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First Evidence of Cotton at Neolithic Mehrgarh, Pakistan: Analysis of Mineralized Fibres from a Copper Bead

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The metallurgical analysis of a copper bead from a Neolithic burial (6th millennium BC) at Mehrgarh, Pakistan, allowed the recovery of several threads, preserved by mineralization. They were characterized according to new procedure, combining the use of a reflected-light microscope and a scanning electron microscope, and identified as cotton (*Gossypium* sp.). The Mehrgarh fibres constitute the earliest known example of cotton in the Old World and put the date of the first use of this textile plant back by more than a millennium. Even though it is not possible to ascertain that the fibres came from an already domesticated species, the evidence suggests an early origin, possibly in the Kachi Plain, of one of the Old World cottons.

Résumé: L'analyse métallurgique d'une perle en cuivre, provenant d'une tombe néolithique (VIe millénaire av. notre ère) de Mehrgarh, Pakistan, a permis la découverte de plusieurs fibres textiles, conservées par minéralisation. Elles ont été caractérisées par une nouvelle méthode, combinant l'utilisation d'un microscope à lumière réfléchie à celle d'un microscope électronique à balayage, et ont été identifiées comme étant du coton (*Gossypium* sp.). Les fibres de Mehrgarh constituent la plus ancienne attestation du coton dans l'Ancien monde et son utilisation a pu être reculée de plus d'un millénaire. Bien qu'il ne soit pas possible d'attribuer avec certitude les fibres à une espèce déjà domestiquée, ces nouvelles données suggèrent une origine ancienne, éventuellement dans la Plaine de Kachi, d'une des espèces cotonnières de l'Ancien monde.

Keywords: COTTON, FIBRE PLANTS, COPPER BEAD, NEOLITHIC, BALOCHISTAN.

Introduction

The fibres discussed in this article were discovered during the metallurgical analysis of a set of eight copper beads found in a Neolithic burial at Mehrgarh in central Balochistan. Situated at the foot of the Bolan Pass, in the northern part of the Kachi Plain, Mehrgarh occupied a strategic position in the zone of transition between the mountainous regions of the Iranian Plateau and the alluvial Indus Basin (Figure 1). The excavation of several sites in this area (Mehrgarh, Nausharo, Pirak), carried out by the French Archaeological Mission under the direction of Jean-François Jarrige, has revealed a continuous occupation during almost 6000 years, from the 7th millennium BC until the 1st millennium BC (Jarrige, 1995, 1996: 829). Owing to the presence of water and arable soils, the Kachi Plain formed a particularly favourable environment for human settlement and the analysis of faunal and floral remains has shown that agriculture, together with pastoralism, constituted the base of subsistence already in the earlier periods

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Figure 1. Localization of the archaeological sites mentioned in the text (© M.A.I., J.-F. Haquet).

(Costantini, 1984; Costantini & Costantini-Biasini, 1985; Meadow, 1996, 1998).

The occupational sequence at Mehrgarh, the oldest of the Kachi sites, begins in the early 7th millennium BC and stretches into the first part of the 2nd millennium BC. According to the chronology established by the French Archaeological Mission, an initial aceramic Neolithic period I and Neolithic period II are followed by a Chalcolithic occupation (periods III–VII) (Jarrige *et al.*, 1995). The Neolithic sequence is characterized by the alternation of habitation levels and burial levels. More than 300 graves, attributed to the aceramic Neolithic period I, have been excavated and the copper bead (MR.84.03.158.01b) containing the cotton fibres was found in one of these graves dated to the first half of the 6th millennium BC (Jarrige, 2000). The funerary chamber, sealed by a low mud brick wall, contained the remains of two persons, one male adult and, at his feet, a child, approximately one or two years old. The adult lay on his left side, with the head towards the East and the legs flexed backward (Figure 2), this being the most common position in the Mehrgarh burials. Even though many of the graves contained funerary deposits, the grave goods of this one—a set of eight copper beads, found next to the adult's left wrist—were exceptional as metal beads have been recorded from only two of all the Neolithic burials excavated and even among all the adornments discovered so far (Barthélémy de Saizieu, 1994, 592, 599).

Description of the Beads

The copper beads are annular and their diameters vary between 2·2 and 4·8 mm. Their average weight, in the present state of preservation, is 0·13 *g*. All the beads have been X-ray radiographed at the *Centre de Recherche et de Restauration des Musées de France*, as a part of a larger research program on the development of early metallurgy in Protohistoric Balochistan (Haquet, forthcoming; Mille, forthcoming). The radiographic image clearly shows that the beads were formed by rolling of a narrow metal sheet around a circular rod (Figure 3). Only a plastic material, such as metal, could have been worked in this way, so the use of malachite cut into beads in the way of semi-precious stones like at Çayönü Tepesi can be excluded (Muhly, 1989: 6–7).

