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Ancient Monuments Laboratory
Report 22/94

THE APPLICATION OF XERORADIOGRAPHY TO THE ANALYSIS OF ARCHAEOLOGICAL ARTEFACTS

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Summary

A preliminary survey was made of the differences in images produced by X-radiography and xeroradiography in the examination of archaeological material. The technique of xeroradiography is described, and examples of its use on a variety of archaeological materials is included (painted window glass, iron with mineral preserved organic material, textile and metal threads, and jet shale).

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Introduction

X-radiography is commonly used for the non-destructive analysis of archaeological artefacts. In simple terms, it is based on the principle that x-rays are absorbed to a different degree by materials of different density or thickness. A conventional x-ray image is produced using photochemical techniques, whereby short wavelength electro magnetic rays are passed through an artefact onto a film coated with a photo sensitive substance, such as silver nitrate. The film can then be developed in the same way as photographic film. Xeroradiography uses the same physical principle but is a photoelectric, rather than a photochemical process. This study illustrates the differences in the images produced by the two methods, and suggests that, while xeroradiography is not a replacement for film radiography, it is a useful supplementary tool which has some unique and informative features.

The Technique

Xeroradiography uses the properties of materials known as photoconductors, which are conductors only when exposed to light or ionizing radiation. A thin layer of a photoconducting material, such as vitreous selenium, is attached to a rigid aluminium base. A charge is applied to the base in total darkness, and the photoconductor acts as an insulator to the metal backing to prevent it from discharging. When exposed to electromagnetic radiation, the conductivity of the selenium is increased and the surface is discharged according to the thickness or density of the material through which the radiation has passed.

In this way, a latent image of the artefact is created on the surface of the plate, in the form of an electrostatic charge pattern. This image is then developed in a closed chamber; charged blue powder (toner) is sprayed onto the surface of the plate, where it is attracted to the charge pattern. The powder image is made permanent by transferring it to plastic coated paper, which is heated so that the plastic and the powder fuse. A positive or negative image can be produced by changing the polarity of the electric field within the development chamber.

For this study, a Xerox 125 system was used. Figure 1 is a schematic diagram of the equipment. The selenium coated plates are stored in the conditioner (3), where a charge is applied to them immediately before use by the scorotron (4). A plate is then deposited into a light proof cassette (5) and exposed to the x-rays. Development takes place in the processor, and once the image has been transferred to the paper, the plate is cleaned to remove any remaining powder (12). Plates are deposited in a storage box (13) which, when full, is placed in the conditioner (1) and each plate is heated to disperse any residual charge (2). The plates are then ready for re-use. Figure 2 is a flow chart of the various stages of the process.

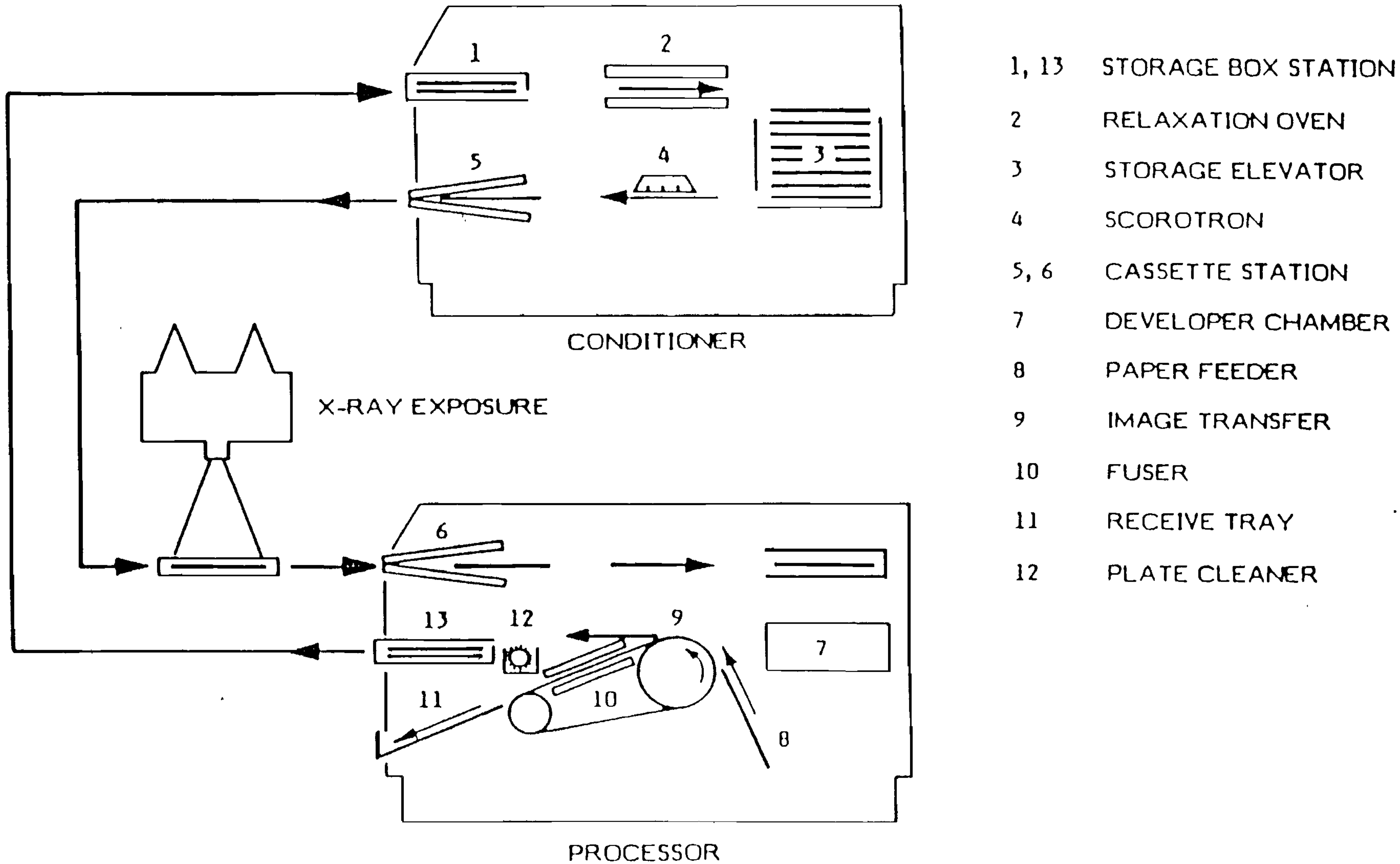


Figure 1: Schematic diagram of xeroradiographic equipment.
(From Xerox 125 system - operators' manual)

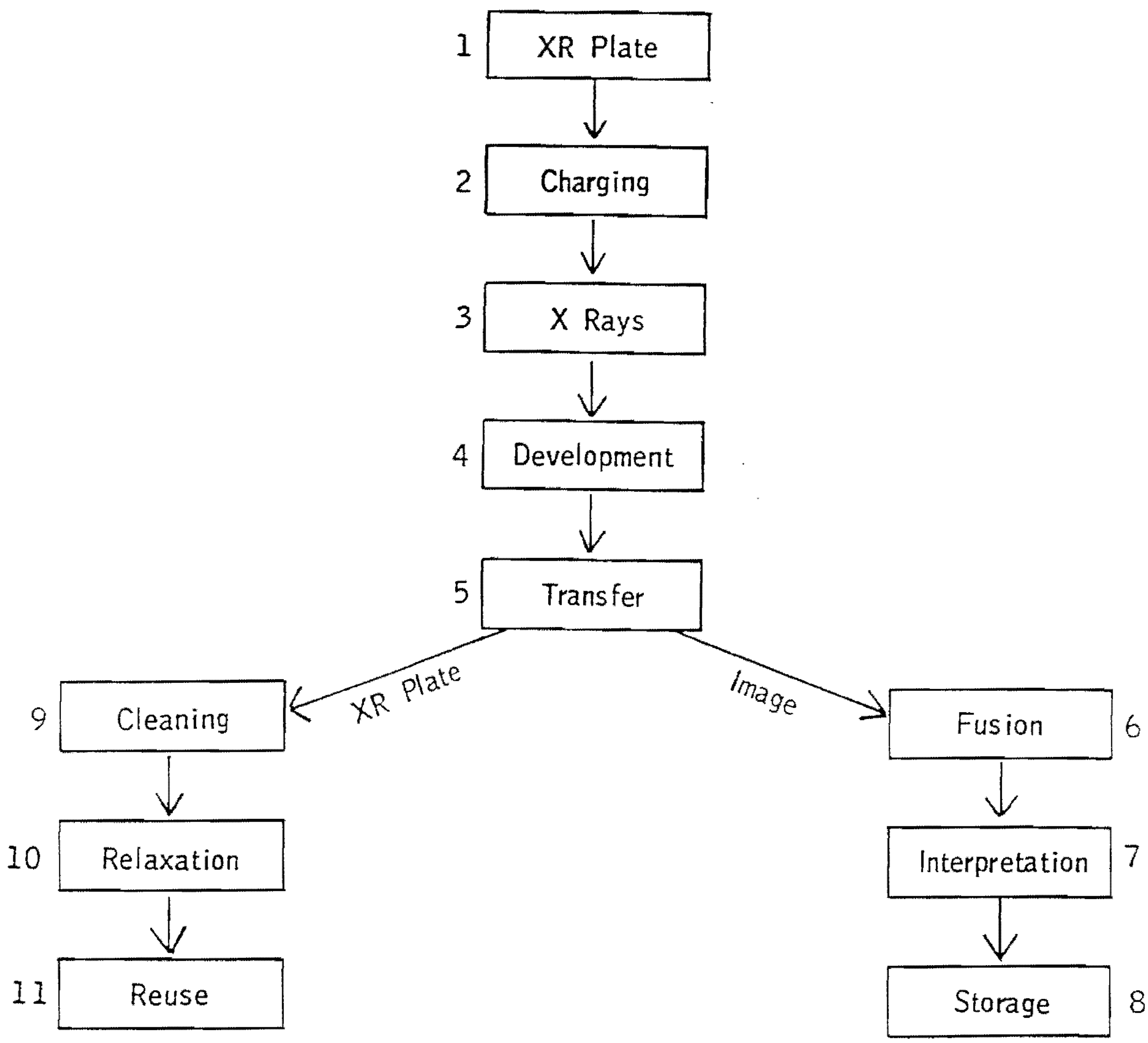


Figure 2: Flow chart of the various stages in the xeroradiography process.
(From Xerox 125 system - operators' manual)

Properties of Xeroradiographs

Xeroradiographs differ from film radiographs in a number of ways. They have a wide latitude of exposure since the development process tends to respond to localised charge differences rather than absolute charge levels. It is more difficult to achieve good detail in the same exposure for materials of widely differing thickness or density using conventional film radiographic techniques.
The response of xeroradiography to localised charge differences results in their characteristic property of 'edge enhancement'. When the charge pattern is developed, extra powder is attracted to the interfaces between areas with different amounts of charge, so that fracture lines, and borders between materials of different density are accentuated. Figures 3 and 4 illustrate the process by which the development process enhances edges. This property does mean that xeroradiography is not a reliable method for illustrating the comparative densities of different materials.

