Nails from the wood panelled nave ceiling of Peterborough Cathedral

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Brian Gilmour

Introduction and background

A re-appraisal of the exceptional painted, wood-panelled nave ceiling forms part of the assessment of conservation work in this phase of the extensive programme of restoration within the Cathedral. The ceiling would appear to be a largely complete survival of the panelled and painted ceiling which was attached to the underside of the nave roof framework. A recent extensive dendro-chronological survey of the remnants of the medieval nave roof structure have shown that this was installed the period 1220 - 1230 (Tyers 1999). The nave is characteristically late Norman in style and the panelling was designed and painted in a repeating lozenge or diamond shaped pattern, done with perspective in mind, to give the impression of vaulting when viewed from the ground. It would appear that a stone vault was originally planned but that signs of instability in the walls forced a change of plan when the nave had reached roof height.

All that now remains of the original medieval roof structure are the parts to which the ceiling was fixed, although even some of these were replaced during later restoration or repair work. However, the ceiling itself appears to have survived more or less complete. Clearly this survival has involved later maintenance and restoration, but the extent of later work is uncertain, as is when it took place.

Once scaffolding was in place - firstly in the eastern half of the nave - close examination of the ceiling from above and below finally became possible. Apart from the inevitable restoration of some of the paintwork, it was clear that some panels had been taken out in the past and either put back, not necessarily in the same position, or replaced with newer panels. However, gauging the extent to which the original panelled ceiling had been previously taken apart and re-assembled, was found to be very difficult although it was noticed that several different types of nail had been used to attach the wooden panels to the framework above. It was realized that if these nails could be dated in some way then they might provide a method for separating and even approximately dating earlier phases of restoration to the ceiling. With this in mind the aim of this investigation was to take examples of the different types of nail used, identify the production technology in each case, and match the results with relevant known developments in iron production technology.

Since the panels were nailed from below, and given that the ceiling is suspended 25 m (80 ft) above the floor of the nave, it seemed unlikely that much work like this could have taken place except when parts of the nave were fully scaffolded. As far as could be seen from initial examination, three different types of nail had been used to fix the panels in place at one time or another, suggesting two main phases of restoration. It appears from Cathedral records that the nave was last extensively scaffolded in the early 19th century and earlier on during restoration work of *c*1740, but it is not known what happened before that. It is perfectly possible that the three types of nail used to fix various of the ceiling panels correspond to the three known main phases of work involving scaffolding in the nave but this cannot be assumed. To match the nails with these known (or any other) building phases the nails need to be dated.

Nothing is now left of the original medieval nave roof and even the main joists, from which the ceiling framework is hung, are replacements. The minor joists, which form the lateral struts of the ceiling frame, would all appear to be original. An original feature of the ceiling are a series of longitudinal-struts running between the minor joists and above the panelling. These are slightly odd because they do not all coincide with the panelling layout below, although they do where this is essential for the fixing of parts of the boards. They are of interest here because each end was jointed into one side of the minor joists by means of a birds beak-shaped joint and held in place with an iron nail. Some of these longitudinal struts had been removed, presumably during later restoration work, usually leaving behind the fixing nails when they were pulled out. Several of these nails were removed for this study.

Changes in post-medieval iron production and their detection

It is known from historical records that iron production technology went through a series of changes (in this country) during the post-medieval period, most markedly during the industrial revolution in the 18th and 19th centuries. The indirect production of plain iron (or wrought iron as it became known), by the 'fining' (oxidation) of cast iron in a special furnace known as a finery, followed the introduction of blast furnace technology into Britain which is recorded as having taken place in Sussex in 1496 (Tylecote 1976, 82). Before this, all iron in this country was made by the much more ancient 'bloomery' process. In this process iron ore was reduced directly to a malleable form of iron, during the smelting process, although what was left in the furnace was a porous, spongy iron mass which had to be hammered together, a procedure known as bloom consolidation, to rid it of most of the non-metallic slag with which it was mixed.

Iron produced by the bloomery process is usually distinctive in having an uneven metallic structure which can be recognized by metallographic examination (mainly by looking at a polished and etched section using an optical microscope). Even after bloom consolidation the iron will still contain a relatively small proportion of the non-metallic slag left over from the smelting process. The density, form and composition of these slag inclusions can be identified by metallography and (electron-probe) micro-analysis, which can also be used to measure the proportion of alloying impurities in the metal.

By about the middle of the 17th century (in this country) bloomery iron had been more or less completely replaced by finery iron although telling the two apart is not easy because the finery process re-introduces non-metallic slaggy material to the iron leaving it very similar to bloomery iron. However, much more oxidizing atmospheric conditions were used the finery process, leaving the iron with a much more even, more or less carbon free structure. Differences in the slag density, form and composition should be detectable by metallography and micro-analysis especially after the mid 1780's when developments in the finery process for making forgeable iron led to the introduction of the 'puddling' process in which the metal was separated from the fuel. Puddled iron continued to be made throughout the 19th century although after about 1860 it was gradually replaced by mild steel which is different in composition and comparatively free of non-metallic inclusions.

The purpose of the present investigation was to identify the structure and determine the composition of each type of nail, and match the results with what we can expect from known details of the history of iron production technology.

Technological investigation of the nails

The eight nails examined in this investigation were selected on site. Four pairs of nails were chosen, each pair consisting of two good examples of each of the four varieties of nails observed in the ceiling. They were chosen from known positions and are thought likely to represent two different parts of the original ceiling structure, and two phases of later restoration, possibly those of *c*1740 and *c*1830. It was anticipated at the outset that more might need to be examined later depending both on the outcome of this investigation and on questions that arise as the restoration work progresses. All the eight nails were sectioned longitudinally and, in each case, the heads plus upper parts of the shanks mounted and examined metallographically, including a Vickers micro-hardness survey (for which a 100 gm loading was used in each case) across the structures observed in each section. The sections were all etched with 2% nital (nitric acid in ethanol). One of each pair was then subjected to electron-probe micro-analysis (EPMA), this part of the work by necessity being split into two parts; one involving the analysis of the metal at various points across a particular section, while the second entailed pin-pointing particular non-metallic inclusions and analysing these separately. The results of micro-analysis are shown in Tables 1-4 below. For the results of this part of the work to be valid the different types of inclusions present had to be approximately identified by eye (under the microscope) and then a representative selection analysed.

Nails thought to belong to the original ceiling structure

1. Ceiling panel fixing nails.

Nails identified as being used originally to fix the painted panels in position are typically about 50 - 52 mm (2 inches) long with a more or less square shank and a comparatively wide head, approximately 20 mm (¾ inch) wide, with a flattish convex profile. The shanks retain a squarish profile along most of their length, tapering from about 4.5 mm across at the top end the shanks, down to approximately 2.5 mm across at a position about 15 mm down the shank, and from there on taper more gradually, except near the tip where they are more pointed (Fig 1). For each nail the dimensions and profiles vary a little in just the way expected of hand-made nails, even where a particular pattern and size of nail was being aimed at. The two nails examined from this group were found to consist of rather variable low carbon iron, and although the structures varied quite widely in detail, they were found to be very similar in the type of iron used.

One of these (HM 57) appeared, at first glance, to be relatively even in structure when examined at low magnification as can be seen here in Fig 2a, which does however show a very uneven, but not very dense dispersion of non-metallic slag, here visible as black specks of very variable size and shape. However this overall appearance is misleading as the whiter areas represent more or less carbon free iron (ferrite), visible as medium to large grain ferrite when viewed at higher magnification (Fig 2b) whereas the slightly darker grey areas are actually fine gain ferrite with about 0.1% carbon (Fig 2c). This rather diffuse variability is fairly typical of a low carbon bloomery iron with very little phosphorus, as is its hardness which mostly varied within the range 95-110 HV.

The second of these nails (HM 55) was much more obviously variable in its structure as seen in Fig 3a. In this view the pale head of the nail plus the pale left hand side of the shank are made up of very variable plain iron with very large grained ferritic zones (ASTM 1-3) irregularly interspersed with medium grained areas (ASTM 4) together with scattering of mostly quite small non-metallic inclusions visible as tiny black spots in this view. A few much larger inclusions are also visible as longer dark streaks, mainly stretched out across the head of the nail. The appearance and hardness (approximately 150 -175 HV) would suggest that the pale parts of this nail consist of a phosphoritic iron but one with a very uneven phosphorus content mostly varying within the range 0.2-0.4%. By contrast the very much darker etched iron of the central and right hand side of the shank (as seen in Fig 3a), which is made up of fairly fine grain ferrite (ASTM 6) with more non-metallic slag than the paler areas, is much softer (with a mean hardness of 90 HV) suggesting this part of the nail to be made of a separate piece of iron very low in phosphorus. The clearly defined lines between the head and shank, as well as between the pale and darker sides of the shank might mark the position of welds. This and the dissimilarity of the iron of the adjacent pale and dark areas suggest the possibility that this nail was made of recycled iron.

The first of these nails (HM 57) was also analysed by scanning electron micro-probe (EPMA) which confirmed it to be made of iron not only low in phosphorus but generally low in alloying impurities (Table 1a). Most of the non-metallic inclusions are made up of iron silicates together with aluminium oxides and lesser but still significant proportions of magnesium and calcium oxides plus potassium levels strongly indicating the presence of potash which must have come from charcoal, in this case a residue of the fuel used to fire the bloomery smelting furnace in which the iron was made.

Overall, a combination of the appearance of the iron used for this nail plus the chemical profile of the non-metallic inclusions in the metal strongly indicates the use of bloomery iron to make this nail, and in this case there is no sign of the use of recycled iron. The second nail (HM 55) is clearly rather different in that it does appear to be made up of small recycled pieces of two different types of iron welded together, one relatively pure (ie low in alloying impurities) and the other consisting of iron with an inconsistent but generally quite high phosphorus content, probably around 0.3% and a non-metallic slag content again high but different in size and shape distribution. The general unevenness of the iron of the different parts of this nail would again suggest a bloomery origin for the metal. In both cases the nails are made of iron which is entirely consistent with the identification of these nails as being part of the original ceiling construction of 1220-1230.

2. Nails used to attach the birds beak joints of the longitudinal struts above the ceiling.

These nails are both bigger, heavier duty and different in shape to the nails used to fix the painted panels in place. They were approximately 80 mm (3⅛ inches) long, with a flat head about 15 mm across and rectangular section shanks, approximately 6 mm by 4 mm at the top, which taper down gradually towards the tip along both sides (Fig 4). In section the two nails of this type were also unexpectedly very different overall to the early panel-fixing nails examined. They both consisted of phosphoritic iron, which appeared relatively featureless at low magnification after etching, and both contain an uneven (both in terms of size and distribution) dispersion of non-metallic slag inclusions although, overall, there is relatively little slag present (Figs 5a and 6a).

In both structure and hardness the metal of these two nails is typical of iron high in phosphorus. The structure in both cases is uneven, typical of a bloomery iron, and consists of very large grain ferrite (ASTM 1-3), aspects of the structure of both sections are shown here in Figs 5a and 6a.

Micro-analysis revealed the iron of one of these nails (HM 60) to be low in all alloying elements except phosphorus for which the content was found to vary between about 0.1 and 0.7% with a mean of 0.4%. This corresponded well with the hardness values for this nail which varied between 162 and 212 HV with a mean of 183 HV. The second of these nails varied in hardness between 149 and 195 HV suggesting an overall phosphorus content of approximately 0.3 to 0.4%. Micro-analysis of the inclusions in the first of these nails (HM 60) showed these to be rather different to those in the panel fixing nails although the difference is not as great as might first appear (Table 2). The inclusions are again predominantly of silicates, this time with rather less though still significant amounts of magnesium, aluminium, calcium and potassium, the latter again the residue of potash from using charcoal as a fuel when making the iron, the main difference being a much higher phosphorus content, only to be expected for a high phosphorus iron. The compositional profile of these non-metallic inclusions as well as the uneven appearance and uneven phosphorus distribution are again typical for bloomery (ie directly smelted) iron.

Nails thought to belong to later restoration work on the ceiling

The other two groups of nails were examined to test likelihood that they to belong to later periods of restoration work and to see if there was any possibility of matching them to the work known to have been carried out in *c*1830 and *c*1740, or possibly earlier.

