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Differential Development of Sickle Polish Due to Moisture Content of Herbaceous Plant Material

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Abstract

This experiment uses four experimental sickles containing flint and novaculite blades to harvest wet, growing grass and mature, dry rye in an effort to determine the differences in the development of sickle polish and other use wear traces caused by moisture content and other plant characteristics. During harvesting, samples of harvested material averaging about two handfuls were collected. These samples were massed, dried, and massed again to determine moisture content of the plants. The sickles were each used for approximately 13 hours. Each blade was then cast using high resolution dental epoxy for microscopic inspection. An edge survey was conducted along each blade starting at 100x magnification and increasing as needed to 200x. Microscopic examination of the sickle blades shows varying development of sickle wear stages. The flint blades used to harvest wet grass show higher levels of development of sickle gloss overall, with sickle gloss continuously coating the surface of the stone. The novaculite blades used to harvest wet grass show slightly lower levels of development of sickle gloss, with gloss discontinuously coating the surface of the stone. Both sickles used to harvest dry rye show barely developed sickle gloss, with gloss existing in isolated, discontinuous patches. The blades used to harvest wet grass show increased numbers of highly rounded microplating margins when compared to the rye sickles. Additionally, the difference in the abrasive nature of the plants generated different forms of striations. The tougher, more abrasive rye heavily striated the surface of the blades. The softer, fibrous grass produced finer striations on the surface of the blades. Microscopic inspection of the blades shows the process of rounding over the edge is likely a tandem process between edge abrasion and microplating, with the abrasion occurring first. While it is clear that moisture content affects the development of sickle

gloss, other variables such as plant density, hardness, and abrasiveness were not controlled for and, therefore, potentially play an important role.

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Introduction

Humanity's transition into an agrarian subsistence strategy necessitated an innovation in hafted lithic technology. During this transition, innovations in tools, such as sickles, played a crucial role. Sickles increased the efficiency of harvesting by diminishing the effort required to reap the crop. Additionally, in the case of herbaceous plants such as grass, sickles increased the harvest by permitting continued plant growth as the sickle cleanly cuts the top of the plant without harming the root structure. Due to these characteristics, the sickle makes an appearance in the record of agricultural societies around the globe, including Africa, the Middle East, Europe, and the Americas to harvest crops such as rye, barley, oats, wheat, corn, and grass for hay and construction(Becker and Wendorf, 1993; Borrell and Molist, 2007; Clark, 1995; Curwen, 1935; Harlan, 1967; Heizer, 1951; Kadowaki, 2005; Perino, 1990; Unger-Hamilton, 1989; Winter, 2006).

The sickle is present in the archaeological record in many styles. It can be straight or curved. It can have different hafting material, such as wood or bone. The lithic material can vary as well, such as flint or obsidian (Becker and Wendorf, 1993; Borrel and Molist, 2007; Clark, 1995; Heizer, 1951; Kadowaki, 2005; Perino, 1990; Quintero, Wilke, Waines, 1997; Winter, 2006). Implementation of the sickle can vary between individuals or design of the sickle as well, with drawing strokes, sawing motions, and push strokes common (Quintero, Wilke, Waines, 1997).

With use, the characteristics of the sickle are known to change. The purpose of this project is to evaluate these changes related to both the moisture content and type of plant material harvested. While extent of use certainly plays an important role in the development of the use traces investigated in this study, it is less clear how much of an affect the plant type and water content have (Kay, 2014).

In accordance to the long standing Locard's principle, contact between the sickle's blades and the plant material leaves indelible traces (Briuer, 1976). After extensive use, the sickle's blades are coated with a contact residue. This residue was characterized as a "glazed polish" early in the development of lithic analysis (Kay and Mainfort, 2014; Witthoft, 1967). This polish, commonly referred to as sickle polish, or sickle sheen, seems to be largely composed of an additive layer of dissolved silicates in the plant material(Kay and Mainfort, 2014, Kamińska-Szymczak, 2002). This additive layer is possibly composed of a mixture of dissolved silica from the stone recombined with phytoliths from the plant stalks (Anderson, 1980). In its macroscopically visible form, the silicate layer causes a glossy appearance on the stone (Kay, 2014; Kay and Mainfort, 2014; Quintero, Wilke, Waines, 1997). This visible sickle gloss is bright and tends to take on a melted appearance (Kay, 2014). Due to the macroscopic characteristic of the gloss, sickle polish drew the interest of early archaeologists (Whittaker, 2010). The macroscopic nature of sickle gloss has been understood for quite some time (Curwen, 1930; 1935; Spurrell, 1892). The level of development of the polish, however, is most evident upon microscopic evaluation.

Within the polish it is common to see crystallization spots, which appear as bright areas under microscopic inspection (Kay, 2014; Kay and Mainfort, 2014). It has been shown that these crystals form on the trailing edge of use, which indicates directionality of cutting (Kay and Mainfort, 2014). In addition to the presence of the polish, scratches, commonly referred to as striations, form resultant to use. The development of these striations hints at the level of use as well as the material which the blades impacted (Unger-Hamilton, 1985). Striations, caused by abrasive particles or crystalline structures in the plants, illustrate the kinematics of the tool use (Kay and Mainfort, 2014). While these striations are diagnostic they are not dominating factor in the production of sickle gloss (Anderson, 1980).

This additive plating of dissolved silicates is one cause of decreased efficiency of the blade (Kay and Mainfort, 2014). The development of sickle polish can effectively overwrite the normal microtopography of the stone, filling in low spots and rounding over the edge (Anderson, 1980). The silicate plating, referred to as microplating, can, in later stages of development, take on a viscous appearance with margins made up of undulating flows (Kay, 2014; Kay and Mainfort, 2014). Microplating is a particularly useful wear trace due to its lack of time sensitivity, ability to bind to the microtopography of the stone, and rewrite the microtopography with continued use (Kay, 2014; Kay and Mainfort, 2014).

As sickle polish, and the microplating it is made of, appears to be a biochemical reaction during the friction of the cutting event it begins its development on the edge of the blade (Kay, 2014; Whittaker, 2010). This development begins as simple organic accumulation on the blade's surface away from the edge. With use the sickles begin to exhibit an emergent microplating layer localized to the edge. This microplating layer eventually builds to cover the microtopography of the stone (Kay, 2014). Early development of sickle gloss happens very quickly. Less than an hour of cutting seems to be enough to begin the developmental process (Kay, 2014). Later stages of development progress more slowly. Experimental evidence suggests later wear stages may take upwards of 20 hours of use to develop (Anderson, 1991; Kay, 2014).

It is clear that the extent of use affects the development of the polish. What is less clear is how much of a role the plant type and water content play (Kay, 2014). Research has been done to determine the effect of moisture content of the contact material on the development of sickle polish. Experimentation indicates the macroscopic gloss forms as a result of the moisture content of the plant harvested, with moist plants increasing the developmental speed and dry stalks impeding the polish (Kay, 2014; Quintero, Wilke, Waines, 1997). It has been noted that the brightness of the polish increases with the water content of the contact material as well (Anderson, 1980). Unfortunately the experiments have only included cereal grasses such as wheat and barley (Quintero, Wilke, Waines, 1997). It is likely that sickles were used for a variety of plant materials, as harvesting would have been necessary for more than just food crops. Noncereal grasses make for effective and abundant materials for thatch, tempering clay products, and hay for domesticated animals.

Therefore, it is the goal of this research to ascertain the affect that moisture content of the contact material and type of contact material has on the development of sickle polish by examining the development and characteristics of sickle polish on blades used for harvesting grass and harvesting rye. The grass is harvested as the "wet", or high moisture content, plant material. The rye is harvested as the "dry", or low moisture content, plant material. The University of Arkansas Agricultural Research and Extension Center offered a stand of rye and a field of wild grass, consisting of a variety of species similar to the types commonly hayed for farm animals or used in daub construction, in which the experiment could take place.

Methodology

Field Methods

Four experimental sickles were created in total, two sickles each for grass and rye. Each sickle was only used for its respective plant type. One sickle of each contact type was created using novaculite blades, and one using Osaga Boone flint. For the purposes of this study the proximal end of the sickle is the reference point for description of the blades. All four sickles are horizontally hafted in wood, with space between the blades kept to a minimum. All of the blades used were whole blade flakes. The sickle blades were not oriented in any particular pattern, instead maintaining a continuous cutting edge was the goal. While sickles in the archaeological record were commonly hafted with bitumen (Borrell and Molist, 2007) these sickles were initially hafted with wax. Early into the experiment it was obvious that the wax could not adequately adhere to the stone. As the orientation of the blades relative to each other needed to remain constant, and any haft wear traces are beyond the scope of this study, Loctite epoxy was used to permanently seat the blades in the haft. Each sickle was assigned a visible label to avoid any confusion. The sickles used to harvest grass were given the codes WG1 and WG2. The sickles used to harvest rye were given the codes DW1 and DW2. Further, each individual blade was assigned a letter in order with "A" starting at the proximal end. When not in use, the sickles were kept in a polyethylene bag to eliminate potential damage during storage.

Both grass sickles are distally curved. WG1 (Figs. 1,2) measures 31.5 centimeters long with the hafted section measuring 15 cm in length and contains six blades. Each blade of WG1 is flint. Blade A measures 3 cm long with a maximum height from haft of 1 cm. Blade B measures 2.5 cm long with a maximum height from haft of 0.7 cm. Blade C measures 3 cm long and has a maximum height from haft of 0.6 cm. Blade D measures 2.3 cm long and has a maximum height from haft of 0.5 cm. Blade E measures 2.5 cm long and has a maximum height from haft of 0.7 cm. Blade F measures 2 cm long and has a maximum height from haft of 0.8

cm.

Figure 1: Wet grass sickle 1, referred to as WG1, in early stages of use. Wax mastic is still in place in this picture. Blades are labeled A-F starting at the proximal end. Centimeter scale is visible at the bottom.

Figure 2: Reverse side of WG1 in early stages of use. Centimeter scale is visible at the bottom.

The distal three blades of WG2 (Figs. 2, 4) are novaculite while the proximal blade is flint. WG2 measures 31 cm long with the hafted section measuring 16 cm in length and contains four blades. Blade A measures 3 cm long with a maximum height from haft of 1.1 cm. Blade B measures 3.7 cm long and has a maximum height from haft of 1.1 cm. Blade c measures 4.9 cm long and has a maximum height from haft of 1.2 cm. Blade D measures 4.5 cm long and has a maximum height from haft of 1.1 cm.

Figure 3: Second wet grass sickle, referred to as WG2, in early stages of use. Blades are labeled A-D starting at the proximal end. Wax mastic is used in this photo. The proximal blade was later lost and replaced with another blade. Centimeter scale is visible at the bottom.

Figure 4: The reverse side of WG2 in early stages of use. Centimeter scale is visible at the bottom.

Both of the sickles used to harvest dry rye are straight sickles. The blades of DW1 (Figs. 5, 6) are all flint and each blade is denticulated. DW1 measures 34.5 cm long with a hafted length of 18 cm and contains four blades. Blade A measures 4.5 cm long with a maximum height from haft of 0.5 cm. Blade B measures 4.3 cm long with a maximum height from haft of 0.7 cm. Blade C measures 4.3 cm long with a maximum height from haft of 1 cm. Blade D measures 4.2 cm long with a maximum height from haft of 1 cm.

Figure 5: The first rye sickle, referred to as DW1, in early stages of use. Wax mastic is in use in this photo. Centimeter scale is visible at the bottom.

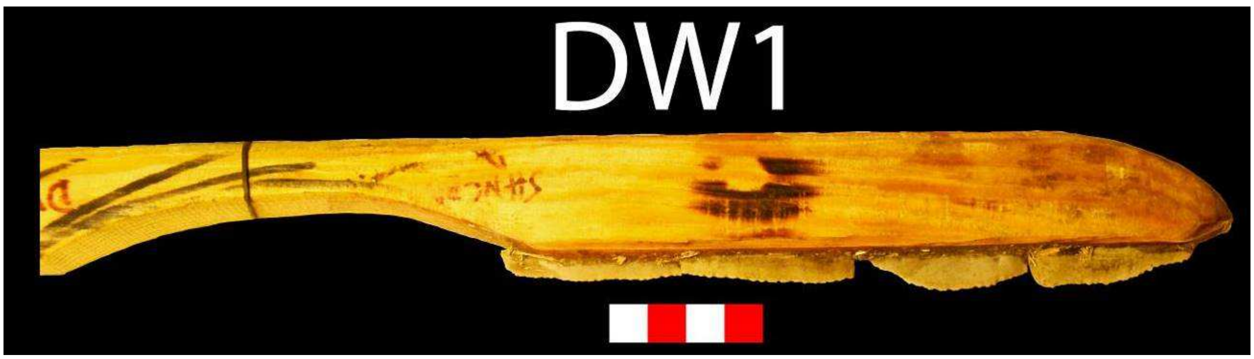

Figure 6: The reverse side of DW1 in early stages of use. Centimeter scale is visible at the bottom.

