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# Last Glacial Maximum Microblade Production at Shizitan 29 and its Implications for North China Pressure Technology

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## ABSTRACT

A techno-functional approach applied to the lithics of the Late Upper Palaeolithic Shizitan 29 site allows the identification of previously unrecognized technical features of microblade pressure production and new behavioral understanding of its evolution beginning ca. 26,000 CAL B.P. These technical features may relate to the evolution of so-called boat-shaped cores, including the development of two blade scar sequences and the 8-like contour of the striking platform (likely related to fixing cores in a holding device). Counter to traditional typological lithic analyses centered on final core morphologies, we seek to identify technical objectives related to the required pressure production. In doing so, we argue that earlier semi-conical cores may have maximized the exploitation of the core volume, while subsequent boat-shaped cores developed to maximize the efficiency of the production of straight profile, regular blades. This allowed microblades to become a critical adaptation for final Pleistocene hunter-gatherers in northern East Asia.

## KEYWORDS

Late Upper Palaeolithic; pressure production; techno-functional approach; semi-conical microcore; boat-shaped microcore; lithic analysis; hunter-gatherer adaptations

## Introduction

The origins and evolution of microblade production in East Asia during the final Pleistocene have remained cloudy due not only to limited reporting of controlled excavations with reliable chronology but also, we argue, due to the interpretive emphasis on morphological typology of final micro-core forms. Here, we offer a techno-functional approach as an alternative that allows new, behavioral insights into the evolution of this adaptive technology of the Last Glacial Maximum (LGM) among hunter-gatherers in North China. We present the first reconstruction of the evolution of the operational sequences of early microblade production in behavioral terms, employing data from the Shizitan 29 site, located on the Loess Plateau.

Geographic areas in East Asia proposed as centers of origins of microblade production include North China (Zhao et al. 2021; Barton, Brantingham, and Ji 2007), Northeast China (Yue et al. 2021), southern Siberia (Transbaikal) (Terry, Buvit, and Konstantinov 2016; Yi et al. 2016), northern Mongolia and the Altai (Kuzmin 2007; but see Kuzmin and Keates 2021), and the Korean peninsula (Kuzmin and Keates 2021; Keates, Postnov, and Kuzmin 2019), with origins dating to the LGM or earlier and spread tied to climate changes (Zhang 2021). However, the typological orientation common to many discussions (see Zhang 2021) cannot appropriately identify technological origins and evolution. In contrast to the traditional approach centering on the morphotypology of finalized cores, we, instead, following the orientation of Inizan and colleagues (1999), Inizan (2012), and Gómez Coutouly (2018), who define “true” microblade production as requiring pressure production, advocate for a techno-functional, behavioral approach focusing on operational sequences related to pressure technology.

The stratigraphic sequence of the open-air site of Shizitan 29 (Jixian County, Shanxi) provides rare data to observe the evolution of pressure production from an early appearance during the LGM through subsequent developments during the Terminal Pleistocene (see Song et al. 2019, 2017). The site’s eight cultural layers date from ca. 28 kya CAL B.P. to 13 kya CAL B.P. (with a gap from 18–13.5 kya CAL B.P.). The technical changes observed allow new behavioral understandings of microblade assemblages as a key adaptation of northern Asian hunter-gatherers.

## Upper Palaeolithic North China

In China, the Upper Palaeolithic includes initial (IUP), early (EUP), and late (LUP) periods, but these differ from western Eurasia (Qu et al. 2013; Bar-Yosef 2002). The IUP, following Kuhn and Zwyns (2014), begins ca. 41 kya CAL B.P. with laminar blade production with Levallois elements and prismatic blade reduction at Shuidonggou 1, 2, and 9 (Ningxia) (Peng et al. 2020; Li et al. 2019). The IUP is seen as intrusive, coming from the Siberian Altai and Mongolia (see Zwyns et al. 2019), but putative migrations (Li et al. 2016, 2013), technological diffusion (Peng, Wang, and Gao 2014; Brantingham et al. 2001), or which human species produced these assemblages remain uncertain (Bar-Yosef and Belfer-Cohen 2013; Li et al. 2019).

The EUP is represented by advanced core-and-flake assemblages at Shuidonggou 2, 7, and 8, from ca. 33 kya CAL B.P., thought to be an indigenous development out of earlier core-and-flake industries without technological influence from the IUP. Additions include the exploitation of high quality chert, soft-hammer percussion, large proportions of bipolar reduction bladelet-sized blanks, finely

retouched endscrapers, and irregularly-shaped grinding slabs (Li et al. 2019; Peng et al. 2018; Qu et al. 2013).

## Evolution of Microblade Production

Although there are arguments that microblade pressure production should originate from IUP blade productions (Kuzmin and Keates 2021; Yue et al. 2021; Zwyns et al. 2019; Pei 1948) or EUP core-and-flake industry bipolar small pieces (Yue et al. 2021; Bettinger et al. 2010; Barton, Brantingham, and Ji 2007), how such techniques could evolve into the full suite of requirements for pressure production has not been demonstrated, although some synthetic discussions have been published (Zhang 2021; Chen and Ye 2019; Keates, Postnov, and Kuzmin 2019; Chen and Qu 2018; Gómez Coutouly 2018).

Microblade pressure production—distinct from other blade productions—is the marker of the LUP in North China. Its initial development, likely during the LGM, has remained unclear, as, technologically, has its subsequent evolution and broad-ranging dispersal over the Terminal Pleistocene (a “socio-technologically adaptive radiation,” following Zhang 2021, 2). Here, LGM dating of 27.54–23.34 kya CAL B.P. follows Hughes, Gibbard, and Ehlers (2013) and Hughes and Gibbard (2015); also see Mingram and colleagues (2018).

Several factors hinder understanding of the evolution of microblade production. First, published reports from controlled excavations of well-dated sites are limited (see Li et al. 2019). Discussions of Xiachuan (Shanxi) (Du et al. 2019; Tang 2000; Wang and Wang 1991), Longwangchan (Shaanxi) (Zhongguo and Shaanxi 2021; Wang 2014; Zhang et al. 2011), Xishantou (Heilongjiang) (Liu, Li, and Yang 2019), Youfang (Nihewan Basin) (Nian et al. 2014), Dingcun Locality 77:01 (Chaisi) (Shanxi Institute of Archaeology 2014; Wang, Tao, and Wang 1994), and Dingcun Locality 94:01 (Tao and Wang 1995) lack technological descriptions and only present idealized morphological types from fully-expanded microcores, although the recent Longwangchan excavation report provides detailed morphotopological descriptions of lithics from locality 1 (Zhongguo and Shaanxi 2021). Such typological approaches may award evolutionary significance to arbitrary blade width cut-offs, as in the analysis of the larger blade cores and smaller microcores from Xishi and Dongshi (Henan): these morphotypes are assumed to be in a developmental sequence despite their being contemporaneous at the site, appearing relatively early, ca. 26 kya CAL B.P. (Zhao et al. 2021).

Secondly, the lack of technological criteria in identifying true microblade productions results in inaccurate identifications that can become entrenched in the subsequent literature. For example, Xishantou (ca. 27.5 kya CAL B.P.) is argued to be one of the earliest microblade sites (Yue et al. 2021; Liu, Li, and Yang 2019), but no true microblade pressure production can be observed (Kuzmin and Keates 2021).

Thirdly, the typological approach lacks standardized criteria for the classification of commonly-identified microcore morphotypes, e.g., boat-shaped, wedge-shaped, etc. (see Jin, Yi, and Zhang 2021; Feng 2020). A related problem is that when analyses center upon these final morphologies of spent cores, other elements of the assemblages representing other stages of the reduction sequences are ignored that could provide behavioral information, including the

technical objectives of each stage of the reduction sequences (Song et al. 2019). Thus, overemphasis on microcore morphotypes results in wedge-shaped vs. boat-shaped being considered the central adaptive achievements (e.g., Feng 2020; Yi et al. 2016; Shao 2010; Chen 2007, 1994; Ji et al. 2005; Xie 2000) or even being considered as markers of social groups (e.g., Zhang 2021; Chen and Zhang 2018; Kato 2015). While the technical roles of core morphology are traditionally under-valued, our techno-functional analysis shows that changes in these roles are critical in understanding the evolution of microblade pressure production.

## Shizitan 29

Shizitan 29 (36° 2' 54" N, 110° 35' 22" E, 723 masl) is located along the Qingshui River, 9.5 km east of the Yellow River (Figure 1). Approximately 1200 m<sup>2</sup> were excavated in 2009–2010, revealing human activity (e.g., 285 hearths and over 80,000 artifacts) through 15 m deposits comprised of 8 cultural layers. Proveniences of cultural materials were recorded in three dimensions. 39 AMS radiocarbon determinations date the sequence across the LGM (Shanxi University School of History and Culture and Shanxi Institute of Archaeology 2017; Song et al. 2017). For details on the environmental reconstruction and dating, see Song and colleagues (2017).

