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Knappers working together.

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Front cover image: *Knappers working together* (by Georgeta Simion).
Title image: *Modern aboriginal knapper in Kimberley, NW Australia* (by Val Waldorf, based on a photograph).
Back cover image: *A flint knapper* (by Georgeta Simion).

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Contents

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Event reviews

Second year and running strong

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Welcome to another issue of the Journal of Lithic Studies. This issue in fact marks our second year of publishing. We are definitely pleased with the progress that we have made so far and some of the new ideas that we have tried out.

One of our objectives in establishing JLS has been to introduce new ideas of how academic material can be published. Not only have we been encouraging researchers from a variety of countries and regions to submit their research to this journal, but we are also trying out different ideas to see how best we can disseminate research, findings, and other news.

This year we have started to publish in additional languages. A general topic issue, guest edited by Xavier Mangado, will be published in Spanish later this year. In connection with our publishing in Spanish, we have updated the journal’s web site interface which is now available in both English and Spanish. Yan Axel Gómez Coutouly is guest editing a French language special topic issue on *chaîne opératoire* which we expect to come out in the middle of next year.

As well, we have started to other publish special topic issues. In addition to the *chaîne opératoire* issue currently in production, we are planning several other special issues, which are currently scheduled throughout 2016.

This has been a good year for collaborations with symposia, meetings and other academic events. We will be publishing the proceedings of several UISPP and EAA sessions from 2014 as well as independent symposia from 2015 as either special topic issues or issues dedicated to those events. The previously mentioned special topic issue on standing stones and megaliths is comprised of articles from presenters at the 2014 UISPP session “Standing stones and megalithic monuments in context”. Also from the 2014 UISPP is a special theme issue based on presentations from the session “Beyond the reduction sequence: new insights in lithic technology” which is being guest edited by Sara Cura. We have agreed to publish the proceedings of the "Ground Stone & Society" international workshop (Haifa, July 2015), organised by the Association for Ground Stone Research (http://agsr2015.haifa.ac.il/). Danny Rosenberg will be guest editing this special topic issue. Not least of all, we are again collaborating with the organisers of the International Symposium on Knappable Materials (http://www.ub.edu/cherts-symp2015/), hosted by the University of Barcelona in September this year. This issue holds particular interest for us since the first issue of JLS was also dedicated to the proceedings of the previous symposium in this series. We are also discussing collaborations with other scientific event organisers about publishing their proceedings. We are very happy to lend our support to any lithics related event.

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Over the last year we have also been working hard to increase circulation and recognition of the journal by getting it included in international databases and indexes. Among these, some of the more well-known include DOAJ (the Directory of Open Access Journals) (https://doaj.org/toc/2055-0472), ERIH PLUS (the European Reference Index for the Humanities and the Social Sciences) (https://dbh.nsd.uib.no/publiseringskanaler/erihplus/periodical/info?id=486045), and recently Thomson Reuters Web of Science ESCI (Emerging Sources Citation Index).

We have published the six month and twelve month download and view reports for articles in the 2014 issues. We intend to continue doing this so that the status of our articles can be publicly evaluated and to keep our journal as transparent as possible. We feel that it is important for potential authors to be able to evaluate how much (or how little) coverage their articles would likely get if they publish in JLS. Very few journals do this but we hope that this policy will catch on throughout the academic publishing industry.

We have done very well in these first two years. We have moved forward a great deal. Hopefully we will carry on with the momentum and continue to develop and try out new ideas. In this way we also hope to attract the interest of an even larger audience. We are always interested in new ideas on how to improve academic publishing - how to make it more accessible, how to make it more appealing to more people, how to attract more readers. We look forward to another year of success in 2016.

Otis Crandell

Editor-in-Chief
Journal of Lithic Studies

Research articles

Arran pitchstone (Scottish volcanic glass): New dating evidence

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Abstract:

In the present paper, the author offers new absolute and contextual dating evidence for Scottish archaeological pitchstone. Much archaeological pitchstone from the Scottish mainland is recovered from unsealed contexts of multi-period or palimpsest sites, and pitchstone artefacts from radiocarbon-dated pits therefore provide important dating evidence for this material group and its associated exchange network. In Scotland, all archaeological pitchstone derives from outcrops on the Isle of Arran, in the Firth of Clyde, and on the source island pitchstone-bearing assemblages include diagnostic types from the Mesolithic, Neolithic and Early Bronze Age period. Off Arran, pitchstone-bearing assemblages never include Mesolithic types, such as microliths, suggesting a post Mesolithic date. This suggestion is supported by worked pitchstone from radiocarbon-dated pits, where all presently available dates indicate that, on the Scottish mainland, Arran pitchstone was traded and used after the Mesolithic period, and in particular during the Early Neolithic period.

Keywords: pitchstone, volcanic glass, Neolithic, radiocarbon dating, contextual dating, pits, prehistoric exchange

1. Introduction

In 2009, the author concluded the project *Archaeological Pitchstone in Northern Britain* with the publication of a monograph in which he discussed various issues relating to this topic (Ballin 2009a). The main reason for undertaking the project was the fact that the number of artefacts in this raw material, as well as the number of pitchstone-bearing sites, had multiplied exponentially. When Williams Thorpe & Thorpe (1984) published their important paper on the topic, only approximately 1,400 pieces of worked pitchstone were known, from *c*. 100 find locations, but in 2009 approximately 20,300 pieces had been recorded, from *c*. 350 sites. The aim of the present paper is to present new absolute and contextual dating evidence for Scottish archaeological pitchstone.

Before proceeding any further, it may be relevant to first explain to readers based outside Scotland what pitchstone is. Basically, pitchstone is a very close ‘relative’ of obsidian.

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Obsidian and pitchstone are both defined as being forms of acid volcanic glass, but first and foremost by containing more or less water. In Ballin & Faithfull (2009, 5), the authors wrote:

> Pitchstone is glassy, usually silica-rich, igneous rock with a characteristic lustre resembling that of broken pitch. Pitchstones are generally held to be hydrated equivalents of obsidians, although the usage of both terms [...] has often been imprecise (cf Pellant 1992).
>
> The International Union of Geological Sciences has recently published a comprehensive nomenclature scheme for these and other igneous rocks (Le Maitre 2002). Here, the term pitchstone is restricted to hydrated glassy rocks (typically 3–10% H^2O), while obsidians are nearly anhydrous (< 1% H^2O). Most pitchstones have > 5% H^2O, and most obsidians < 0.5%.

Some definitions suggest that obsidian is pure whereas pitchstone contains crystalline inclusions, but this statement is so overly general that it must be characterized as less than helpful. Some rare obsidians (low water content) contain phenocrysts, spherulites or crystalites, whereas some pitchstones (high water content) are entirely aphyric. Although the higher water content frequently gives pitchstone a tar-like lustre (thus its name), whereas obsidian generally has a highly vitreous lustre, it may be almost impossible to distinguish (on the basis of hand-samples) between the purest aphyric pitchstones (such as some of the material from the 'greater' Corriegills district on the Isle of Arran, Scotland; Ballin & Faithfull 2009) and common obsidian (see Figure 1). As it is the impression of this author that there are more similarities than differences between pitchstone and obsidian, he has recently suggested that pitchstone ought to be perceived as a form of obsidian (Ballin 2014).

The main publication of the project *Archaeological Pitchstone in Northern Britain* (Ballin 2009a) dealt with a number of different issues relating to the procurement of pitchstone on the Isle of Arran – the location that has been proven, by petrological and geochemical analyses, to be the source of all archaeological pitchstone (Preston *et al.* 1998; 2002) – as well as the manufacture, distribution, use, and deposition of pitchstone artefacts throughouth northern Britain (Figure 2). One of the most interesting questions relating to prehistoric pitchstone use is arguably the procurement and exchange of this raw material and of pitchstone artefacts, and what this tells us about the nature of Neolithic society (Ballin 2008). However, for this discussion to take place, it was necessary to date archaeological pitchstone, both on the source island Arran, and at locations off this island. Any interpretation of a pitchstone exchange network would obviously be affected by the dates relating to artefacts in this raw material, that is, whether the exchange took place between more or less stratified societies.

When Williams Thorpe & Thorpe (1984) presented their paper, the dating evidence was weak, and it was generally thought (and understandably so) that pitchstone might have been exchanged across northern Britain during most of Scottish prehistory, including the Mesolithic, Neolithic and Bronze Age periods. In 2009, after the recovery of much more archaeological pitchstone, it was possible to show that the exchange of this raw material, from Arran to the rest of northern Britain, probably mainly took place during the Early Neolithic period (two diagnostic chisel-shaped arrowheads from Biggar and Glenluce Sands indicate that this exchange may have ended around, or shortly after, the Early to Middle Neolithic transition; Ballin 2009a), although with some later use in Argyll & Bute (which might have formed one part of a social territory in which Arran was also included) and Orkney in the far north (which in many respects represents a 'special case'; ibid.). Since 2009, a considerable amount of new dating evidence has come to light, and this has confirmed a Late Neolithic phase of pitchstone use and exchange along the western seaboard of Scotland and extending as far north as Orkney (Richards 2005). This appears to be part of a reciprocal movement of ideas, objects and people at that time – the use of Grooved Ware and timber and stone circles spreading south-westwards down the Atlantic façade and, among other things, pitchstone northwards along the same route (Sheridan 2004).

Figure 1. Pitchstone blades and microblades from Auchategan, Argyll & Bute (Marshall 1978; Ballin 2006) (photo by Beverley Ballin Smith).

The purpose of the present paper is to present this new evidence, which generally relates to the recovery of pitchstone from pits, and which makes available a series of absolute radiocarbon dates. The archaeological pitchstone from pits is also dated indirectly through association with prehistoric pottery, and in addition this pitchstone provides supporting dates, through association in these same pits, for the importation into Scotland of axeheads of tuff (petrological Group VI) from Great Langdale in Cumbria (Bradley & Edmonds 1993).

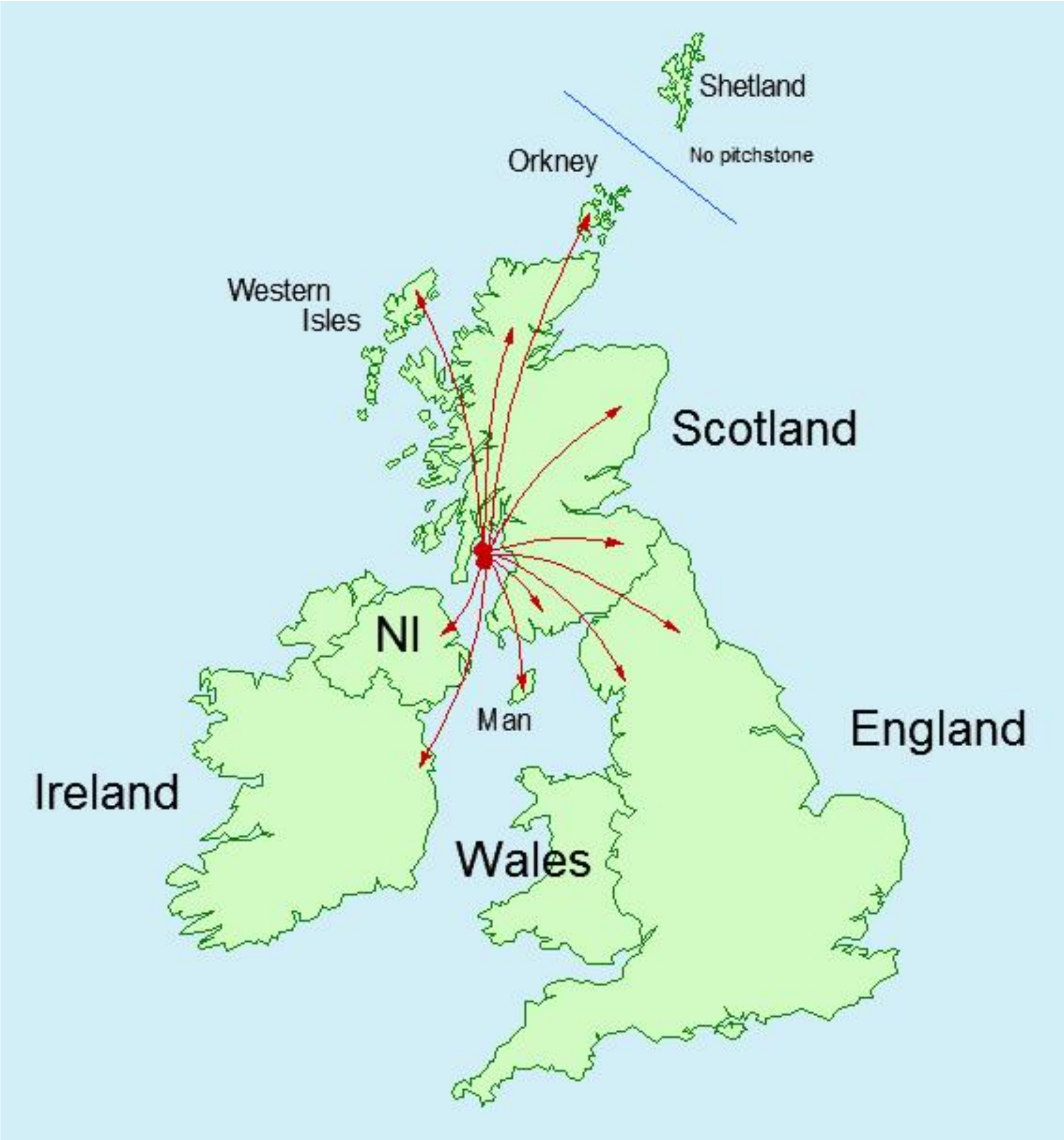

Figure 2. The distribution of archaeological pitchstone across northern Britain from the Isle of Arran in the Firth of Clyde, west of Glasgow. The only part of northern Britain where pitchstone artefacts have not been recovered is Shetland, where a marked insularity in the use of raw materials is evident (Ballin 2011c). The distance from Arran to Orkney is c. 400km. Pitchstone is expected – in due course of time – to be identified in assemblages further towards the south where it may have been misidentified as black chert, black flint, jet or glassy slag (Ballin 2008).

2. General dating evidence

The dating of archaeological pitchstone, as presented in Ballin (2009a), relies partly on positive evidence (the *presence* of diagnostic elements) and partly on negative evidence (the *absence* of diagnostic elements). The author fully accepts that absence of evidence is not necessarily evidence of absence, but when specific types, raw materials, technological attributes, etc. remain elusive in a large body of finds (such as the now numerous pieces of worked pitchstone recovered on the Scottish mainland) absence of for example certain implement forms may represent important circumstantial evidence.

On Arran itself, pitchstone was clearly used throughout the Mesolithic – Early Bronze Age period. The project *The Early Settlement of Arran: the archaeology of the Water Ring Main*, carried out by GUARD, University of Glasgow in 1999, showed that all diagnostic types usually associated with Mesolithic lithic assemblages are known from Arran, such as microliths and burins (pers. comm. John Atkinson, GUARD Archaeology Ltd.). Other diagnostic pitchstone artefacts have also been found on Arran, such as leaf-shaped, chisel-shaped, oblique and barbed-and-tanged arrowheads (Haggarty 1991; Finlay 1997; and author's inspection of finds in Arran Museum).

The author's examination prior to 2009 of almost all archaeological pitchstone recovered on the Scottish mainland, and on other Scottish islands, showed that although most pitchstone blades are as narrow as those usually associated with Late Mesolithic assemblages (Figure 1, bottom row), the large number of available pitchstone artefacts from these parts of Scotland included no diagnostic Mesolithic types – not a single microlith was identified. Furthermore, the probable absence of pitchstone microliths on the Scottish mainland has recently been confirmed by the recovery of a large pitchstone assemblage at Stanton West, near Carlisle, which included microblades but no diagnostic Mesolithic types (Dickson forthcoming). Although, at Stanton West, the pitchstone artefacts were associated with a Mesolithic scatter, the context from which they were recovered was unsealed and as the site in general also includes diagnostic Neolithic material (Brown 2013) this association has little value in terms of safely dating the pitchstone artefacts.

However, leaf-shaped points – an Early Neolithic artefact type – are known off Arran, as are a small number of Middle Neolithic chisel-shaped arrowheads. This, and other supporting evidence, led the present author to suggest that, in general, the pitchstone exchange network on the Scottish mainland probably dates largely to the Early Neolithic, with the exchange slowly decreasing around the Early to Middle Neolithic transition, at the time when we see a massive increase in the importation of Yorkshire flint into Scotland from the opposite direction, as well as the introduction in Scotland of the innovative Levallois-like knapping technique (Ballin 2011a; 2011b).

3. Pitchstone from radiocarbon-dated pits

In 2009, only a small number of pitchstone artefacts were known from radiocarbon-dated pits, and several of these dates were characterized by quite large standard deviations, such as one from Carzield, and one from Chapelfield (Figure 3). Since then, numerous pits containing worked pitchstone have been excavated in Scotland. These are listed in Table 1.

It is obvious from Figure 3 that deposition of pitchstone in pits, and thereby the exchange of pitchstone between Arran and the rest of Britain, is predominantly an Early Neolithic phenomenon, as also suggested by other evidence (above). Although some of the pitchstone in the pits is in the form of flakes, several pieces are microblades or very narrow macroblades (in Scotland, as well as in Norway, blades tend to be generally narrower than those of other parts of Europe, for which reason consensus in Scotland and Norway is to distinguish between microblades and broad blades as pieces narrower and broader than 8mm [Ballin 1996; 2000]; this is essential in terms of distinguishing between the microblade and broad blades industries of Norway and Scotland). Most of the pits also contained other lithics, either flint, chert or quartz, and a flint artefact from Pit 7 (which contained the site's pitchstone) underneath Fordhouse Barrow was identified as an Early Neolithic leaf-shaped point. As many as 12 out of the 14 pits contained Early Neolithic pottery of the Carinated Bowl tradition, in either its ‘traditional’ or ‘modified’ versions (See Sheridan 2007 for a definition of these terms). Four pits contained one or more flakes struck off Group VI axeheads; and four pits contained burnt bone, with the bone from two of these having been identified as human (Maybole).

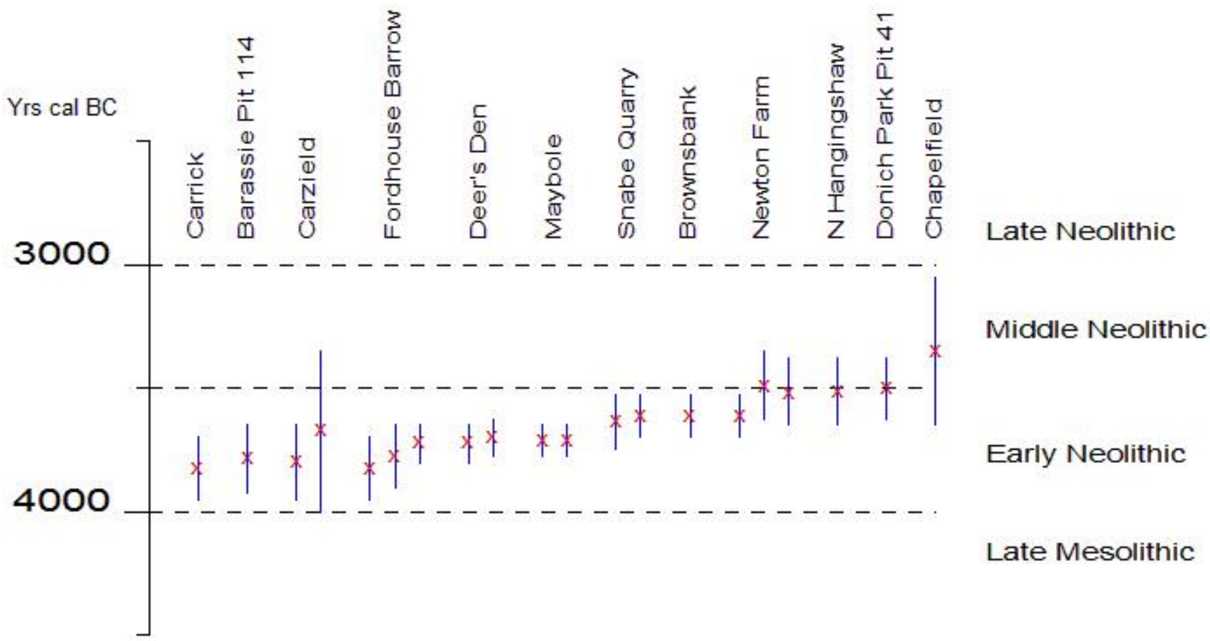

Figure 3. Radiocarbon dates relating to pitchstone-bearing pits (site names along the top of the diagram). Note that the dates from Fordhouse Barrow are TAQ dates provided by charcoal recovered immediately above the pitchstone-bearing pit; a leaf-shaped point from this pit defines the deposition as EN, and the pitchstone from the Fordhouse Barrow pit therefore clearly dates to the first half of the Early Neolithic.

The pit underneath Fordhouse Barrow has not been dated by charcoal from the pit itself, but the leaf-shaped flint point associated with the pit’s pitchstone defines the small assemblage as definitely post-Mesolithic, and the three listed radiocarbon dates (Table 1) are from the barrow’s Phase 3B immediately above the pit, thus providing TAQ dates for the pit.

In addition to the radiocarbon-dated pitchstone listed in Table 1, pitchstone has also been indirectly dated by association with Early Neolithic pottery of the Carinated Bowl tradition. Three pitchstone blades or microblades were recovered from three pits at the Elginhaugh Roman Fort (Midlothian), all containing this kind of Early Neolithic pottery (note that in the Elginhaugh publication, the lithics report dates these blades to the Late Neolithic or Early Bronze Age, although the same volume’s pottery report clearly identifies the pottery from the pits as belonging to the Carinated Bowl tradition: Clarke 2007; MacGregor 2007). From a pit at the Roman Fort Bishopton, Whitemoss (Renfrewshire), two pitchstone ‘chips’ were recovered, also associated with pottery of this tradition, as is clear from Piggott’s description:

> ‘Beneath the Roman Fort, Professor Piggott found eight shallow oval or circular pits containing black greasy soil, a flint leaf-shaped arrowhead and a scraper, two chips of Arran pitchstone, and pottery of the type found at Bantaskine, Easterton of Roseisle and Lyles Hill, Belfast’ (Trump 1956, 218).

Furthermore, a small collection of worked pitchstone was recovered from what is now perceived to be an Early Neolithic timber hall – the greater of the two halls at Doon Hill, East

Lothian (Ballin 2009b; Brophy & Sheridan 2012, 62). A 10mm wide pitchstone blade was recovered from one of two twin roof-bearing posts in the central part of the hall, with another five pieces of burnt pitchstone deriving from two southern wall posts. In addition, a 12mm wide blade was recovered from a posthole in the hall’s north-eastern corner. Moreover, the pitchstone was associated with a leaf-shaped arrowhead of flint, recovered from a posthole in the hall’s northern long-side, as well as pottery of the Carinated Bowl tradition.

4. Conclusion

In general terms, the evidence provided by the pitchstone artefacts from radiocarbon-dated pits, and the common association of the worked pitchstone with pottery of the Carinated Bowl tradition, strengthens the date of archaeological pitchstone suggested in Ballin (2009a), that is, that the exchange of pitchstone from Arran and across northern Britain was predominantly an Early Neolithic phenomenon (apart from the aforementioned later exchange route along the Atlantic seaboard) which slowed down and finally fell apart as a new exchange system, and perhaps a new form of social organization, was born, that of Yorkshire flint (Ballin 2011b).

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Table 1. Radiocarbon-dated pits containing worked pitchstone, plus details of the radiocarbon dates that provide a taq for pitchstone use at Fordhouse Barrow.

CAT	Site	Local authority areas	Ref.	Context	Code	Lab date BP	cal BC, 95.4% probability	Carinated Bowl pottery	Group VI	Full assemblage (CB = Carinated Bowl)
1	Carzield	Dumf & Gall	Maynard 1993	Pit	Beta-68480	5010±70	3960–3660	x	x	2 pitchstone microblades, 3 flint flakes, 3 flakes from Group VI axehead; CB pottery
2			do	Pit	Beta-68481	4920±110	4000–3350			
3	Deer's Den	Aberdeenshire	Alexander 2000	Pit 1028	OxA-8132	4945±40	3800–-3640	x		1 pitchstone flake, 61 lithics, 64% of which flint, 36% quartz, 1 leaf-shaped point in flint; CB pottery
4			do	Pit 1028	OxA-8133	4895±40	3770–3630			
5	Nether Hanginshaw	S Lanarkshire	Ward 2014	Pit F20	GU-12113	4780±40	3650–3380	x	x	1 pitchstone flake, 13 chert flakes, 1 flake from a Group VI axehead; 1 piece of burnt bone; CB pottery
6	Brownsbank	S Lanarkshire	Ward 2014	Pit F2	GU-9303	4865±45	3709–3538	x		1 microblade and 1 flake in pitchstone, 4 chert flakes, 1 flake of 'siltstone', burnt bone, and CB pottery
7	Chapelfield	Stirling	Atkinson 2002	Pit VIII	GU-7202	4640±90	3650–-3050	x		4 pitchstone microblades, some coarse stone tools; CB pottery
8	Fordhouse Barrow	Angus	CANMORE 2014	Barrow's Phase 3B	OxA-8222	5035±40	3960–-3710			7 pitchstone microblades, 3 pitchstone flakes; 1 burnt leaf-shaped point in flint, 1 chert chunk [**provide TAQ dates for pitchstone in C507 (Pit 7) beneath Ph. 3B**]
9			CANMORE 2104	Barrow's Phase 3B	OxA-8223	4920±45	3790–-3640			
10			CANMORE 2014	Barrow's Phase 3B	OxA-8224	4965±40	3910–3650			
11	Donich Park	Argyll & Bute	Clare Ellis *pers. comm.*	Pit 41	GU-29791	4714±33	3632–-3376			2 pitchstone flakes
12	Snabe Quarry	S Ayrshire	Maureen Kilpatrick *pers. comm.*	Pit 22	GU-32479	4872±42	3763–-3535	x	x	1 pitchstone flake, 5 flint chips, 2 flint microblades, 1 edge-retouched flake from a Group VI polished stone axehead; sherds of CB pottery
13			do	Pit 22	GU-32480	4820±42	3695–-3520			

CAT	Site	Local authority areas	Ref.	Context	Code	Lab date BP	cal BC, 95.4% probability	Carinated Bowl pottery	Group VI	Full assemblage (CB = Carinated Bowl)
14	Maybole	S Ayrshire	Becket & MacGregor 2009	Pit 10	GU-16716	4939±30	3780–3650	x		30 flaked lithics, mostly flint but also pitchstone; CB pottery; burnt human bone
15			do	Pit 18	GU-16715	4940±40	3780–-3650	x	x	14 flaked lithics, mostly flint (2 of which scrapers) but also 3 pieces of pitchstone, 1 inner flake from Group VI axehead; CB pottery; burnt human bone
16	The Carrick	Argyll & Bute	Becket & MacGregor 2012	Pit 0510573	SUERC-19349		3950–-3700	x		1 pitchstone flake; CB pottery)
17	Newton Farm	S Lanarkshire	O'Brien 2009	Pit 104	GU-17330	4835±35	3700–-3520	x		2 pitchstone flakes and various other lithics; CB pottery
18			do	Pit 110	GU-17331	4685±35	3630–-3360	x		Various lithics, including aphyric pitchstone; CB pottery
19			do	Pit 102	GU-17329	4710±35	3640–-3370	x		1 pitchstone blade, 1 burnt flint flake; CB pottery
20	Barassie	S Ayrshire	Iraia Arabaolaza	Pit 114	GU-35500	4966±39	3915-3653			9 chips of flint or quartz

Pattern recognition of universal mathematical constants in Acheulean biface formats

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Abstract:

The similar design formats of many Acheulean bifaces has prompted several studies into the use of 'mental templates', leading to controversial claims that there may be a relation between length and width equal to the Golden Ratio. To avoid subjectivity, these studies have used aggregate data from assemblages that, by definition, mask the individuality of each tool, its material, any retouching and the original imposed design. Visual pattern recognition is widely used in psychological research and some branches of engineering and a similar technique is presented to highlight the formats of two samples of the Boxgrove assemblage (one random) and examine the presence of universal mathematical constants. A probabilistic analysis suggests that the repeated use of the numbers 2, Pi and Phi and the relationship between them could not have been produced by chance. These relationships appear to be constant over very long time periods and are still used today in modern gemstone design.

Keywords: Acheulean; biface; geometry; format; mathematical constant; aesthetics

1. Introduction

A number of researchers have called attention to the apparent constant relation between the length and width of Acheulean bifaces over time and geographical area. McPherron (2000) notes that: "the length and width plot is remarkable for the degree of similarity displayed among handaxe assemblages. What this suggests is that there is an underlying factor that affects handaxe shape in some fundamental way. But the strong association between length and width does not in itself mean that all of these handaxes have the same shape." Pope et al. (2007) suggest that: "the concept of 'mental templates', at least in part guiding reduction strategy, is now an important component of explanations for biface form." Based on the regression analysis of the measurements made by McPherron (2000), they also state that: "there are compelling results which appear to show a broad agreement between biface shape and the 'Golden Section', a ratio controversially claimed to have particularly aesthetic properties."

Similar observations have been made by Le Tensorer (2006) in which the analysis of several thousand examples of bifaces from the Nadaoiyeh site indicated a preferential length to width ratio of 1.62 – the Golden Ratio ("*Le nombre d'or des Grecs correspond a une*

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proportion d'environ 1,62. La mesure de plusiers milliers de bifaces de Nadaoiyeh nous a montré une tendance à la standardisation et la reproduction d'un rapport longuer-larguer preferential assez caractéristique pour chaque faciès. – le nombre d'or"). Gowlett (2011) examined 394 bifaces from Kilombe, 60 from Kariandusi Upper Site (obsidian), 186 from Kariandusi (all from about 1 million years ago) and 103 from the Spanish sites of San Isidro and Pinedo, concluding that: "The evidence suggests a more complex picture: that there was a general and very widespread tendency for hand-axes to be made with breadth/length proportions having a mean value of about 0.61, but also that this central tendency emerges from a swarm of other values; that the allometry factor has the consequence that far broader and far narrower bifaces were regularly made; and, in some biface sets, other proportions tending towards 0.50 were actively preferred so strongly that the 0.61 value scarcely occurs; and that the value B/L 0.50 seems actively favoured in long bifaces in all sets, as well as occurring commonly in Thickness/Breadth (T/B) relations. In the face of all the variation, there can be no case for arguing a deep or hard-wired imposition of any particular proportion in artifacts, but the data strengthen the idea that there is some firmly established human disposition to like particular ratios of shape." It should be noted that Gowlett uses the Width (Breadth-B) to Length (L) ratio of 0.61 – or phi, rather than the inverse of 1.61 – Phi; similarly the proportion of 0.50 is the inverse of the constant 2.

Regional or epoch differences in biface formats have been estimated using a "polar coordinate technique" (Wynn. & Tierson 1990), but again, the major problem with regression analysis of the dimensions of large samples of bifaces is that individual aesthetic expression is lost in the aggregate values. Each tool had its own history based on the tastes of the maker, the raw material used and any need for final retouching. This taste or template can be understood as a shape emerging from a complex system of operational sequences guided by simple sets of rules, rather than a fixed and projected design. Thus an examination of any underlying biface geometry needs to be based on this individuality of design.

The 'human eyeball' method of pattern recognition and visual examination is still used in many modern technologies (such as quality control of electronic components) and although the expression "Pattern Recognition" now has a specific meaning in electronic engineering and computer science (the study of algorithms and methodologies used to automatically extract meaningful patterns from big datasets), in this paper, the term 'Visual Pattern Recognition' is used in the wider sense, such as in the field of psychological research. This topic will be explored in greater depth in a subsequent paper by the author on the possible mechanism of the deep seated attraction to these formats.

2. Methods

The Boxgrove assemblage was chosen for this task as the tools were mostly found 'in situ' with minimum 'rolling' and are well-known for their meticulous and craftsmanship. With the kind assistance of the British Museum, high quality images of the assemblage were used, as taken by Dr Mathieu Leroyer during 2010 at Franks House, British Museum, with the aid of CNRS team, 'Ethnologie préhistorique' (UMR 7041) and the University, Paris 1 - Panthéon Sorbonne. Dr Leyroyer selected an initial sample of typical formats encountered in the assemblage, but to avoid problems due to the possible "cherry-picking of samples", in which modern aesthetic tastes determine the tools to be examined, a random sample was also chosen by Dr Leroyer by picking numbers from a hat.

The format to be studied was considered to be two-dimensional (flat) and based on the digitally enhanced outlines using COREL PhotoPaint software. The geometric templates used in manufacture or retouching were determined by retrofitting expressions of Universal Constants onto the digital drawings and allowing the enhanced original shapes to be clearly seen. Particular attention was directed to the format of the butt, the angle of any distinct point formed by straight edges and any curves used on the ‘blades’ forming the point.

An assessment was made to see if this ‘degree of fit’ could be statistically determined using PAST software as in the morphological analysis of bone and stone bifaces from Castel di Guido (Costa 2010), but this option was rejected as this technique ‘masks’ the individuality of each tool and, due to the presence of imperfections or damage on the tools, a visually ‘poor’ fit could offer a better statistical value than an exceptionally ‘good’ fit, if the latter had a partly damaged edge.

To find the best ‘fit’ the outline of the tool was examined to see if the sides were ‘ovate’ or ‘pointed’. Previous experience with images of biface tools and geometric forms had indicated that for ovate tools, the best fit can normally be found by using sections of a Golden Ellipse. The biface ‘butts’ generally conformed to either a circle or a Golden Ellipse. Once the best fit – based on visual pattern recognition - had been established, the relationship of the geometric figures to each other was examined. The presentation allows for individual subjective judgment of these ‘best fits’ and binomial probabilistic analysis examined the probability that the relationships between the geometric figures could be randomly generated.

The expressions of Universal Constants examined were:

- 2 (and the inverse relationship ½);
- Pi – circles and sections of circles
- Phi – expressed as the ratio of Length/Width (L/W), sections of the Golden Ellipse and the angles of 18 and 36 degrees. [An ellipse is a curve on a plane such that the sum of the distances to the two focal points is constant for every point. Ellipses have two mutually perpendicular axes about which the ellipse is symmetric; the larger one is the major axis (LE), whereas the smaller is the minor axis (WE). A Golden Ellipse is one where the ratio between the major and minor axis is equal to Phi. Phi is the unique number in which $Phi^2 = Phi+1$ and can also be expressed as a relation between the numbers 5, 2 and 1, as Phi = $(1+\sqrt{5})/2$ and as the sine and cosine of the angles of 18 and 36 degrees, Phi $=1+2\sin 18^o$ or $=1/(2\sin 18^o)$, and Phi = $2\cos 36^o$.]

3. Results

3.1 The Initial Sample of Selected Shapes

Each specimen is presented with an enhanced outline and the suggested geometry superimposed in semi-transparent red and grey. A short explanation accompanies each figure as a guide. The original scale (with each square being 1 cm) has been left in order to show the dimension of each tool.

Specimen BD 8474

This is a large biface and a very common format. The butt corresponds closely to a circle with both ‘blades’ of the point using the same section of a Golden Ellipse. The diameter of the circle (D) is close to half the length of the ellipse (LE) so that D=LE/2, (LE/D=2.1 to one decimal place). The tangent where the ellipse touches the circle is thus before the midpoint so that the maximum width of the tool is slightly wider than D. The L/W ratio is just under Phi (the point is damaged so the original full length is unknown). See Figure 1.

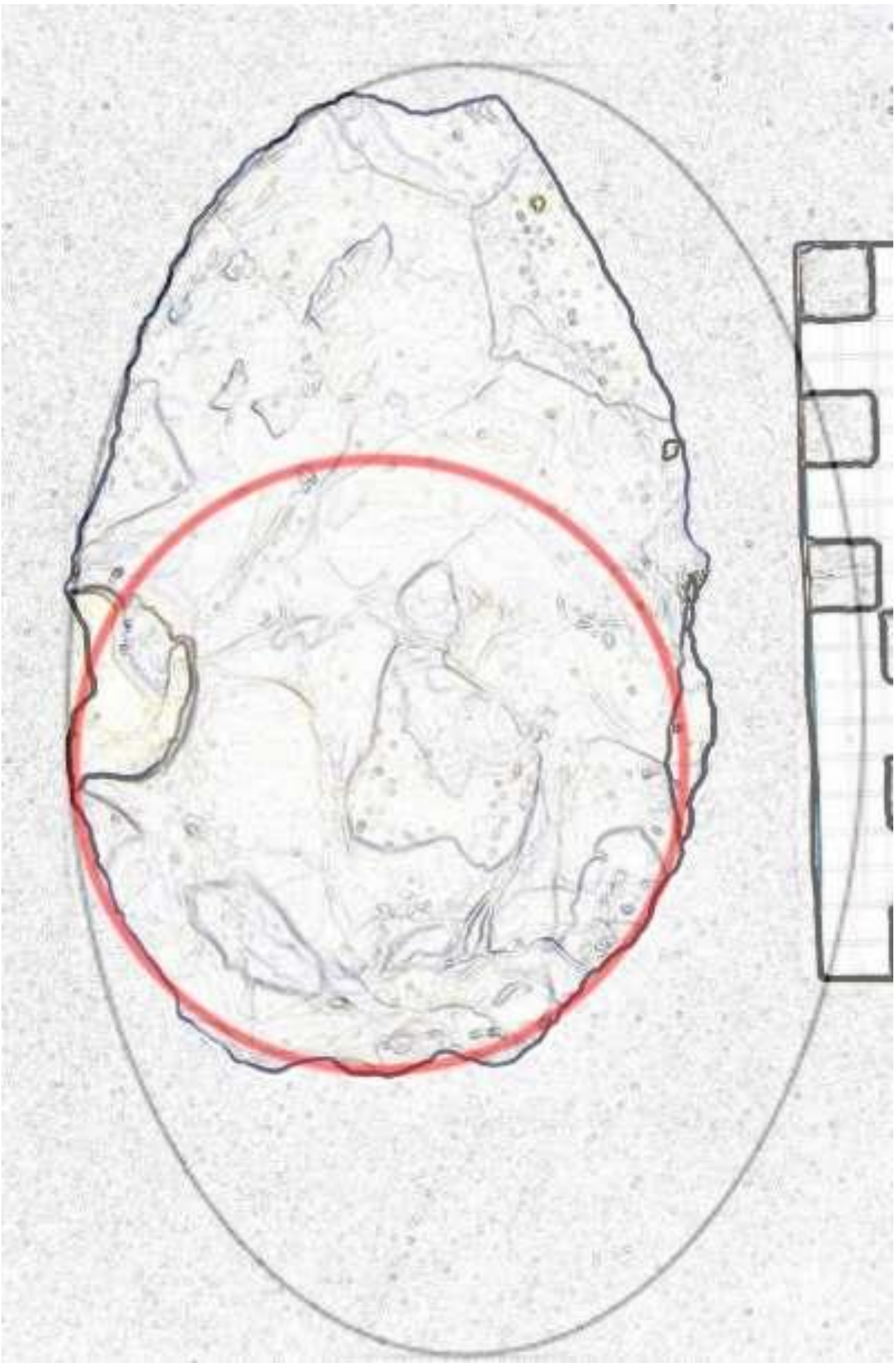

Figure 1. Specimen BD 8474.

Specimen BD 13576-137

In this medium sized biface, both butt and blades form a single continuum in Golden Ellipse format, L/W is thus Phi. See Figure 2.

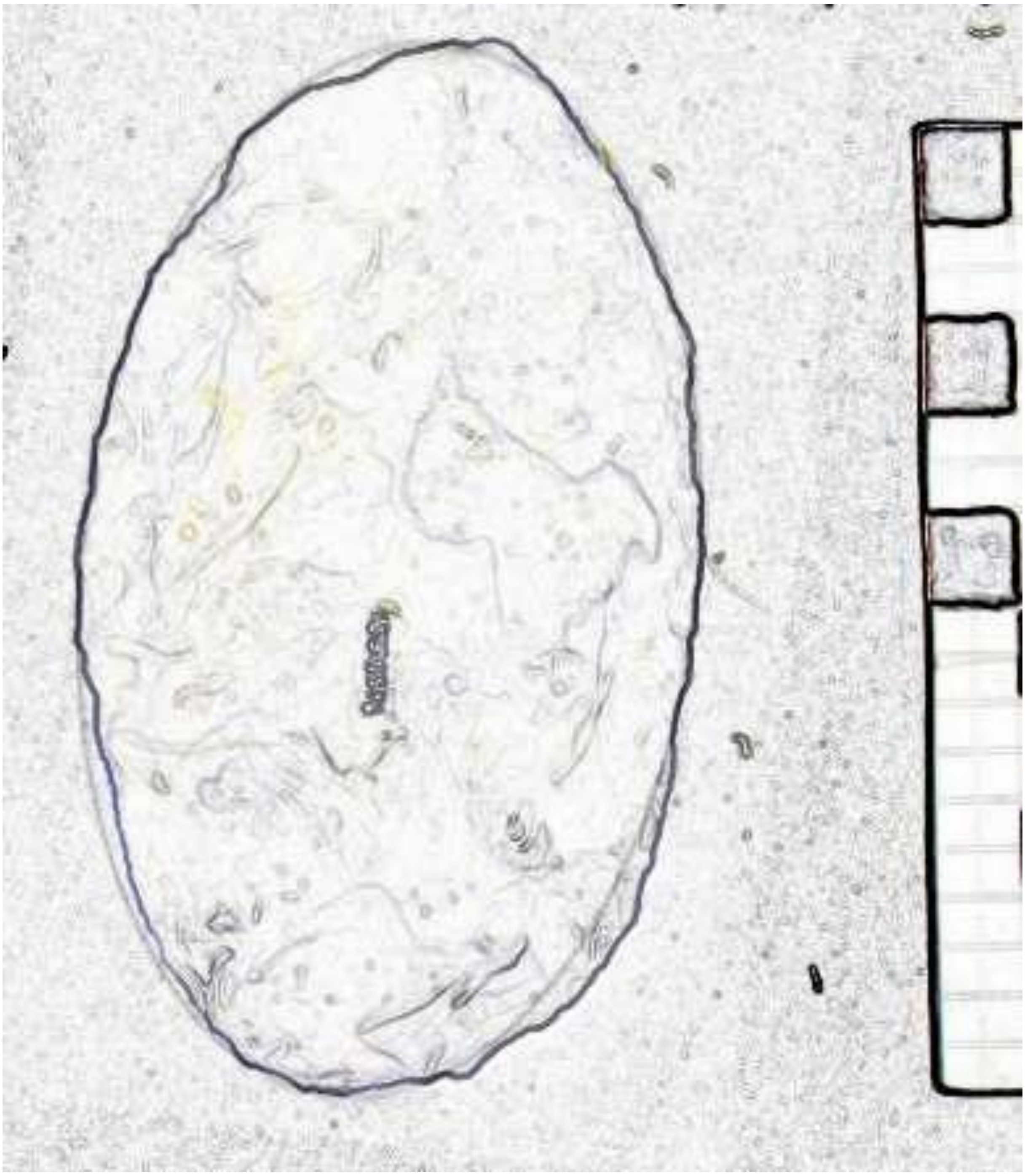

Figure 2. Specimen BD 13576-137.

Specimen 317B

This large biface has an almost perfectly circular butt, with both blades at a tangent forming the characteristic pointed angle of 36 degrees. Both tangents lie on the same arc from the bisecting line of the blades. The broken point does not allow an L/W measurement to be made. See Figure 3.

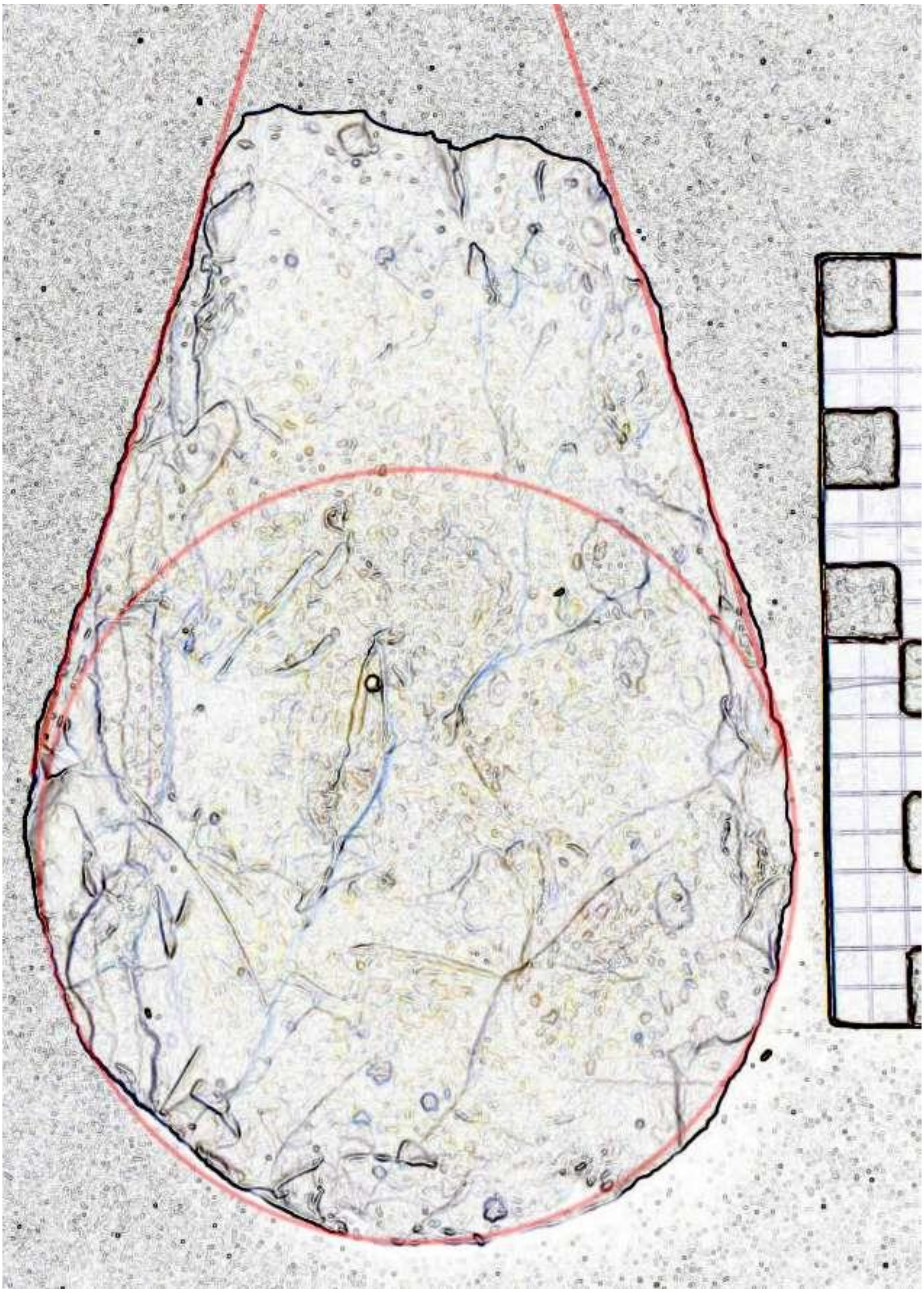

Figure 3. Specimen 317B.

Specimen 31310-31B

Despite symmetry being recognized as an essential feature of Acheulean bifaces, many examples are unsymmetrical as a result of flaws in the raw material, breakage during knapping or through retouching. Elements of basic geometry in this case are retained: the butt is in Golden Ellipse format with sections of the same ellipse incorporated into the blades. L/W=1.6. See Figure 4.

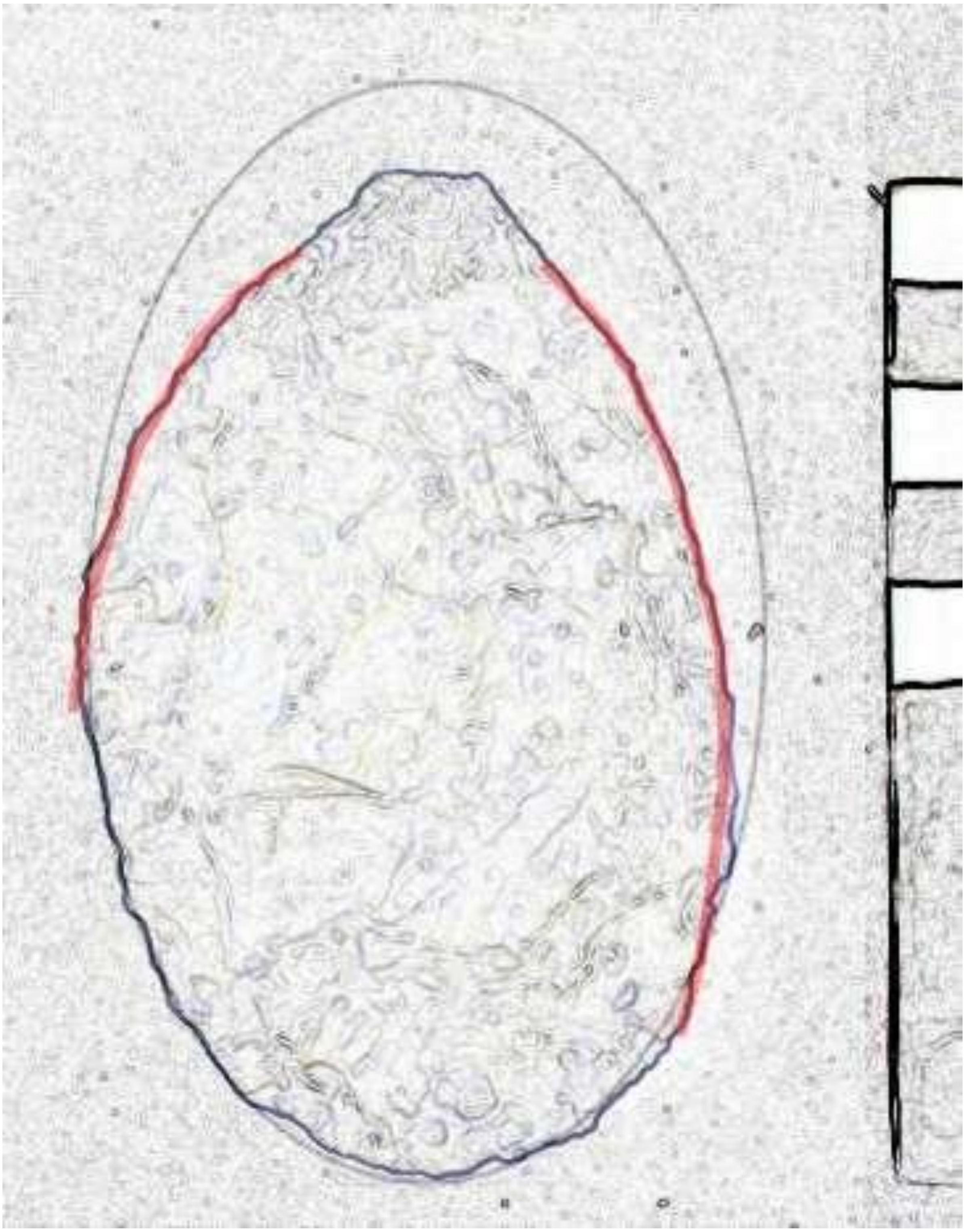

Figure 4. Specimen 31310-31B.

Specimen 31564-33

This small tool has a circular butt and blades formed by sections of a Golden Ellipse, in which D is close to LE/2 (LE/D=1.9) The short sections used give a value of L/W=1.38. See Figure 5.