Each blade of DW2 (Figs. 7, 8) is novaculite. DW2 is 40.5 cm long with a hafted length of 22.5 cm and contains five blades. Blade A measures 3 cm long with a maximum height from haft of 1.3 cm. Blade B measures 3.5 cm long with a maximum height from haft of 1.1 cm. Blade C measures 3.3 cm long with a maximum height from haft of 1.3 cm. Blade D measures 6.4 cm long with a maximum height from haft of 1.7 cm. Blade E measures 5.7 cm long with a maximum height from haft of 1.5 cm.

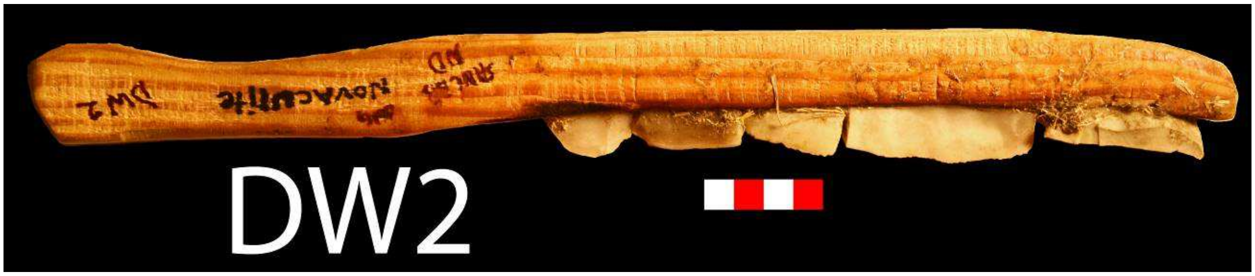

Figure 7: The second rye sickle, referred to as DW2, in early stages of use. Wax mastic is in use in this photo. Centimeter scale is visible at the bottom.

Figure 8: The reverse side of DW2 in early stages of use. Centimeter scale is visible at the bottom.

Upon entering the harvesting field, a standardized procedure was followed for both wet grass and dry rye, with any participants in the experiment instructed in the methods. The ambient temperature and humidity level was recorded using a consumer grade digital thermometer with humidity sensor. Each participant noted the time and date they began and ended harvest in an effort to allow for an approximate total time used for each sickle. The beginning point of each harvester's efforts in the field was marked with a stake, along with the corners at the end of harvesting. From these stakes the area harvested by each sickle was recorded using a standard field tape-measure. Each participant was instructed to offer any comments they felt important including the following: perceived efficiency of their sickle, approximate size of vegetation collected in their grasp, approximate number of strokes needed to get through each handful, which cutting stroke they found to be most effective, any effort to clean the sickle of collected plant material, and any loss of a blade and subsequent recovery. Further, each harvester was encouraged to offer any comments on the feel of the sickle itself. While dulling of the blades was expected, no efforts were ever made to sharpen any of the blades. In an effort to avoid any abrasion caused by soil particulates clinging to the surface of the plant, harvesters were encouraged to cut the rye stalks at least 15 cm above the soil surface. As the grass was more densely growing and not as tall, each harvester was instructed to cut the stalks at least 5 cm from the soil surface.

Each harvesting session, one or more samples were collected, consisting of roughly two handfuls of vegetative material, and stored in a consumer grade sealable polyethylene bag with the date and plant type labeled on the bag. Each sample was then massed and recorded using a consumer grade digital scale. Initial testing of drying methods yielded results congruent with efforts to measure water content of hay for silage (Shewmaker, Thaemert, 2004). Each sample was spread out upon a metal sheet and placed in a convection oven at 225º Fahrenheit for at least 1.5 hours, during which time the sample's bag was left open near the oven to aid in the evaporation of any moisture adhering to the plastic's surface. Upon cooling each sample was recollected into its respective bag and massed a second time. The percentage water content of the plant sample was then calculated and recorded.

Lab methods

After an approximate total of 13 hours for DW1 and 13 hours for DW2, and 12.5 hours for WG1 and 13.5 hours for WG2 the sickles were photographed. Each sickle was then prepared for the evaluation process. Due to the desire to have the potential to evaluate the continuing development of sickle polish at longer lengths of use in the future, the sickles were prepared for a high resolution casting process adapted from techniques used by biological anthropologists in the study of dental use-wear (Banks, Kay, 2003; Kay, 2014; Kay and Mainfort, 2014). The creation of permanent casts of each blade a targeted time of use allows for the continued use of the sickles without loss of previous data. The process of casting with dental silicone has been shown to yield results of incredible fidelity (Banks and Kay, 2003). Though the casting process is simple, care must be taken to prevent any issues that may mar or otherwise obscure the microscopic wear traces. In an effort to remove any plant material, soil particulates, or accumulated oil, the sickles were placed within a polyethylene bag and submerged in an ammonia solution bath within an ultrasonic cleaner. As the microplating layer has been shown to be chemically resistant, the ammonia solution was able to remove the oil and particulate matter without harming the sickle polish (Kay, 2014). Each sickle was submerged in the ultrasonic tank until no visible particulate matter was present. After cleaning, the sickles were allowed to dry for a period of 24 hours and then each was photographed again in entirety in preparation for high resolution casting.

Using a Coltène/Whaledent dispensing gun with attached mixing tip an appropriate amount of fine grain, regular body surface activated dental silicone and hardener mixture was deposited onto a clean sheet of cellophane. Then, in compliance with previously established casting techniques, the sheet was carefully used to envelope each blade starting from the edge and working towards the haft while being constantly massaged in an effort to eliminate air pockets (Banks and Kay, 2003). Any excess silicone was, whenever possible, used to take an impression of the ends of any adjacent blades. In many cases the configuration of the blades of the sickles allowed multiple blades to be molded at once. Whenever this situation occurs the mold was carefully labeled to ensure each blade remained identifiable. After the silicone's short curing time the molds were carefully removed and Coltène/Whaledent two part President soft dental putty was used to bridge any gaps in the silicone mold, help create a collar to contain the casting material, and level the mold to avoid spills. Each mold was labeled with the blade and the direction towards the distal end of the sickle. The molds and sickles were then photographed with each other to ensure proper orientation of any future casts.

Epoxy Technology's two part epoxy kit 301 1LB mixture was prepared with a small amount of brown pigment concentrate. The mixture was stirred together for at least one minute to homogenize the mixture and eliminate as many air bubbles as possible. The pigment potentially aides in the contrast of visible use-wear traces during microscopic inspection. Care should be taken during the mixing process to ensure complete dissolution of the pigment, as the pigment may settle during the curing process. Additionally, bubbles not removed during the mixture process may become trapped in the cast. Each mold was filled with an amount of epoxy mixture sufficient to make a complete cast and provide a shoulder of epoxy to aid in the mounting and handling of the cast. After curing each cast was photographed in proper orientation with the sickle. As there is some concern over the effect of ultraviolet light on the casts, when not in use each mold and cast was stored in a polyethylene bag with a label inside a covered box. To minimize the risk of oil spots each cast was handled carefully by the shoulder of epoxy created during the molding process. Whenever handling by the shoulder was not possible latex gloves were worn.

Each cast was then examined using a differential interference binocular microscope with polarized light and Nomarski optics. The Nomarski optics offer a superior view of the microtopography of the stone (Kay, 2014; Kay and Mainfort, 2014). The casts were each mounted to a slide plate using an amount of standard modeling clay with enough pressure to ensure no movement during manipulation of the specimen. As the microscopic wear traces are extremely sensitive to the orientation of the cast the planar orientation was changed as necessary to maximize their visibility (Kay and Mainfort, 2014). Blasts of compressed air were used, as needed, to remove dust particles. Where the compressed air failed, a soft bristled paint brush was used to brush the particles away. In rare circumstances the particles could not be removed and remain in frame. As the sickle polish develops from the edge inward, the casts were each examined at 100x magnification starting with a survey of the edge and working towards the haft. Any significant use-wear was then photographed using a Canon Rebel T3i digital camera body attached to a camera tube on the microscope. The location of the photomicrograph was noted on a reference image of the cast. Each photomicrograph was then recorded using a standard data sheet with a description of the captured image. The images were then labeled with a number, blade identifier, magnification, side of the blade, and, if multiple exposures of the area were taken, the exposure number. If deemed possible and necessary magnifications of the wear traces were increased to 200x or 400x. As the question this study seeks to answer is focused on the total development of sickle gloss, the results are largely restricted to 100x and 200x magnification for a general survey. Upon completion of the examination, each blade's orientation was then recorded on a reference image by aligning the cast with the image and marking the edge of the slide plate (Kay and Mainfort, 2014). As the microtopography of the stone is rarely level enough to allow one photomicrograph to capture the entire field in focus, multiple exposures of varying focal depths were often taken for wear traces. The images were then subjected to digital manipulation, as necessary, using Adobe Photoshop Elements. As the nature of the optics in use mirrored each image both horizontally and vertically, each image was digitally mirrored in both directions. In any case of multiple exposures of the same feature, the images were digitally stitched together into one composite image.

The development stage of sickle gloss in each image was categorized using a scale developed in Kay's previous works. Gloss development is divided into four stages. Wear stage 1 exhibits macroscopically visible organic bands set back from the tool edge. Minor development of microplating, often minute and highly discontinuous, is exhibited at this stage localized to the edge. Wear stage 2 also shows organic bands. Microplating at this stage remains close to the edge of the tool, while showing signs of developing into later stages. In wear stage 3 organic bands tend to be absent. Microplating at this stage is fairly continuous near the edge, tending to continue into the tool. Wear stage 4 sickle blades show large amounts of macroscopically visible sickle gloss. Microplating at this stage has largely overwritten the normal microtopography of the stone. Edge rounding at this stage is significant, and striations are abundant (Kay, 2014).

In an effort to better quantify the development of the sickle polish, rough estimates of the area covered by the sickle polish in selected images was then calculated using ImageJ, an open source image analyzer commonly used by microbiologists. The abilities and precision of ImageJ have been well discussed and, while not developed with this application in mind, is certainly accurate enough to provide a rough pixel area of the image (Baviskar, 2011). Only images of 100x magnification were selected for this analysis. Images from both sides of each blade were measured in ImageJ and then averaged together for general illustrative purposes. The total pixel area of the blade was calculated first. ImageJ's ability to select areas of the picture based on contrast, brightness, and color were used to select areas of microplating while avoiding areas of unaltered stone (Fig. 9). As microplating is reflective and colorful when viewed at the proper angle with the Nomarski optics the dark areas of each image were considered to be unaltered.

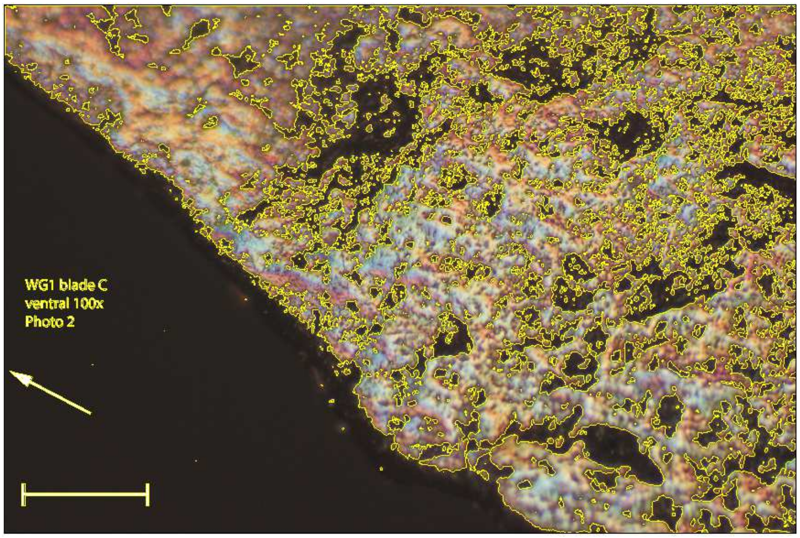

Figure 9: WG1 blade C ventral side at 100x, location 2. Scale bar is 100 microns long. This image shows the selective abilities of ImageJ. The yellow lines outline the areas selected as microplating, while the dark areas of remodeled stone are left unselected.

