INFLUENCES ON SELECTION OF LITHIC RAW MATERIAL SOURCES AT HUIZUI, A NEOLITHIC/EARLY BRONZE AGE SITE IN NORTHERN CHINA

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ABSTRACT

At Huizui, a major centre of ground stone tool manufacture, five main lithologies were used, each for a particular purpose: oolitic dolomite for spades; diabase for axes, adzes and chisels; fine micaceous sandstone for knives and sickles; other sandstone for grinding slabs; and fine limestone for lime. This reflects the functional properties of these lithologies. Diabase, oolitic dolomite and fine micaceous sandstone are tough and take sharp edges, which for diabase are particularly sharp and easily resharpened. All five rock types are probably available within 8 km of the site. Ground stone tool production may have been located at Huizui because of its proximity to the adjacent sandstone hills, which provided abundant abrasive material. Overall, raw materials are dominated by oolitic dolomite, which was quarried from a single thin-bedded layer that outcrops as flat pavements. Diabase was sourced from river cobbles, and micaceous sandstone was quarried. All three of these lithologies were extracted as raw material that required minimal shaping to make tools. This factor was probably responsible for the choice of oolitic dolomite over fine-grained dolomite, which is more common and occurs closer to Huizui, but cannot be easily quarried. The small amounts of probably exotic lithologies (including red rhyolite, marble, turquoise, ?jade) may have been used for elite items.

INTRODUCTION

The Huizui archaeological site is located close to the modern village of Huizui in Yanshi county, Henan province, in the Yiluo Basin of the middle Yellow River region, northern China (Figure 1a). Huizui appears to have been a regional centre during the Neolithic cultures of the Yangshao (c. 5000-3000 BC) and Longshan periods (c. 3000-2000 BC), and then became a secondary centre of the early Bronze Age Erlitou state (1900 to 1500 BC) (Liu *et al.* 2004).

The lithic technology evident at the Huizui site varied substantially through time. Flakes recovered from the Yangshao deposits are scarce and made from cobbles available in the nearby river, with no dominant lithology, suggesting that the Yangshao population at Huizui produced stone tools only for their own uses. However, starting from the late Longshan period the site became a stone tool production locus, whose major product, oolitic dolomite spades, was distributed to the surrounding areas (Liu *et al.* 2004; Liu and Chen in press). The Longshan deposits at Huizui yielded numerous flakes and spade blanks, predominantly of oolitic dolomite among several other rock types. Spade manufacturing occurred in workshops located within the residential area (Chen 2005), and was most likely practiced by a large part of the community.

During the Erlitou period, lithic manufacture at Huizui expanded. The Erlitou culture was a complex society with craft specialisation, social stratification, extensive resource exchange networks and bronze metallurgy (Liu and Chen 2003; Liu 2006). Lithic industries were important because stone tools were used for everyday purposes; bronze was used mainly for ritual objects and weapons. At Huizui raw material specialisation is evident in the manufacture of several different types of tools, each of which was made from predominantly one lithology (Table 1): spades from oolitic dolomite (94%), axes, adzes and chisels from diabase (80%), knives and sickles from fine micaceous sandstone (86%), and grinding slabs from several varieties of sandstone (100%). The lithology used is linked to the function of the tool, e.g. woodworking tools are primarily made from diabase, whilst cutting tools are made from micaceous sandstone, suggesting that choice of raw material was at least partly due to its mechanical properties. Overall, raw materials are dominated by oolitic dolomite (at least 47% by number of all lithic material - tools, blanks, flakes and indeterminate pieces), followed by much smaller proportions of other materials (Table 2).

This paper will firstly describe in detail the main rock types used, and, as far as possible, relate the characteristics of a lithology to the purpose of the particular tool made from it. Secondly, the likely locations of the sites where the raw materials were extracted will be discussed, by relating the local geology to the petrographic characteristics of the lithologies used for tool manufacture. The choice of site will be assessed in terms of the suitability and ease of extraction of the raw material, and proximity to Huizui.

