Ancient Monuments Laboratory
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Summary

A skull fragment, with what appeared to be glass fused to it, from a cremation from Mucking Anglo-Saxon cemetery II was analysed. The glass was found to be soda glass of a type typical of Anglo-Saxon glassware. Further investigation was carried out into temperature of cremation.

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Investigation of a skull fragment from cremation 704, Mucking, Essex

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Introduction

The large multi-period site at Mucking, Essex, was excavated from 1965 to 1978 by Margaret and Tom Jones. An area of 18 hectares was examined which included prehistoric, Roman and Anglo-Saxon occupation[1]. The Anglo-Saxon phase contained 53 post hole buildings and 203 'sunken hut' (*grubenhäuser*) type buildings. Associated with this settlement were two cemeteries, Anglo Saxon cemetery I which contained 62 inhumations and Anglo Saxon cemetery II with 274 inhumations and 480 cremations[2].

A piece of bone from cremation 704 with what appeared to be a piece of glass fused to it was examined. The bone came from the skull vault of an unsexed adult[3] dated from the 5th to early 7th centuries AD[4]. The remains were found within a pot with a number of objects, including 9 green glass beads and what was thought to be the remains of a green glass vessel[5].

The aim of this investigation was to determine whether the substance fused to the skull fragment was a manufactured glass sinilar to that of the glass objects found with the remains, or whether it was an accidental glass produced during cremation. It was also an opportunity to investigate cremation temperature by studying the bone and 'glass' and their relationship with each other.

Method of analysis

The sample was sawn in half so as to give a section across the 'glass' and bone. The portion to be examined was mounted in epoxy resin, polished to 1μ, and carbon coated. The 'glass' element of the sample was analysed using an energy-dispersive X-ray (EDX) analysis system (Oxford Instruments ISIS) attached to a scanning electron microscope (SEM) (Leica Cambridge S440i). Analysis was carried out using the default ZAF calculations at 15kV, 1000pA, 50 seconds live counting time.

Quantitative analysis of glass component of sample

Quantative analysis was carrried out at three points, distributed over the surface of the sample.

Compound	Analysis 1 (%)	Analysis 2 (%)	Analysis 3 (%)
Na_2O	15.33	15.13	11.86
MgO	1.86	1.15	1.61
Al_2O_3	2.14	2.40	2.62
SiO_2	64.08	65.90	64.74
P_2O_5	1.01	0.39	1.16
SO_3	0.43	0.55	0.53
Cl	0.75	0.86	0.72
K_2O	1.75	1.83	2.45
CaO	8.37	7.46	9.73
TiO_2	n.d.	0.40	0.39
MnO	2.12	1.47	1.69
FeO	1.88	2.36	2.31
CuO	0.03	n.d.	n.d.
ZnO	0.27	0.11	0.19

n.d. = not detected

The above results have been normalised. Actual total percentages for each analysis are as follows.

analysis 1	analysis 2	analysis 3
91.08 %	92.51 %	88.88 %

Reasons for these low values may be poor sample preparation, and also the fact that the default standards were measured at a voltage of 20kV and the analysis performed at 15 kV. This is the standard voltage for analysing glass and is desigined to allow analysis of the widest possible range of elements, without over heating the sample. Over heating results in the loss of such volite elements as sodium, giving inaccurate results.

It was not possible to analyse the other glass objects found within cremation 704 for comparison so the results from the analysis of the fused 'glass' were compared with other analyses of early Anglo-Saxon glass. Comparison with the chemical composition of colourless and green glass beads from Apple Down

Anglo-Saxon cemetery in Sussex showed the Mucking 'glass' to have a composition similar to these glass beads, but with significantly higher levels of zinc[6]. Comparison with soda glass vessels from Spong Hill,[7] Norfolk, showed that the Mucking sample was similar, but less closely matched to these Anglo-Saxon vessel glasses.

In the Mucking glass, the low levels of potassium (an element that would be present in quantity in an accidentally formed glass), lends support to the case that it is the molten remains of a manufactured glass artefact. Accidental glass forms due to a high temperature reaction between silica-rich materials and potassium-rich compounds, two components which are common in a cremation (e.g. potassium from wood, silica from soil). Firman and Mortimer's analysis of fuel ash slag (i.e. acidentally formed glassy material) showed that by percentage weight K_2O made up 31 times more of the material than Na_2O[8]. The Mucking glass is therefore a soda glass typical of those used in Anglo-Saxon glassware.

