Quaternary International 347 (2014) 91–96

Contents lists available at ScienceDirect

Quaternary International

journal homepage: www.elsevier.com/locate/quaint

The discovery of Late Paleolithic boiling stones at SDG 12, north China

Xing Gao [a,*], Ying Guan [a], Fuyou Chen [a], Mingjie Yi [b], Shuwen Pei [a], Huimin Wang [c]

[a] *Key Laboratory of Vertebrate Evolution and Human Origins at the Institute of Vertebrate Paleontology and Paleoanthropology, Chinese Academy of Sciences, 142 Xizhimenwai Street, Beijing 100044, China*
[b] *School of History, Renmin University of China, Beijing 100872, China*
[c] *Institute of Archaeology of the Ningxia Hui Autonomous Region, 121 Limin Street, Yinchuan 750001, China*

ARTICLE INFO

Article history:
Available online 10 August 2014

Keywords:
Fire cracked rocks
Stone boiling
SDG 12
Late Paleolithic

ABSTRACT

A large number of broken stones were unearthed from the ash layer dating 11–12 ka at Shuidonggou Locality 12 (SDG 12) during archaeological excavations in 2007. Morphological and lithological analysis of these stones indicated that they were selected by humans, heated, used, and then crushed. Simulation experiments using the same type of rock demonstrated that these stones ruptured after being heated at high temperatures and immersed in water, suggesting that they were boiling stones used for boiling water and cooking liquid foods. The testing and analysis of the groundwater and surface water quality in the area revealed that the *Escherichia coli* level was extremely high, and that the water was not drinkable before boiling to eliminate the hazard. Ecological and environmental data indicated that various plants for human consumption had grown in that location since the late Upper Pleistocene and that certain edible seeds had to be cooked before being eaten. The fire cracked rock is the first recognized and demonstrated archaeological evidence of stone boiling in China, a kind of complex and indirect fire usage by prehistoric humans, which has significant implications in exploring the adaptation strategy of the occupants of the site, the development of human fire-usage history, as well as the origin or source of Amerindian “stone boilers”.

1. Introduction

The Shuidonggou site complex near Yinchuan, the capital city of Ningxia Hui Autonomous Region of China, has been drawing significant academic attention since its discovery in 1923 (Licent and Teilhard de Chardin, 1925; Kozlowski, 1971; Gao et al., 2013a). Among the rich cultural remains excavated from several localities of the site, certain stone artifacts demonstrate the obvious technical style of the Middle and Upper Paleolithic industries of western Eurasia, which is unique in the Chinese Paleolithic industries, and thus have become an academic focus for studying human migration in the late Pleistocene, East–West cultural exchanges and ancient humans' capability and adaptability to a specific ecological environment (Guan et al., 2012; Peng et al., 2012; Li et al., 2013; Zhou et al., 2013; Yi et al., 2013).

Between 2003 and 2007, the joint archaeological team from the Institute of Vertebrate Paleontology and Paleoanthropology under the Chinese Academy of Sciences (CAS) and the Ningxia Institute of Cultural Relics and Archaeology conducted a series of systematic excavations at a few key localities of the site. Other than stone artifacts, ornaments, bone tools, and animal bone fragments, a large amount of hearth remains and associated materials such as charcoal, ash, burnt stones and bones were also unearthed (Gao et al., 2013b). These remains of fire usage were encountered in cultural horizons with clear symbiotic relationship with stone artifacts and animal bone fragments. The fire-usage remains discovered at localities 2, 8, and 12 were the most concentrated and abundant and were well-preserved. These fire-usage materials belong to two periods, providing important information about the major shift in fire-usage among Upper Paleolithic populations in the region, and facilitating research on the development of fire-usage at a global scale. The present paper is a case study of Paleolithic fire-usage behavior at SDG 12, including the observation, analysis, and experimental research of the fire-usage materials, and accordingly exploring the adaptation strategies and intellectual development of Late Paleolithic groups in the region.

