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Origins of prehistoric flints: The neocortex memory revealed by scanning electron microscopy

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Abstract

Flint has been widely used during prehistoric times and the question of determining the origin of specific pieces is recurrent in archaeological discussions. We have run a scanning electron microscope examination of the surfaces of both natural flints from geological deposits and flaked artefacts excavated from prehistoric sites in the Massif Central (France). These samples exhibit mineralogical textures resulting from genomorphic and phenomorphic processes, dispersed alteration in the form of erosion as well as the dissolution and migration of more or less mobile elements. Rocks used to manufacture artefacts at Sainte-Anne 1 (Haute-Loire, France) and Payre (Ardèche, France) show various kinds of alteration related to the range of phases of transport and deposition to which they were subjected, beginning with their first exposure in a geological context and following through to the post-depositional phase, (i.e., following abandonment as artefacts in an archaeological site). Later phenomena do not however completely obliterate stigma imprinted prior to their prehistoric collection, because the main late-phase change that occurs on flat surfaces prior to their collection is preserved in the hollows of remnant natural surfaces on archaeological tools. With the scanning electron microscope, five distinct morphologies representative of different environments have been characterised by establishing associations between the different forms and by plotting their regional distribution. ***To cite this article: P. Fernandes et al., C. R. Palevol 6 (2007).***

Résumé

Provenance des silex préhistoriques : la mémoire des néocortex révélée au microscope électronique à balayage. Les silex ont été largement utilisés par l'homme pendant la préhistoire, et la question de leur provenance est récurrente dans la démarche archéologique. Un examen au MEB a été conduit sur des surfaces de silex naturels et d'objets taillés provenant de gîtes et de sites préhistoriques du Massif central. Ces échantillons présentent des textures minéralogiques découlant de processus génomorphiques et phénomorphiques : l'altération s'est développée, sous la forme d'érosion, de dissolution et de migration d'éléments plus ou moins mobiles. Les roches ayant servi à la fabrication des outillages de Sainte-Anne 1 (Haute-Loire, France) et de Payre (Ardèche, France) montrent des formes variées contrôlées par les différentes phases de transport et de résidence des silex, de la mise à l'affleurement à la phase post-dépositionnelle, c'est-à-dire après l'abandon de l'objet dans le site archéologique. Les phénomènes tardifs n'oblitèrent

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cependant pas complètement les stigmates antérieurs à la collecte préhistorique, car la phase tardive principale enregistrée sur les surfaces planes des silex avant collecte est préservée dans les creux des surfaces restées naturelles sur les objets archéologiques. Cinq morphologies distinctes, représentatives de milieux différents, ont été caractérisées au MEB. Des critères d'association de formes et de distribution de ces dernières distinguent ces types. ***Pour citer cet article : P. Fernandes et al., C. R. Palevol 6 (2007).***

Keywords: Flint; Neocortex; SEM; Middle Palaeolithic; Gathering outcrop; Haute-Loire; Ardèche; France

Mots clés : Silex ; Néocortex ; MEB ; Paléolithique moyen ; Lieux de collecte ; Haute-Loire ; Ardèche ; France

Version française abrégée

Introduction

La détermination de la provenance des matières premières minérales est depuis longtemps considérée comme indispensable à la connaissance des comportements des sociétés préhistoriques [3,15,23,33,35,36,45]. Les approches antérieures n'ont pas assez pris en compte les transformations que subit le silex lors des phases post-génétiques. La diagenèse produit des silex de compositions variables, que les stades post-génétiques conduisent vers des associations minéralogiques plus homogènes et plus riches en quartz dans les zones périphériques des volumes naturels [7,22,49,52]. Le silex possède une texture palimpseste qui enregistre d'abord des mécanismes d'usure et d'altération liés aux processus post-génétiques (commencés au sein même de la roche-mère) [16,51], puis des altérations et des marques d'usure témoignant de transports et d'immobilisations successifs dans divers milieux de résidence avant la collecte par l'homme préhistorique.

Pour une lecture des modifications de la surface des silex, on a sélectionné des critères caractéristiques des conditions de transformation et comparables avec des modèles théoriques et des résultats expérimentaux [1,2,4–6,8–11,13,14,19–21,24–27,29–32,34,37–39, 41,43,44,46–48]. Cette méthodologie renouvelée implique la comparaison entre l'état final (archéologique) d'un matériau et une série d'échantillons géologiques, initialement cogénétiques, du même matériau, provenant de gîtes subprimaires et secondaires, dont les environnements géologique et géomorphologique ont été précisément déterminés.

Nous présentons les premiers résultats de l'observation en ultramicroscopie (MEB) de néocortex d'échantillons géologiques et archéologiques d'Ardèche et de Haute-Loire, qui ont conservé la mémoire de phénomènes permettant de mieux caractériser les zones de collectes préhistoriques.

Les échantillons

Les échantillons ont été prélevés dans le Massif central et sur sa bordure méridionale, dans le Barrémo-Bédoulien de Cruas (Ardèche), dans le Sannoisien du Puy-en-Velay (Haute-Loire) et dans les outillages du Paléolithique moyen ancien de Payre (Rompon, Ardèche) et de Sainte-Anne 1 (Polignac, Haute-Loire).

