Paleopedological evidence of human-induced environmental change in the Puebla – Tlaxcala area (Mexico) during the last 3,500 years

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ABSTRACT

A review of research on human-induced environmental change in the Puebla–Tlaxcala area of Mexico for the past 3,500 years is presented. The human impact on the soil environment is felt and registered in form of increasing sedimentation rates causing colluvial accumulation on mid-slopes, foot-slope cones and alluvial fills in valleys. Land-use changes related to cyclic political developments were the driver of environmental changes. Climatic conditions (e.g., rainfall variability, drought) had no primary effect on accelerated soil erosion. In central Mexico phases of soil erosion were asynchronous both in time and in space.

Key words: soils, erosion, human-induced, climate, environment, central Mexico.

RESUMEN

Se presentan resultados de las investigaciones sobre cambios ambientales inducidos por el hombre durante los últimos 3,500 años en el área de Puebla–Tlaxcala, México. El impacto humano en los suelos se manifiesta en forma de crecientes tasas de sedimentación que producen acumulación coluvial en la parte media y baja de las laderas y rellenos aluviales en los valles. Los cambios en el uso del suelo relacionados con procesos políticos cíclicos fueron los responsables de los cambios ambientales. Las condiciones climáticas (variabilidad de la precipitación, sequía) no tuvieron un efecto directo en la erosión acelerada de los suelos. En el centro de México las fases de erosión de suelos no fueron sincrónicas en el tiempo ni en el espacio.

Palabras clave: suelos, erosión, inducida por el hombre, clima, medio ambiente, centro de México.

INTRODUCTION

In the basin of Puebla–Tlaxcala in central Mexico (Figure 1), there has been a pronounced relationship between climate change, geomorphology and soil erosion on the one hand and the development of the ancient civilizations on the other hand (Heine, 1978a, 1983, 1988; García-Cook 1986). The region is privileged by favorable natural conditions and by being a continuous melting place of ideas and commerce between different cultural regions of the central Mexican highland and adjacent lowlands. The Puebla–Tlaxcala region was the scene of the development of a mosaic of cultures that were among the most vigorous ones of Mesoamerica. Cholutecas, Olmecas–Xicalancas, Toltecas–Chichimecas and Tlaxcaltecas, to mention but some of them, brought their cultural influence to nearly all of the prehispanic Mesoamerica. Records exist about bands of hunter-gatherers as well as of well-organized agrarian