2. The recovered fire cracked rocks and taphonomic information

SDG 12 is located approximately 4 km north of the center of the Shuidonggou site complex, and the geographic coordinates are N38°19′40″, E106°29′49″. This locality was discovered in 2005, and

* Corresponding author.
E-mail address: gaoxing@ivpp.ac.cn (X. Gao).

http://dx.doi.org/10.1016/j.quaint.2014.07.003
1040-6182/

a small-scale excavation at an area of 12 m^2 was conducted in 2007. The cultural horizon, a thick brown layer of ash containing fine sand and cultural remains, was buried in the mid-upper section of terrace II of the Yellow River. AMS ^{14}C and Optically Stimulated Luminescence (OSL) dating indicated that the cultural layer was formed 11–12 ka (Liu et al., 2009).

The range and thickness of the Paleolithic ash layer preserved at the site are extremely rare, implying a long period and a large scale of fire-usage behavior and high fire dependency of its occupants (Gao et al., 2009). A large part of the deposits containing cultural remains at the site has been destroyed by brick making, but a layer of ash is still visible on the residual section extending over 50 m north–south and approximately 10 m east–west, with a lenticular distribution. The thickness of the ash at the most concentrated area is 1.6 m. According to local people, there were thicker and more concentrated ash accumulations to the west of the remnant sediments. This ash layer is a mixed accumulation of ashes, charcoals, sands, stones, and bones, with no clear stratification (Fig. 1). Numerous stone and bone artifacts and animal bone fragments were unearthed from this horizon. The stone artifacts include micro-cores, micro-blades, side-scrapers, end-scrapers, partially polished stones axes, grinding slabs, rubbing stone or rollers; the bone artifacts include delicate awls, needles, and grooved pieces. Burnt bone specimens were found among the animal bone fragments.

A large quantity of stone pieces was recovered from the sediments, and most of them were burnt and cracked. During the 2007 excavations, more than 13,000 pieces of burnt stones or fire cracked rocks, with a total weight of 307 kg, were collected, and they were irregularly and densely distributed in the 12 m^2 excavation area, mixed with other cultural remains. These burnt stones are in various shapes, mostly irregular polyhedrons, and no percussion marks, smashing, or other artificial processing traces were found on the rocks other than cracking and discoloration signs of burning. The stone sizes vary; most are between 12 and 280 g, with 60% of them between 20 and 50 g, 18% between 50 and 100 g, 5% between 100 and 150 g, and only 1.5% more than 150 g. The individual diameters of 55% of the stones are between 2.5 and 5 cm. Overall, the sizes of the individual fire cracked rocks do not vary greatly; most are small, which is most likely a result of human selection and usage.

Approximately 98% of the stones are broken after being burned, with cracks on the surface and colored light gray and gray-brown (a result of high temperatures), which is apparently different from the rocks' original color after being tapped open. A small number of fire cracked rocks are still intact but display irregular cracks on the surface (Fig. 2). Approximately 40% of the fire cracked stones retain their original cortices, suggesting that these stones were natural ones directly utilized as burning stones. A small number of specimens had traces of ash adhering to their surface when excavated. Statistical lithological analysis indicated that the common stone types of the region were limestone, dolomite, quartz sandstone, and quartzite, whereas the materials of the fire cracked rocks were almost entirely quartz sandstone and dolomite (with the former commoner than the latter). Limestone, this region's commonest stone material, was not found in burning stones, and flint, quartz and other raw materials popular for making stone tools at the site are seldom present in the burnt category.

Such physical and lithological characteristics suggested that these burnt stones were not naturally broken rocks randomly distributed in the stratum, but were intentionally selected and transported to the site by humans for heating; in addition, these stones were not raw materials for stone tool manufacture that were burnt accidentally, but were heated at high temperatures for a long period for specific purposes. Based on their size, shape, frequency of occurrence, and degree of fracture, these rocks were not the circle stones of hearth or stove that are found on archaeological sites or used for modern wild life either. Our hypothesis is that these stones were heated for cooking food or boiling water and thus were the remains of ancient “stone boiling”, reflecting the occupants' special skills of fire and heat usage and their adaptation strategy to a particular ecological environment.

Fig. 1. The stratigraphy of Shuidonggou Locality 12 (Layer labelled “11” is the cultural horizon).

