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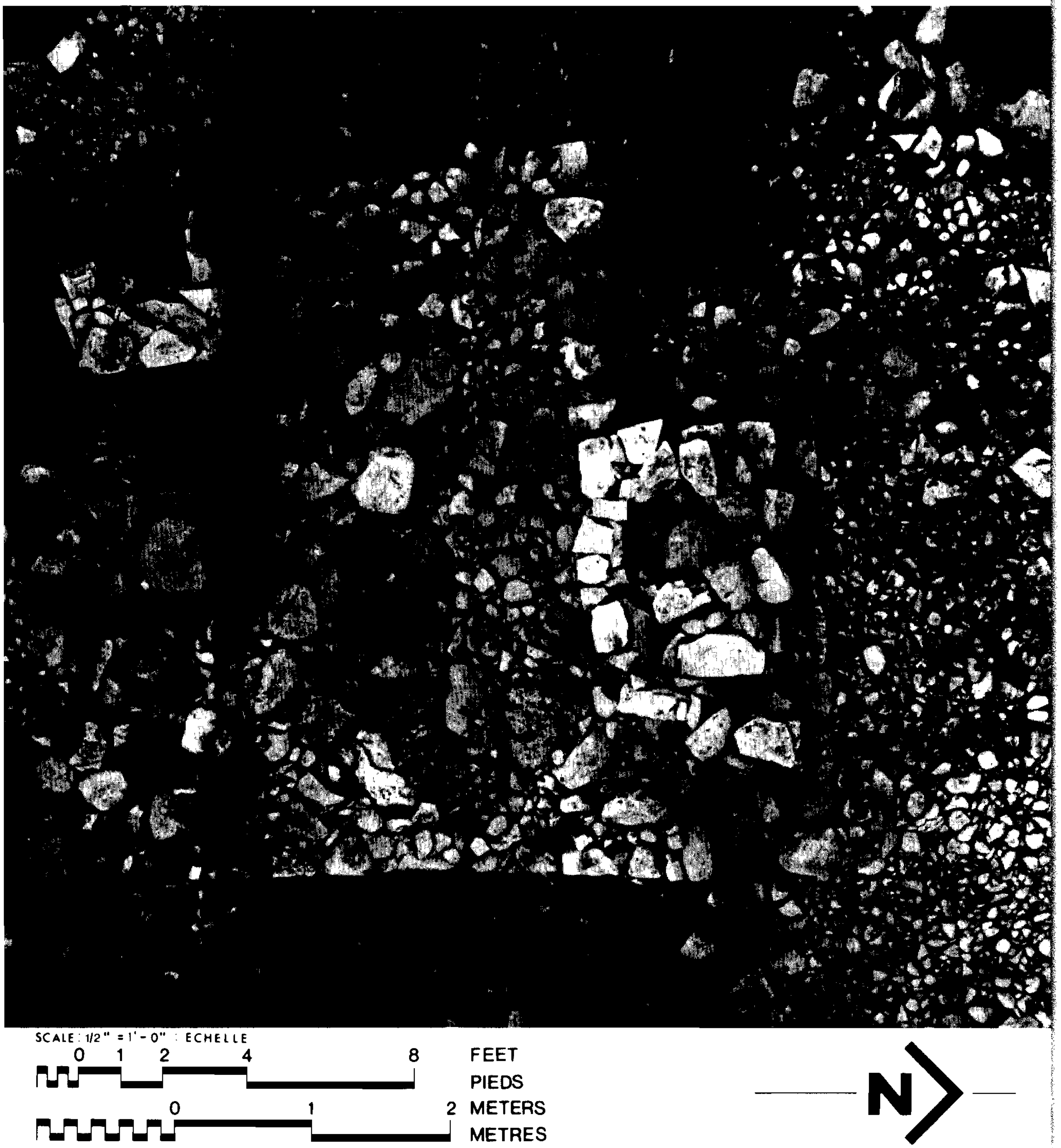
1796 - 1812

John D. Light

and Henry Unglik



Photogrammetric record of blacksmith shop. (Photo by B. Chapman)

A Frontier Fur Trade Blacksmith Shop 1796 - 1812

John D. Light and Henry Unglik

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Tinker, Trader, Soldier, Smith: A Frontier Fur Trade Blacksmith Shop, Fort St. Joseph, Ontario, 1796-1812

with particular reference to

the arts and mechanics of farriering, coopering, trap-making, gunsmithing, tinkering, locksmithing, tool-making

and general blacksmithing

along with

descriptions of ceramic, glass, smoking pipes and tools of the period

to accompany

an analysis of both archaeological and historical material used to determine the original layout of the smithy and its chestnut tree, all of which is rooted in the scientific method

and given with

proper and due reference to correctly constituted authorities in various fields of endeavor

John D. Light

ABSTRACT

This report deals with a fur trade blacksmith shop excavated during the summer of 1978 which operated at Fort St. Joseph before the War of 1812. The artifacts are examined to determine the shop layout, the ownership of the shop, and the kinds of activities in which the smith engaged. Accordingly, a plan of the shop is given and it is determined that the smithy belonged to fur traders rather than to the military or the Indian Department. The activities of the smith are shown to include farriering and tinkering as well as general blacksmithing. Appendices dealing with the history of the shop and a related structure are included.

Submitted for publication 1979, by John D. Light, National Historic Parks and Sites, Parks Canada, Ottawa.

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In this report I have had the unstinting assistance of many people, notably Robert Allen, Jean Brathwaite, Dennis Carter-Edwards, Stephen Cumbaa, Dorothy Griffiths, Charles Hanson, Olive Jones, Karlis Karklins, Ted MacDonald, George Miller, Mary O'Donnell, Peter Priess and Ron Whate. These people have either provided me with valuable information or pointed me encouragingly in the right direction.

I would like, however, to thank especially Les Ross, National Historic Parks and Sites Branch, Parks Canada; Ellen Lee, who dug the site for Ontario Region; and the late Per Guldbeck, Chief Conservator for Parks Canada, Ontario Region, who not only provided me with an endless stream of details about the technicalities of blacksmithing 200 years ago, but who did it in a competent, friendly and extremely humorous manner.

This type of analysis is possible only when complete structures are excavated. No system of test-trenching, no matter how cleverly devised and statistically viable, can yield synthetic information. Thanks are therefore due to the planners and archaeologists at Parks Canada who are conscious of the many and varied exigencies of research and who have kept the ultimate purposes of troweling ever in mind.

INTRODUCTION

The blacksmith shop described in this report was located on the east side of Old Fort St. Joe Point on St. Joseph Island, Ontario. The point was occupied from 1796 to 1828, although the British fort was burned by an American force in 1814. After the war of 1812-14, only a minor British force remained on the point, the main force having moved to Drummond Island in 1815. The blacksmith shop was outside the fort precincts (Figs 39, 40).

Although the exact date of construction is unknown, it is reasonably certain that the building was in use before 1810. The shop was a wooden building on a stone foundation which lay directly north of an unexcavated semi-subterranean structure with which it may be associated. As no superstructural remains were found during excavation, and as there was no evidence of burning, likely the smithy was removed, possibly to Drummond Island. The maximum dimensions of the irregularly shaped shop are 16.0 ft east-west and 18.7 ft north-south. Apparently it had a dirt floor resting on a base of rounded boulders, rather than a wooden floor. There was a forge located against the interior northern wall of the structure, a base for the anvil located in the centre of the building, and a low masonry wall of irregular shape and unknown function located in the southwest corner of the shop.

Post-excavation research has been concerned with two problems: the layout of the shop and identification of work areas within it; and the attempt to associate the smithy with one of the three social components at the site, the military, the Indian Department and the trading community.

SHOP LAYOUT

The excavation revealed the remains of the forge and a hole containing the remnants of a spruce stump (Fecteau 1979) which served as the anvil base. The stump had been held in position with several large rocks and then packed with earth, small stones and scrap iron. The forge, constructed of limestone blocks which were apparently dry laid, measures 5.5-6 ft east-west and 4.5 ft north-south. Only one to two courses of stone of the outer shell of the forge remained, although a large scatter of limestone found around the forge appears to have been a part of it. The core was filled with cobbles and earth.

The exact height of the forge is unknown, although it must have been approximately 3 ft to allow the smith to stand comfortably while working. The tuyere, the nozzle through which air is forced into the furnace, was not found, although one piece of clinker had a fragment of the pipe embedded in it (Fig. 1b). This was found, upon analysis, to have been made of ferrous metal. It was originally thought that Figure 1b represented a bottom tuyere, but the viscous flow of the slag/clinker is such that an open bottom pipe would be clogged in a short time. A discussion of the technology of this type of forge may be found in Light 1987.

Besides the presence of the side tuyere, examination of the clinker also revealed that forging was done in a charcoal fire set on a sand fire bed. The presence of glass in the clinker and small particles of sand and charcoal adhering to the underside of the clinker led to these conclusions. The forge would therefore have been a rectangular box filled with rubble over which a sand fire bed was laid and through which the tuyere protruded. The charcoal fire was then laid on the sand. A thorough metallurgical analysis of the clinker by Henry Unglik producing a more complete picture of the forging process that took place in this smithy accompanies this report.

The charcoal was kept in an outside bin located on the northwest corner of the building (Fig. 2). Keeping the fuel outside to prevent spontaneous or accidental combustion was a common practice. The charcoal samples analyzed had all been produced from hardwood species which can be found locally. Either the smith had no choice or he was indiscriminate in his choice of fuel, for the species represented in the shop are ash, sugar maple, white elm, birch, poplar, willow, red maple, beech and red oak (Fecteau 1979, p. 19). Ash, birch and beech, however, dominate the sample taken, and these are good fuels.

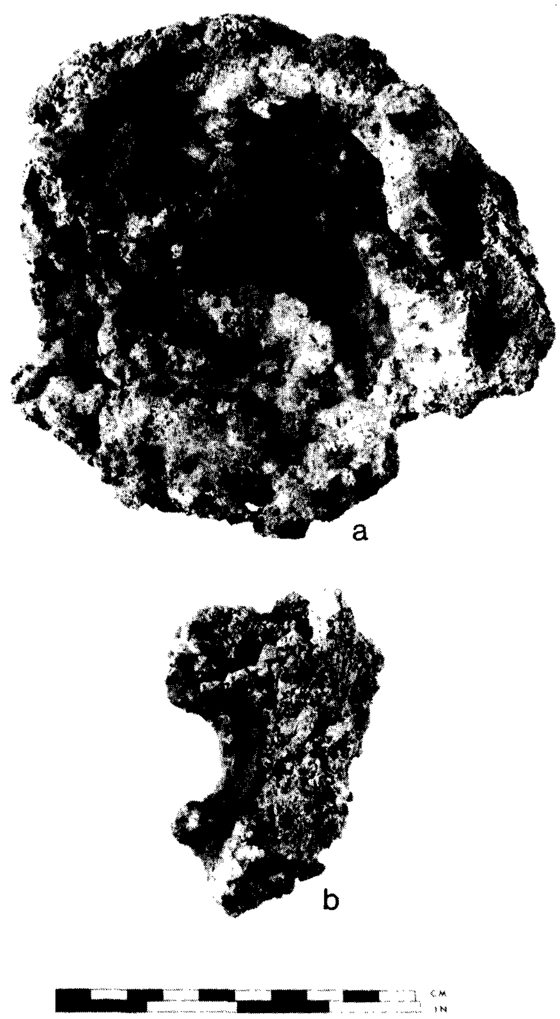

Figure 1. Clinker showing side tuyere. The bottom portion of the pipe remains in specimen b. (Photo by R. Chan)

Besides the forge, the anvil base and the fuel bin, excavation also revealed several concentrations of waste material from the smithy (Fig. 2). The largest and most heterogeneous pile of material was found outside the southeast corner of the building, and extended along both the south and east walls of the structure. This pile consisted of clinker from the forge, scrap iron and copper alloy waste, as did the small pile in the southeast interior corner; however, because the earth wall of the semi-subterranean building to the south of the smithy rises quite sharply, this pile was probably deposited in its present location by erosion after the building wall was removed. Another pile containing the same kinds of material was found inside the northeast corner of the building. It was also in this corner that the bellows were probably located. Because bellows are, of necessity, elevated, it is common to find scrap beneath them.

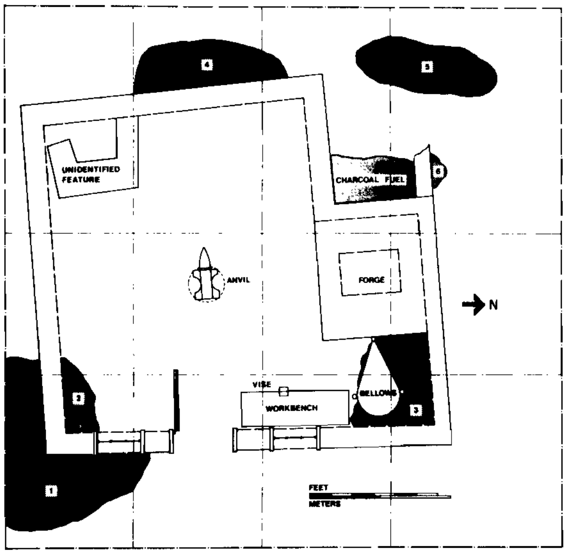

Figure 2. Known layout of shop. The composition of the numbered piles is as follows: 1) clinker, copper alloy and ferrous scrap; 2) probably an extension of no. 1, contains the same type of material; 3) clinker, copper alloy and ferrous scrap; 4) clinker, the pile is not evenly distributed, the majority of the material being on the north side; 5) ceramic and glass; 6) glass. *See* Figures 3 and 4. (Drawing by P. Handy)

Generally, one expects the type of scrap found inside a shop beneath a bellows to be reusable in some way, and an exterior pile of scrap to be worthless. In this instance, however, there appears to be no significant difference between the type or size of the scrap in either the pile beneath the bellows or the pile at the southeast corner of the building. Unfortunately, the remains of the bellows support posts were not found and therefore the location of the bellows cannot be conclusively demonstrated. Because, however, the other possible location at the other end of the forge would place the bellows both outside the shop and above the fuel pile, the location shown is more logical.

An additional dump was found along the west side of the building (Fig. 2). Because it consists almost entirely of clinker (Table 1), the smith apparently used to fill his fuel bucket with clinker whenever the quantities warranted it and dump the clinker at the back of the shop before refilling it with fuel for the forge. In this same area was found the base of a sheet metal pail and one side of a sheet metal pail with a lug attached. These two sections and the accompanying several hundred pieces of scrap sheet metal may be part of the same pail. Also, this pail may have served as the smith's fuel bucket, although there is nothing other than its location and size to support this hypothesis.

The two remaining piles of scrap material consist of items probably broken within the shop. The smaller of the two, found against the exterior north wall of the fuel bin, contained exclusively glass, whereas the remaining dump at the northwest corner of the shop consisted of both glass and ceramic.

The location and approximate extent of the various disposal dumps and of the various features discussed to this point are shown in Figure 2. The northern wall of the fuel bin probably extended farther than is shown in the drawing, for the charcoal deposit extends in a rough line west of the existing wall, but as no foundation was found in this location it was omitted from the drawing.

Figure 2 shows as well the windows, the door, the workbench and the vise, the locations of which were determined by artifact distribution as no structural remains were found. Two concentrations of pane glass indicated the relative location of the windows

(Table 2), and the fact that the area between the windows was almost entirely devoid of artifacts, as an area of heavy traffic should be, indicated the presence of a door. The relative locations of the forge, the semi-subterranean building and the various dumps almost preclude the possibility of a door being in any other location, although a door in the west wall is not impossible. The door is shown opening inward as is generally the case (Ted Macdonald 1979: pers. com.). As well as allowing for a storm door, this arrangement facilitates securing the door and protecting the opening against the vicissitudes of weather. Where archaeological evidence on this point exists at Fort St. Joseph, it was found that the doors open inward (Karklins 1978: n.p.). The final feature shown in Figure 2, the workbench and on it the vise, was located by means of soil analysis (Appendix A). The presence of scale from metal working indicates the general location of the vise, but as the vise must be mounted on a workbench, the location of both items can be determined by soil analysis. The location of the window supports this conclusion because good lighting is necessary to facilitate manipulation of the small objects normally worked on the vise. This is substantiated by the fact that the majority of objects of a size to be worked on the vise, such as gun parts, are indeed found in the northeast corner of the shop. It is not known whether the vise was a leg vise or a bench vise, although a proper blacksmith's leg vise seems more probable because it is sturdier.

Figure 2 shows only those features about which knowledge is either certain or highly probable. By contrast, Figures 3 and 4 represent hypothetical arrangements of the interior of the smithy and should be viewed comparatively. Given the information contained in Figure 2, together with additional clues from the material assemblage and a knowledge of the tools required by the blacksmith, it is possible to recreate a plausible layout of the shop. Two drawings have been provided to

Table 1. Clinker (slag) distribution.

Provenance	No.	% of total by suboperation	Wt (kg)	% of total by suboperation
1H51A1	3		0.0782	
1H51A2	116		3.3196	
1H51A4	91	17.80	9.4792	28.06
1H51B2	51	4.32	2.3913	5.21
1H51C2	22		0.295	
1H51C3	2	2.03	0.213	1.10
1H51D2	48		0.5279	
1H51D5	1	4.15	0.015	1.18
1H51E1	2		0.053	
1H51E2	12	1.19	0.0552	0.24
1H51F1	1		0.4162	
1H51F2	26		0.8365	
1H51F5	2	2.46	0.6166	4.07
1H51G1	28		0.9333	
1H51G2	21		1.695	
1H51G3	95		2.9765	
1H51G4	2		0.0245	
1H51G5	2	12.54	0.0173	12.31
1H51H1	1		0.0115	
1H51H2	36		0.7213	
1H51H3	10		0.536	
1H51H5	6	4.49	0.0194	2.81
1H51J2	90		5.9	
1H51J5	21	9.41	0.8725	14.76
1H51K1	2		0.122	
1H51K2	13		0.702	
1H51K4	206		4.5436	
1H51K5	88	26.19	2.9568	18.14
1H51L1			0.1377	
1H51L1	2		0.450	
1H51L2	7		4.3859	
1H51L3	135		0.4639	
1H51L5	35	15.17		11.85
1H51M2	2		0.0986	
1H51M7	1	0.25	0.0205	0.26
Total	1180	100.00%	45.885 kg	99.99%

Table 2. Pane glass distribution.