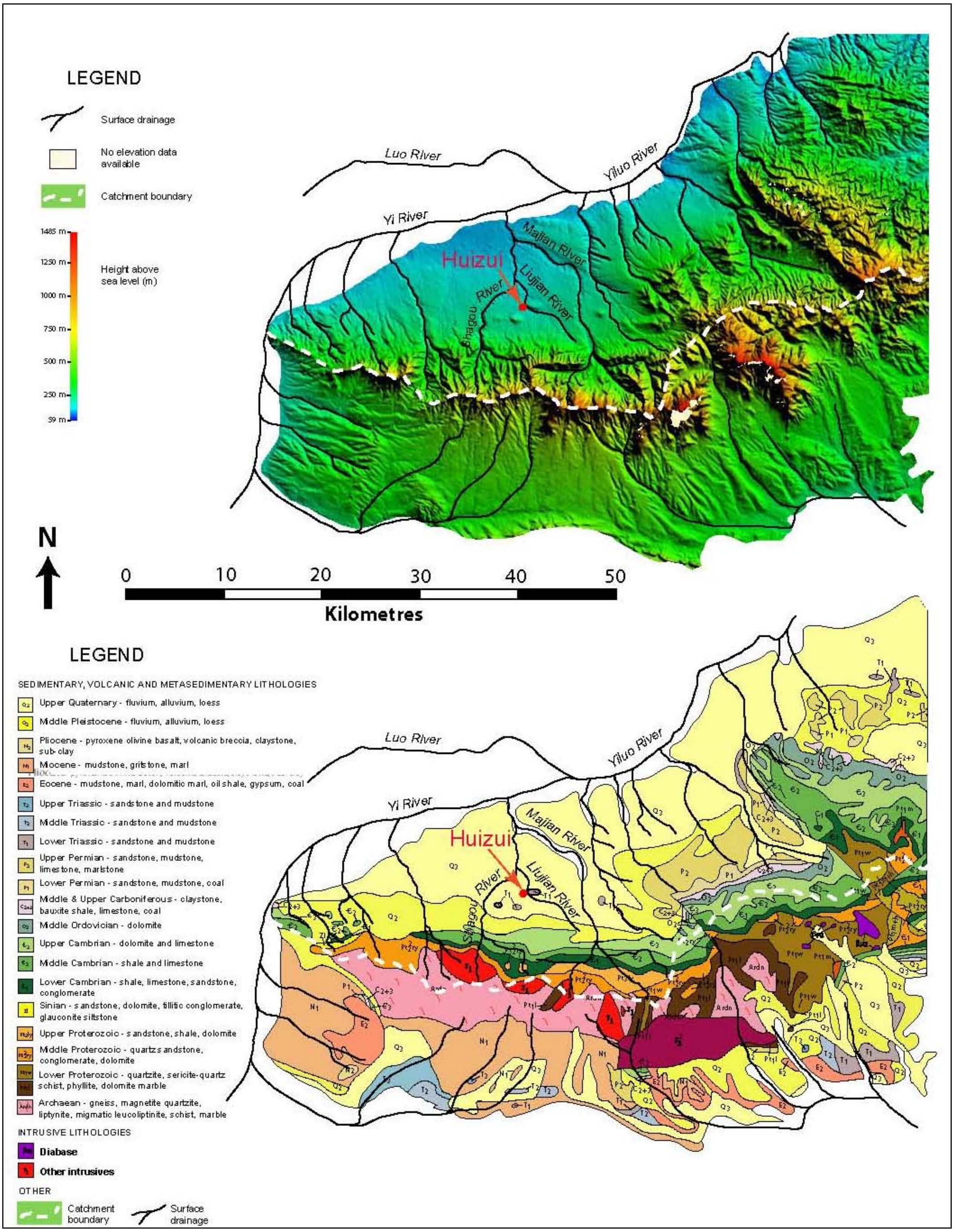

Figure 1. (a) Topographic setting of Huizui. (b) Regional geology of area around Huizui, particularly the Songshan Mountains (from Bureau of Geology and Mineral Resources of Henan Province, 1984).

Table 1. Number and proportion of major tool types made from particular lithologies.

	number	%
spades	157	
oolitic dolomite spades	148	94.3
axes, adzes, adzes/axes, chisels	86	
diabase axes, adzes, adzes/axes, chisels	69	80.2
knives, sickles	49	
fine micaceous sandstone knives, sickles	43	86.0
grinding slabs, abraders	31	
sandstone grinding slabs, abraders	31	100

Table 2. Number and proportion of different rock types within all lithic material recovered from Huizui excavations (tools, blanks, flakes, indeterminate pieces).

	number	%
oolitic dolomite	910	47.0
other sandstones	330	17.0
diabase	187	9.7
micaceous fine sandstone	152	7.9
lime	87	4.5
fine limestone	81*	4.2*
fine dolomite	19	1.0
chert - grey, black	40	2.1
siltstone - silicified, unsilicified	27	1.4
rhyolite - red, grey, ignimbritic	21	1.1
marble	18	0.9
quartz	14	0.7
quartzite	8	0.4
dolomite, calcite crystal	8	0.4
aplite	7	0.4
gneiss	6	0.3
slate	5	0.3
granite/diorite	4	0.2
iron oxide	3	0.2
schist	2	0.1
turquoise	2	0.1
?jade	2	0.1
stalagmite	2	0.1
conglomerate	1	0.1
total	1936	100.0

*not differentiated from fine dolomite in one survey

LITHOLOGIES USED

Approximately twenty-five different lithologies were utilised at Huizui, but only four were used in large amounts (>5% of assemblage; Table 2): oolitic dolomite, diabase, micaceous sandstone and other types of sandstone. In addition, a substantial amount of fine limestone and lime was recovered from the Huizui excavations, along with small amounts of other lithologies (Table 2).

Oolitic dolomite

The oolitic dolomite at Huizui is a uniform dark grey rock type that on close examination is composed of small dark grey circular bodies (oolites), averaging around 1 mm in diameter, set in a white cement (Figure 2a,b). The distinctive fine spotted appearance of this rock type is particularly evident on polished surfaces, and means that spades made of oolitic dolomite are easy to identify. Broken surfaces show sparkling crystal faces of dolomite. Thin section examination of the oolitic dolomite under a petrographic microscope reveals that it has a sugary texture of interlocking crystals of dolomite (Figure 2c, d). Originally this rock was an oolitic limestone (called a grainstone, i.e. composed of grains cemented together); the oolites were composed of very fine-grained calcite, and were surrounded by a cement of medium-grained calcite. The calcite of the limestone has been replaced by coarser-grained more uniform dolomite; the oolites are still visible despite the replacement, as very clear or faint outlines.

The nature of the oolitic dolomite is one of the reasons it was selected to produce stone tools. Its homogenous structure of interlocking crystals means that it will generally break evenly and predictably when it is being worked, and that it is relatively strong and tough. Dolomite is a soft material (hardness 3.5-4) and is easily ground by harder rocks (e.g. quartz sandstone) to give sharp, effective edges and very smooth faces that can take a high polish. However, its softness means that it is readily scratched, and the thin edges of dolomite tools would chip if struck against harder rocks.

Diabase

Diabase is a medium-grained intrusive basic igneous rock, also known as dolerite. The diabase at Huizui is generally grey to dark green (occasionally brownish red) and varies in grain size from fine to (mostly) medium to coarse; on polished surfaces it can be seen to consist of interlocking elongated crystals. Thin section examination shows that the diabase consists of sericitised elongate plagioclase laths up to 0.6 mm long, together with needle-like actinolite crystals and grains of chlorite, epidote and often abundant fine opaques, all embedded in a very fine-grained matrix that is generally altered to clay. There is some variation in composition and texture, with differing amounts of plagioclase and actinolite present, and the grain size varies from fine to coarse; the plagioclase laths may be highly elongate and spinifex-textured (strongly interlocking) in some samples. The diabase has undergone low-grade greenschist metamorphism, accounting for the presence of chlorite and epidote.

Diabase was used to produce woodworking tools (axes, adzes and chisels) that require strong edge-holding capabilities. Diabase is very suitable for ground-edge tools as its uniform texture of interlocking crystals of relatively hard minerals (hardness 5-6.5) means that it is relatively strong and tough, able to withstand considerable force and therefore unlikely to break during use (Garber 1989: 15). Diabase grinds smoothly to strong, sharp working edges, which are easily resharpened.

