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# Early subterranean chert mining

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**Abstract.** The world's known sites of underground chert mining from essentially pre-Neolithic times are considered. The formation and composition of cherts is described, together with their modes of geological occurrence. This is then related to early mining strategies in Europe, Africa and Australia. The paper includes a discussion of the known or probable antiquity of the various subterranean mining traces, and there is brief reference to early ochre mining evidence. The writer concludes that mining technology of the Pleistocene has so far been almost ignored world-wide, and has not before been discussed on a comparative basis.

## Introduction

Thousands of tonnes of Pleistocene stone artefacts have been recovered or observed in all continents other than Antarctica, which raises the question of the origins of the raw material for their manufacture. Throughout the world, surprisingly little evidence is available for pre-Neolithic mining. Most of the minerals utilised by humans of the Pleistocene and early Holocene were probably collected from beaches, scree slopes and alluvial cobble deposits, or were quarried from surface exposures and outcrops of suitable materials. Recent evidence suggests, however, that a part of them was also mined underground, and sometimes by extraction techniques comparable to those of the European and North African Neolithic. They involved artificial lighting, scaffolding and the use of mining tools. These techniques are the principal subject of this paper.

Neolithic flint mines in Europe are so well known that they are only mentioned in passing here. The mining and workshop complex of Grimes Graves, Norfolk (Sieveking et al. 1973), is perhaps among the best known, its Brandon Flints being found throughout the British isles. This was essentially shaft mining through chalk deposits, with shafts of up to 9 m depth. Thousands of implements provide an indication of the mining methods: deer antlers and bones were applied as chisels and levers, bovine scapulae as shovels, and in the deeper shafts, remains of torches were found, and stone cups containing soot which appear to have served as lamps.

Numerous other Neolithic flint mines have been found elsewhere, in Britain as well as in many parts of the European mainland, in Africa and in Asia. Prevalent in the English literature are perhaps the Sussex mines at Harrow Hill (Felder 1982), Cissbury, Church Hill and Blackpatch Hill (Curwen 1954), in the Newhaven Member of the Sussex White Chalk Formation (Mortimore 1983). On the European mainland, flint mines have been reported from many countries, especially Poland (Babel 1986; Budziszewski 1986), Belgium (e.g. Stockmans et al. 1979), Germany (Weiner 1986), Romania (Comsa 1986) and Hungary (Simán 1986), but also from other countries, notably in western and northern Europe. The technology of these traditions has been studied extensively in Europe (e.g. Vértes 1964; Sieveking et al. 1972; Burleigh 1975; Lichardus 1980; Weisgerber 1980, 1986; Lech 1981; Felder 1982; Hubert 1985; Bácskay 1986; Salacinski 1986; Sieveking and Newcomer 1986), and much less so elsewhere (e.g. Novikov and Radililovsky 1986).

By comparison, the question of the raw material procurement in the far longer Palaeolithic period has received considerably less attention. Among the sparse reports of known Palaeolithic surface quarries are those of the Mount Avena Aurignacian quarry in Italy (Lanzinger 1986); a series of sites in the Moravian Karst (Stelcl 1986); and from the late Palaeolithic quarry Krzecwów in Poland (Cyrek 1986). Extensive trading networks have been postulated on the basis of flint distribution, even from the Palaeolithic period. For instance, Vértes (1960) and Dobosi (1886) report large numbers of lithics made of 'Baltic flint' from the Hungarian Palaeolithic. Satani Dar is a major Palaeolithic obsidian quarry in the Aragatz massif of Armenia (P. Ossa, pers. comm.).

Recent specialist literature on the general subject of chert mining, and particularly on underground mining, maintains that all such mining evidence is more recent than 12 000 years BP, and that most of it dates from 6000 to 4000 years ago (e.g. Weisgerber 1980; Vermeersch et al. 1989). This misconception in Europe has only been corrected recently (Bednarik 1986a, 1990a).

## About sedimentary silicas

In examining chert mining it is helpful to consider the geological setting, the nature and diagenesis of sedimentary silicas, and the reason for the formation of chert deposits. 'Flint' is merely a type of chert, and the term's petrological application, in contrast to its archaeological use, is restricted by chronological and possibly geographical connotations as well as by physical attributes (cf. Tarr 1938; Oakley 1939; Midgley 1951; Shepherd 1972; Hauptmann 1980; Slotta 1980): it describes a nodular, almost black, opaque siliceous sedimentary rock occurring in limestone, especially in the Upper Cretaceous chalk deposits of western Europe. Its colour will persist to thicknesses of only 30-40 microns in transmitted light (Weymouth and Williamson 1951) and is a function of its physical composition.

Similar nodular compact silicas are known from other carbonate facies such as Jurassic and Tertiary limestones, and even from gypsums. The frequent archaeological practice of describing these microcrystalline and chalcedonic quartzes as flint is not acceptable (Zeuner 1960; Milner 1962). True flint consists of a dense aggregate of frequently anhedral, locally euhedral silica crystallites of greatly varying size. The dark colour of unpatinated flint has been attributed to various agents. Carbonaceous matter, present as rhombohedral calcium carbonate in concentrations of somewhat less than 1% is thought by some investigators (Washburn and Navias 1922; Oakley 1939) to contribute to, if not determine, the colour. According to Hurst and Kelly (1966), the preferential absorption of some wave lengths by impurities determines the colour's hue, and their amount influences both chroma and value, while the ratio of transmitted light to diffused and reflected light decides the value of the flint's colour. Weymouth and Williamson (1951) noted distinct discolouration after oxidising the carbonate at low temperature (to avoid calcination of the silica). In the light of Folk and Weaver's (1952) corroboration it is justified to attribute colouring phenomena to the optical properties of microscopic pores. This, of course, is precisely what causes the dramatic change of colour through patination, which archaeologists are so familiar with (Bednarik 1980).

The questions surrounding the formation of flint and other cherts and chalcedonies have attracted considerable attention, and are of significance in considering aspects of their mining. Later in this paper it will be necessary to appreciate why such minerals occur in predictable formations, so the processes responsible for these deposits are considered here in some detail. Some writers believe that the salts of sea water, acting as electrolytes, induce precipitation through flocculation or coagulation of the colloidally suspended silica. This hypothesis was initially investigated by Tarr (1917) and propagated by others despite the inability of subsequent workers to duplicate his results (cf. Moore and Maynard 1929: 283). The syngenetic argument is also advocated by Twenhofel (1950) and Murray and Gravenor (1953). Tarr's attempt to refute the replacement origin thesis, pioneered as early as 1908 and 1912 by Van Tuyl, was parried by its author by assembling eight phenomena clearly supporting it (Van Tuyl 1918). After the case for an epigenetic formation of chert had found the support of Correns (1926), Wroost (1936) reinforced it by proposing an intricate process involving, in essence, the mobilisation of opaline silica inclusions of limestone, by percolating ionised carbonic acid exceeding the matrix's solubility limit, and the polymerisation of the silica upon arrest of the $CO_3$-ions by more soluble zones (e.g. aragonite) and its eventual dehydration. Bramlette (1946) advances the variations in the silica concentration of sea water as a function of depth in favour of organic agents, and Roy (1945) asserts that silica of natural waters is molecularly, and not colloidally, dispersed, after pursuing established concepts of another discipline, chemistry. Krauskopf (1956) agrees with White et al. (1956) on the magnitude of Aoki's solubility limit for amorphous silica, about 100-140 p.p.m. at 25°C.

