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Raw Material Quality and Prepared Core Technologies in Northeast Asia

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The design and assembly of lithic toolkits is mediated by a number of factors including the abundance and quality of raw materials available. In general, low raw material abundance and high raw material quality are thought to lead to formal tool designs, whereas high raw material abundance and low raw material quality lead to informal designs. Low raw material quality is seen as the overriding factor producing informal tool designs, even where low raw material abundance would favour formal designs.

In North China, the predominance of simple flake and core technologies, based on relatively poor quality raw materials, and the near absence of sophisticated prepared core technologies seems to corroborate the importance of raw material quality in toolkit design. Recent studies of a late Pleistocene lithic assemblage from the Lower Grotto at Tsagaan Agui cave, Mongolia, suggest however that raw material quality is not an absolute constraint on the development of sophisticated core reduction strategies. Levallois-like and other prepared core forms based on large flake blanks are conspicuous in the Lower Grotto assemblage, despite the poor quality of raw material available at the site. Contrary to expectations, these core forms appear to have developed directly in response to poor raw material quality. The implication is that raw material quality alone cannot explain the apparent technological simplicity of the North Chinese Middle and Upper Paleolithic.

Keywords: RAW MATERIAL QUALITY, TECHNOLOGICAL DESIGN, MONGOLIA, CHINA, MIDDLE PALEOLITHIC, ARCHAEOLOGY.

Introduction

Although Siberia and Mongolia are geographically adjacent to North China, there are striking differences in the Middle and Upper Paleolithic raw material economies of the two regions. In Mongolia and Siberia, sophisticated prepared core technologies such as Middle Paleolithic Levallois cores and Upper Paleolithic blade cores were used extensively (Okladnikov, 1965, 1978, 1981; Vasil'ev, 1992, 1996; Fairservice, 1993; Goebel, Derevianko & Petrin, 1993; Goebel & Aksenov, 1995; Derevianko & Markin, 1997; Derevianko, 1998; Derevianko & Petrin, 1995*a*, *b*). In North China, however, only a handful of sites contain Middle or Upper Paleolithic prepared core technologies (Boule *et al*., 1928; Li Yanxian, 1993; Lin Shenglong, 1996; Yamanaka, 1995). Rather, generalized core and flake technologies dominate the North Chinese archaeological record (Wu Rukang & Olsen, 1985; Miller-Antonio 1992; Schick, 1994; Lin Shenglong, 1996; Gao Xing, 1999).

The apparent technological and typological "simplicity" of the North Chinese Paleolithic record has been explained in a number of ways including: (1) differences in the historical biogeography of hominid populations having radically different behavioural adaptations (Swisher *et al*., 1994, 1996; Huang Wanpo *et al*., 1995; Larick & Ciochon, 1996; see also Chen Tiemei & Zhang Yinyun, 1991; Foley & Lahr, 1997); (2) differences in cultural or ethnic traditions (Movius,

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1944, 1948; Schick, 1994; but see Huang Weiwen, 1993); and (3) differences in the stone raw materials available for tool manufacture and use (Movius, 1948; Pope, 1989; Clark, 1993; Schick, 1994, pp. 586–589). This last explanation has attracted much attention in recent years with the realization that differences in stone raw material abundance and quality may place strict constraints on archaeological variability (Goodyear, 1989; Inizan, Roche & Tixier, 1992; Kuhn, 1992, 1995*a*; Luedtke, 1992; Andrefsky, 1994; see papers in Ellis & Lothrop, 1989; Roth & Dibble, 1998). Stone raw materials are abundant in North China, but generally are of low quality. Quartzite, sandstone, limestone, hornfels and a handful of other intractable lithologies form the bulk of the raw materials found at North Chinese Paleolithic sites (Wu Rukang & Olsen, 1985; Chen Enzhi, 1990; Jia Lanpo & Huang Weiwen, 1991; Li Yanxian, 1993; Schick & Dong Zhuan, 1993; Lin Shenglong, 1996). It is suggested that these poor quality raw materials were mechanically unsuitable for manufacturing sophisticated prepared core technologies, and that Pleistocene hominids thus abandoned complex core reduction strategies in favour of simple flake and core technologies (or other raw materials such as bamboo) that required less overall investment in procurement, manufacturing and maintenance activities.

In this paper, we present evidence collected from a deeply stratified Paleolithic cave site, Tsagaan Agui, in the northern Gobi desert, Mongolia, which suggests that late Pleistocene hominids in certain areas of northeast Asia successfully applied sophisticated prepared core technologies despite the poor quality raw materials available to them. The Lower Grotto assemblage and lower stratigraphic layers in the main chamber at Tsagaan Agui contain two related types of prepared cores. The core reduction strategies are reminiscent of classical Levallois cores (Boëda, 1990, 1995; Van Peer, 1992; see also papers in Dibble & Bar-Yosef 1995), but with significant strategic modifications aimed at circumventing the poor quality of chert available at the site. Prepared cores in both the Lower Grotto and lower component of the main chamber at Tsagaan Agui are based on large flake blanks with smooth, convex ventral surfaces and steep lateral and distal margins. The use of large flake blanks as foundations for prepared core technologies has two distinct advantages over cobble blanks when raw material quality is especially poor. The production of large flake blanks allows for rapid assessment of the quality of any given piece of raw material by exposing the interior of selected cobbles, and also provides volumetrically ideal (*sensu* Boëda, 1990, 1995) starting points for systematic core preparation and removal of primary flakes. The innovations in core technologies represented at Tsagaan Agui suggest that poor raw material quality alone is insufficient for explaining the near absence of prepared core technologies in North China.

		Raw material quality	
		High	Low
Raw material abundance	High	Formal and informal technology	Primarily informal technology
	Low	Primarily formal technology	Primarily informal technology

Figure 1. A model for the relationship between stone raw material abundance, raw material quality and the design of lithic toolkits. Redrawn after Andrefsky (1994, p. 30).

The Constraints of Raw Material Quality

The design and assembly of lithic toolkits is thought to play an important role in mobile hunter-gatherer adaptations (Kelly, 1983, 1992; Nelson, 1991; Kuhn, 1994, 1995*a*; Shott, 1996). Investment of time and energy in the design of lithic toolkits is seen as a form of risk management associated with procuring both stone and food resources distributed at disparate points on the landscape (Binford, 1979; Torrence, 1989; Cashdan, 1992). Lithic toolkits may be designed to satisfy a range of demands, including technological reliability, transportability, flexibility, maintainability and versatility (Bamforth, 1986; Bleed, 1986; Nelson, 1991, p. 66; Bousman, 1993; Kuhn, 1994; Dibble, 1995). Technological design is seen therefore as an optimization problem of maximizing one or more of these design dimensions, while minimizing the rate of raw material consumption. Such design concerns influence both primary core reduction strategies and patterns of tool retouch (e.g. Dibble, 1995; Kuhn, 1992, 1995*b*; Van Peer, 1992).

Both raw material quality and abundance constrain the design and assembly of mobile toolkits, although in fundamentally different ways (Figure 1) (Goodyear, 1989; Andrefsky, 1994). Variability in raw material abundance leads to differences in the design and assembly of toolkits primarily as a function of energetic constraints. Technologies based on rare or exotic raw materials are expected to be designed to maximize core or tool use-life.* Maximizing tool use-life cuts down on the costs of "expensive" long-distance raw material procurement forays (but see Binford, 1979). Formal core designs that maximize the ratio of edge length to volume of raw material, or tool designs that guard

*Distinguishing exotic or non-local raw materials from "garden variety," local raw materials is often problematic since the sources are frequently unknown.

against breakage, for example, may be technological responses to low raw material abundance. In contrast, minimizing raw material waste is not a major concern where raw materials are abundant in the environment. In such contexts, most toolkits are casual and display little effort to extend tool use-life. At the same time, abundant raw material provides a certain degree of flexibility to design formal toolkits if the need arises.