Lithologies similar to diabase have been used for ground-edge tools elsewhere in the world. Greenstones, basic igneous rocks (dolerites, basalts, andesites) altered

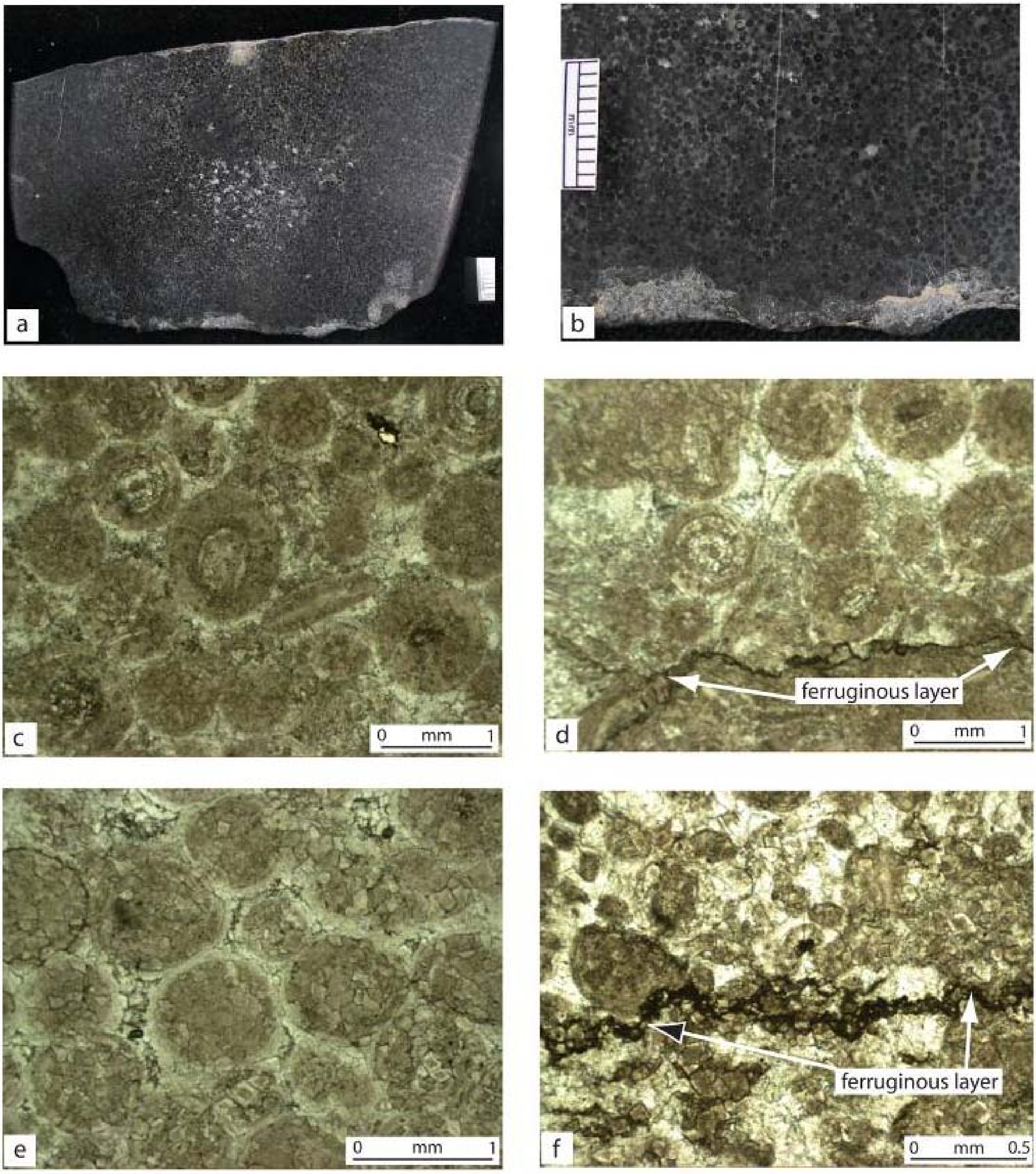

Figure 2. (a, b) Polished surface of oolitic dolomite spade; oolites appear as dark spots embedded in pale cement. (c, d) Photomicrographs of oolitic dolomite from outcrop; oolites appear as mostly circular bodies, some concentrically banded, within pale cement; oolites and cement replaced by blocky crystals of dolomite, sample traversed by thin bedding-parallel ferruginous layer. (e, f) Photomicrographs of oolitic dolomite from spade; note strong similarities to oolitic dolomite from outcrop, and well-marked outlines of blocky dolomite crystals replacing oolites.

by low-grade greenschist metamorphism, are composed predominantly of interlocking actinolite crystals, and were preferentially used for ground-edge axes in south-eastern Australia (McBryde and Harrison 1981). Testing of mechanical properties showed that greenstone has high fracture toughness and Young's modulus of elasticity, reflecting the fact that this lithology is extremely tough, and accounting for its strong edge-holding properties (Domanski *et al.* 1994). Greenstone has higher elasticity and fracture toughness values than siliceous lithologies used for flaked stone artefacts.

Fine-grained micaceous sandstone

The fine-grained micaceous sandstone at Huizui is green or brown, even-grained and composed predominantly of quartz grains, with a small but distinctive component of muscovite (white mica) flakes aligned parallel to bedding. The mica flakes are strongly reflective and give the sandstone a characteristic sparkle on bedding planes. Thin section examination under a microscope shows that the sandstone contains a substantial component of calcite grains, the same size as the quartz grains, along with scattered rounded pellets of brownish glauconite and flakes of chloritised biotite, as well as occasional tubular fossil fragments. The sandstone is well-cemented by overgrowths on the quartz and calcite grains. It is thin-bedded, and interbedded with relatively soft red-brown and green siltstone, as shown by a small number of tools that contain thin siltstone laminae.

The micaceous sandstone was made into knives and sickles; these are thin, rectangular or semi-circular tools, manufactured by trimming and bevelling only the working edge (Ford 2001: 60). The body of the tool received only a light grinding or polishing to smooth the surface. The thin bedding of the micaceous sandstone meant that sheets of ideal thickness for tool blanks could probably be selected at the quarry site. The fine, even, well-cemented texture and the predominant quartzose mineralogy (quartz is tough with a hardness of 7) meant that tools of micaceous sandstone take a moderately sharp edge that is resistant to chipping (Xie 2005).

Other varieties of sandstone

A large number of irregular sandstone fragments have been recovered from the Huizui excavations, as well as several grinding slabs and smaller pieces with flat surfaces that have been used to abrade tool faces. These are made of a variety of sandstone types: fine, medium and coarse-grained, and composed predominantly of quartz, although the coarser-grained ones generally have a substantial component of weathered feldspar grains. The colour of the sandstone varies considerably, from maroon or violet to pale grey or cream; the feldspathic sandstones tend to be lighter coloured. The finer sandstones may have ferruginous laminae and very thin ferruginous layers coating the quartz grains, giving them a reddish or purple colour.

At a ground stone tool manufacturing site like Huizui large amounts of abrasive material are required, and this was supplied by the sandstone (Ford 2001, 2004). The coarser sandstones were probably used for initial grinding of the tool, with the finer sandstones employed to smooth surfaces and sharpen edges (Owen 2006). Final polishing would have required a finer medium still, using very fine sediment (clay/silt), animal and/or plant products.

Fine limestone and lime

Fine-grained grey limestone occurs occasionally as tools (predominantly spades). It is finer and less even grained than dolomite (although much the same hardness), and so may fracture more unpredictably, making it less suitable for tool manufacture.