La démarche est adaptée aux conditions gîtologiques d'un même matériau [16–18]. À partir des zones d'affleurement subprimaires, nous avons prélevé 50 échantillons par gîte dans différents dépôts de colluvions, d'alluvions et d'éboulis, en respectant les polarités (verticale et antéropostérieure). Parmi les objets archéologiques des deux gisements, nous avons sélectionné ceux, du même type, qui présentaient une surface naturelle héritée.

Méthode d'observation

Chaque échantillon a d'abord été examiné à l'échelle macroscopique et à la loupe binoculaire. Afin de prendre en considération l'ensemble des évolutions (en particulier les plus tardives), nous avons lié les associations de stigmates à la morphologie générale de l'échantillon naturel, en respectant les polarités génétiques et post-génétiques (différence entre zone exposée et zone protégée). Cette reconnaissance permet d'évaluer les différents équilibres entre les actions mécaniques et les processus chimiques.

L'observation au microscope optique permet ensuite de caractériser le microfaciès par sa texture, les éléments figurés de la proche surface et sa minéralogie et les types de porosité. La zone périphérique apparaît toujours plus transformée que la zone interne, et il existe, dans le cas des objets archéologiques, une différence de vieillissement entre la zone sous le néocortex et la zone sous la surface taillée.

L'imagerie au MEB (Jeol JSM-6460 LV) a été réalisée en électrons secondaires sous une tension de 20 kV après métallisation à l'or, avec des grossissements compris entre 100 × et 6000 × . Il s'est avéré que les faces planes et les dépressions dans les zones les moins exposées conservaient les témoins les plus pertinents. Dans le cas des objets archéologiques, un prélèvement a été effectué sur la surface naturelle, qui porte les indices prédépositionnels, et sur la surface taillée, qui a enregistré les processus post-dépositionnels.

Résultats

Différentes associations de stigmates cataloguées à la surface des échantillons géologiques ont été retrouvées sur des objets des niveaux archéologiques Gb de Payre et J1 de Sainte-Anne 1 : en dépit de processus génomorphiques et phénomorphiques [32] très différents, ces faciès sont convergents. On peut donc, dans les deux cas, considérer les surfaces naturelles des artéfacts comme de bons témoins de stades spécifiques d'évolution de différents milieux de résidence, dans lesquels les hommes préhistoriques ont collecté leurs matières premières lithiques (Table 1). Ces examens permettent de proposer un modèle d'évolution des surfaces. L'utilisation du MEB permet d'observer la progression des processus de transformation dans les cinq types de gîtes secondaires reconnus.

Néocortex de position primaire

Leur chaîne évolutive est la suivante : phase génétique → phase altéritique → immobilisation finale → disponibilité pour la collecte.

À ce stade, le silex est dépourvu de toute trace de choc, mais, dans certains milieux très percolés, l'altération hydrique commence bien avant la mise à l'affleurement [42] : dans les gîtes primaires, nous n'avons observé à ce jour que des faciès transformés.

Néocortex dits « de surface », indiquant une position subprimaire

Exemple du type génétique F14, échantillon 338-1-8-Le Pontet (Le Teil, Ardèche) et objet archéologique Q8 72.5 de Payre (Rompon, Ardèche) (Fig. 3), dont la chaîne évolutive est la suivante : phase génétique → phase altéritique → phase altéro-détritique (détachement et léger déplacement) → disponibilité pour la collecte.

Il s'agit de silex ayant subi une mise à l'affleurement et donc une ou plusieurs évolutions liée(s) à des phénomènes météoriques et pédologiques au sens large. Les surfaces de ces échantillons sont moyennement à fortement modifiées par les agents actifs et ne portent pas de traces de transport sensu stricto. Néanmoins, des traces de chocs dus aux légers déplacements (par ruissellement ou par gravité) sont visibles sur les arêtes principales, lorsqu'elles ne sont pas totalement masquées par les dissolutions tardives ou les cimentations dues à l'immobilisation finale.

Néocortex de colluvions

Exemple du type génétique F 14 : échantillon 333-1-6, Terre du Charnier (Lagorce, Ardèche) et objet archéologique M5 1224 de Payre (Rompon, Ardéche) (Fig. 3). La chaîne évolutive est la suivante : phase génétique → phase altéritique → phase altéro-détritique → phase colluviale (incorporation à un dépôt, déplacement, altération) → disponibilité pour la collecte.

Les néocortex de colluvions correspondent à la surface des silex ayant subi les deux étapes décrites ci-dessus, avec comme étape supplémentaire l'intégration à un dépôt de pente n'entraînant qu'un déplacement limité suivant le profil transversal de la vallée.

Néocortex de type alluvial du réseau hydrographique récent

Exemple du type génétique F3 : échantillon 280-1, lit de la Borne (Saint-Vidal, Haute-Loire), objet archéologique S26-588 de Sainte-Anne 1, unité J1 (Polignac, Haute-Loire) (Fig. 3). La chaîne évolutive est la suivante : phase génétique → phase altéritique → phase altéro-détritique → intégration directe à un réseau hydrographique ou après phase colluviale (déplacement, immobilisation) → disponibilité pour la collecte.

Les galets observés ne possèdent pas (ou plus) les caractères particuliers propres au régime torrentiel. La phénomorphie est principalement déterminée par un gradient de polissage fort et par la remobilisation de la silice en surface.