Of particular relevance here is Walker's (1962) examination of the reversible nature of the limestone - chert replacement process. He proposes an explanation involving an inverse solubility relationship under conditions of high alkalinity, controlled by otherwise negligible fluctuations of pH.

Thus both the diagenesis and composition of sedimentary silicas had been satisfactorily explained a few decades ago. The physico-chemical nature of chert patinae was also known: the appearance of the altered veneers manifests an etching of the microcrystalline grains that alters the mineral's reflective properties, i.e. its colour. The questions that are crucial to the archaeological evaluation of the leached cutaneous layer were elucidated (Bednarik 1980) by explaining the process of patina formation and introducing methods for the quantitative analysis of the phenomenon.

More recent developments are the emergence of analytical techniques that have facilitated a more precise understanding of the geochemistry of silicification processes. The typical formations one encounters are horizontal, nodular chert bands that range from vague concentrations of scattered nodules and casts of burrows, to more diffuse, semi-tabular networks of coalesced burrows, particularly of *Thalassinoides*; vertical paramoudras, with a limestone core, the centre of which may contain pyrite; or sheet flint which transgresses other formations and is related to fractures. The first-named is by far the most common form. It is attributable to a contrast in porosity or permeability between the burrow fill and its matrix: the greater this contrast is, the more the silicification process is confined to the burrow itself. Clayton (1986) has recently sought to attribute the silicification to bacterial sulphate reduction and the associated $H_2S$ oxidation at the oxic-anoxic boundary in the limestone where calcite is being dissolved. This leads to precipitation from pore waters being highly supersaturated with respect to crystalline silica. The silica is generally derived from siliceous sponges, and radiolarian and diatom remains.

It follows that structural and distributional characteristics of chert facies in limestone strata are highly predictable: they are generally related to the (at least initially) horizontal stratification of the limestone beds. This is simply due to the silicification process of the limestone matrix, which is entirely restricted to specific geological layers, i.e. those that are more readily soluble. A silica-bearing stratum can extend for many kilometres, and it is entirely possible to predict its occurrence from geological observation: the bedding of the limestone, attributable to its sedimentary origin, is highly regular, and a geological sequence can be memorised and recognised. Economic decisions on the potential viability of proposed mining operations can be based on such geological observation. Irrespective of whether it is made by modern a mining engineer or by a Palaeolithic chert miner, the principles are essentially the same: there has to be a belief that the expected investment of labour and resources is warranted by the perceived value of the resource to be gained, within the economic risk limits considered acceptable.

The economics of human activities in the Pleistocene can sometimes provide an excellent opportunity to reason about these people's capacity of making such 'conscious', calculated decisions about the potential results of a specific course of action. I posit that this kind of information could lead to more relevant data about cognitive processes in the early intellectual development of humans than some of the criteria so far proffered for this purpose (Bednarik 1990b, 1991), such as the unproductive speculations about language origins (e.g. Davidson and Noble 1989, 1990; Noble and Davidson 1991) or 'symbolic behaviour' (Chase and Dibble 1987, among others), or similarly tenuous speculations, for example about 'self-awareness' on the basis of bead production (White 1989). Although I shall not explore these fascinating issues here

(I have perused them elsewhere recently, e.g. Bednarik 1992a) I should like to present some data that would facilitate such an enquiry. I will therefore describe the subterranean silica mining evidence currently known from various regions.

The tendency of archaeologists to explain 'unusual' phenomena or those they find difficult to categorise as having to do with ceremonial, religious or metaphysical practices, often borrowed from ethnological or pseudo-ethnological interpretations, should be appreciated (for a detailed discussion of Australian misuse of analogies, see Huchet 1992). Of the numerous examples of this tendency, one is of immediate interest. The extensive silica mining traces in Koonalda Cave, Australia, are found hundreds of metres into the cave and bear witness of dangerous and laborious mining activities. There are surface exposures of similar material on the coast to the south, so to account for this activity it has been proposed that the stone brought out of the cave may have had some special significance related to its provenance. But this seems to be an unwarranted and selective use of ethnographic analogy: recent Aboriginal people throughout Australia avoid caves and generally refuse to enter them, and there is no evidence of any Holocene human presence in any deep cave in Australia. Since the Pleistocene Australians can be assumed to have had a significantly different attitude towards caves one should not attribute to them any other recent cultural motives. Their reasons for the subterranean forays may have simply been that the coastal exposures of the seams existing prior to the Holocene transgression could have been exhausted or inaccessible then, or too far to walk to. They may have understood the stratified occurrence of the cherts and known that the inevitably horizontal seams are as likely to be exposed in caves as is the watertable.

**Palaeolithic chert mining in Egypt and Europe**

The most securely dated example of Pleistocene mining activity comes from Upper Egypt (Vermeersch et al. 1984a; 1984b). Excavations at the Nazlet Khater 4 site, in the Nile valley between Asyut and Sohag, have uncovered extensive quarrying evidence from the early Upper Palaeolithic period. At this site, a basal sediment of greenish silts and fine sands is overlain by a 1.5 m-thick substratum of Nile gravels that is rich in chert cobbles of up to 20 cm, and covered by brown silts, a wadi deposit of local limestone gravels and aeolian sands with a desert pavement. A 9 m-long open trench of about 2 m width and a group of no less than seven vertical shafts have been dug to the silica-rich substratum, and have subsequently become filled with gravelly spoil material and aeolian sands. The infill contains several hearths and concentrations of dispersed charcoal, and a series of radiocarbon dates obtained from them ranges from 35 100 to 30 360 years BP.

Some information has been recovered about the people responsible for the quarrying. Numerous lithic artefacts were fashioned from the chert cobbles of the substratum, and they include blades and bifacially trimmed axes. On the summit of a boulder hill 400 m to the north-west, at Nazlet Khater 2 site, two graves were discovered. One contained the outstretched remains of a human, probably a sub-adult male, the other was of a human foetus. The former had been covered with loose aeolian sand and several boulders, some exceeding 0.4 m in diameter (Vermeersch et al. 1984b: Fig. 7). Next to the cranium (an archaic *Homo sapiens*, op. cit. Fig. 9), a 12 cm-long axe head was found in the grave fill, possessing concave sides for hafting, and matching the axe heads at the nearby mining site in every respect (Vermeersch et al. 1984a: Fig. 3).

Here we are primarily concerned with the mining evidence, and the technological inferences to be drawn from it. It seems that the presence of the silica-rich substratum was originally recognised from its natural exposure at the north-eastern margin of the site. The people conducting the mining apparently possessed the necessary understanding of geological phenomena to observe that the upper strata continued horizontally, and they predicted correctly that the substratum should continue below them. They excavated vertical shafts through the overburden of three 'sterile' deposits to reach the cobble deposit below. Bell-shaped pits were then produced by removal of the silica-rich deposit around the base of the shaft, similar to those in the Neolithic mines of Europe. The long trench may have resulted from the merging of several such bell pits. Galleries extended horizontally for some metres from them, where miners followed the substratum.