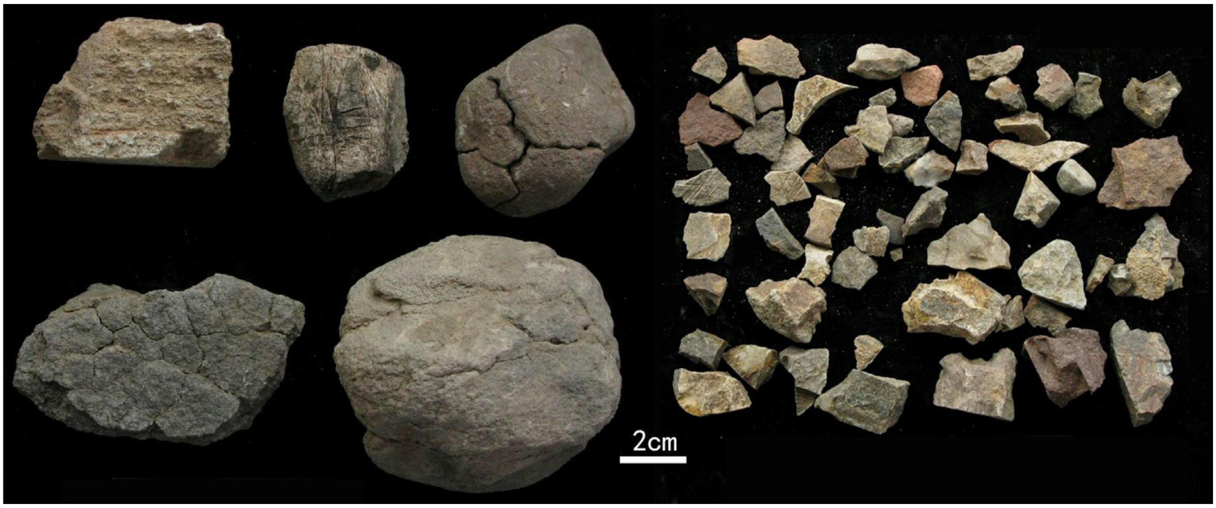

Fig. 2. Burning stones unearthed from Shuidonggou Locality 12.

3. Simulation experiment

In order to understand the nature and cause of these burnt stones, we conducted a series of burning simulation experiments by using gravels and rocks collected around the site that had the same lithology and morphology of the excavated fire cracked pieces, along with some limestone. The basic design of the experiment is as follows: a. the collection and selection of comparable raw materials; b. the observation of morphological changes in the stones after heating at a low temperature (including both non-water immersion and water immersion methods); c. the observation of morphological changes in the stones after heating at a high temperature (including both non-water immersion and water immersion methods); d. repeated heating and immersion steps using the already immersed burnt stones; and e. using the excavated fire cracked rocks for the same experiment procedures.

To obtain a fire temperature close to that produced by the inhabitants of the site, we tried two types of hearth modes:

3.1. Open hearth

To simulate a simple, open hearth, a shallow pit in the ground was selected, local shrubs and small trees were used to light bonfires and a natural, low-temperature flame was created to heat the stone materials placed on the fire. For this open hearth, the external temperature of the flame was recorded as 500–600 °C. After heating for 15 min, the morphological changes in the stones with different lithology were recorded with and without water immersion. The results are: 1) Heated but not immersed stones did not rupture, but some had cracks on the surface (we refer to this situation as Class 1 Rupture). 2) After immersion, some stones split into two, mostly along the stone's original joints (this situation is defined as Class 2 Rupture). 3) The water for immersion was either not boiling or had not been boiling for a long period.

3.2. Stove-style hearth

A relatively closed stove-style hearth was built using gravels, with a vent facing the natural wind direction. In case of no wind, artificial blowing for combustion was conducted to produce a relatively high temperature. The external temperature of the flame was recorded as up to 600–800 °C. After heating for 15 min, the morphological changes in the stones with different lithology were recorded with and without immersion. The results are: 1) Most heated but not immersed stones had cracks on the surface but did not rupture (Class 1 Rupture), and a small portion of the stones split into two along their joints, with rather smooth surfaces (Class 2 Rupture). Under this condition, the color of the heated limestone was lightened and whitened. 2) When immersed in water after heating, the quartz sandstone and dolomite stone generally ruptured into three to five blocks, with no defined direction of rupture and rough surfaces (this situation is defined as Class 3 Rupture). These features were the same as those of the excavated large burning stones. These types of materials were repeated for the same heating and soaking experiments, and the stones again ruptured into smaller pieces with features identical to those of excavated small burning stones. 3) After being heated and immersed in water, the vein quartz and flint stones burst into debris or coarse particles (this situation is defined as Class 4 Rupture). 4) After being heated and immersed in water, the limestone burst into a powder, making the water turbid. 5) The water for immersion of the heated stones was boiling for a relatively long period of time (up to 2 min). The water could be boiled much longer with the continual addition of heated stones.