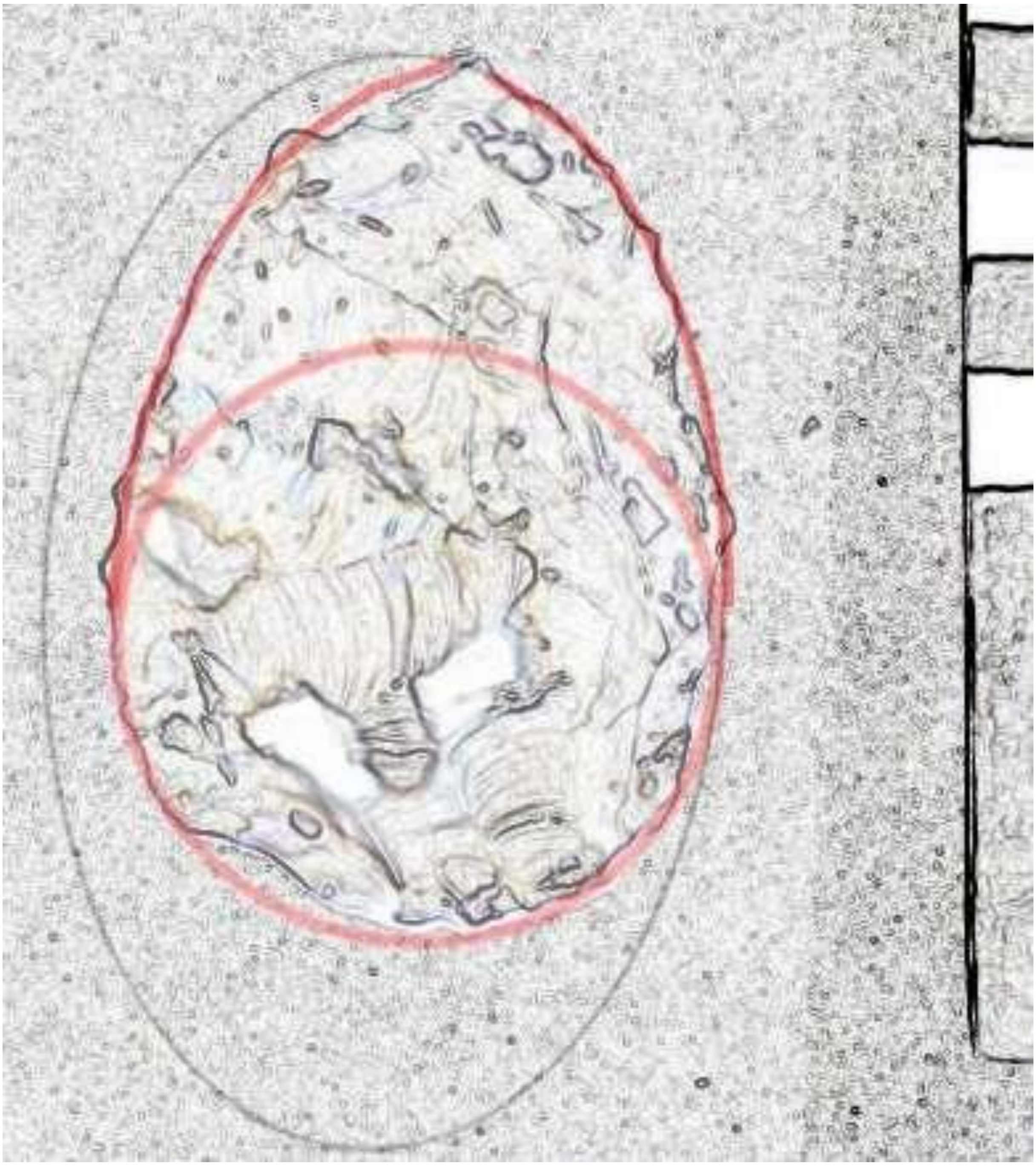

Figure 5. Specimen 31564-33.

Specimen 12043-50B

This large biface is one of the iconic specimens from the assemblage as the patina and excellence of manufacture give the tool a gemstone-like quality. The butt is circular with Golden Ellipse blade sections, where LE/D=2.1 (or close to D=LE/2). L/W=1.61. See Figure 6.

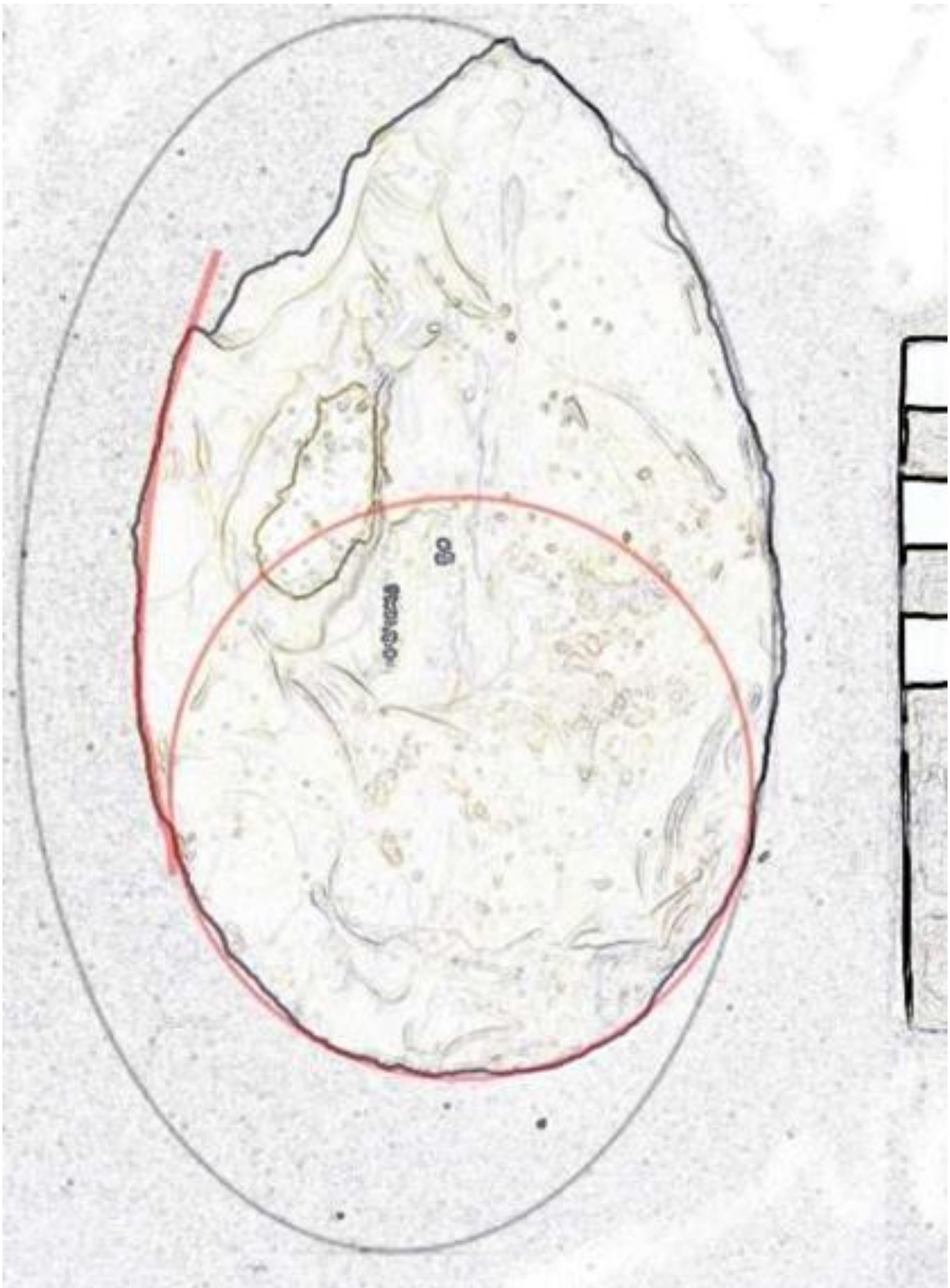

Figure 6. Specimen 12043-50B.

Specimen BD 7812 98

This large and elongated biface has a flawed, damaged or retouched right side. The butt is circular and the long blade is a section of a Golden Ellipse, in this case with the diameter close to the width of the ellipse divided by two (WE/D=1.9). See Figure 7.

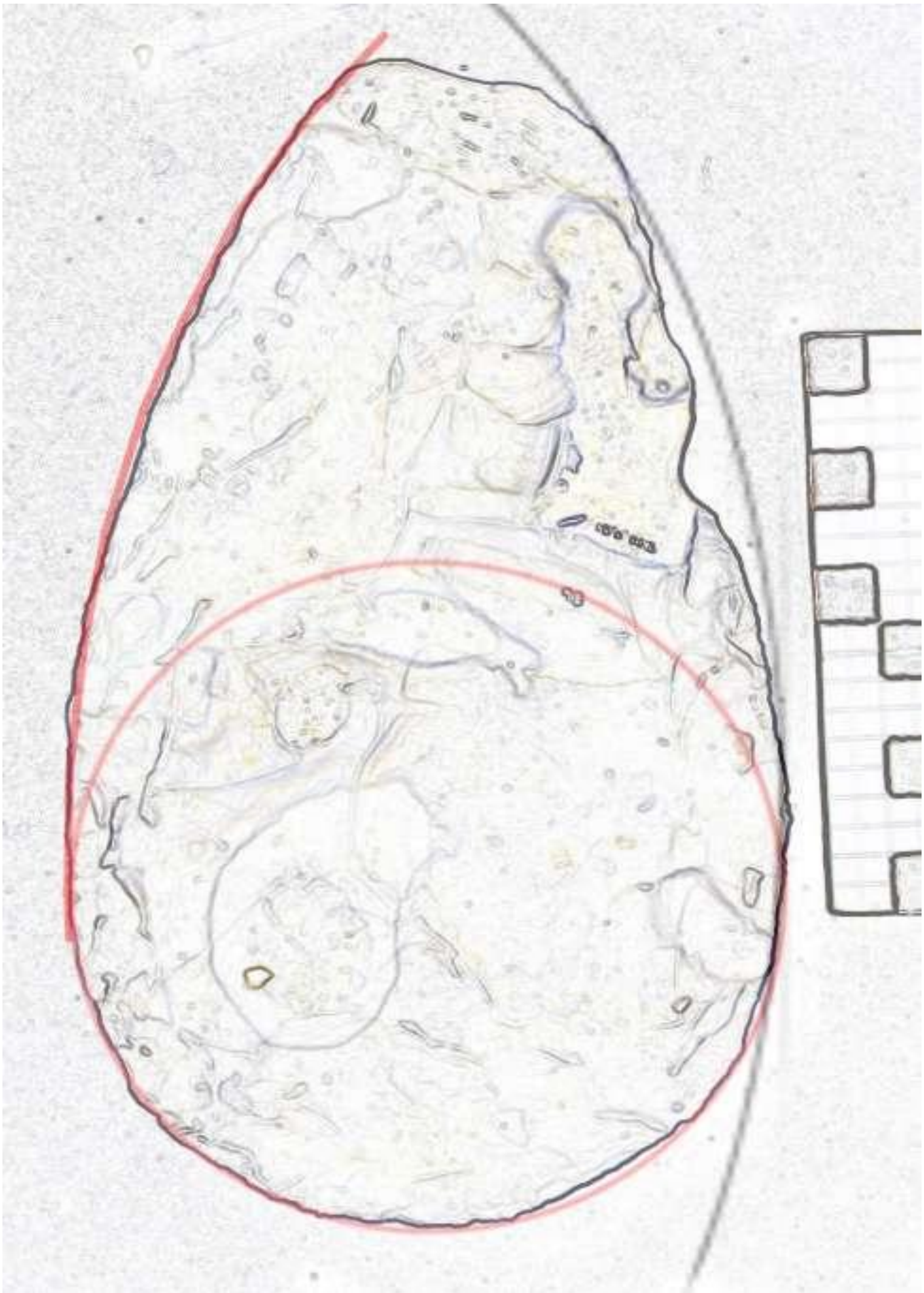

Figure 7. Specimen BD 7812 98.

3.2 Analysis of the Random Sample

Dr Leroyer then randomly selected a sample of 14 bifaces from his collection of images. Of these, he suggested removing artifact 136 as this appears to be a discoid core and not a classic ‘handaxe’, (because of the non-elongated shape without differentiation between a point and a butt and absence of soft hammer percussion and final trimming). It was also suggested that artifact 46 not be considered, as this was taken to be a rough-out (absence of final trimming). Artifact 15 also exhibited similar problems and was excluded by the author, as was Artifact 263 - an irregular and small tool with no discernible geometry.

Specimen BO 9480-335

This is a broken or retouched biface with butt in Golden Ellipse. See Figure 8.

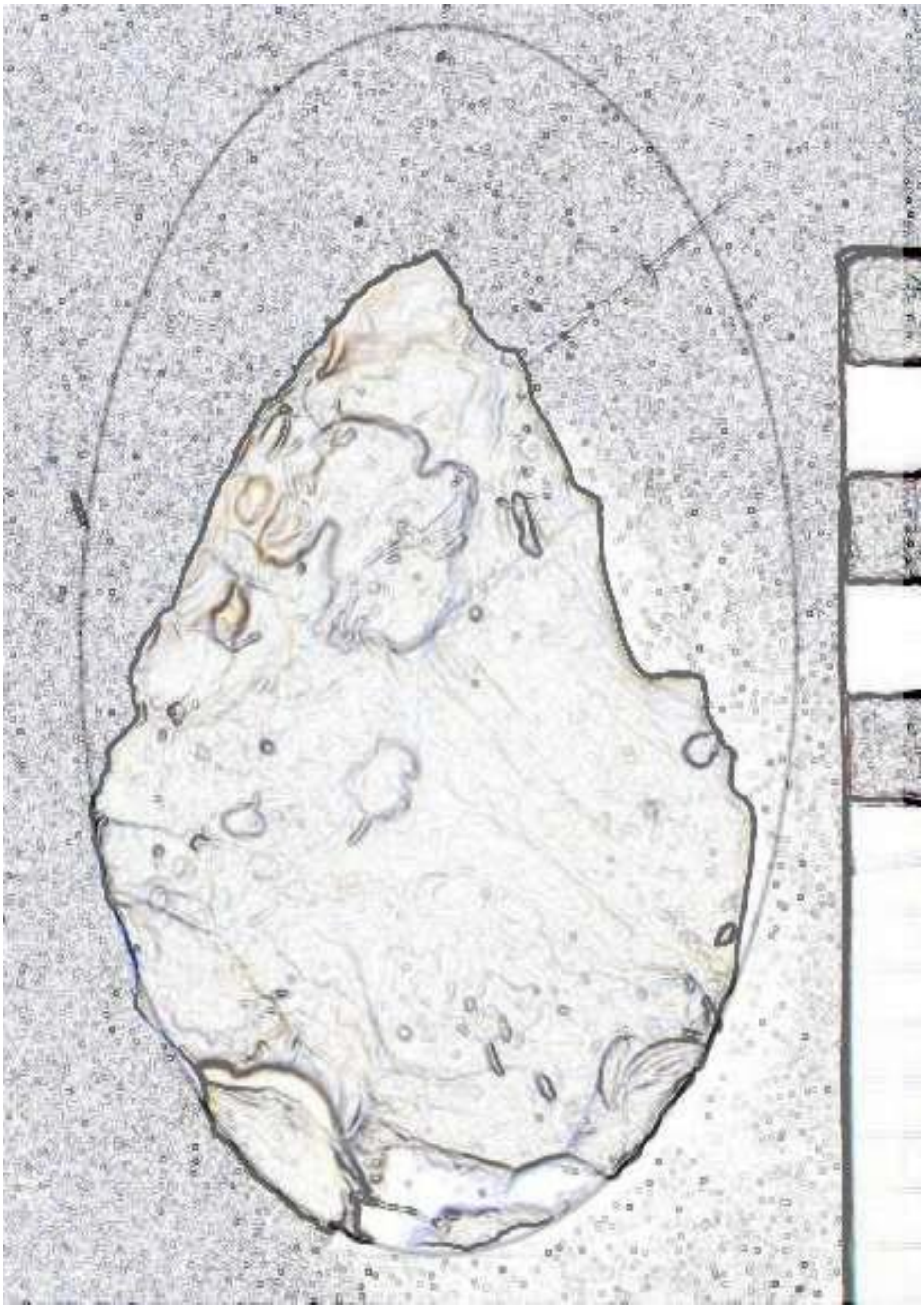

Figure 8. Specimen BO 9480-335.

Specimen BD 11080-122

This is a small biface with LE/D=1.9 and L/W=1.44. See Figure 9.

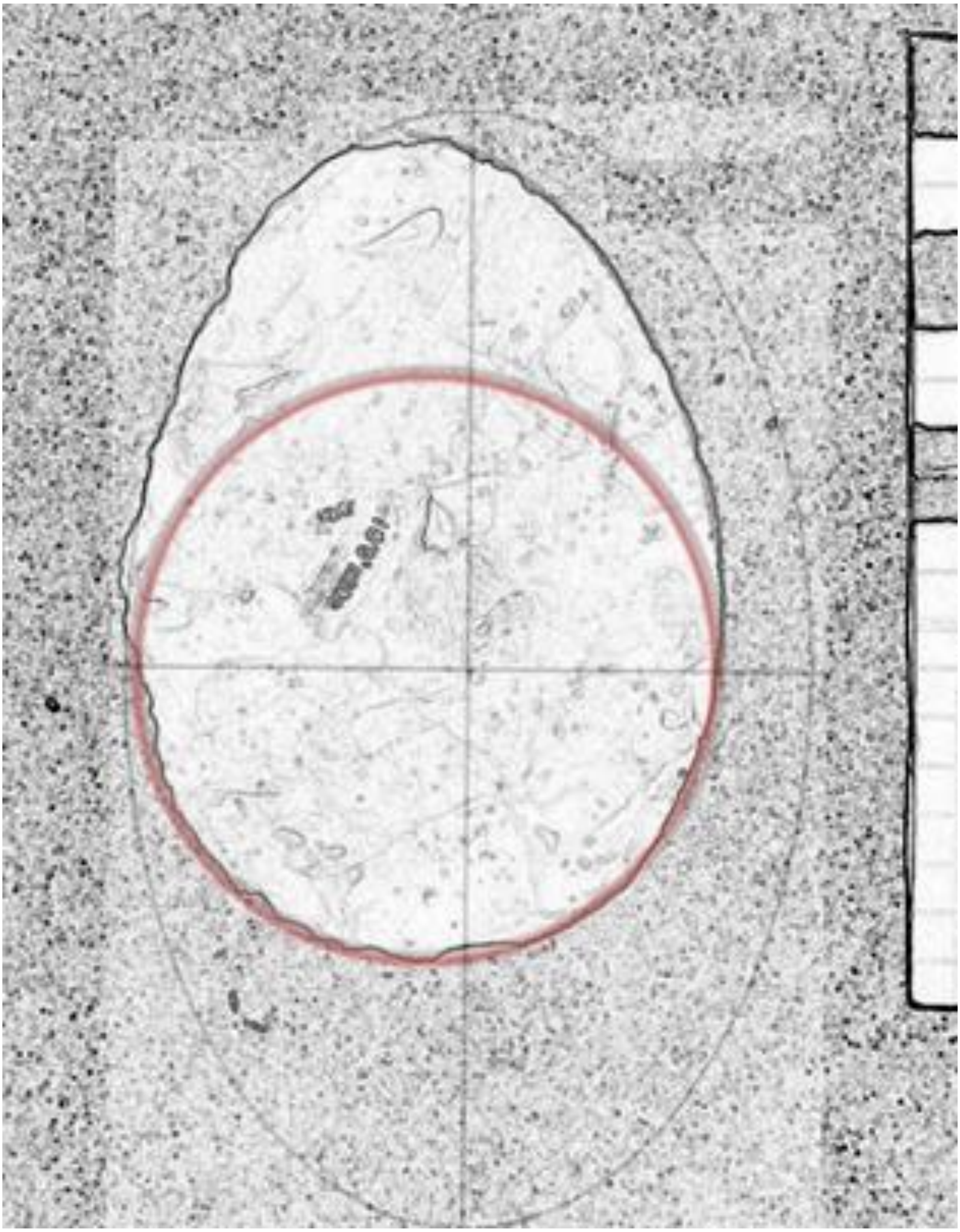

Figure 9. Specimen BD 11080-122.

Specimen BD 12418-128

This is a large biface with a Golden Ellipse format and apparently broken point. See Figure 10.

Figure 10. Specimen BD 12418-128.

Specimen BD 30864-189

This biface has an unsymmetrical point. The butt is a section of a Golden Ellipse and both sides of the point use a section of another ellipse, the ratio between these ellipses (LE2/LE1) is 1.36. L/W=1.67. See Figure 11.

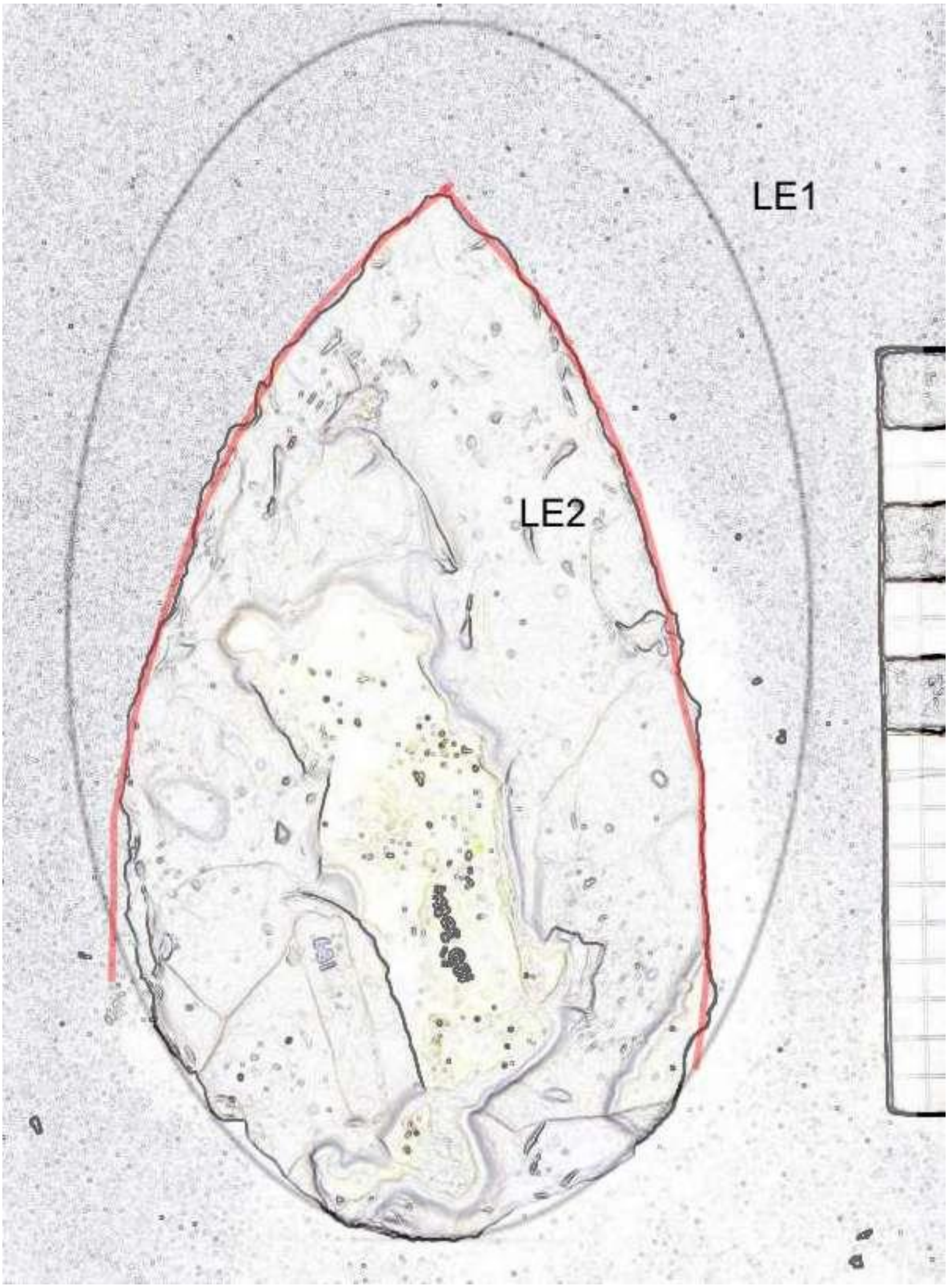

Figure 11. Specimen BD 30864-189.

Specimen 1951-253

The butt of this medium sized biface is a Golden Ellipse (1) with the right blade in a section of another Golden Ellipse (2), where LE1/LE2 = Phi/2. L/W=1.54. During manufacture a large flake appears to have been removed from the point area which may have determined how the shape developed. See Figure 12.

Figure 12. Specimen 1951-253.

Specimen 11984 367

This large axe has L/W=1.55, the butt is circular (with a damaged or flawed section) and the blades set at 36 degrees. The left side has a short ‘transition curve’ between the straight and circular sections to allow for a visually smooth effect. See Figure 13.

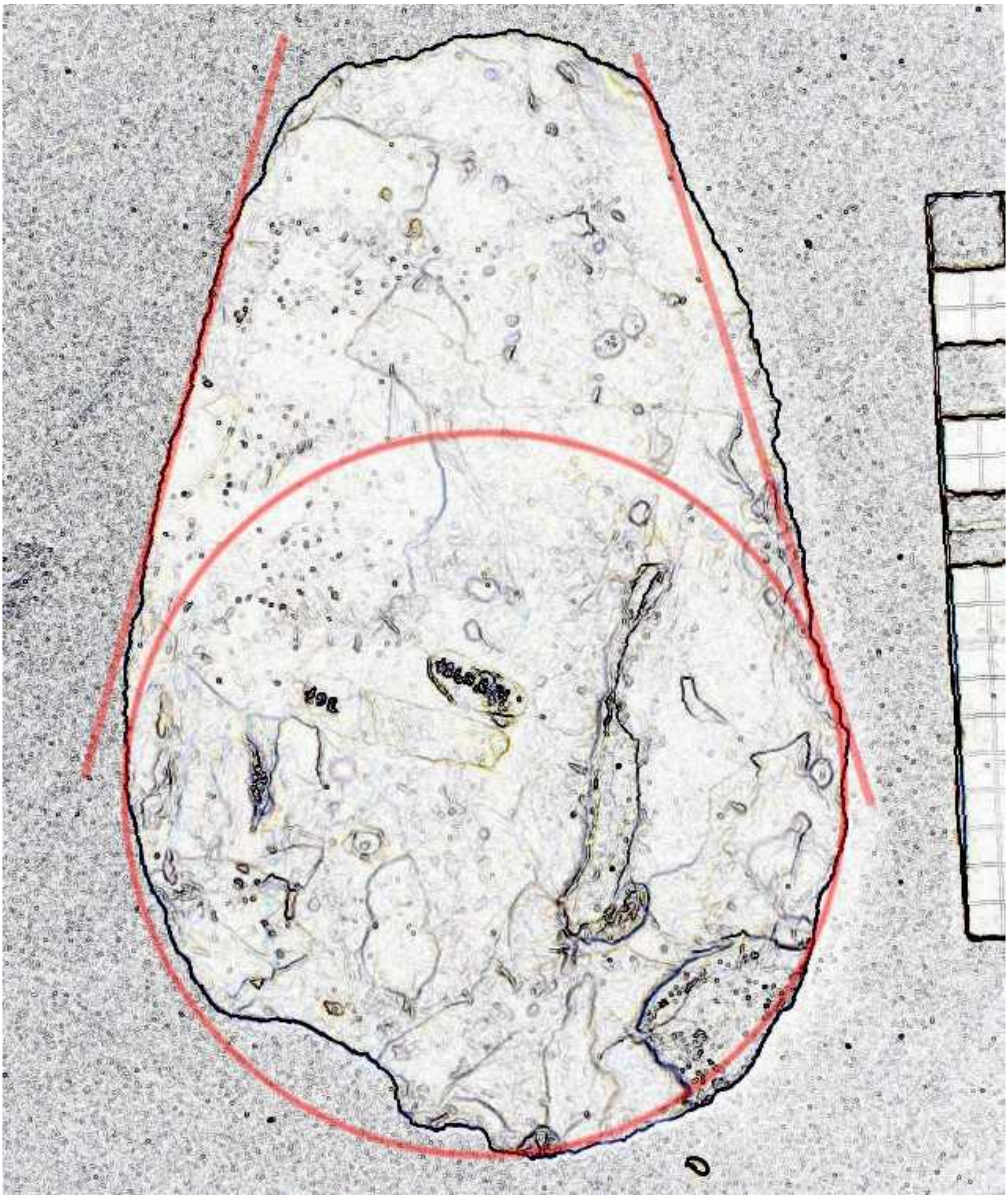

Figure 13. Specimen 11984 367.

Specimen 12556-372

The butt is formed by a near perfect circle with the blades in a Golden Ellipse at the widest point and where WE/D=2 and L/W=1.6. Although the point appears to have been sharpened, the unsymmetrical nature suggests that this may have been retouched. See Figure 14.

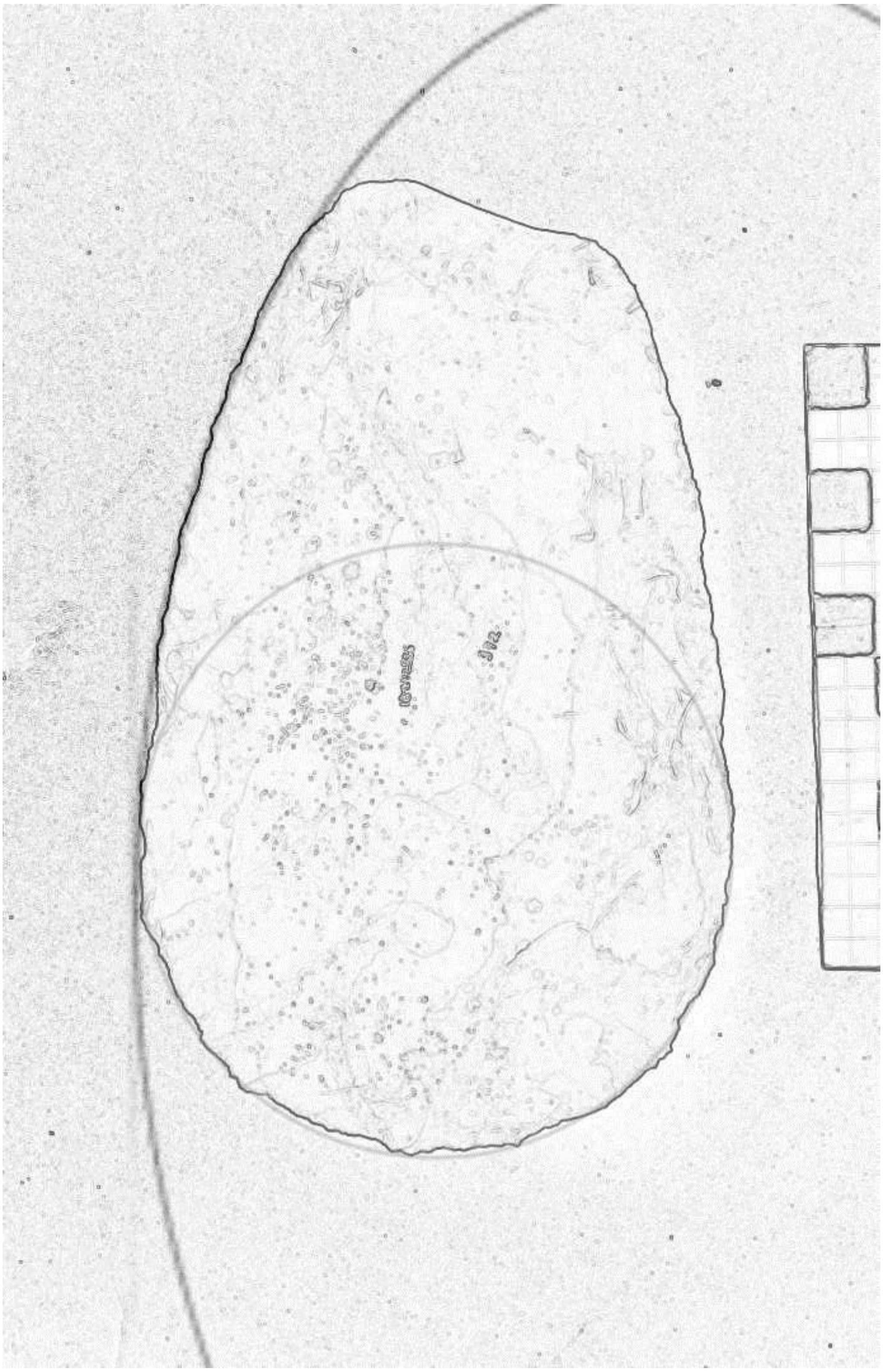

Figure 14. Specimen 12556-372.

Specimen 12201-56

The craftsmanship of this tool is not as high a standard as in other bifaces, however, the butt can be seen to be circular with the blades in a Golden Ellipse with a tangent before the maximum width. This same ellipse forms the 'point' and although L/W is 1.5, the ratio LE/D is 1.61. See Figure 15.

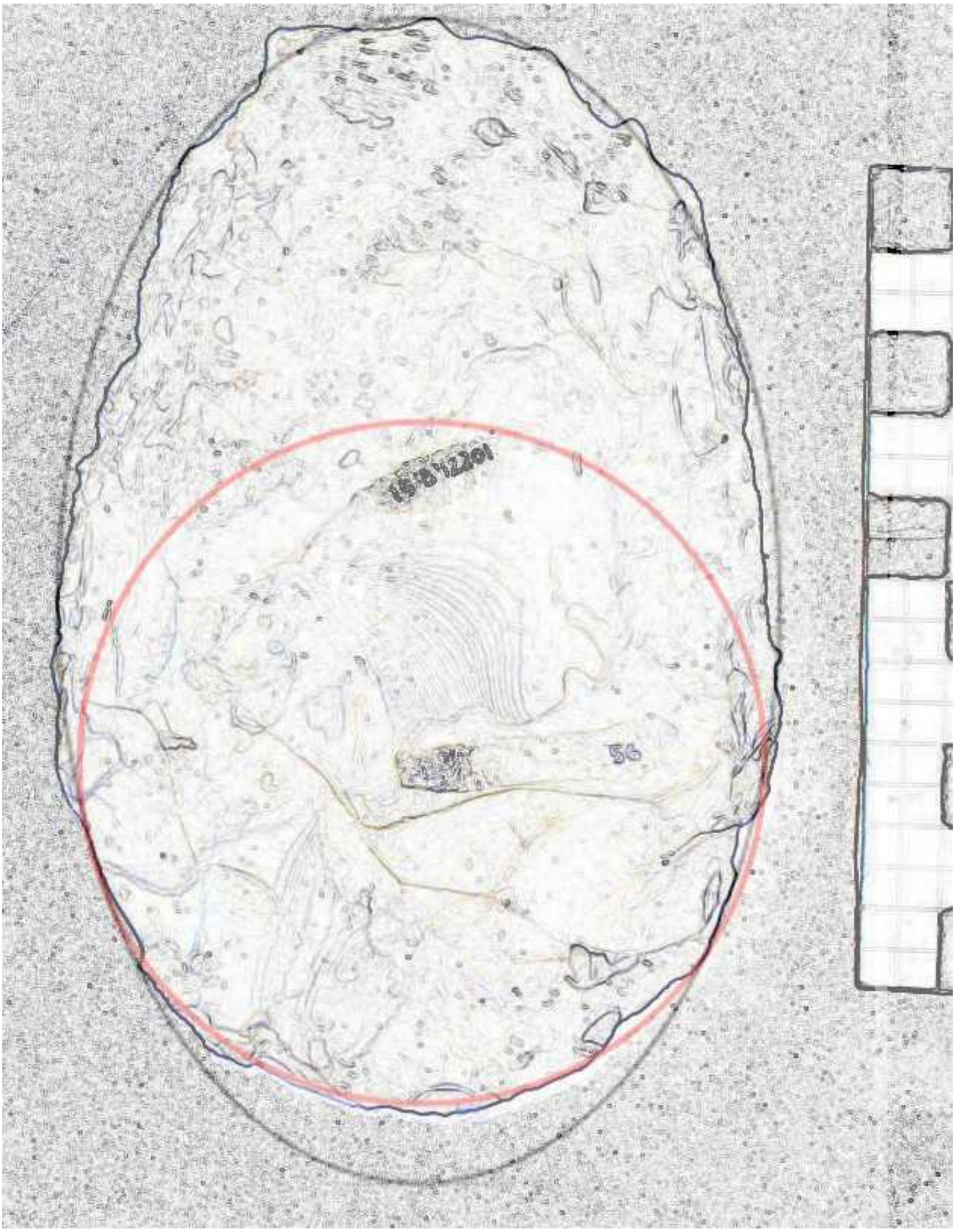

Figure 15. Specimen 12201-56.

Specimen 12881-61

This small biface has circular butt with the right blade as a section of a Golden Ellipse where LE/D=2.1. The point appears to be damaged and un-retouched in the original image, L/W=1.55. See Figure 16.

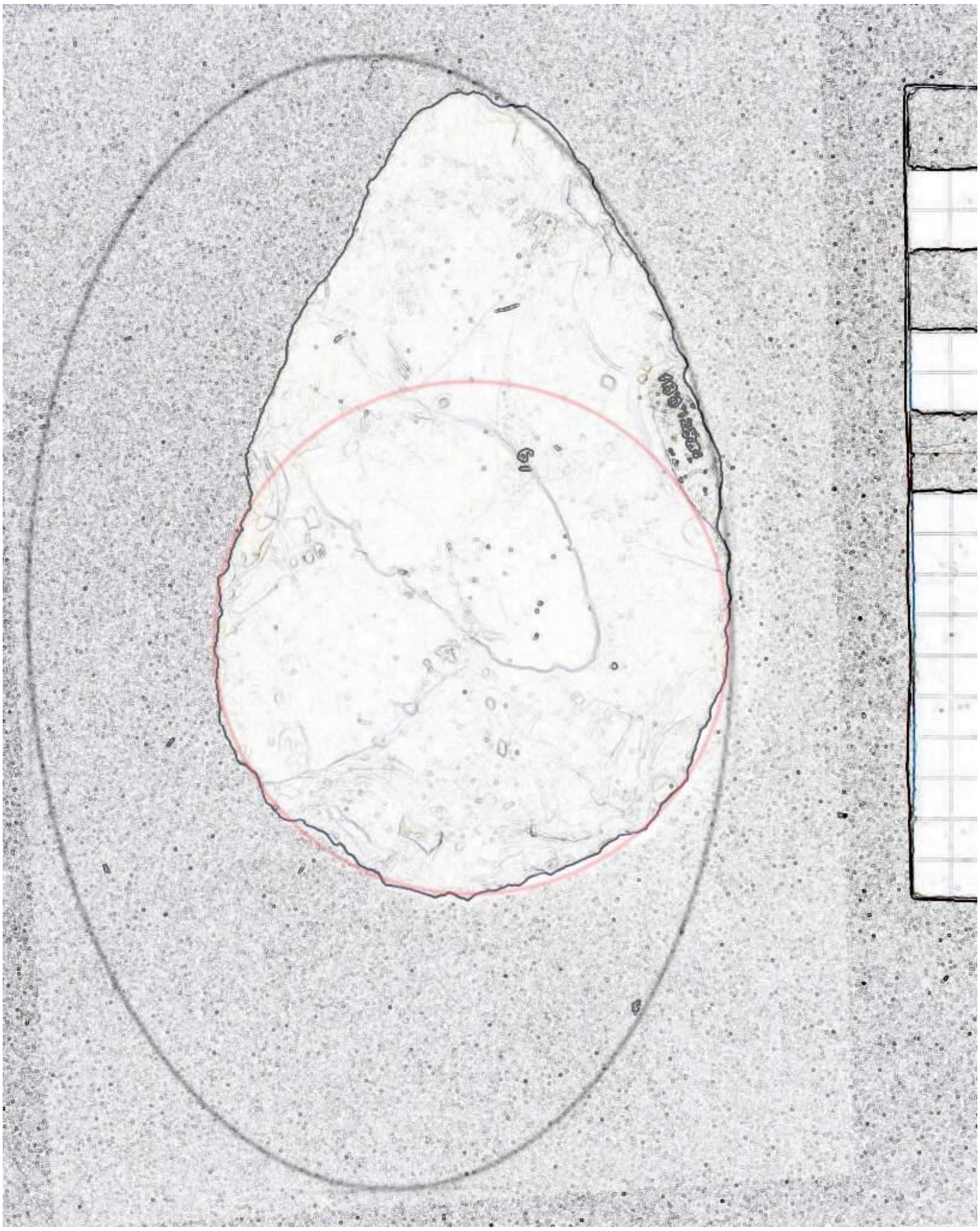

Figure 16. Specimen 12881-61.

Table 1 presents a summary of the expressions recognized (noted in grey). Of the 16 specimens that allow an estimation of L/W, only 6 are close to the value of Phi: the average value of the samples being 1.57. Several bifaces are clearly longer and some of the smaller examples have values that cluster around 1.5 or 1.38. An initial result would thus be that the sceptics are right – there is no Phi based L/W universal template that necessarily determines biface design.

However, both samples show similar levels of geometric expression of the numbers 2, Pi and Phi. Modern notions of ‘attractiveness’ apparently do not create a cherry-picking of samples and this is in itself a strong indication that our modern tastes, in terms of what we find interesting or attractive, are deep rooted in archaic populations.

Of the 16 specimens that were effectively analysed in terms of geometric design, all had expressions of Phi: in the format of the butt, in overall plan and – most frequently - in forming the blades or points as sections of a Golden Ellipse or in a 36 degree angle.

Table 1. Summary of the mathematical expressions and computed relationships in samples of the Boxgrove assemblage.

		Expressions of Constants				
		Pi	**Phi**			
Item	**Initial Sample**	**Circle**	**Golden Ellipse**	**36° angle**	**Relation of D to ellipse**	**L/W**
0	BO 9868 - 336				RTP	1.61
1	BD 8474 - 110				LE/D=2.1	1.59
2	BD 13576 - 137					1.62
3	317 B					
4	31310 - 31 B					1.60
5	31564 - 33				LE/D=1.9	1.38
6	12043 - 50 B				LE/D=2.1	1.61
7	BD 7812 - 98				WE/D=1.9	1.72
	Random Sample	**Pi**	**Phi**			
8	B0 9480 - 335				LE2/LE1=1.62	1.5
9	BD 11080 - 122				LE/D=1.9	1.44
10	BD 12418-128					1.6 (broken)
11	BD 30864 - 189				LE2/LE1 = 1.36	1.67
12	1951 - 253				LE1/LE2= Phi/2	1.54
13	11984 - 367					1.55
14	12556 - 372				WE/D=2.0	1.6
15	12201 - 56				LE/D=1.61	1.5
16	12881 - 61				LE/D=2.1	1.55 (broken)

Notes. The shaded area represents the presence of an expression of the given constant. **Abbreviations**. L = Length of the artefact (its major dimension); W = Width of the artefact (its maximum dimension at right angle to Length); D = Diameter of any circle that best conforms to the tool format – normally the butt; LE = Length of the Golden Ellipse that best conforms to part of the tool format – normally the point or blades; WE = Width of the Golden Ellipse that best conforms to part of the tool on its minor axis; and RTP = resolution too poor for analysis.

Ten specimens had circular butts, some of exquisite craftsmanship, and even the most hardened sceptic would find it difficult to acknowledge that they were designed to be circular in shape.

Once the geometric elements had been adjusted to the best ‘fit’, their dimensions were examined, in particular the length and width of ellipses (LE and WE) and the diameter, D, of any circle. Repeatedly, the ellipses and diameters were found to possess an internal relationship, the most common being the diameter of the circle used (butt) being approximately half the length of the ellipse used for the blades (D=LE/2), which appears five times (items 1, 5, 6, 9,and 16). The use of the width of the ellipse (D=WE/2) is present in two cases (7 and 14) and more complex ratios between the diameter and ellipses three times (11, 12 and 15).

4. Discussion and Conclusions

4.1 Pattern Recognition, Visual Examination and Probabilistic Validity

As both of the samples contained similar geometrical elements, the specimens have been considered as a single sample for analysis. The constant Pi is expressed as sections of circles. Although it is possible that the butt of a single specimen could have been made by chance in the form of a section of a rough circle, the probability that 10 out of 16 specimens could have been made with the same format, however, tends to zero – especially when considering the quality of many designs. The use of the circle can thus be taken as a deliberate and common template.

The second issue concerns the use of Phi in the form of the Golden Ellipse. This ellipse appears in 14 specimens and, in the cases of BD 13576-137 and BD 12418-128, the entire tool is based on a Golden Ellipse. Also of note is that the only tools that do not present butts based on the circle use a Golden Ellipse format: 31310-31B, BO 9480-335, BD 30864-189 and 1951-293. The probability of this choice being the result of chance again tends to zero.

The probability of the relation D to LE and WE being random can be computed by considering that the length of an ellipse (LE) used to form practical blades could be a value of D to about 4D as shown in Figure 17 below; thus for a value of D of 10cm, this implies a LE range of 10 to 40cm.

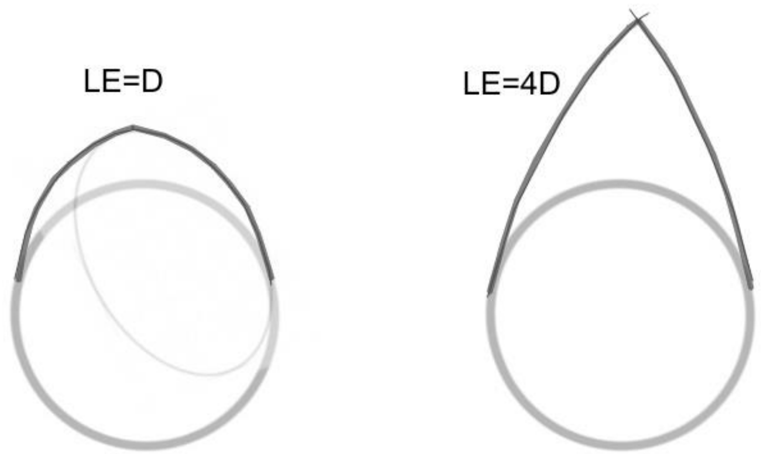

Figure 17. Bifaces formed with points based on LE=D and LE=4D.

For a uniform distribution of values of LE to be within one decimal place for the ratio LE/D=2 (1.9-2.1) implies a tolerance of 1cm above or below the value of 20cm, thus the probability would therefore be 2/(40-10) or 1/15. A binomial distribution appears when a binary random experiment is repeated several times. It computes the probability of obtaining exactly n successes of one event of probability p in N trials. The binomial distribution formula is:

$$\frac{N!}{n!\,(N-n)!}\; p^n \,(1-p)^{N-n},$$

The probability of five specimens having the same value thus in a small sample is a binomial problem that resolves to a value of the order of about two in ten thousand. If the format of WE/D=2 is included in this estimate, then n becomes 7 and the odds of a relationship involving D, LE, WE and 2 being random are less than one in a million. It is therefore very unlikely that these relationships are random.

The angle of 36 degrees is present in only two specimens. The L/W value of 1.36 to 1.38 is found in two specimens. This is often found in modern gem design and biface formats and, although beyond the scope of this present study, it is worth mentioning that this is ***e***/2, where ***e*** is Euler's Constant – the basis of exponential growth and natural logarithms.

Finally, the relationship L/W can also be tested by considering a typical range of values from 1.2 to 2.4 (as typically found in the archaeological record and illustrated in Figure 3.15, Emery 2010) and taking the probability of a specimen having a ratio of 1.6-1.62 as being a uniform chance event, this probability is thus: (1.62-1.6)/(2.4-1.2)=2/12.

The probability of 6 samples in 17 trials conforming randomly to this ratio is again a binomial problem and can be resolved to a value of less than 4%. Hence, although not necessarily a template for all biface designs, there is a very high probability that many L/W values will be within this range and that this clustering around Phi would be detected in aggregate analysis - as has been found in the previous studies of this relationship.

4.2 Testing the Use of these Geometric Relationships over Time

If the use of the same geometry in biface design has been constant over very long time periods, this is an indication that aesthetic taste has been a part of archaic humanity for a similar period. This hypothesis can be checked by examining lithic design over time. At 65kya, for example, the bifaces found at Lynford Quarry together with a large number of mammoth remains (English Heritage 2012) are removed by an order of magnitude from Boxgrove. In the case of specimen 40416 (Figure 18) the dimensions and format are almost exactly the same as 12043-50B from Boxgrove; the butt is circular and the blade is formed by sections of a Golden Ellipse in which LE/D=2 – a stunning example of how strongly these formats may be hardwired and a possible indication that the tools may have been used for similar purposes. Example 40548 (Figure 19) has a 'blade' set at 36 degrees and a butt that is based on a circle.

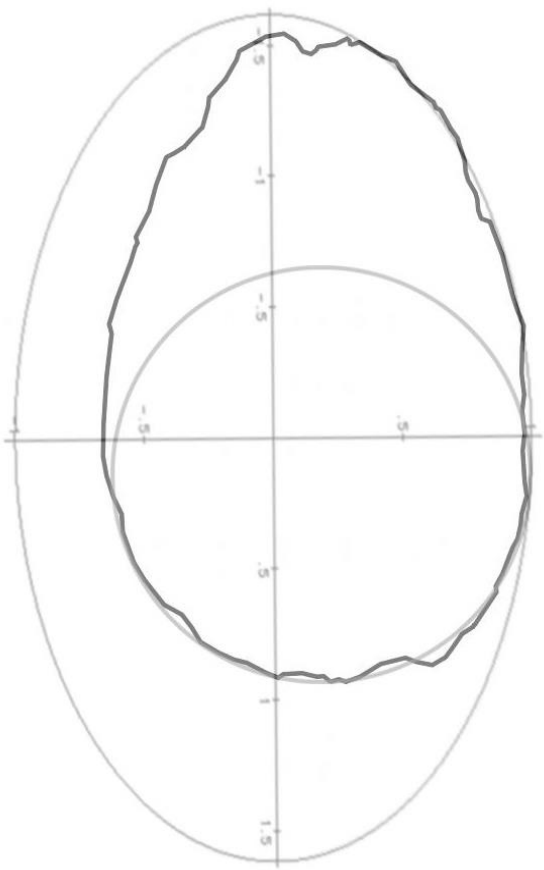

Figure 18. Outline of Specimen 40416, Lynford Quarry (from author's photograph).

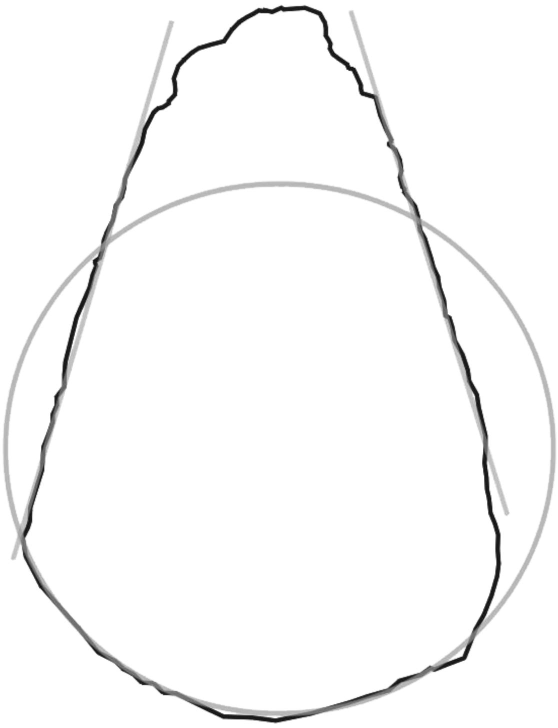

Figure 19. Outline of Specimen 40548 Lynford Quarry (from author's photograph).

4.3 Modern Bifaces

The knapping of bifaces is still carried out in order to understand how these tools were made. The example below in Figure 20 shows a modern "tool" in which the knapper started with a blank with one flat surface and ended with a format based on a golden ellipse, the width of the tool being half the length of the ellipse. When questioned on this, the knapper (a professional paleoanthropologist) mentioned that no specific design was intended – other than the intention to produce a 'handaxe' type tool - no mental template was selected and he was unaware that a golden ellipse had been used or that there was a relation between the width and this ellipse.