Vermeersch and colleagues report no mining implements from the site, and the removal of both the overburden and the cobble-yielding deposit would not have presented great technical difficulties. They emphasise that quarrying was only conducted intermittently; use episodes appear to be spread over several millennia. Nevertheless, the mere fact that a number of shafts were sunk into sterile overburden indicates clearly that the people concerned were sufficiently familiar with the predictability of geological features to embark upon the laborious task of removing initially unproductive deposits. This implies the existence of conscious, logico-rational deduction, possibly language, and the ability to base an economic decision on the capacity of predicting the existence of a concealed resource. I would argue that the most important deduction permitted by the evidence from Nazlet Khater 4 site is not merely that of early exploitation of the alluvial deposit by means of systematic quarrying, but the inferences it allows concerning the cognitive status of the people concerned.

More recently, Vermeersch and Paulissen (1989) reported a large number of quarrying pits at a location further up the Nile (between Dishna and Qena), named Nazlet Sabaha in Vermeersch et al. (1986) and Nazlet Safaha in Vermeersch and Paulissen (1989). These pits are simpler, about 1-2 m wide and up to 1.7 m deep, containing both decortication debris and rejected cobbles. Here, the Nile cobble terrace was covered by less than 50 cm of consolidated sand. The presence of apparent spoil materials in the pit fill leads Vermeersch and colleagues to suggest that this was not removed from the trench during the chert removal process, which probably hampered or even prevented further extraction in depth. This can be only partly correct: one cannot excavate a small pit and simultaneously deposit spoil in it.

The levalloid typology of the site's lithics supports Vermeersch's dating of the quarrying complex to the Middle Palaeolithic. However, further proof would be useful for this because the Levallois technique as such does not define a specific tool industry, nor denote a specific period or age: it occurs from the Lower Palaeolithic of France to the Final Pleistocene of California, and can in fact be observed in all continents other than Antarctica. Moreover, in Upper Egypt the continuation of Levallois-mousteroid elements into the Upper Palaeolithic is particularly typical (Narr 1866: 358; cf. Vermeersch et al. 1985; Paulissen and Vermeersch 1987: 52; Vermeersch and Van Peer 1988) and there is even an 'Epi-Levalloisian' in the Mesolithic (Clark 1965; Smith 1965). Vermeersch et al. (1986) and Vermeersch and Paulissen (1989) both stress the similarity of this Levallois industry with the lithic typology of Nazlet Khater 2, where the 'Upper Palaeolithic' burials were found.

More relevant than the chronological implications of the use of the Levallois technique is the consideration that the number of basic techniques available to decorticate a rounded, flat chert cobble are quite limited, and centripetal flaking will inevitably result in levalloid features. Consequently the postulated Middle Palaeolithic antiquity of the quarrying activity at Nazlet Sabaha cannot be substantiated through typological interpretation of what is largely decortication residue. Conversely, this same argument has been used and rejected before in an identical context: Gallus (1971), when describing silica mining debris in Koonalda Cave, Australia, identified these typologically, and even described Levallois flakes and 'tortoise cores'; this was rejected in Wright (1971).

The first evidence of Palaeolithic silica mining in Europe was recognised in 1981, in the cave art site Bara Bahau, France (Bednarik 1986a). Near the end of a 116 m-long passage is a panel of 18 engraved animal figures, occurring among finger markings as well as cave bear claw marks. There are four distinct chert seams in the middle part of the spacious passage, and randomly distributed nodules occur at various levels, including in the 10 m-long art panel. The generally large animal outlines are superimposed over the finger flutings (Bednarik 1986b). They include depictions of horses, bovids, felines, bears and cervids (Glory 1955). The inclusion of chert nodules to depict eyes, ears or hooves has been noted. While these petroglyphs have often been attributed to an early period of Palaeolithic art, Leroi-Gourhan (1971) places them in his Style IV (Middle and Upper Magdalenian). I consider this purely stylistic dating as most tenuous, and while the absence of superimposed cave bear scratches does tend to support a final Pleistocene age, one could argue, for instance, in favour of stylistic similarities with the Pair-non-Pair assemblage (which is Gravettian or older).

In any case, neither the animal engravings nor the obviously earlier finger flutings need to be of the same age as the mining evidence, even though it occurs in the same vicinity. Many of the chert nodules in this art panel have been fractured by blows administered parallel to the wall, and the impact cleavage surfaces are clearly patinated (Bednarik 1986a). Australian work has shown that the patination of cherts proceeds much slower in a speleo-environment than where they are exposed to weathering (Bednarik 1980), and since no damage marks were detected on the soft limestone next to the fractured nodules it would appear more plausible to attribute the chert removal to a phase preceding that of the rock art production.

The mining evidence is most likely of the early Upper Palaeolithic or of the Mousterian (Mousterian occupation evidence is present in the cave). The cave entrance opens into a steep hill side overlooking the Vézère river, and among the rocky slopes next to it are numerous exposures of chert, with obvious quarrying traces. Therefore it would have been quite logical to search for further exposures of the strata within the cave.

Since the discovery of these early mining traces in Europe, evidence of Mousterian mining has been reported from a cave near Budapest, Hungary. In contrast to western Europe, with its extensive flint deposits, Hungary lacks such ample sources. The most frequent lithic raw materials are quartz porphyries, Miocene obsidians and siliceous rocks of hydrothermal or limnic origin, besides Palaeozoic to Cretaceous chert. Most of the latter mineral was collected from stream pebbles, as shown by the presence of a characteristic cortex (Takács-Biró 1986). However, Gábori-Csánk (1988) has reported subterranean chert mining with Mousterian 'pick axes' from a Hungarian cave.

**Subterranean chert mining in Australia**

The first evidence of systematic Pleistocene underground mining of silica came from Australia. Here, deep limestone caves had been traditionally shunned by prehistorians, because their avoidance by traditional Aboriginal people was well known. Until 1962, when John Mulvaney obtained a date of about 10 000 BP from a shelter called Kenniff Cave, even a Pleistocene human presence had remained unknown to the European researchers, although Aboriginal people had always known about a period called *Mungarari*, the Ice Age (Mowaljarlai and Watchman 1989), through their oral tradition (and about various geomorphological events which researchers are only now learning of).

Undeterred by the scepticism of his peers, Gallus explored Koonalda Cave on the Nullarbor Plain in the late 1950s and through the 1960s, reporting the discovery of extensive cave art and occupation evidence (Gallus 1968, 1971), with radiocarbon dates of up to 31 000 years. Many objections were raised against his first and subsequent reports, but his perseverance eventually led to an expedition by the University of Sydney. It resulted in the confirmation of most of Gallus's claims: the extensive mining traces were validated, as were the rock art (Maynard and Edwards 1971) and the Pleistocene occupation of the cave (Wright 1971). Gallus and Wright merely disagreed on the interpretation of the lithic typology. In addition, Wright discounts the 31 000-year date, but Gallus (1986) has since produced another of similar magnitude.

