THE UNIVERSITY OF ASTON IN BIRMINGHAM

ANCIENT MONUMENTS LABORATORY

REPORT

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THE ANALYSIS OF KNIFE 8862

FROM COPPERGATE, YORK

BY

J G McDONNELL

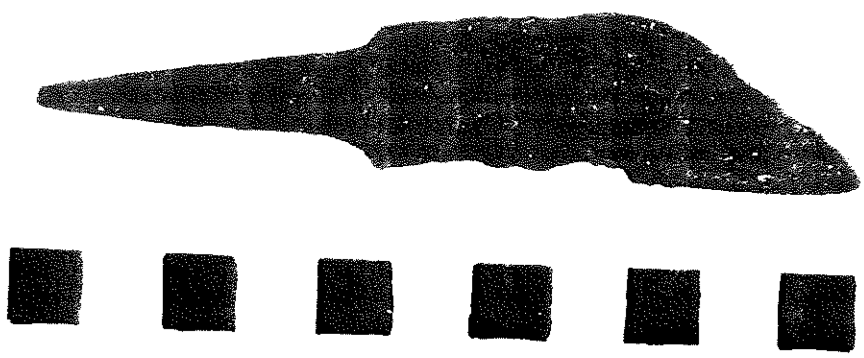

Plate 1 : Knife 8862 (scale cms)

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KNIFE 8862 : YORK LAB. No. AP 86

Knife 8862 is an angle backed knife approximately eleven centimetres long and of varying width. The blade is sixty percent of the total length.

Surface Examination (Plate 1)

The knife appeared to be well preserved, the only serious corrosion occurring midway along the cutting edge, although the whole surface was pitted. The back of the blade had been hammered flat for part of its length. Examination of the surface by low powered microscopy showed no evidence of wear marks. The knife had been conserved by Alkaline Sulphite Reduction, X-Ray Diffraction Analysis of powder scrapings from the surface identified the presence of Magnetite (Fe_3O_4).

X-Radiography Examination (Plates II and III, Figure 1)

Three radiographs were taken at different KV (60, 65, 70) but the exposure was maintained at 12 mA/secs. The radiographs confirm the corrosion midway along the cutting edge, and show the absence of metallic iron in some places. Above the corrosion there is a line that could either be a fracture or corrosion, perhaps, along the line of a weld. The radiographs indicate the presence of two irons of different characteristics. The first area [(A), Figure 1] from the back of the blade, being above a line running from the point to the tang-back junction, and the tang itself. This iron shows little evidence for corrosion or inclusions. The remainder [(B), Figure 1)] i.e. the part of the knife forming the cutting edge, shows evidence of corrosion and slag lines and/or welds lines. This distinction, may solely in part be due to

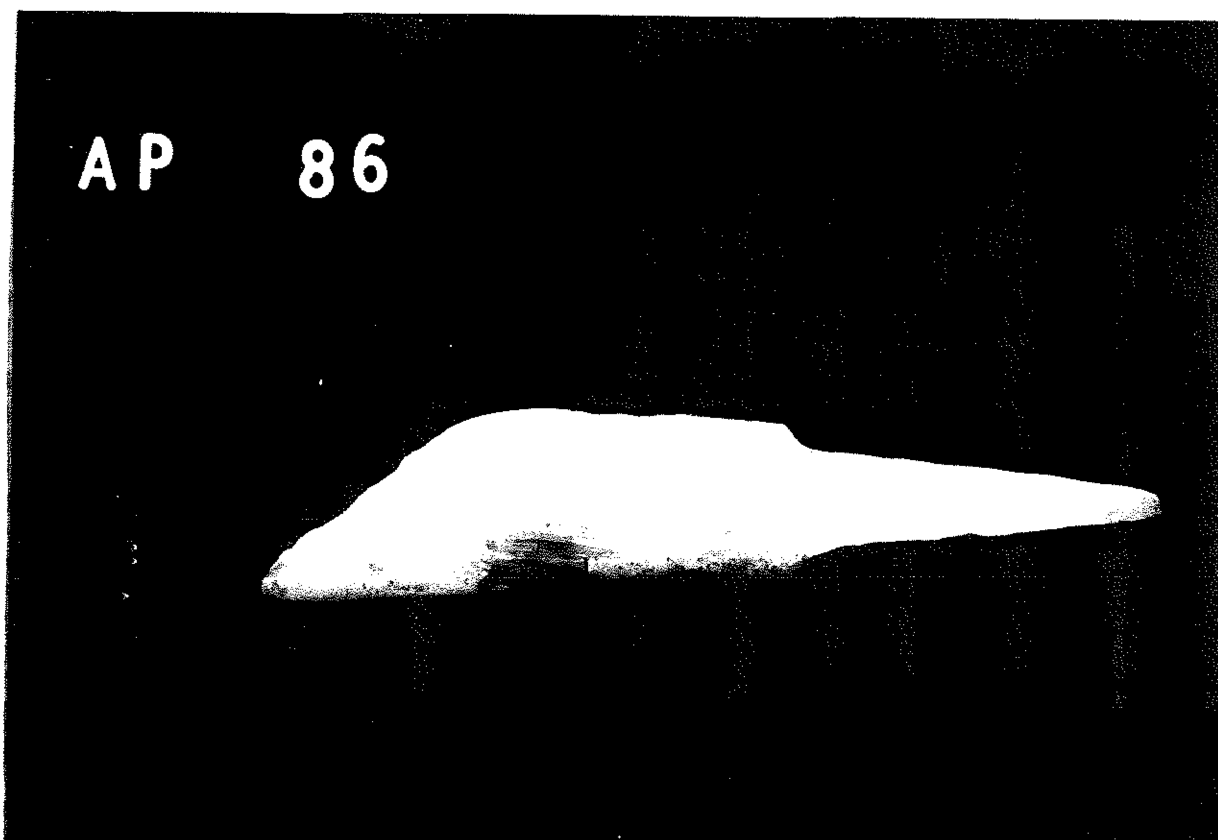


Plate II : X-Radiograph 60 KV, 12 mA/secs. (x.1)

