Critical Thinking in Geology and Archaeology: Interpreting Scanning Electron Microscope Images of a Lithic Tool

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ABSTRACT

As co-instructors of an undergraduate course in Archaeological Geology, we have developed an in-class research project using the Scanning Electron Microscope (SEM) to analyze and interpret physical traces of stages in the history of a unique lithic artifact. This exercise requires preliminary instruction on percussion and pressure flaking, geological materials suited for chipped stone tool manufacture, contextual archaeological analysis, theory of electron microscope use, and post-depositional surface processes, particularly those creating natural wear due to wind or water abrasion. With this background, students acquired four images of surface and edge locations of the study artifact using the SEM. We asked students to write a description of the analytical technique, a compilation of their observations and analytical data, and an interpretation of the artifact's history. Although most students recognized that the artifact recorded multiple stages of manufacture and use, additional comparative images of water- or wind-worn, chipped or ground cherts would give students greater ability to distinguish cultural modifications from those created by post-depositional geologic processes. Students expressed enthusiasm about the project and indicated a high level of engagement on evaluations (mean score=4.3-4.4, median score=4.5-5.0 on a scale of 1 [low] to 5 [high]).

COURSE AND PROJECT GOALS

During the last fifteen years, reviews of national science education have strongly encouraged educators to use concrete, participatory experiences to improve students' abilities to design, implement and evaluate experiments and to retain scientific knowledge (AAAS, 1989; NRC, 1996, 2000). A wide variety of National Science Foundation-sponsored workshops and special sessions at national meetings (e.g., From the introductory classroom to capstone experience - integrating research into the undergraduate curriculum GSA, 2000, and Using data to teach earth processes, GSA 2003) continue to highlight innovative active-learning projects, many of which include primary research.

During the spring (2003) semester at Kansas State University (KSU), we developed and co-taught an interdisciplinary undergraduate course in Archaeological Geology that provided three credit hours in anthropology or geology. As key components of the course, we wished students to acquire: a) knowledge of geological processes that affected past human societies and the archaeological record, b) an introduction to analytical methods used by geologists that aid in the interpretation of our human past, c) an understanding of geologic time and dating techniques, and d) an appreciation for how geologic knowledge is critically applied toward the interpretation of the human past. In order to reach these goals, we designed and implemented seven participatory projects that stressed evaluation of geologic and archaeological data and the use of higher cognition skills, particularly synthesis and interpretation (Bloom et al., 1956).

For one of these activities we asked students to describe, analyze and interpret the history of a complex lithic tool (hafted knife or projectile point). By complex, we mean that the stone tool showed physical traces of multiple stages of manufacture and use. The primary goals of this activity included: a) distinguishing the study object as a cultural (artifact) rather than natural, b) identifying the methods of manufacture, and c) distinguishing characteristics imparted by post-depositional processes. Following macroscopic inspection, students collected compositional data and magnified images using a scanning electron microscope (SEM). Students learned to distinguish between collection of careful observations (data) and interpretation of those observations. Students wrote individual reports of their analyses that included their observations, evaluation of the data quality and an interpretation of the history of the study artifact. Additionally this project required that students synthesize information presented earlier in the class including information about rocks and minerals - particularly chert, a microcrystalline form of quartz - and geologic surface processes.

SETTING THE STAGE

To set the stage for the project, we provided new content on stone tool manufacture and on the theory and use of electron microscopes. Discussion and hands-on inspection focused on the characteristic marks left on tools and stone debris (or debitage) by percussion and pressure flaking. Percussion flaking is the process of forming chipped stone tools by striking near the edge of a stone with a hammer of stone or other material, such as dense antler or hard wood. Resulting fractures on the stone produce flake scars or marks having the distinguishing characteristics of conchoidal form. Likewise, pressure flaking is used to form stone tools through the application of pressure against the edge of a stone with a pointed implement, such as an antler tine. The literature on flintknapping and chipped stone tool analysis is extensive; sources suitable for students with a limited background in archaeology include Andrefsky (1998), Bradley (1989), Crabtree (1967a, b, 1972), Luedtke (1992) and Whittaker (1994). Given the multiple processes likely employed in the manufacture of this tool, we introduced groundstone tool technologies such as pecking, grinding and carving (Peregrine, 2001; Schneider, 1998). Because this course was designed for sophomore-junior geology and anthropology majors and because of the complex nature of use-wear studies (Odell, 2001; Yerkes and Kardulias, 1993), wear caused by tool use (e.g., crushing, chipping or polishing) were only briefly mentioned. Students were not asked to