Limestone is more commonly present as irregular pieces, at least some of which were probably the raw material for lime manufacture. Lime is produced by heating limestone; this converts the calcite (calcium carbonate) of the limestone to a material called lime (calcium hydroxide). Calcium hydroxide quickly absorbs carbon dioxide from the atmosphere and reverts back to a white, chalky form of limestone, hardening in the process. This is the basis for the use of crushed lime as mortar; it is also suitable for making house floors, and may have been used for this purpose at Huizui. A substantial number of irregular blocks of white, chalky limestone were found in the excavations, as well as a small number of broken spades made of the same material.

Seven samples of lime from Huizui were subjected to mineralogical analysis by X-ray diffraction; this showed that six are composed of calcite, as expected. However, the seventh is made up of a mixture of calcite and hydromagnesite, showing that it was originally dolomite (rather than limestone). On heating, dolomite (calcium magnesium carbonate) converts to a mixture of calcium hydroxide and magnesium hydroxide; these then absorb carbon dioxide to form calcium carbonate (calcite) and magnesium carbonate (hydromagnesite). Lime is not generally made from dolomite, as its properties are inferior; today limestone is still strongly preferred for lime manufacture.

Fine dolomite

Fine-grained dolomite was used to manufacture only a small proportion of spades (<5%), despite its abundance in the northern slopes of the Songshan Mountains (discussed further below). The dolomite is grey to cream-brown in colour and generally uniform and massive in appearance, although some samples show distinctive elongate or subcircular spots that represent burrows in the original limestone when it was deposited. Fine dolomite is composed of interlocking dolomite crystals, with some variation in grain size, and probably has similar mechanical properties to oolitic dolomite.

Very fine-grained siliceous rocks (chert, silicified siltstone, rhyolite)

The very fine-grained siliceous lithologies, chert and silicified siltstone, occur in small but significant numbers (total ~3.5%, Table 2). They vary in colour but are mostly grey or black. Red rhyolite is most common in the Yangshao rather than Longshan/Erlitou deposits; it is very fine grained and often lacks phenocrysts. A few pieces of grey ignimbritic rhyolite are also present, identified by their characteristic flattened pumice fragments (fiamme). The very fine grain size and lack of distinctive features often makes chert, silicified siltstone and rhyolite hard to distinguish from each other in the Huizui assemblages. A few tools (chisels, adzes and knives) were made from these lithologies. From the Yangshao deposits, some of the red rhyolite pieces are worked material, with traces of cutting or sawing, and a fragment of bracelet made of red rhyolite was unearthed. These remains testify that red rhyolite was used to made ornaments by the Yangshao people at Huizui, perhaps for their own use.

Marble

Marble is a rare raw material at Huizui and was used to produce a small number of tools, including an axe, as well as more decorative items like a bracelet.

The marble varies substantially in colour (white, green and brown) and grain size (fine to medium); some samples are foliated.

Other metamorphic rocks (gneiss, quartzite, schist, slate)

A variety of metamorphic rocks are present. The higher-grade metamorphics (gneiss) were used for a few tools (e.g. axes); the lower grade rocks (schist and slate) are much softer and were rarely made into artefacts.

Quartz

The few quartz fragments present are poor quality, milky vein quartz.

Medium and coarse-grained igneous rocks (granite, diorite, aplite)

The very small amount of igneous rock material (apart from rhyolite) present was used to make a few tools, e.g. a knife.

Crystalline calcite and dolomite (including stalagmite)

Within the assemblage are several dolomite and calcite cleavage fragments. Both these minerals have perfect rhombohedral cleavage (3 cleavage directions at ~120°), so large crystals that are struck will break into rhombohedral fragments. In addition there are a few pieces of crystalline calcite that display typical stalagmite fabrics: colour banding and/or elongate crystals often arranged in radiating sheaves.

Turquoise and ?jade

Two turquoise beads were found in one excavation. There are also two pieces that may represent poor quality jade; they are patterned in dark brown and green.

RAW MATERIAL SOURCES

To determine where the lithologies used for tool manufacture at Huizui were obtained, it is first necessary to describe the geology of the area around the site.

Geology and geomorphology of the Huizui area

Huizui lies south of the Yilou River on a flat alluvial plain composed of redeposited Pleistocene and Holocene wind-blown loess. Protruding through these Quaternary deposits are several low hills composed of Lower Triassic fluvial and lacustrine sandstone and siltstone (Figure 1a,b), dipping shallowly (20-30°) to the north.

To the south lie the northern ridges of the Songshan Mountains, which close to Huizui consist of two E-W trending asymmetrical ridges, with very steep or cliffed southern slopes and gentler northern slopes, separated by a small valley (Figure 1a). The north ridge rises to 700-800 metres while the south ridge is higher (up to 1500 metres in elevation). They have formed by differential erosion of a shallowly north-dipping (15-20°) sequence of Cambrian carbonates, siltstones and sandstones (up to 1000 metres thick; Figure 1b). These sediments were deposited in predominantly shallow marine environments on a broad open platform (BGMR of Henan Province 1984; Meng *et al.* 1997; Meyerhoff *et al.* 1991; Zhu 1989), where sub tidal oolite shoals, bisected by tidal channels, separated lagoon and peritidal deposits from the open ocean.

The Cambrian strata of the northern Songshan Mountains are divided into eight formations; the lower Early and Middle Cambrian units are dominated by siltstones and limestones; within the siltstone sequences are thin interbeds of fine sandstone. The upper formations consist largely of carbonates, both limestone and dolomite.

The uppermost unit, the Upper Cambrian Fengshan Formation, forms the northern slopes of the Songshan Mountains, closest to Huizui, and is composed of ~150m of light to dark grey mostly thick-bedded dolomite. Originally the Fengshan Formation was deposited as limestones, predominantly fine-grained, laminated and stromatolitic, with occasional beds of oolitic grainstone. All these have been pervasively dolomitised and now consist of coarse mosaics of dolomite crystals, with varying degrees of preservation of the original limestone grains. Most commonly, the dolomitisation is comparatively coarse and uniform, and preserves relatively little of the limestone fabric. Towards the top of the Fengshan Formation is a partly silicified layer, in which scattered irregularly shaped patches of fine-grained quartz (chert) weather out in relief on the bed surface.

