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REVIEW ARTICLE

The 'Sand-Bath' and Lithic Heat Treatment in the South African Middle Stone Age: Myth or Reality?

Patrick Schmidt

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Abstract When heat treatment of silcrete for stone knapping was first discovered in the South African Middle Stone Age (MSA), the procedure used for it was suggested to be similar to the one used for heat treatment of finer rocks in other parts of the world: slow sand-bath heating. This comparison may have been based on published data from the fields of ethnography, experimentation and archaeology, describing sand-bath like structures and processes. In this review, I discuss whether the available data from these three fields indeed justify the suggestions that sand-bath heating was used in the context of MSA silcrete heat treatment. A careful revaluation of the available data shows that, although sand-bath heating is a widely accepted procedure that is documented in other parts of the world, understanding the earliest known cases of heat treatment in the MSA calls for another technical procedure.

Résumé Lors de la découverte du traitement thermique réalisé sur les silcrètes du *Middle Stone Age* (MSA) d'Afrique du Sud, l'hypothèse d'un traitement en bain de sable, processus largement utilisé pour la chauffe des silex dans d'autres régions du monde, a été proposée. Cette assimilation repose sur des données issues des recherches en ethnographie, archéologie ou sur des travaux expérimentaux utilisant des structures similaires à des bains de sable. Cet article considère les données publiées dans ces trois domaines et tente d'évaluer si la chauffe en bain de sable a réellement pu être utilisée dans le contexte du MSA d'Afrique du Sud. Les résultats de cette réévaluation montrent que, même si la chauffe en bain de sable est bien documentée et largement acceptée comme une technique répandue dans le monde scientifique, la compréhension des premiers traitements thermiques dans le MSA d'Afrique du Sud doit faire appel à une autre technique de chauffe.

P. Schmidt (✉)
Department of Prehistory and Quaternary Ecology, Eberhard Karls University of Tübingen, Schloss Hohentübingen, 72070 Tübingen, Germany
e-mail: patrick.schmidt@uni-tuebingen.de

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Introduction

The earliest known records that document heat treatment of raw materials for the production of stone tools date back to the South African Middle Stone Age (MSA) (Brown et al. 2009). Heating of stone appears thus to be one of the earliest fire-related transformative processes of naturally available materials. The investigation of heat treatment, the procedures associated with it, its benefits, its cost for the MSA societies and the reasons why it was invented shed light on many archaeological and paleoanthropological questions: starting when, and why, did people employ heat treatment, what does it tell us about their technology and does it imply complex cognition or social learning processes? The answers to these questions shed light on the behavioural, social and cognitive processes during a key period for the evolution of modern humans. Part of these processes can be understood by investigating the technical complexity of the procedures and techniques used for heat treatment. This is why, since the discovery of silcrete heat treatment in the MSA, there is an ongoing debate about the procedures used for it. In their pioneering paper, Brown et al. (2009) described the experiments they conducted as: '…we placed raw material […] within a sand bath approximately 2–3 cm below the surface. A fire was then built over the sand containing the silcrete' (Brown et al. 2009 SOM, p. 2). This procedure is not unusual or novel, as underground heating similar to this was used before to heat-treat flint and chert from North America and Europe (Eriksen 1997; Griffiths et al. 1987; Mandeville and Flenniken 1974). It creates slow heating rates and low temperatures that allow the avoidance of unwanted overheating of the rocks. On the other hand, sand-bath heating is time-intensive because the stones must be placed under the fire before it is lit, and can only be taken out when it has burned out and the sand-bath cooled down; hence, the procedure requires an investment in time of up to a full day or even more (Eriksen 1997). Because the sediment around the stones consumes the major part of the heat radiated below the fire, underground heating also requires more wood-fuel per heated stone than alternative techniques that would directly use the above-ground fire. The implications of this were highlighted by Brown and Marean (2010, p. A6) when they wrote: 'We argue that silcrete's appearance and disappearance is constrained by the abundance of wood fuels…'. The idea behind this is that silcrete needs to be heat-treated before use and that this heat treatment would consume large quantities of food-fuel.