No such flexibility is postulated for the relationship between raw material quality and technological design. Regardless of abundance, poor quality raw materials necessarily lead to informal technologies. The assumption is that the ability to execute formal technological designs is severely limited by the quality of the raw material. Toolkits based on high quality raw materials are thought to be easier to design because fracture is easier to control (Goodyear, 1989, p. 3; Luedtke, 1992). In contrast, toolkits based on poor quality raw materials are more difficult to design because fracture is unpredictable and results in severe, irreparable errors during reduction. Even where low raw material abundance would encourage formal technological design, raw material quality is thought to be the overriding factor constraining lithic technological organization.

It is important to recognize that raw material quality is not a simple qualitative variable, but rather is composed of several potentially quantifiable properties, including raw material package size, package shape, and mineralogical structure (Inizan, Roche & Tixier, 1992; Luedtke, 1992; Whittaker, 1994; Roth & Dibble, 1998). In theory, raw material package size directly influences the gross efficiency of a given tool or core technology (Baumler, 1995, p. 12). As raw material package size decreases the amount of "tolerated waste" resulting from tool or core preparation must also decrease; at some point preparation becomes more a hindrance than an optimal solution for achieving technological designs because preparation generates too much waste. Thus, increasingly conservative tool or core preparation is predicted as initial raw material package size decreases (e.g. Kuhn, 1995*b*).

The effects of raw material package shape are not entirely independent from those of package size. Many of the fundamental mechanical constraints governing stone fracture are dependent upon raw material package shape (see Cotterell & Kamminga, 1979; Whittaker, 1994, pp. 91–94), although with increasing package size there is greater flexibility to apply reduction strategies to circumvent initial raw material shapes. For example, it is difficult, though not impossible, to initiate flake fracture on a piece of raw material with no natural angles less than 90° (e.g. a perfect sphere). It is possible, however, to produce a prismatic blade core from a sphere of raw material given sufficient starting material to allow for abundant initial waste. But, as initial package size decreases such flexibility also decreases. Initial package shape is most important in determining the course of tool or core reduction for small raw material packages.

Raw material quality is most commonly associated with the mineralogical structure and purity of raw material. A high-quality raw material possesses little or no crystalline structure and contains few impurities, such as fossils or vugs that would interfere with the direction of applied force. In this sense, raw material quality can be defined by identifying four quantifiable properties that characterize the workability of the material: (1) percent crystallinity, (2) average crystal size, (3) range in crystal size, and (4) abundance of impurities, such as fossils, vugs and veins of secondary crystals (Figure 2). These four variables are readily quantifiable through the use of an optical microscope or by visual inspection. Although the relative importance of each of these variables needs to be determined through controlled experimentation, even a basic quantitative analysis of these four variables can greatly improve the assessment of raw material quality.

Common lithic raw materials include obsidian, chert, basalt, and sometimes fine-grained metamorphosed sedimentary rocks such as limestone or hornfels. Percent crystallinity, average and range of crystal size, and abundance of impurities vary widely both within and between these raw material types. Amorphous raw materials (i.e. lacking a crystalline structure) such as obsidian are generally considered ideal for lithic production. Obsidian, however, often contains dispersed crystals or areas of crystalline material that can interfere with flaking. Chert typically has some degree of crystalline structure, although crystal size can vary considerably among cherts and even within an individual sample. Chert also often contains fossils or void spaces that interfere with flaking. Basalt generally has a variety of crystal sizes, with a fine-grained crystalline matrix interrupted by much larger grains of feldspar or olivine crystals. Basalt also usually has an abundance of vugs that can interfere with flaking.

At Tsagaan Agui, where raw material is abundant but of poor quality (discussed below), the prediction is that lithic technological designs will be informal. Indeed, the poor quality of raw material available at the site is expected to prevent the development of formal technologies, even where specialized activities and high foraging mobility would seemingly require the formal design of cores and tools. The following analyses concentrate on quantitatively assessing the effects of raw material quality on core reduction strategies and conclude by presenting evidence for a series of innovative solutions to the technological problems arising from poor raw material quality.

Tsagaan Agui Lower Grotto

Tsagaan Agui cave is located at approximately North 44° 42′ 43·3″, East 101° 10′ 13·4″, in Bayan Hongor *aimag*, Mongolia, some 40 km northeast of the nearest district (*suum*) centre, Bayan Lig. The cave is located in

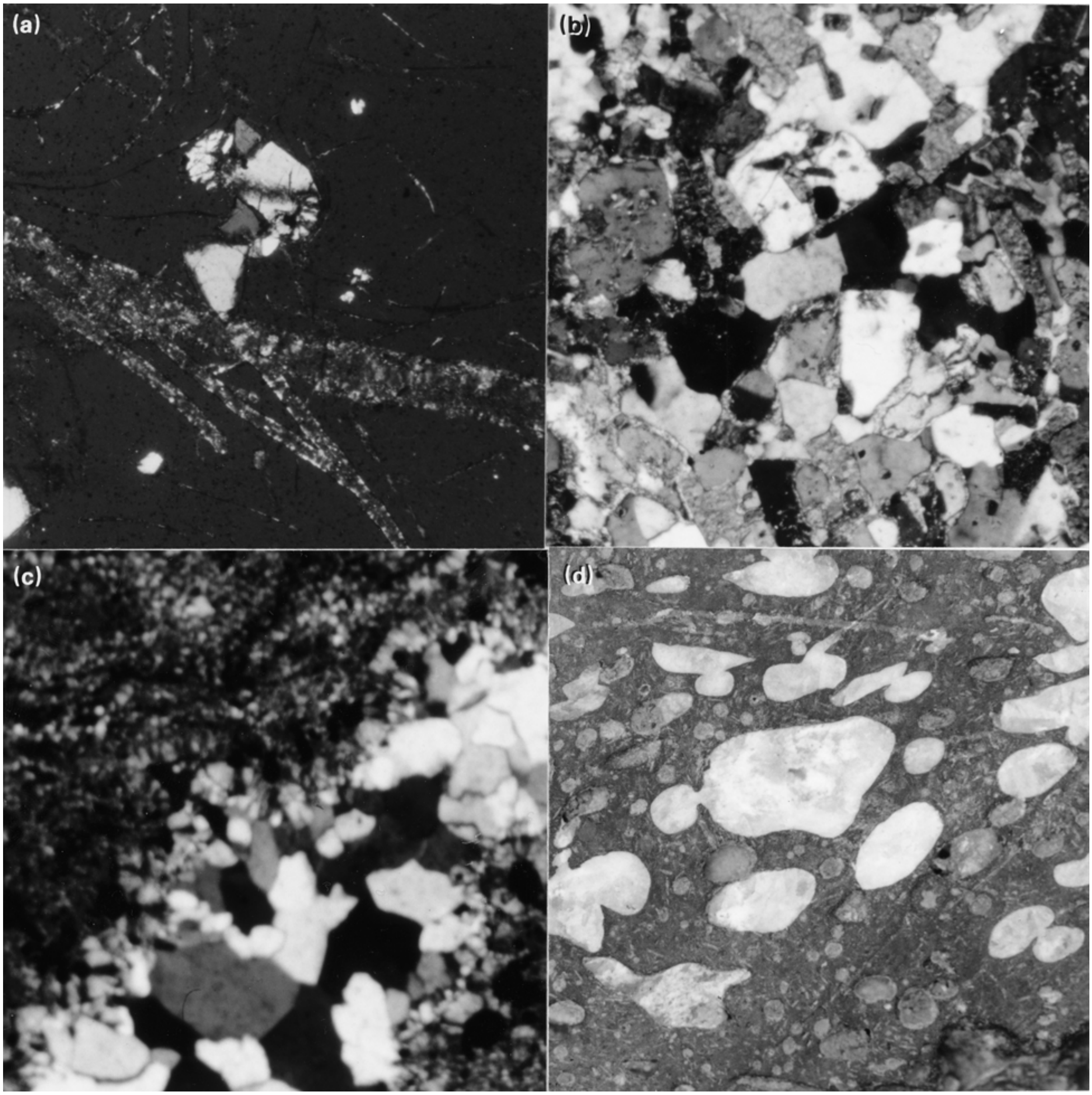

Figure 2. Mineralogical structure is comprised minimally of four variables including (a) percent crystallinity, (b) average crystal size, (c) range of crystal size and (d) abundance of impurities. The impact of these variables on the workability of a stone material is dependent on the scale of their occurrence. (a) Obsidian with variable percent crystallinity. Shown are feldspar and biotite crystals in an amorphous matrix. (b) Hornfels showing a very uniform average crystal size of 300 μm. (c) Chert showing a bimodal crystal size distribution. (d) Basalt with secondary quartz impurities occurring as infillings in previous void spaces. Scale: (a), (b) and (c) are thin sections photographed under 40 × magnification with a field of view of approximately 2·25 mm; (d) is a macroscopic photograph with a field of view of approximately 2·5 cm.