Several phenomena observed in the simulation experiment facilitated an interpretation of the origin and usage of the fire cracked rocks at SDG 12.

1) According to the standards for grading stone rupture in the experiment, most of the unearthed fire cracked rocks at SDG 12 belong to the Class 2 and 3 Rupture categories (particularly Class 3), suggesting that the fire cracked rocks experienced processes of heating at a high temperature and water immersion, and many of these stones were heated and immersed many times. In terms of the usage value, although heating and immersion were two continuous steps, the former should be the latter's preparatory process; that is, the real purpose of producing the fire cracked rocks was to immerse the heated stone in water to heat or boil water or liquid foods.
2) The limestone heating experiment demonstrated that it generally did not rupture at low temperatures, but after being immersed in water, a large amount of flaky debris was generated at the surface. After being heated at a high temperature, it became slaked lime blocks and was immediately decomposed into fine powder after immersion in water and then turned into white, hydrated lime slurry. The high-temperature heated

limestone could not form the morphology of the excavated fire cracked rocks with or without immersion in water and made the soaking water turbid. This phenomenon explains why the most easily accessible limestone at the location was not used as a burning stone.

3) Quartz veins and flint burst into debris or coarse granules after being heated at high temperatures and immersed in water, causing a certain degree of water pollution. If there is food in the water, this debris and sand will be mixed with the food, making it hard to enjoy because of the difficulty in separation. This phenomenon should be the reason that these materials were used to make tools rather than as burning stones.
4) If the above inference holds true, it suggests that the inhabitants of SDG 12 made a significant change in their fire-usage skills. They were no longer satisfied with the earlier, direct method of using fire to grill food, but developed an indirect technique of using fire to heat water and to cook food via burnt stones, that is, stone boiling, which made it easier to control the fire temperature and to more effectively to use the heat. The selection of raw materials for fire cracked rocks indicated that with their practical production and life experiences, these people acquired a deep understanding of the characteristics of various local stones and accumulated a wealth of environmental knowledge, thereby learning how to take advantages and avoid damages in utilizing their resources.

Which objects were heated by using burnt stones, and what type of ecological environment prompted such adaptive responses? We tried to find answers from paleoenvironmental information in the region.

4. Characteristics of the paleoenvironment, food resources, and water quality surrounding the site

4.1. Paleoenvironment and food resources

Shuidonggou is adjacent to the Mu Us Desert at the southwestern margin of the Ordos Plateau, 10 km east of the Yellow River and its alluvial plain. The basin where the site is located is in a transition zone between the Yellow River alluvial plain and the temperate desert steppe, and the site complex itself is located in an ecological niche of river-swamp coastal meadows and low woody plants. Paleoenvironmental data indicate that the area had been in a desert steppe environment for tens of thousands of years since the late Upper Pleistocene. The spore-pollen assemblage characteristics indicate that during the entire process of the site's formation of the sediments, the surrounding vegetation type was mainly dominated by a combination of *Ephedra*, Chenopodiaceae, Zygophyllum xanthoxylon, *Artemisia*, and Gramineae, which was an arid–semi-arid desert grassland-vegetation landscape. When humans occupied the site, they probably lived under a desert grassland-savanna environment, with marsh plants and elm, oak, birch, and other deciduous broad-leaved trees nearby (Liu et al., 2008). From the perspective of human food resources, only a relatively small portion of the roots, stems, leaves, seeds and fruits of these arbors-shrubs were edible. Currently, nearly 20 types of edible wild plants can be found in the region, including Mongolia onion, *Allium*, *Artemisia*, *Agriophyllum squarrosum*, cynomorium, and licorice grow in the desert near the site, and, black fruit wolfberry, bitter herbs, and *Portulaca oleracea* grow at the shallow shore of the nearby basin lakes and rivers (Institute of Inner Mongolian Grassland (1964)). Most of these appeared in the late Upper Pleistocene, and their fruits, seeds, roots, stems, and leaves generally have to be boiled, often for a long period, before being consumed. In addition, the remains of Oryctolagus (*Lepus* sp.), Lepus, badgers (*Meles meles*), deer (Cervidae), antelopes (*Gazelle przewalskyi*), buffalo (*Bubalus* sp.), boars (*Sus* sp.), horses (*Equus przewalskyi*), birds, and rodents were recovered from the cultural layer of the site, with antelopes and rabbits the most abundant. These animals are mainly herbivorous and were likely the residue of human food. Animal meat was probably the main target of stone boiling by humans at the site.