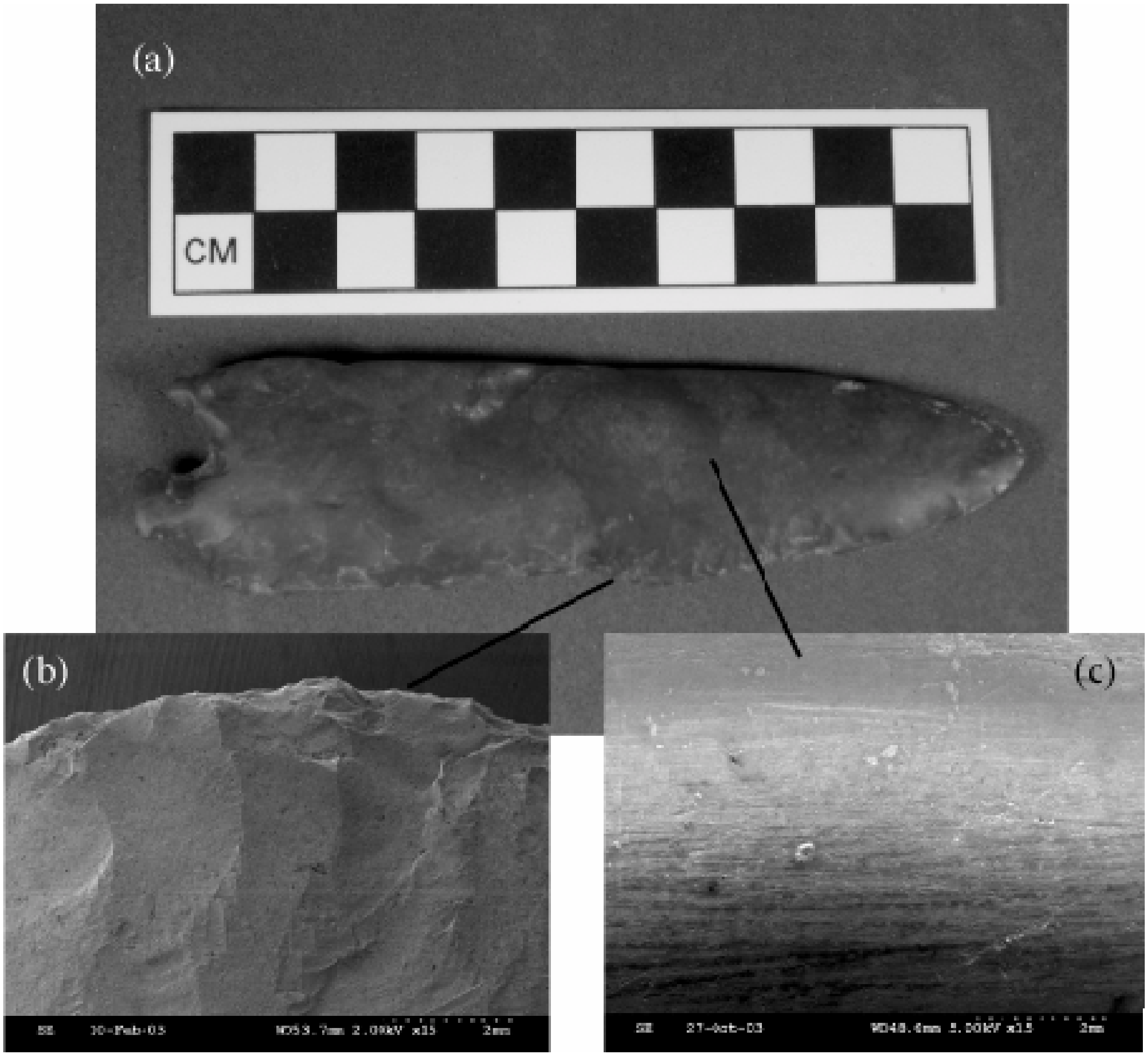

Figure 1. Photograph and scanning electron images of the study artifact showing magnification at 15x of (b) a portion of the unifacially flaked edge and (c) the smooth, abraded surface. Note the generally fresh flake scars along the lateral edge and the longitudinal, subparallel striations on the surface of the artifact. The distal end of the artifact is near the point whereas proximal refers to the end with the notched stem.

identify or interpret tool function(s) based on wear patterns.

A mini-lecture introducing the SEM focused primarily on three of the possible interactions between the primary electron beam and the sample: back-scattering of primary electrons from the beam, secondary electrons generated in the sample surface as incoming electrons "knock out" orbital electrons, and characteristics x-rays generated as outer orbital electrons fill a vacancy created after emission of a secondary electron. Additional information included optimization of the instrument prior to analysis, analytical limitations, and precision of the compositional analysis. An in-depth tour of the instrument was subsequently presented during the data acquisition. Gill (1997) provides an excellent, short summary on the use of electron microscopes, including both the secondary electron imaging and measurement of characteristic x-rays (EDX or EDS) capabilities, and Potts et al. (1995) provide a comprehensive review on the applications of electron microscopy to geosciences.