Provenance	No.	% of total by suboperation	Wt (g)	% of total by suboperation
1H51A2	66		17.7	
1H51A3	1		0.2	
1H51A4	20		9.8	
1H51A5	5	24.15	2.4	20.46
1H51B2	26		7.0	
1H51B5	1	7.09	0.4	5.03
1H51C2	7		9.9	
1H51C3	3	2.62	7.8	12.03
1H51D1	2		0.8	
1H51D2	40		9.8	
1H51D5	3	11.81	1.3	8.10
1H51E1	1		0.4	
1H51E2	27		7.3	
1H51E3	8		2.2	
1H51E4	2	9.97	1.8	7.95
1H51F2	1	0.26	0.3	0.20
1H51G1	5		1.2	
1H51G2	63		20.3	
1H51G3	5		1.9	
1H51G4	39		16.4	
1H51G5	6	30.97	2.8	28.96
1H51H1	3		1.2	
1H51H2	2		1.1	
1H51H4	1	1.57	0.3	1.77
1H51K2	28		10.0	
1H51K5	3	8.14	2.4	8.43
1H51L3	8	2.10	6.4	4.35
1H51M3	4		3.3	
1H51M7	1	1.31	0.7	2.72
Total	381	99.99%	147.1	100.00%

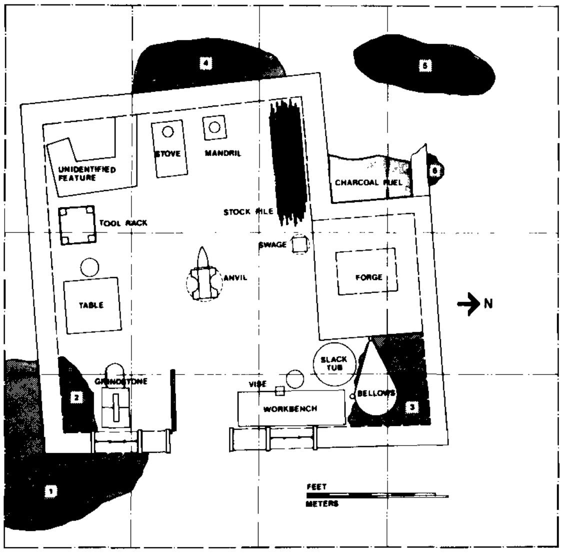

Figure 3. Possible layout of shop. (Drawing by P. Handy)

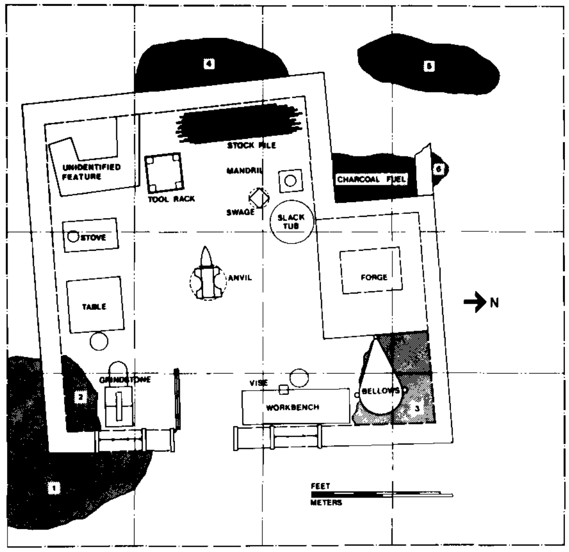

Figure 4. Another possible layout of shop. (Drawing by P. Handy)

emphasize the uncertainty of some of the information.

In addition to the items shown in Figure 2, a grindstone is shown in the southeast interior corner of both alternative drawings. From the quantity of axes found in the shop it is known that axe repair was one of the smith's major activities (Table 8) and this presupposes the existence of a grindstone in the shop. It is known as well that the Indian Department blacksmith at the fort, if this was he, possessed a grindstone (PAC, RG8, I, Vol. 254, pp. 57-59). The grindstone is pictured in this location because of the availability of light from the window.

A table is shown against the southern wall in both floor plans. This was probably the domestic areas of the smithy as almost all the objects related to eating or relaxation were found along the interior southern wall of the shop. The only eating utensils (two knives and a spoon) found during excavation were found here, as were the only folding knife, candle snuffer, musical instrument part (harmonica reed) and all but one of the functional smoking pipes (Fig. 5). In addition, the ceramic tableware not associated with the dump outside the shop all came from along the southern wall. Most of this ceramic consists of miscellaneous sherds, implying this was an area of primary deposition. The only apparent exception to the general pattern in the material found along the southern wall involves container wares, both glass and ceramic, and these are more closely associated with the area around the workbench and forge, although some container glass does appear along the southern wall. Although the domestic area of the smithy was along the southern wall, it was not shown in Figure 2 because the size, shape and type of table is unknown and the exact location or extent of the area is indeterminable.

All of the remaining objects represented in Figures 3 and 4 are shown in different locations. Because the western side of the shop was almost devoid of artifacts, this was probably the section of the shop reserved for general storage. Therefore the stock, the mandril and the swage are shown to the west of the forge. Although this blacksmith possessed stock (Fig. 6), the quantities available to him were probably minimal because there is abundant evidence of the reuse of metal, both steel and iron. The smith was using both files (Fig. 15) and trap springs (Fig. 28) as sources of steel stock, and he was also hammering up

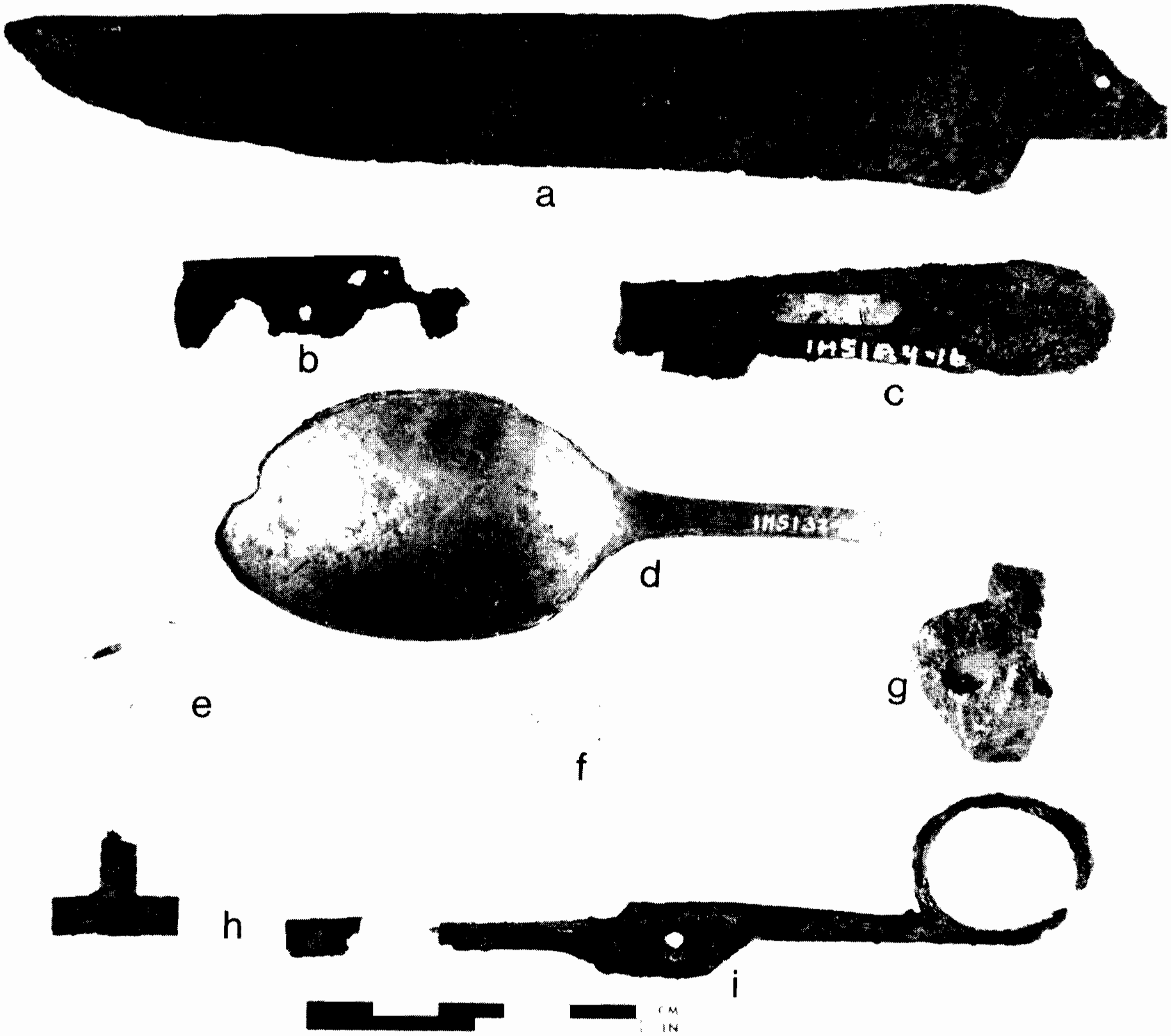

Figure 5. Articles from the domestic area of the smithy: a) knife blade, 1H51A2-13; b) knife blade fragment, 1H51B2-38; c) folding knife with pewter inlay, 1H51A4-16; d) pewter spoon, 1H51B2-14; e) shank-bowl juncture of white clay pipe, "WG" on spur, 1H51C2; f) shank-bowl juncture of white clay pipe, 1H51A4; g) shank fragment of steatite aboriginal pipe, 1H51B2-15; h) harmonica reed, two pieces, 1H51B2-30; i) candle snuffer, wick trimmer - the plate has been brazed back on the shank, 1H51C2-18. (Photo by R. Chan)

scrap iron for stock (Fig. 6a). For these reasons, and because there were only six remnants of iron stock found, all in the immediate area of the anvil, the amount of stock pictured on the floor plan is slightly unrealistic.

The smith might have had neither a swage nor a mandril or he might have had one or both, but neither tool is used to the same extent as the anvil or vise and they are therefore placed in locations both out of the way and yet available. The same reasoning applies to the tool rack, although again the

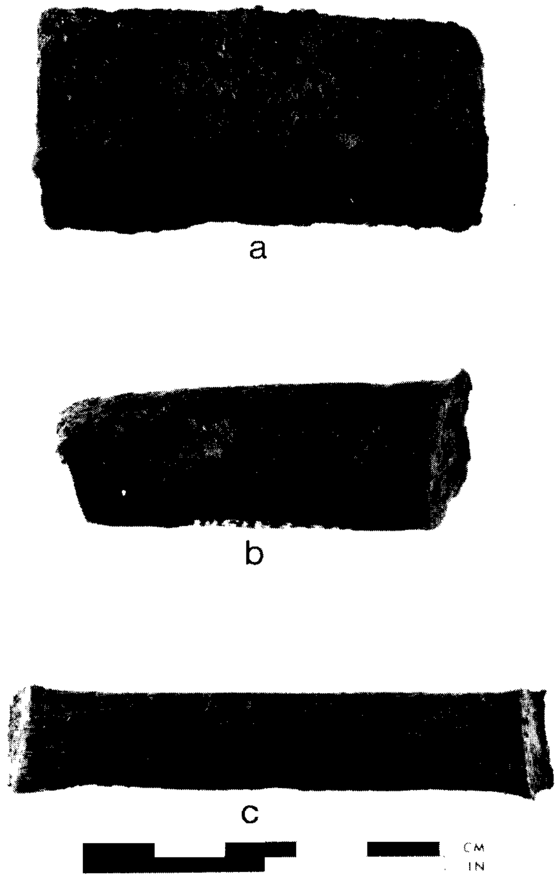

Figure 6. Wrought-iron stock fragments: a) stock made from scrap metal, probably hammered up by the smith, 1H51L3-15; b) round stock, 1H51E3-24; c) square stock, 1H51E3-24. (Photo by R. Chan)

smith might not have had one, preferring instead to mount his tools on the forge. Although no evidence of a stove was found in the forge, one was included on the floor plan because the forge itself could not provide enough heat for the shop in winter, one of the smith's busiest seasons.

Aside from the stools, the only remaining object shown on the drawings is the quenching or slack tub. This is a necessary item in a smithy and it is always located near the forge. If it was not removed from the shop or moved to a different location within the shop, there should be, in the barrel strapping, a clear indication of its presence. Unfortunately, although barrel strapping appeared to the east of the forge, its exact location was not recorded, and there is no guarantee that the strapping is not associated with the deposited material in the northeast corner. The slack tub is nevertheless shown in the northeast corner in Figure 3. In Figure 4 it is shown to the west of the forge because barrel strapping notwithstanding, it appears too large for the corner. If this specific problem had been realized before excavation, all barrel strapping within an arbitrary limit of approximately 3 ft from the forge could have been mapped into the grid and the location of the quenching tub determined, if it remained in the smithy.

Figure 7 shows the north and east walls of the smithy in three dimensions. Although no structural remains of the chimney have been found, it is shown on the west side (the shorter side) of the forge because a forge chimney need not be large. It is unlikely too that the chimney was built on the east side of the forge where it could not be backed against the wall. The quenching tub is shown in the same location as in Figure 3 because of the barrel strapping and because it is closer to the vise in that location. The vise is shown as a leg vise because although it is not unknown for a blacksmith to use a bench vise, the leg vise is more usual because it is sturdier. The windows are depicted as 12 pane windows because this seems to have been the most usual arrangement for the period (cf. the illustrations in Bealer and Ellis 1978), and the door is shown as two layers of board running in opposite directions simply because doors found during excavation of other buildings on the site have been constructed in this manner (Karklins 1978: n.p.).

This blacksmith shop manifests a pattern that should prove to be universally applicable to all smithies that are not mere appendages of other structures. Any blacksmith shop, large or small, should have at least three clearly recognizable functional areas within it, although some may be overlapping and they will vary in their size, complexity and spatial relationships. The most important area is what may be called the working area of the forge, which will include the bellows, the anvil and workbench and vise. In larger, more

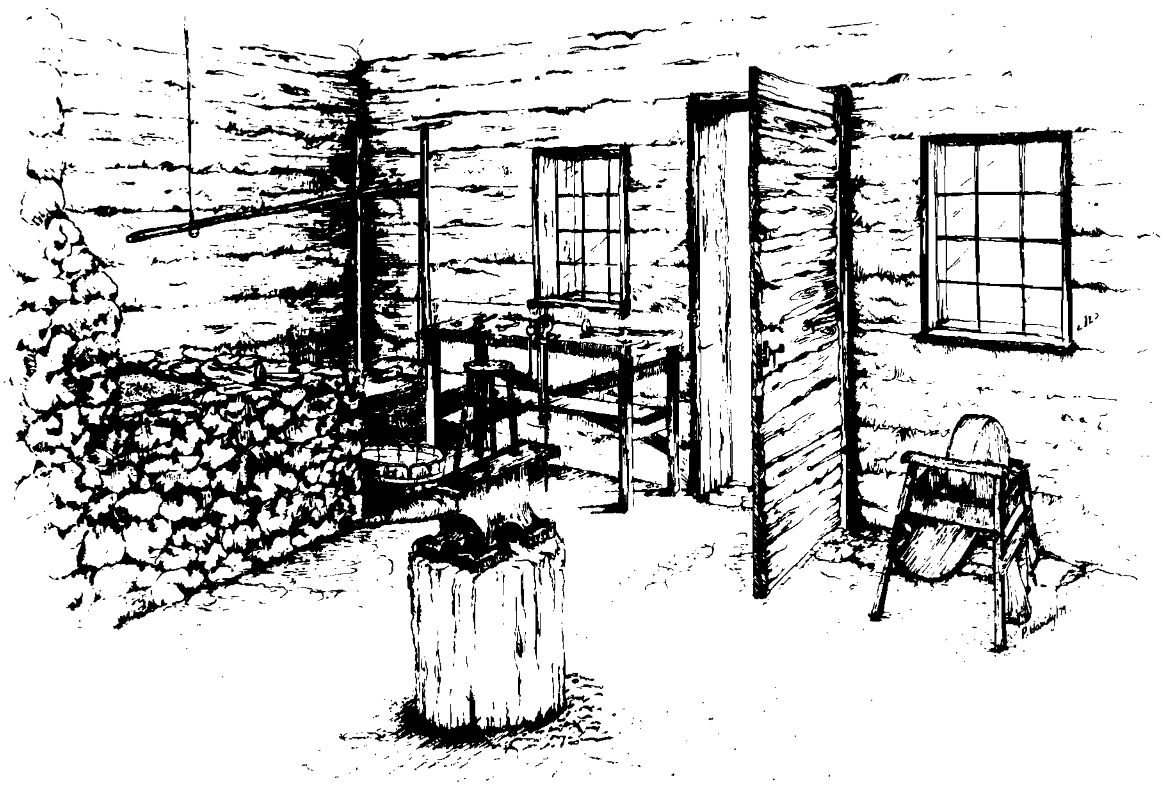

Figure 7. Artist's reconstruction of north and east walls of smithy. (Drawing by P. Handy)

complex shops, it may also include a carriage bay where wagons in need of repair can be temporarily housed close to the forge. There will also be at least one general storage area where such things as stock, seldom used tools, mandrils and swages are kept. Finally, there will be a domestic area where the smith and his friends and clients eat and relax. The preferences of the smith, the architecture of the structure and the available space within it, as well as the complexity and type of the operation will determine how these three areas are arranged and what overlapping may occur.

IDENTIFICATION OF SHOP

The second major problem was to determine to whom the shop belonged. One of the social components, the military, can be eliminated because except for a 41st Regiment button, a cannon carriage tire stud, a cannon carriage bolt head, and an incomplete rear sling swivel which is probably military, there are no artifacts that can be associated definitely with the military in the smithy. It is more difficult, however, to determine whether the shop belonged to the Indian Department or to the fur trade community.

The physical location of the building does not help solve this problem. Although there are numerous references to the Indian Department blacksmith at the fort, there are none referring to the location of his smithy, and there is no general or specific military directive commanding the Indian Department smith to locate his forge within the fort. In addition, all our archaeological and historical information to date leads to the conclusion that any buildings owned by the Indian Department were located outside the fort precincts. The fact that the shop is located close to buildings located outside the fort is therefore possibly irrelevant. If there is a solution to this problem, it must come from the material assemblage.

In general, the kinds of items found in the smithy could point either to the Indian Department or to a fur trade blacksmith. Parts of axes, copper kettles, traps and trade guns are numerous, and clearly the principal activities of the smith involved repair of these items. Although both smiths repaired such items, the Indian Department smith was also engaged in the manufacture of axes (PAC, RG8, I, Vol. 250, p. 422), and there is no evidence of either the waste that accrues from axe manufacture in this smithy (L. Ross 1979: pers. com.) or any significant amount of stock. In addition, the farriering activities of this smith point to his employment by Europeans although an Indian Department official like John Askin could have employed the smith in this regard.

The two arguments that, however, appear conclusive in attributing this smithy to the fur trade community are that none of the items in the shop are marked with a broad arrow at a time when it was the normal practice to mark Indian Department goods in this manner (PAC, RG8, C, Vol. 253, p. 153), and that the building does not appear to have been burned by the Americans in 1814. According to the historical record, the only buildings to escape the fire were those of the South West Company (Vincent 1975: n.p.).

It may be possible to identify the shop not just with the fur trade, but with a fur trading company. The trading community at Fort St. Joseph was diverse, there being the North West Company, the South West Company and several independants at the post. The smithy might have belonged to any one of them. It is noteworthy, however, that between the death of Louis Dufresne, the Indian Department blacksmith in November 1805, and the advent of John Johnson as Indian Department smith in December 1806, the independent company of Messrs. Spenard, Fields, Varin and Pelladeau furnished a blacksmith to the Indian Department for four months (Vincent 1975: n.p.). This same James Fields had brought, in the summer of 1804, a charge of illegal trading against Louis Dufresne (PAC, RG8, I, Vol. 254, p. 223). Because the firm appears to have operated from the post on St. Joseph Island, and because they had a blacksmith, possibly this shop belonged to Messrs. Spenard, Fields, Varin and Pelladeau and there was more to Fields's charge against Dufresne than realized.

There is nothing among the artifacts to suggest ownership by this firm, and it is of course not possible on the basis of the evidence to be definitive about the ownership of the shop, but the fact the firm could supply a smith to the Indian Department on relatively short notice does mean that Messrs. Spenard, Fields, Varin and Pelladeau should be given prime consideration in future research (Appendices B, C).

DESCRIPTION OF ARTIFACTS

The decisions about the layout of the shop and its ownership by a fur trade company have been based almost exclusively on a long and careful study of the artifacts. Therefore I will describe these artifacts to explain in more detail the reasoning that led to these conclusions. The artifacts are described according to artifact classes and with reference to the activities of the smith. Because provenances are referred to frequently, a simplified drawing of the shop showing suboperations is included (Fig. 8).

Only one artifact (a twentieth century bullet) was intrusive. All other artifacts in the blacksmith shop fit the historic period of the occupation of the point.

