AML Report 4415 Site Nº 173

Analysis of York Knife 9045

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January 1984

Plate I   Knife 9045 (scale cms)

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Analysis of York Knife 9045, York Lab No AP87

Knife 9045 is a Type D (Ottoway) aproximately fourteen centimetres long and with a constant blade width of 1.5 centimetres. The blade is seventy-five percent of the surviving length, (the tang is incomplete and would need to be three centimetres longer for the blade to be sixty percent of the length as in Knife 8862).

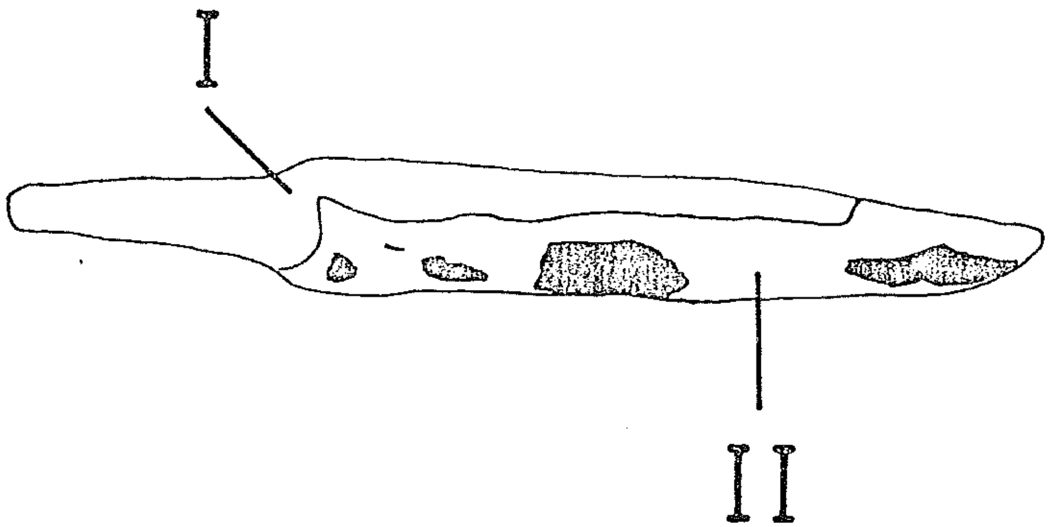
Surface Examination (Plate I)

The knife appeared to be well preserved except for the end of the tang and a circular hole in the centre of the blade, at which point there was also evidence for corrosion of the cutting edge. There was 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 & III, Figure 1)

Four radiographs were taken at different KV (60, 65, 70, 75) with the exposure maintained at 12 mA Mins. A fifth was exposed at 60 KV for 10 mA Mins. Plate I (60 KV for 12 mA mins) shows the areas of the heaviest corrosion. The hole observed in the surface examination (Plate I) is clearly visible in the centre of the heavy corrosion midway along the blade. Further towards the tang, there is another 'hole'. Heavy corrosion occurs at the tip and towards the tang. Slag or weld lines can

Figure 1. Interpretations of X-Radiographs



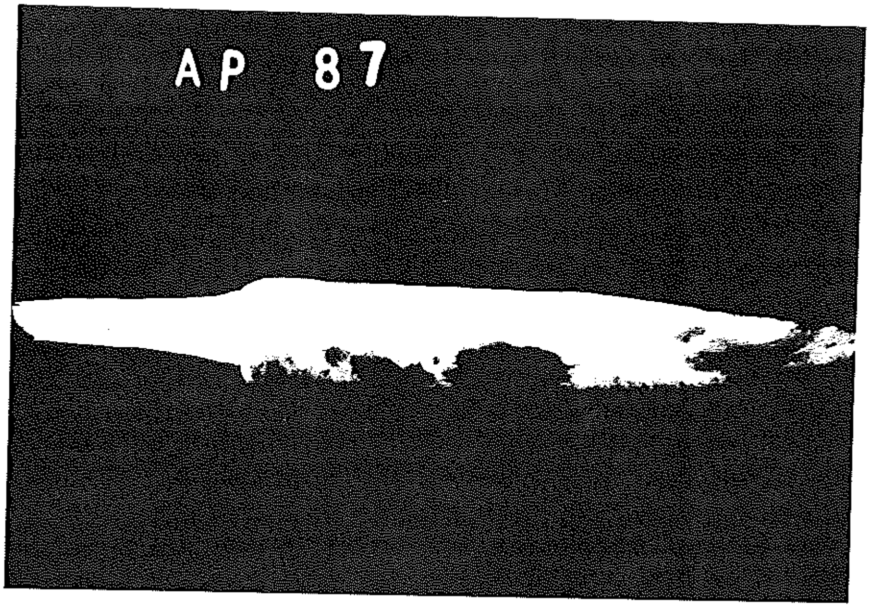


Plate II X-Radiograph (60 KV 12 mA mins)

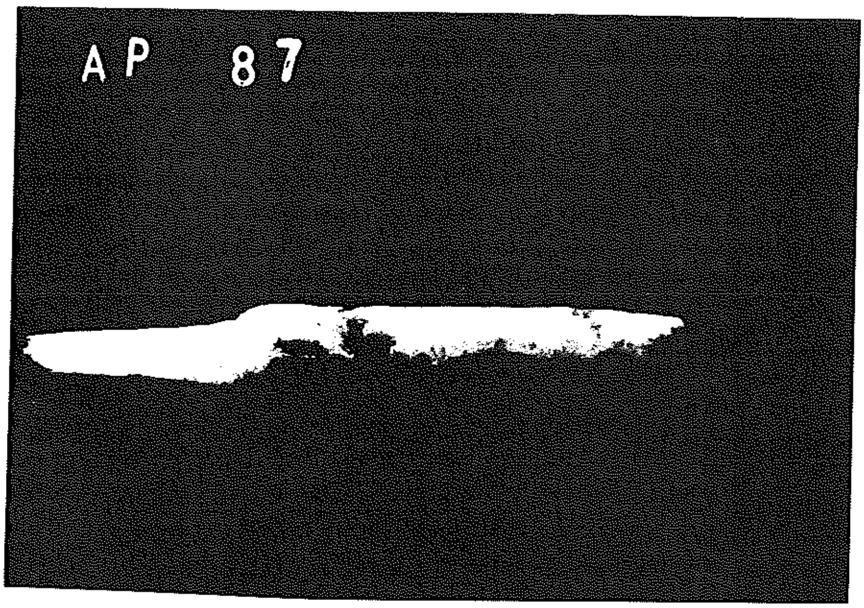


Plate III X-Radiograph (70 KV 12 mA mins) be observed in the partially corroded areas, ie. white lines in grey (eg. at the tip). These are more clearly observed in Plate III (70 KV for 12 mA/mins. The lines run along the blade and are compressed into the tang. The radiographs indicate the presence of two irons of different characteristics. The first area (Iron A, Fig. 1) forms the tang and knife back, it contains slag stringers and/or weld lines and/or piling lines and appears to be more resistant to corrosion. The second area (Iron B, Fig. 1) forms the cutting edge and point and has suffered the heaviest corrosion. The difference between Irons A and B may in part be due to the thickening of the knife towards the back, though the differences can still be seen in Plate I, (the lower energy radiograph).

