued to furnish the major components of the diet until recent times.

Previously, wild plants, animals and salt were gathered from areas as far away as the San Francisco Peaks (near present day Flagstaff) and the Grand Canyon. While the introduction of domestic livestock by the Spanish brought new protein resources, the eventual reduction of the fragile desert vegetative cover by grazing has resulted in erosion and exacerbation of moisture conditions for native and cultivated vegatation (Thornthwaite 1942).

Demographic influences on Hopi food culture and preparation include an increasing population per acre on the reservation and, at the same time, there is an increasing proportion of older people and others who are so engaged that they can no longer devote a major part of the working day to traditional agricultural or kitchen labor. The time consuming nature of food preparation in the traditional manner is emphasized in the practice of maize meal grinding by the Hopi women. Using stone *mano* and *metate*, corn grinding would take 3-4 h daily for the preparation of enough food for one day for the family which usually included 7-9 members. The preparation, cultivation and harvesting of fields using traditional agricultural methods is also recognized as a labor intensive occupation for the Hopi man from mid-April to October (Hack 1942; Forde 1931).

When all Hopi foods were supplied entirely by their native environment (except for the small amounts obtained by trading with neighboring tribes), Hack (1942) and Bradfield (1971) independently estimated the required farmland per capita to be 0.8 ha in corn and 0.2 ha in other vegetables. Thus, approximately 4.2 hl of corn were consumed per person per year (about 316 kg of cornmeal) and an equal amount was stored for lean years (Stephen 1936). In 1893 it was estimated that there were 1458 ha in corn, 810 ha in cultivated vegetables, primarily beans and squash, and 405 ha in peach trees for the total population of 2000 Hopi (Donaldson 1893). Peaches were introduced by the Spanish in the seventeenth century and were a popular food and trade item.

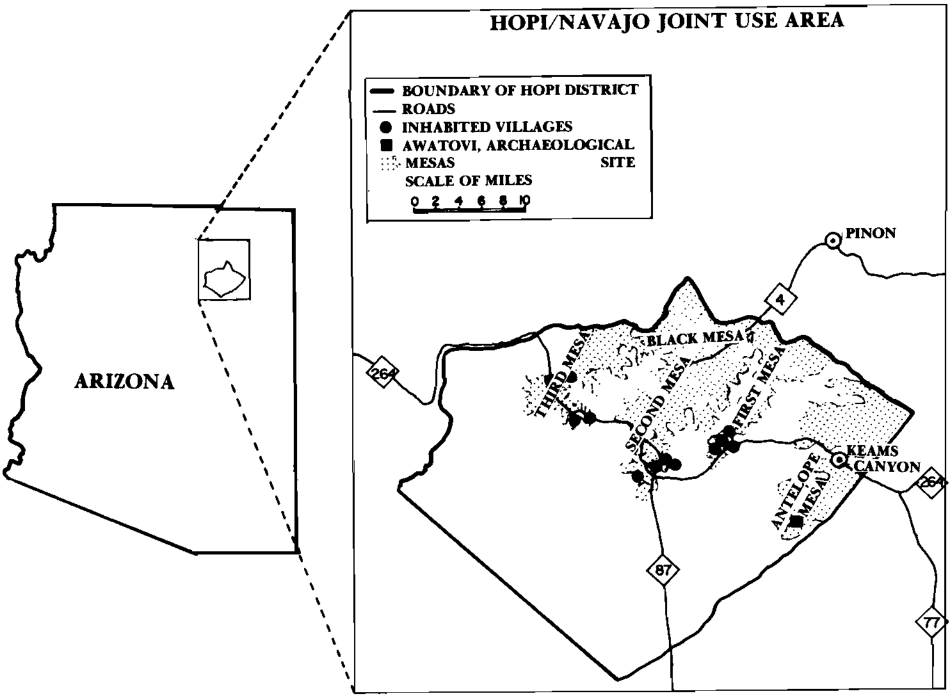

FIG. 1.—The Hopi area in Arizona (boundaries in the Joint Use Area are being negotiated).

For various social and geographical reasons, much of the traditional farmland has fallen out of use. As an example, the Oraibi (a Third Mesa village) Hopi cultivated about 972 ha in the 1890's; in the 1960's Bradfield (1971) recorded only 373 ha under cultivation by this village. In 1974, 2573 ha of "annually or intermittently" cultivated farmland were noted in the Hopi area (BIA 1974). For a population of 7500 Hopi, this averages about 0.3 ha per person. It appears, then, that the use of traditional agriculture and harvested foods has declined.