SAMPLE DESCRIPTION AND METHODOLOGY

The study artifact was recovered from the surface of an archaeological site situated along the shore of a modern reservoir in north-central Kansas. Before construction of the reservoir, this site was located near the confluence of a perennial stream and one of its tributaries. Although apparently formed originally through percussion flaking, this is an unusual lithic artifact for this region because of its highly smoothed surface (Figure 1). Highly polished groundstone tools made of argillite (indurated shale or siltstone) are commonly found in the Arctic and coastal and eastern North America but are, to our knowledge, extremely rare in the Great Plains. We emphasized the singularity of this recent find in the Great Plains, the limited information about the artifact, and the fact that the students would be conducting original research.

After an introduction to the context of this find, the students inspected the artifact macroscopically and collected basic descriptive data. Student volunteers collected general observations, such as measurements of the tool using calipers, and shared these (e.g., length 109.8 mm, maximum width 29.1 mm and maximum thickness 8.2 mm) with the class. Students described the general form of the tool, which is lanceolate with a rounded or blunt tip and with a small stem formed by notching the base of the tool (Figure 1). Each surface, one lateral edge, the rounded tip, and the distal portion of the second edge are dull and smooth. Cultural (i.e., grinding) or natural wear (i.e., chemical weathering and abrasion) have obliterated most of the original flake scars, which are faintly visible on the basal portion of the tool. More recent, largely unifacial flaking is evident along one, lateral edge (Figure 1). The flake scars along this edge are continuous, but extend along only three-quarters of that edge. Also two forms of flake scars are discernable upon close inspection.

To accommodate all the students in the small laboratory holding the SEM, the class divided into two groups. While one group of students performed the SEM analyses, the other group inspected comparative artifacts and participated in a percussion and pressure flaking demonstration. Groups rotated between these activities. Each group acquired secondary electron images of surface and edge locations at different magnifications using the Scanning Electron Microscope (SEM) located in the Department of Entomology at KSU and operated by Kent Hampton. This instrument is a Hitachi S-3500N with an Oxford Instruments Energy Dispersive Spectrometer (EDS) attachment for semi-quantitative compositional analysis. Operating conditions included a working distance of ~15 mm when acquiring images, a 15 kV accelerating potential, and a ~5 micron diameter beam spot. Students chose to acquire images of a smoothed or ground surface and the margins of the artifact in four locations, one along a smooth edge and three along the chipped edges in locations where the flake scars differed in size and concavity (Figure 1).

In addition to obtaining images of the surface and edge of the artifact, the students used the EDS attachment to acquire a compositional spectrum of the artifact material. Argillite typically has high aluminum abundances because of the weakly metamorphosed clay minerals that largely compose this rock type; chert, however, consists of nearly pure silica (SiO_2). The EDS spectrum indicated peaks for silicon and oxygen in roughly a 1:2 ratio; students immediately recognized the chemical composition was identical to that expected for microcrystalline quartz (i.e., chert). This composition ruled out the possibility that the artifact consisted of argillite and re-emphasized the unique nature of this artifact.

We did not attempt to determine the geographical source of the chert because the SEM is not an appropriate analytical tool for chert provenance studies. Chert provenance depends on matching trace element abundances, such as rare earth elements, of a study sample with a database of natural cherts from known locations (e.g., Baugh and Nelson, 1987; Owen et al., 1999; Glascock, 2002; Lyons et al., 2003; Neff, 2003). Trace element compositions are best determined by X-ray fluorescence (XRF), neutron activation analysis (NAA), laser ablation plasma mass spectrometry (LA-ICPMS) or secondary ion mass spectrometry (SIMS), analyses not appropriate given our time and analytical resources. Additionally the comparative database for the abundant chert sources in and around Kansas has yet to be developed. A later class project allowed students to work with published trace-element data from obsidian artifacts and a subset of obsidian source data to give them experience with a comparative provenance study.

STUDENT INTERPRETATION OF ARTIFACT HISTORY

Most students recognized from the flake scars and form of the artifact that it was shaped by humans and resembled a hafted knife or spear point. They also noted that most of its overall surface was smooth and was caused by natural (wind or water) abrasion and chemical weathering or by deliberate grinding by humans. The students noted that the artifact had been smoothed and later modified along a portion of one edge as shown by continuous, flake scars in sharp relief. Most students explained the origin of the smooth surface as resulting from abrasion by water-borne sediments, although many attributed this to movement of the waters of the modern reservoir. Despite the fact that the maximum modern water level fluctuates and some wave action may have impacted the find spot, the extent of polishing on the artifact suggests more aggressive or long-term abrasion. One student offered the alternative interpretation that humans had purposely ground the artifact. Another suggested that the smooth surface and blunt, rounded tip of the artifact suggested possible use as a tool for shaping pottery.

As noted above, macroscopic inspection of the artifact reveals that part of one edge was flaked after smoothing. Secondary electron images along this edge magnify the conchoidal flake scars (e.g., Figure 1b). These images confirm two areas of differing flake scars. The most distal set consists of short, narrow and fairly uniform flake scars. The lower (more proximal) area of retouch is offset more deeply by a break in continuity into the edge of the tool (Fig. 1a). The flake scars on this portion of the tool are generally broad and uneven with some crushing along the edge. Few students described this variation in detail.