a limestone outlier, Tsagaan Tsakhir, situated on the southern piedmont of the Gobi Altai massif, southwest of the Zuun Bogd Uul range (Figure 3). The cave is on the eastern side of the largest canyon that bisects Tsagaan Tsakhir from north to south.

Initial excavations at Tsagaan Agui were conducted by a Soviet-Mongol Archaeological Expedition between 1987–1989 (Derevianko & Petrin, 1995*b*). Excavations resumed in 1995 under the direction of the Joint Mongolian-Russian-American Archaeological Expedition (Derevianko *et al.*, 1996, 1998). To date, four main depositional basins have been identified within the cave system, including the Lower Grotto, entryway terrace, main chamber and inner chamber deposits (Figures 4 and 5). Here we present data primarily from the Lower Grotto, although the conclusions also apply to the lower stratigraphic units (strata 6–13) of the main chamber. The main artifact-bearing

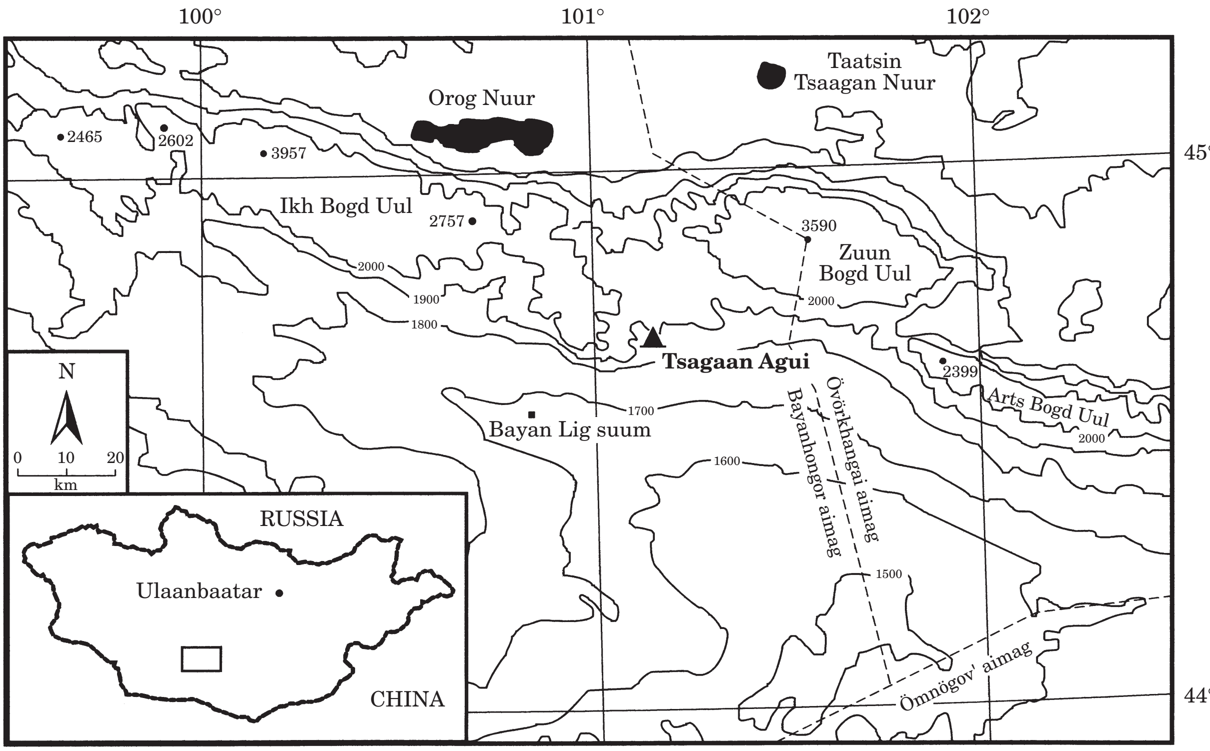

Figure 3. Map showing the geographical location of Tsagaan Agui.

deposits in the Lower Grotto are undated, but are clearly late Middle Paleolithic based on the character of the artifact assemblage and tentative stratigraphic correlations with deposits older than 33 ka from the main chamber. The depositional regime suggests relatively cold, wet conditions, represented by bedded coarse and medium sands, a massive limestone *éboulis* (Laville, Rigaud & Sackett, 1980) and clay lenses varying in thickness from 2–10 cm (Figure 6). The majority of the recovered artifacts ($N=752$) originates from the *éboulis*, designated Stratum 5. The *éboulis* is matrix supported with approximately 40% subangular to subrounded gravels, dominated by limestone fragments, and approximately 50% coarse sands (1–2 mm).

The depositional history of Stratum 5 is particularly complex as a result of both the location of the Lower Grotto in the cave system and the diverse processes commonly involved in the formation of *éboulis* units (see Laville, Rigaurd & Sackett, 1980). The Lower Grotto lies in a position somewhat offset from and at an elevation minimally 6 m below the bottom of the main chamber deposits. The main chamber and Lower Grotto are thought to be connected by an interior solution cavity, perhaps up to 20 m long, which served as a conduit for the redeposition of sediments to the Lower Grotto. The artifacts, sands and gravels comprising Stratum 5 were likely mobilized and redeposited through a combination of fluvial, cryogenic and gravitational processes from one or more strata in the lower main chamber. Deposits lithologically similar to Stratum 5 in the Lower Grotto are represented by Stratum 6 in the main chamber (see Derevianko *et al*., 1996, 1998).

Despite the presumed secondary context of the Lower Grotto deposits, there do not appear to be any substantial biases in the sample of lithics recovered. Most specimens are relatively unabraded and there is no clear evidence to suggest that artifacts were broken only during redeposition. Similar artifact breakage patterns are evident in primary deposits of the main chamber and surface quarry deposits located at the source outcrop. These associated assemblages suggest that patterns of artifact breakage in the Lower Grotto are related primarily to raw material and technology (see below). Winnowing of the artifact assemblage through high-energy water flow is not indicated by the frequency distribution of debitage lengths; 25% of the debitage assemblage is less than 2·2 cm in length, and 50% is less than 3 cm. Furthermore, primary reduction products and secondary retouched tools are represented in frequencies suggestive of on-site reduction, and less commonly seen in heavily reworked assemblages (Tables 1–3).