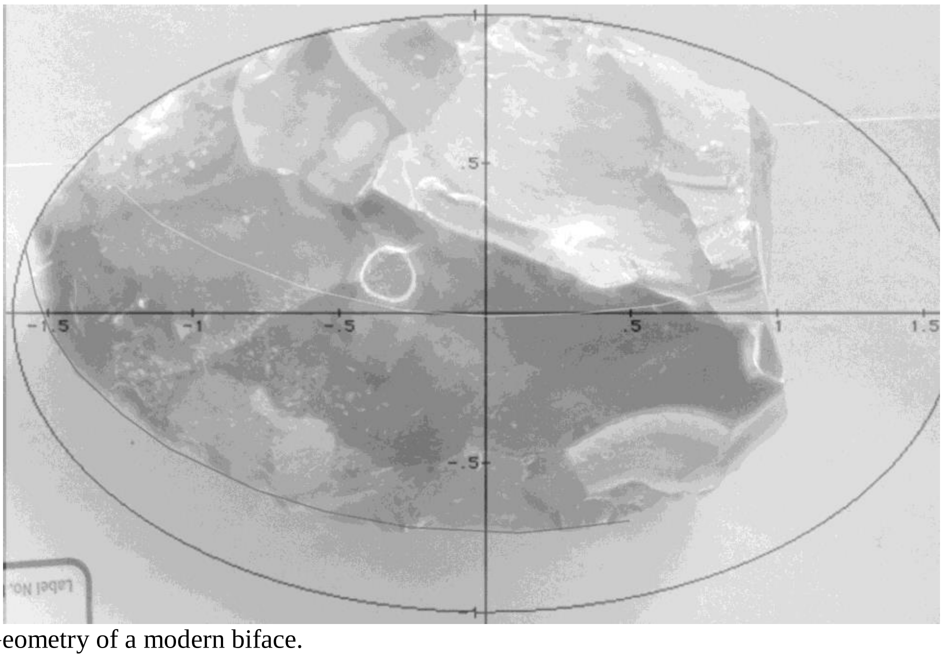

Figure 20. Geometry of a modern biface.

There is one kind of stone artefact which is still being manufactured by highly skilled craftsmen: gemstones. Most gems are made in circular formats; however, according to the Gemological Institute of America (GIA), there are other shapes, termed “fancy”, of which the four main formats are: emerald, pear, marquise, and oval. In 2009 the GIA examined the preferences for length to width ratios for each format. Groups of trade professionals and consumers viewed images and diagrams of unset stones, and were asked to select their preferred design. The surveys indicated that: “particular length-to-width ratios were preferred for each fancy shape with the preference diminishing above or below that ideal. For a Pear Cut both consumers and trade professionals had peak L/W ratio preferences at 1.6. For an Oval Cut both survey groups again preferred ratios around 1.6.” (Blodgett el al. 2011).

It should be pointed out that an Oval Cut is actually an ellipse, thus the preferred shape was essentially a Golden Ellipse. A Pear Cut is based on circles and ellipses and a typical outline for a large stone is shown in Figure 21 superimposed on Boxgrove specimen 12043-50B (scale adjusted so that the diameter of the butt circle for both specimens is the same). A Pear Cut diamond from Botswana (outlined in Figure 21) was sold for 27 million dollars in 2013 and has a L/W ratio of 1.61.

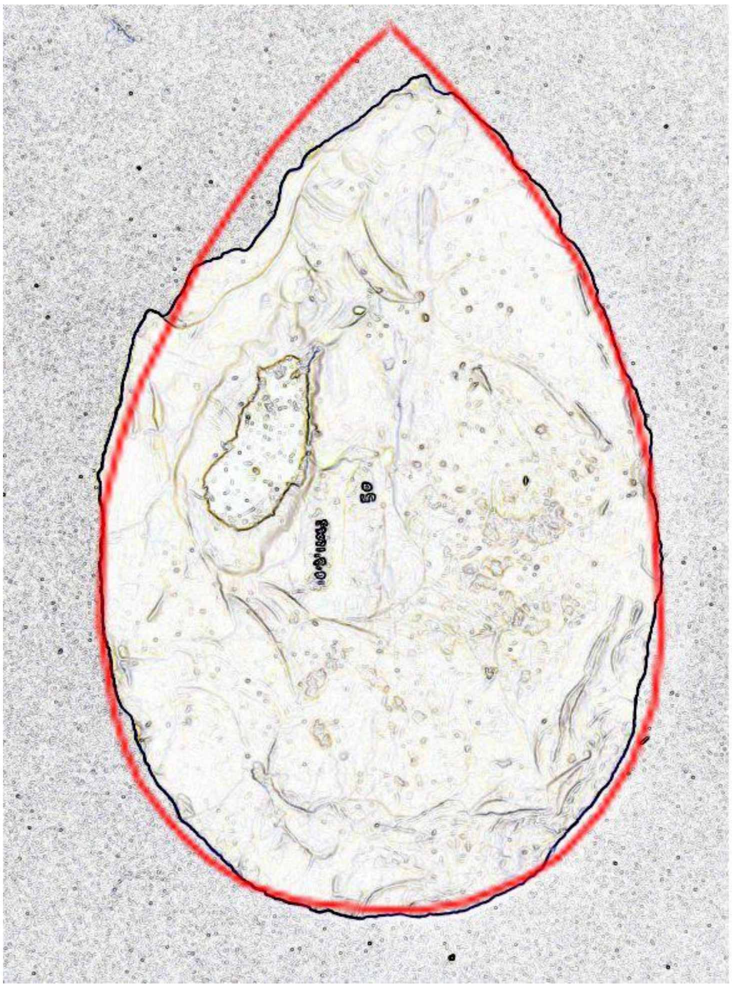

Figure 21. Geometry of pear cut diamond from Botswana superimposed on the outline of Specimen 12043-50B from Boxgrove.

4.4 Why Phi?

An appreciation of symmetry, the number 2, is found throughout the animal kingdom and symmetry has been found to be present in biface formats in a manner that does not fit a null hypothesis (Lycett 2008) and that cannot be explained as a function of animal butchery (Machin et al. 2007). Expressions of Pi (notated below as π for clarity) can also be seen in the full moon, the setting sun and in the eyes of a nursing mother.

Our attraction to Phi, however, is harder to comprehend. If one of the primary functions of large bifaces was in the penetration of flesh, then a refined serrated stone point formed with one or two elliptical sections is highly efficient. A Clovis point had this format, as do modern steak knives. Form and function thus go together.

Although Phi is normally presented as a ratio between lengths, it is perhaps more important in terms of the transition from one to two dimensions. When a single unit of length is increased by an extra unit in all directions from its mid-point, the area formed is a circle of radius 1 and area of π. When the increase in length from the same mid-point is Phi, the area formed is πPhi^2 which is π(Phi+1). Thus as the radius of a circle is increased from 1 to Phi, its area suffers a unit increase of Phi. This is the only number in which linear growth is matched by two-dimensional growth.

For a circle with radius Phi drawn over a circle with a diameter of 1 (radius ½), a line from any point on the former circle that tangents the latter will form the base of a pentagram - the angle of the 5 'points' being 36^o. (See Figure 22.)

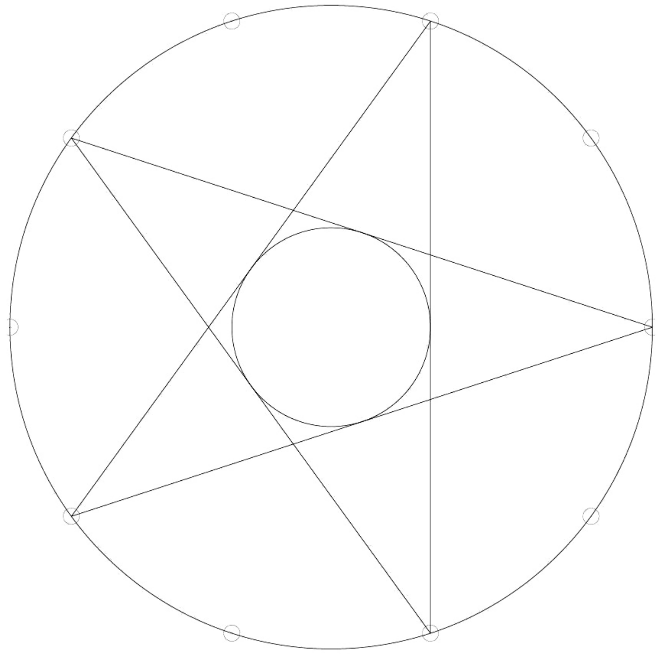

Figure 22. Pentagram based on a circle of radius Phi superimposed on a circle with a diameter of 1.

Humans, like all tetrapods, are pentadactyl with five digits on each limb, thus it is possible that the attraction to expressions of Phi may be related to an appreciation of our own physical structure.

5. Conclusions

Pattern recognition of individual biface formats allows for a more detailed morphological analysis of the geometry used than regression analysis of whole assemblages or larger data bases. An evaluation of random and selected samples of Boxgrove bifaces strongly suggests that several universal mathematical constants were consistently employed in both samples, specifically the numbers 2, Pi and Phi. The use of circles and sections of a Golden Ellipse was common and in many cases there was also a relationship between the constants such that the diameter of the circle was half the length or width of the ellipse used. Binomial probabilistic analysis indicates that these relationships were not made by chance.

These same universal constants appear in more recent Acheulean bifaces indicating that an attraction for these numbers has been continuous over vast time periods, and their preference in modern gem design for purely aesthetic reasons suggests that modern tastes may have been inherited from archaic populations.

The term "mental template" has been applied to biface design and is highly controversial, especially if taken as a conscious process in which a particular shape is the desired end-product of the bifacial reduction sequence. If, on the other hand, this mental template is considered to be an attraction to a simple set of mathematical constants, any final product will end up as an unconscious expression of these numbers (as in the example of the modern knapper and in the diamond industry). This is similar to the concept raised by McNabb (2004) in relation to the formats of British bifaces: "Rather than being a tightly conceived and culturally sanctioned outline form acquired and maintained through social learning, the shape of a large cutting tool was a variable idea in the mind of the knapper".

Much of the recent discussion on 'handaxe' formats has revolved around the shape of the 'points' chosen by the knapper: ovate or pointed. These can be briefly summarized as: the concept of resharpening, in which a 'basic' pointed format resolves into ovate as retouching takes place (McPherron, 1995); and raw material constraints, in which ovates emerge as the preferred form (White 1998). This question was studied in depth by Emery (2010) who concludes that: "it seems likely that the reduction hypothesis cannot be used to explain the point/ovate patterning in the British dataset." As this paper shows, both 'ovate' (elliptical) and pointed formats (when in 36 degrees) can be seen as expressions of the same constant – Phi, the choice of either type of point thus being the result of the individual attraction of the knapper to a specific form, the constraints of the material being used and engineering considerations related to usage.

Expressions of this attraction are seen in bifaces from 1 million years ago, through the Boxgrove samples from some 500 thousand years ago to the Neanderthal specimens from Lyford Quarry from 65 thousand years ago, and the same constants are still used today in gem design. This suggests that this attraction could be considered to be "hard-wired" and possibly related to a neurological mechanism that is even older.

Certain tools are said to: "have artistic creativity" (Letensorer 2006), "show a high degree of craftsmanship i.e., they are "well made" (Iovita & McPherron 2011), appear to be 'over-engineered" (Mithen 2005) or in the case of the giant Cuxton ficron, "be of exquisite workmanship, almost flamboyant" (Wenban-Smith 2004). These qualities are all highly subjective and although it is clear that any appreciation or analysis of format requires that the tool being studied present a well worked shape; at present the study of lithics does not have a standard or guidelines on what constitutes craftsmanship. Rough gemstones are improved in terms of symmetry, shape and reflectivity by the cutting and polishing of facets; a definition of the time and effort involved in biface manufacture could perhaps be expressed in similar terms as the number of 'facets' or visible flake removals, allowing different assemblages to be compared according to their level of craftsmanship. The giant Cuxton ficron, for example, was found in the same context as other "roughly made" ficrons and bifaces yet was deemed to be markedly superior in workmanship, Wenban-Smith (2004) noting that: "both sides are straight and perfectly symmetrical". It is worth adding that these sides form an angle of 18 degrees – once again, an expression of Phi.

Lycett & von Cramon-Taubadel (2008) propose the hypothesis that: "Acheulean handaxe technologies evolved in Africa and dispersed with migrating hominin populations into northern and western Eurasia, under the assumptions of an iterative founder effect (repeated bottlenecking) model." An engineering model of bifaces as hunting tools (Cannell 2014) also suggests that the spread of Acheulean technology closely matches the geographic spread of *Paleoloxodon Antiquus*, thus the high quality of craftsmanship – or over-engineering - of many bifaces could be seen as 'totemic', a token of respect or an effort intended to "attract" the desired proboscidean prey. It remains to be seen if mathematical constants were used in all regions and whether differences in expressions of these numbers are regionally different and if they show a similar dispersal pattern.

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The chert quarrying and processing industry at the Piatra Tomii site, Romania

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Abstract:

Fieldwalking surveys in 2007 and 2008 revealed a moderate sized settlement on Piatra Tomii Hill (Alba County, Romania) which was considered of interest because of its location on top of a natural source of chert, and the large amount of chert artefacts found on the surface. In 2009 the site was excavated during which one of the objectives was to learn more about the chert mining and processing at the site. The ratio of artefact types and lack of use-wear suggests that not only was raw material being extracted at the site, but tools were also being produced locally before being exported. The 2009 excavations also revealed what appear to be the remains of pit quarrying and possibly fire cracked limestone and debris. These finds provide technical insight into potential chert extraction techniques utilised in the Late Chalcolithic and Early Bronze Age. As well, this is as yet the only reported settlement in the Transylvanian basin involved in chert extraction (either quarrying or mining). Given the settlement’s affluence, especially considering its relative isolation, it is likely that the chert industry here was important to communities in the vicinity. Indeed artefacts found at contemporary sites in the Mureș Valley appear to have been made from the same or a similar chert. This paper gives an introductions to the site, describes the artefacts and features found there and provides possible interpretations regarding the processing and export industry, as well as the methods of extracting the raw material during this period.

Keywords: chert; quarrying; lithic artefacts; Chalcolithic; Romania

1. Introduction

One of the main focuses of the excavations was to learn more about the chert industry at the settlement. In particular, there was an interested in how the material was being extracted and how it was being processed afterwards. For this, the research at this site has investigated areas potentially linked to chert extraction. There was also an interest in the general lives of the people who inhabited the settlement so a dwelling was partially excavated. Excavations of the dwelling introduced a new form of Coţofeni dwelling architecture which also became a topic of interest.

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2. Location

The Piatra Tomii site is located in the south-western part of the Transylvanian basin, about half way along the course of the Mureș valley. More precisely, it is located in the Southern Apuseni Mountains at a height of about 300m above the Mureș valley (about 860m above sea level). The site itself is located on the Piatra Tomii hill (from which the site derives its name) on the outskirts of Răcătău village (Blandiana commune), Alba county. (See Figure 1.) The site is connected to the Mureș valley by the Răcătău stream (to the southeast of the hill) which flows down from the mountains and connects to the Mureș valley near the modern town of Blandiana. By following the valleys, the site is located about a 6km walk from Blandiana village to the south and about 12km from the Mureș River.

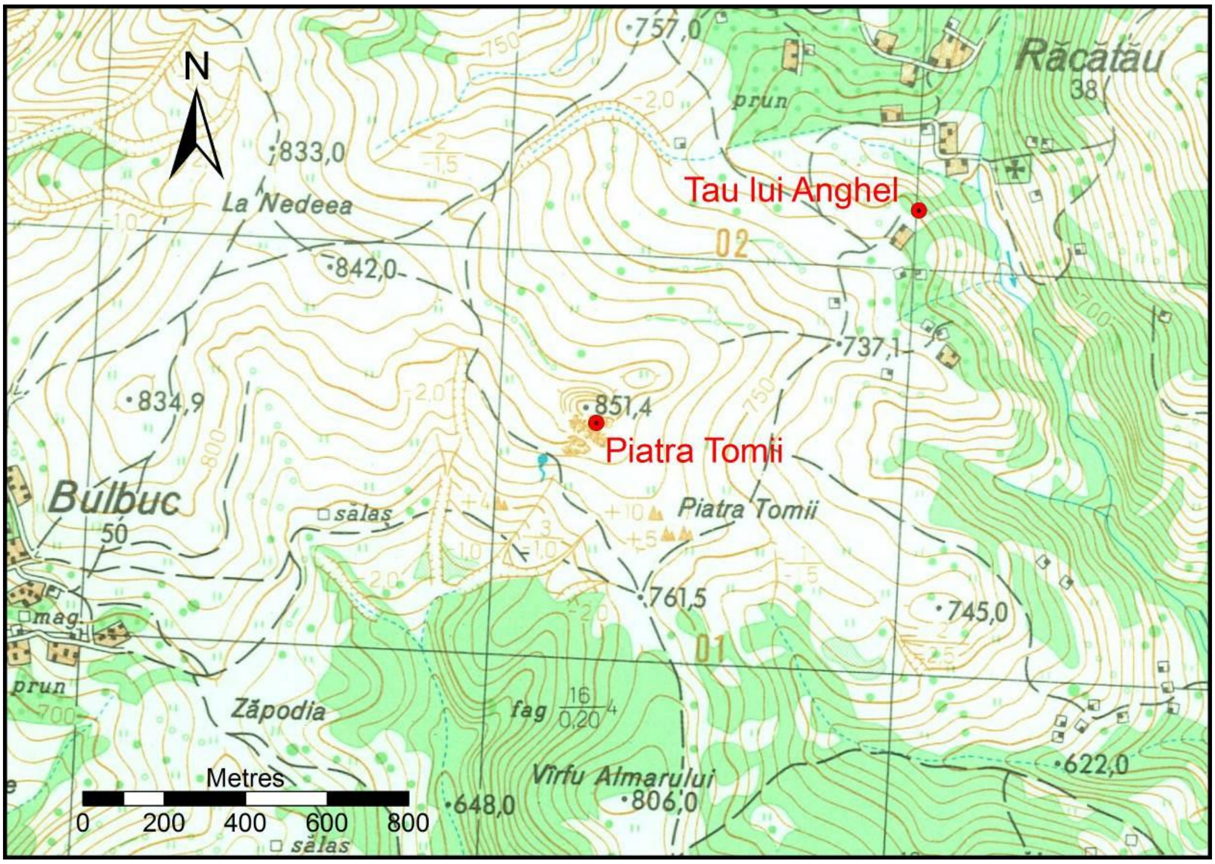

Figure 1. Topographic map of the area around Piatra Tomii. (From Romanian Topographic Map L-34-071-D-c, 2nd Edition, 1:25,000 scale series)

Piatra Tomii hill is in fact a late Jurassic karst tower covered on most sides by a thin layer of topsoil (Giușcă et al. 1967). (See Figure 2.) This limestone outcrop appears to have been tilted over time. What was likely the original top, is now a side of the hill sloping down to the south. The rock has also cracked on the south-western side, causing terraces in some of the cracks which filled in with dirt as well as several deep cracks in the hill. Due to the natural shape of the rock, several terraces have also formed naturally on its south-western, sloped side. Most of the natural surfaces (whether exposed or buried) are worn relatively smooth by weathering. Several springs are located within 100m of the hill. The peak of the hill is about 28m above its base and the entire hill has a surface area of about 0.2ha (being about 200-250m at its widest). The area around the hill is a plateau used today primarily for grazing sheep.

Figure 2. a) Piatra Tomii hill viewed from the east. The trench in Section 1 can be seen in the centre of the photo. b) Piatra Tomii hill viewed from the west.

3. History of Research

The site was first reported in the literature by Gábor Téglás at the turn of the 20th century (for example, Téglás 1901: 21; 1902b: 13; 1902a: 21). The site is mentioned in various later reports, although its location is incorrectly associated with the village of Băcăinţi (Roska 1941: 54, nr. 52; 1942: 44, nr. 156; Roman 1976: 79, nr. 194; Moga & Ciugudean 1995: 52, nr. 15.1; Ciugudean 2000: 64, nr. 56). In 1996, the settlement was rediscovered by Nicolae M. Simina. In 2000 the first archaeological survey and evaluation of the area was conducted by a team consisting of Cristian Ioan Popa, Nicolae Simina and Ovidiu Ghenescu. In the autumn of 2007, Popa organised a fieldwalk survey with Daniel Tentiş Marius Râza, Teodor Muntean, students from the University in Alba Iulia. During the first fieldwalk survey, Otis Crandell was invited along because a large number of chert artefacts had also been found at the site. Upon arriving at the site, it was realised right away that the site is located on an outcrop of limestone which contains chert nodules and lenses. Samples of the chert from the limestone outcrop were taken in 2007 and petrographically analysed in 2008. Further fieldwalk surveys were carried out in 2008. Excavations were carried out at the site by Popa and Crandell in 2009. (See Figure 3 and Figure 4.) These excavations investigated the unusual architectural aspects of the settlement as well as areas potentially linked to chert extraction. A rough topographic survey was carried out at that time. (See Figure 5.) A follow up excavation was carried out in 2010 along with resistivity, magnetometry and topographic surveys. The first images of archaeological materials from this site were published in 2012 by Popa (2012: 12-14, Fig. 1, 8, 10).

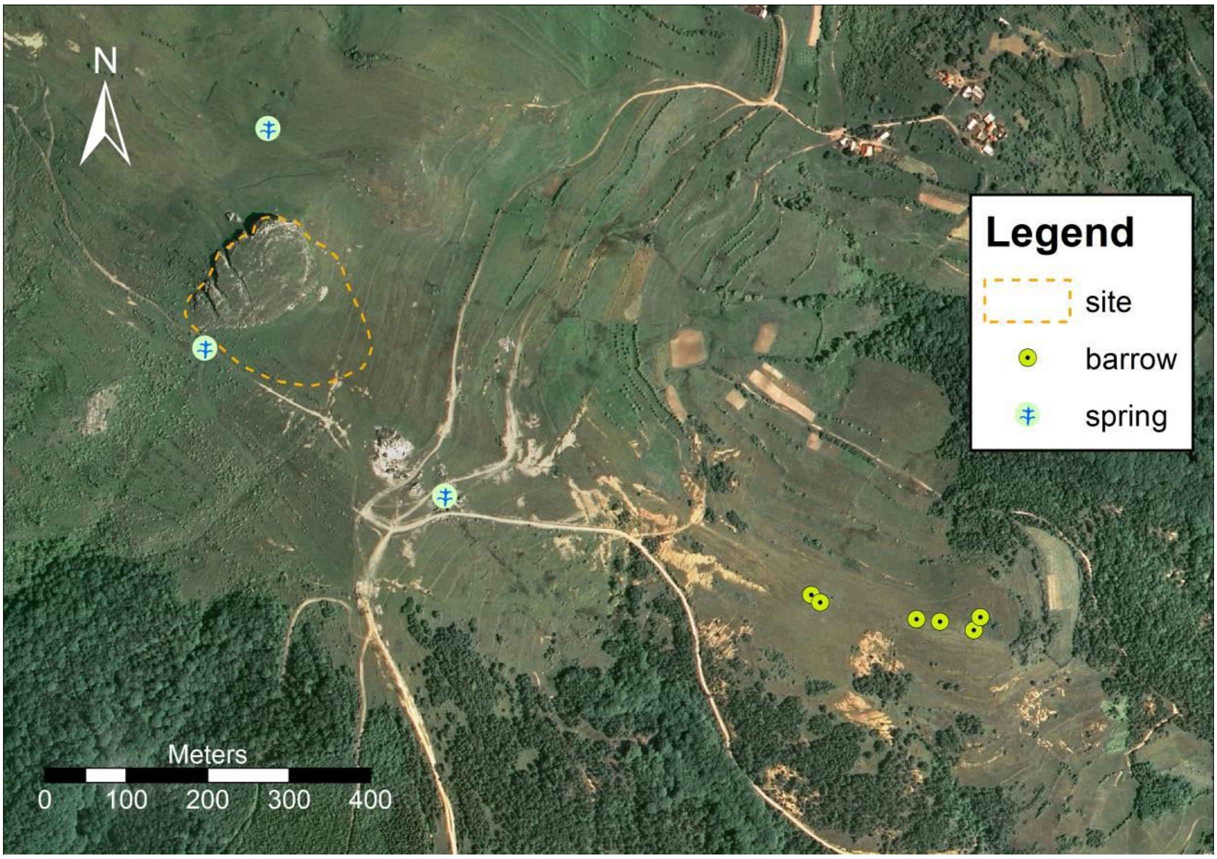

Figure 3. Aerial view of the area around the archaeological site. (Aerial photo from ANCPI orthophoto dataset.)

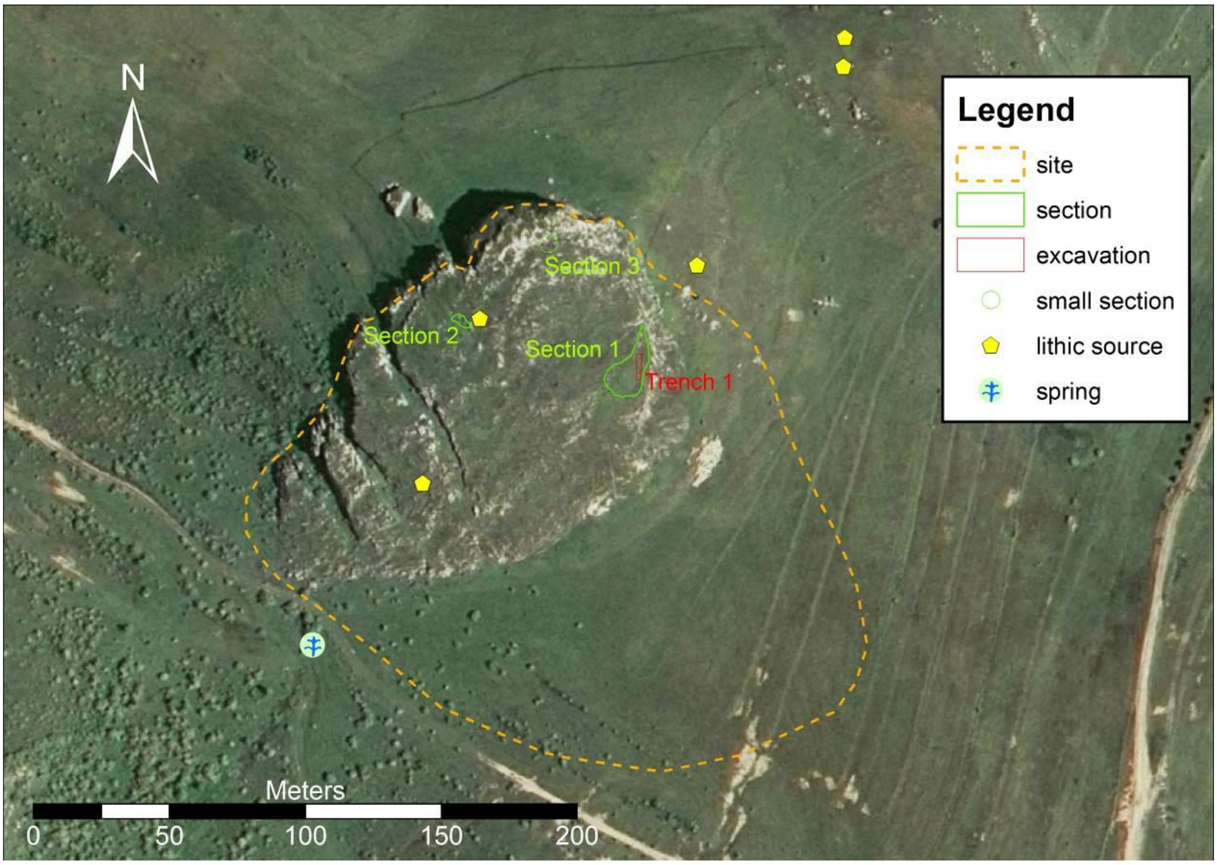

Figure 4. Aerial view of the Piatra Tomii archaeological site around the hill. (Aerial photo from ANCPI orthophoto dataset.)

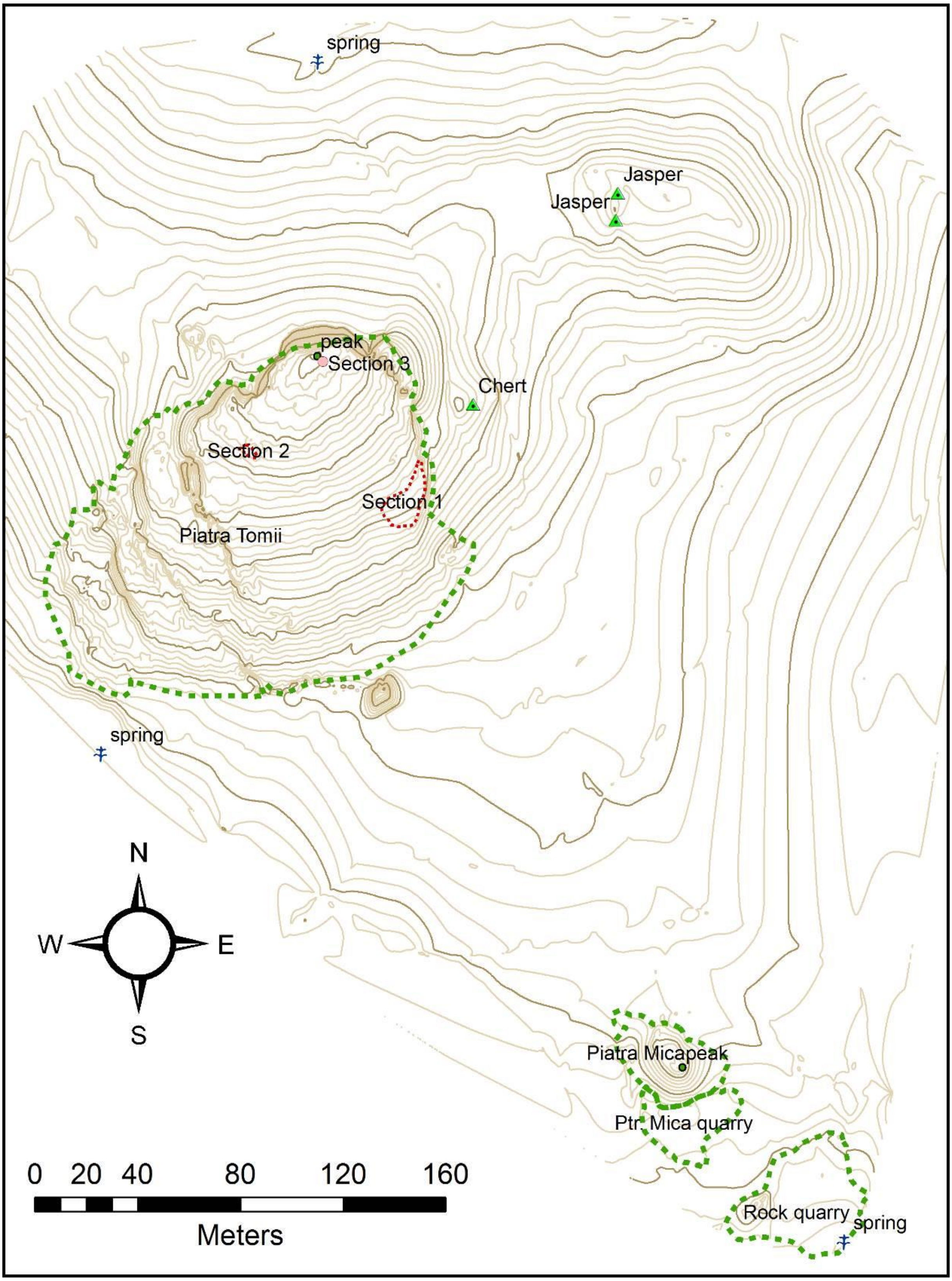

Figure 5. Topographic map of the Piatra Tomii site (topographic survey by the authors, site data recorded during the 2009 excavation and previous field walking surveys). The areas marked by green dashed line represent the main physical features around the site.

4. Chronology of the Site

In and around Piatra Tomii hill, archaeological remains have been found that date from the Neolithic until the Late Iron Age. Vinča (possibly phase B) ceramics were found in Section 3. Petreşti ceramics were found in Section 3 and at the lower levels of the platform dwelling in Section 1. The majority of artefacts, features, and in particular the surface finds from this site come from the latter part of the Coțofeni culture (phase III-b). There is an Early Bronze Age barrow field near the hill. A few shards of Dacian ceramics were found on the hill.

4.1. Pre-Coțofeni

During test pitting in 2009, Vinča and Petreşti type pottery were found at the site (for example, see Figure 6), indicating that the site was in use long prior to the arrival of the Coțofeni population (and possibly abandoned until the late Coțofeni people arrived). The potsherds were found in and next to a possible chert extraction pit. This may indicate a relationship with chert extraction at the site but the evidence is insufficient to make this determination at present. Petreşti type pottery was also found in the lower levels of the platform dwellings excavated in 2009. Whether there was a permanent Vinča or Petreşti settlement, or whether these people only visited the site to extract chert is unclear.

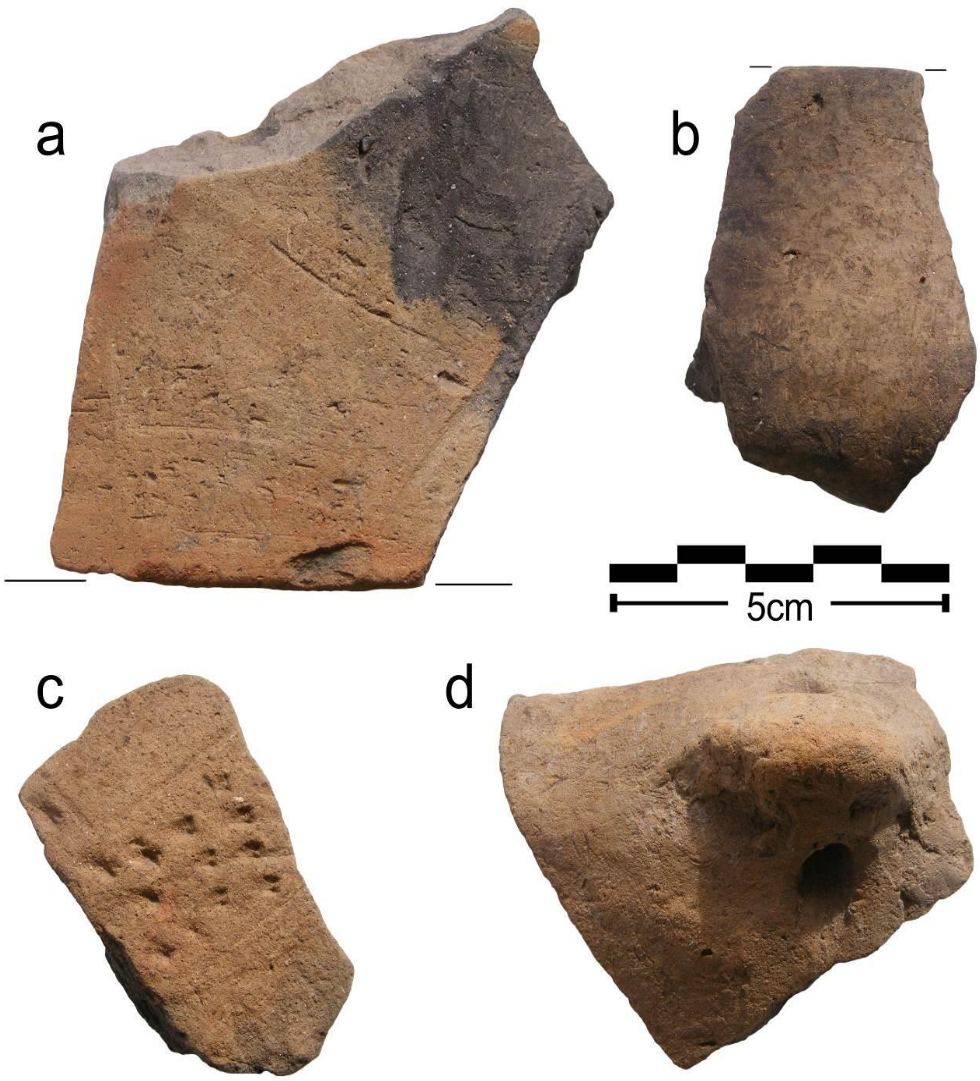

Figure 6. Petrești (a) and Vinča (b-d) culture pottery discovered at the Răcătău-Piatra Tomii site.

4.2. Coțofeni

Primarily this site is known for the Late Chalcolithic to Early Bronze Age settlement. The vast majority of surface finds from the Piatra Tomii site are associated with the end of the Coţofeni culture (phase 3-b). Based on surface finds, test pitting, and initial excavation trenches, it appears that there was a Coţofeni settlement on the slope of the hill as well as the field at the bottom of the slope.

4.3. Post-Coțofeni

Fieldwalks revealed a barrow field nearby. (See Figure 3.) Excavation on one of the barrows was started in 2009. Because the excavation of this feature has not been finished, the dating of the barrows as well as possible funerary function have not yet been established. Most likely though, they belong to a later culture of the Early Bronze Age, such as those found at other sites elsewhere in the Apuseni Mountains. As yet, the relation between the barrow field and the settlement has not been established (if there even is one). Similarly, no other Bronze Age settlement has been located in the vicinity.

Although Dacian (Late Iron Age) pottery was found at the site, it was very rare. One ceramic fragment was found in the trench where the Coţofeni dwellings were excavated. Local villagers have reported that a Dacian coin was found here but this information is as yet unverifiable.

5. Field Survey and Excavation Finds

5.1. Chipped Stone Artefacts

From Section 1 (the dwelling and platform) 111 chert artefacts were found. (For examples, see Figure 7.) Of these, flakes were the most common artefacts. There were 97 flakes, 26 having what appeared to be original outer surfaces of the raw material (cortex or more weathered surfaces) and 71 having all interior surfaces. There were 7 blades or blade fragments, representing 6% of the chert artefacts from this section. There were also 5 scrapers and three cores. A few lithic artefacts were found in Section 2 (the location of a modern poaching and possible quarrying pit) but given the disturbed nature of this section, the number of artefact types from this section will not be discussed at present. Very few artefacts were found in Section 3 (the upper pit formation). The artefacts that did come from this section were mainly pottery and polished stone. At this site, flakes were by far the most commonly found type of chert artefact among the surface finds from field walk surveys on and around the hill. Because the fieldwalk surveys were not conducted with uniform detail, the exact number of those artefacts is not discussed here at this time.

5.2. Polished Stone Artefacts

One fragmented stone axe was found associated with the dwellings in Section 1. Another stone axe was found by a local villager nearby. He claimed that the axe was found at a point named “Tău lui Anghel”. The axe from "Tău lui Anghel" may be connected to occupational activities in the area of those who lived at Piatra Tomii. At present it is not believed that there is a settlement or dwelling at this location. Both axes were carved from igneous rock and perforated using some form of drill. (See Figure 8.)

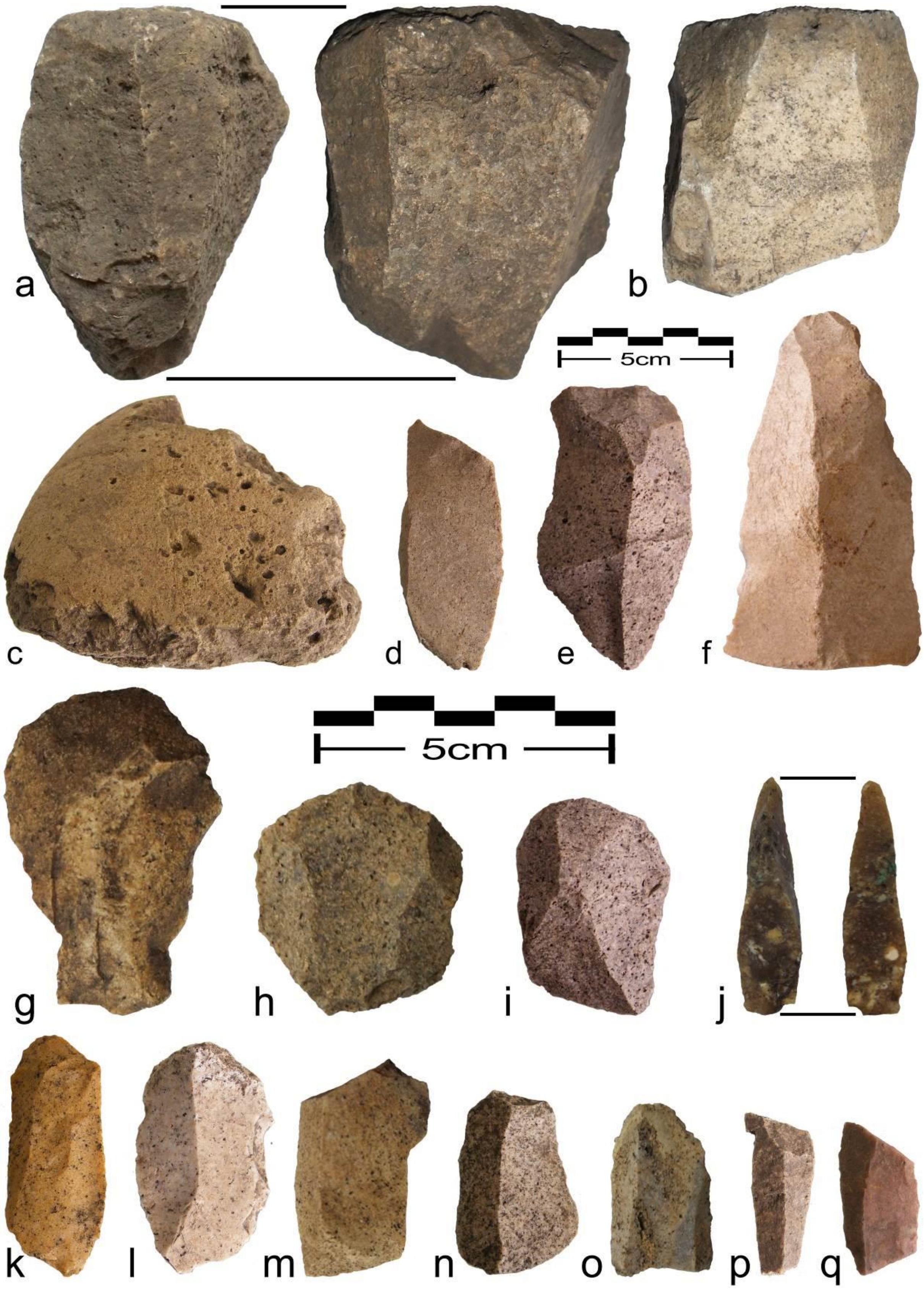

Figure 7. Examples of chert artefacts from the site. a) and b) cores; c) fragment of a hammer stone, pounding stone or grinding stone; d) to f) blades; g) to i) scrapers; j) a perforator; k) to q) blades or blade fragments. (Artefacts *a* to *f* are at the same scale as each other. Artefacts *g* to *q* are at the same scale as each other.)

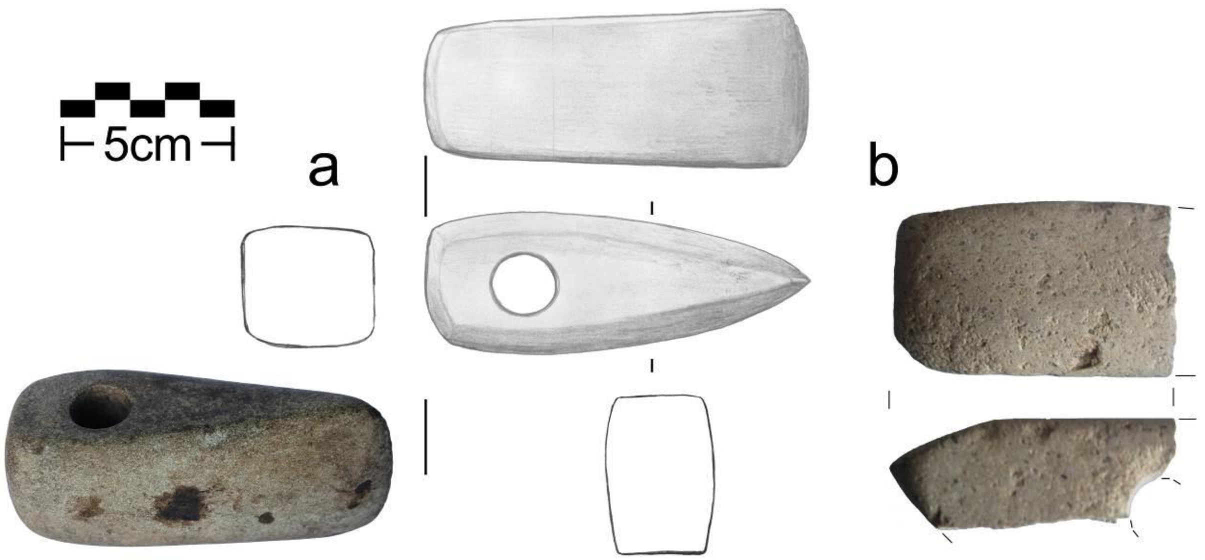

Figure 8. Polished and perforated stone axes from Răcătău. a) An intact axe from the location named Tău lui Anghel. b) A fragmented axe from Piatra Tomii Hill. Both artefacts are pictured at the same scale.

5.3. Pit Features

The 2009 excavations revealed what may be the remains of pit quarrying and heat cracked limestone. At many locations on the hill, one can observe depressions in the soil ranging from 1m to 3m width. Two of these were excavated in 2009. One was at the back edge of the terrace (and into the back wall) of Section 2 (Figure 9.a). The other was in Section 3 (Figure 9.b). Most had a layer of top soil of only 30-40cm thick. The lower soil in and around these depressions often contained organic residue. The rock surface in the depressions was highly cracked and loose. The pieces of rock ranged in size from sub-millimetric grains to gravel and up to 5-10cm (with occasional larger pieces). It should be noted that most of the rock surfaces of the hill that were exposed or uncovered during excavation were of a water-worn or exfoliating type. The areas around the depressions which were not cracked had a large amount of gravel and small rock fragments just above the bedrock surfaces. Ceramic fragments were found in association with both features.

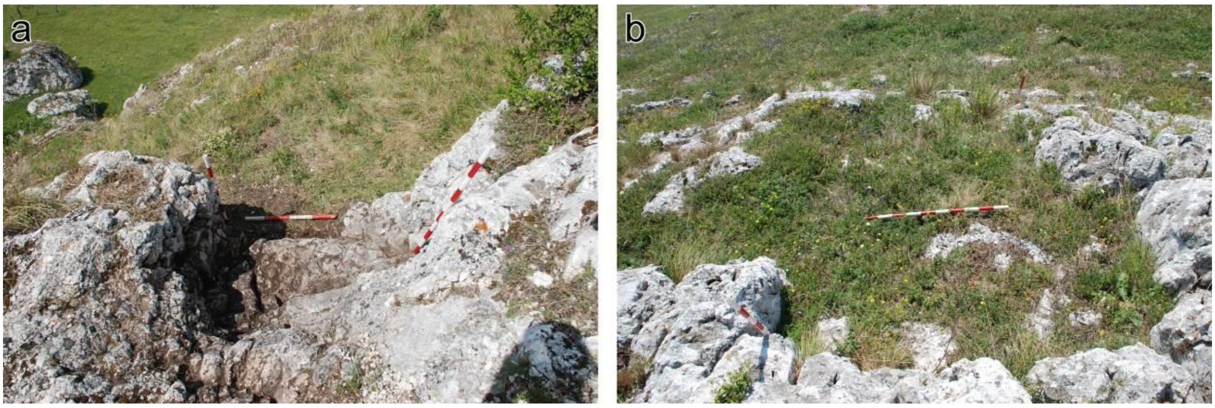

Figure 9. A possible quarrying pits. a) Section 2. b) Section 3.

5.4. Coțofeni Hillside Dwellings

Excavations in Section 1 revealed an interesting aspect of Coţofeni architecture. While excavating in this section, the research team determined that the natural slope (at least in this area) had been terraced with stones to create a step formation. Levelling was carried out with local limestone rocks which had been broken up. Beneath one dwelling the steps were about 30-40cm per 10-15cm increase in height. It was possible to identify two “levels” of this terrace. Above the stone bedding, a floor had been created from yellow clay. This floor formed the base of several dwelling, marked partially by a large quantity of burnt daub and other archaeological materials. Within the steps were post holes. This suggests that part of the dwelling facing downhill was supported by posts while the opposite part was placed directly on the ground. One of the dwellings benefited also from ovens. At the moment, it is difficult to precisely determine the extents of the surface dwellings, owing to the limited dimensions of the surface that was excavated.

This type of architecture represents something new for the Coţofeni culture. The terraces of inhabited rock outcrops have previously been identified, some even in the general area, in the Ampoi Valley, at the Poiana Ampoiului - Piatra Corbului site, for example. Those terraces intended for habitation however, were marked with a border of cobbles at the edge of the slopes (Ciugudean 2000: 18-19, pl. 139; 2001: 77). Other examples of terraces intended for habitation are known also in Coţofeni III sites in Transylvania, such as at Şincai - Cetatea Păgânilor (Lazăr 1980: 15-16; 1995: 251-252), Deva - Dealul Cetăţii (Balázs 1912; Rișcuța & Țuțuianu 2003: 61) and from south of the Danube, for example at Crnajka (Tasić 1995: 66) and Klokočevac-Culmea Skiopuluj (Tasić 1995: 66, 137). A similar method of levelling a platform structure is used today in the modern villages nearby. (See Figure 10 for an example.)

Figure 10. An example of a modern platform structure on sloped ground in the village of Răcătău.

5.5. Fine quality objects

During the 2009 excavations several copper artefacts were found, including ear rings, beads and awls. Numerous ceramic cups and other fine quality ceramics were also discovered. (See Figure 11 for examples.)

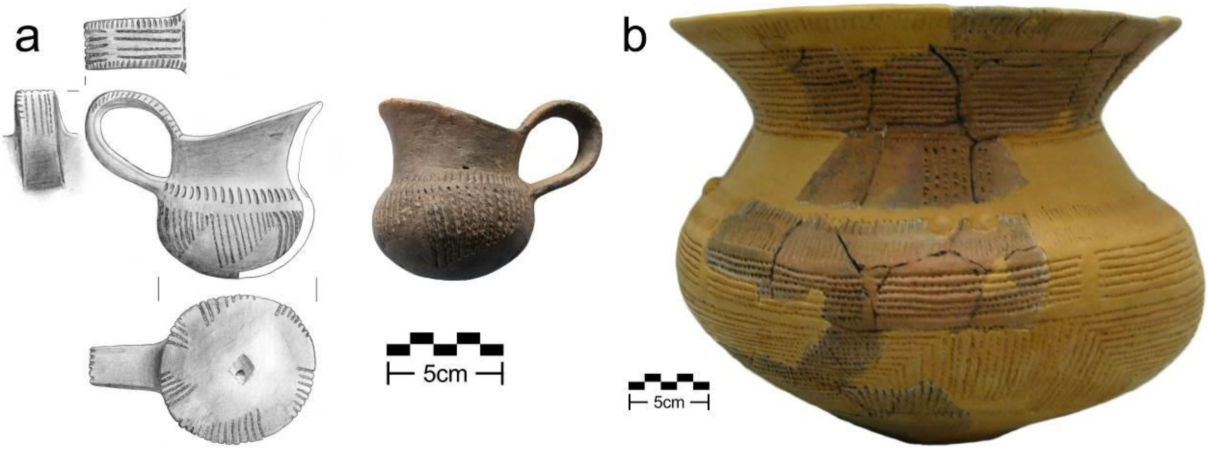

Figure 11. Two examples of a fine quality ceramics found at Piatra Tomii. a) A cup from Section 1. b) A pot from Section 2.

6. Chert Characteristics

The variety of chert found at Piatra Tomii has the same origin and physical characteristics as chert from other outcrops in the Trascău Mts. (particularly in the south). Trascău chert is found in or near to Late Jurassic limestone outcrops (most often karst towers) from around Piatra Tomii in the south and throughout the entire length of the Trascău Mts. (Lupu et al. 1966).