Sectioning of the Knife (Fig. 2)

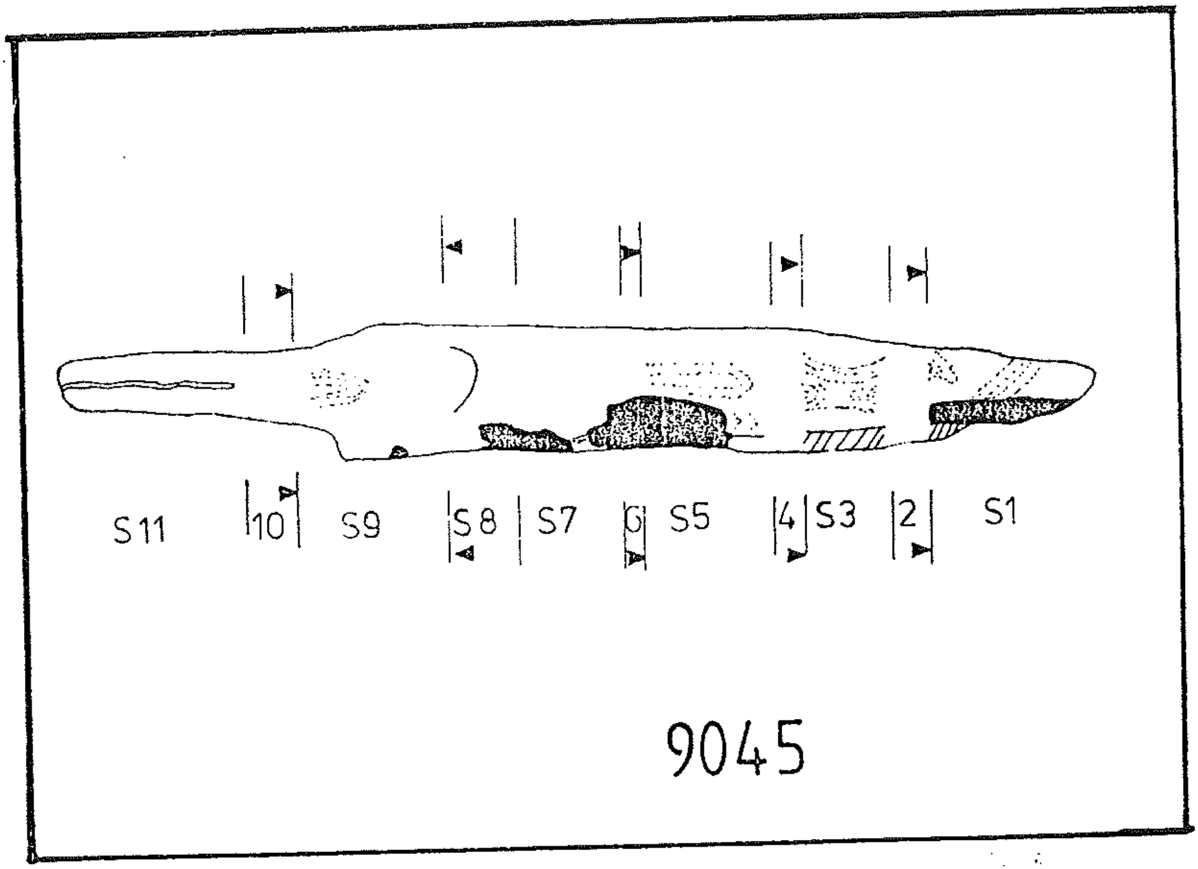
The knife was sectioned alternatively by longitudinal section ('flats') and transverse cross-sections. Eleven sections in all were mounted in conducting bakelite and polished in the usual manner and examined using the standard metallurgical microscope. Figure 2 also indicates the extent of the heaviest corrosion (black), the cutting edge (hachures) and piled structure (stippled lines).

Metallographic Examination

SI - flat, (the knife point)

The knife point had suffered heavy corrosion, such that over 50% of the polished section is missing. The cutting edge was nearly totally absent, and only represented by corrosion products which were plucked out during sample preparation. The back of the blade survived as banded areas of ferrite and degraded pearlite, ie. a piled structure. It would appear from the pattern of the corrosion that the ferrite structure (ie. pure wrought iron) is corrosion resistant though there is some penetration

Figure 2. Sections of Knife 9045



pile lines and especially at ferrite/pearlite, interfaces. A micro-hardness transverse was not considered worthwhile and values for the piled structure are as follows:

Table I - Piled Structure

		HV_1
Ferrite region	-	267
Pearlite region	-	380

S2 - (X-Section)

Evidence of corrosion was present in S2, the section appearing as two halves divided by a band of corrosion. The overall manufacturing technique was visible in this and other cross-sections. It was made by sandwiching the high carbon cutting edge between two strips of wrought iron, as shown in Figure 3. The wrought iron has a ferrite with slag stringer microstructure, while the central cutting edge is a piled structure of pearlite and ferrite with some slag lines.

Little of the tip survives but the evidence indicates a structure similar to that of 8862, ie. tempered martensite.

Since the actual cutting edge was absent only hardness tests could be carried out on the wrought iron and the piled structure. The results are shown in Table II and transverse and longitudinal microhardness transverses are shown graphically in Figure 4.

Table II

		HV_1
Wrought Iron	-	175
Piled Core	-	290

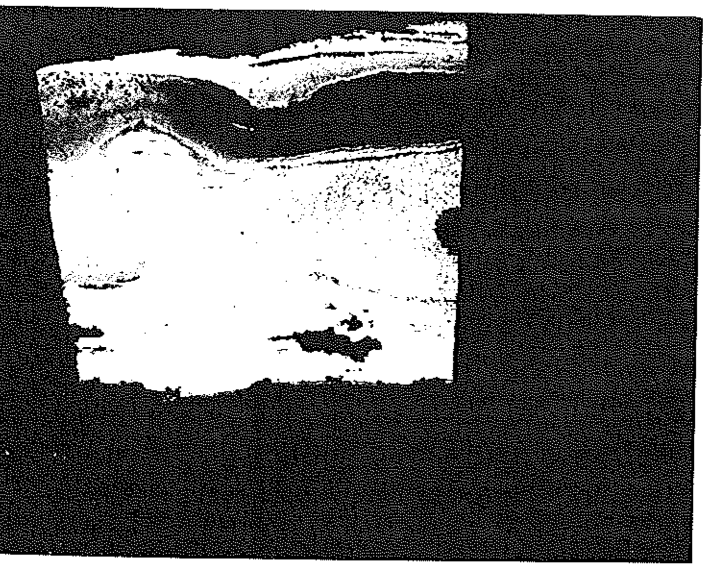


Plate IV S3, (x5) Note Cutting edge (black), piled structure (grey/white) and ferrite (white) above cutting edge