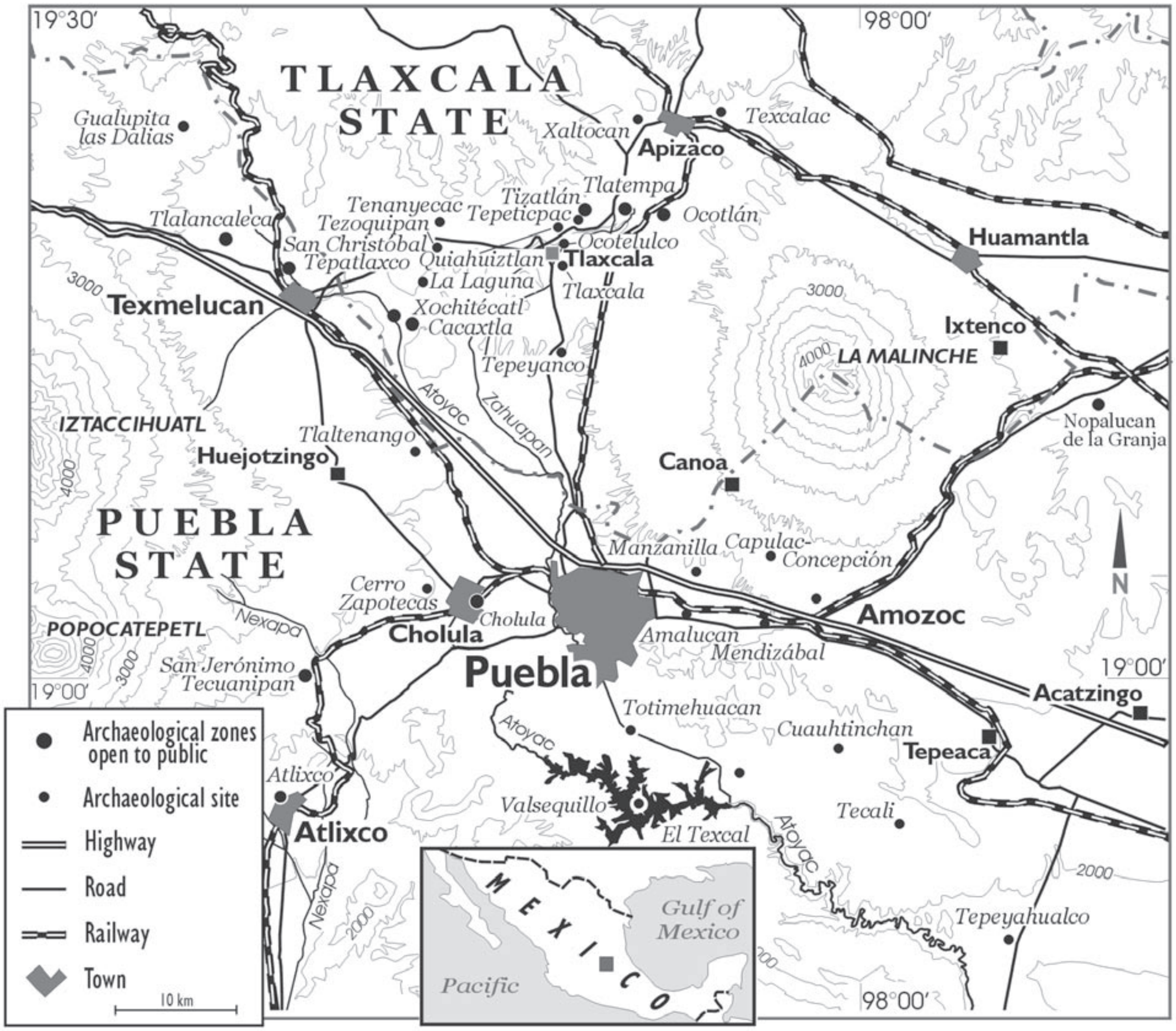

Figure 1. Location map with archaeological sites (after García-Cook, 1995).

societies and settlements with magnificent towns, big pyramids such as Cholula, and exceptional wall paintings like those of Cacaxtla, which symbolize the cultural amalgamation of Teotihuacanan and Mayan elements. The basin of Puebla–Tlaxcala, therefore, always rivaled with the basin of Mexico (García-Cook 1995).

PREVIOUS INTERPRETATIONS

Although the cultural and architectural accomplishments of the Poblano–Tlaxcalteca region have been intensely studied, less is known about the physical environment in which the cultures developed (Lauer, 1981; Heine, 1988). The severely degraded landscape of the central Mexican highland has been the focus of considerable debate (Figure 2). What was the state of the environment when the first civilizations developed more than 3,500 years ago? And what effect did they have upon the environment? Three assumptions have insinuated themselves into the public consciousness (Butzer, 1993): 1) that prehispanic agriculture was environmentally benign (see *e.g.*, García-Cook 1986); 2) that Spanish colonial forms of land-use, especially stock-raising, were highly destructive; 3) and that, more generally, traditional farming systems are inherently conservationist and point to ways in which to reduce environmental degradation today (Butzer, 1993). As early as 1978, Heine (1978, see also Heine, 1983, 1987, 1988) provided convincing evidence for one center of Mesoamerican civilization, the basin of Puebla–Tlaxcala, that runs directly counter to these assumptions. Heine (1978, 1983, 1987, 1988) provides data from profiles of slope sediments, alluvial valley fills, fossil soils, and tephra layers that allow distinction to be made between environmentally undisturbed

Figure 2. Erosion and accumulation in the basin of Puebla–Tlaxcala. Interpretation of a color soil map published by Aeppli and Schönhals (1975). 1: Erosion of top soil down to extremely cemented tepetate horizons or bed rock; 2: Development of deep barrancas (gullies); 3: Linear and sheet erosion, yet thin soil profiles are present; 4: eolian sandy cover sediments; 5: fluvial accumulation (alluvial soils), a) clay, b) silt, (c) sand, d) gravel, e) lake sediments; 6: volcanic sedimentation, a) sand, lapilli, breccia, b) lava flows; 7: volcanic ash soils (Andosols) on slopes above 3,000 m a.s.l. with different erosion features caused by human activities; 8: slope colluvium.

periods with no or little human influence on nature and periods that document severe manipulation of the natural processes of soil development and accelerated soil erosion. The profiles are dated and cross-correlated by ^{14}C, archaeological findings, tephra horizons, and fossil soils. The archaeological project of Puebla–Tlaxcala in the same area provided a regional archaeological sequence (Abascal *et al.,* 1976; García-Cook 1976, 1986, 1995) and made it possible to compare the soil erosion and land deterioration phases with the cultural and settlement development during the last 3,500 years.

RESULTS

Two examples from our area of investigation demonstrate how profiles of colluvial sediments, alluvial valley fills, paleosols, and tephra layers together with archaeological findings and radiocarbon age determinations provide data for human-induced environmental changes.

North of Puebla, slope deposits and barranca fills of the Cerro San Pablo (Figure 3) show the development of slopes since the late Pleistocene. The formation of the paleosol fBo1 occurred on toba sediments (1) (for details of the development and age of the late Quaternary paleosols in central Mexico see Heine, 1975, 1976). Simultaneously, small valleys formed until about 20,000–22,000 years BP (2). Presumably because of greater glacial aridity, valley formation stopped during the early Late Glacial (3). The Becerra deposits, containing a late Pleistocene fauna, formed during the late Glacial and early Holocene. Between roughly 8,000 and 5,000 years BP a paleosol (fBo3) developed (4). About 700 years BC accelerated soil erosion started and continued during the Texoloc and Tezoquipan phases (the cultural phases are shown in Figure 4); the fBo3 soil was partly removed from the upper slopes and deposited on the foot slopes (5, 6). At the same time a barranca formed at the lower slope. These processes came to a still stand around AD 100 (6). Soil formation started. Later (7) the barranca was filled with sediments; this valley fill documents erosion processes on the upper slopes during the Texcalac/Tlaxcala phases. After about AD 1,000 an eolian cover sediment was deposited (8). The material stems from the ash fall of the Popocatépetl eruption (P1) dated to about AD 1,000 by Miehlich (1974). Again barranca formation took place and a removal of parts of the valley fill occurred.