It is the intent of this report to describe the changing nutritional environment of the Hopi with regard to selected dietary minerals. A description of general dietary change is followed by data on selected minerals contributed to several indigenous Hopi foods, and comment on those minerals of particular interest. Finally, mineral data from seventeenth century and contemporary Hopi deciduous teeth permit comparison of human accumulation of certain minerals in preindustrial and current settings.

DISCUSSION

Dietary Change

A dietary study of 420 Hopi women and children in 1974-75 has confirmed the above geographical and social trends and shown an infrequent use of traditional Hopi food (Kuhnlein and Calloway 1977a). During the survey period, less than 25% of the individual daily records contained one item of traditionally prepared foods. The composition of the contemporary diet is primarily of items distributed in commercial food networks throughout America. The work of early anthropologists which was thoroughly compiled and expanded by Whiting (1939) in *Ethnobotany of the Hopi* permits a summary of foods used in pre-Spanish times. This is compared to the foods of the contemporary Hopi family in Table 1. The most prevalent items in terms of quantitative consumption are noted. It can be seen that the total variety of food plants was much greater in the earlier period, and that the composition of the diet in all food categories has dramatically changed.

While the diet was previously composed primarily of corn, beans, squash, seeds, wild greens, and fruits and water, today the diet is primarily beef, mutton, eggs, wheat, potatoes, some canned vegetables, fruits, and fruit jucies, lard and other fats, coffee, tea, milk, and several commercial pastries and sweets. Although the contemporary diet is not strikingly deficient in nutrients (including essential minerals) when compared to other American low-income populations (Kuhnlein and Calloway 1977a), there is a preponderance of refined cereals, animal fats, and sucrose-rich foods, all of which were not used previously. These items have been associated with dental caries, obesity and concommitant degenerative health problems which have been documented in contemporary Southwest Indians (Sievers 1966; Sievers and Cannon 1974).

TABLE 1.—*Indigenous and Contemporary Hopi Family Foods*[a]

Food Category	Indigenous[b]	Contemporary[c]
Fruit	agave, hedgehog cactus, juniper, tomatilla, cholla, prickley pear, squawbush, currant, rosehips, yucca (seasonal, some preservation)	melon, peach, apple, grapes (seasonal), orange, banana, commercially preserved fruits and juices*
High protein	beans*: tepary, lima, kidney, scarlet runner (ca. 20 var.), pinyon nuts, seeds* (many), wild game	Beef*, pork, mutton*, eggs*, poultry, fish, small amt. wild game, peanut butter, beans*, nuts
Vegetable	fresh sweet corn*, wild potatoes, pumpkin*, squash*, fresh beans, wild greens*; (ca. 39 sp.) (seasonal, some preservation)	sweet corn*, snap beans*, tomato, lettuce, chili*, squash, spinach, potatoes* (commercial and local grown, some preservation)
Grain	corn* (12-14 var., ca. 70 methods of preparation, often with culinary ash) Indian rice grass, millet	wheat*: yeast bread, fry bread, quick breads, tortilla, pasta, etc. (mostly commercial) corn: mush, grits, occasional old Hopi dishes (piki, nokquivi, etc.), rice, various breakfast cereals*
Separated fat		lard*, margarine*, oil*, butter
Dairy products		milk*, cocoa, cheese, preserved milk*
Other beverages	water*, herb tea	coffee*, tea*, pop*, sweetened juice drinks, powdered sweet drinks*
Sweets and snacks	sweet roots: 11 species (seasonal)	milk pudding*, candy*, jello*, chips* and other crisp and salted snacks, pastry*, jam

[a]Adapted from Kuhnlein and Calloway (1977a).

[b]Pre-Spanish

[c]Foods identified in a survey of 420 women's and children's diet records in 1974-1975.

TABLE 2.—*Approximate Percentage of Desired Daily Intake[a] Provided by 200 g Portions of U.S.D.A. Commodity and Hopi Cereals.*

Element (need)	Calcium (800 mg)	Magnesium (350 mg)	Manganese (7 mg)	Iron (15 mg)	Zinc (15 mg)
Cereal	(% of above contained in 200 g)[b]				
Commodity					
Corn Meal	1	23	7	36	8
White rice	1	15	34	41	16
White flour	5	15	17	35	7
Rolled Wheat	9	72	91	45	35
Hopi					
Corn meal	2	80	18	43	35
Piki bread	40	102	56	121	55
Bivilviki	142	159	57	224	49

[a]Desired intakes are arbitrary but reflect presumed upper needs levels of healthy adults or NRC allowances (1973).
[b]Products contained 88-92% dry solids, i.e. "as is" dry product basis.
From Calloway et al. (1974).