Although this project served primarily as a class exercise, the students' interpretations caused us to look at the artifact more closely and further develop our own interpretation of the object. Initially our working hypothesis was that the smooth surface formed through natural abrasion in a stream. Faint, parallel grooves on the surface of the artifact, however, indicate a uniformly longitudinal direction of abrasion (Figure 1c) that is unlikely in a stream environment (see below). Also the high degree of abrasion (including on slightly depressed portions of the artifact's surface) suggests that humans purposely ground a previously flaked tool to produce the smooth surface. This grinding occurred after the initial formation of the artifact by percussion flaking. The form of the individual flake scars (Fig. 1b), as well as two breaks in continuity along the flaked edge (Figure 1a), suggests initial retouch of the distal, ground edge by pressure flaking. This appears to have been followed by use of the artifact and finally coarser pressure or percussion flaking to resharpen the proximal half of the retouched portion of the tool.

After completion of the class, we collected a sample of reference images to test whether natural abrasion and weathering in a stream would in fact result in comparable surface features. These and other images should provide a useful addition to the project during the next iteration of the course. Comparison of images of the surface of a chipped chert artifact found by a local

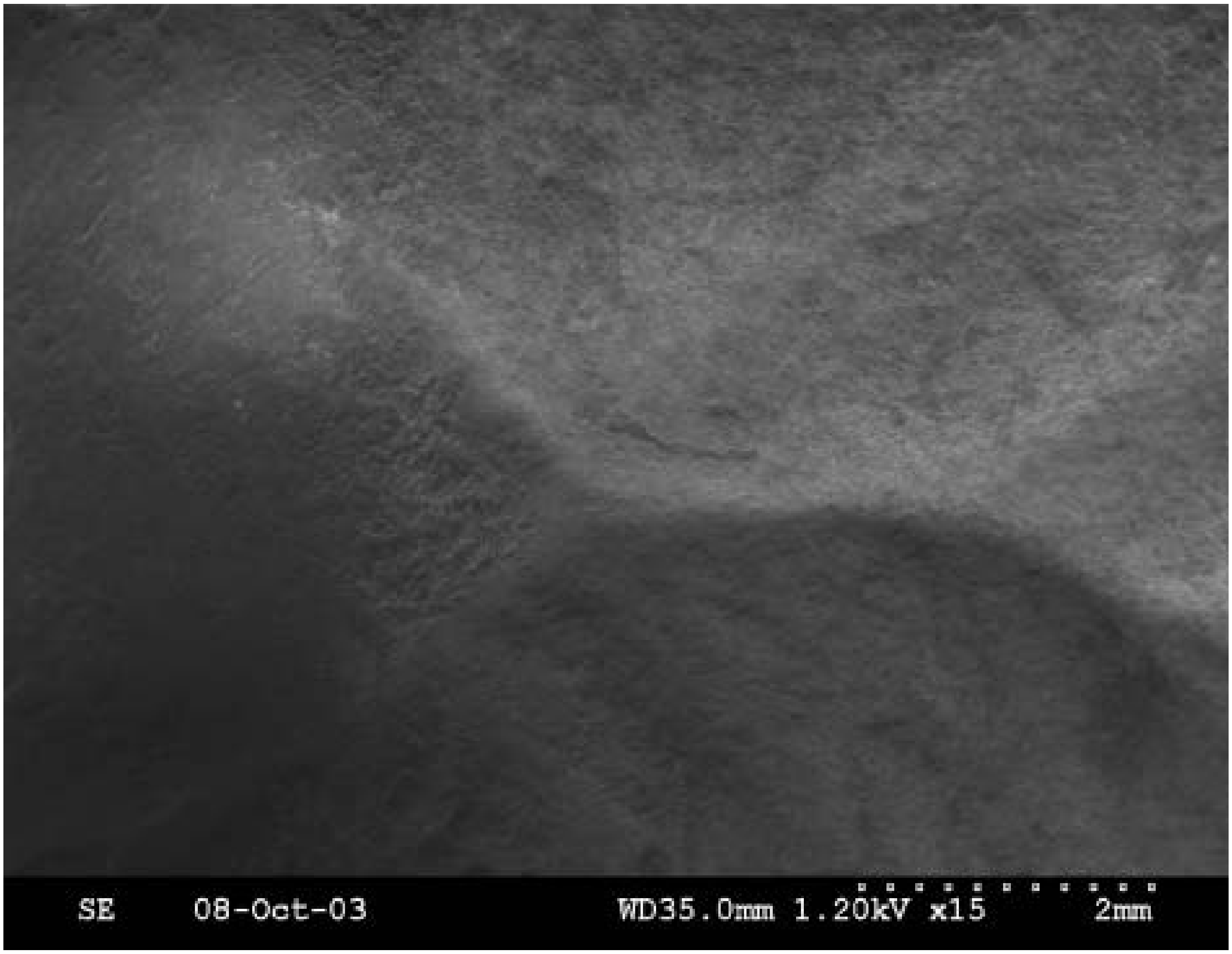

Figure 2. Scanning electron image of a chipped stone artifact recovered from a stream environment. This image shows, at 15x magnification, a uniformly rounded arris (ridge between flake scars), likely due to natural erosion from water-borne sediments and weathering. Compare with the relatively fresh flake scars on the study artifact (Figure 1b).