About 20 km east of Puebla we studied erosion and accumulation processes in the Cerrijón de Amozoc hills, an area of Cretaceous limestones (Maltrata Formation), and in the adjacent valleys and basin (Figures 5, 6 and 7). The hill slopes on both sides of the crest are completely bare of the Pleistocene cover sediments (mainly toba material). On the mid-slope of the northern flanks, indurated tepetate horizons show that erosion processes were not able to remove these duricrusts which developed on toba material and which are remnants of the paleosol fBo1 (age: 26,000–21,000 years BP). On the southern side of the Cerrijón de Amozoc, caliche layers represent the paleosol fBo1. There, caliche duricrusts formed due to the high content of $CaCO_3$ in the parent toba material. At the lower slopes, remnants of the Becerra sediments with Holocene paleosols on top (fBo3) are found. The aeolian cover sediments were completely eroded with the exception of those sites where stone debris of pre-Spanish residential structures protected the sandy material and barro soils from denudation by rain and running water. The foot-slopes and the basin areas of Amozoc–Tepeaca are more or less covered by the late Pleistocene/early Holocene sediments and soils. On the slopes, the Becerra Formation is of aeolian origin (Heine and Schönhals, 1973), and in the basin of fluvial–lacustrine origin. No erosion processes can be observed during the Holocene until the Tezoquipan cultural epoch. During the Tezoquipan phase, gullies that were filled with gravel and boulders originating from the La Malinche volcano developed in the basin. Intense floods must have been occurred, otherwise the coarse gravel would not have been transported so far into the basin. At the same time there is no transport of limestone pebbles from the nearby Cerrijón de Amozoc into the basin. This observation is interpreted as evidence for stable soil conditions on the slopes of the Cerrijón de Amozoc, although the Tezoquipan phase is characterized by rapid sedimentation in the basin, representing accelerated soil erosion in the upper catchment (southeastern flanks of La Malinche volcano, area of Amozoc, etc.). During the Tenanyecac phase, sedimentation in the basin was absent. In the Tlaxcala phase, sedimentation in the basin documents a new period of accelerated soil erosion that continued until the colonial phase. The sediments of the basin stem from the nearby slopes and thus can be correlated with the eroded soils of the slopes of the Cerrijón de Amozoc (Figures 5, 6 and 7). According to the distribution of archaeologically dated settlements (huts, walls, field terraces, etc.), the erosion of the soil started on the upper slopes where Tlaxcala phase ceramics provide evidence for dwellings and land-use at least until this cultural phase. During early colonial time, because of eroded soils, land-use was no longer possible on the upper slopes. During late colonial time, even the middle slopes were uninhabited because of severe soil loss. The archaeological survey of the surface shows a certain pattern of the distribution of the ceramics and dwellings of the different cultural phases. On the heavily eroded slopes, only traces of land-use and small settlements (hamlets) that belong to cultural phases of pre-Colonial times were found. The Texcalac and Tlaxcala material was found all over the slopes, whereas the younger early Colonial material is not present on the upper parts of the slopes and the youngest late Colonial material is confined to the lowermost parts. This proves, together with the correlated sediments of the basin, that soil devastation proceeded slowly down slope from the crest to the foot-slopes and that soil erosion led to the abandonment of the slopes from the crest to