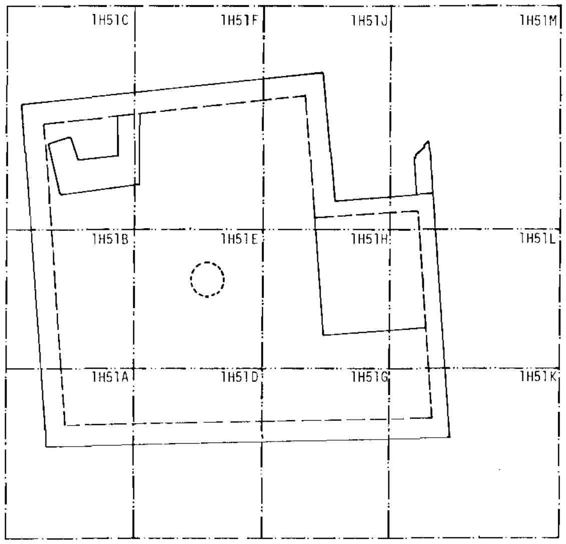

Figure 8. Floor plan of blacksmith shop showing layout of archaeological grid.

Ceramic (Table 3)

The total vessel count for operation 1H51 is ten objects of which eight are tableware or teaware, one is a food or liquid storage vessel and one is a food preparation vessel. Although the latter vessel is present in the shop, it is unlikely that food was being prepared in the smithy. The shape-function of an object is not necessarily its use-function and as there are no other objects of any kind to indicate that the building might have been a domicile as well as a shop, we must assume that the smith lived elsewhere, perhaps in the semi-subterranean building next door, and brought his food to the shop to eat.

The eight tableware objects include the following: one creamware hollowware object, possibly a cup; one press-moulded pearlware hollowware object, probably a teapot, and probably painted; three plates - one plain creamware, one pearlware shell edged, and one transfer printed pearlware; and three pearlware bowls - one fluted polychrome painted (Fig. 9), one underglaze blue painted (Fig. 10) and one probably painted. All of these objects were made likely before 1810.

Table 3. Ceramic distribution of ware type.
*A single object.

Provenance	Sherds	Ware type	Description & comments
1H51A2	1	PW	blue shell edge, possible mend with 1H51M3-2
1H51A2	1	CW	undiagnostic, probably flatware
1H51A4	2	PW	undiagnostic, probably flatware
1H51B2	1	PW	undiagnostic, probably flatware
1H51B2	1	PW	burnt, possible mend with 1H51F2-18
1H51B2	1	PW	flatware
1H51B2	1	CW	flatware, brink sherd
1H51B2-44	2*	PW	flatware, blue transfer print
1H51C2-22	1*	CW	hollowware
1H51F2-18	7*	PW	burnt, bowl, base~14 cm or 5.5 in. diam; design missing or none; includes 2 pcs. burnt PW from 1H51C2 (dump)
1H51G2-29	2*	Stoneware	salt glaze, Lambeth, storage container or jug
1H51G2-30	1*	CW	flatware, undiagnostic cf. 1H51A2, 1H51B2
1H51G4	1	PW	flatware, possible mend with 1H51M3-2
1H51J3-1	44*	PW	small slop bowl, UG blue painted chinoiserie (dump)
1H51K2-4	9*	PW	press moulded, probable teapot, outside bldg
1H51M3-1	77*	PW	fluted slop bowl, polychrome painted (dump)
1H51M3-2	64*	PW	shell edge muffin, blue UG (dump)
1H51M3-7	2*	CEW-RED	container, probable milk pan or mixing bowl,

Four objects, representing 86 per cent of the ceramic sherds found in the operation, were found in the scrap pile labeled 5 in Figure 2. One additional object, slightly burnt, was found with the pile of clinker labeled 4 in Figure 2. Together they represent half the objects and 89 per cent of the ceramic sherds from the operation. One object, the teapot, was found outside the building in the northeast corner of the operation, and was an isolated find, unrelated to anything in the shop. The stoneware container was associated with the workbench area. The remaining objects and undiagnostic sherds are either from or associated with the domestic area of the shop. Some of the sherds found along the interior south wall of the shop either mend or probably mend with ceramic found outside the west wall of the smithy, thus indicating that the area along the south wall was an area of primary deposition, and that the dump at the northwest corner contained material from the shop.

According to George Miller's system of classification and economic scaling of ceramics in which the prices of various types of ceramic are related to the price of plain creamware as a base, this assemblage, cumulatively, has an index value of approximately two (Miller 1980). Although the number of vessels in the shop is too small, given the possible date range of the shop, to apply this system rigidly, had the purchaser of the ceramic bought entirely creamware, he might have expended less than half the cost. Furthermore, because this is a work area, dishes of lesser quality than normal domestic tableware should theoretically have been used.

Figure 9. Fluted pearlware underglaze polychrome painted bowl, made ca. 1785-1805, English, 1H51M3-1. (Photo by R. Chan)

Figure 10. Pearlware underglaze cobalt blue painted bowl with chinoiseries design, made ca. 1785-1805, English, 1H51J3-1. (Photo by R. Chan)

The social status of a blacksmith at this time and in this place was middle to upper-middle class (R. Allen 1979: pers. com.) and the ceramic assemblage from the shop reflects this. It would, however, be necessary to apply Miller's scaling system to all the civilian structures on the site to produce a relative social ranking. Which of the civilian structures, for example, are likely to have belonged to the Askin social circle and which to the average fur trader? How do the assemblages in the houses compare with those in the shops and other facilities? Unfortunately, only 2 of 15 civilian structures, 13 of 26 semi-subterranean buildings and only 1 tradesman's shop have been excavated.

Glass (Table 4)

A minimum number of 15 vessels, of which two were table glass, two liquor, three patent medicines, and eight dried food containers, were found in the excavation of the smithy. Most of the recovered sherds (70%) and a high percentage of objects (40%) came from two dumps at the northwest exterior corner of the building. These two dumps are labeled 5 and 6 in Figure 2. Some glass from these dumps had been scattered along the exterior north wall of the structure.

The majority of the table glass or possible table glass sherds (83%) were found either in the two dumps at the northwest corner of the building or scattered along the north wall of the structure. One object, a possible wine glass which represents 9 per cent of the table glass sherds, was found in the southern part of suboperation D and may be associated with the domestic area of the shop. The rest of the table glass was scattered about the shop in no apparent order, except that in suboperation E only two glass sherds were found. The use of the table glass is unclear. No area of primary deposition was determined as the glass was well scattered within the shop and no cross mends were found. Possibly the complete objects were used either as tableware or as secondary containers, but without intensive cross mending it is impossible to answer this question. It does seem, however, that the wine glass at least was being used as such.

Table 4. Container and table glass distribution.

Provenance	Sherds	Description & comments
1H51A2	1	colourless, lead glass, undiagnostic
1H51A2	3	light green container glass, undiagnostic
1H51A3	1	colourless, lead glass, undiagnostic
1H51A4	2	light green, probably container, burnt
1H51C2	1	colourless, lead glass, undiagnostic
1H51C2-23	26*	dark green container, liquor; probable location outside in dump; may represent more than one bottle. Possible mends: C2(13), D2(2), F2(7), F4(1), G4(1), J4(1), K5(1). No X-mends. Only dark green container glass in shop. No duplicate shapes.
1H51C2-24	3*	dried food container, colourless, square lead glass, indented chamfers
1H51D1	8	colourless container, lead glass, undiagnostic
1H51D2-38	1*	colourless container, lead glass, shoulder, probably medicine vial
1H51D2-39	20*	colourless lead glass, table glass, possible wine glass; mends: D1(2), E2(2)
1H51G2	5	colourless lead glass, undiagnostic
1H51G2-31	14*	dried food or mustard container, light green lead glass, probably secondary use; x-mends: B2(1), D2(1), G1(2), G2(6), G4(1), G5(1), K4(2)
1H51G3-44	15*	colourless lead glass, Turlington's Balsam of Life bottle, fiddle shaped, secondary use; x-mends: A5(6), B2(2), G3(6), H2(1) about 1/3 of bottle remains
1H51G4	2	colourless lead glass, undiagnostic
1H51G4-14	41*	green, octagonal, dried food or medicine container. Secondary use. X-mends D2(2), G2(21), G4(18). Blowpipe pontil.
1H51G5	2	colourless lead glass, undiagnostic
1H51H1	1	colourless lead glass rim, undiagnostic
1H51H2	4	colourless lead glass, undiagnostic
1H51H2-30	2*	light green dried food container; secondary use
1H51J1	1	colourless lead glass, undiagnostic
1H51J2	1	colourless lead container glass, undiagnostic
1H51J2-8	22*	light green container, lead glass, indented chamfers, secondary use. X-mends J2(6), J5(6), M2(6), M3(4). From dump.
1H51J3	2	colourless lead glass, undiagnostic
1H51J4	2	colourless lead table glass, 1 rim, 1 affected by fire, undiagnostic
1H51J5-9	8*	colourless lead container glass. Square bottle, flat chamfers. Dump.
1H51K2	8	colourless lead glass, undiagnostic
1H51K2-10	5*	essence of peppermint, colourless lead glass, secondary use
1H51K4	2	colourless lead glass, undiagnostic
1H51L2	1	colourless lead glass, undiagnostic
1H51L2-2	11*	amber container glass, liquor or spa water. Vertical striations on neck produced by a primary mould. Secondary mould was dip mould. Probably French or Continental. Highly patinated.
1H51L3	17	colourless lead glass, undiagnostic
1H51L3	14	colourless lead container glass. Includes two sherds with folded-out flat-sided lips. Undiagnostic.
1H51M2	27	colourless lead glass, undiagnostic; mend: 1H51K2(1), dump
1H51M2	26	colourless lead container glass. Includes 1 folded-out, flat-sided lip. Undiagnostic. Dump.
1H51M3	22	table glass rims, colourless lead glass. Total circumference of rims greater than circumference of tumbler base (cf. 1H51D2-39 and 1H51M3-10). Undiagnostic. Includes 1 pc. 1H51K2 and 1 pc. 1H51L3 as possible mends. X-mends: 1H51L3(2). Dump.
1H51M3	91	colourless lead glass, undiagnostic
1H51M3	80	colourless lead container glass. one flanged lip frag. Undiagnostic. Dump.
1H51M3-8	39*	colourless lead dried food container. Square bottle with flat chamfers. Dump.
1H51M3-9	24*	colourless lead dried food container. Indented chamfers. Dump.
1H51M3-10	7*	tumbler base, lead glass, pontil mark and push up. Base diam. 6.8 cm. Dump.

*A single object.

The area of the workbench and the forge has associated with it 18 per cent of the sherds and 33 per cent of the objects. The objects are either dried food containers or patent medicine bottles. These bottles were probably not being used for dried food or medicine, but for lubricants, fluxes and acids. This secondary usage is hypothesized partly because of the nature of the building, partly because of the high quantity of these vessels (73% of the objects in the shop were either dried food containers or patent medicines) and partly because of the location of the objects. The tiny medicine bottles were probably used for acids like HCl or tannic acid for cleaning metal, or for bluing or browning or for fluxes. They may also have been used for lubricants like whale oil. The larger containers, however, probably contained powders like borax for welding or oils like Neet's foot oil for leather. Lamp black for stoves is another possibility. They also may have been used for compounds like varnish, shellac or linseed oil used in wood finishing, but as there were no traces of these tenacious substances that is unlikely (Per Guldbeck 1979: pers. com.).

One of the "liquor" bottles was unusal. It was made of poor quality amber glass and had vertical striations on a champagne neck (Fig. 11). Only one other example, from Fort Beauséjour, is known in the Parks Canada collection. The bottle was probably of continental origin, possibly from France, and may well have contained spa water rather than liquor (O. Jones 1979: pers. com.). It is not known whether this or the other liquor bottle had a secondary use.

Outside the building in the extreme southwest corner of the operation were found two objects, a liquor bottle and a dried food container, which may be associated with a similar dump behind the semi-subterranean building to the south of the smithy. The type of glass, as well as its location, point to this conclusion. Suboperation F to the west of the shop contained only eight pieces of glass, and these were all dark green container glass sherds found in the southern part of the suboperation. Any link between the objects in suboperation C and those in suboperation J thus seems tenuous. In addition, the west end of the semi-subterranean building was partially excavated just before the blacksmith shop was exposed, and several glass objects were recovered. Among them were a dark green liquor bottle and a colourless lead glass dried food container of the same type as those found in suboperation C of the blacksmith shop. Although there were no duplicate shapes, cross mending of the glass in the two operations proved inconclusive. If the semi-subterranean building is ever excavated, however, it may be possible to demonstrate some connection between the two buildings in this regard (Appendix D).

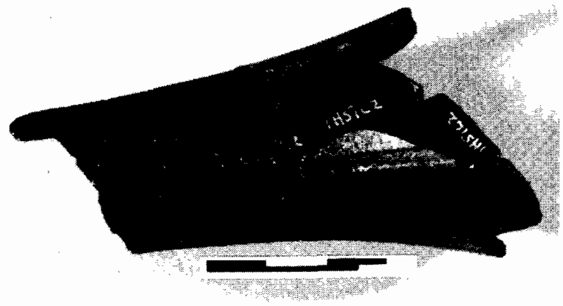

Figure 11. Amber container glass with champagne neck and vertical striations from primary mould, possibly French, 1H51L2-2. (Photo by J. Light)

Pipes (Table 5)

The operation contained only 38 pipe fragments, all but one of which are white clay and all of which are consistent with the period 1790-1830. The other pipe fragment was from the shank of an aboriginal pipe, which may indicate that the smith was doing work for Indians. The complete assemblage represents only four functional pipes: the aboriginal pipe which is unique to the assemblage, and three white clay pipes as represented by the shank-bowl juncture. There was one manufactured bite, and a bowl/stem ratio among the clay pipes of 8:29. Thirteen white clay pipe fragments are known to have been found outside the walls of the smithy, and a total of eight of these were in the scrap piles labeled 1 and 5 in

Figure 2. Of the remainder, 36 per cent, including two functional pipes, were found in the domestic area of the shop, but some of these may have been outside the shop as they were discovered before the walls were found and none of them were mapped into the grid. The only functional pipe not discovered along the south wall was found near the forge, and may have belonged to the smith.

These figures generally confirm the domestic area of the shop was along the south wall; however, the total number of fragments appears curiously low.

Although we do not know how long the shop was occupied, the quantities of other material associated with the shop, notably 46 kg of clinker, point to a well-used forge. The number of pipes associated with the shop then appears low, considering that a blacksmith shop, by reputation at least, resembled a contemporary country garage. It was the warmest place in town in winter, and there was always someone chatting with the smith waiting for the work to be completed. This analogy apparently does not hold here because this may be the shop of Messrs. Spenard, Fields, Varin and Pelladeau. We know there was an Indian Department smith at the fort, and there may have been a North West Company shop as well. If this was the case, then the shop of Spenard, Fields, Varin and Pelladeau probably struggled for its economic existence, and this may well be a source of the enmity James Fields obviously felt for Louis Dufresne. A blacksmith would undoubtedly make useful business contacts, but as Dufresne was not legally empowered to trade with the Indians, his use of his position to indulge in illegal activities must have been sorely resented by Fields, who was under no such constraint. It may also account for a relative paucity of customers for Fields's shop and hence a small number of pipes. It may also be, of course, that the smith was not convivial and that nobody stayed to chat while the work was being done. Whatever the reason, the pipes were few. They are also particularly undistinguished.

Table 5. Smoking pipes (all pipe remains are fragmentary).

Provenance	No.	Description
1H51A2	2	stem
1H51A4	2	stems (1 manufactured bite)
	1	bowl (shank-bowl juncture, Fig. 5)
1H51B2	1	stem
	1	bowl (TD partial, on bowl)
1H51B2-15	1	aboriginal pipe, carved and drilled steatite, socket shank pipe, grey, decoration, geometric abraded, frag. of shank (Fig. 5)
1H51C2	1	stem
	1	bowl (shank-bowl juncture with WG on spur) (Fig. 5)
1H51C3	1	stem
1H51C4	1	stem (reworked bite, teeth marks)
1H51D4	1	bowl
1H51D5	2	stems (1 repair)
1H51E1	1	stem
1H51E5	1	stem
1H51G2	1	stem
1H51G4	1	bowl (smoking stains)
1H51G5	2	stems
1H51H2	3	stems
	1	bowl (shank-bowl juncture with WG on spur)
1H51H3	1	stem
1H51H5	1	stem
1H51J2	2	stems
1H51J4	1	stem
	2	bowls
1H51K2	1	stem
1H51K5	1	stem
1H51M2	3	stems
1H51M3	1	stem

Building Hardware (Table 6)

Except for a relatively large number of butt hinge fragments in the area of the workbench, which may be from shutters attached to the window above the workbench, the building hardware yields no structural information about the shop. Bcause the building itself was probably removed from the site, this

Table 6. Building hardware distribution.

1H51A2-34	latch plate, incomplete, possibly from shutter (3.2 x 1.5 cm)
1H51A2-36	tear-drop strap hinge finial (1.8 x 3.9 cm)
1H51A4-27	butt hinge fragment; 1 knuckle (2.1 x 2.2 cm)
1H51B2-39	butt hinge fragment; 1 knuckle (2.3 x 2.4 cm)
1H51D2-26	stock lock escutcheon plate (6 x 4.3 cm)
1H51E1-7	shutter dog support post (12.6 x 1.1 x .7 cm)
1H51E2-40	barrel bolt keeper (1.8 x 1.2 cm)
1H51E2-46	latch hook fragment (12.3 x 3.6 cm)
1H51F2-13	latch hook (8 cm long)
1H51F2-14	strap hinge finial fragment, 1/2 tear-drop finial probably from door hinge
1H51G1-17	strap hinge finial fragment (4 x 3.8 cm)
1H51G3-29	hinge fragment, oval finial
1H51G3-30	butt hinge fragment, 1 complete side, 3 attachment holes (5.1 x 3.5 cm)
1H51G3-31	2 butt hinge fragments (2.2 x 2.3 cm) (1.5 x 1.6 x 1.8 cm)
1H51G5-12	butt hinge, 2 knuckles and fixed pin (2.6 x 5.7 cm)
1H51H2-21	ward lock key (13.3 cm long)
1H51H2-22	lock guide, stock lock (4.5 x 2.6 cm)
1H51H2-25	latch hook (14.7 cm long)
1H51J4-8	double strap hinge, fixed pin, 4 attachment holes each side probably furniture hinge, complete, distorted (20.1 x 3.1 cm)
1H51K4-9	latch bar with rivet, incomplete
1H51K4-14	ward lock spring, incomplete (4.6 x 1.3 cm)
1H51K4-15	key post guide plate (4.5 x 4.1 cm)
1H51K5-20	lock bolt from ward lock, brazed (12.6 cm long)
1H51K5-28	hinge pin with 2 fragments of knuckles (10.7 cm long)
1H51L3-12	key blank (9.2 cm long)
1H51L3-16	strap hinge eye and portion of shank, incomplete, broken, at third attachment hole, probably door hinge (13 x 3.2 x 2.3 cm)

is not remarkable. The hardware remnants in the shop all come from latches, locks or hinges, either broken and awaiting repair or in the midst of the repair process. Forty-four per cent of the objects are in the northeast interior corner of the building where the dump is located, and fully 58 per cent are in the working area of the forge. The objects in Figure 12 represent repairs to building hardware made by this smith, in this case in his capacity as locksmith.

The nails from the building also provide minimal structural information. The majority of nails were standard forged rose heads and were evenly distributed around the walls of the structure. From the even distribution of these rose heads the structure was likely weather-boarded but this conjecture cannot be substantiated. The average size of the complete rose heads is compatible with this conclusion.

Several extremely unusual nails (Fig. 13) were discovered in three locations, either around the anvil or in the two scrap piles on the east side of the shop. Apparently these were produced by the smith, but their use is unknown unless the nails with oversized heads were used for leather or as decorative nails. At least one nail, a common rose head with a twisted shank, was clearly the result of a diversion by the smith (Fig. 13d).