Data

Field Data

Grass Harvesting

While most of the grass harvesting was done from mid-August to early September, the first harvest was in late June. The ambient temperature varied widely from the high 60's to high 90's in degrees Fahrenheit, consistent with late summer temperatures. The percentage humidity and water content both seem to consistently hover near 50% (Fig. 10). Over the harvest period WG1 harvested an approximate total area of 104.78 square meters while WG2 harvested an approximate 119.2 square meters. The harvest was not intensive, with the maximum time spent harvesting in one day being two hours. Early in the harvest, the proximal blade of WG2 was lost and not recovered. The blade was replaced with another flint blade. On September 2nd the distal blade of WG1 loosened sufficiently to need refitting. Each harvester noted that the grass was difficult to cut through, often requiring several strokes. Handfuls ranged in size between harvesters with an estimated average diameter of 4 cm for the grass bundle.

Any harvester who used WG2 noted almost immediately that they felt the sickle performed most efficiently using a push stroke instead of a pull stroke. The stroke began at the tip of the distal blade then followed the curve of the sickle, with the proximal blade providing the last cut through the push. Users of WG2 felt that the three most proximal blades performed most of the cutting motion, an observation confirmed by the use-wear discussed later. At the end of each stroke the sickle was reset at the tip of the distal blade for the next stroke. The sickle seemed to average about four strokes to cut through one handful. After extensive use, at around 8 hours, the sickle's efficiency seemed to decrease and the number of strokes necessary increased to about five or six.

Grass	Undried mass (g)	Dried mass (g)	Water Content (%)	Temperature (F)	Humidity (%)
25-Jun	72.8	33.8	53.6	76	63
27-Jun	54.6	26.3	51.8	79	59
27-Jun	69.9	33.2	52.5	79	59
17-Jul	78	28.2	63.8	67	62
17-Aug	59.6	33.3	44.1	91.6	43
20-Aug	40.4	24.1	40.3	88.3	41
21-Aug	39.1	21.8	44.2	89	45
23-Aug	68.2	37.4	45.2	90.1	38
24-Aug	77.5	36.1	53.4	98.6	31
29-Aug	78.1	48.7	37.6	77	58
30-Aug	102.4	61.1	40.3	82	53
31-Aug	75.2	41.8	44.4	89.6	43
1-Sep	62.7	35.9	42.7	86.2	51
2-Sep	74.3	38.5	48.2	81.5	52
6-Sep	106.6	41	61.5	72	64
7-Sep	120.8	69.5	42.5	83	45
9-Sep	133.5	67.8	49.2	90	45

Figure 10: A table detailing the data recorded during grass harvesting.

It was noted that, unlike WG2, WG1 seemed to perform most efficiently with a pull stroke. The stroke began at the end of the proximal blade then followed the curve of the sickle in a straight pull. Users of WG1 felt that the four most distal blades performed most of the cutting motion while in actuality the use-wear later discussed shows it to be more complicated. Users alternated between resetting the sickle to the proximal blade at the end of each stroke and using a sawing motion. The sickle seemed to average about four strokes to cut through one handful. After extensive use, at around 6 hours, the efficiency seemed to decrease and the number of strokes necessary seemed to increase to about six or seven.

The sickles developed a bright organic banding extremely early in the harvesting process, approximately one half hour, consistent with other experimental results (Kay, 2014). This banding began a few millimeters in from the edge of the blade and ran the length of the blade.

Plant particulate and other detritus collected in small amounts between the blades and in the groove between the blade and the haft. Harvesters never felt any need to remove collected plant detritus by using what has been termed a cleaning stroke (Kay, 2014). Collected plant debris between the blades was pulled free periodically, though, with the reason most often cited as annoyance. When questioned about the annoyance caused by the collected plant debris no harvester felt that it had negatively impacted the efficacy of the sickle, instead it simply bothered them.

The flint blades of WG1 exhibited other macroscopic signs of use-wear earlier than the novaculite blades of WG2. Edge damage, in the form of microflaking, began on the sickle after about one hour of use. Both sickles began to exhibit edge rounding around about 4 hours of use, before appreciable amounts of sickle gloss accumulated. Macroscopically visible sickle gloss began to manifest on the edge of the blades in isolated spots at after 4 hours of use. After about 7 hours of use the visible gloss covered the entirety of the edge of the blades and began to manifest further in from the edge. By about 10 hours, select blades began to exhibit almost total coverage of visible gloss.

Rye Harvesting

The rye harvest began late June and ended early August. The ambient temperature ranged from the high 70's to a maximum of 103 in degrees Fahrenheit. The humidity percentage varied widely. The water content of the samples showed a steady decline in moisture with sudden spikes shortly after rain storms. The rye began at about 30% but quickly fell to about 7%. (Fig. 11) DW1 harvested an approximate total area of 352.8 square meters while DW2 harvested an approximate total of 337 square meters. The harvest began with a leisurely pace but quickly built up intensity with the maximum time spent harvesting sitting at four hours in one day for DW1 and two hours in one day for DW2. Cutting through the rye's thicker stalks proved to be more difficult than anticipated. Rye was gathered into handfuls of an average of about 5 cm in diameter.

Rye	Undried mass (g)	Dried mass(g)	Water Content (%)	Temperature (F)	Humidity (%)
25-Jun	24.8	17.3	30.2	76	61
29-Jun	58.3	52.7	9.6	89.4	54
29-Jun	43.3	39.8	8.1	89.4	54
30-Jun	47.7	41.9	12.2	92	42
1-Jul	76.1	70.3	7.6	91	46
18-Jul	110.3	87.2	20.9	76.3	52
19-Jul	88.7	84.1	5.2	79.7	48
23-Jul	118.5	110.1	7.1	89.4	56
1-Aug	56.9	52.6	7.6	89	35
3-Aug	48.4	45.1	6.8	96.8	37
4-Aug	70.9	65.9	7.1	89.2	40
5-Aug	40.9	38.4	6.1	87.1	43
6-Aug	56.5	52.2	7.6	103.6	28

Figure 11: A table detailing the data recorded during rye harvesting.

Harvesters who used both rye sickles noted that a sawing motion seemed to work best. Sawing motions dominated DW1's use, with the majority of the work seeming to be done by the middle blades, an observation partially confirmed by the use-wear discussed later. The denticulated blades of DW1 initially cut much more efficiently than DW2's nondenticulate blades. DW1 began harvesting with approximately 3 strokes to cut through one handful. DW2 began harvesting with approximately 6 strokes to cut through one handful. Sawing motions largely dominated DW2's use with a focus on deliberately using the entirety of the sickle. Even so, the majority of harvesters felt that the middle three blades seemed to do most of the work, an observation that was partially accurate as confirmed by the use-wear discussed later. The efficiency of DW1 decreased steadily. After approximately 4 hours of use DW1 needed approximately 6 strokes to get through a handful. After 10 hours of use DW1 needed approximately 8 strokes to get through one handful. DW1 and DW2 became similarly efficient at the 10 hours mark of harvesting.

DW1's denticulations began rounding over very rapidly. At the 5 hour mark, DW1's denticulations had visibly begun to lose sharpness. At the end of harvesting the denticulations are very nearly nonexistent macroscopically.

DW2 began showing macroscopic use-wear traces after approximately 3 hours of use in the form of small scale microflaking. The microflaking intensified rapidly, causing the sickle's blades to take on a seemingly pseudo-denticulated form at the end of harvesting. The proximal blade on DW2 has large scale edge damage in the form of a 0.5 cm long lunate chip missing from the edge. This damage took place somewhere around the 6 hour mark.

Macroscopically visible sickle gloss developed on both sickles initially at around 8 hours of use. This gloss was extremely discontinuous and noninvasive. The gloss was localized to the edge and, in the case of DW1, the peaks in the topography of the stone. This early stage macroscopic gloss was difficult to see. After approximately 11 hours of use the gloss became more visible but remained discontinuous.

Both sickles exhibited signs of edge rounding at around the 7 hour mark. DW1 exhibited such rounding largely in the form of the loss of its denticulations. DW2's edge rounding did not impact its performance much and, in fact, was difficult to see macroscopically until the 12 hour mark.

Lab data

Taphonomic Alterations

Taphonomic considerations must be made during the evaluation of the sickle casts. These alterations include cleaning strokes, abrasion, dust, and anything else that might obscure the desired use-wear traces associated with sickle use. While these alterations are occasionally important, they fall beyond the scope of this study and are excluded from the analysis.

It has been noted that as microplating rounds and dulls the edge, the loss of efficiency is perceived to be a result of macroscopically visible collected plant material on the edge of the blade (Kay, 2014). In an effort to restore the lost efficiency, harvesters will often attempt to clean the blades by removing the plant material with their fingertips or nails (Kay, 2014). Removing this plant material in the safest way results in roughly parallel striations that end in a curve (Fig. 12). These unique striations are referred to as cleaning strokes (Kay, 2014). These cleaning strokes are easily confused for other abrasive striations.

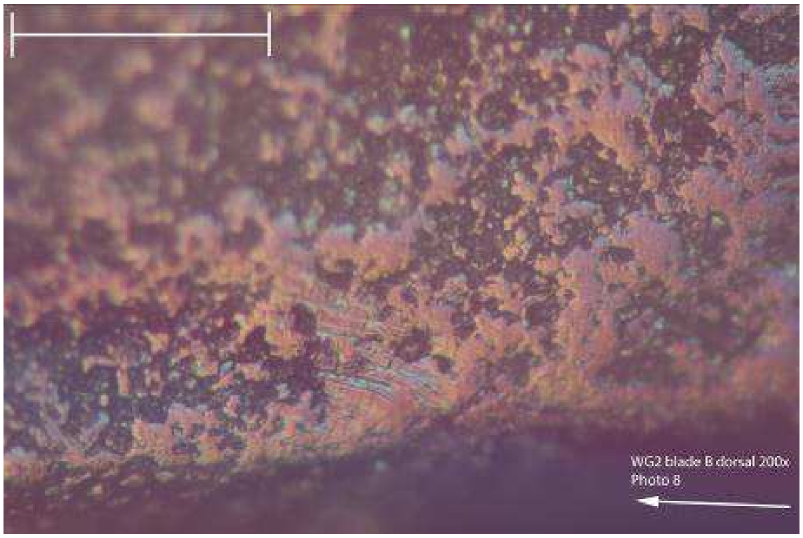

Figure 12: WG2 blade B dorsal side at 200x, location 8. A possible cleaning stroke is visible as a set of striations curving into the edge of the blade. This area shows to be stage 2 sickle gloss. The scale bar is 100 microns long.

Abrasive particles tend to alter the microtopography of the stone with deep cuts which obliterate collected microplating (Fig. 13). These particles are often soil particulates but may also be plant opals. The presence of aerosolized abrasive particles was not controlled for in this experiment. Stalks of each plant likely had wind blown soil particulates adhereing to its surface.

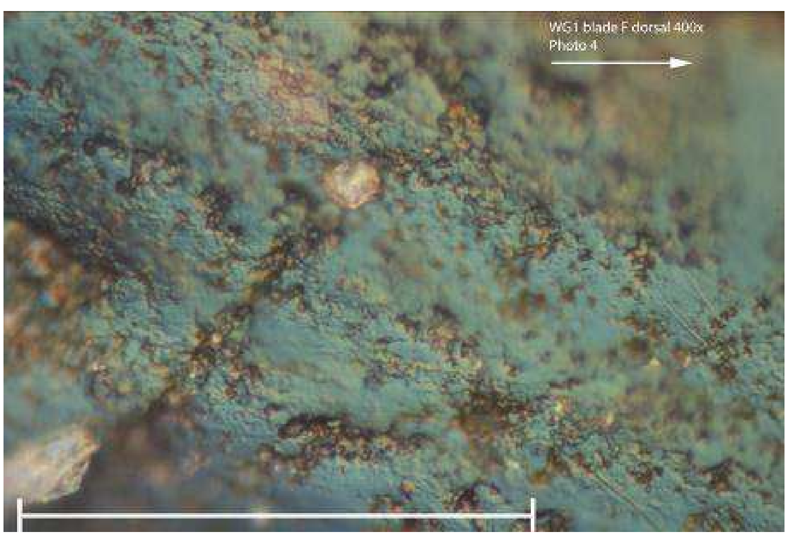

Figure 13: WG1 Blade F dorsal side at 400x, location 4. An abrasive particle is visible just above the center of the frame cemented into the microplating at the end of the long striation it cut into the stone. This area is stage 3 sickle gloss. Scale bar is 100 microns long.