In terms of colour, this material is medium to dark browns, brown-grey, medium dark greys (almost black), and medium dark orangish-yellowish brown. In terms of Munsell colour codes, the chert from Piatra Tomii falls within the following ranges of colours - 7.5R-10R 2.5-3/1, 2.5YR-5YR 2.5-4/1, 5YR-7.5YR 5/8 to 4/6, 7.5YR-10YR between 5/1, 2.5/1 and 2.5/2, 10YR 5/8 to 3/6, 2.5Y between 5/1, 6/6 and 2.5/1, 5Y 2.5-6/1, and 10Y 2.5-6/1 (Munsell Color 2009). It is sub-translucent to translucent (occasionally being very opaque), with medium to fine grained surfaces with a matt (sometimes satiny or slightly waxy) lustre, and it often contains relics of its parent rock (limestone). Some samples show slight banding parallel to original lens orientation. (For explanations of descriptive terms, see previous publications by Crandell (for example, Crandell 2005; 2006).) This is likely caused by the original limestone sedimentary orientation. When broken, this material produced a good conchoidal fracture and sharp edges. (For examples, see Figure 12.) The darkness and intensity of the colour varies. Weathering may cause a white, opaque patina on the surface, as well as pitting. The patina may also obtain a bluish tint. Observations on chert in general in the Trascău Mts. have been made by previous researchers (Ilie 1950: 130; 1952; Ciupagea et al. 1970: 48-49; Crandell 2008; 2009; 2012).

Microscopically the main component of this material is microgranular quartz. (For examples, see Figure 13.) The grain size varies but except for rare in-filled cracks or voids, none of the grains are large enough to be seen with the naked eye or a loupe. The size is generally larger than that of flints which were imported into the region (which are also more equigranular than the chert found in the Trascău Mts.). The quartz rarely forms as microfibers or macrocrystals. In addition to quartz this material often contains large amounts of calcium carbonate, as large masses, as distinct clusters of particles, or spread throughout the material as small particles. This component is likely a remnant of the original parent material. The quantity of Fe oxide and hydroxide varies from little (or none) but is not nearly as abundant or concentrated it is in the jaspers of the Metaliferi and Trascău Mts. The Fe often tends to be blended with the quartz or to occur as small dark particles, sometimes clustered in an area. The iron content causes the orange and yellow colours that this material often exhibits. Some samples contain occasional dolomite rhomb-shaped crystals (for example, in Figure 13.b).

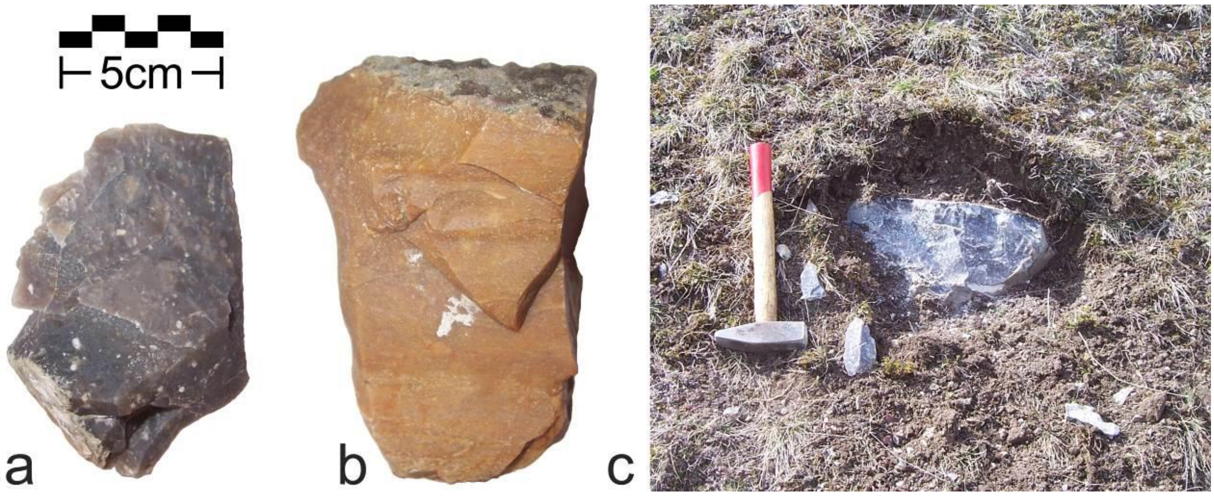

Figure 12. a) and b) Photos of chert samples from Piatra Tomii showing macroscopic variation. c) A nodule of chert *in situ* on the hill (the 2kg hammer in the photo is for scale).

A few of the artefacts from the site were petrographically analysed to verify that they exhibited the same characteristics as the raw materials. They appear the same and there is no reason to doubt that they were not made from the locally available material. (See Figure 14 for an example.)

7. Discussion

7.1. Chert Industry

One of the objectives of the project was to learn more about the chert extraction and processing at the site. It is presumed that these were two of the primary occupations of this settlement. There are numerous outcrops of medium to high quality chert on the Piatra Tomii hill (which is in fact a late Jurassic karst tower with a thin layer of top soil covering it). Near the Piatra Tomii hill there are a few other smaller limestone outcrops, several of which also contain chert nodules and lenses. Indeed a large quantity of chert artefacts can be found on the surface at the site amongst potshards. In the excavation trenches of 2009, there were found several cores as well as fractured and whole blade blanks (unused blades). Petrographic analyses of the raw material at Piatra Tomii match those of the artefacts found at Neolithic and Chalcolithic sites in this region such as Tărtăria.

7.2. Mining Technology

One of the interpretations of these finds is that a form of fire-setting may have been used to extract the chert. After people located a band of chert or an area of large nodules, they would have covered the chert and built fires on top of the limestone to heat it up. They likely then would have swept away the embers and threw a large quantity of water on the still hot bedrock. (There are numerous springs within a few meters of the Piatra Tomii hill.) This would cause the rocks to shatter, making it easier to extract both the limestone rubble from around chert outcrops. (For a visual explanation, see Figure 15.) Stone axes and chisels may have been used to cut wood brought to the site. (Of course they were also likely used to cut and carve wood for constructions and other daily functions.) Without bronze or iron tools, it would have been time consuming and labour intensive to use only hammer stones to carve away at the limestone. This is not to say that they did not also use hammer stones (hand held or fixed in a handle), as percussion-worn river cobbles were also discovered during excavation of the hillside dwelling.

Although the limited excavations carried out so far are insufficient to determine with certainty that this was indeed what was happening at Piatra Tomii, the evidence so far shows similarities to the chert mining activities at Kleinkems (Germany) (Schmid 1980a; Diethelm 1997; Engel & Siegmund 2005), Veaux-Malaucène (France) (Schmid 1980b) and Sélédin (France) (Roden 1983).

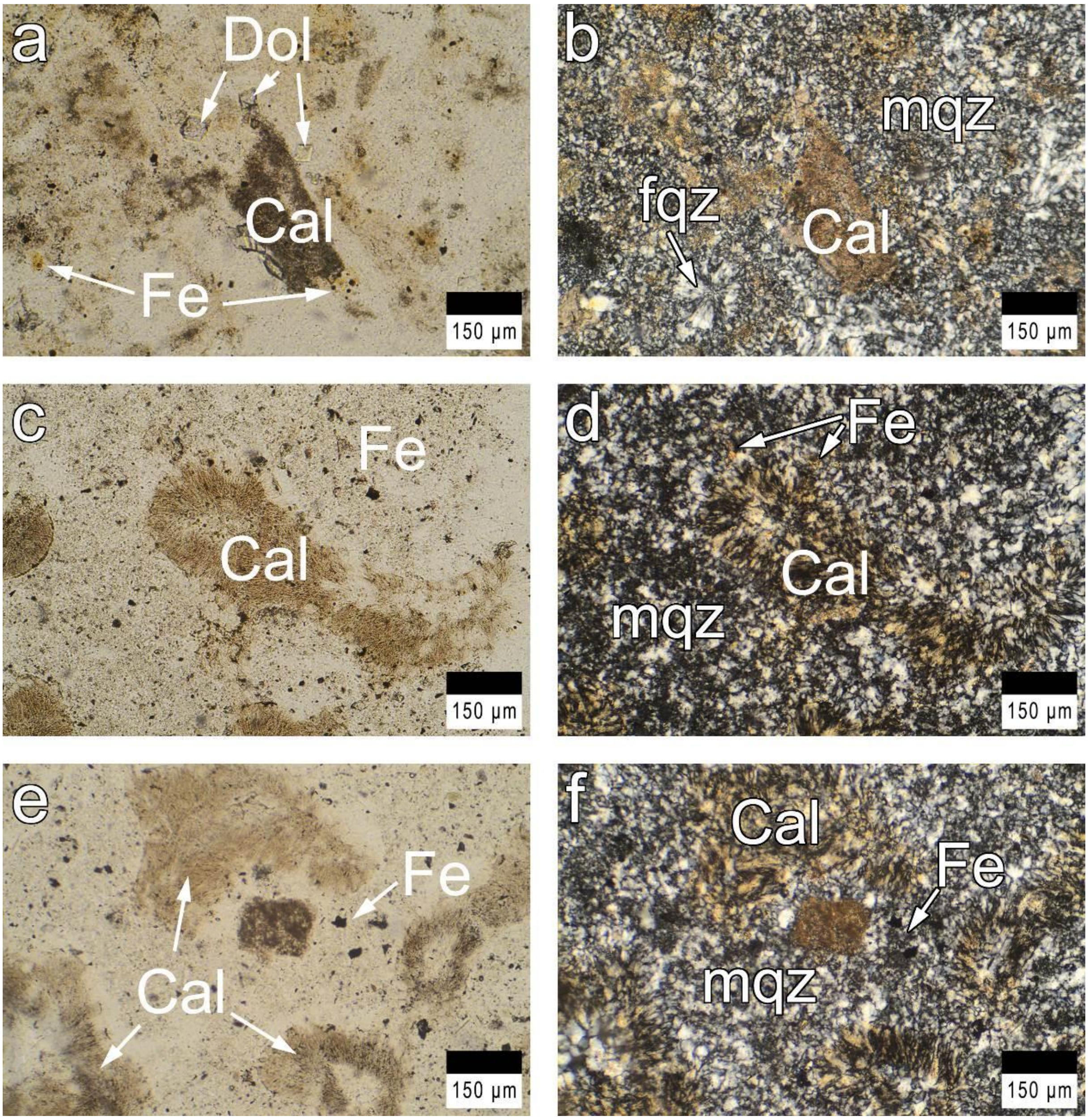

Figure 13. Microphotos (polarized light) of chert from Răcătău-Piatra Tomii. a) to f) Well developed microcrystalline quartz mixed with calcite and with small clusters of fibrous microquartz. Fe compounds are restricted to small areas. Left side, one polarizer (1P). Right side, the same with crossed polarizers (+P). Abbreviations: mqz for microgranular quartz, fqz for fibrous quartz, Cal for calcite, Fe for iron phase, Dol for dolomite.

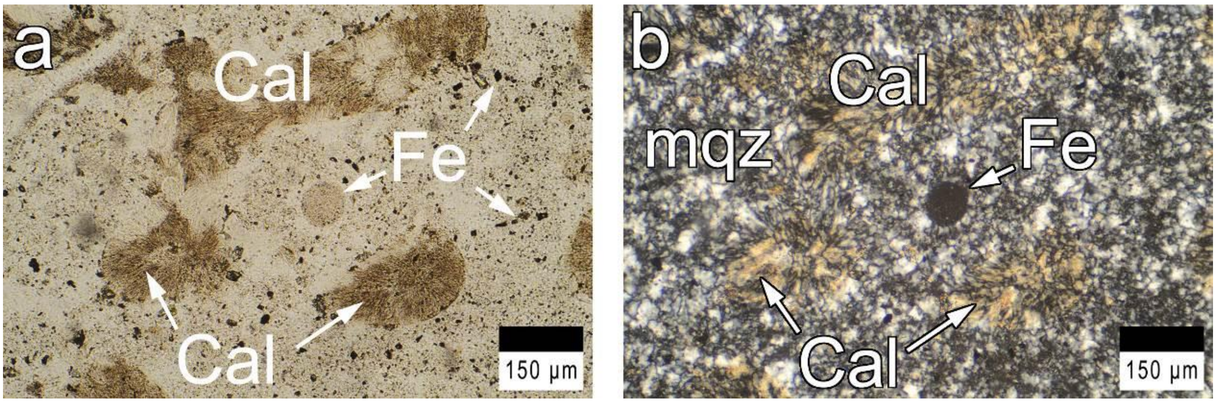

Figure 14. a) & b) Microphotos (polarized light) of a typical chert artefact from Piatra Tomii. Well-developed microcrystalline quartz mixed with calcite; Small clusters of fibrous microquartz and Fe compounds restricted to small areas are seen. Left side, one polarizer (1P). Right side, the same with crossed polarizers (+P). Abbreviations: mqz for microgranular quartz, Cal for calcite, Fe for iron compounds.

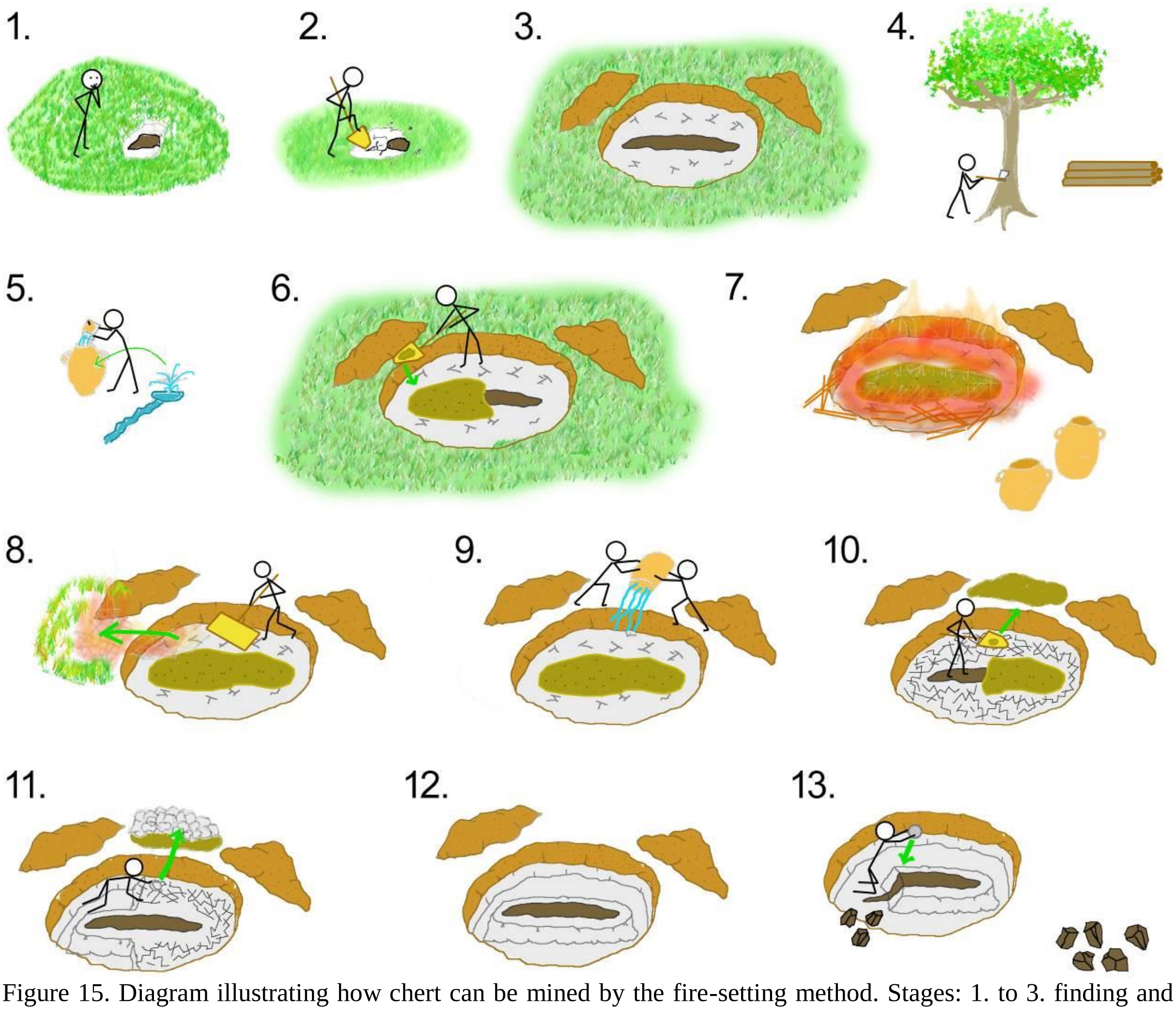

Figure 15. Diagram illustrating how chert can be mined by the fire-setting method. Stages: 1. to 3. finding and uncovering an outcrop of chert; 4. collecting wood; 5. collecting water; 6. covering the outcrop with soil; 7. making a fire over the limestone bedrock; 8. removing the embers; 9. pouring water on the hot limestone; 10. uncovering the chert; 11. & 12. removing the cracked limestone until only the chert band remains; 13. removing the exposed chert.

It should also be mentioned though that there are other possible explanations of the finds at this site. In Section 2, the carved rock face may have been part of a dwelling or other structure. It may have also been used by the people who lived there for easy access between the artificial terraces. The depression in Section one may have created to level the ground for a structure. It may also have been excavated to obtain rock for creating plaster or whitewash.

7.3. Affluence

It is worth noting that although the Piatra Tomii settlement is rather remote (in regards to distance from the Mureș Valley and in altitude) the occupants appear to have been more affluent than those living at other Coțofeni settlements in this region.

7.4. Architecture

Although this type of architecture has been observed in other cultures (and is still used today in the region) this is one of the first time that it has been observed at a Coțofeni site, suggesting a local evolution of the culture in its final phase. The presence of constructed dwellings also suggests permanent occupation (or repeated seasonal re-occupation) of this site by the same people.

7.5. Connection to Other Sites

At the mouth of the Răcătău Valley, where it opens into the Mureș Valley, across the Mureș River is the Tărtăria - Gura Luncii archaeological site (approximately 15km from Piatra Tomii). At the Tărtăria site researchers have discovered Vinča, Petreşti and Coțofeni artefacts (Vlassa 1963; Paul 2011). Visual and petrographic analysis of the chert artefacts from Tărtăria show a match with the type of chert found at Piatra Tomii. It is quite possible that the inhabitants of Tărtăria obtained their chert from Piatra Tomii. Indeed, the outcrop at Piatra Tomii is the nearest source to Tărtăria. At present, it is unclear whether they visited Piatra Tomii for raw materials or traded for it. It is possible that the material used at Tărtăria and other nearby sites may have also come from other chert sources but those sources are further away. In addition to Tărtăria, there are various other sites in the Mureș Valley occupied by the Vinča (Suciu 2009), Petreşti (Paul 1992; Gligor 2000) and Coţofeni (Ciugudean 2000) cultures which may have had connection with and acquired chert from Piatra Tomii. (Several contemporary sites are indicated on the map in Figure 16.)

There are no sources of copper or copper ore at this site. The nearest sources of these would be to the north in the Ampoi Valley. Numerous Coțofeni settlements have been found in the Ampoi Valley (Ciugudean 2001). It is quite likely that the copper artefacts found at this site are from the Ampoi Valley but may have also come from other sources in the general region.

8. Conclusions

This site is significant for several reasons. These finds give us a technical insight into possible late Chalcolithic and early Bronze Age chert mining techniques. If the occupants of this site were indeed extracting the chert from the bedrock, then this site is the only chert quarrying settlement documented so far in the Transylvanian Basin. Regardless of whether the chert was being quarried or simply collected from previously eroded nodules of chert, this sites still gives us information regarding the beginning stages of lithic trade routes of the area. The collection and processing of raw materials represents the early stages of the *chaîne opératoire* for lithic tools.

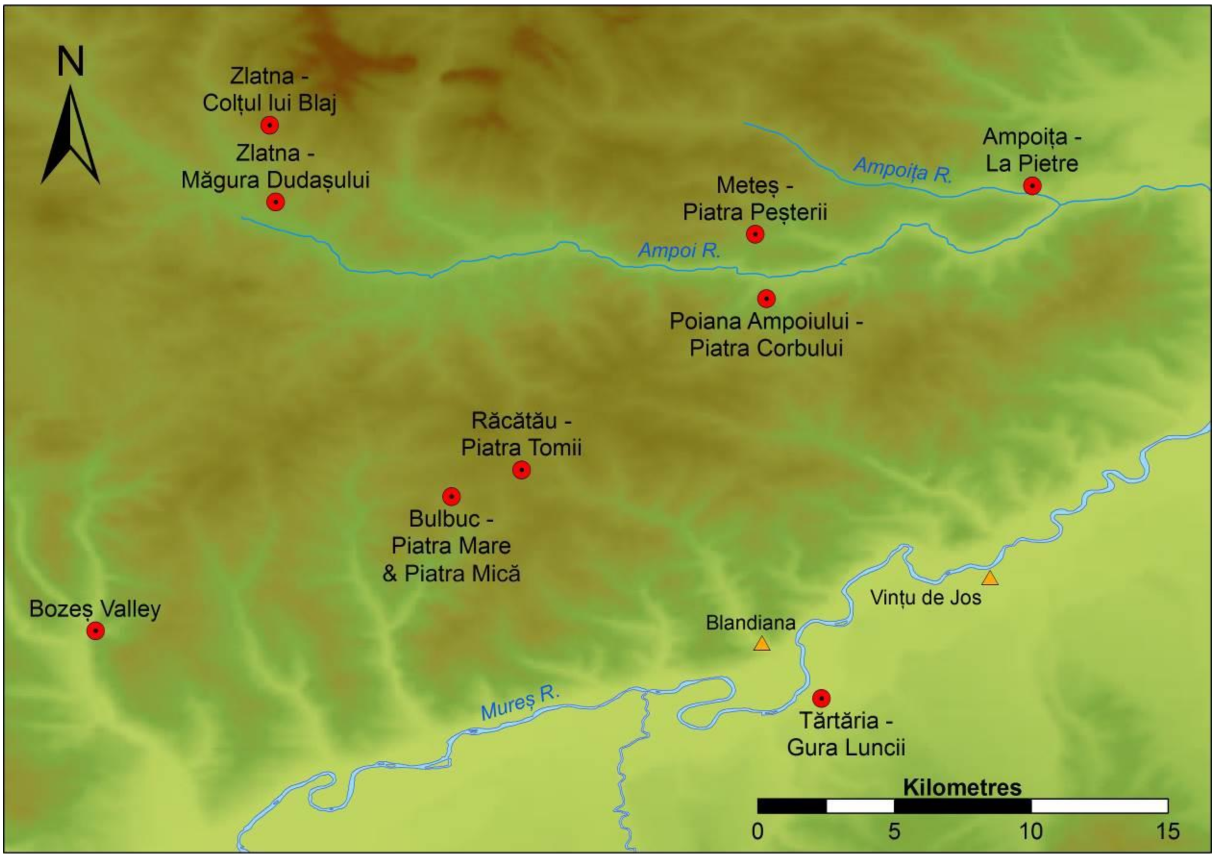

Figure 16. Map showing the location of Piatra Tomii relative to the Mureș and Ampoi Valleys as well as other contemporary archaeological sites (indicated by red circles on the map). (Modern settlements are indicated by triangles.)

The cores, unused blades, and the minimal use-wear on the lithic artefacts suggests that not only were the occupants of the settlement extracting raw material, but that they were producing tools at the settlement before and exporting the chert in the form of blank blades, cores or premade tools. It likely that they supplied contemporary lowland settlements in the Mureș Valley within 10 to 20 km. Given its affluence, especially considering the relative isolation of the settlement, it is likely that the chert industry here was important to communities in the vicinity.

Although the majority of the artefacts so far found at the site are from the Coțofeni population, the presence of artefacts from earlier cultures at the settlement indicates that the site was already in use by the middle of the Neolithic by people of the Vinča and Petreşti cultures. Based on comparisons of Neolithic chipped stone artefacts found at nearby settlements with the geological material at Piatra Tomii as well as the nature of the pre-Coțofeni finds, it seems likely that the Vinča and Petreşti people who were at Piatra Tomii were there to exploit the chert source.

Since only a small percentage of this site has been excavated, it is also possible that remains of Vinča dwellings simply have not yet been found at Piatra Tomii. It is also possible, given the very shallow layer of soil above the bedrock, the steep slope of the hillside and the relatively small surface area, that most of the remains from the preceding settlement were intentionally removed when a new settlement was established in order to make room for new dwellings of the current inhabitants. Some materials may have also slid down the hillside due to erosion. This is one possible explanation for why very few remains of settlements prior to the last one were found on the hillside.

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A note on handaxe knapping products and their breakage taphonomy: An experimental view

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Abstract:

The notion that broken artifacts provide a good indication of the taphonomic history of lithic assemblages is commonly accepted in prehistoric archaeology. High frequencies of broken artifacts are frequently viewed as an indication of the possible role of post-depositional processes such as high-energy fluvial transportation, trampling or plowing. Yet another alternative is that the breakage resulted from the knapping process itself.

In this study, the knapping byproducts of biface shaping and thinning (the final stages of handaxe production) originating in several experiments were systematically studied and their breakage frequencies and patterns were determined. The breakage patterns observed for the experimental assemblages were then used in a model designed to simulate the effect of breakage resulting from post-depositional processes, providing the breakage patterns expected for such an assemblage.

The breakage pattern and frequencies observed in the experimental assemblages and those provided by the model were then compared to an archaeological assemblage representing the production of Acheulian assemblages that include bifaces from the site of Gesher Benot Ya‘aqov (GBY), Israel. The results indicate that high breakage rates are inherent to the final stages of the Acheulian bifacial knapping process. Furthermore, they demonstrate that taphonomic (post-depositional) breakage changes the breakage pattern of the production stages in a systematic trend. Finally, the results show that the lithic assemblage of GBY presents breakage frequencies and patterns that are more similar to those of the experimental assemblages than those generated by the model. In the light of these results, it is suggested that this assemblage was not subjected to any breakage caused by post-depositional processes.

Keywords: taphonomy; breakage; handaxes; experimental knapping; modeling

1. Introduction

The analysis of lithic assemblages is one of the most basic tools of Paleolithic research. The most prevalent method of analysis is morpho-typo-technological attribute analysis (Bar-Yosef & Goren-Inbar 1993; Debenath & Dibble 1994; Andrefsky 2005). This method is selected due to its relative accessibility and efficiency in processing large amounts of material and the vast amount of quantitative information that it provides. The method usually utilizes

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three groups of attributes focusing on different aspects of the assemblage: 1) a group of typological attributes such as the location and type of retouch; 2) a group of technological attributes such as the type of striking platform and the configuration of the dorsal face; and 3) a group of preservation-related attributes such as the extent of abrasion and patination.

One attribute that is regularly recorded in these analyses is breakage. Breakage occurs when high levels of energy are transferred to the material (Cotterell et al. 1985; Andrefsky 2005), causing fracturing of the mass into two or more pieces. From a mechanical point of view, breakage is identical to flaking, since it possesses the same physical mechanisms of initiation, propagation and termination. Breakage therefore leaves distinctive and easily identifiable features on the material. Breakages are most evident on flakes and flake tools, as they consist of fractures secondary to the initial fracture that produced the flake. Their secondary status derives from the fact that they take place only after the flake on which they occur has been removed from the core. Consequently, the breakage leaves a distinctive surface that cuts the original faces of the flake at an angle close to 90º (Andrefsky 2005). Breakage can occur on various locations of the flake, and hence each of the resulting new pieces retains some features of the original flake. Broken flakes and flake tools can be classified either according to the position of the breakage (Bar-Yosef & Goren-Inbar 1993; Goren-Inbar & Sharon 2006; Goren Inbar et al. in preparation) or according to the features of the original flake that they retain (Sullivan & Rozen 1985).

The breakage of a flake or flake tool may occur in three different phases of its life history: production, usage and post-deposition. Theoretically, each of these phases can be associated with high-energy events that may cause the breakage of the item. Naturally, each of these possibilities has different implications for the interpretation and understanding of the assemblage (Hiscock 1985, 2002). For example, breakages occurring during the production or usage phase must be related to direct human interaction with the artifacts and provide no information about the post-depositional phase of their life history. Equally, breakages that occur as a result of post-depositional processes are completely detached from the behavior of their makers and users. Hence, the importance of the correct interpretation of the origin of breakages in a given assemblage is evident.

In light of the fact that breakage can result from completely different phenomena, several studies, which mainly employ an experimental approach, have attempted to replicate and characterize breakages related to specific incidents. For example, numerous studies have attempted to describe the effects of high-energy fluvial transport on the morphology of items as reflected in breakages caused during the process (Chambers 2003; Hosfield & Chambers 2003; Grosman et al. 2011). Other studies have attempted to characterize the breakage pattern of lithic assemblages that have been subjected to various agricultural activities (Mallouf 1982; Rust & Earl 2011). A different approach was to experimentally produce lithic assemblages originating in the production of specific items and to define the typical production-related breakage patterns (Amick et al. 1988; Mauldin & Amick 1989; Jennings 2011). The results of such studies are often used to address such issues as the taphonomic integrity of archaeological assemblages (Bertran et al. 2012; Schoville 2014).

In this study we attempt to assess the nature of breakages caused by post-depositional processes in comparison to breakage patterns encountered in pristine assemblages. These results are then used to discuss the taphonomic status of an archaeological assemblage. Initially, we present the breakage pattern of debitage originating in actualistic experimental production of bifaces mimicking those of the Acheulian. These assemblages were combined to form a simulation of an actual archaeological assemblage consisting of the products of numerous reduction events. The combined breakage pattern was then inputted into a computerized model aiming at simulation of the effects of breakage caused by post-depositional processes. This model provided a new breakage pattern representing the degree and manner in which the original breakage pattern changes as a result of such processes. The original experimental breakage pattern and that produced by the model were then compared to an archaeological assemblage from Gesher Benot Ya'aqov (GBY) that has been interpreted as resulting from the production of Acheulian bifaces (Goren-Inbar & Sharon 2006).

However, it should be stressed that this study is not aimed to provide a simple straightforward comparison between the lithic assemblages of GBY and the experimental ones. The purpose of the paper is to demonstrate that high proportions of breakages can be caused during the final stages of biface production and that they do not necessarily reflect the result of post depositional processes. Hence, the assemblage of GBY serves here only as a case study to illustrate the above.

2. Materials and Methods

2.1. Materials

The assemblages used in this study were produced during an extensive knapping experiment that took place in 1999. This experiment attempted to reconstruct the reduction sequence of Acheulian handaxes excavated at the site of GBY, located in the northern Jordan Valley, Israel (Madsen & Goren-Inbar 2004). The experiment comprised the production of several dozen replicas of Acheulian handaxes by an expert knapper. The handaxes were made on similar raw materials to those occurring at the site, which include local flint collected in the vicinity of the site. The entire production sequence, from acquisition of raw materials through core design and large flake production to the final flaking, thinning and finishing stages, was consistent with methods and techniques observed at the site. The knapping was restricted to the direct percussion technique, using hard and soft hammers of various materials (basalt, limestone and antler) and sizes. Although the purpose of the knapper was to produce handaxes, the resulting byproducts were collected, labeled and stored separately to form assemblages representing the production of each handaxe. As the initial production stages were carried out elsewhere, the assemblages of byproducts (debitage and chips) are limited to the final stages of the handaxe production, i.e., the thinning and finishing stages (Newcomer 1971). Of the extensive experimental byproducts, five flint debitage assemblages were selected randomly for the current analysis (Table 1). These assemblages are formed by a reduction sequence aimed to produce handaxes on flakes. All the lithic assemblages of GBY are assigned to the Large Flake Acheulian, a particular tradition within the Acheulian Technocomplex in which all bifaces (both cleavers and handaxes) are made on flakes (Sharon 2007).

Table 1. Sizes of the assemblages.

Assemblage	Number of artifacts
C-35	238
C-36	103
C-37	71
C-45	115
C-50	63
GBY Area C	462

The archaeological assemblage used in this study originates in the Early to Middle Pleistocene Acheulian site of GBY. The site is located in the northern Jordan Valley, Israel, and consists of a series of stratigraphically superimposed and undisturbed waterlogged settings. The excavations at the site have provided a wealth of botanical and faunal remains as well as rich lithic assemblages that mainly represent three distinct *chaînes opératoires* (Goren-Inbar et al. in preparation). The assemblages used in this study originate in Area C, Layers V-5 and V-6, two directly superimposed Acheulian entities that are considered here as a single assemblage (see for example, Rabinovich et al. 2012).

In accordance with many of its attributes, the archaeological assemblage was shown to include the thinning and finishing stages of bifacial tool production. However, as flint cores and flake tools with secondary modification were also recovered in this area, it is clear that the complete assemblage cannot be attributed exclusively to the production of bifaces (Goren-Inbar & Sharon 2006). For this reason, only debitage and items classified as originating in the production of handaxes (i.e., flakes, *éclat de taille de biface* and biface sharpening flakes; note that not a single flint cleaver was found in the excavations of GBY) were included in the analysis (Table 1; Figure 1). These components consist 72.64% of the entire flint assemblage from layers V-5 and V-6. While it is true that this selection cannot guarantee that all the artifacts included in the analysis necessarily originate from the reduction of handaxes, we believe that it provides a relatively good representation of this type of reduction sequence. One should note that unless a particular type of raw material was used exclusively for the production of bifaces, the analysis of an Acheulian assemblage by the present methods cannot differentiate between products originating from different reduction processes. Although the assemblages originating in Area C are dominated by flint, flint handaxes comprise less than 1% of the entire biface assemblage of the site. This, along with the evidence of rapid burial (see for example, Feibel 2001, 2004; Ashkenazi et al. 2010; Rabinovich et al. 2012), indicates that the great majority of the flint handaxes produced at the site were transported out of it by hominins (Sharon & Goren-Inbar 1998; Goren-Inbar & Sharon 2006).

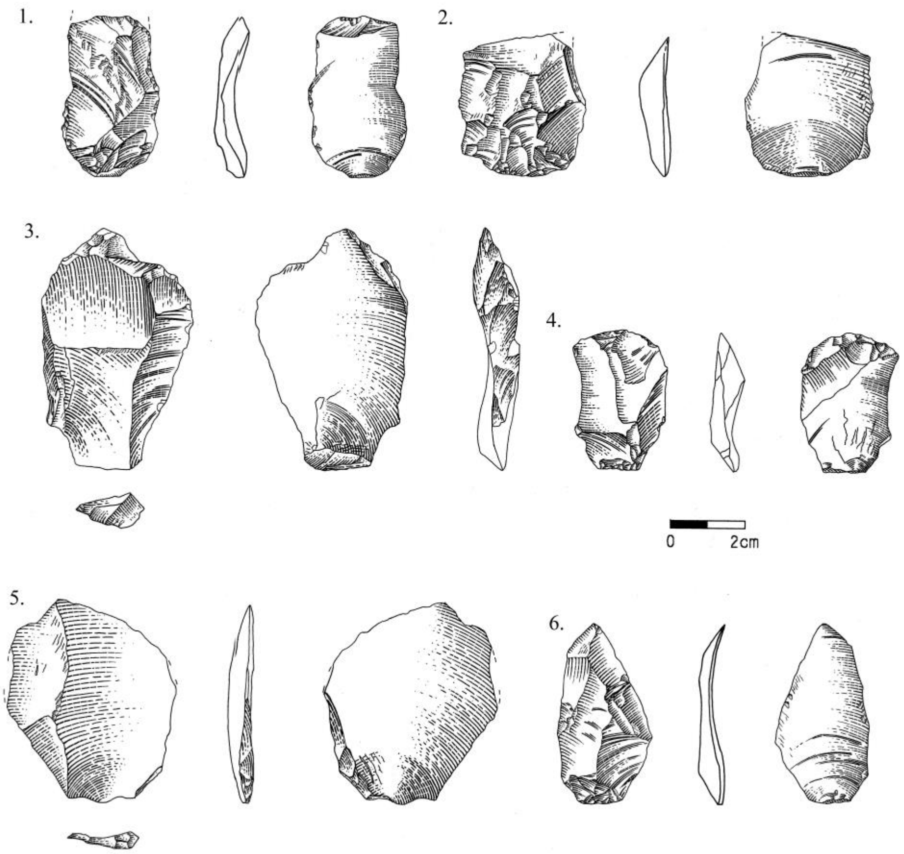

Figure 1. Examples of artifacts from the archaeological assemblage. All artifacts are ***éclat de taille de biface*** except for no. 3 which is a flake. 1. #7635 Layer V-5; 2. #7633 Layer V-6; 3. #7667 Layer V-6; 4. #7677 Layer V-6; 5. #7657 Layer V-5; 6. #5485 Layer V-6.

2.2. Methods

Both archaeological and experimental assemblages were analyzed using an attribute analysis method designed for the GBY lithic assemblages (following Bar-Yosef & Goren-Inbar 1993; Goren-Inbar et al. in preparation). This method analyzes many preservation, typological and technological attributes to provide as comprehensive a description as possible. For the analysis of the experimental assemblage, however, only a selection of relevant technological attributes was employed. These include, among others, the size of each flake, the type of striking platform, the scar configuration of the dorsal face of the flakes, the direction of blow and the mode of breakage. However, as this study is concerned primarily with breakage, these attributes will not be dealt with here. The analysis of both archaeological and experimental assemblages included only artifacts larger than 2 cm in maximal dimension.

In the analysis employed at GBY, the breakage attribute describes the location of the breakage or breakages on each flake. According to this classification, each flake can be defined as either complete or broken. When it is broken, it is defined according to the location of the breakage, such as a proximally, distally or laterally broken flake. When the flake presents more than a single breakage, it is defined according to the locations of all the breakages; for example, a proximally and distally broken flake or laterally and distally broken flake. In this method an item is defined as a fragment if it is too broken to be oriented. The advantage of this classification method is that it provides a high descriptive resolution that is capable of detecting significant patterns in the locations of the breakages. However, it has two drawbacks, especially in respect to the computerized post-depositional breakage simulation model. These are its high complexity and lack of hierarchy. To address these issues, a second classification method for the description of broken pieces was employed. This method is a modification of the debitage classification method presented by Sullivan and Rozen (1985). The method consists of the hierarchical description of breakages based on the various feature retained on each piece. According to this classification, an artifact is classified as a fragment (FT) if it has no discernible remnant of its striking platform; as a split flake (SF) if it presents a sheared axis of flaking and a split striking platform (*éclat siret*); as a proximal flake (PF) if it has a complete striking platform and one or more signs of breakage on the distal end or one of the lateral margins; and, finally, a complete flake (CO) only if all of its margins are undamaged (no signs of breakage). The proximal flake class is further subdivided into proximal flake with a single breakage (PFS) and proximal flake with multiple breakages (PFM).

This hierarchical method reduces the descriptive resolution of the former classification method into three main categories: complete items, items with an intact proximal end (proximal flakes with a single or multiple breakages) and items lacking a complete proximal end (fragments). Naturally, from an analytical point of view the high-resolution classification is preferable to the hierarchical classification. However, we have decided to use this method in the model simulations because of its simplicity and hierarchical nature, which allow the simulation of additional breakage events in a simple and straightforward manner. For example, assuming that a complete flake is broken into two pieces, the hierarchical method will necessarily classify these two pieces as a proximal flake and a fragment, while in the GBY method there are many more possible classifications with regard to its location on the original item. For this reason, in order to allow the simulation of post-depositional breakage, both the archaeological and experimental assemblages were described using the hierarchical method in addition to the high-resolution breakage classification. The conversion of values was performed in accordance to the following criteria (Table 2). Distally or laterally broken flakes (i.e., broken flakes with a complete proximal end) were reclassified as proximal flakes with a single breakage (PFS). Similarly, flakes with multiple breakages but with a complete proximal end were reclassified as proximal flakes with multiple breakages (PFM). Proximally broken flakes or flakes with multiple breakages, one of which is proximal (i.e., flakes without an intact proximal end) were reclassified as fragments (FT). Non-orientable items that were classified as fragments in the high-resolution classification method retained their classification and were included in the fragment category of the hierarchical classification. Complete flakes and flakes with *siret* breakage also retained their classification.

Table 2. Conversion terminology for the two methods for classification of breaks.

High-resolution breakage pattern	Hierarchical breakage pattern
Complete flake	Complete flake
Distally broken flake (proximal end intact)	Proximal flake with a single breakage
Laterally broken flake (proximal end intact)	Proximal flake with a single breakage
Proximally broken flake	Fragment
Distally and laterally broken flake (proximal end intact)	Proximal flake with multiple breakages
Distally and proximally broken flake (broken proximal end)	Fragment
Proximally and laterally broken flake	Fragment
Fragment (non-orientable broken flake)	Fragment
Split flake	Split flake

2.2.1. The Computerized Model

The breakage patterns presented by the experimental assemblages are strictly limited to the production phase and not influenced by any taphonomic agent. Therefore, it could safely be assumed that if such an assemblage were a component of the archaeological record and had been subjected to further breakage caused by post-depositional processes (such as high-energy fluvial transport), its original breakage pattern would have been changed. The computerized post-depositional breakage simulation model was designed to attempt an assessment of the effects that such processes may have had on the pattern and frequency of breakages. The computerized model was built as a stand-alone program using Python's Integrated Development Environment version 2.7.5.

The hierarchical classification method is of great importance to this model, as it allows prediction of the outcomes of a breakage event based on the type of item that is broken. For example, a complete flake subjected to breakage will no longer be classified as a complete flake but will yield a proximal flake and one or more additional fragments. This trait was used as the basis for the model's simulation of the effects of post-depositional processes on the breakage pattern.

The model is limited to a single aspect of the physical state of the artifact and ignores other aspects such as abrasion, patination and spatial distribution, which may be other effects of post-depositional processes. The basic assumption underlying this model is that breakage caused by post-depositional processes simply inflicts additional breakages on an existing assemblage. The input of the model consists of the absolute number of items in each breakage category of the hierarchical classification method and the number of additional breakage events to which the assemblage is subjected. The user also selects the number of requested simulations for a given assemblage. The results obtained by a set of simulations are then averaged to provide a more robust prediction. The results are presented as absolute numbers and the frequency of each category of items.

Post-depositional breakages, whether anthropogenic or not, are unpredictable due to the abundance and complexity of factors involved in the process. Therefore, the item to be subjected to a breakage event is selected randomly out of all items in a given assemblage. The probability of selecting an item from a particular breakage category is directly related to the frequency of that category in the assemblage. It should be noted that this assumption is a somewhat simplified version of a realistic scenario in which flakes with a larger surface area and smaller thickness are more prone to breakage than items with a smaller surface area and greater thickness. Such trends, which are based on the correlations between the different dimensions of flakes, are inherent to the basic principles of fracture mechanics. We avoided introducing such variables into the model for the sake of simplicity. Thus, the chance of each type of item being selected is directly dependent on its occurrence in the assemblage. For example, if the assemblage is composed of 40% proximal flakes and 60% fragments, a fragment is more likely than a proximal flake to be broken. The outcome of each breakage event is hence dictated by the frequencies of the different breakage categories.

The model simulates the breakage in the following manner: for each additional breakage event an item from one of the categories is selected to be broken, based on their frequency in the assemblage. Figure 2 is a flow chart illustrating the mechanism of the simulation which describes step by step the process of modeling that is also described as follows:

If a complete flake is selected, one item is subtracted from the CO category. This breakage could result in two or three new pieces. The possibility of a single breakage event fragmenting one piece into three is documented in the presence of items with multiple breaks in the experimental assemblages, where each item was subjected only to a single high-energy event (i.e., its removal). The probability of such an event in the model was determined according to the frequency of items with multiple breakages in the combined experimental assemblages. If the item breaks into two pieces, one item is added to the PFS category and another to the FT category. If the items break into three pieces, one item is added to the PFM category and two items are added to the FT category.

If a proximal flake with a single breakage is selected, one item is subtracted from the PFS category and one item is added to the PFM category. If the item breaks into two pieces, one additional item is added to the FT category, while if the item breaks into three, two items are added to this category.

If a proximal flake with multiple breakages is selected, no items are subtracted from any of the categories. If the item breaks into two pieces, one additional item is added to the FT category, while if the item breaks into three, two items are added to this category.

If a split flake is selected, no items are subtracted from any of the categories. If the item breaks into two pieces then one additional item is added to the FT category, while if the item breaks into three, two items are added to this category.

If a fragment is selected, no items are subtracted from any of the categories. If the item breaks into two pieces, one additional item is added to the FT category, while if the item breaks into three, two items are added to this category.

Simulations were performed on the breakage pattern of the combined experimental assemblage, simulating the breakage of 10%, 20% and 30% of the items. A series of ten simulations was conducted for each group of additional breakages.

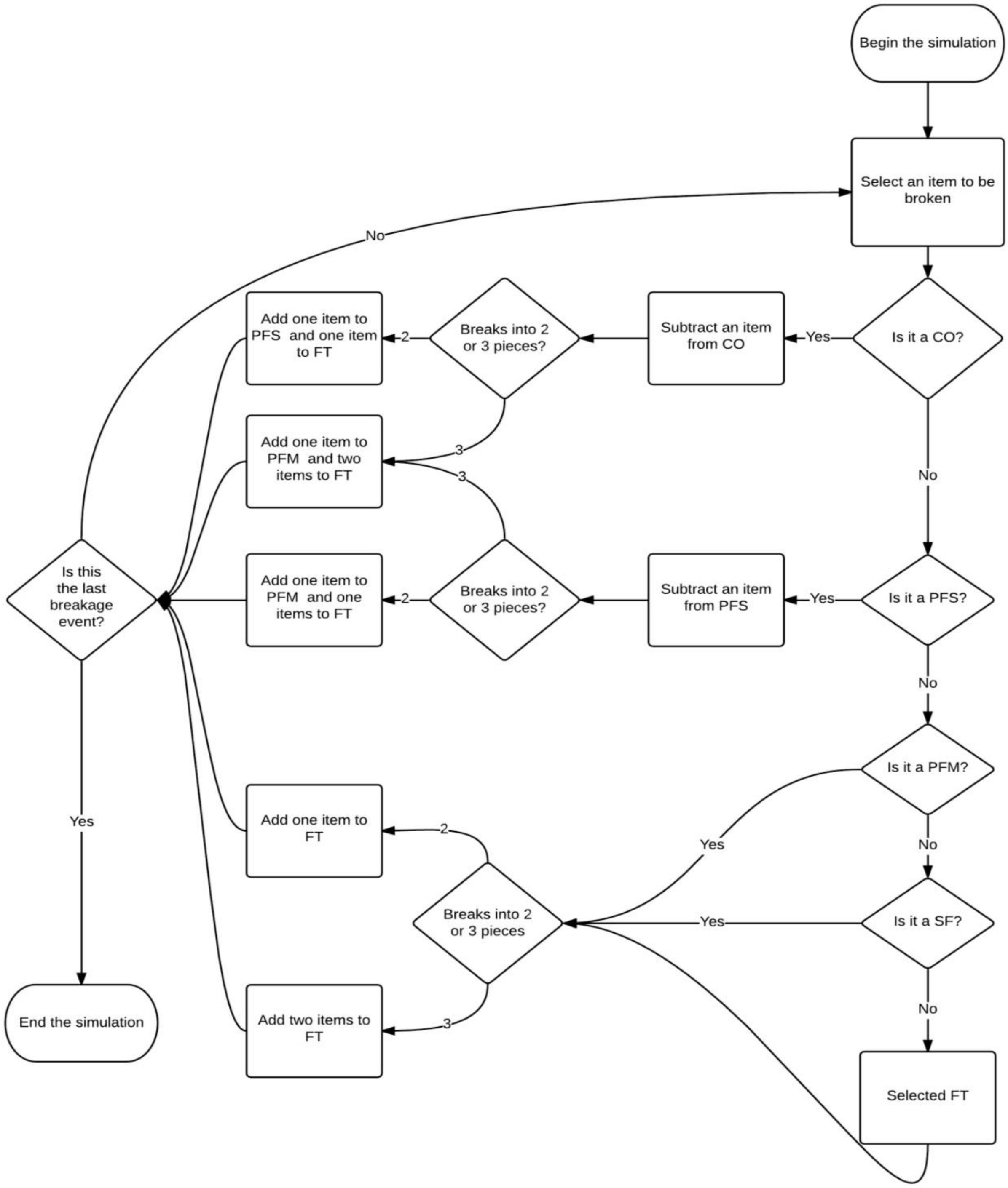

Figure 2. A flowchart describing the model's algorithm. An item to be broken is randomly selected. The frequencies of the different breakage categories making up the assemblage are changed in accordance with the type of item selected. CO = complete flake, PFS = proximal flake with a single breakage, PFM = proximal flake with multiple breakages, SF = split flake, FT = fragment.

3. Results

The breakage patterns and frequencies of the six experimental assemblages are first presented here using both classification methods (Table 3). The results of the experimental and archaeological breakage patterns are presented and compared in detail using the high-resolution classification method. However, since the simulations of post-depositional breakage are based on the hierarchical classification method, their results are discussed and compared to the archaeological assemblage using this classification method. The results of the hierarchical classification method are presented at three levels. The first is the ratio of complete to broken flakes. This level represents the coarsest level of analysis and shows the proportion of complete flakes relative to the total amount of broken flakes and fragments in each assemblage. The second level presents the distribution of breakage types amongst the broken items in the assemblage. The third level displays the breakage type distribution amongst the proximal flake category. This three-level approach enables the systematic characterization of the breakage pattern in each assemblage.

Table 3. High-resolution and hierarchical breakage classifications of experimental and archaeological assemblages. Abbreviations: CE - Combined Experimental; TE - Total Experimental.

High-resolution classification

	C-35		**C-36**		**C-37**		**C-45**		**C-50**		**CE**		**GBY**	
Category	N	%	N	%	N	%	N	%	N	%	N	%	N	%
Complete	69	28.99	34	33.01	34	47.89	43	37.39	18	28.57	198	33.56	237	51.30
Distal	43	18.07	16	15.53	12	16.90	16	13.91	11	17.46	98	16.61	76	16.45
Lateral	15	6.30	7	6.80	7	9.86	16	13.91	7	11.11	52	8.81	26	5.63
Proximal	26	10.92	23	22.33	11	15.49	18	15.65	7	11.11	85	14.41	40	8.66
Distal & Lateral	15	6.30	4	3.88	2	2.82	8	6.96	8	12.70	37	6.27	18	3.90
Distal & Proximal	33	13.87	11	10.68	1	1.41	2	1.74	0	0.00	47	7.97	15	3.25
Fragment	15	6.30	1	0.97	0	0.00	6	5.22	4	6.35	26	4.41	41	8.87
Proximal & Lateral	12	5.04	7	6.80	3	4.23	2	1.74	8	12.70	32	5.42	9	1.95
Split	10	4.20	0	0.00	1	1.41	4	3.48	0	0.00	15	2.54	0	0.00
Total	238	100	103	100	71	100	115	100	63	100	590	100	462	100

Hierarchical classification

	C-35		**C-36**		**C-37**		**C-45**		**C-50**		**TE**		**GBY**	
Category	N	%	N	%	N	%	N	%	N	%	N	%	N	%
Complete	69	28.99	34	33.01	34	47.89	43	37.39	18	28.57	198	33.56	237	51.30
Proximal Single	58	24.37	23	22.33	19	26.76	32	27.83	18	28.57	150	25.42	102	22.08
Proximal Multiple	15	6.30	4	3.88	2	2.82	8	6.96	8	12.70	37	6.27	18	3.90
Fragment	86	36.13	42	40.78	15	21.13	28	24.35	19	30.16	190	32.20	105	22.73
Split	10	4.20	0	0.00	1	1.41	4	3.48	0	0.00	15	2.54	0	0.00
Total	238	100	103	100	71	100	115	100	63	100	590	100	462	100

3.1. Artifact Sizes

To address the issue of similarity between the breakage of artifacts in the archaeological and experimental assemblages, comparison of a selected size attribute was carried out. A ratio was chosen for the comparison consisting of the surface area of an artifact divided by its thickness. This ratio is calculated by multiplying the length of each artifact by its width in order to assess its surface, a value that is then divided by its thickness. This ratio will increase as the surface area of the flake increases and its thickness decreases. Hence, when this index is higher the artifact has a greater chance of breaking if subjected to a high-energy event.