The first argument against sand-bath heating was made by Schmidt et al. (2013). This work showed that the structural and crystallographic properties of silcrete do not require slow heating but that, on the contrary, silcrete from the South African west coast can be heated with relatively fast heating rates. The paper concluded that silcrete could have been heat-treated using the embers of domestic fires, requiring little investment in time, because of the faster heating cycle, and no extra investment in resources because regular hearths used for cooking, heating or social activities could be used. However, this idea was not widely accepted by archaeologists working in South Africa. Wadley (2013) argued that slow heating in a sand-bath was more reliable than heating in a fire and a year later, Wadley and Prinsloo (2014) published a description of their heat treatment experiments during which they found that heat treatment cannot have been conducted with open fires.

Thus, the concept of heating in a sand-bath is still actively debated by scientists working on the South African MSA. There is much scepticism with respect to heat treatment in embers, and underground heating is often thought to be 'more likely' or 'less risky' than direct heating in a fire. So where does the idea of a sand-bath come from? There are three lines of argumentation that may lead one to assume the sand-bath technique in the context of the South African MSA: ethnographic, experimental/mineralogical and archaeological. In the following pages, the data available from these three fields will be examined to establish (1) the likelihood that the sand-bath technique was used during the South African MSA and (2) what direct material evidence exists to support the use of the technique.

Ethnographic Evidence of the Sand-Bath

Although ethnographic data are available from different locales around the world, the majority come from accounts of North America Indians. Hester (1972) and Mandeville (1973) both published very helpful reviews of the North American data, and even though most of these records seem to describe the use of fire for fracturing or spalling off pieces of stone, some make mention of heat treatment prior to stone knapping. Among these, a small number describe heat treatment of stone in a sand-bath beneath a fire. For example, Shoshone Indians near the west coast of North America were described as '…placing them [obsidian or other stone] in damp earth covered with a brisk fire…'. (Powell 1874, p. 27). In a similar fashion, Grinnell (1895, p. 147) wrote that Indian groups from the north-central part of the USA (referred to as 'plains tribes' by him) had heat-treated chalcedony and obsidian '…buried in wet earth, over which a fire has been built…'. Two other records describing sand-bath techniques come from the Horn of Africa and Australia. Arthur (2010, p. 234) described Konso women from southern Ethiopia who heat-treat chalcedony and milky quartz by placing it '…on top of a broken piece of pottery with an insulator such as leaves, domesticated animal hair, wool, cotton, or additional pottery sherds in a pit under her [a woman's] hearth', and Akerman (1979) mentioned a technique used in the Australian Kimberleys to heat-treat chert in a pit filled with sand and embers. These ethnographic descriptions of the sand-bath technique may be used for interpreting archaeological heat treatment. However, it is not the only known technique, and other accounts mention heat treatment of stone using very different methods. Schumacher (1877, p. 547), for example, described the heating procedure of the Californian Yurok Indians as such: '…[stone] is heated in a fire, and then rapidly cooled, after which it is struck…'. Using a similar technique, 'Stone [was] "cooked" first in fire, then broken into small pieces' (Voegelin 1938, p. 28) by the Tübatulabal Indians, and Goldschmidt (1951, p. 419) mentioned that Nomlaki Indians heat-treated flint '…by contact with hot stones and chipped [it] with hard blue pebbles…' before pressure flaking. Another well-documented case of heat treatment comes from Khambhat (India) where beads of heat-treated red agate (carnelian) were first knapped for preforming, then ground for shaping. There, the pieces of raw material were stacked in ceramic pots, creating an oven-like heating environment, and then heated by fine embers surrounding these pots (Kenoyer et al. 1991). Thus, the available ethnographic data from different parts around the world do document sand-bath heating but they also describe several other techniques. Unfortunately, most of these records, especially the ones from the nineteenth and beginning of the twentieth century, are short and rather imprecise, but it is noteworthy that they all describe fine-grained rocks such as flint, agate or chert. I know of no ethnographic account that explicitly describes heat treatment of silcrete. Thus, using the available ethnographic data for interpreting heat treatment in the South African Middle Stone Age, where silcrete was heat-treated, may be problematic.