Failure to completely mix the pigment also shows up during microscopic inspection, often as fields of bright red which can, depending on their extent, obscure the microtopography of the blade (Fig. 14). Small pigment flakes are usually not an issue as they do not obscure the use-wear in its entirety. Occasionally, if the unmixed pigment flake is large enough it can completely obscure the field.

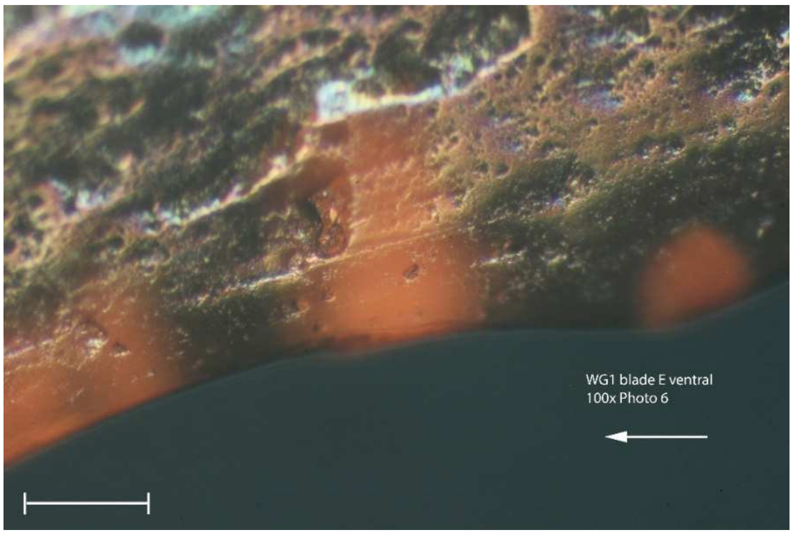

Figure 14: WG1 blade E ventral side at 100x, location 7. Three pigment flakes are visible at the edge of the blade as bright red spots. The sickle gloss is at late stage 2 or early stage 3.Scale bar is 100 microns long.

Occasionally, dust particles or polyethylene fibers from the bags adhere to the surface of the cast (Fig. 15). These dust particles are easily confused for crystallization. As such, whenever possible, the particles should be removed gently.

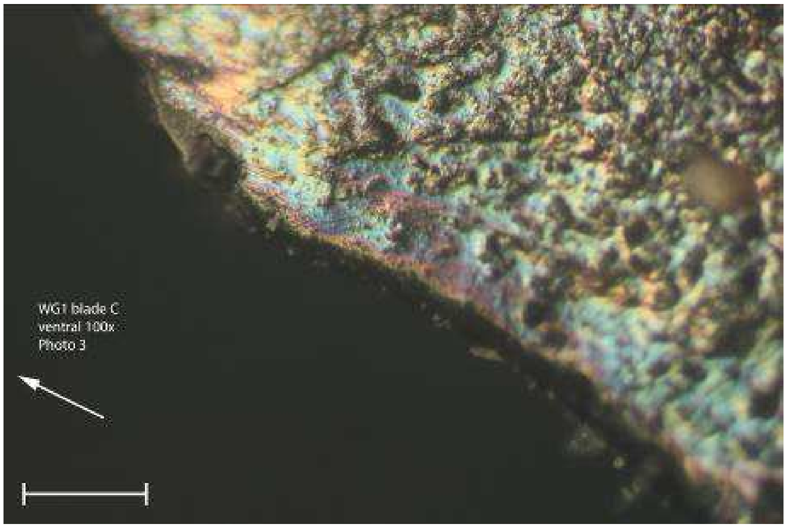

Figure 15: WG1 blade C ventral side at 100x, location 3. Dust particles are visible clinging to the edge of the blade. The surface of the blade is heavily remodeled with stage 3 microplating. Scale bar is 100 microns long.

Pseudowear

Occasionally the casts depict use-wear traces that are not indicative of any normal sickle use. These traces are often classified as pseudowear. Pseudowear's importance lies in the fact that it often obscures relevant use-wear traces. Oil spots, bubbles, voids, and other casting defect can all appear to be normal use-wear traces but are in fact pseudowear.

Care must be taken while handling the casts as any natural skin oils may easily adhere to the surface of the cast and obscure relevant wear traces (Fig. 16). Oil spots on the surface of the cast appear as bright, smooth areas that cover the microtopography of the stone. These spots may be confused with microplating. Oil spots tend to fill in low spots in the microtopography.

Figure 16: WG2 blade A ventral side at 100x, location 5. An oil spot is visible in the center of the frame. Scale bar is 100 microns long.

Bubbles remaining in the cast show up during microscopic inspection as voids in the cast, or bright shells that obscure the microtopography (Fig. 17). Depending on the number of bubbles entire areas of the cast may become unusable. Voids in the cast indicate a loss of any available wear traces in that area.

Figure 17: WG1 blade A dorsal side at 100x, location 7. A bubble is visible just above an isolated field of microplating. This is early stage 1 microplating. Scale bar is 100 microns long.

Wear Traces After 13 Hours of Use

Macroscopic examination of the sickles shows minimal macroscopically visible sickle gloss on the rye sickles. When present, the gloss is isolated to the edges of the blade or exposed ridges on the cutting surface. DW1 shows most of the macroscopically visible gloss as isolated pockets within what is left of the denticulate scars. Both rye sickles show macroscopically visible striations running the length of the blades. At this stage of use both sickles are still quite serviceable. The edges of the blades feel reasonably sharp. DW1 remains quite sharp, even with the loss of most of its denticulation. Conversely, the grass sickles feel smooth. WG1 maintains serviceability, though the sharp points of the blade, tactilely, are isolated to the microflaking along the edge. WG2 still cuts, though feels quite dull. The edges of this sickle have a silky feel, indicating the extent of the edge rounding.

Microplating runs the length of the edges of the blades for both grass sickles. Interestingly, microplating is quite invasive and can be seen along the surface of the stone up to the haft. The developmental level of this microplating is quite low, though, sitting at stage 1 after moving several hundred microns in from the edge. The rye sickles show similar invasiveness and similar developmental levels associated.

Comparing both sides of each blade shows a small disparity in the development of the microplating. Often the ventral surface is more developed as it is usually flatter than the dorsal side and, as such, has more contact with the plant stalk (Kay, 2014). It would be regarded as the leading edge in sickle use. Thus, the side exhibiting more developed microplating is deemed to be the leading edge of the blade, indicating the kinematics of sickle use. Therefore, in analyzing the differences between sickles, a comparison is best made between the leading edges of each sickle. Further, as the two types of stone used differ slightly in crystalline grain size and chemical composition (Flenniken and Garrison, 1975; Tullis and Yund, 1982), comparing like stone should show the most accurate differences in sickle gloss development. A total of 19 blades were examined for microscopic use-wear traces. Of those 19, 16 blades exhibit typical examples for illustrating the differences in use-wear development.

Examining WG1 location 8 (Fig. 18) shows a well-developed microplate field centered in the frame. The microplating at this location has almost completely overwritten the microtopography of the stone. Microplating coats the previous microflaking edge damage. The edge has been rounded over extensively with microplating accumulation. Viewing the area at 200x magnification shows the extent of the remodeling of the surface of the stone. Microplating at this location is a high stage 3 beginning at the edge. As it moves back from the edge the wear stage diminishes rapidly to a stage 2.

In contrast, DW1 blade A's ventral side shows minimal microplating at location 5.(Fig. 18) Viewing the location at 100x magnification shows discontinuous microplating concentrated at the edge. Edge damage is visible, but has just begun to be coated with microplating. The edge is slightly rounded with microplating accumulation. Viewing the location at 200x shows discontinuous microplating isolated to the edge. The peaks of the microtopography have been covered in microplating, yet the low spots remain. Sickle gloss at this location is at a high stage 1.

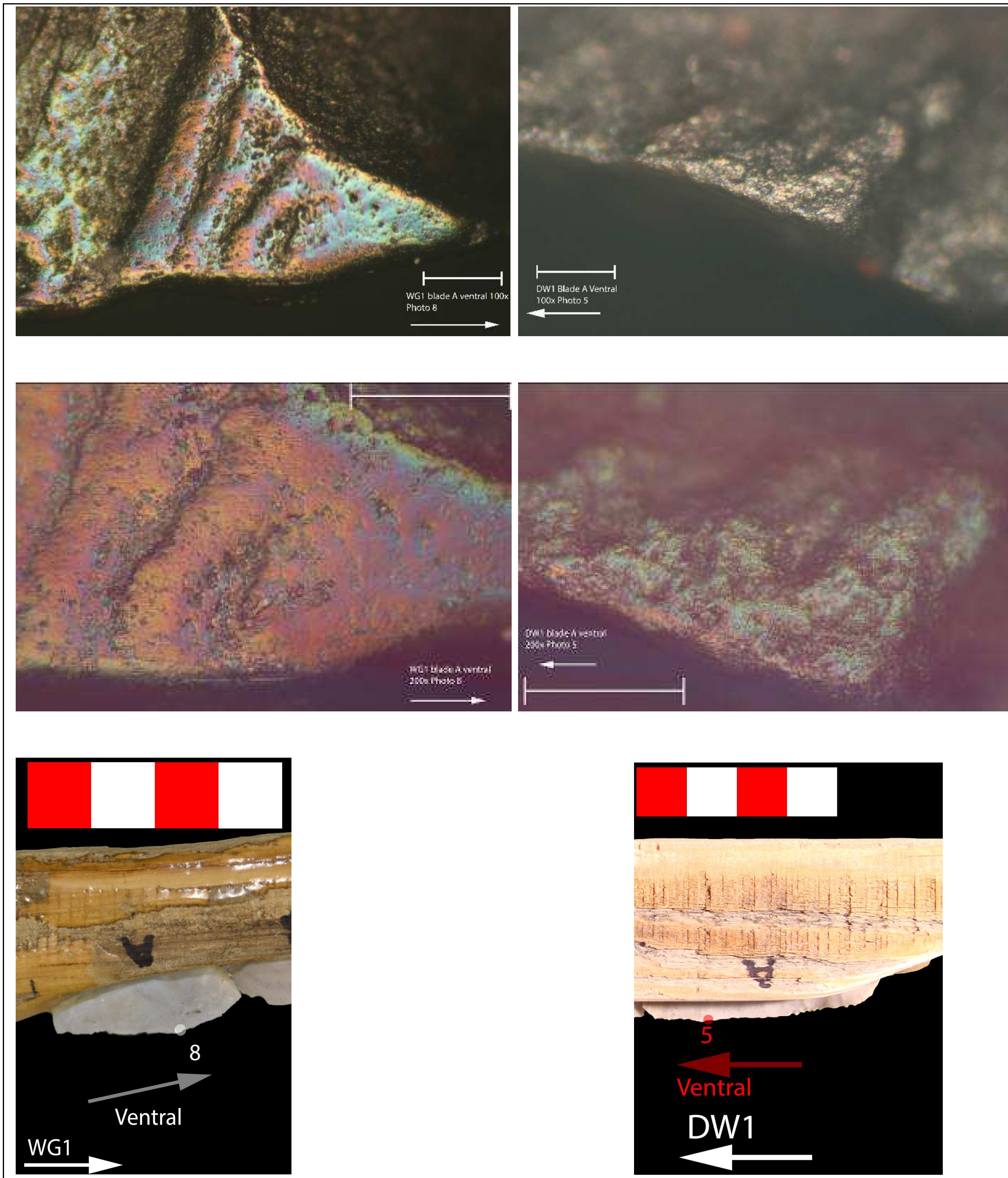

Figure 18: On left WG1 blade A ventral side location 8 at 100x and 200x. WG1 blade A shows stage 3 sickle gloss development. Right: DW1 blade A ventral Location 5 at 100x and 200x. DW1 blade A shows early stage 1 sickle gloss development. Scale bars are 100 microns long. Scale blocks on reference images are 1 cm.