Raw material is abundant in the immediate surroundings of Tsagaan Agui, but it is also of poor quality. The material is a banded chert formed during diagenesis of the limestone formation containing the cave, and derives from a heavily weathered outcrop located 50 m above the cave. It occurs as angular boulders and cobbles ranging in size from approximately 40 cm to less than 10 cm in maximum dimension. Voids and large secondary crystalline

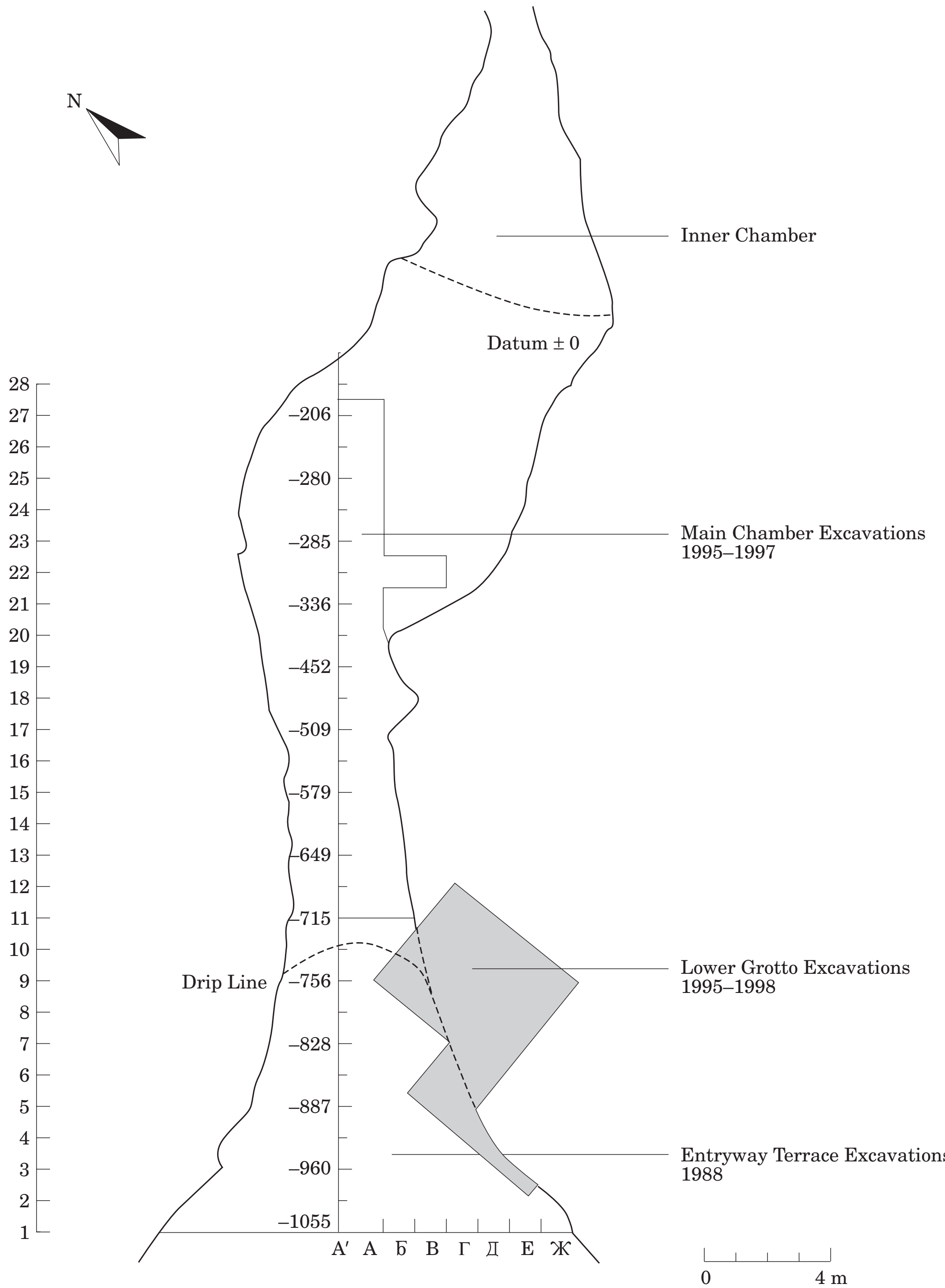

Figure 4. Plan map of Tsagaan Agui cave showing the location of the inner chamber, main chamber, entryway terrace and Lower Grotto deposits. The Lower Grotto is a solution cavity located below the primary cave and thought to be connected internally with the main chamber. Elevations are centimeters below the site datum.

infillings are common throughout the material. Preliminary quantification suggests that between 5–10% of the material volume is comprised of such impurities (Figure 7(a)). The rock matrix is greater than 95% crystalline with an average crystal size of approximately 10 μm. Where secondary minerals occur as infillings in void spaces crystal sizes may reach 200 μm (Figure 7(b)). The voids and impurities cause the chert to fracture irregularly; the resulting flakes are very angular and thick, and both flakes and cores often

Figure 5. Tsagaan Agui cave looking east. The photograph shows the entryway terrace deposits as well as openings to the main chamber (large cavity at upper left) and Lower Grotto (small cavity at lower right).

exhibit severe hinge and step terminations. However, where voids and inclusions are absent, the Tsagaan Agui raw material fractures more predictably.

Results of Lithic Analyses

The impact of raw material quality on primary reduction is evident at several levels. Here several different measures are employed to assess the extent to which raw material quality interfered with primary reduction and how these constraints were sometimes circumvented. Previous analyses of nearly 1400 artifacts from the quarry workshop located above the cave allow us to quantify the frequency in which raw material impurities were encountered during the course of primary reduction. In Figure 8, the variable ISCAR measures the number of flake removal scars on a given artifact exhibiting at least one (>1 cm) void or crystalline impurity. The variable DSCAR is a count of the total number of flake removal scars for those same artifacts. Thus, a flake with five dorsal scars of which three contain voids or inclusions will have an impurity encounter rate of 60%. It is clear in Figure 8 that the majority of artifacts (57%) exhibits an impurity encounter rate of at least a 20% (i.e. one of every five removal scars contains severe voids or inclusions). More surprisingly, nearly 20% of the workshop sample exhibits a 100% impurity encounter rate (i.e. every flake removal scar contains severe voids or inclusions).

Such high impurity encounter rates severely constrained core reduction, as indicated by the quantities of core and flake shatter recovered from the Lower Grotto† (Table 4). Cores and flakes frequently broke along impurities producing many unusable small, angular fragments. In the Lower Grotto assemblage, shatter comprises more than 50% of the primary reduction products.

Raw material quality also was a constant constraint throughout all stages of core reduction. Here we employ percentage remaining cortex on a specimen as a general measure of reduction stage. Percentage remaining cortex is a valid proxy for reduction stage in the absence of a strong unidimensional association

†Flake shatter is defined as distal flake fragments missing all of the platform. Core shatter is defined as lithic chunks possessing only flake removal scars and generally less than 3 cm in maximum dimension. Core and flake shatter is frequently very angular and irregular in shape, reflecting catastrophic failure during percussion.