The radiographic examination also reveals the heavy corrosion of the beads (Figure 4). One of them was

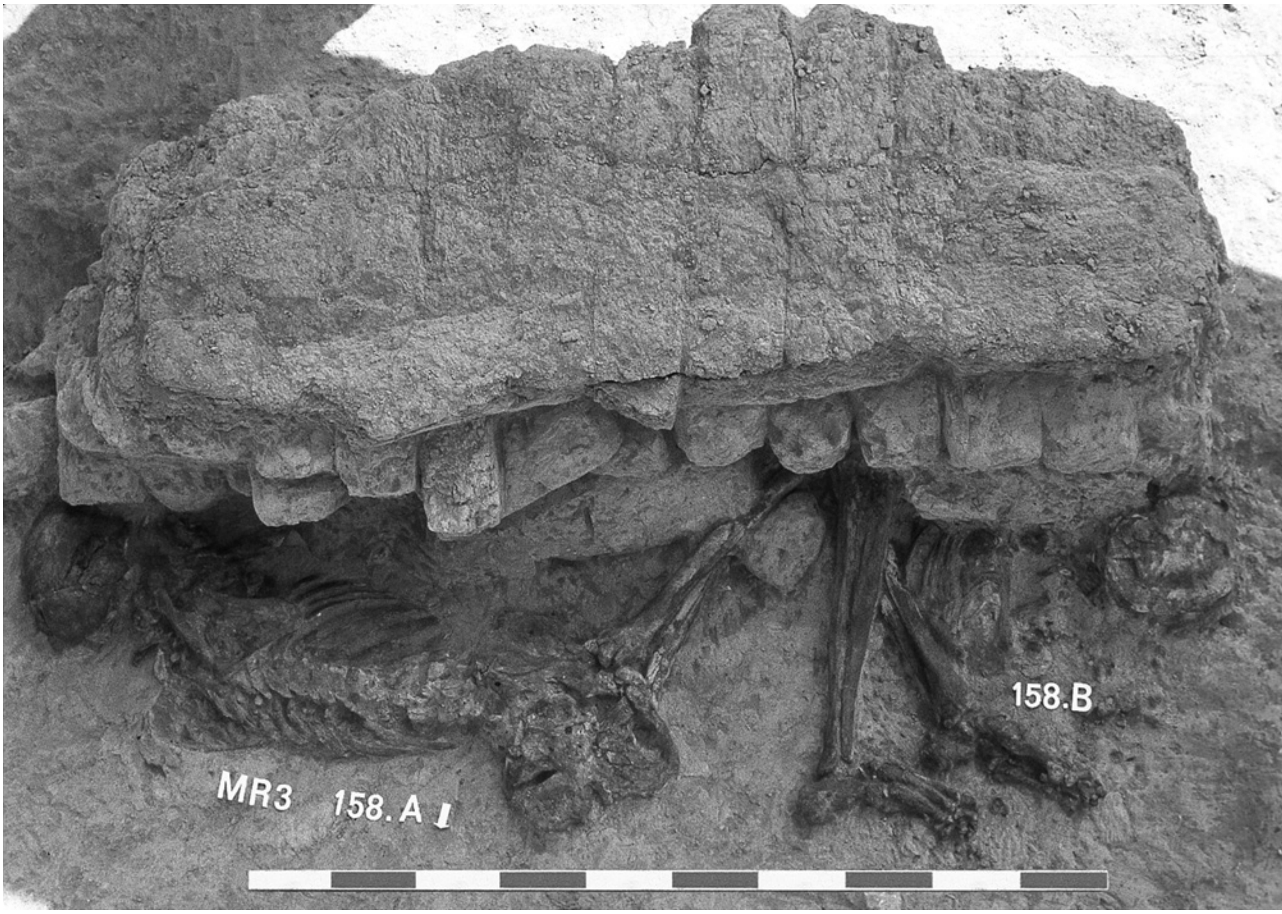

Figure 2. Grave (MR.84.03.158) with the mudbrick wall sealing the funerary chamber (© M.A.I., C. Jarrige).

selected because of its higher density; a metallographic section was carried out perpendicularly to the rolling axis. The observation of this section, under a reflected-light microscope as well as a scanning electron microscope (SEM, Figure 6A), shows that the metal that originally made up the bead has been entirely mineralized (Figure 5) and transformed mainly into copper oxide and copper chloride (Figure 6B,D,F). The width of the metal sheet can be estimated as approximately 0·8 mm on the basis of the distribution of the quartz grains that follow the original surface of the bead (Figure 6C). Besides the copper, and a few small precipitates of metallic silver trapped between the internal and external layers of corrosion (Figure 6E), no other metallic elements were detected.

Quite exceptionally, the earliest metal artefacts found at Mehrgarh date back to the aceramic Neolithic period. The copper beads described had been worked according to specific metallurgic procedures in which hammering and probably also annealing techniques were used alternatively. However, the state of preservation of the bead does not allow a detailed study of its microstructure.