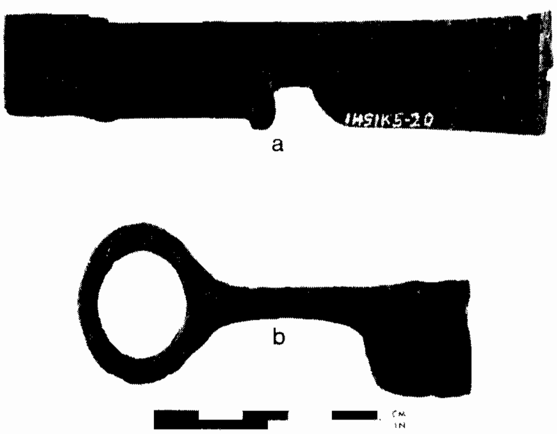

Figure 12. Building hardware repair: a) sliding lock bolt - the head has been brazed back on the shank, 1H51K5-20; b) key blank, 1H51L3-12. (Photo by R. Chan)

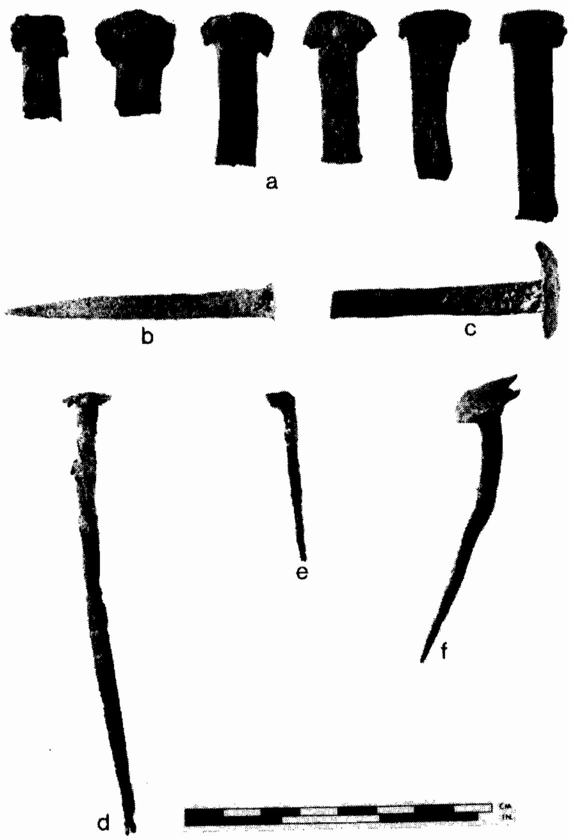

Figure 13. Nails: a) six T-head, square shank nails - all heads have been applied and all shanks are hot-cut, 1H51E2-35; b) headless, rectangular-tapered, sharp-pointed nail, 1H51A4-17; c) square, flat, oversize head, square to hot-cut round shank, 1H51E2-33; d) rose head nail with twisted shank, 1H51D1-4; e) L-head, rectangular shank, sharp-pointed nail, 1H51D2-11; f) square, flat, oversize head, square shank, sharp-pointed nail, 1H51A2-22. (Photo by R. Chan)

Tools

Files (Table 7)

The smithy contained 37 files or portions of files, of which only one, a smooth, double-cut warding file, was complete. The rest were either broken or reworked. A wide variety of types are represented: either single-cut, double-cut, or rasp; smooth, second-cut, bastard, coarse, or rough; 3-square, flat, knife, or 1/2-round.

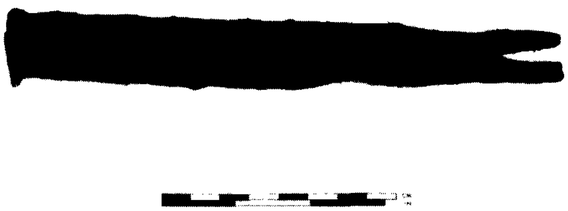

Figure 14. Pry bar made from file, 1H51G3-11. (Photo by R. Chan)

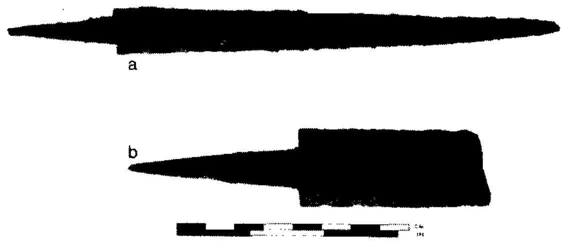

Figure 15. Files: a) warding file with illegible mark, 1H51J2-1; b) 1/2-round, double-cut file, broken on shaft, marked "MV&Co," 1H51L5-1. (Photo by R. Chan)

Table 7. Files - overall dimensions are given.

1H51A4-4	flat rasp, bastard, single-cut rough edges, broken, 2.9 x 2.1 x .9 cm
1H51B2-6	3-square, smooth, double-cut file, reworked into a punch, 4.9 x .7 x .7 x .6 cm (may have been knife file)
1H51B2-7	3-square, smooth, double-cut file with circular point rewofked into a punch, 3.5 x .7 x .7 x .7 cm (mends with 1H51C3-3)
1H51B2-35	two round files: 1) cut, tooth pattern indistinguishable, 3.8 x .5 cm; 2) broken, tooth pattern indistinguishable, 3.4 x .5 cm
1H51C2-2	1/2 round rasp, coarse reworked, 9.3 x 2.5 x .6 cm
1H51C2-3	flat, tapered, single-cut, bastard, reworked, 2.3 x 1.7 x .5 cm
1H51C2-4	3-square, smooth, double-cut file with tang; broken on blade; 11.8 x .9 x .9 x .9 cm tang length, 5 cm
1H51C3-3	3-square, beveled corners, smooth, double-cut, reworked into a punch, ends broken, 6.6 x .8 x .8 x .8 cm (mends with 1H51B2-7)
1H51D2-4	flat, tapered, double-cut, second-cut, hot-cut one end, broken other end, 4 x 2.5 x .7 cm
1H51D2-5	flat, double-cut, second-cut tapered file; point and portion of blade, broken; 5.5 x 1.7 x 5 cm
1H51D2-6	flat rasp, tapered, bastard, single-cut rough edges, broken, 3.5 x 1.6 x .6 cm
1H51D2-7	flat, double-cut, second-cut file with tang, brazing on teeth and on broken end, 9.4 x 2.2 x .5 cm
1H51D2-31	two file tangs, hot-cut: 1) 6.5 x 1.6 x .8 cm; 2) 5.3 x 1.3 x .6 cm
1H51E2-6	3-square, second-cut, double-cut, hot-cut one end, broken other end, 6.1 x 1.2 x 1.2 x 1.2 cm
1H51E2-7	flat file, reworked, tooth pattern indistinguishable, 10.2 x 2.6 x .6 cm
1H51E2-8	flat, single-cut, bastard file, reworked, distorted, 5.6 x 2.5 x .9 cm
1H51E2-9	knife, smooth, double-cut file, portion of blade, hot-cut, 2.3 x .8 x .8 x .7 cm
1H51E2-10	1/2 round, double-cut, bastard, reworked, distorted, 5.5 x 2.6 x .7 cm
1H51E2-11	two pieces of metal butt welded together, at least one of which was a file; tooth pattern indistinguishable; irregular shape; 8.4 x 2.1 x .9 cm
1H51E2-47	3 flat tiles, all reworked: 1) 13.3 x 2 x .6 cm, tooth pattern indistinguishable; 2) 9.3 x 2 x .8 cm, tooth pattern indistinguishable; 3) coarse, double-cut, 2.5 x 2.1 x .6 cm
1H51E3-4	round, reworked, distorted, tooth pattern indistinguishable, 6.1 x 1 cm
1H51E3-5	flat, double-cut, second-cut, broken, reworked, 3.8 x 2.7 x .7 cm
1H51E4-1	1/2 round, coarse rasp, broken, blade fragment, 1.8 x 2.3 x .7 cm
1H51F2-12	flat, tapered, second-cut file, single-cut one face, double-cut other face; blade hot-cut; 3.1 x 2.7 x .5 cm
1H51G2-2	flat, coarse, double-cut file, hot-cut one end, broken other end, 7.5 x 2.3 x .7 cm
1H51G3-10	flat, double-cut, second-cut, hot-cut one end, broken other end, 2.7 x 2.2 x .6 cm
1H51G5-1	flat, double-cut, bastard, broken, 2.1 x 2.1 x .7 cm
1H51H5-1	1/2 round, double-cut, second-cut, rounded point, hot-cut, 6.2 x 1.9 x .7 cm
1H51J2-1	smooth, single-cut, warding file, complete with tang; mark radiographed - illegible total length 18.9 cm; width at shoulder 1.6 cm (Fig. 15a)
1H51J4-1	1/2 round, coarse, double-cut file point, broken on blade, 7.7 x 2.6 x .6 cm
1H51J4-2	flat, rough, single-cut file, reworked, 5.7 x 3.6 x 1.2 cm
1H51L3-2	1/2 round, coarse, single-cut, reworked, 5.7 x 3.6 x 1.2 cm
1H51L3-3	flat, single-cut, bastard, possible warding file, broken, 12.7 x 2.5 x .7 cm
1H51L5-1	1/2 round, double-cut bastard; tang and portion of shank, broken, 12.5 x 2.7 x .8 cm; marked "MV & Co" (Fig. 15b)

Files are, of course, used as woodworking, metalworking or farriering tools, and this smith was undoubtedly using them as such. However, he regarded them equally as stock; indeed, worn files probably served, given his situation, as his chief source of high grade steel. Sixty-eight per cent of the files from the shop show signs of reworking and at least one tool found in the shop, a pry bar (Fig. 14), was made from a file. In addition, 32 per cent of the files from the shop were from the area immediately around the anvil, and all of these had been reworked. Two files bore marks of the tangs (Fig. 15). One was indecipherable and the other was marked "MV & Co." At least one other example of a file marked "MV & Co" is known. It was found during the excavation of Edmonton House III and is described by Nicks (1969: 133) who notes that it is "most closely associated with the Hudson's Bay Company." This mark is at present unidentified, but as Fort St. Joseph has no associations with the HBC, the mark cannot be uniquely associated with that company.

Axes (Table 8)

Remnants of 20 axes were found in the shop. None were complete. The majority of these objects are axe bits snipped from the blade (Fig. 19; 20d, e; 21f). This is a common

Table 8. Axes.

Provenance	No.	Description & comments
1H51A2-2	1	Portion of bit. Snipped off. A common item of waste from axes with drawn bits. If the shape is wrong, or it is incorrectly drawn or if the bit is chipped, it is snipped off and redrawn.
1H51B2-4	1	Portion of bit. Snipped off.
1H51B2-5	1	Probable pole.
1H51C2-1	1	1/2 axe eye. Edges broken. Almond-shaped eye of single bitted axe. No poll. (Fig. 18)
1H51C3-2	1	Bit. Snipped off. An attempt has been made to narrow the bit which has resulted in a slight buckling of the thin portion. A section of the cutting edge has been dulled by striking the hot object. Has been file sharpened.
1H51D1-1	1	Overlay, knife-edged bit, with steel slug. Fractured across blade, probably by being struck in very cold weather. (Fig. 18)
1H51D2-25	2	Portions of two bits. Snipped off.
1H51E2-5	1	Hatchet bit. Thin blade (8 mm). File sharpened. Broken across blade.
1H51E3-3	1	Single bitted. Knife edged. Inlay bit. Leading edge straight. Back edge tapered toward eye. Fractured at base of eye. Apparent beginning of ear. Mark indecipherable on right blade below eye. Rectangular stamp with scalloped edges. (Fig. 18)
1H51E3-6	1	1/2 axe eye. Edges broken. Almond-shaped eye of single bitted axe. No poll.
1H51F2-1	1	Blade and bit. Hot cut below eye. Inlay bit. Knife edged. Leading edge straight. Back edge tapered toward eye.
1H51F5-1	1	Blade and bit. Fractured across blade below eye. Knife edged. Overlay bit. Leading edge curved, back edge straight. "D" stamped on left blade near bit. (Fig. 18)
1H51G3-9	1	Blade and bit. The blade, just below the eye, has been constricted, and this has apparently caused the fracture. Knife edged. Inlay bit. Leading edge straight, back edge tapered toward eye. (Fig. 18)
1H51G3-27	1	Highly distorted fragment of 1/3 eye and segment of blade of folded strap axe. All three terminal edges hot cut. Both blade and part of eye have been constricted by hot working of the metal.
1H51G5-11	1	Bit. Snipped off. Knife edge is distorted by an attempt at narrowing.
1H51H2-3	1	Portion of bit. Snipped off.
1H51H2-4	1	Portion of bit. Fractured across blade and at back edge. Knife edge. Inlay bit.
1H51K5-5	1	Bit. Snipped off as prelude to reshaping bit.
1H51M2-1	1	Blade and bit. Snipped off. Very distorted due to an attempt at narrowing. Marks of both anvil and hammer visible on sides of blade. Knife edged.

Figure 16. Single-bitted, folded strap axe with portion of ear; indecipherable mark contained within rectangular box with scalloped edges on blade near eye, 1H51E3-3. (Photo by G. Vandervlugt)

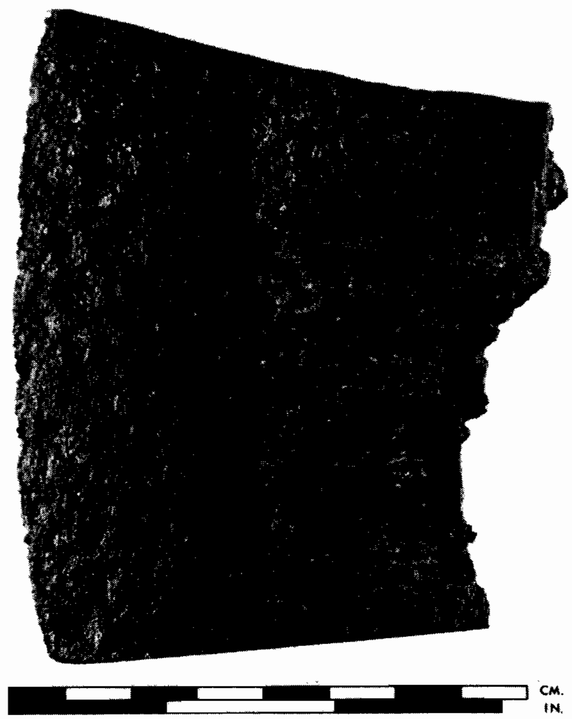

Figure 17. Single-bitted, folded strap axe with inset bit - marked "D," 1H51F5-1. (Photo by G. Vandervlugt)

item of waste from the repair of axes with drawn bits. If the shape is wrong, or if the bit is chipped, it is snipped off and the bit is redrawn. Forty-five per cent of the axes in the shop show this type of repair. A different sort of repair is indicated by the presence of a probable axe pole among the artifacts. This pole had been shaped but not yet applied to the axe (Fig. 21c), presumably indicating the smith was periodically requested to modify axes to make them heavier cutting tools. At least one item may have been originally a repair. It was a very deformed axe which the smith appears to have been hammering up into new stock (Fig. 21a, b).

The remaining axes (Fig. 18) are all "shattered." It appears from analysis (Unglik 1987, this volume) that the fracturing is due to the metal being brittle under extremely cold conditions, which in turn can be directly attributed to the forging of the axes. If they were broken in use during the winter, then the owners brought them to the shop for repair. One axe (Fig. 18d) that had been heat-treated subsequent to the original forging had been repaired by a smith before it broke.

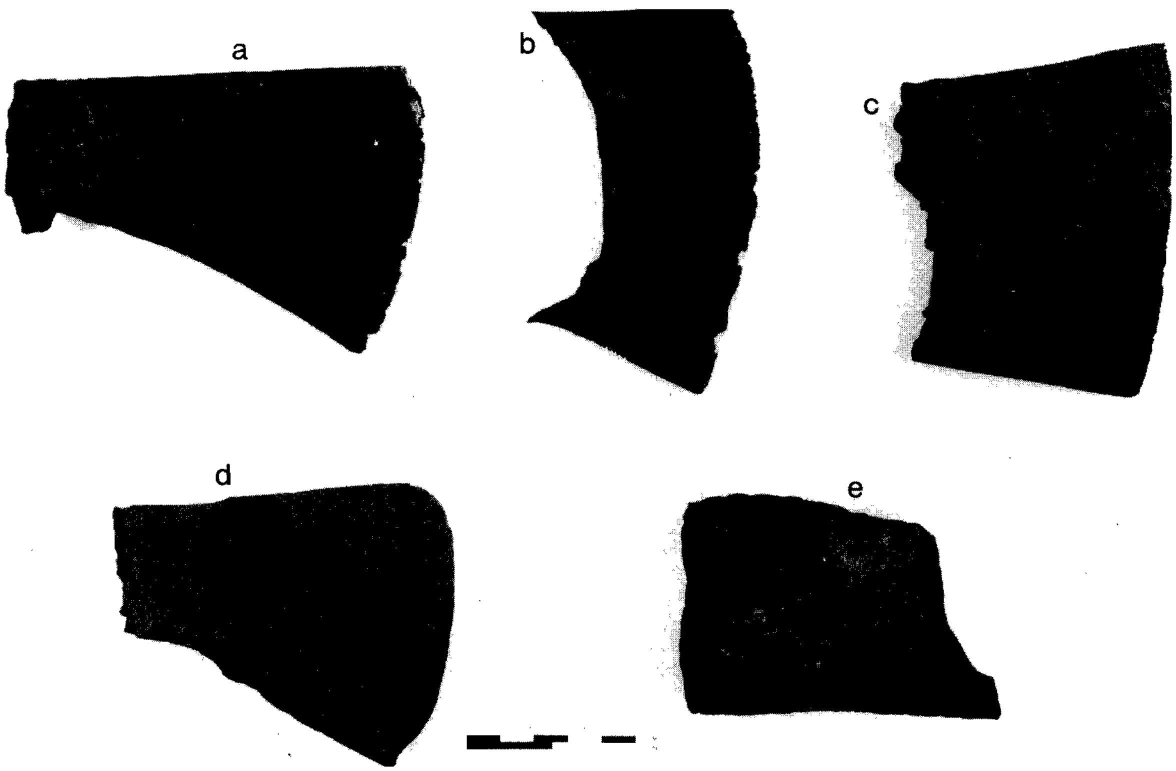

Figure 18. Shattered axes: a) single-bitted, folded strap axe with portion of ear and indecipherable mark, 1H51E3-3; b) folded strap axe with probable inset bit, 1H51D1-1; c) single-bitted folded strap axe with inset bit - marked "D" on the back, 1H51F5-1; d) single-bitted, folded strap axe with probable inset bit, distorted by hot working just below eye, 1H51G3-9; e) half almond-shaped eye of single-bitted, folded strap axe - no poll, 1H51C2-1. (Photo by G. Vandervlugt)

Presumably the original bit had been snipped off and the cutting edge reformed and heat-treated. However, as very little steel was left and as the attempt at hardening was unsuccessful, the bit was relatively soft and had been dulled through use.

Two of the axes were marked (Figs 16, 17), but only one of these marks, a "D", was decipherable. This may have been the mark of Louis Dufresne, the Indian Department blacksmith at Fort St. Joseph, but as the Indian Department smithy has not been excavated, and as no other examples of this mark are known, this hypothesis cannot as yet be verified. Even if this was Dufresne's mark, it was not his shop because although there is evidence that the blacksmith was repairing axes, there is no evidence to indicate that he was manufacturing them. If manufacture had been carried on in the shop we should have found discarded mistakes, clipped poll fragments, eye moulds and the corner cuts made preparatory to inserting a bit (L. Ross 1979: pers. com.), but none of these objects were recovered. Only two of the suboperations were without axe fragments, and over half (53%) of the axes were found in the working area of the forge.

