Anthropogenic Sedimentological Changes during the Holocene in Mexico and Central America

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For Middle America this paper briefly describes the erosion and sedimentation processes. The data reviewed indicate that only very few records concerning Holocene anthropogenic sedimentation exist.—Man's impact on the soil environment is felt and registered in form of increasing sedimentation rates in the central Mexican highland over the past 2500—3000 years, in the Maya lowlands during the past 2500 years, and in the areas of the middle classic Maya colonization during the past 1500 years. During the last decades it appears that agricultural activities have accelerated soil erosion in a great extend all over Mexico and Central America. This will lead to one of the greatest environmental impoverishments that did not occur at any time of the Holocene.

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General geographic and climatic characteristics

Middle America is defined here as the land which extends from the U.S.A. southwards and eastwards to the Atrato Lowlands in Colombia. It thus takes in the territory of the eight republics of Mexico, Guatemala, Belize, Honduras, El Salvador, Nicaragua, Costa Rica, and Panama. The territory covered by the countries mentioned stretches from latitude 32° to 7° N and from longitude 77° to 117° W. Its longitudinal axis, which runs NW/SE, is 4,800 km long and the total mainland area covered is 2,5 million km^2.

Few parts of the earth of similar size have such a varied and complex surface configuration and geology as Mexico and Central America. Most of this area is high and mountainous. Plateaus bordered by steep, rugged escarpments range from 1200 to 2500 m in altitude and individual volcanic peaks tower more than 5000 m above the sea. Lowlands consist mainly of relatively narrow coastal strips and occasional inland depressions or deep valleys. The flattish Yucatan Peninsula is the only extensive lowland of all Middle America. The great diversity of surface configuration, together with the complex pattern of climate, vegetation, and animal life, has here afforded man a large number of natural environments in which to live (West, 1964a) (Fig. 1).

According to morphotectonic features Middle America can be divided up into two large units which differ completely from each other as regards geological history and structure. The northern part exhibits a continental type of crust with Paleozoic or even older metamorphic rocks, anatexites, and plutonites; they are overlain by Upper Paleozoic, Mesozoic, and Tertiary sediments which underwent deformation. In the Tertiary and Quaternary Northern Central America and central and southern Mexico were the scene of an extremely violent continental volcanism. The southern part, from about Nicaragua to Panama, is formed by Cretaceous oceanic type crust on which thick marine sediments and volcanics were deposited during the Tertiary (Weyl, 1980). Middle America lies in the circumpacific seismic

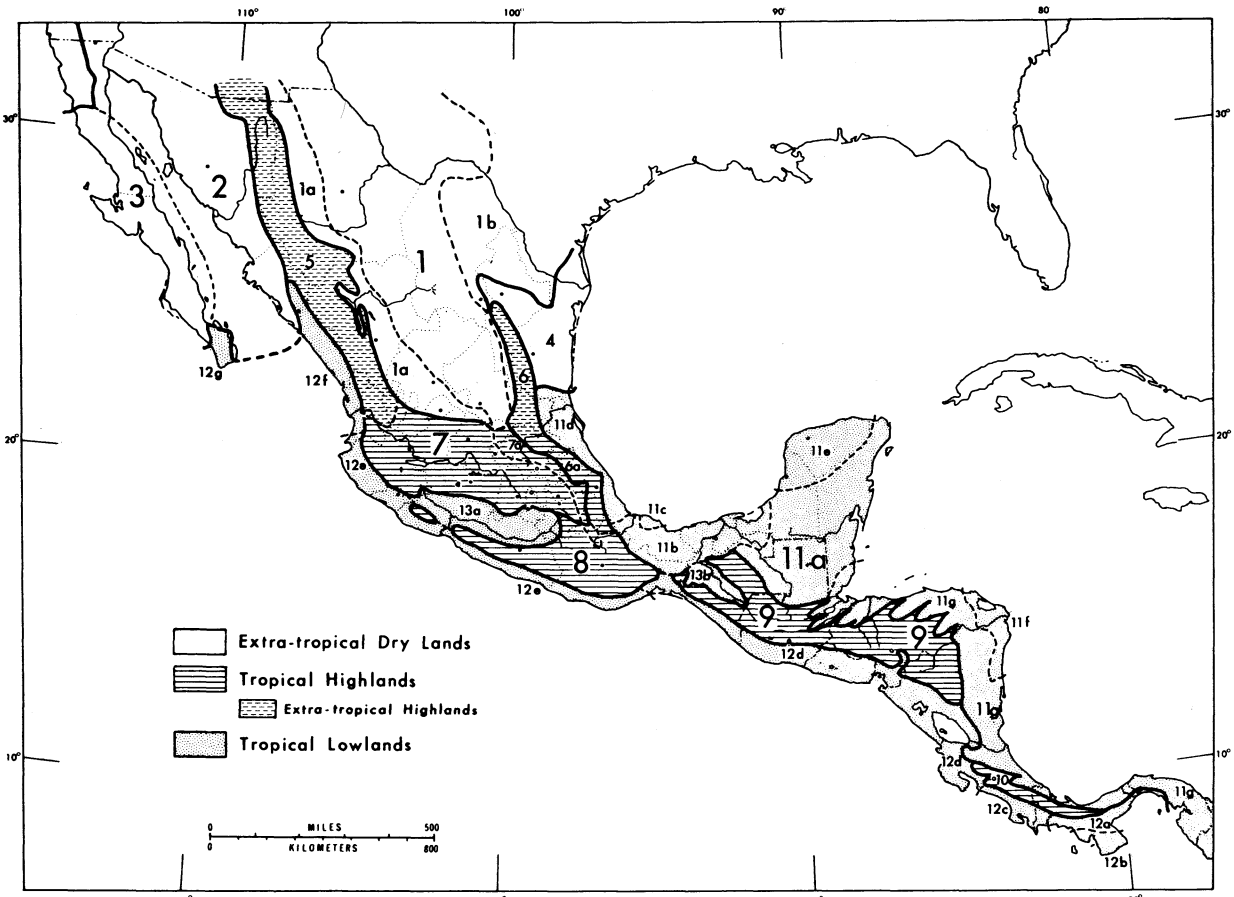

Fig. 1. The natural regions of Middle America (after West, 1964b).

Key to numbered subdivisions in fig. 1:

A. Extratropical dry lands
1. Mesa del Norte (desert)
   1a. Steppe lands of western margin
   1b. Steppe lands of eastern Coahuila and northern Nuevo Leon
2. Sonora and northern Sinaloa
3. Baja California
4. Tamaulipas subhumid lowlands

B. Tropical highlands and extratropical appendages
5. Sierra madre Occidental
6. Sierra Madre Oriental
   6a. Tropicla extension of the Sierra and eastern plateau escarpment
7. Mesa Central
   7a. Arid rain-shadow strip
8. Sierra and Mesa del Sur
9. Highlands of northern Central America
10. Highlands of Costa Rica and western Panama

C. Tropical lowlands
11. Caribbean-Gulf lowlands
    11a. Peten-Yuctan rain-forest area
    11b. Southern Veracruz-Tabasco rain-forest area
    11c. Los Tuxtlas
    11d. Deciduous forest area of northern Veracruz
    11e. Northern Yuctan
    11f. Mosquito coast
    11g. Caribbean rain-forest area of Central America
12. Pacific lowlands
    12a. Savanna of Central Panama
    12b. Azuero rain-forest area
    12c. Rain forest of wouthwestern Costa Rica
    12d. Volcanic lowlands of Central America
    12e. Coastal lowlands of southwestern Mexico
    12f. Coastal lowlands of Nayarit-Sinaloa
    12g. Cape region of Baja California
13. Dry interior tropical basins
    13a. Balsas-Tepalcatepec basin
    13b. Valley of Chiapas

belt; the main earthquake zone is situated near the Pacific coast.