Néocortex de type alluvial des formations anciennes

Exemple du type génétique F34 : échantillon 451-1, Naussac (Lozère) et objet archéologique R27-300 de Sainte-Anne 1, unité J1 (Polignac, Haute-Loire) (Fig. 3). La chaîne évolutive est la suivante : phase génétique → phase altéritique → phase altéro- détritique → intégration directe à un réseau hydrographique ancien ou après phase colluviale (déplacement, immobilisation en surface) → disponibilité pour la collecte.

Le gradient de polissage est fort, l'uniformisation de la surface est caractéristique. Ce type de surface très évoluée est caractéristique des épandages mio-pliocènes à galets aux limites de l'Ardèche et de la Haute-Loire.

Discussion

Les mécanismes naturels et/ou la taille par l'homme préhistorique contribuent, par l'affaiblissement des surfaces qu'ils affectent, à intensifier les processus d'altération. Les phénomènes mécaniques induisent la porosité secondaire et permettent la pénétration ou le départ d'éléments plus ou moins mobiles. Le mouvement des carbonates, de la silice et des autres éléments semble pouvoir être suivi à l'échelle de l'objet. Les différentes associations minérales et variétés morphologiques à la proche surface des éléments lithiques devraient pouvoir servir d'indicateur de mouvements à l'échelle métrique. La dissolution des différents minéraux provoque la mise en place d'une pellicule siliceuse [28,50,53], plus ou moins riche en quartz et en éléments exogènes. Chaque discontinuité majeure dans le développement du néocortex correspond à une discontinuité de la dynamique sédimentaire [12,42].

C'est l'examen simultané des facteurs mécaniques et chimiques, de leurs interactions, ainsi que de leurs relations avec la morphologie et le microrelief de l'échantillon, qui a permis de recenser cinq grandes familles néocorticales propres à trois types génétiques microcristallins présents dans les sites archéologiques étudiés (F14, Barrémien, F34, Bédoulien, F3, Sannoisien).

Conclusion

Les surfaces naturelles des outillages de Payre (Ardèche) et de Sainte-Anne 1 (Haute-Loire) portent encore les témoignages de plusieurs modifications antérieures à la collecte, significatives d'une histoire paléoclimatique et paléomorphologique complexe, comprenant des périodes d'altération chimique, des processus mécaniques, des chocs thermiques et une évolution de la composition due à la migration d'éléments plus ou moins mobiles ; leur comparaison avec les surfaces d'échantillons géologiques provenant de gîtes secondaires permet de reconstituer cette histoire prédépositionnelle, et participe donc très utilement à la reconnaissance des lieux de collecte.

L'exoscopie des silex, intégrant la diversité texturale et les polarités, révèle de nombreuses informations sur leurs milieux de résidence successifs et permet donc de caractériser des familles de gîtes secondaires identifiées par leur chaîne évolutive. Les grandes étapes de transport, naturel et anthropique, depuis le gîte primaire

Table 1
Theoretical presentation of the surface maturation during the silica evolutionary chain
Tableau 1
Présentation théorique de la maturation des surfaces lors de la chaîne évolutive de la silice

Types of outcrops	Stage	Morphology	Genetic surfaces or cortex	Postgenetic surfaces or neocortex
Primary	Alteritic	Original	Homogeneous or bipolarity (sedimentary criteria)	Not or little transformed
Sub-primary	Altero-detritic	Little transformed	Feeble heterogeneity or bipolar heterogeneity	Feebly heterogeneous
Colluvium	Colluvial	Partly to totally transformed	Feeble heterogeneity	Average to highly heterogeneous
Recent alluvial	Continental detritical	Partly to totally transformed	No more homogeneity or genetic bipolarity	Bipolar heterogeneous towards homogeneous
Old alluvial	Continental detritical	Totally transformed	No more homogeneity or genetic bipolarity	Quasi totally homogeneous
Marine	Marine detritical	Totally transformed	No more homogeneity or genetic bipolarity	Homogeneous

jusqu'au site archéologique, via les gîtes secondaires, sont ainsi décryptées.

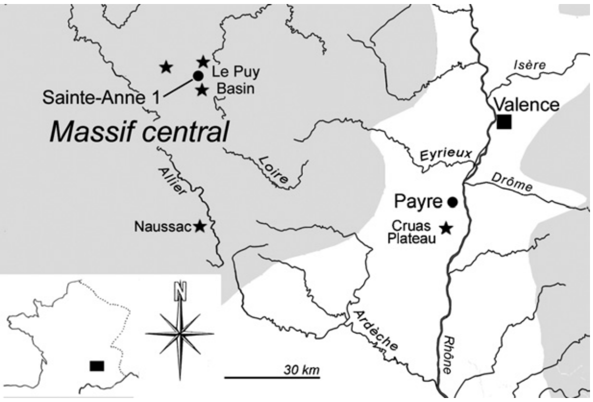

Fig. 1. Location map.

Fig. 1. Carte de localisation.

