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The Ecology of Early Food Production in Mesopotamia

Prehistoric farmers and herders exploited a series of adjacent but contrasting climatic zones.

Kent V. Flannery

Greater Mesopotamia—broadly defined here as the whole area drained by the tributaries of the Shatt al-Arab—has long been the scene of popular interest and scholarly research. In recent years attention has been drawn to the fact that this was one of the few areas in the world where agriculture and animal husbandry seem to have arisen autonomously. A number of excellent cultural-historical reconstructions of the way food production began in the Near East are already available (*1*; *2*, p. 147), but most of these reconstructions do not deal directly with some of the ecological questions most commonly asked by the interested nonspecialist. This article examines some of those questions.

The Environment

From the standpoint of agriculture and grazing potential, the area under consideration includes four main environmental zones: the alluvial plain of Mesopotamia proper, the steppeland of Assyria, the woodland belt of the Zagros Mountains, and the edge of the high central plateau of Iran (see Figs. 1 and 2). The first three of these zones have already been described by Hatt (*3*); I have added the high plateau, although it is not actually drained by the Shatt al-Arab system, because its mineral resources figured prominently in the early village period.

1) *The central plateau of Iran.* Central Iran is an interior drainage basin at altitudes of 900 to 1500 meters, with annual rainfall as low as 100 to 230 millimeters. The basin is filled with sierozem and desert soils, overlain in places by shallow brackish lakes surrounded by salt-crusted flatland. Rugged mountains jut unexpectedly from the plain, some of them ore-bearing; there are veins of copper just east of the prehistoric site of Tepe Sialk, and one of the world's major turquoise sources lies in the northeast corner of the plateau near Meshed. Both turquoise and copper were traded as far away as the Assyrian steppe zone by 6500 B.C. (*4*).

Herds of gazelle (*Gazella subgutturosa*) and wild ass (*Equus hemionus*) would have been available to hunters in the area, but without irrigation the high plateau is very marginal agricultural land; the only source of hope for the early farmer would have been the alluvial aprons of mountain soil produced where streams break through the Zagros to enter the salt lake basins. Despite the uncertain rainfall, some of these "oasis" locations appear to have been permanently settled by 5500 B.C., especially those near copper sources.

2) *The oak-pistachio woodland belt.* The Zagros Mountains break away from the eastern edge of the high plateau and descend in tiers toward the Tigris-Euphrates basin. In places the mountains form parallel ridges which are separated by long, narrow, synclinal or anticlinal valleys, frequently poor in surface water; in other areas there are irregular mountain masses bordering wide flat valleys. Acting as aquifers, these porous mountain masses may trap tremendous quantities of winter snow or rain and release it through springs, which in turn feed permanent poplar-bordered streams. At elevations of 600 to 1350 meters there are alluvial valleys of chernozem, chestnut, brown, or reddish-brown soils, with alpine meadows scattered through the surrounding peaks. Summers are warm and dry, winters cool and wet; depending on altitude and topography, the annual rainfall varies from 250 to 1000 millimeters, and hillsides have varying densities of oak, maple, juniper, hawthorn, pistachio, and wild pear. On well-watered slopes grow hard-grained annual grasses like wild emmer wheat (*Triticum dicocoides*), barley (*Hordeum spontaneum*), and oats (*Avena fatua*).

Much of the area is too rugged for large-scale agriculture, but even the narrower and drier valleys have been used for sheep or goat grazing since at least 8500 B.C.; broad valleys with annual rainfall in excess of 300 millimeters have been farmed for at least the same length of time.

3) *The Assyrian steppe.* The Zagros Mountains fall away through a series of foothills and eventually level off onto a steppe region of great natural winter grassland at elevations of 150 to 300 meters; these plains have reddish-brown or brown prairie soils of high fertility. Here the mountain streams have collected into larger rivers like the Tigris, Karkheh, Diz, and Karun, which flow into the area through erosional valleys and have wide, farmable floodplains. Hot and dry in the summer, the Assyrian steppe

The author is an associate curator of archeology in the United States National Museum, Smithsonian Institution, Washington, D.C.

is transformed by 250 to 380 millimeters of winter rain into meadows of Bermuda grass, canary grass, and wild narcissus. Herds of gazelle, wild ass, and wild cattle once roamed the plain, and the rivers had carp and catfish. The Assyrian steppe is oil country, and one of its most widely traded commodities in prehistoric time was bitumen or natural asphalt, used for cementing flint tools into their handles.

Some parts of the steppe, too salty for effective agriculture, are used for winter grazing. Other areas are real breadbaskets for winter wheat (like the upper Khabur plain; the area near Mosul, Iraq; or the Khuzistan plain of southwest Iran), and the density of prehistoric villages in these regions is staggering. Adams' comments on northern Khuzistan (*5*)—that the adequate rainfall, underlying gravels, and consequent good drainage in this zone facilitated the crucial transition from dry farming to irrigation—may apply to other favored parts of the steppes.

4) *Southern Mesopotamia.* Below 150 meters the Assyrian steppe gives way to the lower drainage of the Tigris, Euphrates, and Karun, as they flow together and empty into the Persian Gulf. Here the annual rainfall is under 250 millimeters (an amount usually inadequate for dry farming) and the grassland is replaced by two kinds of biotopes: alluvial desert and blowing sand dunes on higher ground, and reed-bordered swamps in the low-lying areas. The delta area is a subsiding geosyncline, slowly settling and filling with river alluvium, across which the big rivers run between their own natural levees, flooding and changing courses periodically (*6*). Contrary to what was once believed, the area has never been under the waters of the Persian Gulf (at least not since the Pliocene), and in prehistoric times it must have looked much as it does today. It was in this environmental zone that urban life, civilization, and writing began, about 3000 B.C. When permanent settlement began here is undetermined, but villages dating back

