One million years of anthropogenic global environmental change

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Preface

by Henry Hooghiemstra

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Natural climatic influence on the environment

The impact of natural climatic change on the environment is quite obvious and documented by thousands of records all over the world. These records have been based on different variables from 'natural archives' and the time axis was calibrated by making use of various dating techniques. Sometimes, exceptional effort has been given to study changes at small distances in the sediment cores to arrive at a fine time resolution. Thanks to these efforts, we have several marine and terrestrial records, documenting climatic change, that reach with astonishing precision back in time up to several millions of years.

In its turn, climatic change is responsable for changes in the environment; we may say 'our environment' for that part of geological time that Man arrived on the scene of evolution. Recently, it becomes apparent how climatic change may have influenced the evolution of man and in this respect I like to warmly recommend the book 'Paleoclimate and evolution with emphasis on human origins', which was composed by Elisabeth Vrba with so much dedication.

Anthropogenic influence on the environment

How incongruous that so little is known about anthropogenic influence on our environment when we ignore the period of industrial revolution. Up to recently, only some palynologists claim that pollen records show evidence of human action during the last 100,000 years or so. In these cases, the presence of charcoal, e.g. in a long Australian pollen record, is the main evidence. But it is still unsure if this charcoal originated from natural fires, or from human action.

In general, the relationship between climatic and environmental change at one hand, and positive and destructive developments of civilizations in several places in the world at the other hand, supports the concept that the history of civilizations is not just a miracle independant from changes in the natural conditions during the Holocene, the last 10,000 years. Some fascinating, and recently published examples of this statement have been listed in the references.

This discrepancy in understanding the sources of environmental change led to the topic of this symposium: One million years of global anthropogenic environmental change.

Multi-proxy evidence

In this symposium several specialists have shown the story of 'their proxy' and we were quite fascinated when prof. Salomon Kroonenberg was able to put a new proxy on the scene: the Pleistocene history of coal fires in China which is most probably related to the history of local presence of Man.

Also prof. Joop Goudsblom discussed the relation of fire to people and environment in an original way, viz. as part of their social evolution.

Prof. Sytze Bottema discussed the impact of the first farmers on their environment in the Near East based on the evidence of fossil pollen.

Prof. Leendert Louwe Kooijmans selected some modern topics of discussion concerning our environment, such as the disturbance of the local environment by man, the influence of various agricultural techniques on the environment, and aspects of landscape ecology, and projected these modern topics on communities of farmers in prehistoric time. (Not included in this volume).

Dr. Bas van Geel showed us the record of prehistoric human occupation in parts of northwestern Europe based on unconventional microscopic fossils. This led to an interesting discussion to which degree a changing environment, forced by climatic change, has caused dramatic changes in the local history of human occupation in many archeological sites.

Using a long time scale of some 5 million years, prof. Henry Hooghiemstra summarized the significant evolution of climate and environment, especially in Africa where human evolution originated.

Dr. John de Vos showed us the evolution of fossil Man and showed us the link between gradual changes in the morphology of the skull and major changes in the environment where early Man developed.

Acknowledgements

This symposium was organized in the framework of the 'Raad voor de Aardwetenschappen' (Commission for Earth Sciences) of the Royal Dutch Academy of Sciences. I thank the chairman, prof. Jan van Hinte, for the initiative to focus attention to this challenging topic. Prof. A.J.M. Meijerink is thanked for his help with the selection of topics to be addressed during the symposium. The Royal Dutch Academy of Sciences (KNAW), is thanked for organizing and

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Anthropogenic changes in the environment of the Near East: the impact of the first farmers

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Summary

Farming developed shortly after the Pleistocene-Holocene transition, c. 10,000 uncalibrated radiocarbon years before present in the Fertile Crescent, a mountaneous arc in the Near East. The environment at that time, reconstructed through palynological research, was dominated by steppe vegetation. The wild ancestors of the crops that still form an important part of our daily diet, were then taken into cultivation, after which they developed domestication traits.

The impact of the scarce first settlers upon their natural environment is not demonstrated by palynology, but this discipline is eminently capable of indicating large-scale changes in climate. The study of botanical macrofossils from archaeological excavations informs us about agriculture and its history and on the further impact of early farming. The example of 'Ain Ghazal, excavated by Köhler and Rollefson, demonstrates that early farmers destroyed a complete ecosystem by overexploiting their environment.

Introduction

It may be assumed that early farming, starting around 10,000 BP, had some impact upon the environment. The question is how great this impact was, and especially whether the changes which were caused by these early farmers are still detectable after 10,000 years. Immediately following this question, other questions arise that have to be answered first. What did the environment at the time of the first farmers look like? Were there any mechanisms other than farming that had an impact, maybe overriding the impact of the early settlers?

The decision to study the possible impact of the first farmers especially in the Near East requires some explanation. The Near East was chosen because archaeological and paleobiological investigations have revealed that the earliest agriculture on this planet was practised in the foothills of the mountain arc that runs through the Levant from Israel through northwestern Syria, along the south Anatolian Taurus and down again along the Iranian Zagros (fig. 1). The wild ancestors of various crops are found even now in these foothills, which are called the 'Fertile Crescent' because this was the cradle of agriculture. Various crops were found in excavations of early sites in this region and these crops show certain characteristics that point to domestication. This agricultural food production is dated by radiocarbon, beginning, at Tell Aswad for instance, around 9750 BP, soon after the transition of the Pleistocene to the Holocene (Van Zeist and Bakker-Heeres 1979).

The earliest settlements with evidence of food production in the Fertile Crescent are indicated by Gebel (1982) on TAVO map BI 11. Most of the early sites are found at altitudes that are described as foothills, but some occur lower, towards the Syrian plain, at an elevation of 300 m. The vegetation of the landscape where the early farming villages arose has been reconstructed by means of palynology.

The earliest known appearance of farming and farmers took place at a time when the world numbered about 4 million inhabitants (Ponting, 1991). For every living person around 10,000 BP the world now contains 1500 people. The present world population is almost entirely fed by agriculture, whereas 10,000 years ago most of the 4 million people were hunter-gatherers and only a small number initially turned to farming. This reduces the potential impact resulting from the activity of the earliest Neolithic people to a minimum. The traces of this small impact are very likely to remain unnoticed and at any rate will not have caused any global effect.

The paleoenvironment

The Late Quaternary climate change

At the end of the Late Glacial a global change in climate took place as the temperature rose. From ice cores collected in Greenland and the Antarctic and from marine cores taken in the Atlantic Ocean, changes in the value of various indicators have been traced (for instance, δ O18 as an indicator of temperature change, snow accumulation, dust accumulation as an indicator of steppe or ammonia as a measure of the amount of wetlands). The rapid change of these values at the Pleistocene/Holocene transition is particularly striking. The evidence suggests that the global temperature increased from the low Glacial temperatures to the much higher Holocene temperatures within a few decades. For more information the reader is referred to the literature quoted in PAGES (1994).

Calculations of temperature in the polar areas do not necessarily imply that the temperature in the Near East behaved in a parrallel fashion. Yet microchemical investigations on annually laminated cores from Lake Van in eastern Anatolia do suggest that a similar rapid change in environmental conditions occurred in the Near East at the Pleistocene/Holocene transition (Lemcke, 1994).

The early-Holocene environment

A first prerequisite for analysing any early Holocene anthropogenic change in the environment of the Fertile Crescent is to define the basic environment itself. Only after the natural environment has been described can we try to look for early anthropogenic impact.

The reconstruction of the Pleistocene and Holocene landscape is first of all based upon paleobotanical research. In these reconstructions the most important part is played by palynological studies. Macrofossils obtained from excavations, mostly charred seeds but also parts of plants or pieces of wood, are a source of information on agriculture especially, but may give supplementary evidence about general vegetation patterns. We must be well aware that, although vegetation to a large extent defines the visual aspect of the landscape, there are other agents playing an important part in the shaping of past landscapes. Sea-level rise caused losses in habitation when coastal plains, for instance in the Levant or in southern Greece, were flooded. The abiotic factors of soil and climate largely define the presence and type of the vegetation. Geomorphological research, for instance, is necessary to reconstruct the past shape of the landscape and the way this landscape evolved. Since vegetation is largely conditioned by climate, vegetation studies enable us to obtain information on past climate from the subfossil pollen record.

Palynological evidence

The reconstruction of the Quaternary vegetation of the Fertile Crescent is based upon the evidence supplied by pollen cores taken in various parts of the Near East (fig. 1). Five pollen sites in the area concerned have been studied: the Hula marshes in northern Israel (Baruch and Bottema, 1991), the Ghab Valley in northwestern Syria (Niklewski and Van Zeist, 1970; Van Zeist and Woldring, 1980), Lake Van in eastern Anatolia (Van Zeist and Woldring, 1978; Van Zeist and Bottema, 1991; Bottema, 1995), and Lake Zeribar and Lake Mirabad in the Zagros mountains in northwestern Iran (Van Zeist and Bottema, 1977). Many of the other sites shown in the map of figure 1 contribute to our understanding of the past vegetation of the Near Eastern landscape.

Glacial conditions in the Near East had formed a steppe vegetation that included *Artemisia*, Chenopodiaceae, *Ephedra distachya* and various umbelliferous plants, such as *Ferula*. Trees were absent or had found refuge in very small numbers in the mountains in edaphically favourable spots. Still the Fertile Crescent did not act as a homogeneous terrain. This is of course not to be expected, since nowadays the area does not carry a homogeneous vegetation either. One might expect the Crescent to display a climatic development that showed the same trend throughout, in terms of increasing drought or moisture. For the Late Glacial period the pollen evidence indicates that the major part of

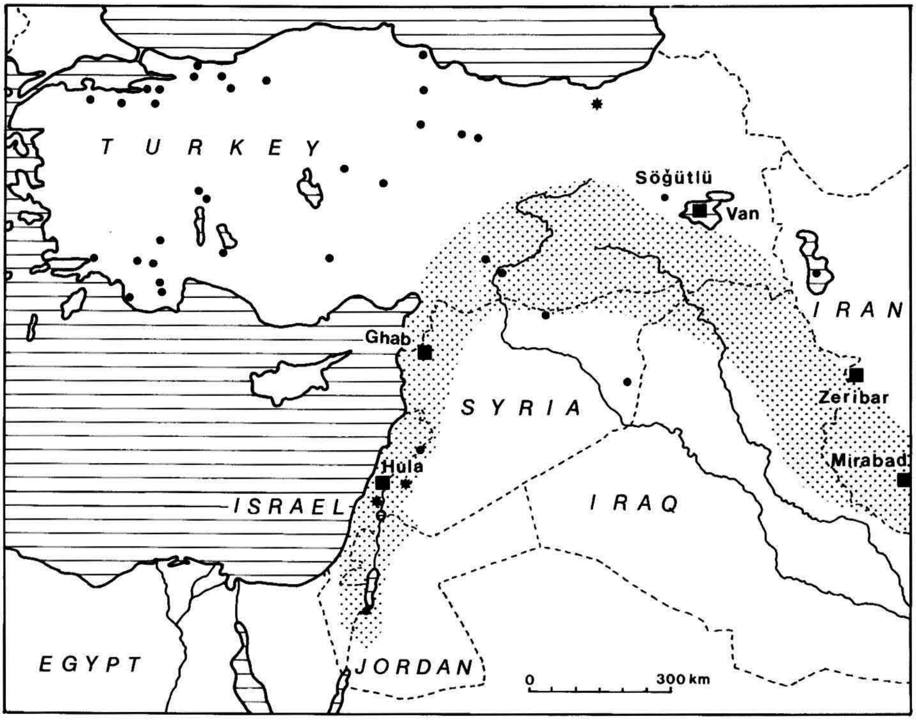

Fig. 1. Map of the Near East indicating the Fertile Crescent and the pollen core locations. The pollen sites used in this study are indicated with a black square.

the Near East was dominated by cold-dry steppe, apart from the Hula marshes in northwestern Israel, which showed a different development (Baruch and Bottema, 1992). On the hills around the Hula Basin a forest steppe had developed around 14,000 BP. From that time on, conditions progressively improved for the development of Tabor oak forest and by 12,000 BP a fairly dense forest was found in northern Israel. Around 11,500 BP conditions in northern Israel suddenly changed, as is deduced from the sharp decrease in deciduous oak pollen. During the Late Glacial other parts of the Fertile Crescent maintained an almost treeless, steppic character. A change from steppe conditions towards forest took place somewhat before the Pleistocene/Holocene transition in northwestern Syria, where the slopes of the Jebel Alaouite were covered with oak, pistachio, cedar and oriental hornbeam (Niklewski and Van Zeist, 1970), at the very time when further south in Israel a strong decrease in tree cover came to an end. In other parts of the Fertile Crescent, treeless vegetations persisted and it would take several millennia before vegetations developed that resembled those present nowadays. In the neighbouring Pisidian Lake district in southwestern Anatolia this occurred after 9000 BP (Van Zeist *et al.*, 1975; Van Zeist and Woldring, 1980), around Lake Van in eastern Anatolia at about 7000 BP (Van Zeist and Bottema, 1991; Bottema, 1995), while near Lake Zeribar Zagros oak forest developed only after 6000 BP (Van Zeist and Bottema, 1977) (fig. 2).