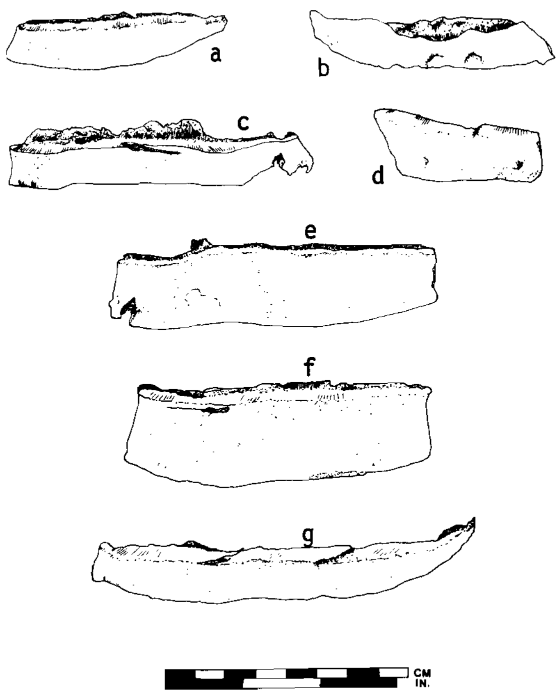

Figure 19. Axe bits. All have been clipped from the blade preparatory to reshaping the bit: a) 1H51A2-2; b) 1H51B2-4; c) 1H51D2-25; d) 1H51D2-25; e) 1H51G5-11; f) 1H51C3-2; g) 1H51K5-5. (Drawing by P. Handy)

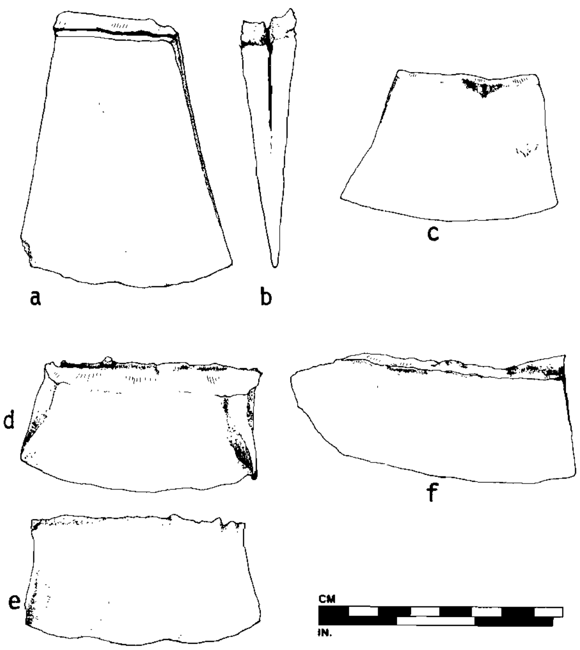

Figure 20. Axe parts: a,b) side and end view of axe blade and bit - the end view shows the weld line typical of a folded strap axe - the blade has been hot-cut from the eye, 1H51F2-1; c) blade and bit of thin axe, probably a hatchet - the blade has been broken, 1H51E2-5; d,e) front and back view of axe bit distorted by trying to narrow the bit and subsequently snipped from the blade, 1H51M2-1; f) axe bit - the bit has been shattered, not cut from the blade, 1H51H2-4. (Drawing by P. Handy)

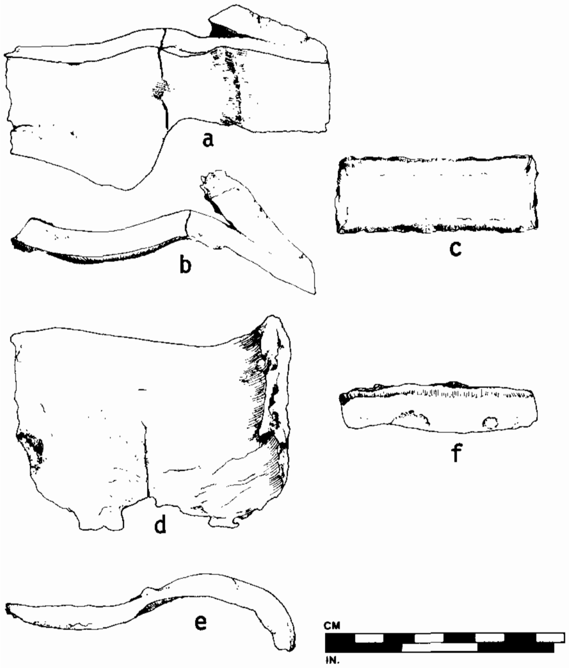

Figure 21. Axe parts: a,b) distorted eye and portion of blade from a folded strap axe - the edges have been hot-cut and the smith was apparently hammering up this piece into new stock, 1H51G3-27; c) probable pole, cut but not yet applied to the axe, 1H51B2-5; d,e) interior and end view of an almond-shaped eye from a folded strap axe - the object has been shattered, either from extreme cold or in a forge-related accident, 1H51E3-6; f) axe bit snipped from the blade, 1H51H2-3. (Drawing by P. Handy)

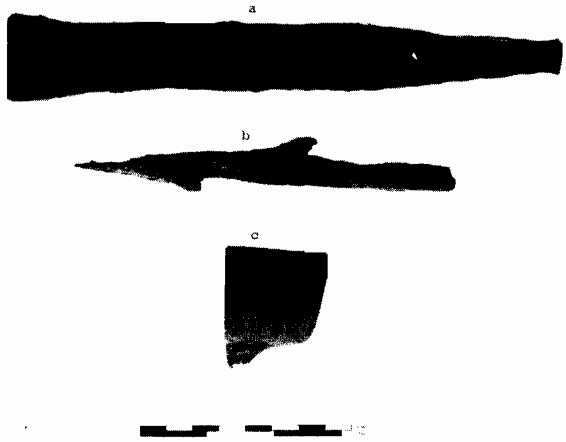

Figure 22. Tools: a) chisel, possibly a mason's, 1H51C2-5; b) muskrat or sturgeon spear, 1H51C2-19; c) hoe eye from small hoe, 1H51G3-23. (Photo by R. Chan)

Tools Other than Files and Axes

The remaining tools in the shop may conveniently be divided into two categories: tools used by the smith, and tools apparently brought to the smith for repair. The majority of tools in the latter category are three chain links, four shovel parts, and four wedges, but also included are a muskrat or sturgeon spear, a rake, a hoe eye and a chisel, possibly a mason's chisel (Fig. 22). Two hammer head fragments represent tools possibly used by anyone, although the blacksmith was the likely owner. This is also the case with the pry bar made from a file. The only tools that belonged indubitably to the smith are several punches, a tap, a pair of fire tongs and a hot chisel (Fig. 23). Only one of these tools is at all unusual. The tap, probably a gunsmith's tap, is very roughly made, and could have been a product of this forge.

Farriering (Table 9)

Evidence of farriering activity in the form of horseshoe fragments and horseshoe nails is concentrated along the front of the shop. This is to be expected because the shop is too small to accommodate horses inside. The shoeing must have been done outside the shop, possibly near the road or lane that probably joined the buildings along the east shore of the point. Most of the nails (55%) are associated with the scrap pile at the southeast corner of the building. There is also

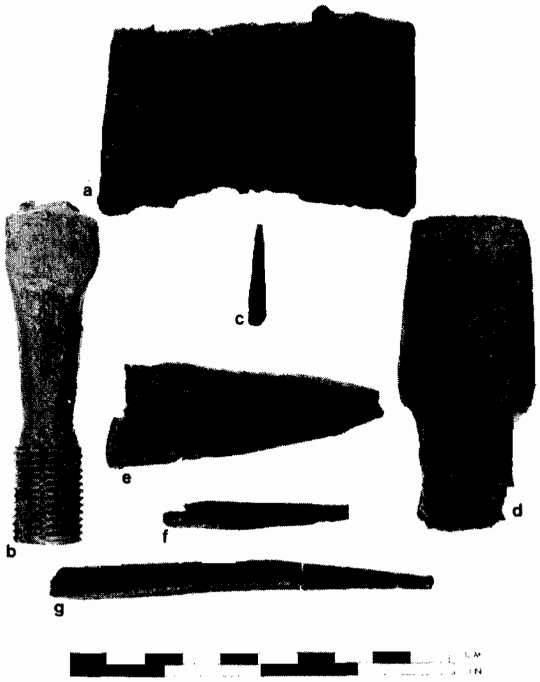

Figure 23. Blacksmith's tools: a) stock cut with chisel (*see* "d"), 1H51B2-34; b) tap, probably a gunsmith's tap, 1H51K4-3; c) punch tip, 1H51A2-27; d) hot chisel (*see* "a"), 1H51B2-8; e) fire tongs - the handles have been clipped from the tongs, 1H51G5-2; f) square punch tip, made from file, 1H51B2-6; g) small round punch, made from file, 1H51B2-7 and 1H51C3-3. (Photo by R. Chan)

a proportionally high number of nails (25%) in the work area (E-H), reflecting not only the fact that the smith manufactured these items himself but also perhaps that a nail having been dropped is too small to bother picking up. The area around the anvil was indeed strewn with small objects, suggesting the smith had sloppy work habits. The horseshoe nails themselves are irregular and crude (Fig. 24).

Table 9. Horseshoe nails and horseshoes (in parentheses).

Provenance	No.	Description & comments
1H51A2-11	14	3 complete, 10 incomplete, 1 fragment
1H51A4-2	4 (1)	1 complete, 3 incomplete, right heel of shoe, no crease, no calk, 2 holes (1H51A4-15)
1H51A5-1	1	complete
1H51B2-13	8	incomplete
1H51B5-1	1	complete
1H51C2-9	3	1 complete, 2 incomplete
1H51C3-1	1	complete
1H51D1-3	1	incomplete
1H51D2-1	8	2 complete, 6 incomplete
1H51D5-2	1	incomplete
1H51E2-17	12 (2)	2 complete, 10 incomplete, 2 horseshoes (1H51E2-1 and 1H51E2-2). Both left side and hind calk. One shoe partially reworked.
1H51E3-1	2 (1)	complete, 1 horseshoe (1H51E3-12); left hind calk and portion of shoe
1H51G1-7	1	complete
1H51G2-8	2	one complete, one incomplete
1H51G3-15	2	1 complete, 1 preform having upset head, not yet formed to fit in crease; preform shape of head is square
1H51G5-5	1	incomplete
1H51H1-3	2	1 complete, 1 incomplete
1H51H2-10	1	complete
1H51J2-3	(1)	right hand calk and portion of shoe, no crease, no holes
1H51K5-10	1	incomplete
1H51L3-6	1	complete

The complete horseshoe nails range from 4.3 to 6.8 cm long but most range from 5.2 to 5.6 cm. Although each nail, being handcrafted, is unique, they all conform to the following description: Head -- merely a widening and thickening of the shank (back of head parallel to shank), top tapered from head to back; shank -- rectangular, flat, tapered; point — sharp.

Figure 24. Horseshoe nails made by the smith. (Photo by R. Chan)

Of a total of five shoe fragments, which represent at least four different shoes, three were found near the anvil and one in the scrap pile at the southeast corner of the shop. One was a pony shoe. Three had fairly long calks (2, 2.3 and 2.5 cm) designed to increase the gripping power of the horse, and were probably for draught animals.

Farriering cannot be considered one of the smith's major activities although from the volume of material in the shop there were apparently enough animals on the site to keep the smith periodically busy. Strangely, however, although we know there were oxen at Fort St. Joseph (Askin 1931: Vol. 2, p. 649), there were no ox shoes found in the smithy.

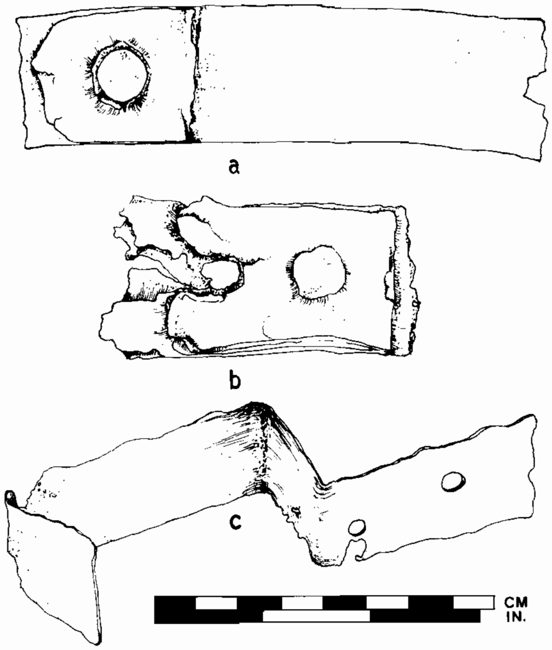

Figure 25. Barrel strapping: a) barrel strap, hot-cut near rivet, 1H51A4-11; b) barrel strap, hot-cut near rivet, 1H51A2-10; c) stake pocket, possibly made from barrel strapping, 1H51A2-32. (Drawing by P. Handy)

Coopering

The smith may, from time to time, have been engaged in coopering, or at least in repairing broken or rusted barrel strapping. It is impossible to be definitive about his activities in this regard because although 94 pieces of strapping were recovered during excavation, only 24 of these are definitely barrel straps. Barrel strapping is unusual in that the only way its presence can be determined with certainty is by the fragments containing the rivets, smoothed on one side to fit the barrel. There are many pieces of metal in the shop that are probably barrel strapping, but they cannot be distinguished from strapping of other kinds. The rivets yield artifactual data; the bare strapping is merely artifictional.

Of 24 known barrel straps in the smithy, none were from complete hoops, none were associated with wood of any kind, all were ferrous, and almost all (18) had been hot-cut near the rivet. They were also recovered in every suboperation except "J" and "M," although there were ten barrel strap fragments in the dump at the southeast corner of the building, three in the area of the forge, and three in the scrap pile in the northeast interior corner of the building. As mentioned earlier, the barrel strapping did not indicate the location of the quenching tub, nor does it indicate the fact that the smith was engaged in coopering. Although there was a high percentage of straps that had been worked by the smith, he may have been merely salvaging straps from old discarded barrels, rather than repairing still utile ones. This is indicated by a stake pocket which may be from barrel strapping (Fig. 25c). Although this may not originally have been a barrel strap, all the strapping in the shop measured between 3 and 3.5 cm wide, and the stake pocket is the same width. It is also approximately the same gauge as the barrel strapping.

General Domestic Repair

At least some of the blacksmith's time was spent repairing small domestic objects, either for himself or for other members of the fur trading community. Various objects (Figs 26, 27) found around the shop ranging from furniture hardware to a book hinge appear to confirm this.

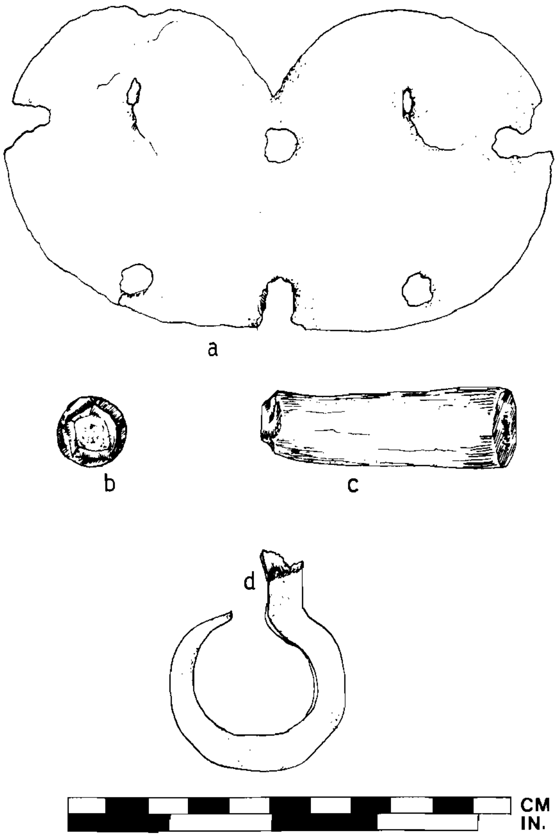

Figure 26. General domestic repair: a) trunk handle escutcheon plate, 1H51C2-10; b,c) side and end view of incompleted piece of antler, probably intended as a handle for a small tool or utensil - the end has been carved with a knife, 1H51J4-6; d) rat-tailed hanger hook for a kitchen utensil - the shank has been hot-cut, 1H51L3-11. (Drawing by P. Handy)

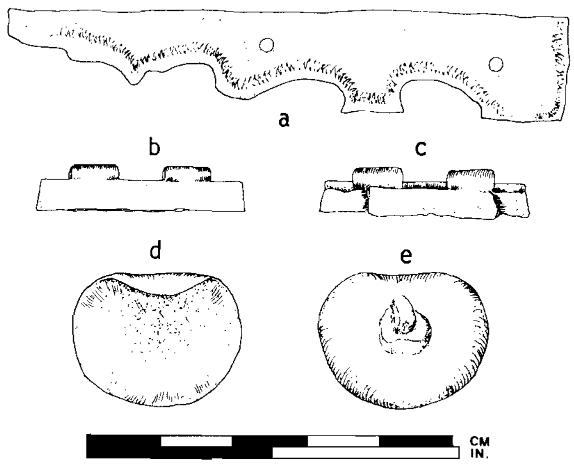

Figure 27. a) decorative brass strip with wiggle-work engraving, probably from a patch box, 1H51A4-2; b,c) pewter book hinge from a Bible or ledger, front and back views, 1H51G4-1; d,e) front and back view of possible small drawer pull - a ferrous object, possibly a screw, is imbedded in the brass flange, 1H51G3-24. (Drawing by P. Handy)

Traps (Table 10)

Repairing traps appears to have been a common activity of this smith. There were 34 fragments of traps in the shop: 19 springs with eyes, 3 springs without eyes, 7 jaw posts, 2 pan posts, 2 jaws and 1 catch (Figs 28-30). Of these 34 parts, 22 had been hot-cut, and 21 of 22 springs had been cut. The broken springs were being used as a source of steel (Fig. 28). The spring steel was likely used to make new springs, and judging from the size of the cuts in the trap springs, the new, smaller springs that he was manufacturing were for guns (*see* "Weapons and Weapon Hardware").

Because only fragments of traps were found in the smithy, and because no frames were included in the assemblage, it is difficult to identify the type of trap the smith was repairing. There is apparently no literature that attempts to relate the size of trap parts to the kind of animal being trapped. The speculations that follow are therefore based on personal communication with Lester Ross of Parks Canada, Ottawa, and Charles Hanson of the Museum of the Fur Trade, Chadron, Nebraska.

There are three basic sizes of traps, small, medium and large, or what may be loosely called rat traps, beaver traps and bear traps. There are wide variations within these "sizes," caused, it seems, by both the kind of material

Table 10. Trap parts (all measurements show interior diameter of the eye).