collector in a river appears to support the interpretation that the polishing of the study artifact was not caused by natural abrasion in a stream environment. Figure 2 shows the smoothly rounded arris of the water-worn artifact. High magnification (200x) of the surface of the study artifact (Figure 3a) reveals the detail of one of the longitudinal grooves on the study artifact. Similar magnification of the surface of a water-worn artifact reveals pitting rather than development of fine grooves (Figure 3b).

PROJECT ASSESSMENT

We assessed student learning in the course by evaluating individual performance on activities, group performance on a final poster project, mid-term and final evaluations, and comparison of pre- and post-test results (e.g., Nuhfer, 1993, 1996). Because the SEM activity evolved after the class had started, the pre- and post-course assessment evaluated only some of the content related to this activity (Appendix A). However, we asked students to evaluate all activities on mid-term and end-term evaluations by ranking their response to assigned exercises using the following scale: 5 - strongly agree, 4 - agree, 3 - neither agree nor disagree, 2 - disagree, 1 - strongly disagree. Students ranked this exercise positively based on the following statements: a) "The in-class SEM demonstration provided me with a useful introduction to the use of the SEM" [Response: mean=4.39, median=5.0, n=17 respondents]; b) "The SEM assignment was useful in making me think more deeply about how artifacts are interpreted" [Response: mean=4.28, median=4.5, n=17 respondents]; and c) "The SEM assignment was well designed" [Response: mean=4.28, median=5.0, n=17 respondents].

Written comments from students included: "I enjoyed this exercise", "Great intro to SEM", and "I was very interested in [the exercise] and would have liked to [do] more with it". Student response to the SEM activity was generally higher compared to the other activities and assigned readings (rankings of 3.35-4.44). An assigned reading discussing the impact of the Iceland Laki eruption on 18th century Europe was the only activity to receive a higher rating (mean=4.44, median=5.0) than the SEM exercise. Notably, three students asked for an update on the SEM research project approximately six months after completion of the class.

IMPROVEMENTS TO PROJECT DESIGN

Students did not recognize flake scars obscured by the grinding, but given more time to visually inspect the artifact, we expect that they might notice the subtle remnants of these scars. They could then use those observations to infer that the manufacturing process included percussion flaking prior to the grinding.

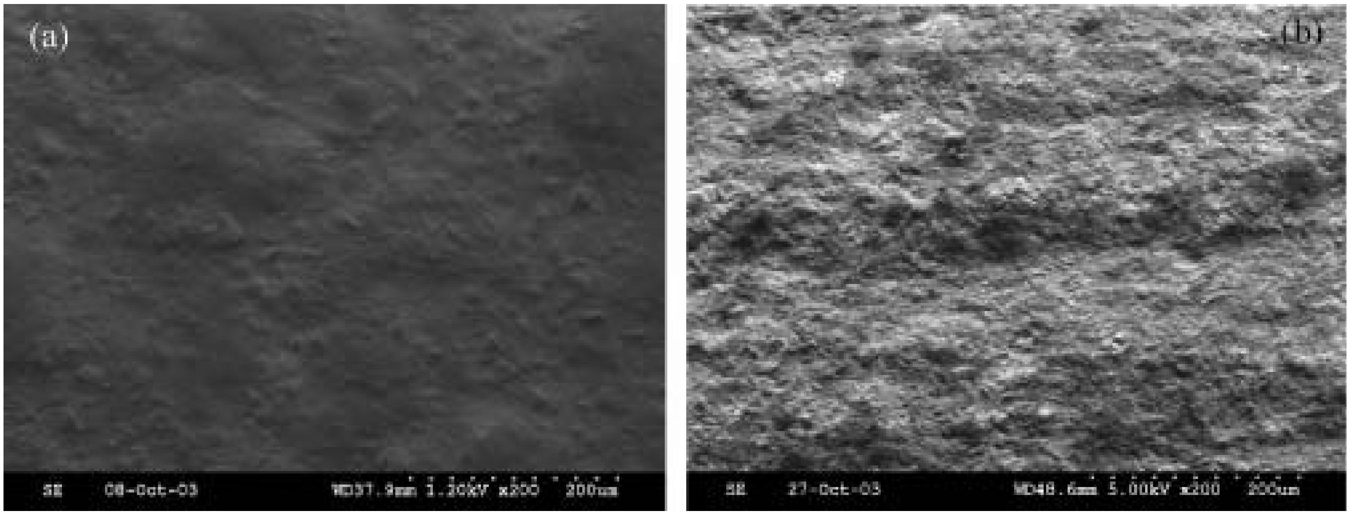

Figure 3. Scanning electron images at 200x of the surface of the study artifact (a) and a comparable image of the surface of a water-worn artifact (b). Note the visible striation on the study artifact (a) in comparison with the pitted surface (b) of the water-worn artifact.