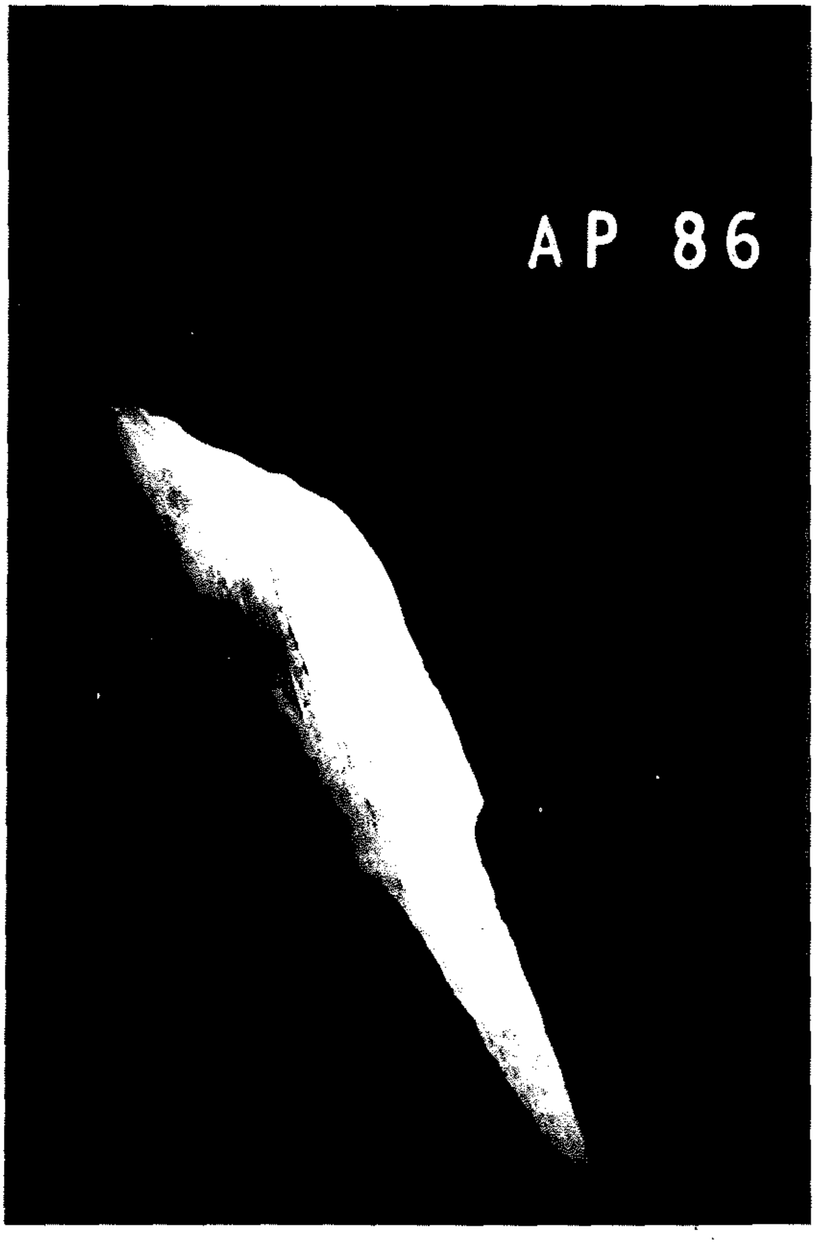
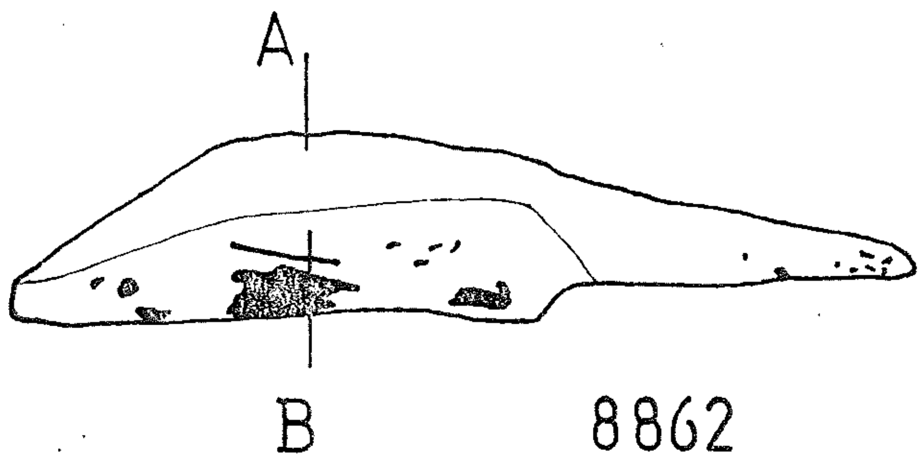


Plate III : X-Radiograph 65 KV, 12 mA/secs. (x.1)

Fig 1



Interpretation of X-Radiographs

the thickening of the knife towards the back.