Another advantageous feature of this technique is that, since x-ray scatter does not dissipate the charge to a great extent, the xeroradiographic images of larger objects do not suffer from blurring to the same degree as film radiographs.

Examples of the use of Xeroradiography

There have been earlier studies of the application of xeroradiography to the examination of archaeological artefacts (Heinemann 1976, Alexander & Johnston 1982). These have concentrated on applying the technique to look at mummified remains, stone, ceramics, iron and wood. Some interesting conclusions were reached; the wide latitude of exposure was useful for examining a mummified fish, since the details of the scales and fins could be seen on the same radiograph as the much denser skeletal material. Xeroradiographs of large ceramic vessels produced accurate scatter-free profiles, precise enough to replace the time-consuming hand drawing methods. The texture of the ceramic body was also visible, with aplastic inclusions highlighted due to the edge enhancing properties of this technique. Throwing marks were identified, as were joins and repairs. heinemann suggested that xeroradiographic could be used by dendrochronologists to accentuate the different tree rings.

The aim of the current study was to conduct a preliminary investigation into the information which xeroradiographs could reveal about a range of materials and artefacts. Positive and negative xeroradiographic images were compared to the conventional film images of artefacts.

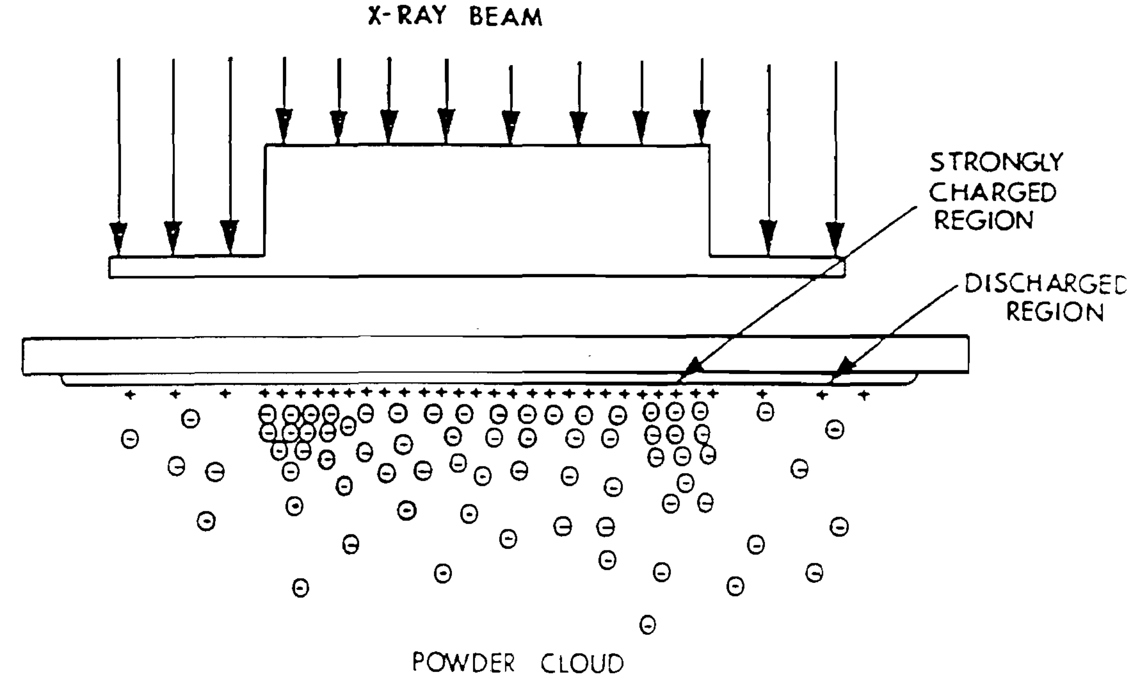
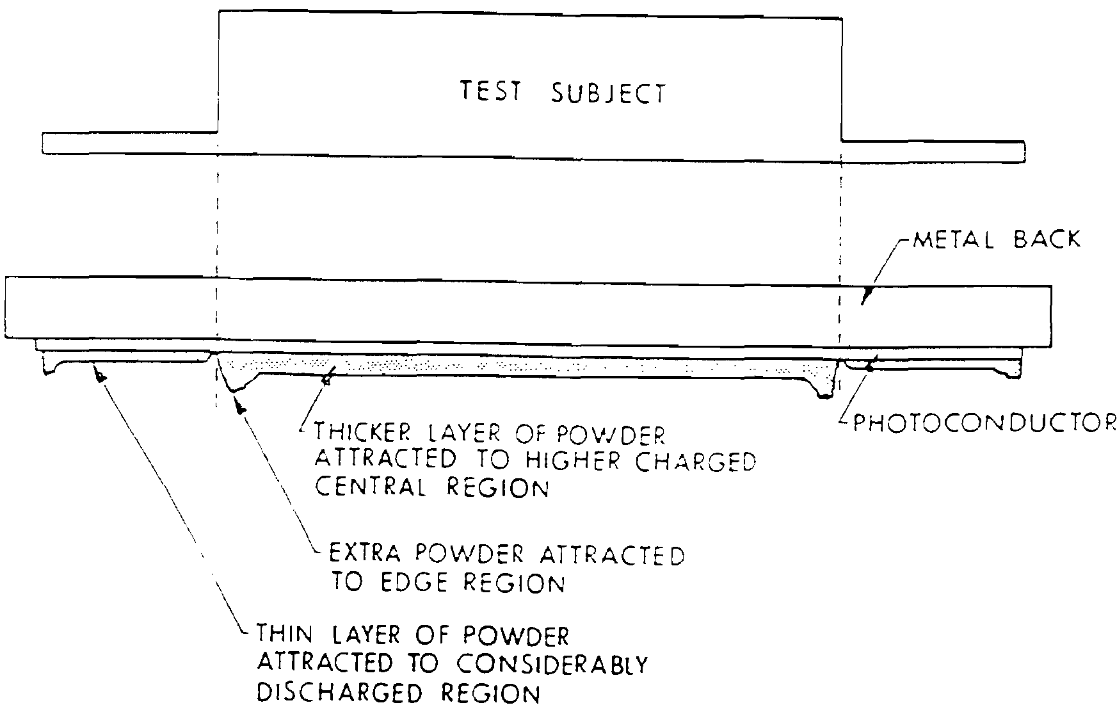


Figure 3: The charged powder is attracted to areas where the x-ray beam has been prevented from dissipating the charge on the plate. Concentrations of powder build up at at the interfaces between areas of high and low charge.
(From Xerox 125 system - operators' manual)

Figure 4: The result of the effect illustrated in figure 3 is a thicker layer of powder at the edges of highly charged areas - the characteristic 'edge enhancement'.
(From Xerox 125 system - operators' manual)



1. MEDIEVAL PAINTED WINDOW GLASS. Figure 5 is a film radiograph of fragments of painted window glass from Bayham Abbey and Denny Abbey. Figure 6 and 7 are positive and negative xeroradiographs, respectively. Some of the fragments were opaque and corroded, and one had been treated with EDTA to remove the metal ions which had leached in during burial. It is possible to image the design on corroded glass using beta-backscatter radiography (Knight 1989). Whilst the imgaes produced by xeroradiography do not reveal any new information, the positive image does enhance the detail of the painted decoration, and of the corrosion pits and the process by which the glass is decaying. The metal ions which form both the painted decoration and the corrosion products are more dense than the surrounding glass, so the edge enhancement effect accentuates these areas.

2. IRON COFFIN NAILS FROM YORK MINSTER. These iron clench nails were surrounded by preserved organic material. Close examination revealed that much of the organic material was wood, and sufficient had survived for conclusions about the original construction to be drawn (Edwards & Watson 1987). The nails appear to join two pieces of wood, between which a layer of fibre mat was observed. The suggested original structure is illustrated in Figure 8a, and Figure 8b shows the structure of the organics preserved with each nail.

Whereas iron salts from the nails had impregnated the wood, and seem to have been responsible for its preservation, none had impregnated the fibres. A likely hypothesis was that the coffins had been constructed from re-used boat timbers. The fibrous material may have been part of a waterproof layer, so that bitumen or pitch (which no longer survives) had originally provided a barrier against iron salts from the corroding nails, and against bacteria and other agents of decay. Whilst the film radiograph clearly revealed the detail and texture of the mineral preserved wood (figure 9), the fibrous material could not be distinguished.

It was hoped that a xeroradiograph might accentuate the interface between the wood and the fibres. Figure 10 is the positive xeroradiographic image. The different texture of the fibrous material can be distinguised on nail 12, where a loose piece of the fibre mat was x-rayed separately. On nail 10 a layer with a fibrous texture can be distinguished. This layer is not as clear on the negative xeroradiographic image (Figure 11), but fibres are visible on nail 7. The interfaces between the wood and the fibre mat are not as clear as was hoped, but better results may be achieved by tailoring penetration voltages and exposure times for each individual nail.

3. IRON/COPPER ALLOY/WOODEN KNIFE HANDLE FROM HINTON HALL HADDENHAM

When the samples taken for wood analysis were examined, a resinous material was seen to be blocking the pores. A faint white outline was noted on the film radiograph (figure 12), which may suggest that the knife was resin coated. The negative xeroradiographs (figure 14) illustrate this line clearly, in particular figure 14a, and the side view, figure 14d Both the negative and positive xeroradiographs depict the way the iron salts have begun to impregnate the wooden handle - the variation in density can be seen. Figure 14c another side view with a slightly shorter exposure time clearly accentuates the outline of the iron decoration and the copper alloy rivets.