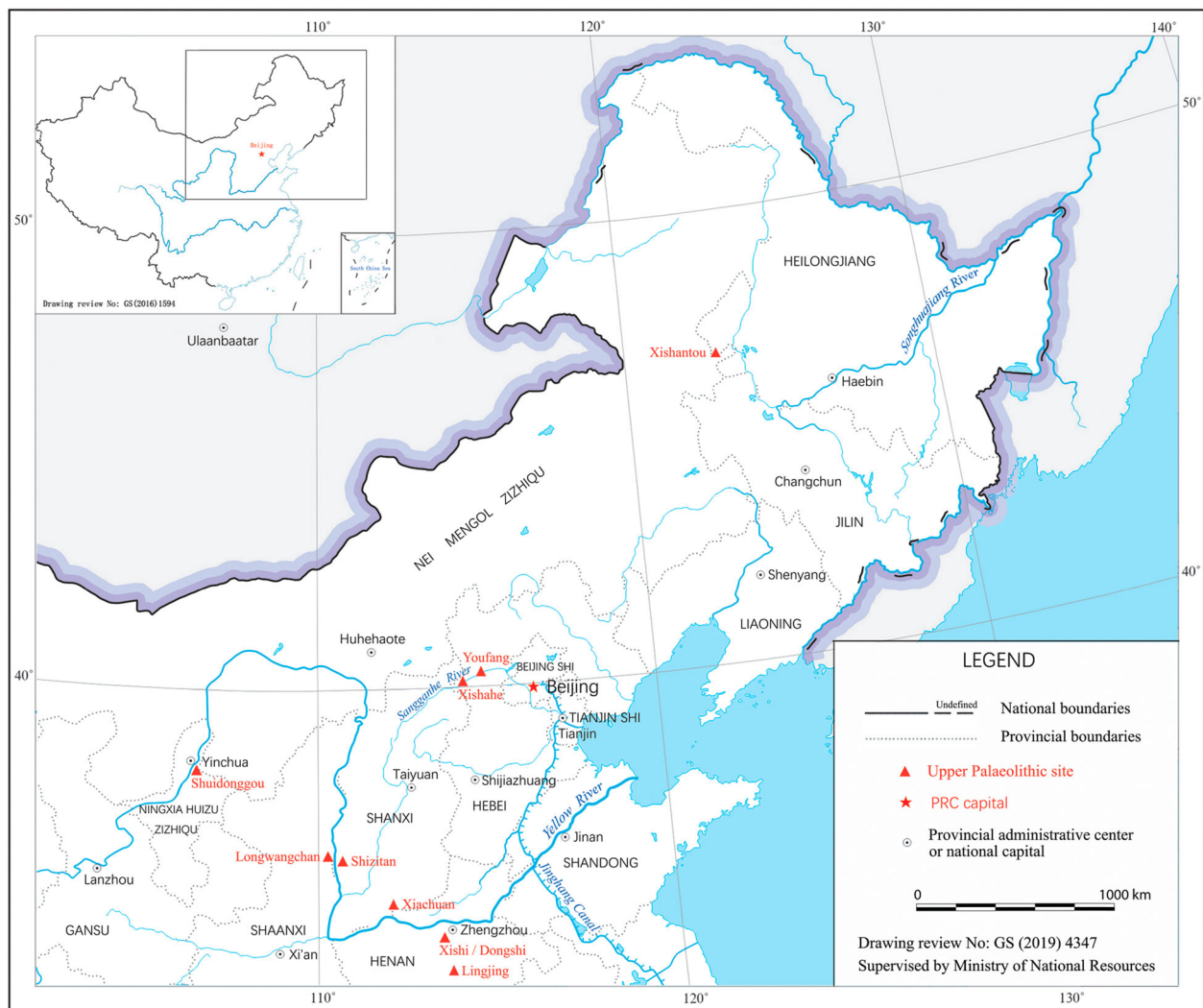
Shizitan 29 Layer 8 (28 kya CAL B.P., predating LGM) and the lower part of Layer 7 feature an EUP advanced core-and-flake assemblage. Microblade production appears during the cooler, drier LGM in the top part of Layer 7, ca. 26–24 kya CAL B.P. (Song, Cohen, and Shi 2022; Song et al. 2019, 2017), making it one of the earlier microblade productions in North China. Song and colleagues (2019) present the technological features of these earliest layers to demonstrate the advantages of techno-functional approach interpretations.

Layers 6, 5, and 4 date to ca. 24–19.5 kya CAL B.P. and demonstrate substantial cooling and drying associated with LGM. The return of cervids in Layers 4 and 3 (ca. 20 kya CAL B.P.) perhaps indicates ameliorating conditions. Layer 2 (ca. 19–18 kya CAL B.P.) marks the end of Last Glacial conditions. The site was abandoned from ca. 17–13 kya CAL B.P. Layer 1 (ca. 13 kya CAL B.P.) represents Shizitan 29's last occupation during warmer, more humid conditions. Micro-morphology indicates that during these periods, Shizitan 29 was ephemerally but repeatedly occupied, with extensive periods of no human activity at the site (Song et al. 2017).

## Pressure Production at Shizitan 29

### Methodology

Clear distinctions must be made between pressure technique, pressure flaking, and pressure production. Pressure technique is a technological achievement used to modify a stone tool/core; the goal is to remove flakes/blades by pressing on the stone with a pointed instrument (e.g., antler punches) rather than by percussive striking with a hammer—this provides greater control over the application of force. Pressure flaking is mainly an intentional retouching activity for accurately shaping tool edges. It does not require special devices: the core and the punch are usually held in the hands (see papers in Desrosiers 2012; Inizan and Tixier 2000; Johnson 1978).



**Figure 1.** Map showing the location of the open-air site of Shizitan 29 (Shanxi) and other Upper Palaeolithic sites in North China mentioned in the text. The scale indicates longitudinal distance at 40°N, and north is indicated by the longitude lines.

Pressure production refers to the systematic, highly standardized production of blades (Crabtree 1968; see also contributions in Desrosiers 2012). Different from pressure flaking, pressure production is limited by physical gesture (which can only be learned through accurate training) and requires much technical knowledge and expertise related to the selection and preparation of raw material, core maintenance, and the use of core holding devices specifically devised for the varying requirements of the production, such as of large vs. small blades. The main technical characteristics to recognize pressure production of blades have been extensively described (Pelegrin 2012, 1988; Inizan et al. 1999). Here, we identify pressure production following the criteria presented by Gómez Coutouly (2018).

### **Rejection of arbitrary size distinctions**

We must emphasize that under our approach, the term “blade” is to be used regardless of size, so it includes those blades commonly classified as microblades in China, as well as potentially others. Our methodology requires the analyst to reject the a priori arbitrary size-based distinctions commonly made in the East Asian literature between tool morphologies, such as blade, bladelet, and microblades (following Song et al. 2019; Gómez Coutouly 2018). Thus, in this

study, we use the term “blade” regardless of size, although in parts of our discussion, to allow clear connections between our statements and previous typological studies, we may still use the term “microblade” out of convenience.

Here, the technological term “blade” refers to any elongated, morphologically standardized blank showing parallel edges and scars, regardless of the size. Blades may be divided into regular or irregular blades according to the level of standardization of their technical features. No further sub-classification based on dimensional difference is made. This is because blades’ morphological and dimensional features should be considered as technical by-products of the technological reduction sequence(s) adopted by the human groups.

Furthermore, classification of core morphotypes (categorized as boat-shaped, wedge-shaped, semi-conical, etc.) is often a main objective of the traditional approach, but this lacks formalization and a basis in behavioral questions. The analytical primacy given to spent cores ignores the behavioral information available over the entire production sequence. In failing to consider the behavioral significance of differences in the reduction sequences or other technological aspects of production, the traditional approach limits its capability to draw evolutionary connections between sites, regions, and time periods. As with the term “microblade,” we

use the terminology of the traditional morphotypological distinctions between cores only to share the language proliferated in the literature: in fact, as we reveal below, these morphological differences between cores find their origins in previously unrecognized technical features.

Our approach considers any core during each stage in its reduction sequence as an adaptable tool used by human groups to produce their stone blanks. Instead of the morphometrical characteristics given primacy in traditional approaches, our analysis is based in more significant technical features, namely, the nature of the produced blanks (flakes, blades, etc.), the production sequence of the blanks, how the core volume has been managed, if and how the core has been held in a stable device during the production of blades by pressure, and technical expedients. This allows us to highlight the specificities and peculiarities of each analyzed assemblage within the Shizitan 29 sequence and leads to the identification of previously unrecognized diachronic changes.

### Raw material selection

Two types of good quality flint were exploited at Shizitan localities throughout the LUP (see Song et al. 2019) (Figure 2). The “Black flint” is found in Permian deposits P1 and P2 (China Geological Survey 2004): our team has located and sampled outcrops 150 km and 30–40 km from Shizitan. While the quality of the Black flint is generally very good, it frequently contains deformations caused by tectonic stress, so suitable blocks for knapping are generally reduced in

size. “River flint” are rounded pebbles several centimeters in length with a translucent, multicolored lithotype that are found along the banks of the Yellow River, beginning ca. 9.5 km from the site (Song et al. 2019): they have an overall good knapping attitude. Other riverbank raw material exploited at Shizitan are quartz and quartzite pebbles. Chert, limestone, sandstone, and other stone were less relevant, but one obsidian artifact in Layer 7 Top will be discussed in a future long-distance sourcing study.

### Lithic sampling

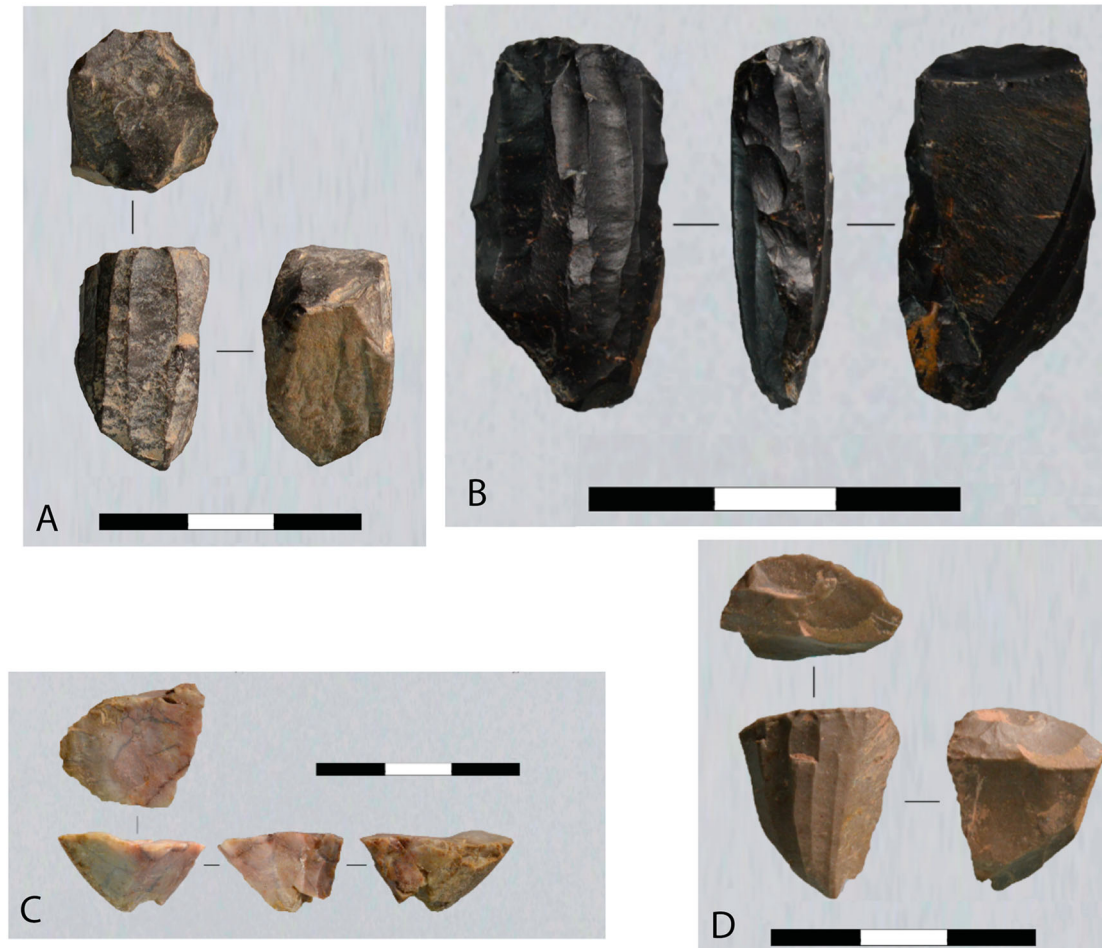
The recovery of 74,735 stone artifacts at Shizitan 29 required sampling of the assemblages.