Identification Methods and Description of the Fibres

Thousands of stone and shell beads were found in the Mehrgarh burials but none of these has allowed the recovery of vegetal fibres. Mostly, these remains, like organic material in general, decay rapidly and survive only rarely in archaeological contexts. Specific preservation conditions like the corrosion of metal artefacts, can nevertheless account for their survival in a mineralized state (Janaway, 1989; Chen, Jakes & Foreman, 1998) as in the case of the Mehrgarh cotton fibres. For mineralization to occur, the organic material has to be in close contact with the metal object, which, in turn, should be composed of rapidly corroding metals such as copper alloys or iron. The fibres are then preserved by substitution of the organic material by metallic salts.

Traditional methods of analysis, using a transmitted-light microscope, do not generally permit precise identification of mineralized textile fibres. Therefore, a new method of identification was developed at the *Centre de Recherche et de Restauration des*

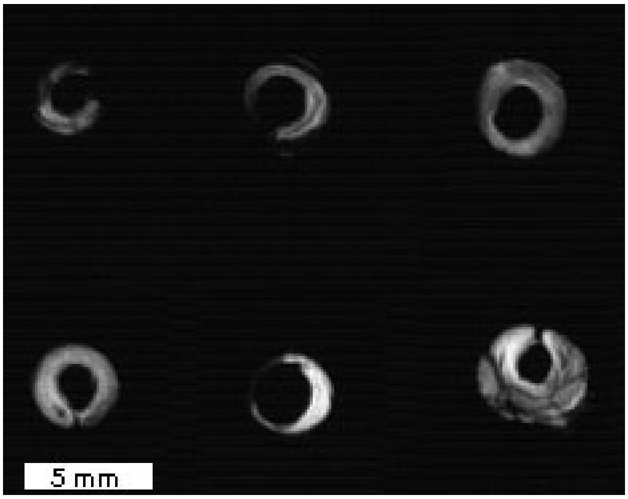

Figure 3. X-ray radiograph of the copper beads from the set (© C2RMF, T. Borel).

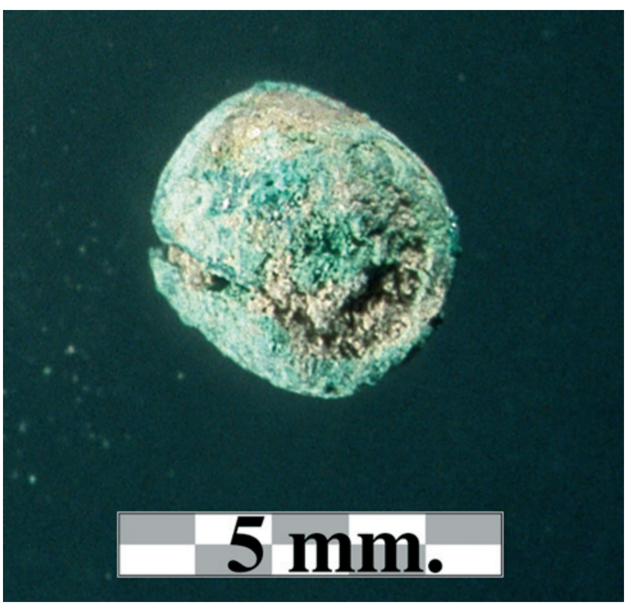

Figure 4. Copper bead (MR.84.03.158.1b) with remains of mineralized fibres (© C2RMF, D. Bagault).

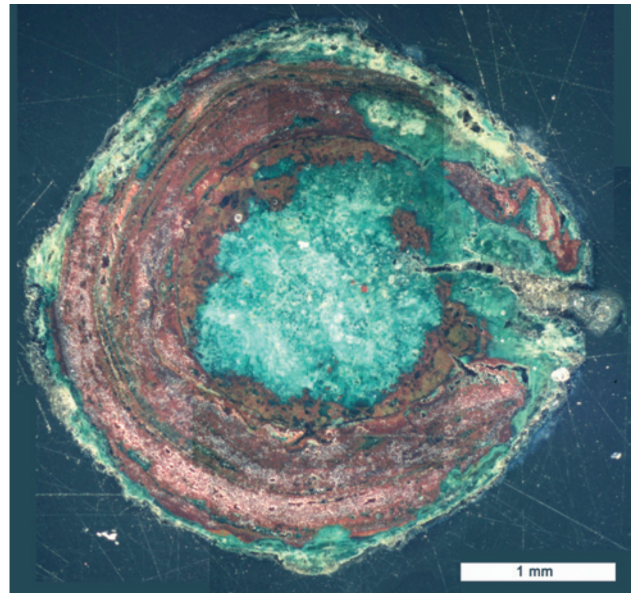

Figure 5. Reflected-light micrography of the section of the bead, dark field. (© C2RMF, B. Mille).

Musées de France (Moulherat, 2000). This method is based on the combined use of a SEM and a reflected-light microscope in order to study the particular morphology of each fibre. Different features such as the morphology of the scales, the presence or absence of a lumen, the shape of the lumen etc. are observed in both longitudinal and transversal sections and compared to modern fibres from a reference collection.