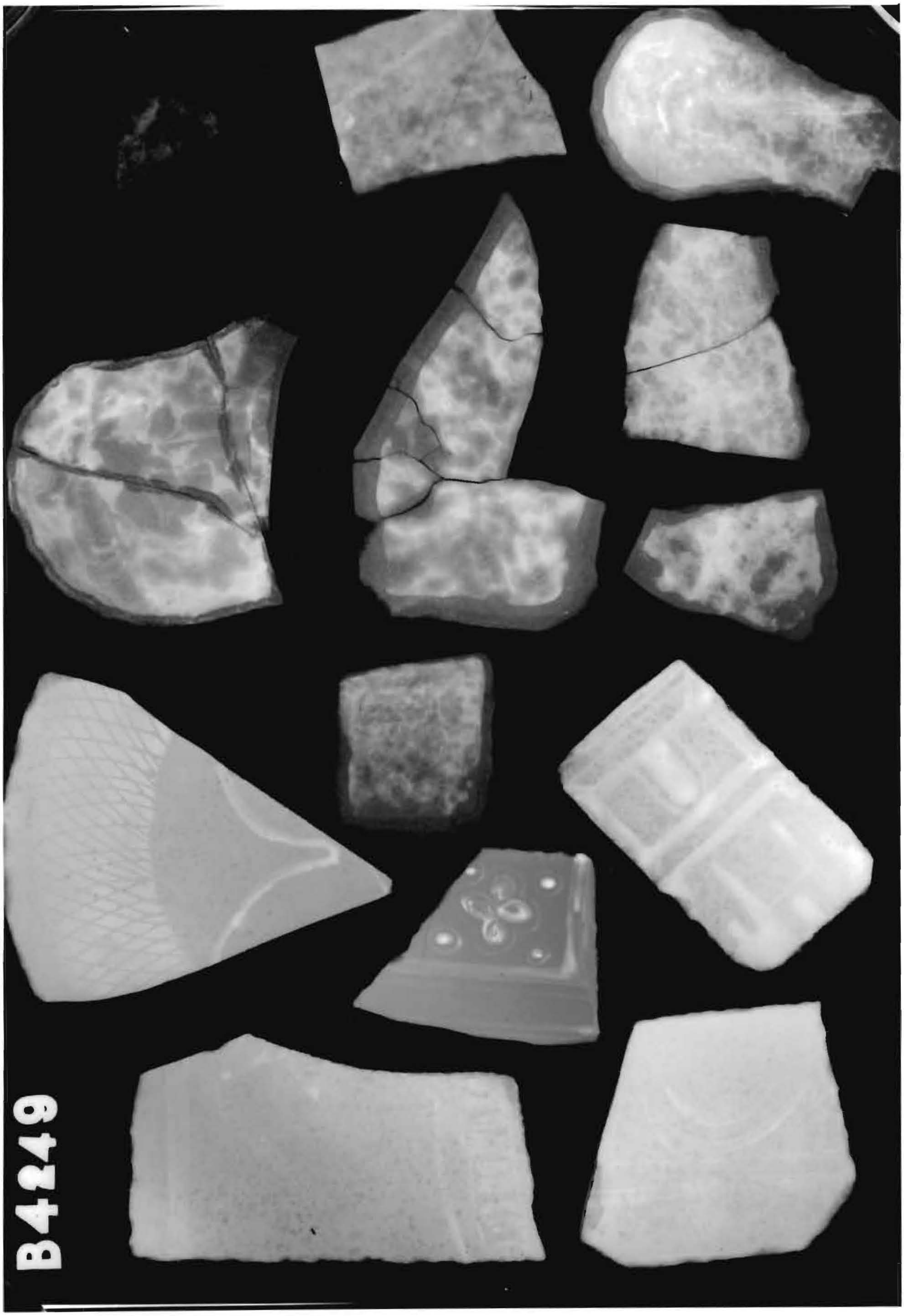


Figure 5: Film radiograph of medieval window glass from Bayham Abbey and Denny Abbey. 30kV 10mA 50 seconds.

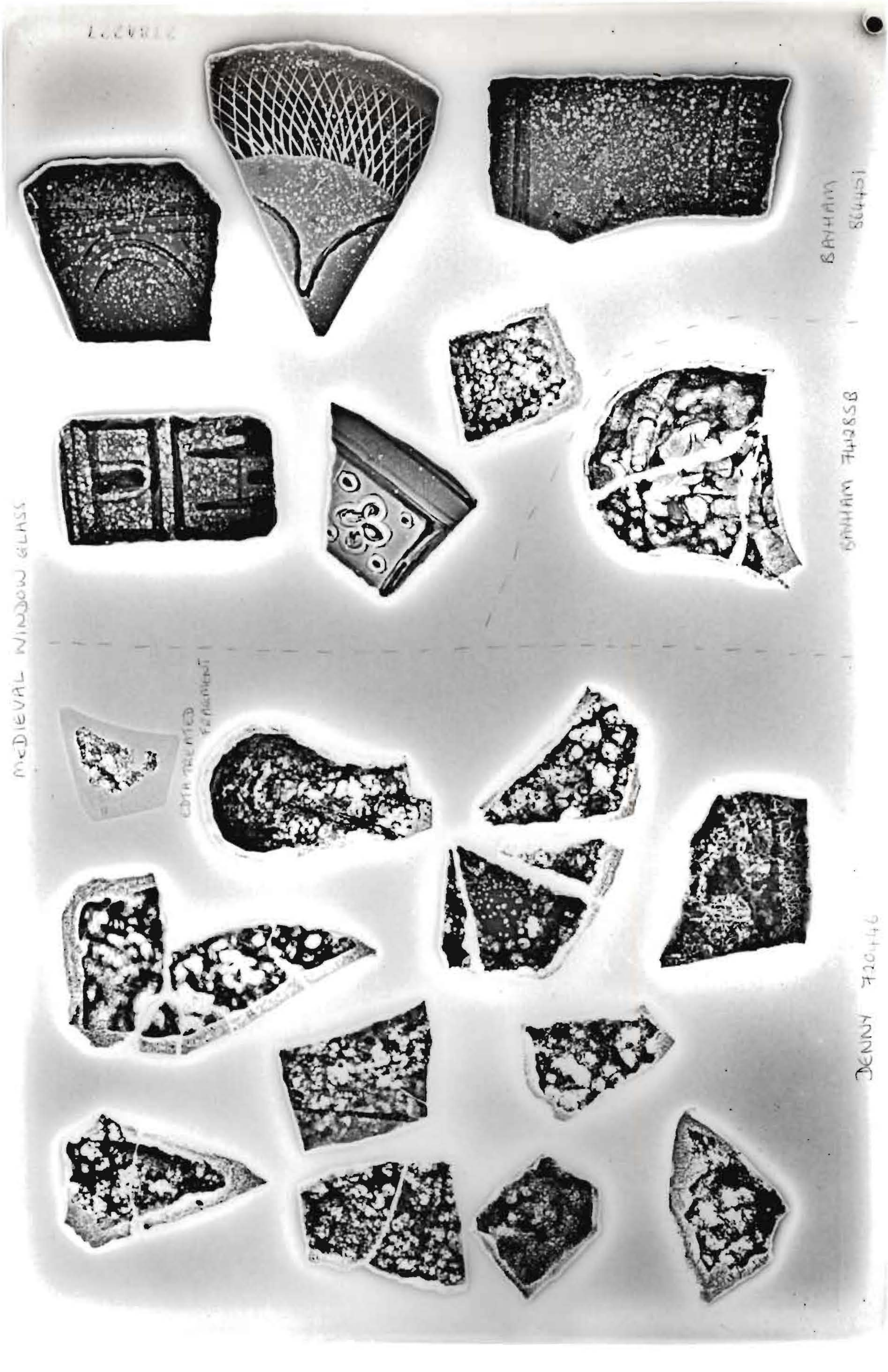


Figure 6: Positive xeroradiograph of medieval window glass from Bayham Abbey and Denny Abbey. 30kV 10 mA 50 seconds