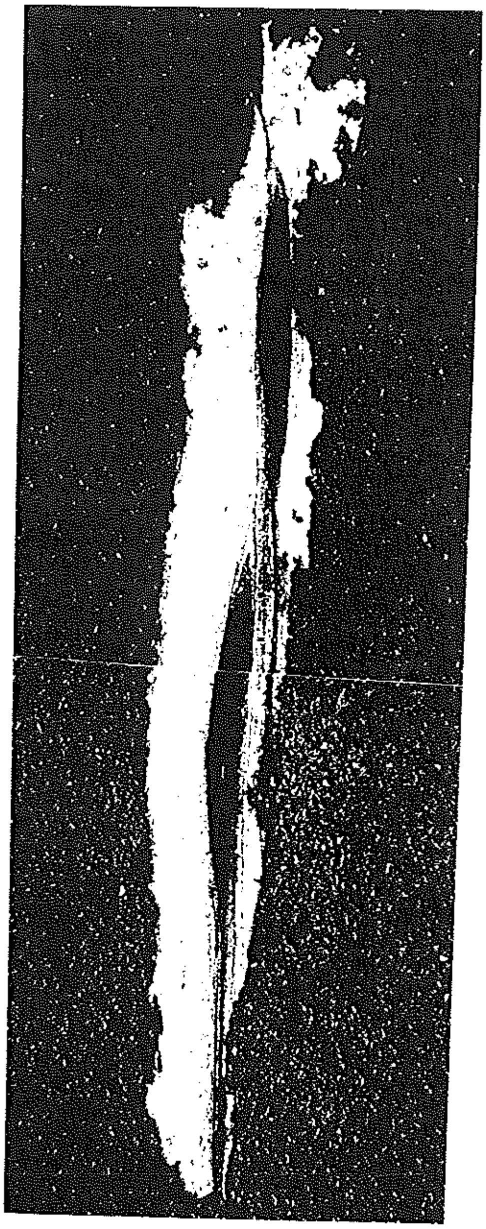
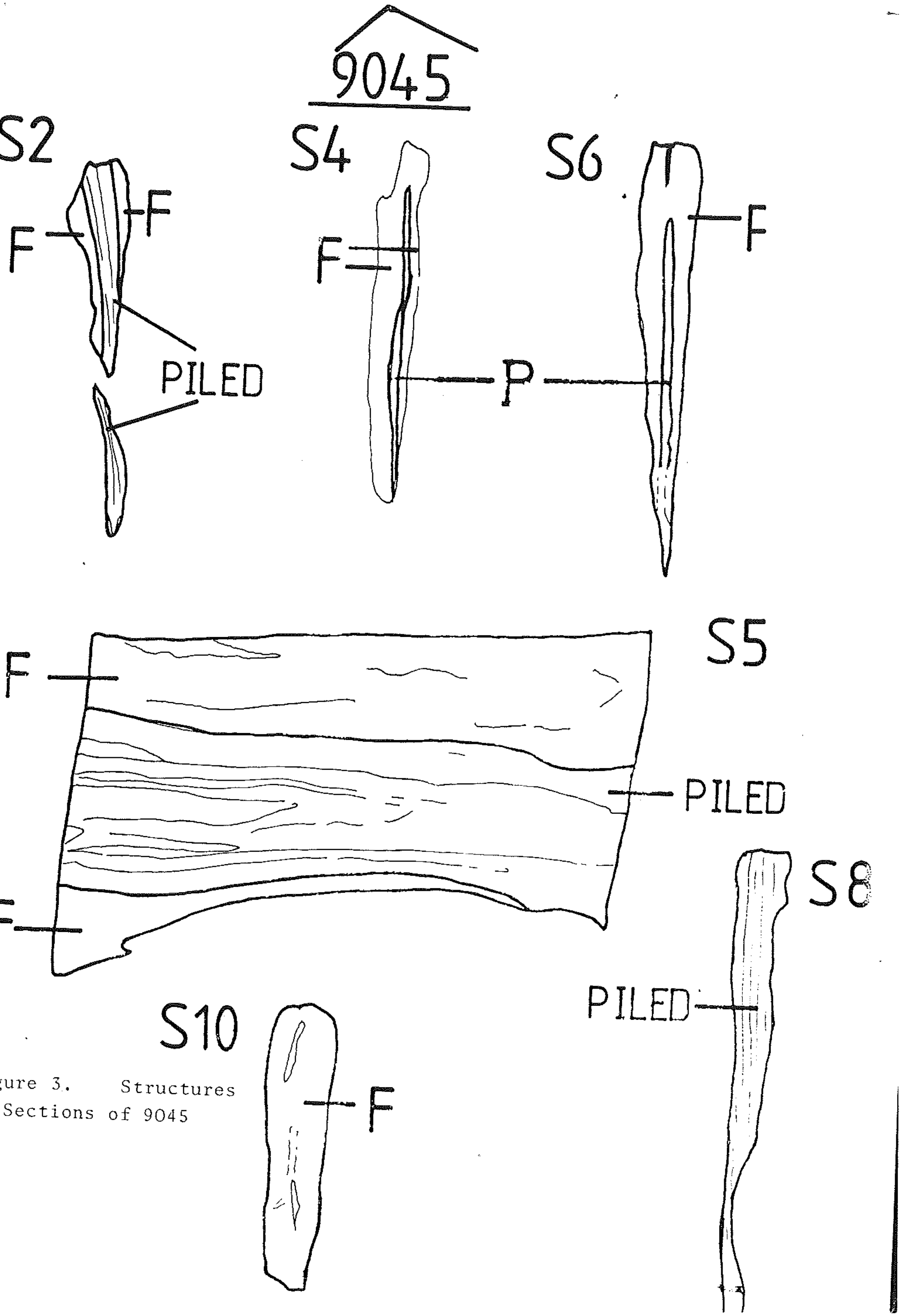


Plate V S4 - Composite (x10.8) Note pearlitic core (black) and piled wrought iron



gure 3. Structures
Sections of 9045

S3 - (flat) (Plate IV)

Section S3 was less corroded and part of the cutting edge survived. In the etched condition, four structures could be identified. Firstly, the high carbon martensitic cutting edge, secondly, a band of wrought iron that is probably a remnant of the wrought iron sheath to the carbon core. There is a distinct weld line of intermittent slag inclusions and carbide structures between the wrought iron and the third structure which is a ferrite and degenerated pearlite structure. The fourth is a pearlite structure running through the ferrite/pearlite structure. Structures three and four form the piled higher carbon core of the knife which in turn emerge as the cutting edge, structure one. The cutting edge also shows evidence of piling in that it is banded at the structure one/two boundary.

The range of hardnesses are shown in Table III below:

Table III

	HV_1
Wrought Iron	175
Cutting Edge	480
Piled	180
Core	400

Table IV

	HV_1
Wrought Iron	230
Decarb band	225
Pearlite	336

S4 - (X-Section) (Plates V, VI, VII)

Section S4 is similar in all respects to S2 (Fig. 3). A sheet of wrought iron envelopes a higher carbon piled structure which forms the cutting edge. As in S2, the actual edge is absent due to corrosion. Decarburisation occurs at both edges of the core structure, but there is no evidence of weld lines in the form of slag inclusions. There are slag lines running through the wrought iron and probably derive from the