Probable 19th century nails

By far the most common and easily recognized of these two groups of nails was one with a shank of rectangular section (approximately 6 mm by 4 mm near the top) which was parallel-sided down the wide side and the shank only tapered down the narrow section (Fig 7). The tops of these nails measured approximately 15 mm across and with a distinctive, flattened pyramidal shape with four equal facets. Parallel-sided along most of its length the wide side of the shank ended in a sharp point and in many cases this end of the wide side was also slightly spade-shaped (Fig 7). These nails varied between about 65 and 70 mm in length.

When first examined at low magnification the first example of this type (HM 53) of nail was very obviously much more regular in overall structure along its length (Fig 8a). It had a distinctive, even stripy appearance with alternate pale and darker bands running exactly parallel to the (wide) sides of the shank. At higher magnification it is clearer that this nail is more or less carbon-free, consisting of large grain ferrite in the pale bands and medium grain ferrite along the darker bands. It also contains much more slag than the nails already described and the slag is much more evenly distributed across the section and much more elongated along the shank (Fig 8b). Slag can sometimes be expected in this quantity in poorly consolidated bloomery or finery iron but not elongated and distributed relatively evenly in the way seen here.

However this is a typical product of the puddling process and therefore unlikely much before 1784 when puddling replaced fining as the standard method for oxidizing cast iron to produce plain iron (Tylecote 1976, 111). Although more efficient overall, puddling had the effect of leaving the iron with much more slag in every case. Crucial to the success of the puddling process was the contemporary development of a more effective rolling mill, one with grooved rollers, which squeezed and broke up the large volume of slag which this process produced, into long discontinuous strands, while the iron was being formed into long rods. Iron rods of different sizes were produced and the iron used in this form depending on what was required. Although the final nails may still have been produced by hand the overall process was in part mechanized and the effects of this are visible in section.

More unusual for puddled iron is the alternate pale/dark banded appearance seen here in Fig 8a In the case of this particular nail metallography would suggest that the pale bands consist of large grain, phosphoritic iron and the darker grains to be medium to fine grain plain iron. However the slag distribution would suggest that all the iron is of puddled origin but it is less clear (at least at this stage to me) whether this separation is the result of combining two different batches of puddled iron before the rolling process, or whether it is possible for phosphorus in sufficient quantities to become partitioned into roughly equal zones within the puddling hearth. A more varied product of the puddling process is perhaps to be expected earlier on in the period of production, before the scale of output got bigger.

Electron micro-probe analysis confirmed that the laminated appearance of this nail in section is the result of bands of iron, alternately high and low in phosphorus, being present. Phosphorus levels for the pale bands are around 0.3% whereas for the darker bands the level is about 0.1% (although the results are interleaved and therefore not so obvious in Table 3). This might seem a tiny difference but the effects of phosphorus on the microstructure of iron become much more marked above about 0.2% as is clear in the case of phosphoritic iron nails (HM 59 and HM 60) used in the earlier 13th century birds beak joints in this roof. In compositional terms the slag inclusions in this stripy-section nail (HM 53) are all typical of iron produced by puddling and are quite different to those observed in the nails from the original ceiling construction. As expected the inclusions are mainly of mixed iron oxides and iron silicates but there is more uniformity in overall composition, and the quantities of alumina present are very low and magnesium is absent altogether. Crucially the potassium levels are very low indicating the use of a reverberatory furnace -central to the puddling process- in which the fuel is separated from the iron being produced.

The second nail (HM 56) of this group is a rather more typical product of puddled iron-making. It contains even more slag than the banded nail (HM 53) and its rather fibrous appearance in section at low magnification is the classic appearance of 19th century puddled wrought iron. The large quantity, distribution and very elongated appearance of the slag is again the typical of puddled iron after it has been through a rolling mill to produce long flat bars or rods. In this case the evenness of the nails in section would suggest that in this case that the metal was rolled into flat bars, perhaps around 50 mm (2 inches) wide which would then have been passed though a slitting mill to produce rectangular iron rods for the final forging of the nails. This type of iron was produced in increasing quantities from the late 18th to early 20th centuries, but the form of these nails plus the slightly unusual make-up of the first of these nails (HM 53) suggests an earlier rather than later date, perhaps in the first half of the production period, ie *c*1800-1850.

Probable 17th - 18th century nails

The second group of nails suggested as belonging to post-medieval restoration work was more difficult to sort out as far as identifying their specific type and likely period of manufacture. This was partly because two different sizes, of what are otherwise quite similar nails, seem to be involved (Fig 10). However, they look similar and the larger has a relatively narrow slightly faceted, domed or flattish head, approximately 10-12 mm across, and is approximately 70 mm (2¾ inches) long with a rectangular section shank (approximately 5 mm by 4 mm across near the top) tapering gradually on all four sides down to the tip. The other has a more obviously faceted head also 10-12 mm across with a similar shank except smaller. They are approximately 50 mm (2 inches) in length with a shank measuring approximately 3 mm by 4 mm across near the top. Before it was realized that two different types of nail might be involved here two nails only were chosen for metallographic investigation, which largely by chance happen to be one longer (HM 54) and one shorter nail (HM 58), although only the longer nail was also micro-analysed.

Even after examination by metallography and micro-analysis this longer nail is still something of a puzzle although, overall the quality of iron used is low. Unlike 19th century puddled iron which characteristically contains a lot of slag but evenly distributed and very elongated by its passage through rolling mills, the longer of these two nails (HM 54) clearly contains much slag although its distribution is very irregular and is mainly concentrated in the upper part of the shank and on one side of the head (Fig 11a). In section there is a tendency towards paler/darker banding across the head and down the shank, but this is not very pronounced and almost certainly the result of phosphorus segregation and the use of iron with an irregular phosphorus content. Electron micro-probe analysis confirmed the phosphorus content of the iron to be variable within the range 0.05-0.2% although there was little else in the way of alloying impurities.

Micro-analysis of the non-metallic inclusions revealed these to be much more like those of the puddled iron nails already described than those of the bloomery iron nails used in the original ceiling construction. There is however a much higher proportion of iron oxide in the inclusions of nail HM 54 and this is clearly visible in the section at higher magnification (Fig 11b). Like the puddled iron nails there is no magnesium, little aluminium and, perhaps more significantly, very little potassium. The lack of potash again indicates that the fuel was kept separate from the metal as the iron was being made, suggesting the use of a reverberatory furnace similar to that used for producing puddled iron.

Overall this nail (HM 54) is tricky to identify as far as its underlying technology goes. The lack of potash would suggest a reverberatory furnace-puddling origin but its appearance would suggest this nail to predate the later 18th century introduction of more efficient rolling mills. A more crudely rolled and slit piece of bar iron would appear to be indicated here and a 17th or 18th century date would be possible for this. Various attempts were being made to improve iron-making technology during this period, particularly later, and at the moment an 18th century date looks most likely for this nail although further work would be necessary to be more sure of this.

By its appearance in section the shorter nail also looks to be 18th century or earlier, and possibly is made of recycled iron. The outer parts appear to be made of an unevenly phosphoritic iron, with a hardness in different places in the range 130-180HV, suggesting a phosphorus content varying between about 0.2 and 0.4%. The central darker band, which fades out lower down the shank, consists of a fairly even fine grain, low carbon iron (ferrite with some pearlite), with a carbon content of about 0.1%, the highest of all the nails examined although still low. The structure and hardness of this area (112 HV) would suggest it contains very little phosphorus. Much less slag is visible in either area of metal and what is present is unevenly distributed and variable in size, although mostly quite small (Fig 12a). The non-metallic slag in the phosphoritic iron mostly appears to consist of smallish dark silicate phase inclusions, whereas the inclusions in the darker (pearlitic) central area show two phases, probably iron silicate plus iron oxide. A bloomery origin seems likely for the phosphoritic iron, but perhaps less so for the more pearlitic iron although this is far from certain.

The heads of these smaller nails are relatively uncorroded suggesting that they are comparatively recent and possibly much the same date as the longer nails (like HM 54) which they most closely resemble. Before we can be more sure about this last group of nails, which may in fact be two groups, at least one more nail of each of these types needs to be examined in detail and one of the shorter nails needs subjecting to micro-analysis. However at present an 18th century date seems most likely for both of them, but we cannot be sure at this stage. The reported restoration of *c*1740 would appear to be very likely to have involved the longer nails and possibly the shorter ones too, although a third phase of restoration, not yet identified, is also a possibility.

Overall conclusions

The technological work done so far on the nails from the nave ceiling shows that the nails used in the original ceiling strut, birds beak joints and the early panel fixing nails are made of different iron, but in both cases of bloomery origin, consistent with their early 13th century date. Of the other two groups of nails separated out for this investigation, the one with the most regular appearance, is identified here as being made of puddled wrought iron and is almost certainly the type of nail used for the restoration of *c*1830.

Roughly two thirds of some 60 odd nails recovered at random from the ceiling (because they were loose) were of this 19th century type which might suggest (?removal and) re-fixing of many of the original panels in that phase of work and therefore that a major programme of restoration work was carried out on the panelled ceiling at that time. It seems less likely that the later nails were just more prone to falling out than the earlier ones but a nail survey, if this can be done, might help to show how extensive the painted panels were reset in the earlier 19th century.

Less clear were the results from the second group of nails thought possibly to be part of another phase of restoration, possibly that said to have taken place in *c*1740. This is partly because it seems, somewhat belatedly, that we might in fact be dealing with two other groups of nails, similar looking, but one larger than the other. The larger of these two types looks a likely 18th century product although more work is needed to be more sure about this. The smaller nail seems unlikely to be earlier to be later than the 18th century and could be slightly earlier but more detailed analytical work is needed to understand this better. Two more nails would have been suggested for the present programme of technological if we had realized earlier that more than one size/type of nail was represented in what was isolated as one group.

Recommendations

At least two more nails from the present batch should be looked at with a view to solving the problem of the nails in the last group discussed above, and which may or may not both belong to 18th century restoration work.

If possible this programme of technological investigation work should be repeated when the scaffolding is moved further along the nave, both as a check on the results so far, and also to look at any anomalies that might be encountered, particularly if any kind of nail survey is attempted, which is also to be recommended if possible.

Acknowledgements

I would like to thank Chris Salter of the University of Oxford, Department of Materials for carrying out the electron-probe micro-analysis on the nails and for discussing problems relating to their manufacture.

References

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Tylecote, RF 1976: *A History of Metallurgy*, London: Metals Society.

Fig 1. Wide headed nails originally used to fix the nave ceiling panels in place in 1220-1230.