TABLE 3.—*Composition of Hopi Chamisa Ash[a]*

	g/kg		mg/kg
Na	1.57	Mn	710.00
K	174.00	Fe	3840.00
Ca	125.00	Cu	96.00
Mg	52.00	Zn	169.00
P	10.80	Se	8.00
		Br	98.00
		Rb	189.00
		Sr	1060.00
		Pb	11.00

[a]From Calloway et al. (1974).

Minerals in the Hopi Nutritional Environment

Culinary Ash.—A striking nutritional quality of traditional Hopi foods is the addition of essential elements in the preparation of blue cornmeal foods with a culinary ash. X-ray fluorescence analyses of samples reveals that sodium, potassium, calcium, magnesium, manganese, iron, copper, zinc, bromine, rubidium and strontium are all added with the ash (Calloway et al. 1974). It can be seen in Table 2 that the Hopi have a much better probability of meeting their mineral needs by consuming their own native foods than by using refined substitutes. Piki is a wafer thin bread prepared from blue cornmeal, ash and water. Bivilviki is from the same ingredients, but shaped into dumplings and boiled in water. Both are enriched with mineral nutrients because of the addition of ash.

Beaglehole (1937) and Nequatewa (1943) recorded that in addition to the usual midday and breakfast corn foods, piki and bivilviki, the Hopi commonly prepared at least 10 additional dishes of blue or pink cornmeal with a culinary ash. The preferred ash varies for different dishes, cooks and villages, but the most commonly used ashes are prepared by burning the green plant leaves and stems of *chamisa* (four-wing salt bush, *Atriplex canescens*) or dry bean pods and vines (*Phaseolus* sp.) The rich mineral content of Hopi chamisa ash is noted in Table 3. Culinary ash is also prepared from juniper branches, corn cobs or sheep dung. Today, some cooks substitute baking soda for ash, as the alkalinity produces a similar color change in the anthocyanin pigment within the cornmeal.

Salts.—Trace elements were also contributed to the earlier diet by the use of crude salts which were gathered by the Hopi from several geological deposits in the area. Sites in the Grand Canyon and Zuni Lake were most often frequented (Hunter 1940). Mineral levels in 11 salts from northeastern Arizona which are known to have been used by Native People are given in Table 4 with data from one commercial salt sample. The indigenous salts contained iron, arsenic, bromine, rubidium and strontium in substantial levels.

If the average Grand Canyon sample contained about 500 ppm iron, and 5 g of salt were consumed on a daily basis, this would provide 2.5 mg of iron, which is one-fourth to one-eighth the normal human requirement (Food and Nutrition Board 1974). Absorbability, however, is not known. The effects of these quantities of arsenic, bromine, rubidium and strontium are also not known. The small amounts of manganese, copper, zinc, nickle and selenium probably had only minor influence on improving mineral adequacy of the diet.

Sherds.—Ceramic sherds from the Hopi area were identified at the Harold F. Colton Research Center in Flagstaff and analyzed by x-ray fluorescence. The data given in Table 5 have been summarized in a recent report (Kuhnlein and Calloway 1979a). These fragments of ceramic vessels used in the Hopi area were found to contain considerable amounts of all the trace elements analyzed. It is possible that if these were used for food vessels, some of the minerals would leach out into foods, especially if the food pH was low. Today the Hopi rarely use ceramic containers for food.

Calcium.—This mineral is especially interesting for study in traditional Hopi foods because milk was not used in the culture except when infants were breast-fed. It was found that there were several excellent sources of calcium in Hopi foods which were clearly important in pregnancy and childhood when skeletal growth is rapid.