1. Introduction

Determining the origins of lithic raw material has long been considered essential to understand the collection behaviours of prehistoric societies. However, flint has usually proved relatively resistant to this approach. Numerous attempts to source this material based on its macroscopic aspect [15], on textures visible using an optical microscope [35], examination using a scanning electron microscope [3], by identifying its bioclastic contents [36], and by determining its chemical composition [33,45] have produced uneven results. However, the combination of ICP with petrographic tests gives good results [23]. The techniques that we applied decipher the evolution of flint according to its initial composition and its sedimentary environment [7,22,49,52]: the diagenesis yields flint of variable composition produced by post-genetic events that lead to mineralogical associations that are more homogeneous and richer in quartz in its peripheral zones.

Former approaches did not take sufficient note of the transformations that affected the flint during post-depositional phases. Identifying specific signatures in an artefact wholly modified by natural factors is a difficult operation. Flint possesses the texture of a palimpsest that first registers wear and alteration mechanisms linked to post-genetic processes (beginning within the very mother rock) [16,51]. Alteration and wear marks then appear, bearing witness to successive transport and static events in various different environments. Then follow processes involving gain or loss of material that conflict with and transform the initial textural aspects, especially those close to the surface. Some initial mineralogical components (calcite, opal, etc.), less stable than quartz, may experience important and early modifications, which have to be distinguished from late evolutionary transformations. The discriminating criteria are peculiar to the last place of residence of the flint and provide the characteristics for the end of the 'pre-depositional phase of the evolutionary chain', before the object was gathered by prehistoric man.

For a better reading of the modifications of the flint surface, and to give the most precise identification of prehistoric sources, we selected criteria characteristic of transformation conditions that can be compared to theoretical models and experimental results [2,14,37]. We relied on the conclusions of a large number of earlier works [1,4–6,8–11,13,14,19–21,24–27,29–32,34,37–41,43,44,46–48]. Nevertheless, this novel methodology does not imply any regularly occurring correspondence between the final state of a material (archaeological) and its initial state (geological). Archaeological pieces

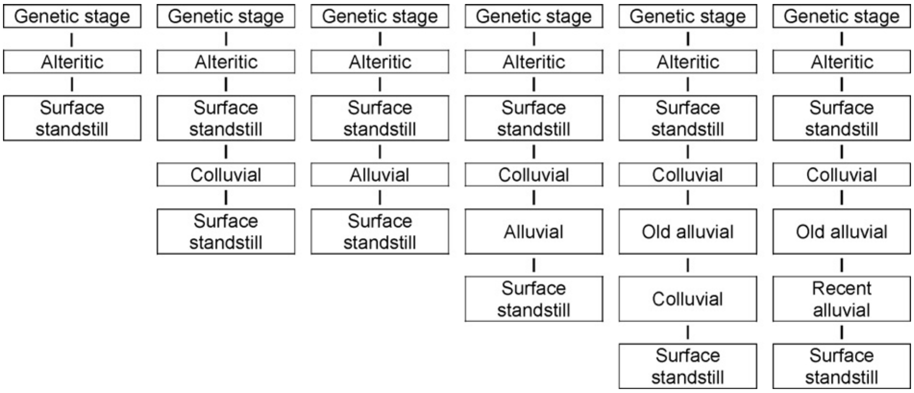

Fig. 2. Diagram of some phenomorphic evolutions of the post-genetic phase observed on artefacts from Payre and Sainte-Anne 1.

Fig. 2. Schéma de quelques évolutions phénomorphiques de la phase post-génétique, observées sur les objets archéologiques de Payre et de Sainte-Anne 1.