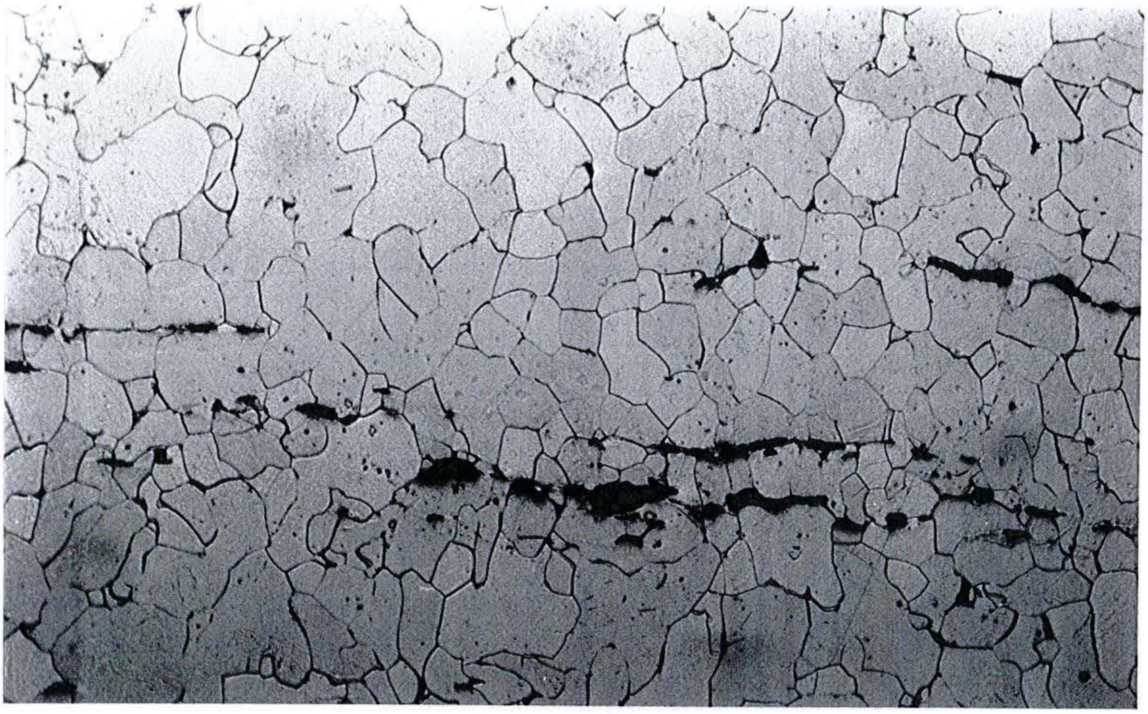

Fig 2c. Detail of the same section showing medium to fine grain ferrite plus pearlite (carbon content approximately 0.1% max): magnification x 200; etched 2% nital

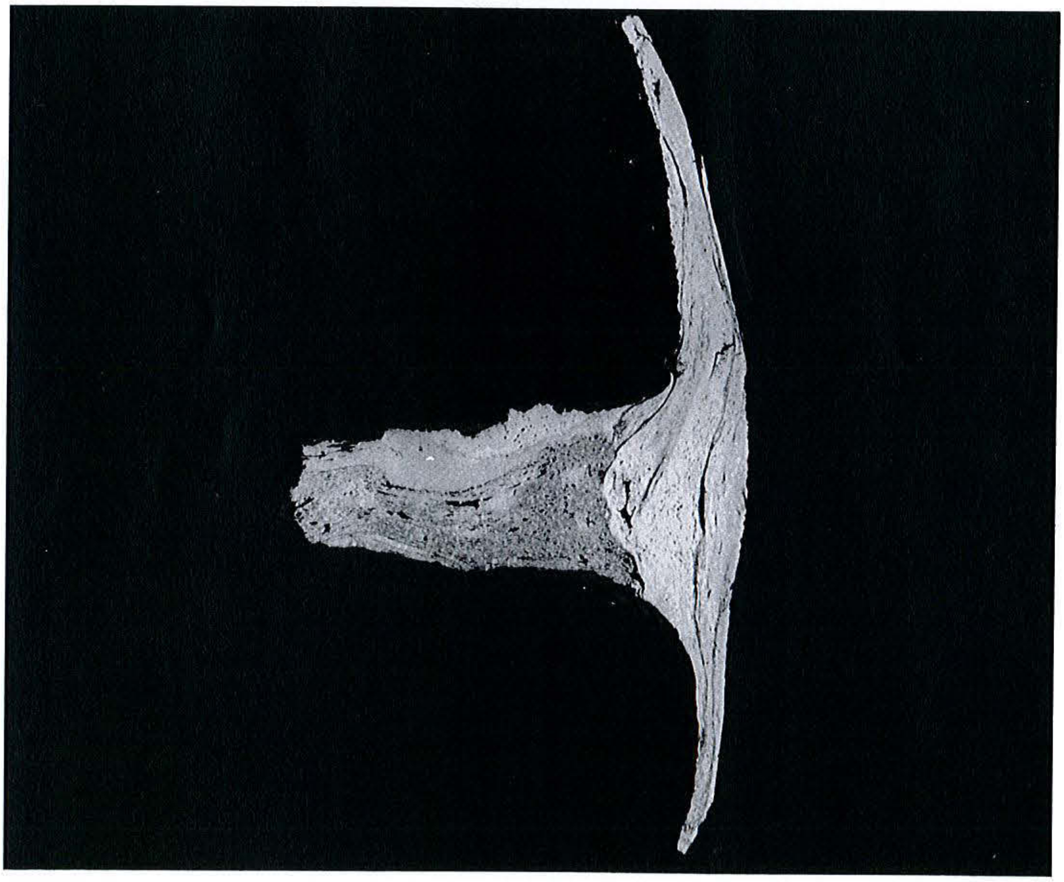

Fig 3a. Photomacrograph of a longitudinal section through a second early panel fixing nail: magnification x 6; etched 2% nital.

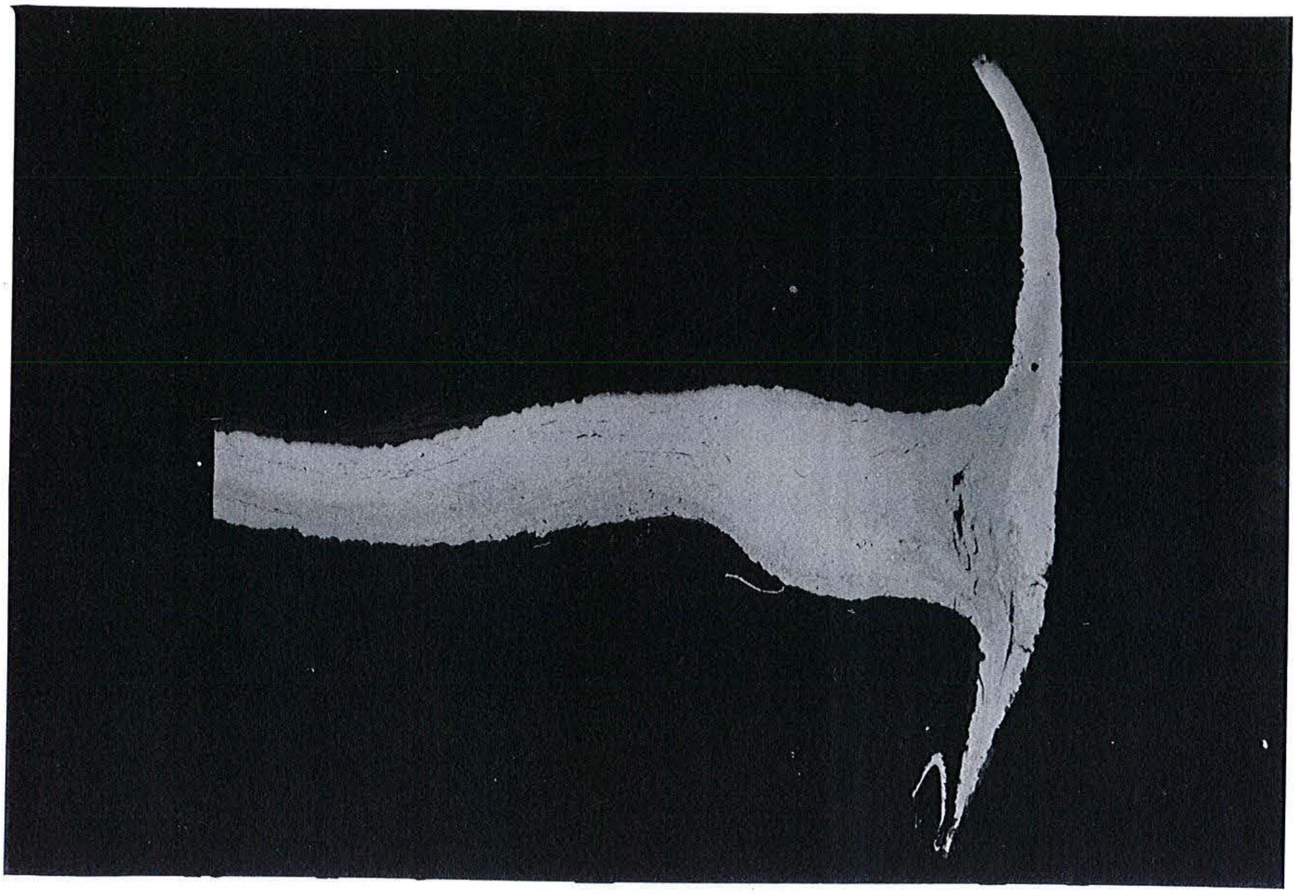

Fig 2a. Photomacrograph of a longitudinal section through one of the early panel fixing nails: magnification x 6; etched 2% nital.

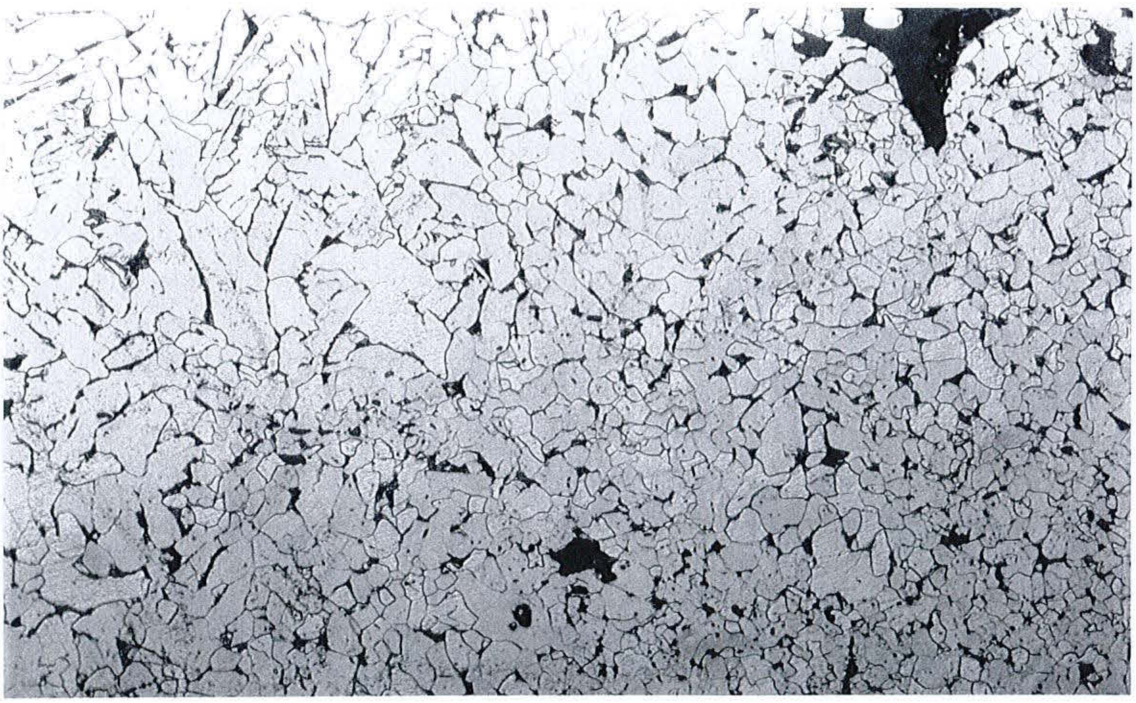

Fig 2b. Detail of the same section showing medium grain ferrite and some non-metallic slag inclusions of both one and two phases: magnification x 200; etched 2% nital.