### Layers 8 and 7 Base

The lithics are described by Song and colleagues (2019) and are not discussed here. They represent a core-and-flake industry without evidence of blade production.

### Layer 7 Top

Also described by Song and colleagues (2019). We analyzed all cores and retouched flakes from the entire excavated area.<sup>1</sup> For the large quantities of other lithics, we selected a 150 m<sup>2</sup> sampling zone (units 60-70 North/85-100 East) where the thickest anthropogenic deposits are found and radiocarbon and pollen samples were collected, from which we analyzed all lithics. The discussed data slightly differ from Song and colleagues (2019): only the Black and River



**Figure 2.** Color images of cores showing the two types of flint exploited at Shizitan 29 for pressure production of blades, Black flint and River flint. A) Black flint core from Layer 7 Top (12785); B) Black flint core from Layer 7 Top (12474); C) refitted River flint core from Layer 5 feature 5H21 (79-91-1); and, D) River flint core from Layer 7 Top (60-101).

**Table 1.** Shizitan 29 lithic assemblages discussed in the text. The lithic sample in each layer divided between technological groups and raw material.

Layer	Raw material	Cores	%*	Retouched blades**	%*	Unretouched blades**	%*	Retouched flakes	%*	Total
Layer 2	Black flint	16	21.3	4	5.3	43	57.3	12	16.0	75
	River flint	46	25.4	0	0.0	112	61.9	23	12.7	181
		62		4		155		35		256
Layer 5	Black flint	24	16.3	4	2.7	98	66.7	21	14.3	147
	River flint	57	26.0	6	2.7	107	48.9	49	22.4	219
		81		10		205		70		366
Layer 6	Black flint	15	57.7	5	19.2	0	0.0	6	23.1	26
	River flint	38	41.3	22	23.9	16	17.4	16	17.4	92
		53		27		16		22		118
Layer 7 Top	Black flint	26	30.2	4	4.7	20	23.3	36	41.9	86
	River flint	20	35.1	6	10.5	14	24.6	17	29.8	57
		46		10		34		53		143

\*Expressed as the % of that raw material's total artifacts.

\*\*Only unbroken blades are counted.

flint materials are discussed, and fragments and indeterminate blanks are excluded. 143 items are analyzed (46 cores, 44 unbroken blades, and 53 retouched flakes).

### Layers 6, 5, and 2

These assemblages provide the main technological changes in blade production seen at Shizitan 29 and are this study's main focus. Fragments and chunks are excluded. 747 items are included, representing all cores ( $n = 202$ ), unbroken blades (retouched or not;  $n = 418$ ), and retouched flakes ( $n = 127$ ) (Table 1).

### Layers 4 and 3

Despite being analyzed, these assemblages are not presented here, as no relevant technological differences from Layer 5 were noted.

### Layer 1

This surface layer is not studied, as some doubts about its integrity could arise.

## Results

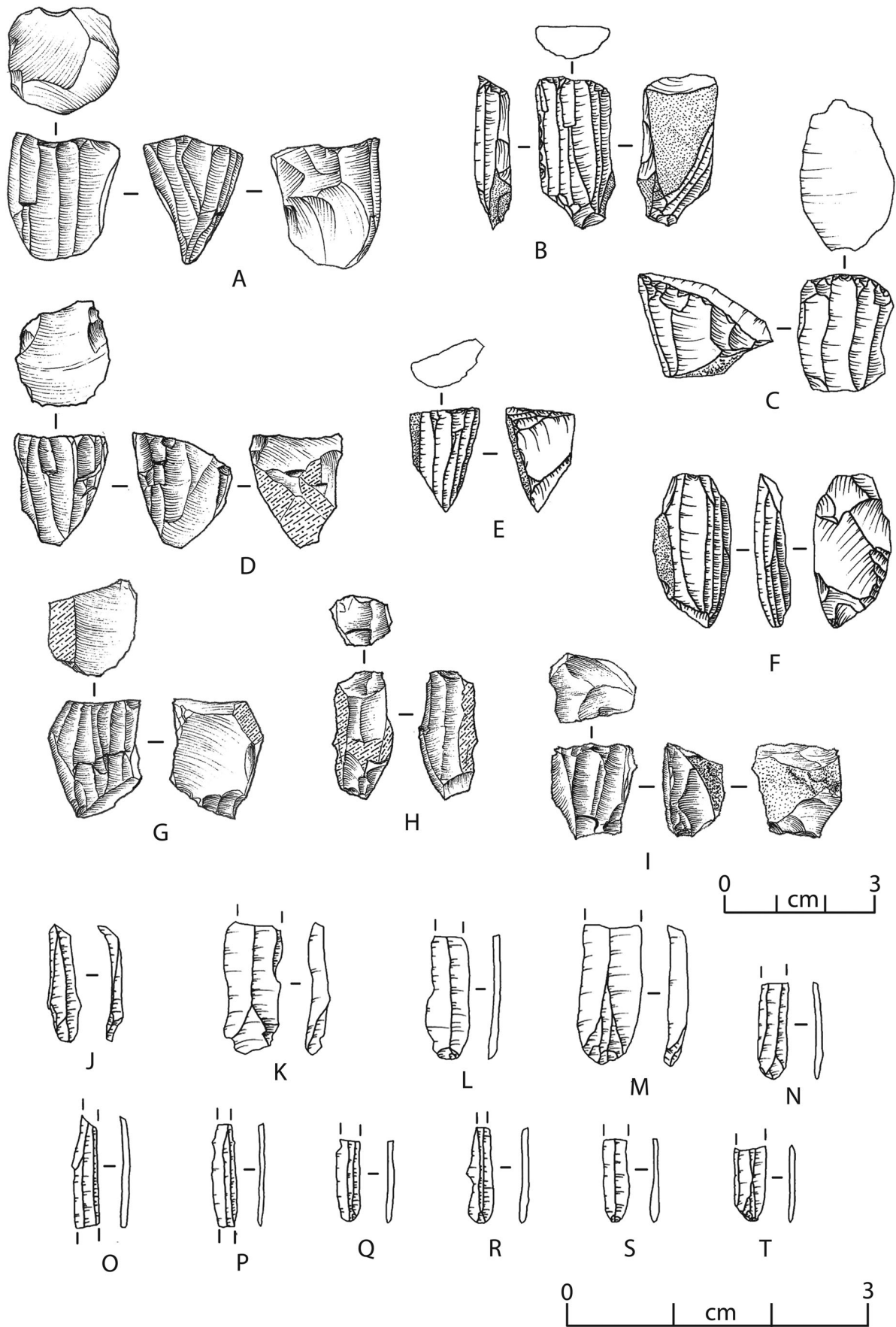
### Layer 7 Top: the earliest appearance of pressure production

Layer 7 Top marks a distinct technical change at Shizitan 29 with the sudden, initial appearance of a true pressure production ca. 26/24 kya CAL B.P. A detailed reconstruction of the reduction sequence is described by Song and colleagues (2019). In short, cores and blades show all the technological traits of pressure production (after Gómez Coutouly 2018) without any noticeable difference observed between items made from Black flint or River flint (Figure 3). Technological achievements probably involve heat-treatment of the cores (analysis is ongoing). Significantly, the site does not show evidence for a local emergence of the new operational sequence required to produce these blanks: instead, the operational sequence appears at Shizitan 29 in an already developed form, and this should be considered an introduced or intrusive technology.

The unbroken blades ( $n = 44$ , see Table 1, Figure 3J) show the longest average length, width, and thickness within the whole Shizitan 29 lithic assemblage. The retouched blades are the longest at the site, excluding the few outlier "oversized" blades of Layer 6 (see below). Fragmented blades (Figure 3K–T), not discussed here, are abundant in this layer; they could serve functional purposes or be related to accidents during production. Most of the unbroken blades

show straight profiles, but twisted or convex profiles are also observed. From a technical perspective, twisted and convex blades should be considered as by-products useful in maintaining the working surface of the core to allow the production of blades with a straight profile, here suggested to represent the pursued technical objective. Only 10 blades show retouched edges (Table 2); preliminary functional observations (Song et al. 2019) reveal macro and micro use-wear related to different materials but mainly from cutting activities. Retouched flakes ( $n = 53$ , see Table 2) have been retouched as endscrapers, while scrapers and marginal retouch are also present.

Independent of raw material, the 46 cores show a very high level of technical variability. They can be divided into several groups according to their blank production. The most abundant type of blank is made from cores producing flakes or elongated flakes. The earliest appearance of blade production is represented by the presence of cores producing regular and irregular blades. The regular blades represent the earliest evidence of well-developed (but intrusive) pressure production. The presence of irregular blades may demonstrate attempts to shape microblade cores on site (these cores show cortex, technical errors such as fractures and scars from hinged flakes, etc.). Independent of the blank type, the most relevant technical feature shown by the cores is the morphology of their rear side, meaning the side which is opposite to the surface from where the blades are struck off: this technical feature is also what provides the morphological shape traditionally considered as semi-conical (Figure 3A–I). Thus, the semi-conical morphology is mainly due to the knapper's choice to produce blades from one side of the core, exploiting as much as possible the volume of the core moving towards the rear side. These cores show a D-shaped striking platform, and blades are produced from the convex side. The preparation of the rear side of the core differs according to the raw material morphology and/or to occasional needs to modify or repair the core morphology. The irregular blocks of Black flint may be pre-formed to shape the rear part of the core to give a flat or also slightly angulated profile; as a certain waste of raw material is needed to prepare the cores, both lateral surfaces of the semi-conical cores from Black flint are almost completely prepared. Given their natural rounded profile, River flint pebbles do not need heavy preparation; accordingly, the rear part of the semi-conical cores made from River flint may bear traces of cortex. The presence of other types of blade cores (for instance, prismatic and semi-prismatic), even though rare in this layer, is difficult to explain from a behavioral perspective.



**Figure 3.** Shizitan 29, Layer 7 Top lithic assemblage. A–I) Semi-conical cores, which first appear at the site in this context. J–T) Blade production.