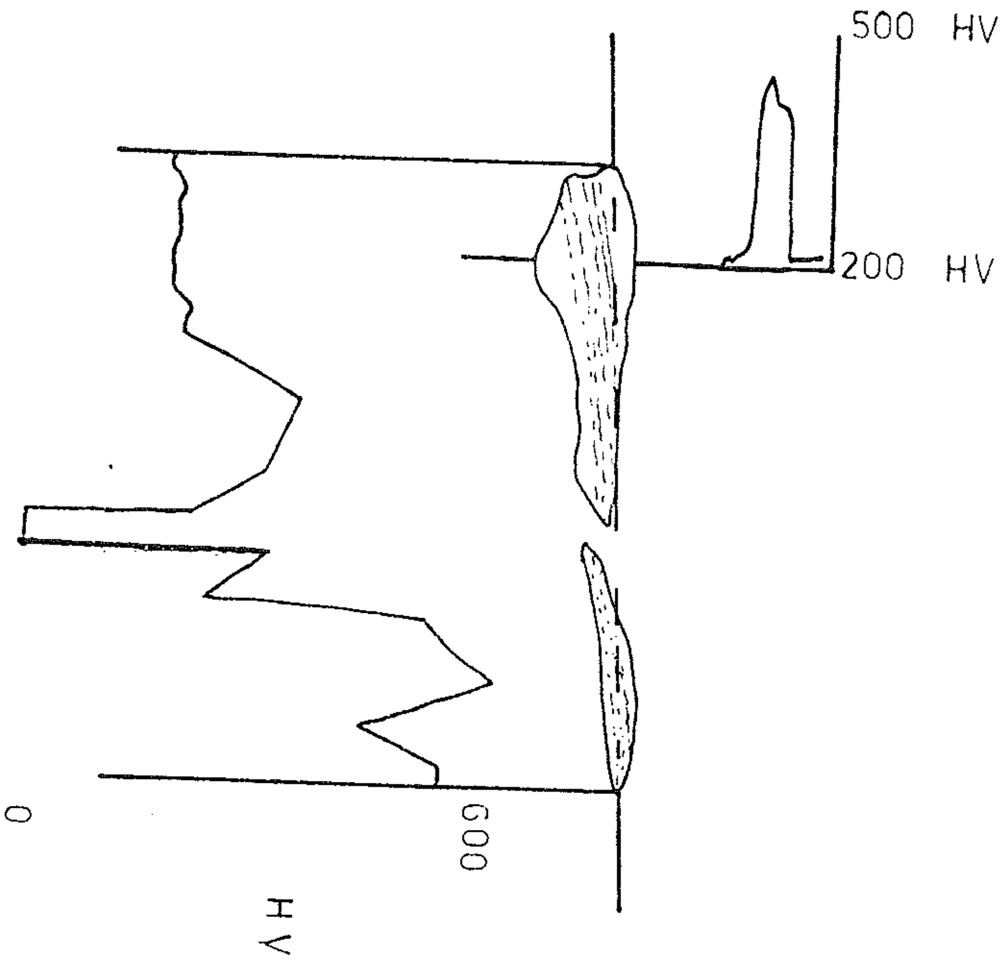


Figure 4. Microhardness Transverses S2

working of the iron during fabrication. Table IV lists microhardness results (above).

S5 - (flat)

S5 encompasses the area of heaviest corrosion and the cutting edge is totally absent. In the etched condition, three structures can be distinguished. The first is a ferrite structure next to, or in place of, the cutting edge. It is the wrought iron sheath surrounding the higher carbon core. The core does not lie centrally between the wrought iron sheath, this is particularly well illustrated in S4, Fig. 3, where the ferrite, on one side, extends as far as the surviving cutting edge, while the cutting edge is exposed on the other. Structure two is a higher carbon pearlitic structure, showing evidence of decarburisation on each edge, and also displays a piled structure. The third structure is of ferrite with a typical slag distribution. The succession of the structures is probably due to the section not being prepared as a longitudinal cut through the knife, but at a slight angle, thus exposing the ferrite sheathing on the cutting edge and the back of the knife. The hardness tests gave the expected results and are listed in Table V.

Table V

	HV_1
Ferrite (back of knife)	214
Piled Structure	375
Ferrite (cutting edge)	257

S6 - (X-Section) (Plate VIII)

The overall structure is similar to that of S2 and S4, of a wrought iron sheath cladding a piled higher carbon core. The cutting edge has suffered from corrosion and there is a crack running between the top of the piled

Plate VI S4 - Piled structure (x84)

Plate VII S4 - Piled pearlite/ferrite boundary (x336) structure to the top of the back of the blade. There is evidence of decarburisation at the core and a weld line. Hardness results are similar to those of the other specimens.

S7 - (flat)

Section S7 is uncharacteristic since there is only a small band of pearlite in the region of the cutting edge, the remainder being a typical ferritic structure of wrought iron. The pearlitic band may have extended further but has been replaced by corrosion products. The overall ferritic structure may indicate that the section has cut through the wrought iron sheath only and not the piled core. Slag lines do not run only longitudinally through the structure, but are folded, probably as a result of the original working of the wrought iron. Hardness of the ferrite is in the range of 150 - 200 HV_1. This section is recorded at this thickness and will be polished back to expose the core structure, if present.

S8 - (X-Section)

S8 is similar to S7 in that the structure comprises only of ferrite and slag inclusions with very small quantities of pearlite present. It would indicate that S7 will be, at least in part, wholly ferritic. The structure of S8 does not suggest a piled structure. The heavy corrosion, just above the tip (Fig. 3, S8) could suggest the location of a higher carbon structure, ie. the cutting edge. The hardness values are of the same order as S7.

S9 - (flat, tang-blade junction)

Section S9 exhibits a primarily ferritic structure, but with some piling of pearlite and ferrite. There is no evidence of the structure of the cutting edge. There are areas of severe corrosion within the structur but the most noticeable feature is an S-shaped weld line that runs fro the top of the back of the blade and through the centre of the tang/blac interface and then runs along and parallel to the tang. This weld must b associated with the tang/blade joint but it is of poor quality.

S10 - (X-Section - tang) (Plate IX)

The tang cross-section shows a ferritic structure with a number of wel lines, defined by intermittent slag lines often associated with pearlite and a region of piled ferrite and pearlite. The principal weld runs dowı the centre of the section but does not completely bisect the section suggesting that the strip was folded over and then welded. The S-shapec weld of S9 shows as a transverse weld that starts just below the surface is slightly U-shaped until it meets the centre weld. This is probably the end of the folded strip. On the opposite side of the centre weld is a series of parallel welds, of finer quality, the piled structure and a poor weld running at an angle from the central weld to the surface. The welds showing in the tang cross-section do not make clear whether the tange was made by folding a single strip of metal longitudinally or whether several strips were welded together. Hardness tests show the ferrite to have values of HV180 and the pearlite associated with the welds of HV220-230. The three major welds are generally of poor quality being heavily slagged, and formig a coarse line with voids. The association of the pearlite and slag inclusions is of interest since decarburisation is generally expected with weld lines. The pearlite bands are thin and the slag inclusions can be as large as 50% of the band width, thus the true relationship between the slag and the pearlite is difficult to understand. The overall impression is that the slag inclusions/lines result from the welding together of high and low carbon strips, ie. piling and the slag should lie between the two bands rather than in the pearlite or the ferrite.

S11 - (flat - tang) (Plate X)

Section S11 exhibits the same structure as S10. Its structure is ferritic with some pearlite/ferrite piling. The U-shaped transverse weld present in S10 (the S-shaped weld of S9) ran the length of S11, and had resulted in corrosion penetration at the broken tang end. Hardness values for the structures were between HV 170 - 200.

The Overall Knife Structure (Plate XI)

There were three structures present in the knife:

(I) The Cutting Edge

A tempered martensitic structure that had suffered heavy corrosion resulting in the actual cutting tip being absent. This structure formed part of the central core.

(II) The Piled Structure

Piled structures of pearlite/ferrite or martensite/ferrite formed part of the central core. Also some piled structure is present in the ferrite sheath and tang.

(III) The Ferrite Structure

The ferrite structure normally contained a small amount of degenerated pearlite, but can be considered a typical wrought iron structure ie. ferrite grains with slag inclusions. The inclusions are commonly orientated and form lines and stringers, resulting from the manufacturing process or the welding of strips of wrought iron together, (ie. piling of wrought iron).