In keeping with its diversity of geology, surface configuration, and climate, Middle America is characterized by a large variety of terrestrial water features; surface streams range from the ephemeral channels of the northern deserts to the wide, perennial rivers of the wet eastern versant of southern Mexico and Central America. In areas of porous limestone, such as Yucatan, underground water channels typify the drainage. In much of the arid northern plateau of Mexico and in districts of recent volcanism streams flow into interior basins rather than to the sea. Lakes of many types and in various stages of development are found throughout Middle America. Springs are prevalent particularly in both young volcanic and limestone regions, where they often form sources of headwater streams. The terrestrial hydrography of Mexico and Central America has been of special significance to man since Pleistocene, and continues to be so today. In preconquest times the streams,

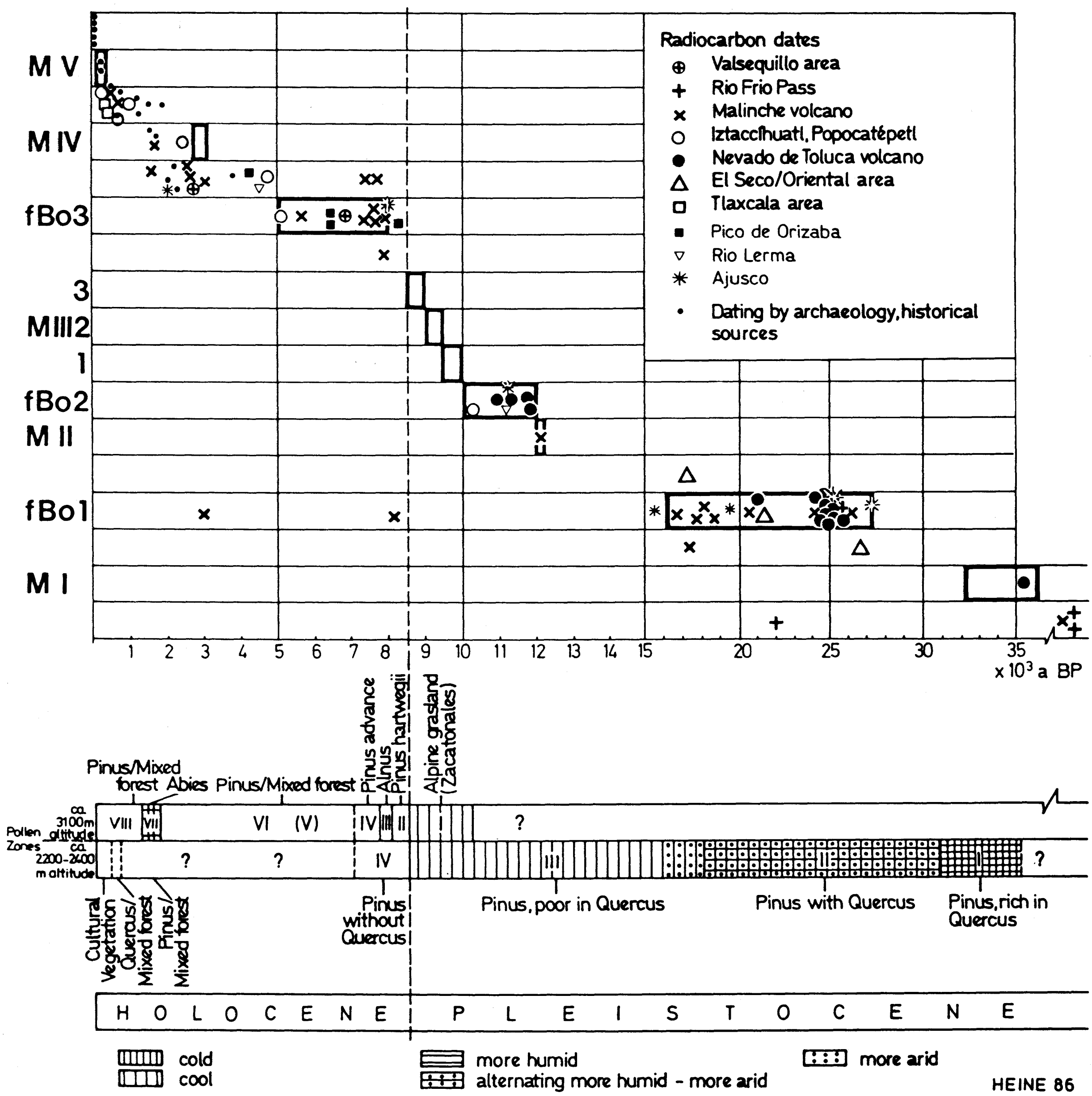

Fig. 2. Correlation diagram. Geologic-climatic unit boundaries are based on radiocarbon ages, tephrochronologic correlations, soil development, pollenanalyses, sedimentologic criteria, and topographic position. The pollen zones refer to Ohngemach and Straka (1983).

lakes, and springs afforded man water for sustenance, aquatic plant and animal life for food, moisture for rudimentary irrigation, and in some places a water surface for transport (Tamayo, 1964).

Middle America is affected throughout the year by the northeast trade winds; this air flow not only moves horizontally, but also trends upwards as it approaches the thermal equator, then causing heavy rainfall. During the summer the thermal equator migrates northwards to about latitude 12° N bringing on the rainy season over much of Central America and southern and central Mexico. Most of the year the trade winds are forced to rise and cool along high, windward-facing mountain slopes; hence, the high escarpments along the Gulf of Mexico and the Caribbean are enveloped in cloud and drenched with moisture for most of the year. The deserts and steppes of northern and northwestern Mexico are under the influence of the subtropical high pressure belt of calms during the entire year; occasional precipitation in northern Mexico originates in local convectional summer storms or in incursions of cold fronts of the midlatitude westerly wind belt. Furthermore large masses of cold polar air from central north America and Canada ("northers") penetrate into Mexico and Central America from October to May. Tropical cyclones affect mainly the Caribbean and eastern coasts of Mexico during August through October. According to the foregoing aspects a great diversity characterizes the weather and climate of Middle America. The temperature of the air and the amount of rainfall vary enormously from place to place. Hot, humid lowlands are only a few tens of kilometer distant from cool, dry highlands. Parts of northwest Mexico receive less than 100 mm of rain yearly, contrasting with the Caribbean coast of Central America, where in places over 6000 mm rain falls annually. This diversity of temperature and precipitation is fundamental in the distribution of natural vegetation and is reflected in various facets of aboriginal culture, such as agriculture and shelter (Vivó Escoto, 1964).