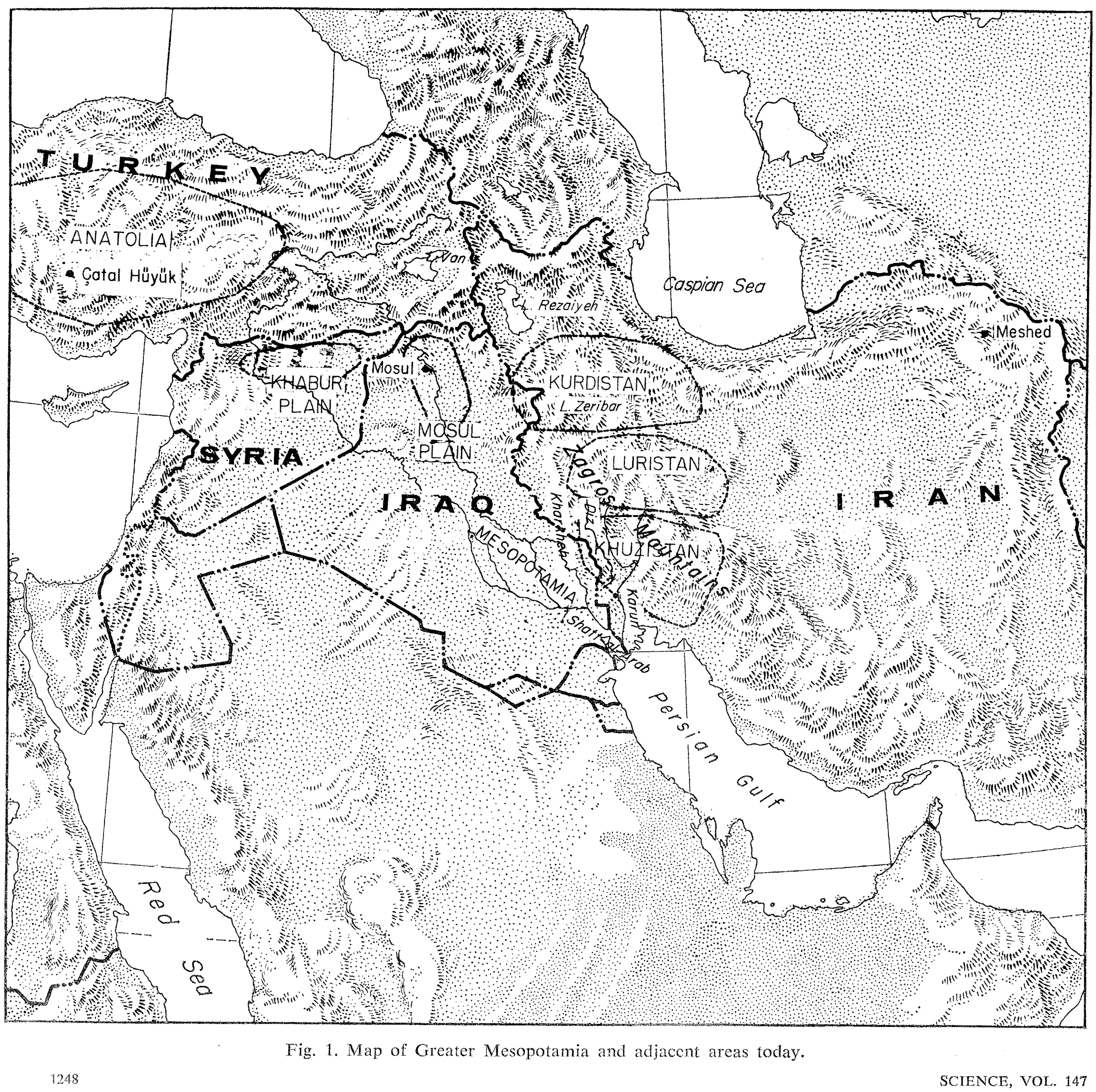

Fig. 1. Map of Greater Mesopotamia and adjacent areas today.

to 5500 B.C. are known even in the bleak area west of the Euphrates. Surely these villages must have followed the old swamps and watercourses, beyond which agriculture would have been impossible and grazing difficult.

The Local Climatic Sequence

The possibility that the environment in the Near East might have been different during the beginnings of agriculture has intrigued archeologists for generations. The few prehistoric pollen sequences we have suggest that, although some climatic fluctuations did occur, they were not on a scale capable of creating or destroying the complex of plants and animals that were eventually domesticated. The facts we have are too few to permit us to say dogmatically that climatic change played *no* role, but it appears that the problem is cultural rather than climatic; the inescapable conclusion is that agriculture began in an area where, then as now, only about 10 percent of the land surface is suitable for dry farming (*7*).

One pollen sequence comes from Lake Zeribar in the wooded mountains of western Iran, at an altitude of about 1200 meters. Studies by van Zeist and Wright (*8*) show that during the late Pleistocene the area was steppe, characterized by the sagebrush-like *Artemisia*, which implies a cool dry climate. About 11,000 B.C., at the end of the Pleistocene, the area became warmer and the vegetation made the transition to savanna, with scattered oaks and pistachios. The savanna thickened to oak forest about 3500 B.C., either through increased precipitation or through lowered temperature. Cereal-type pollen (possibly wild wheat and barley?) is present throughout the entire sequence, so climatic fluctuation would seem not to have been a