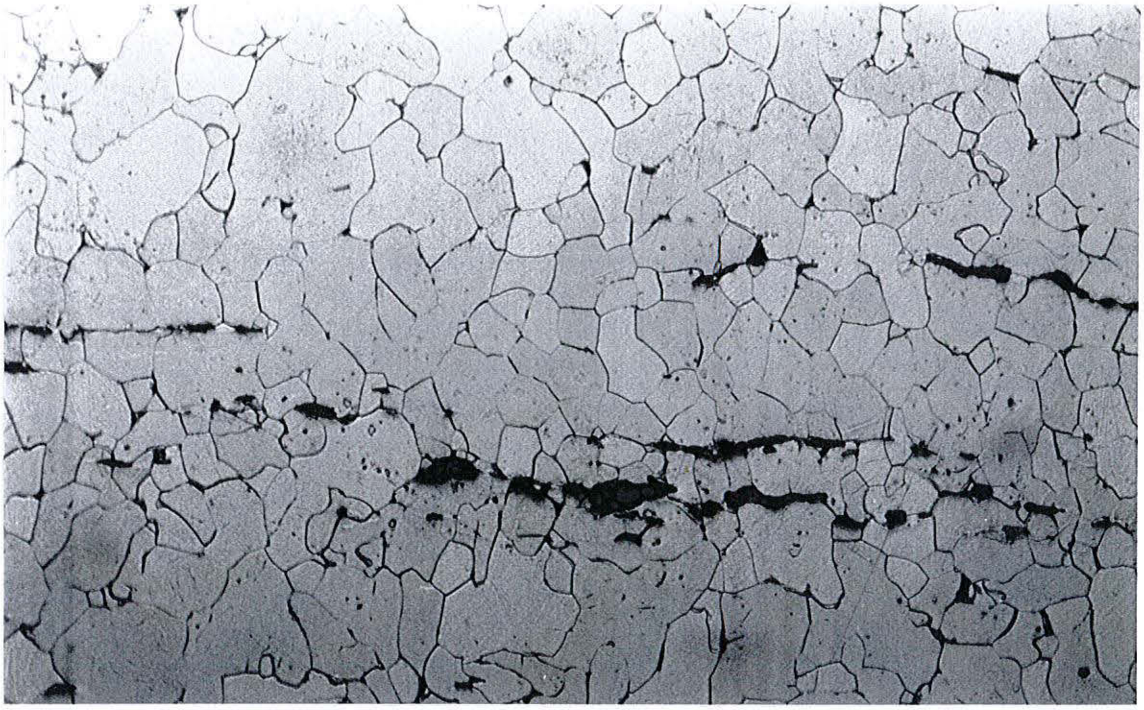

Fig 2c. Detail of the same section showing medium to fine grain ferrite plus pearlite (carbon content approximately 0.1% max): magnification x 200; etched 2% nital

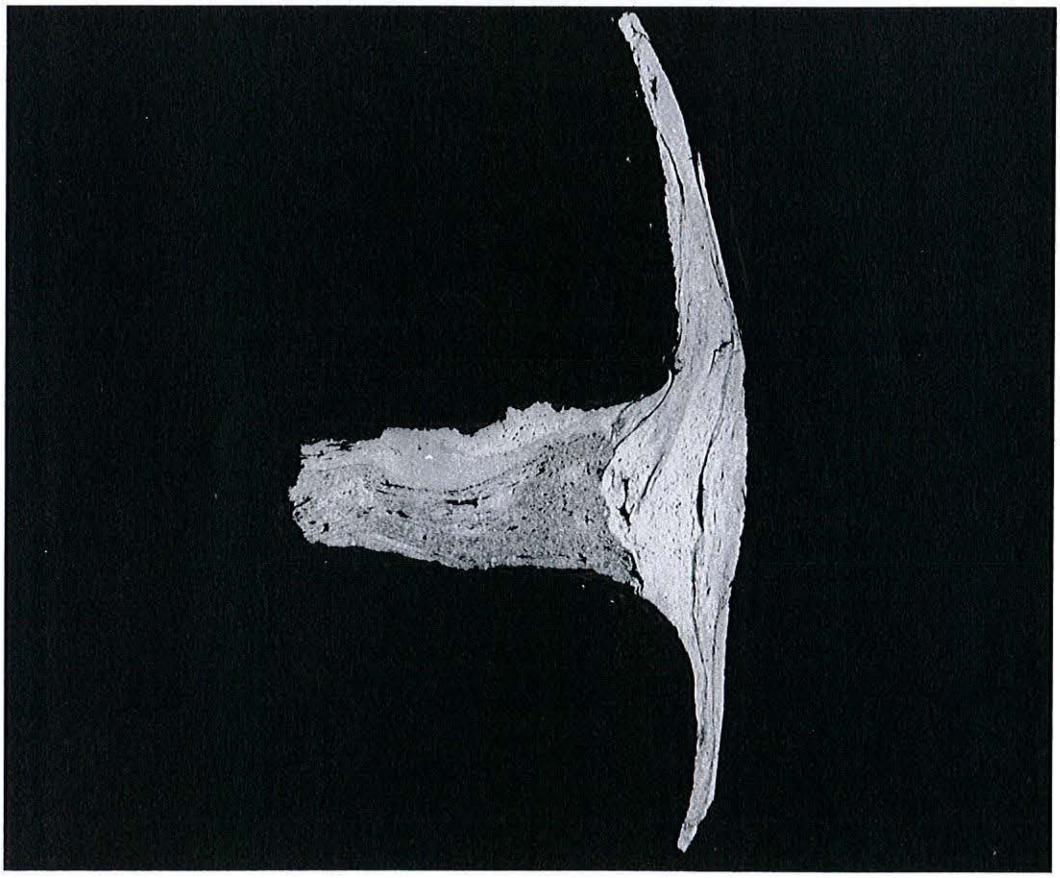

Fig 3a. Photomacrograph of a longitudinal section through a second early panel fixing nail: magnification x 6; etched 2% nital.

Fig 3b. Detail of the same section showing probable welds between two large grain high phosphorus parts (pale areas top and left) and a fine grain, low phosphorus area (lower right): magnification x 50; etched 2% nital.

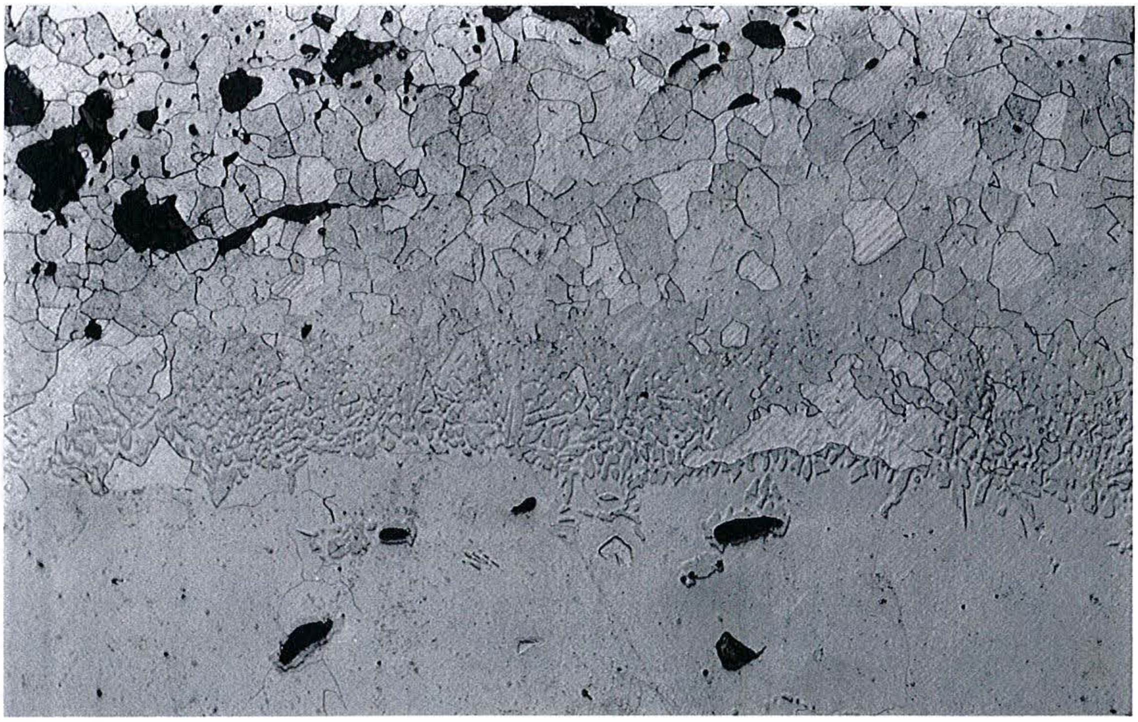

Fig 3c. Detail showing 'phosphorus ghosting' (a segregation effect) along the intermediate zone between the large grain, high phosphorus iron at the side of the shank (bottom in this view) and the medium grain area, low in phosphorus, further across the shank: magnification x 100; etched with 2% nital.

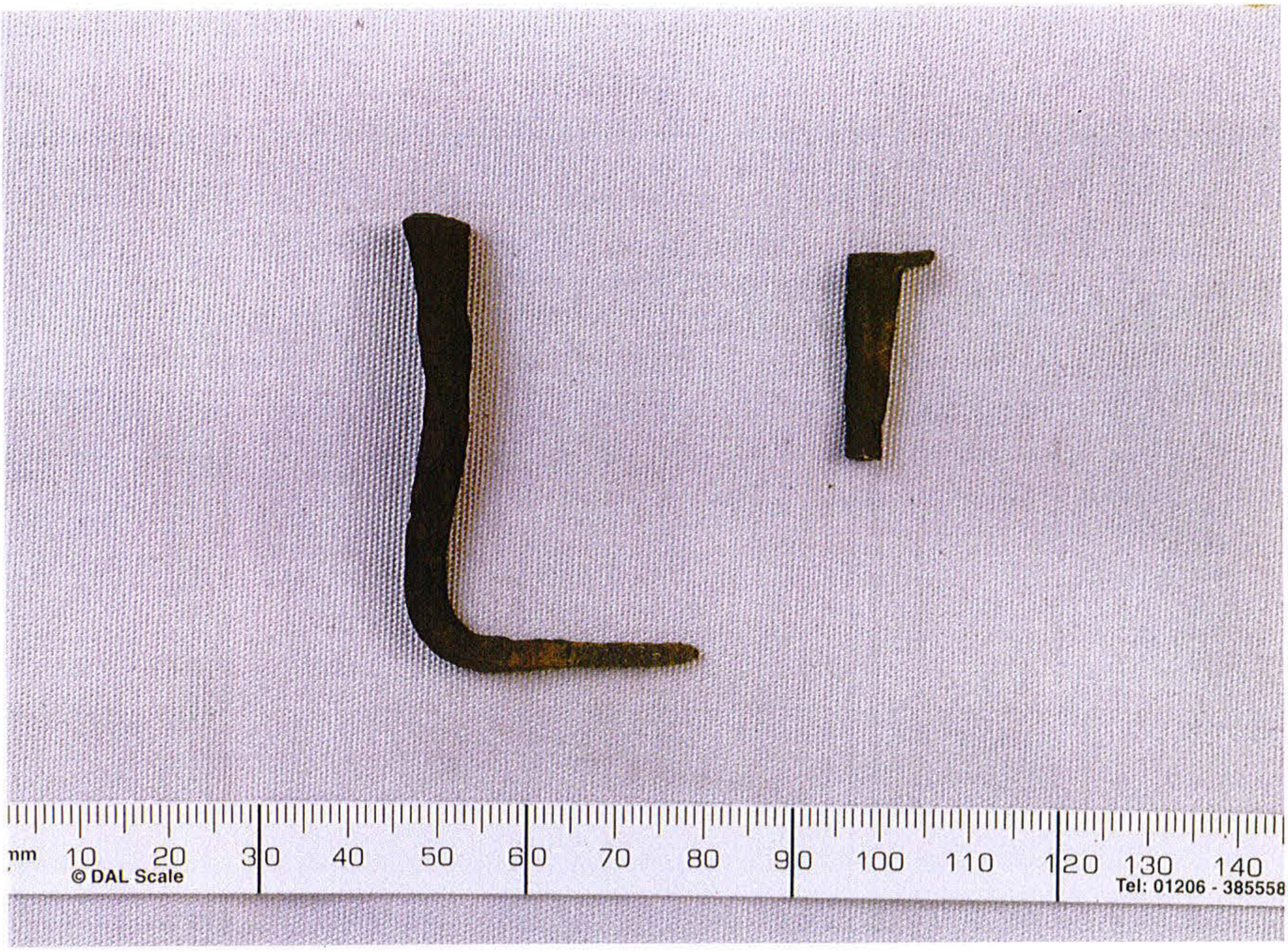

Fig 4. Nails from birds-beak joints of the longitudinal struts, part of the original ceiling construction above the wooden panels (most of heads missing).