TABLE 4.—*Elements in Indigenous Salts From the Hopi Area Compared to Commerical Brand.*

	Cu	Zn	Mn	Fe	As	Br	Rb	Sr	Pb
				(ppm)					
Zuni Lake Domestic	<2	5±1	<9	13±5	2±1	34±2	< 1	4±2	<4
Zuni Lake G3-411	3±2	2±1	< 8	36±5	2±1	11±1	< 1	4±2	< 4
Grand Canyon G3-419[b]	3±2	3±1	<9	15±5	12±1	420±21	224±11	<2	<4
Grand Canyon E2345[c]	6±2	11±2	36±7	1530±70	414±20	1060±50	194±9	45±2	6±3
Grand Canyon E2346	3±1	5±1	<11	505±25	69±3	554±27	103±5	50±3	< 4
Grand Canyon E2347[d]	3±1	6±1	10±6	360±18	127±6	372±18	130±6	15±2	< 4
Grand Canyon G3.790	2±1	3±1	< 8	57±5	22±1	288±14	85±4	5±2	< 4
Camp Verde G3.230	8±2	3±1	< 8	13±5	< 1	18±1	<1	<2	<4
Camp Verde G3.69	2±1	< 2	< 8	18±5	< 1	2±1	< 2	2±1	<4
Medicine Cave NA863.1[e]	3±2	4±1	< 8	436±21	< 1	< 1	<1	9±1	<4
Wupatki 405M.44	< 3	2±1	10±7	265±13	< 1	4±1	5±1	5±2	3±3
Co-Op Iodized	< 3	2±1	< 8	5±4	< 1	67±3	< 2	1±1	< 4

[a]Except where noted, undetected elements were: Cr < 12 ppm; Ni < 3 ppm; Se < 2 ppm. Zuni Lake Domestic Salt was obtained from a Hopi kitchen and Co-Op Iodized was purchased in California. All other samples were generously provided by the Museum of Northern Arizona - museum catalog numbers are given.

[b]Se = 5±1

[c]Ni = 3±2

[d]Ni = 3±2

[e]Ni = 12±2

TABLE 5.—*Elements in Seven Pot Sherds from the Hopi Area.*

206	Fe	Mn	Cu	Zn	Hg	As	Sr	Pb
				(ppm)				
Tusayan corrugated	1.8%	83±30	45±2	49±2	6±3	7±2	195±8	32±7
Leupp black-on-white	1.7%	320±70	44±2	62±2	6±3	10±2	142±6	31±8
San Bernardo polychrome[a]	1.8%	180±50	35±2	90±4	6±3	13±2	95±4	22±8
Tusayan black-on-white	1.6%	110±30	32±2	50±2	5±3	< 5	215±9	35±8
Tusayan corrugated	2 %	130±40	95±2	68±3	7±3	5±2	179±8	46±8
Tusayan corrugated[b]	3 %	120±40	36±4	70±3	< 9	6±2	149±6	34±8
Contemporary First Mesa redware	6 %	50±20	24±3	209±8	15±4	9±3	43±5	32±11

[a] Typical style made in Awatovi.
[b] Found in Awatovi.

In Table 2 it can be seen that if only 200 g (dry weight) of cornmeal-ash foods were consumed, this would provide about 730 mg of calcium, which should be sufficient to meet nutritional needs, even if total availability were in question. Other good sources of calcium are water (Dutt and McCreary 1970) and seasonally collected green plants (Kuhnlein and Calloway 1979b) and probably other locally-grown plant foods as well.

Iron, zinc and phytate.—Iron is another nutritionally essential mineral of interest in Hopi foods. Geological formations in this area of Arizona are highly colored with iron-containing minerals, but iron is thought to be limited to the diets of most contemporary low-income women and children in North America (USPHS 1973; DNHW 1973). In addition, the appearance of porotic hyperostosis in skeletal remains of early Pueblo populations dependent upon a maize diet has prompted the speculation that the phytate content of whole-grain corn, by interfering with absorption, precipitated iron-deficiency anemia. This, in turn, may have caused the skeletal deformities (El-Najjar and Robertson 1976; El-Najjar et al. 1976). Zinc is also known to form insoluable complexes with phytate (Reinhold et al. 1976).

The content of iron, zinc and phytate in some traditional Hopi foods was investigated. In Table 2 it is seen that both piki and bivilviki (the most common traditional corn foods) contain ample iron and zinc in a 200 g portion. These samples were prepared from ash and cornmeal ground by modern Hopi with an electrical stone grinder. The amount of iron and 3 other minerals added to the cornmeal during the various stages of traditional *mano* and *metate* grinding and during mechanical grinding is shown in Table 6. Iron is accumulated in the meal prepared with *mano* and *metate* grinding in considerable quantity, probably as minute particles of rock. Manganese, calcium and phosphorus are also added in the traditional procedure. The electric grinder with stone rubbing surfaces did not make significant additions of any of the minerals analyzed, even though the resultant meal can also be classified as "stone ground." Zinc was not added in either procedure.

