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The Good, the Bad and the Ugly. Selection of flint nodules, first step of the *chaîne opératoire*: data from ST6 Neolithic mine (Spiennes, Belgium)

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Abstract
Shaft ST6, exploited during the Middle Neolithic II (4200-3600 BCE), is the last extraction feature of flint excavated according to the most recent planned research at *Petit-Spiennes*. The objectives of this study are to determine the criteria used by Neolithic miners to select blocks in shaft ST6. It also aims to estimate the impact of flaws in raw material on the selection process (in particular extensional fractures), as well as any variability between the beds mined. Furthermore, the presence of hammerstones, flakes and some roughouts in the underground mining works raises the question as to whether any knapping was carried out in these levels.

Keywords: Neolithic, flint, mines, raw material, Spiennes

Résumé
Le puits ST6, exploité au Néolithique moyen II (4200-3600 avant notre ère), est la dernière structure d'extraction de silex fouillée dans le cadre des recherches programmées à Petit-Spiennes*. Les objectifs de cette étude sont de déterminer les critères de sélection des blocs dans le puits ST6 par les mineurs néolithiques. Il s'agit également d'estimer l'impact des défauts dans la matière première (en particulier des fractures d'extension) dans le processus de sélection ainsi que l'éventuelle variabilité entre les bancs exploités. En outre, la présence de percuteurs, d'éclats et de quelques ébauches dans les niveaux d'exploitation souterrains soulève la question d'une éventuelle activité de taille en sous-sol.*

Mot-clefs : *Néolithique, silex, mines, matière première, Spiennes*

1. INTRODUCTION

On the site of the Neolithic flint mines of Spiennes (Hainaut, Belgium), the combined presence of flint extraction features (the mine shafts) and semi-finished tool production structures (the surface knapping workshops) allows us to sketch out hypotheses on exploitation strategies. A previous study of a large quantity of discarded nodules, fragments of nodule and flakes in the underground mining levels of shaft ST20 revealed a strict selection of flint nodules as knapping blanks among a profusion of nodules (Collet & Woodbury, 2007). The flint waste left underground results from the extraction and exploitation of flint by the Neolithic miners and constitutes, besides the chalky waste, the majority of the mining backfill. The presence of test removals on the nodules revealed that those ranging from 15 cm to 20 cm long were chosen to be brought up to the surface. It was hypothesised that such sizable nodules were linked to specific production objectives namely axeheads or blades.

After ST20 and ST11 mine shafts (fig. 1), ST6 is the third extraction feature excavated according to the most recent planned research headed by the *Agence wallonne du Patrimoine* (AWaP) in collaboration with the *Société de Recherche préhistorique en Hainaut* (SRPH) at *Petit-Spiennes*. These three features quite close to each other belong to the same geological context and they benefited from a similar research methodology. As for other mine shafts known at *Petit-Spiennes*, only the first beds at the top of the chalk were exploited and the number of exploited beds generally varies from one to three. This allows us to compare them even if there were not strictly contemporaneous. ST20 and ST6 were exploited during the Middle Neolithic II

Fig. 1 – Map of the Neolithic flint mines of Spiennes and location of ST6, 11 and 20. M. Woodbury © SPW-AWaP. Background map ©IGN-NGI.

(4200-3600 BCE) and ST11 during the Late Neolithic (3600-2900 BCE).

Following the ST20 study, our main objectives are to determine whether (1) the same block selection criteria were used in ST6 and (2) whether these are constant across the different exploited beds. We assume that similar blanks choices correspond to identical production objectives. The observation of frequent extensional fractures (diaclases) in the flint nodules raises another question: (3) how did these fractures impact the selection? In addition to this, the presence of hammerstones, flakes and some roughouts raises the question as to whether (4) any knapping was carried out in the underground mining works. Is it related to the extraction process (ex: shaping or rejuvenation of the numerous flint picks found underground) or is it related to other motives?

We will first describe all these different aspects with a sample of discarded flint from the underground mining works of the ST6 and then compare the data with those from the nearby ST20 mining shaft in order to determine whether the same blank selection criteria were applied in both mines. We will also discuss the question of hypothetic underground knapping regarding the artefacts found in the mining works. The second part of the paper will try to determine whether the selection of blanks differs according to the different flint beds.

In the paper 'mine', 'mine shaft', 'shaft' and 'mining feature' are used indiscriminately to indicate an underground mining feature as opposed to simple pits without underground mining and to open air quarries. The word 'mines' refers to the entire site or to several mining features. The vocable 'mine' is the usual name used to indicate prehistoric flint exploitation in prehistoric sciences. It differs from the legal terminology of the 'mining law' in which the vocables 'mine', 'minière' and 'carrière' are based on the material exploited. Access shaft is used when speaking of the vertical part of the mining feature used only to access the flint. 'Underground mining works', 'underground works' and 'mining levels' indicate the underground part of the mining feature at the bottom of the access shaft where the flint was extracted.

2. ARCHAEOLOGICAL CONTEXT

The Neolithic flint mines of Spiennes are located within the Mons Basin (Hainaut province, Belgium), one of the three main Cretaceous outcrop areas in Belgium with the Mehaigne/Petite-Gette (Hesbaye) and the Liège-Limburg area (Robaszynski *et al.*, 2001). Several Neolithic flint mines are known on the northern and southern edges of the Basin, Spiennes is the most significant of them all (Collin, 2019: 36). The Mons Basin mines constitute one of the flint mining complexes between the Paris Basin and Northwestern Germany.

The site spreads over a hundred hectares and has revealed a large number of extraction features ranging from open quarries and simple pits to underground mines from 4 to 16 m deep, knapping workshops, as well as an enclosed settlement dated to the Middle Neolithic II. The workshops produced mainly large axeheads (12 to 28 cm long) and large blades (13 to 23 cm long) (Collet, 2012; Collet *et al.*, 2014; Denis *et al.*, 2020). The mining activities are divided into three sectors: the *Versant de la Wampe* which stands on the slope of the Wampe river, *Petit-Spiennes* on the plateau overlooking the left bank of the Trouille River and *Camp-à-Cayaux* on the plateau overlooking the right bank of the river (fig. 1). About 20,000 to 40,000 mines were exploited between about 4200 and 2200 BCE according to the most recent estimates (Collet & Collin, 2023).

ST6 is located within the *Petit-Spiennes* mining area. It has been excavated from 1999 to 2004 and from 2014 to date. It lies approximately 11 m from ST20, which has been dated to 3980-3770 cal BCE (2 sigma) (Collet *et al.*, 2012: 60-63), and 9 m from ST11, dated to 3500-3100 cal BCE (2 sigma) (Collet *et al.*, 2008: 97). Both radiocarbon dates come from the mining waste left underground and date directly the mining activity. The ST6 mine is still under excavation, however the mining floor of the mine was reached in 2020 in one area (quadrant A) at a depth of 10.7 m. One notable fact is that the backfilling of the access shaft of the ST6 mine yielded a human skeleton dated to 3712-3637 cal BCE (2 sigma) (Collet *et al.*, 2017: 47). No organic material comes from the underground working levels and therefore those remain undated. According to this sole date, ST6 backfilling of the access shaft would be more recent than the Neolithic exploitation of ST20. However, as the underground mining works of ST6 are undated, they could turn out to be contemporaneous to ST20. Indeed, the settlements and collapses through the remobilisation of the shaft filling material can lead to multiple episodes of shaft backfill over centuries or even millennia.

In addition to both being exploited during the first half of the 4th millennium, ST6 and ST20 have both delivered bifacial flint picks, including some made from exhausted blade cores (Denis *et al.*, 2020: 38, fig. 3). These commonalities in structure type, chronology and operating methods make them relevant for comparison.

3. SPIENNES FLINTS: GEOLOGICAL ASPECTS

Marine flints originate from the re-precipitation of biogenic opal used by certain organisms (siliceous sponges, diatoms, radiolarians) to form their skeleton (A-opal) (Maliva *et al.*, 1989; Kidder & Erwin, 2001; Tribovillard, 2013). After the death of these organisms, A-opal dissolves; the dissolved silica migrates, to precipitate in the sediment in the form of CT-opal, which transforms with time into microcrystalline quartz (Kastner & Gieskes, 1983; Williams & Crerar, 1985; Maliva & Siever, 1989). CT-opal is best settled in pre-existing voids in the sediment: sea urchin test, galleries dug into the sediment by burrowing organisms. This second occurrence is the most frequent. These are usually galleries called *Thalassinoides* (trace fossil), whose present-day equivalents are dug by decapod crustaceans called *Callianassa*. In the Upper Cretaceous it was most probably *Protocallianassa* that dug the *Thalassinoides* burrows (Swen *et al.*, 2001; Mourik *et al.*, 2005). These crustaceans dig a network of galleries in a consolidating sediment (firmground). The galleries can remain empty of sediment for a long time or be more or less filled with loose particles. CT-opal crystallises first in the empty spaces of the *Thalassinoides* (pore filling), but then crystallisation progresses beyond the simple gallery network, by progressive replacement of the surrounding sediment (chalk) (Bromley & Ekdale, 1984). As a result, the original form of the *Thalassinoides* network ceases to be immediately recognisable and becomes a more rounded nodular flint. The internal texture of the flint depends on the nature of the pre-existing sediment structure (pore filling or replacement, micritic or calcarenitic sediment) (Clayton, 1986; Hesse, 1989; Luedtke, 1992). It also depends on the speed at which replacement takes place: when the rate of crystallisation is high (saturation) it favours the incorporation of undigested parts of the original sediment (inclusions). On the contrary, slow growth favours a very pure microcrystalline silica free of inclusions.