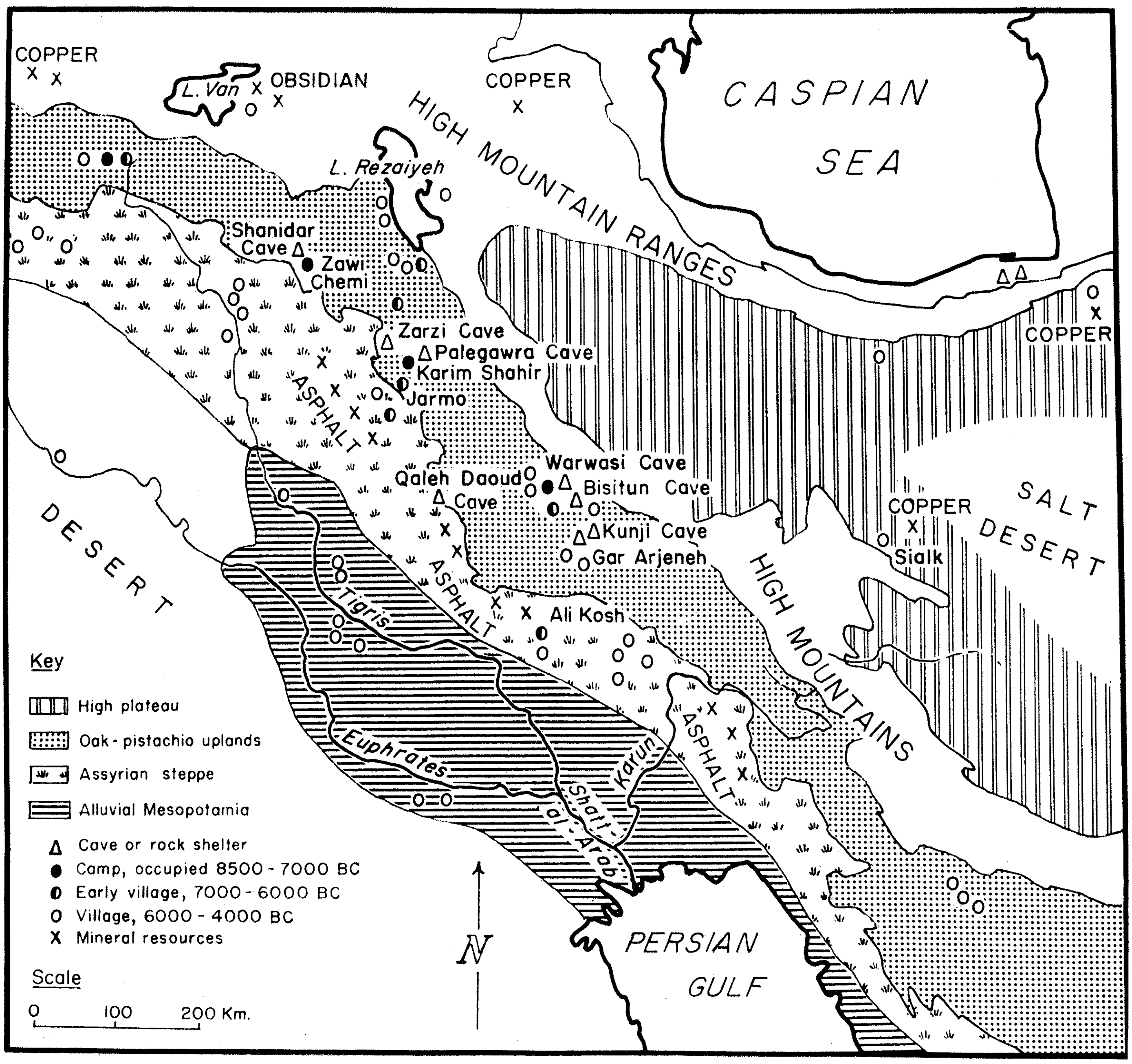

Fig. 2. Map of Greater Mesopotamia, showing environmental zones, mineral resources, and archeological sites. Only sites mentioned in the text are labeled.

determining factor in the beginning of agriculture there.

Six hundred meters lower, in the Zagros Mountains of Iraq, a slightly conflicting pollen story is available from human occupational debris in Shanidar Cave. More striking climatic fluctuations are implied, one of which Solecki interprets as the "shock stimulus" which triggered the beginnings of food production (*9*). Actually, however, the late-Pleistocene to early-Recent pollen sequence from Shanidar is not in much conflict with that from Lake Zeribar: at about 10,000 B.C. a "relatively cool climate" changed to "a warmer one similar to the present climate." Cereal pollen is known at least as early as 14,000 B.C., and potential animal domesticates (sheep and goat) are present in the cave debris even at 40,000 B.C.

Neither of these pollen sequences supports the age-old myth that the Near East was once lush and well watered, then suffered from desiccation. Nor do any of the inferred climatic fluctuations imply the sudden, overnight appearance of wheat, barley, sheep, or goats. I do not feel qualified to evaluate the "shock stimulus" theory, but I suspect that, although drastic climatic change explains why certain plants and animals become extinct, it does not explain how or why cultures change.

Pre-Agricultural Subsistence Pattern

Scattered caves, rock shelters, and open-air sites have given us only hints of how man lived in this part of the world before domestication of plants and animals. All appearances are that his way of life conformed to a flexible, "broad-spectrum" collecting pattern, keyed to the seasonal aspects of the wild resources of each environmental zone, with perhaps a certain amount of seasonal migration from zone to zone. The less mobile members of society appear to have collected such resources as snails, turtles, freshwater clams and crabs, and the seeds of wild annuals and perennials, while more mobile members pursued wild ungulates by special techniques, according to the species involved. Although cave remains include fish, birds, and small mammals, the bulk of the meat diet—often more than 90 percent (*10*)—came from ungulates, like the wild sheep, goat, ox, pig, wild ass, gazelle, and deer. Note that the first four were early domesticates.

Hunting patterns were influenced by the topography of the region. In the steep, rugged rockslide area around Shanidar Cave, wild goat (*Capra hircus*) was the animal most frequently taken. The goat, a resident of the limestone crags, is difficult to hunt by means of drives; it is best pursued by small groups of agile men who know their country well and are equipped with light projectiles. Rockshelters or caves overlooking broad, flat valleys are usually rich in the bones of the wild ass, a plains-dwelling animal which could best have been hunted by drives or surrounds, then dispatched with a larger weapon, like a thrusting spear. Gazelles and hares are also creatures of the flat valley, while the wild sheep of the Near East (*Ovis orientalis*) frequent rolling, round-top hills and are hunted today by ambush in the brushy stream-canyons where they hide during the noon hours. Some of the smaller rockshelters excavated in the Zagros Mountains seem to have been stations or overlooks used mainly for hunting or butchering a single species of ungulate, or two species at most (*11*).

In recent years the oak-pistachio uplands, in the 400- to 1000-millimeter rainfall belt at altitudes of 450 to 900 meters, have been singled out as an "optimum" zone which includes all the potential domesticates (*12*). Actually, topography is a much more important ecological factor for wild sheep and goats than either altitude or rainfall; sheep range down to sea level along the Caspian Sea, and up to 2700 meters in the Zagros Mountains, if rolling mountain meadows are available. Goats reach sea level on the foothills flanking the Persian Gulf, and are as much at home on the last rugged sandstone hills separating southwest Iran from southern Mesopotamia (180 meters above sea level) as they are on the 3000-meter crags of the northern Zagros. Pigs range over a wide area, from sea level to timberline, and if we knew more about the ecological requirements of wild cattle we might find their range equally broad (*13*). The crucial factor for hunters of wild ungulates, or early herders of semiwild ungulates, would have been the ability to move from upland to lowland as seasonal pasture was available, a pattern known as "transhumance."

Let me give one example. Khuzistan, the Iranian arm of the Assyrian steppe, is lush winter grassland from December to April while many of the mountains to the east are covered with snow. Through late spring and summer the steppe becomes blisteringly hot and dry, while the melting snow on the mountains gives rise to good spring and summer grassland. The Persian herder classifies the steppe as *quishlaq* (winter pasture) and the mountains as *yehlaq* (summer pasture), and he moves his herd from one to the other as the season demands. Prehistoric hunters may have followed game over the same route; and as for prehistoric herders, Adams reminds us (*5*): "It is, in fact, erroneous to consider the upper plains as a zone of occupance distinct from the surrounding uplands. Both together constitute a single natural ecosystem, whose seasonal alternation of resources provides as strong an inducement to migratory stockbreeding as to intensive, settled agriculture."

The wild plants of southwestern Asia have much the same seasonal aspect. MacNeish's work in the New World (*14*) has shown that a long period of intensive plant collecting preceded agriculture there; archeologists have long assumed that this was the case in the Near East, but preserved plant remains were not available to tell us which specific plants were used in the pre-agricultural era. New light was thrown on the problem in 1963 by a collection of some 10,000 carbonized seeds from basal levels at the site of Ali Kosh in lowland southwestern Iran (*15*). The area, a part of the Assyrian steppe, lies outside the range of wild wheat and barley, but locally available plants were intensively collected; the most common were wild alfalfa (*Medicago*) and the tiny-seeded wild legumes *Astragalus* and *Trigonella*, as well as fruits like the wild caper (*Capparis*), used today mainly as a condiment. These data indicate that intensive plant collecting may have been the pattern everywhere in southwest Asia, not merely at the altitude where wild wheat grows best. Moreover, the fact that *Astragalus* and *Trigonella* occur in the mountains as well as the lowlands suggests that prehistoric collectors could have harvested one crop on the Assyrian steppe in March, moved up to 600 meters for a harvest in April or May, and arrived at 1500 meters for another harvest in June or July. Somewhere between 600 and 1200 meters these migrant collectors could have harvested the seeds of the annual grasses ancestral to domestic wheat, barley, and oats. These cereals, which are dependent on annual rainfall of 400 to 750 millimeters, do not range down to the Assyrian steppe today, although they are available over a surprisingly wide area; according to Helbaek (*16*), wild barley "grows in the mountain forest, on the coastal plain, in the shade of rock outcrops in semidesert areas, and as a weed in the fields of every conceivable cultivated crop" from Morocco to Turkestan.