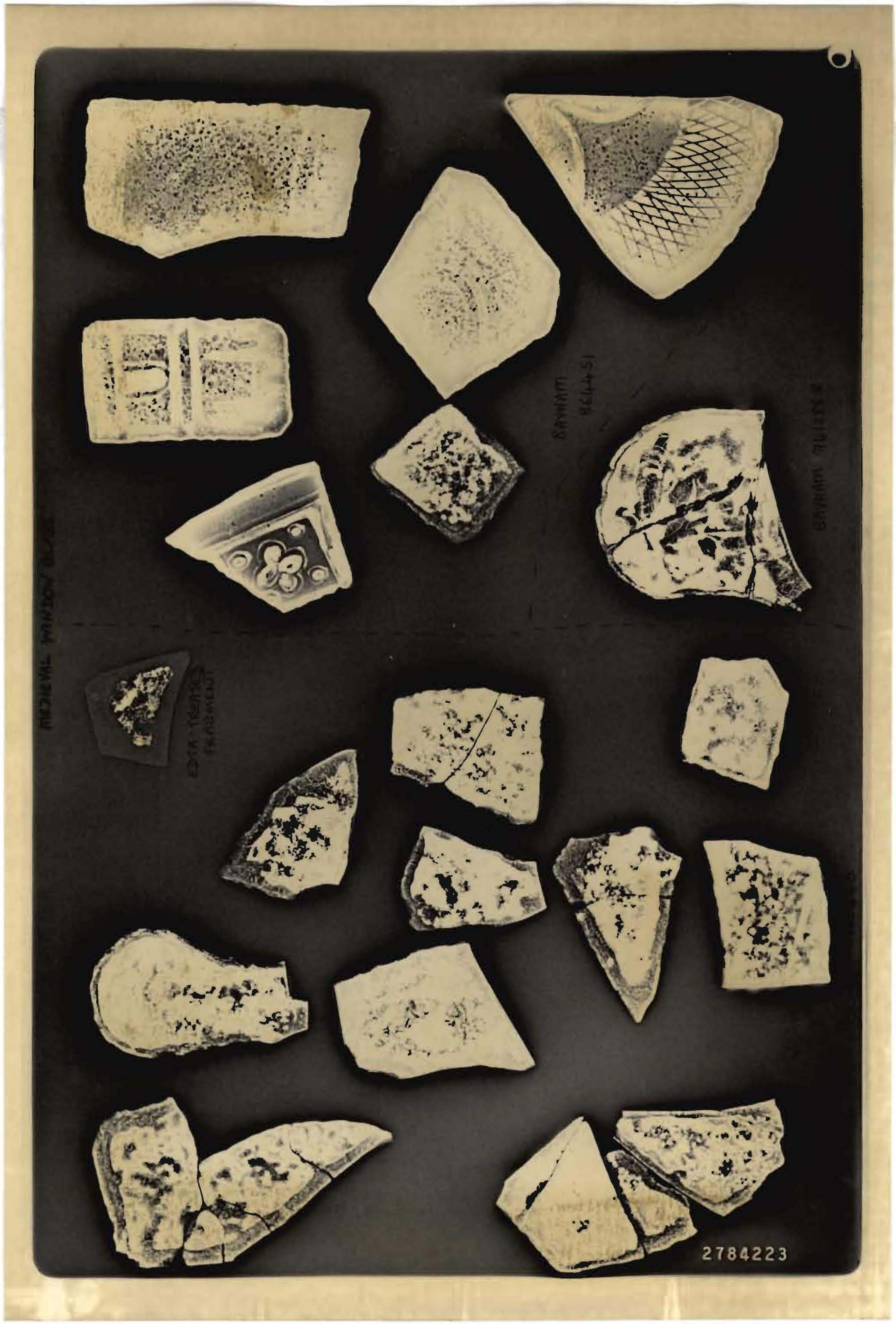


Figure 7: Negative xeroradiograph of medieval window glass from Bayham Abbey and Denny Abbey. 30kV 10 mA 50 seconds

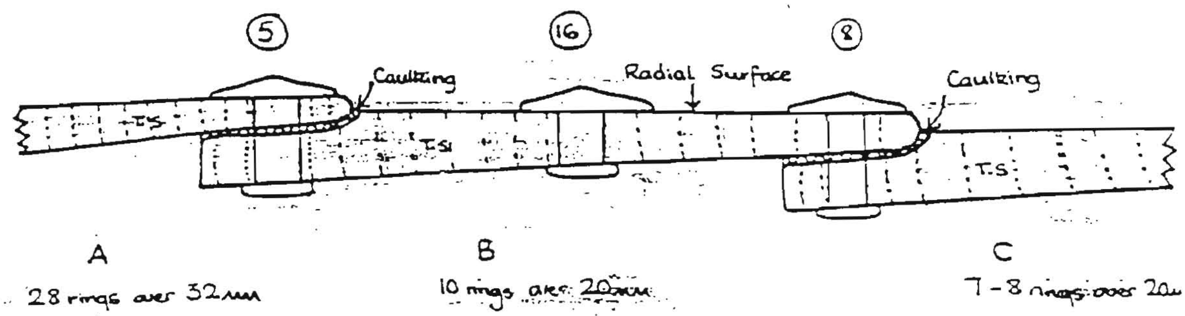
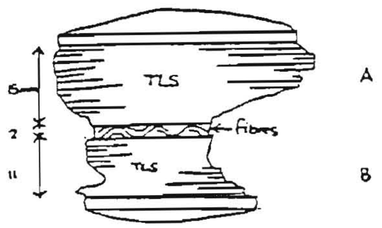


Figure 8a: Suggested original construction of the timbers
(From Edwards & Watson 1987)

2



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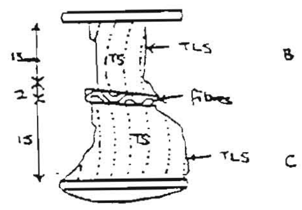

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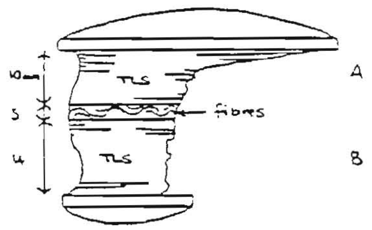

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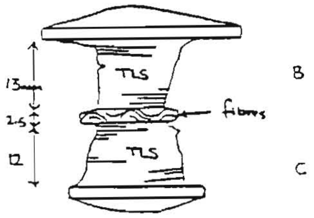
Plank A has 28 annual rings over 32mm.

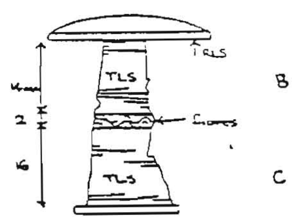
7



12

Nail joins two planks of wood with fibre mat between them. Both planks originally had surfaces of radial section (RLS), one with an annual ring count of 7 over 20mm.

14



16

Plank B has 8 annual rings over 23mm.

This nail only pierces plank B, which has 10 annual rings over 20mm.

Figure 8b: Illustration of organics preserved on each nail.
(From Edwards & Watson 1987)

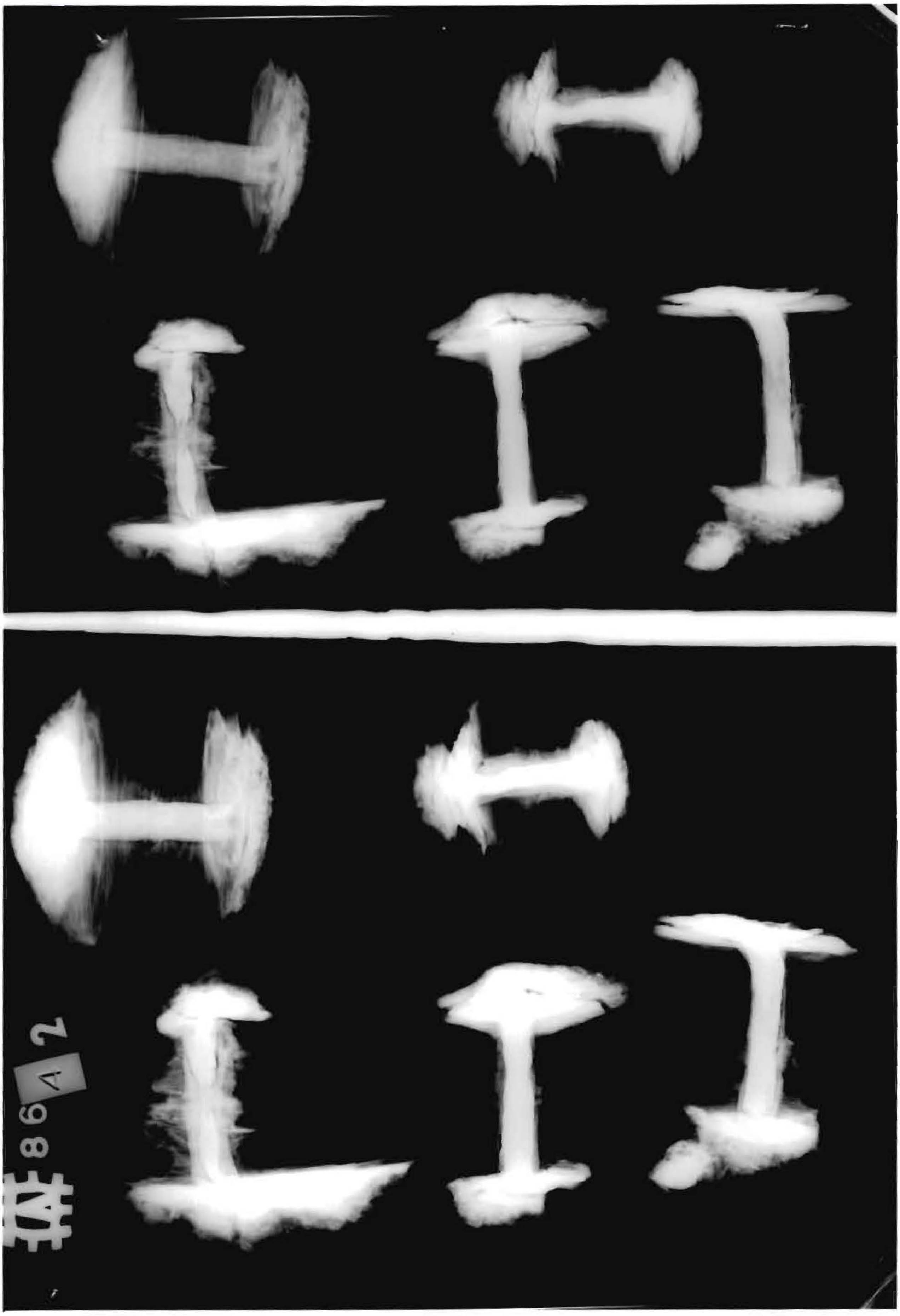


Figure 9: Film radiograph of coffin nails from York Minster. 80kV 5mA 40 seconds/90kV 5mA 60 seconds.

Figure 10: Positive xeroradiograph of coffin nails from York Minster.
60kV 5mA 20 seconds.

Figure 11: Negative xeroradiograph of coffin nails from York Minster.
60kV 5mA 20 seconds.