A sample of less than 5 mm^2 was isolated from inside the Mehrgarh copper bead and then covered with a fine, conducting layer of gold in order to allow observations to be made by SEM. Later, the same sample was encased in a cube of translucide epoxy that, after having been polymerized, was polished with diamond paste. Carefully chosen sections were then observed with a reflected-light microscope in order to determine the morphology and diameter of the fibres.

The observations made in the transverse section allowed us to identify the fibres as cotton, *Gossypium* sp. They show a characteristic oval and sometimes slightly flattened shape with, in most cases, a large lumen (Figures 7 & 8). Several degrees of ripeness could be identified among the Mehrgarh fibres, according to the thickness of the cellular walls. Dead fibres, even though they have attained their final length and diameter, present very thin cellular walls and thus a large lumen (Figure 9). Unripe fibres are often slightly flattened and have somewhat thicker cellular walls. Ripe cotton is characterized by thick secondary walls and a reduced lumen. Finally, overripe fibres present very thick walls and an even narrower lumen, features making them less flexible than the other types of fibres (Institut Textile de France, 1984). The co-existence of both ripe and unripe cotton fibres, as observed here, is commonly attested in archaeological contexts.

The diameters measured on a hundred of the Mehrgarh fibres (Table 1) fall into the range of several present-day cotton species, in particular *Gossypium herbaceum* (Henry, 1924). However, considering the morphological evolution of the domesticated cottons during millennia of cultivation (see below) these measurements cannot be used to identify the Neolithic cotton fibres as definite modern species. In general, the lack of comparable reference material makes the identification of prehistoric archaeological cotton fibres to the species level highly improbable.

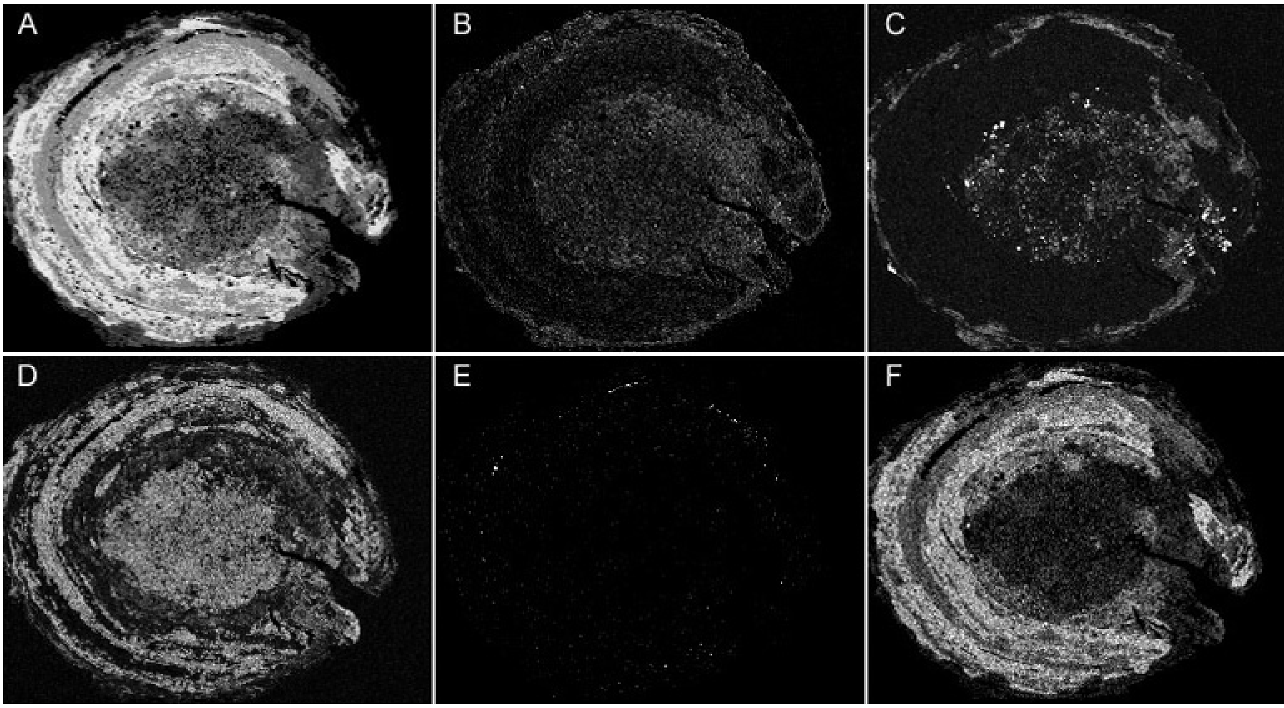

Figure 6. (B, D, F) SEM map element of the section of the bead: A. back-scattered electron image, B. Oxygen, C. Silicon, D. Chlorine, E. Silver, F. Copper (© C2RMF, B. Mille).