The flint beds of the Spiennes Formation (Upper Campanian) are divided into two main *macrofacies* corresponding to two distinctive *habitus*: the irregular nodules and the tabular slabs. Flint from the Spiennes Formation can present different states of silicification as well as various degrees of

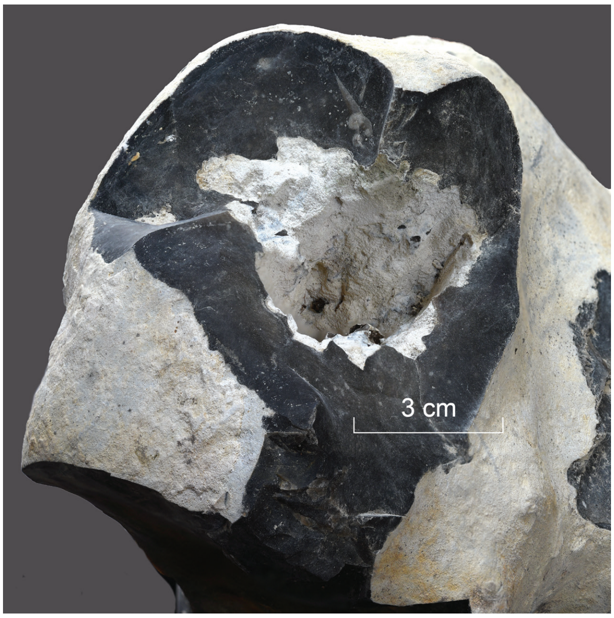


Fig. 2 – A: Fragment of nodule showing a coarse granular silicification; B: Chalky inclusion in a fragment of nodule. M. Woodbury © SPW-AWaP.

weathering (local dissolution). They can present fractures, light grey 'coarse granular silicifications' (fig. 2A), 'chalky inclusions' (fig. 2B) where a part of the interior volume of the nodules is not silicified (Allard *et al.*, 2005: 62-63). The flints exploited in the ST6 mine correspond to the first *habitus* made up of centimetric to multi-decimetric horn-shaped nodules. As a result of climate eccentricity and precession phenomena, some beds extracted in ST6 are double (Hennebert, 2012; Hennebert *et al.*, 2009). These flints have a single-phase granular white cortex usually of sub-millimetric thickness (for a full description, see Collin, 2019: 108). Many specimens from ST6 show a yellowish-brown film of iron hydroxide covering their surfaces (mainly on fractured surfaces and on cortex). The matrix revealed by freshly broken surfaces is dark grey to black and later evolves to a light grey to blue-grey

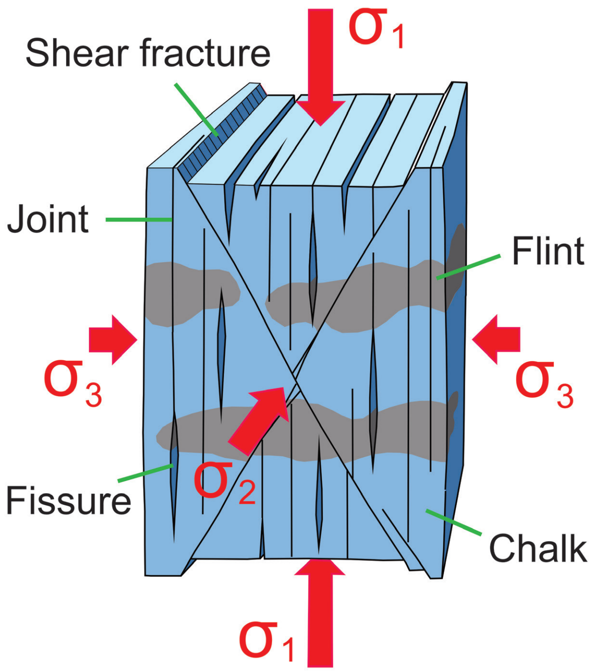


Fig. 3 – The forces applying to a given volume of rock are set as σ1 > σ2 > σ3, which are mutually perpendicular. These forces can lead to brittle deformations, σ1 corresponds to a compressive deformation (or contraction) and σ3 to an extension. Shear fractures are referred to as conjugate: they form dihedrals with an angle of less than 90° in the direction of σ1 and greater than 90° in the direction of σ3. The surfaces are often ridged in the direction of relative displacement. Extensional fractures are usually perpendicular to σ3. The characteristics of the various fractures (orientation, etc.) depend on the spatial orientation of the stress and their respective intensities (ratios σ2/σ1 and σ3/σ1). Reality is often more complex than shown in the figure because the local σ1, σ2, σ3 vary over time as a function of stress on a more global scale (plate tectonics) and movements along regional faults. M. Hennebert, modified from Fossen, 2010.

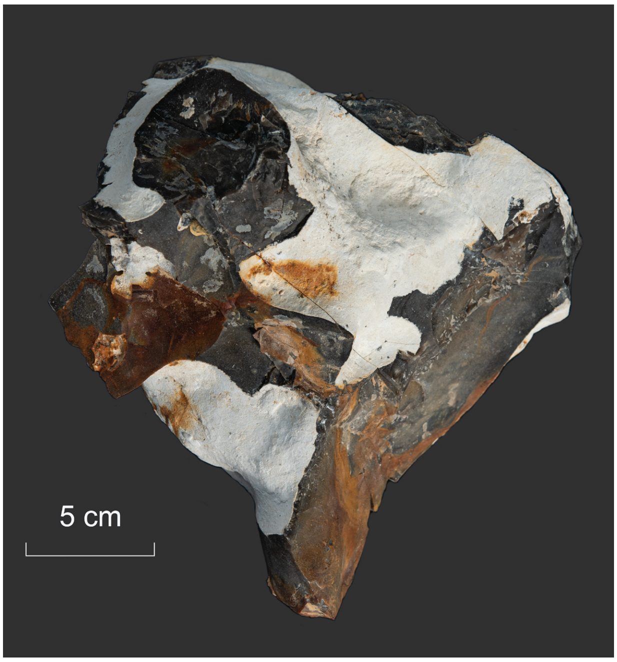


Fig. 4 – Fracture (tectonic joint) and yellowish-brown film of iron hydroxides in a fragment of nodule. M. Woodbury © SPW-AWaP.

colour when patinated (Gosselin, 1986: 43).
The forces applied to a volume of rock can lead to brittle deformations (in compression or in extension). This state of stress creates fractures, i.e. discontinuous surfaces in rock (fig. 3). Shear fractures or faults (or micro-faults), accompanied by slipping (rejection), are much less common than other types of fractures and not usually visible in flints. Extensional fractures (or diaclases) do not show slip (or displacement). This specific type of fracture will be of interest for us. Tectonic joints are extensional fractures that remained closed. Fissures are other types of extensional fractures, also open, and which also do not show any slip. These two kinds of extensional fractures are not always easy to differentiate, as there is no clearly defined boundary. Extensional fractures or diaclases (tectonic joints and fissures) are very common in the Spiennes Formation of the Mons Basin (Vandycke *et al.*, 1988, 1991; Vandycke & Bergerat, 1989). These fractures can be plane or irregular within flint, depending on the internal structure of flint itself, either homogeneous or irregular. They are easily distinguished from anthropogenic fractures by the yellowish-brown film of iron hydroxides covering their surface following water circulation (fig. 4). The mobilisation of iron is further facilitated by the Plio-Pleistocene alteration of Cenozoic sands, mainly Thanetian sands (Grandglise sands), from which the glauconite (silicate of iron, magnesium and potassium) was oxidised. These sands, which covered the entire region, almost disappeared when the valleys were dug in the Pleistocene. Shreds of these iron rich Thanetian sands remain at Spiennes above the chalk-with-flints deposit.

4. MATERIALS AND METHODS

4.1 Excavation

The excavation of shaft ST6 was carried out in four quadrants (A, B, C & D) in order to obtain two full-height sections (fig. 5). Quadrant A has been fully excavated, down to a depth of 10.7 m. Quadrants C and D are partially excavated to a depth of 8.4 m. The excavation of Quadrant B was limited to the top

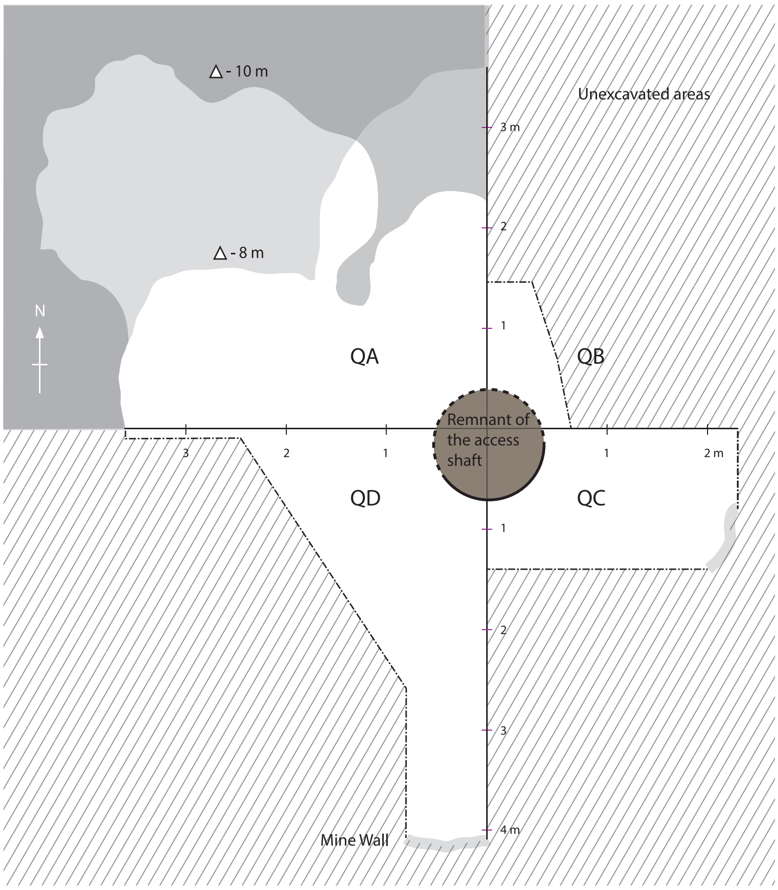


Fig. 5 – Map of the ST6 ongoing excavation. M. Woodbury © SPW-AWaP.

of the mining fills between 7.2 m and 7.8 m deep (Collet *et al.*, 2020: 66). This area collapsed during the Neolithic period. Therefore, substrate instability in this quadrant prevents excavating most of it. As of 31st October 2021, approximately 21 m³ of the mine ST6 have been explored, compared to 30 m³ for ST20 where for safety reasons, from a depth of 5.4 m, the excavation was carried out as a survey of 5 m by 2 m. This area is estimated to half the structure of ST20 (Collet & Collin, 2011: 66).