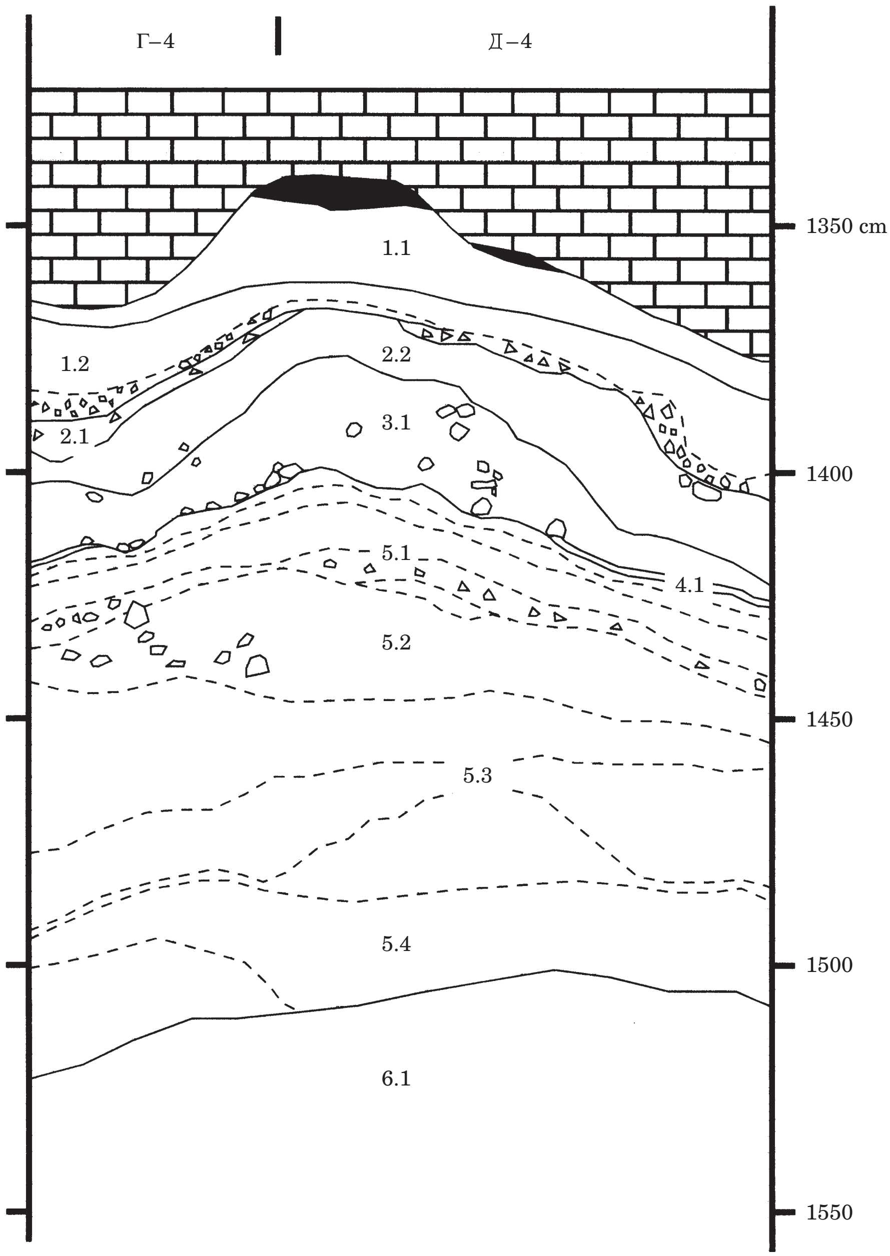

Figure 6. East wall stratigraphic section (units Γ – 4 and Γ – 4) from the Lower Grotto at Tsagaan Agui. Clay lenses are represented by strata 1·1, 2·1, 2·2 and 4·1. Bedded sands are represented by strata 1·2, 3·1 and 5·4. Strata 5·1 through 5·3 comprise the massive limestone *éboulis*, and are the source of the Lower Grotto assemblage. Strata 6·1 is a massive, sterile red clay. Elevations are centimeters below the site datum.

between cortex distribution and artifact size (Table 5), and where there is a strong association with number of reduction scars (Table 6) (Kuhn, 1995*a*; Roth & Dibble, 1998). In the Lower Grotto, percentage cortex appears to be tracking extent of reduction rather than simply artifact size. Using this measure it is clear that shatter frequencies are high in both early and late stages of reduction (Table 7). In addition, frequencies of flake shatter produced during each stage of core reduction are statistically similar to those for intact flakes (Mann-Whitney U=10486·00, p=0·493; Single Sample KS=0·385, p=0·998), indicating that flake

Table 1. Lower Grotto general typological inventory

		Count	%
General Type	Flake Core	121	16·1
	Flake	159	21·1
	Technical Element	27	3·6
	Retouched Flake	47	6·3
	Retouched Core	3	0·4
	Flake Shatter	138	18·4
	Core Shatter	257	34·2
Total		752	100·0

Table 2. Lower Grotto flake types

		Count	%
Flake Type	General Flake	151	81·2
	Levallois Flake	5	2·7
	Kombewa Flake	1	0·5
	Edge Element	19	10·2
	Other Technical Element	9	4·8
	Hammer Spall	1	0·5
Total		186	100·0

shatter is a constant byproduct of flake production regardless of reduction stage. Raw material imperfections occur consistently throughout any given cobble, therefore simply removing additional portions of exterior core material does not decrease the likelihood of encountering those imperfections. Indeed, increasing the extent of core preparation, without attention to the character of the initial blank, does not diminish the negative effects of raw material quality.

Despite these severe constraints, efforts to negotiate the effects of raw material quality are evident in core reduction patterns seen in the Lower Grotto. The majority of cores from the Lower Grotto are non-diagnostic pieces worked in multiple directions and at various intensities. The casual nature of these cores appears to be one response to the poor raw material quality available at the site; multiple flaking directions were exploited both as a function of the irregular, angular shapes of initial cobble blanks and to avoid severe raw material impurities. Most casual cores are only moderately reduced, displaying fewer than five flake removal scars and >50% remaining cortex (Table 8). The lack of preparation and organization seen on these cores may be interpreted as a ‘‘path of least resistance’’, or minimum investment in pieces unlikely to be very productive.

A smaller subset of cores follows a more systematic pattern of reduction, schematically shown in Figure 9. Importantly, the reduction strategies represented by these cores also appear to be a response to poor raw material quality. Some of these prepared cores are reminiscent of the Levallois method, but with significant strategic differences. In particular, the reduction strategies involve the exploitation of the smooth ventral surfaces, or the steep lateral and distal margins of large flake blanks. The large flake blanks are generally greater than 10 cm long in maximum dimension, and derive from large, boulder-sized masses of raw material occurring in abundance at the source. The ventral surfaces of large flake blanks possess natural lateral and distal convexities ideal for producing volumetrically organized core surfaces similar to the Levallois method (*sensu* Boëda, 1990, 1995; see also Inizan, Roche & Tixier, 1992; Van Peer, 1992; Pelcin, 1997). Steep flake edges (or naturally split margins) similarly provide a natural basis for parallel flake removals, a strategy that reasonably may be classified as opportunistic bladelet production. In contrast, the angular cobbles used in manufacturing casual cores begin with no regular convexities, while the density of raw material impurities prevents establishing organized striking platforms and surfaces of detachment directly on the cobble blanks.

Table 3. Lower Grotto core types

		Count	%
Core Type	Tested Pebble	3	2·5
	Chopping Tool	1	0·8
	Casual Core	84	69·4
	Large Biface	1	0·8
	Broad-faced Core	18	14·9
	Narrow-faced Core	11	9·1
	Change-of-Orientation	1	0·8
	Other	2	1·7
Total		121	100·0

Broad-faced prepared cores from Tsagaan Agui are based on the ventral surfaces of large flake blanks and may be classified as either (1) convergent unidirectional cores, or (2) convergent unidirectional cores with distal end trimming (Figure 9(b),(c)). Both core forms generally possess faceted platforms and moderately prepared edges. In pattern and degree of preparation these cores resemble simple Levallois point cores (see Bordes, 1980; Van Peer, 1992), but also are reminiscent of Kombewa flake cores found in some African and Western Asian Acheulian assemblages (Clark, 1970, p. 84; Inizan, Roche & Tixier, 1992, p. 57). They may also share some features with Levantine Mousterian cores-on-flakes, sometimes referred to as truncated-faceted pieces, or the Nahr Ibrahim Technique (Solecki & Solecki, 1970; Dibble, 1984; Goren-Inbar, 1988). There is some ambiguity whether truncated-faceted pieces actually served as cores, or were rather retouched tools (Dibble, 1984, p. 29; but see Goren-Inbar, 1988, pp. 41–42). In the case of Tsagaan Agui broad-faced cores, however, there is little doubt of their primary function. The large size of both the initial flake blanks and ventral face removals, as well as the degree of platform preparation suggest exclusive use as cores.