The Nullarbor silica seams occur in the Upper Eocene Wilson Bluff limestone, a friable biomiorite underlying 15-30 m of Lower Miocene Nullarbor limestone, a hard, crystalline and well-jointed biosparite (Frank 1971). Consequently the silica deposits are exposed in caves or along the often vertical, usually unscaleable coastal erosion cliffs along the Great Australian Bight to the south. At Wilson Bluff, near Eucla, the seams are exposed on the surface and here the Mirning tribe had an important quarry, called Kaldilyerra, which Bates (1914, cited in Wright 1971: 6) describes as 'one of the great hereditary commercial assets'. There is no evidence that the Mirning knew of the existence of subterranean chalcedony or chert exposures.

Evidence of underground mining had also been reported from three other caves on the Nullarbor. Evans

(1919-20) observed evidence of chert mining in Weebubbie Cave, and the Cave Exploration Group of South Australia reported silica mining traces from Warbla and Mullamullang Caves (Hill 1966). However, as Wright (1971: 9) observes, this evidence may be as remote in time as the quarrying in Koonalda Cave.

The discovery of cave art near Mt Gambier, in the far south-east of South Australia, led to numerous further finds of cave art sites in that region, beginning with 1980 (more than 30 were recorded by 1991). Like the Nullarbor, this district is for the most part a Tertiary karst. The Gambier limestone was formed in the Oligocene and lower Miocene. The uppermost strata of this substantial deposit contain several well-pronounced silica beds. They are exposed along the coast (e.g. 9 km east of Port MacDonnell), in several caves, and as surface outcrops, such as a rock ridge at Malangine Cave, near Cape Northumberland. At the latter location occur vast quantities of quarrying residues, all of which are amply patinated. Extensive underground mining evidence has been studied in six caves (Bednarik 1986a) with rock art such as finger flutings, tool marks on walls and deeply carved petroglyphs of basically non-iconic motifs (Bednarik 1990c). There is, however, no actual proof of contemporaneity of the mining activity with any of the art traditions. As in Koonalda Cave, the art phases begin with finger flutings on soft, or formerly soft, wall and ceiling deposits (usually of *montmilch*), followed by linear wall marks made with stone tools (limestone clasts as well as chert pieces). Structural design elements or recognisable motifs are always more recent. The only art tradition that occurs in all caves where art is found together with mining evidence are the finger flutings. Underground chert mining evidence has been located in five caves near Mt Gambier so far.

Whereas there is some stratigraphical evidence that at Koonalda Cave, both the silica mining and the cave art predate about 20 000 BP (cf. Bednarik 1986a), both types of activity traces remain essentially undated at the Mt Gambier sites, although a firm minimum dating has been obtained for the two most recent art phases at Malangine Cave; they are of the mid and early Holocene respectively (Bednarik 1984, 1985). However, there is circumstantial dating evidence available. The massive deposits of loose silica nodules now found along much of the coast, which contain tens of thousands of tons of high-quality, flint-like, cryptocrystalline dark cherts, are a Holocene feature related to recent sea levels (Bednarik 1989). It appears that during the Pleistocene, only the generally inferior inland sources, at outcrops and in caves, were available, because they account for the older lithics of the region. Unless we are to assume that Holocene people would have ignored the vast surface deposits of good material a few kilometres away, in favour of poor material that had to be laboriously extracted from dark, dangerous and poorly accessible places, we must consider that the underground mining evidence in the Mt Gambier region is also largely or even entirely a phenomenon of the Pleistocene.

This view is supported by the few Pleistocene stone tools observed in the area, occurring in the so-called terra rossa soils (their carbonate content is too high in my view to be classed as a true terra rossa) which are of the Pleistocene. They consist of the poor-quality cherts from the caves, and they are typologically of the Kartan, an industry characterised by large implements and steep working edges, choppers and waisted axe-like tools. The Kartan is thought to be the earliest phase of Australian stone tools, and it is interesting to note that the Hallett Cove Kartan consists entirely of inferior siltstone, although there are banks of fine-grained quartzite pebbles nearby (Cooper 1959). These were probably concealed by the talus slope at the time in question - a situation that may be analogous to that at the Mt Gambier coast.

**Subterranean chert mining technology in Australia**

Pleistocene mining may have been far more common than the surprisingly meagre global evidence suggests, but most silica and ochre mines probably continued to serve subsequent populations which would have obliterated the earlier evidence. Subterranean silica mining in natural caves is more likely to provide older traces, because here the exploitation of the resource is more likely to have been limited to a particular period or society. This seems to be the case in Australia, which also provides good examples of the incredible scale of mining that is possible with an essentially Palaeolithic technology.

At the ochre mine of Wilgie Mia, Western Australia, a 20 m-deep open cut was excavated in solid rock, and numerous galleries branch off from this pit to follow the ochre seams. This large mine was still in use well into the 20th century (Flood 1983: Pl. 25), when men used fire-hardened wooden wedges of up to half a metre length to pry away lumps of 'ochre' (hydrous oxides of iron with significant impurities). Pole scaffolds were erected to work at different heights, and there is ample evidence that the mine was in use for millennia (Flood 1983: 239), resulting in the removal of thousands of tonnes of rock. Robinson (1966: 600-1, cited in Flood 1983) reports observing Tasmanians mining ochre at Mt Rowland in 1834, using hammer stones and chisels made of pointed sticks, but here the miners were Aboriginal women.

The actual use of ochre extends back to the Lower Palaeolithic in at least three continents (Bednarik 1992a), and mining evidence as such extends into the Middle Palaeolithic or Middle Stone Age. Extensive ochre mining evidence occurs in the Lion Cavern, Swaziland, where it has been dated to over 43 000 years BP (Beaumont and Boshier 1972). That evidence includes stone mining tools and tens of thousands of implements of the Middle Stone Age. Beaumont (1973) has described many other early ochre mines in southern Africa, and he and Boshier consider that ochre mining at Ngwenya most probably began about 70 000-80 000 years ago.

While subterranean Pleistocene chert mining evidence would appear to be less extensive than that of ochre mining, it may have been better preserved in Australia than in Africa or Europe, where such traces are likely to have been largely obliterated by subsequent activities. The common avoidance of deep caves by Holocene Australians has helped preserve much of the mining evidence sufficiently well to permit the identification of several basic mining methods.