The surface/thickness ratio was calculated for each of the assemblages and for three different breakage categories, which were defined following the high-resolution classification method. These categories are complete, broken and fragments (Figure 3). Two main insights results from this comparison. The first is concerned with the variation in the values of the ratio between the breakage categories. While there is a pronounced similarity in values between the complete and broken categories, the values of the fragments category are significantly lower. This result is to be expected, given the fact that the fragments category is composed of small items that have broken off from items included in the two other categories. Thus, they will usually maintain a fairly constant thickness value, while their surface area becomes smaller. The similar values of the complete and broken categories indicate that items that are not extensively broken and hence could not be oriented still maintain a fairly constant ratio of surface to thickness. This trend is identical in the archaeological and experimental assemblages. The second insight is concerned with the differences between the archaeological and experimental assemblages. It is clear that the archaeological assemblage presents significantly lower values than the experimental one. This observation indicates that the artifacts of GBY are thicker in relation to their surface area than those in the experimental assemblage. Hence, the results of the comparison suggest that in conditions of an identical post-depositional process causing breakage, the artifacts in the archaeological assemblage will be less prone to breakage than those in the experimental one.

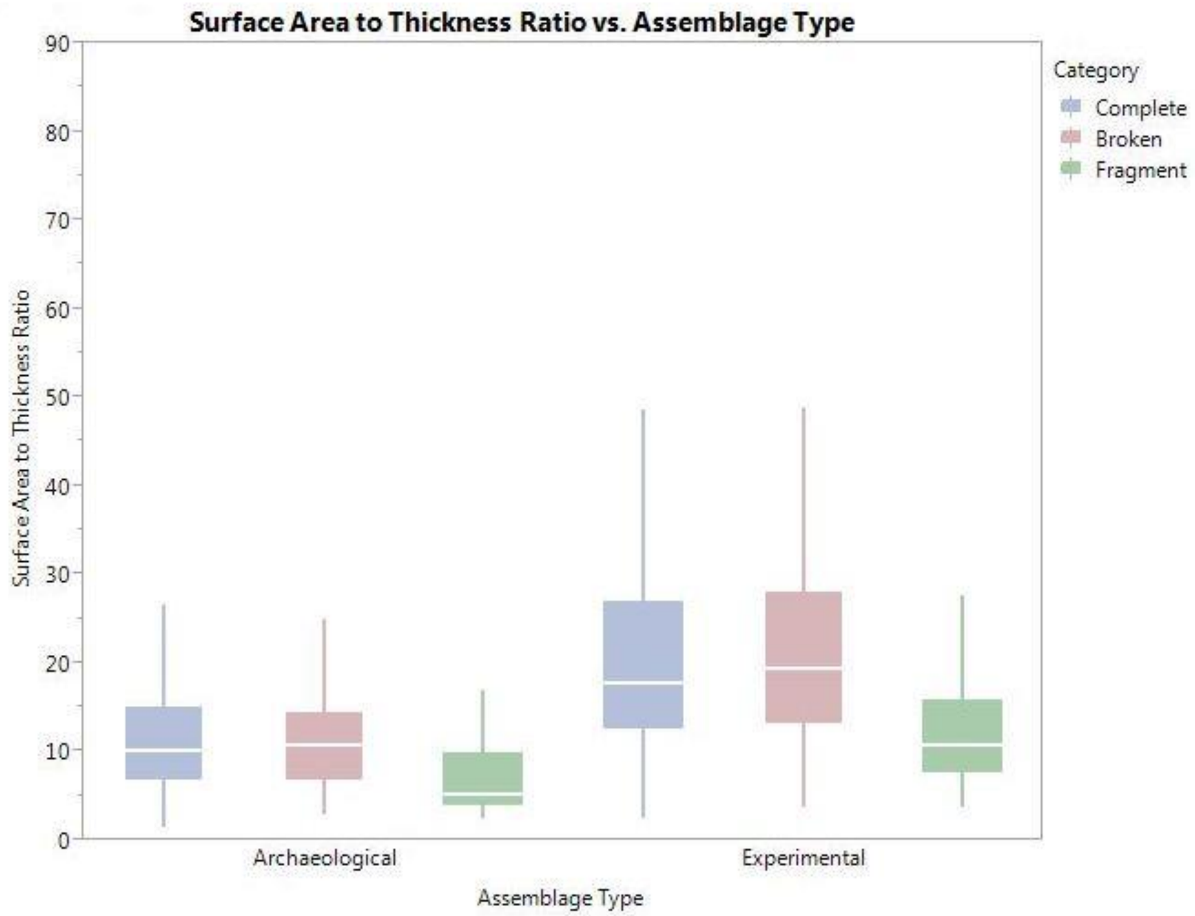

Figure 3. Box plots of surface area to thickness ratios of the different breakage categories and assemblage types.

3.2. The breakage pattern of the experimental assemblages

It is apparent that all the experimental assemblages present an unequivocal majority of broken pieces (Table 3). Assemblage C-50 presents the highest breakage rate, 71.43% of the assemblage, while in assemblage C-37 only 52.11% of the items in the assemblage are broken. In the combined assemblage 66.44% of all pieces are not complete.

The most common breakage category in the combined experimental assemblage is that of distally broken flakes, 16.61% of the items. This category is the most common in all assemblages except C-45 and C-36 and ranges from 18.07% in C-35 to 13.91% in C-45. Following this category is that of proximally broken flakes, 14.41% of the items in the combined assemblage. This category ranges from 22.33% in C-36 to 10.92 in C-35 and is the most common in assemblages C-36 and C-45. The next most common category is that of laterally broken flakes, which comprises 8.81% of the items in the combined assemblage. It ranges from 13.91% in assemblage C-45 to 6.30% in assemblage C-35. These categories conclude the items with a single breakage (Table 3).

There are four categories of items with multiple breakages: distal and lateral, proximal and lateral, proximal and distal, and fragments. Generally, these categories are less frequent than those consisting of items with a single type of breakage. In the different experimental assemblages, each of the categories with multiple breakages usually comprises less than 7%, with a few exceptions in which one or two of these categories comprises more than 10% of the assemblage. In the combined assemblage these categories account for 24.07% of the items, in contrast to the 39.83% represented by the previous three breakage categories.

The final breakage category is split flakes. This category is singular in that it can be formed only during the production phase. The category comprises 2.54% of the artifacts in the combined assemblage, reaching a maximum of 4.20% in assemblage C-35, while it is completely absent from others such as C-36 and C-50 (Table 3).

In general, the distribution of breakage categories among the different experimental assemblages is fairly uniform. Although there are variations in the frequencies of the different categories, they are minor and do not substantially affects the general breakage pattern. The variations could be related to minor differences in the specific raw materials used or to incidental differences in particular reduction sequences performed by the same knapper.

3.3. The breakage pattern of the archaeological assemblage

The ratio of complete to broken flakes is substantially higher in the GBY archaeological assemblage (Table 3). The complete flakes form more than half of the assemblage (51.30%). Even the experimental assemblage with the highest number of complete flakes (C-37) has 3.41% fewer complete flakes than the archaeological assemblage.

Regarding the distribution of breakage types, the general trend observed is one of similarity to the experimental assemblage, with a few specific differences. Within the category of broken items, the distally broken flakes are the most common category (16.45% of the items). However, in contrast with the combined experimental assemblage, all the other breakage categories are distributed in a fairly homogenous manner, with none exceeding 10% of the items. Nonetheless, similarly to the combined experimental assemblage, the categories of items with a single breakage make up 30.74% of the assemblage, while the categories of items with multiple breakages represent only 17.97% of the cases. It should be noted that fragments are twice as common in the archaeological assemblage, while split flakes are absent.

3.4. Simulations of post-depositional breakage

The breakage pattern of the combined experimental assemblage formed the basis for simulations of the effect of post-depositional breakage. The results present the predicted breakage pattern of the combined experimental assemblages after 59 (10%), 118 (20%) and 177 (30%) additional breaks. As the model uses the hierarchical classification method, the results of the simulations are presented using the three-level method (Figure 4; Table 4).

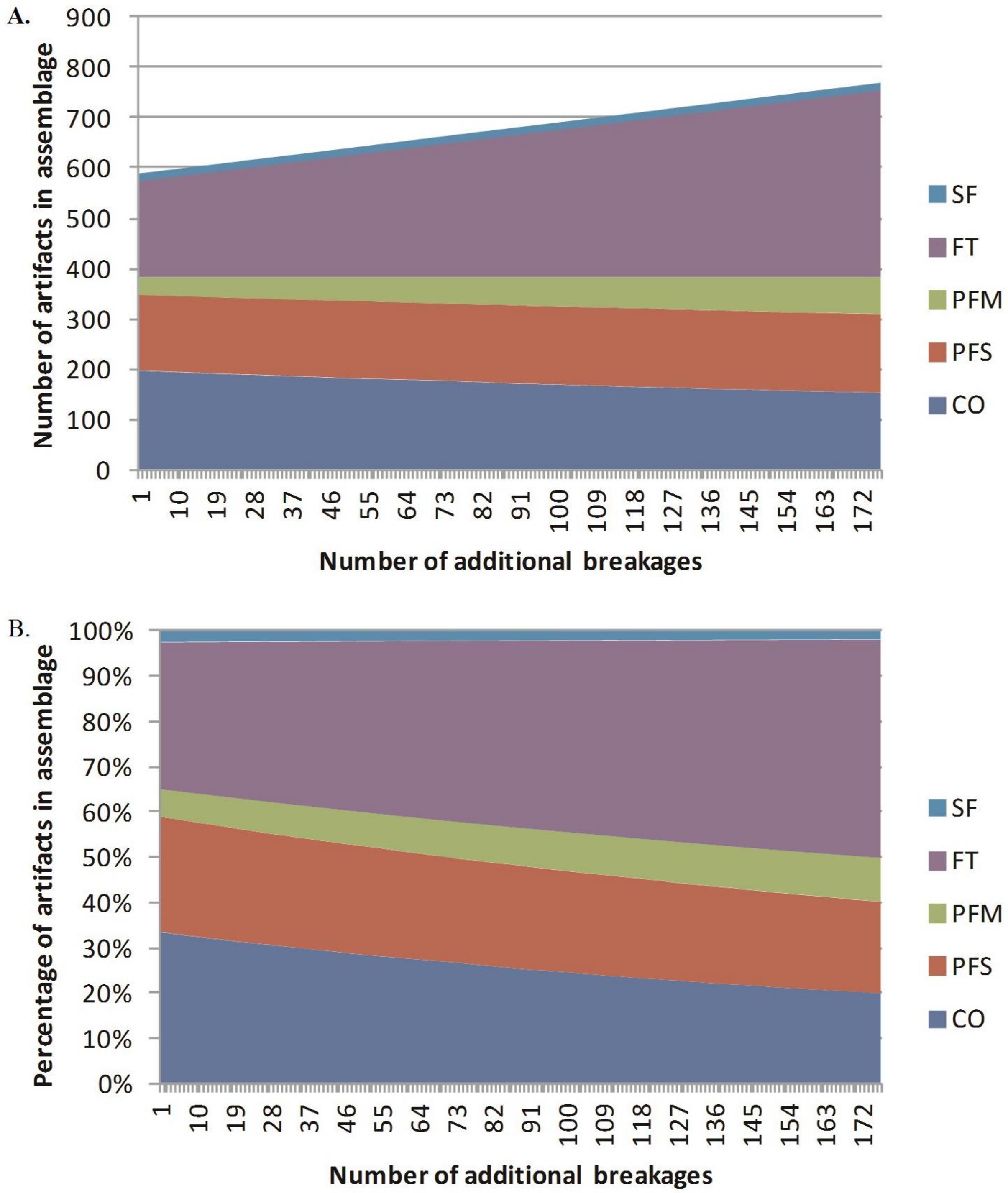

Figure 4. Curves representing changes to the breakage patterns with increasing number of additional breakages caused by a post-depositional process. Notice the increase in the absolute number of artifacts in the assemblage. A. Absolute change in the breakage categories. B. Proportional change in breakage categories.

The most prominent effect of the addition of breaks was an increase in the absolute number of broken items in each assemblage. The increase was in direct proportion to the number of additional breaks, as each breakage event adds at least one item to the assemblage. Naturally, this addition also causes an increase in the absolute numbers of broken items and a corresponding decrease in the complete to broken ratio in the assemblages. The frequencies of broken items in the assemblage increased by 5.91%, 10.18% and 13.71% after 59, 118 and 177 additional breakage events respectively (Figure 4).

Table 4. Breakage assemblages described by hierarchical classification of archaeological, experimental and post-depositional simulation.

Assemblage	GBY		Combined experimental pristine		Combined experimental after 59 additional breaks		Combined experimental after 118 additional breaks		Combined experimental after 177 additional breaks	
	N	%	N	%	N	%	N	%	N	%
Complete	237	51.30	198	33.56	180	27.65	166	23.38	153	19.84
Broken	225	48.70	392	66.44	471	72.35	544	76.62	618	80.16
Total	462	100.00	590	100.00	651	100.00	710	100.00	771	100.00
	N	%	N	%	N	%	N	%	N	%
Proximal Flake	120	53.33	187	47.70	206	43.74	219	40.26	232	37.54
Fragment	105	46.67	190	48.47	250	53.08	310	56.99	371	60.03
Split	0	0.00	15	3.83	15	3.18	15	2.76	15	2.43
Total	225	100.00	392	100.00	471	100.00	544	100.00	618	100.00
	N	%	N	%	N	%	N	%	N	%
Proximal Single	102	85.00	150	80.21	153	74.27	153	69.86	155	66.81
Proximal Multiple	18	15.00	37	19.79	53	25.73	66	30.14	77	33.19
Total	120	100.00	187	100.00	206	100.00	219	100.00	232	100.00

The proportion of breakage types in the assemblage was also greatly affected by the additional breaks. The proportion of proximal flakes decreased by 3.96%, 7.45% and 10.16%, simultaneously with an equivalent increase in the proportions of fragments for the three additional breakage groups respectively. The proportion of the split flake category was only slightly modified, giving its initial rarity in the experimental assemblages and the fact that it can be created only during the production phase (Figure 4).

Finally, the addition of breakage events altered the proportion of the proximal flake breakage types. While in the combined experimental assemblage proximal flakes with a single breakage formed slightly more than 80% of all proximal flakes, this amount gradually decreased by 5.94%, 10.35% and 13.40% with the addition of breakages.

4. Discussion

4.1. Production-related breaks

The combination of the results of all the experimental assemblages can be used as a general reference point and a reliable estimation of breakage patterns caused in the final stages of Acheulian bifacial knapping. Although some variability is observed among the different assemblages, it can be seen as a natural intrinsic variability that occurs during a homogenous knapping process by a single expert knapper. The main trends that appear in all experimental assemblages, and thus are also expressed in the combined sample, are as follows:

The assemblage is characterized by a majority of broken pieces in frequencies ranging from 52.11% to 71.43%.

There is a relatively high frequency of broken artifacts with a single breakage, ranging between 44.66% and 35.29% of the assemblages, with proximally or distally broken flakes being more frequent than laterally broken ones.

There is a relatively low frequency of broken artifacts with multiple breaks, ranging between 31.75% and 8.45% of the items. In most cases none of the breakage categories exceeds 10%.

There is a low frequency, not exceeding 5% and at times a total absence, of split flakes.

The importance of this pattern lies in the fact that it represents only breaks that occur during the production phase. As the assemblages are experimental, the artifacts are completely free of the effects of use or post-depositional processes. Hence, they demonstrate that a majority of broken items in an assemblage is inherent to the final stages of Acheulian bifacial knapping, regardless of any processes to which the artifacts may have been subjected during the discard and post-depositional phases of their life history

Another important aspect highlighted by the study of these assemblages relates to the variability that may exist between similar assemblages. All of the six experimental assemblages used here were produced by the same expert knapper using similar reduction sequences and knapping techniques. Nevertheless, some variability is apparent in their breakage patterns. This observation should be noted and taken as a warning of the fact that knapping is a highly dynamic process that may produce variable results under the same conditions.

4.2. Post-depositional breakage

The breakage simulations of the effects of the post-depositional process also provide some important insights. With increased intensity and duration of such process a clear trend can be seen, which is directly expressed in the increase of the amount of additional breakages to which the assemblage is subjected (Figure 4). As the number of additional breakages increases, the absolute number and proportions of complete flakes in the assemblage decreases. Another effect is a decrease in the proportions of proximal flakes, even though their absolute number increases. This effect is due to the fact that the increase in the absolute number of fragments is substantially greater than that in the proximal flake category, as each breakage event adds at least one fragment to the assemblage. The final effect is that of a decrease in the proportions of proximal flakes with a single breakage, along with an increase of proximal flakes with multiple breakages.

The mode of change in the different categories derives from their hierarchical definition. The complete flake category diminishes continuously, as no new complete flakes are added to the assemblage and no fragments or proximal flakes with multiple breakages are removed from it. This causes the proportions of those categories in the assemblage to decrease and increase respectively with intensification of the post-depositional process. The category of proximal flakes with a single breakage, which can both gain and lose items, maintains a fairly constant absolute number of items, although its proportion decreases moderately due to the increase in the number of items in the assemblage. A similar trend is seen in the split flake category, which can neither gain nor lose items.

The comparison between the original breakage pattern of the combined experimental assemblage and those provided by the model yields a pattern that could be applicable to interpretations of the taphonomic integrity of archaeological assemblages. This pattern consists of a low ratio of complete to broken flakes, a low ratio of proximal flakes to fragments among the broken items, and a low ratio of proximal flakes with a single breakage to proximal flakes with multiple breakages. Such a breakage pattern could indicate that an assemblage was subjected to breakage caused by post-depositional processes.

4.3. Interpretation of the archaeological breakage pattern

The breakage pattern of the GBY Acheulian archaeological assemblages provides an intriguing picture: not only is the pattern the opposite of one that possibly indicates the influence of post-depositional processes, but it actually hints at a more pristine state than that of the combined experimental assemblage. The ratio of complete to broken flakes is substantially higher than that seen in any of the experimental assemblages. Applying the high-resolution method to the analysis of the breakage of the experimental and the GBY assemblages results in generally similar patterns. Broken items with a single break have a high frequency of 30.74%, with the highest being that of distally broken flakes and the lowest of laterally broken flakes. The broken items with multiple breaks comprise 17.97%, with none of the categories exceeding 10% and split flakes are absent.

When the breakage pattern is examined using the hierarchical method, the ratio of proximal flakes to fragments among the broken items is higher than that seen in the combined experimental assemblage, but is similar to those seen in assemblages C-37, C-45 and C-50. The ratio of proximal flakes with a single breakage to those with multiple breaks is moderately higher than that of the combined experimental assemblage, but is similar to those of assemblages C-36 and C-37.

The similarities and differences between the archaeological and experimental assemblages provide some insights into the taphonomic state of the GBY assemblages. The proportion of proximal flakes among broken pieces and the ratio of proximal flakes with a single break to those with multiple breaks indicate that the breakage pattern of the GBY assemblages is most similar to that of the combined experimental assemblage. However, the fact that the ratio of complete to broken flakes is substantially higher in the archaeological assemblage is a peculiarity that may have several reasons. For example, the presence of cores and flake tools in the area and layers in which the GBY assemblages originate suggests that some of the unmodified flakes included in the sample were probably derived from other reduction sequences, unrelated to the production of bifaces. Furthermore, the significantly lower surface area to thickness ratio in this assemblage may have reduced the frequency of breaks caused during production. It should be noted that even when examining this ratio only for those items that are defined as *éclat de taille de biface* and biface sharpening flakes, the values are still lower than those seen in the experimental assemblage. Finally, the frequencies of breaks that occur during production may be greatly influenced by the knapper as well as by random factors related to specific individual reduction sequences, as indicated by the experimental assemblages. Notwithstanding the fact that the experimental reduction sequences are generally identical to those reconstructed for the GBY assemblages, the lower values of the surface area to thickness ratio may be the outcomes of such factors.

Nonetheless, the high complete to broken ratio, which contrasts with the trend of a decreasing ratio with increasing intensity of the post-depositional process, highlights the pristine taphonomic state of the GBY assemblage. These observations on the breakage pattern of the GBY assemblages strongly suggest that it was never subjected to intense or prolonged post-depositional processes causing breakage. Therefore, the observed breakage pattern probably indicates that most of the breaks were caused during the knapping process.

Notwithstanding these conclusions, a word of caution is in order. Naturally, both the experimental approach and the simulation modelling simplify the extensive complexity that exists in the deposition of archaeological assemblages. Issues such as the effect of varying size and reduction sequence of items on breakage, assemblage mixing, winnowing and collection bias were not considered in the model. For archaeological assemblages, these issues too may have a strong effect on the observed breakage pattern. However, the breakage patterns of the pristine experimental assemblage and the simulation of the effects of post-depositional breakage provide some degree of referential framework for the taphonomic state of debitage created during biface production. Moreover, the identification of a systematic trend of breakage associated with an increase in duration and intensity of post-depositional processes may permit a better understanding of the nature of lithic assemblages.

With regard to the GBY assemblage, the current conclusions join various other lines of evidence supporting the notion of rapid burial and sealing of the archaeological horizons. These consist, among others, of the recovery of abundant microartifacts from Layers V-5 and V-6 (and all others), providing an indication of a lack of winnowing. Furthermore, microartifacts were found spatially clustered, for example by raw material and by burning (phantom hearths) (Alperson-Afil 2008; Alperson-Afil et al. 2009; Alperson-Afil & Goren-Inbar 2010). The presence of unsorted macroartifacts, different-sized mammal bones, small fragments of micromammals (Rabinovich & Biton 2011), small botanical remains (Melamed et al. 2011), and conjoinable bones of medium-sized and large mammal bones (Rabinovich et al. 2012) all provide additional indications of minimal post-depositional effects (Goren-Inbar et al. in preparation). Hence, the results and conclusions of the present study provide further support for the generally undisturbed taphonomic state of the lithic assemblage from Area C at the site of GBY.

5. Conclusions

The systematic analysis of the breakage patterns of experimental Acheulian biface production assemblages, the simulation of effects of post-depositional breaks and their comparison to the GBY archaeological assemblages have provided several valuable insights. First, it was shown that the final stages of bifacial knapping produce assemblages that are characterized by a high ratio of broken items. Second, it was shown that breakage caused by post-depositional processes changes the production breakage pattern in accordance with a well-defined and systematic trend. Moreover, the higher the number of additional breaks, the larger the differences in the breakage patterns. Comparison of the experimental and modeling results with the biface production debitage assemblages of GBY indicates that the latter were probably not subjected to breakage caused by post-depositional processes. These insights may assist in achieving a more accurate interpretation of the taphonomic state of other archaeological assemblages.

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Lithic raw material procurement for projectiles points in the prehistory of Uruguay

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Abstract:

This paper focuses on current research on early colonisation of the Atlantic coast of South America during the early Holocene. We present advances in the investigation of raw material procurement at the *Rincón de los Indios* site, located in the eastern part of Uruguay. The technological studies suggest that some aspects of different styles of projectile points are related with environmental adaptation processes, experienced by the first American people in the New World. The occupation of new spaces and new forms of exploitation of resources changes the organisation of lithic technology. The distance to good quality rocks were critical for the opportunities and economic organisation of hunting groups. The study of changes in lithic procurement strategies for projectile points helps us develop a more comprehensive knowledge of this important social adaptation process which occurred during this period. These patterns started to become stabilised in the latter part of the early Holocene across the extended territory and confirm the efficient land occupation associated an intensive hunter-gatherer economies.

Keywords: Uruguay; early Holocene; lithic procurement strategies; projectiles points

1. Introduction

The Atlantic coast of South America was inhabited by hunter-gatherer societies during the Pleistocene-Holocene transition (Miotti 2006). In Uruguay is represented by site Urupez II in Maldonado coast (Meneghin 2006). These groups were contemporary with mega-fauna mammals which they eventually hunted, and produced a single type of projectile point called a "fishtail point" (ca. 10,700-10,200 B.P.) (Prates et al. 2013). Early human dispersal episodes along the Atlantic coast were related to the evolution of the biomes of the Atlantic Forest and Pampa, and were also associated with extended lowlands (Dias 2011; López Mazz 2013). During that period new projectile point styles adapted to new faunal and environmental conditions emerged (López Mazz 2013). During the Holocene (ca. 9,000-6,500 B.P.) lithic technology shows stabilised technological patterns for projectile points. Femenías & Iriarte (2000) described four types of projectile points to the Holocene in different region of Uruguay according a metric variable, shapes and stem bases (i.e., Yaguanesa, Zapucay, Paso del Puerto

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and Yaguarí styles). This paper describes and analyses the set of projectile points recovered during research at Rincón de los Indios archaeological sites (López Mazz 2001, 2013) (see Table 1). The databases permit the identification of procurement strategies and know the preference resources of lithic raw material used by the ancient people in the region. This information allow us to discuss about social mobility and economic organisation of post-Pleistocene hunter-gatherer groups.

1.1. Landscape and human settlements

Uruguay situated mostly along the border between temperate and sub-tropical zones (30-35º S to 58-54 W) (Figure 1). The Uruguayan landscape shares environmental characteristics with its neighbours, Brazil and Argentina - extended fluvial plains and lowlands (*bañados*), grassy plains (*pampas*), hills (*sierras*), lagoons, and marine coast.

The radiocarbon database for early human occupation distinguishes two different and large areas (López Mazz 2013). The first one is on the North side of the Uruguay River Basin, ca. 10,900 Pay Paso site (Suarez 2009), close to the tropical lowlands of Matto Grosso. The second large area is the Atlantic Ocean and La Plata River, ca. 11,600 Urupez II site (Meneghin 2006), with an extended border of grass plains, lowlands, lagoons and marine influence. As explained in the following paragraphs, better social and economic possibilities for human life took place during the Early Holocene in both regions.

Before approximately 10,000 B.P, there was a narrow river called the Paleo Paraná (Ayup 2006; Bracco et al. 2011) where the La Plata River is today. The Paleo Paraná flowed into the Atlantic Ocean by an ancient delta-shaped drainage, close to the marine platform.

The Pleistocene-Holocene transition was dominated by changes in the climatic conditions with an increase in temperature of 3 or 4 ºC , larger and more developed alluvial plains, lagoons and lowlands landscapes. The post-Pleistocene environmental landscape was composed of a mosaic of ecological zones, affected by latitude, topography and marine influence; with expanded lowlands and seasonal forest (Leal & Lorscheitter 2007).

The rising of the sea levels began around 17,500 B.P., starting at ca. 120 m below sea level, and reaching and submerging the coastal plains around 6,000 B.P (Ayup 2006; Bracco et al. 2011). This event produced more restrictions on the lands available for settlement and submerged early archaeological sites. Research on the lowlands landscapes of *India Muerta* (Iriarte 2006) shows vegetation and climate changes since 14,810 B.P. For the La Plata River (Cavalotto & Violante 2004) research has identified sea level fluctuations with the development of marshes and flooded environments. The ecological structure of the Pleistocene-Holocene landscape influenced the economic organisation and social mobility of the hunter-gatherers. We believe that the colonisation of the north, centre and east of Uruguay, was highly influenced by the dynamic of the border between the Atlantic Forest and the Pampa Biome.

The formation, development and expansion of the Atlantic Forest Biome began during the Pleistocene-Holocene transition, stimulated by an increase in humid and warm conditions. This Atlantic Forest was limited at the end of the Pleistocene to the bottoms of the valleys (Leal & Lorscheitter 2007). Between ca. 12,300 and 9,800 B.P., the Atlantic Forest expanded to the South, and arrived ca. 7,000 to 4,000 B.P. at the Río Grande plateau, with the coast line stabilising around 3000 B.P. (Días 2011:359). The Atlantic Forest was one of the most bio diverse forests with tropical species, associated with seasonal communities. This forest was connected through open spaces to ecosystem strongly influenced by fluvial and maritime dynamics extended (IBGE 1986). At the border between Uruguay and Brazil a palm forest (*Butia capitata*) associated with human land occupation extended since 8,400 B.P. and specially during the mound builder period ca. 5,000-2,000 B.P. (López Mazz 2001).

The first archaeological settlements of Uruguay and the south of Brazil took place around ca. 11,000 B.P. (Meneghin 2006, Suárez 2009) they correspond to hunter-gatherers camp sites with similar domestic discard pattern and seasonal occupation, which suggest high foraging mobility (López Mazz & Bracco 1994; Dias 2004, 2011; Suárez 2009; López Mazz 2013). These early settlements were situated close to important rivers and water bodies (in Uruguay - the La Plata and Negro Rivers, and the Negra Lagoon) (Guidon 1989; Hilbert 1991; Austral 1995; Suarez 2009; Nami 2013), throughout the rocky marine peninsula (Atlantic Coast) (López Mazz 2001 López Mazz et al. 2009, 2011) as well as on hilltops (e.g., Cerro Los Burros) (Meneghin 2004, 2006).

1.2. Rincón de Los Indios Archaeological site.

The Rincón de Los Indios archaeological site is situated in a strategic crossing place in an extended lowland landscape close to hills (Figure 1), and exhibits an intensive occupation between ca. 9000 B.P. and the 17th century. The archaeological sequence shows that the site was occupied by "mound builder" groups, since 4000 B.P. (López Mazz 2001) and in historic times by *Güenoa* or *Minuan* Indians (17th century) (López Mazz & Bracco 2010).

The information produced recently by excavation (25m^2) came from two dated (C14) hunter-gather occupation levels, with ages between 8,800 and 7,100 years B.P. (n= 6) (Table 1). The distribution of radiocarbon dates in the stratigraphy shows a first occupation level (SU 23/34) with two radiocarbon dates of 8,800 B.P. From the next occupation level (SU 6/15) there are three radiocarbon dates between 8,500 and 8,300 B.P. (see Figure 2), without not a sterile layers between them.

The both archaeological assemblage is composed of lithic material, produced during different stages of the lithic production system. There are also very fragmentary remains of bone, teeth, and samples of charcoal (López Mazz 2013). At this excavation a very compact occupation as an occupation soil, with a hearth structure, small post holes and other features was identified. Faunal remains recovered from cultural levels (8800 - 8300 B.P.) were composed of *ñandú coq* eggs (*Rhea americana*) *nutria* (*Myocastor coypus*) rodents teeth, fish sp. and cervidae sp. Burned palm fruit (*Butia capitata*) seeds were also recovered.

Previous analyses of the lithic material (López Mazz et al. 2011) suggest a procurement strategy organised around the exploitation of local (up to 15 km distance) white and transparent quartz. The procurement system includes regional (from 15 to 100 km distance) rhyolite and quartzite. Because of its quality for knapping projectile points, production was oriented towards the acquisition of extra-regional (more than 100 km) raw material such as agate, chert, chalcedony, jasper and other microcrystalline rocks (Figure 3) (López Mazz et al. 2011).

Table 1. Radiocarbon dates in year B.P. for the. Rincón de los Indios site.

Stratigraphic Unit (SU)	Date	Laboratory
SU 6/15	7,100±160	URU515
SU 6/15	7,220±840	AA99811
SU 6/15	8,384±63	AA1000363
SU 6/15	8,510±40	CURL6078
SU23/34	8,800±60	AA10298
SU23/34	8,809±56	AA99813

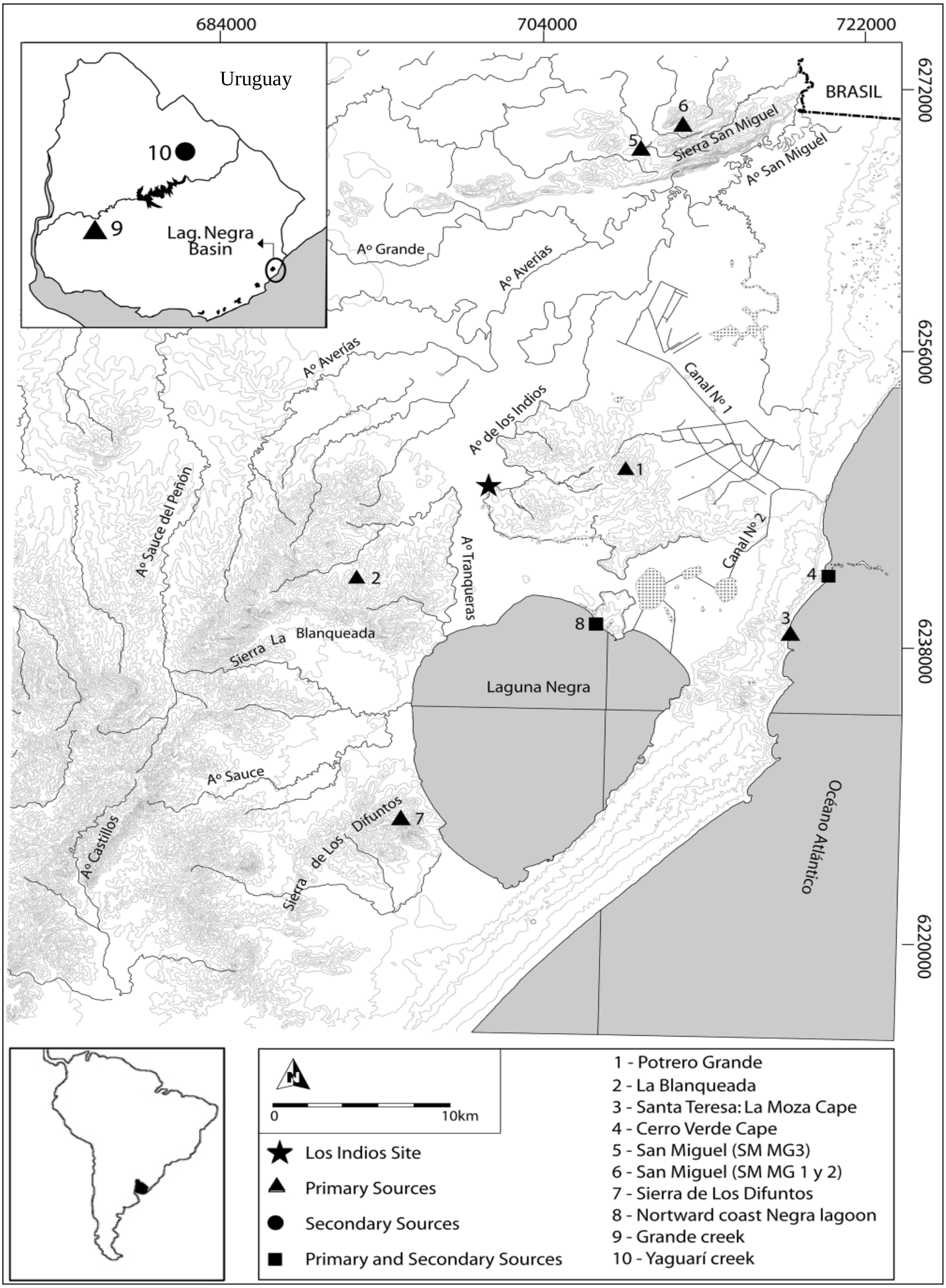

Figure 1. Rincón de los Indios archaeological site and raw materials quarries. (Modified from López Mazz et al. 2011).

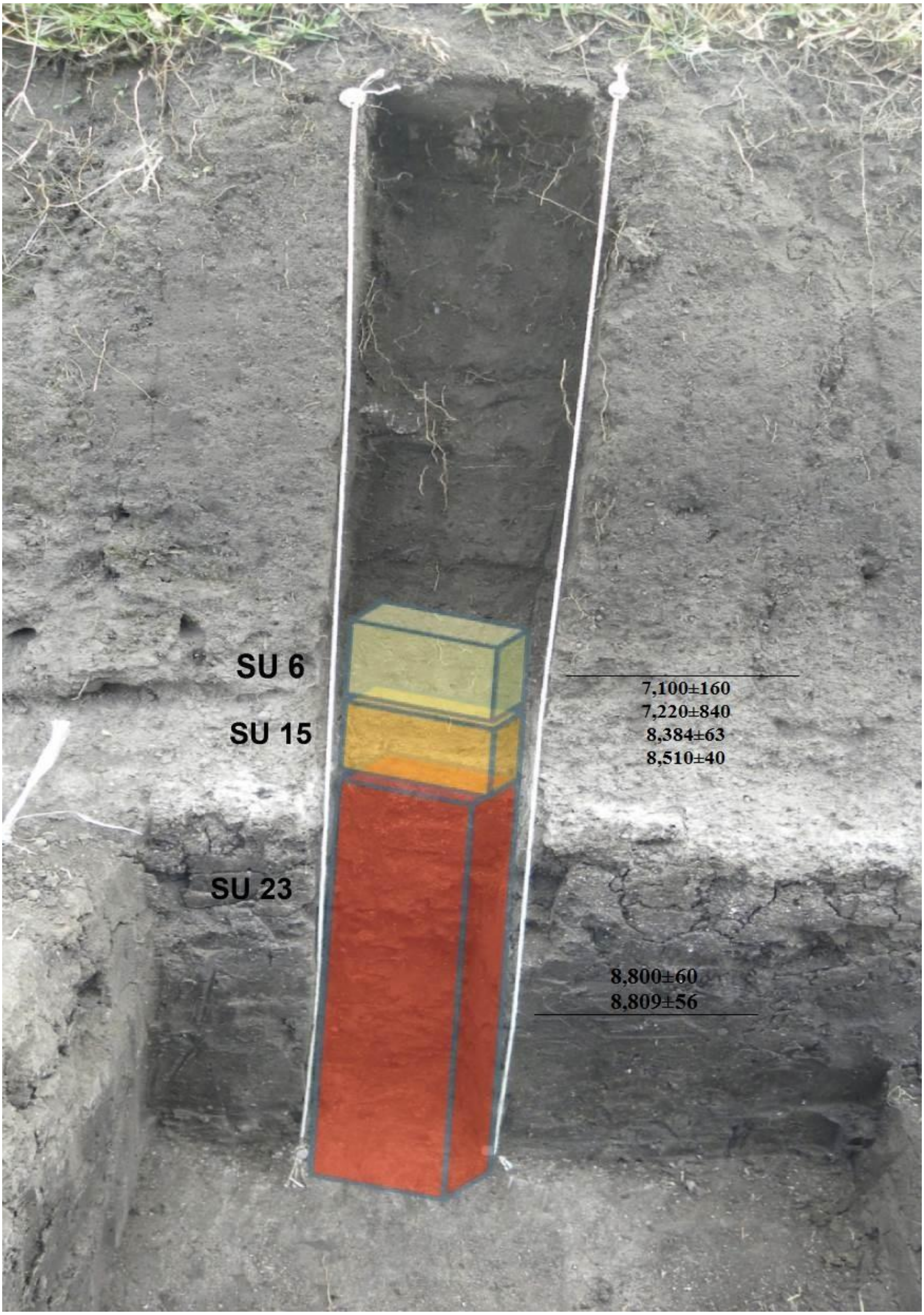

Figure 2. Profile with dated stratigraphic units.

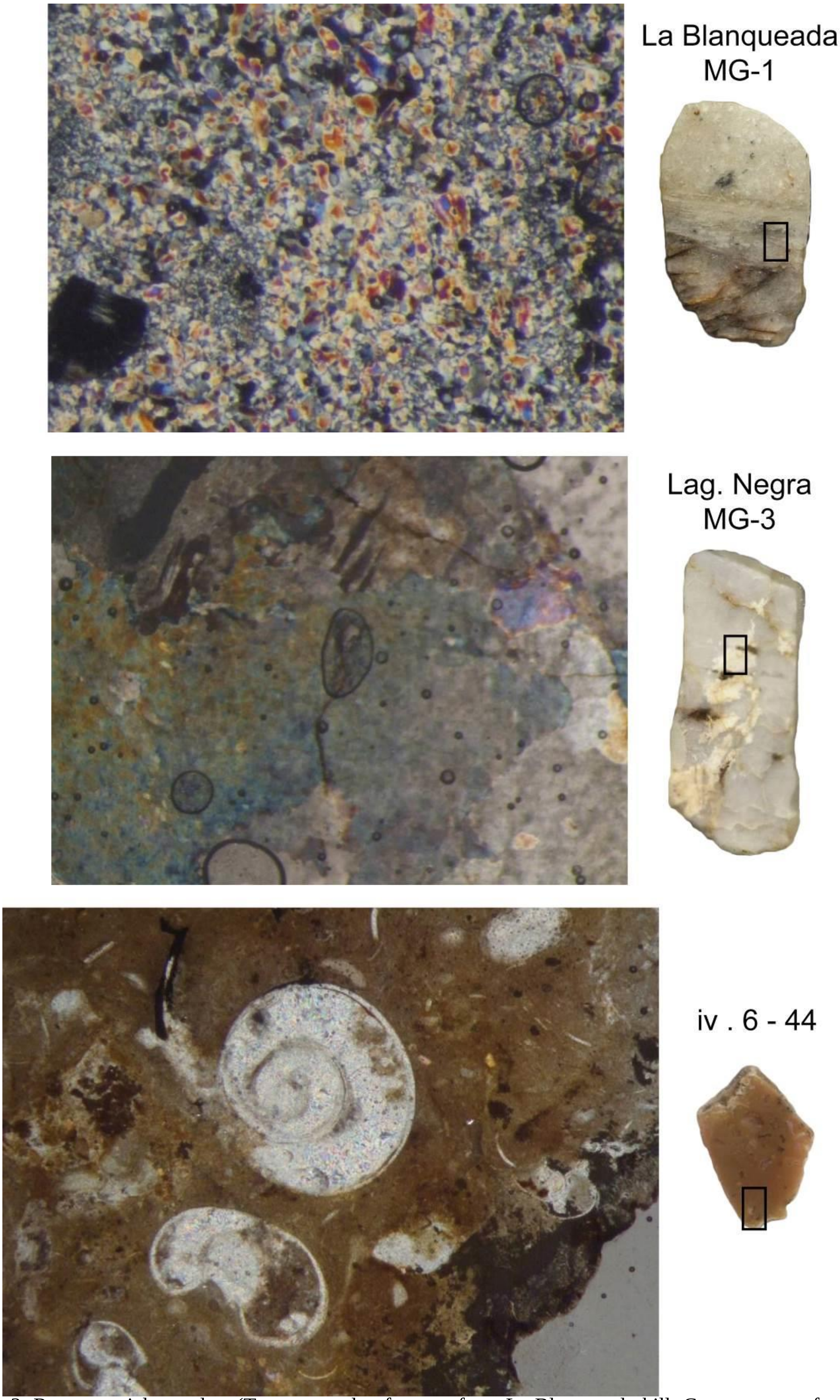

Figure 3. Raw material samples. (Top: a sample of quartz from La Blanqueada hill. Centre: quartz from Negra Lagoon. Bottom: archaeological chert) Scale x 100, cross-polarised light.

2. Methods

Our methodology includes a previous petrographic examination to characterize lithic resources recovered from *Rincón de Los Indios* archaeological site. This descriptive procedures and assign is based in this previous analyses (see: López Mazz et al. 2009, 2011) and include representative samples of most raw materials presents in the archaeological record in the prehistory of Uruguay. In the previous work were examined 19 thin sections of archaeological materials from the earliest level of the Rincón de Los Indios site, and 13 geological materials from quarries and potential quarries (see Figure 1) using a Leitz Wetzlar Laborlux 12 pol S model petrological microscope at 100-300X magnification (López et al 2011). The mineral identification criteria of Kerr (1965) and Mason's classification of metamorphic rocks (1990) were adhered to.

Samples of local raw material were collected in the nearby hills (La Blanqueada, Potrero Grande, De Los Difuntos, and San Miguel) and coastal headlands and gravels (northern coast of the Negra lagoon, the Atlantic coast, and the La Moza and Cerro Verde outcrops). One sample taken from an extra-regional archaeological quarry (see for details López Mazz et al. 2011). The archaeological samples were selected from among the most common (near 90%) flint-type lithic materials found at the Rincón de Los Indios site (i.e., quartzite and quartz).

On the other hand, we analysed the spatial distributions of the raw material characterize in this previous analysis. We looked for the distributions, distances and morphologies of the raw materials to explore evidence of variation in technology organization and economic systems. Finally, we applied comparative analyses of the assemblages from the earliest components (8,800 – 8,300 B.P.). Our focus stresses the formal variation and morphological aspects of the assemblages, to discuss general trends emerging from our analysis of this data set.

3. Results and discussion

Research over the last 20 years has produced a collection and database of new samples of lithic raw materials for hafted biface and unifaces. A database (N= 95) was produced from the Rincón de los Indios site (Figure 4). Raw materials used for production were quartzite (number= 30), chert (N= 22), quartz (= 19), opal (n=7), agate (n= 6), rhyolite (n= 5), fossil wood (n= 3), unidentified (n= 2) and quartzitic sandstone (n= 1). Raw materials confirm the economic strategy previously proposed (Gascue et al. 2009), based on a combined exploitation of extra-regional (chert, agate or chalcedony, opal) regional (quartzite; rhyolite) and local (quartz and quartzite) materials from outcrops or secondary sources (e.g., boulders) (López Mazz et al. 2009).

Archaeological samples from the end of the Pleistocene-Holocene transition and the Early Holocene come from the Los Indios site. Excavation at this site enabled the comparison between two different early occupations and produced a historic interpretation of human adaptation processes.

For both SU which were dated a great variety of raw materials in very similar percentages were recovered. Quartz and quartzite is the most representative. The results of lithic analyses from both SU's are very similar, and suggest that between 8800 and 8300 B.P. the procurement strategy and economic mobility were almost the same. The lithic procurement strategy and the tools produced (projectile points and scrapers) show a well-established production system, as Dias (2004, 2011) has suggested for the south of Brazil.

The lithic variability in the early cultural levels of the site, shows a great number of hafted bifaces in different stage of production, reshaping and discard (n= 39) (Figure 5). The hafted bifaces from SU 23/34 (n=20) were produced from quartzite (5), quartz (6); chert (4);

opal (3), agate (1) and rhyolite (1). For SU 6/15 (n= 19) they were produced from quartz (5); chert (5); quartzite (3); agate (3); and opal (2) and rhyolite (1).

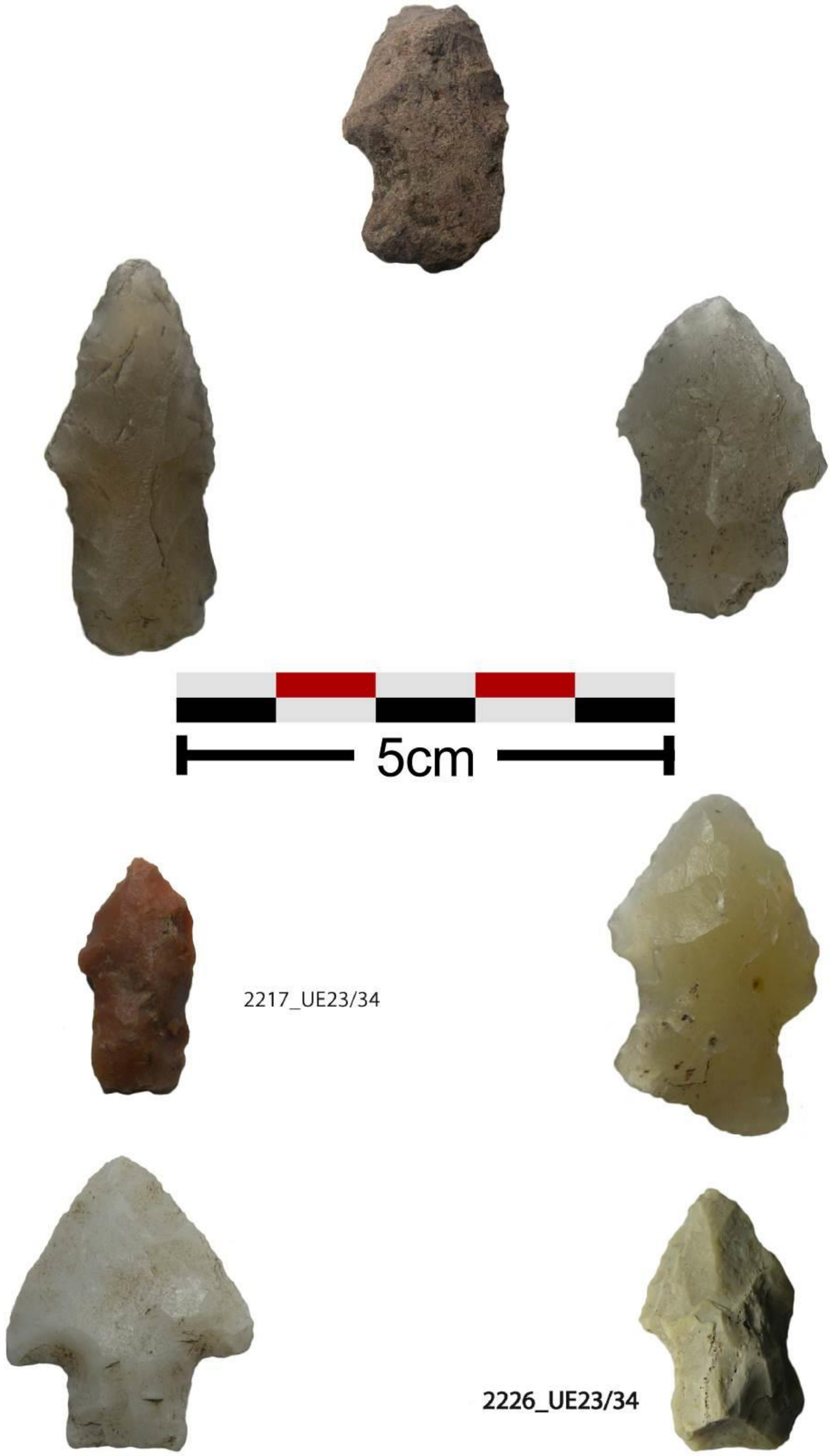

Figure 4. Hafted bifaces recovered from excavation.

From a technological perspective, in SU 23 there are three formal types of artefacts. Mostly all are projectile points with bifacial reduction (11/16) but only one was thinned by soft percussion flaking with patterned flake removal sequence. The rest of the sample has only marginal bifacial retouch. The projectile points are mostly fractured (n= 7). Only two stems were recovered and one of them has "fishtails" characteristics. The samples show evidence of maintenance and recycling among some of the scrapers and knives. Most of the projectile points are triangular, stemmed shapes with shoulders with a wide range of morphological and size differences. The evidence suggests that the quality and size of raw material available and the extended long usage history produce variability in forms.

The rest of the samples are two bifaces and a micro end-scraper from a unifacial flake with marginal retouch. Both bifaces are made from quartz. One of them presents bifacial retouch and is fractured in the final stage of manufacturing and the other one was abandoned in the first stages of manufacturing.

