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New applications of archaeological microscopy in the field: ceramic petrography and microwear analysis

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Introduction

The application of advanced scientific techniques to archaeology has contributed immensely to the discipline. Methods such as Electron Spin Resonance Thermometry, Inductively Coupled Plasma-Atomic Emission Spectroscopy, Auto-Regenerative Thermoluminescence Dating, to mention but a few, are pushing back the frontiers of scientific archaeology as they continually find new applications for deciphering ancient lifeways. A perusal of *Journal of Archaeological Science* or *Archaeometry* issues of the past five years reveals that the vast majority of the newest scientific applications are performed in the laboratory using expensive apparatus and highly skilled operators and technicians. The techniques, by and large, therefore become relatively inaccessible to most archaeological researchers once the initial research project is completed, due to cost and location considerations. Moreover, the further from the field that analysis is undertaken, the less relevance the technique has for the field archaeologist, whose job is deciphering the actual field situation. It is essential that we achieve a balance between the development of new techniques and the refining and application of established techniques. In developing new techniques, we should not just concentrate on high technology methods which provide detailed and sophisticated data for only a small portion of the artefactual record. Instead, some emphasis should be given to development of lower technology techniques capable of providing data for a more complete artefactual record (Tite 1991).

There is a further, and perhaps more important, development in the discipline which supports the requirement for the advancement of lower technology techniques applicable away from the laboratory. This is the growing concern by many countries for the protection of their cultural and archaeological heritage, which manifests itself in the banning of, or severe restrictions on, the export of cultural artefacts. Even though foreign archaeologists are permitted to conduct research in these countries, often all the 'hands on' research on the artefacts must be completed within the countries' borders. As many of these countries lack extensively equipped laboratories, it is necessary for the field archaeologist to extract as much information as possible from the artefacts while in the host country.

The foregoing concerns are amongst those which point to a need to develop methodologies which maximise the amount of useful data which can be extracted in the field using relatively inexpensive and readily portable equipment. Other benefits of such developments include on-site screening of artefacts designed to 1) minimise the transport of cultural material, 2) assist in interpreting the significance of features during excavation and thus 3) guide excavation strategies by revealing areas of special interest. Archaeometallurgical laboratory techniques have been adapted and used in the field for many of the same reasons (e.g. Helmig *et al.* 1989).

Two areas of archaeological investigation which are at present almost entirely laboratory based and which, if properly applied in the field, could alleviate many of these concerns are ceramic petrology and microwear analysis of lithic and bone tools. The lack of field portable systems to identify and record mineral inclusions and textures in ceramics, or polish and striations on prehistoric tools, has undoubtedly resulted in many instances in the loss of valuable diagnostic information and misguided excavation strategies. Cumbersome and expensive existing laboratory equipment can of course be transported to the field, and has been in many cases. However, transport difficulties and the necessity of having delicate and sensitive apparatus such as professional microscopes away from laboratories for months at a time usually makes this option unattractive.

This paper describes new applications for an extremely compact, commercially available, microscope currently undergoing modification and testing to render it suitable for field use in both ceramic petrography and microwear analysis of stone and bone tools.

Microscope description

The microscope system is based on the McArthur biological microscope manufactured by Kirk Technology of Milton, Cambridge, shown in figure 1. The McArthur model was designed by John McArthur in 1932 for performing medical diagnoses under unfavourable conditions (Watt 1993: 27). It is a transmitted light microscope which achieves its compactness by folding the optical path into a smaller space, as shown schematically in figure 2. A traditional simple mirror, or an optional integral light source powered by two AA batteries and featuring a halogen bulb, provides illumination. This light travels downward through the adjustable iris and the condenser, and passes through the slide mounted on the stage, then on through one of the objectives, deflected by two mirrors in the optical light tube and finally upwards through the ocular. Three high quality objectives are mounted on a sliding plate under the stage and are currently available in magnifications of 10X, 40X, and 100X. Coupled with the standard 10X ocular, this provides total magnifications of 100X, 400X, and 1000X. An optional 5X ocular extends this range to include 50X, 200X, and 500X magnifications. The unit is focused with knurled knobs situated on either side of the housing.

In microscopes, the initial magnification (the magnification provided by the objective) equals the optical tube length divided by the focal length of the objective (Kerr 1977: 28). Because the optical tube length has been shortened compared to laboratory models, shorter focal length objectives are required to maintain comparable magnification levels. This unfortunately results in shorter working distances. However, for the two applications described in this paper, this does not present a problem because the specimens under examination in both cases lie flat on glass slides.