Origin and Domestication of Cotton in the Old World

Cotton, whether wild or domesticated, belongs to the genus *Gossypium* of the family Malvaceae. Among other traits, the members of this genus have in common the presence of epidermal hairs, or fibres, covering the seeds. It was certainly the usefulness of these hairs that first drew the attention of ancient populations and which eventually led to the domestication and cultivation of several of the *Gossypium* species. Today, cotton is the most important fibre-crop in the world and is cultivated in more than forty countries (Brubaker, Bourland & Wendel, 1999: 4).

The genus *Gossypium* comprises around fifty species which grow essentially in tropical and subtropical regions (Valicek, 1979). Four of these are cultivated: *Gossypium arboreum* L., *G. herbaceum* L., *G. hirsutum* L. and *G. barbadense* L. While the diploid *G. arboreum* and *G. herbaceum* originate in the Old World, the two others, both tetraploids, were domesticated in Meso- and South-America. The Old World cottons can further be subdivided into an Asiatic (*G. arboreum*) and an African (*G. herbaceum*) subgroup, each comprising several races that developed under cultivation (Brubaker, Bourland & Wendel, 1999: 7–8). Presently, *G. arboreum* is mainly cultivated in the Indian subcontinent, China and Southeast Asia but can also be found in southern Arabia and eastern Africa, where it often grows sympatrically with *G. herbaceum*. The last species is most common in Africa and Arabia but its distribution extends into the Levant, Iraq, Iran as well as northern and western India (Valicek, 1979: 239). It is noteworthy that these two Old World cottons have in recent times been replaced to a large extent by the more profitable *G. hirsutum*.

G. arboreum and *G. herbaceum* are easily hybridized, creating a fertile first generation. Subsequent generations tend, however, to be less vigorous and to show frequent anomalies (Brubaker, Bourland & Wendel, 1999: 6). Interspecific introgression over millennia in the regions where the two species have been grown together, may in part explain a considerable morphological overlap that often leads to misidentifications. Still, from a genetic point of view, there is no doubt that *G. arboreum* and *G. herbaceum* constitute separate species (Wendel, Olson & Stewart, 1989). Moreover, they seem to originate from two different progenitors that diverged from a possible common ancestor long before domestication took place (Wendel, Olson & Stewart, 1989: 1805). This contradicts the hypothesis according to which *G. herbaceum* would have been the ancestor of *G. arboreum* (Hutchinson, 1954). Instead, the Old World cultivated cottons seem to have resulted from two independent domestication events. There are few certainties as to where and when these events took place. A possible ancestor of *G. herbaceum* has been detected in southern Africa where a wild form, *Gossypium herbaceum* L. subsp. *africanum* Watt (Vollesen, 1987), grows as an indigenous element in open forests and grasslands (Vollesen, 1987: 343–345). From a genetic point of view this subspecies could be