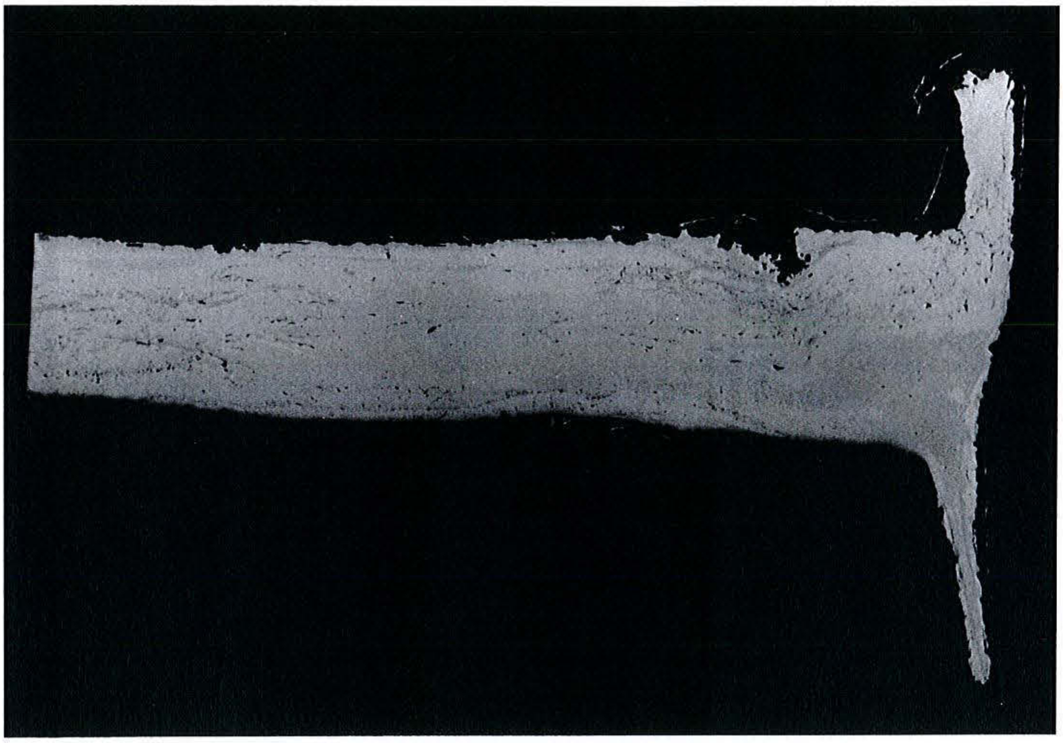

Fig 5a. Photomacrograph of a longitudinal section through one of the early 'birds-beak' fixing nails: magnification x 6; etched 2% nital.

Fig 5b. Detail of the same section showing very large grain phosphoritic iron structure plus an uneven scattering of one and two phase non-metallic slag inclusions: Magnification x 40; etched 2% nital.

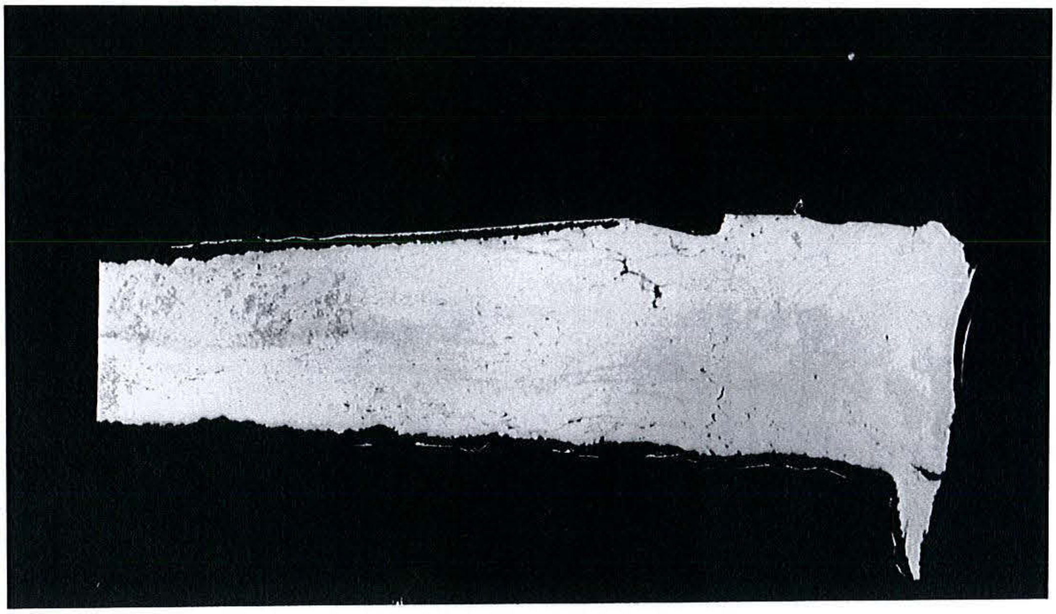

Fig 6a. Photomacrograph of a longitudinal section through a second 'birds beak' fixing nail: magnification x 6; etched 2% nital.

Fig 6b. Detail of the same section showing a localized phosphorus segregation effect plus neumann banding, the result of cold hammering, in the lower right hand corner: magnification x 50; etched 2% nital.

Fig 7. Nails probably from the restoration work of *c*1830.

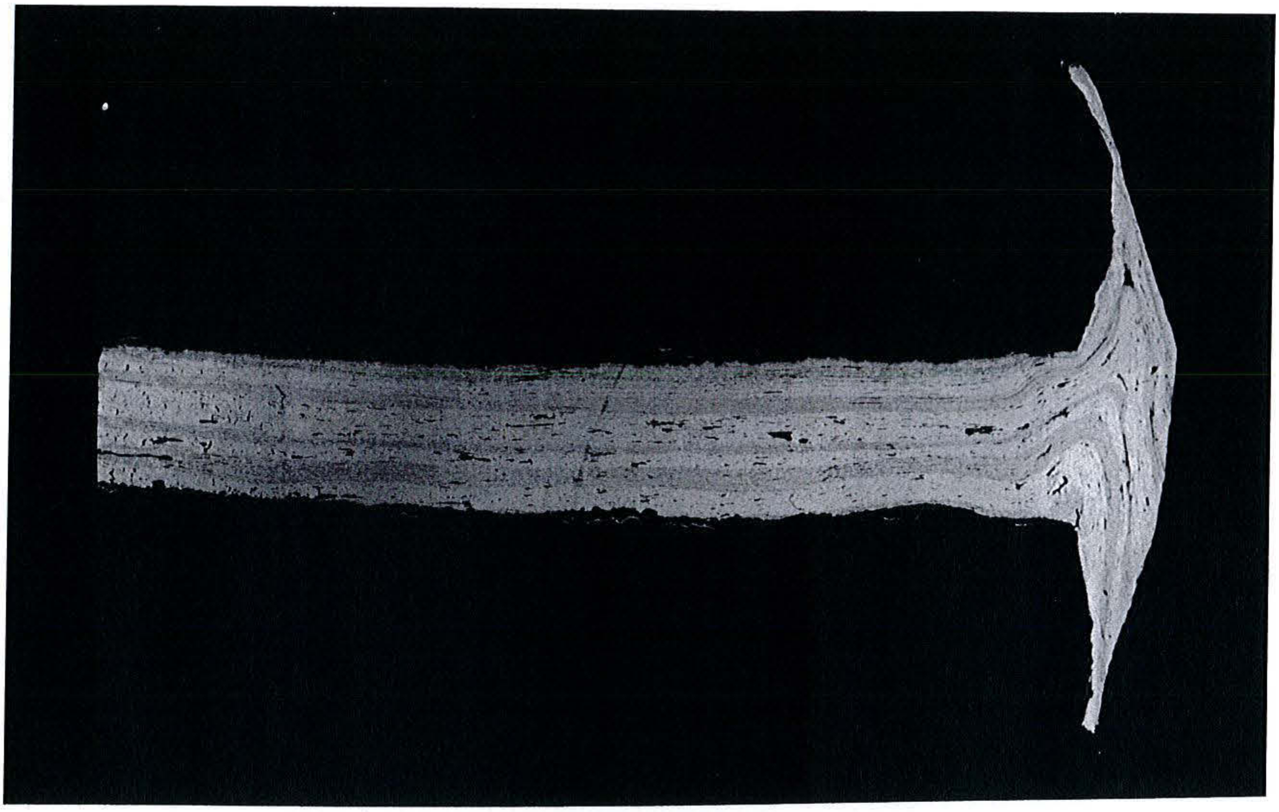

Fig 8a. Photomacrograph of a section through one of the probable 19th century puddled iron nails, showing a distinct banded appearance along its length: magnification x 6; etched 2% nital.

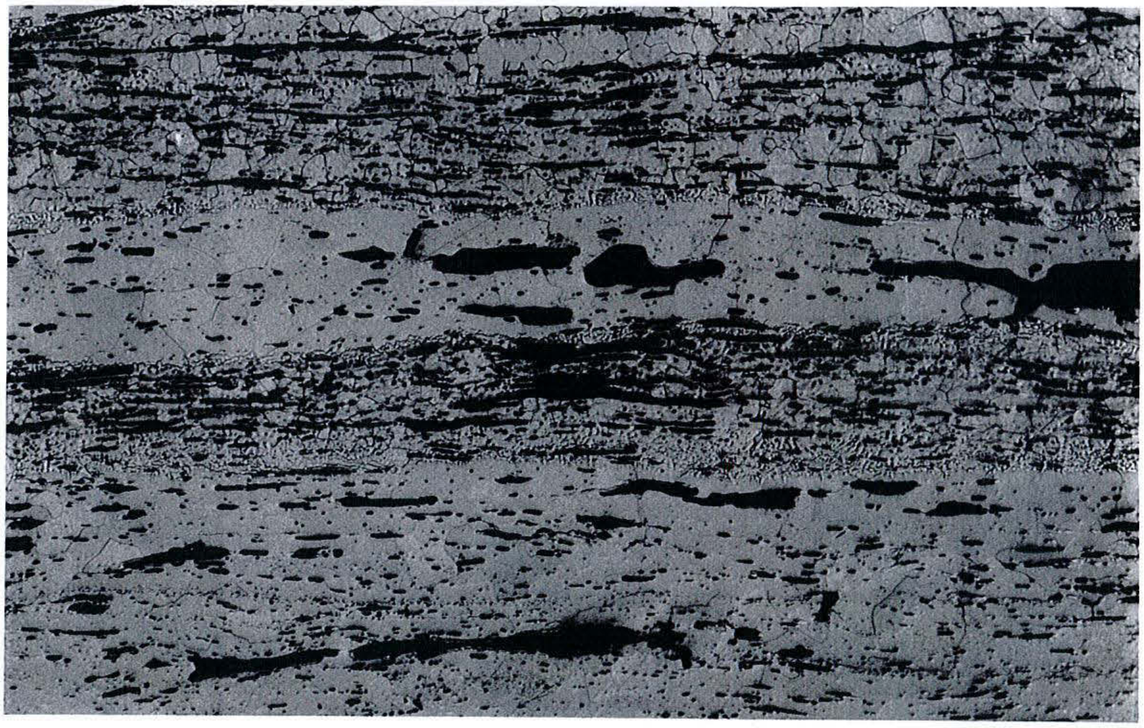

Fig 8b. Detail of the same section showing the high slag content plus the alternate large grain (high phosphorus) iron with medium grain (lower phosphorus) iron bands between: magnification x 50; etched 2% nital.