X-ray diffraction investigation of heating temperature of bone

It has been noted that when bone is heated, the size of the crystal hydroxyapatite ($Ca_5(PO_4)_3(OH)$) within the bone structure, increases. These crystals are very small in unheated bone, and so when analysed by X-ray diffraction (XRD) do not diffract the X-rays well. As heating progresses, and the crystals grow and become more formed, the diffraction pattern seen becomes more pronounced. Several experimental studies have been performed in which bone has been heated to known temperatures and the X-ray diffraction patterns recorded[9].

It was decided to perform X-ray diffraction on bone from the Mucking skull sample and compare the diffraction pattern with those recorded from herring bones heated to known temperatures. Herring bone has the same chemical compostion as human bone. It was hoped that this would give a temperature range for the cremation. The bone sample was crushed to a powder using a ball mill and analyzed by powder diffraction using a Phillips PW 1840 diffractometer. The results were compared against ICDD standards. Fig 3 shows the diffraction pattern of the Mucking skull fragment compared to those of herring bones heated to 800°C and 1000°C. Each of the peak patterns is solely due to presence of hydroxyapatite.

The diffraction pattern recorded corresponds most closely with that of herring bone heated to 1000°C. This temperature, however, cannot be taken as being the maximum temperature of cremation because it is known that the burial conditions of the bone can also cause enlargement of the crystals[10]. Without knowing the extent of the diagenetic effect on this sample, more precise conclusions cannot be drawn. It is also proabale that othere areas of the body, those with more body fats, would burn at a higher temperature than the skull. Thus any point temperature from a cremation may not bear much relation to the entire combustion system.

Investigation of interface between glass and bone

The interface between the glass and the bone was examined to see if any reaction had taken place. At most places glass and bone were separated by a line of bubbles suggesting there had been little reaction in this area. Qualitative examination using an EDX linescan was performed across the interface. The linescan allows levels of up to four pre-determined elements to be mapped along a line on the sample. This would show any difference in the proportion of an element at varying distances from the interface, which might provide evidence for a reaction between the two substances. The Kα lines of four elements were chosen, calcium and phosphorus which are major components of the bone, sodium from the glass, and iron as a control. The scan revealed consistently high levels of phosphorus and calcium in the bone, and a consistent high sodium level in the glass section. Iron was constant throughout. This indicates that any reaction taking place at the interface is not involving these elements. The cause of the bubbles could have been soft tissues from the bone, matter that was subsequently burnt off, or the release of CO_2 from the heating of $CaCO_3$ contained within the bone[11].

A number of small irregularly shaped voids, differing in form from the bubbles, were noted and inspection at higher levels of magnification showed one of them to be surrounded by small crystals formed within the glass matrix. Figure 1 shows a back-scattered electron image of one of these voids. A back-scattered image shows the heavier elements/compounds as brighter areas, and the lighter ones as darker areas.

It was suggested that this void was formed by a piece of bone, An X-ray map was produced of the area allowing concentrations of calcium and phosphorus, two of the elements that make up bone, to be plotted. This revealed high concentrations of these two elements around the void, so it is probable it was formed by a piece of bone which was subsequently lost, perhaps during sample preparation. The crystals were qualitatively analysed, and proved to be rich in silicon, calcium and oxygen (fig 2). It is likely that the calcium in the crystals originate from the bone fragment.

Calcium silicate crystals are rare in nature so an attempt was made to identify them precisely using X-ray diffraction (XRD). If the crystal could be identified, its temperature of formation would be known, giving information about cremation temperature. The same method was used as for the bone sample. The results from the XRD gave no crystal structure, just the background results expected from glass, because of its amorphous nature . The crystals seen by SEM must have been very rare within the section of glass prepared for XRD, below the detection limit for XRD.

Discussion

The main aim of this investigation has been fulfilled, to characterise the glass fused to the bone. The glass is a soda glass with a composition comparable to Anglo-Saxon soda glass used in beads, so it is presumably from a manufactured object.

The second line of inquiry, that of the cremation temperature is a more difficult subject area. The diffraction pattern of the Mucking bone is similar to that of herring bone heated to 1000°C, a temperature consistent with the melting point of soda glass, 900°C[12]. However, due to the unknown effects of diagenesis, the figure given by the bone data must be used with caution.

If the crystal seen around the void in the glass had been identified this could have given us the formation temperature of the crystals.