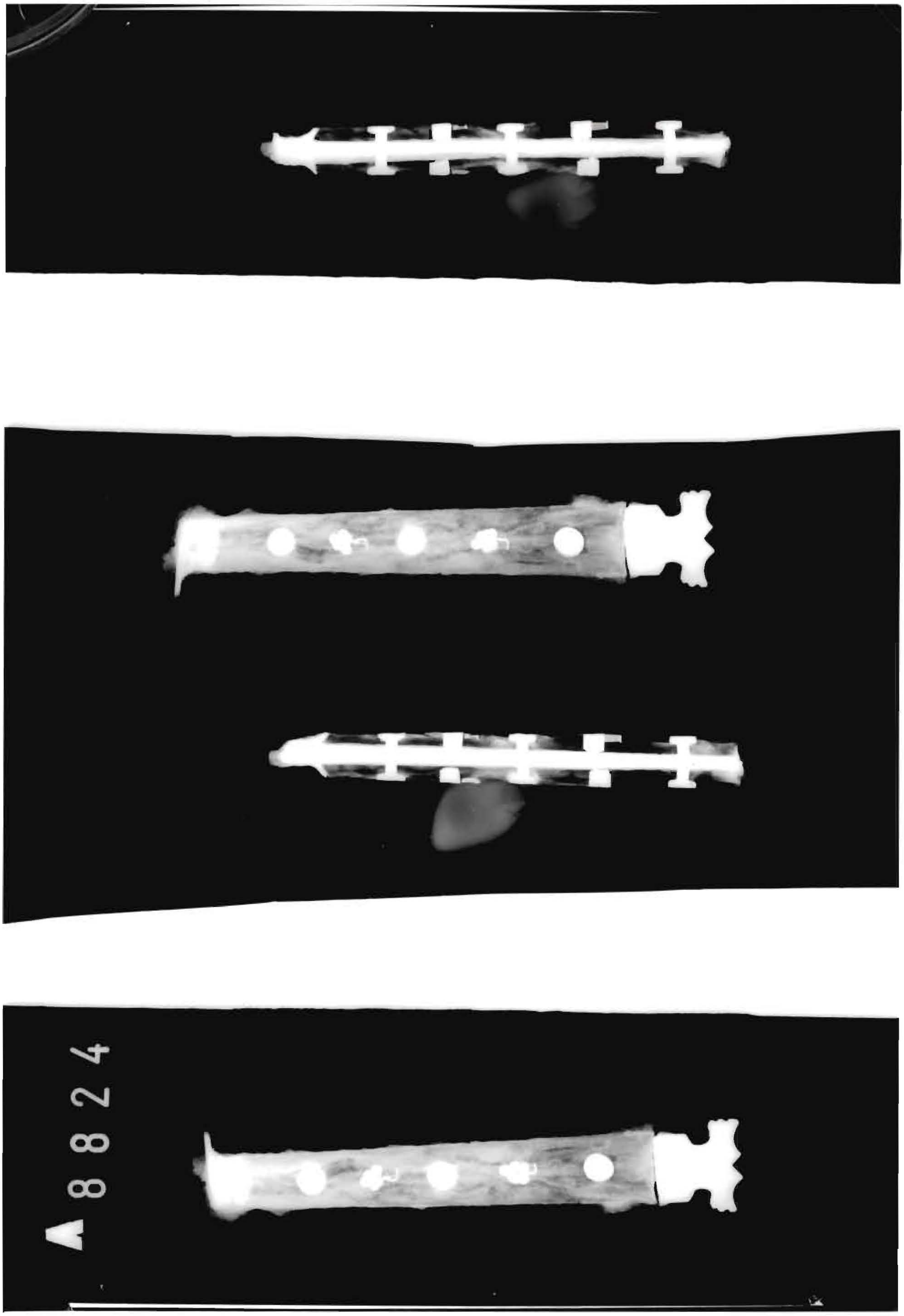
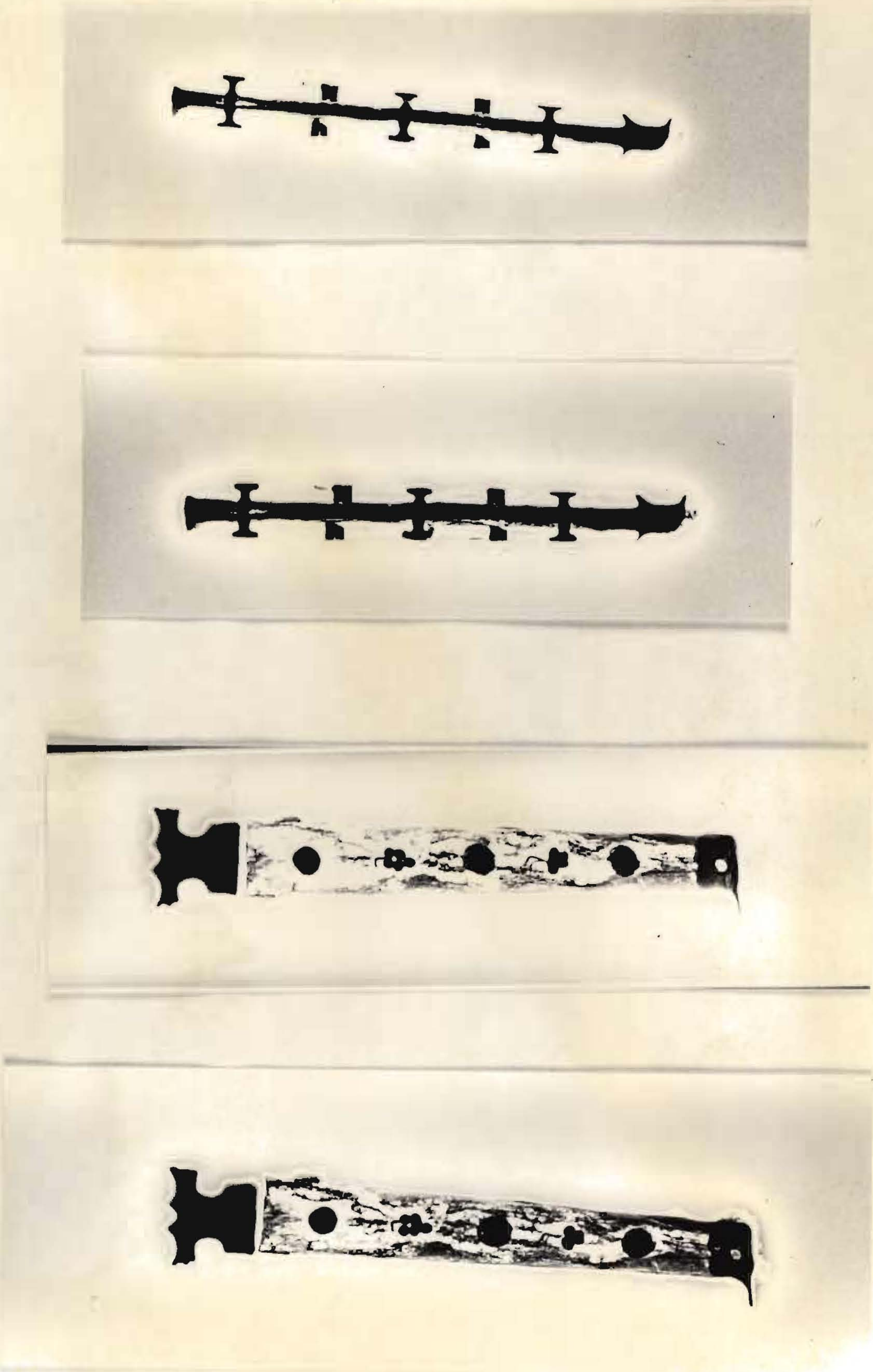


Figure 12: Film radiograph of knife handle from Hinton Hall Haddenham. 70kV 5mA 20 seconds (A&B)/70kV 5mA 30 seconds (C&D).



13: Positive xeroradiograph of knife handle from Hinton Hall
am. 70kV 5mA 20 seconds (A&C)/70kV 5mA 30 seconds (B&D).

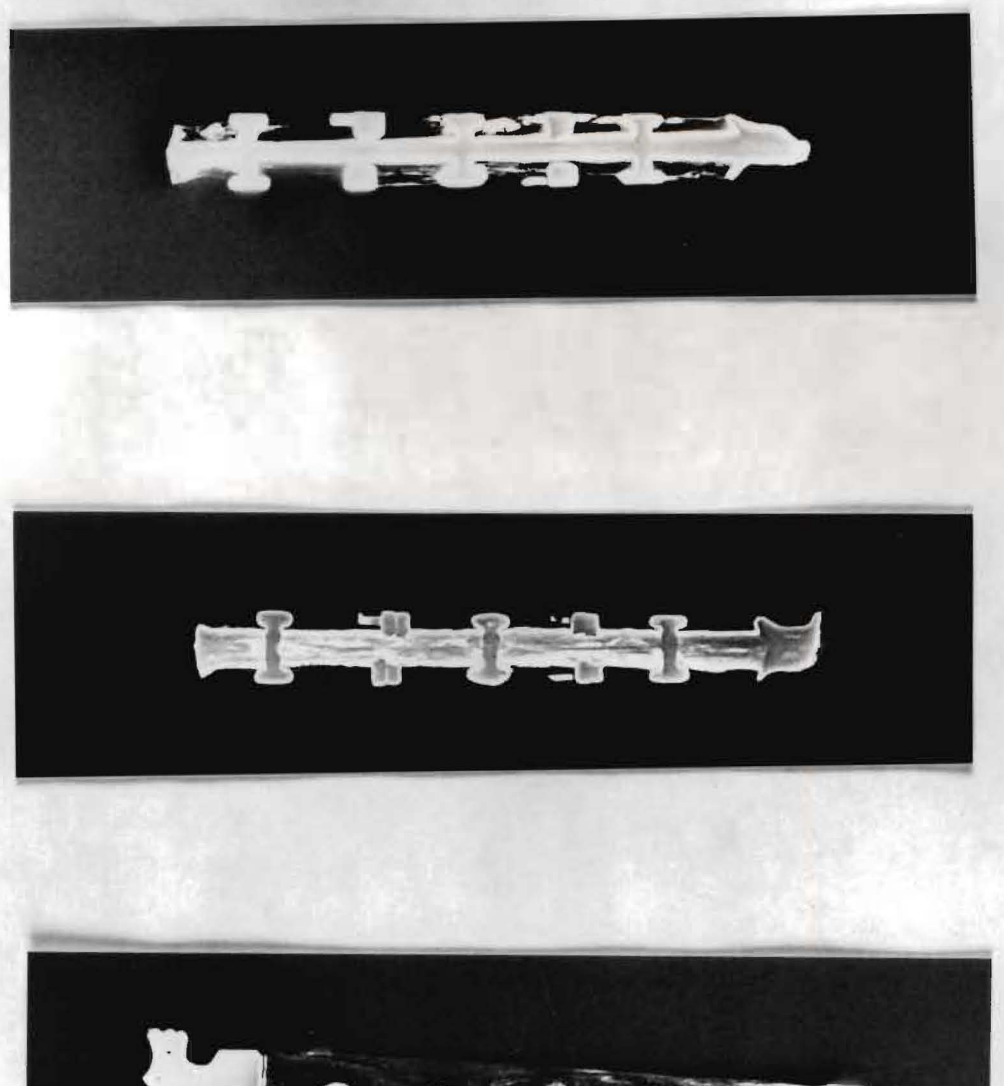


Figure 14: Negative xeroradiograph of knife handle from Hinton Hall Haddenham. 70kV 5mA 20 seconds (A&C)/70kV 5mA 30 seconds (B&D).