The exact nature of distribution, environments, and man's past influence on the natural vegetation are not well known for parts of Middle America. The region contains a rich diversity of flora and vegetation cover ranging from extreme desert and alpine grasland to tropical rain forest. In accordance with the complex patterns of climate, vegetation, and relief, parent materials have weathered into soils of great variety.

Environmental changes since the late Pleistocene

The change from Pleistocene to Holocene palaeoenvironments in Mexico and Central America occurred approximately 10,000 (yr BP = radiocarbon time; B.P., B.C. = sidereal time), although tighter radiocarbon control may indicate that locally the rate of change was more rapid earlier or later than this date (Bradbury, 1982). For latitudes south of the transverse Mexican volcanic axis the climatic change appears to have been from cooler and drier climates in the Pleistocene to warmer and moister Holocene climates. The various approaches to establish palaeoenvironmental changes of the Holocene have used proxy records such as pollen records, palaeosols, lake-level fluctuations, geomorphic evidence of glacial advances, and alluvial stratigraphy in Mexico and to a lesser extent in Central America (Bradbury, 1982).

Lake-level fluctuations in *tropical southern Mexico and Colombia* suggest that the climate was cooler and drier during the late Pleistocene; the lakes register moister conditions between 10,000 and 6000 yr BP. By 6000 yr BP lakes record relatively dry conditions, but consideration of individual lakelevel fluctuations (Bradbury, 1971), however, shows that this period of aridity may only be a short-lived event centered on 6000 yr BP (Harrison and Metcalfe, 1985). By 3000 yr BP high lake levels were registered throughout the Middle American tropics. Increasing aridity after this time is reflected by falling lake levels, the present day situation shows that this trend towards increasing aridity has peristed (Harrison and Metcalfe, 1985).

By 12,000 yr BP a belt of high to intermediate lakes over *northern Mexico* was established; by 10,000 yr BP there is evidence of a drying trend in the northern parts of Middle America, with many lakes falling to intermediate or low levels. This trend became more pronounced by 9000 yr BP and a well-developed arid zone had formed by 6000 yr BP (Harrison and Metcalfe, 1985).

According to Bradbury (1982) the establishment of chronostratigraphic subdivisions within the Holocene is premature for Central America and he emphasizes that the scarcity and the complications involved in their interpretation suggest that the timing and nature of Holocene climatic variations in this region is poorly understood.

The best record of changing palaeoenvironments comes from central Mexico where series of late Quaternary moraines, fossil soils, sedimentary infillings, and pollen sections have been studied (Fig. 2). During the period between 10,000 and 8500 yr BP the complex of the M III-moraines were formed. It is interesting to note that during the M III 3-glaciation the formation of ice-cored moraines was very common on the Nevado de Toluca volcano (Heine, 1976, 1984). The M III-glacier advances reflect a lowering of the climatic snowline during the period 10,000—9000 yr BP of approximately 800 m in reference to the snowline of 1850 AD. According to palynological investigations the upper tree line was lowered by about 1000 m during the M III-glaciation (Heine and Ohngemach, 1976). Since about 9000 yr BP the mean annual temperatures increased so much that the relationship between temperature and precipitation led to a rapid shift of the climatic snowline to higher elevations. Only a few recessional moraines give evidence of minor glacier fluctuations during the period 9000 to 8500 yr BP. The rapid deglaciation terminated ca. 8500 yr BP. According to the radiocarbon dates of the palaeosol fBo3 the period between 8000 and 5000 yr BP was slightly warmer than recent times; the development of andosols took place even in areas up to 4200 m altitude (today andosol development is restricted by low temperatures over 4000 m altitude). The postglacial climatic optimum is documented in the central Mexican highland by the palaeosol fBo3. During the last 5000 years two periods with glacier advances occurred. The M IV-glaciation is dated to about 3000 to 2500 yr BP and thus corresponds to high lake levels (Hutchinson et al., 1956; Harrison and Metcalfe, 1985). The pollen cores described by Ohngemach and Straka (1983) postulate vegetational changes at sites in 3000 m altitude; judging from the higher *Abies* percentages in the diagrams the climate must have been more humid around 300/400—1000 AD. There is evidence that the glacial M IV-advance and the *Abies*-rich pollen zone did not occur at the same time (Heine, in press). A minor glaciation can be correlated with the Little Ice Age. Since about 1850 to 1972 AD, the ice caps and glaciers of the highest volcanoes were reduced to small remnants of ice. The preliminary results obtained through research on the history of drought in Mexico since 1500 yr BC show that man has constantly suffered from the effects of droughts, since they attacked the pre-Hispanic people at the very core of their sustenance: the farming of grains (Cervera and Arias, 1981). There is no doubt that it was because of this that those societies created a science, astronomy, dedicated to the study of the relationships between meteorological phenomena, the patterns and orientation of fields and settlements, and the agricultural and cultic cycle (Tichy, 1983).

In Central America, only in Yucatan the transition from an arid, glacial Late Pleistocene to an early Holocene moist period has been documented. An early