Experimental and Mineralogical Data Indicating the Sand-Bath

Another line of argumentation for or against the sand-bath technique in the South African MSA comes from experimental data and the mineralogy and structure of silcrete itself. A good argument for sand-bath heating would be that silcrete does not support high temperatures and fast heating rates as they occur in open fires. Then it could be argued that heat treatment was only possible with a specially constructed heating environment creating specific heating conditions comparable to a sand-bath (i.e., maximum temperatures of <400 °C and ramp rates as slow as 0.2 °C/min (Eriksen 1997)). This argumentation has been widely accepted for rocks like flint and chert and has led many researchers to admit sand-bath heat treatment in Europe and North America (Anderson 1978; Bordes 1969; Inizan and Tixier 2001; Wilke et al. 1991). Experiments have shown that, when heated too fast or to excessive temperatures, these rocks fracture, shatter or even explode (Patterson 1995; Schmidt 2014), making them unsuitable for stone knapping. The reason for this overheating is that chemically bound water must be evacuated from the rocks during heat treatment (Schmidt et al. 2011). This evacuation is achieved through the network of intergranular pores leading to the surface of the rocks (Fukuda et al. 2009; Schmidt et al. 2012). If temperatures rise too quickly during heat treatment so that there is not enough time for progressive water evacuation, the vapour pressure of not-yet evacuated H_2O rises until a critical point, resulting in the release of pressure through fracturing (Schmidt 2014). The same is true for the maximum heating temperatures tolerated by rocks like flint and chert. Part of their water is held in fluid inclusions (Flörke et al. 1982; Graetsch et al. 1985) and cannot be evacuated, resulting in rising vapour pressure during heat treatment (Burnham et al. 1969). At a critical temperature, which is a function of the size of fluid inclusions in a given rock, this pressure is released by fracturing (Schmidt et al. 2012). Thus, rocks such as flint and chert require relatively slow heating rates and low maximum temperatures as they are produced in a sand-bath (Schmidt et al. 2015a). The important question is whether this is also the case for silcrete heat treatment. The content of water in silcrete is significantly lower than in flint and the pore-space allowing its evacuation is up to 5× larger (Schmidt et al. 2012; Schmidt et al. 2013). Silcrete can therefore be heated to up to 550 °C and with heating rates as fast as 20 °C/min (Schmidt et al. 2015b). This means that the heating conditions need not be as specific as those produced in a sand-bath.