Because of time limitations, we did not have reference SEM images of fresh and worn, chipped-stone artifacts. One student suggested the project would be improved by incorporating reference images of wind- and water-worn objects or purposely ground chert for comparison with the SEM images of the project artifact. Since this exercise, we have collected a few comparative images of two artifacts recovered by local collectors from stream environments. Additionally, we have collected wind-abraded glass and freshly flaked chert. We plan to give future classes the option to acquire SEM images of these reference materials.

Changes to the pre-project preparation will include greater student participation, additional information on geologic and biological post-depositional processes and an introduction to the concept of use-wear on stone tools. Discussion of post-depositional processes, focusing specifically on chemical and physical processes that can alter the surface of lithic materials (e.g., wind and water related abrasion), should be expanded to provide students better information for formulating alternative hypotheses for interpreting the surface form of the study artifact. Biological post-depositional processes are at least indirectly relevant to this study; for example, the students could be encouraged to consider trampling by ungulates and humans after reading experimental studies, such as those by Flenniken and Haggerty (1979), McBrearty et al. (1998) and Nielsen (1991) as a possible explanation for the sharpened edge. Originally we did not have sufficient time to allow more than a brief demonstration of pressure and percussion flaking, but the project will incorporate more student involvement in the future. This study was not designed as a use-wear analysis (e.g., Odell, 2001; Yerkes and Kardulias, 1993); however, an introduction to use-wear studies should be included to demonstrate the next potential step in a detailed study of this and other lithic tools. Finally, based on our assessment and some comments by students (e.g., "I could have used [more] information on how exactly the microscope worked and definitely would have liked to have had more time observing it in action"), we plan to spend three or four class periods, instead of two, on the entire activity.

ADDITIONAL POSITIVE OUTCOMES

In addition to the extremely positive response of students to this learning experience, the project had several outcomes. This course has created a new cross-departmental connection, one of the few examples of interdisciplinary teaching in science at KSU. We will repeat this project in subsequent sections of Archaeological Geology and plan to continue our interdisciplinary analysis and interpretation of this artifact with student input. Developing this course initiated and strengthened a teaching and research collaboration between us. Since the completion of the course, we successfully applied for an in-house grant to mentor a separate undergraduate research project that combines geology and archaeology. The student we asked to undertake the second research project participated in this course, and several other students were recruited into archaeology or geology as a result of their participation.

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REFERENCES

American Association for the Advancement of Science (AAAS), 1989, Project 2061: Science for All Americans: A Project 2061 Report on Literacy Goals in Science, Mathematics and Technology, AAAS, Washington, D.C.

Andrefsky, Jr., W., 1998, Lithics: Macroscopic Approaches to Analysis, Cambridge University Press. 258 p.

Baugh, T.G., and Nelson, Jr., F.W., 1987, New Mexico obsidian sources and exchange on the southern plains, Journal of Field Archaeology, v. 14, p.313-329.

Bloom, B. Englehart, M.B., Furst, E.J., Hill, W.H., and Krathwohl, D.R., 1956, Taxonomy of Educational Objectives: The Classification of Educational Goals: Handbook I, The Cognitive Domain, Longman, New York.

Bradley, B., 1989, Flintknapping. INTERpark, Cortez, CO. (Videotape)

Crabtree, D.E., 1967a, Notes on Experiments in Flintknapping: 3 The Flintknapper's Raw Materials: Tebiwa , v. 10, p. 8-25.

Crabtree, D.E., 1967b, Notes on Experiments in Flintknapping: 4 Tools Used for Making Flaked Stone Artifacts, Tebiwa, v. 10, p. 60-73.

Crabtree, D.E., 1972, An Introduction to Flintworking, Occasional Papers of the Idaho Museum of Natural History, No. 28.

Flenniken, J., and Haggerty, J., 1979, Trampling as an Agent in the Formation of Edge Damage: An Experiment in Lithic Technology, Northwest Anthropological Research Notes, v. 13, p. 2008-214.

Gill, R., 1997, Electron Beam Methods, In Gill, R. (ed) Modern Analytical Geochemistry: an Introduction to Quantitative Chemical Analysis for Earth, Environmental and Materials Scientists. Longman, Harlow, England, p. 215-234.

Glascock, M., 2002, Geochemical Evidence for Long Distance Exchange, Praeger Publishers, 296 p.

Luedtke, B., 1992, An Archaeologist's Guide to Chert and Flint. University of California Press, Los Angeles, 156 p.