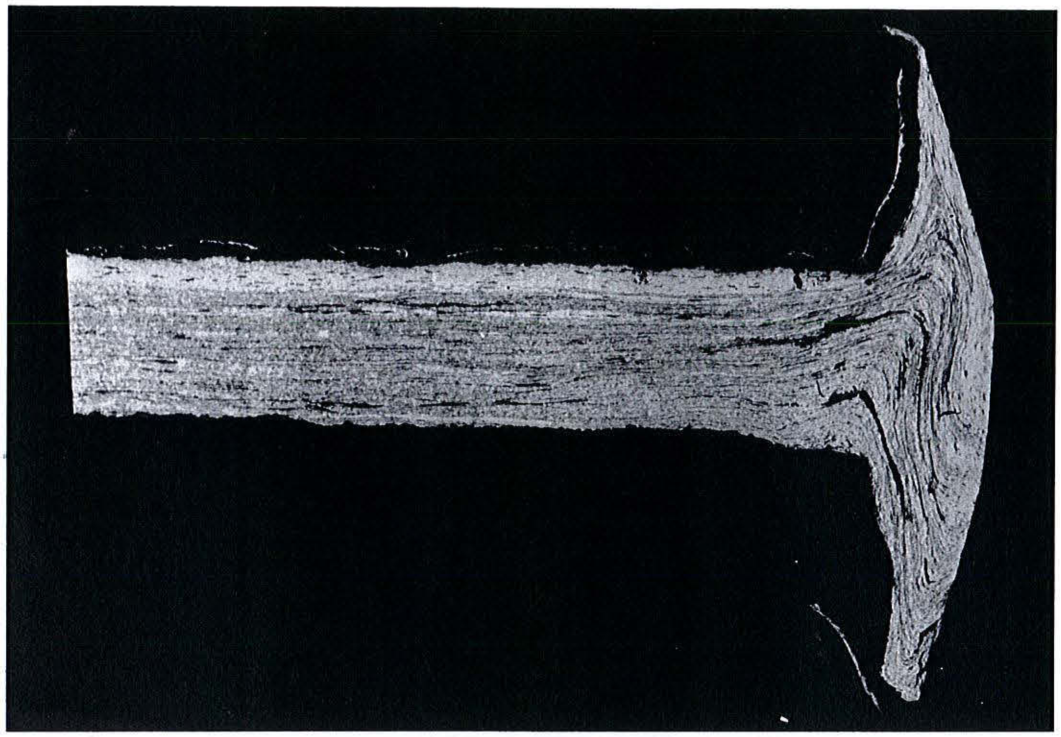

Fig 9a. Photomacrograph of a longitudinal section through a second probable 19th century iron nail, showing the fibrous appearance typical (at low magnification) of puddled iron after it has been through a rolling mill: magnification x 6; etched 2% nital.

Fig 9b. Detail of the same section again showing the high slag content and mainly medium grain iron (ferrite). The larger slag inclusions contain varying proportions of iron oxide and iron silicate, visible as varying proportions of pale and darker phases: magnification x 100; etched 2% nital.

Fig 10. Nails belonging to a second (and possibly a third) phase of restoration work; possibly that reported in *c*1740.

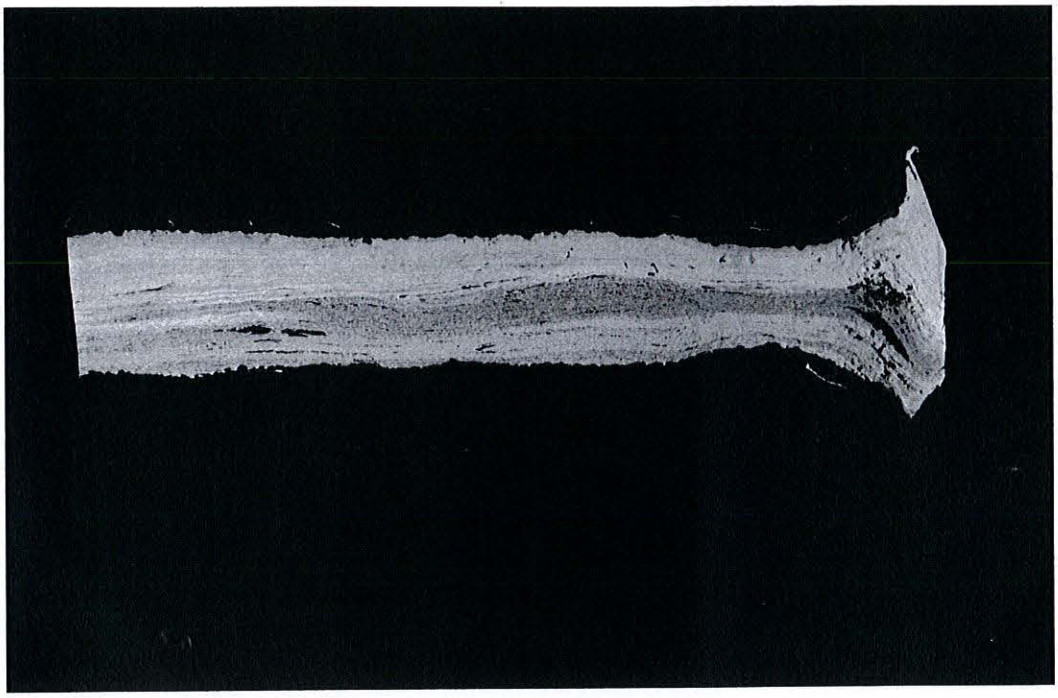

Fig 12a. Photomacrograph of a longitudinal section through one of the shorter nails showing the paler phosphoritic zones, and the darker, low carbon areas also low in phosphorus: magnification x 6; etched 2% nital.

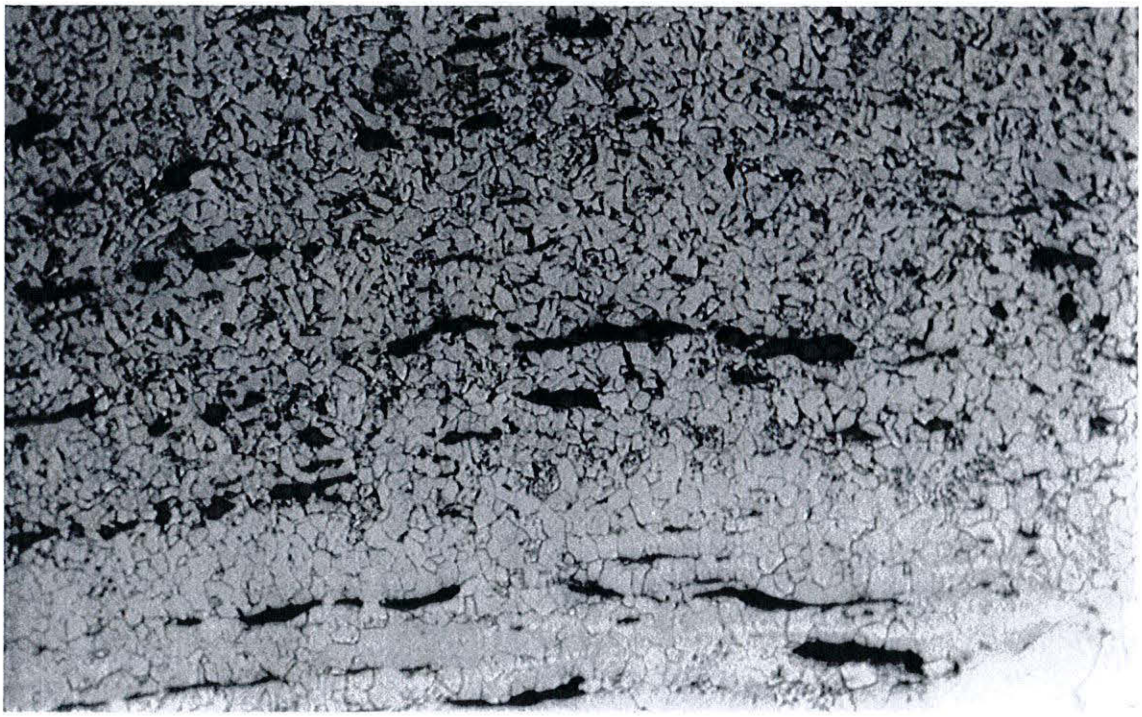

Fig 12b. Detail of the same section mainly showing the fine grain ferrite plus pearlite structure of the darker low carbon part near the centre of the nail, with a small area of large grain phosphoritic iron showing lower left in this view: magnification x 100; etched 2% nital.

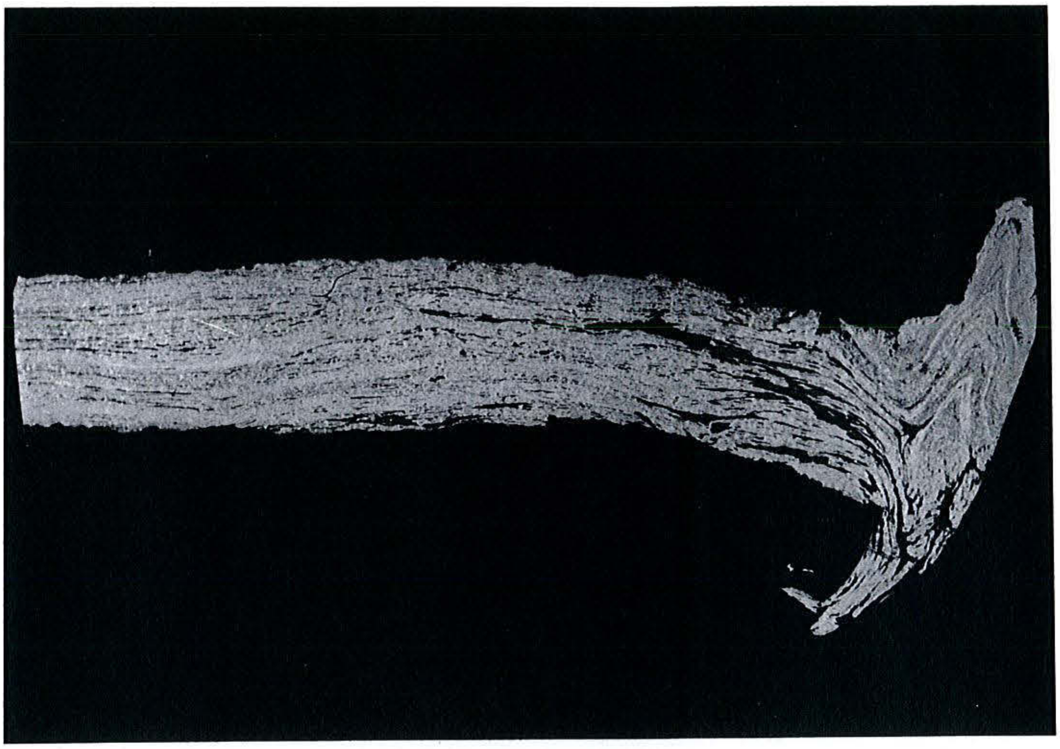

Fig 11a. Photomacrograph of a longitudinal section through one of the longer nails from this group, showing the poor quality of the iron with uneven, localized areas very high in slag: magnification x 6; etched 2% nital.

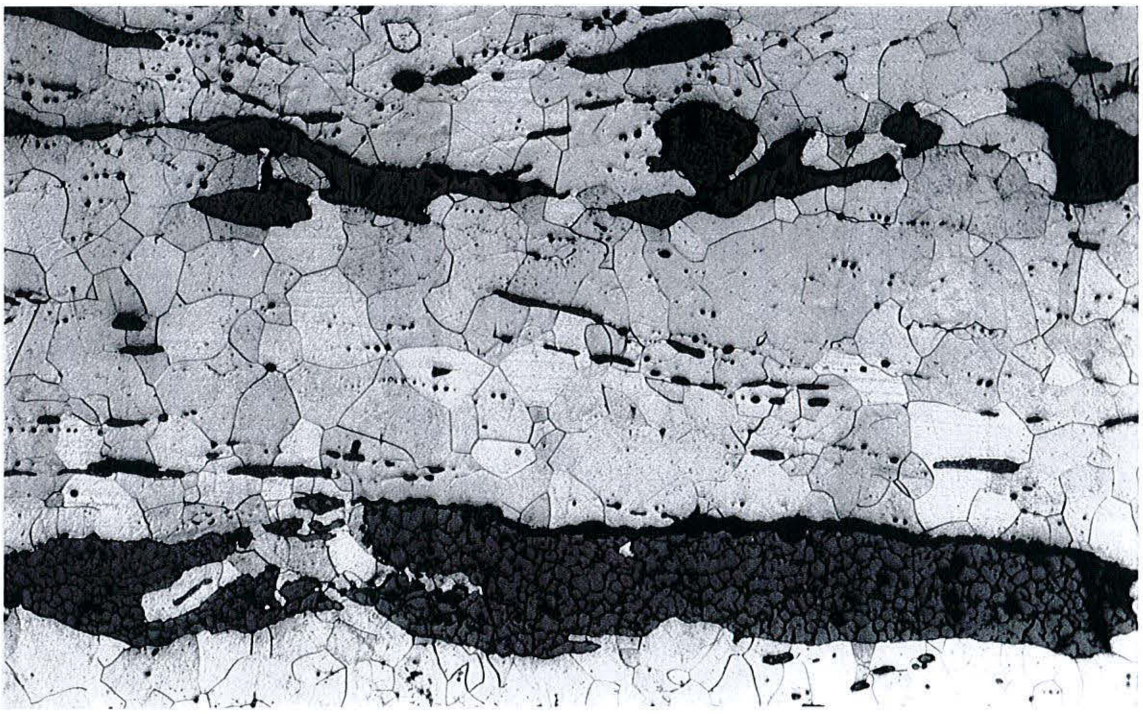

Fig 11b. Detail of the same section again showing a medium grain iron (ferrite) and the variable iron oxide/iron silicate proportions of some of the large slag inclusions: magnification x 100; etched 2% nital.