4. TEXTILE WITH METAL THREADS. Threads of various types of metal had been woven into these textiles from St. Augustine's Abbey. The film radiograph (figure 15) and both the xeroradiographs (figures 16) illustrate the way the corrosion products from the metal threads are impregnating the surrounding organic fibres, so that it is difficult to distinguish the metal threads from the rest of the textile. The rendering of detail in the xeroradiographs is poor in comparison to the film image. Areas of fine detail, in which there are numerous interfaces of varying charge, may be causing the powder to blur in the development process.

5. JET/SHALE. Recent work has investigated the application of film radiography to the examination of jet, jet-like and shale artefacts (Davis 1990, Hunter 1991). The radiographs not only reveal information about the boring techniques used in the manufacture of beads, they can also be used, in combination with elemental analysis, for the classification of the various black lithic materials. Shale has a higher absorption coefficient than jet, so it is more opaque to x-rays. Materials such as cannel coal and lignite usually have intermediate densities, but are variable, so elemental analysis is needed to distinguish some examples from jet or shale.

Figures 17, 18 and 19 are film radiographs of these materials. Objects of similar thickness are exposed on the same plate, and it is possible to distinguish three groups of material: translucent, intermediate and opaque. The images of geological samples of jet, cannel coal and shale (figure 17a) fall into these three categories, respectively. The xeroradiographs (figures 20 - positive, and 21 - negative) have different characteristics. The contrast between the dense and the less materials is not so obvious, as a result of the wide exposure latitude. The texture of the materials, and the outline of the inclusions and cracks, are highlighted. Very clear detail can be seen on the positive image (Figure 20) - the markings on the dice (MOL HOO 88 <265>), for example, and the woody texture of the bead <MOL HOO 88 <264>. It has been suggested, as a result of a large scale study of samples and artefacts, that different textures in shale may represent different sources of material (F.Hunter pers. comm.). Obviously this needs further investigation, but the ability of xeroradiographs to depict the texture of materials is clearly demonstrated.

Conclusions

This study illustrates some applications which xeroradiography may have to the analysis of archaeological artefacts. All of them need more detailed research. There has only been time in a project of this nature to carry out a preliminary survey. In some of these images, the resolution was poorer than expected (especially in comparison with the film image which was on Kodak AX medium resolution film), and more detailed experiments varying the charge applied to the plate, may result in levels of contrast which render detail more clearly. Since the selenium is grainless, it is the size of the powder particles which limits the resolution. Finer powder would also improve the detail of the image.

Xeroradiography obviously has some advantages; a positive image is easier for the eye to interpret and useful for publication purposes. No darkroom is required to develop the image, and there is no need for

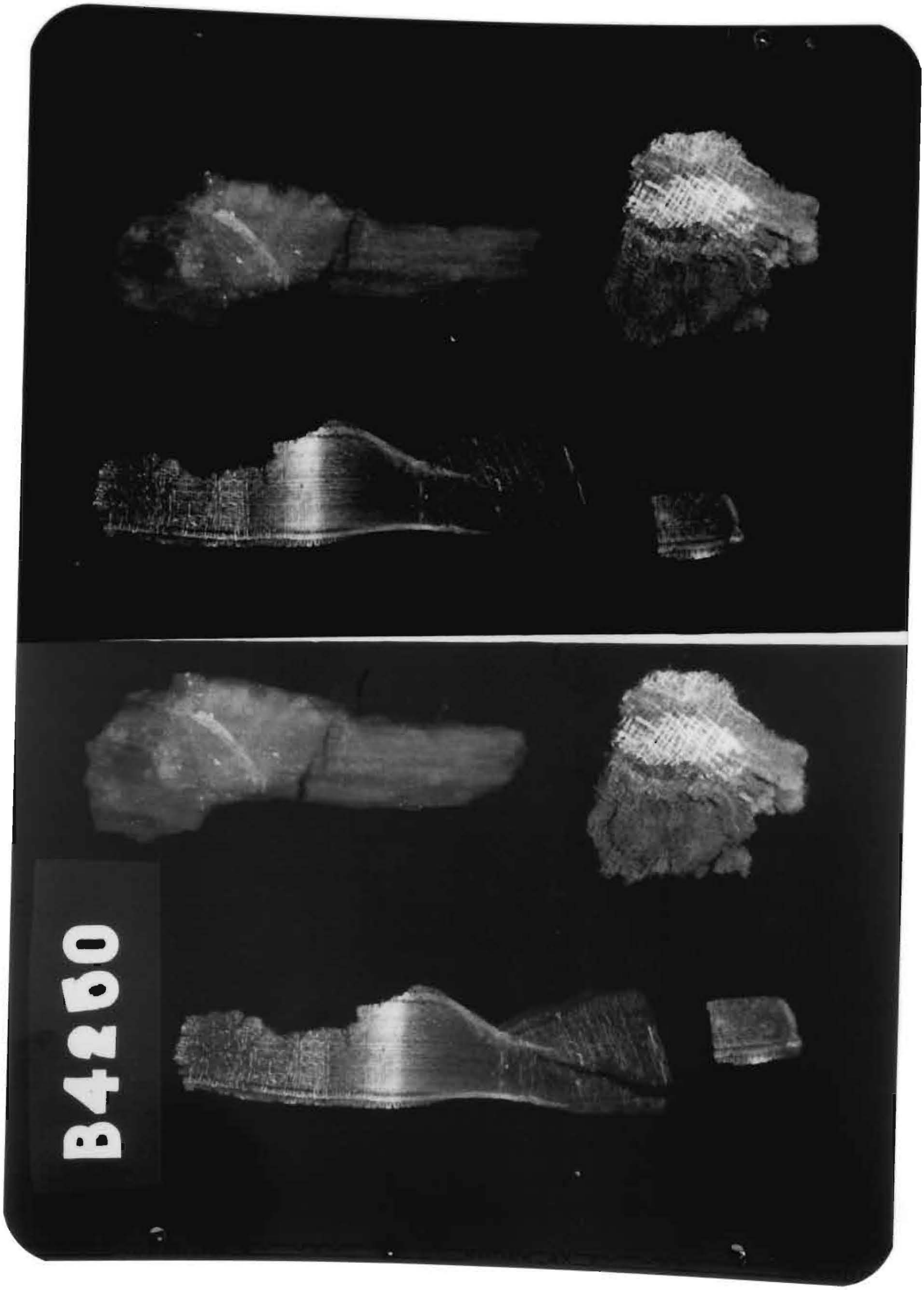


Figure 15: Film radiograph of textile from St Augustine's Canterbury.
30kV 10mA 40 seconds.

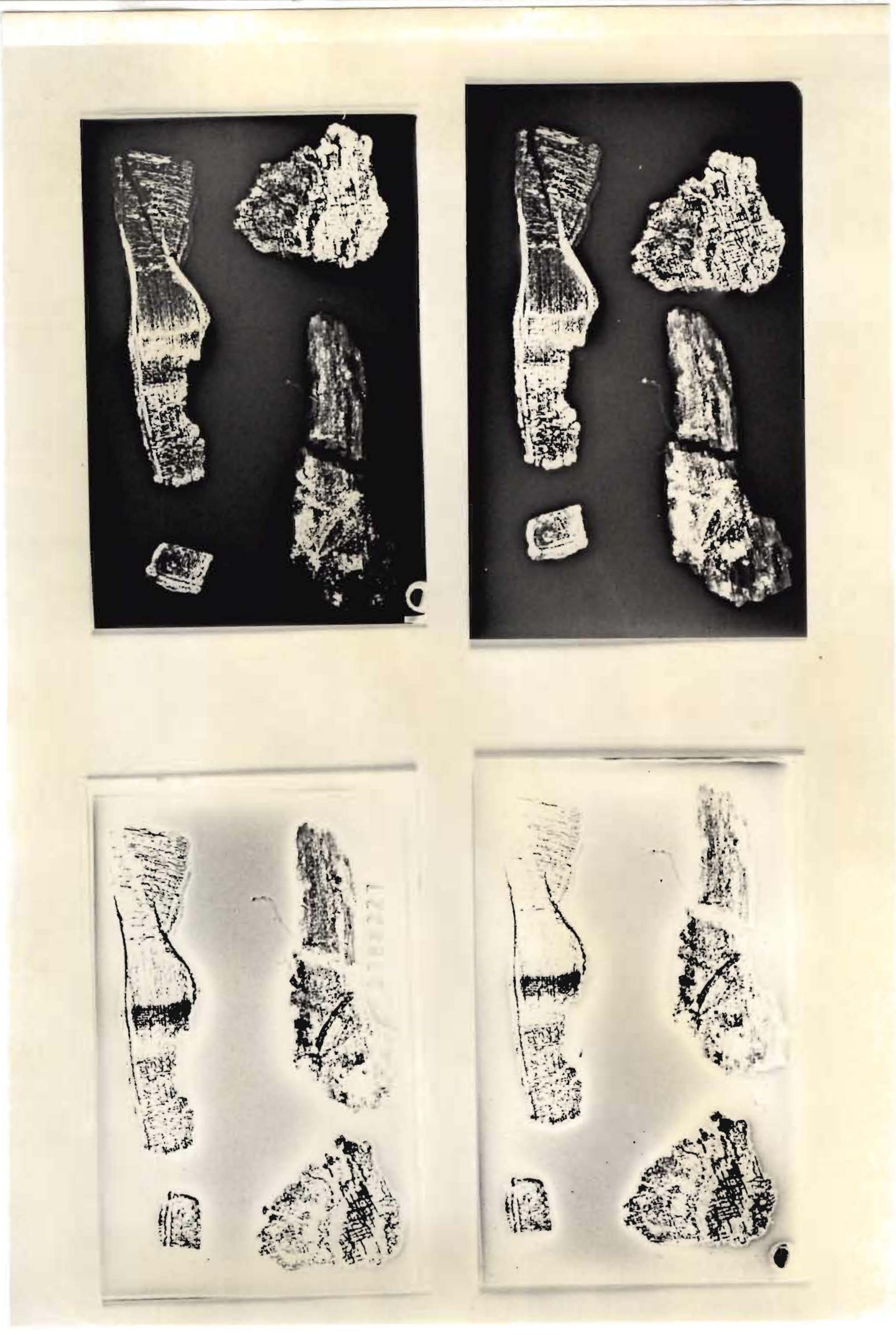


Figure 16: Positive and negative xeroradiographs of textile from St Augustine's Canterbury. 30kV 10mA 40 seconds (A&D)/ 30kV 10mA 40 seconds (B&C)