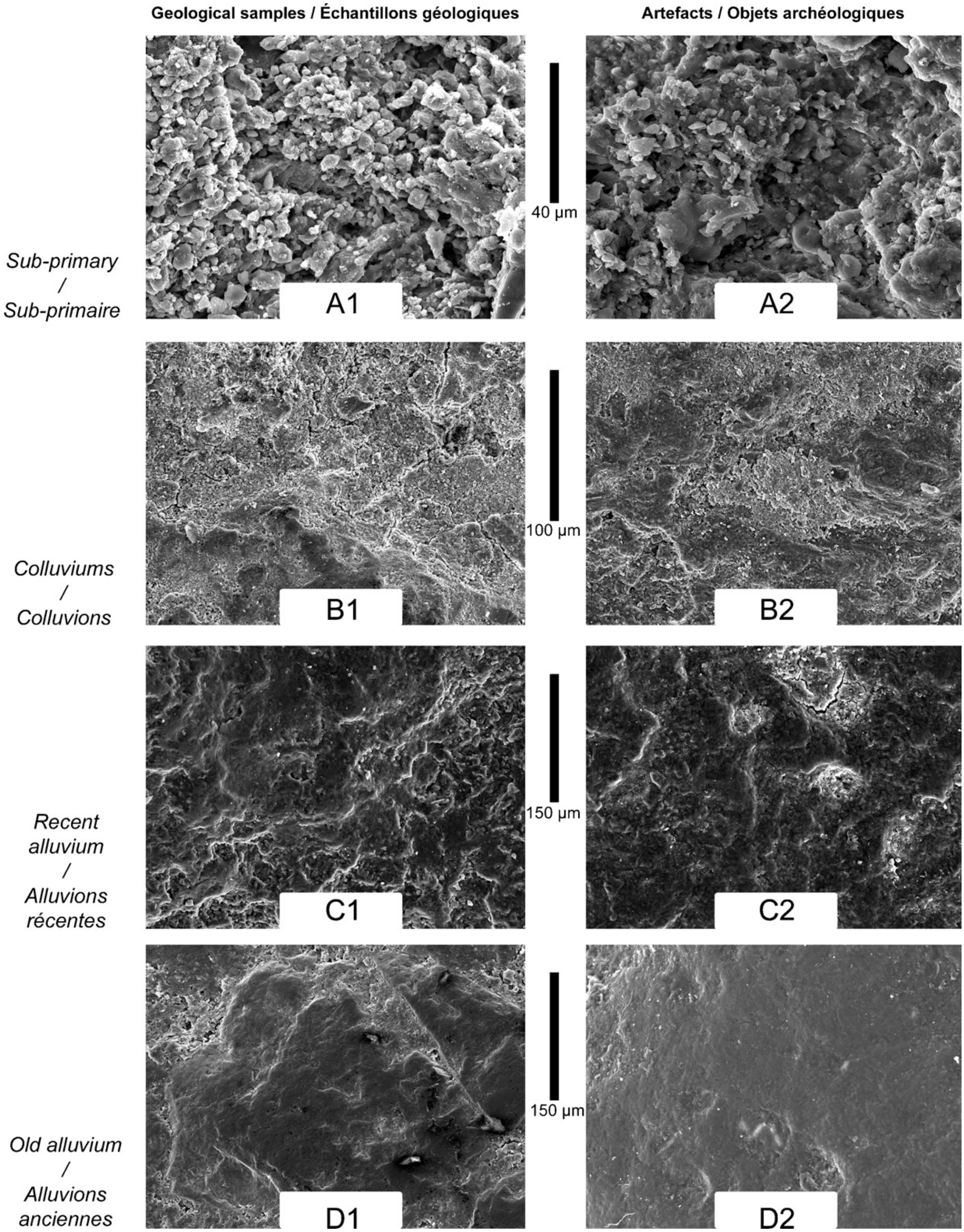

Fig. 3. SEM examination of the micromorphology of neocortex (surface, colluvium, recent alluvium, old alluvium). Facies of natural surfaces of geologic samples and of artefacts from Sainte-Anne 1 (Haute-Loire, France) and Payre (Ardèche, France). A1: Type F14, Barremian, hemi-pelagic facies, Le Pontet (Le Teil, Ardèche), sample in sub-primary position. A2: Type F14. Payre (Rompon, Ardèche), archaeostratigraphic unit Gb, artefact Q8 72.5, OIS 7. B1: Type F14, Barremian, hemi-pelagic facies, Terre du Charnier (Lagorce, Ardèche), sample in secondary position in colluvium.

were not – *ex abrupto* – compared to a sample coming from a primary deposit, but to a series of samples of the same material, initially co-genetical, derived from sub-primary and secondary deposits whose geological and geomorphological environments had previously been determined precisely.

Here we present the initial results of our microscopic observations of neocortex on geological and archaeological samples from the Ardèche and the Haute-Loire. The retained 'memories' of various mechanical and physicochemical phenomena provide a reasonably precise characterisation of prehistoric gathering places.

2. Samples

Samples were collected in the Massif Central and on its southern border (Fig. 1), during field prospecting in the Barremo-Bedoulian formations at Cruas (Ardèche), in the Sannoisian basin of Le Puy-en-Velay (Haute-Loire), and in the old Middle Palaeolithic industries of Payre (Rompon, Ardèche) and Sainte-Anne 1 (Polignac, Haute-Loire).

Our process is well adapted to comparisons between the depositional conditions for similar materials. We chose to analyse well-defined genetic types [16–18] of flint, whose presence in prehistoric sites is verified by macroscopic examination. The sub-primary outcrop zones in which we sampled included various colluviums, alluviums and scree deposits. For each deposit, 50 samples were collected, noting their internal polarity (vertical or horizontal) for comparison with the polarities in the mother-rock, and the relationship of the exposed surface of the sample to the one preserved in the alteration zones of the deposit. Among the artefacts of the two sites, we selected those belonging to the same type and that showed an inherited original natural surface.

3. Method of observation

Every sample was examined macroscopically and then using a binocular microscope. In order to consider all the evolutionary stages, particularly the most recent, we linked the stigmatic associations to the general morphology of the natural sample with respect to the genetic and post-genetic polarities (difference between exposed zone and protected zone). At this stage, it was necessary to examine several zones on the same sample, for the acquisition of stigma greatly depends on the successive morphologies acquired during transport phases. Morphometric examinations took into account the characteristics produced by blunting, flattening and the distribution of their products over the surface of the object. These parameters contribute to the recognition of the various mechanisms present at the production stage of any stigmatic associations. Once these mechanisms are identified, an evaluation can be made regarding their various interactions and the imprints they bear of subsequent mechanical actions and chemical processes.

In the case of artefacts, it is necessary to distinguish between those pre-depositional transformations for which stigma are preserved on the natural surface (neocortex), and those from the post-depositional changes that are only identifiable on the flaked surface. In the case of the geological samples, only neocortex is compared to the previously characterised surfaces. This process allowed us to distinguish between different geomorphological sites, and therefore the collection locations through the nature of the stigma associations that are identified and their repetition on the surfaces of the sample.