#### **Layer 6: the evolution of core preparation**

The analyzed assemblage comprises 53 cores, 27 unbroken retouched blades, 16 unbroken unretouched blades, and 22 retouched flakes (see Table 1, Figure 4). Black flint is less

represented overall, but cores are made from both raw materials (58% on Black flint, 41% on River flint). While the high number of cores vs. unbroken blades is interesting, as the sample does not include the fragmented blades, it

**Table 2.** Shizitan 29 lithic assemblages discussed in the text. Typological classification of retouched flakes/blades. Note: only unbroken blades are counted.

Layer	Blades or flakes	Marginal steep retouch	Marginal retouch	Endscraper	Pointed tool	Scraper	Denticulate/Notch	Other	Total
Layer 2	Blades	2	0	1	0	0	1	0	4
	Flakes	0	0	17	3	14	0	1	35
Layer 5		2	0	18	3	14	1	1	39
	Blades	2	8	0	0	0	0	0	10
	Flakes	1	1	50	1	15	1	1	70
Layer 6		3	9	50	1	15	1	1	80
	Blades	21	2	3	1	0	0	0	27
	Flakes	0	0	8	5	9	0	0	22
Layer 7 Top		21	2	11	6	9	0	0	49
	Blades	0	2	1	2	3	1	1	10
	Flakes	0	4	33	1	7	1	7	53
		0	6	34	3	10	2	8	63

remains difficult to suggest if blades were transported away from the site.

From a typological perspective, a striking difference in formal tool types may be seen between retouched blades and retouched flakes (Table 3): the blades (Figure 4L–Z) are mainly shaped by means of a marginal retouch into backed tools, while the flakes are mainly transformed into end-scrapers, scrapers, and pointed tools. 58% of blades made from River flint and all blades from Black flint ( $n = 5$ ) were retouched: this relative abundance of retouched blades is one of the main features that makes this assemblage look somewhat different in terms of site function when compared to the other layers in the sequence. Preliminary functional analysis suggests that this presence of backed blades is related to a hafting technique used for cutting tools rather than for projectile points.

Average dimensions of blades and cores are shown in Table 2. While the average length of the cores is 20 mm, and most of the blades (37 out of 43) have a length shorter than this, the presence of a few larger blades (but still within the size range of what traditional morphotypologies term “microblades”) made from River flint is very interesting, as the small, local River flint pebbles could not produce blades of this size (Figure 4Aa–Ab). A possible explanation for these “over-sized” blades could be related to the exploitation of occasionally available (but not archaeologically recovered), larger pebbles of River flint; a more intriguing explanation is that they were produced elsewhere and introduced into the site as finished products. They could have been made further upstream along the Yellow River, where larger River flint pebbles were observed by author Y. S. during surveys in March and August 2021 (also Song 2016).

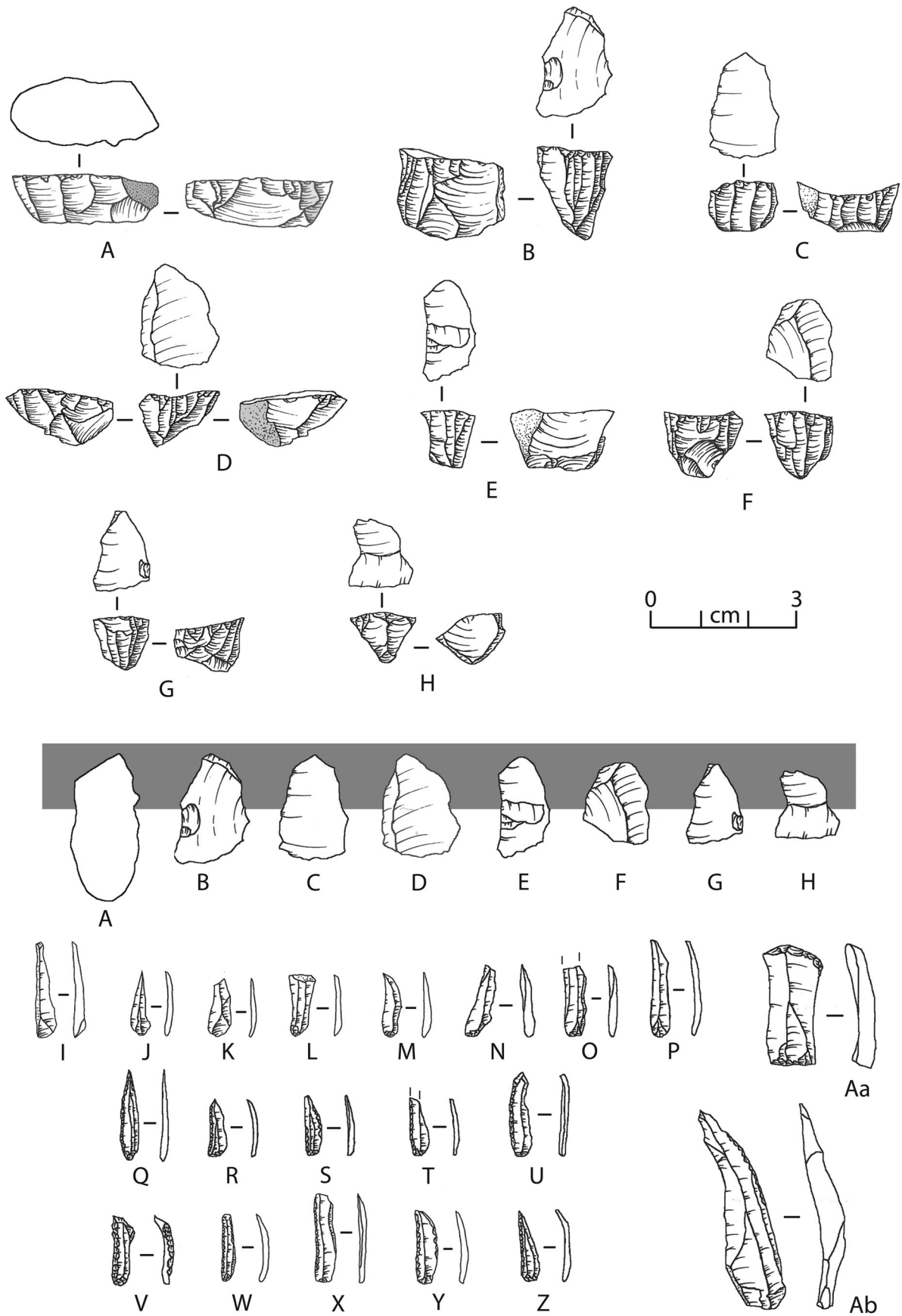
Regardless of being retouched or not, blade profile is mainly straight (about 60% of the blades); more rarely, blades show a left twisted profile (i.e., looking from the butt, the blade’s distal part is asymmetrically oriented to the left). In Layer 6, the disproportion of blades with straight profile vs. left (and, more rarely, right) twisted profile could be the result of sampling bias, as only unbroken blades were analyzed, and blades may suffer breakages during the knapping activity or they may be intentionally fragmented to shape them into unretouched cutting tools. This bias is tentatively supported when the orientation of the blade scars observed on cores is calculated. 40% are straight scars, while twisted scars are equally present on the cores: 28% of visible scars are twisted right scars, and 31% are twisted left. These numbers confirm the standardization of the blade production. Thus, a key conclusion is that blades showing a straight profile can be assumed to be the technical objective of the production; accordingly, blades showing a twisted profile

are struck off to manage the working surface of the core to allow the production of blades with a straight profile.

### Two sequences of blade production

Observation of the blade scar sequence on the production surface of the cores allows the identification of two sequences for blade production. This methodological approach was developed mainly by French scholars (see for instance Binder et al. 2012; Binder and Gassin 1988; Binder 1984), and it is largely applied to define the diachronic sequence of blade scars. Here, however, we adopt other terminological options in order to better clarify the Shizitan 29 technological peculiarities we observed in the lithic assemblage and to highlight the positioning of the straight blades as the technological objective of the sequences, which is not a feature of previous production sequence coding. The most common sequence for detaching blades is here called alternated (Figure 5A); this characterizes 55% of the cores. Removals in an alternated sequence proceed in an alternating pattern from both lateral sides of the core to the center: its aim is to obtain one or two—rarely more—straight profile blades from the center by first removing twisted blades from either side. An example of an alternated sequence would be 1 2 3 2' 1', where 1 and 1' are the earliest removals (twisted blades), followed by the 2 and 2' removals (twisted blades), and then, lastly, the 3 removal, which is a straight blade. In the alternated sequence, the production of the twisted blades has the function of managing the lateral convexities of the core by removing part of the core’s flanks (“debordant” blades). When a sequence is over and the blade(s) with a straight profile have been produced, a second sequence may start, again from both lateral sides of the core. Most of the cores (62%) showing an alternated sequence of scars have been abandoned after the production of the last blade with a straight profile: about one third of these cores have been abandoned because the last blade with a straight profile was reflected, generating irreversible damage on the production surface of the core. 34% of the blade cores ( $n = 10$ ) were abandoned after one or more blades with a twisted profile were removed.

The other sequence for blade production is here called progressive but is observed only on eight cores (15%). Six of these cores were abandoned after the detachment of a last straight blade, usually located at one of the extreme sides of the production surface. Two subgroups may be distinguished (see Figure 5A): the first (5 cores) is a truly progressive sequence where blades are detached in a row from one side of the core to the opposite side; the second, here called semi-progressive (3 cores), is characterized by an irregular progressive sequence of scars. This type of sequence will gain more importance in Layer 5 (see below).



**Figure 4.** Shizitan 29, Layer 6 lithic assemblage. A–H) The earliest boat-shaped cores found at the site, showing the 8-like contour of their striking platform; (center) core platform view of cores A–H with the grey area indicating where the rear side of the cores possibly would have been inserted into a holding device (also see Figure 5B). I–P) Unretouched blade production. Q–Z) Retouched blade production. Aa–Ab) The over-sized blades cited in the text.