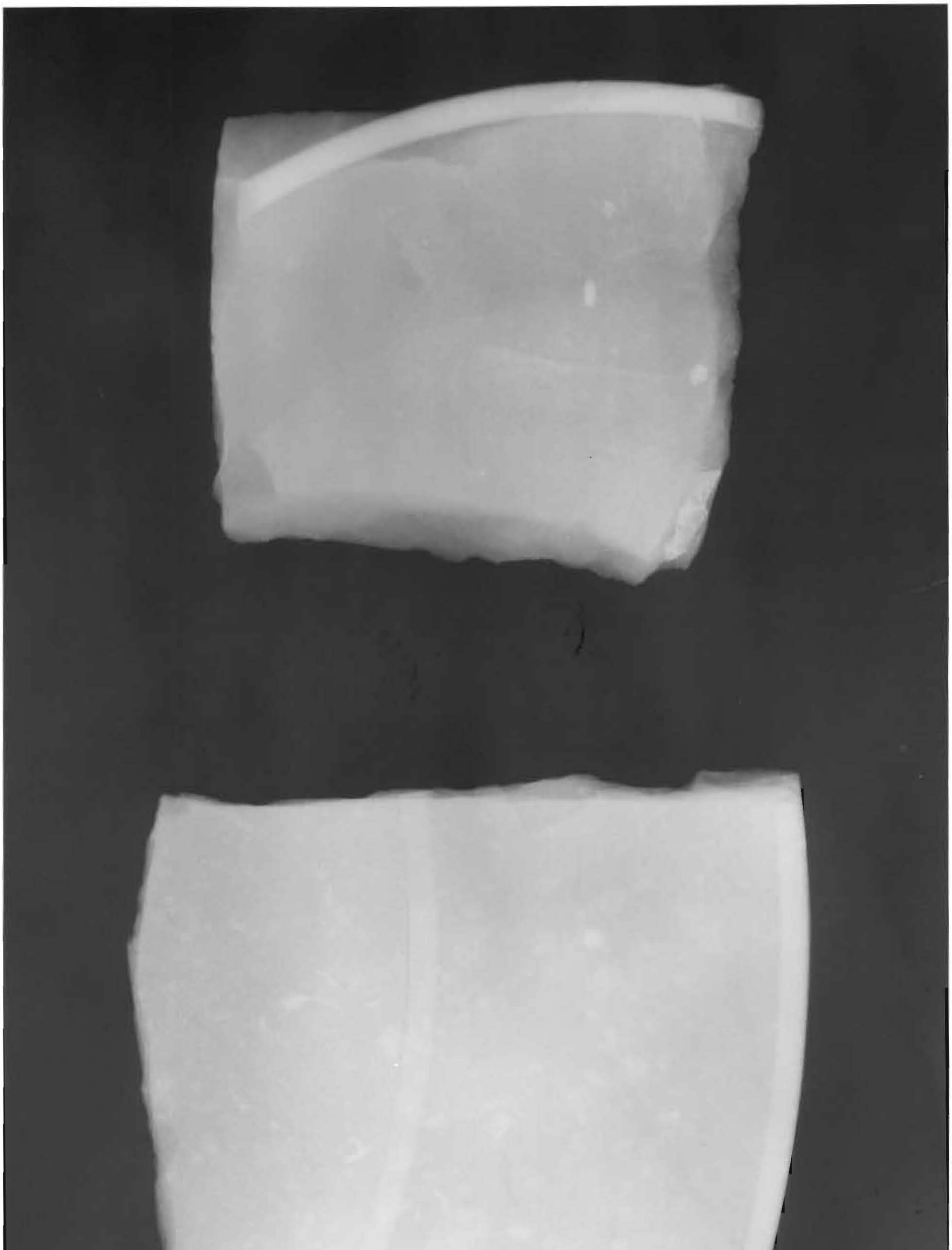


Figure 17: Film radiograph of shale platters from the Museum of London. 30kV 5mA 90 seconds.

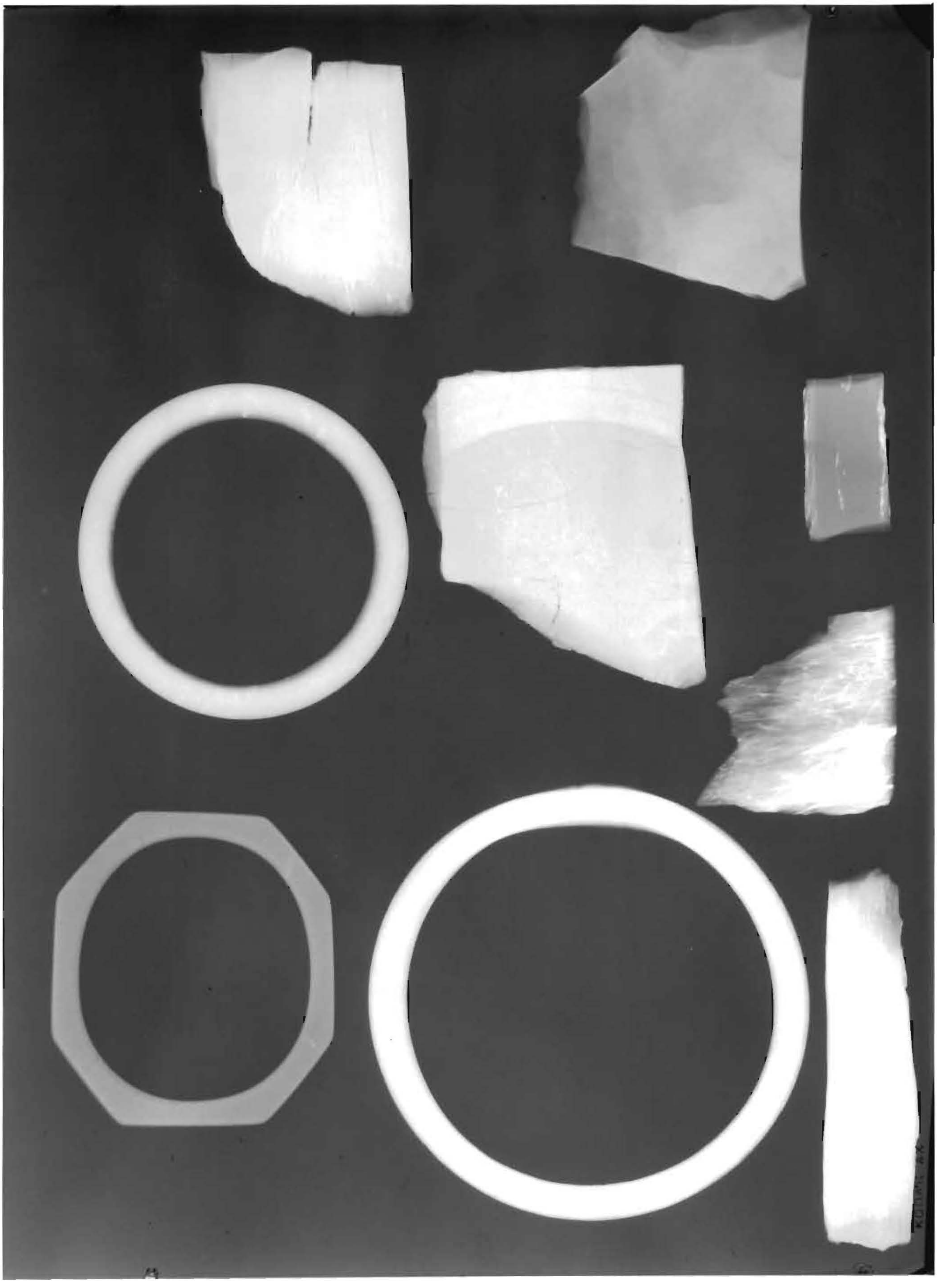


Figure 18: Film radiograph of jet/shale from various sites, and geological samples of jet, shale and cannel coal. 30 kV 5mA 90 seconds.