Examination by optical microscopy then permits the characterisation of the microfacies by its texture and mineralogy, the figured elements close to the surface and the porosity types. We can define three petrographic types for each mineral present:

B2: Type F14. Payre (Rompon, Ardèche), archaeostratigraphic unit Gb, artefact M5 1224, OIS 7. C1: Type F3, Sannoisian, lacustrine facies, Saint-Vidal (Haute-Loire), sample in secondary position in recent alluvium of minor bed. C2: Type F3, Sainte-Anne 1 (Polignac, Haute-Loire), archaeostratigraphic unit J1, artefact S26-588, OIS 6. D1: Type F34, Bédoulien, hemipelagic facies, Naussac (Lozère), sample in secondary position in old alluvium. D2: Type F34, Sainte-Anne 1 (Polignac Haute-Loire), archaeostratigraphic unit J1, artefact R27-300, OIS 6.

Fig. 3. Micromorphologies néocorticales (surface, colluvion, alluvion récente et alluvion ancienne) vues au MEB en électrons secondaires. Convergences de faciès entre les surfaces d'échantillons géologiques et les surfaces naturelles des objets archéologiques des sites de Sainte-Anne 1 (Haute-Loire, France) et Payre (Ardèche, France). A1 : Type F14, Barrémien, faciès hémipélagique, Le Pontet (Le Teil, Ardèche), prélevé en position subprimaire. A2 : Type F14. Payre (Ardèche, France), unité archéostratigraphique Gb, objet archéologique Q8 72.5, stade isotopique 7. B1 : Type F14, Barrémien, faciès hémipélagique, Terre du Charnier (Lagorce, Ardèche), prélevé en position secondaire dans des colluvions. B2 : Type F14. Payre (Ardèche, France), unité archéostratigraphique Gb, objet archéologique M5 1224, stade isotopique 7. C1 : Type F3, Sannoisien, faciès lacustre, Saint-Vidal (Haute-Loire), prélevé en position secondaire dans le réseau hydrographique actuel. C2 : Type F3, Sainte-Anne 1 (Polignac, Haute-Loire), unité archéostratigraphique J1, objet archéologique S26-588, stade isotopique 6. D1 : Type F34, Bédoulien, faciès hémipélagique, Naussac (Lozère), prélevé en position secondaire dans les alluvions anciennes. D2 : Type F34, Sainte-Anne 1 (Polignac, Haute-Loire), unité archéostratigraphique J1, objet archéologique R27-300, stade isotopique 6.

- replacement, in the case of substitution of a precursor mineral;
- cementation or infill, in the case of mineral precipitation in a void;
- recrystallisation, with subsequent change of size and shape of the crystals – this is usually a final stage in the sequence.

The peripheral zone of the object is generally transformed to a greater extent than the internal portions and, in the case of artefacts, an age difference is evident between the zone immediately beneath the neocortex and that beneath the flaked surface.

The SEM images (Jeol JSM-6460 LV) were made with magnifications from 100× to 6000× in secondary electrons under a tension of 20 kV after metallisation with gold. Observations were made to distinguish the lower from the upper faces as well as differentiating between protected and exposed zones (when the latter are discernible). In the first place, we took, for each zone, samples on each relief type (border, main edge, flat surface, and depression). One observation was that flat surfaces and depressions in the less exposed zones retained pertinent differentiating characteristics. In the case of artefacts, a sample was taken on the natural surface carrying pre-depositional characters and on the flaked surface that registered post-depositional processes.

4. Results

Various stigma associations identified on the surface of geological samples were also found on artefacts from units Gb at Payre and J1 at Sainte-Anne 1, despite the existence of very different genomorphic and phenomorphic processes [32]. These facies are convergent. We can then consider, for both cases, the natural surfaces of the artefacts as good indicators of the presence of specific stages of evolution within the resident environment from which prehistoric people gathered their raw material.

Our study allows us to propose a model of the surface evolution of flint pieces (Fig. 2). Depending on the distance from the source, the general tendency is a gradual disappearance of assemblages and genetic forms. Simultaneously, the development of secondary porosities (vesicular or intra-matrix), of impregnations with exogenous elements and the arrival of new mineral forms occurs. However, the most common phenomenon is the accretion of a surface film that becomes richer in silica through time. This appears first as a coating, then develops into a cementation. SEM allows the observation of the progression of these processes in the five recognised types of secondary deposits (Table 1).

4.1. Primary position neocortex

The evolutionary chain is as follows: genetic phase → weathering and decaying phase → final stasis → availability for gathering.

As soon as flint is formed, it acquires a peripheral mineral texture (the cortex) that constitutes part of its memory. The zones formed during this development permit, in most cases, the characterisation of its original geological contextual layer. At this stage, flint lacks any trace of mechanical alteration but, in some active hydrological environments, hydric alteration begins well before the flint becomes exposed to the atmosphere. Until now, we have only observed transformed facies in primary deposits. We classify these surfaces as neocortex resulting from weathering and decay, the flint having been subjected to alteration in the heart of its mother rock, but never having moved from that location. The surface of such samples is little modified, and its evolution is restricted to dissolution and remobilisation of silica. The general appearance of the surface is of a mass of grains aggregated in the protected zones; on more exposed parts they are poorly compacted, but carry areas of a coating that forms thin flows.