Examining WG1 blade B's dorsal side at location 5 (Fig. 19) shows a well-developed microplate field coating the surface of the stone. The field extends from the edge in, with domed margins. Microplating accumulation has significantly rounded the edge at this location. The sickle gloss at this location is at wear stage 3 at the edge, diminishing to stage 2 about 120 microns from the edge. Blade C's dorsal side at location 4 (Fig. 19) shows a highly developed microplate field overwriting the microtopography of the stone. The surface of the microplating is smooth with fine striations. Sickle gloss at this location is at wear stage 4, diminishing to stage 3 about 100 microns in from the edge. Blade E's dorsal side at location 3 (Fig. 19) shows another highly developed stage 4 microplate field. The sickle gloss diminishes from stage 4 to stage 3 about 200 microns in from the edge. Fine grained striations run parallel to the edge. Edge rounding is significant. On the left of the image a microflake scar is faintly visible, having been covered liberally in microplating.

Examining DW1 blade B's dorsal side at location 7 (Fig. 19) shows the disparity in sickle gloss development. This location exhibits some of the most developed microplating along the edge of this blade. Microplating at this location is isolated to the high points of the microtopography. A flake of polyethylene is visible on the upper left of the image. The isolated area of wear stage 2 sickle polish is localized to within 100 microns of the edge. Edge rounding, while present, is not significant. Blade C's dorsal location 1 (Fig. 19) shows a similar microplate field. A wear stage 1 microplate field has slightly rounded the edge near the center of the frame. This microplate field develops towards stage 2 distally. Microplating at this location is isolated, discontinuous, and not invasive. Blade D's dorsal location 9 (Fig. 19) shows an isolated wear stage 1 microplate dome slightly rounding the edge of the blade. Dust particles are visible clinging to the edge of the blade. Edge rounding is slight at this location.

Viewing WG1 blade F's dorsal side location 1 (Fig. 20) shows incipient microplating, with some microplate domes, along the edge of a ridge of the blade. This location shows some of the least developed sickle gloss along the entirety of the sickle's edge. Microplating at this location is at wear stage 1. The microtopography of the stone is clearly visible as the microplating is highly discontinuous.

In contrast, DW1blade D's dorsal side, location 1 (Fig. 20) shows the rye sickle's least developed microplating. Emergent microplating has just begun to coat the peaks of the microtopography of the stone at this location. Sickle gloss here is at the earliest of stage 1. The most prevalent forms of use wear at this location are the abundant striations crossing the surface of the stone.

As WG2 blade A is also made of flint it is useful to examine here. Blade A's ventral side, location 3 (Fig. 21), shows a highly developed stage 4 microplate field cut into by a microflake scar on the left of the field. The surface of the microplating is smooth with fine striations running parallel to the edge of the blade. Unaltered stone is barely visible throughout the field. The stage 4 microplate field extends several hundred microns in from the edge. Microplating has begun to coat the microflake scar as well, showing a mid-stage 2 development. Viewing the margins of the scar at 200x magnifications shows the stage 4 field rapidly encroaching upon the flake scar. Wider, partially filled in, striations are visible running transverse to the edge for about 100 microns in length.

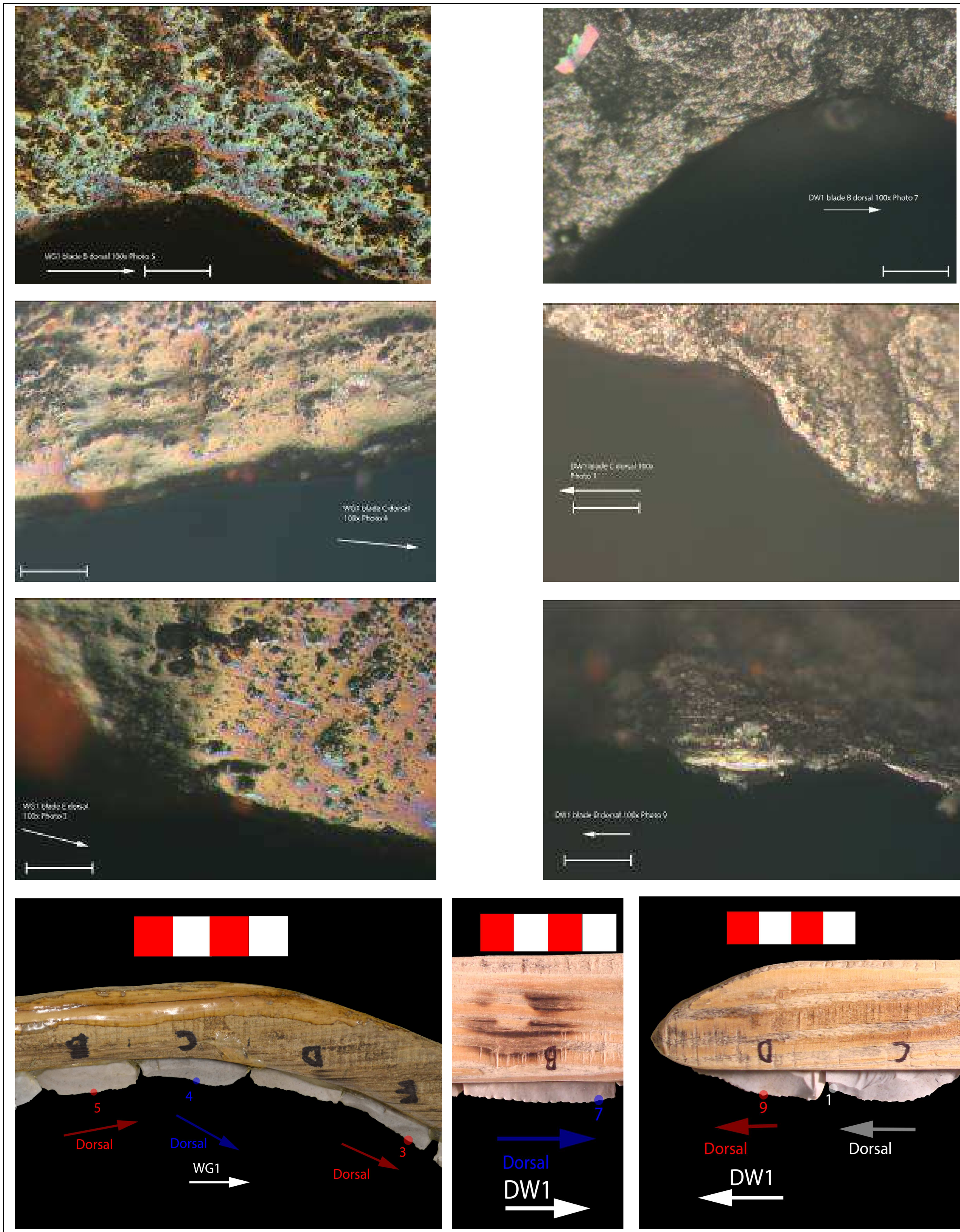

Figure 19: Left: WG1 blade B dorsal location 5, C dorsal location 4, E dorsal location 3 at 100x. Right: DW1 blade B dorsal location 7, C dorsal location 1, D dorsal location 9 at 100x. Scale bars are 100 microns long, scale blocks are 1 cm.

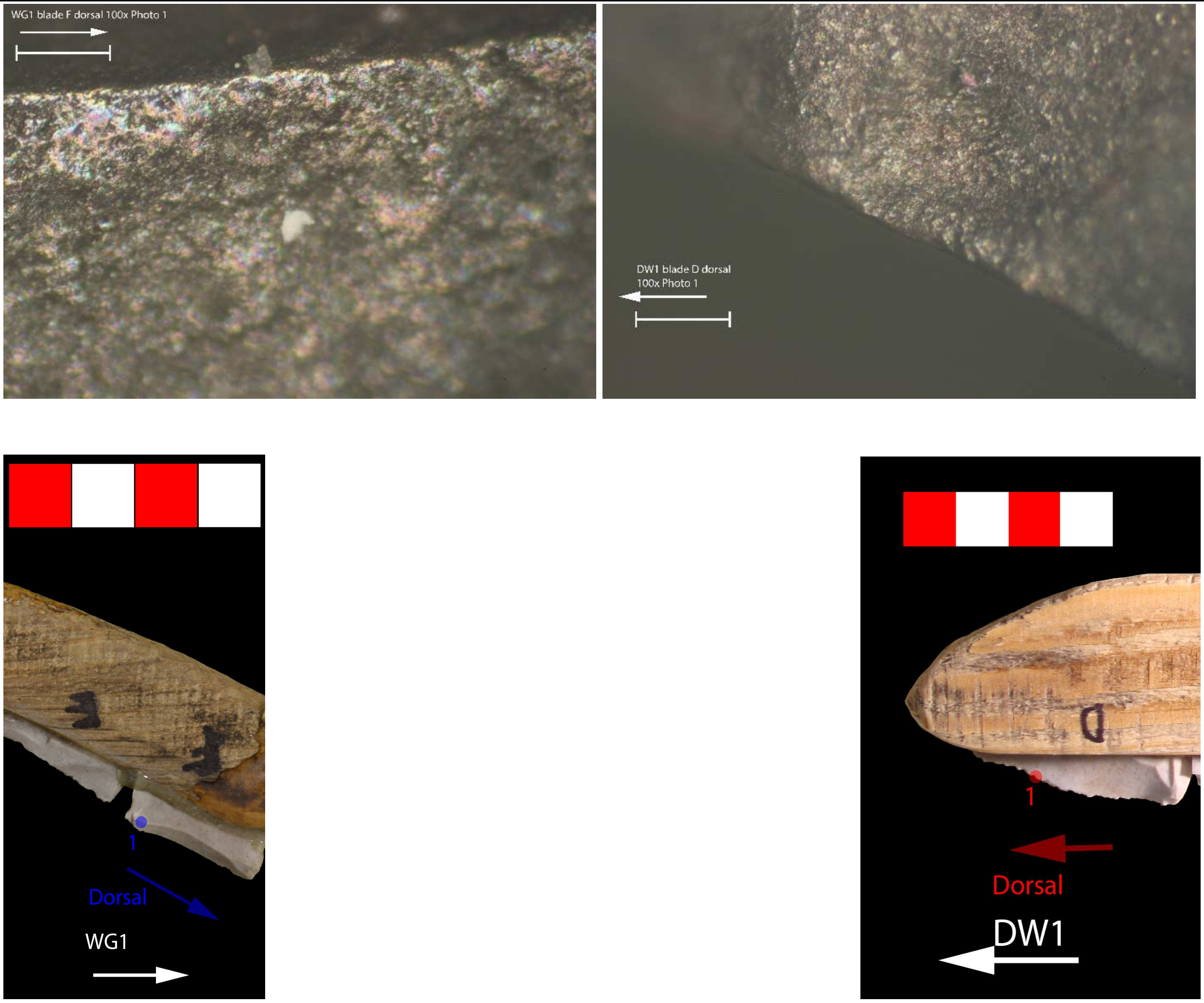

Figure 20: Left: WG1 blade F dorsal location 1 at 100x. Right: DW1 blade D dorsal location 1 at 100x. Scale bars are 100 microns long, scale blocks are 1 cm.

WG2 blade A's dorsal side location 1 (Fig. 21) shows the terminal margins of a stage 4 microplate filed rounding over a ridge of the blade. At the ridge the field shows stage 3 microplating rapidly diminishing to stage 2 within 100 microns of the ridge and further diminishing to stage 1 about 200 microns in from the edge. Location 2 (Fig. 21) on the same side shows an extensive stage 4 microplate field with smooth surfaces covered in fine striations running parallel to the edge. Edge rounding is significant at all of these locations. Blade A shows the highest development of sickle polish out of all flint blades and all of WG2's blades in particular.