In the lower part of the Fengshan Formation is a readily distinguishable unit comprising a beige laminated dolomitic siltstone (marl), ~10m thick, overlying about 15m of dolomitised grey oolitic grainstone (Figure 3); the oolites are still evident as tiny, spherical, dark grey bodies (up to 1 mm in diameter). There are also two thin beds of oolitic dolomite, less than 1m thick, within the laminated siltstone itself. The oolitic beds show overall low angle hummocky topography, enhanced by the beige siltstone, which drapes the topography. The siltstone weathers much more readily than the overlying and underlying dolomites, so in the hillsides it occurs as a slightly lower gradient step that is uniformly grass-covered and lacks rock outcrop (Figure 3a,b). The oolitic dolomite beneath frequently outcrops as a 2-15m high cliff; the top of the bed forms a pavement (Figure 3c) that is sometimes used as a convenient location for trackways through the mountains.

Underlying the Fengshan Formation are over 100m of Upper and Middle Cambrian grey limestone, both oolitic and fine-grained massive. These lithologies outcrop on the very steep or cliffed southern (but not northern) flanks of the northernmost E-W ridge of the Songshan Mountains near Huizui (Figure 4).

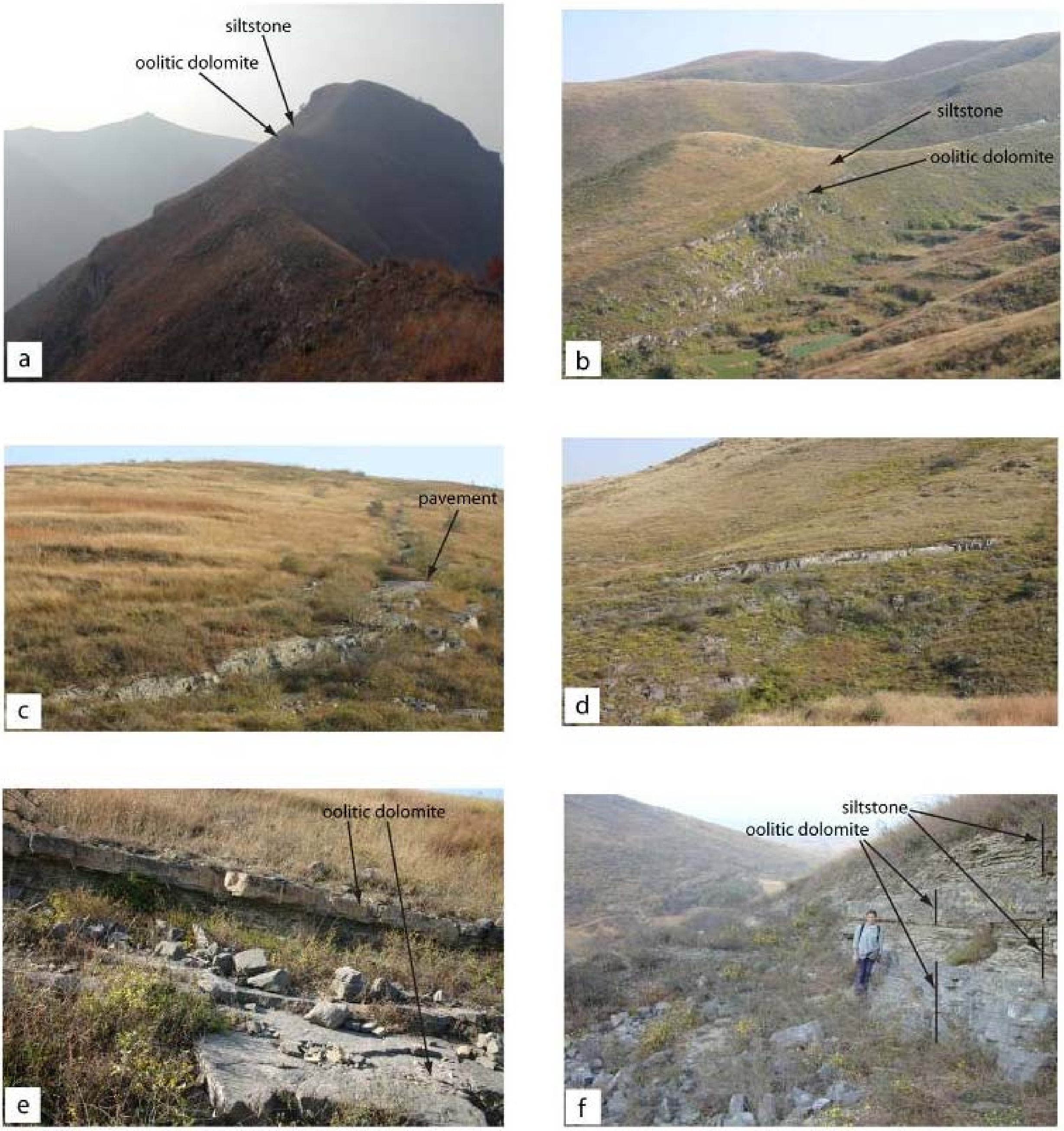

Figure 3. Outcrop characteristics of oolitic dolomite and overlying siltstone. (a, b) In hillsides oolitic dolomite forms small cliff; siltstone occurs as grassy, less steep slope. (c) Unquarried outcrop of oolitic dolomite, showing natural pavement at top of bed. (d) Premodern quarry in oolitic dolomite; note rubble slope below quarry. (e) Quarried pavement of main bed of oolitic dolomite, with overlying siltstone containing a thin separate bed of oolitic dolomite; note tendency of oolitic dolomite to split into thin slabs. (f) Premodern quarry in oolitic dolomite; note thin-bedded nature of main (lower) bed.

Overlying the Cambrian strata are thin Carboniferous beds of claystone, bauxitic siltstone, limestone, sandstone and coal, deposited in alluvial fan, swamp, or lacustrine environments. Succeeding these are Permian river, swamp and lake sediments consisting of sandstone, mudstone, and minor coal, overlain by Triassic strata. In the Huizui area the Carboniferous and Permian sediments are covered by the Quaternary redeposited loess, but both bauxite and coal are extracted from underground mines.