Other plants useful to the collector —and eventually, in some cases, to the primitive cultivator—were ryegrass (*Lolium*), *Aegilops* grass, wild flax (*Linum bienne*), and large-seeded wild legumes like lentil, vetch, vetchling, chick pea, and *Prosopis* (a relative of mesquite). The lowlands had dates; the foothills had acorns, almonds, and pistachios; and the northern mountains had grapes, apples, and pears.

Most of the important species occurred in more than one zone, and their months of availability were slightly different at different altitudes —key factors from the standpoint of human ecology. An incredibly varied fare was available to the hunter-collector who knew which plants and animals were available in each season in each environmental zone; which niche or "microenvironment" the species was concentrated in, such as hillside, cliff, or stream plain; which species could be stored best, and which it was most practical to hunt or collect. From 40,000 to 10,000 B.C., man worked out a pattern for exploiting the natural resources of this part of the world, and I suspect that this pre-agricultural pattern had more to do with the beginnings of food production than any climatic "shock stimulus."

Beginnings of Food Production

Leslie White reminds us (*17*) that "we are not to think of the origin of agriculture as due to the chance discovery that seeds thrown away from a meal subsequently sprouted. Mankind knew all this and more for tens of thousands of years before cultivation of plants began." The cultivation of plants required no new facts or knowledge, but was simply a new kind of relationship between man and the plants with which he was most familiar.

One striking aspect of the late pre-agricultural pattern in the Greater Mesopotamian area was the trading of obsidian from its source in central and eastern Turkey to cave sites in the central Zagros, such as Zarzi and Shanidar (*9, 12*). Natural asphalt was traded in the opposite direction, up from the tar pits of the Assyrian steppe to campsites in the mountains, wherever flints had to be hafted. By 7000 B.C., handfuls of emmer wheat from the oak-pistachio belt had reached the lowland steppe of Khuzistan (*4*). Typical of the prehistoric Near Easterner was this penchant for moving commodities from niche to niche within environmental zones, and even from zone to zone.

It has been argued that the last millennia of the pre-agricultural era were a time of "settling in" to one's area, of increasing intensification and regionalization of the exploitation of natural resources (*12*, p. 180). This is indeed reflected in the flint tools, but such "regional specialization" may not be the essential trend which led to food production. From the standpoint of human ecology, the single most important factor may have been the establishment of the above-mentioned pattern of interchange of resources between groups exploiting contrasting environmental situations—a kind of primitive redistribution system. It was this pattern that set the stage for the removal of certain key species of edible grasses from the niches in which they were indigenous, and their transferral to niches to which they were foreign.

With the wisdom of hindsight we can see that, when the first seeds had been planted, the trend from "food collecting" to "food producing" was under way. But from an ecological standpoint the important point is not that man *planted* wheat but that he (i) moved it to niches to which it was not adapted, (ii) removed certain pressures of natural selection, which allowed more deviants from the normal phenotype to survive, and (iii) eventually selected for characters not beneficial under conditions of natural selection.

All that the "settling in" process did for the prehistoric collector was to teach him that wild wheat grew from seeds that fell to the ground in July, sprouted on the mountain talus in February, and would be available to him in usable form if he arrived for a harvest in May. His access to those mature seeds put him in a good position to bargain with the goat-hunters in the mountain meadow above him. He may have viewed the first planting of seeds merely as the transfer of a useful wild grass from a niche that was hard to reach—like the talus below a limestone cliff—to an accessible niche, like the disturbed soil around his camp on a nearby stream terrace. Happily for man, wild wheat and barley both grow well on disturbed soils; they will sprout on the back-dirt pile of an archeological excavation, and they probably did equally well on the midden outside a prehistoric camp (*16*). It is obvious from the rapid spread of agriculture in the Mesopotamian area that they grew as readily on the midden outside the forager's winter camp at 180 meters as they did in his summer camp at 900 meters, in the "optimum" zone.

Viewed in these terms the advent of cultivation may have been a rather undramatic event, and the concept of "incipient cultivation" (*12*) becomes rather hard to define. Was it a fumbling attempt at cultivation, or only the intensification of an already existent system of interregional exchange?

Biological Obstacles to Early Food Production

The transfer of species from habitat to habitat made the products of all zones available to all people; but it was a process not without difficulty, since some of the plant and animal species involved had not yet developed the most tractable or productive phenotypes, from man's point of view.

Some of the biological obstacles faced by early agriculturalists were as follows.

1) The difficulty of harvesting wild, brittle-rachis grains. One adaptive mechanism for seed dispersal in wild wheat and barley is a brittle rachis or axis which holds the seeds together in the mature head of grain. When a dry, ripe head of wild barley is struck by a twig or a gust of wind, the rachis disintegrates and the seeds are spread far and wide (*18*). The disadvantages of this mechanism for the prehistoric collector are obvious: the slightest tug on the stem of the plant or the slightest blow with a flint sickle might send the seeds scattering in every direction.

2) The difficulty of removing the grain from its husk. Even after a successful harvest, the prehistoric collec-