Sectioning of the Knife (Figure 2)

The general intention of cutting alternating longitudinal sections ('flats') with cross sections from point of tang was changed to accomodate the area of corrosion, thus both S2 and S3 are cross sections. Cutting was by hacksaw. The specimens were mounted in conducting bakelite and polished in the usual manner and examined using the standard metallurgical microscope.

Metallographic Examination

S1 - (flat), [the knife point].

At low power magnification the section showed three different structures, the cutting edge, the body of the knife, and the back. The cutting edge was a tempered structure of martensite at the cutting edge, degrding to bainite towards the centre of the knife. The body of the knife was a piled structure of ferrite with carbides at the grain boundaries, which had broken down from pearlite. The junction between the tempered martensitic edge and the piled body was a sharp boundary indicating that the edge had been welded on. The back of the blade was a piled structure of bands of pearlite, slag lines and some ferrite, (Plate iv).

Hardness tests gave the following results.

Table 1 (Mean Results)

		Hv_1
Cutting Edge	(Martensite)	660
	(Bainite)	464
Body of Knife		150

Two microhardness traverses were also taken, the results are shown graphically in Figure 4. These results are in broad agreement with

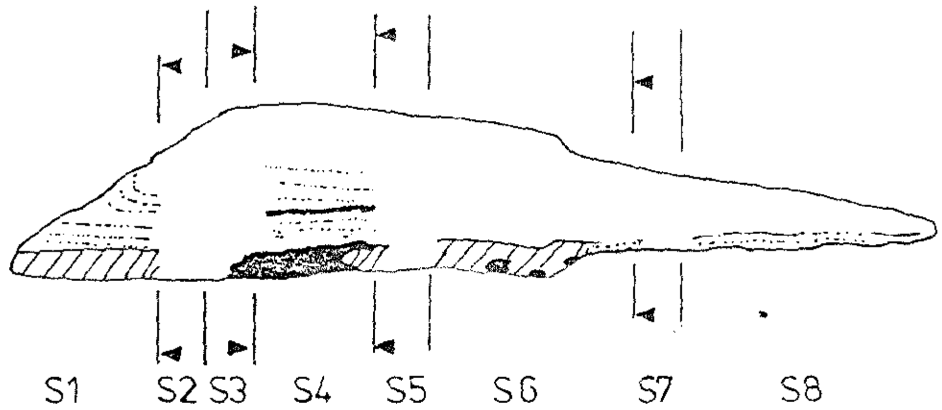


Fig 2

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Sections

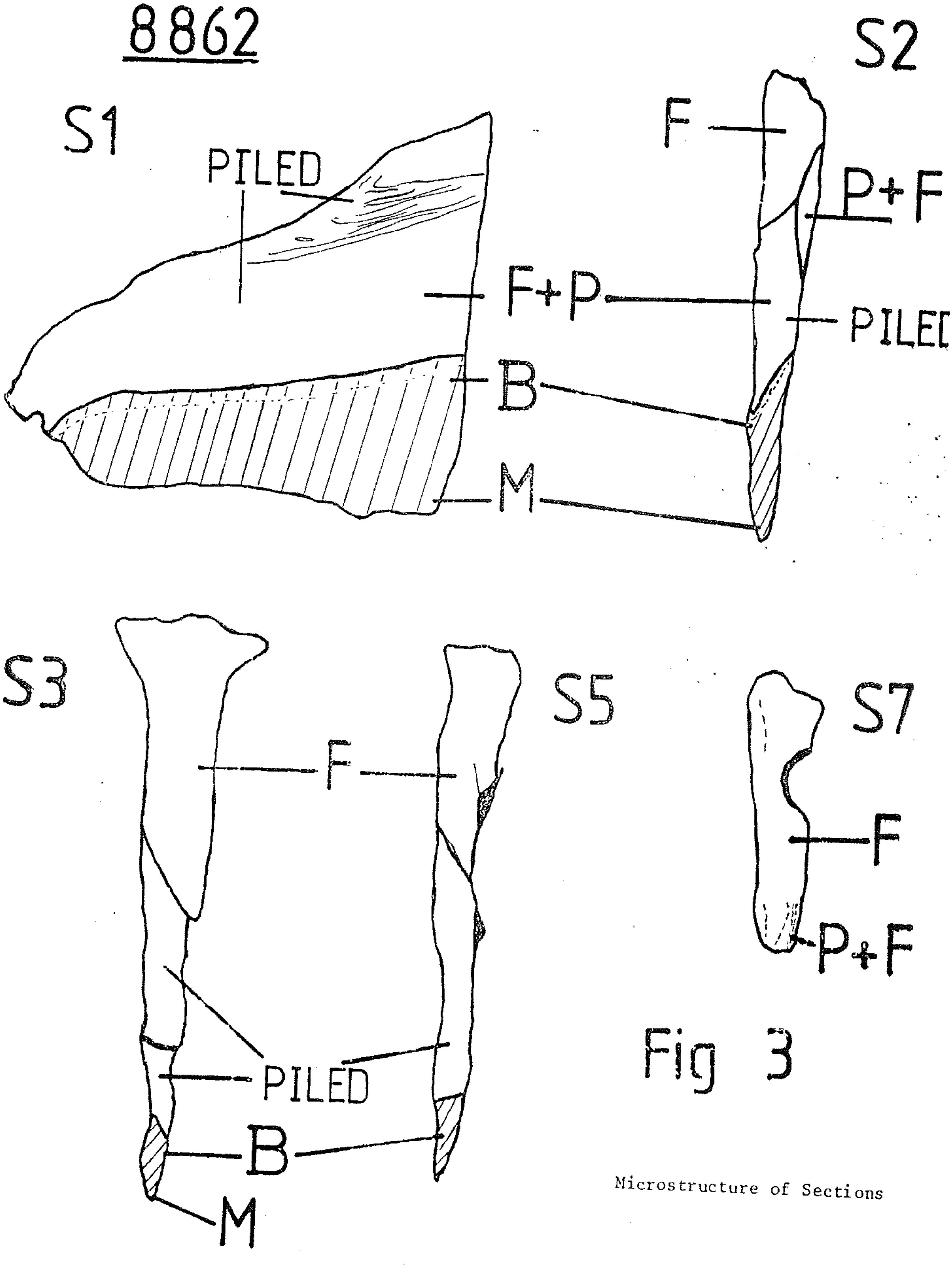
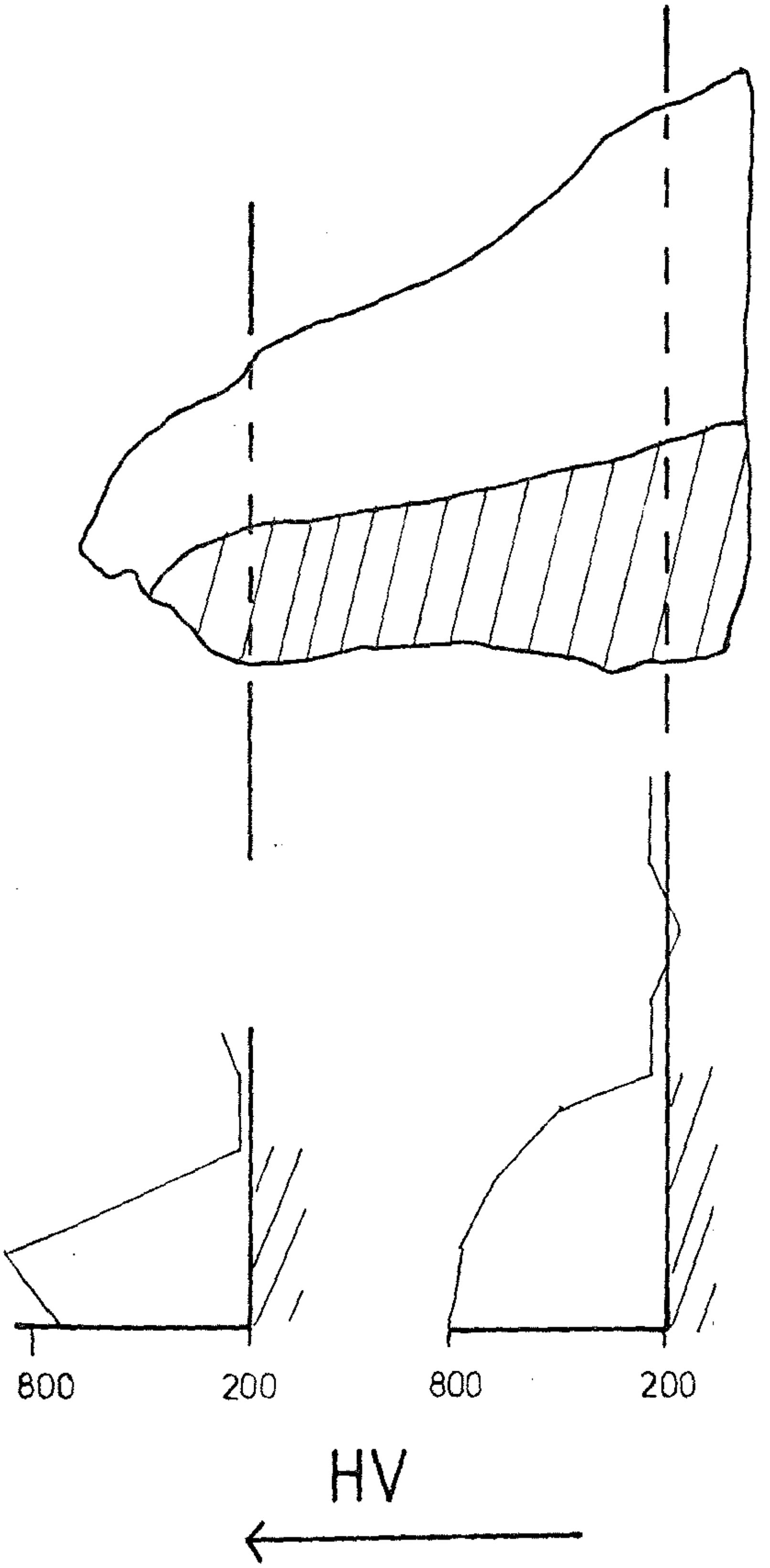