The unit measures 10 x 9 x 5 cm, and weighs only about 500 g with the lamp unit and batteries installed. The body has hitherto been manufactured from three separately milled aluminium blocks, but current production models are now milled from a single block. This provides optimum rigidity and durability. Optional extras include a gliding stage (shown in the foreground of Figure 1) for easy and accurate movement of slides, a camera attachment, a tripod, and a protective case.

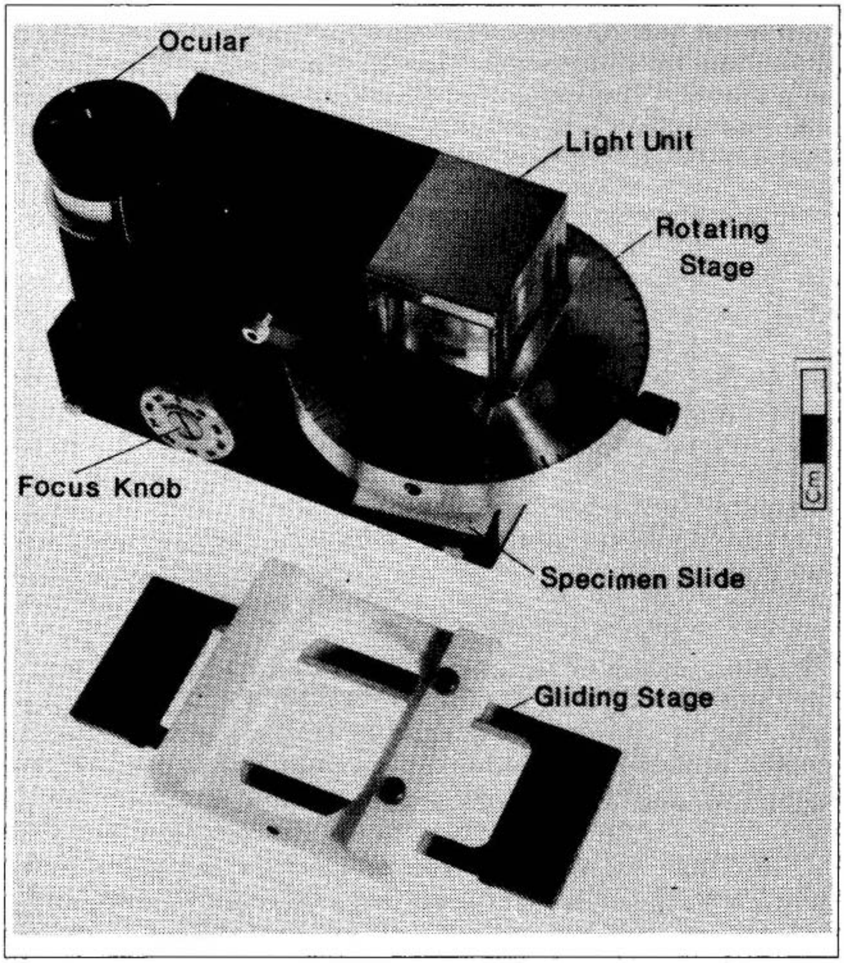

Figure 1 McArthur microscope.

Application to field petrography

The value of conducting ceramic petrology in the field is significant. An excellent example is given by Johnson (1992), who undertook petrographic field analysis in order to compare fabric types assigned during certain previous seasons' post-excavation processing by observation with the naked eye, with fabric types established by petrographic examination. He found no clear patterns of correlation between the two, which suggested that 'it can be extremely difficult to maintain consistency or to pick out significant features without the aid of petrography' (ibid.: 184), and recommended that 'ceramic petrography should be part of the initial stages of finds processing and ceramic fabric classification rather than simply a later stage of scientific analysis' (ibid.: 185). While the results of his investigation may or may not reflect the accuracy of the initial sorting, they nevertheless indicate a need for accuracy in classifying ceramic fabric types at the outset of a project. A reliable means of classification can be obtained by observation of each fabric in thin section. Without this, entire collections may have to be re-examined later, and excavation strategies may develop on the basis of ideas that later prove to be misconceptions.