The Cambrian carbonates and siltstones overlie Precambrian (Archaean and Proterozoic) basement that outcrops in the southern Songshan Mountains (Figure 1b; BGMR of Henan Province 1984; Meyerhoff *et al*. 1991). The Archaean igneous and high-grade metamorphic complexes consist of hornblende gneiss, quartzite, migmatite, schist and marble, and have been intruded by granites and

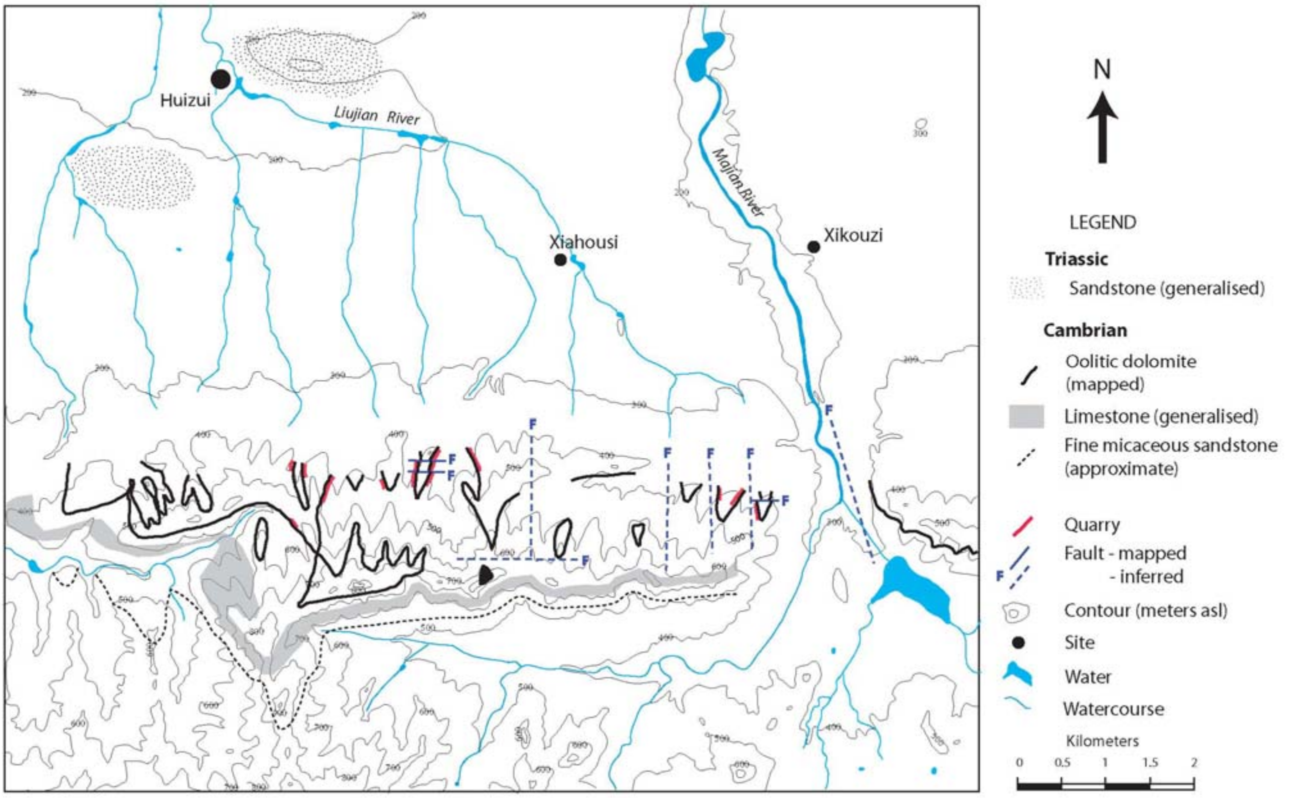

Figure 4. Distribution of most of the common rock types used for artefact manufacture at Huizui. Distribution of oolitic dolomite based on mapping carried out during the present study; sites of premodern quarries shown.

diorites, with very minor pegmatite. The younger Proterozoic deposits are divided into three units; in stratigraphic order these are the Songshan Group (quartzite, schist, phyllite, slate and dolomite marble), Ruyang Group (quartz sandstone, conglomerate and dolomite) and Luoyo Group (sandstone, siltstone, and dolomite). Upper Proterozoic medium to large granites and granodiorites and minor shallow-level diabases intrude these Proterozoic strata. In some locations Upper Proterozoic carbonate and terrigenous sediments, including glacial tillite and glauconitic siltstone, overlie the Luoyo Group.

Oolitic dolomite and fine dolomite (quarried from outcrop)

The Cambrian Fengshan Formation forms the northern flanks of the Songshan Mountains, adjacent to Huizui. Outcrops are composed almost entirely of thick-bedded massive fine dolomite, and there are only a few beds of oolitic dolomite; the most prominent is the bed beneath the beige siltstone (Figure 4). This unit was most probably the source of the oolitic dolomite used for spade manufacture at Huizui, based on the strong similarity of the two lithologies and its ease of quarrying. The other beds of oolitic dolomite within the Fengshan Formation are thin, generally contain smaller, more densely packed oolites and lack the overlying siltstone.

The oolitic dolomite beneath the siltstone is thin-bedded, and breaks readily along bedding parallel cracks into thin slabs (Figure 3e); the surfaces of these slabs often have a very thin reddish-purple ferruginous coating (Figure 2d). The dolomite consists of dark grey, spherical, mostly medium to large oolites (0.5-1 mm in diameter), often concentrically laminated, embedded in a white cement (Figure 2c,d). In some samples the oolites have been replaced by clear, coarse, randomly oriented crystals (oomoulds), and are lighter in colour. Smaller oolites (0.2 mm) may be present, along with minor amounts of echinoderm and trilobite fossil fragments. The oolites and oomoulds are composed of medium-sized blocky dolomite crystals, occasionally oriented radially, and sometimes rhombic rather than irregular in shape; in some samples the original very fine-grained calcite composition of the oolites has been retained in patches. The cement in the pore spaces between oolites has been replaced by equant dolomite crystals.

A detailed petrographic examination of the oolitic dolomite used to manufacture spades at Huizui shows that it is very similar to the oolitic dolomite beneath the siltstone (Figure 2e,f). The oolitic dolomite of the spades consists of dark grey small (0.2 mm) to mostly large (1 mm) oolites and oomoulds surrounded by white cement, all composed of blocky dolomite crystals. The crystal textures of the oolites and cement show no differences to those in the oolitic dolomite beneath the siltstone. Many of the spade blanks often show a thin purplish coating on both sides, undistinguishable from that evident on bedding planes in an oolitic dolomite outcrop.

The oolitic dolomite bed has been quarried at a number of locations in the northern foothills (Figures 3d-f; 4), as close as ~4 km to Huizui; these quarries were used to supply blocks for house foundations for local villages up until ~50 years ago. However, it is possible that these quarries were also used in Longshan and Erlitou times.

There are two factors that make the oolitic dolomite bed beneath the siltstone particularly suitable for quarrying. Firstly, its thin-bedded nature means that it splits readily into thin slabs (Figure 3e,f), close to the desired thickness for spade manufacture. Secondly, the oolitic dolomite is overlain by relatively soft siltstone that is often removed by weathering. As a result, its upper surface is often exposed as a pavement that is immediately suitable for breaking off large slabs (Figure 3c). Furthermore, the overlying laminated siltstone is soft and easily excavated during quarrying operations to reveal the oolitic dolomite beneath (Figure 3e,f). None of the other dolomite beds of the Fengshan Formation that outcrop abundantly in the same area (many of them closer to Huizui) exist in similar outcrops. Together these factors explain why the oolitic dolomite, which makes up less than 5% of the dolomite outcrops on the northern slopes of the Songshan Mountains, accounts for >90% of the dolomite material in the Huizui excavations.