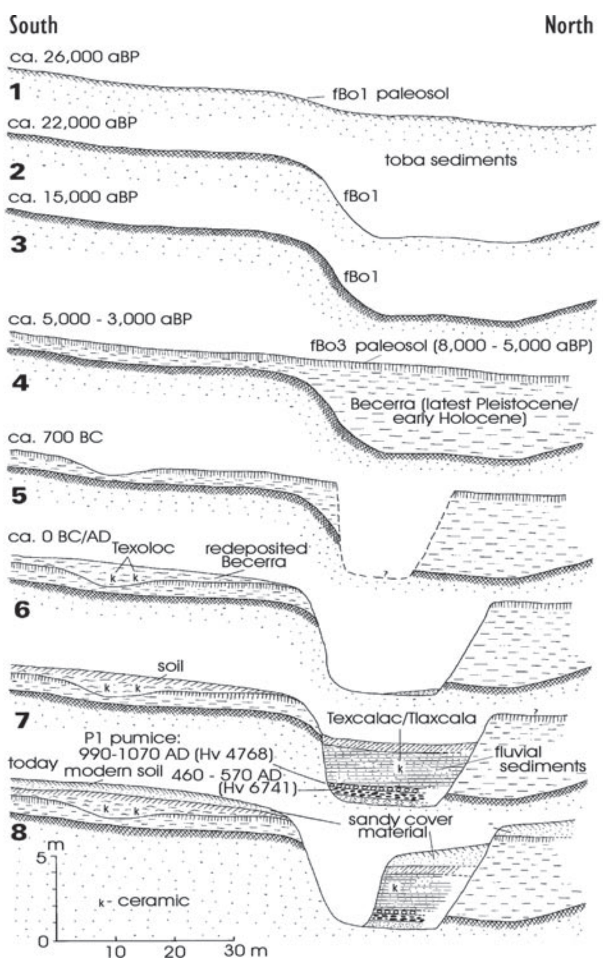

Figure 3. Erosion and accumulation processes of Cerro San Pablo, north of Puebla, during the late Pleistocene and Holocene as deduced from paleopedologic, sedimentologic and archaeologic evidence. For explanation see text.

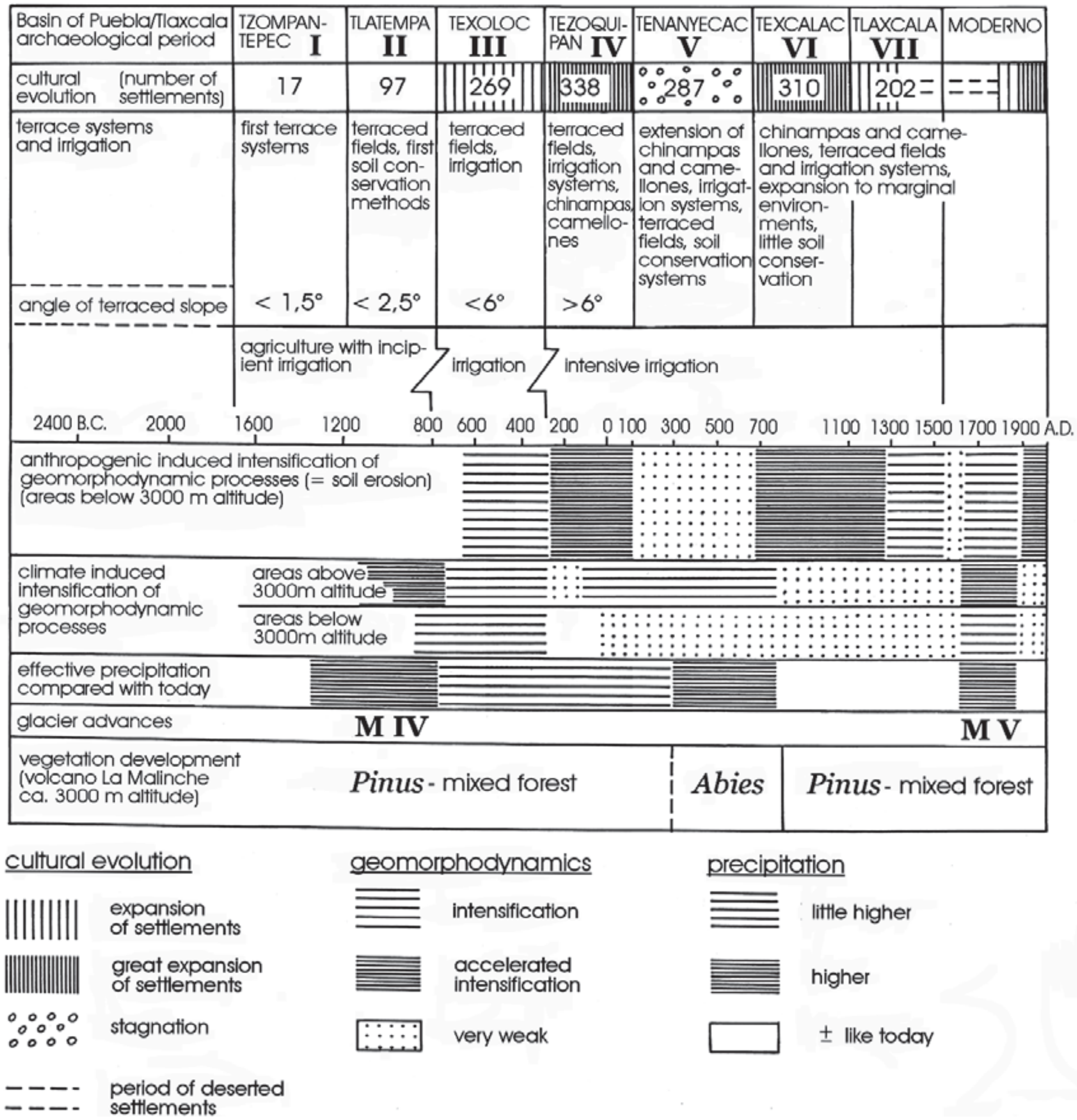

Figure 4. Cultural evolution, geomorphodynamics, and some environmental factors for the central Mexican highland (Puebla–Tlaxcala area).

the lower reaches. The examples mentioned above are representative for many investigated sites in the Puebla–Tlaxcala region.