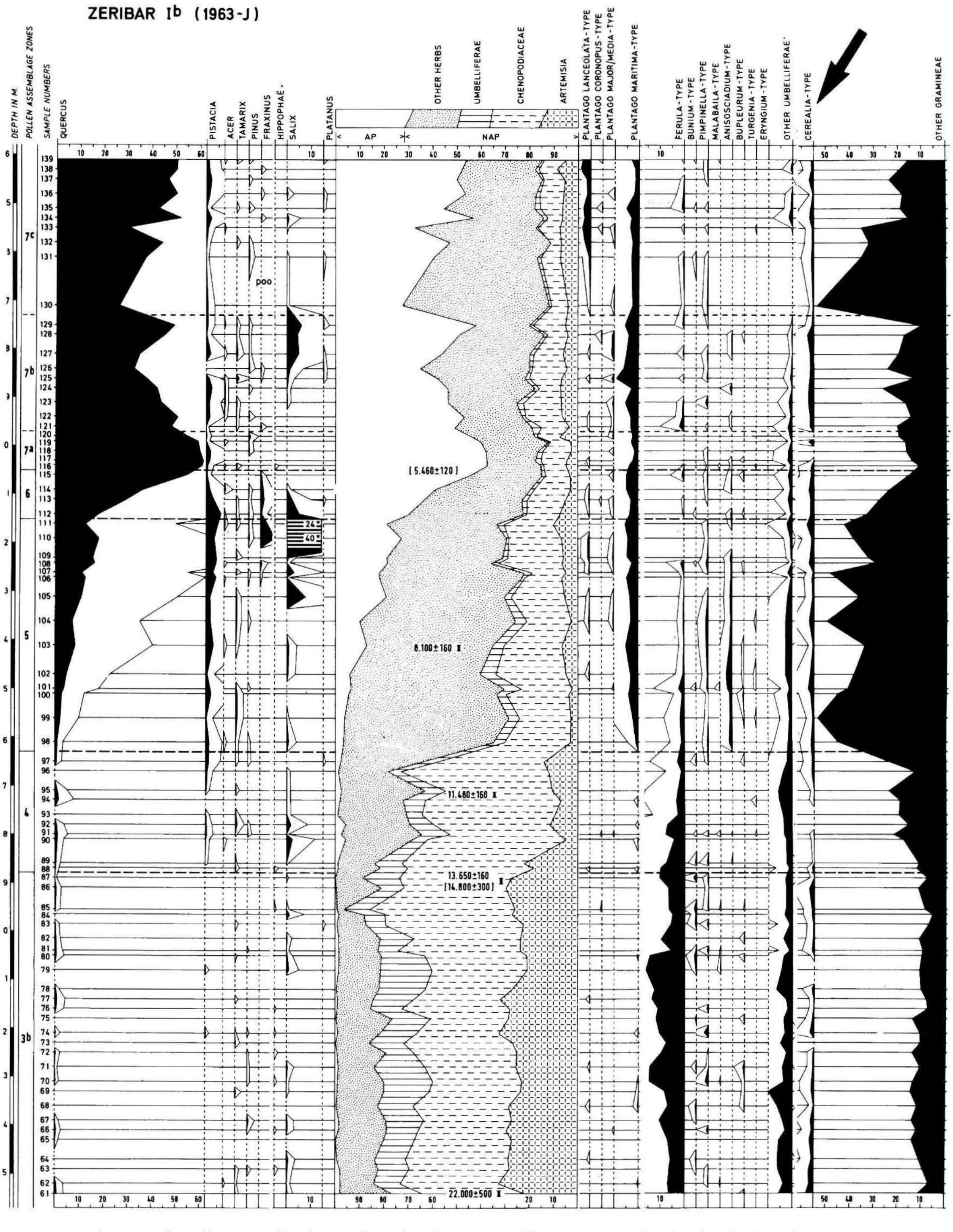

Fig. 2. Pollen diagram of Lake Zeribar showing a Cerealia-type curve for the time before the evolution of agriculture (after Van Zeist and Bottema, 1977).

The potential crop plants

The foregoing presented some aspects of the naturally occurring changes in the vegetation of the Fertile Crescent. For this paper we shall focus upon the beginning of the Holocene when farming started. The main trend in the Near East then was an open steppic landscape, at the lower levels dominated by grass steppe with some *Artemisia* and Chenopodiaceae, whereas in higher parts some forbs, bushes or small trees such as pistachio, almond and hawthorn were found in the grass steppe.

It is this open space which is the natural habitat for a series of fruit- or seed-bearing plants which will have played a role in the life of hunter-gatherers, and which certainly played an important part in early farming because they formed the initial crop plants. It was stated above that the Fertile Crescent witnessed important climatic changes during the transition from Pleistocene to Holocene, which mainly concerned a major rise in temperature. Increasing warmth in a dry system is not exactly the means to stimulate biomass production, and moisture increase sometimes may have taken millennia to become effective but this also meant that profitable plants such as wild einkorn, wild emmer wheat, wild lentil, flax and various peas still did not need to compete with forest. Early farming developed during a time that was warm compared with the preceding Late Glacial and where the landscape was predominantly open. We have no pollen evidence of changes in the amount of wild crops and their distribution as the Late Glacial turned to the Holocene, but the changing climate will certainly have had an influence.

Proof of crops

How can we be sure that the various crop-plant species wheat, barley, lentil and various peas that are found in a carbonized state in excavations, were in fact grown by farmers and not collected from the wild by settled hunters? Soon after prehistoric farmers took the wild plants into cultivation, certain characteristic changes took place that can still be seen in the carbonized remnants. These characteristics are often found as heterozygotic recessive traits in a population and come to the fore when they are – often passively – selected upon. For instance, the ratio of non-brittle to brittle ears of cereals, shifts towards non-brittle ears under influence of the harvest system. A simple act like sowing favours the largest seeds which have less trouble in breaking through the soil than the smaller ones. The presence of various recessive characteristics, which in homozygote form are fatal flaws in the wild plant, in particular explains the rapid change to domesticates. Selection upon mutants would take a much longer time.

The indicative value of palynology

Palynology informs us about the general vegetational and climate history of the Late Quaternary of the Near East. Seeking to reveal the possible impact of the early farmers upon their natural environment we turn again to this obvious method for obtaining botanical evidence. However, pollen diagrams from the Fertile Crescent do not show changes in the early-Holocene pollen assemblages that point to human activity. There are several reasons why palynological methods are not adequate in this case. Firstly, one must realize that the initial steps towards farming were taken by a small group of hunter-gatherers and their impact was unimportant compared with the large stretches of terrain that remained intact. The area of vegetation that had changed under man's influence was very small compared with the amount of untouched vegetation.

But an even more important question is: to what extent do we expect the farmed vegetation to be different from the preceding natural one? The farmers had promoted naturally growing plant species in their own habitat or close to their original habitat. For instance, wild emmer wheat in the Jebel Druz (southwest of Damascus), at present still forms extensive grain fields that much resemble farmed fields (pictorial information: Patty Anderson, Jalès, France). Clearly, a man-made field would not alter the pollen precipitation noticeably, at any rate in the initial stages. This is especially true for the early period when crops had not yet been bred to change from cross-fertilization (through wind-pollination) to self-fertilization and hence poor pollen dispersal. By the end of the tenth millennium, when the first farmers had grown to a larger number of well-established agriculturalists, one might expect a visible change in the pollen precipitation to have taken place. Unfortunately, even then no solid proof of the farming effect in the Fertile Crescent could be shown because of the small share of crop plants in the pollen precipitation. The wheat and barley varieties which were used were naturally selfing plants, einkorn scoring highest with up to 9% cross-fertilization. The large (40–60 μ) pollen grains remained mostly in the bracts and only a very small number ended up in the pollen precipitation (Bottema, 1992). These then need to be separated from the pollen of those wild grasses that had the same pollen type. For this reason pollen diagrams from the Near East always show a category of 'Cerealia-type' that includes pollen of wild and domesticated cereals and some grass species (fig. 2). Henry (1992) suggests that the Late Glacial mobile and settled foragers in the Levant benefited from an increase in wild cereals, which he thought, took place after 13,000 BP. Pollen diagrams of the Fertile Crescent, however, demonstrate that Cerealia-type pollen occurred with about the same values during the last glacial as in the Holocene.

Wild and domesticated lentils, vetches, peas and chick-peas all are leguminous species which are insect-pollinated and under-represented in the pollen precipitation in sediments that mainly receive wind-blown pollen. Identification of these species raises problems, since some of them can only be ascribed to the level of the genus or higher and thus cannot be attributed to a specific crop. One may wonder to what extent pollen analysis does contribute to the demonstration of human impact upon the vegetation. One has to realize that most agriculture, after it spread from the original locus in the Fertile Crescent to other parts of Asia and to Europe, took place in areas where the wild ancestors of the crops were lacking and, even more important, where forest formed the natural vegetation. The beginning of agriculture in such regions further away from the original source resulted in far-reaching vegetation changes, including the destruction of the original vegetation, in most cases forest, and the introduction of a series of crops, new plant species (albeit often hardly detectable palynologically), as well as accompanying species that became known as weeds and secondary vegetation that appeared after fields were laid fallow or abandoned.

In those parts where the natural vegetation was forest, agricultural activity is palynologically far more demonstrable than in the Fertile Crescent itself. But the first signs in pollen diagrams even from forested areas, for instance Anatolia, are visible only from about 4000 BP (Bottema and Woldring, 1986; Bottema *et al.*, 1995). The part of the pollen assemblage indicative of vegetation changes caused by human activity, starting in the late third millennium, seems more to be the effect of grazing by herds of domestic animals than the effect of crop cultivation. The effect of herding reaches far beyond the direct settlement activity. Especially after disturbance of the natural vegetation through *transhumance* (seasonal migration of herds and herdsmen, see among others Reinders, 1994), the replacement of the original vegetation by weeds and secondary vegetation must have played an important role in the pollen rain.

Impact demonstrated by archaeological evidence

There are, however, other ways to measure the influence of early farming upon its surroundings: a careful excavation and thorough interpretation of the results. An impressive example of such work is the excavation of the early-Neolithic site of 'Ain Ghazal by Ilse Köhler and Gary Rollefson. In the following demonstration of early impact, quotations mainly are from Köhler-Rollefson and Rollefson (1990).