Manufacturing Method of Knife 9045

The knife was simply manufactured by the preparation of a high carbon strip (Structures I and II) to form the core of the knife, which was sheathed by a V-folded wrought iron strip (Structure III), which also

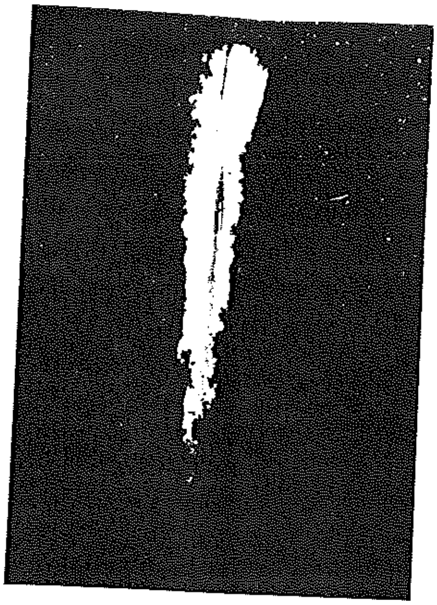


Plate VIII S6 (x5) Note pearlitic core

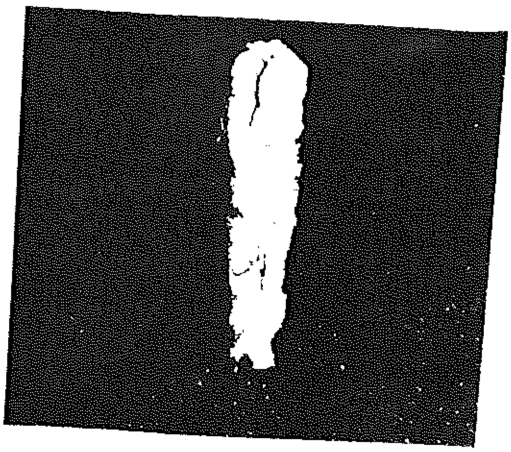


Plate IX S10 - (x5)

Plate X S11 - (x5)

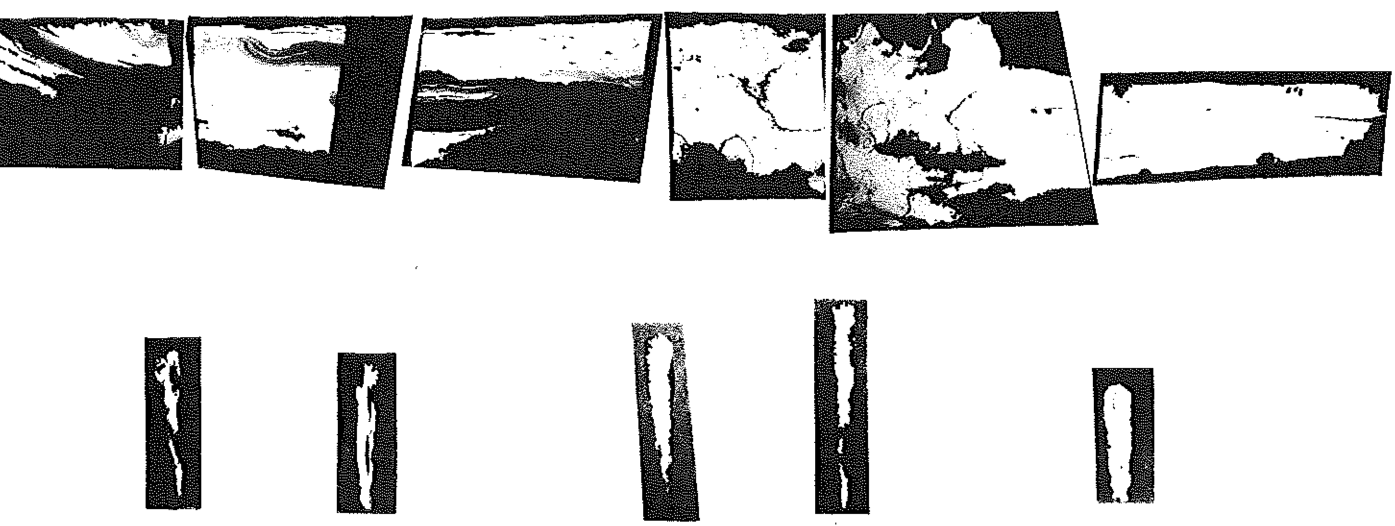


Plate XI   Knife 9045, Composite

formed the tang. The sheath and core were welded and the cutting edge protuded beyond the sheath. The core did not extend the full length of the knife, extending from the tip as far as S7, ie. approximately 70% of the blade length. The evidence of S8 may suggest that the core thins down and occupies one side of the cross-section as far as the tang, ie. instead of being in the centre of the sheath, the cutting edge forms one face of the sheath. This would account for its absence from S9 and the information from the radiographs (Plates II and III) which indicate that the cutting edge extends from the tip to the tang.

The Chemical Analysis of Knife 9045 (by EPMA and SEM)

The metallographic analysis of the knife sections show that there are three basic structures, tempered martensite, and piled ferrite/pearlite which formed the core and the cutting edge, and the ferrite structure forming the sheath and tang. The chemical analysis was directed to the investigation of differences, if any, between the core and the sheath. Analytical methods were the same as used for Knife 8862.

Elemental scans of the core and sheath from different specimens showed consistent results. No elements except Iron, Phosphorus and Silicon were significantly above background to be detected. The silicon was probably due to the presence of slag inclusions, since in carefully selected inclusion free areas very low silicon contents were recorded. The silicon content is liable to vary considerably due to the presence or absence of small inclusions. The traces showed the presence of high (and varying) phosphorus contents in the ferrite areas, but was absent from traces of the core structure.