Fig 3

Microstructure of Sections

Fig 4 S1 microhardness traverses



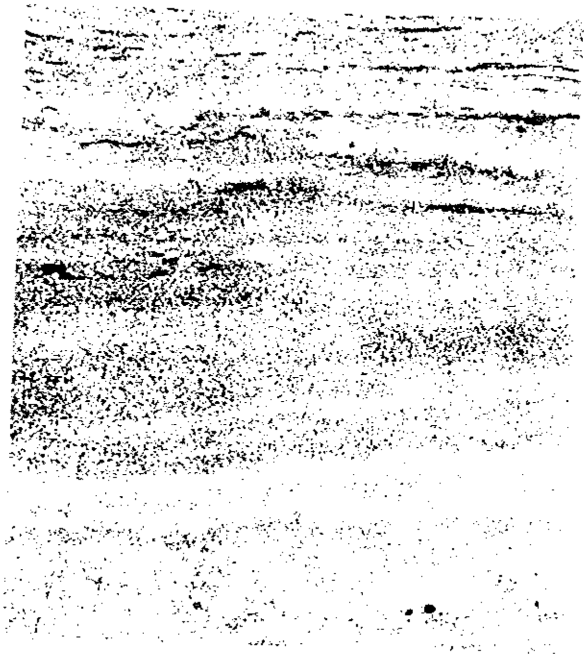


Plate IV : S1. Piled structure of Ferrite (white) and Pearlite (dark), with slag inclusions (black). (x.27).
(Etch 2% Nital)

Table 1, though higher results are obtained in some cases for the piled structures.

S2 - (X-Section)

The cross section showed a more complex structure, comprising four basic structures. The cutting edge structure of tempered martensite was present as in S1 (Plate V). The boundary between the martensite and the piled body was not so distinct, and at an angle of about 45^{o} from the vertical. The remainder of the section was in effect a piled structure, but of varying carbon content (Figure 3).

The direction of the piling also varied. Next to the cutting edge the piled structure of ferrite and pearlite had a trend parallel to the angle of the martensite/piled structure weld line, this was separated from the remainder of the body by an intermittent slag line parallel to the weld line. The remaining structure of piled ferrite, pearlite and slag inclusions, ran in the vertical direction. The carbon content varied widely; the back of the knife comprised of ferrite, slag inclusions and a very small amount of pearlite. Below this area was an area of high carbide content, which degraded into ferrite/pearlite/slag piled structure.

A composite photograph shows the structure of S2 (Plate VI).
Hardness tests gave the following results

Table II

	Hv_1
Back of Blade (piled ferrite + slag)	156
Body of Blade (piled ferrite + pearlite + slag)	178
Cutting Edge (Martensite)	636

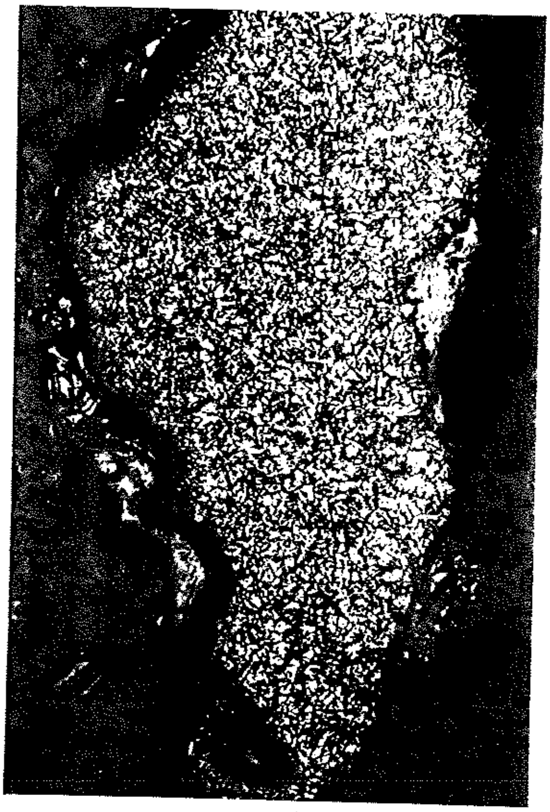


Plate V : Cutting edge, Martensitic structure (x.84). (Etch 2% Nital).