4.2 Selection of corpus

Mining levels are the backfill contemporaneous with the extraction work left behind in the galleries and at the base of the access shaft. These are mainly nodules and fragments of nodules which were not selected for knapping purposes. This backfill differs greatly from that of the access shaft, filled with heterogeneous materials (lœss, chalk, knapping waste, animal bones, etc.), and where the lithic elements have been dumped from the surface. Furthermore, the access shaft backfill is post-mining and contains materials that may be largely diachronic and was therefore excluded for this paper. The survey sample of the ST6 discussed below consisted of 2800.628 kg of flints. These flints came from all layers of the mining chamber levels excavated as of 31st October 2021 and from across the various quadrants, according to the progress of excavations: quadrants A (58.5%), C (23.5%) and D (16%), with a small portion in quadrant B (2%). By comparison, a 15 m^3 survey was made in the working levels for ST20 and a sample of 1328.829 kg from this excavation was analysed (Collet & Woodbury, 2007: 151). Flint from the Spiennes Formation represents 2771.153 kg or 99% of the corpus selected for ST6 (table 1). The remaining 1%, i.e. 29.475 kg, are intrusive elements. These include Upper Campanian flint nodules remobilised in the Thanetian greensand, a Cenozoic marine layer located between 4.4 m and 5.2 m deep (Collet & Woodbury, 2007: 152); undetermined flints with a beige, brown or mottled patina, with blunt edges, from the Mesvin alluvial layers located above the previous one between 3.2 m and 4.4 m deep, attributed to MIS 8 and recently reviewed to MIS 9 and 10 (Pirson *et al.*, 2009; Haesaerts *et al.*, 2019); flint flakes with light blue to white patinas similar to those found in the archaeological layers of the

ST6	Number	Weight (kg)
Nodules	975	1116.305
Fragments of nodule	1035	1201.207
Protrusions	309	92.601
Flakes	3760	80.193
Positive scars of picks	827	2.418
Debris	18293	250.861
Chips <20 mm		27.568
Flints from thanetian greensand	1212	12.534
Flints from the alluvial layer	1032	13.502
Flint flakes from the knapping floors	66	2.732
Burnt flints	14	0.707
TOTAL	27523	2800.628
Flints from the Upper Campanian	25199	2771.153
Intrusive elements	2324	29.475
TOTAL	27523	2800.628

Tab. 1 – Sample composition.

knapping workshops and which therefore probably lingered at the surface. Those intrusive elements have been excluded from the present study, as well as burnt flints, as no evidence of hearths has yet been found in the ST6 underground working levels.

4.3 Typology and sorting of lithics

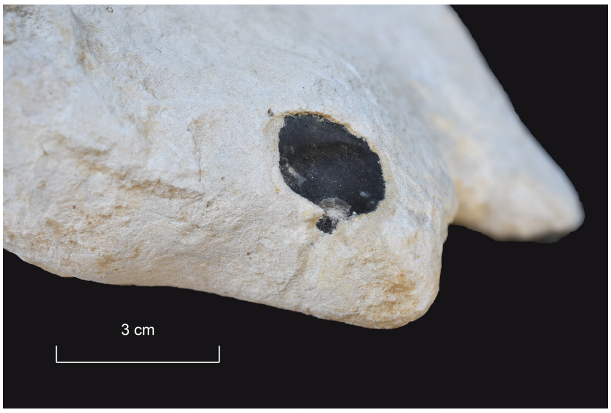
The differentiation between nodules and fragments of nodule established in the ST20 study has been maintained (Collet & Woodbury, 2007: 152). 'Nodules' include the flints that seem morphologically complete: pieces covered by cortex, which may nevertheless show a bit of removal.

Fractured or flaked nodules that do not allow the original shape to be reconstituted have been classified as 'fragments of nodule'. This fracturing may be natural, accidental, or voluntary. In the latter case, the fragments are considered the result of lithic reduction and have to show several of the following signatures: bulbs or scars of bulb of percussion, striking platform, ripple marked surface or hackles.

The 'protrusions' are the tips of the horn-shaped nodules. It was sometimes quite difficult during the study to clearly distinguish a nodule's protrusion from a very small nodule fragment or a very thick cortical flake. Therefore, was considered as protrusion the hornlike piece whose thickness (measured perpendicularly to the flaked surface) was longer than the diameter of the flaked surface.

A 'removal' is here considered as a negative or scar left by an anthropogenic percussion fracture. A differentiation was made during the study between two types of removals: (1) superficial removals (fig. 6A) only involve a sub-cortical part no thicker than a few millimetres (less than 5 mm), with a diameter no greater than 25 mm, and result either from accidents (shocks) during handling or knocks during extraction; (2) deliberate removals (fig. 6B) have cut deeper into the sub-cortical area and left different scars associated with the same removal: scars of bulbs of percussion, striking platform, ripples or hackles. Only the latter type will be discussed in this article. The identification of superficial removals as 'accidents' is supported by empirical observations. It is also backed up by a comparison between ST6 and ST20. While there is a somewhat comparable rate of superficial removals compared to the total number of nodules in both mines (22.5% in ST6 versus 26% in ST20), the number of voluntary removals is drastically different between both mines (see below).

Only the artefacts showing the signature of intentional debitage were studied as flakes, and among these, only the proximal fragments of broken flakes were counted to evaluate the minimum number of individuals. Distal fragments were therefore



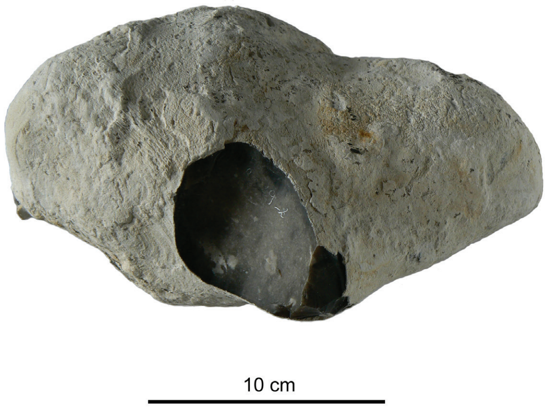


Fig. 6 – A: 'Superficial' removal on a nodule; B: 'Deliberate' removal on a nodule. M. Woodbury © SPW-AWaP.

excluded. We have kept the flakes classification method used in the ST20 sample study in order to be able to compare the results. This analysis grid is inspired by a model elaborated by Anne Augereau (1995: 146-147; 2004: 79), in association with Jacques Pelegrin (1995: 159-165). This classification method was also used recently at the Ri mine (Ghesquière *et al.*, 2021: 260). It is based on the relevance of the combination of two criteria – surface condition and thickness – in order to place the flakes within the lithic reduction sequence as the quantity of cortex and thickness decrease along the reduction process. 'Cortical flakes' are covered with cortex over more than 3/4 of the surface and may have missing cortex only in the proximal part. 'Partially cortical flakes' are covered with cortex over less than 3/4 of their surface. 'Non-cortical flakes' have no cortex or only distal cortex. 'Thin flakes' are less than or equal to 5 mm thick; 'thick flakes' are 5 to 15 mm thick and 'very thick flakes' are over 15 mm thick. Thickness and surface condition were combined to differentiate flakes (ex: thick non cortical flakes). Even if we are dealing with material coming from the extraction levels, and not from chipping floors, the classification method of Anne Augereau was used in order to easily compare various assemblages across the site (including from the underground) and also to detect possible parts of the lithic reduction sequence present in the mining levels.

'Picks' and 'positive scars of picks' were isolated for refitting purposes. Most of the picks must have been processed at the surface as shown by the distinctive surface colour (a lighter aspect that is not strictly speaking a patina but is correlated to exposition to daylight and weathering). Blanks used to shape some of them are axe roughouts and exhausted blade cores, artefacts typically discarded in the surface workshops. Positive scars of picks show the same distinctive surface aspects, removal scars on the upper surface typical of bifacial pieces, incrustations of chalk indurated by use impacts, as well as a particular fragmentation initiating from the active part that distinguish them from flake obtained during debitage (Collin & Collet, 2011: 72). These fragments therefore result from the shattering of picks during use, and not from a rejuvenation flaking process. In the 2007 study of shaft ST20, these positive scars of picks were not isolated from flakes. To compare both assemblages, positive scars of picks from ST20 were re-examined and isolated.

All flint waste that does not fit into any of the other categories and does not show signs of debitage is considered to be 'debris'. Elements smaller than 20 mm were not counted and are included in the debris category, solely in terms of weight. Regarding blanks selection, research carried out on various mines at Spiennes has shown that the (fragments of) nodules left underground are unsuitable for the main production objectives on the mining site i.e. the obtention of large axeheads or blades (Gosselin, 1986; Collet & Woodbury, 2007). The study of these rejects makes it possible to determine selection criteria based on this inference. The nodules are therefore examined according to several criteria: flaws in the raw material, weight, size and presence or absence of test removals. As already stated, these criteria allow comparison with the results already obtained for mining levels of the ST20 mine.

5. RESULTS

Nodules and fragments of nodules constitute the main part of the sample in weight. According to those criteria they represent 80% of the aban-

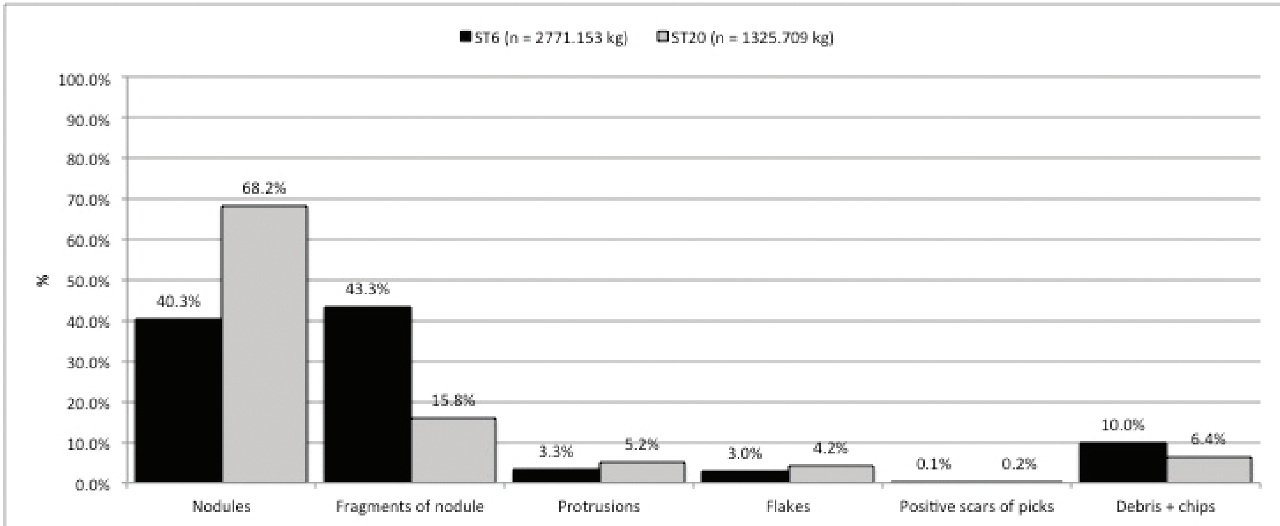


Fig. 7 – Category distribution by weight.

doned flints (fig. 7). Not surprisingly the flakes and especially the debris account for the largest part of the studied flints, in number (fig. 8). ST6 presents an almost equal distribution between nodules and fragments of nodules both in terms of weight and number of pieces. The distribution by number of pieces is substantially different from the results of ST20. ST6 yielded approximately 20% less flakes and 25% more debris. The latter category is the most important in ST6. Debris can result to a limited extent from the extraction activity and the material handling, as already highlighted at *Petit-Spiennes* (Collet & Woodbury, 2007: 153; Gosselin, 1986: 130). However, their very high number in ST6 should be related to the omnipresence of extensional fractures within the flint, which weren't observed in such quantity in ST20 (see Spiennes flints: geological aspects).