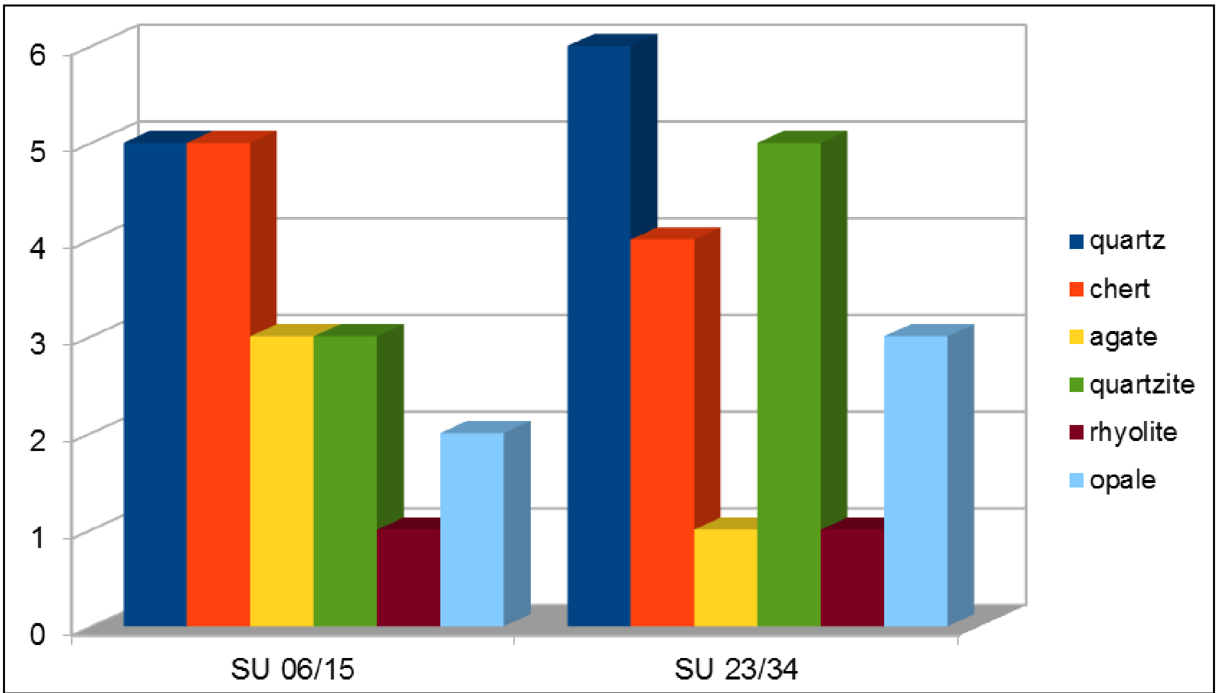

Figure 5. Raw material for each Stratigraphic Unit.

4. Conclusions

The technological analyses of the lithic artefact samples recovered from 2012-2013 at the VE excavation, support similar results previously reached (López Mazz et al. 2009; 2011; Gascue et al. 2009). In this sense, archaeological inference and interpretation on the strategy of lithic procurement can be reported with a more empirical basis (see: López Mazz et al. 2009, López Mazz & Gascue 2007). On the other hand, work hypothesis about economic organisations and social mobility require better conditions to be confirmed.

Lithic raw material procurement shows a post-Pleistocene adaptation process to a minor reduction in social mobility, oriented towards exploitation of the regional concentration of resources. In the Middle Holocene (Mound Builders Period), the best quality lithic resources came far from this lowlands territory in construction (López Mazz et al. 2009; Gascue et al. 2009; Iriarte & Marozzi 2009). More siliceous rocks will allow the production of well finished instruments and allowed a broad set of knapping tools, nevertheless projectile points (in different styles) were made from all the recorded raw materials. Projectile point has been adapted to available regional and local rocks, but there is a reduction of the possibilities to apply controlled forces in knapping. As in previous works (López Mazz et al. 2009; Gascue et al. 2009; Iriarte & Marozzi 2009) we observed that the quality of bifacial reduction and retouching became worse than the ones produced from good quality rocks. The bifacial technology started to lose quality.

Technological studies of projectile points suggest that some aspects of different styles are related with environmental adaptation processes, suffered by the first people in the New World. New environmental conditions (more forest and lowlands) could help to develop variability in projectile types. Other variable aspects are related with a life history and recycling processes of the projectile points, as shown in Fig. 4. The size, form and variety of metric dimensions of hafted bifaces are very sensitive in life history of a projectile point (Flenniken & Raymond 1986). However, the presence of arrow-sized points could be related with the introduction, dispersal of bow and arrow and replacement of the atlatl. The coexistence of the two weapons systems seems possible at the early Holocene. This aspect just has begun to be studied in the new regional database set recovered.

The presence of projectile points of different raw materials in both SUs could be related to new patterns of mobility, exchange and land use practices. The early cultural levels of the site (excavation VE - SU 23) indicate only a minor presence of projectile points from extra-regional sources. We hypothesize that replaced damaged projectile points were not brought back to the residence camp, instead, they are replaced with local raw material in the field. Those brought back to camp were resharpened and were used like scrapers or cutting tools.

The established patterns of projectile points since ca. 9000 B.P. across the extended territory (and interactive cultural sphere) from La Plata River to São Paulo State (Brazil) confirm the efficient land occupation. This shows an intensive hunter gatherer economy (Miller 1987; Schmitz 1987; López Mazz & Bracco 1994; Mentz Ribeiro 1991; López Mazz 2001; Juliani et al. 2011) is consistent with a progressively social complexity and new interaction cultural sphere (Días 2004, 2011).

A change in lithic procurement strategies for projectile points helps us to develop a more comprehensive knowledge of the singular social adaptation process. Changes in distance to good quality raw materials are critical for hunting options and for economic organisation could reflect new patterns of settlement and social mobility.

Moreover, the chronological sequence of projectile points has become a very useful methodological tool to classify different occupations in the post-Pleistocene by the Atlantic coast of South America.

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Deciphering the behavioural heritage of knapped flakes

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Abstract:

The major dimensions of a flake are shown to accurately capture how a knapper's actions manage the impact dynamics responsible for flake formation. When weight and density are also known, those same dimensions convey essential information about the volumetric geometry of a flake, including basic flake shapes typically valued for tools or to control core morphology. Combining the complementary modes of information allows the culturally imbedded heritage of a removed flake to be sufficiently represented that lithic analysts can reliably evaluate the mechanisms of flake formation without needing to be skilled flintknappers themselves. Presuming that habits of making flakes are culturally determined, it should be feasible to distinguish signature traits between lithic traditions.

Keywords: flake morphology; knapping behaviour; impact dynamics; fracture mechanics

1. Introduction

Flakes are the residue from one of humanities earliest technological advances and certainly its most persistent; in fact, the vast majority of archaeological evidence consists of flakes. Archaeologists routinely associate flakes and their scars with knapped tools presumed to be responsible for their creation but, unfortunately, there is no universal guide for interpreting the information available from flakes. Identifying for certain how a stone tool was made is complicated by the equifinality problem, referring to the difficulty in discerning the distinction between separate means of achieving the same result. There are three basic modes of archaeological flake manufacture: direct percussion, indirect percussion, and pressure. Each mode can be accomplished by myriad knapping tools and their capabilities are known to overlap considerably. A practical approach for examining the relationship of flake formation processes to cultural behaviour and decision making would be of significant value for resolving the manner in which early people formed their lithic tools.

Since few present-day practitioners create stone tools in a traditional context, analysts typically must rely on comparing attributes of recovered flakes with those whose knapping tools and manner of use are documented. Optimally, this requires an exhaustive survey of all possible knapping tools and knapping processes, a daunting task for anyone and not practical for the typical lithic analyst. Practicality often dictates that analysts rely on their limited personal experience. Furthermore, most professional archaeologists lack the time to become

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sufficiently proficient in diverse flintknapping techniques. Controlled experiments that make flakes by dropping steel balls on the edges of plate glass may seem to emphasize the difficulty with comparing mechanically produced flakes to archaeological examples. However, Pelcin (1996) succeeded in isolating particular variables that were responsible for producing the important attributes of flakes. This paper resolves the few variables deemed important by Pelcin into quantifiable indices that can be easily applied to general archaeological investigation by representing specific attributes of knapping behaviour, core morphology, and reduction strategy without requiring input from a practitioner of lithic technology. The goal is to demonstrate how ingrained habits of knappers produce unique, quantifiable characteristics in flakes that allow assessment of how knapping tools and cores were physically manipulated within specific lithic traditions.

1.1. Limitations of fracture mechanics

Fracture mechanics, as exemplified by Cotterell and Kamminga (1987), provides essential insight into the tripartite phases of initiation, propagation, and termination of flakes, each with their separate mechanisms that contribute to flake formation. However, Cotterell and Kamminga are careful to point out that they have described only the most basic mechanisms. Although fracture mechanics allows prediction for fracture paths within geometrically simple objects like thin rectangular plates, real-world cores and bifaces are currently beyond our computational reach. The kind of information necessary for deducing culturally relevant information may be found in empirical extrapolations of artefacts and experimental replications of their important features. Rather than attempt to isolate individual attributes, my approach is to capture the cumulative effect of knapping gestures and decisions. Each flake should contain observable evidence of the culturally transmitted knapping behaviour of the craftsman.

Pelcin (1996) noted that “variation in core morphology may be the most important independent variable for the production of dimensional flake attributes.” For computational simplicity, many researchers remove flakes from the edge of plate glass, simulating the longitudinal centre plane of a wider and more complex-shaped core. Extrapolation from plate-like cores to complex-shaped cores may be dubious. Typically, the test core is immobilized in a holding devise that does not represent a hand-supported core and seems more representative of pressure flaking than percussion. Aspects of impact dynamics that will be discussed later bring the relationship to practical knapping behaviour into question.

2. Methods

The study in this paper draws heavily on experiments conducted by Andrew Pelcin, who determined from exhaustive controlled experiments that indenter type and core surface morphology are the primary independent variables responsible for the linear flake attributes of length, width, and thickness (1996:318). The remaining independent variables (indenter mass, indenter velocity, indenter diameter, platform bevelling and width) were found to determine the mass of the flake. Mechanisms responsible for the flake dimensions were not within the scope of Pelcin’s study, but impact location was shown to determine how deep beneath the core surface a fracture will travel and the remaining factors relate to the kinetic energy available to promote fracture.

Later, when Tony Baker (2002) decided to simulate fracture paths by computer, he used Pelcin’s data as a control to calibrate his modelling. Observed differences between Baker’s model of Folsom fluting and archaeological data prompted replication trials conducted by Patten (2005) in order to bring modelling into agreement with actual knapping practice. Even after Baker simulated dynamic loading through finite-element analysis to describe and validate variables controlling the path of fracture, practical application of the results for interpretation of archaeological material was limited. Baker subsequently used a "dynamic loading model" (2004) to explain discard of hand axes, raising the prospect of applying the same concept to describe individual flakes in terms of the conditions responsible for their creation. Although data from Pelcin's early study provides an unbiased test of the dynamic loading model, he produced flakes under mechanical conditions not obviously relevant to archaeological material. Therefore, a new set of data was developed by collecting flakes made by deliberately contrasted methods of manufacture considered relevant to actual practice.

The data used for this study reflect measurements of ninety six reference flakes that were knapped with antler billets and hard hammer stones, using direct and indirect percussion, with both unyielding and minimal core support in a conscious effort to provide a comprehensive data set representative of diverse knapping methods and tools. Flakes were selected from all stages of reduction, whether the flake satisfied the knapper's intended morphology or not, because the goal was to identify characteristics that reveal underlying culturally-influenced knapping behaviour. To avoid potential bias and ambiguity, dimensions gathered for this study are standardized as maximum measurements. Correlating the major dimensions of flakes with the behaviour responsible for their proportion allows the knapping action to be expressed as an index representing a metric property that may provide distinctions between lithic traditions. Relative conformance of that property should be useful for determining how uniformly a tradition adhered to culturally standardized processes.

In his exhaustive study of the relationship between flake attributes, Pelcin (1996:320) concluded that "flake mass is an ideal attribute through which to examine the changes produced on different core types, with different indenter types, and/or bevelled platforms without concern for the effects of these independent variables." Since mass is a function of volume it seems appropriate to find a way to relate the major dimensions of a flake to its volume. Shapes of flakes are too complex and variable to be exactly modelled, but Patten (2007:71) found that flake volume could be represented by a percentage of a box volume represented by the flake's maximum dimensions of length, width and thickness. Since flakes that fill their boxed volume are relatively stiffer than those which do not (Patten 2005:190) the boxed representation of a flake's geometry will be used as a proxy while describing the mechanical properties of a flake. Comparing the boxed volume of a flake to volume derived from weight provides information about how the mass of a flake is distributed.

2.1. Causes of dimensional flake attributes

Rather than depend on arbitrary landmarks or flake typologies, the dimensional flake attributes suggested by Pelcin (1996) are reviewed in order to appreciate how knapping decisions and behaviour contribute to each of those critical dimensions.

Length of a flake reveals how impact at the platform transmits sufficient stress some distance from the impact site in order to detach the flake from its parent core. For a fracture to extend the full length of the core or biface, the core had to be subjected to critical bending stress throughout that distance. If only inertia counters the force of impact, then the fracture is not likely to reach further than the centre of mass. For the flake to travel further than that, the core must be supported by the knapper's hand-hold or an anvil. However the knapper thinks about the support, the path of the flake is automatically directed to the strongest point of resistance to the blow. Fixing the preform to a support serves to direct the flake toward that point of support. Therefore, consistently directed full-length flakes indicate that support was deliberately applied to the location on the edge where the flake was expected to travel. Flake length is obviously related to biface width, particularly when full-length flakes are utilized. Angle of blow, amplitude of impact, and choice of knapping tool all contribute to determining the direction and force that had to be countered by the support. Rotating the support against the direction of blow can cause flakes to arc dramatically from edge-to-edge. The arc of fracture flattens in proportion to the opposing counter-rotation to the blow. Regardless of all other factors, the fracture will progress only as long as load is applied to the platform. It is therefore desirable to introduce a flexible support for the core, in order to maintain tool contact until the fracture can be completed.

Thickness of flakes is primarily controlled by how far the impact is offset from the face of the core or biface (Patten 2005:76). Maximum flake thickness is often in the bulb of force, which Cotterell and Kamminga attribute to Hertzian initiation during hard hammer percussion (1987). Blows directed perpendicular to a platform surface typically cause the most severe swelling of the bulb of force. Support of the core and magnitude of blow also have much to do with how far the fracture travels below the surface morphology. Flexible support can allow fractures to travel in an arc near the exterior surface while nearly plane fractures, promoted by very stiff support conditions and inertial mass of the knapping tool, may remove a flake of considerable thickness.

Width of flakes is primarily controlled by surface morphology because prominences, such as arrises, stiffen and guide developing flakes. Thicker flakes generally appear to be less affected by surface morphology, but are necessarily wider than if the fracture were shallow. Knappers familiar with how surface morphology guides flake shape can intuitively draw a predicted flake outline with considerable confidence. The most common source of error is simply that the actual depth of the fracture is greater or less than anticipated, meaning that flake width is usually dependent on thickness. A knapper controls the intended outline and thickness of the flake through a combination of conscious decision and cultural influence.

2.2. Dynamic loading effects

Fundamental tools and techniques have long been understood to generally involve using hammer-stones to break apart large rocks, soft hammers to thin bifaces or smaller cores, and pressure tools to refine edges. Each basic tool set overlaps greatly in capability because they conform to the same physical properties. As such, hammer-stones can be used to make projectile tips rivalling those made by soft hammer or pressure. Knapping tool kits are distinguished primarily by their size, density, and stiffness; properties that influence how tools transmit force to an object. Each component of a knapping system, including the craftsman, can be described as springs each having characteristic rates of compression and rebound. Stiffness of a spring is described mathematically as dividing the load by the amount of deflection. Since the interaction is dynamic, the rate at which the load is exchanged between components of the complete knapping system is critical. Too stiff a spring action, (i.e. hammer-stone) can shock the impacted object and cause shatter or irregular fracture paths when there is not enough time for the parent rock to distribute the stress. A weaker spring action (i.e. soft hammer) allows the incipient flake time to bend away along a smoothly arced path of fracture. Not only does the spring principle explain the effects of impact, it can help us understand many of the common defects that plague flintknappers.

If the core is too stiff or the blow too fast, the crack will not have time to run its full course before contact is lost as the hammer bounces, allowing hinges to occur as they use up energy stored in the core. Step terminations are different than hinges and occur when energy is insufficient to propagate the crack. Increasing support, whether by grounding the object against an anvil or gripping with the hand more tightly, can add stiffness that increases fracture speed, while freehand support reduces stiffness and lengthens the time available for a fracture to complete because the object takes longer to compress and rebound.

The shock of impact during percussion is a transient phenomenon expressed by the duration and amplitude of energy. Because the hammer and the core each have a characteristic rate of compression and rebound, their impacting frequencies may not correspond to each other. However, to obtain the longest flakes requires matching the duration of a complete impact cycle between hammer and core because a fracture can progress for only as long as the hammer and core remain in active contact. As the frequencies of the hammer and the core approach each other, their energy amplitudes combine and produce the maximum level of energy when the impact frequencies match exactly.

Any hammer can be easily mishandled, causing damping of impact to yield a poorly-formed flake indicating an undesirable interaction between the core and hammer, typically resulting in exaggerated conchoidal-shaped fracture, hinge termination, and a generally short flake. However, impact that appears to be matched with the support frequency produces the flakes with the shallowest ventral features, like undulations, that are capable of travelling the furthest.

A knapper must manage energy amplitude by actively avoiding energy damping effects. Clamping a core in a holding devise effectively binds the core to a larger mass and increases the energy necessary to initiate fracture. Even holding a preform in one's hand dampens the energy available for fracture, so the lightest possible support is recommended. Inertial mass sets a practical minimum support. Wielding of the hammer follows the same prescription - lighter is better - as long as sufficient energy is available. Tension in the muscles of either arm can be equally detrimental to effective flake formation. Stone hammers are generally spherical because the vector of impact automatically passes through the centre of mass of the hammer. Since antler batons are not spherical, any impact other than longitudinal can cause vibration that may interfere with frequency matching. The effect may be negligible for light flaking but is crucial for driving full-face flakes from a core or biface.

Baker (2004; see also Bradley, et al 2010:45) provided plots of length vs. SQRT(width × thickness) for various core configurations to illustrate how resistance of the core to dynamic bending load apparently imposes limits on the proportions of hand axes at abandonment. The prospect of using basic dimensions to objectively quantify the resultant behaviour of unique knapping traditions is intriguing. Rather than having to deal with a primary product, it seems advantageous to study the removed flake. Not only is the stage of production not critical, flakes are far more numerous and less subject to subsequent modification through use than the functional tools or cores they were derived from. Baker's "dynamic loading model" can be thought of as illustrating how support of the impacted object counters deflection introduced by impact.

$$\text{Dynamic Loading Model number (DLM\#)} = (\text{Width} \times \text{Thickness})^{1/2} / \text{Length}$$

Although the expression was empirically derived, it explained 97 percent of the variation in Levallois core dimensions. The DLM# allows characterization of impact via a number derived from the dimensions of a flake. The expression is independent of scale and thus should be equally applicable for any size of flake.

3. Results

The DLM# roughly characterizes how the impact frequencies of hammer and core interact. The higher the DLM#, the greater will be the mismatch in impact frequency between hammer and core. Since the history of a flake's formation is condensed into a single value by the DLM#, it can be treated as an index value that describes a fundamental numeric property of a flake. Maximum measurements of flakes were divided by thickness to make them non-dimensional in order to avoid distortions that would have been introduced by scale. Flake thickness is more readily controlled by a knapper than any other dimension and actual measurements could be easily compared to the proportional data set.

The proportional major dimensions were then plotted against the computed DLM# to see what correspondence might be evident (Figure 1). Because the major dimensions describe a box volume that is not equal to the volume determined by weight, a separate volumetric index was plotted against DLM# to assess the influence of how flake mass was distributed. As detailed in the following sections, graphic depiction of the data led to important implications for improving lithic analysis.

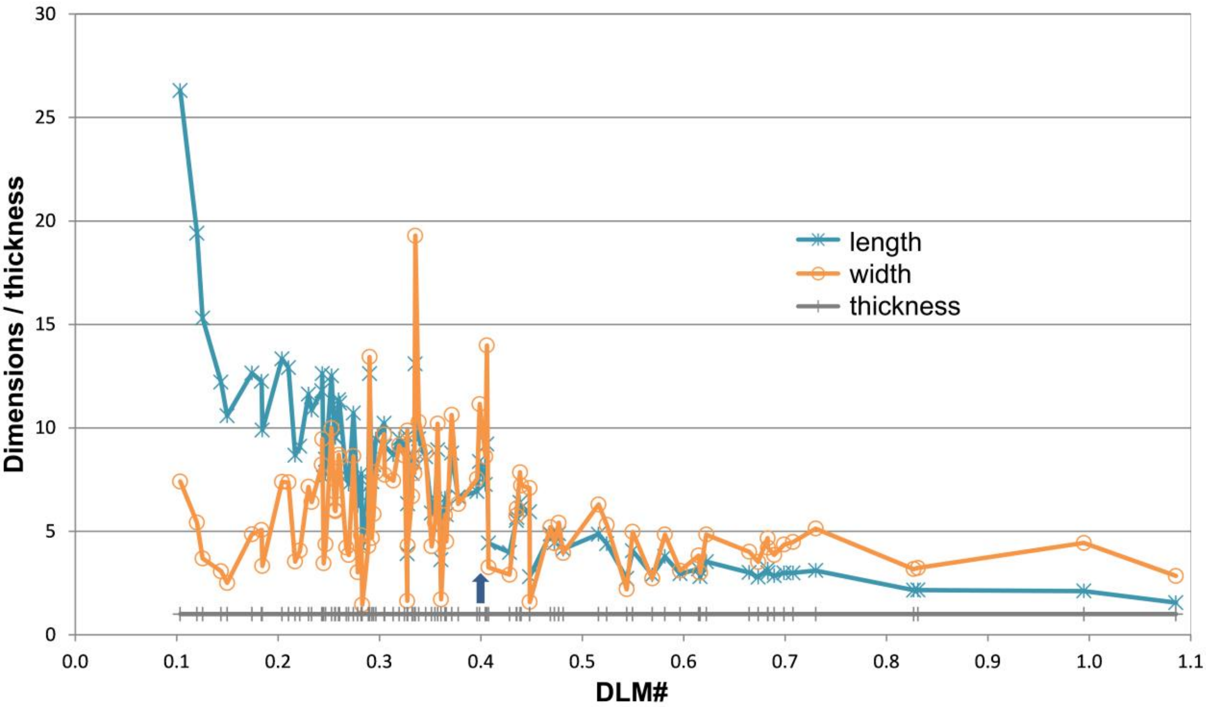

Figure 1: Co-variation of flake dimensions is shown by plotting the behavioural (DLM#) index in relation to major flake dimensions (divided by thickness to illustrate proportionality). An arrow indicates a discontinuity separating marginal flakes on the left from off-margin flakes on the right.

3.1. Indexing by behaviour

When the DLM# was plotted against proportional maximum dimensions (Figure 1), an apparent discontinuity was revealed between major regimes at a DLM# = 0.4, most visibly represented as reversals in flake length to width proportions. Fortunately, data were available as to whether each flake was removed by impact on the margin (edge), or off-margin (away from the edge). Ninety percent of the margin and non-margin flake assignments agree comfortably with the division by DLM#. The importance of where a blow lands may be understood by realizing that experience with knapping trains the craftsman's body to automatically increase muscle involvement when preparing to strike a point on the platform offset from the flaking face in anticipation of the additional fracture strength of the stone that must be overcome in order to remove a thicker flake from the core. The distinction corresponds to the difference between a striking an object supported only by inertial mass and one braced against impact, allowing DLM# to be characterized as an index that captures the cumulative expression of knapping behaviour based on stiffness. Off-margin flakes are initiated either by Hertzian fracture that is accompanied by a bulb of force, or as a wedge (Cotterell and Kamminga 1987:698). Furthermore, the flakes can be so thick that they demand more energy than is delivered by the blow, which leads to step and hinge terminations. High DLM#'s (> 0.4) represent increasingly stiff flakes from cores that need to be well stabilized against movement. Marginal flakes are routinely made by soft hammers, while hard hammers are seldom used to strike an edge. Flake initiation from an edge occurs by a bending initiation that leads to a stiffness-controlled propagation and compression-controlled feathered termination (Cotterell and Kamminga 1987:697-698). Low DLM#'s (< 0.4) represent flexible flakes that are most readily produced with yielding preform support.

The effect of knapping behaviour on DLM# values is supported by subjective observations (Table 1), where the manner of blow delivery is seen to sometimes favour one regime of fracture mechanism over another. There is a strong correlation between muscular reinforcement of a blow and where it lands for DLM# values < 0.4. However, the association is less clear for DLM# values > 0.4.

Table 1: Subjective data regarding the manner of blow delivery for each flake show that the mechanisms of fracture are greatly affected by how a knapper delivers a blow.

# of flakes with DLM# < 0.4	# of flakes with DLM# > 0.4	Manner of blow delivery
11	32	indirect rocker punch
25	28	direct percussion
6	41	relaxed blow
30	19	forced blow
6	54	margin impact
30	6	off-margin impact

That a dimensional expression can characterize flake formation under dynamic loading without introducing properties of materials may seem unlikely, but when we recognize that the regimes defined by the DLM# operate with distinctly different mechanisms of fracture, it is less mysterious that linear dimensions can be used to pick them out. After all, each mechanism distributes stress differently through the impacted object.

A knapper uses biofeedback to intuitively manage the relation of impact and support in a manner that strives to optimize the effective extension of a flake. In turn, the dimensions of the flake quantify how effectively the knapper achieves his goal. It thus seems appropriate to use the DLM# as a meaningful measure of knapper skill in that it reveals how well the craftsman uses biofeedback to manage a mechanical collision between two objects of variable size and material composition. Skilful manipulation of less than optimal tools can lead to low DLM#'s, meaning that the index reflects the resultant action instead of a contributing component.

3.2. Indexing by flake volume

The boxed volume of a flake was found to approach double that of the actual volume for a long prism shape or six times that of the flake when it resembled a slender wedge. Long, flattened flakes are inherently flexible while more compact shapes are relatively resistant to bending. Specific conditions can be shown to affect one dimension significantly more than another but the geometric properties may still retain a degree of interdependence.

Comparing volume (V), determined by dividing the weight of a flake by its density, with box volume (V_B), based on major dimensions characterizes the extent to which the flake fills the box volume. Lower values can be seen to indicate flakes where edges parallel the box frame, while flakes with high ratio values generally have complex shapes. Those distinctions can be roughly correlated to stages of manufacture and specialized flake shape requirements as diverse as blades or expanding flakes. Although many knappable materials have essentially the same density because they are commonly composed of silica, care should be exercised to confirm density when determining volumes from weight. Substituting other than maximum dimensions would also distort the volumetric ratio.

The volumetric index has the potential for identifying the use of deliberate strategies designed to provide specific flakes for use as tools or to control core morphology. Although we cannot expect all knapping to resolve into tidy categories, there is reason to continue with this line of investigation because of the prevailing human tendency to conform to actions of those around us. The range of variation displayed will bear witness to how tightly (or not) people adhered to process controls. Low variability may be interpreted to mean that rigid controls were utilized (Patten 2012).

3.3. Combining the behavioural index with the volumetric index

The DLM# identifies whether a flake is formed by a stiffness-controlled fracture in the case of marginal impact, or a compression-controlled mechanism in the case of off-margin impact. On the other hand, V_B:V describes how the volume of a flake is distributed, with low values representing narrow, thick flakes and high values representing wide, thin flakes. Mapping the two indices in a matrix (Figure 2) therefore conveyed an extraordinary amount of specific information about individual flakes.

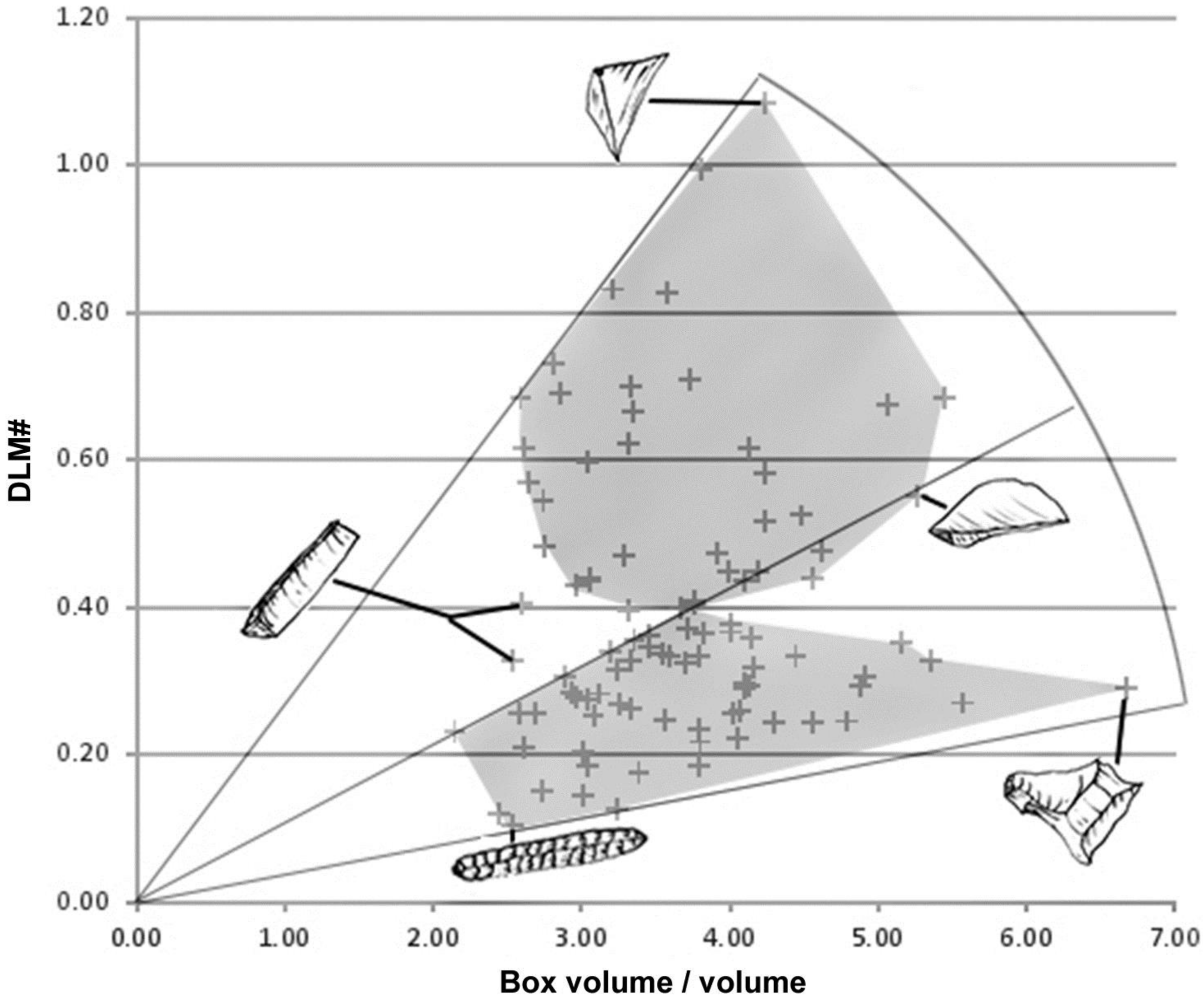

Figure 2: Data mapped as a matrix with the behavioural index (DLM#) on the vertical axis and the volumetric index (box volume divided by volume) on the horizontal axis. Shaded areas of the matrix emphasize how data is separated into two regimes of flake mechanics. The role of flake geometry is illustrated by the morphology represented at selected specific data points.

Despite an earlier suggestion that the volume of a flake may be a set percentage of the box volume (Patten 2007:71), the matrix shows that that only applies to flakes from a particular stage of reduction or from a similarly shaped core. Otherwise, using the boxed dimensions of a flake to derive the DLM# seems to remain valid since the matrix highlights the appropriate volumetric relationship.

Radial trends in the matrix plot are associated with gross morphological trends. The central portion of each radial sector is generally represented by flakes that are thickest in the centre and have nearly equal length and width. As DLM#'s decrease, relative thickness decreases. Increasing VB:V ratios lead to progressively more acutely feathered distal flake terminations as the DLM# decreases. Flakes with low VB:V ratios tend to follow a central prominence or arrise while those with increasing ratios indicate a transition to feathered terminations with fan-shaped outlines, following branching arrises. Not only are arrises responsible for gross morphological trends in the distribution of a flake's volume, they play a substantial role in the behavioural index. Flakes characterized by DLM# values greater than 0.4 generally have arrises that are twice as thick as those on flakes having DLM#'s less than 0.4.

4. Conclusions

Having commented on the limitations of fracture mechanics at the beginning of this paper, the proposed indices appear to place flakes along a continuum that spans the blended tripartite phases of flake formation described by Cotterell and Kamminga (1987). The ability to characterize mechanisms controlling flake formation using a discrete, quantifiable index numbers derived from maximum dimensions of complete flakes associated with a specific lithic tradition provides the means to objectively assess differences in knapping behaviour and decision-making that are impossible to observe directly. With knowledge of likely characteristics of knapping implement and preform support, additional parameters, such as platform structure or damage, can be used to enhance the analysis. Meaningful correlation between a flake's DLM# regime and subjective observations of how the blow was delivered (Table 1) indicate that it may be possible to design future experiments that will better quantify the contributions of a knapper's action to the DLM# of a flake.

Replicative experiments demonstrate that tightly controlled conditions are capable of producing flakes of various size and shape with highly correlated index values. A lithic tradition is unlikely to adhere to any single knapping behaviour over all others, but it is not unreasonable to expect that a consistent pattern would be detectable from a large, culturally representative assemblage of flakes. Non-conforming flakes from early-stage regularization of cores, or isolated problem-solving are not likely numerous enough to distort a cultural trend. The first step toward such a comparison would consist of controlled studies of deduced knapping techniques and core strategies. With those studies in place as benchmarks, sufficient data should already exist to quantify index values for various sites and complexes. If archaeological data shows index values to be generally highly variable for a given lithic tradition, it may be assumed that the processes used were not highly controlled. Assuming that lithic traditions grew out of pre-existing behavioural patterns, it is reasonable to expect that indices will provide useful signals to help trace their developmental lineage.

Lithic traditions bear the imprint of habitual practice learned through generations, although we have little assurance that ancient processes were as highly controlled as is generally necessary for experimental data. In fact, as core size decreases, the prospect of variation rises. Using an anvil or holding devise to increase support has the effect of making a core act as if it were much larger than it is on its own, while freehand support can be unpredictable. The linkage between flake morphology and knapping tool suggests that habitual use of certain knapping tools may constrain the resulting indices in ways unique to a cultural tradition. Consequently, it is advisable to compare each range of flake size to learn whether the physics of flaking remain constant for a tradition or vary as reduction progresses. Reducing flake geometry to four easily quantified variables establishes a meaningful baseline for addressing myriad independent variables including: platform structure, impact offset, flake curvature, fracture strength, and external support. Once pertinent associations can be established on complete flakes, it may be feasible to estimate dimensions of incomplete flakes by comparison to complete but otherwise identical examples.

Individuals who have demonstrated competence in replication of artefacts related to the lithic tradition being studied, will continue to assess knapping behaviour, but the use of unambiguous measurements to characterize behaviour sidesteps many objections related to potential bias, whether justified or not. Since experimental data has now shown that highly specific techniques may produce equally specific and unique products, experts may now be expected to quantify their claims in ways that assure analysts unskilled in replication that the conclusions are relevant to the lithic tradition under investigation. In combination, the quantitative indices discussed in this study avoid the equifinality problem because all components of the contributing behaviour need not be known. Cultural lithic indices developed from reference studies eventually should be compared to see if they can resolve questions of lineage. Flakes may ultimately allow cultural associations to be determined even when there are no traditionally diagnostic lithics at a site.

Future studies can be expected to provide a clearer view of distributions that may be representative of debitage resulting from quarrying, base camp, and transient occupations. Most studies would examine behaviour on a population level, but special circumstances of isolated flake depositions should allow occasional investigation of behaviour by individuals. Although the proposed indices are non-dimensional, it is possible to screen data on box volume or flake thickness in order to detect possible differences in approach between early and late stages of reduction. Flakes that serve an apparent technological purpose, whether it is to further a stage of reduction or to use as a tool, may be found to exhibit signature indices. Even the difficult task of separating cultural from non-cultural flakes may be aided by the indices. As existing metric data is reprocessed and new experimental correlations are identified, we can learn how consistent the actions of populations were, whether those actions arose to achieve the morphology of a desired tool form, or if ingrained behaviour persisted even when a new form had to be adopted.

Confirming that metric properties of flakes can be used to decipher knapping behaviour in the context of fracture mechanics opens a new line of inquiry into the origins and transmission of lithic traditions. Instead of treating flakes as inconvenient artefacts of questionable worth, they may now provide fresh new insights.

Acknowledgements

This study would not have been attempted without the pioneering efforts of Tony Baker and I truly regret that he was not able to see its completion. Comments by Metin Eren and Harry Lerner were invaluable in restructuring and tightening the arguments.

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Summary, synthesis, and annotated bibliography articles

Flint economy in the Pyrenees: A general view of siliceous raw material sources and their use in the Pyrenean Gravettian

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Abstract:

The aim of this article is to present a very general view of siliceous raw material sources in the central Pyrenees, with support from recent bibliographic references. To illustrate the use of these materials in the Upper Paleolithic, we chose the example of the Gravettian occupation of Gargas Cave (Hautes-Pyrénées, France). Finally, we describe a few economic characteristics of the Pyrenean region, which are distinct from the Perigordian context in several ways.

Keywords: Gravettian; flint economy; Pyrenees; raw material sources; Lepidorbitoide flints; lithic industries

1. Introduction

Our knowledge of flint procurement sources in the Pyrenean context has become increasingly precise over the last twenty years, drawing on the work of pioneers such as Louis Méroc (1947; 1953) and Robert Simonnet (1981; 2003). (For the early historiography on this topic, see S. Lacombe's doctoral thesis (1998).) In the 1990's, research was conducted in the framework of the collaborative program entitled *Lithothèque régionale*, directed by P. Chalard (1994-1996) and then F. Briois (1997-1999), but this work remains largely unpublished (Briois et al. 1997; Briois 2000). The doctoral thesis of S. Lacombe (1998) on the Late Glacial lithic industries of the Pyrenees presents an updated synthesis of both the siliceous material resources and their use in the Magdalenian and Azilian periods. The most recent articles by R. Rimonnet (1999; 2003) present a synthesis of his work and complement his *lithothèque* (raw material reference collection) constituted through field surveys conducted over nearly 50 years. This reference collection is kept at the TRACES laboratory (UMR 5608 of the University of Toulouse Jean Jaurès). For interested readers, we provide most of R. Simonnet's scientific works on the characterization of Pyrenean siliceous raw materials. These include: his general synthesis articles (recent and earlier: 1981, 1996, 1999a, 1999b, 2002, 2003), in which there are paradoxically very few petrographic or geological analyses, as well as a micro-paleontological description by J. Villatte "that could serve as an inventory of

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the bioclasts of Danian flint"); and his earlier articles on more general subjects (1967, 1969, 1973, 1976, 1982, 1985) or thematic topics (e.g. Paleolithic portable art: 1990), in which there are a few analyses of flint, or studies inserted within monographs (Mauran, La Vache: 1994, 2003). Recent research has drawn largely on petro-archaeological and geological analyses, such as that of lepidorbitoide flints (Séronie-Vivien & Foucher 2006; Séronie-Vivien et *al.* 2012). (There are also a few university theses, at the Master's level, for example, Solène Caux, Guilhem Constans, Théo Minet.) The efficacy of these analyses has been demonstrated and they have revealed the complexity of Pyrenean lithic resources. Finally, the collaborative project led by P. Fernandes, contributing to the preceding research questions on a trans-regional scale, should provide a cartographic and archeo-petrographic database that will be very useful to prehistorians and provide an opportunity to remobilize research in the Pyrenees (Fernandes et al. 2013).

2. Flint from the Petites Pyrénées and Plantaurel (central Pyrenees)

The Petites Pyrénées and Plantaurel (their eastern extension) are one of the largest sources in terms of their geographic extension (Figure 1). They have furnished very diverse flint types (Danian, Paillon, Montsaunès, Foix-Berdoulet of Urgonian in the Foix basin, "black of Couterets", "brecciated flint of Pellegrin-Jean Nègre", "flint with charophytes": cf. Simonnet 1981; 2003).

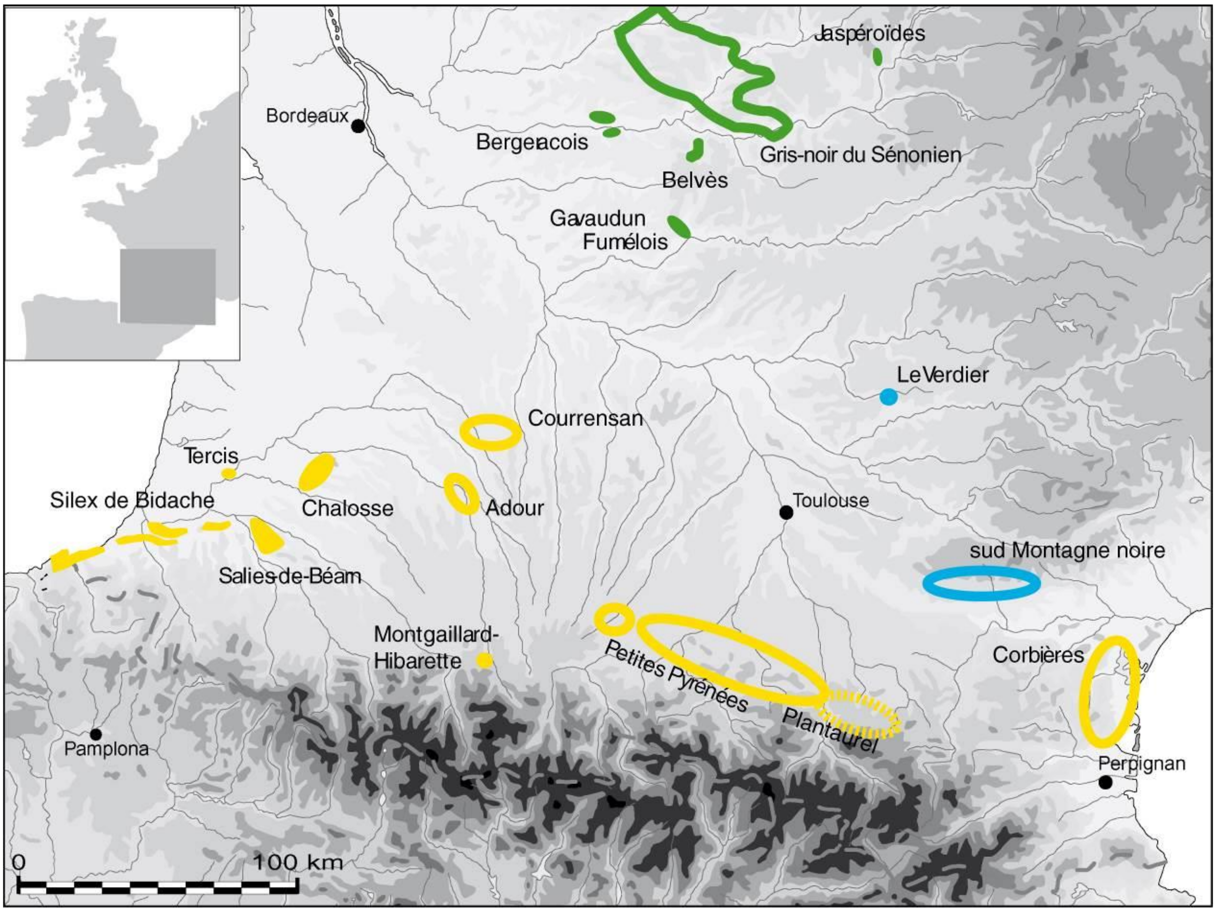


Figure 1. Map of flint sources in the Pyrenees. (From R. Simonnet, Ch. Normand, M. et M.-R. Séronie-Vivien, F. Bon, A. Tarriño, A. Morala, A. Turq, P.-Y. Demars, F. Briois, S. Grégoire).

– **"Blue" flint**, originating from the Danian formations is "a smoky, and especially blueish, translucent flint used throughout time and known by the local populations by this name. Prehistorians called it "*chalcedonious*". Its appearance is similar to the so-called “Tertiary” flints of other regions” (Simonnet 1999b). It is a very ubiquitous and found throughout the Petites Pyrénées and Plantaurel chains. S. Lacombe (1998) distinguished, as did R. Simonnet for a time, the “Blue” and “Smoky” types based on colorimetric and morphological data, the latter having much smaller useable volumes and traversed by numerous tectonic fractures.

– The Danian formations of the Petites Pyrénées and Plantaurel formations furnished other flint types similar to the “Blue”, but with other features. We can cite the types designated by R. Simonnet as: “Mixed”, “Saint-Michel”, "Dôme d’Aurignac", etc.

- A specific flint a “blond” flint type, originating from the Danian formations of the Dôme d’Aurignac, was identified and found flaked in the Aurignacian of Tuto de Camalhot (Bon, Simonnet, Vézian 2005). It is a “very good material in the Pre-Pyrenees context. It is found in the form of regular blocks with a diameter greater than 10 cm and is fine-grained with a homogeneous texture”.

– **Paillon flint**, originating from Maastrichtian formations (Saint-Martory, Haute-Garonne), was described in the late 19th century (Leymerie 1881). Though it is a very characteristic and easily identifiable flint, no detailed petrographic analysis of it has yet been realized.

– **Foix-Berdoulet flint**, originating from the Urgonian formations of the Foix region. Other flints have been observed in the Lias and Albian-Aptian formations (according to Simonnet).

– **Montsaunès-Ausseing flint** originates from Maastrichtian formations. It is characterized by a high density of foraminifera and orbitoids (according to R. Simonnet). We find it localized in the southern part of the Boussens water gap (Montsaunès, Ausseing Mountain: see Figure 2). We presented a precise analysis of it when the **Tarté flint** was found and defined (Séronie & Foucher 2006). This latter, which contains many lepidorbitoides was defined based on the archaeological assemblage recovered during the early excavations at Tarté (Aurignacian and Gravettian archaeological site). Its intrinsic characteristics (structure similar to that of the Montsaunès-Ausseing flint and cortex type) and the large quantity of it flaked at the site, suggest that the procurement sources must be nearby, probably in the Boussens water gap zone, which is highly adapted to their formation (in terms of the geomorphological context). Meanwhile, we have not yet found these sources.

3. The other Pyrenean sources

3.1. Pyrenean Flysch flint

The outcrops of Pyrenean Flysch flint also yielded an abundant and high quality siliceous material in the Montgaillard-Hibarette region (Barragué et al. 2001), as well as in the Bidache and Iholdy regions further west in the western Pyrenean zone (Tarriño 2007 and C. Normand archaeology field survey).

– **the Montgaillard-Hibarette type**. This name covers many aspects. Hibarette corresponds to the Paleolithic flaking workshops located at secondary procurement sources (Poudingues de Palassou), constituted in part by the dismantling of the Flysch limestones (Upper Cretaceaous); these latter outcrops are located at Montgaillard where flint nodules are found in their primary position (Barragué et al. 2001).

– **Orignac flint** was defined by S. Lacombe (1998) in the outcrops (Turonian to Santonian) located at the Adour Valley outlet. This flint is similar to that of Montgaillard-Hibarette but smaller in size (centimetric slabs).

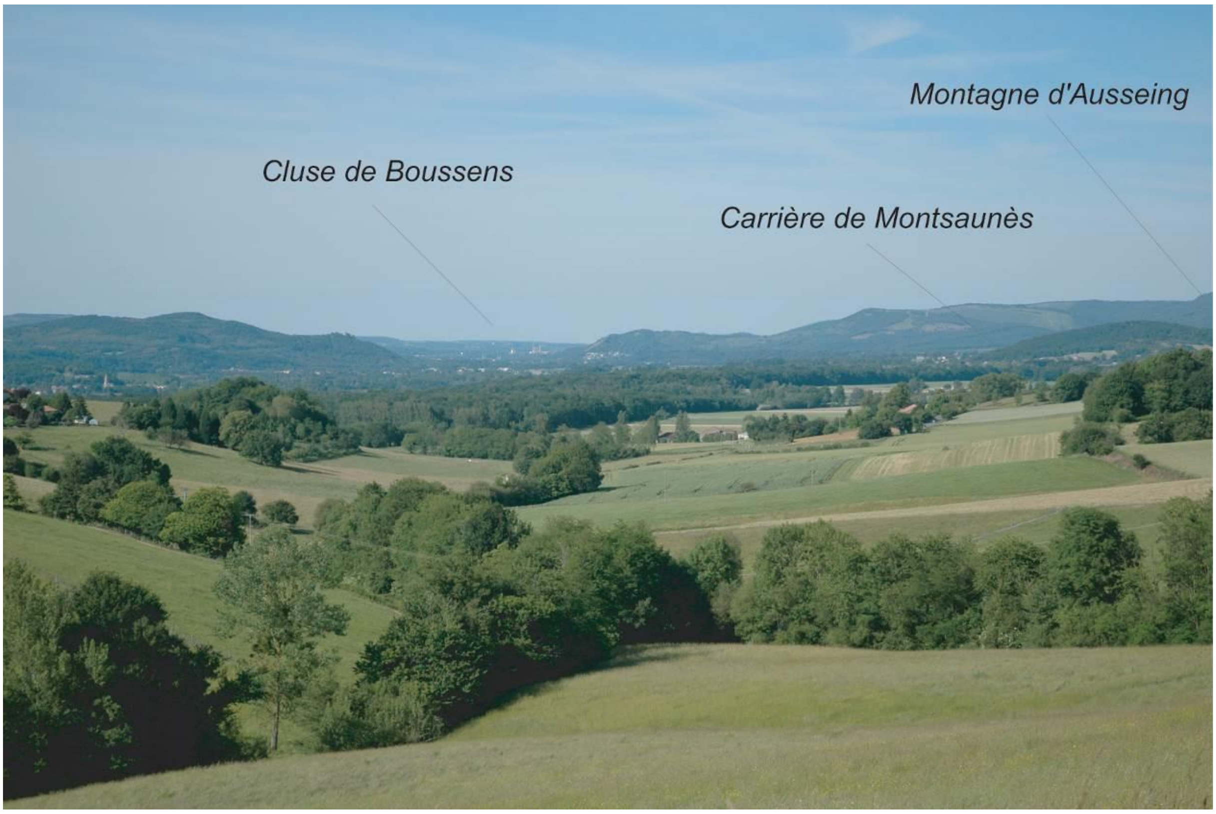


Figure 2. View from the S-W of the Boussens Pass.

3.2. Courensan flints

This flint type, very similar to the Pyrenean "Blue" type, is located in the Gers department in the commune of Courrensan (Simonnet 1996). This zone was also surveyed by G. Duclos (1991), who discovered numerous Paleolithic surface sites.

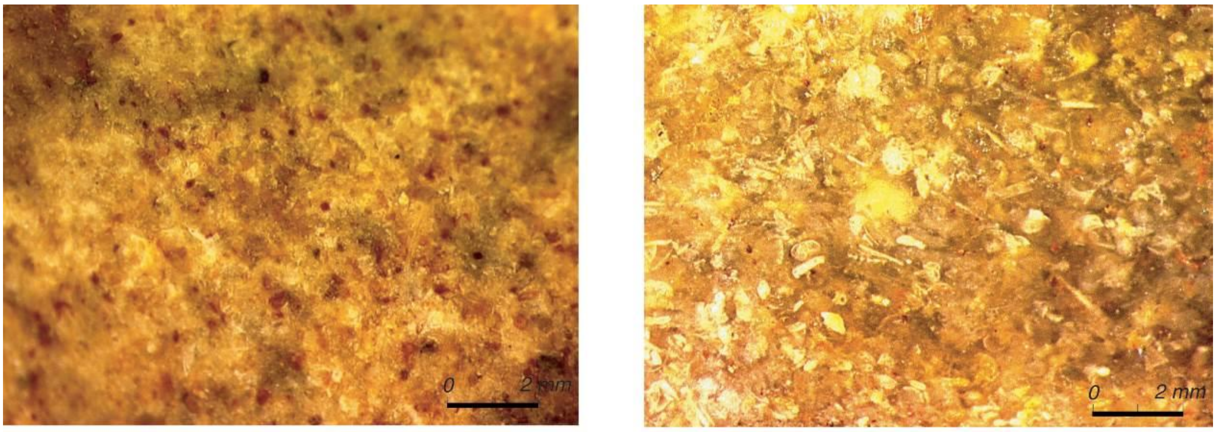
3.3. The sandstone sources of Armagnac

Though it is found in the northern part of the Gers department, beyond the Pyrenean foothills zone, we can mention the siliceous sandstone of Cazalège (Castelnau d'Auzan). This is a very tough raw material, well adapted to flaking, that was mainly used during the Acheulean (Millet et al. 1999).