The early farming site 'Ain Ghazal was found in a suburb of Amman, the capital of Jordan. The elevation of the prehistoric settlement is about 700 m above sea level. The average annual precipitation is between 250 and 300 mm. Locally the area is defined by the urban sprawl and outside of it not much vegetation has been preserved in a rather desolate landscape.

The culture periods found by the excavators include the Pre-Pottery Neolithic B (PPNB) dated 9200–8000 BP, Late-Aceramic Neolithic C (PPNC) from about 8000–7500 BP, and the Yarmuk Ceramic Neolithic from 7500–7000 BP. The excavators show that the PPNB farmers of 'Ain Ghazal provided their vegetal food by growing einkorn and emmer wheat, two-row hulled barley, lentils, peas and chickpeas. Their protein supply, according to the study of the bone finds, came mainly from hunting. The animals that were bagged, or that ended up in the settlement, are an interestig mix. They include badger, pine marten and squirrel, very characteristic of forest and more especially forest as is found in central and northern Europe. Typically boreal animals found are hedgehog and goshawk. The list of animal species is very long and includes species with a broader ecological range that covers forest as well as more open terrain, such as aurochs, red fox and wild cat. The presence of these typically forest-dwelling mammals and birds demonstrates that the 'Ain Ghazal area carried forest, whereas nowadays even the memory of trees in this area seems absurd. The scarce presence of Tabor oak north of Amman is an indication that especially deciduous oak forests with a forest fauna were found in this region.

The excavation shows that the inhabitants of 'Ain Ghazal lived in houses with large-diameter postholes which show that heavy trees were used which must have grown in the vicinity. The excavators explain that house-building did not only require heavy trees for construction purposes. The extensive use of plaster will have demanded more wood for lime-burning than for construction purposes.

The bone assemblage and the use of wood changed rather abruptly shortly after 8200 BP. Goat bones then formed 70% of the total. Bones of goat were present in small numbers even at the beginning of the PPNB-settlement but they strongly increased in number towards the end of the ninth millennium BP.

Towards the end of the PPNB massive posts disappeared from the houses and the use of wood became restricted to thinner pieces; finally around 8200 BP wood was no longer used in house building and people took to stone piers and interior walls. Charcoal was now found in small amounts only and in very small pieces. The nature of the ashes in fireplaces points to the use of dried dung for fuel.

From the above it is clear that a very characteristic forest fauna was destroyed and its habitat, the forest itself, finished by the demands of house-building and above all the enormous energy demand of lime-burning. Even when the forest tried to regenerate after lumbering, this was prevented by the growing number of goats that would browse away any sapling that appeared on the forest floor.

Thus the first clear impact of farmers upon their environment, demonstrated by Köhler-Rollefson and Rollefson (1990) for the Jordanian Pre-Pottery Neolithic, was the destruction of a diverse forest community of Tabor oaks and characteristic mammal and bird species. In about a thousand years, not so much the arable land with its crops had changed the landscape, as the thoughtless exploitation of the forest outside the settlement together with 'the machine' that during the Holocene would devastate most of the Mediterranean, the Near East and large parts of Asia.

This agent was to be called 'the black plague of the Middle East' but the domestic goat was in fact created and kept by man himself. During the millennium of the Pre-Pottery Neolithic the effect of some phenomena increased considerably. The population of 'Ain Ghazal grew and the number of inhabitants by the beginning of the PPNB is estimated to have grown fourfold (Köhler-Rollefson and Rollefson, 1990). The population exacted its toll from the environment and the existing ecosystem was consequently disappearing. The loss of the wild fauna forced people to breed more domestic animals for their meat supply. Apart from this change from wild resources that were over-killed, the constantly growing population also caused an increasing demand for meat that was met by breeding goats.

The growth of the flocks prevented any regeneration of the forest and finally even secondary and following vegetation types gave up in the struggle against the ever-browsing goat flocks. The biomass of the 'Ain Ghazal area had been reduced to a fraction of what was there initially. Indeed a conflict must have arisen between crop cultivation and goat herding. The feeding behaviour of goats had to be controlled by herdsmen of the 'Ain Ghazal site because these early farmers practised a mixed farming from the start. This in contrast with their predecessors who had domesticated crops before they domesticated animals. It is only after a certain period that grazing had to take place increasingly far from the settlement because there was no longer any food available in the vicinity. The large numbers of goats were a threat to the crops and near the village the fields had to be watched over constantly.

This situation may have led to a changed agro-economic setup in the settlement during the Ceramic Neolithic of the Yarmuk. The number of inhabitants of 'Ain Ghazal dropped in that period and it is assumed that part of the population had moved to the steppe with the goats; an assumption that is supported by the fact that Köhler-Rollefson and Rollefson (1990) mention imports of stone from the steppe. Thus the impact of the grazing is extended to the open landscape, where the herding of sheep and goat soon started to influence the original steppe.

One factor was able to curb human impact in the steppe. Those parts that were devoid of natural springs could not easily be used by nomads, who had to water their flocks. Thus the central part of Syria, low mountains up to about 800 metres, retained a pistachio forest-steppe up to recent times when finally water was brought in with small trucks or when deep wells were sunk. The northern steppe in Syria shows a vegetation of *Carex stenophylla* and lichens as a final stage of overgrazing that hardly produces any food for flocks.

The finding of bones of a medium-sized half-ass (*Equus* cf. *hemionus*) and a desert monitor (*Varanus* sp.) in 'Ain Ghazal during the PPNC (8000–7500 BP) demonstrates that the steppe encroached upon the former woodland site, clearly manifesting the changes in environment caused by its early inhabitants.

The grazing effect, first around the PPNB-site and later further away in the steppe, is due to the difference in numbers of the wild herbivores and the domestic flocks. Köhler-Rollefson and Rollefson (1990) report a modern density of 0.6–4.1 wild goat per square kilometre in Pakistan. At the same time the Greek island Theodorou numbers 134 head per square kilometre under domestic conditions.

One must realize that it is very difficult to estimate potential populations because the natural conditions have significantly changed. Not only has the potential vegetation as a grazing source fundamentally changed, the absence of natural (non-human) predators also plays a considerable role. Still it is clear that between grazing by natural fauna and by protected herds there is great difference. The keeping of goats was profitable for man but, biologically speaking, also for goats. The latter category prospered but at the same time exerted extreme pressure upon the vegetation, first around villages and later at greater distances in the steppe.

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Changing environments for human populations around 2650 BP in the Netherlands as a consequence of rapid climate change, and evidence for climatic teleconnections

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Extended abstract

A sudden and sharp rise in the ^{14}C-content of the atmosphere, which occurred between c. 850 and 760 calendar years BC (c. 2750–2450 BP on the radiocarbon time scale; see fig. 1), was contemporaneous with an abrupt climate change. In NW-Europe, as evidenced by paleoecological and geological studies, the climate changed from relatively warm and continental to a more oceanic (cooler, more humid) one (Godwin, 1975; Kilian *et al.*, 1995; Van Geel *et al.*, 1996, 1997). As a consequence of this change, there were considerable changes in environmental conditions in areas in the northern Netherlands, which regions were already marginal from a hydrological point of view. Mires and raised bogs suddenly increased in surface area. Also, the species composition of peat-forming plants in raised bogs changed rapidly: *Sphagnum papillosum* and especially *Sphagnum imbricatum*, which prefers an oceanic climate, started to play an important role. Forest vegetation reacted by a decline of *Corylus* (Van Geel, 1978).

Archaeological and paleoecological evidence for the sudden abandonment of the area of West-Friesland (fig. 1) and other marginal areas in the northern Netherlands is interpreted as the effect of a rise of the water table and an extension of peatland, which caused loss of cultivated land (Buurman *et al.*, 1995; Van Geel *et al.*, 1996, 1997). Human populations in such areas could survive the effects of climate change by migration and colonization of the new salt marshes in the northern Netherlands (Waterbolk, 1959). The first appearance of these salt marshes was caused by a slowing in relative sea level rise. This

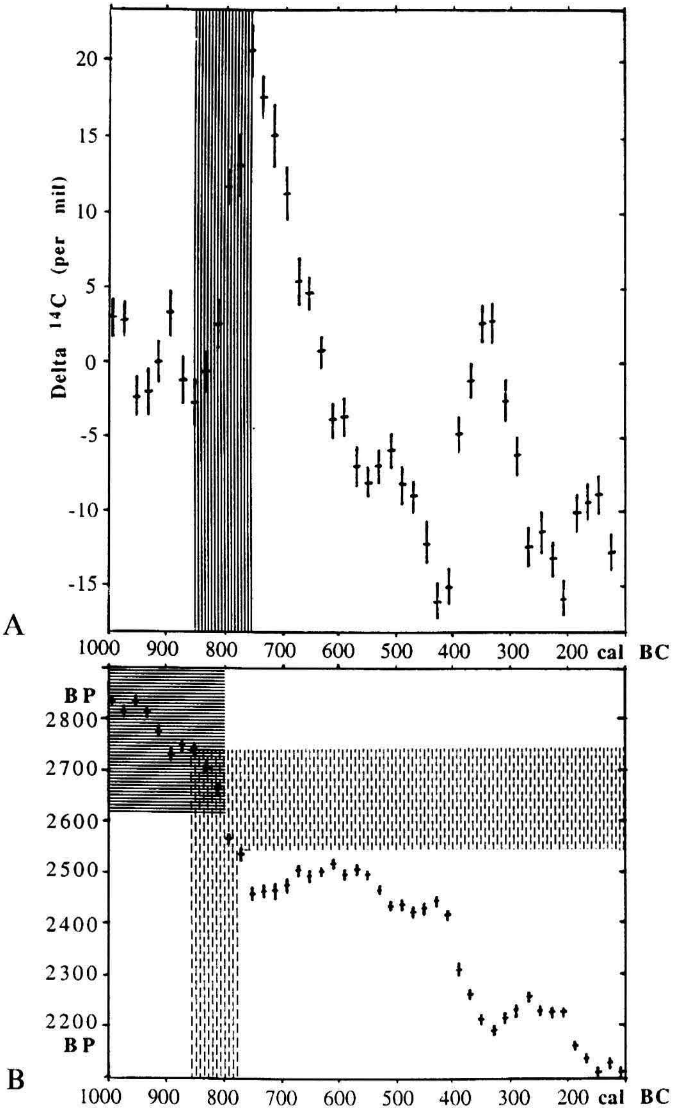

Fig. 1A. Relevant part of the ^{14}C-calibration curve with corresponding fluctuations in the ^{14}C-content of the atmosphere (Δ^{14}C), after Stuiver *et al.* (1993). The ^{14}C-content of the atmosphere shows a strong increase between c. 850 and 760 cal BC (period with vertical hatching).

B. As a consequence, c. 300 radiocarbon 'years' (between c. 2750 BP and c. 2450 BP) passed within a period of c. 90 calendar years. The later part of a settlement period in West-Friesland has been indicated with horizontal hatching.

Kilian *et al.* (1995) have shown by wiggle matching of series of radiocarbon dates that the vegetation change in raised bogs, which is related with the Subboreal/Subatlantic climatic transition, occurred during the phase of sharply rising Δ^{14}C values (see vertical broken lines fig. 1B). The youngest date of the settlements in West-Friesland (2620 ± 20 BP) and the oldest date of settlement sites in the salt marsh area in the northern Netherlands (2555 ± 35 BP) both coincide with the period of the sharply rising radiocarbon content of the atmosphere and the contemporaneous evidence for climate change obtained from NW-European raised bog deposits (van Geel *et al.*, 1996, 1997).

phenomenon possibly was a consequence of declining pressure on the coast by the Gulf-stream and/or thermic contraction of ocean water.