4.2. Water quality test

A phenomenon observed by the archaeological team during excavation drew our attention to the Shuidonggou local water quality and prompted us to conduct relevant tests. There is a deep well near Locality 1 in the site's central area. The locals use the water in the well as drinking water for livestock but not for humans because of the poor water quality that can cause diarrhea. To investigate the availability of the water supply that was accessible to ancient humans living in the area, we extracted samples from two water sources to test the water quality. Water sample 1 was collected from undercurrent springs in the gravel layer underneath the 2nd terrace deposits in the area. The undercurrent is approximately 11–15 m deep under the ground, springing out at various locations. Water sample 2 was collected from Red Mountain Lake near the site. Red Mountain Lake is a flowing body of water formed by ditch water of the Biangou River. The test results of the water samples are presented in Table 1.

Test results in Table 1 demonstrate that most sensory traits and general chemical indicators of water sample 1 met the drinking water standards; although the visible objects and iron exceeded the standards, drinking the water would not make people experience obvious or defined physical discomfort. Drinking water with excessive fluoride can greatly affect the bones and teeth but will not significantly harm the human body in the short term, and the damage is not lethal. The total number of coliforms in water sample 1 was up to 70 per liter, which was much higher than the 3 per liter standard. Directly drinking this water would immediately cause significant harm to humans, including abdominal pain and diarrhea, and the harm can be more severe to children and elders. However, the quality of *Escherichia coli*-contaminated water is immediately improved after being boiled. After boiling, the water becomes drinkable. In addition to the same over-the-standard indicators as in water sample 1, the sulfate, chloride, total dissolved solids, and total number of bacteria in water sample 2 were also higher than the standards; the total dissolved solids in sample 2 was nearly 3 times higher than those in sample 1, and the total number of bacteria in sample 2 was 30 times higher than that in sample 1. It is noteworthy that although the total number of bacteria varied greatly between water sample 1 and sample 2, the proportion of *E. coli* was similar in the deep-underground water sample 1 and in the surface water sample 2. Water sample 2 was modern flowing water, inevitably containing modern industrial and agricultural pollution ingredients. Water sample 1 was underground water, to a certain extent representing the quality of usable water accessible to ancient humans in this area. The test results revealed that the locals, both in the terminal Pleistocene and in the modern age, have not directly drunk the local water. They have to boil the water before drinking it, which should be the main reason why the occupants of SDG 12 invented the technique of stone boiling and thus left us a large number of fire cracked rocks at the site. The quality of modern water is certainly different from that of the water used by prehistoric humans. Therefore, the conclusion must be confirmed with further research.

Table 1
Shuidonggou area water-quality test results.