The perhaps most energy-intensive of these is best exemplified in Gran Gran Cave, near Mt Gambier, South Australia (Figure 1). In this cave, a near-horizontal chert seam (dipping 3° E) is exposed, 15-16 cm thick where it is well developed. Wherever it is accessible it bears continuous scars of impact fractures, and there are extensive mining traces extending over some 65 m of seam length. In one location, where the seam is only about a metre

*Figure 1. Horizontal mining cut in Gran Gran Cave, South Australia. The scale (10 cm long) is placed at the face of the tabular chert seam, which forms the deepest part of the cut. Long wedge marks can just be discerned on the sloping roof.*

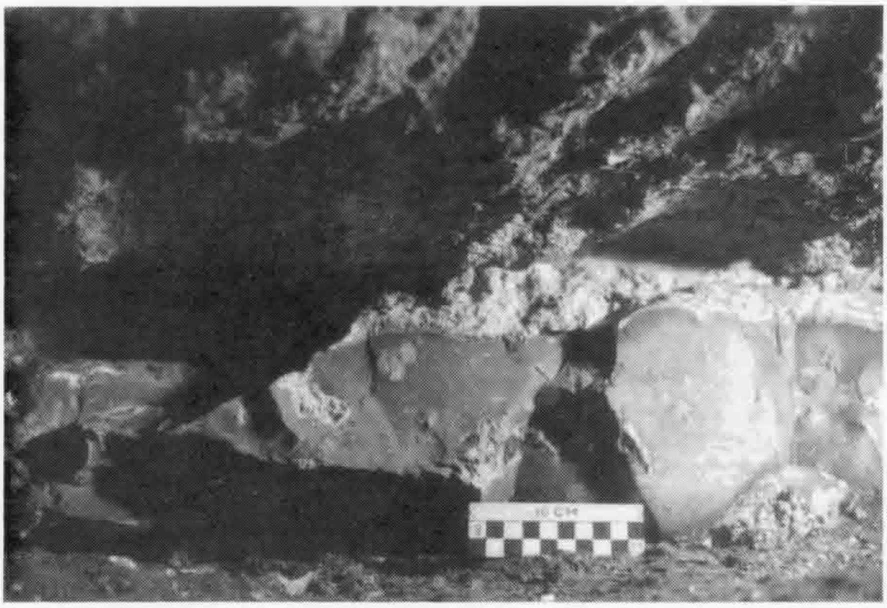

*Figure 2. The mined face of the chert deposit in Figure 1. Wedge marks are visible on the limestone above the seam, conchoidal fractures and traces of battering are discernible on the chert. Note the deeply patinated surface of the limestone, indicating the age of the mining face.*

*Figure 3. The floor of the mining cut is formed by the limestone underlying the chert seam. The horizontal seam is visible across much of the width of this photograph. Gran Gran Cave.*

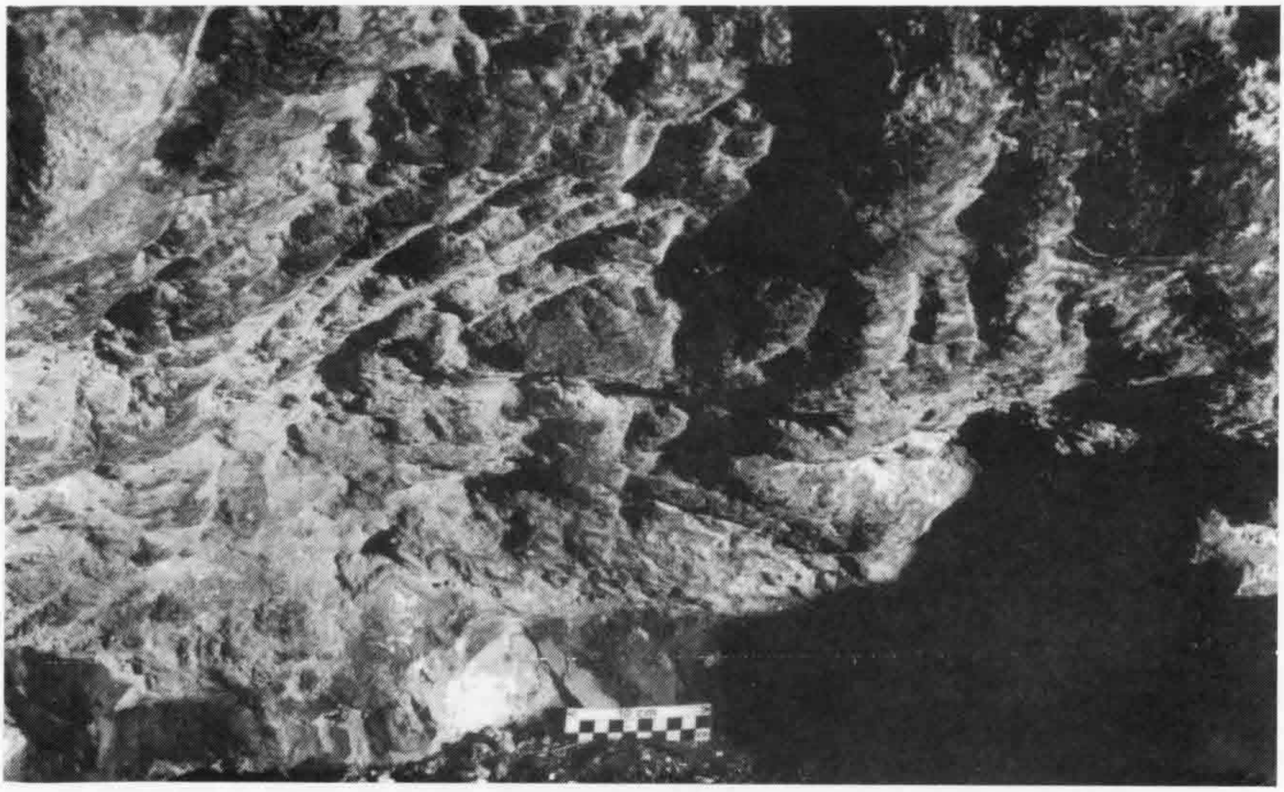

***Figure 4.*** *Detail of the sloping roof of the mining face in Figures 1-3. Some of the score marks produced by very long wooden wedges are clearly visible, centre left, and two more, centre right. The scale is placed against the face of the chert seam. Observe dark, almost black patination of the white limestone and some subsequent speleothem growth. Gran Gran Cave.*

above the floor, this includes the removal of massive limestone above the seam: here, over two tonnes of solid rock has been removed with pointed wooden sticks, in order to expose the upper surface of the tabular chert deposit (Figure 2). This wedge-shaped opening is 4 m wide, 72-97 cm deep, and between 45 and 80 cm high (Figure 3). There are some 40 or 45 marks on the sloping roof of this recess, indicating that the gangue rock has been removed by driving in wooden pointed stakes just like those described from the Australian ochre mines mentioned above.

The marks, though extensively corroded and covered by a thin, exfoliating lamina of reprecipitated limestone, provide considerable information of the work process (Figure 4). They are between 10 and 40 cm long, semi-circular in section and up to 25 mm wide. Most of the stakes were between 10 and 20 mm thick (one was up to 35 mm thick), straight, and where the impression of the point has been preserved in the rock it provides a clear profile of the tool point: the stakes were tapered at the end but had a fairly blunt, symmetrical point. It is clear that at least some of them must have been over 1 m long. The angle at which they were driven in varies from 32°, at the highest part of the recess, to only 15° from horizontal, in the deepest part. In plan view, the orientation of individual stake marks varies but nearly all are angled from the right to the left as they enter the recess, suggesting right-