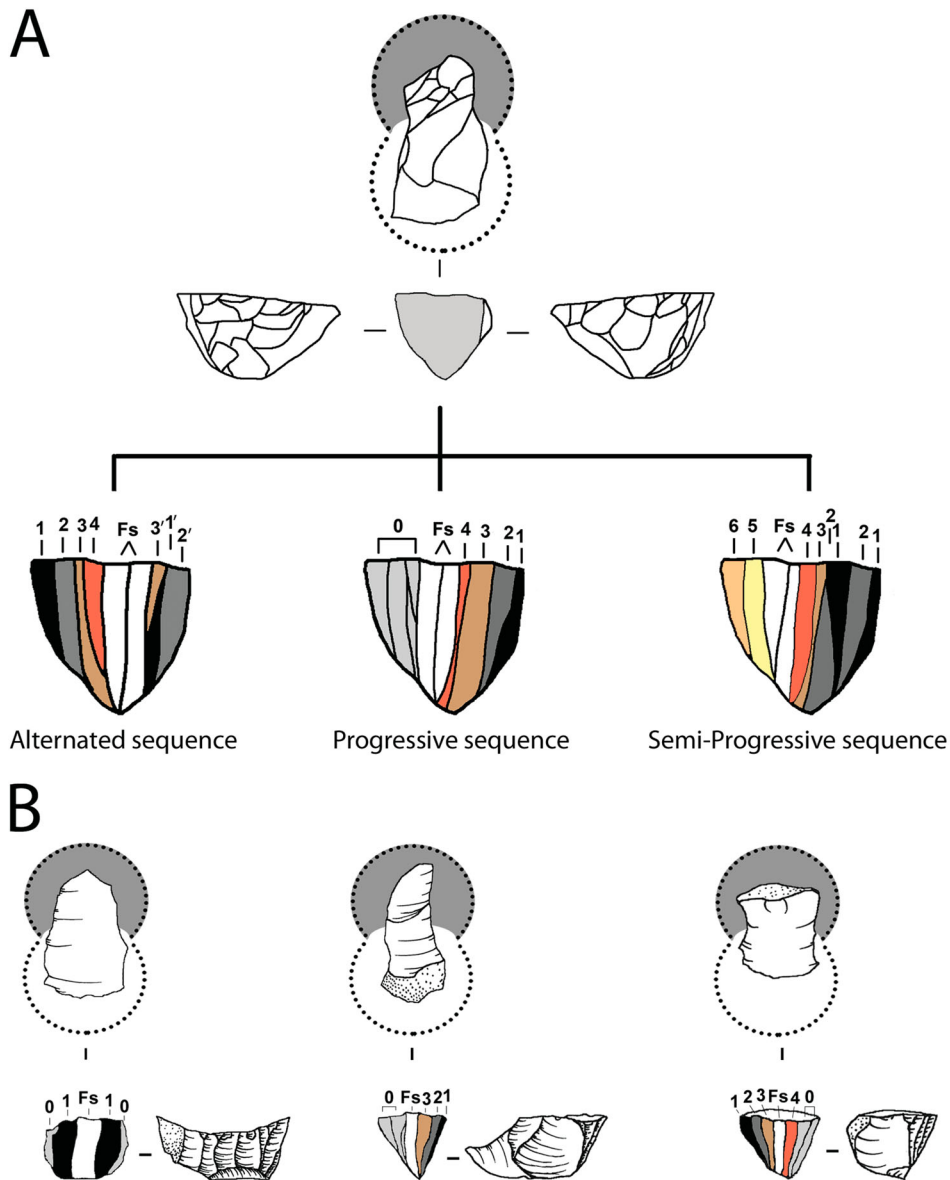
**The 8-like contour**

In Layer 6, a new way of shaping the striking platform of some cores appears that should be noted: when we look at these cores from above, their striking platform looks like it

has taken on a contour shaped like an 8 (see Figure 5A). At least eight cores showing this 8-like contour are found in Layer 6 (Figure 4A–H). From a traditional perspective, these would all be classified as boat-shaped cores. This

**Table 3.** Shizitan 29 lithic assemblages discussed in the text. Average dimensions of unretouched/retouched blades and cores vs. raw material. Note: only unbroken blades are counted.

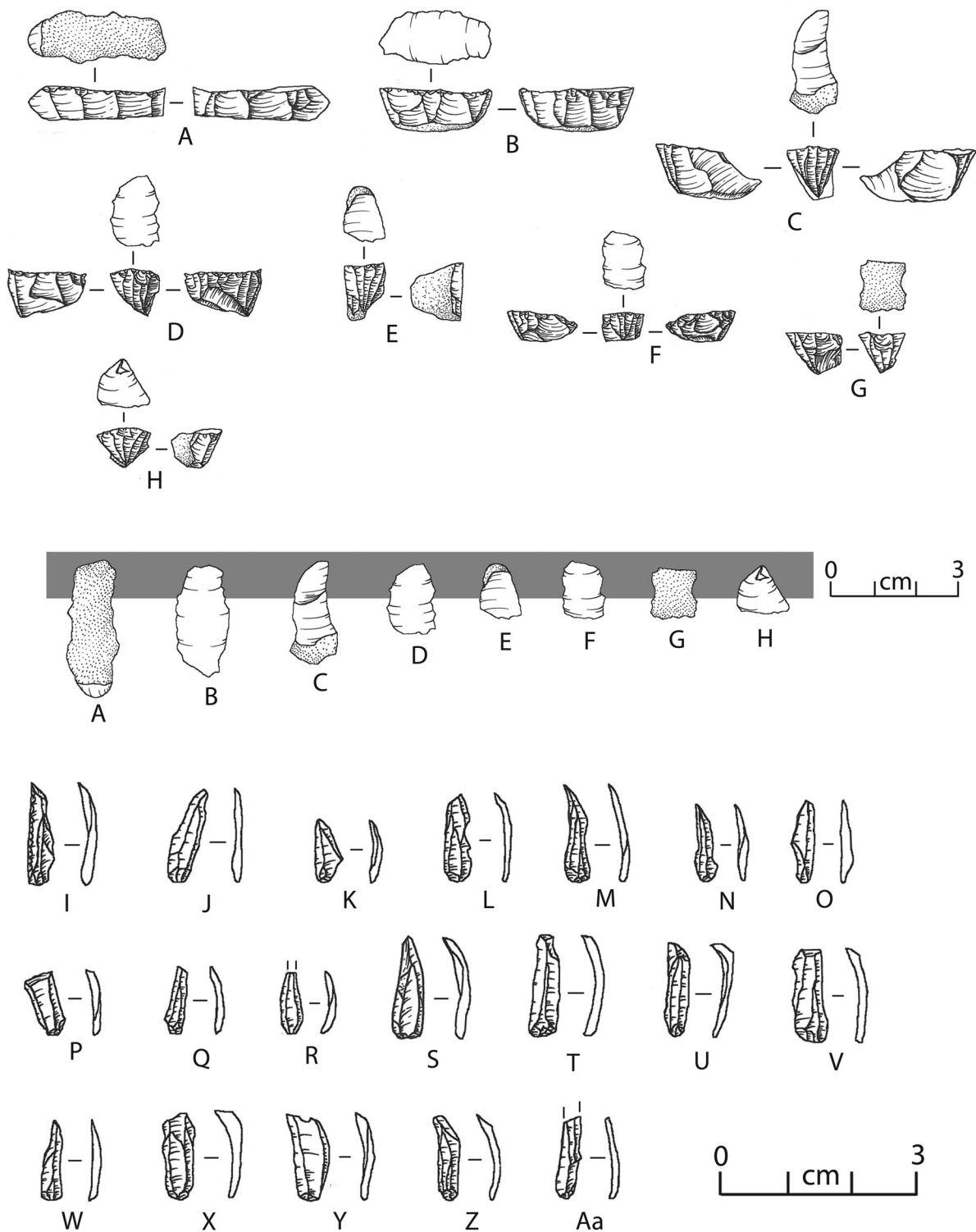
Layer	Raw material	Retouched blades			Unretouched blades			Cores		
		L	W	T	L	W	T	L	W	T
Layer 2	Black flint	8	3	1	9	3	1	11	12	23
	River flint	0	0	0	11	4	1	11	15	26
Layer 5	Black flint	11	4	1	11	3	1	10	11	17
	River flint	13	4	1	12	4	1	12	13	16
Layer 6	Black flint < 20 mm Length n. 4 + 0	13	4	1	0	0	0	14	13	15
	River flint < 20 mm Length n. 20 + 13	14	4	1	13	5	1			
	Black flint > 20 mm Length n. 1 + 0	25	8	2	0	0	0			
	River flint > 20 mm Length n. 2 + 3	44	10	5	20	5	3			
Layer 7 Top	Black flint	20	9	3	14	5	2	5	2	14
	River flint	37	10	3	16	4	1	4	1	19



**Figure 5.** Schematization and examples of the main technological features shown by the microblade assemblages from Shizitan 29. A) Top: the 8-like contour as seen from the platform perspective. The darker greyed region demarcates the rear part of the core that possibly would be placed inside a holding device (also indicated in Figures 4, 6, and 7); the dotted circled region below it demarcates core volume available for production. Bottom: schematization of the differing blade scar sequences seen on the production surface of the cores (lighter greyed area in the center figure). Left: alternated sequence; center: progressive sequence; and, right: semi-progressive sequence. Numbering follows the order of scars from the earliest to the most recent one, until the final scars (Fs) of the sequence: note that Fs usually show a straight profile and that "0" indicates the presence of a scar of a previous progressive sequence not relevant for the next, numbered one. B) Archaeological examples from Shizitan 29 of the schematized blade-scar sequence shown above each (for visibility, not to the same scale). Left: alternated, from Layer 6 (see Figure 4C); center: progressive, from Layer 5 (Figure 6C); and, right: semi-progressive, from Layer 2.

contour is produced intentionally either by removing some small flakes by hitting both lateral sides of the core (producing a symmetrical 8-like shape) or one lateral side of the

core (producing an asymmetrical 8-like shape). This slightly shrinks the striking platform and delimits the exploited volume of the core from its rear part.



**Figure 6.** Shizitan 29, Layer 5 lithic assemblage. A–H) Boat-shaped cores showing an 8-like contour of their striking platform; the grey area demarcates the rear side of the cores possibly inserted in a holding device. I–Aa) Unretouched blade production.

We here suggest that this peculiar way of shaping these cores is related to a new way of firmly holding the core in a device during its exploitation. If this hypothesis is correct, the size of the cores showing a striking platform with an 8-like contour, significantly, may provide us with the threshold for the minimal whole core dimensions needed by the human group to produce their blades. In Layer 6, the minimal size for cores with an 8-like contour—and with no visible knapping accident which could have stopped the production of blades—is never less than 1 cm in length and in width and not less than 1.5 cm in thickness.