In contrast to the oolitic dolomite, the fine dolomite tools and fragments are not lithologically distinctive and could have been quarried almost anywhere on the northern flanks of the Songshan Mountains.

Diabase (collected from river gravels)

Most of the diabase tool blanks present at Huizui are made from waterworn cobbles. The source of the cobbles is uncertain; gravels in the nearby Liujian River lack diabase as this river runs entirely through Cambrian carbonates and Triassic sandstones (Figure 1b). The diabase may have been derived from the Shagou River, which runs as close as 2 km to Huizui to the northwest (Figure 1a); during the present study diabase cobbles were collected from gravel beds in this river about 3.5 km to the west of Huizui. The headwaters of the Shagou River lie in Precambrian basement, which presumably contains diabase outcrops, although none are mapped (Figure 1b). The gravels could also have been sourced from the Yi and/or Majian Rivers, which lie respectively 10 km or more to the north and 6 km or more to the east of Huizui; the upper reaches of both rivers run through extensive areas of Precambrian rocks (Figure 1b), which are likely to contain diabase outcrops.

Selecting diabase cobbles as tool blanks minimised the amount of production required, as there is little change in size and shape between the natural cobble and the finished tool. Only the lateral margins are squared and the working edge created before the tool was ready to use (Ford 2001: 58; 2004: 73).

Fine micaceous sandstone (quarried from outcrop)

The presence of slabs of unmodified raw material at Huizui shows that the fine micaceous sandstone was available locally. It was most probably quarried from outcrops of the Middle Cambrian Zhangxia Formation at the base of the steep southern flanks of the northernmost E-W ridge of the Songshan Mountains (Figure 4). The basal part of the Zhangxia Formation in this area contains a 15m thick siltstone section with as many as 8 thin interbeds of fine micaceous sandstone up to 20 cm thick. The sandstone beds are often plane laminated and split into thin sheets along the laminations. Thin section examination of the fine micaceous sandstone shows that it is very similar to the artefact sandstone, in that apart from quartz and muscovite it contains a substantial component of calcite grains, along with minor amounts of brownish glauconite pellets, flakes of chloritised biotite and occasional tubular fossil fragments.

The sandstone interbeds in the other Early and Middle Cambrian formations in the area were examined in thin section; while they are superficially similar to the micaceous fine sandstone from which knives and sickles were made, they all differ in significant ways (e.g. grain size, fossil content).

The sandstone beds in the Zhangxia Formation lie within 6 km of Huizui (Figure 4), but because a high ridge separates Huizui and the outcrops, a journey of at least 8 km would have been required to reach them.

Other varieties of sandstone (quarried from outcrop)

The Lower Triassic sandstones outcropping in the two hills located within one kilometre of Huizui (Figure 1a,b) differ in colour and composition. The outcrop ~1.5 km to the southwest of Huizui is white, medium coarse grained and feldspathic, whilst the hill to the northeast, which lies within 500 metres of one of the excavation sites, is composed predominantly of fine-grained quartzose ferruginous violet coloured sandstone. Both outcrops show evidence for quarrying, although much of it appears to be sub-modern; in addition large sandstone boulders and cobbles litter the hillsides, and could have been easily transported to Huizui. Similar sized cobbles and boulders have been found at Huizui in their natural state (Ford 2001: 45).

Petrological examination under a microscope showed that the sandstone fragments found at Huizui encompass a variety of lithologies (feldspathic and quartzose, fine to coarse grained, often ferruginous), and were probably sourced from both hills. The location of Huizui near these sandstone outcrops is important for a ground stone tool manufacturing site, as the sandstone provided the abrasive for tool preparation (Ford 2001, 2004).

Fine limestone and lime (quarried from outcrop)

Limestone does not occur on the northern slopes of the Songshan Mountains, but there are abundant outcrops on the very steep or cliffed southern flanks of the northernmost E-W ridge of the Songshan Mountains (Figure 4). Although dolomite is present much closer to Huizui, limestone is strongly preferred for lime manufacture, because of its superior properties. The limestone pieces and tools found in the excavations are not distinctive and could have been sourced from anywhere on the southern flanks of the ridge. Just like the fine micaceous sandstone,

Table 3. Factors influencing the choice of particular lithologies

Lithology (major use)	Proximity of source	Functional properties	Extraction at source	Appearance
Oolitic dolomite (spades)	min. 4 km	Strong and tough, takes sharp edge but soft and chips easily	Quarried from pavement as thin slabs	Fine spotted
Diabase (axes, adzes, chisels)	min. 2 km	Very strong, tough and hard; takes sharp edge and good edge-holding properties	River cobbles	Dark green
Fine micaceous sandstone (knives, sickles)	min. 8 km	Strong, tough hard; takes moderately sharp edge	Probably quarried as thin slabs	Mica sparkle
Other sandstone (grinding material)	0.5-1.5 km	Good abrasive	As irregular blocks	Irrevelant
Fine limestone (lime source)	min. 8 km	Appropriate for lime manufacture	Probably as irregular pieces	Irrevelant

which also outcrops in this area (Figure 4), a journey of at least 8 km would have been required to reach the limestone outcrops from Huizui.

Other lithologies

Among the less common raw materials there is probably a mixture of local and exotic lithologies. Many of the rock types are known to outcrop in the Precambrian basement in the southern Songshan Mountains (gneiss, marble, schist, slate, quartzite, granite and diorite), and vein quartz and aplite are most likely to occur there also. Thus these lithologies could be derived from gravels deposited by the Majian River, which flows within 5 km of Huizui and drains an area where these rock types occur (Figure 1b). Quartzite cobbles are present within these gravels, and rounded aplite cobbles have been found in the Huizui excavations. Alternatively the rock types could have been quarried from outcrops distant from Huizui (at least 10 km on the other side of the high ridge of the Songshan Mountains; Figure 1a,b). Some of these raw materials are found predominantly as finished tools, suggesting that they were produced off-site and are therefore exotic. The tool blanks that have been found are of indeterminate form, making their origin inconclusive.

The calcite and dolomite crystals could have been derived locally from veins within the Cambrian carbonate sequence. Likewise the stalagmite material could also be local, as small caves are known within the northern Songshan Mountains.