There is an increasing amount of evidence for similar, synchronous climatic change in other parts of Europe (Barber, 1982; Berglund, 1991), in N. America (Filion *et al.*, 1991; Jirikowic *et al.*, 1993) and in the Andes Mountains in tropical South America (Melief, 1985; Salomons, 1986). In Central-West-African areas with tropical rain forests the vegetation changed into more open, dry forest types (Reynaud-Farrera *et al.*, 1996). We consider the world-wide evidence for rapid climatic and environmental change around 2650 BP as indicative for climatological 'teleconnections' (PAGES 1995) as a consequence of changes in circulation patterns of the atmosphere and the ocean currents. The forcing mechanism for the observed changes is still unknown.

The strategy of ^{14}C wiggle-match dating (Van Geel and Mook, 1989; Kilian *et al.*, 1995) is a new approach to absolute age determination. The reconstructed ^{14}C-fluctuations from a series of samples in an organic deposit are visually matched with the standard calibration curve based on dendrochronology. Wiggle-match dating improves the precision and accuracy of dating assessments of organic deposits. This strategy is also a useful tool to identify mechanisms forcing climate change. It will help to unravel the possible relationships between changing ^{14}C-production in the atmosphere and climate change (Stuiver *et al.*, 1991; Stuiver, 1995), and the impact of such changes in the past on hydrology, vegetation and human communities.

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Since we submitted the present paper there was considerable progress in the interpretation of the observed phenomena around 2650 BP (Van Geel *et al.* in press and submitted). The discussed ^{14}C-oscillation was caused by changing solar activity. An important effect of a reduced solar activity is an increase in the cosmic-ray flux leading to a higher production of ^{14}C in the atmosphere. This increased cosmic ray flux caused a reduction in the amount of solar energy reaching the earth surface through mechanisms such as a reduction in the ozone layer density, the development of an aerosol layer, an atmospheric veil and increased cloudiness and precipitation. All these factors amplified the effects of a reduced solar activity, which apparently was the forcing mechanism behind the change to cooler and wetter conditions at middle and high latitudes in both hemispheres. The recorded synchronous change to dryness in tropical areas was explained (van Geel and Renssen, in press) as the effect of a decrease of the latitudinal extension of the Hadley Cell circulation and a possible associated weaking of monsoons. Furthermore an expansion of the Polar Cells and a repositioning of the main depression tracks at mid-latitudes towards the equator may have occurred. The evidence supports the idea that solar/cosmic ray forcing is an important factor in the present climate and also may dominate climatic changes in the near future.

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People, fire, and environment

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Summary

Humans have made their impact upon the environment as part of their social evolution. This process has been marked by increasing differences in behaviour and power between humans and all other larger animals. The changes in the balance of power are reflected in three successive ecological transformations instigated by humans: the domestication of fire, the emergence of agriculture and livestock raising ('agrarianization'), and the rise of large-scale industrial production ('industrialization'). The three transformations show some remarkable structural similarities, including a peculiar immanent dynamic.

Introduction

Let me begin with a word of caution. I want to avoid the expression 'Man and the environment', and speak about 'human groups' or 'people' instead. There are two reasons for this. First, the word 'man' in the singular makes us conjure up a picture of a lonely Robinson Crusoe, whereas it is in the very nature of human relationships with fire that they always concern a plurality of people. Moreover, the plural form allows me to refer to humans as 'they' or 'them' and not as 'he' or 'him' – pronouns which would make us inadvertently ignore half of humankind.

My contribution is based on the idea that the impact made by humans upon the environment is to be seen in the context of the social evolution of humankind, and that a generic characteristic of this evolution has been the increasing differentiation in behaviour and power between humans on the one hand and all other larger animals on the other. During the first discernible stages, say at the time of 'Lucy' (Johansen and Edey, 1982), this process of differentiation went together with irreversible biological mutations; after the emergence of *Homo erectus*, socio-cultural development became increasingly more important. Since the emergence of *Homo sapiens*, differentiation in behaviour and power appears to have proceeded mostly through changes in social organization and cultural equipment.

These changes are reflected in three successive ecological transformations instigated by humans: the domestication of fire, the emergence of agriculture and livestock raising ('agrarianization'), and the rise of large-scale industrial production ('industrialization'). The beginnings of these ecological transformations lay widely apart in time; the transformations as such continue to this very day. Each of them added to the uneven balance of power between humans and other animals.

Three ecological transformations

The original domestication of fire in the Paleolithic may be regarded as the first major ecological process set in motion by humans. When exactly this process began is still a matter of dispute among the experts; estimates vary from somewhere between 2.000 and 50.000 generations ago. The second ecological process set in motion by humans was 'agrarianization': the rise of agriculture and animal husbandry, which began around 400 generations ago. The third was industrialization, the emergence of large-scale mechanical industry around 10 generations ago.

It makes good sense to look at these three ecological transformations in similar terms. For one thing, they are clearly related in a sequential order. It is hard to conceive of industrialization without the preceding process of agrarianization, and likewise agrarianization could hardly have occurred if people had not already acquired a measure of control over fire enabling them to cook their food and to open up land for cultivation by slash and burn.

We can see in retrospect how the three processes interlock sequentially: how the domestication of fire was a precondition for agrarianization, and agrarianization was a precondition for industrialization. This does by no means imply, however, that this sequence could in any way have been foreseen or planned. It is patently absurd to envisage a groups of Paleolithic cave dwellers devising a 2.000 generations plan involving first the mastery over fire, then agriculture, then large-scale industry.

The sequence of domestication of fire, agrarianization, and industrialization is a clear example of an unplanned long-term process. There is no ground for regarding it as the realization of a previously drawn up design. At the same time, this sequence could never have occurred without human plans. The long-term process is the unintended outcome of human actions involving intentional striving toward certain short-term goals.

In order to explain this dialectic relationship between intended short-term goals and unintended long-term outcomes it is helpful, I think, to recognize that in the long trajectory from the original domestication of fire to the present stage of large-scale industrialization every new step may be understood as an attempt to increase human control over natural forces such as fire, vegetation, and fossil energy. These attempts were deliberate. In the long run, however, every intended increase in control tended to lead to an unintended increase in dependency.

Applying this general perspective, each of the three ecological transformations may be understood better in the light of the other two. We can use our knowledge of agrarianization and industrialization to form a picture of what the original domestication of fire amounted to. Conversely, a sharper idea of the basic principles of the domestication of fire may help to bring into focus the central features of agrarianization and industrialization.

The domestication of fire

The fact that humans have acquired control over fire is something highly special and noteworthy. In order to appreciate this it may be useful to compare fire with water. More than two thirds of the surface of the earth is covered by water, which in most cases is continuously present. Fire is much rarer. What natural fires there are, are usually of short duration. All animals, and in fact all forms of life on earth, need water. No animal, and only a very small group of plants and trees (the so-called 'pyrophites'), needs fire. Among animals, only humans have developed a need for fire – to such an extent that they have also developed into a 'pyrophite', virtually unable to live a life without fire.

The original domestication of fire in the Paleolithic was by no means an 'absolute beginning'; it represented a new stage in an ongoing process. The *preconditons* enabling humans to attain some control over fire were shaped during the preceding stages in the bio-social evolution of hominids. Granting the importance of this long prehistory is not to deny, however, that the domestication of fire and, in its wake, the establishment of a species monopoly of the control over fire by humans, were of crucial significance for the further development of the relations between humans and the rest of the animal world. Today all humans tend to conceive of 'man' and 'animals' as two distinct categories; if my view is correct, this experience of being essentially different from all other animals is in its origins directly related to the formation of the species monopoly of control over fire.

The process of combustion that we call fire is in itself a blind natural process. We tend to regard it as destructive, because it reduces highly organized matter to a lower state of organization or integration, and it does so in a manner that is irreversible. In the longer run, however, the primarily destructive effects of a fire may be conducive to processes of reorganization and re-integration at a higher level. This happens in ecological systems when a fire clears away dead matter and fungi, thus giving new scope for plant and animal life. It is also what has happened in the domestication process, in the course of which humans have come to control to some extent the energies released by combustion and to use these in the organization of their social life.

During the first stage of the domestication process, our early ancestors passed from the incidental and mostly 'passive' to more regular and 'active' use of fire (cf. Goudsblom, 1992, 16–20). As can still be observed today, wildfires do not just scare the animal world; in fact, many animals know how to take advantage of a fire which is burning itself out, using it as a source of heat and light and of easily obtainable and tasty food. Bush fires have been described as a 'true feast' for predatory birds, and many herbivores are known to be fond of licking at salty ashes. None of these animals, however, learned to influence a fire – to keep it burning so as to be able to benefit from it not just incidentally but regularly. Only hominids proceeded toward a more 'active' and regular use of fire. They 'tamed' this external source of energy, and incorporated it into their own groups.

In order to accomplish this they had to learn, first of all, to preserve the remains of a fire at its original site and, subsequently, to transport the burning matter to a secure place. Preserving a fire requires, as we all know, that it be provided with fuel. What is common knowledge today, however, was not so for our remote ancestors; they had to learn, by experience and by example, not only that a fire needs fuel and air, but also that the fuel needs to be dry, that different kinds of fuel produce different kinds of fire, etc. None of this knowledge was given to them (or to any other animal) as innate information. It all had to be found out; and, in order not to be forgotten, it had to be shared with and transmitted to others. Knowing how to preserve a fire was, therefore, typically an element of 'culture': a pattern of behaviour that was 'learned, shared, and transmitted'.

The control over fire involved, of course, a great deal more than knowledge of fuel. It is important to realize that such activities as gathering and storing wood and 'feeding' the fire with it were forms of 'detour behaviour' which were performed not as an innate reaction to a physical stimulus, but as a meaningful means toward some future end. When humans began to carry wood to be used as fuel, they devoted a part of their energies to maintaining something non-human, something outside their own 'gene pool'. Of course, they were not acting 'unselfishly'; the point is that maintaining a fire required not only technical knowledge but also a measure of foresight and self-restraint which had to be learned as well.

Thus human groups gradually developed a new *ecological regime*, a 'fire regime'. When they used fire to clear land and to hunt or to ward off other animals, they imposed this socio-cultural regime upon their natural environment. The fire regime made human groups stronger as 'survival units' (cf. Elias, 1978) vis-a-vis both hominid and non-hominid competitors. It served what, at a much later stage of social differentiation, came to be called 'economic' as well as 'military' functions. In the long run, human survival units with fire proved more viable than those without fire, and the latter eventually disappeared. Possession of fire became a universal characteristic of all human societies.

It also became an exclusively human characteristic, a 'species monopoly'. As long as the use of fire was mainly passive, many different animals could benefit from it more or less equally. But then, as hominids became more skillful in handling fire, they would be able not only to keep a fire going but also to chase others away from the site by using burning sticks as weapons. At one time, related primates such as *Australopithecus* or the ancestors of the chimpanzee may have come close to having the potential for developing the specific configuration of traits that enabled hominids to domesticate fire. If this were so, they never got a chance fully to realise this potential. Once the humans had established control over fire, they managed to monopolize it (perhaps after fierce elimination struggles), and from then on they used it to extend their domination over all related animals.

In doing so they could profit from the principle of mutually reinforcing advantages which operated in various ways in the monopolization process. Thus, to begin with, social organization and cultural transmission were indispensable preconditions for acquiring and maintaining the capacity to keep a fire; these preconditions tended to be strengthened, in turn, by the very exigencies of keeping the fire burning.[1] Similarly, a measure of self-restraint was needed for each individual in order to be able to face a fire without being either unduly panicky or reckless; this self-restraint was facilitated in turn by the social experience of growing up safely in a group with fire and seeing that fires could indeed be controlled. A third, and more concrete example of the principle of mutually reinforcing conditions is furnished by the occupation of caves. Possessing a fire greatly enhanced the chances for driving out large predators from a cave entrance and for making it into a reasonably secure dwelling place for humans. At the same time, access to the cave made it much easier to keep the fire burning and to protect it against rain or raids.