A total of 15 boat-shaped cores are identified in the Layer 6 assemblage and represent the first evidence of this core type in the Shizitan 29 sequence. The total number could be higher: although 40 boat-shaped cores were previously reported for this layer (Shanxi University School of History and Culture and Shanxi Institute of Archaeology 2017), we adopt a close-to-data approach, more strictly defining the clearest techno-morphological features of this core type. All 15 boat-shaped cores respect the minimal size observed above. Quite interestingly, boat-shaped cores—a technical innovation—appear with or without an 8-like contour of

their striking platforms and as cores showing the alternated sequence of blade production ( $n = 8$  cores), as well as the progressive sequence ( $n = 5$ ). It was impossible to establish the type of sequence for the remaining two boat-shaped cores. We suggest that the 8-like contour is present on those cores that required shaping for a proper fit in the holding device.

### **Layer 5: the importance of good quality flint**

The analyzed assemblage comprises 81 cores, 10 unbroken retouched blades, 205 unbroken unretouched blades, and 70 retouched flakes (see Table 1, Figure 6). From Layer 5 upward, semi-conical cores disappear, and only boat-shaped cores are present.

The selection of raw material seems to be the key to interpreting the assemblage from this layer (see Table 1). Both River flint (60% of the assemblage) and Black flint (40%) products are generally made from good to very good quality raw materials. Differing from the previous assemblage, cores (29% from River flint and 69.5% from Black flint) are no longer the dominant group, as they represent only 22% of the assemblage.

Very few blades show a retouched edge, while retouched flakes are dominant (see Table 3). All blades show a marginal abrasion, tentatively associated to the hafted side of the tool; most retouched flakes have been transformed into endscrapers (62%) and scrapers (19%). Other flakes show marginal retouch, notches, etc.

A striking homogeneity in length is observed when blades and cores are compared (see Table 2). We suggest this could be related to a very short production of blades which took place on-site just before the abandonment of the cores. Unlike Layer 6, no over-sized blades are found.

Blade profile also shows great homogeneity between River and Black flints. 48% of blades show a left twisted profile; 32%, a straight profile; and, only 12% show a right twisted profile. Unlike Layer 6, the high number of unbroken blades in Layer 5, as well as the homogeneity between River and Black flint observed in other techno-morphological characteristics, allow the exclusion of a sampling bias. If so, the abundance of left twisted and, to a lesser extent, of straight blades, should be seen as a consequence of a technical change in the production mode.

It was possible to define the blade production sequence on 32 cores. Similarly to Layer 6, the alternated and the progressive blade production sequences are both present (see Figure 5A). Both sequences show common features, namely the production of blades with straight profile, which in most cases represent the last scars before the abandonment of the core. Cores showing an alternated blade production sequence (11 cores) share the same features described for Layer 6, with the only difference being a more standardized exploitation of the core volume represented by the coincidence of the last scar of a blade with right profile with the most prominent area of the striking platform (usually this area is located at the center of the striking platform).

Much more interesting is the increased presence of the progressive sequence. Here, the semi-progressive subtype is dominant (12 cores) vs. a truly progressive sequence (9 cores). In the semi-progressive subgroup, each core produces several blades with a straight profile (averaging between 3–4 blades per core); when compared with Layer 6, the semi-

progressive sequence in Layer 5 is more standardized, as the earliest scar of the sequence is always on the extreme side (left or right) of the core. Another relevant characteristic of Layer 5 is the increased number of cores showing the 8-like contour of their striking platform ( $n = 33$  cores, or 40% of the cores) (Figure 6A–H).

### **Layer 2: standardization of the blade production sequence**

The analyzed lithic assemblage comprises 62 cores, 4 unbroken retouched blades, 155 unbroken unretouched blades, and 35 retouched flakes (see Table 1, Figure 7).

In this layer, River flint becomes the dominant raw material exploited (69% of the sample), while Black flint represents 29% of the sample. Cores made from these two raw materials are quite balanced as a percentage of their raw material: 25% of River flint items are cores and 21% of Black flint items. However, blades made from River flint reach 70% of the total count of blades.

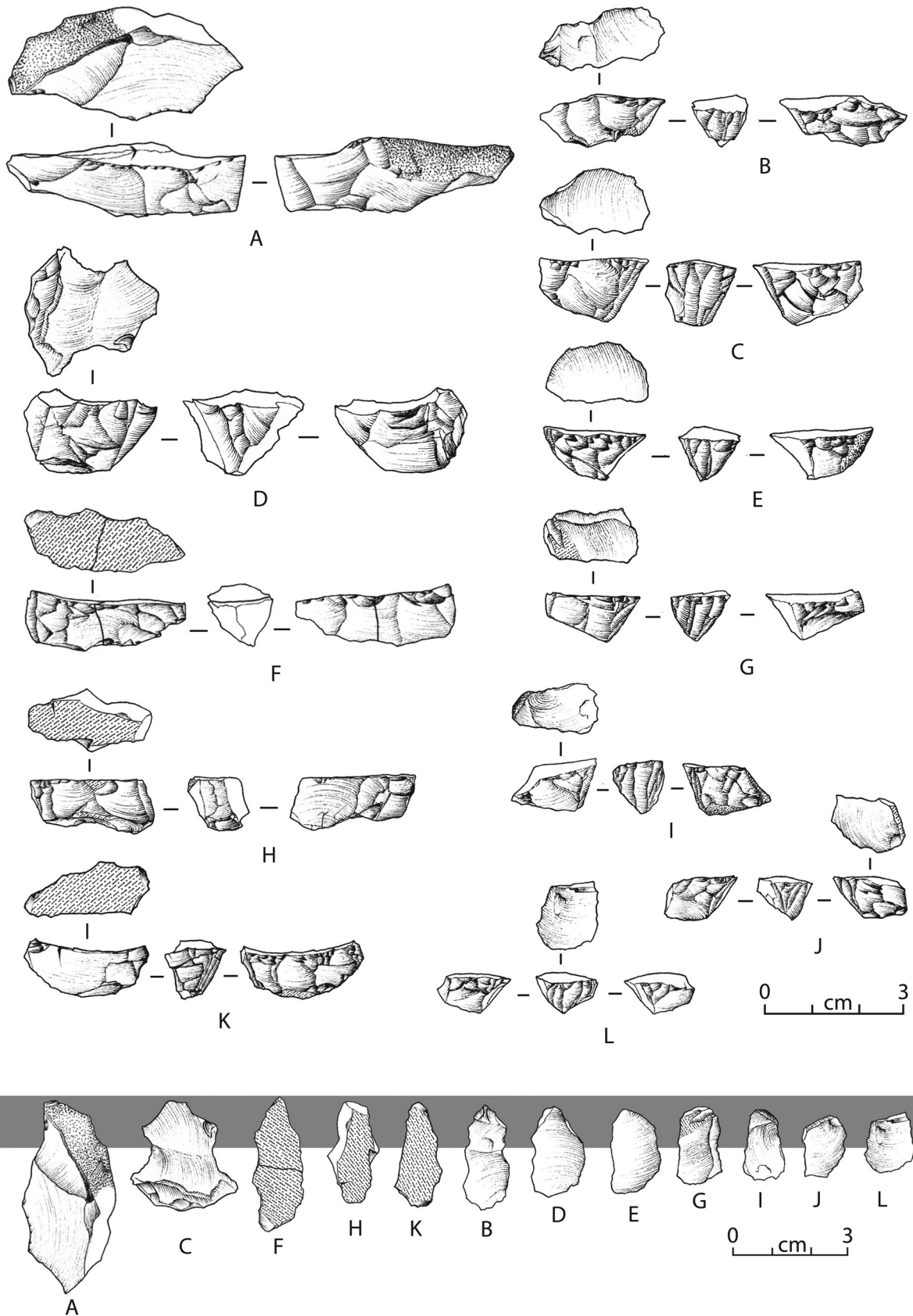
Only four blades made from Black flint were retouched (two with marginal steep retouch, one into an endscraper, and one shows a notch). Among the flakes, endscrapers (48% of the retouched flakes) and scrapers (40% of the retouched flakes) are the most common retouched tools (see Table 3).

Despite a slight increase in the average width of blades made from River flint in comparison with blades made from Black flint, when blades and cores are compared, the assemblage shows great dimensional uniformity, like that observed in Layer 5 (see Table 2).

Blades with a straight or twisted left profile are equivalent (45% and 38% of blades, respectively). Unlike earlier layers, the low presence of twisted right blades cannot be explained by the reduction sequence shown by the cores. In fact, as we have already seen in Layer 5, the alternated sequence and the two sub-groups of the progressive sequence are present with the same technical characteristics we have previously seen. The difference in Layer 2 is the high level of standardization observed in the progressive sequence, where, for instance, the last blade is always represented by the fourth scar and by a straight profile. Similarly, in the semi-progressive sequence, the last scar is usually represented by the third one in the sequence and is always with a straight profile. In this layer, almost all the cores may be considered in traditional terms as boat-shaped, and among them, 23 cores (37% of the cores) feature an 8-like contour of their striking platform (see Figure 7).

## **Discussion**

Pressure production technology is a revolutionary behavioral change marking the LUP in North China (Morgan, Barton, and Bettinger 2019; contributions in Kaifu et al. 2015; Bar-Yosef and Wang 2012; Norton and Jin 2009), and it appears with the production of the blades commonly typologized as microblades. Several hypotheses have been suggested regarding its origins, including direct evolution from earlier blade assemblages found in the Altai or Mongolia (Keates, Postnov, and Kuzmin 2019; Kuzmin, Keates, and Shen 2007) or a local development from preceding advanced core-and-flake assemblages, particularly from anvil (i.e., bipolar) technique flake and shatter (Barton, Brantingham, and Ji 2007;



**Figure 7.** Shizitan 29, Layer 2 lithic assemblage. A–L) Boat-shaped cores showing an 8-like contour of their striking platform; the grey area demarcates the rear side of the cores possibly inserted in a holding device.

Brantingham et al. 2001; Madsen et al. 2001). None of these consider the significant differences existing in operations and technical knowledge between productions based on direct or indirect percussion vs. those employing pressure production, which involves technical devices and tools, heat-treatment, and thus a complex, shared knowledge of the methods and

techniques required to exploit it (see Gómez Coutouly 2018). Others attribute the appearance of this technology in North China to a re-colonization process during and after the LGM led by human groups who brought in a new technology (Wang 2018; Goebel 2002), but this only shifts the geographic location of the problem of origins and does

not offer an explanation for the technological evolution of pressure production.

The earliest appearance of pressure production in Shizitan 29 is found in Layer 7 Top at about 26–24 kya CAL B.P. Using the terminology adopted by the traditional literature, semi-conical and prismatic cores suddenly appear in association with a core-and-flake industry that includes anvil technique (Song et al. 2019). Following our perspective, however, the semi-conical or other morphologies must be considered technically rather than by final shape of the core. Technically, the semi-conical core morphology is explained by: 1) the exploitation of cores showing a flat—cortical or not—rear side opposite to the surface from where the blades are produced; 2) the exploitation of one of the long sides of the core; and, 3) the need to exploit as much as possible the entire volume of the core while still only exploiting one side. These features lead to a morphological consequence: the reduction of only one of the three dimensions of the core, namely the thickness, and this results in the abandonment of cores roughly showing a squared or, more rarely, triangular working surface.