There is of course a problem in comparing what happened archaeologically with experimental evidence. Other factors such as volatiles from the bone, and the presence of water could effect reaction temperatures. The reaction between a liquid and a solid at high temperature is complicated one and not easy to reproduce.

Modern cremations are carried out in a temperature range of 600-1000 °C. Within modern crematoria the temperature conditions are very finely controlled and the source of heat (gas burners) is only applied until the body fats ignite. At this stage, the heat produced by these burning fats is sufficient to burn off most of the body matter[13]. Within a funeral pyre, the heat conditions would very different, as fine control over the temperature would not be possible. It has been suggested by McKinley the actual maximum temperature in a pyre would be greater than in a modern crematorium[14]. This would be necessary to maintain an adequate heat to burn a body, in an environment with very large heat loss to the atmosphere. It is clear from this that the temperature throughout a pyre would not be constant as in a crematorium, and that there would be zones of greatly different temperature within the fire itself. So even if we were able to estimate a maximum temperature for burning of one piece of bone this may not aid us much in understanding the pyre cremation system as a whole.

Acknowledgments

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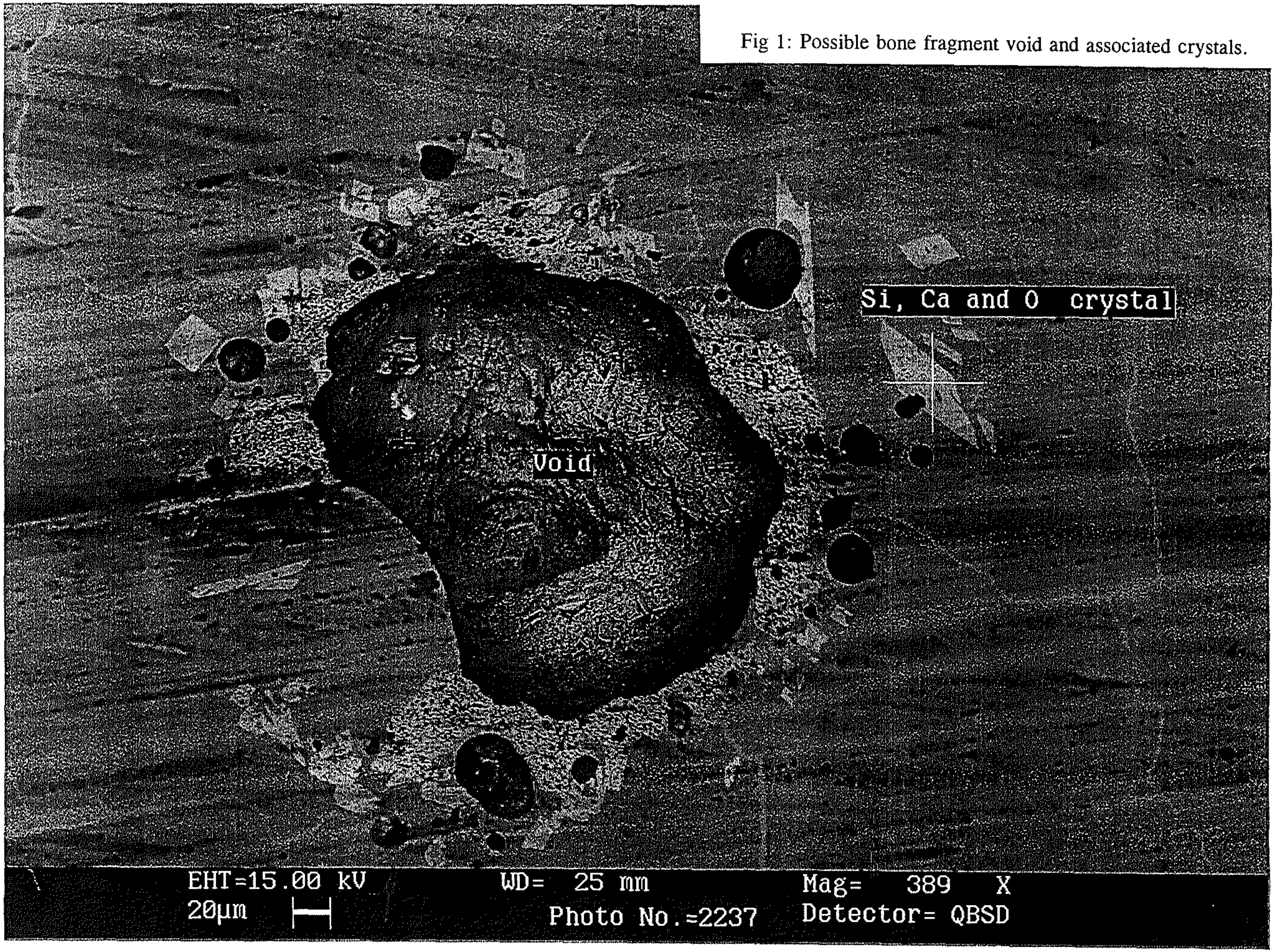
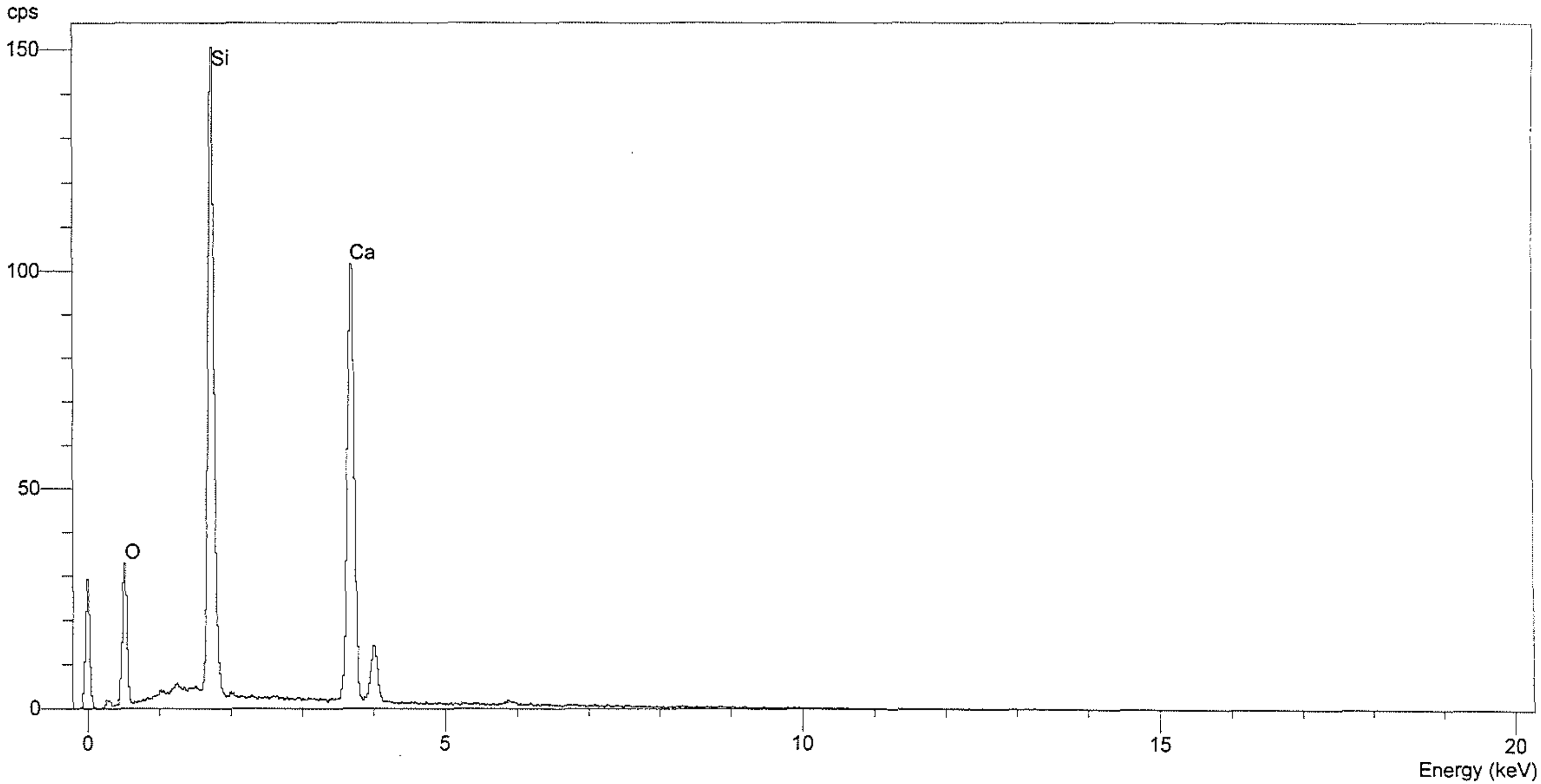


Fig 1: Possible bone fragment void and associated crystals.