Provenance	No.	Description
1H51A2-37	1	complete 1/2 trap jaw post
1H51A2-38	1	preform trap jaw post
1H51A4-28	1	trap spring eye frag. hot-cut, approx. 2.5 cm
1H51A5-8	1	complete 1/2 trap jaw post
1H51B2-40	1	trap spring eye, hot-cut from shank, 2.6 cm
1H51C3-14	1	trap spring eye, hot-cut from shank, 2.2 cm
1H51C3-15	1	trap spring eye 1/2, hot-cut bilaterally, approx. 2.5 cm
1H51C3-16	1	trap spring, eye and shank, 2.6 cm
1H51D2-34	1	trap spring catch
1H51E2-50	2	trap spring arms (2) clipped springs, apparently making gun springs
1H51E2-51	1	2/3 trap spring eye, hot-cut across eye, 3.1 cm
1H51E2-52	1	1/2 trap spring eye and shank, hot-cut bilaterally, 2.5 cm
1H51E2-53	1	whole trap spring eye and portion of shank, hot-cut from shank, 2.3 cm
1H51E2-54	1	trap jaw post leg frag.
1H51E3-22	1	trap spring eye frag. hot-cut one end, other end broken
1H51E3-23	1	trap spring eye and portion of shank, broken, 2.1 cm
1H51E4-6	1	trap spring eye frag. hot-cut, approx. 3.2 cm
1H51F2-15	3	trap spring eye and shank frags., all hot-cut, one cut bilaterally, 2.8 cm
1H51F2-16	1	trap jaw post 1/2 post
1H51G1-18	1	trap jaw post complete with 3 rivets, jaw frag. cut
1H51G1-19	1	trap pan post frag.
1H51G2-25	1	trap jaw frag. with pivot hole
1H51G3-32	1	trap pan post
1H51G3-33	1	trap jaw frag., broken, with pivot hole
1H51G3-34	1	trap jaw post with leg, complete, 3 rivets, jaw fragment cut
1H51G5-13	1	trap spring showing steel salvage; probably making gun spring
1H51H2-27	1	trap spring eye and shank, frag. broken from eye, hot-cut across shank, 2.8 cm
1H51J3-6	1	trap spring eye, cut across eye, 1.6 cm
1H51K5-29	1	trap spring eye and shank, hot-cut from shank, 2.9 cm
1H51K5-30	1	trap spring eye, cut across eye, 2.7 cm
1H51L3-17	1	trap spring, no eye, incl. portion of bend, broken

available to the trap maker and his individual predilections in matters of style. The height of the trap jaw post, for example, depends on the length of the spring, the size of the bend in the jaws, and the quality of steel available for the spring. Up to approximately the middle of the nineteenth century, the individual smith and the quality of materials available to him accounted for a large variation in the type and size of traps (cf. the trap illustrations in Russell 1967). Toward the end of the nineteenth century, however, with the rise in factory production and the decline in general blacksmithing, traps became more and more standardized. They also became smaller as the quality and uniformity of material available from the smelters improved. Looking in late nineteenth century catalogues for information about early nineteenth century trap sizes and types is therefore unwise.

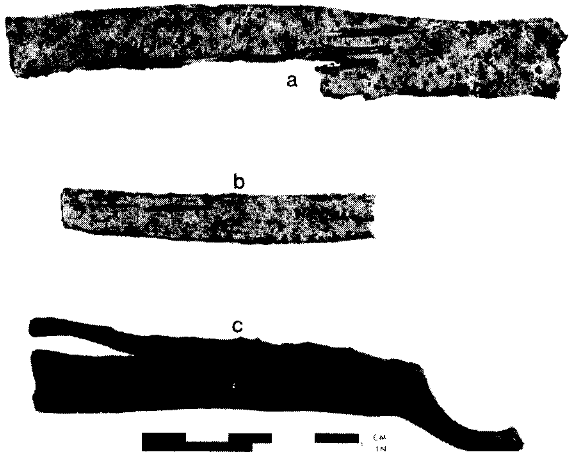

Figure 28. Trap springs scavenged for steel: a,b) probably from the same piece of steel, 1H51E2-50, "b" closely resembles a gunspring; c) spring and portion of eye - the cuts along the length of the spring are clearly visible, 1H51G5-13. (Photo by R. Chan)

The technological changes of the nineteenth century notwithstanding, there is still a necessary correlation between the size of the trap and the kind of animal being trapped, because if the trap is too small or weak it will not hold the animal, whereas if it is too large it will break or cut the animal's leg and the trapper will lose his fur. Because the holding power of the trap depends directly on the spring, the spring seems to provide the best information about the kind of animal being trapped if one only has trap parts and not the whole trap with which to work.

All the trap springs in the smithy have round eyes or bows. At least two were double-eyed springs, and they may all have been double-eyed, this being the most common type of trap. If they are double-eyed springs, then there is an additional complication in that the upper eye which slides up the jaws is always larger than the lower eye which merely rests on the frame below the jaw post. One is unsure, therefore, whether an isolated eye is a lower eye from a large trap or an upper eye from a smaller trap, etc. If the trap has been well used, however, wear marks may be on the inside of the eye at the point where the eye

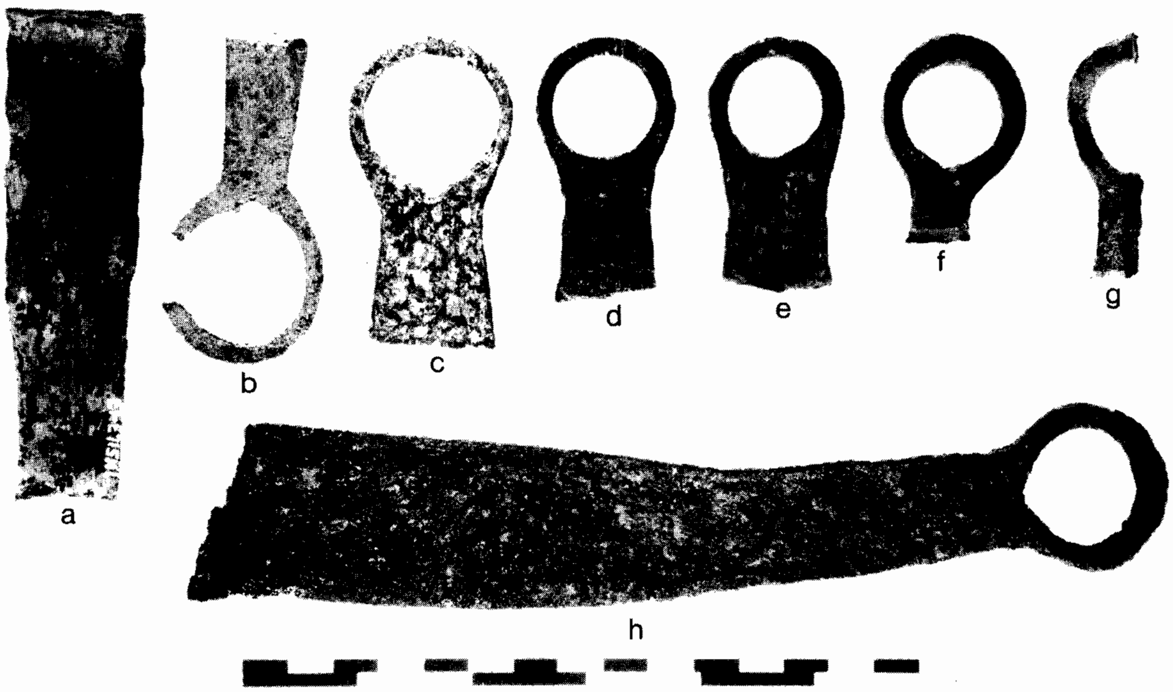

Figure 29. Trap springs: a) trap spring with portion of bend - hot-cut near eye, 1H51L3-17; b) trap spring eye with broken eye and hot-cut shank, 1H51H2-27; c) trap spring with hot-cut shank, 1H51K5-29; d) trap spring eye with hot-cut shank, 1H51E2-53; e) trap spring eye with broken shank, 1H51E3-23; f) trap spring eye with hot-cut shank, 1H51C3-14; g) trap spring eye, hot-cut bilaterally and across shank, 1H51C3-15; h) trap spring eye and shank - broken, 1H51C3-16. (Photo by R. Chan)

rubs either the jaws or the jaw post. This mark(s) should appear on the upper spring only. There are two springs in this assemblage that show what may be wear marks, and both have an interior diameter of 2.8 cm. According to Hanson, these are probably from beaver traps, or at least from traps for medium-sized fur-bearing animals. Accordingly, if one allows for both a reasonable variation of size within a trap type and for the fact that the upper eye is always larger than the lower eye, spring eyes with an interior diameter of 2-3 cm (plus or minus a couple of millimetres) should be from traps for medium-sized fur-bearing animals. Anything smaller than that should be a rat trap and anything larger a bear trap.

One limitation to this hypothesis is that the lower spring from a bear trap could fall within the 2-3 cm range, and anyone attempting to apply or test this hypothesis should note this exception. According to this hypothesis, one of the traps in the smithy was a rat trap, one was a bear trap and the rest are from beaver traps. Because beaver was the most common fur gathered at St. Joseph, the majority of trap parts found in the blacksmith shop should be of a medium size.

This is an interim hypothesis only and may be either proven or disproven. It is, however, proffered in the hopes that it may assist in subsequent research.

Weapons and Weapon Hardware (Table 11)

Except for the items mentioned in "Identification of Shop," the weapon parts are all from non-military equipment or they

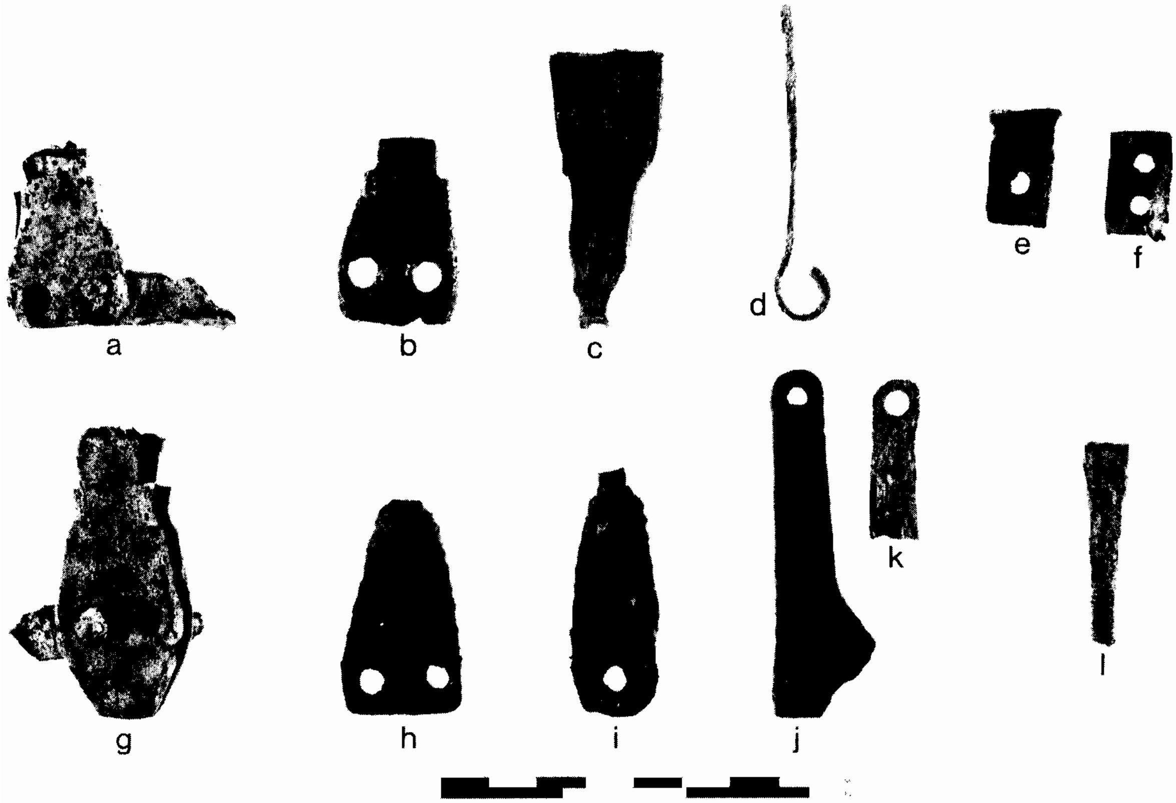

Figure 30. Trap parts: a) trap jaw post with two rivets and portion of hot-cut jaw, the post has been forcibly removed from the frame, 1H51G3-34; b) single leaf of trap jaw post, 1H51A2-37; c) preform trap jaw post, 1H51A2-38; d) trap spring catch, 1H51D2-34; e) complete trap pan post, 1H51G3-32; f) single leaf of trap pan post, broken, 1H51G1-19; g) trap jaw post with three rivets and portion of hot-cut jaw - the post has been forcibly removed from the frame, 1H51G1-18; h) single leaf of trap jaw post - the attachment flange, probably of the threaded type, has been cold cut off, 1H51F2-16; i) single-eyed trap jaw post - the attachment flange, probably of the threaded type, has been hot-cut, 1H51A5-8; j) flared trap jaw, broken, 1H51G3-33; k) trap jaw fragment, broken, 1H51G2-25; l) probable trap jaw post attachment flange, threaded and hot-cut from post, 1H51G3-25. (Photo by R. Chan)

are indeterminate concerning type. Of a total of 40 items found in the shop, 32 are parts of flintlock weapons. As in other instances, this smith, as a gunsmith, is engaged exclusively in repair work, and springs are the most numerous single repair item. Of 32 parts, 12 are springs and all of these were broken. Fourteen trap parts (44%) were found in the area of the workbench, and 67 per cent of the springs were found in the same area. Because the spring parts found in the shop are those segments of the spring that remained attached to the lock after the spring had been broken in use, apparently these items were removed by the smith after the gun had been brought in for repair. They were found mostly around the workbench because they were likely removed there. The new springs were probably fashioned on the vise rather than on the anvil because of the available light from the window

Table 11. Weapons and weapon hardware.

1H51A2-1	trigger guard fragment, copper alloy, possibly pistol
1H51A2-4	gunflint, wedge-shaped, incomplete, reused, possibly for fire steel
1H51A2-12	breech plug, distorted, small bore, probably trade gun
1H51A4-2	patch box moulding
1H51A4-13	sidelock screw
1H51A4-14	cock jaw screw frag.
1H51B2-1	trigger guard, trade gun
1H51B2-10	gunflint, wedge-shaped, incomplete, reused
1H51D2-11	frizzen spring, non-military
1H51E2-18	mainspring, incomplete
1H51E2-19	mainspring, non-military, incomplete
1H51E2-20	lead shot, 5 mm diam.
1H51E2-21	mainspring, non-military, incomplete
1H51E2-22	trigger plate, trade gun
1H51E3-9	top jaw from cock, non-military, distorted, incomplete
1H51E3-10	cannon carriage bolt head
1H51E3-11	ramrod pipe-trade musket
1H51F1-2	ramrod pipe-trade musket
1H51G1-4	artillery carriage tire stud
1H51G1-5	gunflint, incomplete
1H51G1-8	sear spring, non-military, incomplete
1H51G1-9	rear sling swivel, probably military
1H51G1-11	mainspring, trade gun
1H51G1-16	trigger guard, trade musket
1H51G2-1	41st Regt. button, pewter
1H51G2-4	gunflint, incomplete, wedge-shaped
1H51G2-5	gunflint spall
1H51G2-9	frizzen spring, trade gun, incomplete
1H51G2-10	mainspring, non-military, fragment
1H51G2-11	copper jacket bullet - 9 mm, 20th cent., intrusive
1H51G2-12	top jaw from cock, incomplete, probably pistol
1H51G2-26	frizzen spring, fragment
1H51G3-2	ramrod pipe - trade musket
1H51G3-14	sear, trade gun
1H51H2-5	possible musket jaw driver pick
1H51H2-11	frizzen, trade gun
1H51J4-3	sear, trade gun
1H51J5-1	butt plate from trade musket - copper alloy nailed
1H51K4-2	copper alloy ramrod pipe - trade musket
1H51K4-6	sear spring, trade gun, incomplete
1H51L2-4	side lock screw

and the delicate nature of the work. It is noteworthy that steel was in short supply and that one of the blacksmith's sources, perhaps his chief source, for spring steel was trap springs (Fig. 28).

Tinkering

Much of the blacksmith's time seems to have been occupied in repairing pots and kettles. There were numerous pieces of sheet copper and brass from cooking vessels in the scrap piles on the east side of the structure, most of which were undiagnostic. Almost three-quarters (73%) of the undiagnostic material came from the east side of the building, 35 per cent of it from the scrap pile in the southeast corner of the operation, and 25 per cent in the pile beneath the bellows. Enough significant material has survived in the assemblage, however, to describe the repairs undertaken by the smith.

Old copper and brass kettles, not worth repairing, were used by the smith as a source of patches for other kettles and as raw material for the manufacture of rivets, roves and probably lugs. Folded rivets, and probably roves as well were used for securing patches on kettles in need of repair. The smith made his own rivets for these patches by folding diamond-shaped pieces of sheet copper into a rivet shape. The method of manufacture of these rivets is illustrated in Figure 31 together with at least two rejected methods, several roves, and a fragment of a patch with the folded rivets in place. Another patch (Fig. 32c) has four of these rivets still embedded in it. The same patch is covered on both sides in Stockholm tar (Per Guldbeck 1979: pers. com.), as are several other copper items possibly from the same kettle because they are all covered in the same tar (Fig. 32a, b). This kettle may have been used to boil pine pitch after it had served its purpose as a cooking vessel. The lug indicates the original shape-function of the object, and the patch and the use-wear on the lug indicate heavy use. Because the pine pitch has permeated every crack on the patch and the lug, it was probably used to boil and not merely to contain the tar. Because the patch had been cut from the kettle, and because another piece covered in tar (Fig. 32b) was being used to make rivets and roves, the kettle had evidently outlived its secondary use as a tar pot and was being used as a source of raw material.

Brass kettles appear to have been common at the post on St. Joseph Island. Several lugs from brass trade nesting kettles (Wheeler et al. 1975, p. 57) were found in the blacksmith shop along with other objects made from sheet brass and probably from brass kettles (Fig. 33). Two dog-bone lift fasteners from pot lids were also found, and these had been worked in a manner suggesting they were being used as a source of metal, probably for brazing (Fig. 33c, d).