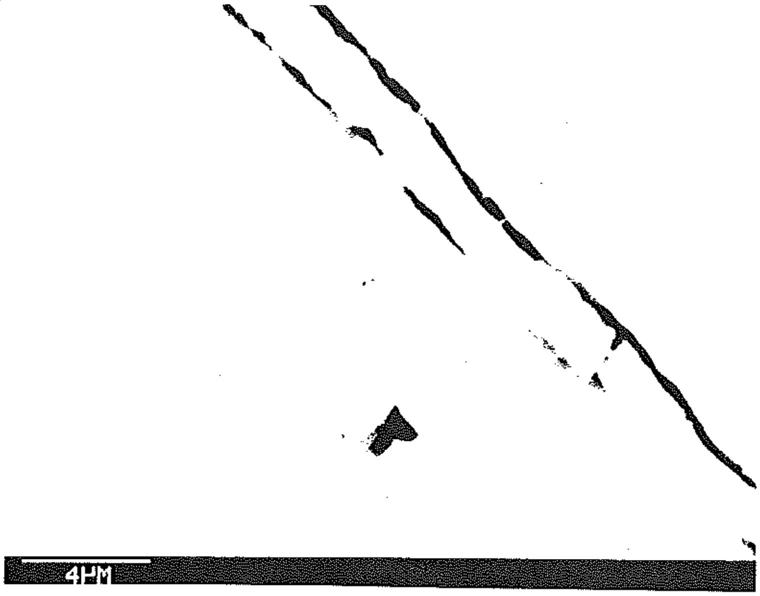


Plate XII Slag Inclusion (single phase) SEM Electron Image

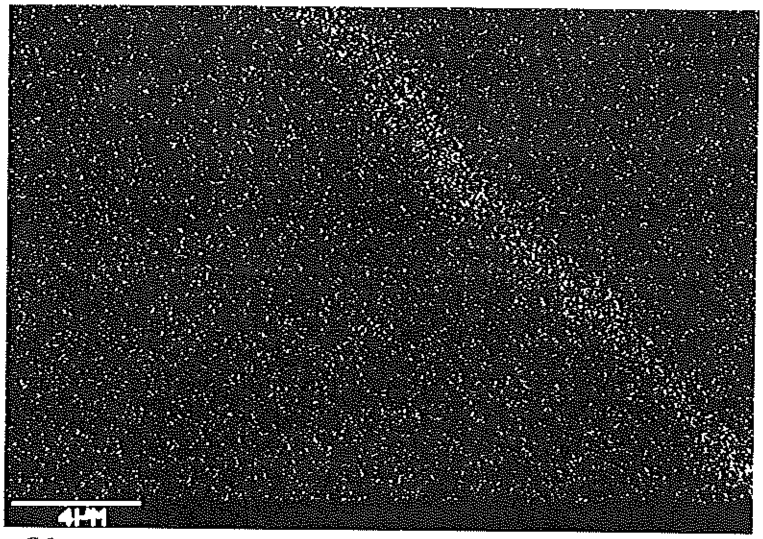


Plate XIII Slag Inclusion (single phase) Si Distribution
(white dots = Si X-rays)

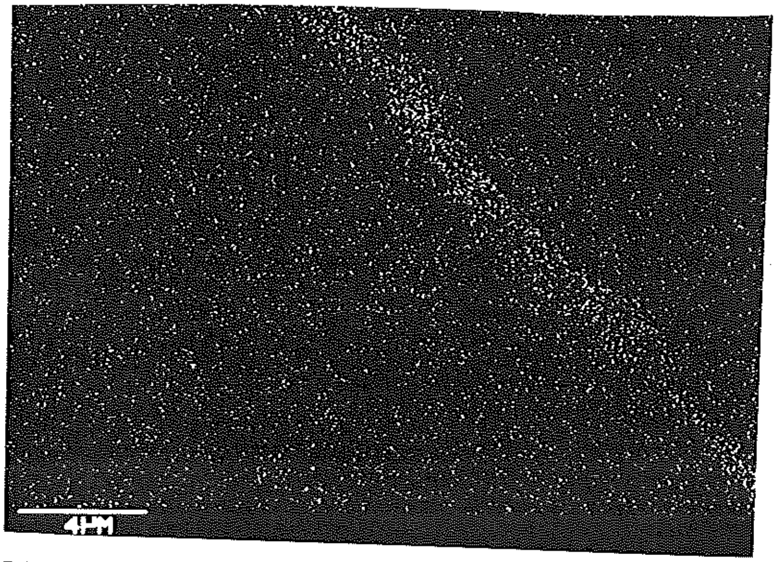


Plate XIV Slag Inclusion (single phase) P Distribution
(white dots = P X-rays)

SEM Slag Inclusions Analyses (Silicate Phase) in Knife Y09045

Table IX - Steel Core

	S6				S3		
Incl. No	1	2	3	4	5	6	7
Mg	0.3	0.6	0.2	0.3	0.4	0.3	0.2
Al	2.2	2.6	1.9	3.2	2.7	2.6	1.8
Si	12.6	15.6	12.8	10.5	11.3	11.6	10.0
P	1.1	0.2	0.1	2.0	1.4	2.0	1.1
S	ND	ND	ND	ND	ND	ND	0.1
K	1.8	1.9	1.6	1.1	0.9	1.0	1.0
Ca	1.1	1.1	0.8	0.8	0.6	0.7	1.3
Ti	0.2	0.3	0.1	0.1	0.2	ND	ND
V	ND	ND	ND	ND	ND	ND	ND
Cr	ND	ND	0.3	ND	ND	ND	0.1
Mn	9.0	9.6	6.0	0.5	0.9	0.9	0.7
Fe	44.9	31.2	51.1	50.9	45.3	46.6	48.2
Co	ND	0.1	ND	ND	ND	0.9	ND
Ni	ND	ND	0.1	NA	0.1	0.8	0.1
Cu	ND	0.2	ND	NA	NA	NA	NA

Table X - Ferritic Sheath

	S6		
Incl. No	8	9	10
Mg	ND	0.2	0.1
Al	3.7	5.8	3.0
Si	11.4	14.4	9.6
P	2.2	2.7	2.3
S	ND	0.2	ND
K	1.1	3.0	1.0
Ca	0.7	2.1	0.7
Ti	0.2	0.4	0.1
V	0.1	0.1	ND
Cr	ND	ND	0.1
Mn	0.6	0.7	0.6
Fe	45.7	33.1	50.2
Co	ND	ND	ND
Ni	0.2	ND	ND
Cu	0.1	0.1	ND

ND - Not Detectable (below background)