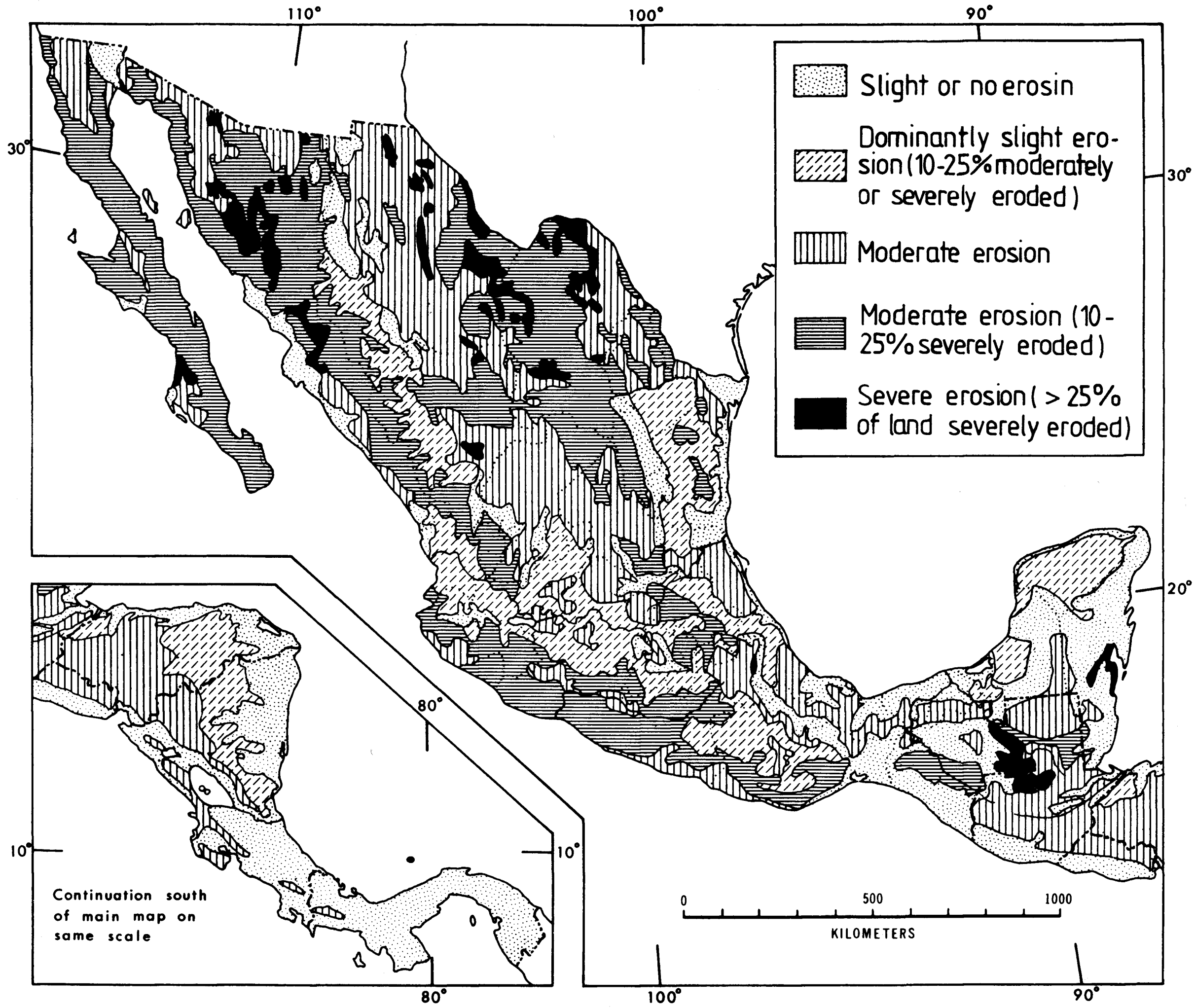

Fig. 3. Soil erosion in Middle America, 1950 (after Stevens, 1964). The map is adapted from the Soil Erosion Survey of Latin America.

Holocene stage of deep lakes and mesic forest (Deevey et al., 1983) is clearly correlative with the M III-glacier advance. In lake Quexil (Peten, Guatemala), the Holocene lake level rose to within 15 m of the present depth by ca. 8400 yr BP, and appears not to have fallen significantly thereafter (Deevey et al., 1983). Intermittant desiccation after ca. 8500 yr BP is suggested by ^{18}O data from Lake Chichancanab (Yucatan) (Deevey et al., 1983). If later Holocene climatic fluctuations affected the Peten (Yucatan), the evidence is masked by intensive human disturbance (Deevey et al., 1983).

Facies of anthropogenic sediments

Little evidence of the facies of anthropogenic sediments is available from most parts of Middle America. What evidence there is needs to be compared with the picture that is beginning to emerge for the importance of anthropogenic induced intensification of geomorphodynamic processes.

The alluvial history of the central plateau of Mexico was studied by Vita-Finzi (1970, 1977). Two broadly synchroneous aggradational phases throughout the area have been identified; the older fill (Becerra) antedates 4500—8000 yr BP and the younger fill (Noche Buena) dates from about 500—1700 AD (Vita-Finzi, 1970). Vita-Finzi found identifiable sherds in the younger fill. The morphology and internal character of the fills in the southern Mexican plateau point to deposition of the older by ephemeral flows and of the younger by perennial or seasonal stream discharges (Vita-Finzi, 1977). The older fill, which has a maximum observed thickness of 19 m, consists predominantly of silts, with bands and lenses of clay, sand, and gravel. Both the silts and the sands are in places cross-bedded; cut-and-fill features are common; the deposit is cemented by calcium carbonate to varying degrees (calcrete development); it includes horizons of redeposited tufa (Vita-Finzi, 1977). The younger fills has a maximum thickness of 7 m. It too is dominated by silts, and includes bands of sand and gravel; horizons of reworked volcanic ashes and pumice-lapilli as well as material from A_h-horizons of different

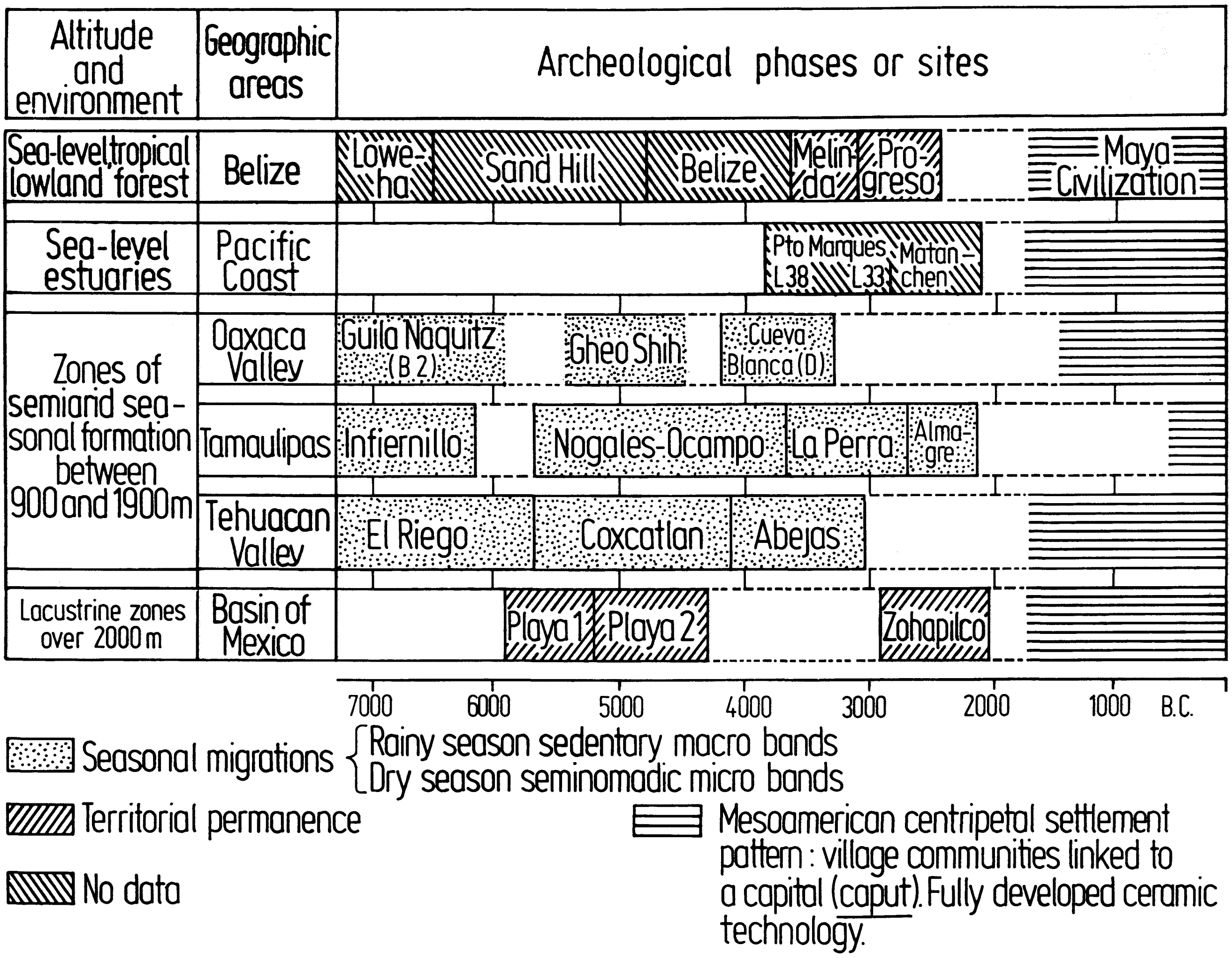

Fig. 4. Patterns of territorial occupation in Middle America between 7500 and 1000 B.C. (after Niederberger, 1979, supplemented).