3.4. Lepidorbitoide flints

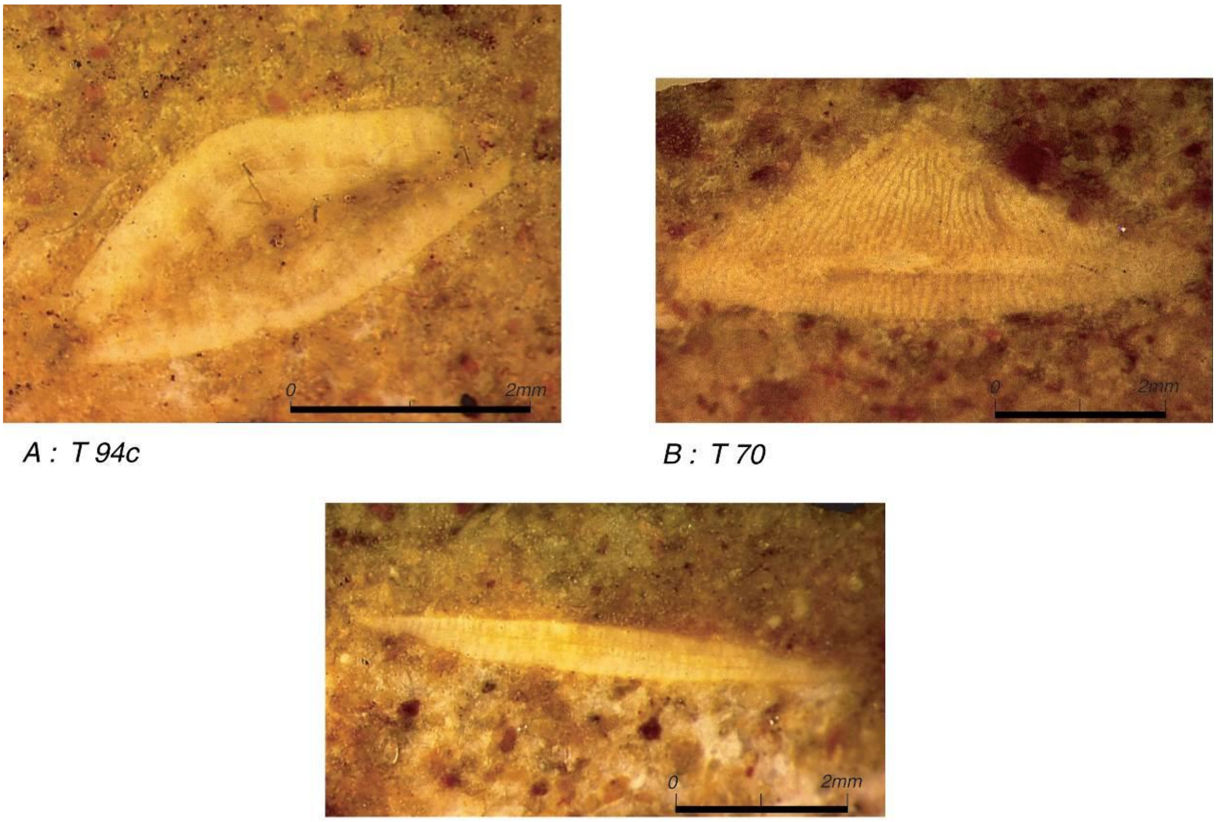
The important discoveries made in recent years most specifically concern one raw material type: Lepidorbitoides flints (Figures 3 to 5). This is a typical Pyrenean flint that does not exist in the Dordogne region. It was defined based on the work of Ch. Normand (1986), M. Séronie-Vivien (1994), and F. Bon et al. (1996). We formerly thought that this flint existed only in Chalosse, but it has also been identified in the Petites Pyrénées, in the Boussens water gap (Séronie-Vivien & Foucher 2006), and other sources were recently discovered in the northern part of the Gers department (Colonge et al. 2011), as well as further south in the Adour basin (Séronie-Vivien et al. 2012).

These new data completely change the direction or orientation of the circulation of this material type and underline that the Pyrenean resource site context is not as simple as we thought just fifteen years ago. Now the discovery of a tool in Lepidorbitoide flint does not forcibly indicate that it came from Chalosse.



A : T 20e B : M 305

Figure 3. Textural types of the Tarté and Montsaunès flints. A) Tarté type: wackestone texture with rounded intraclasts, often brownish, and lignitic fragments). B) Montsaunès type: packstone texture with rounded intraclasts and many bioclasts (ostrocods and small forams).



D : T 20dd

Figure 4. Orbitoïdinés. A) Orbitoides media (Tarté T94c). B) Clypeorbis mamillata (Tarté T70). D) Lepidorbitoides socialis (Tarté T20dd).

4. Flints from the western and eastern Pyrenees

In Chalosse, the Audignon-Montaut anticline and the Bastennes-Gaujac diapir are zones that are very rich in flint sites (alterites) and Paleolithic flaking workshops. Other more sparse sources are found at Tercis and Salies-du-Béarn (Tarriño 2007 and C. Normand archaeology field survey).

In the western part of the Pyrenees, large sources were discovered and described in the Corbières and to the south of the Black Mountain (Briois 2005; Grégoire & Bazile 2019; Grégoire *et al*. 2010).

We should also note that the large fluvial systems transported significant quantities of stone materials (flint and quartzites) and they were collected from the areas in which they were accessible during Prehistory, such as the Adour (all along its course from its exit from the foothills at Montgaillard) and the Garonne (in the Boussens water bank, at least until its confluence with the Tarn).

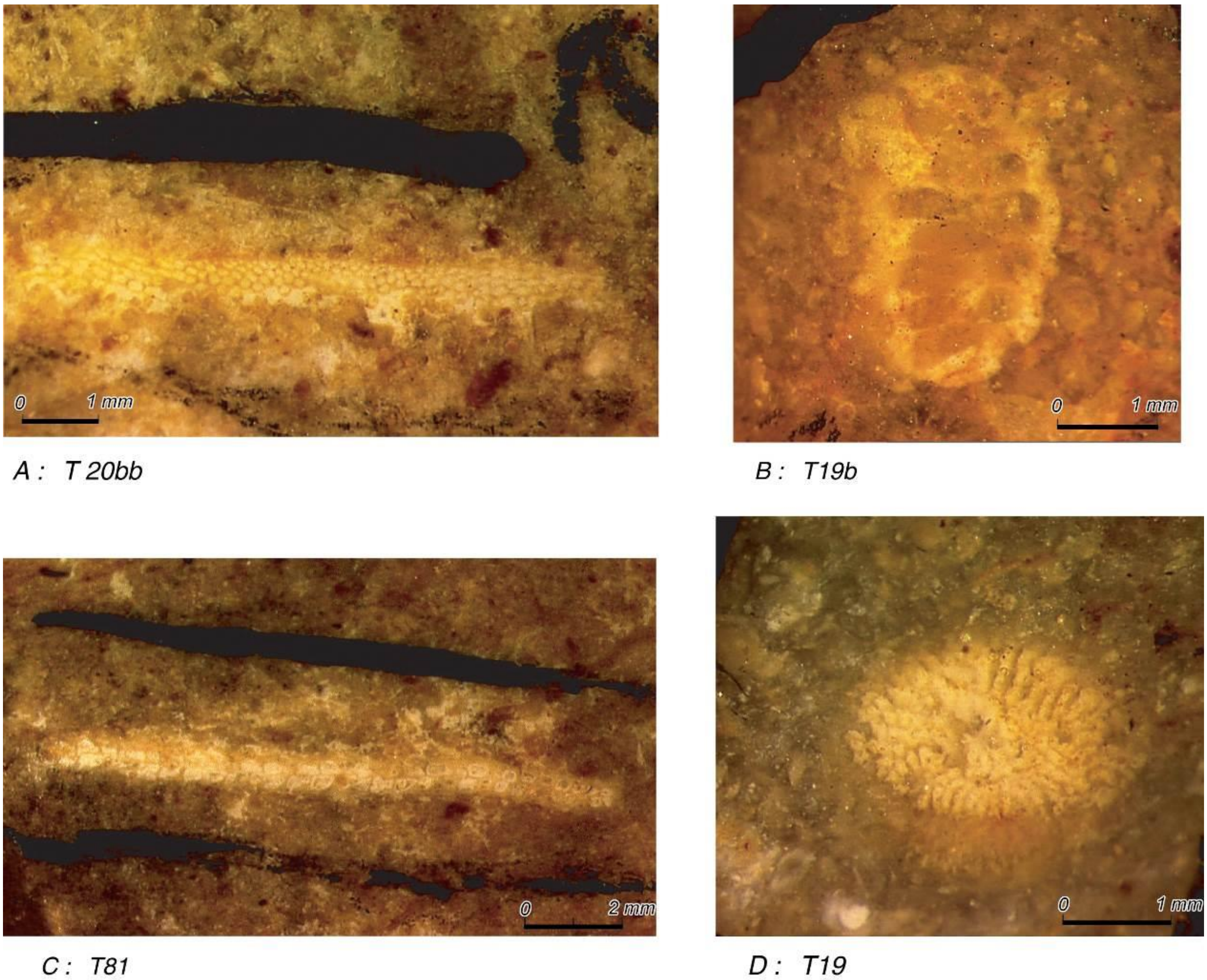


Figure 5. Algues: A) cf. Polygonella (possibly solénoporacée) Tarté T20bb. B) Neomerys (dasycladacée) Tarté T19b. C) Munieria (dasycladacée) Tarté T81. D) Neomerys (dasycladacée) Tarté T19.

5. Flint beyond the Pyrenees

These flints, qualified as allochthonous, are frequently found in Pyrenean sites throughout the Upper Paleolithic: Aurignacian, Gravettian, Solutrean and Magdalenian (Lacombe 1998; 2014; Bon 2002; Foucher 2004)**.** They are very diverse and come mainly from the Quercy and Perigord regions: Verdier, Gavaudun, Fumelois, Belves, Gray-black Senonian from the Perigord region, Bergeracois, Jasperoids from the periphery of the Massif Central, or even the upper-basin of the Èbre (Tarriño 2006). The main studies of raw materials in the Perigord region are Séronie-Vivien & Séronie-Vivien (1987), Morala & Turq (1990), Demars (1994; 1998), Turq (2000). An analysis of Verdier flint is currently in progress (personal communications with Christian Servelle).

6. Flint economy in the Pyrenean Gravettian

6.1. Gargas Cave (Hautes-Pyrénées, France): a few reminders

Gargas Cave is one of the reference sites for the European Gravettian due to its exceptional parietal art and its rich archaeological deposits. The latter were excavated from the end of the 19th to the early 20th centuries.

The most extensive excavations were realized by F. Régnault as early as 1873, followed by É. Cartailhac and H. Breuil in 1911 and 1913, but the work of these latter researchers was not published until forty-five years later, based on their field notes and a synthetic typological study of the industries discovered (Breuil & Cheynier 1958).

During the 20th century, research in Gargas Cave was mainly focused on the parietal art (Foucher et al. 2007). The first painted handprints were discovered in 1906 by F. Régnault (1907, 1910) and a complete study of the hands and engraved panels was undertaken during the following years by H. Breuil and É. Cartailhac, in collaboration with H. Obermaier (Cartailhac 1907; 1909; Cartailhac & Breuil 1910; Breuil 1952; 1958). In 1976, C. Barrière published a very complete monograph on the parietal art and the engravings in particular, following an attempted synthesis by M. Cantet and A. Clot in 1974. Continuing the work of A. Sahly on the hands (1966), and that of A. Leroi-Gourhan (1967), in 1987 M. Groenen published a critical analysis with the first reasoned and completed inventory on this theme, until then treated in a very partial manner (Groenen 1987; 1988). A ^{14}C date of 26 860 BP ± 460, realized on a bone wedged into a fissure of the Great Hand Panel, established an indirect Gravettian framework for the parietal art (Clottes et al. 1992).

Since 2004, we have conducted a research program on this cave (Foucher et al. 2008; 2011; 2012; San Juan & Foucher 2010). Our main aim is to obtain a detailed stratigraphic sequence of the site in order to define the succession of its occupations more precisely than was achieved by the synthetic scheme produced by the early excavators. It also provides an opportunity to conduct a paleo-environmental study of the site, which has never been done before. Since the stratigraphic sequence is thought to cover a broad chronological period (Mousterian, Chatelperronian, Aurignacian and Gravettian), this study will be the first of its kind in the Pyrenees.

This new field research also takes a broader, more global approach to the site, including a revision of the early Cartailhac-Breuil collections and an integration of both its decorated cave and habitation site aspects, with the goal of obtaining a better understanding of the functional, spatial and chronological features of its occupation by the authors of the parietal art. Through this research, we hope to integrate an ensemble of reliable chrono-cultural elements that will enable us to better situate the occupations and art of Gargas within the regional and European contexts.

6.2. The Pyrenean Gravettian lithic industries: typo-technological data

The data on the lithic industries of Gargas Cave are part of the more general data set associated with the Pyrenean Gravettian. We have already presented a first synthesis that included the results obtained from a revision of the early Cartailhac-Breuil collections (Foucher 2004). The data collected through the new excavations with contribute more precise information, but will probably not change the general scheme defined some fifteen years ago.

The main elements of the synthesis that we presented at the colloquium in Les Eyzies (France) remain current (Foucher *et al.* 2008a). What we observe is a high degree of homogeneity in the Gravettian lithic industries of the Atlantic and central Pyrenees, characterized by:

– Noailles burins (dominant),

– backed pieces (Gravette and Vachons points, and microgravettes),

– scaled pieces (*pièces esquillées*).

These three typological groups dominate in the lithic assemblages of all the Pyrenean sites (Foucher 2004). They are followed by backed blades and bladelets, bladelets with marginal retouch, truncations on blades or bladelets, and then endscrapers, truncated and dihedral burins. We also observe that the tools are very small (microlithism), as much among the Noailles burins as the Gravette points (microgravettes), and the bladelets with marginal retouch (Figure 6).

The absence of Font-Robert points is another characteristic typological feature of these assemblages: they paradoxically appear much further west at the sites of Irikaitz (País Vasco), Cueva Morín (Cantabria) and La Viña (Asturias), as well as in the Pyrenean hinterland to the north at the Les Battuts rock shelter (Tarn), even if their presence there is almost anecdotal. The recent discovery of an open-air site near Bayonne (Le Prissé) that yielded one Font-Robert point (personal communication Marina Redondo) barely modifies the general context. We must await the publication of this site, as well as that of Viña (and revise the data from Cueva Morín), and then reevaluate the possible relationships with Irikaitz in order to understand the significance of this typological component that seems to be more localized on the Cantabrian Cornice.

Minor statistical variations exist between the sites, but they do not seem to indicate a chronological evolution (Foucher 2004); they could as well be due to factors other than cultural ones (frequent biases in statistical calculations due to selective sorting by some early excavators), or functional variability ("specialized" sites). In any event, the lithic assemblages from sites excavated long ago (Isturitz, Gargas, Tarté), and others more recently (Enlène), show great similarities in both the general composition of their tool assemblages and in the forms and manufacturing techniques of some pieces (Gravette points, Noailles burns, scaled pieces). This is even more evident if we consider the variables forcibly introduced by the heterogeneity of the occupations and the possible functional differences of the sites.

The new data concern the chrono-cultural attribution of the shouldered points at Brassempouy. The context of their discovery by E. Piette being too vague, later attempts to attribute them hesitated between the Gravettian and Solutrean (Delporte 1968; Foucher 2004: 139-143). The discovery of new points in stratigraphic position during the excavations by H. Delporte (sector GG2) permitted their attribution to the Gravettian (Goutas & Simonet 2009). In addition, in his work at Isturitz, Aurélien Simonet defined a particular point type with an angled back, present only at the top of the Gravettian sequence (Simonet 2009).

From a technological point of view, the techniques for manufacturing blades and bladelets were relatively simple (both unidirectional and bidirectional laminar flaking, continuity from blade to bladelet detachment). A systematic analysis of the butts of the blanks detached indicates the use of soft stone hammer percussion (a large proportion of highly abraded, or even polished, butts). There was also an autonomous production of flakes and elongated flakes (Isturitz, Enlène, Gargas). There seems to have been little selection of raw materials according to the tool types to be manufactured (Foucher 2004; Simonet 2009). We can note just the one counter example of the shouldered points at Brassempouy, made exclusively from Chalosse flint (Goutas & Simonet 2009). The quality of the siliceous materials from the Pyrenees nonetheless had an influence on the size of the laminar blanks. Due to the dimensions of the nodules available in the central Pyrenean sites, in this zone (Gargas, Enlène), only small blades and bladelets could be manufactured; to find productions of larger blanks, one must move closer to the Chalosse and Flysch flint sources (Isturitz, Brassempouy, Tercis).

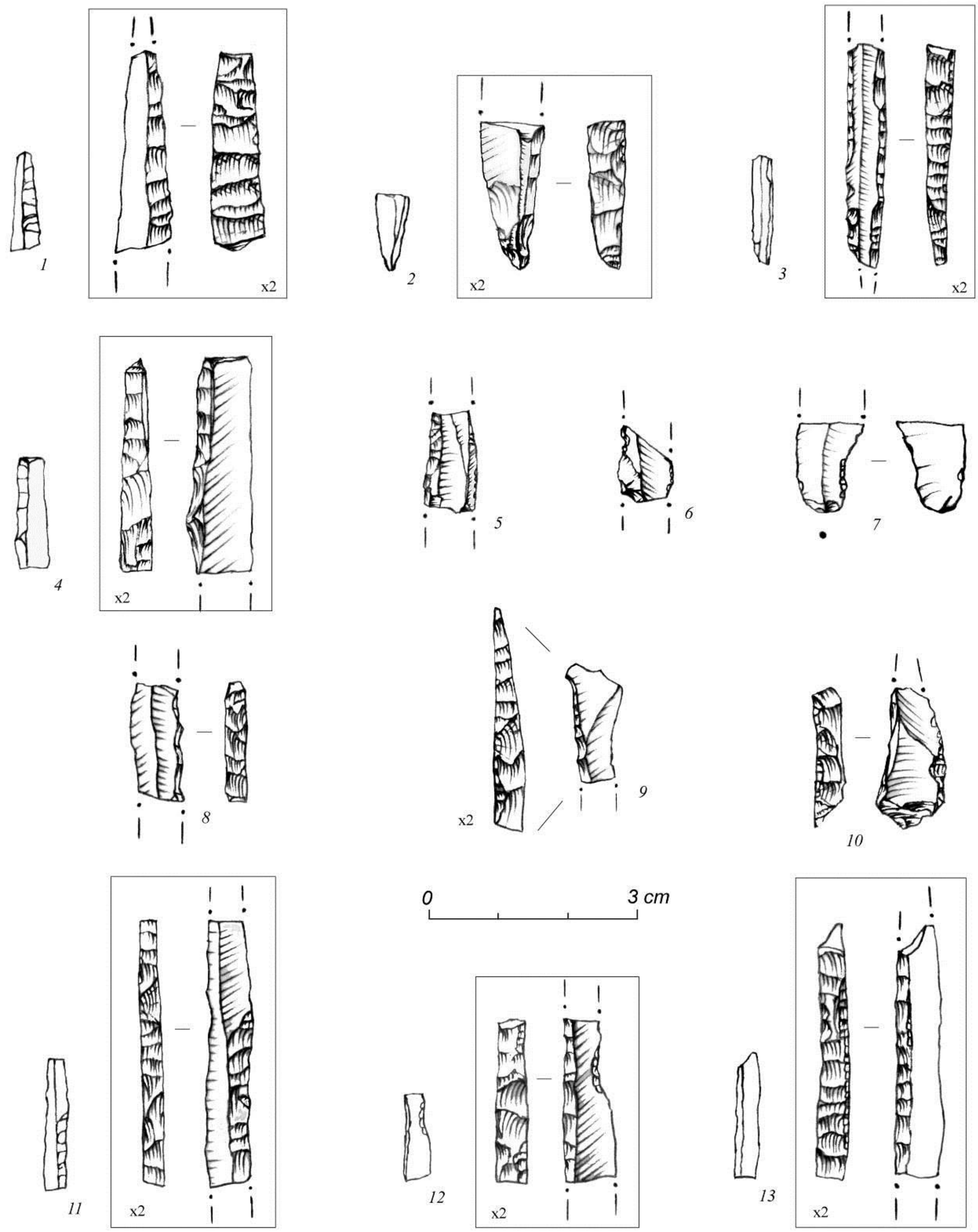


Figure 6. Microgravettes and micro backed bladelets of Gargas Gravettian.

In any event, it is not yet possible to refine the chrono-cultural framework or to imagine the existence of "sub-facies" based on technological data alone (Simonet 2009).

It is also worth noting that in the central and western Pyrenees, we do not find the other industrial entities or technical procedures defined in the Perigord, such as Flechettes, Font-Robert points, the procedures associated with Raysse burins, etc., considered as markers of chrono-cultural trends in the Gravettian.

6.3. The Pyrenean radio-chronological framework

For information on the Pyrenean radio-chronological framework, we recommend several articles (Foucher et al. 2011; Foucher 2013).

For the Gravettian occupations at Gargas, the results suggest long term occupations of the cave (3000 years), with a period of more intense occupation from 27,000 – 25,000 BP. From a chrono-cultural point of view, we observe an early phase with Noailles burins, during the 28,000 – 27,000 BP interval and a middle phase with an identical facies, between 27,000 and 25,000 BP.

6.4. Siliceous raw material circulation: economic data

The map of Figure 7 illustrates the preliminary results obtained at Gargas on the siliceous raw materials used in the lithic industry. The percentages mentioned are calculated based on the tool assemblage.

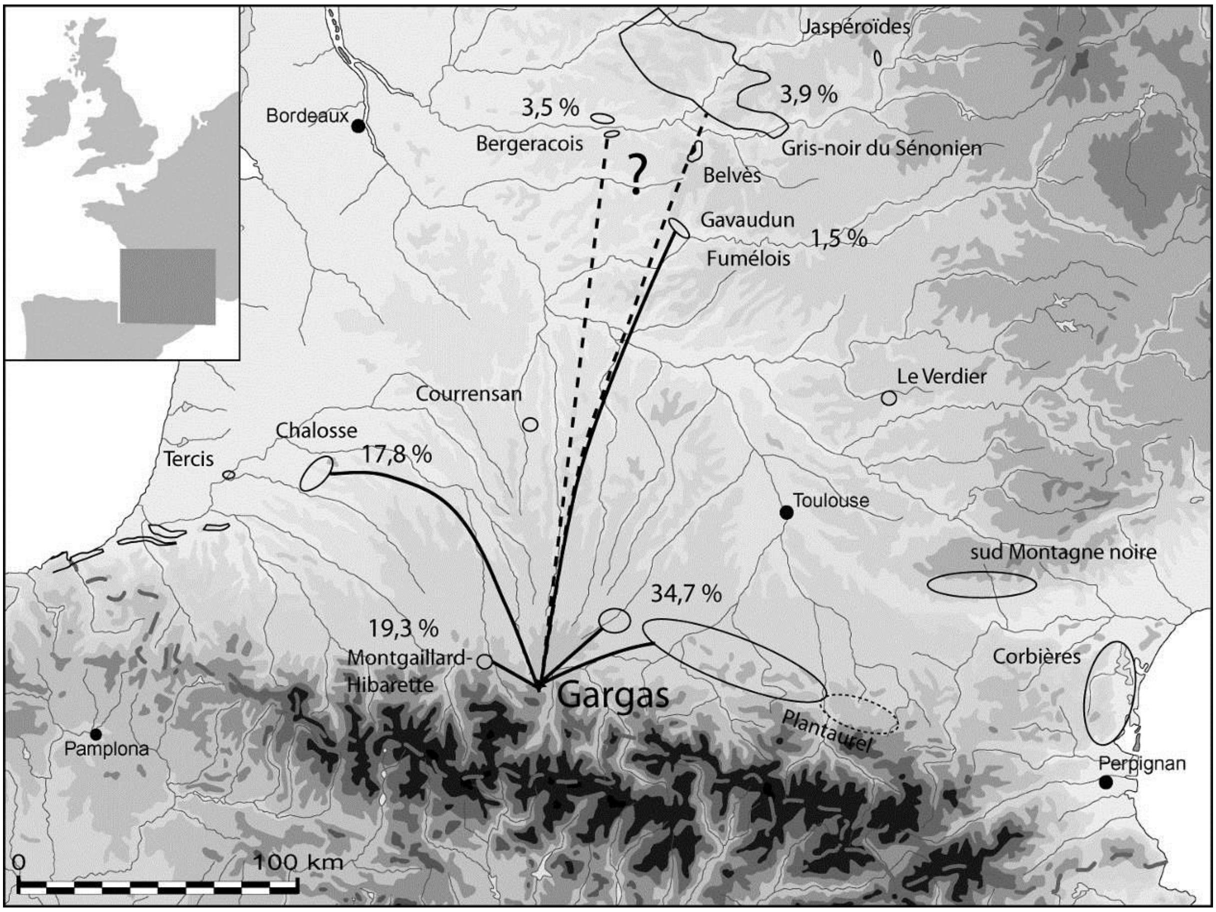


Figure 7. Map of siliceous raw materials used in the lithic industry at Gargas Gravettian (Cartailhac-Breuil collections).

The flint of the Petites Pyrénées is dominant (34.7%), followed by Flysch flint (including Hibarette: 19.3%) and lepidorbitoides (17.8%). Gargas is thus unusual in that it is a Pyrenean occupation site located relatively far from the local raw material sources (20-40 km); the closest ones are 24 km to the north (Lespugue-Montmaurin- Blajan sources) and the Flysch-Hibarette sources 42 km to the west-north-west. We should note the high proportion of flint with lepidorbitoides (17.8%) whose precise provenience remains to be determined (Chalosse or Adour-Gélise basin or Cluse de Boussens). There are several flint types (7.4%) whose origin in the Perigord region remains to be verified. On the other hand, Fumelois and

Gavaudun flint is clearly present (1.5%). These latter could appear anecdotal, but are significant in the orientation of the north-south movements of Gravettian people. Finally, there is one allochthonous flint that could come from the Èbre valley basin (personal communication A. Tarriño).

Given our current knowledge of the raw materials used by Gravettian people, we can reasonably assume that flint procurement was not very difficult in the Pyrenees. Though there are gaps in the distribution of siliceous resources (Figure 1), those available cover the entire Pyrenean zone and could provide prehistoric peoples with abundant and high quality materials.

This specific context nonetheless implies that the Gravettians developed different procurement strategies depending on where they were, including actions to anticipate their future needs. On one hand, we can distinguish an economy of abundance in proximity to the large Chalosse and Flysch flint sources, and on the other, a more rational economy in the Petites Pyrénées zone, where raw materials were more scarce and more heterogeneous in quality This local economy is accompanied by the procurement of more long distance flints (example of Gargas: Figure 7).

A few broad socio-economic traits can be deduced from all of these data:

- constant contacts and exchanges among Gravettian groups in the Pyrenees, in a geographic zone covering at least the Greater-South-West of France; it is possible that this was facilitated by certain very mobile individuals specialized in the prospection of siliceous materials;

- two large north-south and west-east circulation axes in the Atlantic river basin, probably periodically followed in both directions. We also observe these movement directions in other materials, such as shells (San Juan-Foucher, Foucher 2010; San Juan-Foucher 2011; 2013).

Acknowledgment

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Biographies

Biography of Are Tsirk (1937-2015): Flintknapper and scholar

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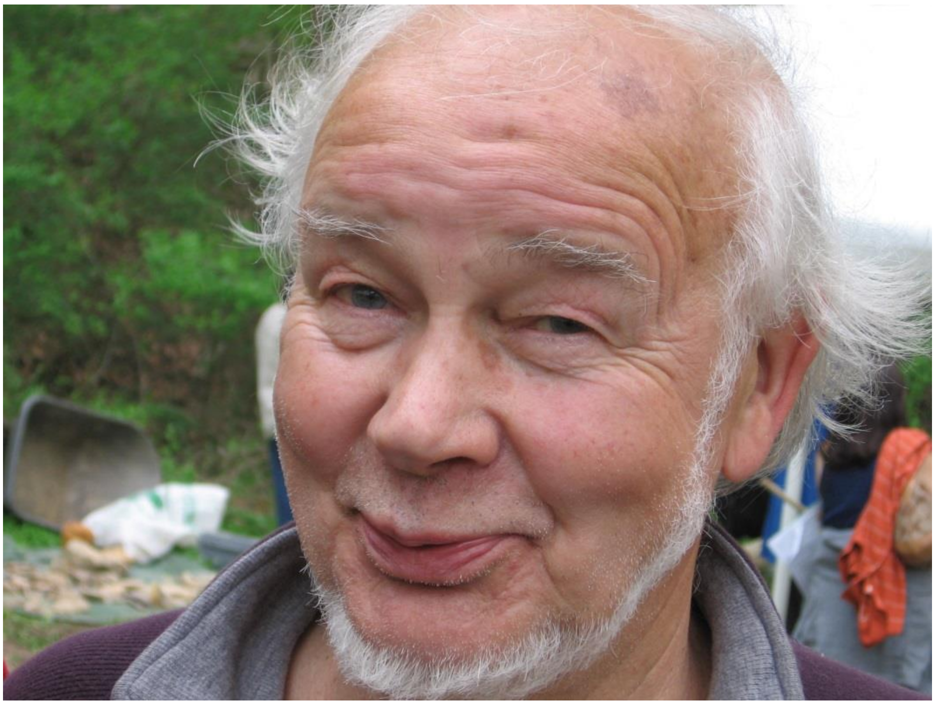

Are Tsirk in 2008, at the Primitive Technology Weekend, Oregon Ridge Nature Center, MD, USA. (Photo by Ming Diaz.)

Are Tsirk was as much a scholar as he was a flintknapper. These disciplines were intertwined and expressed in his experimental research, by way of his exploration of fractography, and his replication of stone tools which spanned the archaeological record of several continents.

He was born in 1937 in Tallinn, Estonia. As the Soviet Union brutally occupied this small Baltic country in September 1944, his family fled by boat to the West, living as war refugees in a DP (Displaced Persons) Camp in the American Zone of Germany, until they emigrated to the United States in 1951.

As a young man, his athletic ability was exercised in competitive swimming as the Captain of the New York University team in the late 1950's. He was also an avid recreational

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downhill skier and ski jumper, and participated in other robust activities. It was while he was a student that he met his future wife Epp (also from Estonia) whom he married in 1963. After serving in the early 1960's in the U.S. Army Corps of Engineering in Arizona and Okinawa, Are earned all of his academic degrees, BCE (1959), MCE (1964), PhD (1968) in Civil (Structural) Engineering at NYU.

In 1968, purely by chance, he read Francois Bordes' seminal volume "The Old Stone Age" (Bordes 1968) and became enthralled with prehistory, especially stone tool manufacture and fracture analysis. In a small Manhattan apartment he used a toothbrush handle to pressure flake industrial glass which he procured by following fire trucks to burned-out storefronts. The strength of this fascination led him to Don Crabtree's flintworking field school in 1973 and the Idaho workshops addressing the intricacies of knapping technologies became invaluable experiences. He enrolled once again at NYU but this time in the Department of Anthropology. Are received his MA in Anthropology in 1974, completed all of the required course work and exams for a Doctoral degree but in the end did not complete his dissertation for sheer lack of available time. Over the span of decades after, Are would relate lessons he had learned and impressive feats of knapping skill performed by his renowned early mentor to both his fellow knappers and beginners alike. The anecdotes of his observations and experiences as a student of Don Crabtree provided unique first-hand insights into the master's teaching style and skill; Crabtree encouraged Are toward presenting, recommending him for demonstrations and lectures. Later in life he would reference his ongoing studies relating fractography to flintknapping as an outgrowth of this period, a response to Crabtree's suggestion that he pursue the finer points of a shared curiosity. When he published his 2010 paper titled "Popouts and Related Fractures" (Tsirk 2010), his concluding acknowledgements began by stating "This article is a belated response to the inquiries by Don Crabtree, in 1973, and Jaques Tixier, in 1975, on popouts. I am grateful to them for the stimulating inquiries. For any merits of the study, they deserve the credit."

Another trusted mentor was Ralph Solecki, most widely known for his illuminating Mousterian excavations at Shanidar Cave in Iraq between 1957 and 1961. Reflecting on Are's analytical insights, he commented that due to circumstances of timing, "Are did not participate in my local or Near East work – although I do regret that I did not meet him sooner. He would have been a tremendous asset to our investigations." (personal correspondence with Ralph Solecki in 2015). Ralph and his wife Rose Solecki maintained an abiding friendship with Are throughout the remainder of his life.

Are's passion for stone tools was boundless as was his enthusiasm and persistent analysis of fractures and fracture markings. His advanced education in engineering and anthropology, formal training and experience in archaeology, and a legacy of extensive knapping provided a strong background particularly outfitting him for his unique research. This is reflected in his numerous publications on fracture mechanics, fractography, and lithic technology, and his membership in both the Society of American Archaeology (until 2011) and the Society of Primitive Technology (until 2013), as well as being a Fellow of The American Society of Civil Engineers. In his capacity as a civil engineer, Are formed an independent engineering and consultant firm. Among his efforts in design and research his tasks included:

- Development of methodologies, design and testing of missile silos for blast effects;
- Investigation of failure and distress of structures, including brittle fractures;
- Research on seismic isolation and vibration of structures; and
- Teaching graduate courses on structural analysis and design of structures, including structural dynamics, seismic effects and finite element methods. He held positions as an Associate of Weidlinger Associates, Associate Professor at the New Jersey Institute of Technology, and was the Principle Research Engineer for the Metropolitan Transportation Authority of New York.

In reference to his professional activities related to lithics he was a fractography consultant, with reports given to A. Steffen, W. Parry, P. Kelterborn, E. Callahan, J. Pelegrin, J. Tixier and others. In the 1970s he participated in over fifteen archaeological excavations, and analysis of the J. R. Coates collection of over 12,000 lithic specimens at the Heye Foundation. He was also a long-term consultant with V. D. Frechette, S. W. Freiman and H. G. Richter on fractures. His contributions drew from a unique professional perspective which evolved from a personal interest in flintknapping; through the course of over forty years of practice he offered demonstrations at:

• Archaeological Societies of New York, Illinois and Maine;

• Montclair State University of NJ in association with Peter Siegel, and many other local universities including NYU, Hunter College, Adelphi University, and The New School;

• The nationally and historically significant Estonian University of Tartu, and two additional universities in Estonia, the University of Science and Technology and the University of Archaeology and Anthropology , both in his native Tallinn;

• Grimes Graves Flint Mine, Brandon, UK with John Lord (1980);

• First International Conference on Fractography of Glasses and Ceramics, and Alfred University (1986); and

He also taught flintknapping at the University of Maine (1974), University of Tartu (2004 and 2010) and Montclair State University (2011). A sample of his teaching method may be discerned in his lecture notes from the 1997 presentations at Tartu University in Estonia titled "On Flintknapping" (Tsirk 1997). It is reasonably sequenced and well organized, covering topics introducing the subject, the history of knapping, knapping studies, raw materials, knapping tools, basic techniques and principles. From this substantial foundation he proceeds next to introduce fractography, followed by an exploration of how this science relates to knapping. There is a sprinkling of mathematic equations, and many microphotographs and drawings illustrating the finer details of his discussions, providing a clear and cohesive entry of the topic to his larger subject. He concludes with explanations of the process of learning to knap, followed by a couple of appendices which include an extensive recommended reading list. Are identified the study of fractography as an obvious component of flintknapping as clearly as he saw fracture markings on blades and flakes, and this is reflected in the unified manner of presentation offered to his university students in Tartu. The material is uniformly rich and at times references the empirical evidence borne of his research and experimentation, as well as ample in-class material samples and knapping demonstrations.

The relationship he saw between fractography and knapped stone offered an analytic tool of potential utility. In his Tartu lecture notes he observed that "To make use of mechanics in flintknapping, the key is to recognize what these elements are and what the field of mechanics can do…. Application of mechanics can pose questions and point to relevant data not apparent otherwise." (Tsirk 1997). To the flintknapper and lithic analyst, the vision of fractured stone Are described illuminates the nature of instantaneous force delivery. Flakes, blades, and cores disclose finely detailed information through subtle yet distinct markings which give the passage of energy a permanently identifiable character.

He perceived merit in the ability of fracture markings to identify force direction, fracture velocity, core to blade geometry, artifact breakage (whether during manufacture or after, from usage or post-depositional accident), and more. An assessment of such features could provide a more precise means of analysis and additional depth to functional studies. From obsidian flakes and blades he examined microscopic evidence of liquid-induced fracture, and experimented flaking with water, saliva, blood, and honey to verify the characteristic markings associated with liquid media of varied viscosities (even knapping with both pressure and percussion underwater). These experiments suggested that "a significantly smaller force" is required to promote fracture when the stone is wet, a factor pertinent to enhancing control within the variable dynamics of flintknapping (Tsirk 1997). Although he had notions of how his applications could avail interpretive tools to lithic analysis he invited others to engage them for their own research questions and hypotheses.

Professor George D. Quinn is a specialist in ceramic materials, an engineer, fractographer and material scientist; nearly all of his work has been with modern high tech ceramics and glasses. He is also the author of the book "NIST Recommended Practice Guide: Fractography of Ceramics and Glasses" (2006), and a researcher at the National Institute of Standards and Technology, Gaithersburg, MD. On the topic of Are's contributions, he has offered the following thoughts:

> *Are helped bridge the high tech ceramics and lithic communities. Many researchers in the high tech ceramics and glass field were unaware of the insightful work on lithics that could be applied to modern materials. As a result of Are's suggestions, over the years we invited some well-known lithics fractographers such as Terry Engelder, Brian Kulander, and Otto Muller, to participate in the quadrennial Fractography of Ceramics and Glasses conference series organized by Alfred University. This culminated at the end of the July 2006 conference, when Professor Engelder led a memorable and inspirational field trip of the Devonian Catskill Delta Complex in the vicinity of Corning, Watkins Glen, and Ithaca, New York. Note [the] photo. The bridge shows Are next to Engelder, who unfortunately has his back to the camera.*
>
> *The bridge is an apt metaphor here. Engelder and Tsirk were bridging the high technology ceramics and lithics communities. Are contributed to these conferences with some fascinating presentations on liquid induced fracture markings. Are's book will reinforce this bridge and be a valuable aid in the future to both the lithic and engineering ceramic communities.*
>
> *Are's enthusiasm was on display when he brought some of his collection to these conferences and put on live knapping demonstrations for the attendees. These were not only entertaining, but very informative.*
>
> *As an example of Are's influence on the high tech ceramic community, he alerted us to prior lithic research on* 'edge chipping' *methodologies and analyses. Edge chipping is a common problem with engineered ceramic component fractures. Edge chipping is also a leading cause for ceramic and composite dental restoration (bridges and crowns) fractures. Test methods and analyses are being devised by the engineering and dental communities to evaluate a material's chipping resistance. Are pointed us to the wealth of experience and prior art in the lithic community that provided great insights to workers studying other materials.*
>
> *I am in the process of preparing the second edition of my book "Fractography of Ceramics and Glasses", and it shall include some important scarp, wake hackle, and gull wing images that Are kindly furnished to the author. I am grateful for his enthusiasm and help to our field.*
>
> *George Quinn*
> *NIST*
> *(Personal correspondence with George Quinn in 2015)*

Figure 1. Are Tsirk and Terry Engelder in 2006 at the Devonian Catskill Delta Complex in the vicinity of Corning, Watkins Glen, and Ithaca, New York. (Photo by George Quinn.)

Beyond the discipline of research, his familiarity with fracture markings in stone exceeded the limits of the microscope, commenting in his 1997 Tartu lecture notes that, "… markings, especially the finer ones, depend on grain size. Some markings not seen on a small chert flake may be observed on cliffs of even coarser sandstone, for example." (Tsirk 1997).

Any biography is a terse summary of an expansive life studded with notable achievements and distinctive qualities necessarily selected from outstanding characteristics, often at the expense of those which best exemplify the subject's individuality and vitality. Are Tsirk's influence and legacy are tantamount to the significance of his work as a scholar and teacher. His enthusiasm and passion was embedded among his greatest contributions, an ability to cultivate growth. He was eminently approachable and amiably expressed himself with a sense of humor and wit. At gatherings, events, and flintknapping convocations he would often be seen working on square-section axes, punching blades from a core or simply bifacing, always welcoming inquiries with simple honesty and a desire to share. He was widely recognized among his friends and those whom he influenced in the lithic community as a kindred flintknapper and rock chaser.

During his last several years, he decided that over four decades of flintknapping and research needed to be distilled into a presentable summary of his findings and observations. This included a re-examination of many thousands of fracture samples which he had knapped and curated, a daunting task in itself. The resulting text representing his life's work was published by Archaeopress Ltd. in Oxford in 2014, and titled "Fractures in Knapping" (Tsirk 2014). In referring to this final work, Ralph Solecki has remarked, "I believe the book Are wrote is the best authoritative writing on the subject." (personal correspondence with Ralph Solecki in 2015). And long-time consultant and colleague in lithic pursuits Scott Silsby considers that, "in the history of flintknapping Are is likely the first and only person to have achieved a commanding expertise in the craft while also mastering the principles of modern engineering. As a polymath he grasped the knapper's practice of causing and controlling fractures in stone, while his study of fractography, a discipline of studying failures in similar materials, derived from both processes. Are's book documents a convergence of the intuitive and empirical where lithic studies engage fracture mechanics. Without doubt, it will become a required text in institutions of advanced learning as it embodies the highest order of understanding exploring the relation between these subjects. The glossary he wrote codifies a scientific language of concise terms which render accessible a unified dialog between the lithic community and fractographers to facilitate a precise, mutually beneficial exchange. This contribution holds promise for the on-going study of these disciplines and represents just a fraction of his legacy." (Personal communications with Scott Silsby in 2015).

Figure 2. Are punching blades (left) and bifacing (right) in 2007 at the Experimental Archaeology Weekend, Washington's Crossing State Park, NJ, USA. (Photos by Jack Rabin.)

It was not long after he received the first copy of his book, with great satisfaction, that he died after a valiant struggle with cancer, at home with his wife Epp in Upper Montclair NJ, USA on February 17, 2015. Are Tsirk leaves behind very many whom he inspired, educated, and motivated through his erudition, companionship, kindness and generosity. His distinguished bearing and sense of dignity were complemented by his genuine humility and authenticity.

Figure 3. A sampling of Are’s square-section axe work. (Photo by Jack Cresson.)

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Biography of Jack Holland (1926-2014): Chert expert

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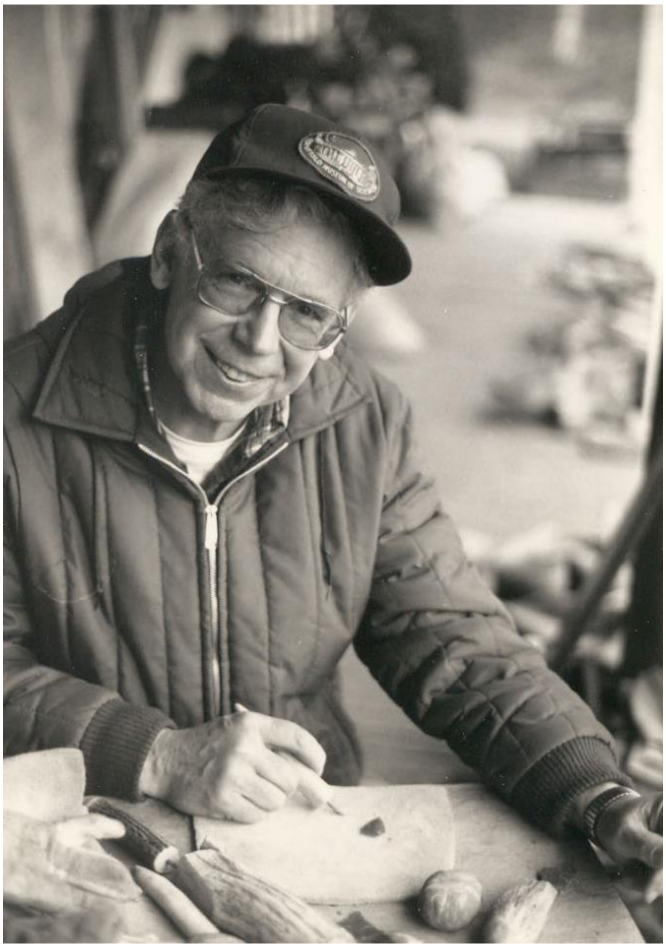

John (Jack) Davies Holland: July 10, 1926 – December 16, 2014.

Jack was born and grew up in Lock Haven Pennsylvania, the son of William G. Holland and Florence (Davies) Holland. He had an older brother, William and a younger brother, Donald. Jack spent much of his boyhood roaming the surrounding flood plains of the West Branch of the Susquehanna River looking for arrowheads. As Jack recalled, his parents gave him a great deal of freedom, just asking that he be home in time for dinner. Dr. T. B. Stewart,

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a Lock Haven dentist, encouraged Jack's early archaeological interest, helping him to identify specimens. Dr. Stewart had an extensive archaeological collection and had worked with Donald Cadzow, Pennsylvania's State Archaeologist (1929-1939). Dr. Stewart was also one of the founders of the Society for Pennsylvania Archaeology, an organization with which Jack would later become involved and that bestowed their J. Alden Mason Award on him as a professional who encouraged society members in the "proper pursuit of archaeology."

Figure 1. Jack Holland. (Photo by Jack Holland.)

Jack was an athlete in high school, participating in wrestling, track, and serving as captain of the Lock Haven football team. He met his future wife, Louise, in high school and they married in the summer of 1944 after graduating from high school. On July 29, 2014 they celebrated their 70th anniversary. Also in 1944 Jack turned 18 and was called up for the draft but failed the eye exam. With World War II continuing, Jack hitchhiked to Philadelphia where he joined the Merchant Marine, only to have an old football injury to the cartilage in his leg cause him to be discharged. However, due to a shortage of manpower, physical standards were lowered and Jack volunteered for the Army Air Corp in which he served for a year and a half as an electrical engineer.

Following World War II, Jack was hired as an electronics technician, first at Sylvania and then American Aniline, both in Lock Haven. During this time he took electrical industrial correspondence courses from Pennsylvania State University. In 1953 he went to work at the Ford Stamping Plant south of Buffalo, New York, working there for 32 years. At Ford he honed his analytic skills in fixing malfunctions in the huge electrical control panels. As he recalled, he also practiced what might be called social engineering, quietly approaching someone who might have sabotaged production to take a break by saying something like: "Why don't you flip that switch to see if that will start things up again." He also recalled being supportive of minority workers when they were hired. This supportive, non-confrontational manner was to characterize his later involvement in the archaeological community.

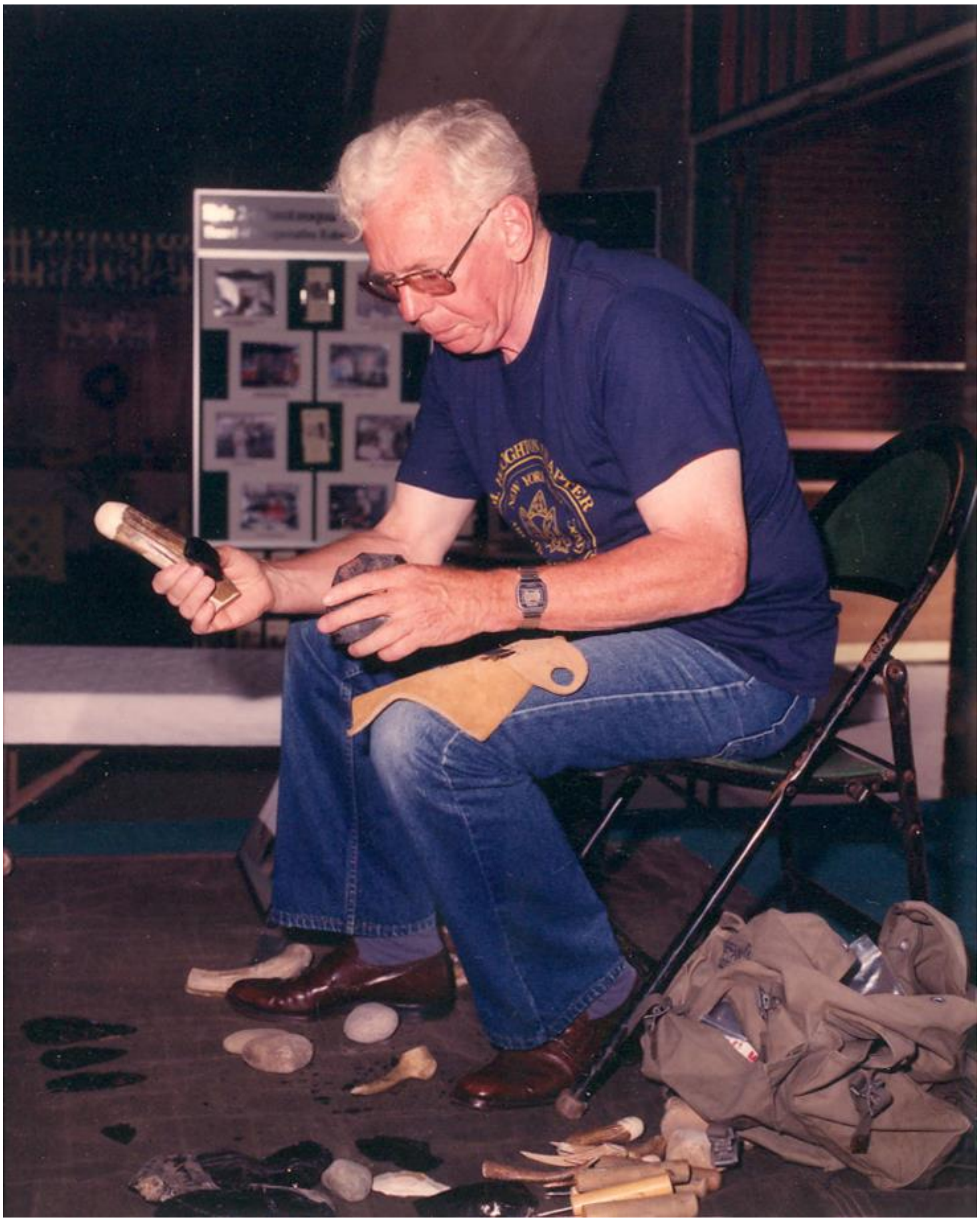

Figure 2. Jack Holland demonstrating knapping techniques. (Photo by Jack Holland.)

Jack became active in archaeology again in 1958 when Dr. Marian White, then associated with the Buffalo Museum of Science, began salvage excavations on the Kleis site in Hamburg, NY, located not far from his home in West Seneca. He volunteered on this and a number of subsequent projects with Marian White. When the Houghton Chapter (Buffalo Chapter) of the New York State Archaeological Association was established in 1961 by Marian White, Jack became one of the founding members.

In 1964 his archaeological volunteer work was put on hold when he took up black powder shooting with his son, winning numerous first place national championship awards and learning about gunflints and rifle parts in the process. Then in the early 1980's while still working at the Ford Stamping Plant, Jack entered Empire State College's individualized degree program in which students meet one on one with an instructor, having mutually agreed on a specific topic of study. The senior author was privileged to work with Jack on a number of contracts, but Jack was to soon surpass his instructor when it came to the study of stone tools. While a student at Empire State, Jack took a flint knapping course from D.C. Waldorf, followed by a course in stone tool manufacture from Frank Cowan at the Center for American Archaeology at Kampsville, Illinois. He then attended Errett Callahan's class in knapping at Glass Buttes, Oregon. On his own he devised a use wear experiment using 25 different types of chert, each type being used for the same duration for the same tasks. Presentation of the results garnered a state-wide award from Empire State College, from which he graduated in the summer of 1985, having retired from Ford that spring.

Figure 3. Jack Holland demonstrating a stone drill. (Photo by Jack Holland.)

Starting in 1982, Jack began volunteering on archaeological projects with Dr. Mike Gramly, then at the Buffalo Museum of Science. He worked at the Potts site in New York, in Dover Tennessee, and at Fort Laurens in Ohio among many others. His skill at playing the harmonica around an evening campfire was always welcome and Jack made many friends both in the field and at archaeological meetings. Jack helped organize the first knapp-in at the Buffalo Museum of Science, bringing together D.C. Waldorf, Bruce Bradley, and Gene Titmus. The popularity of this event grew over the next few years and eventually it moved to Letchworth State Park where it is still held annually, generally the last weekend in August.