Fig.2 Qualitative EDX analysis (at 15 kV) of crystals formed around void.



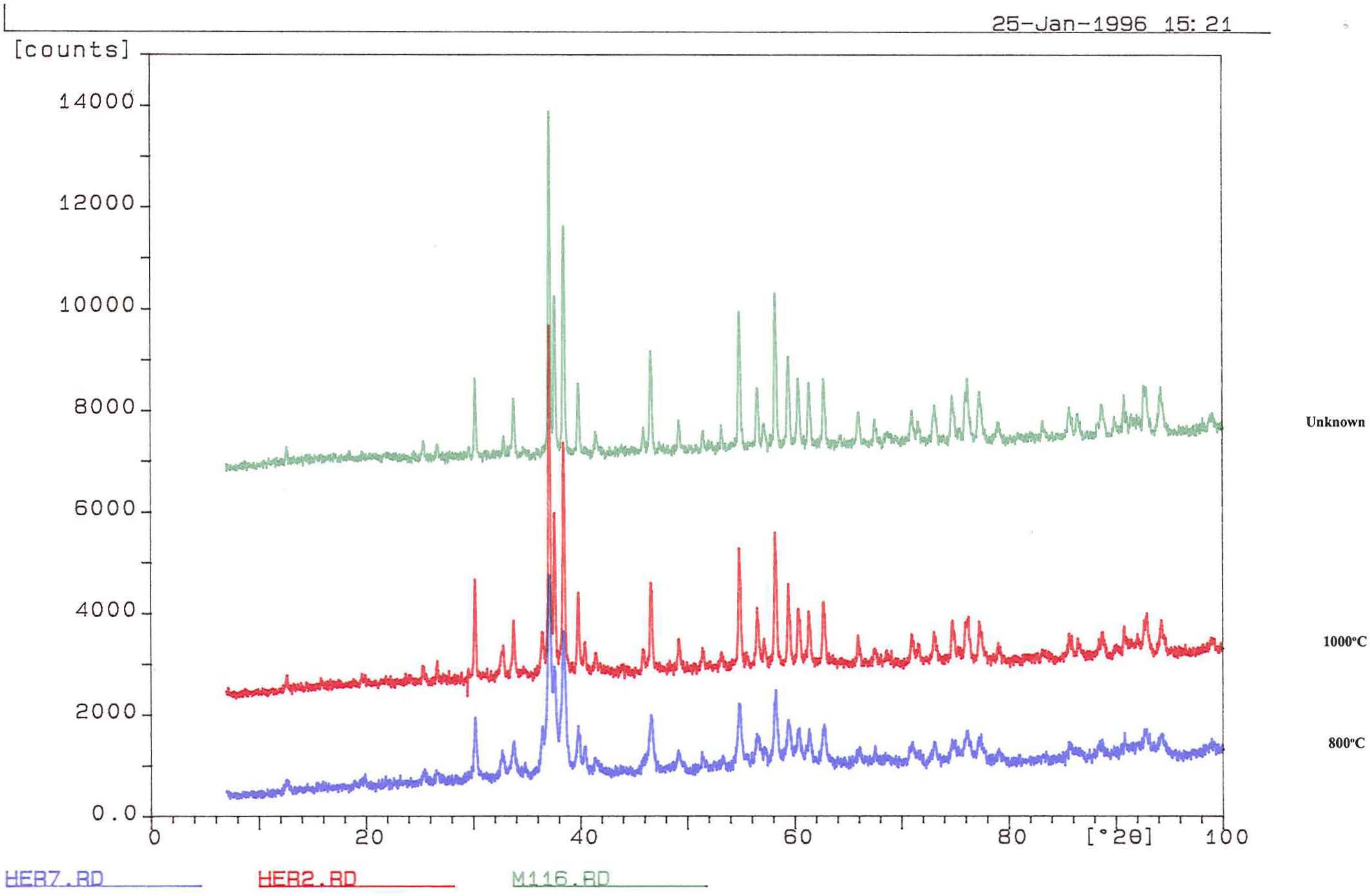


Fig 3: X-ray diffraction pattern of Mucking skull fragment compared to those of Herring bones heat treated in air at temperatures of 800°C and 1000°C.