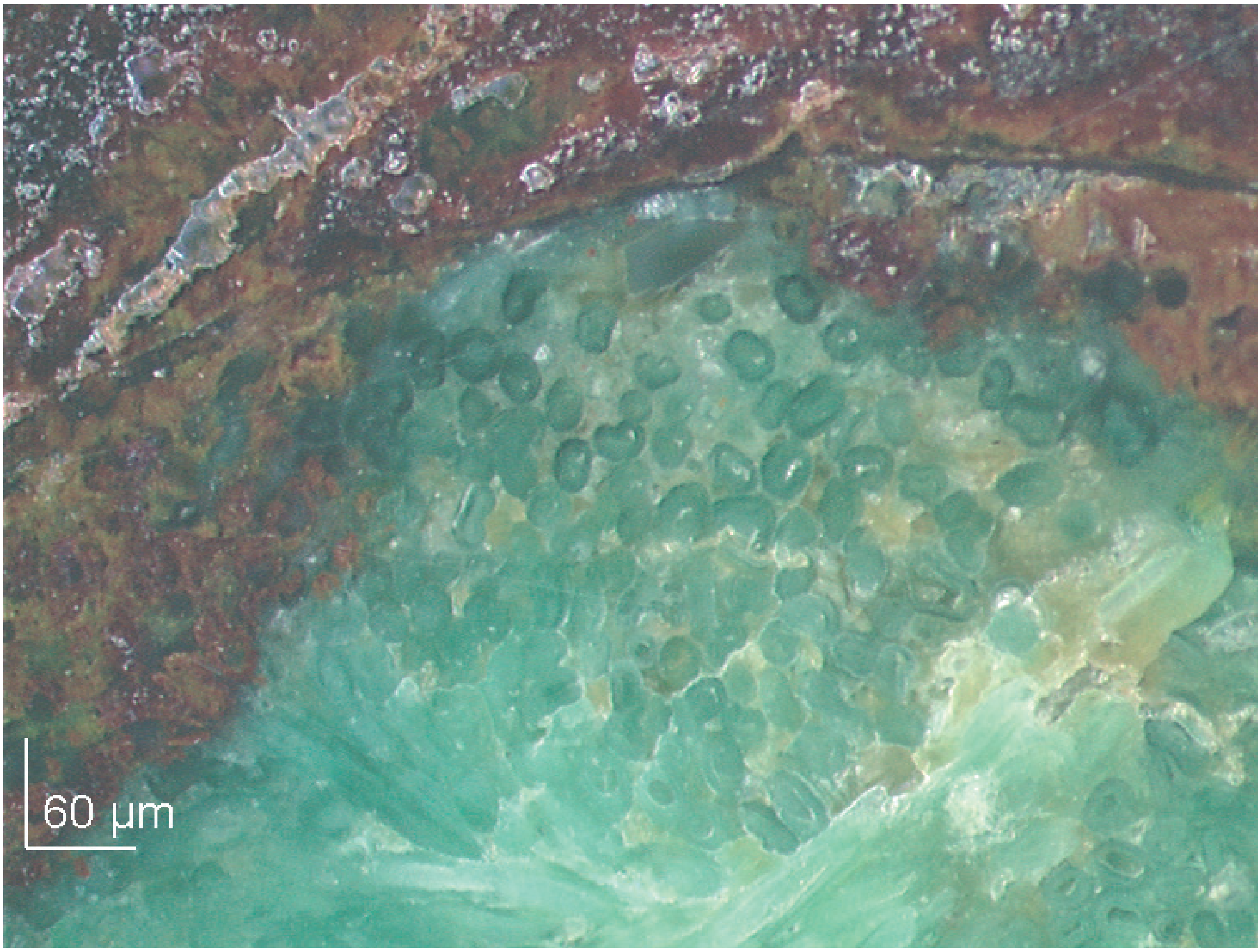

Figure 7. Reflected-light micrography of the mineralized cotton fibres (X200) (© C2RMF, C. Moulherat).

the ancestor of the cultivated *G. herbaceum* (Wendel, Olson & Stewart, 1989: 1805) but the geographical disjunction between the progenitor and its derivative is somewhat problematic as *Gossypium herbaceum* subsp. *africanum* grows exclusively in southern Africa, i.e. far from the areas where its domesticated counterpart is found. It has therefore been suggested that either the wild subspecies was more widely distributed in the past, or it was brought by human groups to northern or eastern Africa where it was domesticated outside its natural range (Wendel, Olson & Stewart, 1989: 1805, Brubaker, Bourland & Wendel, 1999: 20).

No wild form of *G. arboreum* is known so far but it is likely that the domestication of this species took place within the range of its most primitive race "indicum", i.e. somewhere between India and eastern Africa. The Indus Valley has been suggested as a possible centre of domestication and diffusion (Brubaker, Bourland & Wendel, 1999: 21) but in the light of the early cotton find from Neolithic Mehrgarh, it seems that cotton was used and perhaps even domesticated in the Kachi Plain of central Balochistan, several millennia before the rise of the Indus Civilization. Even though no wild *Gossypium* species is known from this part of Pakistan today, the open woodland or pseudo-savannah that characterized the surroundings of Mehrgarh in the past (Tengberg, Thiébault, in press) could have constituted a favourable environment for the possible progenitor of *G. arboreum*. Besides the fibres described above, a few seeds attributed to *Gossypium* sp., were found in a period II context (5th millennium BC) at the site (Costantini, 1984: 32). It is true, however, that neither the fibres, nor the seeds from Mehrgarh allow us to assert that cotton was actually domesticated in the Kachi Plain during the Neolithic and the use of wild cotton fibres remains equally possible. Nevertheless, we should bear in mind that the early inhabitants of the site were already experienced agriculturists, well acquainted with the cultivation of several crop plants (Costantini, 1984; Costantini & Costantini-Biasini, 1985).

The processing of crude cotton fibres in order to obtain the thread attested at Mehrgarh would have required a certain experience of the use of fibre plants. Flax seeds, which are often found in the crop