Phytate analysis was performed on modern Hopi corn for which mineral data were available, and these results are given in Table 7 (Kuhnlein and Calloway 1979b). The phytate ranged from a low value of 0.4% for lyophilized fresh sweet corn to 2.2% in mature yellow corn normally used for hominy. When chamisa ash was used to make the bivilviki, the levels of calcium, iron and zinc were increased and the molar ratios of phytate/mineral were reduced. Molar ratios of phytate/minerals were lower for the sweet corn than for the mature corn. The high level of calcium in the bivilviki might accentuate the formation of an insoluble phytate complex.

TABLE 6.—*Elements in Hopi Blue Maize Cornmeal Prepared with Mano and Metate vs Mechanical Stone Grinder*[a]

Sample Treatment	Fe (ppm)	Mn (ppm)	Ca (mg/g)	P (mg/g)
Mano and metate ground				
A1 After removing kernels from cob by hand	30±2	10±2	0.05	1.63
A2 After washing with stored water	33±2	10±2	0.06	1.52
A3 After coarse grinding	323±16	10±2	0.07	2.40
A4 After roasting in iron kettle	372±18	8±2	0.08	2.50
A5 After fine grinding	496±24	18±2	0.73	2.23
A6 After sifting with wire sifter	576±28	18±2	0.67	1.42
Mechanically stone ground[b]				
B1 After removing kernels from cob mechanically	31±2	9±2	0.04	1.83
B2 After washing	27±2	8±2	0.04	1.30
B3 After coarse grinding with "meat grinder"	47±2	9±2	0.05	2.43
B4 (No. B2) After fine grind by machine[b]	29±2	8±2	0.04	1.19
B5 (No. A2) After fine grind by machine[b]	26±1	9±2	0.05	1.44
Laboratory controls				
CA6 After microwave cooking and lyophilizing	502±25	20±2	n.a.[c]	n.a.
CB4 After microwave cooking and lyophilizing	29±2	8±2	n.a.	n.a.
CB5 After microwave cooking and lyophilizing	33±2	10±2	n.a.	n.a.

[a] From Kuhnlein and Calloway (1979a).
[b] "Little Jiffy" Electric Grinder, All Grain Co., Tremonton, UT S/N 1442
[c] Not analyzed

Also given are mineral values for corn excavated from Antelope House in Canyon de Chelly[1] (dated about A.D. 1200) where porotic hyperostosis was identified in skeletal remains. The iron and zinc values are similar to the contemporary Hopi corn, but calcium is substantially higher. Unfortunately, enough sample for phytate analysis was not obtained.

Questions regarding the quantitative binding of minerals to phytate in foods, the various complexes formed between the many different minerals and phytate, and ultimate availability in the gut have still to be elucidated (Oberleas et al. 1966). However, it is tempting to speculate that the use of culinary plant ash emerged as an experiential response to limited amounts of animal foods with high content of absorbable essential mineral nutrients (particularly iron, zinc and calcium) and consequent dependence on a largely cereal-legume diet.

Strontium.—High levels of strontium in the Colorado River and in northern Arizona soils and plants indicate that this area of Arizona is rich in natural strontium (Kopp and Broner 1967). This is shown in elevated levels in some native salts reported here, and also in water, water-extracts of soils, native leafy green plants and other Hopi foods (Kuhnlein and Calloway 1979a). The culinary ash used by the Hopi in blue cornmeal foods contains large amounts of strontium as well as calcium and was very likely a major contributor of both elements in the indigenous diet. Strontium and calcium are closely interrelated, biologically, and it is thought that strontium can substitute for calcium in the apatite complex of skeletal tissue (Likens et al. 1961).

Analyses of Hopi harvested foods reveal 10-30 Mg Sr/g Ca and these ratios are considerably higher than the ratios of the contemporary Hopi diets (about 5 mg/g Ca) (Kuhnlein 1976). This is not unusual considering that relatively small amounts of cornmeal-ash foods are included in modern Hopi diets.