4.2. Surface neocortex, indicating a sub-primary position

In the case of genetic type F14, sample 338-1.8, Le Pontet (Le Teil, Ardèche) and artefact Q8 72.5 from Payre (Rompon, Ardèche) (Fig. 3), the evolutionary chain is as follows: genetic phase → weathering and decaying phase → altero-detritic phase (removal and slight moving) → availability for gathering.

These flints have been exposed in outcrops and then subjected to one or more changes linked to weathering and pedological phenomena. Surfaces are mildly to highly modified, but do not exhibit traces of mechanical transport *sensu stricto*. Nevertheless, traces of mechanical wear due to slight movements (by rainwater or gravity) are visible on the main edges, unless these are completely masked by dissolution of the edges late in the evolutionary sequence or by cementation following final stasis. At this stage, our diagnosis is based on the absence or coalescence of abrasion in the hollow parts of the micro-relief. If evidence of abrasion is present, the sample cannot be listed in the ‘surface neocortex’ category.

Other phenomorphic characters present include the following:

- progressive detachment between adjacent grains;

- appearance of intense dissolution surfaces in the flatter parts and in the depressions (in exposed zones);
- presence of inherited surfaces (thus far protected);
- commencement of a coating on the prominent (or flatter) parts.

These coatings, sometimes invasive, are thin and mostly porous. Shrinkage cracks gradually appear in the recently exposed zones. The coating gradually takes on a flaky aspect (a dissolution indicator). For this type of facies, the variability is usually the consequence of the genetic porosity of the samples. This deposition of a coating that gradually increases in thickness over time modifies the sample's mineral composition as the original elements disappear through replacement.

4.3. Colluvium neocortex

On genetic type F 14, sample 333-1-6, Terre du Charnier (Lagorce, Ardèche) and artefact M5 1224 from Payre (Rompon, Ardèche) (Fig. 3), the evolutionary chain is as follows: genetic phase → weathering and decaying phase → altero-detritic phase → colluvial phase (incorporation in a deposit, movement, alteration) → availability for gathering.

In this group, the surfaces of the flint have been subjected to both stages described above, followed by integration into a slope deposit. They have subsequently undergone a limited movement that usually follows the transversal profile of the valley. The main phenomorphic characters are the following:

- most of the surface is covered with a thin coating;
- depressions receive a clear coating;
- surfaces are progressively invaded by solutions originating from the exterior environment.

The first environment obliterates the original inherited characteristics, traces of which are usually only preserved in hollows. For this facies, the less stable genetic forms have disappeared, and many shrinkage cracks develop. Coating dominates the surface, and cementation is localised on prominent protuberances. Individual grains remain visible under the coating. Furthermore, in most cases, this coating is thicker (90 μm at most) than the general surface cortex. On other areas, dissolution of pedological origin removes the coating and reveals areas where individual grains are more or less detached from each other. This process generally begins along the margins of shrinkage cracks. Under this coating, the more or less sharp angles of the grains remain discernible and light to medium etching or scraping marks due to minimal movement are also evident. Traces of mechanical actions like battering are confined to the prominent edges. This facies type seems to indicate a proximal environment, close to the outcrop zone.

4.4. Alluvial-type neocortex from the current hydrological network

On genetic type F3, sample 280-1, minor bed of river La Borne (Saint-Vidal, Haute-Loire) and artefact S26-588 from archaeostratigraphic unit J1 at Sainte-Anne 1 (Polignac, Haute-Loire) (Fig. 3), the evolutionary chain is the following: genetic phase → weathering and decaying phase → altero-detritic phase → integration into a hydrological network directly or following a colluvial phase (moving, stasis) → availability for gathering.

None of the observed pebbles possesses the characteristics specific to extensive weathering expected from their presence in a torrential flow. However, the surfaces exhibit a high polish gradient and show evidence of recent weathering of the exterior. This facies has a thick coating that covers the whole object, but becomes thinner towards the margins. The coating is smooth in protected zones and flaky in exposed zones. Recent polishing and weathering events obliterate most of the usually crescentic or V-shaped scars produced by mechanical events. The few cusps and conchoidal fractures that are visible apparently belong to a previous stream-borne phase. The substantial edges retain deep and unpolished crescentic traces indicating either recent battering or the preservation by the surface relief of a previously battered zone. From the thickness and distribution of the coatings as well as the concentration of the traces of mechanical modifications, it seems that this facies originates in an alluvial environment of low to medium energy. Furthermore, the presence of dissolution traces (areas with flaky surfaces) indicates that recent pedological processes have also occurred. These traces, in which feebly attached grains abound, mainly extend out from crack depressions and the borders of features produced by mechanical surface alteration.

4.5. Neo-cortex of ancient alluvial type

These samples originate from Mio-Pliocene alluvial deposits, of genetic type F34: sample 451-1, Naussac (Lozère) and artefact R27-300 from archaeostratigraphic unit J1 at Sainte-Anne 1 (Polignac, Haute-Loire) (Fig. 3). The evolutionary chain is as follows: genetic phase → weathering and decay phase → altero-detritic phase → integration into a hydrographic network either directly or after a colluvial phase (moving, stasis) → availability for gathering.