The increased security was one of the advantages which formed, so to speak, the *postconditions* or, more familiarly, the 'functions' that served as the rewards of the fire regime and thus kept the process of the domestication of fire going. Cooking extended the range of edible food; as a source of heat, fire made cold regions more easily inhabitable. It could also be used as a source of light, to ward off enemies, to clear land for hunting and gathering, and for various other purposes. Altogether, the control over fire enhanced human chances for survival, for territorial expansion, and, in the long run, for population increase.

The latter point, I think, is crucial for understanding the further course of social development. Increasing human numbers facilitated, among other things, the organization both of more effective protection against predators and competitors from the animal kingdom and of more massive hunting parties. However, at the same time that humans were thus extending their domination by means of the control of fire, they also became more dependent upon

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[1] Active use of fire is likely to have strengthened social organization not only within but also among human groups. According to a conventional image, fire formed a focus of inter-group struggles; however, it may just as well have been one of the first bonds of exchange, connecting groups that would help each other out in case one of them lost its fire. Needless to say, such 'fire bonding' would considerably increase human power.

this very means of control – if only because the increased numbers of people needed continued exploitation of the fire monopoly for their survival.

Thus, after a certain balance of control and dependency had been established, it tended to become self-perpetuating in a compelling way. Human groups, grown to a certain size, accustomed to a certain diet, used to ranging within a certain territory, all with the aid of fire, could no longer continue their way of life without fire. Like certain plants that can only thrive in an environment regularly visited by fire, they had become 'pyrophiles', addicted to fire.

Agrarianization

The emergence of agriculture around the end of the last Ice Age is sometimes regarded as the 'First Revolution', the first great step toward human civilization. The entire period preceding agrarianization is treated as one of stagnation in which few important developments took place (see, for example, White, 1959, 44–45). It will be clear from the foregoing that I take a different view. Long before agriculture made its first appearance, the domestication of fire heralded an ecological transformation of comparable significance and magnitude.

This is not the place to enter into the discussion about the reasons why certain groups in the late Paleolithic turned from foraging to cultivation. I am inclined to agree with the view that an imminent 'food crisis' (cf. Cohen, 1977) probably triggered off the transition – a food crisis that was caused by the combined impact of climatic changes and highly advanced human hunting techniques resulting in the massive killing and eventual extinction of the mammoth and numerous other species of large mammals. But whatever may have 'caused' the process of agrarianization, there can be no doubt that a previously established predominance of humans over other animals was one of its preconditions. And, again, as happened so often with preconditions, this predominance was strengthened in turn as a result of agrarianization.

Like the domestication of fire, the domestication of plants and animals implied an extension of the human domain. It required a certain balance of power, enabling humans to interfere in the process of natural selection among and within other species. In agriculture, undesired and noxious plants came to be known as 'weeds'; a great deal of agricultural work consisted of attempts at eliminating these weeds and at either destroying or chasing away any competitors, large or small, that might eat the crops before they would be ready for harvesting. Stock raising, although very different in actual practice, rested on the same principle. Animals belonging to favoured species were protected and fed, and predators and competitors were kept at bay.

An interesting aspect of this development, as Fred Spier (oral comm.) has pointed out, is that precisely those species were singled out for domestication which were most threatened with extinction through human gathering and hunting. Throughout the Upper Paleolithic humans had been interfering with increasing efficiency in the process of natural selection between species. In so far as agrarianisation was a response to depletion of resources by intensified gathering and hunting, it implied a reversal of the trend toward extermination of a number of favoured plants and animals. Many rituals expressing ambivalence toward slaughtering either game or livestock may become more understandable when viewed in this light.

With the extension of the human domain a new kind of ecological regime was established – an *agrarian regime*, imposing new constraints upon both the physical environment and the human community itself. Cultivating crops and raising livestock were, like tending a fire, forms of 'detour behaviour' in which people cared for something that lay outside their own gene pool; this detour behaviour was not innate but had to be acquired through social learning. It may well be that the long familiarity with tending a fire helped to prepare humans for the strains of an agrarian regime full of 'deferred gratification' activities.

The domestication of fire was in more than one way a direct precondition for agrarianization. Most of the crops cultivated needed some form of cooking or baking to make them ready for human consumption. No less important was the fact that the soil on which the crops were grown also needed preparation, to clear it from weeds and trees. For this preparation humans could rely upon a particular skill they had acquired through thousands of generations in foraging, equipped with fire – the skill of burning the vegetation at well selected times. It is difficult to imagine how humans could have cleared the forests of Asia, Europe, and Central America if they had not known how to get rid of trees by 'slash and burn'.

Agrarianization brought about a new sociogenetic 'divide' among both plants ('crops' versus 'weeds') and animals. Gradually some species of animals submitted to the agrarian regime, and became 'tame' or 'domesticated'; other species resisted domestication, and remained 'wild'. Interestingly, with a few exceptions such as rabbits and geese, the distinction between 'domesticated' and 'wild' was always species-wide; by and by, there were no longer any wild cows or sheep, nor were hares or antelopes lastingly domesticated.

With regard to both the domesticated and the remaining wild species, the long-standing superiority of humans over other animals – which was one of the preconditions *for* agrarianization – was greatly increased *by* agrarianization; just as at the preceding stage fire had been 'harnessed' into the service of human groups, now a regular supply of plant and animal resources was added to the economic and military potential of human societies. This indeed was a major consequence of agrarianization: when the work invested in toiling the ground was successful, it resulted in larger supplies of food available for human use. Almost by definition, agriculture involved work; if, therefore, we were to follow modern economists who tend to treat productivity as an inverse relationship to individual effort, agrarianization in most cases spelled a decline of productivity (cf. Boserup, 1965). Measured in terms of the overall social product it yielded, however, agrarian labour considerably raised the productivity of the land, by bringing about greater concentrations of vegetation that was edible (or useful in some other way) for humans and their domesticates.

Almost inevitably, the increase and concentration of food made possible by the 'intensification of production' (cf. Harris, 1977) led to an increase and concentration of people. If indeed the rise of agriculture was prompted by the constraints of food shortage and population pressure, the rise in productivity is likely at first to have brought relief to a number of successive generations; but, in the long run, many agrarian populations grew to such density as to live under a perpetual threat of shortage again. In this respect the domestication of plants and animals led to consequences that were similar to those of the domestication of fire: in both cases, increasing control inevitably entailed increasing dependency – upon that which was being controlled (in this case not fire but crops and cattle) as well as upon the technical and organizational means by which such control was exercized.

Along with the growth in size and density, many agrarian populations tended to undergo processes of increasing specialization and organization. The transition from gathering and hunting to agriculture and pastoralism was followed by the emergence, on the one hand, of increasingly more specialized forms of crop cultivation and stock raising, and, on the other hand, of new specialized social functions such as those of priests, warriors, and artisans. The interweaving of control and dependency became particularly evident in societies with a high degree of agrarian specialization, such as rice cultivators or as pastoralists whose entire way of life was strongly attuned to the vital needs of their herds.

It has often been suggested that the relationships between humans and their cattle provided the pattern for master-slave relationships. I am not sure whether the latter did not develop 'spontaneously' in the context of military-agrarian society (cf. Goudsblom *et al.*, 1989, 79–92). But certainly the structural analogy cannot be denied: in both cases there was a balance of control and dependency which enabled the 'masters' to protect and oppress those that were 'entrusted' to them and whose labour they could exploit. The apparatus with which authority was exercised was similar, too: chains and brands, gates and sticks, commands and verbal abuse, food and shelter. These structural similarities should not make us overlook the obvious fact that, in the hierarchy of power, the animals as a rule stood far below the slaves.

In any case, the evolution of human society after the emergence of agriculture can be characterized along the same lines as the changing relations between humans and other large animals. To begin with, agrarianization as such brought a differentiation in behaviour and power *among* those groups that did and those that did not switch to an agrarian way of life. Then, as some agrarian societies adopted more intensive modes of production, increasingly larger differences in behaviour and power *within* these societies developed.

For more than ten thousand years (for over three hundred generations, that is) human societies subsisting from foraging existed side by side with agrarian societies which gradually expanded their domain. It was not until the twentieth century that the last few remaining societies of gatherers and hunters disappeared – along with the great multitude of solely agrarian societies that also were inescapably enveloped by industrialization.

Industrialization

If agrarianization was a 'catalyst' in already ongoing processes of growth, concentration, specialization, and organization of human populations, the same could be said all the more of the process of industrialization that gained momentum two or three centuries ago. The rapidly increasing power resources made available to human societies by the large-scale use of fossil energy enabled humans further to enlarge the distance between themselves and all other animals – that is to say, the distance in power, not necessarily in physical proximity, for as wild animals could be controlled with greater ease they could also be brought to live within the human domain, in zoos, or else their 'wild' territories could be turned into conveniently accessible nature parks and reservations.

Clearly our hominid ancestors, when they gradually extended their control over fire and, by means of fire, over their natural environment, could have had no inkling of the extremely uneven power balances that mark the relationships between humans and other animals today. The development out of which the present conditions emerged has been a very long one. Viewed analytically it consisted of a myriad of small steps, in each and every one of which the deliberate plans and actions of individual human beings played a part. Altogether, however, the overall development as a long-term process was unplanned, and it brought about a great many consequences that were neither foreseen nor desired.

Again and again deliberately sought advances in control were followed by unintended increases in dependency, and the dependency sank deeper and deeper into the infrastructure of society, where it became increasingly less clearly visible. Like agrarianization, industrialization began with conspicuously huge applications of fire. As industrial production became more specialized and highly organized, so did the use of fire. In everyday life in highly industrialized societies, flames are visibly present only in such highly domesticated guises as cigarette lighters, candles for ceremonial use, or wood fires intended to create a sphere of comfort and relaxation. When, on the other hand, a fire is shown on television or in the newspapers, it almost always spells war and disaster. The regularly controlled combustion processes upon which industrial production largely rests have mostly disappeared from public view.

With regard to animals a similar development has taken place. Various kinds of animals are cherished as fully domesticated harmless pets; occasionally a ferocious attack by animals upon a human being is reported; and the massive control of cattle and poultry for the production of meat is relegated to the economic infrastructure, the less palatable side of which is preferably kept out of sight. Except for bugs and other vermin belonging to the category designated by William McNeill (1976) as 'micro-parasites', animals by and large no longer constitute a serious threat to human communities.[2] As the human species has become increasingly dominant, inter-specific struggles with other animals have become less, and intra-specific struggles between human tribes and states, more important.

One result of the increased distance in power between humans and other animals has been the rediscovery of animals as fellow creatures and the rediscovery of the animal in ourselves. Evolutionary biology, psychoanalysis, and ethology have pointed at the common descent, the common drives, and the common forms of behaviour, ceremony and social organization we share with other animals. Among the conditions which made these discoveries possible was, I think, the changed balance of power and the concomitant shift in the 'structure of sentiments' (cf. Gouldner, 1970); most larger animals had lost so much of their menace that conditions could be created not only for physical proximity with them, but also for acknowledging intellectually the animalistic aspects of human nature (cf. also Serpell, 1986; Swabe, forthcoming).

The present stage of differentiation can be observed in numerous institutions, ranging from pet shops to slaughter houses. The degree to which socio-cultural elements enter into the domination of humans over all related animals is perhaps most clearly reflected in the relations toward our closest living relatives in the animal world, the chimpanzees. As measured by many physical properties such as anatomy, physiology, and DNA structure, the chimpanzee is much more similar to man than to any quadruped mammal; yet, the power relations are such that in the zoo the chimpanzees find themselves locked behind bars, along with the wolves and the zebras, while the human public may parade freely in front of them.