5.1 Discarded nodules

The great majority of the flint nodules discarded underground has either flaws (20%) or an inadequate shape (79%), which led to their abandonment. The reason(s) for abandonment of the last 1% remains undetermined. Furthermore, 14% of nodules combine multiple causes, i.e. several flaws (extensional fractures and chalky inclusions)

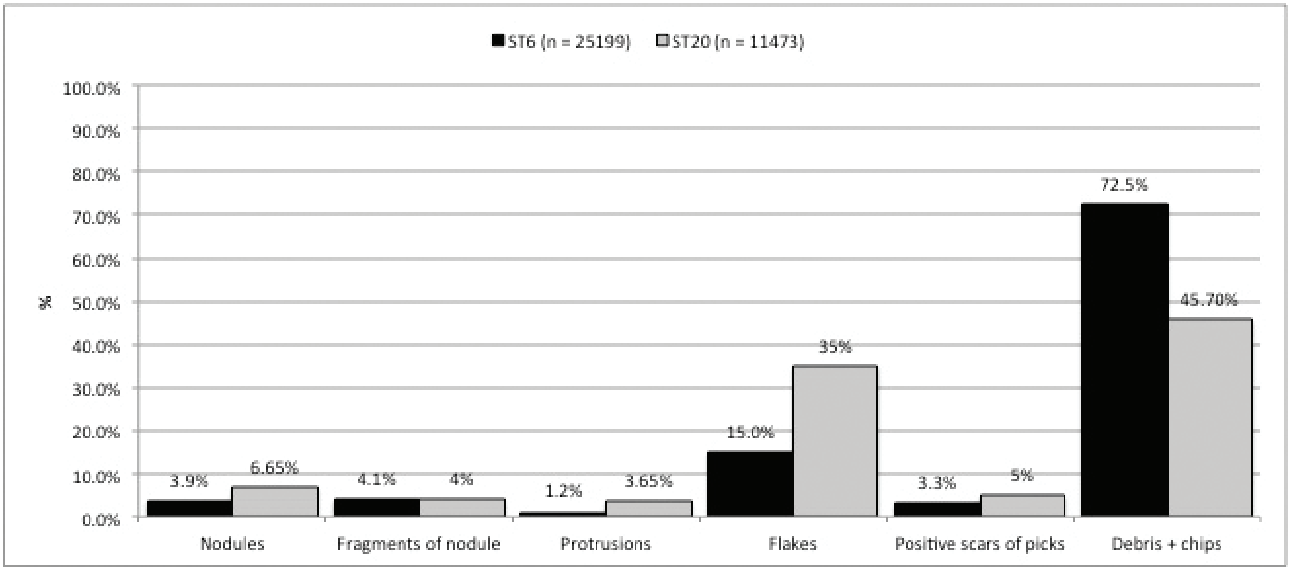


Fig. 8 – Category distribution by number of items.

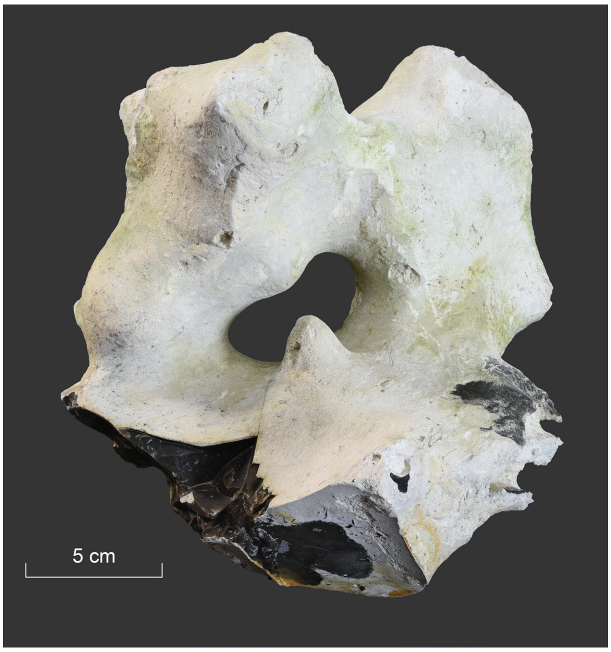


Fig. 9 – Nodule showing an inadequate morphology for manufacturing an axehead. M. Woodbury © SPW-AWaP.

and/or flaws combined with an inappropriate morphology. Chalky inclusions (70%) and extensional fractures (28%) account for most of the flaws observed in the raw material (98%). The oxidised faces of the nodule fragments are indications of these extensional fractures that caused the nodules to shatter during their extraction and are therefore also to be taken in account when examining the flaws in raw material. Flints with light grey 'coarse granular silicifications' are also quite common. But only 2% of them would have been discarded for this reason.

The main exclusion criteria in ST6 are clearly inadequate shape, defined as having insufficient workable volume, in other words lacking dimensions (length, width and/or thickness) or having an unsuitable morphology for manufacturing large tools (e.g. twisted or 'pierced' nodules, fig. 9). Global results obtained for ST6 differ significantly from those obtained for ST20. Inadequate shape is the dominant feature in the majority of the categories of weight in ST6. It is prevalent up to 3.5 kg (53%) and remains significantly important for the categories above 4.5 kg (33-40%). Flaws become important from 3.5 kg. In ST20, on the other hand, flaws prevail from 1.5 kg onwards and significantly dominate from 2 kg onwards (75-89%). Shape is of secondary importance (less than 10% from 2 kg onwards). The fact that morphologies and/or dimensions (mainly thickness) still play a major role in the ST6, even for the higher weight categories, highlights the search for a specific format of nodules larger than in ST20. It should be noted, though, that this observation must be tempered with a high proportion of nodule fragments and debris in ST6, which is probably linked, besides extraction work, to extensional fractures in the raw material and therefore to its quality, which obviously had an impact on the selection criteria.

5.2. Blank selection and testing of nodules

The distribution according to nodule weight and size clearly shows an over-representation of small sizes of discarded nodules. The trends are quite similar for both ST6 and ST20. Over 85% of the blocks weigh less than 2 kg and are less than 20 cm long. The distribution of discarded nodule fragments is similar: more than 80% of the blocks weigh less than 2 kg and more than 90% are less than 20 cm long. We therefore agree with the conclusion reached for ST20, namely that the miners were probably looking for blocks weighing over 2 kg and measuring over 20 cm long.

As already stated, we have regarded as removals those that were considered intentional and previously interpreted as underground 'tests' (Collet & Woodbury, 2007: 155-156). When applying the same reading grid to ST6, the results differ, while the distribution of nodules in weight and size is the same in both mines. In ST6, less than 15% of the blocks (140/975) were tested (fig. 10 & 11) compared to 38% in ST20 (287/763), over twice as much. In ST20, more blocks were tested than untested as from 15-20 cm (66%). Only nodules over 25 cm were almost systematically tested in ST6 (57%). Both categories 15-20 cm and 20-25 cm have less than 30% of tests in ST6. The trend of increasing tests with size categories can be observed in ST6 but in clearly smaller proportions than in ST20. In most cases, the presence of only one (84 out of 140) or two (38 out of 140) removals on the blocks clearly suggests that these are tests. Only the two largest nodules were the recipients of multiple tests with random arrangement. The first, with an exceptional mass of 8.9 kg, has six removals. The second, weighing 7.2 kg, has four removals, as if the ST6 miners were reluctant to give up such pieces.

The lesser proportion of nodules tested in ST6 than in ST20 is similar when we look at the proportions of pieces showing a removal for nodule fragments and nodule's horns in these two pits. In

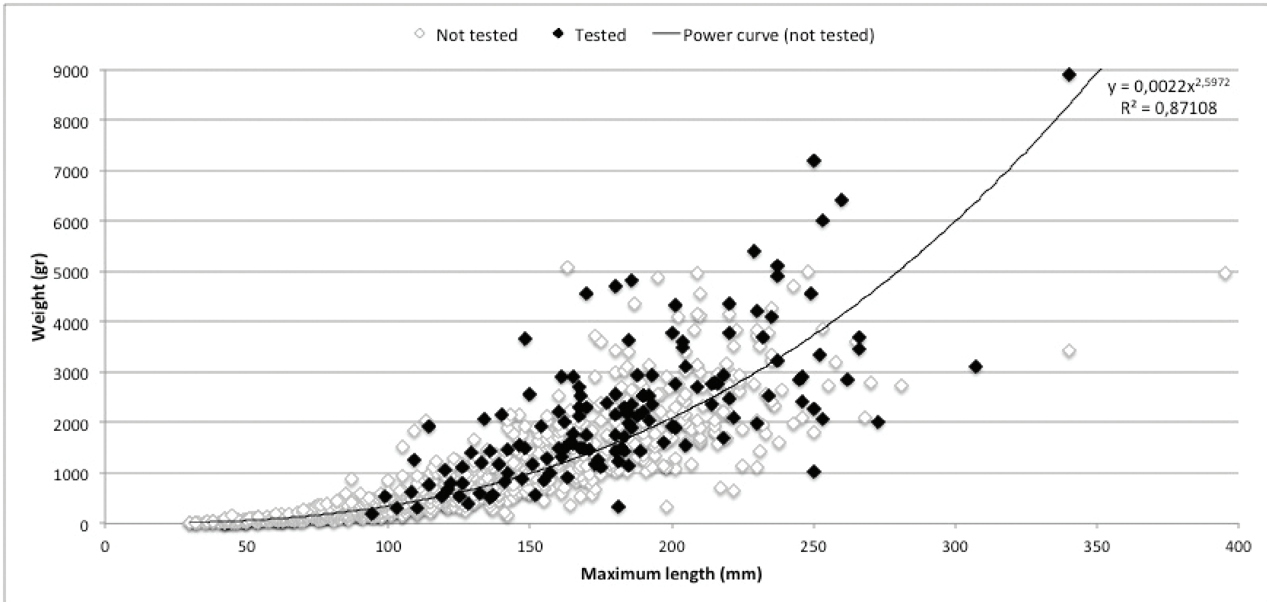


Fig. 10 – Correlation between length, weight, and presence of tests on ST6 nodules. The exponent of the equation is close to 3: it is a power curve (cubic). The weight is proportional to the volume (by the density) and the volume proportional to the cube of the length. It is therefore a logical distribution. NB: if we separate the two populations (non-tested and tested) by making a second trend curve, the curves remain quite close.