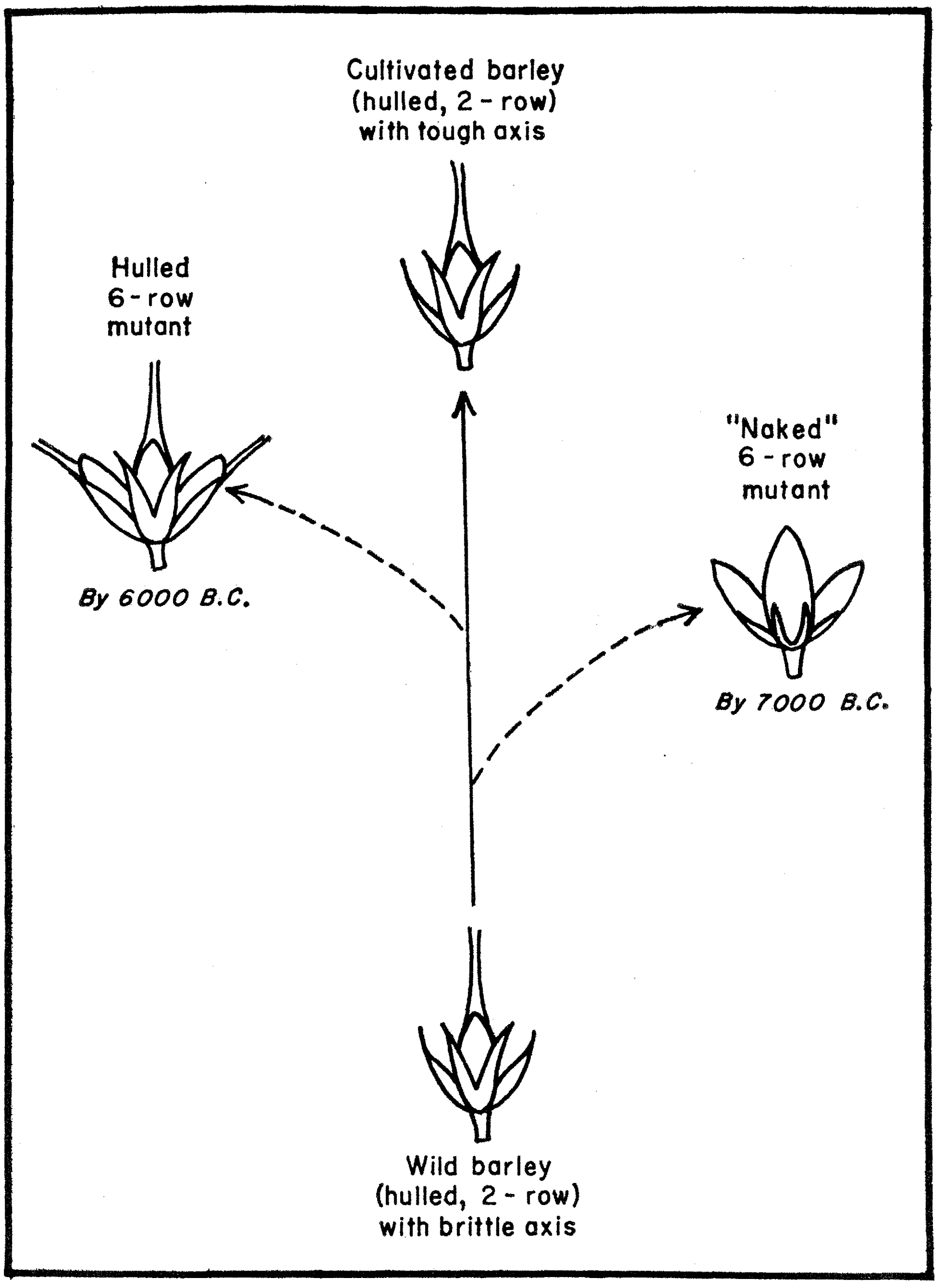

Fig. 3. Simplified diagrams of barley spikelets, showing some of the changes which took place after domestication. Data courtesy of Helbaek (see text).

tor's troubles were not over. Primitive grains like emmer or einkorn wheat have a tough husk, or glume, which holds each kernel in a stubborn grip long after the brittle rachis has disintegrated. Even vigorous threshing will usually not release these primitive grains from the glume so that they can be eaten.

3) The difficulty of farming in the niche to which the grain was adapted. Both wild wheat and barley are grasses of hillsides and slopes, and they usually do not occur on the flat stream floodplains, where it would have been most convenient for prehistoric man to farm. The deep alluvial soils in the valley centers, prime areas from an agricultural standpoint, were already occupied by competing grasses and wild legumes.

Research on archeological grain remains by Danish botanist Hans Helbaek has shown us some of the ways in which early farmers either consciously or unconsciously overcame these three obstacles.

1) Selection for tough-rachis grains. Within the gene pool of wild wheat and barley were variants whose rachis was tough enough so that it did not shatter on contact. Normally these variants would have left few descendents, because of the inadequacy of their seed-dispersal mechanism. When man harvested with sickles or flails, however, he automatically selected *for* the tough-rachis grains because their heads stayed intact despite the rough treatment of the harvest. When seeds from the harvest were planted, the next generation of plants contained an abnormally high proportion of tough-rachis individuals, and each successive generation reinforced the trend.

2) The development of techniques for removing the seeds from their glumes. Sometime before 7000 B.C. man discovered that by roasting the grain he had collected he could render the glumes so dry and brittle that they could be crushed by abrasion; roasting, moreover, killed the wheat or barley germ so that it would not sprout, and the grain could be stored even through the winter rainy season. Many of the preceramic villages excavated throughout the Near East contain clay ovens appropriate for roasting grain in this manner, and nearly all seem to have stone grinding slabs of one kind or another on which the dry grain could be abraded out of its glume. Further grinding resulted in "groats," or coarse grits of grain which could be cooked up into a mush or gruel. (By and large, the tough-glumed primitive grains were unsuitable for bread-making.)

3) Actual genetic change in the grain species themselves, resulting in new strains. Because early cultivated grain was somewhat shielded by man from the natural selection pressures to which uncultivated grain was subjected, the chance that random mutants would survive was much greater. One of the first mutations that occurred, apparently, was a change from the standard adhering-glume kernel to a "naked" kernel which could be easily freed by threshing. According to Stubbe (*19*), a single gene controls the difference between "hulled" and "naked" barley, and when a mutation took place at that locus, sometime before 7000 B.C., free-threshing barley was born. A second genetic change was that which transformed standard wild barley (*Hordeum spontaneum*), which has only two fertile kernel rows, into mutant barley with six fertile rows (*Hordeum hexastichum*). Helbaek, who has actually produced the six-row mutant in his laboratory by subjecting wild two-row barley to x-rays (*20*), feels that ecological factors probably determined the early distribution of these two strains: two-row barley is adapted to the fairly late (April and May) rainfall of the

cool Zagros Mountain uplands, while mutant six-row barley may be more successfully adapted to much drier spring weather and the irrigation farming of the Mesopotamian plain (*16*). Archeological remains tend to support this. The two-row form seems to be the only one known so far from the highlands before 5000 B.C., while six-row barley is known from lowland Khuzistan by 6000 B.C.; the two-row strain does not seem to have caught on in the lowlands, possibly because it was poorly adapted to the climate there. Present data, in fact, suggest that although the cool uplands probably contributed the original ancestor (two-row hulled barley) it may have been the lowland ecology which stabilized the important "naked" and "six-row" strains (see Fig. 3).

Another important early genetic change was polyploidy, an actual increase in the chromosome number, which produced new strains of wheat. Wild emmer wheat (*Triticum dicoccoides*) is tetraploid—that is, it contains 4 × 7 chromosomes and has tough glumes enclosing the kernels. A native annual grass of well-watered mountains, it prefers the 400- to 750-millimeter rainfall zone, from Palestine and Syria to the Zagros Mountains of Iran and Iraq. By 6000 B.C., however, on the Anatolian plateau of central Turkey, a mutant had been produced which was free-threshing: this was hexaploid wheat (*Triticum aestivum*), with 6 × 7 chromosomes (*18*). Such polyploid strains, together with irrigation, were instrumental in the spread of free-threshing wheat throughout southwest Asia.