Furthermore, as mentioned above, pressure production is a very complex adaptation to the raw material involving several factors. One of the most important factors for successful pressure production is the necessity to force the cores to remain in a very stable position (i.e., to restrict movement of the core) during the production activity. In the case of the semi-conical cores, we tentatively assume the core is held in one hand, which generates a certain degree of inaccuracy because the stable position that is needed cannot be maintained well; this could explain, for instance, the presence of some cores producing elongated blanks or irregular blades, the large size of some abandoned cores, and the loss of suitable blanks because of fractures, reflections, and other accidents that may occur during this hand-held production. The contemporary presence of several other types of blade cores, such as the prismatic cores, is difficult to explain here and, even if rare, is an issue that we wish to provide some explanations about in the future.

Layer 6 of Shizitan 29 provides the most intriguing assemblage. Here, along with the presence of semi-conical cores, another type of core—called the boat-shaped core in the traditional literature—makes its first appearance (in what may be its earliest-known appearance in China). These cores are technically very different from the semi-conical ones. They are not conceived to maximize the exploitation of as much volume of the core as possible (as semi-conical cores may have been), but rather, they are conceived to maximize the efficiency of the production of regular blades with a straight profile. We furthermore suggest here that the change of the core shape should be directly linked to the introduction of a new core holding device. (Note that the use of such devices has already been suggested for the later-appearing Asian wedge-shaped cores by Tabarev [2012, 1997], who was influenced by Callahan's [1985] reproduction experiments of Danish Mesolithic microcores, which are larger than, but similar to, Asian wedge-shaped cores).

Because of this, our attention must shift from the working surface where the blades are struck off to the rear side of the core, where evidence for the use of a holding device would be found, and this reveals an interesting story: if such a device is employed to keep the core in a very stable position during production, it must hold the rear part of the core, and

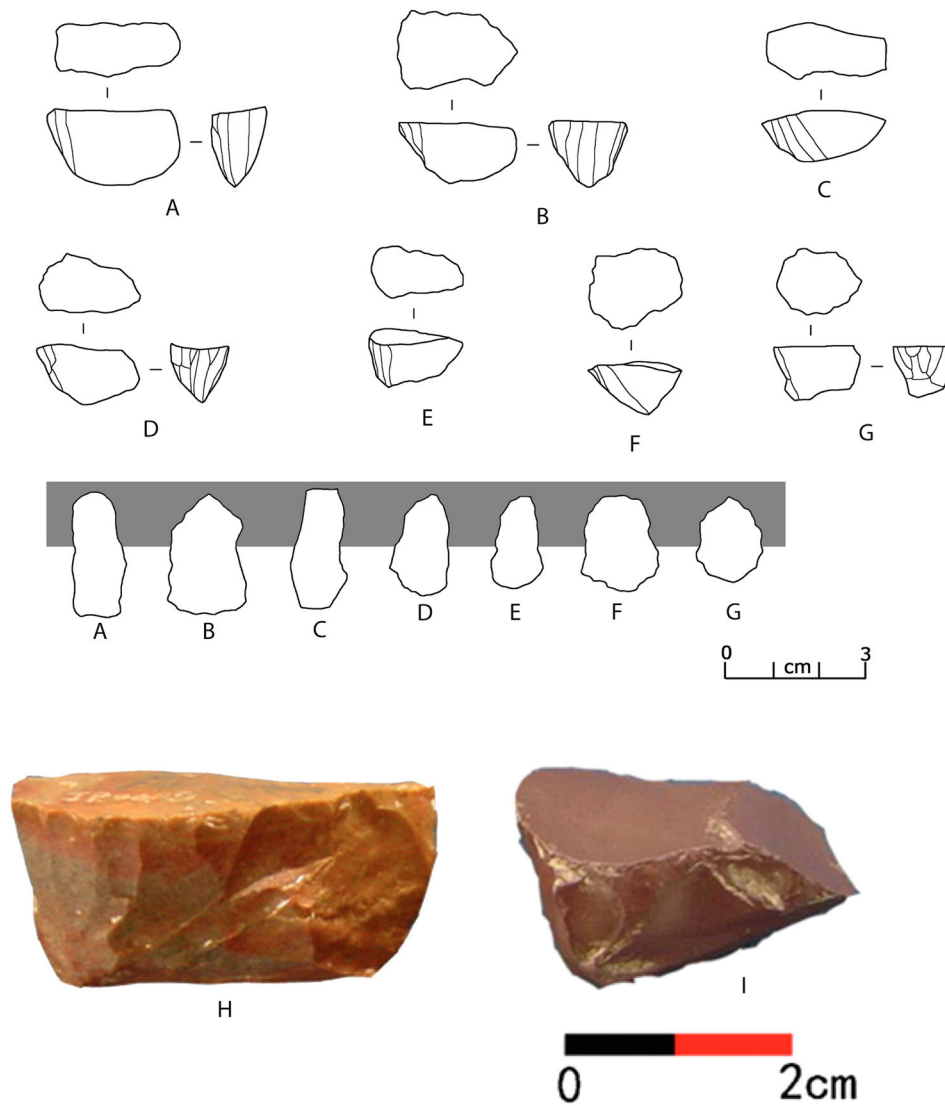
because of this, cores must be prepared in a very standardized shape—in order to be properly fitted in the device—before the start of the production of regular blades. Insertion in a holding device also means that a percentage of the core mass cannot be exploited, as it must be used to hold the core in the device; in other words, only the core volume external to the device can be exploited and transformed into blades. The evidence for this is the appearance of what we are calling the 8-like contour of the striking platform when viewed from above: this feature, that we observe first on cores in Layer 6, represents the boundary between the rear of the volume, which would be placed inside the holding device, and the remaining exposed and potentially exploitable part of the core. A similar core techno-morphological shaping is discussed recently by Gryba (2021, and see references therein): it was previously noticed and either attributed to inadvertent crushing or other forms of unintentional damage from the use of a holding device or hard anvil during blade removal (as it was found in combination with other core damage), or, as Gryba (2021) argues, should be tied in some ways to preform preparation. We explicitly argue that the 8-like contour of the core platform is purposefully knapped and linked to the use of the holding device.

Quite interestingly, Callahan (1985) explains how, in his replication experiments, using a core holding device allows him to produce microblades until the core is just 1 cm long, which would be the minimum length to be able to remove microblades. This is a comparable dimension to what we have shown for the 8-like contour of the Shizitan 29 cores (note the grey areas in Figures 4–7).

The conclusion that the 8-like contour is related to a new technique of bracing the core in a holding device during its exploitation can and should next be tested at other North China sites. Although appropriately drawn illustrations and photographic images of cores tend to be lacking in the traditional typological literature, some interesting details clearly resembling those related to the 8-like contour as we have identified it at Shizitan 29 may be detected in boat-shaped cores drawn in reports for other sites. Although not exhaustive, we show examples of these from nine other LUP sites and localities in North China in Figure 8.

We further point out that the production of blades from a core that was fitted in some sort of holding device or brace will provoke a different exploitation pattern (i.e., what we label the progressive and semi-progressive sequences). This is because once the core is prepared and inserted in the holding device and the first regular blade is obtained from one side of the core, the production of a series of regular blades may start and continue without any further need to stop the production in order to re-prepare the lateral convexities of the core. Such technological innovations can also next be looked at in terms of associated changes in lithic production and function, such as, for instance, the appearance of the boat-shaped cores in association with a unique presence of retouched blades in Shizitan 29 Layer 6.

In the later Layers 5 and 2, the standardization of this production continues and reaches its highest efficiency, producing some left twisted blades in each series of blades in order to maximize the production of blades with a straight profile, but this, however, comes at the cost of a reduction in blade length. In this regard, the selection of natural blanks that provide a raw morphology already adapted to being transformed into a boat-shaped core is also observed in



**Figure 8.** Some examples of cores from other Late Upper Palaeolithic sites in northern China likely showing technical features of the 8-like contour. These are all cores that are traditionally identified as boat-shaped cores. Top: 8-like contour cores redrawn based on line illustrations in reports. Center: the same seven cores with the gray band showing the area of the rear volume of the core that we hypothesize would be placed inside a holding device during pressure production of blades. A) Dakanzi site (Jilin) (98Z DD: 13); B) Longwangchan (Shanxi) layer 4 (2006 1 ③: 6461); C) Donghuishan (Hebei) (d019); D) Erdaoliang (Nihewan Basin, Hebei) (RDL:148); E) Tingsijian (Hebei) (Ti:37); F) Xiachuan site Liushuiyao Locality (Shanxi) (YQL2016T1-4④A3:9); G) Xuchang site (Henan) layer 5 (8L0388). Redrawn based on the following: A) Chen 2001, fig. 3, no. 2; B) Zhongguo and Shaanxi 2021, fig. 4-77, no. 2; C) Hebei Sheng Wenwu Yanjiusuo 1989, fig. 6, no. 1; D) Li, Ren, and Li 2016, fig. 5, no. 1; E) Li, Wang, and Yan 1992, fig. 3, no. 6; F) Shen, Wang, and Du 2020, fig. 4, no. 2; G) Li, Li, and Kato 2014, fig. 4, no. 4. Bottom: Color images of cores from other sites with features of the 8-like contour. H) Dingcun Locality 77:1 (also called Chaisi) (Shanxi) (P0009), from Chen et al. 2013, fig. 5 (also see Shanxi Institute of Archaeology 2014, color pl. 21 no. 4, fig. 8.8, no. 3). I) Xiachuan site (Shanxi), from Chen et al. 2013, fig. 3.

these upper layers. For instance, small, elongated raw blocks of Black flint or half pebbles of River flint may play a relevant role in this regard; this could be a reason for the larger presence in Layer 2 of good quality pebbles of River flint, which was available in the surrounding area of the site.

### Pressure production beyond Shizitan 29

The techno-functional approach we demonstrate at Shizitan 29 provides new, behaviorally-oriented insights into the development of the technical features of pressure production in LUP North China. The diachronic dataset from the site also allows better behavioral—rather than arbitrary typological—understanding of its evolution. The approach can and should be applied beyond the site in order to reveal the origins and spread of these features of pressure production, and thus the overall evolutionary pathways of this technology through time and space. At present, it is quite difficult to compare the technical evolution of pressure production

observed at Shizitan 29 to that of other sites. The lack of well-dated sites with long stratigraphic sequences that can provide a clear line of successive lithic assemblages is one of the main reasons. At present, the Shizitan 29 evidence may only be partially compared to some sites in North China.