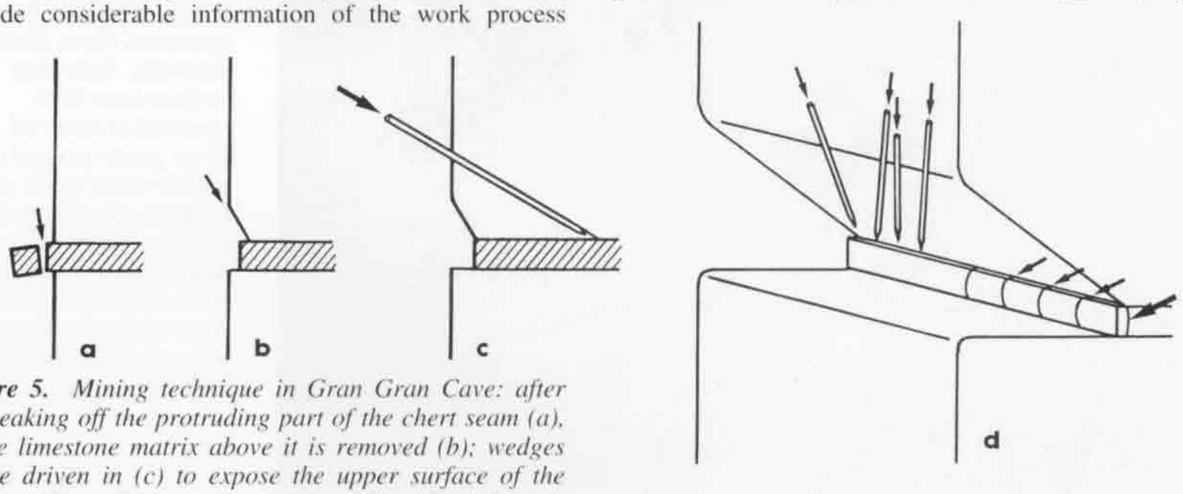


***Figure 5.*** *Mining technique in Gran Gran Cave: after breaking off the protruding part of the chert seam (a), the limestone matrix above it is removed (b); wedges are driven in (c) to expose the upper surface of the seam (d), so that it can be fractured from the right.*

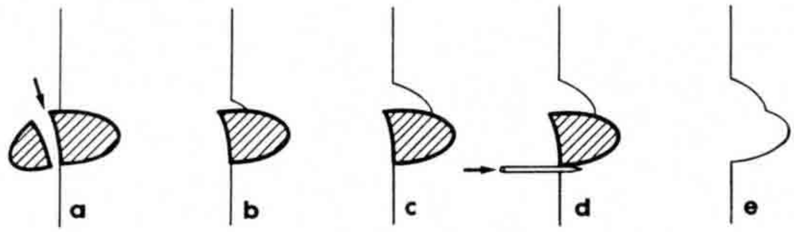


*Figure 6. Removal of individual chert nodules from limestone matrix: a - protruding part flaked off; b - limestone gouged from above nodule; c - upper surface of nodule exposed; d - wedge driven in below nodule; e - empty socket.*

handedness in the miners. Some of the marks veer downwards as they proceed into the recess, no doubt indicating where pieces of matrix rock were being prised from the wall.

The space progressively produced by this laborious removal of limestone was clearly insufficient to effect fracture of the chert from above, and it is confirmed by some of the conchoidal fracture patterns on the seam's face that the fracturing blows were administered horizontally and from the right (Figure 5). This indicates again right-handedness, and suggests that the seam was progressively quarried from the right to the left. There are also step-fractured battering marks present on the seam face, perhaps traces of attempts to shatter it with direct blows. In view of the size of the largest stakes (up to 35 mm diameter and certainly over 1 m length) and the need to hold the stake and at the same time deliver the required, very heavy blows it is unlikely that the task was performed by a single miner. At least two people were required, and possibly a third person to attend to lighting.

Throughout Gran Gran Cave, the fracture scars on the light-grey chert are patinated to a brown hue, and in several cases they are covered by carbonate speleothem formations. The age of the mining evidence is unknown. However, several aspects of the evidence render it unlikely that the mining postdates the Pleistocene. They include: the substantial labour expenditure involved in this mining operation of a chert of microcrystalline, inferior quality, when massive beach deposits consisting of tens of thousands of tons of high-quality chert cobbles existed nearby in the Holocene; the presence in the cave of two panels of finger flutings, a form of rock art that is *sometimes* of great antiquity; the advanced patination stage of the fracture scars; the superimposition in one location of flowstone growth of some centimetres thickness over the fractured seam; the antiquity of chert mining elsewhere in Australia; the frequent avoidance of caves by Holocene Australians; the lack of any ethnographic reference to cave sites in the Mt Gambier district (the region's extensive cave art was unknown until the 1980s); and the geological similarity of the cave cherts with the few Kartan implements ever found in the Mt Gambier region.

Another technique of underground chert mining in Australia involved the removal of individual silica nodules. Here, the removal of limestone matrix was on a very small scale. It was gouged from around them, usually on the upper side of the nodule, in preparation for the insertion of a wedge on the lower side (Figure 6a-e). Some of the remaining empty sockets (Figure 6e) display marks that permit inferences about the technique described, which is particularly prominent in Karlie-ngoinpool Cave, also near Mt Gambier (Aslin and Bednarik 1984). The cave's upper part traverses three distinct, near-horizontal seams of sedimentary silica. Where these are accessible to humans, and up to several metres from the floor, all chert deposits have been mined to the point of exhaustion. Partly removed nodules bear the ubiquitous bulbar cleavage scars, and often signs of

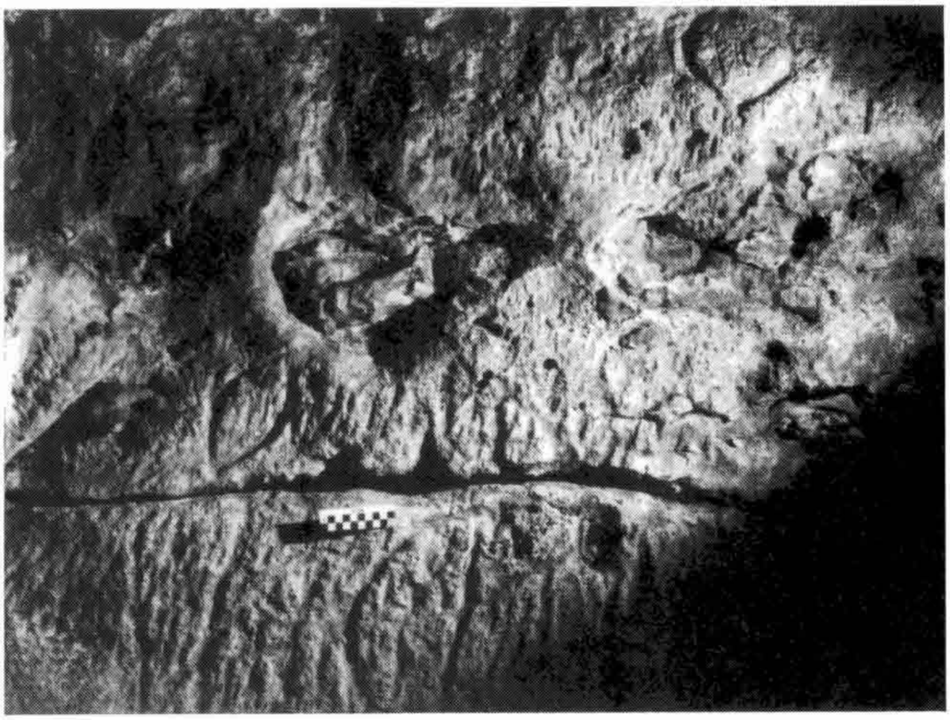

*Figure 7. Chert mining traces among cave petroglyphs, Karlie-ngoinpool Cave, South Australia. Individual nodules have been removed or battered. Note large, partly gouged out nodule above scale, and to the right of it, below the engraved circle, an empty socket where a nodule has been removed. A dense maze of deeply carved petroglyphs of the Karake style can be seen.*