The reduction sequence for Tsagaan Agui broad-faced cores may be divided into several components: (1) the production of a single large flake blank; (2) platform preparation; (3) trimming of the lateral margins (from the ventral to the dorsal surface of the blank); (4) truncation of the distal blank end and occasionally trimming of the ventral surface at the distal end; and (5) sequential, convergent removals from the primary surface. Given the character of the initial blank (i.e. appropriate size, morphology), each component of the reduction strategy can be applied selectively to arrive at a viable core geometry. For example, a flake blank that begins with a smooth, strongly convex ventral surface may require no additional preparation to begin primary reduction.

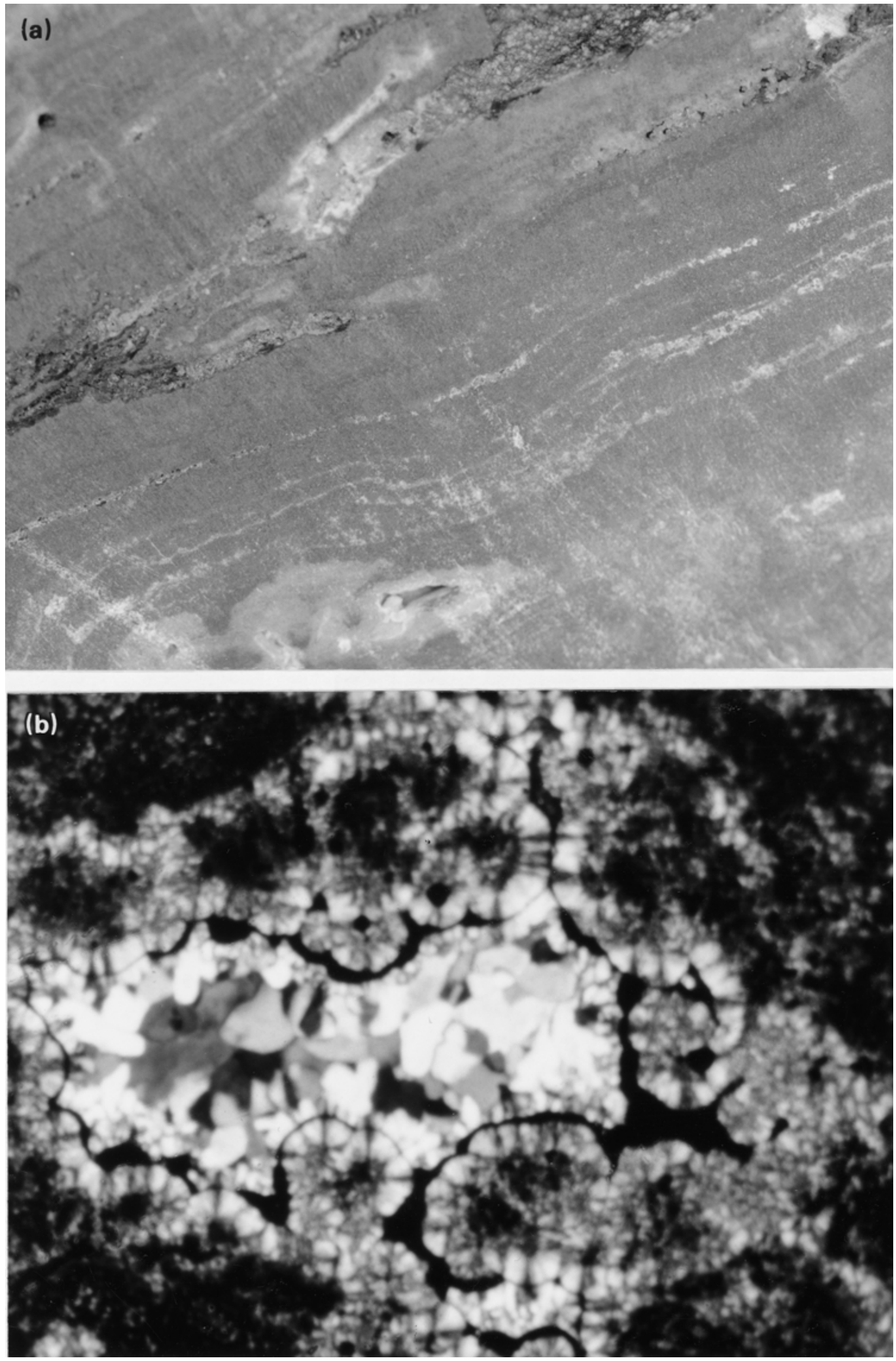

Figure 7. Tsagaan Agui raw material quality. (a) a cut, unpolished (~3·3 × 2·5 cm) section of the raw material showing distinctive banding, secondary quartz infillings and void spaces. (b) a microscopic (40 ×) view of the fine crystalline ground mass, which comprises as much as 90% of the material, void spaces and secondary quartz infilling of voids. Field of view for (b) is approximately 3·3 mm.

Alternatively, a blank of acceptable material, but unacceptable morphology may require additional platform trimming, edge preparation or primary surface shaping. In either case, however, a strategic goal of achieving certain volumetric parameters is apparent.

Narrow-faced cores also appear to be organized around specific geometric or volumetric goals. Like broad-faced cores they are often based on flake blanks, but make use of the lateral or distal margins (or platform area) for producing short, parallel flakes

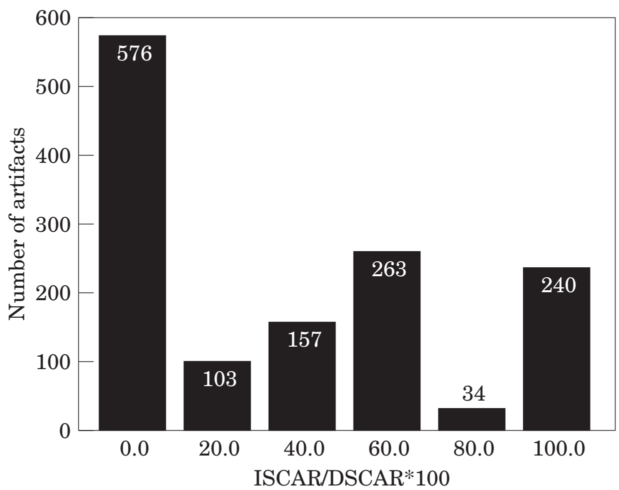

Figure 8. Histogram of the impurity encounter rate (ISCAR/DSCAR*100) for Tsagaan Agui quarry workshop artifacts. ISCAR is a count of the number of flake removal scars showing at least one (>1 cm) void or inclusion. DSCAR is the total number of flake removal scars. An encounter rate of 0 indicates that none of the flake removal scars on a given artifact contain raw material impurities. An encounter rate of 100 indicates that all flake removal scars contain at least one impurity.

(Figure 9(d)). Narrow-face core reduction may be initiated with a "burin-like" removal delivered either from the original flake platform, or at some position along the thick lateral or distal margins of the blank. Split or snapped flakes may be exploited directly without "burin-like" initiation. Narrow-face reduction is most often bi-directional. Despite the lack of diagnostic bladelet blanks or tools in the Lower Grotto collections, there is no independent evidence to suggest that narrow-faced cores are simply a form of retouched tool.