For instance, recent dating for Xishahe (Nihewan Basin) of ca. 27 kya CAL B.P. (from layer 3B) shows that it contains what can be considered one of the earliest microblade assemblages in North China (Guan et al. 2020). As this age is close to that for Layer 7 Top of Shizitan 29, it is quite interesting to note that the variability in core morphology observed in Shizitan 29 (Layer 7 Top) seems to be duplicated at the slightly older Xishahe site: “although the Xishahe microblade cores are well-shaped with platform preparation and successfully yielded parallel-sided flakes, the overall morphology of the cores is variable, lacking a high-level of standardization” (Guan et al. 2020, 44). Moreover, similarly to the earliest assemblages at Shizitan 29, no boat-shaped cores are

reported for Xishahe (Guan et al. 2020). Another feature linking this site to Shizitan 29's earliest pressure production in Layer 7 Top, clearly seen in the drawn microcores in figure 3 of Guan and colleagues (2020, fig. 3), is the presence of microcores with the same technical features as the semi-conical cores in Shizitan 29. Finally, the abrupt technological change observed in Xishahe between the older layer 3B, where the "microblade-free lithic assemblage resembles the so-called core-and-flake or flake-tool industry" of North China (Guan et al. 2020, 45), and layer 3A, where the microblade cores have been found, strongly resembles the technological change between Layer 7 Base and Layer 7 Top in Shizitan 29.

Recent work on the Xiaobaihuageliang locality of the Xiaochuan site in Shanxi (Du et al. 2019) provides stratigraphical and chronological support for evidence of a trend partially comparable to Layers 8 and 7 of Shizitan 29, with an early cultural layer with a simple core-and-flake industry said to date to pre-30 kya CAL B.P. and then a blade-microblade culture appearing ca. 27–25 kya CAL B.P. This later cultural layer is said to contain multiple types of cores, including boat-shaped, semi-conical, conical, and wedge-shaped, together with blade-blank or flake-blank tools: however, the report combines into one unit at least six sublayers in its tally of cores for this cultural layer, so the chronology of their appearance needs to be closely evaluated to see if this is truly an early occurrence of this phenomenon.

The Youfang site in the Nihewan Basin, excavated in 1986 (Nian et al. 2014), is also considered to have one of the earliest microblade assemblages. Three OSL samples with large errors from its 1.2 m thick cultural layer within a 28 m<sup>2</sup> excavated area were re-dated to 26.6 ± 2.1 kya (L2304, 2.1 m depth), 25.1 ± 2 kya (L2305, 2.5 m), and 29.2 ± 2 kya (L2306, 2.9 m) (Nian et al. 2014, 119). Results define a time range of the cultural level that begins at a time older than Shizitan 29 (Layer 7 Top) but ends at possibly a slightly younger date; unfortunately, no precise provenience information is provided to indicate where cores and blades were found or their associations with the OSL samples. The lithic assemblage provided only 13 microcores and 92 microblades found in association with "697 stone artifacts and 2675 chunks or debris" (Chen 2007, 16; Xie and Cheng 1989, 59). Drawings of some of the cores (see Xie and Cheng 1989, fig. 3) show the presence of what we can determine are actually wedge-shaped cores (nos. 2 and 3) and potentially semi-conical cores (nos. 4 and 5; although Xie and Cheng [1989] identify these as prismatic cores), as well as a boat-shaped core (no. 1), but the chronological relationships between the cores cannot be assessed without stratigraphic information.

Longwangchan locality 1, located at a direct distance less than 19 km from Shizitan 29, across the Yellow River in Shaanxi, produced 174 microcores over a three-layer stratigraphic sequence of similar dating and with what we hypothesize could be parallel technological developments to Shizitan 29, although the necessary technological descriptions and illustrations are lacking (Zhongguo and Shaanxi 2021; Wang 2014, fig. 2; Zhang et al. 2011, figs. 2, 3; Yin and Wang 2007). While the bottom of Longwangchan layer 6 has OSL dates of 29 kya CAL B.P., a potential erosion event occurred before the deposition of the top of layer 6, estimated by radiocarbon and OSL to date to 26 kya CAL B.P., which should be used as the more reliable estimate for dating the microcores from this layer, for which no exact provenience information is given. Artifacts from layer 5

are estimated as dating to ca. 25 kya CAL B.P. and from layer 4 to 25–21 kya CAL B.P. (Zhongguo and Shaanxi 2021, 360; Zhang et al. 2011, 1546). Since a clear technological description of the different core types, as well as the proveniences and the exact stratigraphic sequence of their appearance, are not available, we can only argue that the sequence of semi-conical cores appearing earlier than boat-shaped cores at Shizitan 29 is likely also supported by the Longwangchan data, with the earliest clear examples of boat-shaped cores appearing in Longwangchan layer 4, which roughly corresponds chronologically to Shizitan Layer 6, where the first boat-shaped cores also are found. Note that while the Longwangchan report identifies one boat-shaped core in layer 5 (Zhongguo and Shaanxi 2021, 224, fig. 5-93:4, pl. 195:4), neither the drawing nor the photo of the specimen allow the reader to identify this core as boat-shaped.

A recent synthesis of the localities of the Shuidonggou site (Li et al. 2019, 35) highlights the early presence of an "intrusive" IUP in North China, with Levallois and non-Levallois blade production, between 46–33 kya CAL B.P., followed by a local advanced core-and-flake industry until ca. 27 kya CAL B.P. These, however, are followed by a long occupation gap until after the Younger Dryas, when the earliest presence of pressure production at Shuidonggou appears, dating no earlier than 10.5 kya CAL B.P. (at locality 12). Thus, no direct connection can be made between the earlier technologies and pressure production. The occupation gap is explained as due to an abandonment of the Shuidonggou region during LGM arid conditions, with forager groups unable to return until the warmer, wetter conditions of the early Holocene (Li et al. 2019, 128; Liu et al. 2008). Interestingly, the hunter-gatherers who migrated to Shuidonggou in the Holocene brought with them blade pressure production technology with mainly wedge-shaped cores (but also pyramid and cylindrical cores) (Li et al. 2019, 128). This reoccupation of Shuidonggou is thus one aspect of these later, broad dispersals of evolving pressure production technology into many different regions and environmental zones across northern East Asia and into the New World from the Terminal Pleistocene through the early Holocene.

Indeed, the presence of the highly standardized core morphologies dating to the last several millennia of the Pleistocene and the beginning of the Holocene, and that mark the end of the Upper Palaeolithic in North China, could be seen as a technological achievement that developed from the trend toward highly standardized cores described for Layer 2 at Shizitan 29. To confirm this trend, we should expect to find in later sites cores showing an extremely high level of pressure production and an increasing trend towards a rounded volumetry. One such example where these trends could be analyzed could be provided by the Lingjing site in Xuchang, Henan (Li and Ma 2016; Li, Li, and Kato 2014), where pyramidal types of cores form the largest proportion of the assemblage, dating to about 13 kya CAL B.P.

## Conclusions

The stratigraphic sequence at Shizitan 29 provides the rare dataset that allows observation of an inner evolution of pressure production in North China beginning from an early stage of its development during the LGM. We suggest using the more meaningful term "pressure production" for the traditionally-termed "microblade technology" to move away

from the dominance of morphological typology, its inability to answer behavioral questions, and its inherent weaknesses, including arbitrary classificatory criteria and misidentifications. We advocate here for the application of techno-functional approaches to understand pressure production behaviorally, meaning to understand decisions (such as technical objectives) and learning processes that can provide critical insights into the development of this technology across space and time. The data and approach we report above, while not exhaustive, do provide behavioral insights that have been hidden until now into the development of pressure production in North China over the entire sequence of the Late Upper Palaeolithic and have allowed us to detect a series of previously unrecognized major changes and technical achievements characterizing the production of blades by pressure during this period: these should be further investigated using this techno-functional approach at other sites.

Since we see the earliest pressure production of blades, which suddenly appears in Level 7 Top at Shizitan 29, as intrusive, techno-functional studies will need to be applied to lithics from other early sites before the origins of this technology, particularly how it may relate to earlier productions, can be understood. Although we cannot identify the origins of this technology at the site because it is intrusive, the Shizitan 29 evidence allows us to set a current baseline for the appearance of true pressure production in North China to at least 26/24 kya CAL B.P. During the following millennia, Shizitan 29 data show a clear, likely local, evolution of pressure production towards higher levels of standardization in terms of final blanks (short, straight profile blades), as well as of cores (from the core morphology traditionally called semi-conical to that called boat-shaped). Shizitan 29, as such, at present represents the starting point for the development and spread of this technology.

A key outcome of our study is thus the recognition, beginning from Level 6, of the 8-like contour of the striking platform and its entanglement with core-holding devices, the maximization of the production of blades with a straight profile, and the development of the alternated and progressive sequences of blade production. Although these relate to the appearance of the traditionally-termed boat-shaped cores, this recognition required behavioral considerations of all stages of the reduction process rather than classification of a final, abandoned core morphology.

Lastly, the behavioral dimensions of pressure production garnered through the techno-functional approach demonstrated here can allow lithic assemblages across northern East Asia to play more useful roles in understanding changes in site function, mobility patterns, and landscape exploitation strategies during the Late Palaeolithic—including better realizations of hunter-gatherer adaptations to the LGM and the Terminal Pleistocene through Early Holocene transitions to the Neolithic, sedentism, and plant cultivation.

## Geolocation Information

Shizitan 29 site, Jixian County, Shanxi, China (中国山西省吉县柿子滩29遗址): 36.0483333°, 110.5894444°

## Endnotes

1. Unless otherwise expressed, the term “retouched” here and below refers to the intentional retouch of a blank.

## Acknowledgments

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## Competing Interests

The authors declare no competing financial or non-financial interests.

## Data Availability

All relevant data are within the manuscript and its figures. The analyzed lithic materials are stored in the Palaeolithic Laboratory storage facilities of the Shanxi Provincial Museum. Storage is by site/locality name and excavation context (layer), with each artifact individually numbered within the site’s collections. Access to the collection may be made through application to the Director’s Office of the museum at the following address: Office of the Director, Shanxi Provincial Museum, Binhe West Road No. 13, Taiyuan, Shanxi, China. Tel: + 86-0351-8789017. Website: <http://www.shanximuseum.com>, email: [shanximuseum@163.com](mailto:shanximuseum@163.com).

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