With Jack's increased involvement in archaeology and interest in lithic sources came his realization that most archaeologists did not know the sources of the lithic material found on their sites. Furthermore, there was no major repository of lithic material in North America where one could compare a lithic specimen to known sources. When Jack visited the few institutions said to have lithic study collections, what he generally found were small, regional collections or collections of stone tools that were said to be made of specific cherts. If raw material had been collected from the source, the range of variability in the material was rarely represented. Jack decided that a comprehensive North American comparative lithic collection was needed. Thus he embarked on his second career: chert chaser.

Jack would visit the geologic outcrop, taking multiple samples from different accessible areas, recording the location of the specimens collected. This activity took him to all 50 states and he amassed over 22,000 samples representing more than 1,500 named lithic types from the United States and Canada. Early on, Kevin Smith, then at the Buffalo Museum of Science, saw the value of these efforts. Through Kevin Smith's efforts, the collection was housed in the Holland Lithic Laboratory of the Buffalo Museum of Science and Jack became a Research Fellow of the Museum. Jack assisted many archaeologists in the identification of the probable source of the samples they brought or sent to the Lithic Lab. In doing so, he relied on his encyclopaedic memory to check samples against those in the collection. Jack generally did this for no charge, happy to share his knowledge. He also loaned or gave samples to both contract firms and academic departments for their use in sourcing materials. He also assisted many individuals (including the senior author) and CRM firms with lithic analysis.

As part of his research, Jack started systematically going through the geological and archaeological literature for selected regions and found terminological chaos. Archaeologists and geologists frequently used different terms for the same source and some outcrops had multiple names. Jack therefore started a reference bibliography with folders for every lithic source. Over the years, Jack began to produce a number of highly useful reference works for different states, listing the lithic sources for each state along with the alternative names for each source and the bibliographic references for that source. Some of this information remains unpublished, but is preserved in folders associated with the lithic collection.

The importance of Jack's work was recognized by awards from the Society for Pennsylvania Archaeology and the New York State Archaeological Association. In 2001 he received the Crabtree Award from the Society for American Archaeology and in 2008 he was named a Pioneer of Science by the Hauptman-Woodward Institute of Buffalo, the latter honour resulting in a large photograph of Jack being hung in the Buffalo-Niagara International Airport for a year. During the last five years of his life, declining health prevented Jack from continuing his research, though he regularly attended meetings of the Houghton Chapter of the New York State Archaeological Association. In the last year of his life he got rides from his nursing home to go to meetings. Through the efforts of Dennis Stanford, the Holland Lithic Collection and associated documentation was transferred to the Smithsonian Institution where it will serve as a lasting legacy of Jack Holland's contribution to archaeology and geology.

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Book reviews

Book review: From the Yenisei to the Yukon: Interpreting Lithic Assemblage Variability in Late Pleistocene/Early Holocene Beringia

Jennifer Anderson

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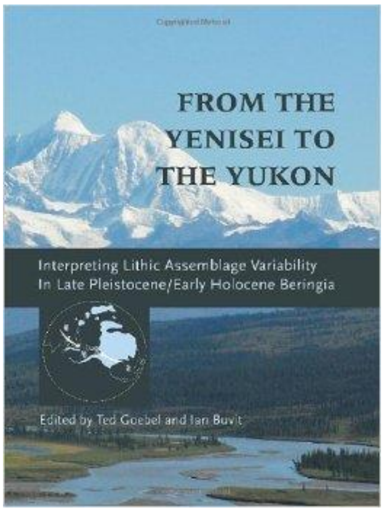

From the Yenisei to the Yukon: Interpreting Lithic Assemblage Variability in Late Pleistocene/Early Holocene Beringia
Edited by Ted Goebel and Ian Buvit
Texas A&M University Press, 2011, pp. 394. ISBN 978-1-60344-321-0
http://www.tamupress.com/product/From-the-Yenisei-to-the-Yukon,6578.aspx

This volume represents the outcome of the "Explaining Lithic Assemblage Variability across Beringia" symposium, held at the 73rd Annual Meeting of the Society for American Archaeology. This symposium was a follow-up to a workshop held at the Centre for the Study of the First Americans, Texas A&M University, in which researchers discussed the current state of knowledge surrounding the Pleistocene peopling of Beringia and acknowledged the need for future research methods to focus on interdisciplinary, multinational approaches. The twenty-one chapters in this volume directly reflect this endeavour, showcasing a diverse array of research that analyses lithic assemblage variability in late Pleistocene Beringia. Though

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individual chapters focus on questions pertaining to specific regions or assemblages in Beringia, collectively they address a conundrum that all lithic analysts face, that of understanding what variability within a given lithic assemblage represents.

In the introduction, the editors provide the reader with the historical framework for the development of the major, heretofore-disparate Beringian lithic technocomplexes. Chapter 2 Graf examines the coeval Afontova and Kokorevo technocomplexes of western Beringia, finding that the variability between the two was not sufficient to consider the two complexes distinct. In Chapter 4, two coeval microblade core reduction sequences were identified in the Lower Vitim Valley of Siberia. The first resembled the Upper Palaeolithic Yubetsu (Diuktai) tradition, given the presence of both wedge-shaped cores and prepared bifaces, while the second resembled the early Holocene Sumnagin tradition with prismatic cores. In Chapter 5, experimental pressure flaking data was compared to pressure flake debitage from Diuktai Cave to determine the type(s) of pressure flaking being used at the site.

Chapters 3 and 16 examine settlement mobility in Beringia. Buvit and Terry examined evidence for increased settlement mobility during the Last Glacial Maximum (LGM) by using the abundance of local raw materials in a given assemblage as a proxy for sedentism. They conclude that due to increased usage of non-local raw materials from the Middle Upper Palaeolithic to the Late Upper Palaeolithic (despite consistent access to locally abundant materials), mobility did seem to increase during the LGM. In Alaska, Reuther et al. determined that the earliest populations were exploiting local obsidian sources. This exploitation continued into the Holocene, when obsidian from these two sources was found in distant assemblages. Chapters 6, 7, and 10 examine the complex migration patterns of several lithic technocomplexes across northeast Asia and western Alaska. Wedge-shaped microblade cores, associated with the Diuktai culture, emerged from western Siberia. Although it has been assumed that these microblade traditions migrated into Alaska, no wedge-shaped microblade cores have yet been recovered from northeast Asia. In Chapter 10, however, Holmes cites the production and reduction of microblade cores by use of the Yubetsu technique at Swan Point as the best evidence for a trans-Beringian “land bridge” migration. This Diuktai-like microblade technology in Alaska became known as the Denali complex.

According to Ackerman (Chapter 15), Denali hunters used microblades as lateral insets for arrowheads in the earliest expression of a North American bow-and-arrow weapon system. In Chapters 8 and 13, analyses of land use show that microblade tools are most often associated with cold weather hunting. One possible reason for this could be that microblades emerged during harsh conditions of the LGM and re-emerged during subsequent cold climatic oscillations, indicating that microblade composite technology was better suited to handle cold weather conditions than brittle bifacial projectiles (Chapter 14).

The Nenana complex (Chapter 12) was a non-microblade lithic tradition that coexisted with the Denali complex in Alaska. Nenana toolkits contained teardrop-shaped Chindadn projectile points, resembling interior North American lithic traditions more so than Asian ones. Similarly, Hoffecker associated the Mesa complex of eastern Beringia (Chapter 9), which contained lanceolate projectile points and was associated with bison hunting, with lithic traditions of the North American Plains. Chapters 17, 18, and 19 examine the expansion of the Denali and Chindadn/Nenana complexes into western Canada.

The remaining chapters offer thought-provoking syntheses by Dumond and Dixon. Dumond’s slightly contrarian (his words) synthesis is a breath of fresh air for those of us who remain unconvinced of the first American’s Asian progenitor. He points out the tenuous connections between Nenana and Clovis cultures and their Asian antecedents. Dixon’s synthesis acknowledges the many difficulties in first identifying, then analysing and interpreting, lithic assemblage variability. His parting words remind us all that although these analyses seem arduous, progress is never hopeless. Certainly this volume attests to that.

Book review: Clovis Lithic Technology: Investigation of a Stratified Workshop at the Gault Site, Texas

John Edward Dockall

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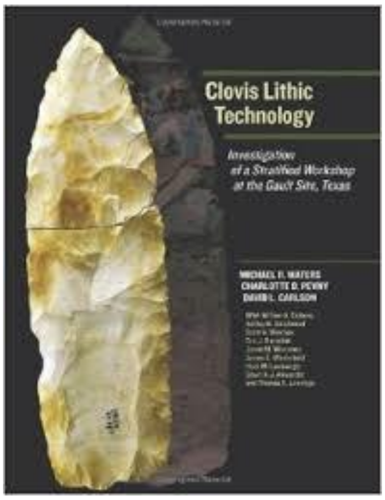

Clovis Lithic Technology: Investigation of a Stratified Workshop at the Gault Site, Texas
by Michael R. Waters, Charlotte D. Pevny and David L. Carlson
Texas A&M University Press, 2011, pp. 226, pl. 99. ISBN 978-1-60344-278-7
http://www.tamupress.com/product/Clovis-Lithic-Technology,6711.aspx

Clovis Lithic Technology presents a detailed technological, typological, and spatial analysis and interpretation of the Clovis lithic assemblage from the Gault Site in central Texas. The Gault site itself is a *sine qua non* of Clovis sites and represents one of the few of such locales that can be identified as a workshop associated with this industry. The technical descriptions, published data, and interpretive detail of this volume make it a welcome addition to the growing body of new technological information on Clovis in general.

The book is organized into ten chapters based on the results of several Master's theses and Doctoral dissertations devoted aspects of the Gault Site lithic assemblage. Chapters 1 and 2 provide introductory background placing the Gault Site into temporal and regional perspective among other Clovis sites in North America. Included are discussions of site stratigraphy, chronology and site formation processes. Site formation processes at Gault have

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become increasingly important in light of more recent research on the pre-Clovis deposits at the site. Chapter 3 clarifies identification of the raw material and discussion of the organization of the blade and biface portions of the lithic technology at Gault. Chapter 4 is devoted to description and discussion of the blade technology. Included are detailed technological descriptions of blade cores, core tablets, crested blades, and cortical and non-cortical blades. Blade attributes are also compared to known Clovis blade cache assemblages such as Pavo Real and Anadarko but also to blades found elsewhere at Gault beyond the workshop deposits in Excavation Area 8. While blades from the workshop deposits bear little resemblance to the cache blades, those from Gault outside the workshop deposits bear striking technology and quality similarities to cache blades from Pavo Real and Anadarko. Chapter 5 details the technology and typology of bifaces found at the Gault Site. Most welcome in this chapter is a good technical discussion of biface production debitage and the importance of overshot techniques in shaping and thinning Clovis bifaces. As with blades, finished and complete bifaces from Gault are evaluated by comparison to known Clovis biface caches like Hogeye and de Graffenried locales. This chapter is also enlightening in its contributions to understanding Clovis point manufacturing trajectories. Chapter 6 is a welcome explanation of the typological and technological character of Clovis endscrapers and other edge-modified tools from Gault. It demonstrates the range of other activities that were also conducted at the site in support of the workshop tasks. Types of edge modified flakes include convex-end unifaces with lateral spurs on either side of the bit and some with hafting notches. Discussion of this part of the Clovis assemblage provides some useful insight into aspects of the technology seldom seen from other sites that have greater numbers of points and fewer other types of tools. Chapter 7 is a complementary to Chapters 4-7 and is devoted to detailed microscopic use wear analysis results of a suite of selected implements that include projectile points, bifaces, a knife, chopper, endscrapers, blades and blade fragments, and modified and unmodified flakes. Results indicate that most tool use was of limited duration. Use wear attributes such as polish and striations are not well represented. Chapter 8 is devoted to the analysis and interpretation of recovered faunal remains from Clovis deposits at Gault. The suite of identified species include horse, bison, deer, rabbits, canids, and a number of other smaller mammals and small, medium and large birds, and turtle. Preservation was noted to be extremely poor (with high fragmentation) and thus results were limited. Spatial organization of workshop activities is presented in Chapter 9. Employing typological and technological results from previous chapters, this chapter applies artifact spatial patterning around features in Units 3a and 3b to discuss feature-related tasks and discard behavior. Results suggest significant differences between these two units, perhaps related to different tasks and different patterns of artifact and faunal discard. It also hints at the presence of some type of activity area on the northern end of the excavation block. Chapter 10 is the summary and synthesis of the preceding chapters. Patterns of tool use, tool manufacture and discard at Excavation Area 8 and how the deposits are interpreted as workshop debris associated with a larger residential base camp are clear. Gault is unique in several aspects. There is no extinct Pleistocene megafauna, the lithic assemblage is almost entirely Edwards chert rather than a mix of exotic raw materials, and the entire manufacture, use, and discard sequence is present.

Clovis Lithic Technology is a welcome addition to the literature on Paleo-Indian technology. The volume is clearly written and well-organized. Metric, technological and typological data are presented for the entire assemblage. The technical interpretations for blade and biface manufacture are sound and based on a thorough study of the Gault lithic assemblage. Typological and functional discussions of the edge modified tools add to the overall value of the monograph as a research tool. While there is not a lot of direct comparison to assemblages from other Clovis sites in North America, the information is presented to assist the reader in that regard.

Book review: Contemporary Lithic Analysis in the Southeast: Problems, Solutions, and Interpretations

John Edward Dockall

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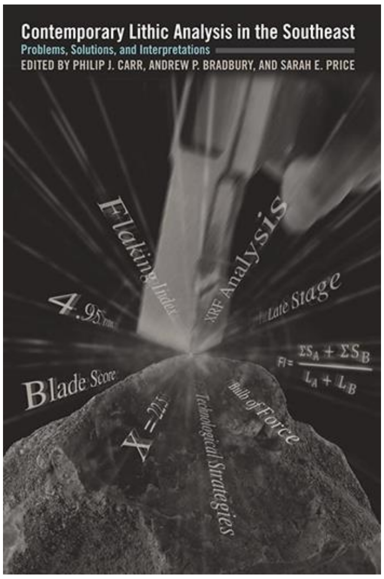

Contemporary Lithic Analysis in the Southeast: Problems, Solutions, and Interpretations
Edited by Philip J. Carr, Andrew P. Bradbury, and Sara E. Price
The University of Alabama Press, Tuscaloosa. 2012, pp. 253. ISBN 978-0-8173-5699-6
http://www.uapress.ua.edu/product/Contemporary-Lithic-Analysis-in-the-Southeast,5318.aspx

This volume represents the outgrowth of practical and theoretical research in lithic analysis in the southeastern United States. Although the papers are regionally specific, the examples and methods used provide ample reason for lithic analysts and interested archaeologists in any region to acquire a copy. The text is organized into thirteen chapters on topics of the individual author's choosing with the caveat that all papers relate to lithic research and analysis in the greater southeastern United States. The editors placed no theoretical or methodological constraints upon the contributors. Each paper follows an organization of technology approach in method and interpretation.

The editors provide the reader with a less-than-favorable critique of the then current state of affairs in stone tool research in the Southeast. Carr, Bradbury, and Price noted a

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decades long lack of concern for theoretical innovation, integration of data, and methodological advances in the region concerning stone tool research. They then provide an excellent discussion of the organization of technology approach. Organization of technology incorporates the entire sequence of procurement, manufacture, use, reuse, and discard of stone tools and places these behaviors within the greater contexts of environment, social and economic strategies and cultural choices. The overall approach and concept of organization of technology is similar to the *chaîne opératoire* concept applied commonly by lithic analysts in European countries (see Soressi & Geneste 2011). The editors note a significant lack of meaningful data among lithic studies in the Southeast.

The editors identify two themes among the selected papers: classification bias and organization of technology. Papers on recovery and classification bias include those by Price, Sain and Goodyear, Pevny, Potts, and Edmonds. Price and Edmonds address recovery bias and interpretive difficulties in terms of screen size used during fieldwork. Pevny addresses artifact and assemblage-level taphonomic bias at the Gault site. Bradbury and Carr examine the differences of inter-observer differences in the identification of blades and bipolar cores and flakes. Sain and Goodyear develop and discuss a measurement technique to distinguish between true blades and blade-like flakes and how different Clovis blade making was in the Southeast compared to the Southwest and elsewhere. Finally, Potts considers classification errors resulting from differences in raw material such as low-quality quartz and better qualities of chert and noted that classification errors were higher among low quality raw materials.

For the second theme of organization of technology, authors relate technological observations and analytical techniques to interpretations of stone tool-related behaviors, raw material provisioning or aspects of tool manufacture. Miller and Smallwood develop a biface-thinning index for analysis of bifaces from Clovis contexts at the Topper site and determine that discrete stages of biface manufacture are difficult to isolate. They argue for a continuum approach to biface manufacture and identified discrete areas of the site where certain parts of the continuum of biface manufacture occurred. Authors Cooper and Thacker (and co-authors) examine the influences of mobility and settlement on raw material procurement, use, and provisioning among Archaic lithic assemblages. They noted that mobility differences among groups and raw material procurement strategies directly influenced the lithic technology. Franklin (and co-authors) provide a useful application of the organization of technology approach to the assemblage from Eagle Drink Bluff shelter in Tennessee. The authors employ both the organization of technology and the *chaîne opératoire* concept..

The final chapters are authored by William Andrefsky, Jr, and George H. Odell. Each author place his own unique perspective upon the papers and place them into broader contexts for the Southeast and lithic studies as a viable research area. Andrefsky delves deeper into a comparison/contrast between the organization of technology approach and the *chaîne opératoire* concept that will be interesting for lithic analysts working on non-North American lithic assemblages. Odell's chapter provides a fitting end for the book as it was published after his death and is dedicated to his memory. Both authors remain optimistic regarding the future status of lithic analysis in the Southeast.

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Book review: The Emergence of Pressure Blade Making

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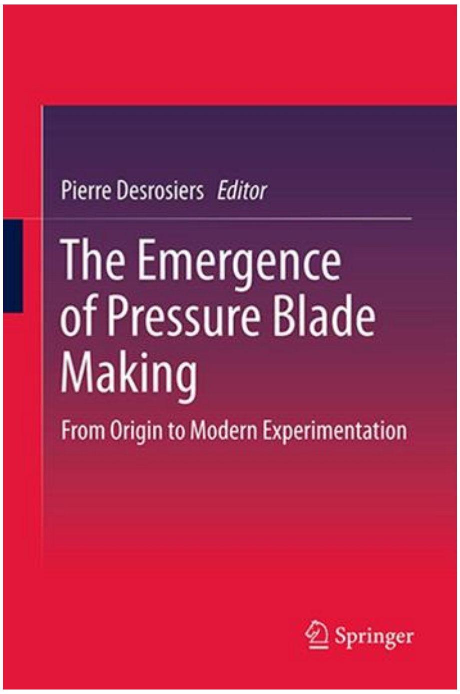

The Emergence of Pressure Blade Making - From Origin to Modern Experimentation
Edited by Pierre M. Desrosiers
Springer Publishing, 2012, pp. 536. ISBN 978-1-4614-2003-3
http://www.springer.com/social+sciences/anthropology+%26+archaeology/book/978-1-4614-2002-6

This ambitious volume represents the outcome of a session held in honour of two key figures in the study of pressure blade manufacture, Jacques Tixier and Marie-Louise Inizan, on pressure blade production at the 2006 congress of the International Union of Prehistoric and Protohistoric Sciences (IUPPS) held in Lisbon, Portugal. This nineteen chapter publication is a synthesis of this session focussing on the invention, diffusion and the adoption (or reinvention) of pressure blade making throughout the Old and New Worlds. This volume can be divided into three main parts.

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An introductory chapter by Pierre Desrosiers is followed by two chapters that focus on the historical framework of pressure blade manufacture. Marie-Louise Inizan starts her chapter by highlighting the quintessential research by Jacques Tixier into pressure *débitage,* with respect to his work in the Epipalaeolithic of the Maghreb, and the importance of the 1964 Lithic Technology Symposium of Les Eyzies. Following this Inizan stresses the role pressure *débitage* has played in the identification of many prehistoric cultures (*e.g.*, the Japanese “microblade tradition”). This is then followed by an overview of Mesoamerican blade experiments from the earliest translations by Edward Tylor to much more recent work of Greg Nunn and James Winn. These chapters are excellent in communicating the history and the breadth of the subject, even including the lesser known experiments by Marc Hintzman and Andrei Tabarev, whilst providing non-specialists with a general introduction into the methods and techniques of pressure blade percussion.

The main body of the text, consisting of fourteen chapters, focusses on current issues and debates within the archaeological evidence for pressure blade production around the world, or more specifically where it has been identified (Asia, Europe, Africa and the Americas). Emphasis is placed on the origins of pressure flaking in Upper Palaeolithic contexts (Chapters 11, 12 and 15) until the terminal period of the Pleistocene (Chapters 4, 9 and 17). As Desrosiers stresses, most of the chapters were written by contributors who are not native English speakers, and as a result, present a unique opportunity for readers to access data and interpretations that are not typically available in the English language. These chapters are refreshing in the variety of methodological frameworks adopted to understand concepts such as local innovation and diffusion, and technological behaviour. The use of frameworks incorporating palaeoenvironmental (Chapter 4) culture-historic (Chapter 12), spatial (Chapter 10), and chronometric (Chapter 11) datasets and analyses, in addition to archaeological and experimental lithic analysis, provide a holistic approach that should be applauded.

The final two chapters focus on recent advances in the experimentation of pressure blade making. Jacques Pelegrin highlights, effectively, how experimental replication reference collections still remain essential to the identification of various elements of archaeological production including the varying scales of added pressure, platform preparation, the different sequences in blade production, and the transmission and development of these techniques. Pelegrin also successfully highlights how various “modes”, or methods of technological production are near impossible without *a posteriori* knowledge. This book closes with ongoing research and a progress report into "measurable flintknapping", *i.e.* the absolute repeatability and precision of flintknapping experiments through engineered detachment machines and lever systems, by Kelterborn. Kelterborn tackles through issues within measurable flintknapping such as torsion, fine tuning experiments, and fracture propagation. A great balance is achieved by credibly analysing variables through robust experimentation, whilst acknowledging that detachment machines do not (and should not) substitute knowledge and experience in traditional flintknapping. Typically inaccessible to readers, due to issues of terminology and research depth, Kelterborn finishes the edited volume by writing about experimentation in lever systems in a manner that is clear and accessible.

This volume would benefit from a more thorough discussion of why pressure blades were adopted. It is felt that whilst certain chapters attempt to tackle this issue, they feature a framework that is largely based on the economics of blade production, with less attention on more social and behavioural aspects of technological evolution and innovation. Overall, this volume should be commended for its successful and holistic effort in highlighting phenomena associated with pressure blade production through experimental, archaeological and historical investigations. This almost Herculean effort is clear, concise and marks a milestone in studies of blade technology. It is quintessential for anyone interested in studies of pressure blade production.

Book review: Das Pedras aos Homens: Tecnologia Lítica na Arqueologia Brasileira (From Stones to Men: Lithic Technology Studies in Brazilian Archaeology)

João Carlos Moreno de Sousa

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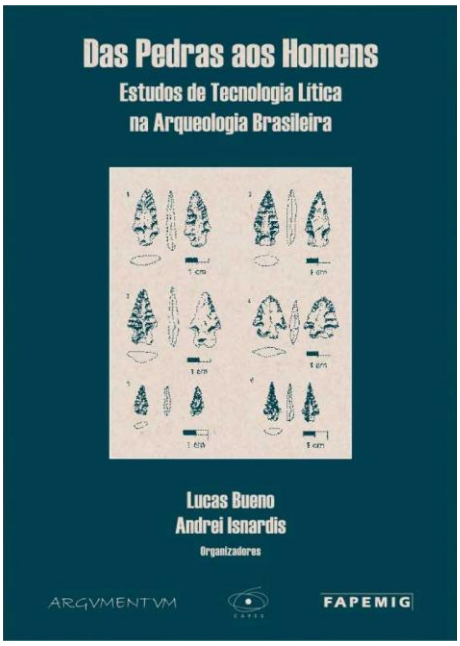

Das Pedras aos Homens: Estudos de Tecnologia Lítica na Arqueologia Brasileira
edited by Lucas Bueno and Andrei Isnardis
Argvmentvm, 2007, pp. 272. ISBN 978-85-98885-24-7
http://www.finotracoeditora.com.br/livros/IS1008/9788598885247/

The book is the result of a Brazilian symposium which took place in 2007, entitled *Lithic technology in Brazil. Theoretical foundations, problems and research perspectives.* The symposium brought together some of the most important lithic studies researchers in Brazil at the time. Each researcher wrote a chapter concerning the aims of the symposium.

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In the first chapter, Schmitz informs the readers about lithic studies related to the National Program of Archaeological Research (PRONAPA) that took place between the 1960's and 1970's, and how this pioneering research in Brazil helped our understanding, for the first time, of the Brazilian archaeological context by creating categories of lithic *traditions* and *phases*, even though that research didn't have a systematic formation.

Dias, in the second chapter, explains and describes an archaeological category created by PRONAPA researches named *Umbu Tradition* – supposedly, a lithic tradition of bifacial points that occupied southeastern and southern Brazil. Dias aimed to demonstrate, based on her lithic studies, that there is technological variability between *Umbu Tradition* sites, and that the *tradition* and *phases* concepts do not explain the relationship between artefact variability and cultural behaviour.

Bueno, using his study cases, presents a chapter about technological organization and Design Theory, regarding lithic industries strategies and performance features. Also on the organization subject, Hilbert presents us with an essay that treats the lithic industries as social organization vectors.

Mello presents an article about the technological approach to expedient industries studies, concerned with the general use of a typological approach in Brazilian lithic studies. Rodet & Alonso, in their chapter, express concern about the lack of homogeneity in Brazilian lithic studies terminology, and also explain the importance of the technological approach, at the same time the description of lithic remains should not only be about their forms and shapes.

Prous, in his chapter, tells us about the importance of experimentation in archaeological studies, pointing out the importance of having contact with the materials and situations which the research may deal with, so that the researcher will have practical knowledge of artefact production and use techniques.

Vilhena-Vialou, in her chapter, demonstrates lithic analysis methods for Pleistocene industries at Central Brazil. The author presents several South American Pleistocene sites and explains the lithic artefact variability at Central Brazilian sites of this same epoch.

Isnardis contributes a chapter regarding the "loneliness" of the lithic industries, aiming to explain that Brazilian archaeologists must highlight their lithic industries interpretations over their artefact categories.

Hoeltz turns her eyes to the South of Brazil presenting its PRONAPA archaeological *traditions*. The author, using case studies, aims to show that these old typological based approach concepts present weak interpretations when compared to interpretations based on technological analysis.

Finally, Shott, the only foreign author of the book, is concerned with the high French influence on technological studies in Brazil and aims to show Brazilian archaeologists advances in stone-tool reduction analysis in the Anglophone world. His chapter is important in the sense that it shows how different lithic studies "schools" have the same general goals, even though the applied methods are not exactly the same.

Even after eight years since this book was published, it is still a current reference in Brazilian archaeology, at the same time the presented questions are still being discussed, and will still be in discussed for some years from now. As well, this book presents some basic knowledge about lithic studies in a Brazilian archaeological context that will make it an excellent reference for new researchers. Unfortunately, only a few Brazilian lithic studies books have been published in recent decades. Considering this, and the excellent team of authors, *Das Pedras aos Homens (From Stones to Men)* is, for sure, one of the most important books for Brazilian archaeology of the last decade.

Book review: Lithic Materials and Paleolithic Societies

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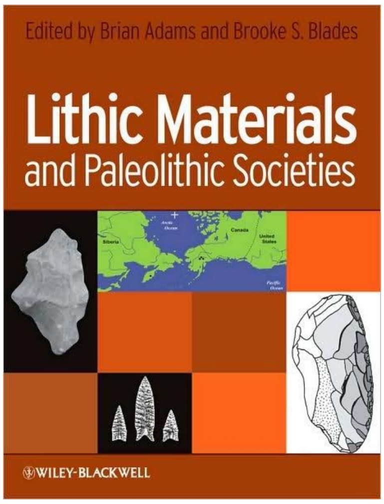

Lithic Materials and Paleolithic Societies
Edited by Brian Adams and Brooke S. Blades
Blackwell Publishing Ltd., 2009, pp. 304. ISBN 978-1-405-16837-3
Publisher's website: doi:10.1002/9781444311976

Lithic Materials and Paleolithic Societies is an edited volume of research papers that provides perspectives on the study of lithic technological organization from around the world. The book contains 20 chapters organized into four thematic sections focused on stone procurement, tool-stone use, the role of tool-stone subsistence and settlement systems, and the clues about social interaction that are gleaned from the study of lithic materials.

Chapter 1 examines decisions made by some of the earliest toolmakers regarding tool-stone procurement and use. Evidence suggests that the properties of high-quality knappable stone were being selected for as early as 2.3 million years ago. Chapter 2 provides a detailed overview of the variability of Middle Paleolithic provisioning and toolkit organization. Chapter 3 considers the implications of long-distance tool-stone transfers at Upper and Middle Paleolithic sites in Western Europe. The study recognizes differences between periods tied to socioeconomic conditions of the periods. Chapter 4 is a Central European case study regarding the advancements in tool-stone provenance studies with special emphasis on the

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value of cooperative research and data sharing. Chapter 5 compares microblade and non-microblade assemblages from sites in the Bering Sea region to examine the ways microblade assemblages reflect distinct behavioral patterns and planning, where non-microblade sites do not. Chapter 6 is an analysis of assemblages in Arnhem Land, Australia that identifies the factors which influence variation within assemblages. The study recognizes the assemblages as dynamic, rather than static components related to a single group and period. Variation is viewed as a result of decision making processes related to stone procurement, tasks, and the associated costs of alternative responses that are active many times at sites.

Chapter 7 is an investigation of Pleistocene hominin preferences and behavior associated with morphologically differentiated tool-stone types. The chapter identifies correlations between raw material characteristics, technology, adaptive strategy, and site selection. Chapter 8 presents an overview of research related to the Gravettian period in Hungary. The author demonstrates variability of tool-stone use within the period. Chapter 9 examines the differences between local and non-local tool-stone in three French Paleolithic assemblages as a function of blank portability and distance attrition. Chapter 10 explores the debitage associated with Paleoarchaic sites in the Great Basin of western North America to test the idea that biface reduction during the period is a product of a single reduction sequence approach during the period with stages of reduction distributed across multiple sites. Transport cost is viewed as a determining factor of reduction behavior.

Chapter 11 is a case study of a Lower Paleolithic site in Nambia. The analysis shows the site is a palimpsest of short, non-domestic reduction episodes. The author provides a discussion of the theoretical implications of this tool production pattern. Chapter 12 provides another case study; the chapter looks at a Lower and Middle Paleolithic quarry in Israel. The site provides an example from the periods that demonstrates the sophistication of intensive tool production and situational awareness reflected in land-use practices. Chapter 13 explores the relationship between tool-stone procurement and subsistence fauna at a Paleolithic rockshelter in France. The pattern of core reduction and faunal species represented is used to infer the nature of movement near the site. Chapter 14 examines the utilization of discrete raw material sources in the mountains of southern Poland during the Middle and Late Paleolithic. Much of the use of the material is associated with hunting activities but the artifacts of one level of the study site are noted to strongly suggest symbolic or ritual behavior. Chapter 15 examines the pattern of raw material use and core reduction strategies over time at an Upper Paleolithic site in France. The patterns reveal changes in the land-use pattern over time.

Chapter 16 is a detailed study of Acheulean bifaces from 10 sites on the Deccan Plateau of India. The analysis determined that tool making was learned by imitation, and two distinct tool types were made in anticipation of specific applications. Chapter 17 analyses the organization of Quina Mousterian lithic technology. The system is shown to be a highly flexible material package and core reduction system that reflects Neanderthal planning for specific needs. Chapter 18 reconsiders the notion that Szeletian assemblages are a product of interaction between Neanderthals and anatomically modern humans. The influence of raw material quality on the composition of lithic assemblages is explored. Chapter 19 examines the factors influencing tool retouch intensity at Paleolithic sites in the Transbaikal region of Siberia. Retouch and raw material selection are shown to be strongly correlated with tool function. Chapter 20 analyzes the patterns of lithic tool-stone procurement at Clovis and Dalton sites. The analysis demonstrates distinct differences in stone procurement between the two cultures indicating that Dalton is not a continuation of earlier Paleoindian lifeways.

Lithic Materials and Paleolithic Societies is a thought provoking collection of theory-driven research related to the lithic technological organization of early tool makers. The contributions from scholars around the world provide valuable diversity in the scales and perspectives of research. This volume is a worthwhile reference for lithic analysts.

Event reviews

Event review: Chipped stone tools workshops 2014, Skopje, Macedonia

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In February and March 2014, HAEMUS, the Center for Scientific Research and Promotion of Culture, organized public stone tools workshops. The workshops titled "The stories written in stone" were held at the Museum of the Old Bazaar in Skopje with the help of the Skopje City Museum. The workshops combined students from both the Department of Archaeology at Saints Cyril and Methodius University in Skopje and the Department of Archaeology at Goce Delčev University in Shtip and were hosted by prehistoric stone tools specialist Vasilka Dimitrovska.

The aim of this project was to educate archaeology students about stone tool analyses. Through a combination of presentations and lectures the workshops covered categories including petrological, technological, typological, use-were and statistical analyses, as well as the interpretation of the analytical results. Due to the comprehensive topics regarding lithic studies, only five students per session could attend the workshops. The lessons were comprised of the following topics:

Topic 1: Introduction to the world of prehistoric stone tools;

Topic 2: Basic principles and criteria for petrological, technological and morphological analysis of stone artefacts;

Topic 3: Basic principles and criteria for petrological, technological and morphological analysis of ground stone artefacts and abrasives tools;

Topic 4: Working with stone material and recognition of prehistoric tools from the archaeological site of Cocev Kamen, based on surface material collected by undergraduate students of archaeology.

The students found the most interesting topic to be typology of the stone tools. During the two field trips which were undertaken in 2013, undergraduate students of archaeology collected surface material in the vicinity of Cocev Kamen (Kratovo district). Cocev Kamen is an archaeological site dated from prehistory until the Mediaeval Ages and the abundance of the lithic material collected in the vicinity of the site allowed students to develop different approaches in identifying types of the stone tools. This approach was complemented with supplementary bibliographical as well as the video material.

The main prehistoric periods or 'ages' were named after the materials used to make artefacts which most identified that period. During the 'Stone Age' (or 'Lithic' Age) stone tools were very common. Although the analysis of stone tools cannot provide precise dating,

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it can shed light on the economic background of the culture. It can also provide a more comprehensive picture of the various characteristics of the stone industry at particular sites or regions, as well as its relationship with other related industries.

At present, the lack of Palaeolithic, Mesolithic and early Neolithic materials makes it hard to answer questions about the evolutionary trends of chipped stone artefacts in Macedonia. The small number of stone artefacts is primarily due to the lack of knowledge about the lithic materials, the absence of sieving and flotation, and the personal choices of the researchers as to which types of finds are to be kept.

These workshops complemented the academic program at both archaeology departments in Macedonia by coving the Stone Age, as well as the basic information about stone tools and types of analyses, topics which are not typically included in university lectures. They are also an attempt to gain more public interest in prehistoric stone materials. Regarding the given interest of the students about lithic studies, we hope that in the future there will be same or a similar type of workshops held by HAEMUS professionals trained in prehistoric stone tools.

Official web site: http://haemus.org.mk/stone-tool-workshops-by-haemus-the-stories-written-in-stone/

Figure 1. Stone tools workshop I, Museum of the Old Bazaar, Skopje, 18 February 2014. (Photos by Vasilka Dimitrovska.)

Event review: The Archaeology Centre Knap-In and Goat Roast, Toronto, Canada

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As a part of its programming line-up, The Archaeology Centre at the University of Toronto hosts a number of faculty and student-run interest groups that bring together archaeologists from the Toronto community. These groups foster interdepartmental and community collaboration among those who share similar research pursuits. In May 2015, the Lithics Interest Group and Food and Subsistence Interest Group organized an end-of-year knap-in and goat roast. Its goal was to introduce students to flintknapping and food production, and to celebrate an excellent year for the Archaeology Centre.

Figure 1. Students practice and learn flintknapping outside the Anthropology Building, University of Toronto (Photo: Paulina Dobrota).

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For the Lithics Interest Group's knap-in, faculty members from the Department of Anthropology kindly donated flints and cherts from around the world, namely Jordan, Texas, and Ontario. On a particularly sunny afternoon after a long and cold winter, flintknappers gathered outside the university's Anthropology Building to practice their skills and learn new ones. The event was well-attended by both novice and experienced knappers, and a few pedestrians from the university campus were able to stop and learn what the anthropologists were doing out on the lawn as well. Instructors were on hand to give aid and lessons to those students who had never knapped stone before. There were a good number of students learning the basics of flake production for the first time, and instruction came with an emphasis on safety and a relatively loose *chaîne opératoire* approach. Many students showed up to enjoy the weather, socialize with fellow colleagues, and simply observe the flintknapping process.

Figure 2. Professor Michael Chazan, Director of the Archaeology Centre, instructs on antler billeting. (Photo by Paulina Dobrota)

After about an hour of instruction and knapping out on the lawn, the students and university community gathered their flakes and moved upstairs to the Flintknapping Lab where they had the opportunity to put the flakes to use! The Archaeology Centre purchased a deceased goat from a local butcher, and with the guidance of the Food Interest Group, all attendees were able to skin and butcher the goat with the intent of gathering the hide and edible meat from the animal.

First, graduate students with experience in traditional butchering guided the hide extraction as many looked on in curiosity and fascination. Flakes with ideal skinning properties were not hard to find from the knap-in assemblage, and it was not long before the goat was ready to be butchered. The Food Interest Group gave general guidance on butchery and meat removal to different groups of students working on various parts of the animal. All attendees who were willing and interested in helping prepare the meat had the chance to choose their tools and carve off the goat, and some managed to use flakes of their own creation as well. Some commented on how surprisingly simple it was to use their flakes on the goat meat when cuts followed the natural fibrous lines inside the animal.

Those interested in hide production spent their time thoroughly cleaning and skinning the remaining meat from the hide with a few basic but effective scrapers. The hide was then salted and sealed for future tanning. The group's labours promise to provide a gorgeous leathered goat skin.

Figure 3. Skinning the goat with the knapped flakes. (Photo by Paulina Dobrota)

The knap-in and goat preparation event concluded when the participants were finished extracting all meat and hide from the goat. The following evening, after the resultant goat meat was marinated and otherwise prepped, the attendees celebrated their afternoon's work with a feast of goat sausage and kebabs at a potluck barbecue with a Mediterranean cuisine theme.

Starting from the practice of basic flake removal, to selecting and curating flakes for the required task, through to the animal butchering and finally the consumption of delicious barbecued goat, all participants were able to walk through the food extraction process and learn what it takes to both knap stone and put it to use. Attendees received a very visual and experiential lesson in the history of food production and the steps involved in extracting food and hide resources from animals.

More information about The Archaeology Centre and its Interest Groups can be found at www.archaeology.utoronto.ca .

Figure 4. The students chose some of their flakes for work on the goat. (Photo by Amy Fox)

Figure 5. Students learn traditional butchering techniques. (Photo by Amy Fox)

Figure 6. Goat sausage and kebabs. (Photo by Amy Fox)

Event review: How Interesting Archaeology Is! - Captivating and Leading-Edge Student Research

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Kyoto City Archaeological Museum situated in Kansai region, the central part of Honshu Island, Japan, has held special exhibitions in collaboration with external organizations every year since 2011. From 2011 to 2013, several universities and even a high school have participated projects, and in 2014, the Kansai Archaeological Association for Students (KAAS) played an important role as partner, producing the exhibit “ここまでわかる！考古学—学生が魅せる最先端” (“How Interesting Archaeology Is! - Captivating and Leading-Edge Student Research”).

The Kansai Archaeological Association for Students, commonly known as ‘Kangakukou’ (the abbreviation of Kansai Gakusei Koukogaku Kenkyukai in Japanese), is a study group which consists of students and young researchers who are studying archaeology in various universities, research institutes, museums, and administrative organizations in the Kansai region. KAAS was established in 2003 by students of the time from several universities, including the author. Since then, KAAS members have had good opportunities to share research results, to develop research skills, and to communicate with each other regardless of their affiliation. Although students have limited knowledge of archaeology and little financial resources, they have unfettered thought, free from previous studies and much time to devote themselves to basic research. These advantages have promoted empirical research since the mid-20th century, and thus ‘student archaeology’ has been one of the notable characteristics of the academic world of archaeology in Japan.

The 2014 exhibition was held from 16 December 2014 to 25 January 2015. During preparation for the exhibition, KAAS members chose 7 research subjects, and as leaders of each subject young researchers continued to investigate and observe archaeological sites, features, and artifacts. The young researchers were assisted by approximately 50 students from 9 universities who participated in the project in order to train to become archaeologists and museum curators in the future (Figure 1). Not only students of archaeology and history but also students of design joined our project. Miyuki Nisii, an undergraduate student majoring in Illustration at the Faculty of Arts and Design, Osaka Seikei University, led the exhibition design of our project. Nisii and her classmates designed signboards, exhibition panels, a pictorial record book, mascot characters, and commemorative rubber stamps (Figure 2). She says that, “This is the first time for us to practice our design skills as work experience.

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It was hard to keep the deadlines of delivery and sometimes we were requested to improve the quality of the products, but this exhibition became a really good experience and we were able to learn many things." The 7 research subjects were as follows: zooarchaeology and sclerochronology of the dietary culture and the site formation process (led by Takashi Nayauchi and Satoshi Hatakeyama); experimental study of iron production (led by Kohei Yamamoto); Cristian artifacts in Kyoto (led by Masayoshi Shimizu); technological analysis of *haniwa*, ceramic funerary sculptures from within tumuli (led by Masahiro Harada); a dynamic approach to identifying the function of horse trappings (led by Katsuki Oe); the decorating method of Jomon pottery (led by Yusuke Seno); archaeological and chemical study of obsidian artifacts (led by the author). This research attracted over 1,800 visitors with the help of exhibition commentary by the students. In the obsidian section, "黒曜岩、600km の旅" ("Obsidian, 600 km Journeys"), Natsuko Matsuo and Ayaka Suzuki, undergraduate students of Nara University, introduced the following research results and explained about materials which they imaginatively displayed (Figure 3).

Figure 1. Activities of the students and young researchers involved in the exhibition. 1. Planning meeting. 2. Observing and making scale drawings of artifacts. 3. Preparation for the exhibition. 4. A gallery talk. 5. Fine adjustment of exhibits. 6. Review meeting.

Figure 2. Signboard and pictorial record book designed by the students of Osaka-Seikei University.

Figure 3. Obsidian exhibition section "Obsidian, 600 km Journeys".

Even considering only major sources, the Japanese archipelago has approximately 200 obsidian sources (Figure 4), a situation owing to the geological background as the part of circum-Pacific volcanic belt. Obsidian sourcing studies have become some of the most important research areas to demonstrate some form of ancient trade. Some researchers have tried to utilize INAA (Ninomiya et al. 1993) and ICP-AES (Miura et al. 2012) for sourcing, but the majority focus on minor elements detected by XRF. EDXRF in particular, is the most popular method in sourcing studies of obsidian artifacts because it is a non-destructive and inexpensive method for analysis. Owing to the progress of analytical instruments and provenance analysis methods, it has been possible to accumulate sourcing data for all lithic artifacts within an assemblage, including debris, in order to obtain quantitative information about the lithic raw material utilization within the assemblage as a whole. Nowadays, on the basis of research carried out by Meiji University, EDXRF analysis can distinguish 85 groups of obsidian source points (Sugihara 2011). Obsidian sources are concentrated in Hokkaido, the eastern area of Honshu, and Kyusyu, but Kansai region, the central area of Honshu, has not even one. Nevertheless, some obsidian artifacts unearthed from the archaeological sites of Kansai region with large number of andesite artifacts imply the existence of ancient inter-regional relationships.

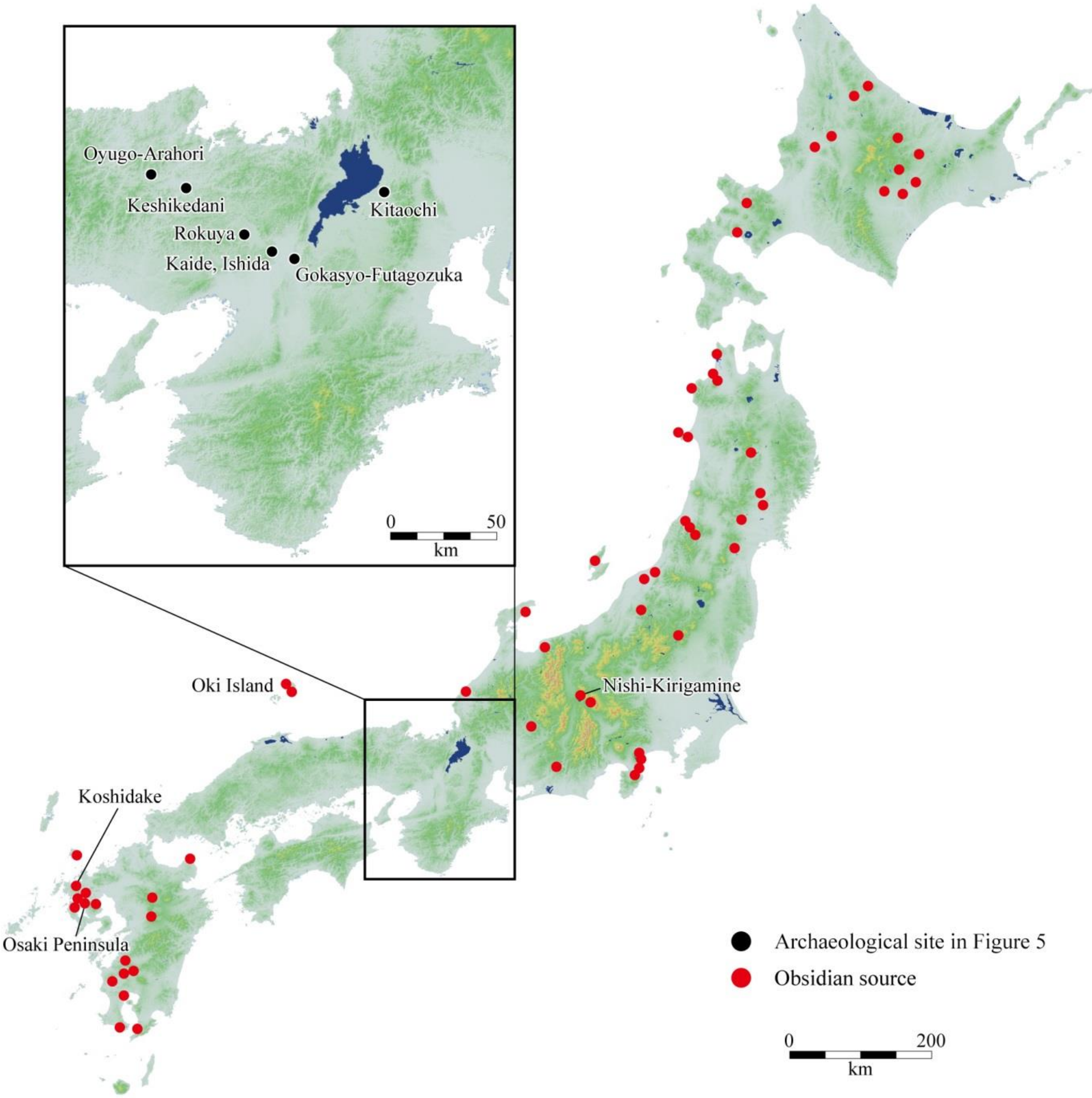

Figure 4. Obsidian source areas of Japanese Archipelago (after Sugihara 2011) and obsidian from archaeological sites discovered in Kansai region (made with Kashmir 3D).

To verify this, it is necessary to identify the petrological origin and archaeological details of these artifacts. 41 obsidian artifacts were selected and borrowed from their custodians and in cooperation with the Kyoto City Archaeological Museum, as a part of the exhibition project, they were observed archaeologically and subjected to provenance analysis by EDXRF. Taro Kannari, a researcher at the Center for Obsidian and Lithic Studies, Meiji University, was in charge of the sourcing study by EDXRF (JSX-3100s) and clarified that the obsidians were transported over long distances ranging from approximately 200 to 600 km. The result prompted the author to try to determine their age by diverse methods. As is often the case with Neolithic archaeology, lithic artifacts are dated on the basis of the relative chronology of pottery which accompanied them. This time, the author cross-checked the age of the obsidian artifacts with the research on lithic typology and technology and with research on the temporal change in lithic raw material utilization patterns, as well as with the pottery chronology. Additionally, the edge sharpness and the degree of damage to flaking surfaces were observed very carefully. They could be considered as "transportation damage" and suggest where the obsidian artifacts were made.

Figure 5. Obsidian artifacts unearthed in Kansai region, Japan (Photography by Masaki Shibata). 1. Backed-blade from the Gokasyo-Futagozuka site, Upper Palaeolithic Period, Nishi-Kirigamine series obsidian (owned by Uji City Board of Education). 2. Point from the Rokuya site, possibly Incipient Jomon Period, Oki Island series obsidian (owned by Kameoka City Board of Education). 3. Arrowhead from the Oyugo-Arahori site, Early Jomon Period, Oki Island series obsidian (owned by Fukuchiyama City Board of Education). 4. Arrowhead from the Keshikedani site, Early Jomon Period, Oki Island series obsidian (owned by Fukuchiyama City Board of Education). 5. Arrowhead from the Kitaochi site, Final Jomon Period, Nishi-Kirigamine series obsidian (owned by Shiga Prefecture Board of Education). 6. Thermal fractured piece from the Ishida site, Final Jomon Period, Osaki Peninsula series obsidian (owned by Muko City Board of Education). 7. Thermal fractured piece from the Kaide site, Final Jomon Period, Koshidake series obsidian (owned by Muko City Board of Education).

In consequence, three patterns were identified in the relationship between the provenance of obsidian and the place of lithic production. In the 1st pattern, after making stone tools near the source areas, obsidian artifacts were transported over long distances. In the 2nd pattern, after procurement and transportation, lithic production was carried out far from the source areas. Obsidian artifacts classified into the 1st pattern have the same typological characteristics as those excavated at sites near the source areas, and have many damages like scratches on their surface. The backed blade of the Gokasho-futagozuka site which has technological features common in eastern Japan and much damage on the surface and ridge, could suggest an aspect of nomadic lifestyle during the Palaeolithic (Figure 5.1). In contrast, artifacts of the 2nd pattern, for instance, the arrowheads of the Oyugo-Arahori site, Keshikedani site and Kitaochi site, have a design common in the area where they were excavated and little damage on their surfaces (Figures 5.3, 5.4, 5.5). The 3rd pattern is, as it were, exceptional; debris produced during obsidian tool making was transported to Kansai region, a non-obsidian region far from source areas (Figures 5.6, 5.7). As a result of XRF analysis, all of the obsidian artifacts classified into this category were revealed to have been transported from Kyusyu Island and were dated to the middle of the Final Jomon Period, c. 3,300 cal. BP.

Why was debris transported? During this phase, the pottery types were uniformized throughout the whole of western Japan. Hence, the movement of obsidian from the Kyusyu region to the Kansai region can be interpreted as a reflection of the same cultural event. This phase corresponds to the start of the early stage of rice-paddy cultivation in the Japanese archipelago. Obsidian could be testimony to an encounter with people living in distant regions.

“Knowing something new and meeting someone new enrich our lives,” says Takuya Asai, the representative of KAAS. Through the special exhibition, we the members of the KAAS exhibition project, fully enjoyed many encounters and learned numerous things from them. The Jomon people may also have learned new cultural elements by encountering distant people. Obsidians certainly know the fact.

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