Variability among broad- and narrow-faced cores is expressed in plan and cross-sectional forms, and especially in intensity of reduction. More intensively reduced specimens are slightly over-represented in the collections (Table 8). Many of the low and moderately reduced broad-faced cores retain dorsal and ventral features of the initial large flake blanks, including dorsal cortex and dorsal flake removal scars (Figure 10). On the whole, core preparation is applied sparingly and appears to be directed towards emphasizing "desirable" volumetric traits of the flake blank. Thus, broad- and narrow-faced core reduction strategies, although more sophisticated than the "path of least resistance," or minimum investment strategy seen in casual cores, also exhibit a conservative tendency in the

Table 4. Frequencies of primary reduction products

		Count	%
General Type	Flake Core	121	17·2
	Flake+Technical Element	186	26·4
	Flake Shatter	138	19·7
	Core Shatter	257	36·6
Total		702	100·0

Table 6. Relationship between cortex distribution and number of removal scars for flake cores

Flake Cores	Percent Cortex			Total
	>50%	<50%	0%	
Low (<5 dorsal scars)	23	3	2	28
Moderate (5–9 dorsal scars)	13	47	9	69
High (>9 dorsal scars)	3	11	10	24
Total	39	61	21	121

Spearman Rank Correlation

Value	Asymp. Std. Error	Approx. T	Approx. Sig.
0·514	0·082	6·533	0·000

Table 5. Artifact size and cortex distribution ANOVA's[a]

Flake Shatter		Sum of Squares	*df*	Mean Square	*F*	Sig.
Surface Area % Cortex	Between Groups	4246682	3	1415561	1·837	0·143
	Within Groups	1·03E+08	134	770517·3		
	Total	1·07E+08	137			
Core Shatter						
Surface Area % Cortex	Between Groups	1413638	2	706819·0	2·322	0·100
	Within Groups	77317033	254	304397·8		
	Total	78730671	256			
Flakes						
Surface Area % Cortex	Between Groups	14167084	3	4722361	3·069	0·03
	Within Groups	2·38E+08	155	1538512		
	Total	2·53E+08	158			
Cores						
Volume by % Coretex	Between Groups	14945·532	2	7472·766	0·256	0·774
	Within Groups	3441163	118	29162·401		
	Total	3456109	120			

[a] Cortex categories are 100%, >50%, <50% and 0%.

Table 7. Shatter frequencies by degree of reduction (percent cortex remaining)

			Percent Cortex[a]				
			100%	>50%	<50%	0%	Total
General Artifact Type	Flake Shatter	Count	18	53	35	32	138
		Expected Count	6·3	34·2	63·6	33·9	
		Residual	11·7	18·8	− 28·6	− 1·9	
	Core Shatter	Count	0	45	147	65	257
		Expected Count	11·7	63·8	118·4	63·1	
		Residual	− 11·7	− 18·8	28·6	1·9	
Total		Count	18	98	182	97	395

[a] Rank order estimate of the amount of cortex remaining on the surface of the specimen. Higher values represent earlier reduction stages.

investment of time and energy in preparation and reduction. The reason for this is related clearly to the fact that excessive core preparation may actually exacerbate the negative effects or poor raw material quality.

Plan and cross-sectional forms for both prepared core types vary according to blank thickness. Thicker blanks tend to have steep preparations on the ventral surface, creating in some cases almost "discoidal" core forms. Steep preparations are particularly characteristic of cores with distal end trimming, which may coincide with intentional truncation, or reflect trimming to emphasize naturally steep distal margins of the blanks. In either case, steep distal preparations may serve to extend the natural convexity of the ventral bulb of percussion, facilitating the production of longer endproducts (see Inizan, Roche & Tixier, 1992, pp. 57–58; Pelcin, 1997).

Platform preparation is generally not as steep as seen on the lateral or distal margins of the blanks, but does vary from faceted to plain and half-cortical forms. Narrow-faced cores show little investment in platform preparation. Platform preparation preceded any shaping of the primary surface or lateral edges for a number of broad-faced cores.

Finally, we note that broad- and narrow-faced prepared cores are not immune to the effects of poor raw material quality. And not all broad- and narrow-faced cores are based on large flake blanks. A number of otherwise prepared cores show severe hinge and step errors, despite their design for circumventing the negative effects of the Tsagaan Agui raw material. Such errors, though not severe enough to abandon prepared core reduction strategies altogether, were probably cause for core discard.

Discussion and Conclusions

Raw material quality influenced Lower Grotto core reduction strategies in two ways. In many cases, systematic core reduction was abandoned in favour of more-or-less random flaking of cores from multiple directions and with little concern for developing organized removal surfaces. This is the expected outcome for situations such as those that exist at Tsagaan Agui of abundant, but low raw material quality. However, a special class of prepared cores also emerged that made explicit use of the convex ventral surfaces or steep lateral or distal margins of large flake blanks. The use of large flake blanks as part of a prepared core technology is important on a number of levels. If the extent of core preparation is limited by the "risk" of exposing further raw material imperfections, then large

Table 8. Degree of reduction for prepared and unprepared cores

			Percent Cortex			
			>50%	<50%	0%	Total
Core Type	Casual Core	Count	31	41	12	84
		Expected Count	26·0	43·1	14·9	
		Residual	5·0	− 2·1	− 2·9	
	Broad-faced Core	Count	3	12	3	18
		Expected Count	5·6	9·2	3·2	
		Residual	− 2·6	2·8	− 0·2	
	Narrow-faced Core	Count	1	5	5	11
		Expected Count	3·4	5·6	1·9	
		Residual	− 2·4	− 0·6	3·1	
Total		Count	35	58	20	113

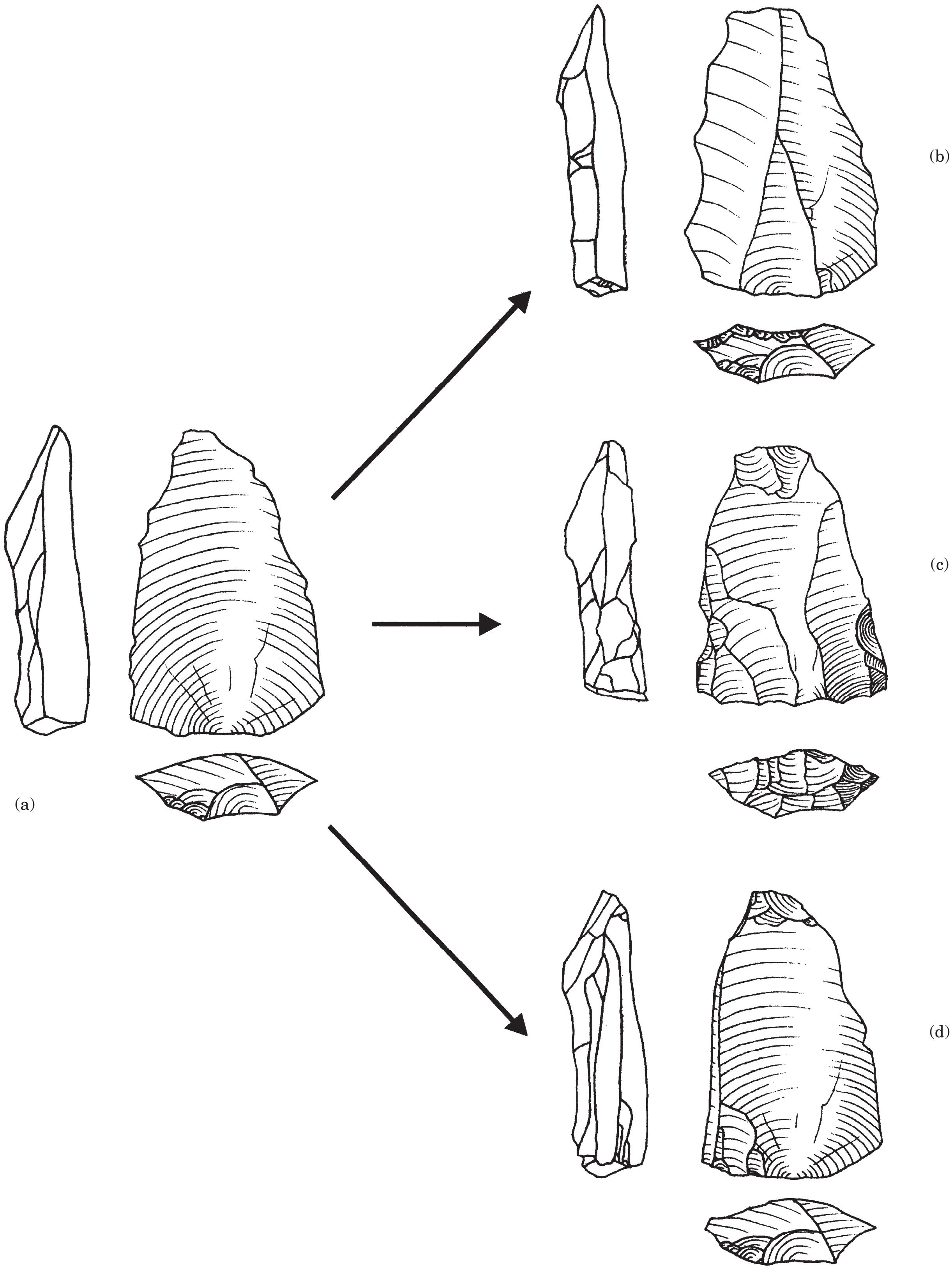

Figure 9. Schematic illustration of prepared core technologies from the Lower Grotto and lower stratigraphic layers of the main chamber at Tsagaan Agui. (a) large flake blank; (b) unidirectional convergent broad-faced core based on the convex ventral surface of a flake blank; (c) unidirectional broad-faced core with end trimming based on a flake blank; (d) narrow-faced core based on the steep lateral margin of a flake blank. Illustrations by K.W. Kerry.