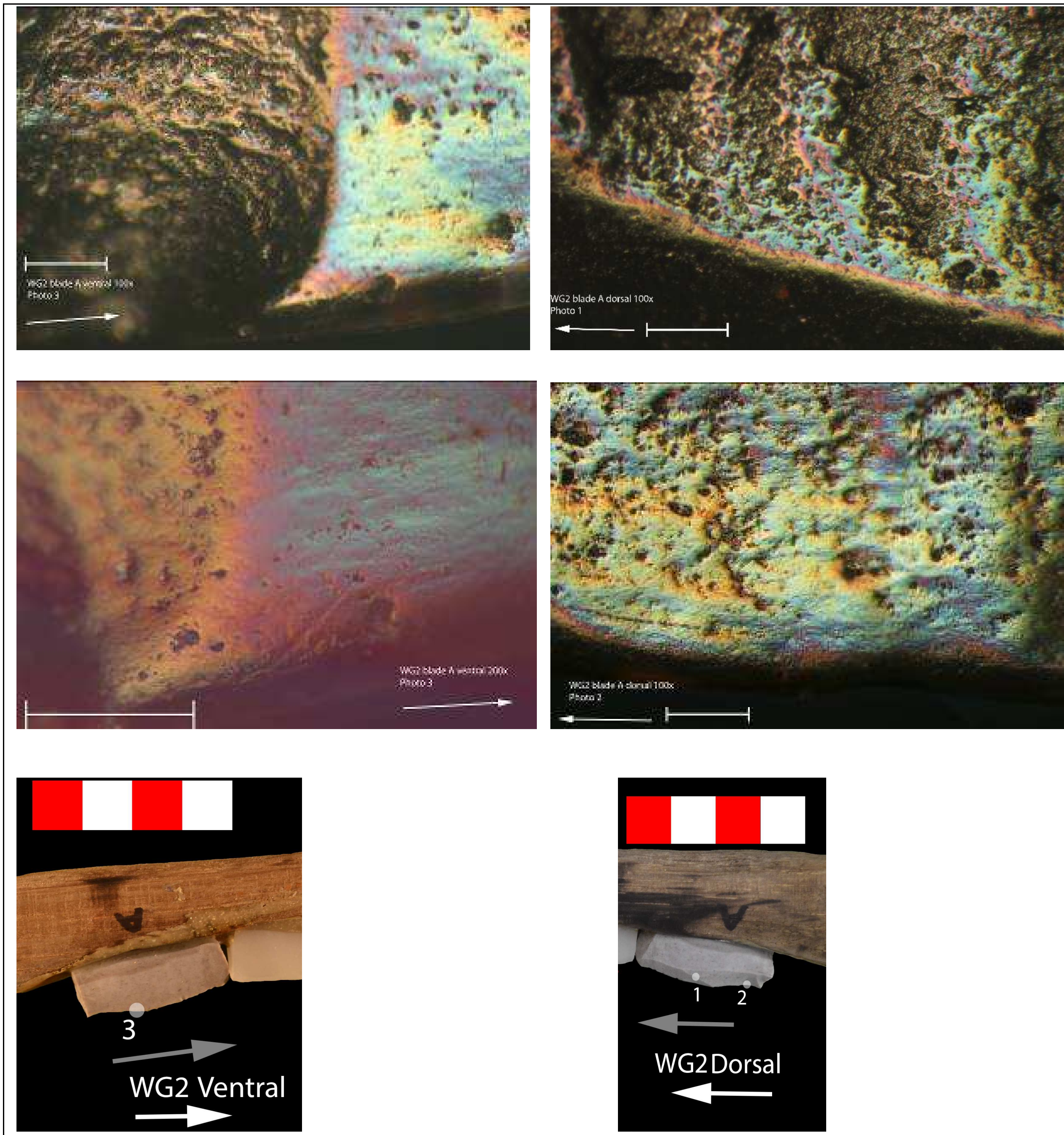

Figure 21: Survey of WG2 blade A sickle development. Left: Blade A ventral location 3 at 100x and 200x. Right: Blade A dorsal location 1 and 2 at 100x. Scale bars are 100 microns long, scale blocks are 1 cm.

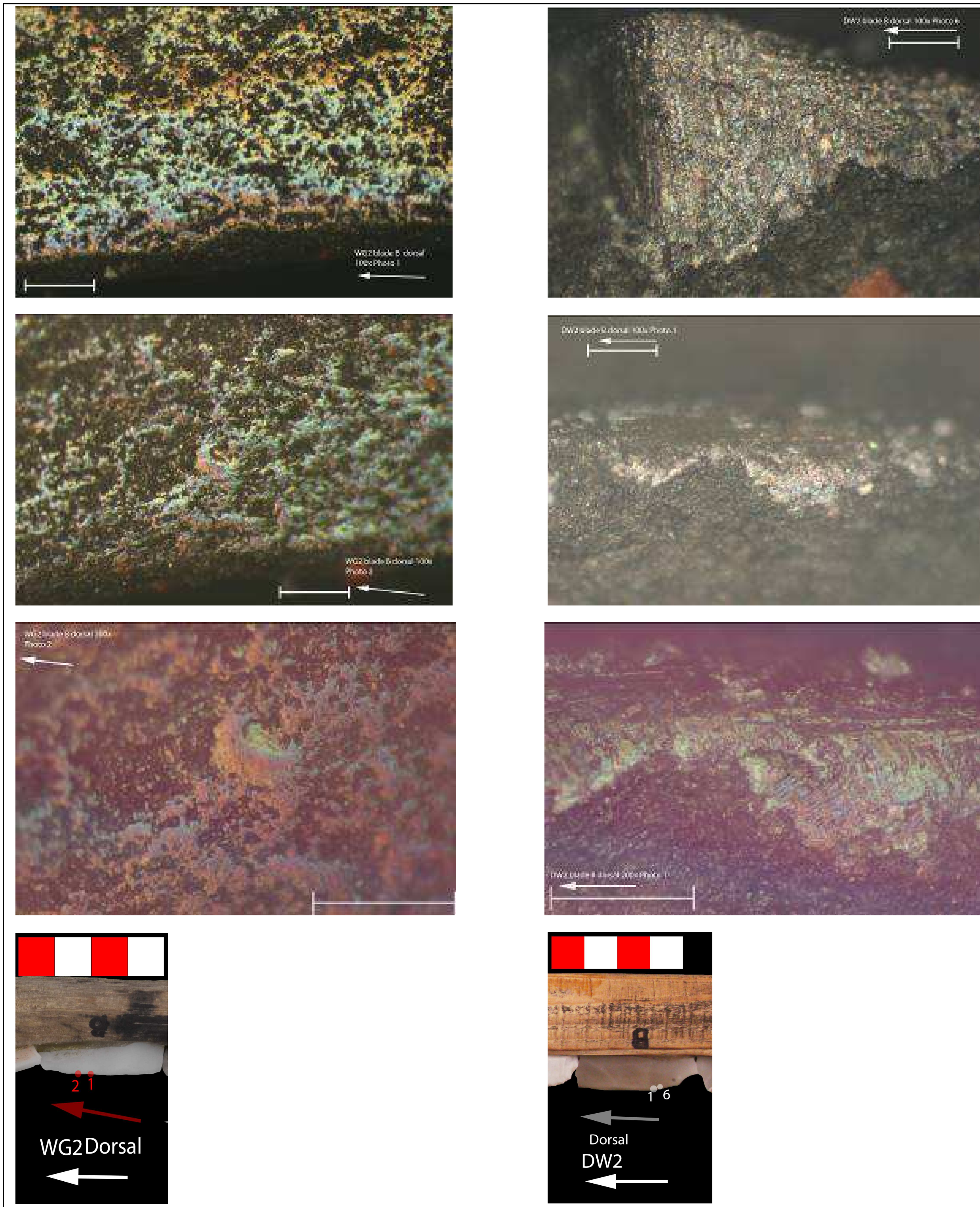

Figure 22: Left: WG2 blade B dorsal side location 1 at 100x, 2 at 100x and 200x. Right: DW2 blade B dorsal side location 6 at 100x, 1 at 100x and 200x. Scale bars are 100 microns long, scale blocks are 1 cm.

The novaculite blades on the grass sickle show lower levels of microplating development compared to their flint counterparts. WG2 blade B's dorsal side location 1 (Fig. 22) shows uniformly discontinuous microplating extending in from the edge of the blade. The microplating at this location is uniformly a high stage 2, almost stage 3. It maintains this level of development several hundreds of microns in from the edge. The edge is significantly rounded, though the microplating has not aggregated. Location 2 (Fig. 22) on the same side of the blade shows similar development. The microplate field at this location is dotted with microplate domes, with one centered in the frame. Viewing location 2 at 200x magnification (Fig. 22) shows the microplating beginning the process of joining together. The microplating at this location is at a high stage 2, possibly stage 3. As with location 1, the microplating extends several hundred microns in from the edge at this development level. The top of the field at 100x magnification shows the microplating diminishing to a stage 1 development.

DW2 blade B's dorsal side at location 6 (Fig. 22) shows a microflake scar on the edge of the blade coated in a stage 2 microplate field. Abundant striations cross the field perpendicular and transverse to the edge at this location. At the edge of the flake scar the microplating abruptly ends. Past this point the microplating is isolated to the peaks of the microtopography at an early stage 1 development. Location 1 (Fig. 22) shows an isolated microplate dome composed of several microplate depositional events. Dust particles confuse the image at the edge of the blade. Despite this, bright crystallization spots are evident along the margins of the microplating. The microplating at this location is mid-stage 2, abruptly ending at the margins and continuing into the stone as an early stage 1. Striations cross the field, generally running parallel to the edge or perpendicular, as seen when viewed at 200x magnifications.

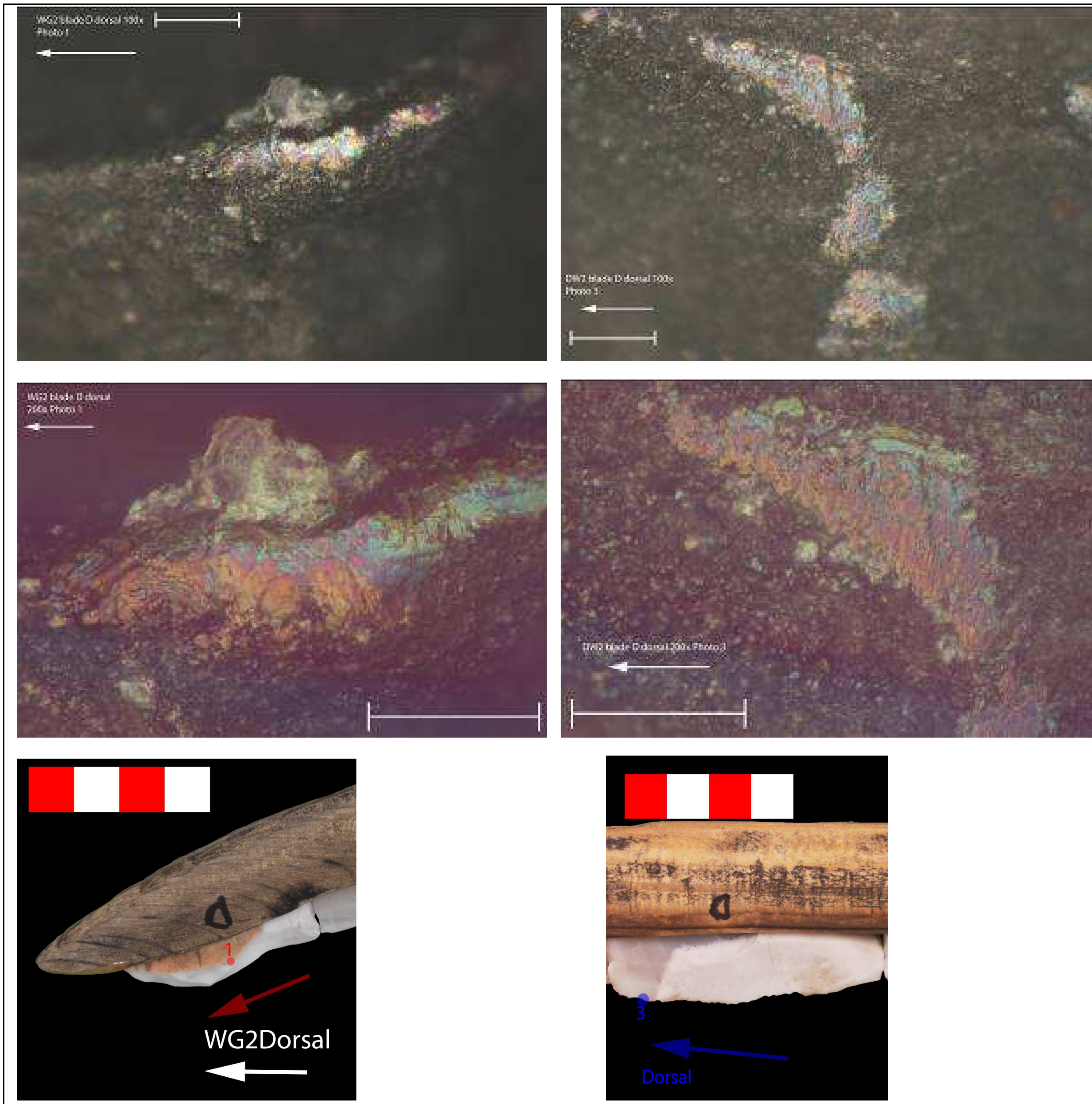

Figure 23: Left: WG2 blade D dorsal side location 1 at 100x and 200x. Right: DW2 blade D dorsal side location 3 at 100x and 200x. Scale bars are 100 microns long, scale blocks are 1 cm.