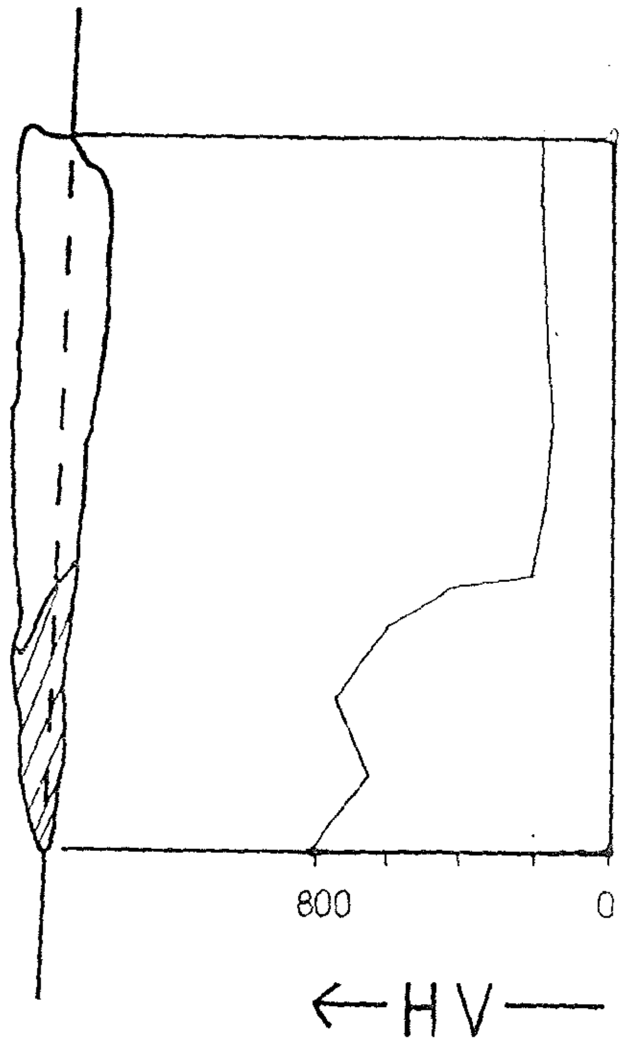


Fig 5 S2

Microhardness Traverses

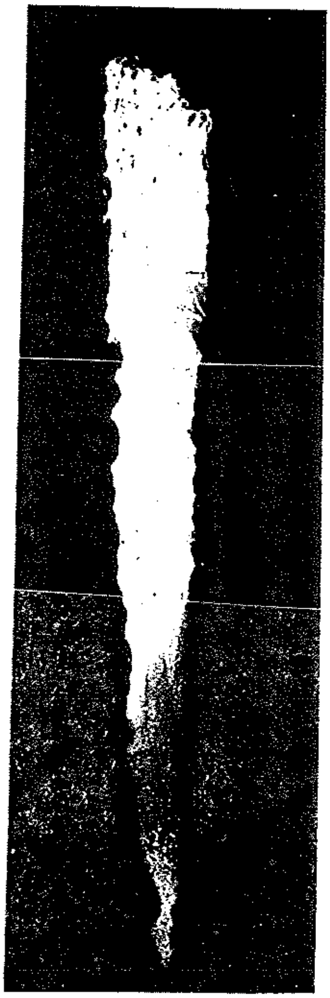


Plate VI : S2. Composite Photograph (x.11)
(Etch 2% Nital).

A microhardness traverse was also carried out and the results are shown graphically in Figure 5. The results are in agreement with those in Table II, though the microhardness results give slightly higher results.

S3 - (X-Section)

This section cut the corroded zone indicated by the radiograph. The corrosion did not extend uniformly through the blade, one side being more heavily corroded, and hence part of the cutting edge survived. The overall structure was similar to that of S2 (see Figure 3) a tempered martensite/bainite cutting edge, a 45^{o} angle weld line, a piled structure parallel to the weld line, and then a thick oxide layer extending horizontally through the knife, (identified on the radiograph). The piling direction became vertical above this line. Both piled structures were of ferrite, pearlite, and some slag inclusions. The pearlite content of the upper piled structure gradually reduced higher up the strain, in a uniform manner to give a boundary line running parllel to the weld line. The remainder of the knife was ferrite with slag inclusions in lines. The slag lines continued in the vertical direction of the piled structure. The back of the blade had been deformed by hammering, which was clearly visible by the splayed form of the back and the elongated grains.

Hardness tests gave the following results

Table III

	Hv_1
Back of Blade (hammered)	178
Piled structure	148
Cutting Edge (Martensite)	636