soils are common (Vita-Finzi, 1977). In basin areas of the central Mexican highland the younger fills are dominated by redeposited toba-sediments, redeposited soils, and occasional gravel, sand, and tufa bands. In their lower parts bedding is generally well developed. Cementation by calcium carbonate does not occur. The younger fills can be seen as a series of independent depositional events, as a complicated sequence of cut-and-fill episodes, or as a single phase of aggradation (Vita-Finzi, 1977; Heine, 1978).

In the valley of Oaxaca and Nochixtlan the examination of alluvial deposits reveals the existence of several layers of black redeposited soil which contained sherds; the sequence of black strata in the valley alluvium is proof that the mountains and slopes were being intensively utilized (Cooke, 1949; Spores, 1969). Thick alluvial deposits are found in all areas of intensive occupations; these anthropogenic sediments do not differ much in composition, because they are the results of the erosion of well-developed dark grey to gray-brown clay soils which were formed under conditions which did not encourage gullying; this suggests a dense vegetation cover, probably a natural oak and pine forest (Spores, 1969).

Lacustrine sediments of the lake district of Peten in the lowland tropics were investigated by Deevey et al. (1983), Binford (1983), and Brenner (1983). The Late Pleistocene bottom layers contain abundance of calcite and gypsum in a clay matrix dominated by montmorillonite with lacustrine shells, sponge spicules, and *Pinus* pollen, and include several bands of gyttja; the overlying organic sediments are of pre-Mayan age. These are overlain by preclassic organic layers and the Maya clay which consists of montmorillonite and some other clay minerals (palygorskite, kaolinite, and mixed-layer clays), and of non-clay minerals, such als calcite, and silicates. The Maya clay is covered by post-Maya organic sediments. According to Steen-McIntyre (1985, written comm.) the Maya clay contains glass-bearing phenocrysts and relatively fresh, fragile glass shards, most definitely the residue of a tropical soil cover; she believes the Maya clay to be reworked tbj tephra from the AD 260 eruption of Ilopango volcano, El Salvador (see Hart and Steen-McIntyre, 1983).

Little is known about Holocene anthropogenic sediments from Central America. The problems of differentiating normal, or geologic, erosion from accelerated, man-made erosion have been emphasized in

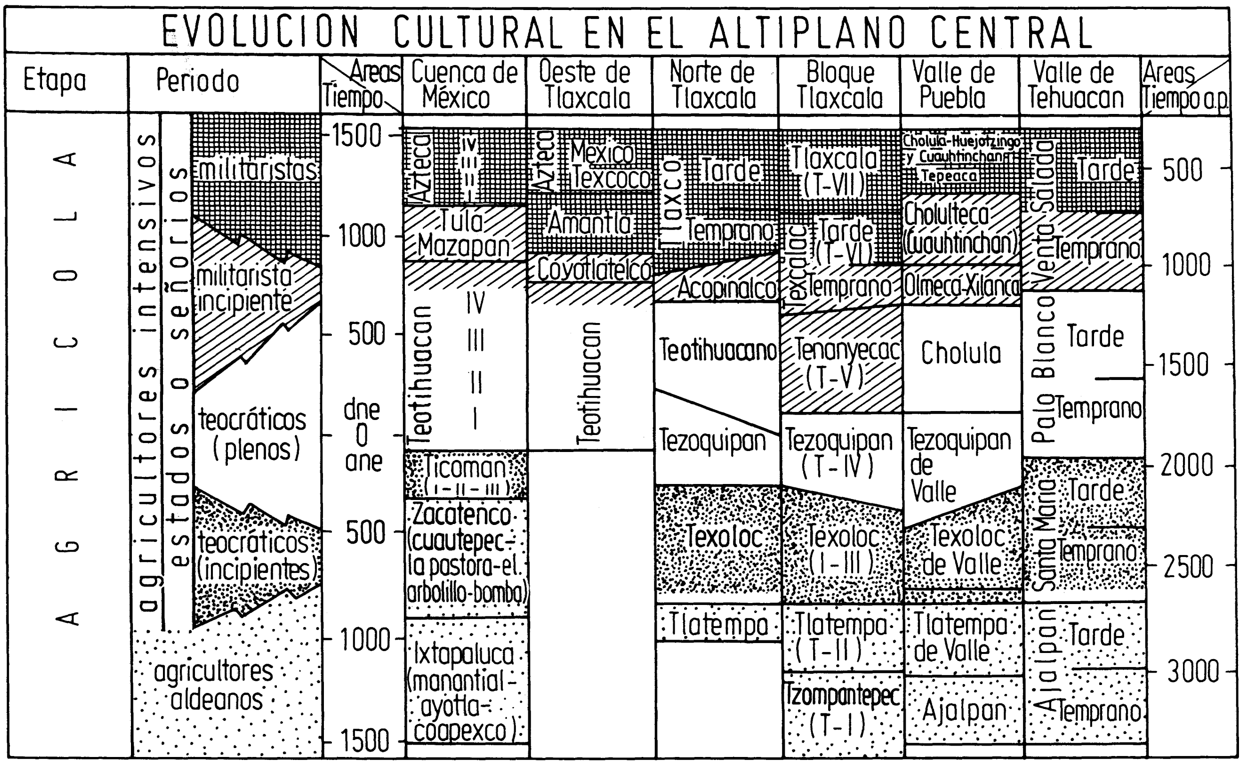

Fig. 5. Cultural evolution of the central Mexican highland (after Cook, A.G., 1983).

the *Soil Erosion Survey of Latin America* (Fig. 3); no part of Middle America is mapped as 'land with soils undisturbed by man' (Stevens, 1964). Therefore we must conclude that most areas of Middle America are affected with anthropogenic sedimentological processes from prehistoric and protohistoric times to the historic and modern period.

In Middle America, apart from the reworked soil material, especially in areas with young volcanic rocks and tephra, catastrophic rains may cause inundations as well as flood sediments which contain even very big boulders (Weyl, 1953, 1965; Helbig, 1961).