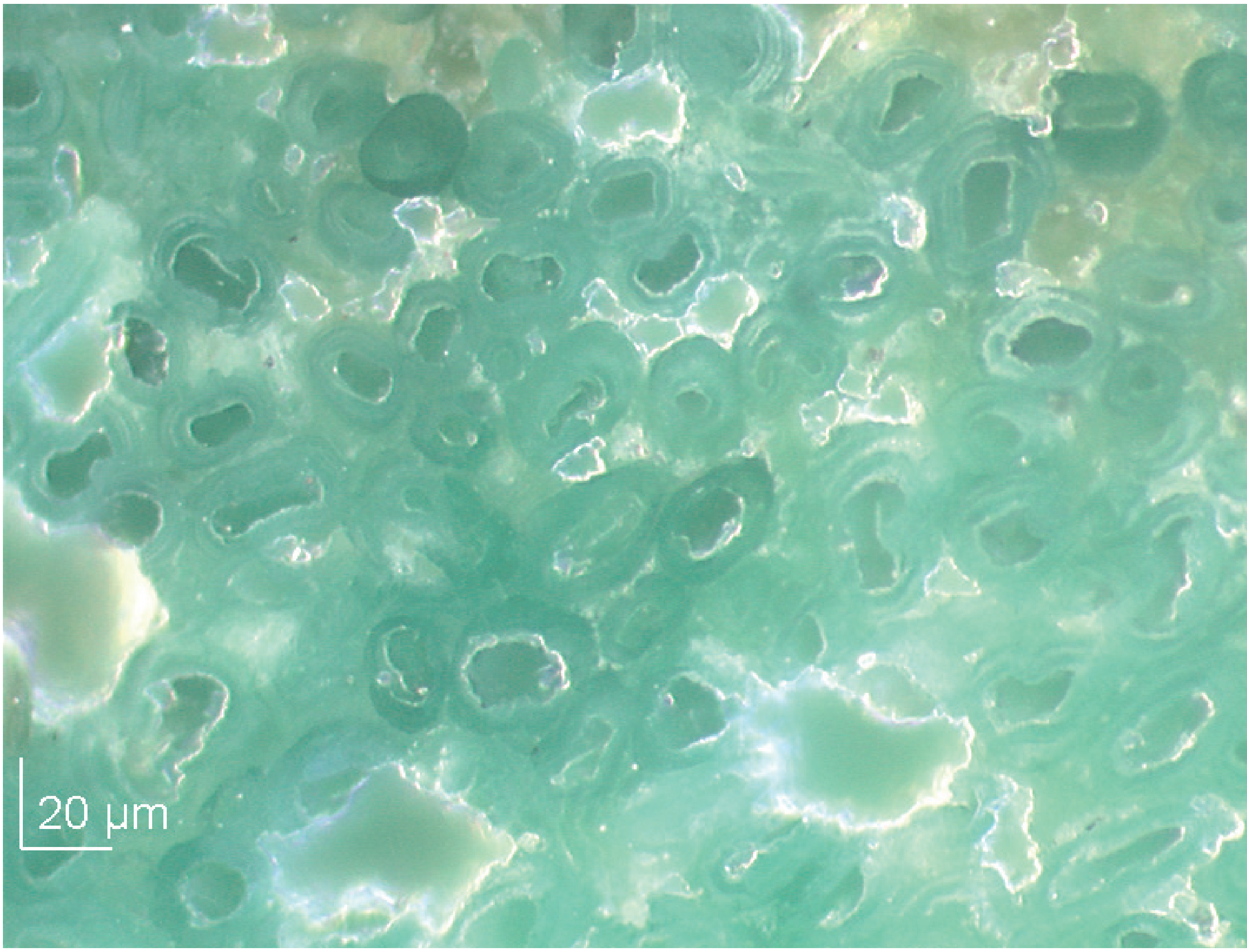

Figure 8. Reflected-light micrography of the mineralized cotton fibres (X500) (© C2RMF, C. Moulherat).

assemblages of Neolithic sites in the Near East, have only been attested in the levels of period VII, i.e. from the 3rd millennium BC (Costantini, 1990: 326). Flax is also present at 3rd millennium BC Nausharo, both in the form of carbonized seeds (Constantini, 1990: 326) and fragments of linen cloth (Moulherat, ongoing research).

Archaeological Evidence of Cotton

Cotton, either in the form of fibres or seeds, has been identified at several other sites in South Asia. Remains of a cotton string, conserved inside a carnelian bead, were found in a 4th millennium grave at Shahi Tump in the Makran division of southern Balochistan (ongoing excavations by the French Archaeological Mission to Makran, preliminary study by Moulherat). So far, no cotton seeds have been recorded from this site (Tengberg, research in progress) but a local origin seems entirely possible. The situation is somewhat different at Dhuweila in eastern Jordan, where fibres and impressions of a woven cotton fabric were also found in a 4th millennium BC context (Betts *et al.*, 1994). For ecological reasons, the Dhuweila cotton was most likely imported from elsewhere, perhaps from the Indian subcontinent. By the beginning of the 2nd millennium BC the evidence for both cotton fibres and seeds becomes more frequent, especially in the Indus Valley and Peninsular India. Fragments of a cotton fabric and a piece of cotton string were preserved in contact with a silver vessel at Mohenjo-daro (Gulati & Turner, 1929; Marshall, 1931: 33). Cotton fibres were also identified at Nevasa (Clutton-Brock *et al.*, 1961) while seeds, a more reliable indication of local cultivation, were present in 2nd millennium BC levels at Hulas (Saraswat, 1993), Chandoli (Kajale, 1991) and Loenbar 3 (Costantini, 1987).

The earliest known remains of cotton in Africa date to the mid 3rd millennium BC and come from a Nubian site belonging to the A Group culture (Chowdury & Buth, 1971). There are, however, doubts as to whether this find, consisting of seeds and lint, derived from a cultivated species and even about the actual use of cotton as a textile plant (Betts *et al.*, 1994: 496).