In his repair of kettles, the smith seems to have been oblivious to any cathodic reactions that may take place in the presence of an electrolyte such as food in a kettle. One brass lug from a nesting kettle had been refastened with a ferrous rivet instead of with another copper one (Fig. 33b). Several folded ferrous rivets were found in the shop of a size and shape to suggest, in light of the object just mentioned, that they were designed for use

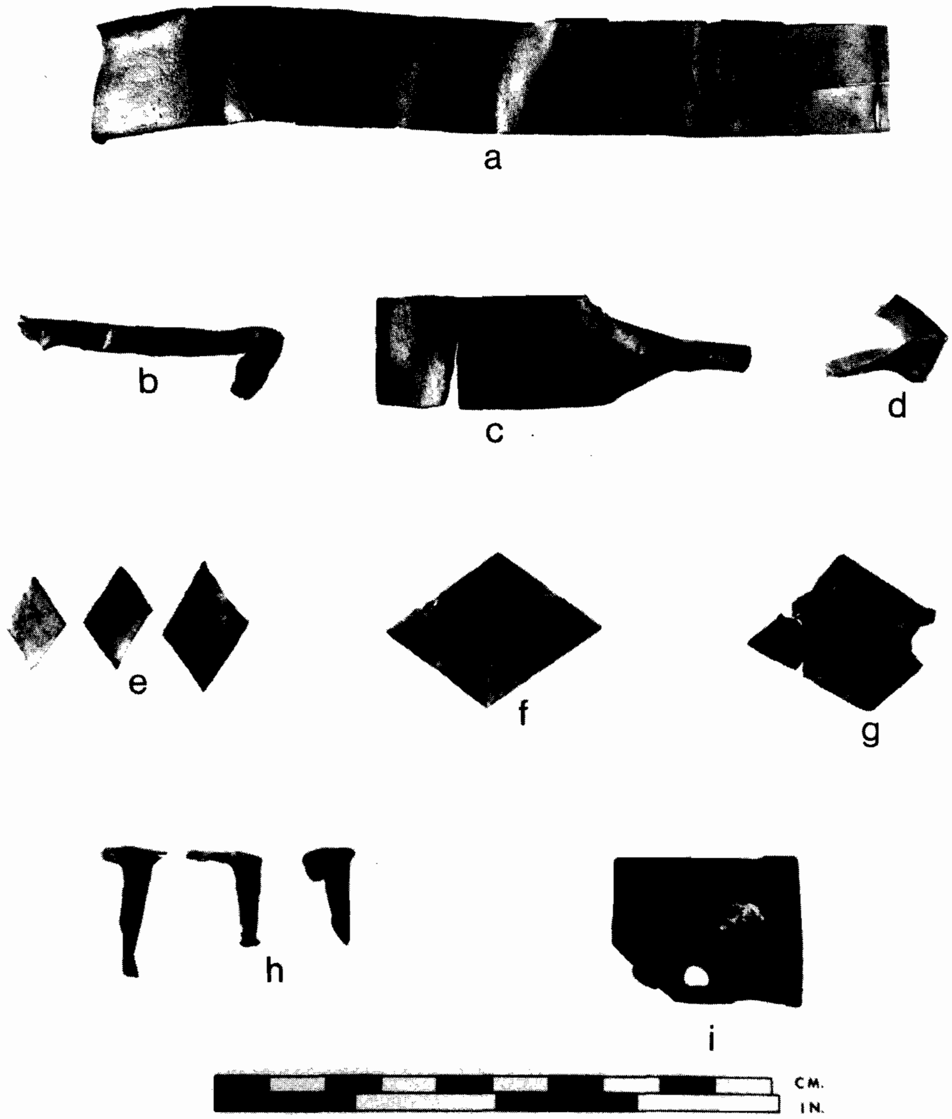

Figure 31. Rivets and roves: a) strip from brass kettle showing cut through rim - probably for making roves, 1H51K5-4; b) rivet preform - rectangular piece of copper folded over itself from both ends, then bent back parallel to the length preparatory to cutting - probably a rejected method, 1H51G2-20; c) rivet preform - rectangular piece of copper folded over itself at one end - it is folded into a rough circle and the folds are centered preparatory to cutting and forming head, 1H51B2-28; d) rivet preform - rectangular piece of copper crimped at one end and folded in the opposite direction at the other end, 1H51G1-1; e) three copper roves, 1H51G4-4; f) rivet preform, copper, 1H51E2-3; g) rivet, unfolded to show preform shape, 1H51G4-2; h) three folded copper rivets, 1H51A2-25, 1H51G3-7(2); i) patch from tin-plated copper preserving kettle showing three folded rivets in place, 1H51A2-28. (Photo by R. Chan)

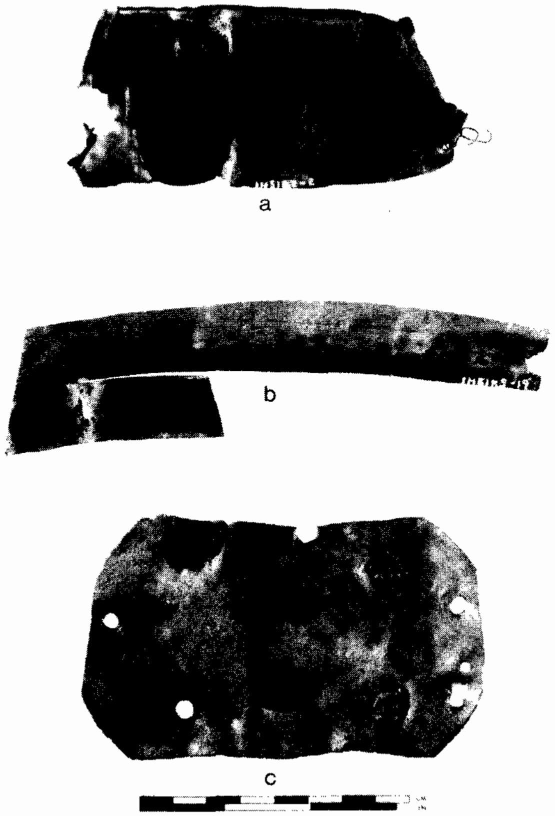

Figure 32. Copper kettle fragments, probably from the same kettle. Each fragment is partially covered with Stockholm tar or pine pitch. a) Lug and portion of kettle including rim - the wire in one end probably for hanging the salvaged lug on the wall until it could be used, 1H51B2-2; b) strip from copper kettle used for making rivets or roves, 1H51K5-19; c) patch from copper kettle with four folded rivets, 1H51D2-3. (Photo by R. Chan)

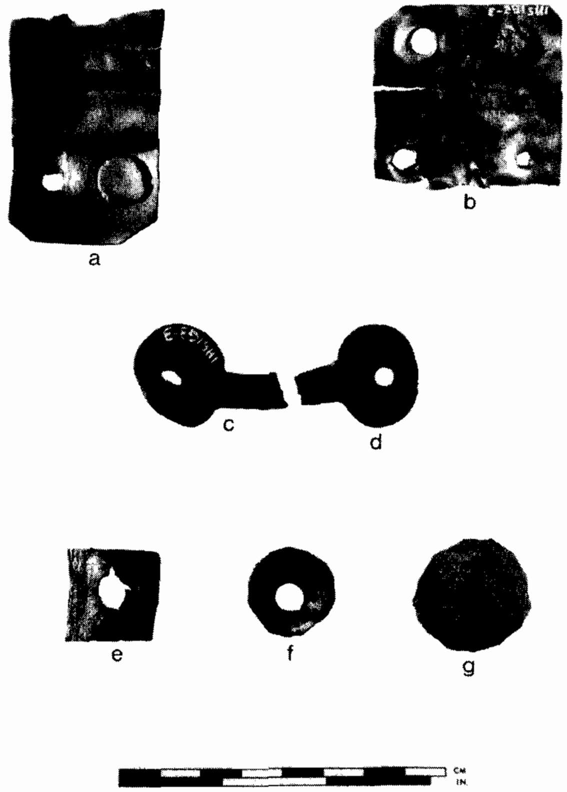

Figure 33. Brass lugs and objects made from brass kettles: a) lug fragment from nesting kettle with original copper rivet - the rivet has been cut, 1H51L3-1; b) lug from nesting kettle with ferrous rivet, probably not original, 1H51B2-3; c) dog-bone lift fastener - one finial has been cut off and the fastener itself has been ripped from the lid, 1H51G3-3; d) dog-bone lift fastener hammered flat, 1H51H3-1; e) rove or washer, 1H51E2-4; f) washer, 1H51A4-1; g) washer preform, 1H51E3-2. (Photo by R. Chan)

with copper or brass kettles (Fig. 34d). Ferrous lugs were commonly used on copper alloy kettles. One large, heavy ferrous lug (Fig. 34a) has copper shims in the attachment holes and yet another ferrous lug had been attached to a brass kettle with a copper rivet (Fig. 34c). Folded copper rivets were also used to repair a sheet metal object, possibly a ferrous bucket (Fig. 36). Very few people in the early nineteenth century knew about the galvanic reaction between dissimilar metals and it is not surprising to find a smith using incompatible metals in this manner. His lack of adequate stock may have hampered him in this regard too, so that he used whatever materials were at hand. Only one small piece of what is apparently copper stock was recovered from the smithy (Fig. 35d).

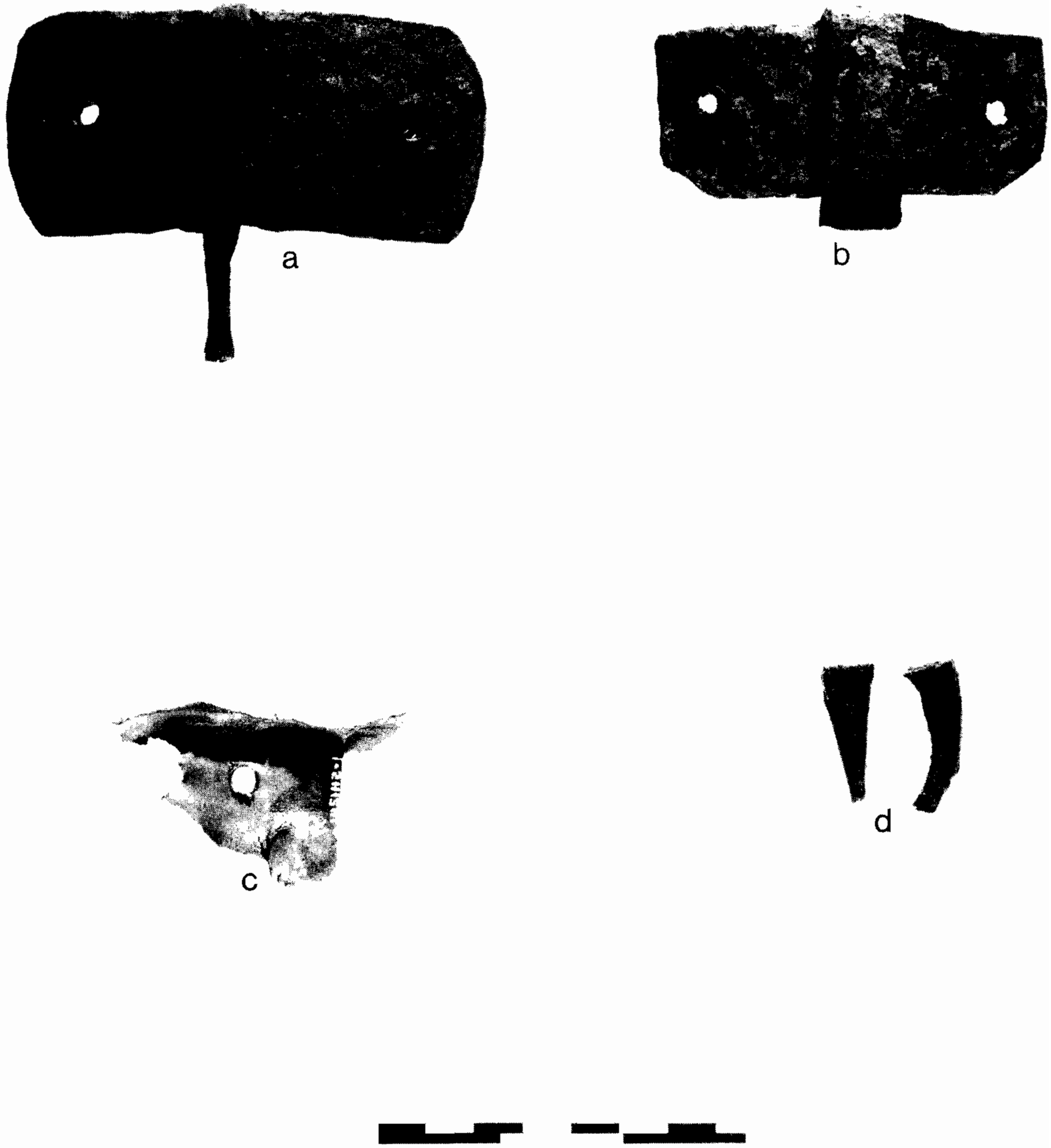

Figure 34. Lugs and rivets: a) ferrous lug for large pot or kettle with copper shims in the attachment holes - one shim has not been fully punched through, 1H51C2-16; b) ferrous lug, one hole has the remains of a copper rivet still attached, 1H51H2-20; c) brass kettle rim with copper rivet - the remains of a ferrous lug are beneath the rivet, 1H51H2-1; d) two folded ferrous rivets, 1H51E2-41. (Photo by R. Chan)

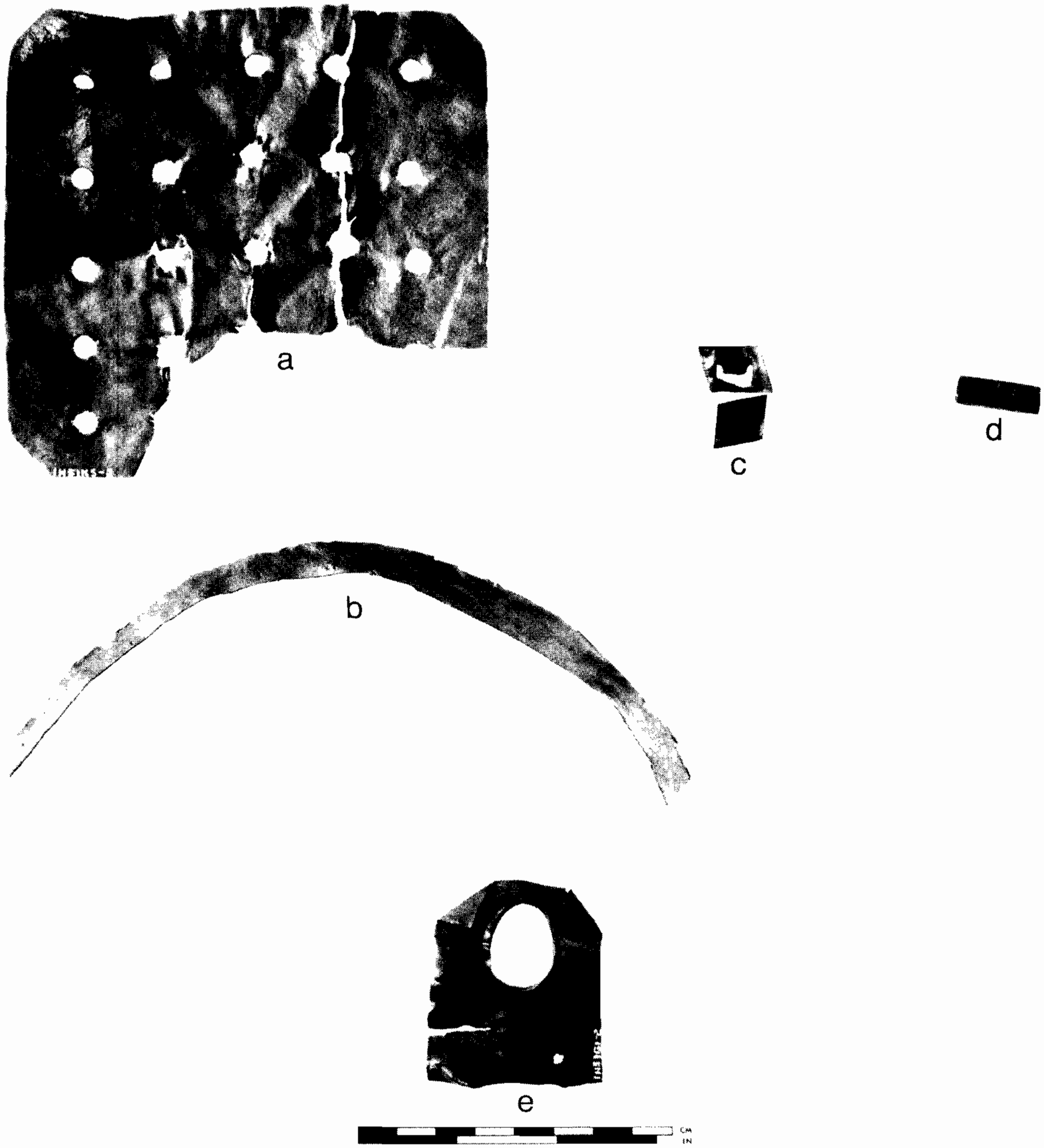

Figure 35. Objects made from copper kettles: a) copper drain cover plate possibly made from a kettle, 1H51K5-2; b) strip cut from copper kettle in a shape suggesting it was probably meant to form either a full or half rim of a vessel when bent and soldered to the body, 1H51G3-8; c) two copper roves - one is preform, 1H51B2-27; d) copper rod, probably stock, 1H51G3-4; e) lug fragment - the handle hole shows signs of heavy wear- the lug probably wore poorly, the metal being too soft to bear much weight, 1H51G1-2. (Photo by R. Chan)

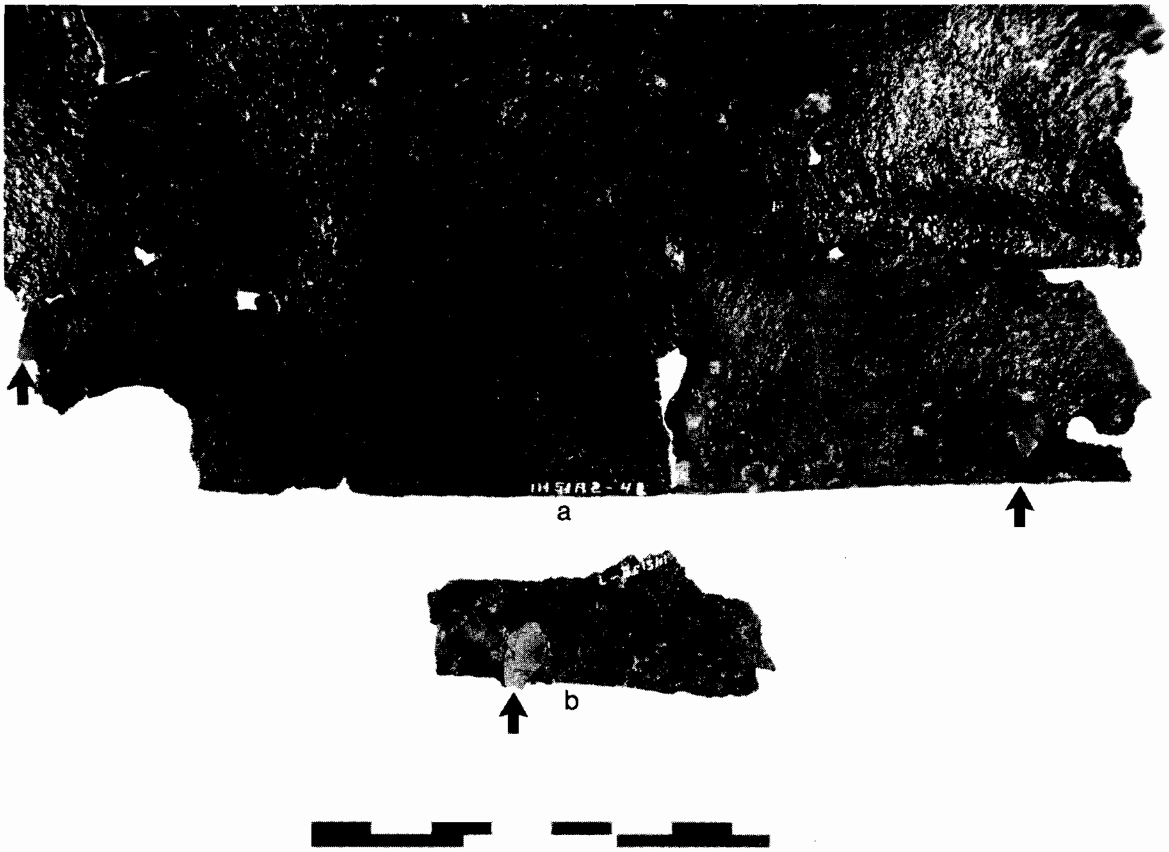

Figure 36. Folded copper rivets in ferrous sheet metal: a) two folded copper rivets (arrows) in unidentified sheet metal with folded edge, 1H51A2-42; b) folded copper rivet (arrow) through ferrous rolled joint of possible ferrous pail or bucket, 1H51J2-7. (Photo by R. Chan)

Faunal Remains (Tables 12, 13)

Aside from the remains of a dog, probably the smith's pet, which had been buried outside the northeast corner of the shop, and a jaw bone from a vole, the faunal remains are from food species (Cumbaa 1979). The distribution of these remains about the shop generally confirms that the domestic area of the smithy was somewhere along the southern wall. Excluding the dog and the vole, 42 per cent of the bones were from along the southern wall; however, by weight the percentage is a considerably higher 66 per cent. A single bone from a sheep, found in the northeast interior corner amongst a pile of scrap metal accounted for 9 per cent of the total weight. There seems to be no discernible pattern to the distribution of the remaining bones, especially the small, light fish bones evenly spread through the smithy. The scatter is probably accounted for by the presence of the dog, as eight bones showed signs of chewing and it is unlikely that these marks were produced by humans (S. Cumbaa 1979: pers. com.). The highest single percentage of bones is found in the area in which the table is shown in Figures 3 and 4.

the east shore, should have been visible to him but he does not mention it. Although Schoolcraft did not visit the site, indeed only passed it by at some distance, he was normally a careful observer and probably did not mention the blacksmith shop because it was not there in 1820. Even if it was still standing, the smith was certainly not burdened by overwork, because any of his clients, actual or potential, had by this time moved to Drummond Island.

This shop was probably part of a complex of buildings and not just an isolated structure, the semi-subterranean building next to the shop being part of the complex. In addition, there was likely a house and perhaps several outbuildings. There may have been a farrier's sling as well because we know that he was shoeing animals. The shop was too small to permit this activity to take place inside, so the sling, if it existed, was likely somewhere in front of the shop.