Typically, a zoo is a *social* institution. The bars that protect the human visitors from the lions and the tigers have not been made by the visitors themselves; these bars are 'social constructions' in the most literal sense of the word. In an encounter between a human individual and a lion the human individual would be stronger only in exceptional cases. Physically a human is certainly not equal to a lion; but neither would his wits be a great help, if he were unable to rely upon social and cultural resources – upon fellow men and material equipment such as weapons.

The increasing differentiation in behaviour and power has enabled humans to establish their dominion over the entire world. The distribution of species

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[2] The changing balance of power between human communities and large predators or 'macro-parasites' makes fascinating history. As late as the sixteenth century wolves were reported to have killed villagers in Flanders; perhaps these killings occurred as acts of desperation by animals whose territory had been greatly diminished by expansion of the human domain and who lived under the threat of starvation. The fact that in Western European folk tales the wolf is stereotyped as hungry seems to indicate that wolves only ventured to attack humans when driven by extreme need. By contrast, as Washburn and Lancaster (1968) report, in wild reservations new generations of bears and lions are now growing up with apparently fewer inhibitions in approaching and attacking humans than their forebears used to have.

living on the earth's surface today is strongly affected by human interference (cf. Crosby, 1986). Not only has the evolution of agriculture greatly enhanced the domination of humans over other large animals, it has also set in motion a process of differentiation of behaviour and power among and within human societies themselves. This latter process has developed a dynamic of its own, leaving each new generation of humans little choice but to continue in the same direction. We have now reached a point where we can look back, and begin to examine the conditions underlying this long, unplanned development.

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Climate-forced evolution and man-forced environmental change

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Abstract

Climate-forced evolution of early man and large African mammals during the Pliocene-Quaternary transition is discussed. Marine records of climatic change in Africa north of the equator during the last 5 million years show that environmental conditions became much drier causing a substantial increase of the Sahara and loss of wet forest. Examples of climate-forced and tectonism-forced environmental changes in northern South America are shown. Man-forced environmental change since at least the last 12,000 years is illustrated with examples from Australia, Guatemala, Colombia and Brazil. On the long time scale human impact on the environment appears more difficult to identify than climate impact on the environment and even climate impact on evolution.

Introduction

The fossil record of African hominids is at least 4 million years old. The human family tree split several times between 3 and 2.5 million years ago (3–2.5 Ma BP), a period of earth history characterized by unprecedented changes in climate and environment. Climate changed on a global scale from relatively warm during the Tertiary to cooler, and regionally drier conditions in the Quaternary. During this transitional period from the Tertiary to the Quaternary ice caps occurred for the first time on the land masses of the northern hemisphere. Related to this important climatic cooling the temperate land masses experienced important surges of migration of floral and faunal elements. For example, the floral record of the Late Cenozoic of Europe shows an important impoverishment of the rich Tertiary flora (Van der Hammen *et al.*, 1971). In North America a surge of mammalian immigrants from Eurasia, most of them large carnivores, arrived toward the end of the Miocene. An even more remarkable burst of intercontinental faunal migrations characterized the Pliocene, and the whole landmammal fauna in North America experienced an extensive turnover between 5 and 3 Ma BP (Webb, 1985).

Between 5 and 3 Ma BP climatic conditions in large parts of Africa north of the equator became drier. As a consequence a considerable part of closed tropical forest was gradually replaced by more open savanne-like vegetation with trees. The development of early man, but also the evolution of the large African mammals, seems related to this important climatic and environmental change: the total area of desert increased, whereas the surface of wooded savanna, deciduous tropical forest and tropical rain forest deminished considerably. During the last 1 Ma, a series of glacial-interglacial cycles caused important repetitive latitudinal shifts of the African vegetation belts north of the equator (Dupont and Hooghiemstra, 1989). Long boreholes in marine sediments include records of climatic change, such as oxygen isotopes, dust flux and pollen. Recently several long records from Atlantic cores became available and show with unprecedented accuracy the long term aridification of Africa between 3.5 to 2.5 Ma. The dramatic influence of climatic change on the evolution of man and the large African mammals is an example of climate-forced evolutionary change. Recently published sediment cores from lowland Guatemala (Islebe et al., 1996) demonstrate the gradually increasing effects of land clearance since 5600 BP and deforestation by prehistoric Mayan inhabitants since 2800 BP, an example of man-forced environmental change.

Climate-forced evolutionary change

Pliocene-Pleistocene transition in Africa

Climatic conditions during the Tertiary were significantly warmer than during the interglacial periods of the Quaternary, although short cold climatic oscillations occurred obviously in the Pliocene (e.g. Van der Hammen *et al.*, 1971; Tattersall, 1993; Tiedemann *et al.*, 1994; Hooghiemstra, 1997). The number of long continuous records of Neogene paleoclimatic change is increasing rapidly, especially oxygen isotope records, dust flux records and pollen records from marine cores.

For subtropical and tropical Africa e.g. Lourens (1994), Leroy and Dupont (1994), Dupont and Leroy (1995), Suc *et al.* (1995), and DeMenocal (1995) studied changes of the climate system and the vegetation cover up to 5 Ma BP. These records show that in the Pliocene most of Africa north of the equator experienced a humid climate. Forests covered a large area which is under present day conditions covered by dry savanna and desert vegetation. Early man experienced this profound change in their environment between 3.5 and 2.5 Ma BP: a changing vegetation cover in large parts of Africa provided early man with a different, more open, environment. A changing fauna must have influenced their possibilities as hunters.

On the other side, the African fauna, including man, also adapted to this new situation and many new mammalian forms came into existence by evolutionary processes. Vrba (1995a) showed evidence that climatic change has forced to a considerable extent, speciation, extinction, and migration of African antelopes. As fossil remains of antelopes are more abundant than fossils of hominids and are often found in the same geological horizons, the fossil record of African antelopes is indicative of environmental and climatic change that was also experienced by early man.

Concepts of the early evolution of man improved considerably (e.g. Kimbel, 1995; Rightmire, 1995; Vrba, 1995b). In Africa the shift toward more arid conditions with more open vegetation after 2.8 Ma BP, based on marine records from the eastern Atlantic, are coincident with major steps in the evolution of African hominids and other vertebrates, suggesting that some Pliocene/Pleistocene speciation events may have been climatically mediated (DeMenocal, 1995; DeMenocal and Bloemendal, 1995).

Reconstructions of the replacement of dense tropical decidious and evergreen forest by more open savanna-like vegetation was up to recently based on poor paleobotanical and palynological data and poor time control. For example Caird and Foley (1994) showed the aridification of Africa in two paleovegetation maps but estimated the age of this important change in vegetation cover incorrectly as Miocene, the period from 20 to c. 5.5 Ma BP (unfortunately, they did not mention their source of information). However, recent data place this change during the transition from the Pliocene to the Pleistocene, thus between 3.5 and 2.5 Ma BP.

Records of aridification of the African continent and human evolution

Long marine records with high temporal resolution document the climate history of western Africa with unprecedented detail. Tiedemann *et al.* (1994) published $\partial^{18}O$ and dust flux records from ODP Site 659 (18°N, 21°W) in the eastern Atlantic offshore northwest Africa. The $\partial^{18}O$ record shows clearly the transition from warm Tertiary temperatures, with high frequency and low amplitude climatic fluctuations, to much colder conditions during the Early Pleistocene. This transition occurred from 3.2 to 2.5 Ma BP. Arid periods in northwest Africa are documented by a high percentage of dust in the marine sediments, reflecting pulses of strong eolian transport. Cycles of northwest African aridity indicate a shift in cyclicity, arguing for a fundamental change in the earth's climate at the Pliocene to Pleistocene transition. During the last 2.5 Ma the dust flux reached a significantly higher level, indicating that the African continent became more arid in which open vegetation and vigerous winds gave rise to important transport of fine terrigenous material.

The pollen record of ODP Site 658 supports the evidence of the $\partial^{18}O$ and dust flux records: a strong aridification of Africa north of the equator during the period from c. 3.7 to 2.5 Ma BP is documented (Leroy and Dupont, 1994; Dupont and Leroy, 1995). Aridification is inferred from a southward shift of the northernmost distribution of mangrove vegetation, a decrease of savanna-characteristic grasses, and an increase of desert-characteristic chenopods. In addition, increased percentages of pollen originating from the western Mediterranean area are indicative of more vigerous trade winds. During this time at the northern fringe of the Sahara an *Artemisia*-dominated vegetation (steppe) developed. Arid periods in the pollen record are coeval with intervals in the marine $\partial^{18}O$ record characterised by a large global ice volume.

Pliocene-Pleistocene transition in South America

Characteristic of the Late Neogene of the western hemisphere is the evolving land connection between Central and South America. A great interchange of fauna and flora elements started, profoundly changing the composition of the biota of the western hemisphere (Stehli and Webb, 1985). The flora of the northern Andes developed rapidly between c. 6 and 3 Ma BP as a response to tectonic uplift as well as migration of flora elements from the north and south (Van der Hammen *et al.*, 1973; Helmens, 1990; Hooghiemstra and Cleef, 1995; Wijninga, 1996). Hoorn (1994) studied the Neogene environmental history of the Amazon Basin on the basis of sediment and pollen records. During the Miocene large scale paleogeographic changes occurred in the peripheral areas of the northeastern Andes. Changes, such as the shift in drainage pattern of the Orinoco River to the east, the genesis of the Amazon as a transcontinental river, and the development of the modern Magdalena river system could be inferred from the Miocene sediments of the Amazon Basin (Hoorn, 1994; Hoorn *et al.*, 1995). These changes are a direct consequence of the uplift of the Eastern Cordillera, a process which is now well documented by palynological, sedimentological and geological studies in the high Andes as well as in the Amazonian lowlands.

In conclusion, the dramatic change in the vegetation cover of Africa, making up to a considerable extent the environment of man, is of more recent age than previously thought. It becomes clear that climatic change played an important role in the dramatic change of vegetation distribution at the Pliocene-Pleistocene transition in Africa north of the equator (Vrba, 1995b) and the regional evolution of flora and fauna.

Man-forced environmental change

Understanding of the impact of climatic change on the evolution of early man and the mammalian fauna of Africa makes much progress and it is remarkable that this aspect is almost better known than the long range influence of man on its environment. Most records of human impact on its environment are limited to the Holocene and based on evidence of charcoal and/or forest disturbance (pollen studies). Examples from Australia, Guatemala, Colombia and Brazil will be shortly discussed.

Australia

In the sediment record of Lynch's Crater, in northeast Australia, downcore changes in the concentration of charcoal may suggest the presence of aboriginal burning. Substantial concentrations have been found up to 40 ka BP whereas the charcoal record continues down to c. 165 ka BP (e.g. Kershaw, 1986; Williams *et al.*, 1993). However, discrimination between culturally determined charcoal and charcoal as a result of natural fires is difficult and subject to discussion (Williams *et al.*, 1993; Singh and Geissler, 1985), making these records of human impact uncertain.