Lyons, W.H., Glascock, M.D., and Mehringer, Jr., P.J., 2003, Silica from sources to site: Ultraviolet fluorescence and trace elements identity cherts from Lost Dune, southeastern Oregon, USA, Journal of Archaeological Science, v. 30, p. 1139-1159.

McBrearty, S., Bishop, L., Plummer, T., Dewar, R., and Conard, N., 1998, Tools Underfoot: Human Trampling as an Agent of Lithic Artifact Edge Modification, American Antiquity, v. 63, p. 108-129.

National Research Council (NRC) of the National Academy of Sciences, 1996, National Science Education Standards, National Academy Press, Washington, D.C.

National Research Council (NRC), 2000, Inquiry and the National Science Education Standards, National Academy Press, Washington, D.C.

Neff, H., 2003, Analysis of Mesoamerican plumbate pottery surfaces by laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS), Journal of Archaeological Science, v.30, p. 21-35.

Nielsen, A. E., 1991, Trampling the Archaeological Record: An Experimental Study, American Antiquity, v. 56, p. 483-503.

Nuhfer, E., 1993, Bottom-Line Disclosure and Assessment, Teaching Professor, v. 7, p.8.

Nuhfer E., 1996, The Place of formative evaluations in assessment and ways to reap their benefits, Journal Geoscience Education, v. 44, p.385-394.

Odell, G.H., 2001, Stone tool research at the end of the millennium: classification, function, and behavior, Journal of Archaeological Research, v. 9, p. 45-100.

Owen, A.W., Armstrong, H.A., and Floyd, J.D., 1999, Rare earth elements in chert clasts as provenance indicators in the Ordovician and Silurian of the Southern Uplands of Scotland, Sedimentary Geology, v. 124, p. 185-195.

Peregrine, P. N., 2001, Archaeological Research: A Brief Introduction, Prentice Hall, Upper Saddle River, NJ. 248 p.

Potts, P.J., Bowles, J.F.W., Reed, S.J.B., and Cave, M.R., 1995, Microprobe Techniques in the Earth Sciences. Mineralogical Society Series, v. 6, Chapman and Hall, London, 419 p.

Schneider, J. S., 1998, Analyses of "Ground Stone" Milling and Processing Implements, Decorative and Ritual Objects, Cutting and Abrading Tools, In, Sutton, M.Q., and Arkkush, B.S. (eds.), Archaeological Laboratory Methods: An Introduction, 2nd ed., Kendall/Hunt Publishing Company, Dubuque, IA, p. 71-107.

Whittaker, J. C., 1994, Flintknapping: Making and Understanding Stone Tools, University of Texas Press, Austin, 341 p.

Yerkes, R.W. and Kardulias, P.N., 1993, Recent Developments in the Analysis of Lithic Artifacts, Journal of Archaeological Research, v. 1, p. 89-119.

APPENDIX

Early in our discussions of course evaluation, we chose to design and give students an exam on the first and last days of class. This seventy-five questionnaire provided qualitative assessment in that students simply reported whether they felt they knew the answer to questions. We required the students to turn in answer sheets, but the accuracy of their responses was not included in their semester grade. We designed the evaluation roughly following guidelines of Nuhfer, 1996. Answer choices included A- I can answer this question completely during an exam, B - I can answer the question partially (at least 50% of the pertinent information), C - I don't know the answer and I'm not sure I could easily find the information. In converting the answers for graphical comparison, three points were assigned to an A answer, two to B and one to C (Figure A-1).

Facets, or groups of related questions included: Archaeology, geology, geologic time and maps (questions 1-13), geologic materials (questions 14-25), geomorphology, archaeological context and transformation processes (questions 26-31), Environmental reconstruction (questions 32-33), volcanoes and archaeology (questions 34-40), relative and isotopic dating (questions 41-53), surface remote sensing (questions 54-59), subsurface remote sensing (questions 60-66), and provenance (questions 67-75). The sequence of the facets and the number of questions within each reflect the sequence and relative time devoted to each topic during the course. We covered some topics (e.g., volcanoes and archaeology and geochronologic dating) in greater detail taking advantage of our personal expertise areas.

Comparison of pre- and post-course results (Fig. A-1) shows that, with one exception, students felt their