TABLE 7.—*Phytate and Minerals in Hopi Corn*[a]

	Phytate gm/kg	Ca gm/kg	Fe mg/kg	Zn mg/kg	Phytate/mineral ratio Fe mole/mole	Zn mole/mole
Blue Cornmeal	18.7	0.09	32	26	50	71
Bivilviki (from the above cornmeal)	14.8	5.67	168	37	8	37
Hominy Corn	21.9	0.07	31	38	59	55
Roasted Sweet Corn	6.5	0.12	64	60	9	11
Antelope House Corn (yellow kernels)	n.a.[b]	0.43	23	26	n.a.	n.a.

[a] From Kuhnlein and Calloway (1979b).
[b] Not analyzed.

TABLE 8.—*Minerals in Deciduous Tooth Dentin*[a]

Element	17th Century Hopi n=10 (1)	Contemporary Hopi n=16 (2)	Contemporary Californian n=12 (3)	"P" Value Column 1 vs 2	"P" Value Column 2 vs 3
		μg/g dentin			
Pb	7.0±3.8[b]	27.6±15.2	16.6±5.4	< .001	.015
Sr	478.0±86.4	97.7±23.3	87.3±13.7	< .001	.260
Zn	134.0±31.1	178.0±52.9	151.0±30.5	.013	.099
Cu	10.1±2.0	22.9±24.4	15.8±16.5	.055	.371
Hg	4.0±1.7	5.6±4.7	5.3±5.4	.237	.908
		g/100 g dentin			
Ca	26.8±1.0	29.4±3.1	25.1±1.5	.005	.001
P	11.6±1.5	10.5±3.0	11.3±0.6	.244	.304
g P/g Ca	0.42±0.05	0.36±0.11	0.45±0.01	.026	.004
mg Sr/g Ca	1.78±0.29	0.34±0.09	0.35±0.09	< .001	.780

[a] From Kuhnlein and Calloway (1977b).
[b] Mean ± S.D.

Lead.—Lead is naturally present in lead and uranium deposits in this area of Arizona, but was not abundant in the indigenous diet because geological conditions, especially that of high soil pH, render lead insoluble and plant physiology excludes lead. Although it has been determined that lead does not enter locally-grown Hopi foods in the agricultural setting (Kuhnlein and Calloway 1979a), some Hopi corn foods were found to contain lead in levels high enough for concern if those foods were to comprise the major part of the diet (Calloway et al. 1974). Lead was not present in large amounts in the native salts reported here, but it was found in chamisa ash[2], and ceramic sherds from the Hopi area (Kuhnlein and Calloway 1979a).

Lead is one mineral element generally thought to have increased in the modern environment due to combustion of fossil fuels which release lead into the atmosphere and to the use of many lead-containing products of technology. For instance, lead in canned milk and canned infant formulas (which have become the preferred substitutes of human breast milk in this area) was greater than 0.5 ppm during the late 1960's (Lamm et al. 1973). Paint, plumbing, cooking equipment and processed foods might all contribute to increased lead in the Hopi environment.

Minerals in Seventeenth Century and Contemporary Deciduous Teeth

Comparison of the composition of seventeenth century and contemporary Hopi deciduous tooth dentin was made to assess the change in the human burden of several elements resulting from the change in diet and general environment since the preindustrial period (Kuhnlein and Calloway 1977b).

Deciduous teeth from 10 individual skeletons dated from the seventeenth century were obtained from the Hopi collection of the Peabody Museum of Harvard University[3]. The excavations were made in the late 1930s from the Franciscan compound in the pueblo of Awatovi, which is located on the eastern section of the current reservation (Fig. 1). The burials were placed within the church after the Pueblo Revolt in A.D. 1680 when the monks were expelled, and presumably before the abandonment of the pueblo around A.D. 1700 (Brew 1949). Naturally exfoliated contemporary Hopi tooth samples were randomly obtained in 1974 directly from reservation-resident children living in several villages. A third group of samples, also naturally exfoliated, were donated through 2 dental offices in 1974-75. These were from healthy, geographically stable children in the same age range living in relatively industrialized, suburban section of northern California. Dentin was removed from the teeth and analyzed for lead, strontium, zinc, copper, and mercury by x-ray fluorescence and for calcium by atomic absorption. Phosphorus was measured with the Fiske-Subbarow method (Kuhnlein and Calloway 1977b).

Strontium and lead were of especial interest since both are potential toxins and are known to accumulate in dentin. Zinc and copper also accumulate in hard tissues in response to diet and are detectable with the same method. Calcium and phosphorus are major elements in teeth and have been used as indicators of skeletal integrity.