DISCUSSION

Syntheses of knowledge from archaeology, archaeoastronomy, ecology, geology, geomorphology, palynology, and soil science provide a valuable means of understanding how past societies have affected their environments and how long these changes can persist (Heine, 1988; McAuliffe *et al.,* 2001). Spores (1969) wrote that his findings in the Nochixtlan Valley (Oaxaca) strongly support Cook's (1949) view that much of the erosion of the valley was an accomplished fact before the Spanish conquest. The possible relationship between human occupation, anthropogenic disturbance and climate change has been discussed in many recent papers. Most authors use their findings to challenge the common view that prehispanic agriculture was environmentally more benevolent than later versions (O'Hara *et al.,* 1993; Metcalfe *et al.,* 1994). While some authors argue that climate change to more arid conditions intensified soil erosion (*e.g.*, Metcalfe *et al.*, 1994), others hold the opinion that in pre-Columbian times cultivation caused severe soil loss that preceded agricultural collapse and land abandonment (*e.g.*, McAuliffe *et al.*, 2001). In view of concerns about climatic instability, Vita-Finzi (1993) mentioned atmospheric factors to cause accelerated soil erosion, such as shifts in the relative importance of combined winter and autumn rainfall produced by latitudinal displacements of the subtropical

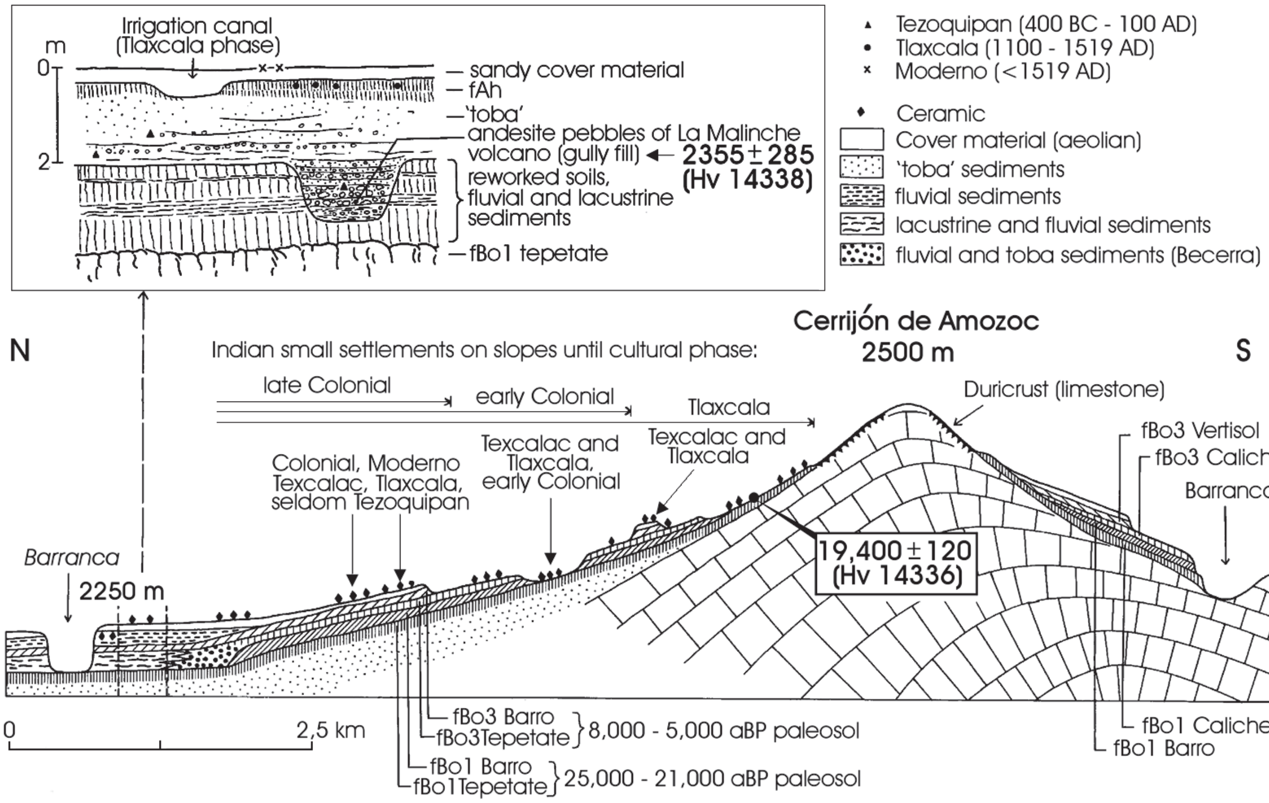

Figure 5. Erosion and accumulation processes near Amozoc, east of Puebla. Relations between hillslopes and valley fills. For further explanation see text.

high-pressure cells. García (1974) concludes that circumstances for the decline and fall of the Teotihuacan culture were, beside environmental and social facts, severe droughts around AD 700 to 750. Heine (1988) stated that the environmental changes caused by land-use change far exceed those generated by climate change over both short and long time scales and especially within the oekumene and that human cultural evolution was not directly related to climatic fluctuations. Although the rise and fall of central Mexican civilizations was never caused immediately by climate conditions, population pressure is reflected in a correlation between intensification of land-use and accelerated soil erosion. However, during the past 3,500 years, humans had thoroughly altered their environments and, in the process, had created ecological problems that had an adverse effect on the respective cultures. Yet, the actual subject of cultural change had always been humans themselves (Lauer, 1981; Heine, 1988).