Mutations and changes in gene frequency also played a role in the establishment of races of domestic animals, and once again there were biological obstacles to be overcome by early herders. Some of the adaptive and nonadaptive changes which took place were as follows.

1) A change in the sex and age ratios within the captive population. If early herds of domesticated sheep or goats were small, as we assume they were, how did the animals avoid being eaten during the winter and survive until the spring lambing season? Work by Charles A. Reed (*21*) and Dexter Perkins (*10*) on archeological bones from early villages in Kurdistan suggests that some kind of conservation may have been practiced. Perkins notes that the proportion of immature sheep relative to adult sheep at Zawi Chemi, Iraq, was far higher than that in any normal wild herd, an observation from which he infers domestication (*22*). Evidently the young animals were eaten, while the older breeding stock was saved. The practice was much the same at the village of Jarmo, where Reed noted a high proportion of butchered young males, as if the females were being held back for breeding. Such practices would have resulted in an abnormally high proportion of adult females in the herd, and consequently in milk surpluses in late winter and early spring. Although wild sheep and goats produce very little milk in comparison to today's domestic breeds, such seasonal surpluses may eventually have been exploited by early herders. Today, milk, yogurt, and cheese are part of the whole trading complex of southwest Asian pastoralists.

2) Changes leading to wool production. Wild sheep (*Ovis orientalis*) have a coat like a deer or gazelle, and are no woolier than the latter. Microscopic examination of their skin reveals two kinds of follicles: "primaries," or hair follicles which produce the visible coat, and "secondaries," which produce the hidden, wooly underfur. In the skin of wild *Ovis* the secondary follicles lie intermingled with the pri-

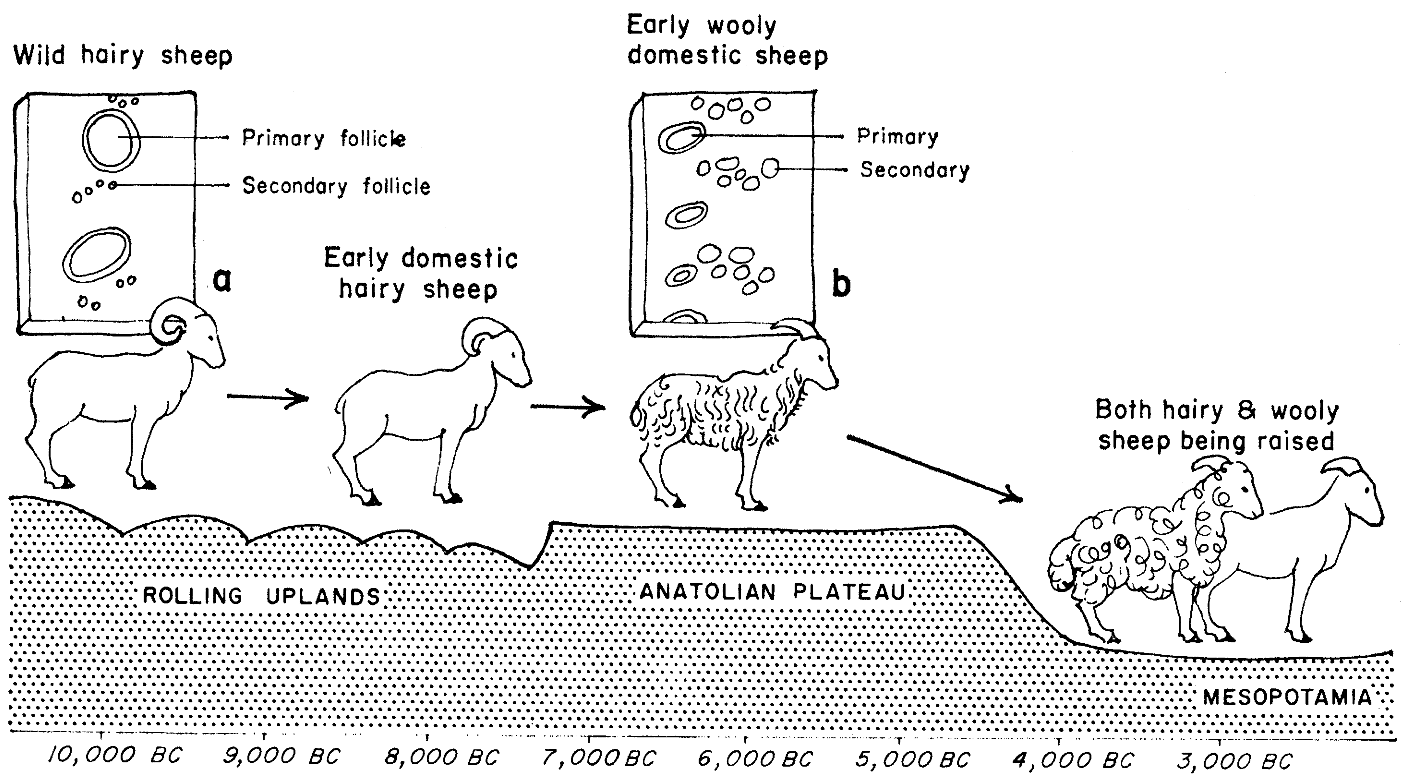

Fig. 4. Simplified diagram showing some of the steps in the evolution of domestic sheep. (*a*) Section, as seen through a microscope, of skin of wild sheep, showing the arrangement of primary (hair) and secondary (wool) follicles; (*b*) section, similarly enlarged, of skin of domestic sheep, showing the changed relationship and the change in the size of follicles that accompanied the development of wool. [After Ryder (*23*); see text]

maries in groups of three to five. After domestication, genetic changes moved the secondaries out to the side, away from the primaries, and greatly increased their numbers; while wild strains of sheep or goat may have a ratio of only two to four secondaries for each primary, the ratio may be as high as seven to one in fine Merino sheep. The wool of the domestic sheep grows from these dense clusters of secondary follicles (*23*). Wool may already have been spun as early as 6000 B.C. at Çatal Hüyük in Anatolia (*24*). Both "hairy" and "wooly" sheep were known by 3000 B.C. in Mesopotamia (*25*), and the now-famous Dead Sea Scrolls, dating to the time of Christ, have been shown by Ryder (*23*) to have been written on parchment made both from hairy and from wooly sheep (see Fig. 4).

3) Nonadaptive genetic changes, such as the twisted horns of domestic goats. One of the most interesting (if poorly understood) changes which followed domestication was one affecting the horns of the goat (*Capra hircus*). The wild goat of the Near East has scimitar-shaped horns whose bony cores are quadrangular or diamond-shaped in cross section near the skull. Sites dating from 8500 to 7000 B.C. are known where goat domestication is inferred from the ratio of immature animals to adult animals, but no changes in the cross section of the horn during this period are noted. By 6500 B.C., from the Jordan Valley to the Zagros Mountains, there are scattered occurrences of goats whose horn cores show a flattening of the medial surface, and thus a triangular or almond-shaped cross section. By 6000 B.C. in the Mesopotamian area, from the Assyrian steppe to the oak-pistachio woodlands, a new type of horn core makes its appearance: the core is medially flattened in section, and it also shows signs of a corkscrew twist like that of the modern domestic goat in southwest Asia. The irregular geographic distribution of the trait suggests that it was strongest in the Iran-Iraq area, occurring only sporadically elsewhere before 4500 B.C.; even at 3500 B.C. not all sites in the Palestinian area show goats of a uniformly "twisted horn" type (*21*). Possibly its rapid spread in the Zagros was due to transhumant herding (see Fig. 5).