Table 1. Peterborough Cathedral nave ceiling: Micro-analysis of an original panel fixing nail of 1220-1230.

a: Analysis of the iron.

	Al	Si	P	S	Mo	Ti	V	Cr	Mn	Co	Ni	Cu	Zn	As	Fe
1	0.011	0.000	0.015	0.009	0.005	0.000	0.002	0.000	0.000	0.010	0.019	0.004	0.001	0.060	99.86
2	0.002	0.000	0.022	0.010	0.000	0.000	0.000	0.000	0.001	0.000	0.010	0.005	0.003	0.000	99.95
3	0.000	0.000	0.000	0.000	0.000	0.083	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	99.92
4	0.000	0.000	0.022	0.006	0.005	0.007	0.000	0.000	0.002	0.009	0.025	0.005	0.000	0.009	99.91
5	0.000	0.000	0.027	0.002	0.004	0.000	0.000	0.001	0.007	0.008	0.033	0.012	0.000	0.000	99.91
6	0.000	0.000	0.029	0.004	0.000	0.000	0.002	0.000	0.004	0.010	0.042	0.018	0.000	0.021	99.87
7	0.008	0.000	0.083	0.008	0.000	0.001	0.001	0.000	0.004	0.008	0.045	0.001	0.000	0.009	99.83
8	0.000	0.000	0.068	0.005	0.000	0.005	0.000	0.000	0.000	0.013	0.025	0.000	0.010	0.000	99.87
9	0.000	0.000	0.073	0.005	0.000	0.000	0.002	0.002	0.003	0.021	0.038	0.006	0.000	0.014	99.84
10	0.013	0.000	0.050	0.007	0.002	0.000	0.000	0.002	0.003	0.021	0.046	0.010	0.002	0.098	99.75
11	0.001	0.000	0.096	0.007	0.000	0.000	0.004	0.001	0.004	0.009	0.039	0.006	0.000	0.000	99.83
12	0.000	0.000	0.102	0.008	0.000	0.000	0.000	0.000	0.001	0.009	0.036	0.006	0.002	0.000	99.84
avg	0.003	0.000	0.049	0.006	0.001	0.008	0.001	0.001	0.002	0.010	0.030	0.006	0.002	0.018	
Std Dev	0.004	0.000	0.033	0.003	0.002	0.024	0.001	0.001	0.002	0.006	0.014	0.005	0.003	0.027	

b: Analysis of the non-metallic inclusions.

	Na	Mg	Al	Si	P	S	K	Ca	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	O
1	0.15	1.27	4.26	11.56	1.27	0.27	1.36	1.83	0.21	0.02	0.01	0.90	43.19	0.02	0.07	0.03	0.00	33.59
2	0.30	2.41	7.98	13.37	2.26	0.13	3.86	2.90	0.30	0.02	0.00	0.41	28.39	0.05	0.00	0.10	0.00	37.52
3	0.02	0.11	3.96	5.80	1.95	0.69	0.19	0.88	0.11	0.00	0.00	0.12	56.12	0.00	0.07	0.00	0.00	30.00
4	0.18	0.19	2.23	9.93	3.16	1.22	0.39	1.62	0.08	0.00	0.00	0.14	47.60	0.01	0.00	0.00	0.01	33.24
5	0.00	0.00	0.39	0.15	0.07	0.04	0.01	0.05	0.16	0.02	0.01	0.00	76.35	0.00	0.01	0.00	0.06	22.68
6	0.22	2.71	8.63	20.46	0.17	0.00	3.18	3.12	0.39	0.03	0.00	0.86	19.04	0.01	0.04	0.04	0.09	41.00
7	0.35	2.07	9.04	22.33	0.15	0.04	3.52	3.07	0.37	0.01	0.03	0.64	15.95	0.03	0.00	0.10	0.09	42.22
8	0.07	1.72	12.39	23.73	0.06	0.03	1.55	3.66	0.64	0.00	0.02	1.15	10.09	0.04	0.03	0.01	0.00	44.79
9	0.22	2.03	10.83	22.37	0.18	0.08	1.98	3.39	0.44	0.01	0.00	1.01	14.09	0.01	0.00	0.09	0.00	43.26
10	0.00	0.00	0.00	0.00	0.03	0.00	0.03	0.01	0.16	0.00	0.01	0.83	76.42	0.00	0.00	0.00	0.16	22.34
11	0.22	1.58	4.59	13.98	0.53	0.09	1.69	2.12	0.08	0.00	0.03	0.93	39.21	0.04	0.02	0.18	0.00	34.72
12	0.21	3.79	11.28	20.17	0.29	0.04	3.32	3.50	0.41	0.00	0.02	0.26	14.06	0.00	0.00	0.00	0.16	42.49
13	0.17	1.79	5.89	16.88	1.19	0.23	2.08	2.43	0.31	0.01	0.01	1.38	29.65	0.00	0.00	0.00	0.00	37.98
14	0.22	1.94	6.02	16.88	0.67	0.21	1.90	2.46	0.25	0.04	0.03	1.47	30.17	0.04	0.02	0.00	0.00	37.67
15	0.00	0.14	2.99	5.38	1.99	0.69	0.20	0.77	0.12	0.05	0.00	0.08	58.28	0.00	0.00	0.00	0.00	29.31

Table 2. Peterborough Cathedral nave ceiling: nail from one of the 'bird's beak' noggin joints of 1220-1230.

a: Analysis of the iron.

	Al	Si	P	S	Mo	Ti	V	Cr	Mn	Co	Ni	Cu	Zn	As	Fe
1	0.009	0.000	0.324	0.013	0.000	0.003	0.000	0.001	0.000	0.021	0.031	0.000	0.007	0.018	99.57
2	0.012	0.000	0.169	0.005	0.000	0.001	0.000	0.002	0.001	0.029	0.043	0.009	0.000	0.027	99.70
3	0.012	0.000	0.134	0.007	0.003	0.000	0.001	0.002	0.002	0.034	0.042	0.014	0.002	0.000	99.75
4	0.000	0.000	0.381	0.017	0.000	0.002	0.000	0.000	0.005	0.015	0.026	0.003	0.004	0.000	99.55
5	0.003	0.000	0.573	0.024	0.000	0.000	0.000	0.002	0.002	0.025	0.032	0.007	0.000	0.022	99.31
6	0.000	0.000	0.706	0.025	0.000	0.004	0.000	0.000	0.000	0.021	0.035	0.000	0.001	0.000	99.21
7	0.000	0.000	0.366	0.021	0.000	0.000	0.003	0.001	0.000	0.018	0.033	0.011	0.025	0.015	99.51
8	0.000	0.000	0.398	0.011	0.000	0.000	0.000	0.000	0.003	0.011	0.034	0.003	0.005	0.000	99.54
9	0.000	0.000	0.360	0.015	0.001	0.000	0.000	0.000	0.003	0.009	0.024	0.017	0.003	0.000	99.57
10	0.004	0.000	0.393	0.025	0.000	0.000	0.002	0.000	0.016	0.017	0.039	0.010	0.008	0.000	99.49
11	0.001	0.000	0.386	0.018	0.000	0.000	0.002	0.003	0.000	0.011	0.025	0.000	0.000	0.000	99.55
12	0.000	0.000	0.442	0.021	0.000	0.000	0.003	0.003	0.004	0.024	0.029	0.009	0.000	0.005	99.46
13	0.000	0.000	0.393	0.016	0.000	0.002	0.002	0.000	0.000	0.015	0.041	0.010	0.000	0.000	99.52
14	0.000	0.000	0.499	0.024	0.002	0.003	0.000	0.000	0.006	0.020	0.042	0.000	0.015	0.050	99.34
15	0.000	0.000	0.206	0.005	0.000	0.000	0.000	0.000	0.004	0.015	0.029	0.015	0.020	0.082	99.63
16	0.000	0.000	0.402	0.012	0.000	0.005	0.003	0.004	0.004	0.031	0.036	0.011	0.004	0.000	99.49
17	0.000	0.001	0.442	0.013	0.001	0.002	0.001	0.003	0.002	0.021	0.023	0.002	0.000	0.030	99.46
18	0.006	0.000	0.405	0.016	0.016	0.000	0.003	0.000	0.001	0.027	0.038	0.005	0.000	0.000	99.48
average	0.003	0.000	0.388	0.016	0.001	0.001	0.001	0.001	0.003	0.020	0.033	0.007	0.005	0.014	
std dev	0.004	0.000	0.130	0.006	0.004	0.002	0.001	0.001	0.004	0.007	0.006	0.005	0.007	0.022	

b: Analysis of the non-metallic inclusions.

	Na	Mg	Al	Si	P	S	K	Ca	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	O
1	0.02	0.28	2.08	6.96	5.89	0.54	0.61	2.46	0.11	0.01	0.03	0.96	46.96	0.00	0.00	0.01	0.01	33.06
2	0.00	0.82	0.59	2.02	8.96	0.55	0.20	1.83	0.03	0.00	0.02	1.50	51.85	0.00	0.00	0.03	0.00	31.60
3	0.14	0.09	1.75	3.77	7.96	0.77	0.37	0.46	0.00	0.05	0.04	0.20	51.96	0.02	0.07	0.08	0.00	32.29
4	0.00	0.00	0.62	1.44	2.09	0.44	0.06	0.29	0.00	0.02	0.01	0.14	69.35	0.01	0.03	0.07	0.00	25.42
5	0.09	0.59	3.20	10.77	5.60	0.39	0.85	3.86	0.12	0.02	0.03	2.41	36.06	0.02	0.00	0.00	0.00	36.01
6	0.00	0.06	1.93	4.63	6.69	1.26	0.26	0.85	0.08	0.00	0.00	0.57	51.41	0.00	0.00	0.00	0.00	32.26
7	0.04	0.36	2.16	6.28	10.03	0.44	0.55	2.28	0.10	0.02	0.03	1.50	40.35	0.00	0.01	0.00	0.00	35.84
8	0.00	0.31	1.94	5.56	7.11	0.87	0.44	2.16	0.10	0.00	0.02	1.22	46.98	0.00	0.10	0.00	0.00	33.19
9	0.09	0.21	0.76	1.73	11.05	0.37	0.19	0.52	0.04	0.07	0.03	1.75	50.29	0.04	0.07	0.02	0.05	32.73
10	0.22	0.82	4.27	14.47	2.33	0.12	0.95	5.27	0.18	0.05	0.02	2.38	32.42	0.00	0.06	0.00	0.00	36.46
11	0.00	0.00	0.02	0.59	2.24	0.05	0.01	0.03	0.06	0.00	0.00	0.00	72.50	0.00	0.00	0.03	0.00	24.47

Table 3. Peterborough Cathedral nave ceiling: Micro-analysis of a nail probably from a restoration of c1830.

a. Analysis of the iron.