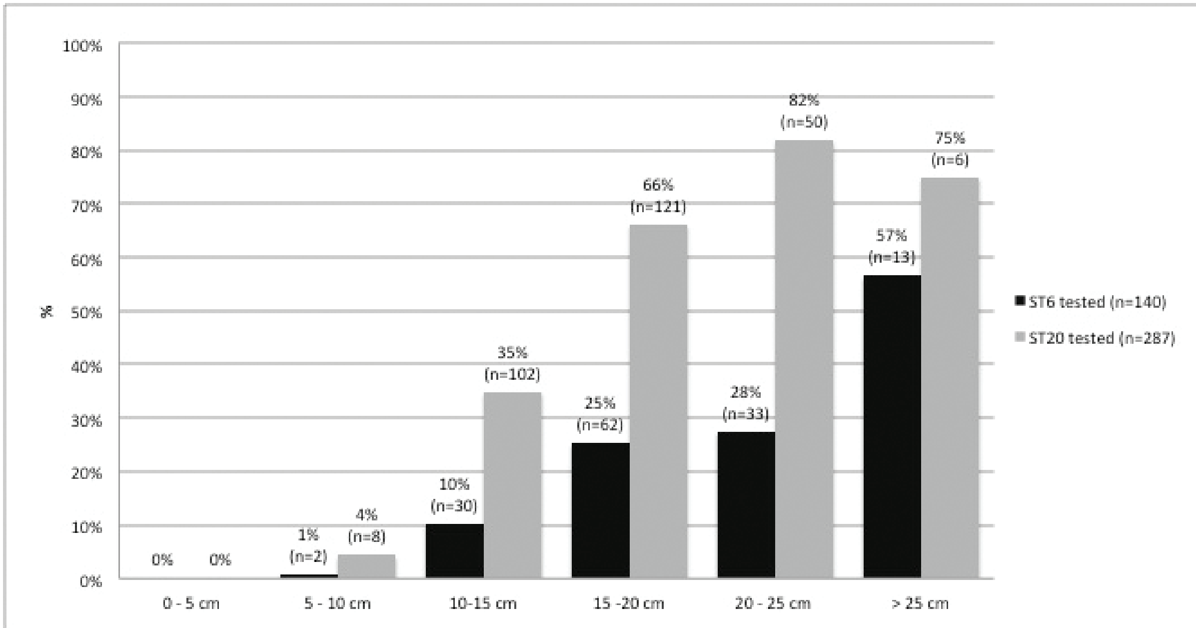


Fig. 11 – Correlation between nodule length and the presence of tests in ST6.

ST20, almost 70% of the nodule fragments show a removal, presumably to test the flint's quality, and 91% of the nodule protrusions (presumably resulting from testing) have been removed. This has led researchers to consider that nodules were quite systematically stripped of their horn-like protrusions before being brought to the surface (Gosselin, 1986: 131; Collet & Woodbury, 2007: 155). In ST6, less than 30% of the fragments show a removal, and this number rises to 34% for the horn-like protrusions of nodules. Many fragments in ST6 show a yellowish-brown film of iron hydroxides on their non-cortical surfaces. This finding suggests that the majority of these fragments and protru-

Fig. 12 – Natural fragmentation of a nodule caused by extensional fractures. M. Woodbury © SPW-AWaP.

sions were already fragmented when extracted due to pre-existing faults and extensional fractures in the substrate (fig. 12).

5.3. Sporadic knapping clues in the underground mining works

Systematic refitting from the underground cannot be achieved due to the overwhelming amount of material. Nevertheless, some observations give us a glimpse of underground knapping practice. In addition to the flint waste, various artefacts such as hammered pieces (i.e. quarzitic sandstone hammers or anvils), flint blocks with primary works, bifacial roughouts and more than a hundred flint picks were found in the mining waste from the underground works. These knapping examples were discovered in the three quadrants that have been most extensively excavated to date (A, C and D). Stratigraphically, these artefacts are found from the beginning of the operation to its end, i.e. between 7.20 and 10 m and are spatially distributed throughout these three quadrants. As already stated, apart from the majority of picks, all this material was never brought to the surface and therefore is strictly associated to the mining works.

Five fragmentary quartzitic sandstone hammers (obj. 527, 549, 816, 888 & 1186) and two very small flakes (obj. 821 & 822) were found among the chalky waste (fig. 13). One of the hammerstones is a re-use of a grinding stone fragment (obj. 549). The material used for each piece is quartzitic sandstone from the Erquelinnes Formation (Hennebert & Delaby, 2017: 31), similar to the raw material from the ST6 and ST11 access pits (Pirson *et al.*, 2001). Three flint artefacts also show signs of hammering. These are a fragment of a nodule with an associated flake which refits (obj. 1098 & 1099). The item shows two crushed areas, one at the flaking point and the other on the opposite side. Another small fragment was hammered (obj. 1100). They may have been used as hammerstones or anvils.

Underground shaping was attempted on some blocks. The first one is 17.3 cm long, 0.85 cm wide, with a thickness ranging from 0.53 to 0.97 cm. It is a fragment of a nodule with three faces showing a yellowish-brown film of iron hydroxides. It offers a sequence of six bifacial and unilateral removals (fig. 14A, obj. 1116). There is no knapping attempt on the opposite site, despite the important thickness and the presence of a protrusion. The second

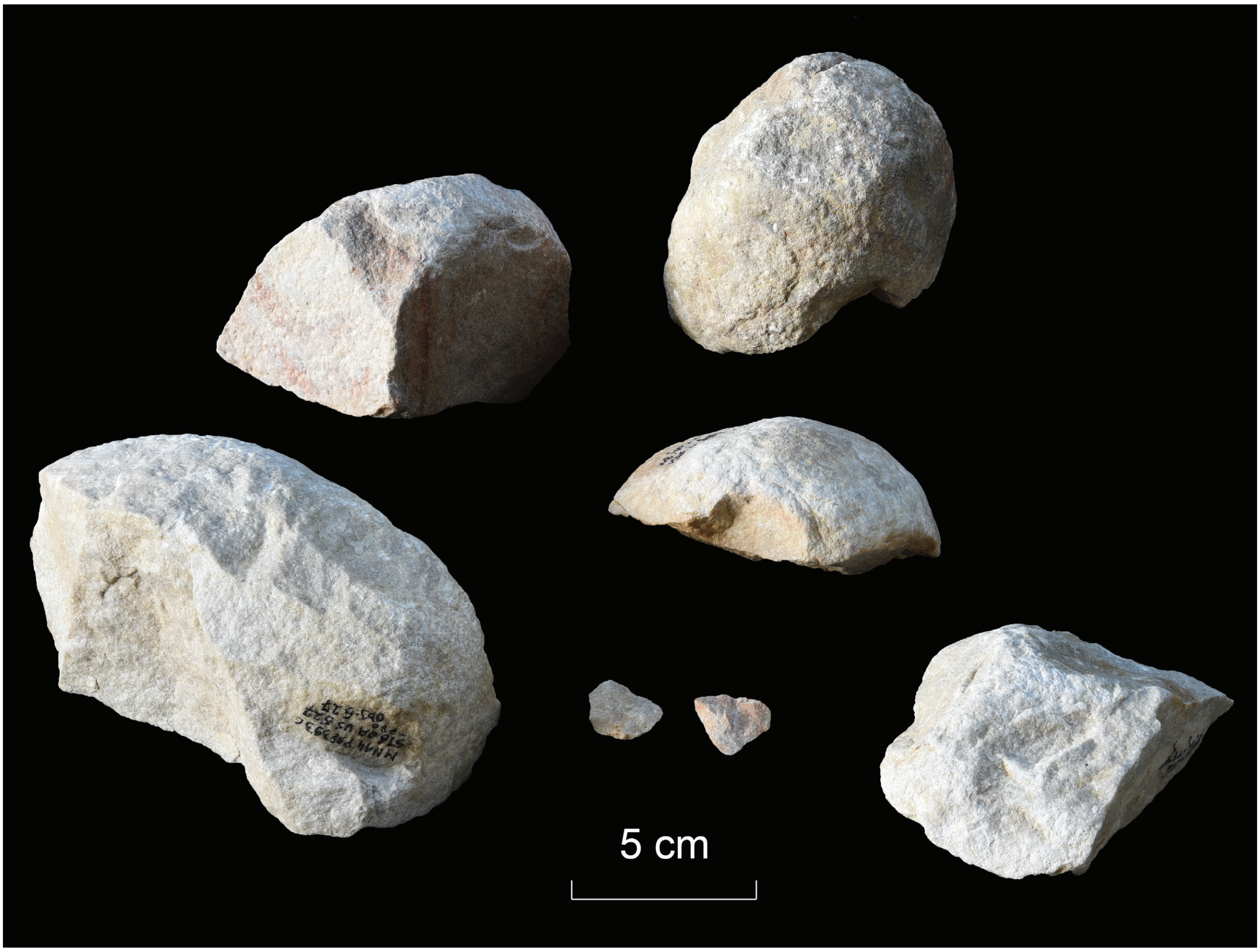


Fig. 13 – Five fragmentary quartzitic sandstone hammers (obj. 527, 549, 816, 888 & 1186) and two quartzitic small flakes (obj. 821 & 822). M. Woodbury © SPW-AWaP.

is a fragment of a nodule with a face showing a yellowish-brown film of iron hydroxides (19.9 cm long, 14.9 cm wide & 0.75 cm thick). It shows three alternating removals along one edge, as well as two removals from the same side on the opposite edge. The last removed flake was found next to the block and can be refitted on it (fig. 14B, obj. 890). The removals revealed several extension fractures that hindered the shaping and certainly led to its discard. The third one is a thick fragment of a nodule with a face showing a yellowish-brown film of iron hydroxides (20.6 cm long, 0.95 cm wide & 0.81 cm thick). It shows a sequence of five removals showing an attempt at bifacial shaping. They revealed an additional extension fracture (fig. 14C, obj. 519). The fourth one has an irregular morphology with a natural hole in the middle of the nodule (initially filled with chalk), which limits the usable volume to 18.5 cm long, 13 cm wide and 8.3 cm thick (fig. 14D, obj. 815). Three alternating removals along one edge constitute the beginning of a bifacial shaping. The fifth one (17 cm long, 12.3 cm wide & 0.62 cm thick) is a flat fragment of a nodule showing several alternating removals from an edge (fig. 14E, obj. 807). An extension fracture as well as 'chalky inclusions' hindered the knapping process. The sixth one (obj. 1146) is a triangular-shaped fragment of a nodule (19.4 cm long, 3.5-9 cm wide & 3.4-5 cm thick) showing bifacial shaping attempt with a sequence of ten removals (fig. 14F).