NA - Not Analysed for

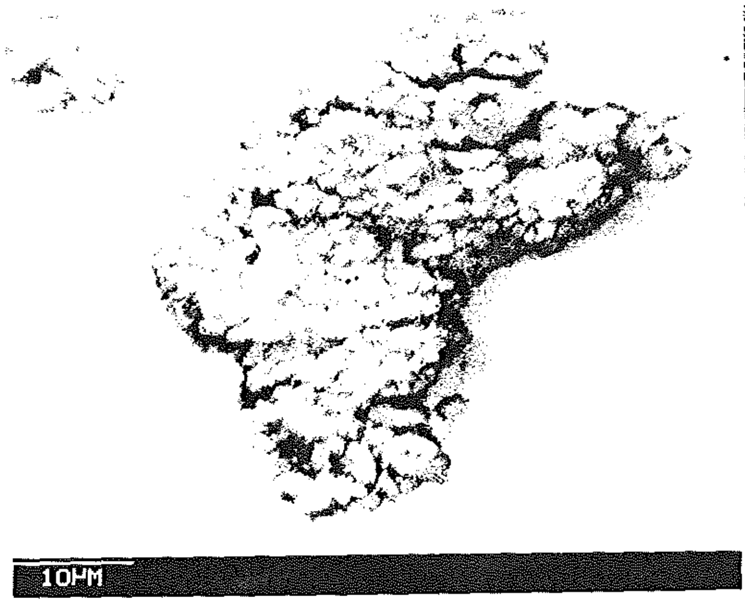


Plate XV Two-phase slag inclusions at core/sheath interface

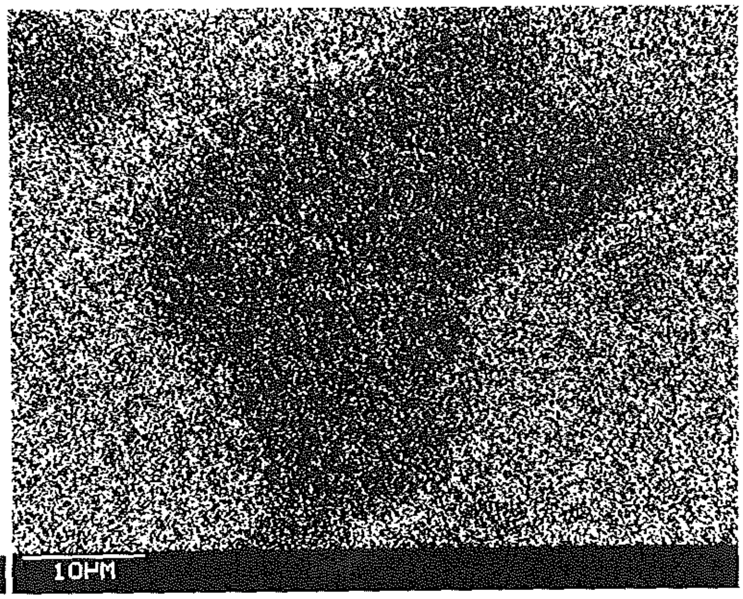


Plate XVI Two-phase slag inclusions at core/sheath interface Fe-distribution

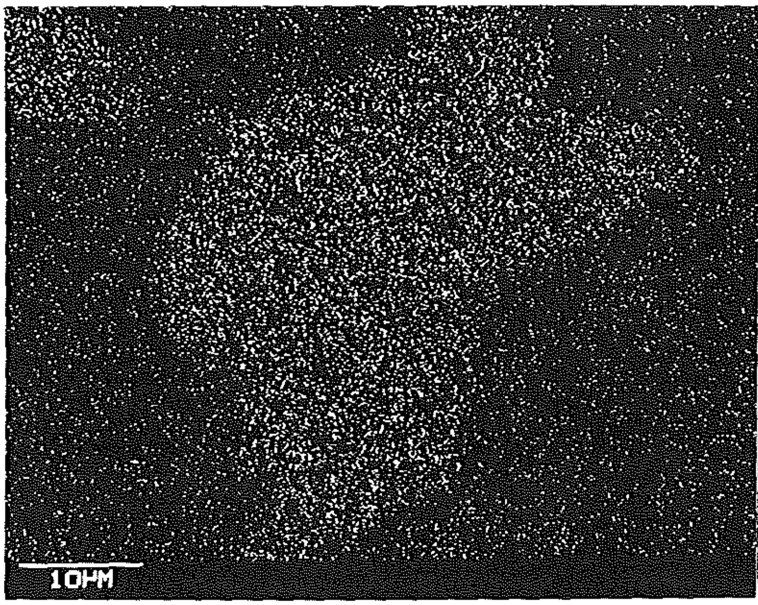


Plate XVII Two-phase slag inclusions at core/sheath interface P-distribution

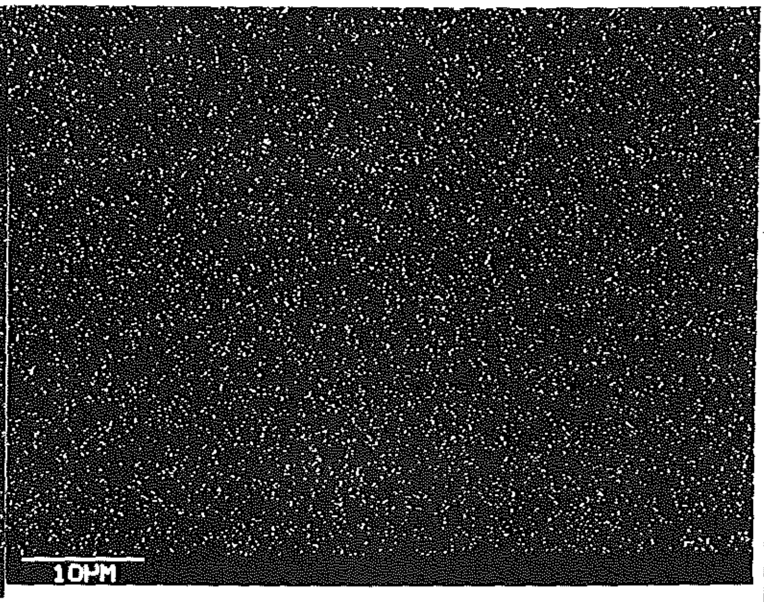


Plate XVIII Two-phase slag inclusions at core/sheath interface Ca-distribution

S3

Table VI

	Fe	P	Ni	Mn	Si	Total
Core (Tempered Martensite)	97.6	0.01	0.06	0.06	0.03	97.8

Table VII

		Fe	P	Ni	Mn	Si	Ti	Co	V	Cu	Cr
	S3	99.26	.21	.09	.04	.01	.01(5)	.05(5)	.01	.07	.01
Ferrite	S2	98.73	.21	.10	.04	.01	.01	.05	.01	.08	.01
region	S4	99.43	.22	.09	.04	.01	.01	.05	.00(5)	.06	.01
	S6	99.33	.21	.11	.04	.02	.01	.05	.00(5)	.08	.01

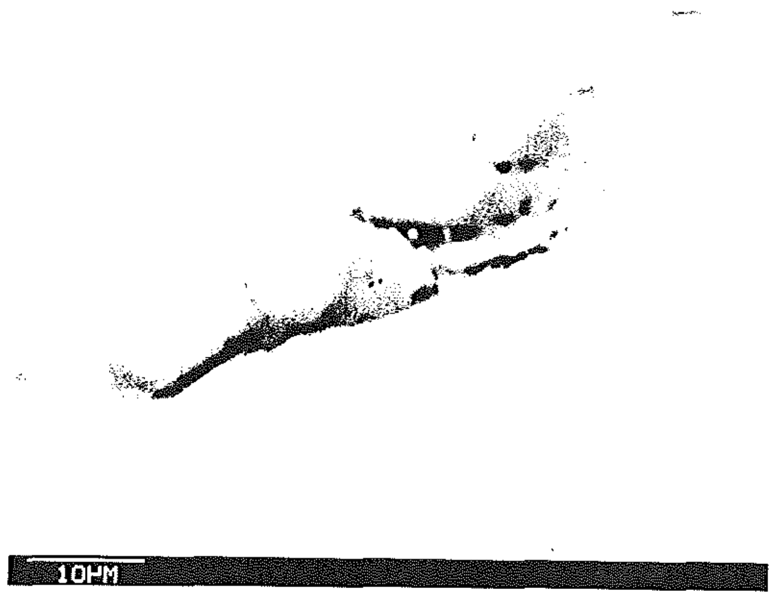
Table VIII

SEM Analysis of S3

	Fe	P	Ni	Mn	Si	S	Ti	V	Cu	Cr
Sheath (Ferrite)	98.8	.2	.2	ND	.1	ND	ND	.1	.1	ND
Core	99.12	ND	.1	.2	.2	ND	ND	ND	ND	ND

N.D. - not detectable (ie. below background level)