Test items		Standards (mg/L)	Test results (mg/L)		Test items		Standards (mg/L)	Test results (mg/L)	
			Water sample 1	Water sample 2				Water sample 1	Water sample 2
Sensory traits and general chemical indicators	Chroma	0°	0°	0°	Toxicology indicators	Fluoride	1.0	2.01	5.05
	Turbidity	5°	<DL degrees	4°		Cyanide	0.05	<DL degrees	<DL degrees
	Smell and taste	None	None	None		Arsenic	0.05	0.0044	0.0014
	Visible objects	None	Microscale sediments	None		Selenium	0.01	<DL degrees	<DL degrees
	Ph	6.5–8.5	7.7	8.1		Mercury	0.001	<DL degrees	<DL degrees
	Iron	0.3	1.10	0.12		Cadmium	0.01	<DL degrees	<DL degrees
	Manganese	0.1	<DL degrees	<DL degrees		Hexavalent chromium	0.05	0.041	0.015
	Copper	1.0	<DL degrees	<DL degrees		Lead	0.05	<DL degrees	<DL degrees
	Zinc	1.0	<DL degrees	<DL degrees		Silver	0.05	<DL degrees	<DL degrees
	Volatile Phenols	0.002	<DL degrees	<DL degrees		Nitrate nitrogen	20	8.89	4.04
	Sulfate	250	118	523	Bacteriological indicators	Total number of bacteria	100/mL	8	240
	Chloride	250	345	367		Total number of coliforms	3/L	70	92
	Total dissolved solids	1000	588	1690		Free residual chloride	mg/L	<DL degrees	<DL degrees
	Total hardness	450	133	310					
	Anionic detergents	0.3	0.01	0.05					
Conclusions	Water sample 1 test results: The content of visible objects, iron, fluoride, and total coliforms did not meet the national drinking water health standards (GB5749-1985); the other tested items met the national drinking water standards. Water sample 2 test results: The content of sulfates, chlorides, total dissolved solids, fluoride, total bacteria, and total coliforms did not meet the national drinking water health standards; the other tested items met the national drinking water health standards.								

5. Discussions and conclusion

Based on morphological, lithological analysis and experimental studies, we believed that these cracked and high temperature-heated stones discovered from SDG 12 were the remains of burnt rocks used for boiling water and cooking food by humans living in this region 11–12 ka. The reason that these Late Paleolithic humans boiled water at that time was because of the large number of *E. coli* bacteria in the water which made the water not directly drinkable. Food, including that from animals and plants, might also have been heated and boiled at that time. The spore-pollen analysis result and the local modern comparable plant species suggest that the ancient humans might use edible fruits, seeds, roots, stems, and leaves from a variety of plants, and some of these food resources had to be cooked before eating. Grinding slabs with rubbing stone or rollers that coexisted with fire cracked rocks in the ash layer at the site could have been used to process plant seeds (Fig. 3). The procedure of mashing and grinding these edible plant seeds might be associated with cooking, which strengthens the credibility of the speculation regarding the ancient humans' cooking behavior at the site.

There are many records of using heated stones for boiling water and cooking food in the Chinese ethnological literature—a technique that is mostly known as the “stone cooking method” (Song et al., 1983). For example, the Oroqen people place food mixed with water into a birchbark bucket or a cleansed stomach from a large animal and cook the food by adding heated stones. During the slaughtered ox ritual, Dai people dig a pit in the ground, pad it with ox skin, fill it with meat and water, and then add heated stones to cook the food. A similar cooking method is also commonly found among the North American Indian tribes (Thoms, 2008, 2009). Among them, the name of the Assiniboine family means “stone boilers”. Assiniboines dig a pit in the ground after slaughtering cattle, place the animal's skin at the bottom of the pit with beef and water inside, start a fire next to the pit to heat stones, and then add the hot stones to heat the meat until cooked. Another option is when the hide is held above the fire with a few sticks, heated rocks are added to accelerate the boiling.

Scholars believe that this cooking method came from Northeast Asia in the Upper Paleolithic, with an unknown origin. The discovery of fire cracked rocks at SDG 12 brought the history of the “stone cooking method” forward more than 10 thousand years and possibly established a new historical tie between the Northeast Asian populations in the late Upper Pleistocene and the Amerindians.