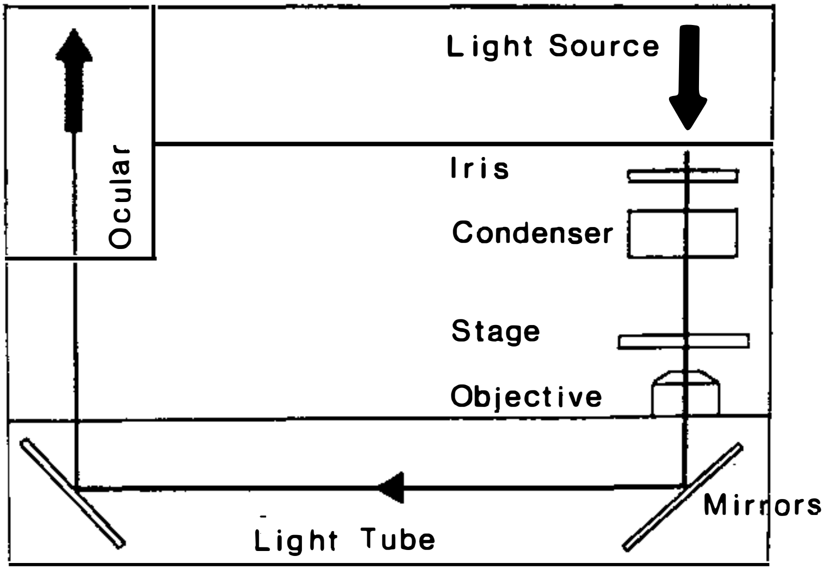

Figure 2 McArthur microscope schematic.

Again at the outset of an excavation, especially a new excavation where test units are being opened, results of on-site petrography can assist in determining those areas upon which to concentrate. For instance, identification of a concentration of stylistically similar but technologically dissimilar pottery in one area could indicate the presence of an intrusive ware, and the researcher may wish to initially concentrate efforts there. Finally, in the situation discussed earlier where artefacts may not be exported, the ability to conduct petrography on location is clearly indispensable.

In order to appreciate the value of the field system discussed in this paper, a very brief outline of ceramic petrography is first provided. Detailed treatment of the topic may be found in Kerr (1977) or Gribble and Hall (1985). Thin sections of archaeological pottery (or rocks) are made by first sawing and polishing a sherd cross-section, then mounting the polished face on a glass microscope slide. With friable, low-fired pottery, it is usually necessary to first consolidate the material with an epoxy resin. The ceramic attached to the slide is then ground down and polished on a lap to a thickness of 0.03mm and a cover slip applied. The specimen is then ready for examination under a polarising microscope.

The polarising microscope is similar to a normal transmitted light microscope but has some additional features which permit identification of mineral inclusions in a thin section. Importantly for archaeologists, identification of mineral inclusions in the clay paste allows characterisation of the paste and, in cases where one can access local clays for analysis, can assist in provenance studies. The additional features of the laboratory polarising microscope include a polariser, analyser, rotating stage, Bertrand lens, auxiliary condenser, and slots for accessory plates.

The key points in adapting the entire preparation and analysis process to field situations are downsizing (i.e. making the apparatus smaller and lighter) and streamlining. Cutting a number of samples efficiently requires a diamond saw. Consolidation and adhesion to the slide requires a thermostatically controlled heat source to cure the currently used laboratory resins (e.g. Petropoxy or Canada balsam), and reducing their thickness efficiently requires a grinding wheel. Finally, and importantly, analysis requires a good quality polarising microscope. Thin sections have been prepared in the field. Hunt and Griffiths (1989) used a rechargeable trimmer as a saw and grinder, and ultraviolet curing resins as an adhesive with acceptable results. Prepared thin sections were then transported to a laboratory for examination and analysis. Johnson (1992) used a portable saw, and Scandiplex, a resin which cured without the aid of heat. The present research project includes furtherance of these concepts designed to overcome some of the difficulties encountered by such previous researchers. Neither of the aforementioned field research projects had the benefit of a quality, portable, polarising microscope.

There are at present no readily available polarising microscopes suitable for field use. An inexpensive, mass-produced polarising version of the McArthur microscope was developed for use by the Open University, but it has fallen into disuse, perhaps because it did not meet the high quality standards required for accurate mineral study. Only two field portable transmitted light microscopes appear to be readily available commercially, one being the Kirk Technology McArthur model earlier described, and the other the Swift Model FM-31. An examination of each revealed that the McArthur would be the most easily modified to a polarising model.

Modifying the McArthur to include all of the devices described above would have entailed substantial redesign, with the concomitant increase in development and production costs. Consequently, in view of keeping these at a minimum, it was necessary to compromise. In analysis of minerals in thin section, the sequence usually is:

1) examination under plane-polarised light (PPL);
2) examination under crossed polars (XPL);
(3) examination of interference figures and determination of fast and slow directions in crystals.