CONCLUSIONS

Figure 4 shows that there is no direct relationship between climate on the one hand and the development of civilization and soil erosion on the other hand. Changes in settlement patterns and other human activities (land-use) have been influenced mostly by human, not natural factors. Soil erosion in the Puebla–Tlaxcala basin has been almost exclusively a result of human activity. As elsewhere on earth, land-use change –and not climate change– is one of the major drivers of global environmental change (Heine, 1994; Slaymaker, 2001). In central Mexico, various phases of increased soil erosion occurred during times of population growth, increased settlement of previously uninhabited upper slopes of the volcanoes as well as intensification of agriculture. Every settlement (hamlet, village) has its own zone of resources, both wild and domestic, that occur within reasonable walking distance of a given village. The research on 'site catchment analyses' (Vita-Finzi and Higgs, 1970) as 'the study of the relationships between technology and those natural resources lying within economic range of individual sites' points to the close relationship between population pressure and anthropogenic induced pressure on the natural/physical environment. This assumption is supported with data from our sources concerning soil erosion processes. As early as 2,000 years ago during the Tezoquipan phase, large areas had been eroded all the way to resistant indurated horizons (tepetate and caliche, see Werner *et al.*, 1978). Geomorphologic, sedimentologic and paleopedologic evidence shows that 2,000 years ago, larger areas of central Mexico were devastated by erosion than at present.

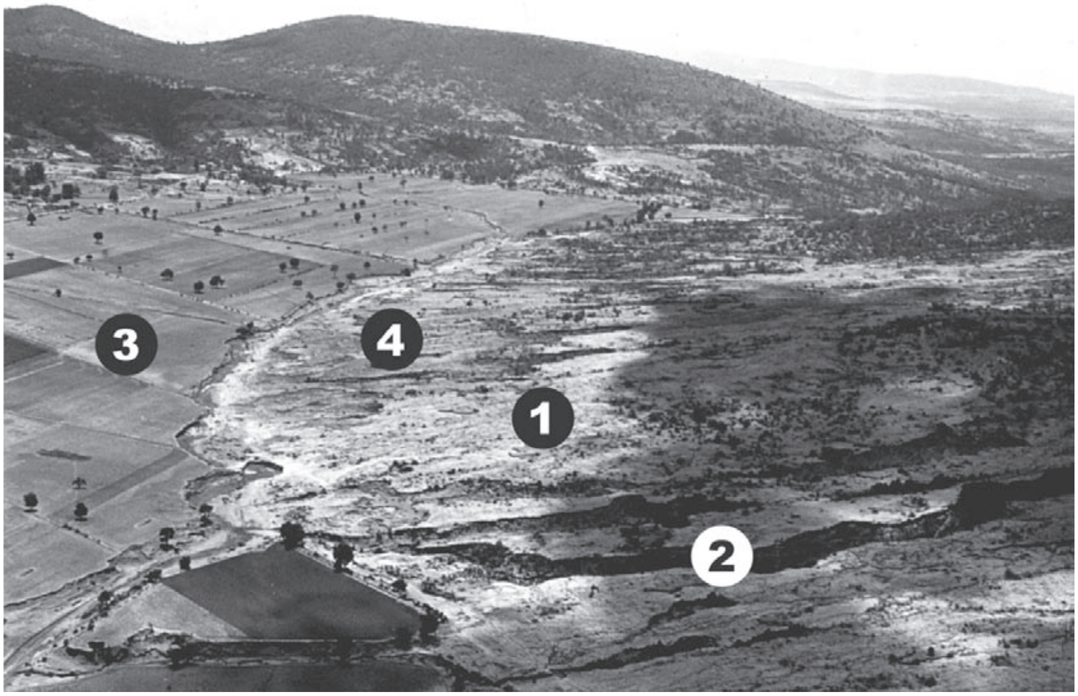

Figure 6. Aerial view of a part of the Cerrijón de Amozoc (at the right) with heavily eroded slopes. 1: Duricrusts (tepetate and caliche) are found at the surface. 2: Deeply incised barrancas (gullies) dissecting the lower part of the slopes are observed in the foreground. 3: In the valley (basin), the eroded soil material was deposited (Figure 7). 4: In the center of the picture, remnants of barro and tepetate soils of Pleistocene (fBo1) and Holocene age (fBo3) are found. A schematic section of the situation is presented in Figure 5.