Finally, a large fragment of a nodule (32.1 cm long, 11.3 cm wide & 0.62-0.74 cm thick) broken in two joining parts (obj. 806 et 812) shows cortical areas remaining on the upper surface and has several bilateral bifacial removals (fig. 15A). On one side, a large surface shows iron hydroxides and manganese dendrites testifying to a natural surface resulting of an extension fracture in the original nodule. The opposite face also shows large patches of iron hydroxides and a small cortical area. Knapping revealed the presence of at least three extension

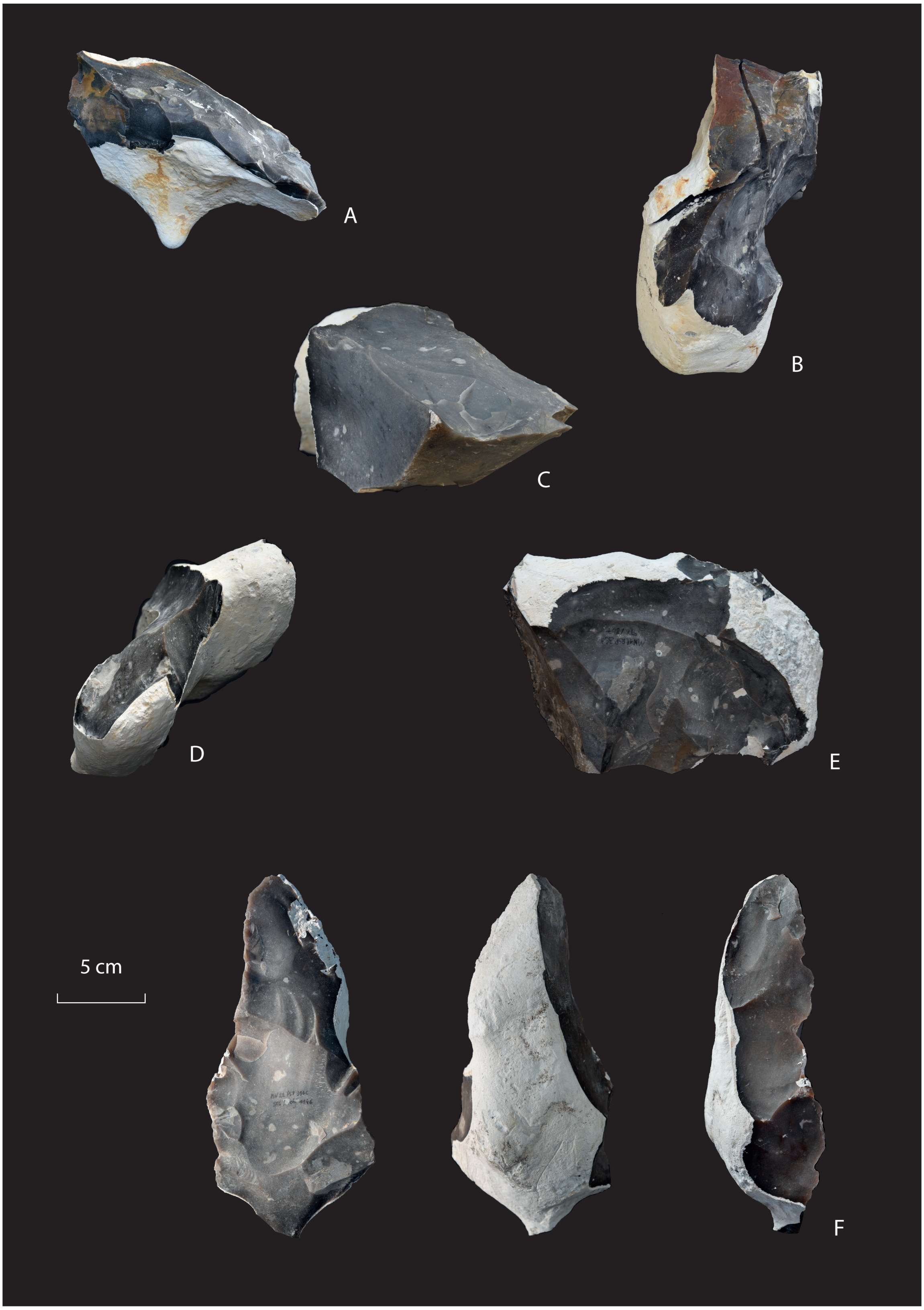


Fig. 14– Shaping attempts in the mining levels. A: obj. 1116, QA, 960-1020 cm deep, US 829; B: obj. 890, QC, 880 cm deep, US 712; C: obj. 519, QA, 720-780 cm deep, US 527; D: obj. 815, QC, 780-840 cm deep, US 582; E: obj. 807, QC, 780-840 cm deep, US 582; F: obj. 1146, QD, 720-780 cm deep, US 888. M. Woodbury © SPW-AWaP.

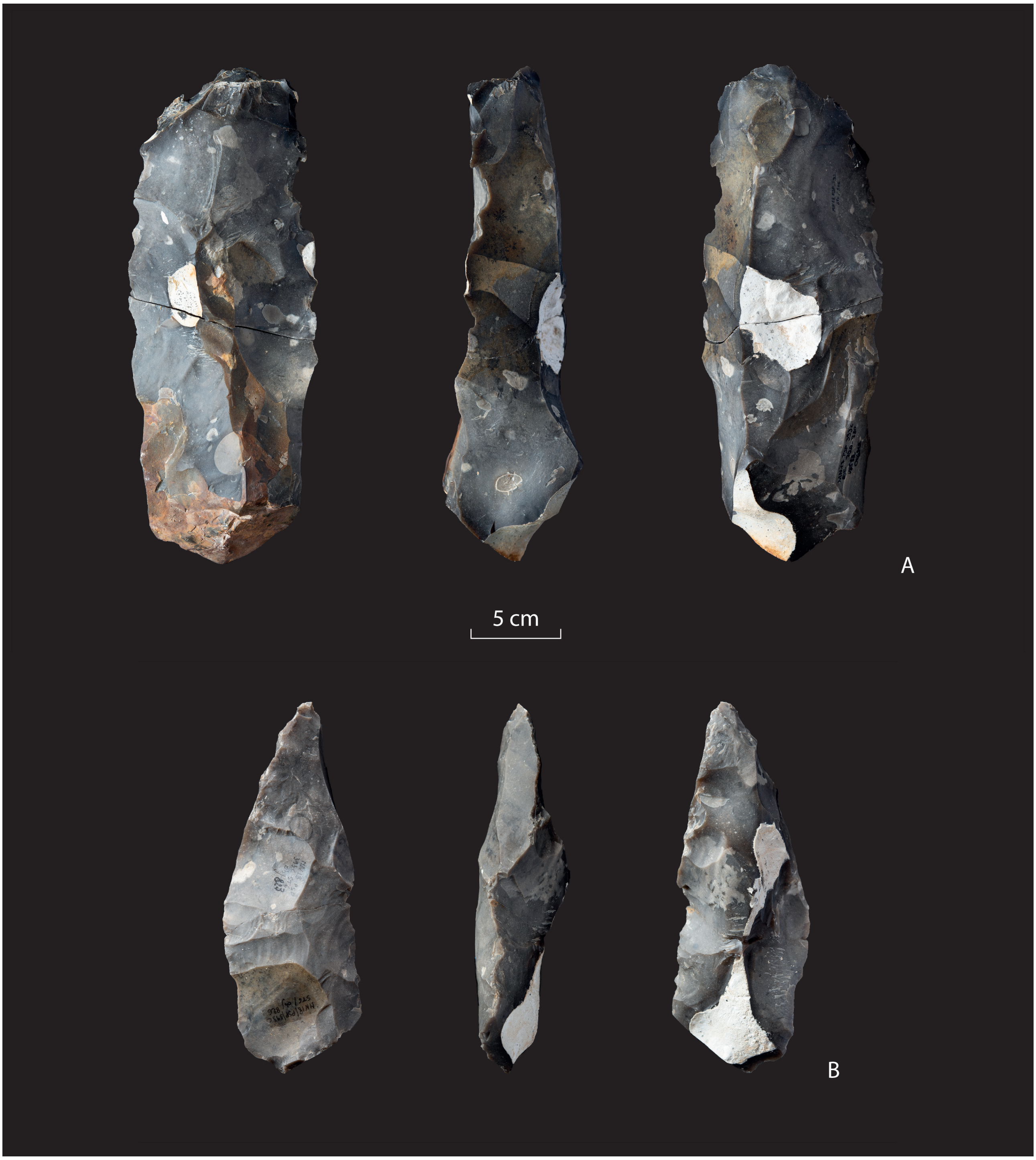


Fig. 15 – A - Fragment of a nodule broken in two joining parts (obj. 806 & 812); Fig. 15B - Pick broken in two joining parts (obj. 823 & 826). M. Woodbury © SPW-AWaP.

fractures. The level of expertise of this artefact was discussed with Philippe Pirson (CETREP) who estimated that the knapper had some skills in knapping but had made mistakes typical of an inexperienced knapper, i.e. an unsuitable blank choice, a poor management of the nodule volume, an overly intrusive removal leading to transverse breakage of the artefact (and its subsequent abandonment). The iron hydroxides, manganese dendrites and remaining cortex on different faces show the initial volume of the nodule, demonstrating that the shaping is not far along.

Fig. 16 – A: Pick made on a cortical flake (obj. 968); B: Pick supposed to have been shaped in the surface workshops (obj. 965). M. Woodbury © SPW-AWaP.

Surprisingly, another artefact found in the mining levels shows the same reasoning problem when choosing the angle in order to reduce the significant thickness at one extremity (fig. 15B). It is a bifacial roughout (presumably a pick when observing the general shape) whose two fragments (obj. 823 et 826) were found 60 cm apart (22.1 cm long, 0.72 cm wide & 0.39 to 0.53 cm thick). It was fashioned on a nodule fragment and shows a face with yellowish-brown iron hydroxides and a cortical area on the opposite face. One shaped point is intact, and the piece was fractured transversely probably during shaping. The pick was shaped bifacially and bilaterally. Deep removal to reduce the thickness of the piece (higher in one spot) would have resulted in the fracturing of the piece. As there is no evidence of chalk incrustation to indicate any use and no use-related removals, the breakage occurred before use, hence an underground shaping seems plausible. An example of these opportunistic picks taking benefit from the convexities offered by a large cortical flake (fig. 16A), is a pick (obj. 968) whose shaping appears less elaborate than other picks found in the chalk fills (fig. 16B). It could also have been knapped in an opportunistic way during the exploitation. It shows chalky incrustations testifying to its use, even if it has few use-related removals. One side has been bifacially knapped. The other side has some very small removals. The remaining cortical area covers more than half of the upper surface.

These artefacts show a limited skill level, with relatively short sequence of removals that are mainly initial shaping or flaking and during which similar types of mistakes occurred: inappropriate blank selection, poor handling of the volume, removals too intrusive. They do not all appear to serve the same purpose. Some of them would be attempts at picks shaping (obj. 823-826 and 1146), sometimes successful (obj. 968). Other artefacts would be the attempts to produce bifacial roughouts that failed (obj. 519, 807 & 823-826). Finally, some artefacts do not seem to match any specific purpose and could reflect bifacial knapping apprenticeship (obj. 815, 890 & 1116). These sporadic underground knapping clues could be interpreted in the general context of the mining sites as a privileged training place due to easy access to raw material and guidance of qualified knappers.