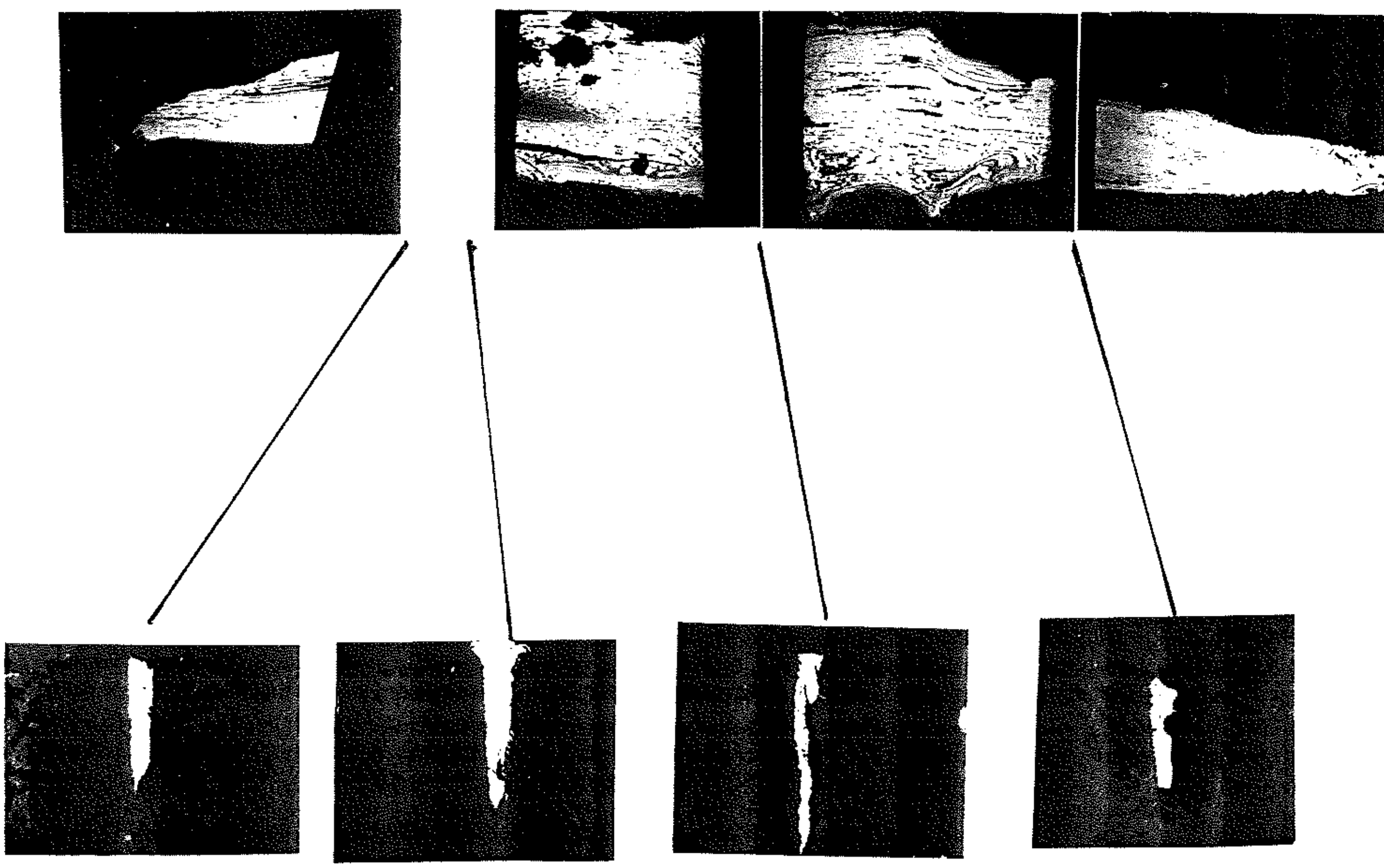


Plate VII : Montage of 8862. (x.1.5)
(Etch 2% Nital).

S4 (flat)

The section encompassed the area of heaviest corrosion, much of the cutting edge was absent, and the crack or weld above the corrosion, recorded by the radiographs was also present.

The cutting edge that did survive was primarily bainite, most of the martensitic structure is assumed to have corroded away. The bainite/piled boundary is distinct, though not sharp, there is no evidence of a 'slag weld line'. The transformation from bainite (plus some ferrite) to ferrite plus degraded pearlite at the grain boundaries occurs over only two or three grains, the corrosion front had also stopped at this boundary, and the remaining structure is similar to that of S3. The lower mid-knife region being piled ferrite/pearlite with slag lines and inclusions. The carbon content varying throughout, and finally declining to give a ferrite plus slag structure for the knife back. Hardness tests are as follows :-

Table IV

	Hv_1
Piled Ferrite	133
Piled Ferrite + Perrite	192
Cutting Edge	341

S5 (X-Section)

A section cut into the area of the corrosion showed much of the cutting edge is absent. The overall structure is the same as S3, but there is no clear distinction in the piling direction as observed in S3 above the cutting edge. In S5 there is evidence in the form of an intermittent slag line to suggest a weld line between the two areas of piling, though the piling lines show little change across the weld line.

The hardness results are also similar to S4 and are as follows:-

Table V

	Hv_1
Ferrite (piled)	165
Ferrite plus Pearlite (piled)	244
Cutting Edge (surviving)	380

S6 (flat)

Section S6 shows the blade/tang interface. The overall structure appears to have changed - the cutting edge has corroded at the edge/tang interface and only a bainite/ferrite structure survives. The reminder of the back of the blade is mostly ferritic with a small amount of pearlite dispersed, and fibrous slag inclusions cut longitudinally by the section. The structure runs into the tang. There is a small are of ferrite/pearlite piled structure between the blade and the ferrite structure, which also forms the 'cutting edge' of the tang. The pile lines at the tang (piling)/cutting edge/blade (piling) junction are complicated, and do not clearly indicate as to whether the tang (piling) and the blade (piling) is a continuous structure.

The hardness tests gave the following results :-

Table VI

	Hv_1
Ferrite	192
Piling (F+P) cutting edge	218
Piling (F+P) tang edge	182

S7 (X-Section of Tang)

The tang section shows a piled structure consisting mainly of ferrite and cross sectioned slag stringers. There is some piling of ferrite and 'pearlite'.

Hardness Results

Table VII

	Hv_1
Ferrite + Pearlite	265
Ferrite	160

S8 (Tang - flat)

The sectin shows the same structure as that of the tang section of S6. A ferrite and degenerated pearlite piled structure on the lower edge, and a ferrite plus slag stringers and some pearlite as the remaining structure.

The hardness results are as follows :-

Table VIII

	Hv_1
Ferrite + slag region	190 (mean)
Ferrite + pearlite "	263

The Overall Knife Structure

In general three microstructure are present in the knife.

(1) The Cutting Edge

A tempered martensitic structure with an average hardness of $Hv_1$644, resulting from the hadening and tempering of a carbon steel. This 'steel' strip is welded to the body of the knife (structures II and III) and then hardened and tempered. The weld line is not horizontal but angled at about 45^{o} from the vertical, this gave two advantages, firstly a greater area for weld contact, and secondly a stronger weld to transverse forces.

(2) Piled Ferrite and Pearlite Structure

These structure were achieved by inter-leavig strips (or plates?) of high carbon and (in effect) zero carbon wrought iron, i.e. steel and wrought iron. They were heated and welded together by hammering, this would not only produce a strong weld but would thin the strips down. The repeated heating and hammering would cause the carbides (Fe_3C) to segregate from the ferrite giving a degenerated pearlite when examined microscopically, culminating in segregation of the carbides at the grain boundaries, or spheroidal carbides.

Since the piled structure is a series of strips welded together it is difficult to identify the welding together of two piled structures.

Both S2 andS3 display two piled structures of different orientation Whether these represent the welding together of two piled structures or slight orientation difference within a single piled structure is not yet certain.