Basically, each step enables the researcher to progress a step further in identifying a mineral inclusion. More often than not, most minerals can usually be identified to the extent necessary for the archaeological field situation using steps 1) and 2) only. The use of the polariser, analyser, and rotating stage alone permit completion of these first two steps. Step 3) requires in addition the auxiliary condenser, the Bertrand lens, and the accessory plates. By limiting the modificationsto the polariser, analyser, and rotating stage, development costs are kept at a minimum while maintaining adequate diagnostic capability in the field. For particularly troublesome identifications, the thin sections can be re-examined later in a fully-equipped laboratory.

Addition of the polariser presents no problem; it easily fits into the filter slot on the microscope condenser arm. This alone provides PPL as required for step 1) of the analysis. The analyser (another, rateable, polarising filter) is simply fixed to the base of the ocular drawtube. Crossed polars (XPL) are easily achieved by rotating the ocular drawtube, with the polariser and no sample in place, until the transmitted light intensity is at its lowest. A prototype rotating stage was designed and manufactured in collaboration with Kirk Technology, made of aluminium and engraved with 360-degree graduations. The design was based on an earlier prototype by Dr. Dafydd Griffiths of the Institute of Archaeology, which had been limited to the lower magnifications due to the restrictions it imposed on working distances. The current prototype is shown installed on the microscope in figure 1. This stage mounts on the condenser housing and is secured in place with two set screws. A clip on the underside of the stage supports the slide and allows it to be manipulated for examination. Future models of the rotating stage are to be manufactured from Nylotron, to permit easier engraving and a smoother rotation. A final modification was the installation of an eyepiece graticule into the ocular, for measuring grain size and area. This was calibrated by way of the stage micrometer.

Preliminary qualitative testing of the McArthur microscope has shown it to be comparable to full-size laboratory polarising microscopes in image quality. A typical thin section was examined under the McArthur and the same image examined under an Olympus Model BH-2 polarising microscope. Using the Olympus as a standard for comparison, it was observed that resolution, contrast, and distortion were all at acceptable levels in the test model. Colour quality appeared identical in both models; although the colour intensity under XPL is somewhat diminished in the McArthur. This is thought to be attributable to the transmission characteristics of the particular polarising filters employed. These did not completely black out the image when crossed, allowing some light to pass through and so diluting the interference colours. The interference colours as seen under these conditions, however, still allowed identification of the mineral under examination. At the time of writing, lower transmission polarising filters are being procured to test. Observations of pleochroism, relief, cleavage, and weathering of inclusions appear to be unaffected. Further, quantitative, testing is under way using a stage micrometer to determine levels of resolution, contrast, and distortion at each magnification to compare with the Olympus model.

Together with a suitably portable diamond saw and grinding wheel, and elimination of the requirement for a thermostatically controlled heating device, the McArthur microscope as modified above offers a high degree of portability. Its reasonable cost, high quality optics, and ease of transport and use make it eminently suitable for archaeological ceramic petrographic analysis in the field. Its efficacy should make it an integral and indispensable part of the field archaeologist's equipment and analysis procedures; thus placing petrographic analysis in its proper place in the sequence - at the outset of excavations.

Application to microwear analysis in the field

Microwear analysis of lithic and bone tools, as previously mentioned, is almost completely restricted to fixed base laboratories. What little is presently done in the field is limited to examination of used tool edges with a hand lens. As with petrographic analysis, the more in-depth analyses are conducted upon returning the artefacts to the laboratory, often years after completion of the excavation. While this sequence still provides invaluable information, and should be continued, there is also often a need to carry out initial analyses in the field as excavations are progressing. For example, during the course of excavation, examination of tools from particular areas may reveal instances of microwear which could prompt the researcher to concentrate efforts on that area.

Furthermore, as in the case of ceramic examination, it provides a category of classification of tools at the early stages of an excavation when the typology scheme is being created. This again precludes a possible situation in which an entire collection would have to be re-examined and perhaps re-classified following laboratory analysis. In addition, conducting the analysis at a later stage can increase the chances of post-deposition microwear, through increased handling. Finally, there also exist the situations outlined in the introduction regarding restrictions on export of cultural artefacts; on-site examination and recording in these situations often represents the only opportunity for microwear data-gathering.