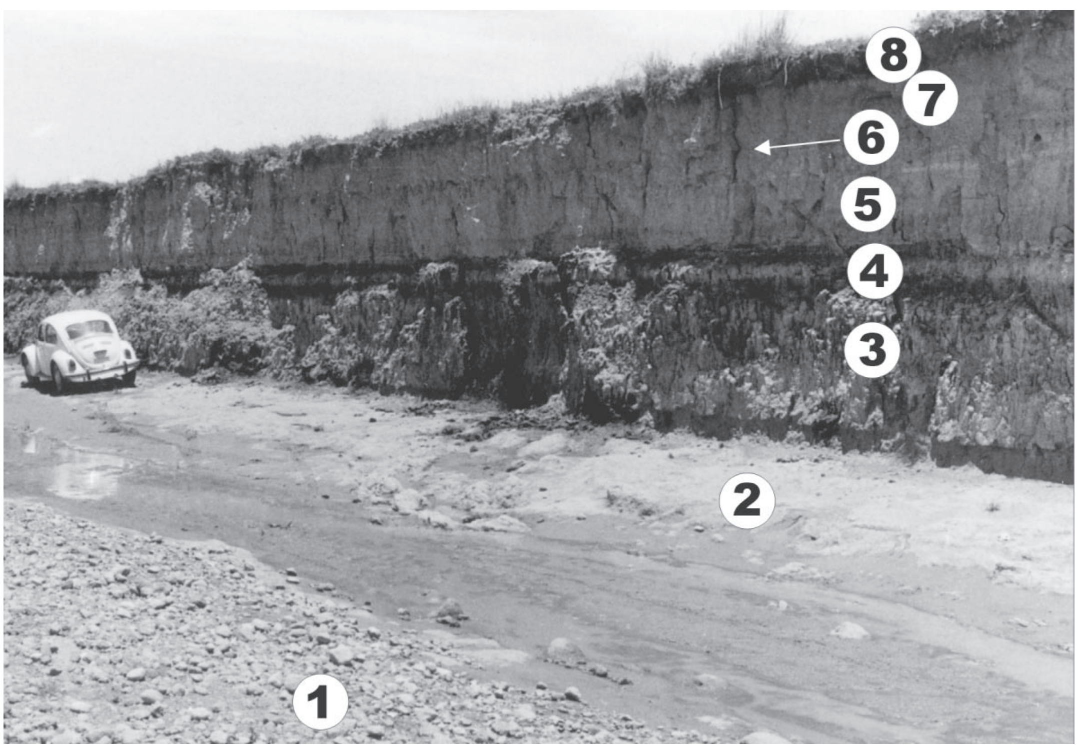

Figure 7. Section of characteristic valley fills in the Amozoc–Tepeaca area (8 km east of Amozoc, Barranca Nueva). The gravel of the barranca bed (1) is deposited on fBo1 Tepetate (2). The fBo3 paleosol (4) is clearly to be seen in the middle of the section. The paleosol developed on alluvial sediments (fluvial–lacustrine) of Becerra age (3). The fAh horizon of the fBo3 paleosol developed in two layers with lacustrine deposits in between. The Tezoquipan phase is characterized by the next sediment complex (5). A fAh horizon of a paleosol (6) marks the stratigraphic gap between the Tezoquipan (5) and Tlaxcala (7) phase. The aeolian cover sediments are on top (8).

During the Tenanyecac phase (AD 100–650), isolated farms were abandoned in favor of villages. While villages increased in size, there was an overall decrease in population. Areas with pronounced soil erosion experienced especially large decreases in population. It appears that people moved to the villages. In comparison, the number and location of villages in the basins, where soil erosion was not widespread, has remained relatively constant since about 600 B.C. The phase of reduced soil erosion between AD 100–650 in the Tlaxcala area coincides with an increase in influence of Cholula and of Teotihuacán on neighbouring regions. At Amalucan (east of Puebla), for instance, a system used both for drainage and irrigation was apparently abandoned since about 200 B.C. and later was covered by colluvial sediments; by AD 700 topsoil had developed over everything (*cf.* Fowler, 1987). Between AD 350–550, during the Xolalpan phase, Teotihuacán was the center of a powerful state that had grown to dominate central Mexico (McClung de Tapia, 2001). At the same time Teotihuacán itself experienced the highest population density of its history. While the demise of the Teotihuacán state by the end of the Metepec phase, around AD 600–650, remains a mystery (McClung de Tapia, 2001), and while Cholula ceased to be the regional center for the Puebla area around AD 600, Cacaxtla took over the control in the Tlaxcala area and became the regional center. While in the Cholula area accelerated soil erosion became less severe, in the Cacaxtla area erosion and sedimentation processes were intense.

After the Tenanyecac phase, population increased during the Texcalac phase, resulting in renewed cultivation of slopes prone to erosion. In the Texcalac phase (Figure 4) there was an expansion of the chinampas and camellones, of terraced fields on the slopes and irrigation systems as well as an expansion of land use to marginal environments leading to little soil conservation. Soil erosion processes led to the removal of topsoil and barro horizons (Werner *et al.*, 1978) on hillslopes and the accumulation of the material caused colluvial mid-slope layers, foot-slope cones and alluvial fills in valleys. Our observations show that degradation and erosion of soils yielded in cascade-like transport and sedimentation processes with the result that an interpretation of colluvium layers from end-point sedimentation basins like lakes (*e.g.*, O'Hara *et al.*, 1993) do not allow reconstructing the exact timing and/or period of land devastation.