The results in Table 8 show significant differences between the seventeenth century and contemporary Hopi teeth. Lead, zinc and copper are higher in present-day teeth, reflecting an increase in environmental levels of these elements. It is unlikely that this increase is due to changing natural background levels in the Hopi area; rather, it reflects the introduction of many technological products in the last 50 years. Mercury was present in similar concentrations in all groups, indicating that the amount deposited in hard tissues has not changed; however, it is not known how well dentin reflects dietary content of mercury.

Recently, lead and zinc have been shown to increase with urbanization and industrialization in Norwegian populations. Deciduous teeth from Medieval Bergen and modern urban and rural communities were analyzed and results gave the same trends as those reported for the Hopi (Fosse and Justesen 1978a, 1978b).

Strontium is more than 4-fold higher in the seventeenth century teeth when compared to the 2 contemporary groups. The Ca/Sr ratio in the seventeenth century teeth is higher than any here-to-fore reported, although Steadman et al. (1958) noted similarly high levels from Tonga and Texas. Since this element is not considered a product of modern technology, its presence in tooth structures can be viewed as a natural consequence of the local geological contribution to the nutritional environment.

Calcium and phosphorus levels in all groups are within accepted limits, but it is interesting that the contemporary Hopi levels differ from the other groups. This is reflected in their higher Ca/P ratios.

It appears, then, that the Hopi have become increasingly exposed to lead, zinc, and copper since the preindustrial period, and that their exposure to strontium has decreased. In fact, it seems that uptake of these minerals from the Hopi nutritional environment today is similar to that of northern California where there is obviously greater industrial development.

CONCLUSION

These data can offer only a few perspectives on dietary mineral ecology of the Hopi. It is clear that the exposure to many minerals has changed since the diet was composed entirely of native grown and prepared foods. It naturally follows that exposure to other nutrients has changed as well, with declining use of cornmeal ash foods, native salts, and other uniquely Hopi food practices, in favor of refined commercial foods, there has been a concommitant decline in intakes of calcium, strontium, iron, zinc, other minerals and also phytate. On the other hand, the deciduous tooth analysis strongly indicates an overall increase has occurred in intakes of zinc, copper, and lead since the preindustrial period. Within the same time, these data confirm a decrease in strontium exposure.

Given the variety of minerals which are important in human physiology, the complexity of assessing mineral availability in foods and the difficulties in estimating human mineral utilization, there is all likelihood that the total picture of change in Hopi dietary minerals from early to contemporary times will never be completely understood. However, these studies do give some understanding of the modern historical change in diet and mineral status. It is also very clear that many traditional Hopi foods were important sources of minerals, and that these are no longer being used to full advantage.

Literature Cited

Beaglehole, P. 1937. Notes on Hopi Economic Life. Yale Univ. Publ. Anthrop. No. 15, Yale Univ. Press, New Haven.

Bradfield, R.M. 1971. The changing pattern of Hopi agriculture. J. Royal Anthropol. Inst. Occ. Paper No. 31.

Brew, J.O. 1949. Franciscan Awatovi. Part I. The History of Awatovi. Part II. The Excavation of Franciscan Awatovi. Papers Peabody Mus. Arch. Ethn. Harvard Univ. 36: 3.

Bureau of Indian Affairs. 1974. Soil and Range Inventory of the Hopi District Six Area. Arizona, U.S. Dept. Interior, Branch of Land Oper., Hopi Agency.

Calloway, D.H. Giauque, R.D., Costa, F.P. 1974. The superior mineral content of some Indian foods in comparison to federally donated counterpart commodities. Ecol. Food Nutr. 3:203.

Department of National Health and Welfare. 1973. Nutrition Canada. National Survey. Information Canada.

Donaldson, T. 1893. Moqui Indians of Arizona and Pueblo Indians of New Mexico. U.S. Census Office Eleventh Census, Extra Census Bull. 15.

Dutt, G.R. and McCreary, T.W. 1970. The quality of Arizona's domestic, agricultural and industrial waters. Report 256. Agric. Exp. Sta., Univ. Arizona, Tucson.

El-Najjar, M.Y. and Robertson, A.L., jr. 1976. Spongy bones in prehistoric America. Science 193:141.

El-Najjar, M.Y., Ryan, D.J., Turner, C.G., iii, and Lozoff, B. 1976. The etiology of porotic hyperostosis among the prehistoric and historic Anasazi Indians of southwestern United States. Amer. J. Phys. Anthrop. 44 (3): 477.