Human history and correlative deposits

Over 70 years of intensive investigations have revealed much of the mysteries of the rise of civilizations in Mesoamerica. Conventional archaeological and ethnohistorical studies of the prehistoric developments in central Mexico and in the Maya area have been augmented in recent years by numerous research efforts. Multidimensional research on the cultural ecology has yielded substantial knowledge of cultural evolution in Mesoamerica and at the same time has served to refine the theoretical framework for observing and explaining developmental processes that were operative in the rise of civilization (Spores, 1969).

In Mesoamerica, finds of Early Man before the time of the final extinction of the Pleistocene megafauna, about 9000—10,000 yr BP, are not numerous. Even during Holocene times the knowledge of Early Man is very poor. MacNeish (1983) gives a short résumé of Early Man and his culture during each time period of the Holocene in Mesoamerica. Patterns of territorial occupation in Middle America between 7500 and 1000 B.C. (sidereal time) are described by Niederberger (1979) (Fig. 4). Archaeologists have defined a large number of local regional chronologies based on changes in ceramic styles (Sanders et al., 1979) (Fig. 5).

The stone age hunter did not influence his natural environment in Mexico and Central America. Yet, as early as 5000 B.C. the people of Mexico began to cultivate different plants (Johnson, 1972; Niederberger, 1979). Primitive irrigation schemes were built more than 4000 yr BP. Therefore, we must be aware of the influence of men on the natural environment—on purpose or unintentionally. During thousands of years civilizations developed and declined, migrating people reached the central Mexican highland or the central American lowlands and fertile volcanic mountain areas; breakdowns of civilizations occurred, new ones rose. The population density varied (Klaus and Lauer, 1983; Harrison and Turner, 1978; Ashmore, 1981; Leventhal and Kolata, 1983; Vogt and Leventhal, 1983), although through the times the number of human beings increased. The settlement of colonization of the antecedents of the modern agrarian societies led to distinct changes of the natural environment. The natural vegetation of the Mexican high plateaus, for instance, was replaced by successive plant communities that were

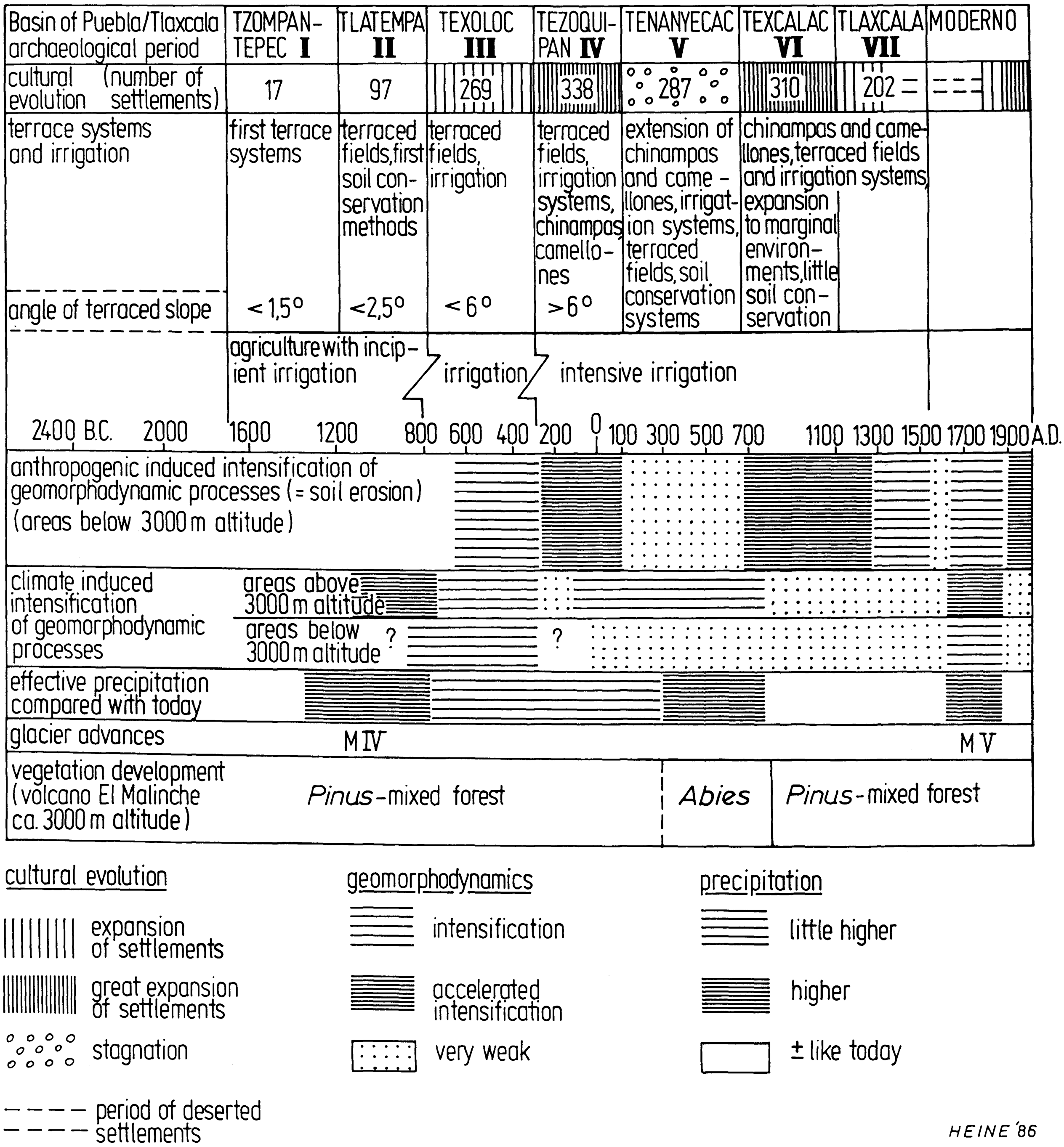

Fig. 6. Cultural evolution, geomorphodynamics, and some environmental factors for the central Mexican highland (Puebla/(Tlaxcala). Cultural evolution after A.G. Cook (1975, 1978, 1983).

used to poorer soils and less water. During the mid-Holocene an oak woodland flourished where today a thorn-thicket covers the slopes. Erosion has destroyed the soils where 2500 years ago the ancient people for the first time cleared the woodland. Soil erosion and anthropogenic sedimentation—in connection with other environmental damages (e.g. lowering of the ground water table)—is due to human influence in Mexico and Central America.

Basin of Puebla/Tlaxcala and Tlaxcala area

In the Puebla/Tlaxcala area of central Mexico accelerated soil erosion started at 800 B.C. together with an extensive acquisition of land. Soil erosion has played since then an important role in history.

The state of our current knowledge on the erosion processes of the Puebla/Tlaxcala area is given in figure 6. This synthesis stresses the difficulty of understanding the Holocene erosion processes that led to the impact on the natural environment in central Mexico. Some questions will be discussed here in brief: (a) Were the geomorphic processes controlled by the climatic milieu during the last 3000 years? (b) Were the late Holocene processes controlled by man's activity? (c) Or must we think of several processes with varying periodicities that may occasionally coincide, reinforcing one another and creating an overall tendency that is strongly unfavorable or favorable to the geomorphic processes?