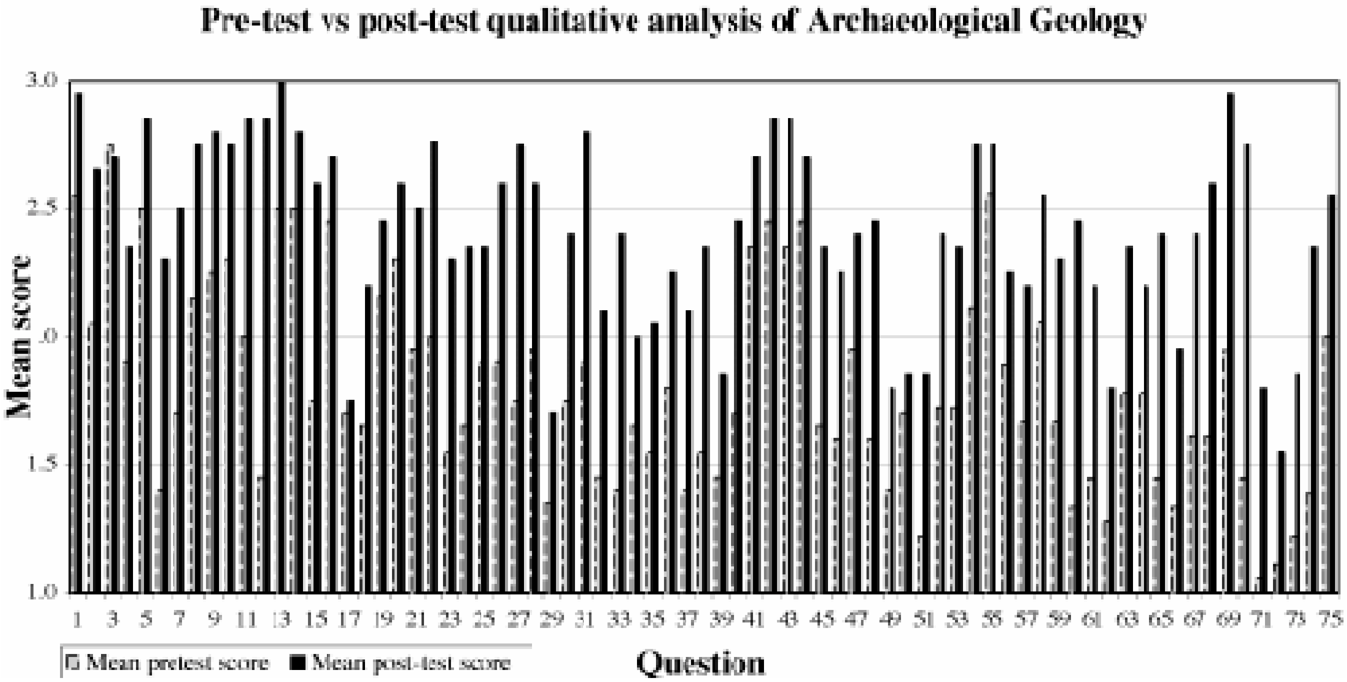

Figure A-1. Histogram of pre- and post-course responses for a qualitative survey of student knowledge. Student answers that indicate complete confidence in their ability to answer a question correlate with a 3 on the histogram. Confidence in answering roughly 50% of the requested information translates to a 2 and inability to answer a specific question give a score of 1. Answers given before the second class (light gray, dashed bars) contrast with higher student confidence in their knowledge base on the last lecture day of class (black bars). There were twenty respondents. The appendix discusses several of the seventy-five questions.

knowledge increased in each category and the most dramatic improvement occurred in areas where students indicated low initial factual knowledge (e.g., remote sensing techniques). Due to time constraints and our overly ambitious content goals, we omitted a few specific case histories to more fully cover other topics. This reorganization is clearly revealed by responses to questions 17, 29, 39, and 49-50 that showed little or no learning. An interesting pattern developed in some cases. For example, when asked "Why are these elements [Rb, Sr, and Y] commonly used for sourcing obsidian?" students showed dramatic increase in their familiarity with this information because of an assigned activity in which students matched obsidian to source areas based on trace element abundance ratios of analyzed artifacts and source samples (Figure A-1, question 70). Apparently, however, we did not emphasize sufficiently the relationship between these data and the analytical technique (questions 71-73).

Several questions assessed content imparted both during the course and the lithic tool activity (Figure A-1, questions 11, 13, 14, 17, 21, 27, 28, 30, 52, 73). These questions ranged from comfort in interpreting binary diagrams (question 11), to the observations one would make to determine a tool's rock type (question 21), to understanding the difference between primary [human deposited] and secondary [affected by geologic and biologic surface processes] contexts (question 30). Question 13, "What attributes distinguish an artifact from a natural object?" is possibly most closely related to their experience studying the artifact. Although their initial scores averaged 2.5 indicating most felt they could provide a partial answer, every student felt they could answer this question at the end of the course. This is the only question receiving such a high response on the post-course evaluation. Finally, question 73 asked students to compare and contrast benefits and problems associated with scanning electron and neutron activation analysis. Most students started the class with no factual knowledge in this area (Figure A-1). Their post-course response was not high (average < 2.0), but this likely reflected our inability to sufficiently cover neutron activation analysis as much as, or more than, shortcomings with the SEM project.

We found this assessment instrument tremendously helpful. The high correlation between the level of knowledge students felt they received and the time spent on each topic is illuminating. The post-test was given the last regular day of class and students had an opportunity to see the comparison during the poster presentation session that occurred during their scheduled exam time. Students expressed interest, surprise and satisfaction with the qualitative results.