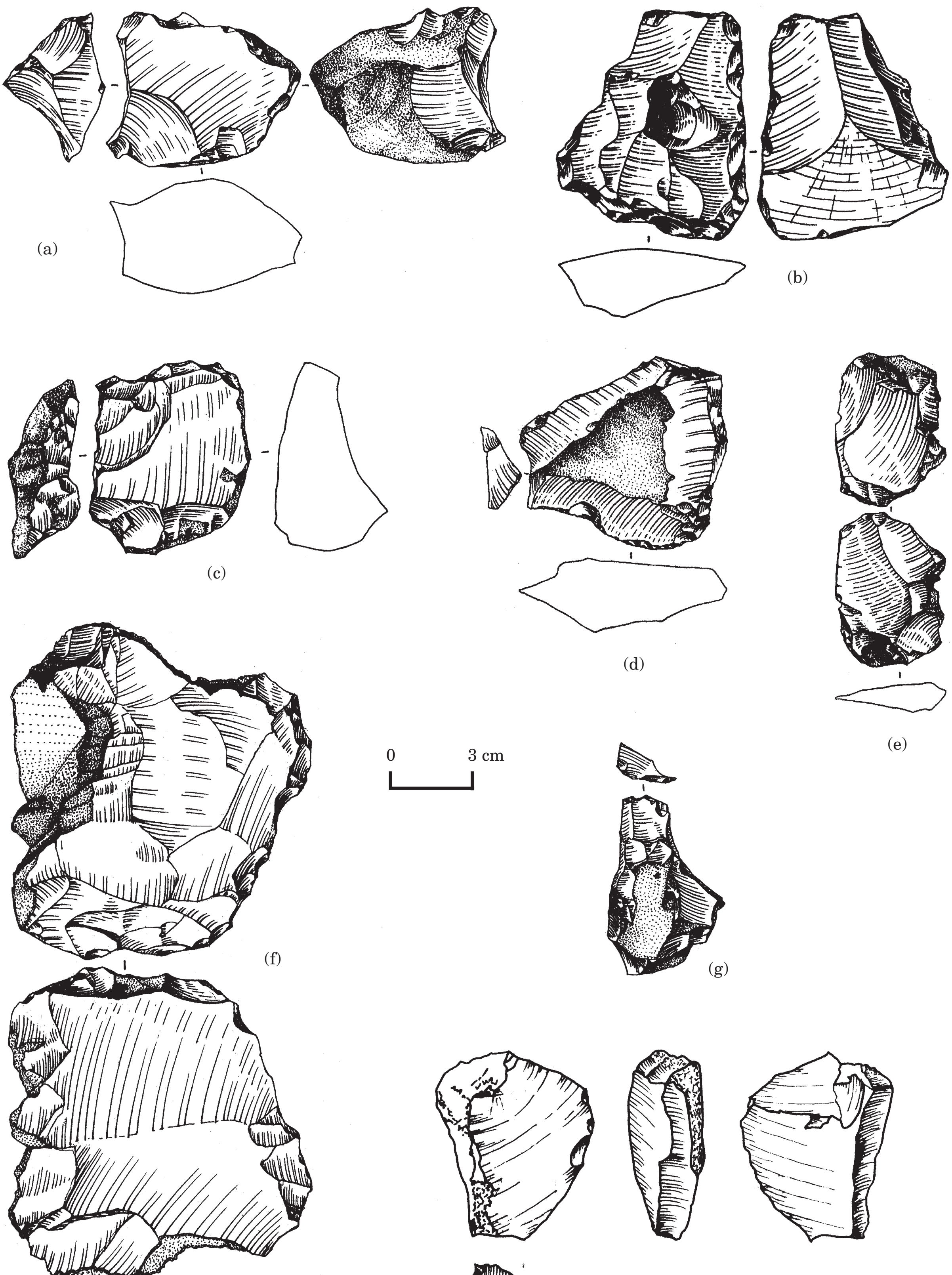

Figure 10. Tsagaan Agui broad- and narrow-faced cores based on large flake blanks: (a) and (e), broad-faced cores from the Lower Grotto; (b), (c), (d) and (f), broad-faced cores from the lower stratigraphic layers in the main chamber; (g), narrow-faced core from the lower layers in the main chamber; (h), narrow-faced core from the Lower Grotto.

flake blanks facilitate both the assessment and minimization of that risk by exposing large surface areas and providing ''ready-made'' core geometries. A similar situation may pertain for coarse crystalline (e.g. coarse grained quartzite or sandstone), or materials with extreme ranges of crystal size (e.g. basalts) where the ''risk'' is excessive errors during core preparation that render the core unworkable. In this case, large flake blanks would allow the knapper to assess the potential for early reduction errors and provide a means to avoid those errors by facilitating primary reduction without excessive preparation. In general, where raw material quality is poor, large flake blanks may provide the most direct means for obtaining properly shaped and oriented flaking surfaces.

The presence of such core reduction strategies in the Lower Grotto assemblage runs contrary to expectations given the high abundance but low quality of raw material available at Tsagaan Agui. However, the reasons underlying the use of more sophisticated core designs in such contexts are not entirely clear. Rates of raw material consumption were not necessarily an issue because of the close proximity to the source. Other design considerations such as technological reliability and maintainability may have been a concern if flakes and cores were transported for use elsewhere. Off-site core, flake and tool breakage may have posed a serious risk to those groups exploiting the Tsagaan Agui material. In this regard, we note that only a small sample of Kombewa-like and Levallois-like flakes were recovered from the Lower Grotto (Tables 1–3). The depressed frequency of these endproducts suggests transport of specialized blanks away from the site. In circumventing some of the negative effects of poor raw material quality by ensuring more standardized core reduction and tool production, broad- and narrow-faced prepared cores may have provided some safeguards against technological failure (see Bleed, 1986; Torrence, 1989).

The implications of these findings for the study of northeast Asian prehistory are significant. In particular, the successful manufacture and exploitation of prepared cores at Tsagaan Agui using poor quality raw materials begs the question of what role raw material quality played in constraining technological diversity in the North Chinese Middle and Upper Paleolithic. The Lower Grotto assemblage illustrates that raw material quality is not an absolute barrier to the design and use of prepared cores. On the contrary, it appears that raw material quality was the impetus behind significant innovations in prepared core technology at Tsagaan Agui. Raw materials common at many North Chinese Paleolithic sites (e.g. quartzite, sandstone and limestone), though decidedly different in specific raw material properties, are no more intractable than that present at Tsagaan Agui. Thus, we conclude that raw material quality may have influenced the character of the North Chinese Middle and Upper Paleolithic, but it cannot be the only factor underlying the near absence of prepared core technologies in such a vast region. Rather, explanations for the character of the North Chinese Middle and Upper Paleolithic may lie, at least in part, in biogeographic, adaptational, or behavioural processes exclusive from the effects of raw material quality.

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