To complete this analysis, all flakes from the sample were examined. Do they only witness test removals or rather stages of lithic reduction sequence that were carried out underground?

When comparing the total proportion of cortical, partially cortical and non-cortical flakes, it appears to be quite similar to ST20: cortical flakes account for 40% versus 36.5% in ST20, partially cortical flakes account for 30% versus 39.5% in ST20 and non-cortical flakes account for 29% versus 24% in ST20 in terms of number. The weight of cortical flakes is slightly heavier in ST6 (55%) than in ST20 (45%) and the partially cortical flakes are slightly heavier in ST20 (47.5%) than in ST6 (36%). Non-cortical flakes represent 7.5% and 10% in each mine. In terms of weight, the majority of ST6 (81%), and ST20 flakes (73.5%), shows an overrepresentation of thick and very thick cortical flakes as also very thick partially cortical flakes (fig. 17). The thick partially cortical and non-cortical flakes account for 12% for ST6 and 16% for ST20. The thin non-cortical

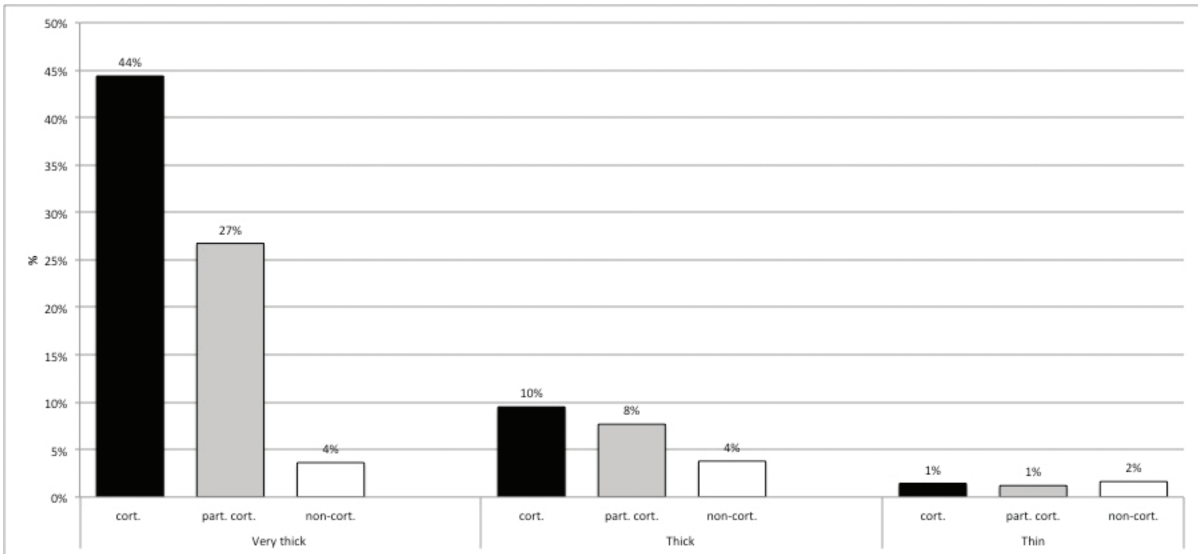


Fig. 17 – ST6 flakes classified by weight, thickness and cortical coverage.

flakes represent respectively only 2 and 2.5% of the total weight of the flakes. This distribution is similar to those of ST20 with a variation of about 10%. We also isolate 827 presumed positive scars of picks weighing 2.418 kg. The majority (84%) of the positive scars from picks are thin (<5 mm), 15% are thick (5-15 mm) and 1% are very thick (>15 mm). As stated before, they result from the shattering of picks and not from rejuvenation flaking.

These observations tend to confirm the hypothesis previously expressed concerning ST20. The majority of these flakes (mostly very thick cortical and partially cortical flakes and thick cortical flakes) are more likely to be the result of 'tests' of the nodules, confirming the results obtained when examining the nodules showing a restricted number of removals. The presence of partially cortical and non-cortical thick flakes as thin non cortical flakes could reflect a knapping activity, like pick shaping or rejuvenation flaking of picks. Nevertheless, the low quantity of such flakes allows to assume that such activities must have been a marginal phenomenon, confirming hence the common shared hypothesis that the vast majority of the picks were probably shaped at the surface in the chipping floors (Collet *et al.*, 2014: 50).

5.4 Correlation between mining waste and flint beds

Morphology of nodules varies from one bed to another. To determine whether this variation affected the selection of blocks by Neolithic miners, the mining waste was studied, i.e. 1281.701 kg of flints from the mining levels of Quadrant A (QA) of ST6, this being the only area fully excavated. The QA lithics represent 58% of the total sample. The ST6 mine contains three double flint beds: lower, medium, and upper beds (fig. 18). The sample from QA was sorted on the basis of its stratigraphic provenance (fig. 19). As mining is carried out from the bottom to the top of the mine, with each bed being exploited after the other and the miners trampling on the flint waste (fig. 20). It is possible to correlate each flint waste layer with the exploitation of a specific bed. We produced a model based on the best correlation between the flint beds and waste, excluding all the stratigraphic units likely to mix two beds.

The sample composition is quite similar to the overall ST6 sample (table 2). However, a trend can be seen: the middle double bed (MB) was the most mined. It has over five times the number of pieces compared to the upper bed and about one and a half times compared to the lower bed. In term of weight, the middle bed is almost four times heavier than the upper bed and almost one and a half times heavier than the lower bed. Several indicators confirm this more extensive mining of the middle bed: only the upper part of the lower double bed (LB) was mined in the QA, its lower part still being in place. The morphology of the upper bed (UB) also differs from the other beds in the ST6 mine. In the QC and QD, part of this upper double bed (UB) of large tabular form is still *in situ* and does not appear to have been mined. In the

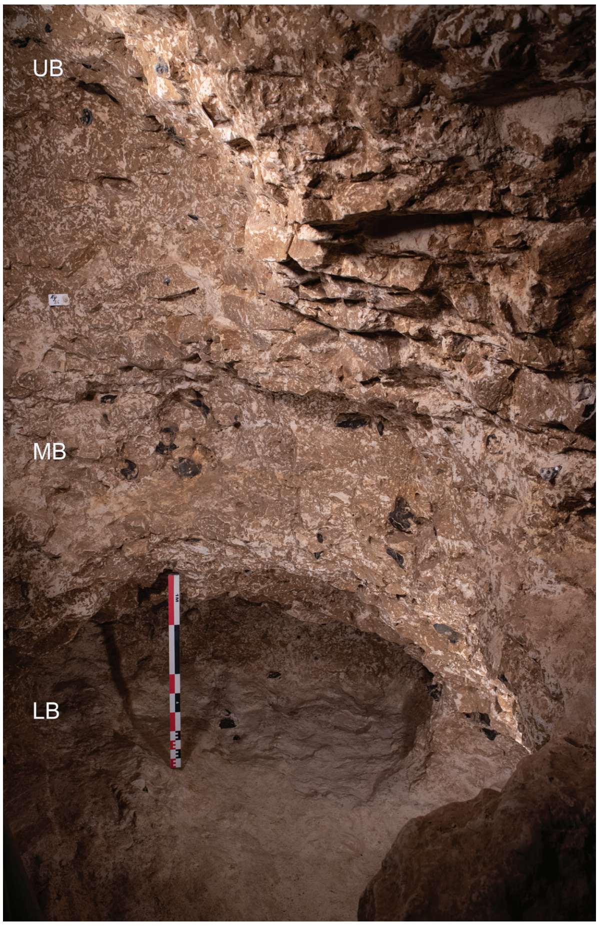


Fig. 18 – Upper, middle and lower beds in Quadrant A. M. Woodbury © SPW-AWaP.

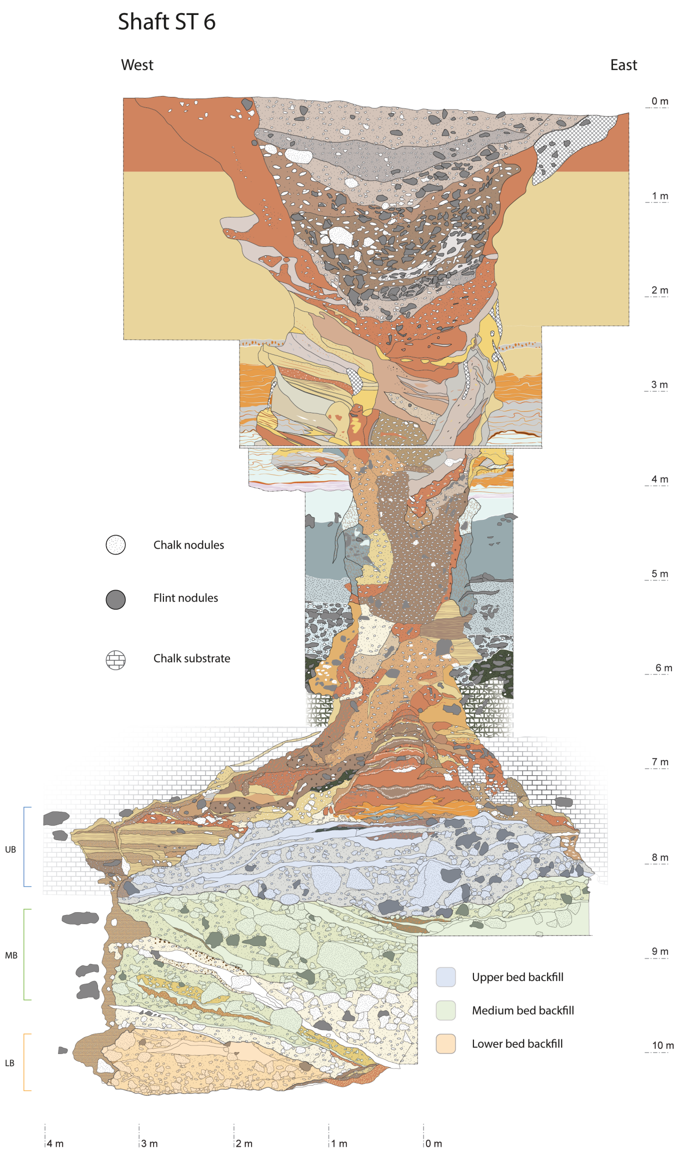


Fig. 19 – Stratigraphic cross-section in ST6 with the flint waste distributed on the basis of its stratigraphic provenance. M. Woodbury © SPW-AWaP.