WG2 blade D's dorsal side at location 1 (Fig. 23) shows an invasive microplate field overwriting a peak of the stone. This location shows some of the least developed microplating along this sickle. The microplating appears smooth at 100x magnification, with few striations visible. What appears to be crystallization is visible adhering to the upper margins of the microplating. At 200x magnification the finer striations are visible. Two sets run either transverse or perpendicular to the cutting direction. At this magnification filaments are visible within the large crystallization.

Conversely, location 3 on DW2 blade D's dorsal side (Fig. 23) shows some of the most developed microplating on this sickle. The microplating at this location is isolated, adhering to what appears to be a ridge in the microtopography of the stone. Abundant striations cross the surface of the microplating running perpendicular to the cutting direction. Viewing the location at 200x magnification shows multiple microplating depositional events. The sickle gloss at this location is at a mid-stage 2, abruptly ending at the margins. Isolated microplating is visible nearby, isolated to the peaks of the stone, at an early stage 1 development.

Striations cross the surface of each blade in abundance. The form of the striations seems to differ between blades used to cut grass and blades used to cut rye. In general, the striations evident on the sickles used to cut grass are narrow with sharp margins. The striations on sickles used to cut rye are, in general, wide and shallow with rounded margins. Figure 24 shows a comparison between WG2's blade D and DW2's blade A at 200x magnification. On the left of the figure the striations visible are fine and sharp (Fig. 24). Width of the striations on WG2 blade D at this location is quite narrow, generally not exceeding a few microns. On the right of the figure the striations are wide and rounded (Fig. 24). Width of the striations on DW2 blade A at this location is quite wide, with several as wide as approximately 10 microns.

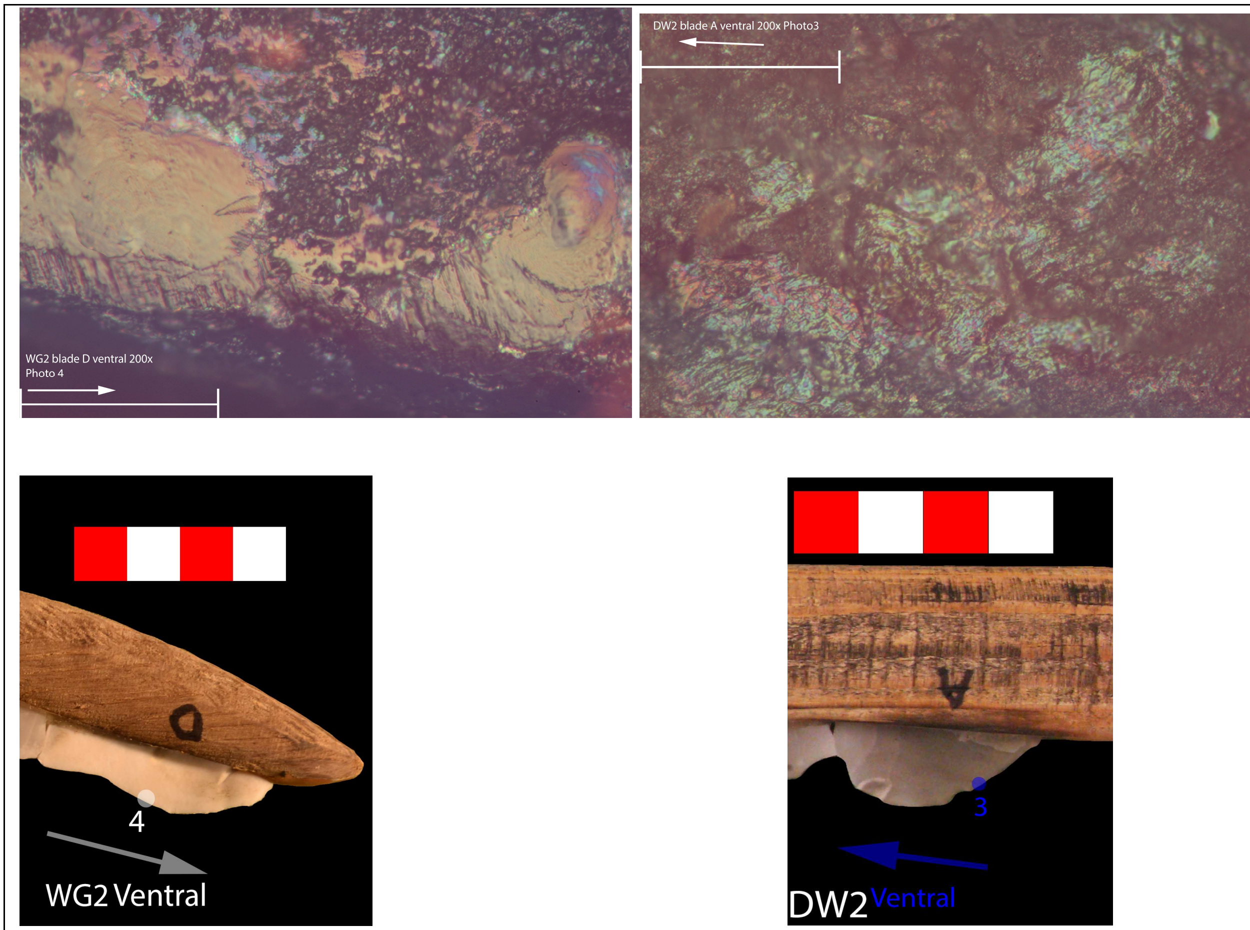

Figure 24: Left: WG2 blade D ventral side location 4 at 200x magnification. Right: DW2 blade A ventral side location 3 at 200x magnification. Scale bars are 100 microns long, scale blocks are 1 cm.

Sickle Wear Stages

Comparing the charts showing general wear stage development (Fig. 25) and average percent area covered (Fig. 27) shows them to be in rough agreement. Interestingly the two charts agree with the harvesters' assessments of the sickles. Figure 25 shows a rough interpretation of the kinematics of the sickles. The orientation and the size of the blades contribute to WG1's profile in the chart. The cutting stroke used is illustrated in WG2's profile. DW1's and DW2's profiles both illustrate the cutting motion used in relation with the size of the blades.

Figure 26 shows each blade's general wear stage plotted against the average water content percentage for each sickle. Notably, the stage 3 and 4 sickle polish is only present on sickles used on grass with an average water content of 47%. Stage 1 and 2 were both present on sickles used on rye with an average water content of 10%.

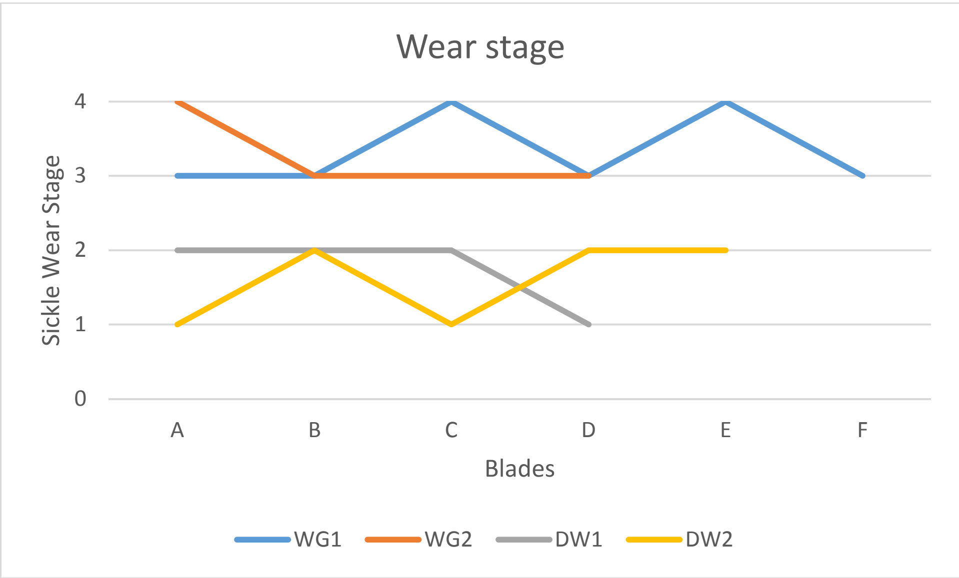

Figure 25: A chart showing the general wear stage development for each blade of each sickle.

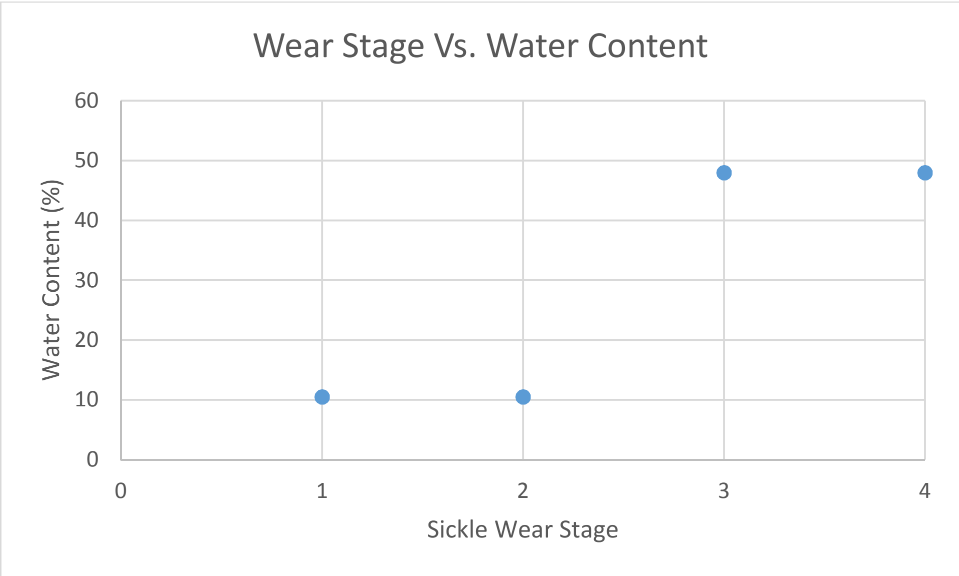

Figure 26: A chart showing the wear stages present and the average water content percentage associated with them.

Sickle	A	B	C	D	E	F
WG1	51.2	61.5	73	75	69.3	52.7
WG2	57.55	54.2	62	39.75	N/A	N/A
DW1	21.2	34.65	32.14	26.8	N/A	N/A
DW2	26.82	38.13	16.98	16.55	35.49	N/A

Figure 27: A table showing average percent of area covered by microplating in select images.

Discussion

The differences in the use-wear generated on sickle blades between growing grass and mature rye are apparent. Higher water content seems to be an important variable in the development of microplating. Measuring the water content of the plant material harvested shows a positive correlation with the development of microplating on the surface of the stone. However, the data indicates that, while an important factor, moisture content is not the sole variable in the development of sickle wear. The hardness and general abrasiveness of the plants seem to play no small part in the remodeling of the stone.

Macroscopically visible use-wear traces developed quickly, echoing results achieved by other experiments (Quintero, Wilke, Waines, 1997). The softer flint blades exhibit edge damage in higher amounts than the harder novaculite blades. The efficiency of the sickles dropped steadily with use until reaching a plateau near the end of the experiment. This would have likely been the point where harvesters would have retouched the blades or replaced as needed.

Edge rounding is significant on both sets of sickles. The edge of the blades have a smooth feel on all four sickles. Microscopic inspection shows edge rounding along nearly the entirety of each blade. This edge rounding is commonly a result of the microplating but is present in areas without microplating visible. It is likely that the development of edge rounding is a tandem process between ablative and adhesive mechanics. Abrasive rounding of the edge seems to precede the microplating of the edge.