How about the use of an open fire for silcrete heat treatment? The temperatures in the lower part of an actively burning fire depend on several factors like the firewood used, the quantity of burned wood-fuel and even the wind speed on that given day. They generally range between 400 and 950 °C (Bentsen 2013; Mercieca 2000; Schmidt et al. 2015b) in different parts of the hearth. At temperatures above 600 °C, silcrete readily fractures, and at higher temperatures, it even shatters into pieces (Mercieca 2000; Mercieca and Hiscock 2008). Consequently, it can be expected that simply throwing silcrete in a fire may lead to thermal fracturing if the silcrete lands in a zone where temperatures are excessive. Wadley and Prinsloo (2014) tested whether silcrete can be heat-treated by placing it directly in a fire or on embers scraped away from the fire. They found that many of their samples heated in this way showed signs of heat-induced failure, and concluded that slow underground heating was necessary for heat treatment of silcrete. However, when evaluating the possibility of direct fire use for heat treatment, two considerations are important: (1) is it possible to heat-treat silcrete without overheating, and (2) what is overheating in silcrete (i.e., which alterations lead to rendering silcrete unsuitable for knapping)? With respect to (1), Schmidt et al. (2015b) demonstrated that blocks of silcrete of up to 700 cm^3 can be heated in the embers of a fire without thermally fracturing. This was done by entirely covering the silcrete with embers in, or beside, a fire (Fig. 1), rather than putting it on top of the embers, which created conditions that prevented the samples from reaching temperatures greater than 550 °C. The measured temperatures were close to 400 °C in most cases. These relatively low temperatures were explained by the partially anoxic conditions in a larger pile of glowing embers. The outer, actively combusting zone of the pile uses up most of the oxygen, restricting the oxygen flow towards the inner zone of the pile. In this way, the temperatures of the embers in direct contact with the silcrete are limited (Schmidt et al. 2015b). The heating rates produced in the silcrete during these experiments were estimated to between 4 and 20°/min. They do not correspond to the heating up of the embers, hence are not heating rates of the heating environment itself, but they are a measure of the heat transfer from embers to the rocks, as they were recorded under the heated silcrete and not in the heating environment (Schmidt et al. 2015b). The temperature range and heating rates produced in these piles did not lead to heat-induced failure in most of the samples. Yet some pieces fractured during the experiments, indicating a higher risk of fracture using the 'pile of embers' method than in a sand-bath. These experiments were all conducted with silcrete from South Africa's west coast, possibly questioning the applicability of their results to site from other parts in the region. However, Wadley and Prinsloo's (2014) ember heating experiments indicate similar results for silcrete from the south coast (three out of six samples heated on embers fractured, three remained intact). Whether the rates of heat-induced fracturing in silcrete from other regions are similar remains to be proven by future studies. Another important aspect to this discussion is that the concept of success or failure of heat treatment (2) appears to be slightly different for silcrete than for flint and chert. As explained earlier, when flint or chert is heated to excessive temperatures, or when it is heated too quickly, the result is an explosive event: the overheated samples shatter into small pieces that can no longer be used for knapping. When silcrete fractures in a fire, the blocks normally part into two or three fragments, each of which is well heat-treated and perfectly knappable. During Schmidt et al.'s (2015b) experiments, such fragments resulting from heat-induced fracturing were perfectly heat-treated, as indicated by the smoothness/gloss of fresh fracture surfaces, indistinguishable from that of fracture surfaces on heat-treated silcrete that did not fracture during heating. Although quantitative data must await future analyses of the mechanical properties, no difference was observed between the improved knapping quality of thermally fractured and intact heat-treated silcrete. Thus, thermal fracturing does not necessarily render South African silcrete unsuitable for knapping. In some cases, the only result is the reduction of the effective exploitable volume. In the context of the South African MSA reduction sequences, this does not appear to be problematic because the average size of the blocks that were heat-treated can be expected to be rather small. During the two periods for which there are data on heat treatment, the Howiesons Poort and the Stillbay, it appears that only relatively small volumes, such as blade cores (Porraz et al. 2013) or small preforms of bifacial pieces (Mourre et al. 2010), were heated. Consequently, heat-induced fracturing cannot be used to evaluate the possibility to heat-treat silcrete with one technique or another. Thus, the available experimental data do not indicate that South African silcrete would require slow heating as in a sand-bath.

Archaeological Evidence of the Sand-Bath

The third and most important line of argument for or against sand-bath heating in the South African MSA comes directly from archaeological data. The archaeological record describing heat treatment of stone in different contexts around the world begins to be quite detailed. However, direct archaeological data on the techniques and procedures used for lithic heat treatment are extremely rare. The best description of a heating structure comes from North America, where Shippee (1963) described an undated pit containing an infill of