More humid periods compared with today occurred between ca. 3000 yr BP and 800 AD and between ca. 1600 AD and 1890 AD. Higher and/or more accentuated precipitation and higher erosion rates are not correlated unless there are modifications of vegetation cover. Relatively rapid precipitation changes may cause an accelerated development of the barrancas (arroyos, gullies) of the gorges, the debris accumulation at the end of these gorges, the debris flows, the landslides, and the solifluction processes of the 'periglacial' belt of the high volcanoes. Figure 6 shows that the erosional processes did not increase in intensity at the beginning of the period with higher effectiveness of precipitation. Soil erosion started only when the population growth made possible improved irrigation systems and the cultivation of marginal areas of the Puebla/Tlaxcala basin. The Tlatempa Phase (1200—800 B.C.) was characterized by 98 settlements with 50 to >350 inhabitants (Mora, 1975). During the Tlatempa Phase no soil deterioration occurred. With the growing population density soil erosion started during the Texoloc Phase and culminated during the Tezoquipan Phase (ca. 300 B.C.—100 AD) (Dávila, 1975). Studies of rates of erosion (Heine, 1978) show that relatively abrupt environmental changes, such as that caused by human clearance of forests and woodlands can lead to sudden changes in the amount of erosion. In Central Mexico the natural vegetation cover was removed rapidly more than 2500 years ago during the Texoloc Phase. The result was accelerated soil erosion which then occurred for the first time during the Holocene. Anthropogenic sediments were accumulated in valley floors, the basins, the lakes.

In the classic period (Tenanyecac Phase, 100—650 AD) intricate patterns that interweave hamlets and ceremonial centers suggest a concentration of settlements along the mountain slopes near the basin floors and even more sophisticated land use technologies and irrigation systems (Cook and Abascal, 1975; Abascal and Cook, 1975). The rise of the Tehuacan culture in the Basin of Mexico is believed to have influenced the Puebla/Tlaxcala area, so that the Tenanyecac Phase is regarded as a period of stagnation. The land that had been affected by severe soil erosion during the foregoing Texoloc and Tezoquipan Phases occupied large areas that could not used for agriculture during the classic period. Consequently anthropogenic sedimentation was extremely low.

A second period of soil erosion started during the Texcalac Phase (Cook, 1975). After the Tenanyecac Phase of stagnation and of decreasing population, the Texcalac Phase reached another apex in the demographic expansion in pre-Spanish times (Cook, 1978; Abascal and Cook, 1975). The erosion processes responded relatively rapidly to the impact on the natural environment that was caused again by the expansion of the rural population and the human clearance of the vegetation. Direct rainfall impact on the exposed soils washed much more material down-slope than would have been eroded under the natural vegetation cover. This erosion period between ca. 650 AD and 1100 AD did not coincide with a period of higher precipitation; the soil damage occurred under the impact of the Texcalac agricultural technology and in response to growing food demands. There is evidence that during the Texcalac Phase the slopes of the volcanoes were intensively cultivated up to 3000 m altitude.

The second destructive period which set in at the beginning of the Texcalac Phase continued until the colonial epoch. According to a rapid decrease in population after the Spanish Conquest (Trautmann, 1974) soil erosion damages diminished slightly. Although several minor climatic fluctuations are recorded for the central Mexican highland during the last 2000 years (Ohngemach and Straka, 1983), no response of rates or erosion to climatic changes could be observed.

It is illustrated by figure 6 which shows not only the periods of soil erosion in relation to the different cultural phases but also in combination to some social (e.g. irrigation) and environmental (e.g. effectiveness of precipitation, vegetation history) factors, that we need multidisciplinary information in order to comprehend the multiplicity of processes involved in resolving and understanding anthropogenic sedimentation problems.

During the last 3000 years, the geomorphic processes of the central Mexican highland up to 3000 m altitude were not controlled by the climatic milieu but by man's activity. In the Puebla/Tlaxcala area the rates of soil erosion demonstrate that periods of strong human impact on the natural environment coincide with phases of cultural and demographic growth when land use was intensified and many new villages and hamlets were founded. Periods of decline with rural depopulation led to a minor human impact on the natural environment. We cannot decide yet, whether the periods of decline were mainly caused by damages of the natural environment. Fluctuations of climatic elements (e.g. precipitation) did not influence the cultural development nor the soil erosion processes either.

Basin of Mexico

Work carried out on fossil shores in the Basin of Mexico (Chalco-Xochimilco lacustrine basin) by Niederberger (1979) yields an attempt to examine the adequacy for all early Holocene Middle America, and especially for the Basin of Mexico, of the model of seasonal moves of early people that was set out in basic works focused on semiarid regions. A reconstruction of regional palaeolandscapes and ancient food procurement scheduling and activities reveals an early sedentary economy in the Chalco-Xochimilco basin since about 3000 B.C. (sidereal time) (Niederberger, 1979). Although today the Basin of Mexico is deforested and subject to severe soil erosion, palaeoecological investigations indicate the Holocene bioclimatic climax between the seventh and fourth millennia with a remarkable continuity and equilibrium of the biocenoses (Niederberger, 1979). There are no signs of anthropogenic sedimentation during the Holocene prior to and during the Zohapilco Phase (see fig. 4).

A first attempt to correlate alluvial sequences with culture sequences in the Basin of Mexico is proposed by de Terra (1948). A summary of the findings of different workers is reported by Vita-Finzi (1977): The various alluvial bodies reported by Cook (1949, 1963) yielded sherds of which some could be attributed to 'pre-Aztec' times and others were probably of late Teotihuacán type (fig. 5). Millon (1957) has described a channel sediment near Teotihuacán which accumulated largely if not wholly after the Teotihuacán times. The Los Remedios terrace of de Terra (1947) contains rolled Archaic and fresh Teotihuacán and Aztec sherds. These mentioned accounts are summarized by Vita-Finzi (1977) as follows. The anthropogenic sediments (younger fill) overlie the older fill (7000 yr BP and older) or occupy channels cut within it, and are now being trenched; they are generally well-stratified and fine-grained. The archaeological and ^{14}C dates are consistent with renewed aggradation throughout the Basin of Mexico and the southern plateau between 500 and 1700 AD. That ties in with the second phase of accelerated soil erosion reported from the Puebla/Tlaxcala area (see above).

The question of possible environmental changes produced by the human utilization of the landscape cannot be answered in detail. If swidden agriculture was widespread during the earlier phases of colonisation, one would expect some erosion (Sanders et al., 1979). The study of the development of Teotihuacán, Tula, and Tenochtitlan reflects the immense population growth and spatial expansion in the Basin of Mexico since about 500 AD (Sanders and Santley, 1983) that coincides with the period of alluvial aggradation.

The assumption that swidden agriculture favors soil erosion more than the intensification of cropping regimes on terraced fields (Sanders et al., 1979) presents further difficulties in correlation between the Basin of Mexico and the Puebla/Tlaxcala area. Therefore the establishment of anthropogenic sedimentation cycles in the Chalco-Xochimilco lake in connection with three major cycles of swidden agriculture (1500—650 B.C., 100 B.C.—750 AD, and 950—1150 AD) must be questioned.