The control and use of fire is a high level of intelligent behavior, which is a capability possessed only by humans. In the long history of human evolution, human's ability to control and use fire has been continuously developed and strengthened. From the archaeological discoveries at the Gesher Benot Ya'aqov (Israel) site and the Zhoukoudian site near Beijing, China, it is known that during the mid-evolution of *Homo erectus* at least 700–800 thousand years ago, humans were already able to use, control and maintain fire (Wu, 1999; Goren-Inbar et al., 2004; Zhong et al., 2014). A large amount of hearth remains unearthed from Shuidonggou Locality 2 of nearly 30-thousand-year-old age indicates that humans at that time had a high dependency on fire, that their ability to control fire had been strengthened, and that they were already able to use fire for heat treating stone materials (Guan et al., 2011; Zhou et al., 2013); however, the use of fire was still in a simple and direct mode. The discovery of 15.5 ka hearth in Spanish El Mirón Cave (Yuichi et al., 2009) and 11–12 ka fire cracked rocks at SDG 12 site, as well as the reflected human's fire usage patterns and functions, indicated that humans' ability to control and use fire underwent a great leap, evolving from simple and direct usage to complex and

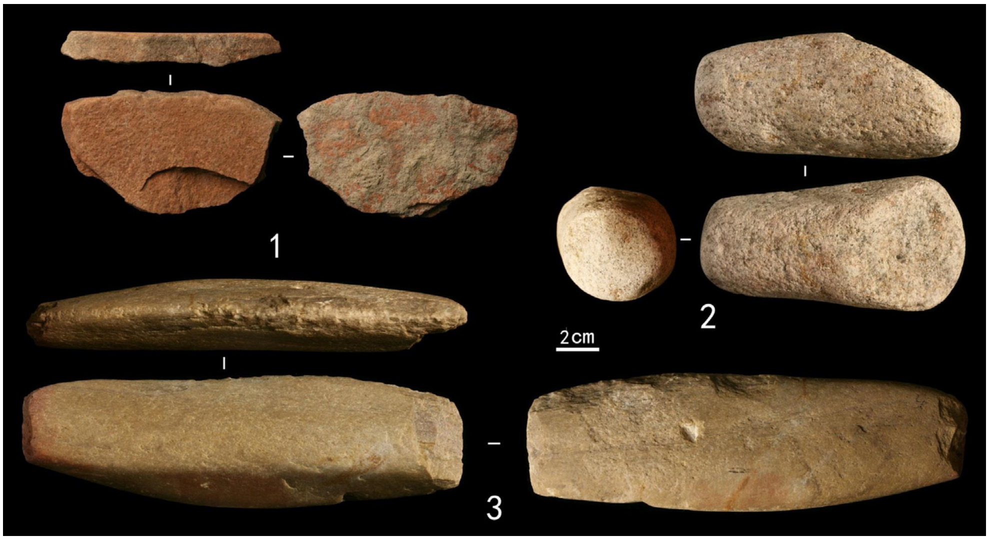

Fig. 3. Grinding Stones unearthed from Shuidonggou Locality 12.

indirect usage; moreover, the fire-usage pattern changed from direct contact between the fire and the heated object to indirect heat transduction using burnt stones. The heated objects were no longer limited to shaped solids but included amorphous and difficult-to-control liquids and thus promoted the invention and usage of containers (Wu et al., 2012). In addition to cooking, heating, lighting, and self-defense, the improvement of water quality was added to the functions of fire, thereby transforming the original non-livable environment to one more conducive to life.

Acknowledgements

The authors are grateful to Liu Decheng, Zhang Xiaoling, Zhang Yue, Zhou Zhenyu, and other members of the SDG archaeological team for their contributions to the fieldwork and data analyses. This research project is supported by the Strategic Priority Research Program of CAS (XDA05130302), the National Natural Science Foundation of China (41102016), and the Key Research Project of CAS (KZZD-EW-15).

References

Gao, X., Wang, H.M., Liu, D.C., Pei, S.W., Zhang, X.L., Zhang, Y., 2009. A study of fire-use activities at shuidonggou locality 12 (in Chinese). Acta Anthropologica Sinica 28, 229–336.

Gao, X., Wang, H.M., Guan, Y., 2013a. Research at Shuidonggou: new advance and new perceptions (in Chinese). Acta Anthropologica Sinica 32, 121–132.

Gao, X., Wang, H.M., Pei, S.W., Chen, F.Y., 2013b. Shuidonggou—Excavation and Research (2003–2007) Report (in Chinese). Science Press, Beijing.

Goren-Inbar, N., Alperson, N., Kislev, M., et al., 2004. Evidence of hominin control of fire at Gesher Benot Ya'aqvo, Israel. Science 304, 725–727.