Maya Lowlands, Guatemala

Understanding of the impact of Central American civilizations on their environment made much progress in recent time. Leyden (1987) studied a complete Holocene pollen record from core Lake Salpeten and drew attention to the relationship between man and climate in the Maya lowlands of northern Guatemala. She inferred that the Maya entered the area 3000 BP (= 3000 ^{14}C years Before Present) and caused extensive deforestation. In a recent multi-proxy study of a core from Lake Peten-Itza, evidence from pollen (Islebe *et al.*, 1996) and stable isotopes, mineral magnetics and geochemistry (Curtis *et al.*, in press) was used to infer an integrated reconstruction of the Holocene history of environmental change in the Maya Lowlands (see the extensive literature survey in Curtis *et al.*, in press). Based on mutiple sources of evidence the following sequence of changes has been inferred: (a) relatively dry conditions in the earliest Holocene (prior to 9000 BP), (b) moist conditions based on the presence of extensive undisturbed native lowland forests during the period 9000–7300 BP, (c) during the period 6800–4800 BP possibly even slightly wetter conditions, but evidence of decreasing lowland forest and increasing evidence of disturbance, which may reflect early human impact on the regional vegetation, (d) forest disturbance was accelerated after 2800 BP reflecting increasing Maya impact on the enviroment, (e) after the collapse of the classic Maya civilization, c. 1100 BP (Hodell *et al.*, 1995), human disturbance declined and natural forest recovery started as evidenced by a high representation of taxa characteristic of secondary forest.

Colombia

In the Western Cordillera the pollen record from Lusitania at 1500 m elevation shows evidence of local presence of man during two successive periods (Monsalve, 1985). The first period of prehispanic human influence is characterized by decline of *Quercus*-dominated forest and intensive maize cultivation. Later, maize cultivation gradually diminished and forest in a different composition returned. Intensive deforestation occurred a second time and now *Quercus* and *Ilex* disappeared almost completely. This period reflects the reoccupation of the area by colonists, which did not cultivate maize (Monsalve, 1985).

In the Eastern Cordillera, in the area of the El Abra rockshelters near Bogotá, Van der Hammen and Correal-Urrego (1978) reconstructed the history of human occupation based on fossil pollen and faunal remains. Early man possibly entered this area already before the beginning of the Late Glacial, but anyhow during the Guantiva interstadial (c. 12,400–10,900 BP) rocks were used as temporal hunting camps. During the El Abra stadial (c. 10,900–10,000 BP) these rock shelters were close to the upper forest line and open alpine paramo vegetation formed the scenery of these early hunters. From 10,000 BP onward the area became forested and early man had to adapt to new environmental circumstances. During the dry period from 5000–3000 BP human presence decreased, but shortly after 2500 BP climate became more humid and first evidence of agriculture (maize) and ceramics was found. Early deforestation increased in the area and culminated in the period following the Spanish conquest (c. 1550 AD).

In the Sierra Nevada de Santa Marta, in northern Colombia, site Buritaca at 1300 m elevation is located in a former 'city' of the Tairona indians (Herrera-de Turbay, 1984). Pollen analysis of soil profiles show the following sequence of changes: (a) a period with original forest in which *Alchornea*, *Weinmannia*, *Hedyosmum* and *Cordia* were dominant trees, (b) a period of human occupation with important deforestation (decrease of *Alchornea*, and increase of the heliophytic pioneers *Croton* and *Cecropia*) and abundant open vegetation dominated by grasses and Compositae. Cultivated plants such as maize (*Zea mais*) and yuca (*Manihot esculenta*) were registered, (c) the site had been abandoned by the Indians around 1400 AD and forest returned in a different composition: *Miconia* and especially Palmae became now more important arboreal elements.

Brazil

A palynological study of a Late Glacial and Holocene pollen record from the region of the Amazon estuary shows evidence which may reflect presence of paleoindians (Behling, 1996). Abundant carbonized particles suggest human activity from as early as 9530 BP. Moderate amounts of charcoal since 10,850 BP may indicate that the first paleoindians in the coastal area of the Amazon arrived around 10,800 BP.

Conclusions

Man-forced environmental change is documented at many places in the temperate zones and in the tropics from the Late Glacial onward, i.e. during the last 12,000 years. Charcoal records as evidence for human impact are more reliable in combination with pollen records, especially when the man-induced vegetation type is not a potential native vegetation type. In this respect the reliability of the long Australian charcoal record as a document for human occupation is doubtful. It is remarkable to note that on the long time scale man-forced environmental change is not better documented than climate-forced evolutionary change. Especially in this last field of research much progress has been made in recent years.

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Pleistocene coal fires in northwestern China: energy for early man?

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Introduction

Fire is one of the oldest ways in which early man has interfered with nature. His discovery of the use of fire must have stemmed from two sparks: one which ignited the fire in the forest or in the grass, and another one in his brain, which made him suddenly realise that he could benefit from it. Neither spark is likely to be ever documented in a more than circumstantial way. We speculate that, apart from fires caused by lightning and volcanism, also fires caused by spontaneous combustion of coal seams might have started the use of fire by man. We will demonstrate that in China natural coal fires have occurred repeatedly in the Pleistocene. This paper resumes data which will be reported more extensively elsewhere (Zhang and Kroonenberg, 1996a,b; Zhang *et al.*, in prep.).

In China coal fires are at present a major environmental threat. It is estimated that at an annual production of 1 billion tons of coal, 20–200 million tons of coal are being lost annually by spontaneous combustion (Guan, 1989). They represent a sizeable part of the CO_2 increase in the atmosphere. A research project has been set up by ITC at Enschede, the Netherlands and the Geological Survey of the Netherlands, the ARSC (Aerial Photogrammetry and Remote Sensing of China Coal), the Beijing Remote Sensing Corporation and other institutes, to monitor and forecast present-day coal-fires in the Xinjiang province in NW China and to design methods to extinguish them, using especially remote sensing techniques (Van Genderen *et al.*, 1995). The research is funded by the CEC. Burning coal seams neatly show up on night-time thermal IR imagery (Zhang *et al.*, 1994). However, careful study of various type of imagery and field data indicate that there are large areas underlain by burnt rocks which do not show any thermal anomaly at all. We present preliminary evidence that some of these paleo-coal fires are at least 0.9 Ma old, and some possibly even much older.

The Liuhuanggou study area in the Xinjiang province is situated on the northern slopes of the Tien Shan Mountains SW of the town of Urumqi, and their transition to the southern margin of the Mesozoic-Paleogene Junggar Basin (Peng and Zhang, 1989; Carroll *et al.*, 1995). The Middle Jurassic Xishanyao Group of lacustrine sediments is the main coal-bearing formation. The Dacao Coal Seam reaches a thickness of about 20 m. The Jurassic sediments have been folded into E-W trending structures, of which the Kelazha Anticline is the most prominent (fig. 1). The northwards flowing Toutunhe River, coming from the Tien Shan Mountains, dissects the anticlines and has formed a series of at least nine river terraces, with an altitudinal spacing of around 10 m between individual levels. They consist of several metres of gravel proceeding from the Tien Shan Mountains.

Occurrences of Pleistocene coal fire

Many outcrops of coal-bearing strata show evidence of past burning, and in most cases no coal is left at all. A typical face-slope outcrop in a cuesta of sandstone-capped burnt-out coal-bearing strata shows the following sequence from bottom to top: (1) 5–20 m of reddened but undisturbed shales of ceramic appearance; (2) 10–30 cm of whitish baked kaolinitic seat earth; (3) an ash layer 5–10 cm in thickness, often rich in gypsum; (4) a 1–20 m thick very porous dark-red breccia with abundant evidence of baking and even melting of rocks. The ash layer has formed by the combustion of a coal seam which, according to borings in unburnt sequences, might be up to 20 m thick. The breccia is the result of the collapse of the hanging wall at the burning out of the coal seam. Many of such outcrops are devoid of any trace of present-day fire and do not show up as anomalies in thermal IR imagery.

On several places such sequences are overlain by terrace gravel of the Toutunhe River. At least three different situations have been found:

(I) Beigou Terrace: this is the presumably oldest occurrence of burnt rock in the area. Along the northern flank of the Kelazha Anticline the Jurassic sequences are steeply dipping southwards or almost vertical. They are unconformably overlain by a few metres of gravelly to loessic alluvial fan deposits. Burnt rocks are found just below the contact of the alluvial fan deposits, suggesting that the fire took place on a pediment-like surface before deposition of the fan. Subsequent uplift up to more than 200 m has led to deep dissection of both the fan deposits and the Jurassic strata, exposing the burnt rock in cross-section over a considerable distance.

(II) Qianshuihe and Louzhuangzi. These outcrops show the classical profile as outlined above. Locally, they are seen to project above the unburnt gravel of the

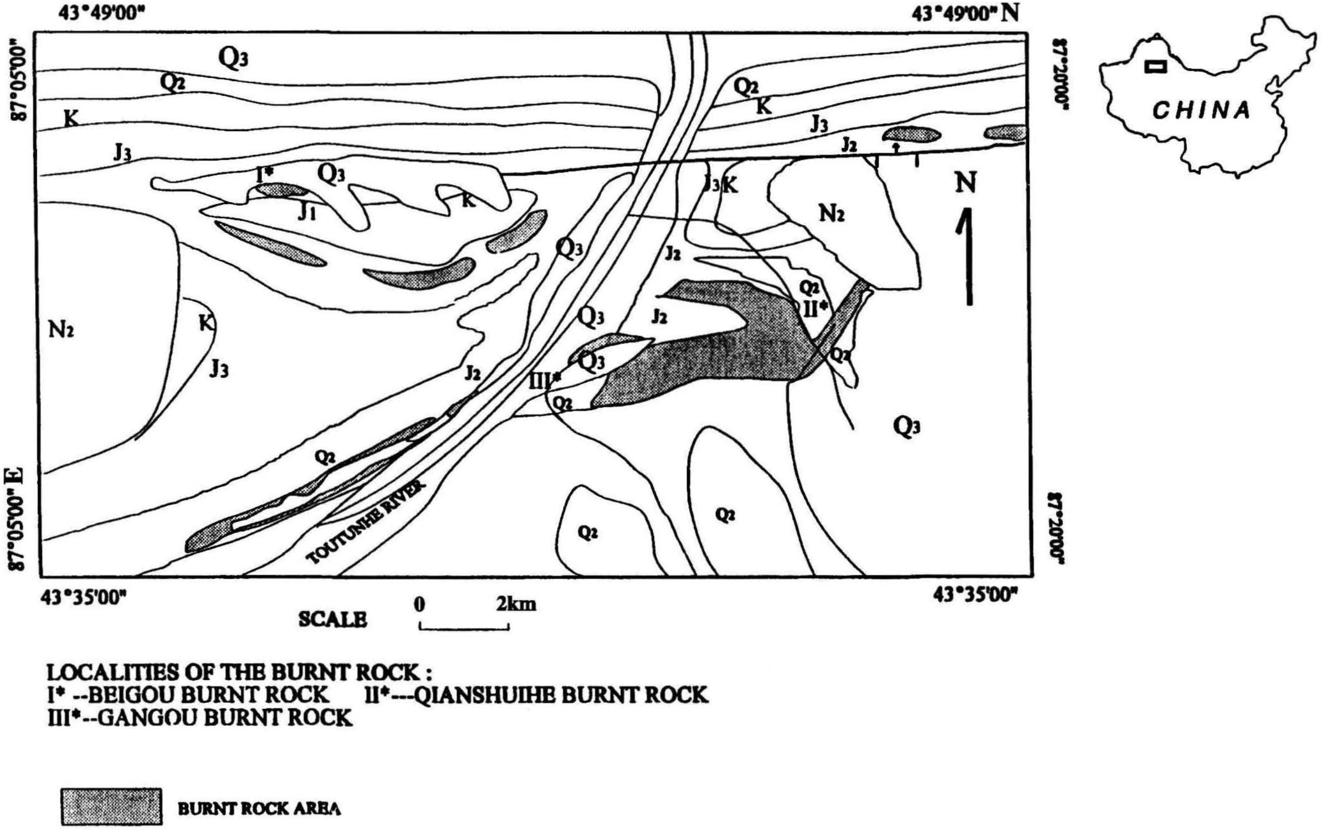

Fig. 1. Location and geology of coal fire deposits. J1,2,3: Lower, Middle, Upper Jurassic. K: Cretaceous; N2: Neogene. Q2: older terraces; Q3: younger terraces. Roman numerals: localities of the burnt rock.