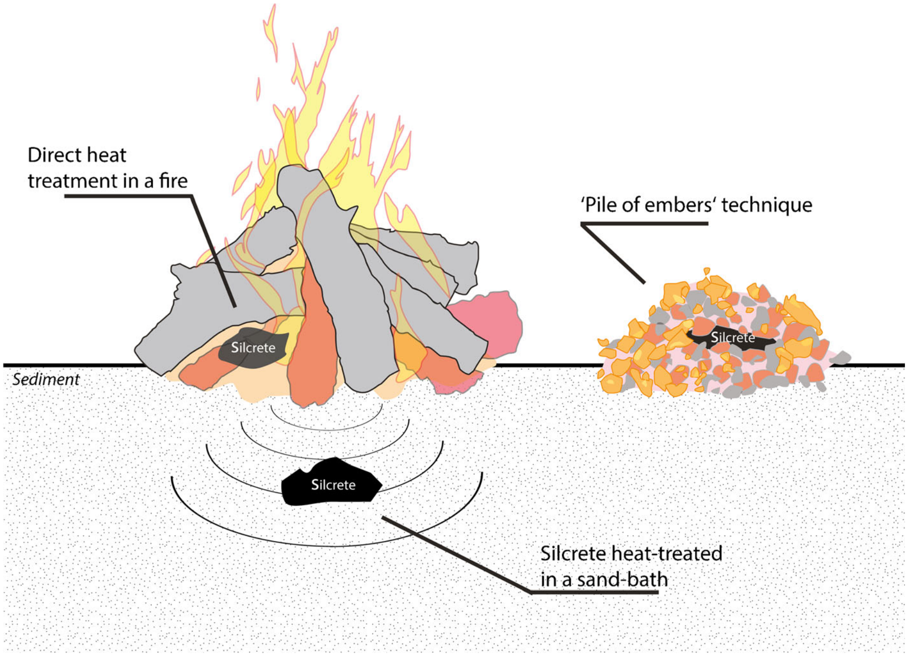

Fig. 1 Schematic illustration of different heat treatment techniques mentioned in the text. During 'Direct heat treatment in a fire', a piece of rock is directly heated in the ash and embers cone at the base of a burning fire. The rock is normally covered entirely by embers and ashes. During sand-bath heat treatment, a piece of silcrete is buried beneath a layer of sediment (of variable thickness) on which a fire is lit. The heat is slowly radiated into the sediment by the fire (schematized by the propagation waves). In the 'pile of embers' technique, silcrete is heat-treated by completely covering it with embers beside a fire

flint and ashes. The ~45-cm-deep pit contained a bed of ashes at its base and flint cores and flakes on top of the ashes. The pit was backfilled with sediment and limestone boulders on top of the layer of flint. Shippee interpreted this structure as a fire-pit for heat treatment of flint. Another structure attributed to heat treatment was found in the Neolithic site of Khunjhun II (India). Clark and Khana (1989) described a pit with reddened walls which they interpreted as an oven for heat-treating chert and chalcedony. These two descriptions of heating structures, similar to earth-ovens, indicate underground heating. However, this picture might be biased because alternative techniques such as heating in the embers of fires would not produce structures or pit features possibly found by archaeologists. Additionally, both described heating structures were used to heat fine-grained rocks like flint and chert, not silcrete, and they were found in significantly younger contexts than the Middle Stone Age and on different continents. Using them to interpret silcrete heat treatment in the South African MSA appears therefore problematic. Finally, Schmidt et al. (2015b) presented direct archaeological data in relation to a technique for heating stone, based on the analysis of heat-treated lithic artefacts from the Howiesons Poort of Diepkloof. This work introduced two new arguments against sand-bath heating in the South African context. First, organic wood-tar ('tempering residue') was found on heat-treated silcrete artefacts, which has an identical microstructure and similar chemistry as wood-tar, that formed on the surface of silcrete experimentally heat-treated in embers. Secondly, heat-induced fracturing was rather common and appears to have been an accepted part of the *chaîne opératoire* in Diepkloof after which knapping continued. The frequency of such thermal fractures on silcrete artefacts (up to 10 % of the lithics show signs of fracturing in a fire after which knapping continued) pleads in favour of a heat treatment technique that involved fast heating rates and aboveground heating, i.e., it pleads against sand-bath heating.

Conclusion

It seems that today, underground heating is part of the common knowledge that is repeated over and over until one is inclined to accept it as proven fact. The reasons for this may be historical, as the first descriptions of heat-treated archaeological material all concerned fine-grained rocks such as flint and chert, which require sand-bath conditions. When heat treatment of silcrete was discovered in the South African MSA, the concept of a sand-bath was adopted without questioning. In light of the available published data, there appear to be no solid ethnographic, experimental or archaeological reasons for this. Even though the sand-bath technique was mentioned, and sometimes described in reasonable detail, in ethnographic accounts from different parts of the world, it is only one technique among many that are ethnographically attested. Heat treatment of stone, directly using aboveground fires for example, was also described by ethnographers and voyagers. Concerning their material properties, the silcrete types analysed by myself and my co-workers do not require particularly slow and careful heating as in a sand-bath, and regular fires can be and have been used to experimentally heat-treat silcrete. Most importantly, the only available archaeological data so far on the MSA heat treatment procedure indicate heating in embers. It is important to stress that up to now, there are no other archaeological data from South Africa that would prove or even suggest underground heating.