Guan, Y., Gao, X., Wang, H.M., Chen, F.Y., Pei, S.W., Zhang, X.L., Zhou, Z.Y., 2011. Spatial analysis of intra-site use at a Late Paleolithic site at Shuidonggou, Nortwest China. Chinese Science Bulletin 56, 3457–3463.

Guan, Y., Gao, X., Li, F., Pei, S.W., Chen, F.Y., Zhou, Z.Y., 2012. Modern human behaviors during the late stage of the MIS3 and the broad spectrum revolution: evidence from a Shuidonggou Late Paleolithic site. Chinese Science Bulletin 57, 379–386.

Institute of Inner Mongolian Grassland, 1964. Grassland Manual (in Chinese). Inner Mongolia People's Publishing House, Hohhot, pp. 152–164.

Kozlowski, J.K., 1971. The problem of the so-called Ordos culture in the light of the Paleolithic finds from northern China and southern Mongolia. Folia Quaternaria 39, 63–99.

Li, F., Gao, X., Chen, F.Y., Pei, S.W., Zhang, Y., Zhang, X.L., Liu, D.C., Zhang, S.Q., Guan, Y., Wang, H.M., Kuhn, S.L., 2013. The development of Upper Palaeolithic China: new results from the Shuidonggou site. Antiquity 87, 368–383.

Licent, E., Teilhard de Chardin, P., 1925. Le Paléolithique de la Chine. L'Anthropologie 25, 201–234.

Liu, D.C., Chen, F.Y., Zhang, X.L., Pei, S.W., Gao, X., Xia, Z.K., 2008. Preliminary comments on the Paleoenvironment of the shuidonggou locality 12 (in Chinese). Acta Anthropologica Sinica 27, 295–303.

Liu, D.C., Wang, X.L., Gao, X., Xia, Z.K., Pei, S.W., Chen, F.Y., Wang, H.M., 2009. Progress in the stratigraphy and geochronology of the Shuidonggou site, Ningxia, North China. Chinese Science Bulletin 54, 3880–3886.

Peng, F., Gao, X., Wang, H.M., Chen, F.Y., Liu, D.C., Pei, S.W., 2012. An engraved artifact from Shuidonggou, an early Late Paleolithic site in Northwest China. Chinese Science Bulletin 57, 1–6.

Song, Z.L., Li, J.F., Du, Y.X., 1983. Prehistory of China (in Chinese). Cultural Relics Press, Beijing, pp. 358–359.

Thoms, A.V., 2008. The fire stones carry: Ethnographic records and archaeological expectations for hot-rock cookery in western North America. Journal of Anthropological Archaeology 27, 443–460.

Thoms, A.V., 2009. Rocks of ages: propagation of hot-rock cookery in western North America. Journal of Archaeological Science 36, 573–591.

Wu, X., 1999. Investigating the possible use of fire at Zhoukoudian, China. Science 283, 299.

Wu, X., Zhang, C., Goldberg, P., Cohen, D., Pan, Y., Arpin, T., Bar-Yosef, O., 2012. Early pottery at 20,000 years ago. Science 336, 1696–1700.

Yi, M.J., Barton, L., Morgan, C., Liu, D.C., Chen, F.Y., Zhang, Y., Pei, S.W., Guan, Y., Wang, H.M., Gao, X., Bettinger, R.L., 2013. Microblade technology and the rise of serial specialists in north-central China. Journal of Anthropological Archaeology 32, 212–223.

Yuichi, N., Straus, L.G., González-Morales, M.R., Cuenca Solana, D., Caro Saiz, J., 2009. On stone-boiling technology in the Upper Paleolithic: behavioral implications from an early Magdalenian hearth in El Mirón Cave, Cantabria, Spain. Journal of Archaeological Science 36, 684–693.

Zhong, M., Shi, C., Gao, X., Wu, X., Chen, F., Zhang, S., Zhang, X., Olsen, J.W., 2014. On the possible use of fire by Homo erectus at Zhoukoudian, China. Chinese Science Bulletin 59 (3), 335–343.

Zhou, Z.Y., Guan, Y., Gao, X., Wang, C.X., 2013. Heat treatment and associated early modern human behaviors in the Late Paleolithic at the Shuidonggou site. Chinese Science Bulletin 58, 1801–1810.