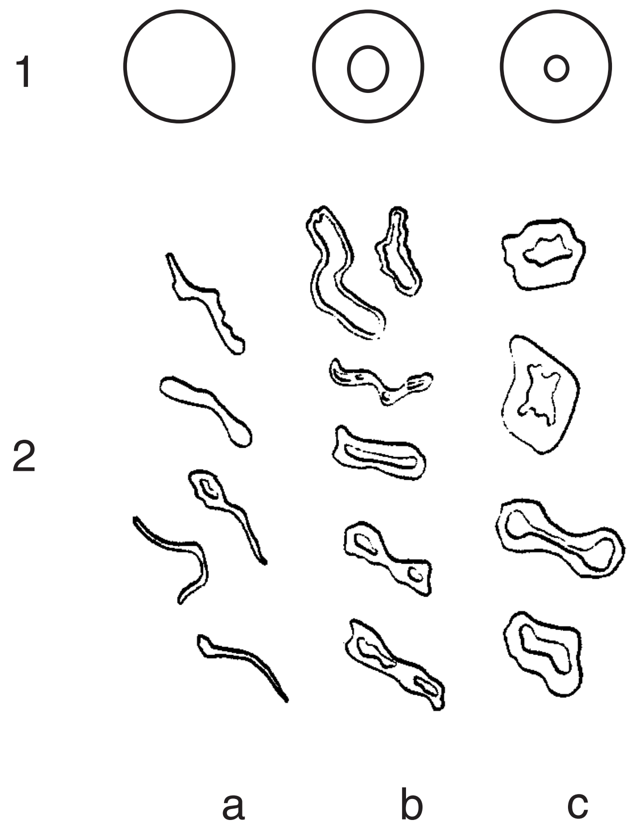

Figure 9. (A) Schematic representations of cotton fibres at different stages of ripeness, as seen in the transversal section: A. Dead fibre, B. Unripe fibre, C. Ripe fibre (after Matthews, 1913, 441). (B) Schematic representations of cotton fibres at different stages of ripeness, as seen in the transversal section: A. Dead fibre, B. Unripe fibre, C. Ripe fibre (after Matthews, 1913, 441). (C) Schematic representations of cotton fibres at different stages of ripeness, as seen in the transversal section: A. Dead fibre, B. Unripe fibre, C. Ripe fibre (after Matthews, 1913, 441).

Table 1. Diameters of the Mehrgarh cotton fibres

Number of fibres measured	Range	Mean	Mode
100	6–31 μm	18,52 μm	17 μm

Each domesticated cotton has undergone important changes during millennia of cultivation, as human selection has brought them further and further away, both morphologically and genetically, from their wild ancestors. From perennial shrubs with small, impermeable seeds, bearing coarse and short hairs, the cultivated species have transformed into annuals with readily germinable seeds covered by a long and smooth lint that is easy to gin. By human transfer of seeds into new regions the cultivated cottons have also spread far beyond the original habitats of their wild ancestors, successively adapting to different edaphic and climatic conditions.

Conclusion

The exceptional preservation of cotton fibres in a Neolithic burial at Mehrgarh results exclusively from the corrosion process of copper in which metallic salts are liberated and can thus impregnate the organic material. This type of conservation is rare, especially for periods before the "true" metal ages, for which metal objects are extremely scarce. The fibres from Mehrgarh thus represent a unique find. They were characterized according to a procedure, specially developed by Christophe Moulherat (Moulherat, 2000) at the *Centre de recherche et de restauration des Musées de France* for the study of mineralized fibres. Only identification of the fibres as semi-ripe cotton could be established with certainty. The results obtained at Mehrgarh demonstrate the potential of this new method for similar material from other sites.

The fortuitous find of the Mehrgarh cotton fibres sheds new light on the early history of this textile plant in the Middle East. The generally accepted end 3rd/beginning 2nd millennium BC dates for the first use of cotton, based on finds from Harappan sites in the Indus Valley, was already pushed back to the 4th millennium BC by the discovery of fibres and impressions from a cotton fabric at Duweilah in Jordan (Betts *et al.*, 1994). The evidence from Neolithic Mehrgarh allows us to consider an even earlier use of cotton in the Old World, dating to the 6th millennium BC. Even though we cannot be sure that the cotton thread used to string copper beads at Mehrgarh derived from an already domesticated species, it seems clear the cotton as such was already known and exploited for its fibres at this period. The accumulation of evidence of early cotton in Pakistani Balochistan (Mehrgarh, Shahi Tump) and in the Indus Valley seems to confirm the hypothesis of a South Asian origin, probably in the Greater Indus area, of one of the Old World cottons (Brubaker, Bourland & Wendel, 1999: 21, Fuller & Madella, 2000; Zohary & Hopf, 1994: 128).

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