Principles and methodologies of microwear analysis are covered in detail in such texts as Semenov (1963) or Vaughan (1985). There are basically two levels of analysis: low-power (up to about 60X); and high-power (60X to 500X or higher). The low-power method allows examination of diagnostic edge microchipping and the high-power method examination of diagnostic polishes and striations. Both methods should be employed in an analysis of microwear. At present, most analyses are conducted using a reflected light microscope in the laboratory. However, at the higher magnifications, observations of wear using the reflected light microscope are hindered because of the restricted depth of field. Moreover, when examining coarser lithic materials such as basalt, quartz, or quartzite, a lack of contrast between the wear and the material presents further identification difficulties. Finally, the only record that can be made is qualitative information and a photomicrograph.

An alternative method which largely overcomes these problems, and permits use of the McArthur microscope for analysis, is the use of acetate peel replicas of the microwear. Earlier used by Young and Syms (1980) and successfully employed on basalt tools (Chandler 1992) and bone tools (LeMoine 1991), the technique has the added advantage of providing a permanent record of the wear pattern. The methodology basically consists of applying liquid acetone to a used tool surface and placing a thin piece of acetate foil over it. The acetone dissolves the acetate. The acetate solution comes into contact with, and fills, the microtopography of the tool surface. Upon drying, the replica is simply peeled off and mounted on a glass slide. This replica is then examined under a transmittedlight microscope. It should be noted here that if any residue analyses are contemplated, they should be done prior to replication, as the process requires the tool edges to be thoroughlycleaned. Moreover, any minuscule amounts of residue will be removed upon lifting off the acetate replica.

The acetate peel replication method provides the researcher with a rapid microscopic scanning capability at high magnifications because the slide and wear pattern under examination lies flat. Because it also produces a permanent record of the microwear, striations and polishes, which assist in defining use areas and contact material characteristics, can be re-examined as often as desired. This is especially valuable for conducting experimental microwear analysis; it produces a permanent record of each stage of wear. Also, handling of the artefacts is substantially reduced, and, more importantly, detailed re-examination away from the country of origin is possible.

The McArthur field microscope is ideal for examining the acetate peel replicas on location. With the rotating stage, polariser and analyser removed, and the optional gliding stage installed, the slide is easily scanned for wear patterns. As with the petrographic application, comparisons were made with the image observed using the laboratory Olympus model. Again, there was no noticeable loss of image quality in the McArthur model.

It may be argued here that the replicas could simply be made in the field and transported back to the laboratory for examination, however this would be a risky proposition. Each replica needs to be examined upon completion to ensure that a good reproduction has been obtained. Without this step, numerous replicas could be made in the field, only to find that, after leaving the collection, poor reproductions had been obtained and valuable diagnostic information lost.

Associated equipment and materials needed for acetate peel replication are fewer than for preparation of ceramic thin sections. All that is required is a small quantity of acetone, a supply of acetate sheets or foil, two-sided transparent tape, microscope slides, and a brush for applying the acetone. The system provides an ideal field kit and offers a significant return in information gained and excavation decisions made.

General and concluding remarks

From a practical point of view, the small size of the McArthur microscope induces eye and back fatigue faster than a laboratory bench model. It is a monocular instrument, and lacks an eye cup on the ocular, whereas the Olympus is a binocular model and incorporates eye cups. This configuration reduces eye fatigue considerably. Also because of its size, the operator must bend down to a normal bench level for viewing through the ocular. The optional tripod brings it up to approximately eye level, and this reduces back fatigue significantly. Examinations can be done holding the microscope in the hand but this does not leave the hands free to manipulate the slide or adjust the focus.

The application of ceramic petrography and microwear analysis as discussed in this paper is in no way intended to replace these techniques as applied in the laboratory. It is intended in both cases to be used as a necessary and critical first step, as an integral part of the overall analysis process. The field examinations are also intended, as previously discussed, to provide valuable input to excavation decisions on location.

The McArthur microscope system as described here, together with the necessary portable thin section preparation systems under development, is to undergo field application in Pakistan in 1994. Thin sections of numerous different types of Early Harappan ceramics excavated from the site of Rehman Dheri will be made and examined on site. Comparisons will be drawn with results of the analysis of thin sections of similar ceramics found at other sites at varying distances from Rehman Dheri. Data gathered will be used to infer distribution patterns of ceramics in the region, an advance on the traditional comparisons based on stylistic considerations alone. Such research projects cannot easily be done without the aid of field portable systems such as the one described here.

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