Chert and siltstone are found close to Huizui, but are of low quality. Chert concretions within the upper part of the Fengshan Formation are small, porous and irregular in shape, and these are probably the source of the small cobbles of poor quality chert present within Pleistocene gravel beds near Huizui. The siltstone in the area is unsilicified and also unsuitable for tool manufacture. It is perhaps more likely that the chert and siltstone artifacts are exotic. Two of the silicified siltstone tool blanks are in slab form, suggesting that that they were quarried rather than picked up as waterworn cobbles.

Rhyolite is not recorded from the Songshan Mountains, so it is almost certainly exotic, along with turquoise and ?jade, and probably the higher quality marble. Among these lithologies, only rhyolite shows evidence of manufacture at Huizui (during the Yangshao period, as discussed above). Turquoise, jade and marble, normally found in elite contexts and preferred for use in elite or ritual items (Liu 2000: 149), were worked at other sites; there is a turquoise workshop near the palace area at Erlitou. The presence of turquoise at Huizui may be evidence of interactions between elite individuals from Huizui and Erlitou.

FACTORS DETERMINING THE CHOICE OF LITHOLOGY AT HUIZUI

There are four main factors that are likely to have influenced the choice of the most common rock types for particular purposes at Huizui: proximity of source, functional properties, extraction at source and appearance (Table 3). Perhaps the most important of these is distance to source. The five main lithologies used at Huizui (oolitic dolomite, diabase, fine micaceous sandstone, other sandstone and fine limestone) together comprise 91% of the excavated material (by number), and all are probably available within 8 km of the site. The main reason for the location of a major stone tool production site at Huizui may have been its proximity to the adjacent sandstone hills, which provided an abundant source of abrasive material. Compared to the other lithologies used on site, sandstone for grinding is heavy and relatively low value, so it would have been advantageous to minimise the transport distance of this rock type.

Each of the most common lithologies was used for one main purpose (Table 1). Diabase was used to produce woodworking tools (axes, adzes and chisels) which require strong edge-holding capabilities, because the composition of this rock type means that it is strong, tough and takes sharp working edges which are easily resharpened. Oolitic dolomite is soft but tough, so it can be relatively easily ground to a sharp edge that will, however, scratch and chip easily. The purpose of the oolitic dolomite spades is not known, but experimental work indicates that they might not have been digging implements (Owen, 2006); whatever their use, their softness was evidently not a problem. The fine micaceous sandstone is hard and tough and takes moderately sharp edges, suitable for its use as knives and sickles. Thus the choice of raw material was at least partly due to its mechanical properties.

All three of these lithologies were extracted as raw material that required minimal shaping to make tools. Oolitic dolomite and micaceous sandstone were quarried at sites where these lithologies split readily into thin slabs, close to the desired thickness for making spades and knives/sickles respectively. For diabase there was little change in size and shape between the natural river cobbles and the finished axes/adzes/chisels. Thus the choice of these lithologies was influenced by their ease of extraction as material immediately suitable for tool manufacture. This was probably particularly important for oolitic dolomite; fine-grained dolomite has similar mechanical properties to oolitic dolomite, is much more common and occurs closer to Huizui, but does not outcrop as exposed pavements that can be easily quarried as thin slabs.

The appearance of the rock types may also have influenced their choice; oolitic dolomite, diabase and micaceous sandstone could all be regarded as attractive. This factor was probably more important in the choice of the exotic lithologies like turquoise and high quality marble.

Thus it would appear that the choice of raw materials used at Huizui was a reflection of proximity to source, functional properties and extraction in an appropriate form for tool manufacture. The stone tool producers at Huizui were making cost efficient decisions based on more than one criterion.

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REFERENCES:

Bureau of Geology and Mineral Resources of Henan Province 1984. *Regional Geology of Henan Province*. Geological Publishing House, Beijing.

Chen, X. 2005. Lithic Production of Early States in China: An Examination of the Development of Craft Specialization. Paper presented to Workshop on Early Chinese Civilization, University British Columbia, Canada.

Domanski, M., Webb, J.A. and Boland, J., 1994. Mechanical properties of stone artefact materials and the effect of heat treatment. *Archaeometry* 36: 177-208.

Ford, A., 2001. *States and Stones: Ground Stone Tool Production at Huizui, China.* Honours dissertation, Archaeology Program, La Trobe University, Melbourne.

Ford, A. 2004. Ground Stone Tool Production at Huizui, China: An Analysis of a Manufacturing Site in the Yiluo River Basin. *Indo-Pacific Prehistory Association Bulletin* 24: 71-78.

Garber, J. 1989. *Archaeology at Cerros, Belize, Central America, Volume 2*. Southern Methodist University Press.

Liu, L. 2000. Ancestor Worship: An Archaeological Investigation of Ritual Activities in Neolithic North China. *Journal of East Asian Archaeology* 2: 129-164.

Liu, L. 2006. Urbanization in China: Erlitou and its hinterland. In *Urbanism in the Preindustrial World: Cross-Cultural Approaches*. G. Storey, pp. 161-189. Tuscaloosa: University of Alabama Press.

Liu, L. and Chen, X. 2003. *State Formation in Early China.* London: Duckworth.

Liu, L. and Chen, X. in press. Non-state crafts in the early Chinese state: An archaeological view from the Erlitou hinterland. *Indo-Pacific Prehistory Association Bulletin*.

Liu, L., Chen, X., Lee, Y. K., Wright, H., and Rosen A. 2004. Settlement Patterns and Development of Social Complexity in the Yiluo Region, North China. *Journal of Field Archaeology* 29(1-2): 75-100.

McBryde, I. and Harrison G. 1981. Valued good or valuable stone? Considerations of some aspects of the distribution of greenstone artefacts in south-eastern Australia, in *Archaeological Studies of Pacific Stone Resources* (eds. F. Leach and J. Davidson), *BAR International Series*, 104: 183-208.

Meng, X., Ge, M., and Tucker, M. E. 1997. Sequence stratigraphy, sea-level changes and depositional systems in the Cambro-Ordovician of the North China carbonate platform. *Sedimentary Geology* 114: 189-222.

Meyerhoff, A. A., Kamen-Kaye, M., Chen, C., and Taner, I. 1991. *China: Stratigraphy, Paleogeography and Tectonics.* Kluwer Academic Publishers, Dordrecht.

Owen, D. 2006. *When to call a spade a spade: An exercise in experimental archaeology on an ancient Chinese stone tool*. B.A. Honours thesis, Archaeology Program, La Trobe University.

Xie, L. 2005. *A Preliminary Study of Functional Analysis in Ground Stone Tools: Usewear analysis of stone axes and knives from Erlitou*. Masters Dissertation, Graduate School, Chinese Academy of Social Sciences, Beijing.

Zhu, X. 1989. *Chinese Sedimentary Basins.* Elsevier Scientific Publications, Amsterdam.