The polishing gradient is high, with characteristic uniformity of surfaces. Coatings are thick, but do not completely obliterate traces of older mechanical alteration, still visible as cups and crescents. The torrential phase is obvious, despite the effects of later processes. Thrusting and saltation activities of coarse elements in the deposits leave their traces on the flat surfaces, a stigma absent from pebbles from later Pliocene networks. These asperities are subsequently affected by intense abrasion and several wear stages can be identified. Prominent surfaces are clean, flat surfaces are irregular, In the deepest depressions, silica spherules produced by deposition of silica-rich solutions or by bacterial activity (or both) are intimately cemented into the coating and give a heterogeneous aspect. Neogene quartz areas are noticeable. Numerous dissolution casts of pedological origin transform the coating, mainly on flat faces, which then exhibits a flaky appearance. Many pores are scattered across the smooth surface, generally surrounding areas of Neogene quartz. Furthermore, some X-shaped cracks, probably old shrinkage cracks, exhibit a polish contemporaneous with the old alluvial phase. This type of much evolved surface is characteristic of the Mio-Pliocene debris-flow deposits of pebbles found around the borders of Ardèche and Haute-Loire.

5. Discussion

The SEM study of more than a hundred geological samples and prehistoric artefacts allowed us to isolate a number of surface characters that distinguish flint objects that have passed through and resided in various geological environments.

By weakening the surfaces they modify, natural mechanisms and/or flaking by prehistoric man contribute to the intensification of the alteration processes. The mechanical phenomena result in secondary porosity that allows the penetration into the surface part of the flint or departure from it of the more or less mobile elements.

Thus in each object we have been able to trace the movement of carbonates, silica and other elements. These different mineral associations and morphological varieties seen close to the surface of lithic elements can be used as a metrical indicator of movement. When the dissolution of the different soluble minerals occurs among the lateral irregularities at the surface and in the secondary underlying network of macropores, the weathering event leads to the deposition of a new siliceous coating rich in quartz and exogenous elements, whose composition is peculiar to the residence environment [28,50,53]. The precipitation of these films or coatings occurs in response to the geological environment and the position of the object within that environment. These characteristics allow the identification of specific localities to be deduced for the artefacts studied.

Each major discontinuity in the development of the neocortex corresponds to a discontinuity in the sedimentary dynamics [12,42]. In fact, most changes and evolutionary steps are linked to the circulation of the dissolving and precipitation processes, which are different for each move made by the object into a new locality or environment, which subsequently produces a new series of surficial alterations.

The well-defined genomorphic and phenomorphic characteristics on the surfaces of the artefacts and their particular and sequential associations allowed us to establish the various stages of transformation to which each sample object was subjected. The micromorphological signatures we describe are the result of the sensitivity of the surfaces to post-genetic alterodetritic processes. Examination of the objects using the SEM allowed us to determine ‘evolutionary chains’ peculiar to the different neo-cortical families.

The simultaneous consideration of mechanical and chemical factors and of their various interactions and relationship with the morphology and micro-relief of the sample allowed us to categorise five broad neo-cortical families peculiar to three microcrystalline genetic types present in the studied archaeological sites (F14, Barremian, F34, Bedoulian, F3, Sannoisian). The five large families defined for the geological area we studied are closely dependent upon their various occurrences within the broader localities, particularly their topography, and also upon the geological processes governing water circulation at every scale.

A comparison between the surfaces of the material in its natural state and their equivalent surfaces preserved on humanly modified artefacts allows us to evaluate the alteration processes and to identify the final resting place from which it was collected in prehistoric times.

This result suggests that, despite the existence of an infinite number of post-genetic variants within one secondary deposit, all flints exhibit a similar evolution when they are subjected to a series of globally similar phenomena. This variability depends mainly on the size, the nature and the distribution of the mineral species constituting the orthochem.

The more evolved the flint surface, the more homogenous it is at the mineral level. The most obvious process we identified is the silicification of the periphery of objects with microcrystalline quartz. The diversity of primary forms (calcite, chalcedony) is low or perhaps modified by alteration a result of ‘aging’. This maturation indicates a balance with the resident environment.

Like other authors, we have noticed that the transfer of materials begins along cracks and the interstices between grains and that it is definitely the width of the intergranular spaces (made of matrix <3 μm) that determines part of the process involving loss of mass. Any cessation of the process probably indicates a change of residence.

6. Conclusion

Setting aside the post-depositional processes, this work attempts to define the pre-depositional dynamic identifying the palaeogeographic position of flint at the time of its collection from the geological environment during prehistory.

The natural surfaces of assemblages from Payre (Ardèche) and Sainte-Anne 1 (Haute-Loire) still carry evidence of several surficial modifications that occurred prior to their collection, and these indicate a complex palaeoclimatic and palaeomorphological history. This history consisted of periods of chemical alteration, mechanical alteration, thermal shocks, and an evolution of the chemical composition due to the migration of soluble elements. Comparisons between the surfaces of the artefacts and the surfaces of geological samples coming from secondary deposits allowed us to reconstruct this pre-depositional history and contributed to the recognition of the various collection sites.

Exoscopy, integrating the textural characteristics and diversity of polarities, revealed information about the successive residence environments and allowed us to characterise the families of secondary deposits identifiable by their positions in an evolutionary chain. The main transport stages, either natural or anthropic, that occurred following primary deposition through secondary deposits until final lodgement in the archaeological site is deciphered with this information.

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