***Figure 8.*** *Close-up view of the partly gouged out nodule in Figure 7. Note the several conchoidal impact fractures and the traces of heavy battering along the upper edge.*

battering along edges (Figures 7 and 8). The scars are again all patinated. Conversely, natural fractures of cherts also occur in cave sites, for instance those resulting from *Salzsprengung* (e.g. in Koonalda Cave), *gelifraction* (not in Australia, and only near the entrance of a cave), from mechanical shearing (e.g. in Grave Site Gran Gran Cave), gravity (e.g. in Karlie-ngoinpool Cave), and various tectonic processes within the caves. All of these are easy to distinguish from well-directed impact fractures that can only be the result of intentional removal where they occur repeatedly.

A third method of chert mining is the simple breaking off of tabular or nodular chert protruding from the wall of a cave. As the surface of a cave wall recedes gradually (due to corrosion or erosion), the resistant chert inclusions remain behind, and tabular cherts often protrude as much as 30 or 40 cm horizontally from the wall. They can be broken off very easily (Figure 6a, Figure 9). This technique is particularly evident in Malangine Cave, Mt Gambier, but it occurs also at most other sites of early subterranean chert mining, including Bara Bahau in France.

The silica in Koonalda Cave, Nullarbor Plain, incorrectly termed 'flint' by Wright (1971: 52), occurs in a diagenetic range of chalcedonic quartzes, from translucent to white and opaque (Bednarik 1980: 48). Natural break-

***Figure 9.*** *The protruding parts of these chert nodules have been broken off by impact. They are located well above the cave floor, out of human reach, where exploitation has been comparatively superficial. The marks on the limestone are animal scratches. Karlie-ngoinpool Cave, South Australia.*

down has produced a huge deposit of boulders in the Art Passage, perhaps in the order of 30 m thick, and large quantities of nodular chalcedony occur among these clasts. Various types of mining activities have occurred (Gallus 1971): the exploitation of chalcedony seams along the wall by methods described above, and the excavation of mining pits among the floor boulders. The floor pits are described as bell shaped and sufficiently large for a crouched man to work in them. Occasionally they contain mining tools and remains of torches, and one was artificially filled in (Gallus 1971: 119). This method of silica extraction is similar to the bell-shaped pits described above from the Nile valley, and from many Neolithic mines in Europe, where these shafts are sometimes called '*Duckelbaue*'. However, the mining pits in Koonalda occur up to 300 m from the cave entrance and in complete darkness.

One more form of mining remains to be mentioned: the recovery of chert or chalcedony from the surface of such break-down detritus, and the superficial digging in the rubble that would have no doubt taken place in these sites. However, actual traces of it cannot be expected to be found, the evidence for it is essentially negative: in a cave that contains a substantial proportion of nodular or tabular silica in its clastic sediments, a lack of surface chert is very likely to indicate that the chert has been gathered from the surface deposit. Obviously this method involves by far the least effort, and it perhaps preceded the more labour-intensive methods.

The only mining tools previously described from early chert mines are stone picks or large scrapers to be used for digging among the rubble. No bone tools such as those from Neolithic mines have been discovered. However, there is clear evidence that wooden stakes were used most effectively to remove rock overburden. Driving these up to a metre long wedges into solid limestone would have involved a very considerable effort, determination and mining skill. The extent of mining traces in some of the Australian caves also suggests that pole scaffolds, such as those described from the Wilgie Mia ochre mine, were employed, which means that the required materials had to be brought into the caves. In the case of Koonalda Cave, for instance, this meant having to negotiate a vertical drop of about 8 m to reach the floor of the sinkhole (perhaps with ropes), then carrying the material down an unstable, very steep boulder slope of about 100 m length, and finally negotiating the even steeper slope of the roof fall in the Art Gallery. This would be no small feat even with modern rope ladders and lighting equipment! In Karliengoinpool Cave, the miners must have entered with the help of a climbing pole, or with ropes, as the entrance is a vertical sinkhole.

There can be no doubt that most of this subterranean mining activity required artificial lighting. Gallus has speculated that several of the charcoal patches on the recent floor of Koonalda Cave are the remains of torches placed on the ground. However, the remains of a lamp similar to those used in the Palaeolithic caves of western Europe have been recently found in one of the decorated caves of Mt Gambier (Bednarik in prep.), which suggests again that the sparse technological information we have about the miners may not be an accurate reflection of their technological capability.

## Discussion

Pleistocene mining may have been far more common than the meagre global evidence suggests, but there are several biases against finding or identifying such sites. Most silica or ochre mines probably continued to serve as mineral sources through at least part of the Holocene, in which case all earlier traces may have been obliterated. This may well be the case in some of the numerous Neolithic silica extraction sites in Europe and North Africa. Subterranean silica mining (especially in limestone caves) is more likely to provide reliable data about Pleistocene mining, because the exploitation of such sources is more likely to have been restricted to discrete periods. This appears to be the case in Australia, where recent populations avoided caves altogether.

Other factors selecting against the identification of Pleistocene chert mines are the lack of archaeological knowledge about the phenomenon, and the paucity of publications on the subject (which contrasts so sharply with the detailed coverage of the post-Palaeolithic period), leading to a lack of expertise of archaeologists in identifying such traces effectively. Various types of minerals were quarried above ground for much of the Palaeolithic period, some probably already in the Lower Palaeolithic. A technological potential of subterranean chert and ochre exploitation can be attributed to peoples of the Middle Stone Age in Africa, the Mousterian and the Upper Palaeolithic in Europe, and to those of much of the known period of human occupation in Australia. A number of instances have been described in isolation, but any global patterns have not been identified so far.

This lack of appreciation of Pleistocene mining technology is, I submit, consistent with a general lack of awareness by most archaeologists, of the technological and cognitive capabilities of Pleistocene peoples. One of the greatest heuristic drawbacks of archaeology as it is being conducted is that it can only provide a model of 'minimum levels' of human capacities: 'prehistoric' archaeologists gain most of their knowledge by sifting through the garbage of past societies, dredging up what has been discarded, worn out, lost or not been wanted. This 'garbology approach', using the surviving material residues of past cultures to gauge their technological, intellectual, cultural, cognitive and even linguistic potentials has been conducted until very recently without any concern for taphonomic processes, which are enormously important in interpreting any so-called archaeological data. Some applications of archaeological interpretations in what is sometimes called 'cognitive archaeology' have led to some spectacularly incongruous hypotheses, while a variety of valid methods to explore early human cognition have been widely ignored. I have addressed several of them elsewhere (e.g Bednarik 1990/91, 1992b, 1992c, 1992d, in press), and here I will consider the implications of the Pleistocene mining evidence.