N.A. - not analysed for



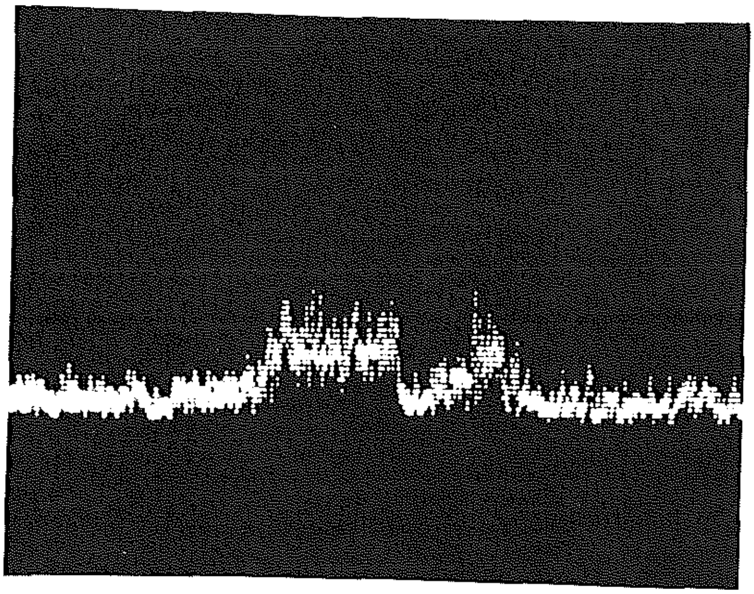
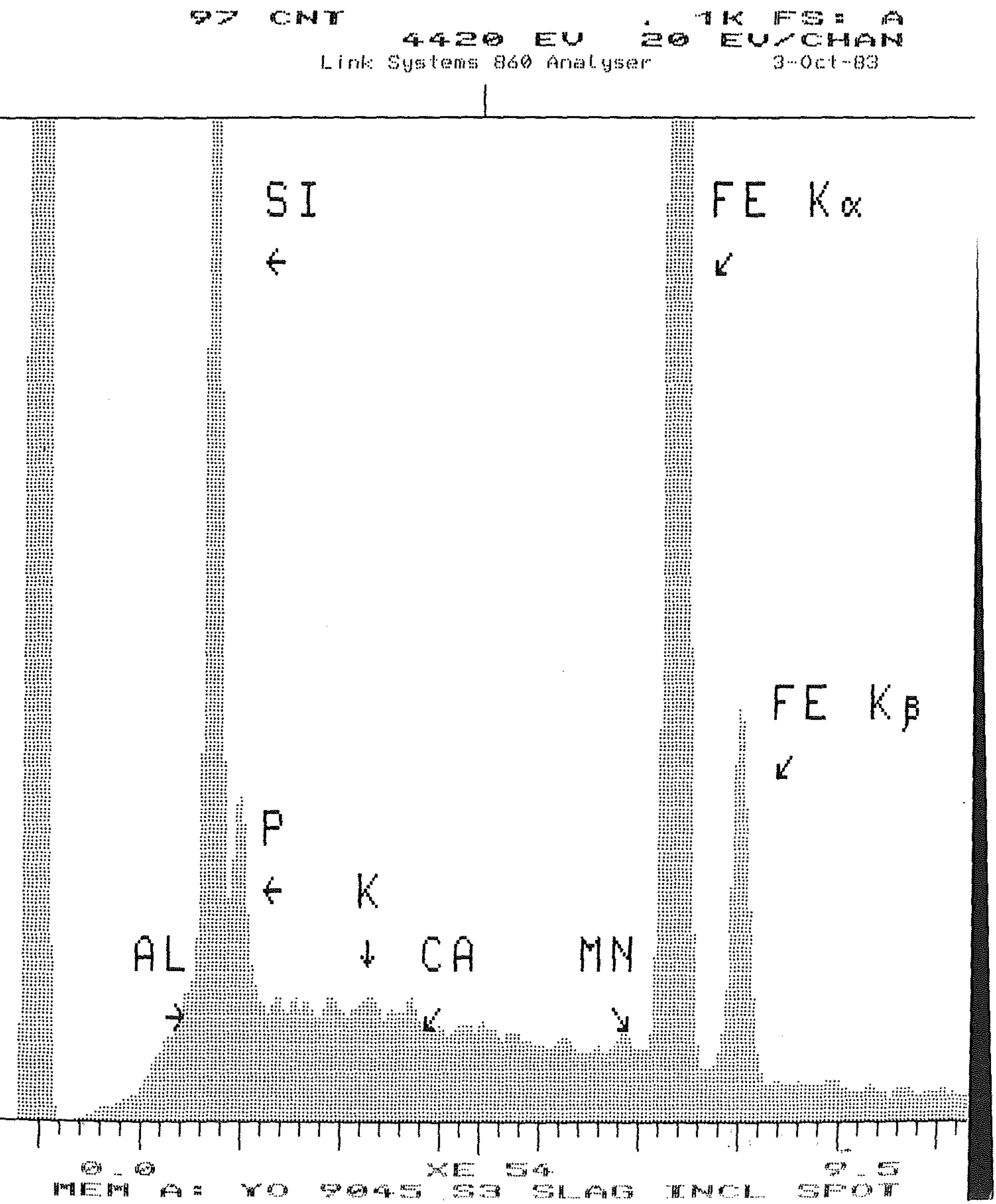


Plate XIX Single phase slag inclusion (core)

Plate XX Phosphorus concentration profile across the inclusion

Figure 5. Spot Analysis of Core Slag Inclusion



<u>Knife 9045 Conclusions</u>

Knife 9045 was manufactured from two irons, a higher carbon piled iron strip forming the core and cutting edge around which a wrought iron sheath was welded on, leaving the cutting edge exposed, enabling it to be heat treated. The high carbon areas are low in Phosphorus.

The standard limited analysis of the core structure from S3 is given in Table VI, the low phosphorus content (0.01%) is commonly found in ancient higher carbon irons. Analyses of ferrite regions in S2, S3, S4 and S6 are given in Table VII, and show very consistent results. The interesting analysis is that of Phosphorus (0.21%) twenty-times that in the core structure. Since Phosphorus is a ferrite former, and also makes the iron cold short, it would be highly detrimental to the cutting edge, thus either a low phosphorus ore is used and the iron produced from it is used exclusively as steel for cutting edges etc, or the phosphorus is removed from iron during its reduction from the ore, when steel is manufactured during the smelting process.

SEM Analyses of the sheath and core were in general agreement with the EPMA results (Table VIII).

Approximately fifty quantitative and semi-quantitative analyses of slag inclusions were carried out in both the ferrite and martensite regions (Table IX and X) and show a wide variation in slag composition. The slag inclusions are of two types, a single phase (a silicate composition) and multi-phase, (normally iron oxide FeO(?) and a silicate). The silicate phases in both slag types are of interest since they will contain the impurities within the slag

Inclusions from both the sheath and the core (Plates XII - XX, Fig. 5) have high phosphorus contents, sheath inclusions being higher (average 2.4% P) than the core inclusions (average 1.1% P). Therefore, the sheath inclusions contain approximately ten times more phosphorus than the surrounding metal (inclusion 2.4%, metal 0.2%) and those from the core about one hundred times (inclusion 1.1%, metal 0.01%).

Plates XII - XX show elemental distributions in three inclusions and the surrounding metal. The Phosphorus is concentrated in the slag. Plate XVIII shows that there is no concentration (as would be expected) of Calcium in the slag inclusion that may suggest the formation of Calcium Phosphate.

The Phosphorus distribution was also studied by etching Specimen S6 in Oberhoffers Reagent, which deposits copper preferentially on regions low in Phosphorus. The etchant distinguished between the core (low P) and the sheath (high P), but examination of some inclusions in the core showed areas of high phosphorus nucleation around the inclusions, (the inclusions do not react with the reagent). This concentration may be due to diffusion of Phosphorus from the slag into the metal during the working of the iron. The distribution of Phosphorus within the structures requires further work since it may provide answers to the question of whether low Phosphorus ores or dephosphorised irons were used.

The wide variation in Manganese (0.5 - 9.6%) cannot be explained but its concentration in the slag is to be expected.

<u>Summary of the Chemical Analyses</u>

The higher carbon core iron is low in Phosphorus while the ferritic sheath has more typical Phosphorus content. Slag inclusions from the two different irons vary in composition but a very high Phosphorus content (< 1%) is not uncommon.