Tehuacan Valley

The research work done in the Tehuacan Valley by MacNeish during four field seasons, 1961—1964, succeeded in establishing an unbroken record of human civilization spanning 9000 years and covering most aspects of man's life (Byers, 1967). A description of the Holocene sediments is given by Brunet (1967). Parts of the valley are filled in proportion to the rate of erosion in the upper reaches. The botanical evidence from the Tehuacan Valley makes it clear that since about 4000 B.C. at least small-scale farming was being systematically carried on. The beginning of the construction of a large dam complex is dated about 700 B.C. By this time, there must have been some three millennia of experience in agriculture (Woodbury and Neely, 1972). Because of the development of hillside farming the silting of the dam complex occurred, indicating erosion and sedimentation processes between about 700 B.C. to 700 AD. Other dams of the region were investigated by Brunet (1967). His reconstructions of the history of the dams of Mequitongo show several stages: (1) natural primitive situation with arroyos, (2) first dam and contemporary structures; the pool above the dams begins to fill with sediments, (3) second and third dams, separated by a mudflow; in the case of superposed dams alluvial sand, silt, and gravel accumulated, (4) fourth dam (principal dam) with silting, (5) abandonment of the region in classic period; the present streams established, natural drains of the dams, (6) return of people in postclassic time, (7) present situation with superimposed alluviums dissected by erosion.

According to the changing trends in the importance of the principal sources of man's diet food production became more important than food collection from Santa Maria times on (fig. 5) (MacNeish, 1967), accomplished by a wide variety of agricultural practices. The depletion of the vegetation owing to this human activity must have caused anthropogenic sedimentation since more than 2500 years in the Tehuacan Valley.

Valley of Oaxaca

In Oaxaca, the rise of civilization is physically expressed clearly by the archaeological site of Monte Albán, which is fitted on a mountain top five hundred meters above the semiarid valley floor, near the point of intersection of all three arms of the valley (Flannery and Schoenwetter, 1970). In the neighbouring Nochixtlan Valley, the earliest substantial occupation is assigned by ceramic crossties with the Valley of Oaxaca and by relative stratigraphic placement to a period extending from around 700 B.C. to about 200 B.C. (Spores, 1969). Examination of alluvial deposits reveals the existence of a medium layer of black soil which contained Las Flores (300 AD to 900—1100 AD) and earlier materials that were deposited during Las Flores times. The existence of a black stratum in the valley alluvium is proof that the mountains and slopes were being intensively utilized in response to increasing demographic pressure (Spores, 1969). There is no indication of hillside erosion before Las Flores times. Once the black soils from the slopes had been removed by a combination of use and erosion, farm plots were produced by the Mixtecs by progressively undercutting the caliche layers of the slope; disastrous erosion was then the result, because Mixtec people wanted to expand and improve the 'lama-bordo' terrace system of agriculture (Spores, 1969). Thick alluvial deposits containing postclassic (ca. 1000 AD—1520 AD) sherds are found in all areas of intensive occupation. After the Spanish conquest many terraced lands were abandoned and lower slopes were allowed to erode. Since the 16th century nearly one third of the productive land has been eroded from the slopes and redeposited over already fertile bottomland; the destruction of the land was directly correlated with the decline in population and abandonment of terraces and settlement on slopes (Spores, 1969).

Yucatan Peninsula and Central America

Human-induced deforestation resulted in accelerated deliveries of dissolved and solid materials to the lakes, the karstic valleys, and the bajos (= polje). Anthropogenic sedimentation can be correlated with population fluctuations. At the existing state of knowledge of Maya agriculture the most startling feature is the revelation of the sheer variety of means of food production known in the Maya lowlands (Harrison and Turner, 1978). The presence of relics of stone terraces and raised fields are evidence of intensive cultivation that was, of course, not limited to these features (Turner and Harrison, 1978). In the Maya lowlands there is much evidence of soil erosion. The temporal sequence of this erosion has not been established in many places (Wilhelmy, 1981; Olson, 1979). The relation of man-made erosion on hillslopes to the sediment yield at some point in the drainage network has not been the subject of detailed research in the Maya lowlands (McDonald, 1976; Furley, 1974).

Palaeolimnologic research was undertaken on sediments of the deeper karst lakes of the Peten, northern Guatemala. The long-term impact of Maya culture on a tropical watershed was assessed. Human population growth is associated with a shift in the composition of the lake sediment to a dominance by inorganic material, the Maya clay formation, beginning ca. 3500 B.P. Increasing settlement densities are correlated with accelerated influxes of phosphorus, carbonates, and siliceous sediment (Brenner, 1983; Deevey et al., 1983). Much of the sediment is delivered as colluvium, and not by running water. Contemporary high sedimentation rates are a residual of Maya activity that virtually ceased some 300—400 years B.P. Chemical analysis of soil samples from test pits in the karst basin support the principal conclusion that bulk soil movement was the mode of nutrient transfer to the lake, following forest clearance by the Maya (Brenner, 1983). Longterm changes of sedimentary particle size distribution in the lake sediments show an inverse correlation between mean particle size and human population size; this is interpreted to mean that disturbance-induced erosion results in delivery of very fine inorganic particles at higher rates (Binford, 1983).

Little is known about anthropogenic sedimentation in Central America. Evidence on which to base estimates of the rate of erosion and sedimentation comes from archaeological studies, which have only become frequent during the past few years (e.g. García-Bárcena, 1982; Healy, 1983). Especially during recent decades, soil erosion became a serious problem in Central America (Helbig, 1959; Weyl, 1972), whereas during the Upper and Middle Holocene sedimentation processes depend on the magnitude and frequency of volcanic and/or tectonic events rather than on climatic factors.

Conclusions on rate and tendency of changes

Man's impact on the soil environment is felt and registered in form of increasing sedimentation rates in the central Mexican highland over the past 2500—3000 years, in the Maya lowlands during the past 2500 years, and in areas of the middle classic Maya colonization during the past 1500 years (Sheets, 1983; Steen-McIntyre, 1985). During the last decades it appears that agricultural activities as well as urbun development changes (Maderey, 1974) have accelerated soil erosion in a great extend. Tropical rain and montane forests are being steadily depleted in all areas of Mexico and Central America. If present rates of misuse and clearance of the forest persist—and they are likely to accelerate—the biomes, now covering still some lowland and montane areas, could be reduced to remnant fragments within less than half a century. This would represent one of the greatest environmental impoverishments that did not occur at any time of the Holocene. If the forests disappear within a few decades, the Middle American people will suffer by way of environmental degradation, decline of watershed services, localized erosion and deposition, and the like. All areas adjacent to the Gulf of Mexico have undergone excessive hurricane damage due to loss of mountain forest cover. If we agree with the postulation that civilizations behave as adaptive systems (Butzer, 1980), then the unexpected coincidence of environmental perturbation, poor leadership, social pathology, and external political stress can trigger a catastrophic train of mutually reinforcing events that Middle America's civilizations are unable to absorb.

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