	Al	Si	P	S	Mo	Ti	V	Cr	Mn	Co	Ni	Cu	Zn	As	Fe
1	0.000	0.000	0.141	0.003	0.007	0.000	0.005	0.001	0.000	0.003	0.031	0.028	0.000	0.000	99.78
2	0.000	0.000	0.219	0.008	0.015	0.001	0.000	0.003	0.005	0.008	0.038	0.032	0.007	0.000	99.666
3	0.003	0.000	0.317	0.012	0.000	0.000	0.000	0.001	0.008	0.009	0.015	0.024	0.014	0.000	99.597
4	0.005	0.000	0.258	0.012	0.006	0.000	0.000	0.004	0.000	0.004	0.013	0.021	0.000	0.000	99.676
5	0.004	0.000	0.130	0.002	0.001	0.000	0.001	0.002	0.010	0.000	0.031	0.013	0.000	0.000	99.806
6	0.000	0.000	0.175	0.004	0.000	0.001	0.003	0.002	0.000	0.000	0.026	0.024	0.000	0.031	99.734
7	0.003	0.000	0.316	0.020	0.000	0.006	0.000	0.001	0.017	0.000	0.019	0.019	0.004	0.000	99.596
8	0.001	0.003	0.306	0.014	0.000	0.001	0.000	0.000	0.001	0.002	0.021	0.022	0.001	0.000	99.628
9	0.002	0.000	0.142	0.002	0.006	0.001	0.000	0.001	0.006	0.000	0.023	0.007	0.000	0.000	99.809
10	0.008	0.011	0.096	0.006	0.003	0.003	0.000	0.004	0.022	0.008	0.028	0.023	0.000	0.000	99.788
11	0.000	0.000	0.178	0.006	0.000	0.000	0.001	0.002	0.008	0.001	0.022	0.022	0.010	0.001	99.749
12	0.000	0.000	0.095	0.001	0.006	0.001	0.000	0.000	0.004	0.000	0.023	0.024	0.017	0.000	99.829
13	0.000	0.000	0.299	0.010	0.000	0.005	0.001	0.000	0.000	0.010	0.017	0.008	0.000	0.009	99.64
14	0.008	0.000	0.327	0.014	0.001	0.000	0.002	0.002	0.010	0.000	0.026	0.013	0.015	0.002	99.579
15	0.002	0.000	0.335	0.019	0.000	0.001	0.000	0.005	0.000	0.008	0.024	0.006	0.000	0.000	99.601
16	0.017	0.000	0.346	0.017	0.000	0.002	0.000	0.000	0.000	0.000	0.026	0.020	0.004	0.000	99.568
17	0.000	0.000	0.406	0.022	0.000	0.000	0.001	0.000	0.001	0.002	0.017	0.019	0.000	0.000	99.532
18	0.000	0.000	0.073	0.000	0.000	0.000	0.003	0.000	0.001	0.014	0.049	0.029	0.000	0.000	99.831
19	0.003	0.000	0.128	0.005	0.000	0.004	0.002	0.000	0.004	0.010	0.028	0.025	0.000	0.000	99.791
avg	0.003	0.001	0.226	0.009	0.002	0.001	0.001	0.001	0.005	0.004	0.025	0.020	0.004	0.002	
std dev	0.004	0.003	0.101	0.007	0.004	0.002	0.001	0.002	0.006	0.004	0.008	0.007	0.006	0.007	

b: Analysis of the non-metallic inclusions.

	Na	Mg	Al	Si	P	S	K	Ca	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	O
1	0.00	0.00	0.05	7.66	3.88	0.64	0.00	0.02	0.00	0.06	0.06	1.56	55.25	0.00	0.00	0.04	0.00	30.78
2	0.00	0.00	0.51	11.67	3.93	0.56	0.24	0.24	0.21	0.04	0.06	2.73	46.02	0.05	0.00	0.01	0.00	33.71
3	0.03	0.00	0.55	10.32	2.82	0.42	0.07	0.15	0.13	0.20	0.08	4.19	48.93	0.00	0.00	0.14	0.08	31.90
4	0.00	0.00	0.04	9.95	3.18	0.64	0.01	0.03	0.00	0.14	0.10	2.30	51.75	0.03	0.00	0.09	0.00	31.76
5	0.11	0.00	0.14	5.35	5.39	0.11	0.00	0.03	0.01	0.12	0.04	3.56	54.87	0.01	0.00	0.06	0.00	30.19
6	0.00	0.00	0.10	0.62	0.62	0.06	0.02	0.02	0.10	0.38	0.15	1.06	73.46	0.00	0.04	0.00	0.00	23.36
7	0.01	0.00	0.12	2.29	2.28	0.22	0.03	0.03	0.07	0.32	0.10	1.89	66.80	0.00	0.00	0.00	0.01	25.83
8	0.00	0.00	0.00	6.29	6.08	0.19	0.00	0.02	0.00	0.07	0.17	1.91	53.73	0.00	0.04	0.07	0.10	31.33
9	0.05	0.00	0.76	12.64	1.68	0.76	0.18	0.26	0.20	0.31	0.11	5.34	44.82	0.00	0.00	0.00	0.00	32.89
10	0.00	0.00	0.00	11.72	3.99	0.97	0.00	0.02	0.01	0.00	0.11	1.92	47.39	0.00	0.03	0.00	0.12	33.71
11	0.07	0.00	0.29	8.38	3.03	0.71	0.08	0.13	0.12	0.15	0.08	3.42	52.53	0.05	0.00	0.01	0.16	30.80

Table 3 (continued)

	Na	Mg	Al	Si	P	S	K	Ca	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	O
12	0.00	0.00	0.28	9.22	4.26	0.40	0.09	0.14	0.21	0.20	0.12	3.66	49.19	0.00	0.00	0.04	0.00	32.19
13	0.00	0.00	0.20	9.89	3.24	0.56	0.08	0.08	0.03	0.15	0.08	2.59	51.26	0.00	0.00	0.01	0.00	31.81
14	0.00	0.00	0.10	3.74	3.82	0.19	0.00	0.04	0.03	0.06	0.02	1.25	62.84	0.00	0.00	0.00	0.00	27.91
15	0.03	0.00	0.00	5.58	6.34	0.24	0.03	0.10	0.02	0.02	0.01	2.00	54.50	0.00	0.00	0.03	0.03	31.07
16	0.06	0.00	0.16	2.44	2.43	0.16	0.02	0.03	0.03	0.03	0.06	0.87	67.69	0.00	0.00	0.04	0.02	25.97
17	0.10	0.00	0.21	5.79	5.83	0.15	0.01	0.09	0.00	0.00	0.01	1.74	55.10	0.04	0.02	0.04	0.00	30.86
18	0.00	0.00	0.35	10.25	4.82	0.92	0.11	0.13	0.10	0.16	0.10	3.85	45.63	0.00	0.00	0.00	0.00	33.58
19	0.00	0.00	0.31	8.82	5.10	0.28	0.13	0.17	0.08	0.00	0.00	3.07	49.47	0.00	0.00	0.12	0.01	32.44
20	0.12	0.00	0.00	12.25	3.62	1.58	0.00	0.00	0.04	0.17	0.08	2.63	45.23	0.01	0.00	0.03	0.12	34.14

Table 4. Peterborough Cathedral nave ceiling: Micro-analysis of a nail from a second restoration phase, possibly that reported for c1740

a: Analysis of the iron.

	Al	Si	P	S	Mo	Ti	V	Cr	Mn	Co	Ni	Cu	Zn	As	Fe
1	0.002	0.000	0.204	0.004	0.000	0.000	0.001	0.000	0.000	0.007	0.029	0.029	0.000	0.000	99.72
2	0.004	0.000	0.053	0.004	0.013	0.000	0.000	0.001	0.000	0.002	0.022	0.028	0.002	0.000	99.87
3	0.000	0.000	0.057	0.003	0.000	0.000	0.002	0.004	0.006	0.004	0.028	0.016	0.000	0.000	99.88
4	0.000	0.000	0.052	0.000	0.005	0.004	0.003	0.000	0.002	0.009	0.022	0.019	0.003	0.000	99.88
5	0.002	0.000	0.189	0.006	0.003	0.004	0.000	0.003	0.000	0.006	0.032	0.025	0.006	0.036	99.69
6	0.002	0.000	0.081	0.001	0.000	0.003	0.001	0.004	0.000	0.000	0.021	0.025	0.005	0.000	99.86
7	0.007	0.000	0.224	0.005	0.001	0.003	0.000	0.000	0.002	0.013	0.021	0.019	0.000	0.000	99.71
8	0.017	0.000	0.023	0.002	0.003	0.003	0.002	0.002	0.000	0.024	0.069	0.042	0.011	0.000	99.80
9	0.002	0.000	0.057	0.003	0.006	0.004	0.000	0.000	0.006	0.008	0.028	0.017	0.000	0.000	99.87
10	0.006	0.000	0.056	0.002	0.010	0.002	0.000	0.000	0.002	0.000	0.026	0.011	0.000	0.008	99.88
avg	0.004	0.000	0.100	0.003	0.004	0.002	0.001	0.001	0.002	0.007	0.030	0.023	0.003	0.004	
Std Dev	0.005	0.000	0.071	0.002	0.004	0.002	0.001	0.002	0.002	0.007	0.014	0.008	0.003	0.011	

b: Analysis of the non-metallic inclusions.

	Na	Mg	Al	Si	P	S	K	Ca	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	O
1	0.00	0.00	0.11	0.12	0.13	0.03	0.00	0.02	0.00	0.00	0.02	0.18	76.85	0.00	0.00	0.01	0.00	22.52
2	0.00	0.00	0.00	4.73	9.39	0.27	0.00	0.00	0.02	0.04	0.02	2.39	49.91	0.06	0.00	0.12	0.15	32.91
3	0.00	0.00	0.00	2.38	4.03	0.16	0.00	0.00	0.03	0.04	0.07	0.86	65.27	0.00	0.00	0.05	0.00	27.11
4	0.00	0.00	0.05	0.78	0.66	0.01	0.01	0.04	0.05	0.00	0.00	0.18	74.82	0.05	0.00	0.00	0.00	23.35
5	0.00	0.00	0.24	0.67	0.34	0.01	0.00	0.00	0.04	0.00	0.00	0.43	75.17	0.00	0.00	0.00	0.00	23.11
6	0.03	0.00	0.54	5.25	3.26	0.26	0.15	0.16	0.11	0.07	0.03	1.89	59.42	0.01	0.06	0.00	0.00	28.75
7	0.03	0.00	0.24	0.18	0.08	0.00	0.00	0.01	0.19	0.15	0.07	0.77	75.58	0.00	0.00	0.02	0.01	22.66
8	0.11	0.00	0.91	8.95	5.34	0.27	0.31	0.31	0.03	0.00	0.00	3.01	47.65	0.02	0.00	0.09	0.00	32.98
9	0.30	0.00	2.77	12.47	1.86	0.94	0.25	3.20	0.03	0.00	0.02	0.52	43.47	0.01	0.04	0.01	0.00	34.10
10	0.00	0.00	0.25	0.01	0.05	0.01	0.00	0.03	0.11	0.03	0.00	0.21	76.73	0.00	0.00	0.10	0.00	22.47
11	0.05	0.00	0.55	6.10	5.94	0.66	0.05	0.11	0.05	0.00	0.00	2.23	52.53	0.01	0.12	0.02	0.00	31.60
12	0.00	0.00	0.31	0.53	0.30	0.13	0.01	0.13	0.02	0.00	0.04	0.20	75.15	0.00	0.00	0.08	0.01	23.09
13	0.14	0.00	0.69	9.43	5.09	0.12	0.08	1.23	0.04	0.00	0.03	0.75	49.20	0.04	0.00	0.00	0.15	33.01
14	0.19	0.00	0.21	0.51	0.12	0.07	0.03	0.08	0.02	0.08	0.03	0.37	75.33	0.00	0.00	0.00	0.08	22.87
15	0.12	0.00	1.04	9.66	4.37	0.51	0.24	1.28	0.00	0.03	0.00	1.09	48.67	0.01	0.00	0.00	0.00	32.97
16	0.09	0.00	0.49	4.90	3.71	0.21	0.05	0.10	0.00	0.07	0.01	1.60	59.96	0.00	0.00	0.02	0.00	28.79
17	0.00	0.00	0.47	7.47	5.60	0.12	0.01	0.09	0.04	0.02	0.00	2.60	51.56	0.00	0.10	0.00	0.00	31.91
18	0.00	0.00	0.30	0.89	0.74	0.06	0.03	0.02	0.08	0.09	0.05	0.56	73.38	0.01	0.00	0.00	0.14	23.65
19	0.07	0.00	0.21	1.76	0.74	0.19	0.05	0.21	0.00	0.08	0.00	0.42	71.92	0.09	0.00	0.01	0.00	24.25
20	0.00	0.00	0.15	0.01	0.00	0.03	0.00	0.01	0.05	0.01	0.04	0.29	76.99	0.00	0.00	0.00	0.05	22.38

21	0.09	0.00	0.95	9.65	4.77	0.72	0.46	1.42	0.00	0.00	0.00	1.08	47.45	0.04	0.00	0.00	0.03	33.34