These findings imply no direct statement about pyrotechnological skills or behavioural complexity of the heat-treatment instigators. The experimentally used 'pile of embers' technique, for example, requires the skilled use of fire to create a pile of embers allows heat-treating at a relatively low temperature. Our understanding of the cognitive effort needed for different heat treatment techniques or their implications for the cultural evolution of modern humans must be investigated in detail before drawing any conclusions. As it stands, future research on silcrete heat treatment at different times and places should not be based on the *a priori* assumption of a sand-bath technique, but rather should search for direct archaeological evidence highlighting the techniques, procedures and gestures used by MSA knappers.

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Compliance with Ethical Standards

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Conflict of Interest The author declares that he has no conflict of interest.

References

Akerman, K. (1979). Heat and lithic technology in the Kimberleys, W. A. *Archaeology & Physical Anthropology in Oceania, 14*, 144–151.

Anderson, D. C. (1978). Aboriginal use of Tongue River silica in northwest Iowa. *The Plains Anthropologist, 23*, 149–157.

Arthur, K. W. (2010). Feminine knowledge and skill reconsidered: Women and flaked stone tools. *American Anthropologist, 112*, 228–243.

Bentsen, S. E. (2013). Controlling the heat: An experimental approach to Middle Stone Age pyrotechnology. *South African Archaeological Bulletin, 68*, 137–145.

Bordes, F. (1969). Traitement thermique du silex au Solutréen. *Bulletin de la Société Préhistorique Française, 66*, 197.

Brown, K., & Marean, C. (2010). Wood fuel availability for heat treatment drives the rise and fall of silcrete as a raw material in the Middle Stone Age of South Africa, Abstracts of the PaleoAnthropology Society 2010 Meetings. *PaleoAnthropology, 2010*, A0001–A0040.

Brown, K. S., Marean, C. W., Herries, A. I. R., Jacobs, Z., Tribolo, C., Braun, D., Roberts, D. L., Meyer, M. C., & Bernatchez, J. (2009). Fire as an engineering tool of early modern humans. *Science, 325*, 859–862.

Burnham, C., Holloway, J., & Davis, N. (1969). Thermodynamic properties of water to 1,000°C and 10,000 bars. *Geological Society of America Special Papers, 132*, 1–96.

Clark, J. D., & Khana, G. S. (1989). The site of Khunjhun II, middle Son Valley, and its relevance for the Neolithic of Central India. In J. M. Kenoyer (Ed.), *Old problems and new perspectives in the archaeology of South Asia* (pp. 29–46). Madison: University of Michigan.

Eriksen, B. V. (1997). Implications of thermal pre-treatment of chert in the German Mesolithic. In R. Schild & Z. Sulgostowska (Eds.), *Man and flint, Proceedings of the VII International Flint Symposium, Warszawa-Ostrowiec Swietokrzyski, September 1995* (pp. 325–329). Warsaw: Institute of Archaeology and Ethnology Polish Academy of Sciences.

Flörke, O. W., Köhler-Herbertz, B., Langer, K., & Tönges, I. (1982). Water in microcrystalline quartz of volcanic origin: Agates. *Contributions to Mineralogy and Petrology, 80*, 324–333.

Fukuda, J., Peach, C. J., Spiers, C. J., & Nakashima, S. (2009). Electrical impedance measurement of hydrous microcrystalline quartz. *Journal of Mineralogical and Petrological Sciences, 104*, 176–181.

Goldschmidt, W. (1951). *Nomlaki ethnography*. Berkeley: University of California Press.

Graetsch, H., Flörke, O. W., & Miehe, G. (1985). The nature of water in chalcedony and opal-C from Brazilian agate geodes. *Physics and Chemistry of Minerals, 12*, 300–306.

Griffiths, D. R., Bergman, C. A., Clayton, C. J., Ohnuma, K., & Robins, G. V. (1987). Experimental investigation of the heat treatment of flint. In G. de G. Sieveking & M. H. Newcomer (Eds.), *The human uses of flint and chert* (pp. 43–52). Proceedings of the Fourth International Flint Symposium held at Brighton Polytechnic, 10–15 April 1983. Cambridge: Cambridge University Press.

Grinnell, G. B. (1895). *The story of the Indian*. New York: D. Appleton.

Hester, T. R. (1972). Ethnographic evidence for the thermal alteration of siliceous stone. *Tebiwa, 15*, 63–65.