4) The problem of pig domestication. One of the questions most frequently asked is why the pig was domesticated at 6000 B.C. in some parts of the Near East, like the Zagros Mountain valleys (*26*), but was apparently never domesticated in prehistoric time in other areas, such as the Khuzistan steppe (*4*). The most common answer is that this was the result of religious or dietary laws; but in fact, the reasons may be ecological. According to Krader (*27*), "the disappearance of the pig from Central Asia is not the clear-cut case of religious determination that might be supposed. The pig is not a species suitable to pastoral nomadism . . . it is nomadism with its mastery of the steppe ecology and movements of herds and herdsmen which is the decisive factor in the disappearance of pigs from this part of the world." Figure 5 shows the sites where domestic pigs are known either to have been, or not to have been, present in the Mesopotamian area between 6000 and 5000 B.C. Since pigs seem to be incompatible with transhumant herding, the areas where they do *not* occur may be those where there was greatest reliance on seasonal movement of flocks.

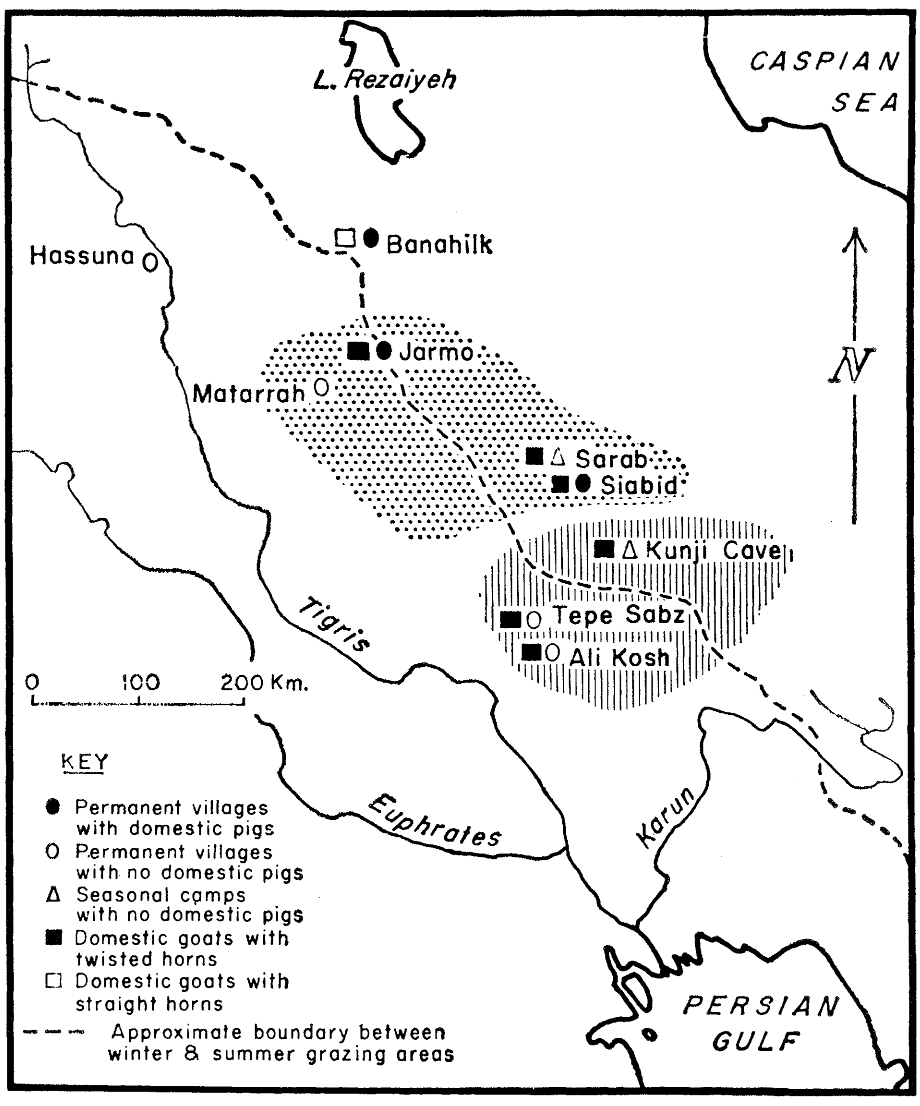

Fig. 5. Map of Greater Mesopotamia, showing areas where transhumance is believed to have been of importance in prehistoric times. Ceramic objects from sites in the stippled area (Jarmo, Sarab, Matarrah) all have one set of traits; those from sites in the hachured area (Kunji, Ali Kosh, Tepe Sabz) all have another set. The rapid spread of the twisted-horn goat in both areas suggests that flocks may have been moved from one elevation to another seasonally; so does the almost complete absence of the domestic pig, an animal unsuitable for transhumant herding. In the summer grazing area (northeast of the dashed line), many sites appear to be seasonal shepherds' camps in caves or on valley floors. These camps seem to have stronger ties, from the standpoint of traits of ceramic objects, with sites in the adjacent winter grazing area (southwest of the dashed line) than with other sites in their own environmental zone (see text).

Effects on Human Life and Cultural Ecology

In the past it has been customary to treat each of the Mesopotamian environmental zones as if it were a "cultural and natural area"—a region characterized by a certain flora and fauna and exploited by a certain group of inhabitants who knew it particularly well (*28*). There are hints that such a situation obtained in Palestine, for there Perrot (*2*, p. 162) has distinguished two archeological traditions, one adapted to the moist Mediterranean side of the mountains, the other adapted to the arid eastern foothills.

In 1956 Fredrik Barth pointed out that the "cultural and natural area" concept did not fit northern Pakistan, and there are a considerable number of data to suggest that it does not fit the Mesopotamian area at 6000 B.C. either. Barth showed that a single valley system might be occupied by three distinct ethnic groups, each of which occupied only a portion of the total resources, leaving the rest open for other groups to exploit. The first group consists of sedentary agriculturalists who practice intensive irrigation agriculture on the river floodplain, growing two crops a year and never moving to a higher elevation. A second group raises one crop a year in this same floodplain area, but its members also migrate annually with their flocks up through five seasonal campsites to high mountain meadows. Still a third group is made up of pastoral nomads who are assimilated into the society of the intensive agriculturalists as a special "herder caste," contributing milk and meat in exchange for grain; they are permitted to use prime grazing land not needed by the sedentary farmers (*29*).