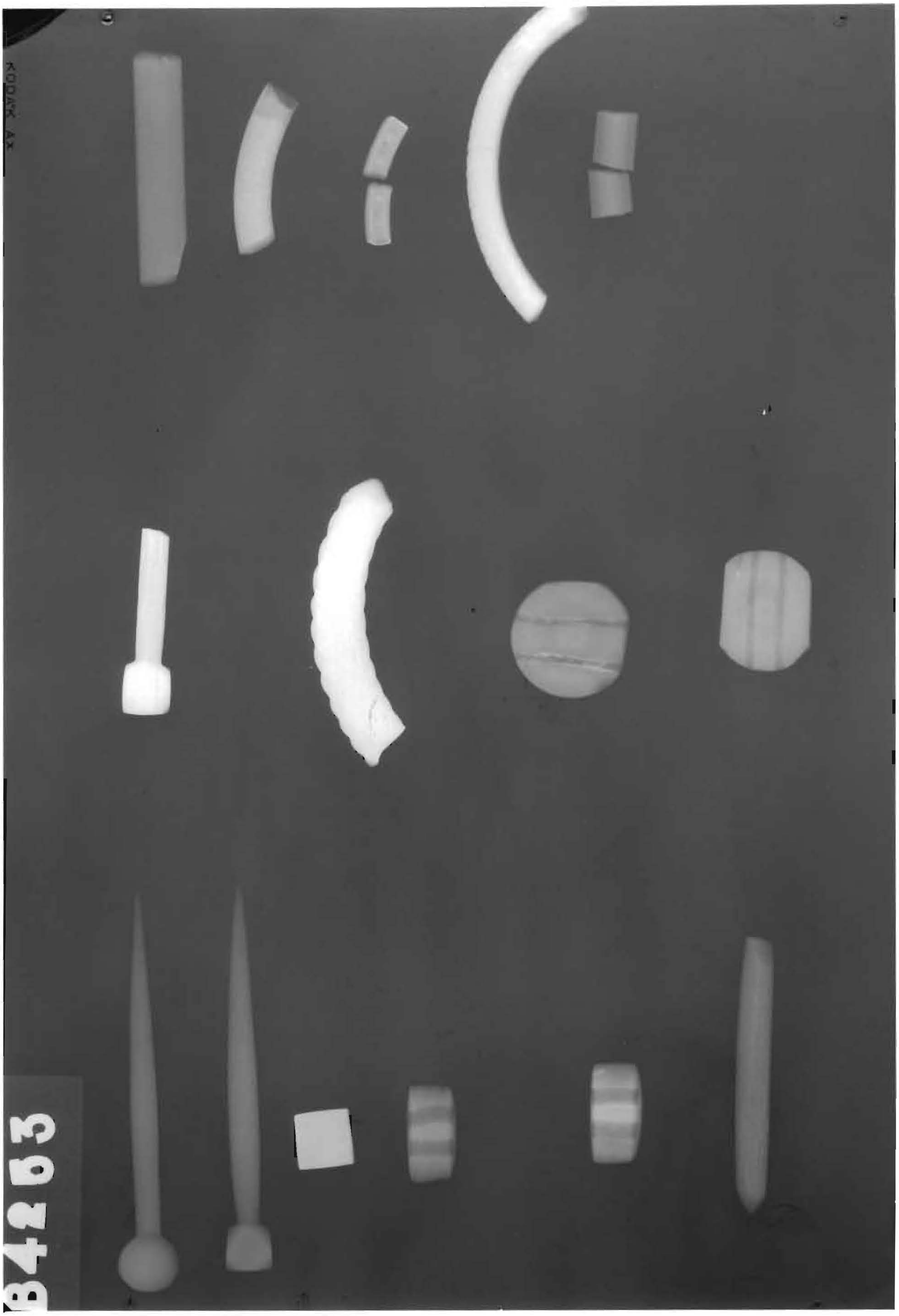


Figure 19: Film radiograph of jet/shale from various sites. 30 kV 5mA 90 seconds.

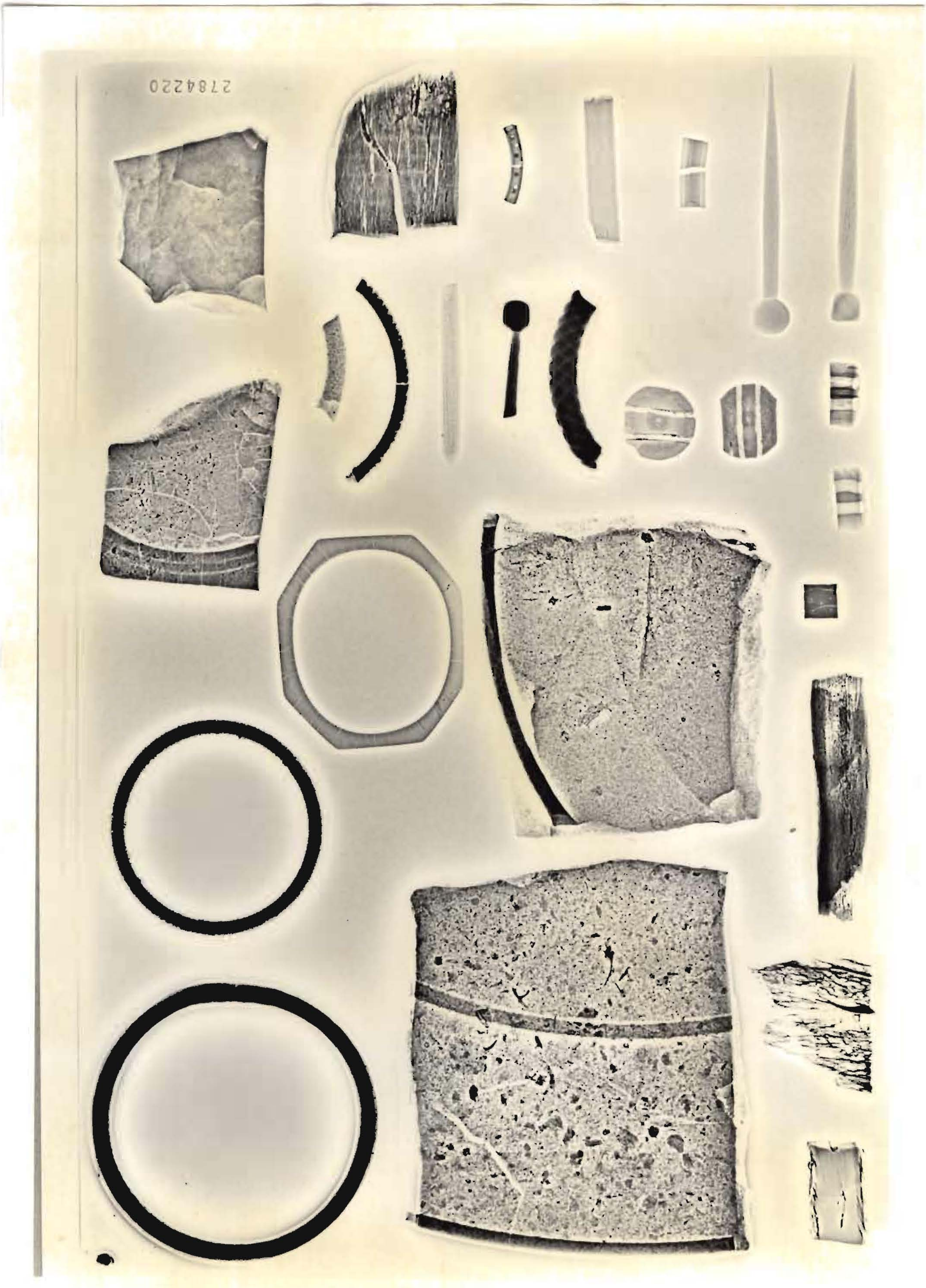


Figure 20: Positive xeroradiograph of jet/shale from various sites.
35kV 5mA 100 seconds.

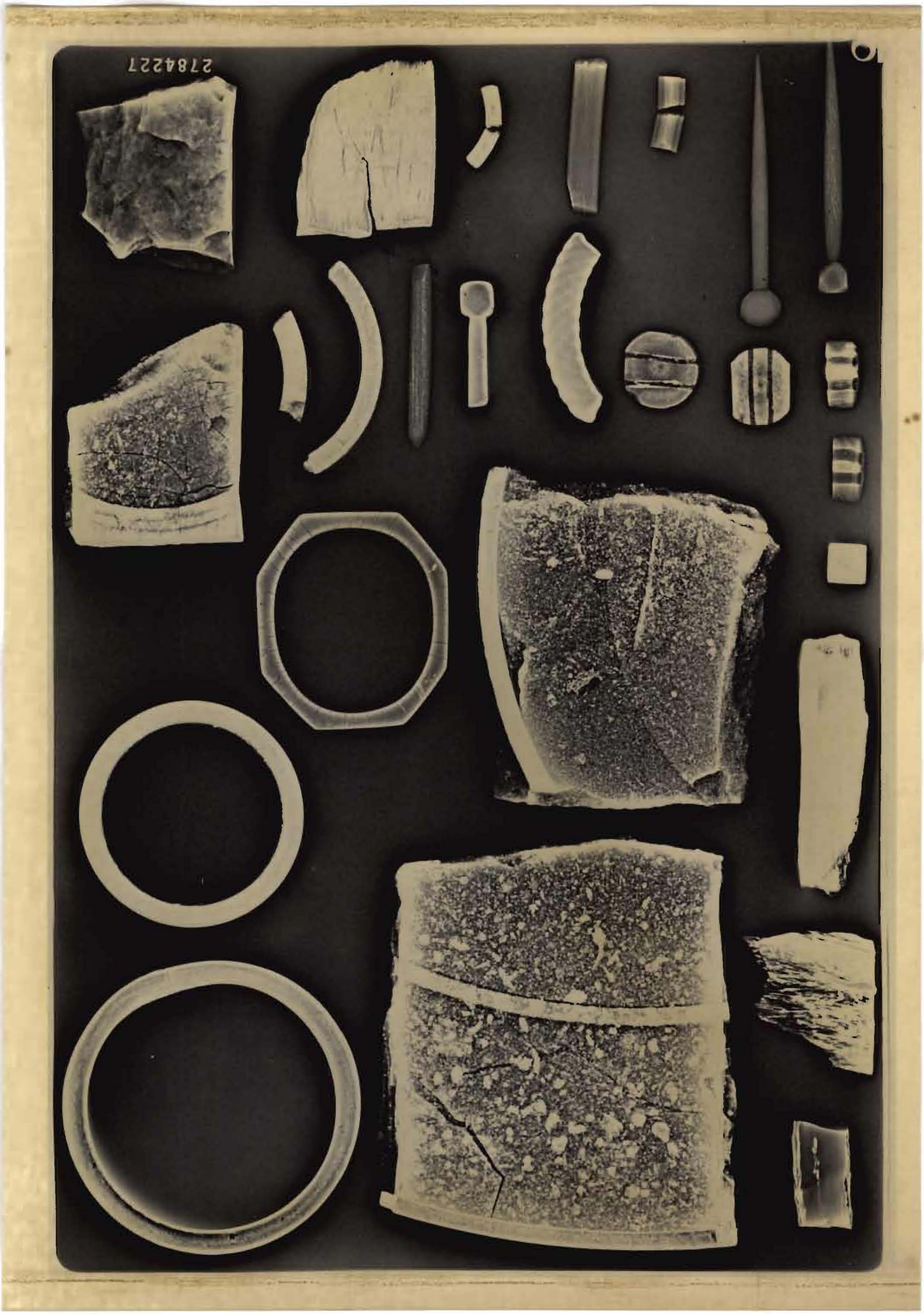


Figure 21: Negative xeroradiograph of jet/shale from various sites.
35kV 5mA 90 seconds.

backlighting to view it. A large disadvantage is the limitation on the size of the object that can be x-rayed - the selenium plate is 34cm X 22cm. Investigation is also needed into the archival stability of the resultant image as a record for the future. It is now generally accepted that records and information accumulated need to be accessible in the future, and new techniques should be subject to the same standards as those which we apply to our standard recording processes.

Acknowledgement

Xerox Medical Systems kindly gave permission for the reproduction of Figures 1-4 from the Operators Manual for the Xerox 125 xeroradiography system.

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