Food and Nutrition Board, National Research Council. 1974. Recommended Dietary Allowances, 8th ed. Natl. Acad. Sci., Washington, D.C.

Forde, C.D. 1931. Hopi agriculture and ownership. J. Royal Anthropol. Inst. 61:357.

Fosse, G., and Nils-Petter Justesen. 1978a. Lead in deciduous teeth of Norwegian children. Arch. Environ. Health 33:166.

______ 1978b. Zinc and Copper in deciduous teeth of Norwegian children. Internatl. J. Environ. Stud. 13:19.

Hack, J.T. 1942. The changing physical environment of the Hopi Indians of Arizona. Papers Peabody Mus. Arch. Ethn. Harvard Univ. 35 (1):1.

Hunter, H.V. 1940. The ethnography of salt in aboriginal North America. Unpubl. M.A. Thesis (Anthrop.), Univ. Pennsylvania, Philadephia.

Kopp, J.F. and Froner, R.C. 1967. Trace metals in waters of the United States. U.S. Dept. Interior. Fed. Water Pollution Control Admin. Div. Pollution Surveillance. Cincinnati, Ohio.

Kuhnlein, H.V. 1976. Strontium and lead in the Hopi nutritional environment and teeth. Unpubl. Ph.D. Dissert., Univ. California, Berkeley.

______ ., and Calloway, D.H. 1977a. Contemporary Hopi food intake patterns. Ecol. Food Nutr. 6:159.

______ . 1977b. Minerals in human teeth: differences between preindustrial and contemporary Hopi Indians. Amer. J. Clin. Nutr. 30:883.

______ . 1979a. Adventitious mineral elements in Hopi Indian diets. J. Food Sci. 44(1):282.

______ . 1979b. Composition of traditional Hopi foods. J. Amer. Dietet. Assoc. 75:37.

Lamm, S., Cole, G., Glynne, K., and W. Ullman. 1973. Lead content of milks fed to infants: 1971-72. New England J. Med. 289 (11):574.

LIKINS, R.C., POSNER, A.S., PARETZKIN, B. AND A.P. FROST. 1961. Effect of crystal growth on the comparative fixation of Sr^{89} and Ca^{45} by calcified tissues. J. Biol. Chem. 236:2840.

NEQUATEWA, E. 1943. Some Hopi recipes for the preparation of wild plant foods. Plateau 16:18.

OBERLEAS, D., MUHRER, M.E., AND O'DELL, B.L. 1966. The availability of zinc from foodstuffs. *In* Zinc Metabolism (A. Prasd, ed.). C.C. Thomas, Springfield.

REINHOLD, J.G., FARADJI, RB., ABADI, P., AND ISMAIL-BEIGI, F. 1976. Decreased absorption of calcium, magnesium, zinc and phosphorus by humans due to increased fiber and phosphorus consumption as wheat bread. J. Nutr. 106:493.

SIEVERS, M.L. 1966. Disease patterns among Southwestern Indians. Public Health Rep. 81:1075.

———., AND CANNON, H. 1974. Disease patterns of Pima Indians of the Gila River Indian Reservation of Arizona in relation to the geochemical environment. *In* Trace Substances in Environmental Health VII. (D.D. Hemphill, ed.). Univ. Missouri, Columbia.

STEADMAN, L.T., BRUDEVOLD, F. AND SMITH, F.A. 1958. Distribution of strontium in teeth from different geograhic areas. J. Amer. Dent. Assoc. 57: 340.

STEPHEN, A.M. 1936. Hopi Journal. (E.C. Parsons, ed.), Columbia Univ. Press, New York.

THORNTHWAITE, C.W. 1942. Climate and accelerated erosion in the arid and semi-arid Southwest and special reference to the Polacca Wash Drainage Basin, Arizona. U.S. Dept. Agric. Tech. Bull. 808.

U.S. PUBLIC HEALTH SERVICE. 1973. Ten State Nutrition Survey. Washington, D.C.

WHITING, A.F. 1939. Ethnobotany of the Hopi. Mus. N. Arizona Bull. 15, Flagstaff, Arizona.

NOTES

[1]Courteously provided by Dr. Christry Turner III, Arizona State University.

[2]The 11 ppm reported in Table 3 is not unusually high. If the fresh weight plant contained a typical level for plant foods, ca. 1 ppm, it would concentrate about 10-fold upon ashing.

[3]These were kindly supplied by Mr. Al Santaluca.