(3) The Ferrite Structure

The ferrite regions normally contain a small quantity of degenerated pearlite, but can be considered as pure wrought iron. The iron contains a large number of slag stringers orientated longitudinally. The overall structure is that of a piled structure, i.e. strips of wrought iron welded together, whether this occurred during the iron making process or as a stage in the knife manufacture cannot, as yet, be determined.

Nor is it clear whether the ferrite-pearlite and the ferrite structure are the result of a single piling operation, as opposed to the welding together of a wrougth iron with a piled steel.

The six blade sections contained all three structures, while the martensitic cutting edge was absent from the tang as is expected. The structures throughout the knife are shown in Plate VIII.

Manufacturing Method of Knife 8862

The knife was made of the three components listed above. It is not yet understood whether the ferrite and piled steel represent one overall structure or two structures welded together. They formed the overall shape of the knife, i.e. blade and tang section. The slag stringers can be clearly seen in S6 (Plate VII) to be running from the blade to form the tang. The cutting edge was scarf welded to the back, and the whole knife heated but only the blade was quenched, thus giving the hard martensitic cutting edge. The blade was then tempered.

The Chemical Analysis of Knife 8862 (by Scanning Electron Microscope and Electron Probe Microanalysis)

These results represent initial analyses, fuller analyses will be obtained at a later date.

The metallographic analyses of the knife sections (S1-S8), shows that these are three basic structures encountered, ferrite, (F) piled ferrite/pearlite, (F/P) and tempered martensite (M). The chemical analysis were directed to the investigation of these structures (EPMA and SEM) and the slag inclusions (SEM).

The EPMA results for the three structures in S3 are given in Table IX, they are obtained using the EPMA in the line mode (rather than the spot mode) so that a larger area is analysed. To obtain a mean analysis of the piled structure the line traverses the direction of piling at right angles, so that both a ferrite and pearlite structure is analysed. The tabulated results are a mean of seven individual line readings.

Quantitative analyses of other sections is currently being undertaken, but all specimens have been qualitatively scanned for all elements down to Magnesium, and only Phosphorus has been detected significantly above background.

Table IX

EPMA Results 8862 S3

Elemental %

		Fe	P	Ni	Si	Si	Total
Ferrite	Structure	99.48	0.03	0.03	0.06	N.D.*	99.60
Ferrite/Pearlite	"	98.88	0.09	0.05	0.03	0.03	99.08
Martensite	"	98.42	0.04	0.06	0.05	0.06	98.63

Individual EPMA results will provide information when related to a corpus of data, but no discussion can arise from a single set of results. However it is interesting to note the low phosphorus content of all three areas. This is uncharacteristic of early iron, (which is often at the 0.1 to 0.3% level), but not unique. The value for the ferrite region is of particular interest since the hardness values are of the order (Hv 150-200), from which a phosphorus content of 0.1% plus may be expected. This discrepancy will be investigated, though a possible explanation would be the presence of Arsenic.

* Not Determined

The result of Energy Dispersive quantitative analysis using an S.E.M. are shown in Table X and XI. Results are given to only one decimal place (i.e. 0.1), and a zero value indicates results below this level.

Table X is a set of results from different areas of the piled ferrite/pearlite structure. The results indicate that an error of 0.2% on all elemental readings (except iron, which will be greater). The rapidity of the techique allows elemental distributions above 0.5% to be investigated, e.g. any segregation of phosphorus.

Table XI are results from the three idfferent structure in S3. The results and deviations are similar to those in Table X, but both sets of results suggest higher concentration of phosphorus and silicon than were measured by the EPMA.

The presence of Arsenic is indicated by the SEM in the cutting edge, but is absent from the remainder, EPMA analysis will be required to confirm its presence.

Table X

S1 SEM Analysis of Piled Ferrite/Pearlite

% element

	Fe	Si	P	S	Ti	V	Cr	Mn	Ni
(1)	95.5	0.5	0.2	0	0	0	0	0.1	0
(2)	100.8	0.1	0	0	0	0	0.1	0	0.2
(3)	99.7	0	0.1	ND	0	ND	ND	0	0.2

Table XI

8862 S2 SEM Analysis

Elemental %

	Fe	Mg	Al	Si	P	S	K	Ca	Ti	V	Cr	Mn	Ni	As
Ferrite	100.5	0	.2	.5	.2	.1	0	.1	.1	0	0	0	.1	0
fferrite/Pearlite	98.0	0	.1	.4	.2	0	.1	0	.1	0	0	0	0	0
Martensite	94.8	0	.1	.6	.1	0	.1	.1	0	.1	0	0	.1	.1

Three semi-quantitative analyses of single phase slag inclusions in the piled ferrite/pearlite area are given in Table 12.

Table 12

% Total

	Al	Si	P	K	Ca	Fe
Inclusion 1	0.2	41.2	0.1	0.8	5.4	52.1
Inclusion 2	0.2	39.0	0.0	0.9	6.0	53.9
Inclusion 3	0.3	30.3	0.0	1.1	4.1	64.1

Summary of Chemical Analysis

The analyses from the EPMA and SEM do disagree, principally on the phosphorus content. The accuracy of the EPMA greatly exceeds that of the SEM and these results are accepted. The discrepancy in these results is still being investigated. The low percentage of phosphorus is of interest and there may be reason to look towards Scandinavia as an ore source. Though considerably more analysis would be required.

Knife 8862 Conclusions

Knife 8862 was manufactured by scarf welding a steel strip to a piled iron. The piled structure may have been manufactured in one piece which included large areas of ferrite, or it may have been produced by welding a wrought iron back to the piled strip. Initial chemical analyses indicate that all irons are low in phosphorus.