Inizan, M. L., & Tixier, J. (2001). L'émergence des arts du feu: Le traitement thermique des roches siliceuses. *Paléorient, 26*, 23–36.

Kenoyer, J. M., Vidale, M., & Bhan, K. K. (1991). Contemporary stone bead making in Khambhat, India: Patterns of craft specialisation and organisation of production as reflected in the archaeological record. *World Archaeology, 23*, 45–63.

Mandeville, M. D. (1973). A consideration of the thermal pretreatment of chert. *Plains Anthropologist, 18*, 177–202.

Mandeville, M. D., & Flenniken, J. (1974). A comparison of the flaking qualities of Nehawka chert before and after thermal pretreatment. *Plains Anthropologist, 19*, 146–148.

Mercieca, A. (2000). An experimental study of heat fracturing in silcrete. *Australian Archaeology, 51*, 40–47.

Mercieca, A., & Hiscock, P. (2008). Experimental insights into alternative strategies of lithic heat treatment. *Journal of Archaeological Science, 35*, 2634–2639.

Mourre, V., Villa, P., & Henshilwood, C. S. (2010). Early use of pressure flaking on lithic artifacts at Blombos Cave, South Africa. *Science, 330*, 659–662.

Patterson, L. W. (1995). Thermal damage of chert. *Lithic Technology, 20*, 72–80.

Porraz, G., Texier, P.-J., Archer, W., Piboule, M., Rigaud, J.-P., & Tribolo, C. (2013). Technological successions in the Middle Stone Age sequence of Diepkloof Rock Shelter, Western Cape, South Africa. *Journal of Archaeological Science, 40*, 3376–3400.

Powell, J. W. (1874). *Report of the explorations in 1873 of the Colorado of the West and its tributaries*. Washington: Govt. print. off.

Schmidt, P. (2014). What causes failure (overheating) during lithic heat treatment? *Archaeological and Anthropololgical Sciences, 6*, 107–112.

Schmidt, P., Badou, A., & Fröhlich, F. (2011). Detailed FT near-infrared study of the behaviour of water and hydroxyl in sedimentary length-fast chalcedony, SiO2, upon heat treatment. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy, 81*, 552–559.

Schmidt, P., Masse, S., Laurent, G., Slodczyk, A., Le Bourhis, E., & Perrenoud, C. (2012). Crystallographic and structural transformations of sedimentary chalcedony in flint upon heat treatment. *Journal of Archaeological Science, 39*, 135–144.

Schmidt, P., Porraz, G., Slodczyk, A., Bellot-Gurlet, L., Archer, W., & Miller, C. E. (2013). Heat treatment in the South African Middle Stone Age: Temperature induced transformations of silcrete and their technological implications. *Journal of Archaeological Science, 40*, 3519–3531.

Schmidt, P., Paris, C., & Bellot-Gurlet, L. (2015a). The investment in time needed for heat treatment of flint and chert. *Archaeological and Anthropological Sciences*. doi:10.1007/s12520-015-0259-y.

Schmidt, P., Porraz, G., Bellot-Gurlet, L., February, E., Ligouis, B., & Paris, C. (2015b). A previously undescribed organic residue sheds light on heat treatment in the Middle Stone Age. *Journal of Human Evolution, 85*, 22–34.

Schumacher, P. (1877). Methods of making stone weapons. *US Geographical and Geological Survey Bulletin, 3*, 547–549.

Shippee, J. M. (1963). Was flint annealed before flaking? *Plains Anthropologist, 8*, 271–272.

Voegelin, E. W. (1938). *Tübatulabal ethnography*. Berkeley: University of California Press.

Wadley, L. (2013). Recognizing complex cognition through innovative technology in Stone Age and Palaeolithic sites. *Cambridge Archaeological Journal, 23*, 163–183.

Wadley, L., & Prinsloo, L. C. (2014). Experimental heat treatment of silcrete implies analogical reasoning in the Middle Stone Age. *Journal of Human Evolution, 70*, 49–60.

Wilke, P. J., Flenniken, J., & Ozbun, T. L. (1991). Clovis technology at the Anzick site, Montana. *Journal of California and Great Basin Anthropology, 13*, 242–272.