90 m terrace of the Toutunhe River, indicating that the fire predates deposition of this terrace.

(III) Gangou profile. The Gangou paleo-coal fire has the same classical sequence, but shows a more complex relation to the river terraces. It is overlain by unburnt gravel of the 60 m terrace, but in the collapsed roof sintered and molten pebbles of an older terrace deposit occur, that apparently predates the coal fire.

Origin of the coal fire deposits

In all cases coal fires have started at outcrop faces and propagated further inside to several tens or even hundreds of metres. The primary cause of ignition may be manyfold. Experiments show that once moist coal has reached a temperature of 80°, oxidation is an exothermic reaction until ignition starts (Banerjee, 1985). Forest or prairie fires may start the process, and our measurements have shown that along favourably exposed slopes, even sun heating alone may be sufficient to overcome the initial threshold (Zhang *et al.*, in prep.). The only prerequisite is exposure to the air. This means that Tertiary folding, and especially Late Tertiary-Quaternary uplift and dissection have greatly increased the chance of spontaneous combustion of coal seams to occur. The Beigou paleo-coal fire apparently predates uplift and dissection. The Qianshuihe and Gangou paleo-coal fires show a distinct relation with river terraces.

River terraces are the result of a process of cycles of deposition and dissection, commonly triggered by climate-controlled variations in sediment supply under continuous uplift (Boll *et al.*, 1988; Veldkamp and Vermeulen, 1989). In the Tien Shan Mountains variations in sediment supply are probably related to glaciation and deglaciation (Qiao, 1981; Molnar *et al.*, 1995). In periods of enhanced sediment supply, accumulation prevails in spite of uplift, while in periods of decreasing sediment supply strong dissection occurs to compensate for uplift in the preceding period.

Exposure of new coal seams will occur especially during the phases of dissection, and in such cases terrace gravel can be expected to occur within the breccias of the collapsed roof, as is the case at Gangou. However, if unburnt gravel occurs on top of burnt rock, it indicates that the river has resumed its course at the same site after burning and roof collapsing. This is feasible in so far, as the thickness of the collapsed coal seam may amount up to 20 m. Roof collapse might then lead to the formation of a depression in the river bed which captures the course in the next aggradational stage.

Age of the paleo-coal fires

The mechanism for the formation of coal fires during dissectional phases of river development allows for approximate dating of the fires. Assuming that terrace formation in Xinjiang is related to the major 100 ka cycles of Quaternary climatic change (Molnar *et al.*, 1995), and assuming uplift rates around 0.1 mm/a most favourable for the preservation of river terraces (Veldkamp and

Vermeulen, 1989), the Gangou 60 m terrace might be around 0.6 Ma. The terrace gravel incorporated in the burnt rock cannot be older than the 70 m terrace because of its position, so the coal fire might have taken place between 0.7 and 0.6 Ma. Similarly, the Qianshuihe paleofire is at least 0.9 Ma, and the Beigou terrace at least 1.5–2 Ma. These figures are very approximative, and more exact dating should be carried out. Molnar *et al.* (1995) assume much higher uplift rates (up to 1 mm/a) in the crests of growing anticlines further west, and in that case the coal fires would be correspondingly younger. But especially in the Beigou case, which predates the initiation of the Late Tertiary – Quaternary uplift and dissection phase, such young ages are unlikely, as it would mean that uplift and dissection would have started only 200 ka ago.

Conclusions

Based on the occurrence of traces of coal fires covered with unburnt Pleistocene terrace gravel, coal fires are a natural phenomenon which repeatedly have occurred under favourable conditions of exposure, especially during dissection of rivers following periods of aggradation.

Evidence of Pleistocene coal fires is not limited to China. In the Bohemian coal basin burnt rocks below river terraces have been dated by paleomagnetics up to over 2.4 Ma (Tyrácek, 1994).

Peking Man at Zhoukoudian used fire at least 460 ka ago (Wu and Lin, 1983), and traces of human habitation at Lantien south of Xi'An at the southern border of the Chinese loess plateau date possibly even back to 1.15 Ma. One might speculate, therefore, that early man in China have observed coal fires and took advantage of it, either simply as a source of fire, or maybe even by using the coal as fuel. That would imply: one million years of mining. There is a task for archeologists to prove it.

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The upright bipedal posture as a response to a changing environment in human evolution

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EXTENDED ABSTRACT

Human evolution is a subject that arouses curiosity continuously. Man has always been curious about his origin. Both from religious and from scientific points of view one is trying to get an answer to the question: 'How and where did we originate?'. The evolution of Mankind is generally considered to be unique and is therefore treated as such. Such diverse facts as the ability to speak, the ability to use complicated tools, the upright posture, the ability to distinguish between good and bad, or the presence of self-consciousness have blurred our understanding of human evolution in such a way, that human evolution is often considered to have taken place on a different level than evolution of other mammals. However, when the evolution of mammals, of which each species is unique, is compared with the evolution of Man there are no differences. Man is, according to Foley (1987) just 'another unique species.'

This paper is meant to stress our conviction that mammalian evolution and human evolution are comparable processes, driven by comparable ecological factors. A human paleontologist or paleo-anthropologist is no other person than a vertebrate paleontologist specializing on the taxon Hominidae. In this framework we pay special attention to the origin of bipedalism.

Many hypotheses have been formulated about the origin of bipedalism. Some of these are plausible, others less so. Based on McHenry (1978) and Angelo and Angelo (1994) we can mention the following: savanna-dwelling, carrying (ancestors adopted the erect position to carry food), tool-making and the use of tools, predation, display, thermoregulation, to look over tall grass, feeding adaptations (such as gathering berries hanging high in shrubs, bioenergetics, to seem taller and more fearful to adversaries, to show sexual attributes, to be able to throw stones, to stand up in the water, reduction of solar exposition of the body, and mechanical and energetic reasons due to a change in diet.

The list is long and can easily be expanded, but none of these explanations can be unambiguously confirmed at the moment. Some hypotheses can certainly be ruled out, such as the one that postulates that hominids adopted the upright posture in order to be able to use tools. The most ancient implements only appeared two million years after the emergence of the upright position.

The most recent data indicate that between 3.5 and 4.5 Ma ago there were hominids that were bipedal, that had a body height of about 1 meter, and that had long arms, relatively large canines, and the brain capacity of a great ape. These concern *Australopithecus* (or *Ardipithecus*) *ramidus* (White *et al.*, 1994, 1995) and *Australopithecus anamensis* (Leaky *et al.*, 1995). Around 2.5–2 Ma ago there were two groups of australopithecine hominids: a gracile one (*Australopithecus africanus*) and a robust one (*Australopithecus [Paranthropus] robustus* and *A. [P.] boisei*) having very large molars. The robust form is a side branch that did not give rise to *Homo* and that became extinct.

Clarke and Tobias (1995) described four articulating hominid footbones from Sterkfontein Member 2. According to these authors the foot was manifestly adapted for bipedalism. Its most remarkable characteristic is that the great toe (hallux) is appreciably medially diverged (varus) and strongly mobile as it is in apes. The bones probably belonged to an early member of *Australopithecus africanus* or to another early hominid species.

Around 2 million years ago there was a third hominid in addition to the gracile and the robust australopithecines: *Homo habilis*, which was able to make stone artifacts. Tobias (1995) claimed that *Homo habilis* was not only the earliest culture-bound primate, but on presently available evidence also the first language-bound hominid. *Homo habilis* was more evolved than the gracile *Australopithecus*.

The next stage in human evolution is *Homo erectus*, its beginning dating around 2.0–1.6 Ma ago, which eventually gave rise to *Homo sapiens*. Bipedalism, which originated well over 4 Ma ago, is thus much older than the genus *Homo* itself. All taxa mentioned above have a smaller brain than *Homo sapiens*. However, postcranially they were already bipedal.

If we want to look for the reason why bipedalism originated in the Hominidae we must, as is always done in vertebrate paleontology, look for an ecological (or a paleoecological) explanation. Morphological changes are to be explained as adaptations to particular ecological circumstances. The strictly bipedal locomotion of the Hominidae is unique within the mammals, and within the living vertebrates it is equalled only by the ratites (ostriches and the like).

There is now a general agreement that a transition occurred from woodland to an open environment in East Africa. Caused by tectonic movements, Africa started to split up about 10 Ma ago along the line which can be observed nowadays as the Rift Valley. The land west of this line remained covered with tropical rainforest, in which the great apes (gorillas and chimpanzees) still live. To the east of the Rift Valley the landscape became dryer, which was most probably caused by disturbed circulation of the air (Coppens, 1994). The paleoclimatic transition to a drier environment can be deduced from a profile at Omo, East-Africa, dating from about 4 to 1 Ma ago, in which faunal changes can be observed (Coppens, 1994). In the lower part of the profile mammals are found indicating a wooded savanna, while in the upper part of the profile there are fast running antilopes indicative of an open environment. In the lower part there is the three-toed horse *Hipparion*, while in the upper part of the profile there is the one-toed horse *Equus*. The mammals adapted to changes in the environment; these changes are reflected in the skeleton and the dentition.

The same processes that played a role in the evolution of horses, bovids, or the like, must have played a role in human evolution as well. In the transition from a forested environment to a more open landscape there was a strong selection on the locomotion system. Animals had less need for a flexible gait, they needed to be able to run faster, and with greater endurance.

Walking in an upright position, with stretched legs has an important consequence; this way of locomotion carries the body-weight without the use of power in the leg muscles. The 'power cost', and thus the amount of energy spent, will be strongly reduced (McNeill Alexander, 1992). In the skeleton of the herbivores (horses, bovids) we notice an increasingly digitigrade locomotion, the animals walk on their toes with (four) straightened legs. As in the primates the locomotion is strongly focused in the hind legs, it comes as no surprise that a selection towards upright walking also concentrates on the posterior extremities. The need to find good balance, which is quite another matter for bipedal animnals than it is for quadrupedal ones, has avoided the hominids from also becoming digitigrade. Again, this is also observed in the ratites among birds.

There is a discussion concerning the speed of the origin of bipedalism. Some scientists believe that, because of the set of changes that took place, this was a gradualistic process. Others believe it to have been a rapid change, after which gradualistic improvements took place.

Here too, a comparison with horse evolution can be made. Sondaar (1994) noticed that the transition from forest-dwelling horses with padded feet and low-crowned molars, to digitigrade open landscape horses with straightened legs and high-crowned molars took place in the Early Miocene. However, the changes in the legs and in the dentition did not take place at the same time. First the locomotive transition (from a padded foot to a tip toe locomotion) took place; the first tip toed horses still had low-crowned molars. This transition – which is a consequence of the lengthening of the central phalanges –

must have occurred rather sudden, as no transitional forms have been found. We subsequently observe a gradualistic increase of the crown height of the molars and further adaptive skeletal improvements. Apparently the adaptation of the locomotive system was of vital importance. Sondaar (1994) called such a structure, which is of vital importance for the survival of a species, a pioneer structure. The subsequent gradualistic adaptations are called settlement structures.

A rather similar pattern can be observed in hominid evolution. Bipedalism is found already in the earliest forms, while the dentition and some other skeletal features, such as the brain capacity, are still rather ape-like. Here too, the locomotion is a pioneer structure, while the adaptation of the dental elements to new food, and the development of the brain are settlement structures. The upright bipedal posture, leaving the hands free, apparently set the stage for the development of our brain capacity.

In conclusion, we postulate that the evolution of Mankind is not unique, and that it must be compared with the evolution of mammals, simply because hominids were (are) mammals that adapted to their environments.

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