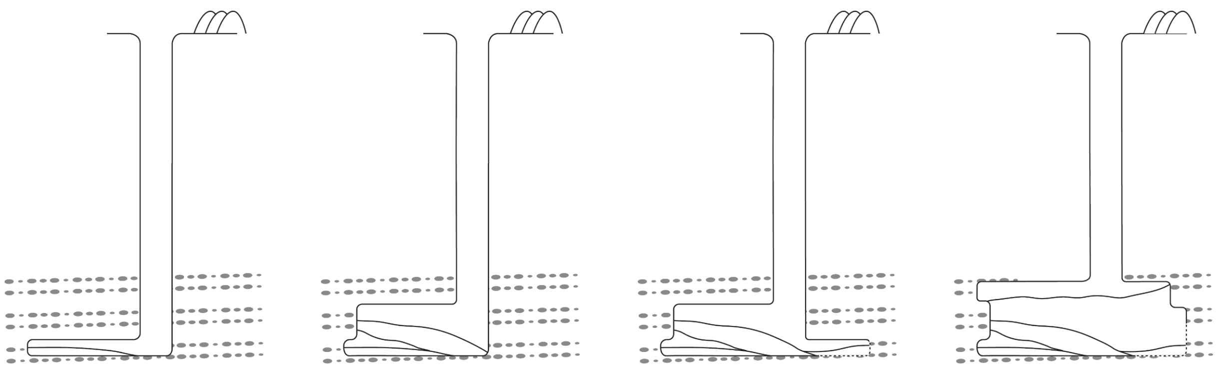


Fig. 20 – Hypothesis of mining technique used underground in ST6. M. Woodbury © SPW-AWaP.

	UB		MB		LB	
	Number	Weight (kg)	Number	Weight (kg)	Number	Weight (kg)
Nodules	59	48.264	226	277.373	150	142.428
Fragments of nodule	66	73.725	260	331.937	196	195.611
Protrusions	26	7.933	82	20.355	45	10.554
Flakes	164	3.012	838	13.458	370	9.165
Positive scars of picks	43	0.109	281	0.825	57	0.25
Debris	820	17.116	4644	58.627	3134	70.959
TOTAL	1178	150.159	6331	702.575	3952	428.967
Nodules	5.0%	32.1%	3.6%	39.5%	3.8%	33.2%
Fragments of nodule	5.6%	49.1%	4.1%	47.2%	5.0%	45.6%
Protrusions	2.2%	5.3%	1.3%	2.9%	1.1%	2.5%
Flakes	14.0%	2.0%	13.2%	1.9%	9.4%	2.1%
Positive scars of picks	3.6%	0.1%	4.5%	0.1%	1.4%	0.1%
Debris	69.6%	11.4%	73.3%	8.4%	79.3%	16.5%

Tab. 2 – Sample composition in Quadrant A.

walls of the QA, blocks of such dimensions are not observed, and they were also not found among the blocks left over from the exploitation levels. It is however possible that this tabular has a different morphology in QA due to lateral variation. Nevertheless, such a tabular flint (not counted in the sample) was recently found in the mining waste the QB. In the mines of *Petit-Spiennes* excavated by the SRPH, the upper bed (the first one met by the Neolithic miners) is also only partially mined perhaps to avoid weakening of the mine ceiling (Gosselin, 1986: 40; Collet *et al.*, 2016).

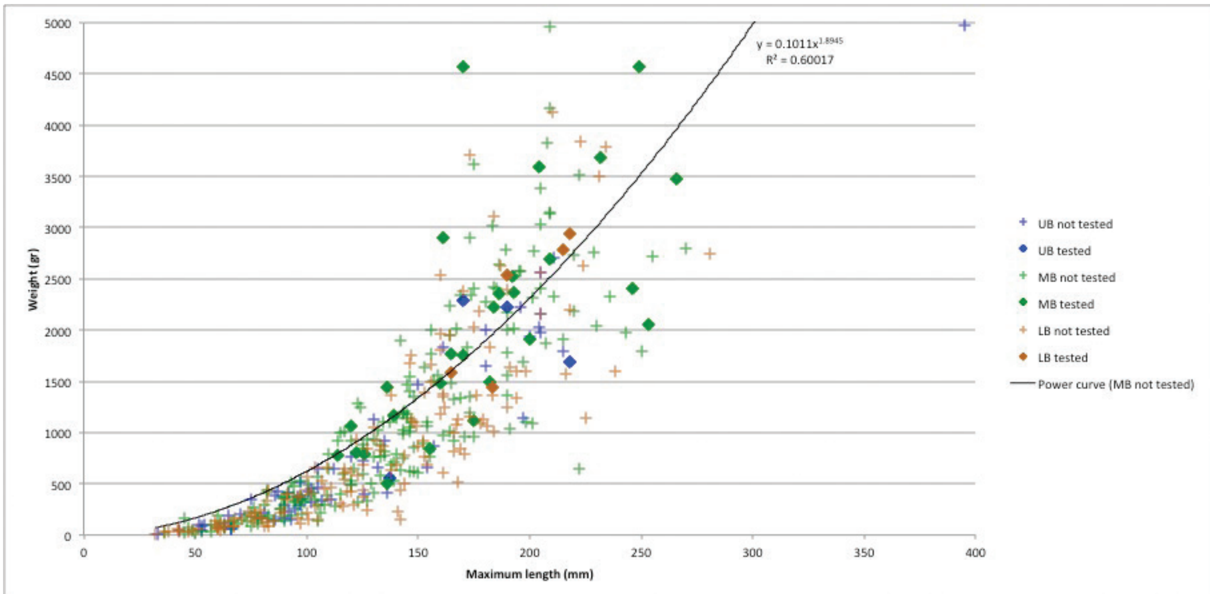


Fig. 21 – Correlation between length, weight, and the presence of tests on the upper bed nodules (blue), the middle bed nodules (green) and the lower bed nodules (brown). The exponent of the equation is around 3: it is a so-called power curve (cubic). The weight being proportional to the volume (by density) and the volume proportional to the cube of the length, this is a logical distribution.

Alongside these observations, the proportion of tested nodules differs from one bed to another. The upper bed has 4 tested nodules out of a total of 59 (6.8%) (fig. 21), the middle bed 27 out of 226 (12%) and the lower bed 5 out of 150 (3.3%). Hence, the question arises as to whether this distribution could be related to the quality of the beds. Inadequate shapes, whether in terms of block morphology or dimensions, still prevail in more than 75% of the discarded nodules. Where flaws are concerned, chalky inclusions still seem to be the major difficulty encountered in more than 70% of the discarded nodules, even if, as we detailed in the previous section, the fragments of nodules and debris also showing fractures must be added to the number of fractures observed.

No significant differences were found when comparing the three flint beds in QA (UB, MB and LB) regarding the type of waste: their distribution is the same for all beds (nodules, fragments of nodules, protrusions, flakes, and debris). What differs is the amount of waste per bed that confirms that the middle bed (MB) was more heavily mined. This also shows that a similar strategy of selection of nodules is followed. The variations therefore seem to depend on whether or not certain beds or parts of double beds should be mined.

In order to understand the choices made by the Neolithic miners, Philippe Pirson carried out a quality test on three tabular flint blocks from the upper bed left in the roof of QD one meter below the top of the chalk (fig. 22). In the case of the ST6, the multi-decimetric flat nodules from the upper bed have a very convenient morphology for axe or blade knapping. The outcome of the knapping tests was identical for all three blocks. They were unsuitable for technically highly invested production (i.e. axehead shaping). Indeed, two of them showed extension fractures on the surface, which also occurred within the block, resulting in chaotic fracturing. The last block had no visible surface extension fractures, but these appeared during shaping, also making it unsuitable for knapping. Fracture of most of the blocks appeared also *in situ* while excavating the remaining part of the QD.

Fig. 22 – "Tabular" flint in the ceiling of the QD. M. Woodbury © SPW-AWaP.

6. CONCLUSION

Overall results for the lithic analysis of the ST6 mining levels show some major trends. Firstly, debris dominates (72%) in terms of number of pieces, and fragments of nodules are significantly more present (25% more) than in ST20 despite a lower rate of testing. This suggests a high fragmentation rate during or prior to extraction, handling or knapping by Neolithic miners. We link it to the presence of extensional fractures. Secondly, the majority of the nodules discarded underground (79%) is neither of adequate size nor morphology to manufacture products such as large axeheads. Thirdly, less than 15% of the blocks were tested in ST6 and fewer flakes were recovered than in ST20 (20% less). Indications of underground knapping have been identified, but they are very limited (0.3%) compared to the number of nodules and fragments of nodules discovered. This activity therefore appears to be sporadic and not relevant in terms of extraction strategies.

Analysis of the ST6 mine waste indicates that, as in the ST20 mine, a significant proportion of the raw material is discarded underground. The main reason for abandonment is related to their inadequate shape, both in terms of size and morphology. Secondly, nodules were also discarded because of the numerous 'chalky' inclusions and/or extension fractures present in the raw material. However, the study also confirms slight variations of flint procurement while comparing ST6 and ST20.

The ST6 raw material shows a lower proportion of flakes and tested blocks than observed in the ST20 mine but the trend in the selection of blocks looks similar. Blocks over 25 cm long are scarce amongst those left underground but are also the most tested. They could therefore be considered as the most valuable and sought-after module selected to be brought to the surface. These kinds of blocks are suitable blanks for high technical investment products such as large axeheads and blades.

This selection of blanks differs from the one observed in ST20 where blocks from 15-20 cm bore more tests. Yet, the number of debris and fragments of nodules in ST6 is much higher, indicating significant fracture of the raw material. This leads us to the hypothesis of a search by the Neolithic miners of bigger blanks for the axe blade or/and blade production, that could be linked to different variables: (1) the selection of larger modules to produce larger artefacts than in ST20, (2) a more limited level of skill of the knappers implying a greater loss of the initial volume of the block, or (3) a lower quality of the nodules of the flint beds mined in ST6 and therefore less reliance on the knapper's ability to control volume loss.

The study confirms the interest in taking into account the geological specificities of each mine on the site, despite their proximity, to better define the mining methods and to understand the choices made by the miners. Flaw analysis of raw material highlights the value of a geological analysis of the constraints at work on flint beds, their lateral variability and their potential impact on the mining operation.

Several lines of research emerged. First, an analysis of all the picks found in the chalk fills needs to be studied from the perspective of identifying surface shaped picks versus underground shaped picks, and thus refine the matter of opportunistic underground shaping and/or rejuvenation. Secondly, a study on the composition of different flint beds has been initiated, especially through comparisons with modern chalk quarries. The aim is to develop a model in order to estimate the yield of the mine and so to provide a hypothesis on the number and size of flint nodules selected by the Neolithic miners for which we have no data. Finally, comparing mines shows that there are strong overlapping trends, but that there are variations in choices and strategies. These observations need to be multiplied in order to put them into a diachronic perspective.

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