At 6000 B.C. there are striking contrasts between archeological sites in the oak-pistachio belt and the Assyrian steppe of the Greater Mesopotamian area which suggest Barth's model. Jarmo, at an elevation of 750 meters in the oak woodlands, was a village of permanent, mud-walled houses with courtyards and ovens; Tepe Sarab, at an elevation of 1260 meters, has no obvious houses, and only the kind of ashy refuse beds that might occur around a tent camp. The pottery objects at the two sites are nearly identical, but Jarmo has goats, sheep, and even domestic pigs, along with two strains of wheat and one of barley, whereas Tepe Sarab has only goats and sheep, and no grinding stones suggestive of local agriculture. The ages of the domestic goats show that Tepe Sarab was occupied in late winter or early spring. In this case we suspect that the camp at 1260 meters may have been occupied by seasonal herders who obtained their grain from more permanent farming villages at 750 meters (*1, 30*).

From the Assyrian steppe of Khuzistan, southwestern Iran, come further data of the same type. From 7000 to 6500 B.C. at the site of Ali Kosh, goat grazing and tiny amounts of agriculture supplemented the collection of wild legumes; from 6500 to 6000 B.C. the growing of wheat and barley greatly increased at the expense of wild plants. At 6000 B.C. a striking expansion of sheep and goat grazing occurred, and amounts of wild wheat and wild barley lessened, while the pod-bearing perennial *Prosopis* came to the fore (*4*). We doubt that this was a simple case of abandonment of agriculture; *Prosopis*, Helbaek reminds us, is intimately associated with herding peoples in southwest Asia, and the increase in domestic sheep and goats suggests that this was a time when, in conformity with Barth's ecological model, Ali Kosh became primarily a "herding village" coexisting in a symbiotic framework with "farming villages" in adjacent areas.

Finally, we have the occurrences of typical Khuzistan pottery at a shepherds' camp in Kunji Cave, 1200 meters up, in the mountains of western Iran (*31*). This part of Luristan seems to have stronger cultural ties with lowland Khuzistan than with other mountain areas in the same environmental zone, suggesting that at 6000 B.C. some valleys in Luristan were summer grazing land for herds that wintered in Khuzistan.

Summary and Speculation

The food-producing revolution in southwestern Asia is here viewed not as the brilliant invention of one group or the product of a single environmental zone, but as the result of a long process of changing ecological relationships between groups of men (living at varying altitudes and in different environmental settings) and the locally available plants and animals which they had been exploiting on a shifting, seasonal basis. In the course of making available to all groups the natural resources of every environmental zone, man had to remove from their natural contexts a number of hard-grained grasses and several species of ungulates. These species, as well as obsidian and native copper, were transported far from the biotopes or "niches" in which they had been at home. Shielded from natural selection by man, these small breeding populations underwent genetic change in the environment to which they had been transplanted, and favorable changes were emphasized by the practices of the early planter or herder.

Successful cultivation seems to have intensified exchanges of natural resources and cultivars between groups, and there are hints that the diversity of environments made village specialization in certain commodities the best means of adapting to the area. We have suggestive evidence that by 4000 B.C. the redistributive economy had produced regional temple-and-market towns which regulated the produce of a symbiotic network of agriculturists engaged in intensive irrigation, transhumant herders, and perhaps even traders who dealt in obsidian, copper, salt, asphalt, fish, and regional fruits (*4*).

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31. F. Hole (of Rice University) and I made a test excavation of Kunji Cave in 1963; the data have not been published.
32. Much of the research leading to discoveries mentioned in this article was made possible by National Science Foundation grants to R. J. Braidwood of the University of Chicago (1959–60) and Frank Hole of Rice University (1963). Hans Helbaek, Frank Hole, and James Neely made suggestions which led to the formulation of many of the ideas presented. I thank Nancy H. Flannery for preparing Figs. 2–5.

Crystallization and Molecular Folding

The properties of high polymers are very sensitive to the way molecules fold during crystallization.

P. H. Lindenmeyer

The physical and in some instances even the chemical properties of crystalline high polymers can be varied over a rather wide range by thermal and mechanical treatments during their transformation into the solid state. For example, polyethylene can be converted from its usual tough, ductile, easily deformable form into a brittle, easily crushed, powdery material by controlling the conditions under which it is crystallized. These changes are reversible and therefore represent changes in the physical state rather than chemical decomposition.

Early attempts to explain the properties of crystalline high polymers evolved the "fringed-micelle" concept (*1*), in which small crystalline "micelles" were assumed to be completely embedded in an amorphous matrix of uncrystallized polymer. Since the polymer molecule was known to be many times longer than the crystalline micelle (or crystallite), a given polymer molecule was assumed to pass from one crystallite to another through the diffuse boundary or "fringed" ends of the crystalline "micelle." The crystallites were believed to act in many ways like cross-links in a rubber-like network of amorphous polymer. The plastic properties of crystalline polymers were assumed to be largely due to the matrix of amorphous polymer surrounding the crystallite, and the variation in these properties was attributed to the size and shape of these crystalline regions and to the fraction of polymer in the crystalline state (that is, the so-called degree of crystallinity). The "fringed-micelle" concept has proved to be extremely useful in qualitatively explaining many phenomena involved in the variation of the properties of crystalline polymers.

In 1949 Flory (*2*) introduced a theory of polymer crystallization which showed that a true thermodynamic equilibrium can exist between a crystalline and an amorphous phase at or near the melting temperature. This theory predicted the extent by which the melting point would be lowered by the presence of impurities, diluents, and noncrystallizable polymer segments. Although most of the predictions of Flory's theory have been subsequently verified, this has had very little effect on the "fringed-micelle" concept, and many workers in the polymer field still visualize a crystalline polymer as consisting of small crystalline regions completely surrounded by an amorphous material.

It was not until the discovery in 1957 (*3–5*) that single crystals of polyethylene of high molecular weight could be grown from dilute solution by a process of molecular chain-folding that people seriously began to question the "fringed-micelle" or crystalline-amorphous concept. The idea that long polymer molecules might crystallize by folding up into thin platelets (or lamellae), as proposed by Keller (*4*), had never been taken seriously, although evidence of lamellar structure and even of single crystals had appeared in the literature (*6*) much earlier. A considerable amount of activity has been devoted in recent years to an attempt to determine why, how, and under what conditions polymer molecules fold when they crystallize. Much to the surprise of almost everyone, it now appears that crystallization of polymers by some sort of molecular chain-folding mechanism is indeed the usual mode of crystallization, not only from dilute solution but also from the melt. In fact, it now seems very likely that crystalline polymers owe their desirable plastic properties to the fact that their molecules are folded in the crystal and can subsequently unfold to produce the large plastic deformations so characteristic of these materials. Thus a more quantitative understanding of the physical properties of crystalline high polymers lies in understanding why, how, and to what extent

The author is manager of Fiber Science at the Chemstrand Research Center, Durham, North Carolina.