Underground mining involves quite a number of both technological and cognitive pre-conditions. To begin with, it requires a preparedness to enter an alien environment which most animal species avoid (Bednarik 1991), or the behavioural flexibility to manage a perhaps genetically determined cortical response pattern to fear of caves. This already provides considerable insights into the level of conscious decision making required in this context. Next, most of the underground work presupposes the availability of artificial lighting, and there is some evidence of lamps and torches having been involved in these quests. It is also obvious from several of the sites that the mining activities must have been team work, involving at least two or three people, who no doubt had to co-ordinate various aspects of their efforts. We know that a variety of mining tools were involved, and we can assume that items such as pointed, perhaps fire-hardened wooden wedges were prepared outside the cave. At a few sites there is evidence of the use of scaffolding, which would imply even more planning. These observations together suggest that fairly complex planning patterns need to be postulated. Finally, some of the caves are of quite difficult access, and the sheer logistics of the mining operations conducted in them must have involved engineering skills of an order of magnitude few archaeologists would be currently prepared to credit any 'pre-Upper Palaeolithic' people with. Not only does the evidence for these abilities permit considerably more insight into the cognitive, intellectual, social and, presumably, linguistic skills of the people concerned than the futile and yet perennial arguments about language ability, the hyoid bone and Broca's area (Bednarik in press), there is still another factor to be considered.

I began this paper by explaining, in some detail, the diagenetic conditions in which sedimentary silicas form, and why they occur primarily as tabular or quasi-tabular deposits. The geological reasons for this are known to us, and we can broadly explain the processes involved. But we have no reason to assume that the early miners were capable of rationalising about these deposits in quite the same way. Yet the evidence seems to suggest, in some cases, that they were capable of predicting the occurrence and spatial extent of an as yet concealed geological feature. While it may be cognitively easy to follow an exposed seam, it is quite a different matter to undertake a calculated course of action that promises no immediate reward, and whose eventual reward is based entirely on the validity of an abstract prediction. Consider the procedure depicted in Figure 5: once the seam became inaccessible to methods of minimal labour input (after step 5b), a decision was made to remove the massive limestone overburden above the seam. This would have involved hours of back-breaking and most unpleasant work, without any guarantee of a reward - were it not for the expectation that the seam would in fact continue inwards. If it did not, the entire work effort would have been in vain. This implies that the miners were reasonably certain that the seam would continue horizontally. In other words they had the intellectual and cognitive capacity of observing and understanding a geological formation such as a tabular deposit; and they were capable of making an informed prediction with a sufficient degree of conviction to warrant the determined labour expenditure which we find documented. We cannot know how they acquired (or transmitted) this knowledge, but we can reasonably assume that they had observed and perhaps exploited such formations elsewhere, and extrapolated from this experience. It seems entirely implausible that such abilities were genetically transmitted, they were almost certainly culturally acquired (Handwerker 1989; Bednarik 1990b).

This action is similar to that of the alluvial chert miners at the Egyptian sites described above. Here the miners dug through substantial sterile overburden in order to expose the chert cobble-bearing alluvial stratum. Here, too, they had to make a decision about an initially unproductive undertaking: what was the likelihood that the productive layer would continue horizontally below the gangue strata? Did it warrant sinking a shaft? We know from the evidence that the miners had the expertise to predict with sufficient confidence that there would be pay dirt beneath, and we can only speculate on the nature of the empirical evidence they based this decision on. Initially, they presumably observed the exposures of the deposit that occur some tens of metres away, and reasoned that this was a horizontal layer that could be located by digging through the overburden. Once initial shafts had been sunk it would have been much easier to observe the structure and course of the concealed formation.

Thus the most significant corollaries to be derived from the evidence of subterranean chert mining presented here have little to do with the mining, its technology or its economic role. They concern the cognitive deductions they seem to permit. Since the beginnings of this technology extend back in time well into the Middle Palaeolithic in both Africa and Europe, it should be considered in all future debates about the cognitive, symbolic and linguistic capacities of humans prior to the Upper Palaeolithic - as I have recently proposed (Bednarik 1992a). Seen alongside the now widely accepted seafaring ability of the Middle Palaeolithic people who first settled Australia, it is clear that these activities involved very similar capacities: the capacity of making conscious decisions about abstract, not immediately apparent, aims and strategies; the capacity of weighing up risks and the possible benefits to be gained from taking them; the capacity of organising expeditions into risky environments, including all the necessary planning and preparations; and the capacity of mastering fairly complex technologies. All of these capacities, and the growing body of evidence suggesting considerable symbolic abilities during the Middle Palaeolithic, even the Lower Palaeolithic (Bednarik 1990b, 1992a), are entirely incompatible with the view that reflective self-consciousness, language and symbolism did not exist prior to the Upper Palaeolithic - notably the Upper Palaeolithic of western Europe.

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***Résumé.*** *On décrit les mines souterraines de silex connues dans le monde, datant essentiellement des temps pré-néolithiques. La formation et la composition des silex sont considérées ainsi que leurs modes d'occurrence géologique. Les résultats sont ensuite reliés aux anciennes stratégies d'exploitation minière en Europe, en Afrique et en Australie. L'article contient une discussion de l'antiquité connue ou probable des traces diverses d'exploitation minière souterraine, et l'on fait brièvement mention de l'évidence de l'extraction ancienne d'ocre. L'auteur conclut que la technologie d'extraction du pléistocène a été jusqu'à présent presque totalement ignorée dans le monde entier, et n'a pas auparavant été discutée sur une base comparative.*

***Zusammenfassung.*** *Die bekannten Untergrund Silex Gruben der Welt aus im wesentlichen prä-neolithischer Zeit werden erörtert. Die Genese und Zusammensetzung von Silexmaterialien wird beschrieben, zusammen mit ihren geologischen Erscheinungsformen. Dies wird dann mit frühen Bergbautechniken in Europa, Afrika und Australien in Verbindung gebracht. Die Abhandlung schliesst eine Besprechung des bekannten oder wahrscheinlichen Alters der verschiedenen Untergrund-Bergwerke ein, und auf frühe Beweise von Ockerbergbau wird kurz eingegangen. Der Verfasser folgert, dass die Bergbautechnik des Pleistozäns bisher weitgehend ignoriert worden ist weltweit, und dass sie nicht zuvor auf einer vergleichenden Basis besprochen wurde.*

***Resumen.*** *Se describen los sitios conocidos en el mundo de la minería subterránea de cuarzo (horsteno) de épocas preneolíticas esencialemente. Se considera la formación y composición del cuarzo, junto con las maneras de su existencia geológica. Todo ello es, entonces, relacionado con las estrategias tempranas de minería en Europa, Africa y Australia. El artículo incluye una discusión sobre la conocida y probable antigüedad de los varios rastros subterráneos de minería, y presenta una breve referencia a evidencia de temprana minería de ocre. El escritor concluye que la tecnología minera del Pleistoceno ha sido, hasta el momento, casi ignorada en todo el mundo, y no ha sido antes discutida sobre una base comparativa.*

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