Examining the grass sickles shows the softer flint blades to have greater amounts of microplating present. The microplating adhering to the surface of the flint has bulbous edges and billows across the stone. WG1 shows areas of almost complete coverage by microplating along the edge of the blade. The proximal blade of WG2, also flint, shows substantially more microplating than its novaculite partners as well.

The macroscopically visible gloss is greatest on WG2 blade A, taking on an almost painted appearance. This could be a result of the softer nature of the stone blade, but is likely a result of the cutting motion used on that sickle. Sickle gloss on the flint blades of both grass sickles can be classified generally as late stage 3 to stage 4. The microplating has, in most cases, completely overwritten the normal microtopography of the stone and has generated a macroscopically visible gloss in large amounts.

Generation of the macroscopically visible gloss evidently occurs in stages. The gloss appears to begin as brilliantly reflecting points caused by aggregated microplating in an area of the blade. The rye sickles show this usually occurs first at the edge, isolated to points that likely catch the microplating first. This sheen can be quite invasive though, with visible areas sometimes occurring on a haft-ward ridge on the surface of the blade before the edge. It is likely that these areas experience less abrasion and, therefore, the development of microplating is not inhibited by the removal of aggregating microplating gel.

Both rye sickles show underdeveloped areas of microplating. Interestingly, the low moisture content of the rye still produces minute microplate domes. Isolated microplate domes are quite common on the rye sickles. None of the areas inspected on either rye sickle show any sickle polish developed past late stage 2. At this point it is quite clear that moisture content directly affects the development of microplating, but may not be the only factor. It is possible that the composition of the plan itself contributes to the development of the microplate domes seen on these sickles.

Microplating clearly forms in laminate layers. The evidence provided by the sickles in this experiment suggest that microplating adheres more easily to previously deposited microplating layers. This could be the mechanism behind the creation of some of the flat margined microplate domes seen on the rye sickles. Moreover, the profile of the margins of any present microplating fields or domes seems to correlate to water content. Rounded margins appear on the rye sickles in low numbers. On both grass sickles rounded or bulbous margins are quite common. Examining the microplate formations on the blades at high magnifications often shows a series of depositional events. This laminate effect is not visible on the rounded or bulbous margins. It is possible that the creation of rounded or bulbous margins on microplating fields or domes is caused by consistent use on a moist material. Collection of the microplating silica gel before the previous deposition can harden could cause a rolling effect, similar to the margins of lava flows. It has been shown that the microplating layer hardens quite quickly (Kay, 2014; Kay and Mainfort, 2014). If another film of silica gel is added to an area such that the previous deposition's margins have only just begun to cure it could create these rounded margins. The flat margins exhibited by the thinner microplating fields on the rye sickles could be caused by a small amount of microplating gel being thinly spread by the pressure of the dry stalks crossing the surface of the stone.

The rye sickles exhibit higher numbers of large crystallized particles adhering to the microplating layers. While crystallization is present on the grass sickles, it is generally smaller and embedded within the microplating. The apparent absence of crystallization could be a result of the high level of development of the sickle polish on those blades. Microplating layers could laminate over previously formed crystallization spots. It is also possible that these crystals could be a result of the lower moisture content in the rye, causing dissolved silicates to precipitate out at a higher rate.

Striations visible on the surface of the stone hint at the difference between the contact materials. Both rye sickles show macroscopically visible striations running the length of the blades. These striations are faintly visible and have a dull sheen to them. Neither one of the grass sickles presents such striations on their blades. The abrasive quality of the rye must, therefore, be quite high. Microscopic inspection agrees with this. All of the blades used to harvest rye show wide, deep striations cutting into the surface of the stone. While these striations do occur on the grass sickles, they are quite rare. On the grass sickles these striations present as abrasion caused by an occasional soil particle. The rye sickles show these striations cutting into the stone in directions consistent with the cutting motions used by the sickles. By comparison, the striations visible on the grass sickles are mostly relegated to the microplated surface. These striations are finer and shallower, with sharp margins.

Because of the presence of these abrasive striations on the rye sickles, it must be considered that the abrasive quality of mature rye actually impedes the development of sickle polish, consistent with previous arguments (Kay and Mainfort, 2014). However, the level of impedance, if any, is not obvious at this level of use. The abrasive nature of the rye stalks may be removing incipient microplating, but the presence of heavily striated microplate fields indicates an ability for the depositional events to outstrip the ablative events. An increase in the concentration of plant opals may be the reason behind the abrasive nature of rye and may contribute to the increased number of observable crystallization areas on the rye sickle blades.

Examining the area covered by microplating shows the assessment of the harvesters to be accurate. The middle set of blades on WG1 show the most coverage, indicating more cutting contact done on these blades. The coverage on the three proximal blades of WG2 indicate more work done by these blades. Similarly, the middle two blades of DW1 show higher levels of coverage. DW2 has coverage percentages that initially seem a bit odd. These numbers are likely a result of shifting between using sawing strokes or full draw strokes. Additionally, upon analyzing many of the harvester's comments, full draw strokes often ended with a rotating follow through to clear the bundle. This could be the reason for the increased microplating on the distal blade. These numbers indicate a relationship between the cutting stroke used and the developmental preference exerted on microplating. Sawing motions seem to cause more microplating on the middle blades of straight sickles. Full draw strokes seem to cause more microplating on the distal end of straight sickles. Full draw strokes on curved sickles seems to cause the middle of the curve to develop more microplating. Push strokes on curved sickles seems to cause the proximal blades to develop more microplating.

Ongoing examination of the sickle casts is necessary. The full relationship between the kinematics and the development of sickle polish is not evident with the edge survey done. Microplating on all the experimental sickles is invasive, but the extent of the invasiveness is not obvious with the imagery at this time. Future examinations should include transects from the edge toward the haft to examine the complete development of microplating along the surface of the blade. This should allow for interpretations involving the complete cutting motion used. Evaluation of the angles and order of striations should be undertaken as well.

Future experiments should include mature, dry grass and growing rye in the harvest. This should allow for the isolation of the cause of the wide striations seen on the rye sickles. Examining a sickle used to harvest dry grass might be able to show whether the abrasive quality of the rye is caused by its moisture content or simply the characteristics of the plant itself, such as increased silica concentrations, hardness, and rigidity.

Additionally, other variables not controlled for in this experiment should be evaluated. Determining the role that aerosolized abrasive particles plays on the development of use-wear traces on sickle blades could offer important insight into the characteristics of sickle polish in the archaeological record. Perhaps by maintaining a dust sampling station near the harvesting area a particulate count could be attained. This could should show the amount of dust adhering to the stalks above the splash zone near the base. Hardness of the plant material should be evaluated as well. Using tools and methods established by the agricultural field should allow for the control of the hardness of the plant stalk. With this variable controlled for, a better understanding of the interplay between the abrasive and additive mechanics could be reached. Finally, for a more accurate comparison of the use-wear traces, experimental sickles should be used on a single plant species throughout its growth cycle. It is possible, by harvesting throughout the growth cycle of one plant, that the interplay between moisture content, hardness, and abrasiveness of a plant and the development of sickle gloss may become more apparent.

The sickles used on mature rye and growing grass should have more harvesting time. Reexamining the sickles after roughly 20 or 25 hours of use time should show the maximum development of their respective use-wear traces. The formation of the bulbous margins of the microplate domes presents an interesting question. An experiment examining the relationship between the profile of microplate margins, intensity of use, and moisture content should help answer several questions. Perhaps by harvesting plant material over 45% water content for several hours at a time and comparing the results to a sickle used for only 20 minutes at a time might yield interesting results.

The use of ImageJ to determine the percentage area covered by microplating is an interesting avenue of investigation. Efforts to better create a quantitative scale of microplating should be encouraged. While the use of ImageJ in this study was simply for general illustrative purposes, the tool has proven to be quite powerful. By generating a method for the random selection of a consistent area in images, a more robust quantitative analysis might be created. Additionally, further investigations should allow for the measurement of the microplating field's margins and thickness. These avenues might allow for an application of a quantitative scale to sickle gloss.

The sickles used in this experiment shed light on the process of constructing a sickle. Removal of the striking platform of the blades would, in future efforts, allow for a better fit for experimental blades. The sickles used here exhibit significant drag in several instances. The configuration of the blades obviously plays a role in determining the most efficient stroke for the sickle. Future experimental constructions should endeavor to create a more uniform cutting edge. This should allow for a better sense of the true efficiency of a sickle design.

Perhaps the most important avenue of future research should be efforts to understand the composition of sickle polish and the mechanics of its development. By using a harvesting blade made of materials devoid of silica one might be able to determine the extent of the involvement of dissolved silica within the plant matter. Understanding the depositional mechanics behind microplating should allow for better understanding behind why moist plants develop sickle polish faster than dry plants.

Conclusion

While many variables, such as plant hardness, abrasiveness, and thickness to name a few, were unfortunately not controlled for it is abundantly clear after examining the data that moisture content of the plants plays a significant role in the development of sickle polish. Both sickles used to harvest wet grass exhibit higher stages of sickle gloss development than do their rye counterparts. The normal microtopography of the stone near the edge of the blades on the grass sickles has been nearly completely overwritten. In contrast, the rye sickles show only isolated clumps of microplating adhering to the high points in the microtopography.

There is a disparity in the level of development of sickle gloss between flint and novaculite blades. Many of the flint blades exhibit large areas of wear stage 4 sickle gloss, while the novaculite counterparts exhibit stage 3 sickle gloss. This disparity could simply be caused by the kinematics of the sickle, or it could be due to the difference in morphology of the grains and chemical composition of the stone (Flenniken and Garrison, 1975; Tullis and Yund, 1982).

Microplating fields seem to exhibit different margin profiles with the different plant contacts. The moist grass seems to develop rounded margins at a much higher frequency than does the drier rye. These rounded margins could possibly be indicative of the intensity of use, though they may simply be a result of large amounts of dissolved silica.

Both sets of sickles exhibit invasive microplating. The sickles used to harvest growing grass exhibit a higher developmental stage extending from the edge towards the haft. Sickles used to harvest mature rye show an overall lower developmental stage, largely isolated to just the edge of the blade.

It is clear, after examining the data that microplating seems to preferentially adhere to previously deposited microplating layers. This lamination mechanic obliterates the microtopography of the stone with time, filling in striations and low points. It was expected that the accretion of microplating laminates on the edge was the main factor in edge rounding and subsequent dulling of the blade. The data suggests that the rounding of the edge is actually a combination of edge abrasion and then, shortly after, adhesion of microplating.

This lamination mechanic may also be responsible for the diminished presence of crystallization on the sickles used to harvest wet grass. It is possible that the successive microplating depositional events coat over the previously formed crystallization spots. An alternative explanation for the increased presence of crystallization on the sickles used to harvest dry rye could simply be the characteristics of the plant. The low moisture content, combined with the rigid structure of the plant, may cause an increase in the deposition of solid or partially dissolved silica crystals.

While the qualitative analysis of the sickle wear stage is useful, further efforts in the production of a quantitative method are encouraged. The use of ImageJ to measure the area covered by microplating in images yielded interesting results. The preliminary application of this software seems to agree with the established qualitative scale. Future applications should look to create a standardized application of the software.

Non-gloss use-wear traces are abundant on each sickle. Unfortunately, as variables such as abrasiveness, hardness, rigidity, and stalk size were not controlled for, only a limited comparison can be made. The data shows that sickles used to harvest rye exhibit wider, shallower striations than do the sickles used to harvest grass.

Additionally, the development of sickle gloss along the length of the sickle is not constant. This indicates differing levels of involvement of each blade. When compared with the field observations of the harvesters, the development stage of each blade largely agrees with the established cutting stroke used and assessment of the workload of the blades. While the data indicates at the ability to determine the kinematics of each sickle, more experimentation is necessary before conclusions may be drawn. The experimental sickles used in this study were not created in the most optimal way. It is, therefore, not surprising that each blade contributes differently to the cut.

Examining the data shows moisture content to be an important factor in the development of sickle gloss. It is, though, not the only factor. As this study did not control for every possible variable, including many important ones, further experimentation is necessary. Future experimentation should control for aerosolized abrasive particles, plant species, hardness of the plant, rigidity of the plant, and even the growth stage of the plant. The data presented here provides a promising start towards understanding the development and characteristics of sickle polish in relation to moisture content. With future experimentation, the ability to determine the type of plant harvested, moisture content, and cutting stroke used might be possible in the archaeological record.

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