When population decreased during the following Tlaxcala phase, soil erosion also became less pronounced. After the conquest of Mexico by Spaniards in AD 1521, disease caused significant reduction in population over a short period of time (Werner, 1988:36; Figure 8). Simultaneously, erosion decreased because large areas of arable land were not cultivated. The catastrophic cocolitzli epidemics, a malignant form of an indigenous haemorrhagic fever of the Mexican highlands, beginning in AD 1545 and 1576 coincided with one of the worst Mexican droughts in the last 500 years (Acuña-Soto *et al.*, 2000; Luckman and Boninsegna, 2001). The epidemics of 1545–48 and 1576–78 killed 45% of the entire population of Mexico (Acuña-

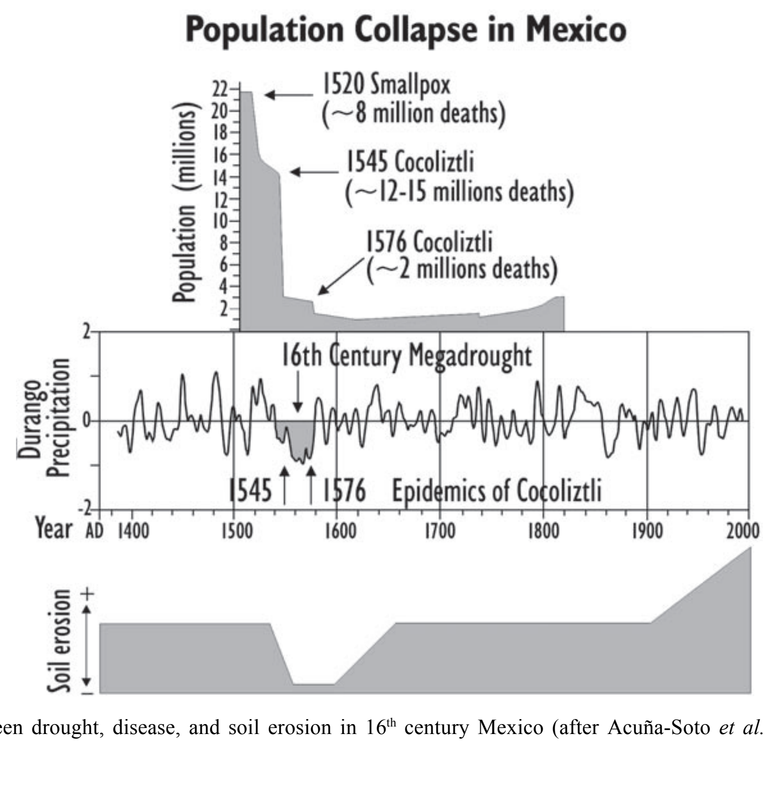

Figure 8. Relationship between drought, disease, and soil erosion in 16th century Mexico (after Acuña-Soto *et al.*, 2000; Luckman *et al.*, 2001, supplemented).

Soto *et al.*, 2000). We cannot decide yet whether a remarkable decrease in soil erosion processes was caused by the reduced number of humans cultivating the slopes of the volcanoes or by the reported severe drought, which definitely must have accelerated the abandonment of rural areas at the lower parts of the mountains. Nevertheless, it should be mentioned that the "16th century megadrought" was not recognized by O'Hara and Metcalfe (1995) who reconstruct the climate of the Basin of Mexico from a variety of primary and secondary historical sources over the last 600 years. It seems highly probable that land-use change, not drought conditions, was the major driver of the environmental change (less people = less agriculture → shrub and forest recovery → less soil erosion).

Since the 16th century, erosion has increased, especially after AD 1,900 (Heine, 1978a, 1978b).

CONSEQUENCES

It appears that the cyclic nature of state buildup and breakdown (*cf.* Marcus, 1992) and, as a consequence of this, land-use changes are the causal links of the observed cycles of soil erosion. The central Mexican case illustrates our point about the human-induced environmental changes during the last 3,500 years. First of all, the expansion of a political domain did not necessarily occur at the same time as population increase and land-use change ('population pressure' does not explain almost everything in Mesoamerican archaeology, such as the origins of agriculture, of irrigation, of ranked societies, and of urban civilizations; see Flannery, 1976: 225–227). Secondly, population increase resulted in a more intense land-use, even on steeper slopes, more sophisticated agricultural practices, and, hence, accelerated soil erosion. Thirdly, devastated soils (*e.g.*, tepetate and caliche horizons at the surface) contributed to the contraction of suitable land for agriculture and thus to a greater vulnerability of the central Mexican states which consisted of a capital city, a nearby core physiographic region, and a series of outlying provinces (Marcus, 1992; McClung de Tapia, 2001). Fourthly, erosion, transport and sedimentation of the soil material occurred in a cascade-like process in a catchment: from upper slopes to mid-slopes, from there to foot-slopes and, finally, to valleys and basins (and lakes). Considering these interrelations and the fact that cyclic political developments occurred in different areas at different times, it is no surprising that phases of soil erosion in central Mexico are asynchronous both in time and space.

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