The deed of transference of the buildings of Spenard, Fields, Varin and Pelladeau to Tousaint Pothier mentions "land, houses, stores, and other buildings" (PAC, RG4, A1, S series, Vol. 84, p. 26,160), and the "Plan of the Post on the Island of St. Joseph," which is dated 1799, shows large lots on both the east and west shores of the peninsula (PAC, National Map Collection, H3/450 - St. Joseph's - 1800). It is likely from the deed of transference that at least one of these lots belonged to Spenard, Fields, Varin and Pelladeau, and if the blacksmith shop belonged to them, then it should be possible to identify the "houses ... and other buildings" belonging to this company. If further archaeology takes place at Fort St. Joseph, it may be fruitful to create a research design in order to define a lot and delineate all the features found within the lot. The logical place to begin such a project would be with one of the three structures already excavated along the east shore. If the blacksmith shop is chosen, for example, then artifact research must centre not merely on the identification and delineation of any individual structures that may be uncovered, but also on the interrelation of these structures. To this end, the artifacts from this structure should be reexamined to find their relationship to artifacts from other buildings. It has already been suggested that the semi-subterranean building next door (operation 48) will be found to have more than a proximate relationship to the smithy, and there may be privies and dumps as well. The shoeing area may be found and the "civilian structure" below the shop by the shore may have a demonstrable connection with the shop.

If such a design is, in the future, conceived and implemented, then ample cognizance must be taken of the synthetic relationship artifacts have, not just to each other - glass to ceramic, to pipe, to metal, etc. - but also to the structure or feature within which they are found. Sometimes such relationships are tenuous, but at other times the artifacts are capable, as in this case, of defining and elaborating the structure itself.

APPENDIX A. IDENTIFICATION OF WORK AREAS IN THE FORT ST. JOSEPH SMITHY

John Stewart, John D. Light
and Louis Laflèche

Introduction

During the 1978 field season at Fort St. Joseph National Historic Park, a blacksmith shop, dating between 1796 and 1828, was excavated by a team under the direction of Ellen Lee. Excavation revealed the walls, the forge, the anvil base and as yet an unknown small stone feature in one interior corner of the building.

One aspect of research has centred on the identification of work areas within the smithy. Where, for example, were windows, the grindstone and the fuel pile? This report is concerned with the search for one of these items - the workbench.

When metal is worked by a smith it gives off scale, or minute pieces of metal, which fall to the ground. As these bits of scale accumulate, the iron content of the soil rises in proportion to the amount of work being done in the area. Hence, in an undisturbed blacksmith shop there will be at least two areas in which the soil has a high iron content, the area around the anvil and the area around the workbench. This idea was used during the excavation to assist in planning the digging strategy. For example, long before the walls were clearly recognizable or the anvil base uncovered, it was known that the anvil was probably located in suboperation E (Fig. 37) because the soil in that area reacted most dramatically to a hand magnet. Further excavation confirmed this observation.

However, some iron compounds are not magnetic, and their presence is not detected by a magnet; furthermore a hand magnet will reveal only the presence of magnetic particles and not their quantity. Soil samples were therefore collected from inside and, for control purposes, from outside the building. These were analyzed for total iron and for the magnetic fraction to ascertain whether one of the interior areas had soil with abnormally high contents of both the total iron and the magnetic fraction.

A use pattern of the shop floor was then made by plotting soil iron concentrations and magnetic fractions on maps of the floor. Both maps showed the presence of two groups: a high group, along the northern half of the east wall and by the anvil, and a low group, in all the remaining areas. Assuming there has been no transfer of soil (by sweeping, etc.), the most likely area for the workbench is along the northern half of the east wall.

Examination

Total Iron

All samples were dried for 24 h at 105°C in an electric oven and ground to pass a 100-mesh sieve (ASTM). The iron was leached with a hot hydrochloric acid solution (1:1) for 16 h. The resulting solutions were then analyzed for iron by atomic absorption spectrophotometry.

TOTAL IRON CONCENTRATIONS

Provenance	% Fe	Provenance	% Fe
1H51A3	2.20	1H51E4	13.84
1H51B3	2.82	1H51F3-1	1.25
1H51B3-1	2.07	1H51F3-2	1.31
1H51C2	.96	1H51F5	.86
1H51D3	5.44	1H51G3-1	10.57
1H51D4	2.71*	1H51G3-2	10.15
1H51E3(A)	6.54	1H51H3	6.11
1H51E3(B)	3.41	1H51H4	.67
1H51E3(C)	6.47	1H51J3	2.89
1H51E3(D)**	33.84	1H51K2	2.67*
		1H51M7	2.28*

* Control samples from outside the building.
** Contaminated.

Samples 1H51D4, 1H51K2 and 1H51M7 are from outside the shop and were included to give a background reading of the iron naturally present in the local soil.

Figure 37 shows the iron concentrations on a floor plan of the blacksmith shop. The areas around the anvil and to the north and east are higher in iron than the rest of the shop. In fact, the existence of two separate groups, high iron and low iron, is valid at the 99.9

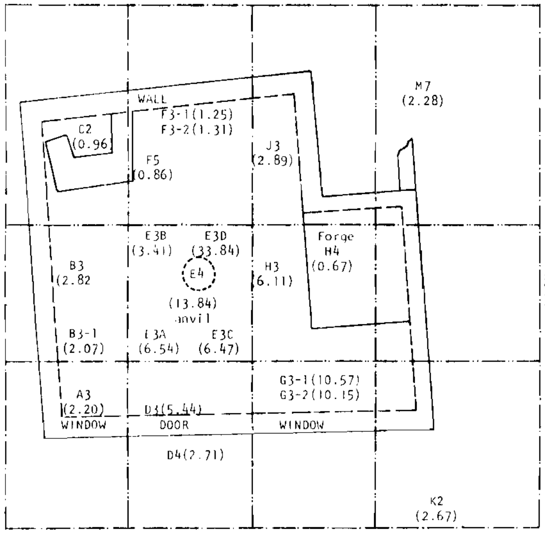

Figure 37. Floor plan of blacksmith shop, showing provenance numbers and total iron concentrations.

per cent level, using t statistics, i.e. there is less than 1 chance in 1000 of there not being two groups.

The low iron group has an iron concentration of 1.67 ± 0.85 per cent, compared with the control samples from outside the building with iron concentration of 2.55 ± 0.24 per cent. This means no iron enrichment of these low iron interior samples has occurred and thus no iron working has been done in the interior low iron areas.

Sample 1H51E3(D) contained an iron nail; although this was removed from the sample before analysis, its corrosion products caused a high iron concentration not directly associated with the working of hot iron. Therefore it was not included in the examination.

Magnetic Fraction

The samples used were the ground, dried samples from the total iron analysis.

A 10-g sample was placed in a 250-ml beaker along with 100 ml of acetone and a pre-weighed teflon-coated magnetic stirring bar (4 x 1 cm). After gently shaking the beaker for 1 h, the bar was removed and replaced in the solution by another pre-weighed bar. After gently shaking the beaker for another half-hour the second magnet was removed. Both magnets were dried and weighed. The magnetic fraction was calculated by

$$\text{magnetic fraction} = \frac{\text{wt of bars after immersion} - \text{wt of clean bars}}{10\text{g}} \times 100$$

Note that to weigh the bars on a single pan balance, they had to be placed on a 30-cm insulating layer of styrofoam.

MAGNETIC FRACTION CONCENTRATIONS

Provenance	% M.F.	Provenance	% M.F.
1H51A3	2.80	1H51E4	19.00
1H51B3	1.40	1H51F3-1	.40
1H51B3-1	1.00	1H51F3-2	2.20
1H51C2	1.40	1H51F5	.60
1H51D3	4.80	1H51G3-1	13.20
1H51D4	4.20*	1H51G3-2	7.60
1H51E3(A)	8.20	1H51H3	9.60
1H51E3(B)	4.60	1H51H4	1.40
1H51E3(C)	8.40	1H51J3	3.60
		1H51K2	1.80*
		1H51M7	1.00*

* Control samples from outside the building.

Figure 38 shows the magnetic fractions on a floor plan of the blacksmith shop. The areas around the anvil and to the north and east are higher in iron than the rest of the shop. In fact, the existence of two separate groups, high magnetic fraction and low magnetic fraction, is valid at the 99.9 per cent level, i.e. there is less than 1 chance in 1000 of there not being two groups.

The low magnetic fraction group has an iron concentration of 1.64 ± 1.04 compared with the control samples from outside the building with a magnetic fraction of 2.33 ± 1.67. This means no iron enrichment of these

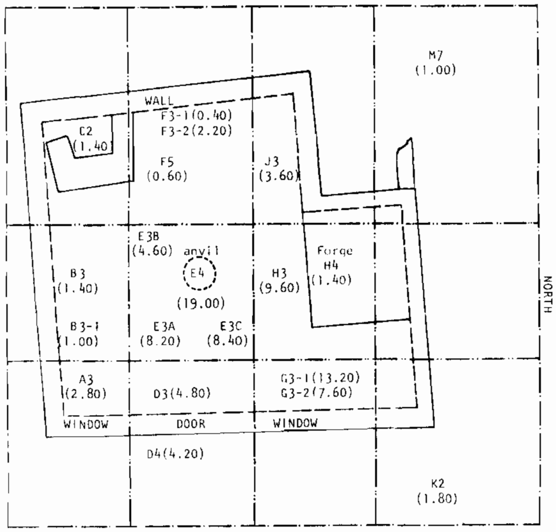

Figure 38. Floor plan of blacksmith shop, showing provenance numbers and magnetic fraction concentrations.

low interior samples has occurred and thus no working has been done in the interior low areas.

Conclusions

Obviously the best evidence for the location of the workbench would have been the archaeological observation of its remains. In this case, however, no such direct evidence was obtained, necessitating a less direct approach. This involved finding the most probable area for the location of the workbench based on examination of the earthen floor of the blacksmith's shop.

Both methods of analysis, total iron and magnetic fraction determinations, lead to the same conclusion. The workbench was most probably located along the northern half of the east wall.

In future only one type of analysis is necessary for work of this nature. Both methods have their advantages and drawbacks. The analysis of total iron is rapid (100 dried and ground soils can be done in 4 days), but the necessary equipment is sophisticated and expensive. A determination of the magnetic fraction, however, requires only two teflon-coated magnets and a top-loading balance, but only five samples can be done per day. The choice of technique will ultimately depend on the resources available in the laboratory.

Table 12. Bone distribution by species, blacksmith shop (1H51) occupation levels (2,3,4) (Cumbaa 1979).

Species	A2	A3	A4	B2	C2	D2	D4	E2	F2	G2	G4	G5	H2	H4	J2	J3	J5	K2	K5	L2	L3	L5	M2	M3	Total
Hare/rabbit																		1							1
Dom. dog																		114*							114*
Dom. pig	3												1												4
Dom. cow				1	1																				2
Dom. sheep																			3						3
Unid. mammal	20		3	2	7	7					1	1	2		1					6			4	1	55
Goose																		1							1
Duck																						1			1
Great gray owl					2																				2
Greater yellowlegs				2																					2
Gull																	1								1
Unid. bird			1	2				1	1						1						1		1		8
Lake sturgeon					1	1	1										1						1		5
Whitefish/cisco		2																							2
Pike/musky						1																			1
Bass																1									1
Unid. fish	3		1			3		2		4		1	1	1	1		5	1*		2					25*
Class unid.			3		1				4	2	1	1						5*							17*
Addenda:																									
Vole																		1*							1*
Total	26	2	8	7	12	12	1	3	5	6	2	3	4	1	3	1	7	123*	3	8	1	1	6	1	246*

*Totals or entries different from Table 22 in Cumbaa 1979.

Table 13. Distribution of faunal remains (excluding dog and vole).

Provenance	No.	% of total by suboperation	Wt (kg)	% of total by suboperation
1H51A2	26		35.2	
1H51A3	2		0.7	
1H51A4	8	27.48	12.4	13.90
1H51B2	7	5.34	153.9	44.28
1H51C2	12	9.16	27.0	7.77
1H51D2	12		31.4	
1H51D4	1	9.92	0.3	9.12
1H51E2	3	2.29	1.0	0.29
1H51F2	5	3.82	0.3	0.09
1H51G2	6		1.2	
1H51G4	2		0.8	
1H51G5	3	8.40	6.5	2.45
1H51H2	4		14.8	
1H51H4	1	3.82	0.3	4.35
1H51J2	3		5.5	
1H51J3	1		0.2	
1H51J5	7	8.40	0.9	1.90
1H51K2	8		2.1	
1H51K5	3	8.40	31.7	9.72
1H51L2	8		17.7	
1H51L3	1		0.7	
1H51L5	1	7.63	0.4	5.41
1H51M2	6		2.3	
1H51M3	1	5.34	0.3	0.75
Total	131	100.00%	347.6	100.03%

CONCLUSION

The structural remains and the artifacts have given us a great deal of information about a fur trade frontier blacksmith in the very early nineteenth century. Probably like all frontier smiths he was a jack-of-all-trades who suffered from a lack of material. He served as a cooper, gunsmith, farrier and tinker as well as a general blacksmith, and he did so without adequate stock, especially steel. Indeed, the reuse of material is evident throughout the artifact assemblage.

There may well have been more than one smith who worked at this forge during its lifetime. Certain habits of cutting, folding and shaping metal became evident as one looks again and again at the artifacts, and there appear to be at least two different styles involved. Whether or not there was more than one man, however, none of the work shows outstanding craftsmanship. Examples of poor technique and sloppy work habits are common, but on the frontier it is function, not style, that is of paramount importance and the products that came from this forge probably served their owners quite well.

The almost 8500 artifacts found during the excavation were deposited in certain clear patterns. The fact that these patterns were still discernable after approximately 170-180 years, coupled with the facts that no disturbed areas were discovered and only one insignificant intrusive artifact (a bullet) was found, strongly suggests that the shop was not disturbed after it was abandoned. Because the building was not burned and appears to have been moved, the following sequence of events may have occurred.

Some time after the beginning of the British occupation of the point in 1796, the building was built, possibly by Spenard, Fields and Varin. It was used exclusively as a blacksmith shop although the interior seems to have been modified at least once, perhaps during construction, because the unidentified stone feature in the southwest interior corner is incomplete. It has been suggested that the feature was a base for the stove, but it seems a curious shape for this function, and the fact that the stones were mortared, and those of the forge were not, seems to belie this function. Whatever its use, this mysterious feature has no discernible function within the smithy.

The shop was abandoned most probably in 1812 when Michilimackinac was taken. The fur traders, who participated in the attack, moved their operations to the former American fort for the duration of the war, and with them probably went the anvil, the bellows, the stock and all the other necessary equipment from the smithy. The slack tub and the usable scrap from the pile beneath the bellows may have been taken at this time as well. The removal of the best scrap from the pile beneath the bellows accounts for the lack of any discernible difference, mentioned in "Shop Layout," between the scrap in this pile and that in the pile(s) at the southeast exterior corner of the building.

After the war, the British returned to St. Joseph Island before moving to Drummond Island, and the traders followed. The forge may have been used at this time because the building does not appear to have been burned by the Americans in 1814. When, however, the British went to Drummond Island, they took with them whatever was worth salvaging. This may well have been one of the buildings taken.

When the building was moved the site was neither cleaned up nor significantly disturbed and was soon covered by vegetation.

If this sequence of events is correct, then the building dates from approximately 1796 to 1815. The manufacturing dates of all the ceramic in the operation fall between these dates and none of the glass is inconsistent with this time frame. These are the only datable items in the shop. Furthermore, Henry Schoolcraft passed St. Joseph Island in 1820 during an expedition from Detroit to the headwaters of the Mississippi. He noted that "the stone chimneys of the former houses are still standing to attest the barbarous policies of war" (Schoolcraft 1821, p. 130). Because he passed down the west channel of the river, and behind Lime Island, he would have had a clear, though distant, view of the east and south shores of the peninsula, but not the west shore. The blacksmith shop, about 20 m from

APPENDIX B. DOCUMENTARY EVIDENCE FOR THE OWNERSHIP OF THE BLACKSMITH SHOP

Dennis Carter-Edwards

The identification of the blacksmith's shop uncovered during archaeological investigations in the summer of 1978 presents a problem in historical documentation. The extensive secondary literature on the fur trade offers little insight into the day-to-day activities of the various firms operating on St. Joseph Island. In particular it is of limited value in determining ownership of the shop. Even the primary sources on the fur trade, scattered among various repositories, have to date provided only tantalizing clues regarding fur trade activity on the island. In the absence of a comprehensive study, this brief report will make some tentative observations on the history of this building.

In 1796 the British garrison withdrew from the post at Michilimackinac and began construction of a new military establishment on St. Joseph Island. At the same time, many merchants based at this important entrepôt for the Great Lakes fur trade transferred their operations to the new British post or at least set up satellite operations. In September 1798 Captain Peter Drummond informed the military authorities that nearly a dozen traders were either building or preparing to build "on the Situation near the new Blockhouse" (PAC, RG8, I, Vol. 251, pp. 256-59; Fig. 39). Included in this list of merchants was a Mr. Pothier, a noted trader in the area, with roots in the "rascally, scrambly trade for pelts" dating back to the French period. He was one of a number of traders competing in the area south of the Great Lakes. In 1804 Pothier entered into a partnership with a group of traders at St. Joseph Island who operated under the name of Spenard, Fields and Varin. Pothier, who had strong links with the merchant community in Montreal through his association with the Northwest Company, was required to "supply the said concern with goods and merchandise" (PAC, RG4, A1, S series, Vol. 84, pp. 26, 160-61). The exact nature of their operation is unclear; however, it appears that Pothier supplied Spenard et al. with trade goods that he likely received on credit from his

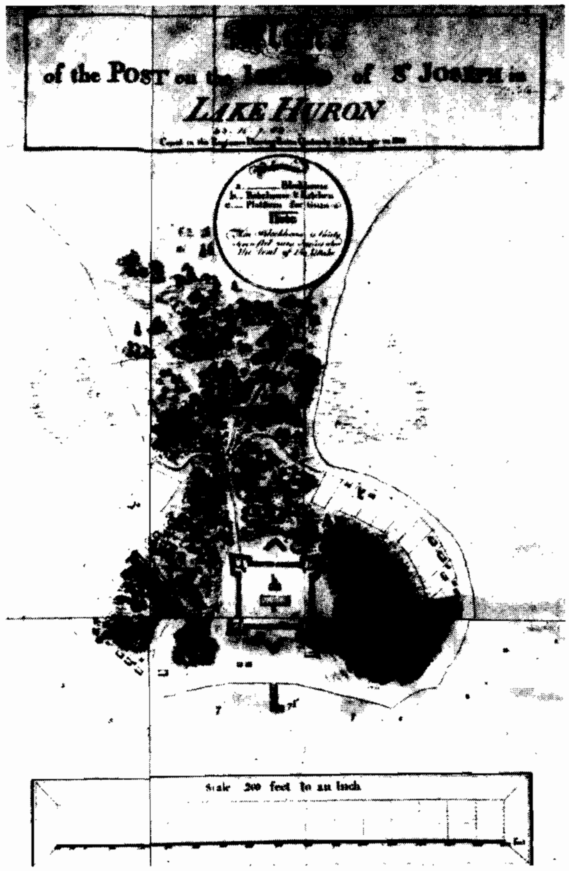

Figure 39. Plan of military post, St. Joseph Island, 1800 by Gother Mann. (Public Archives Canada, National Map Collection, C-57132)

Montreal friends. In return he received a portion of the profits from the furs they took in.

On the island Spenard and his partners had an extensive establishment that also included their own blacksmith and forge. For six months in 1806 they provided blacksmith services for the Indian Department until a replacement for the deceased departmental smith was found (Vincent 1975). The projects carried out on behalf of the department would likely have been performed in Spenard et al.'s own shop. The location of this shop is a matter of conjecture; however, internal evidence indicates that the shop was probably located on

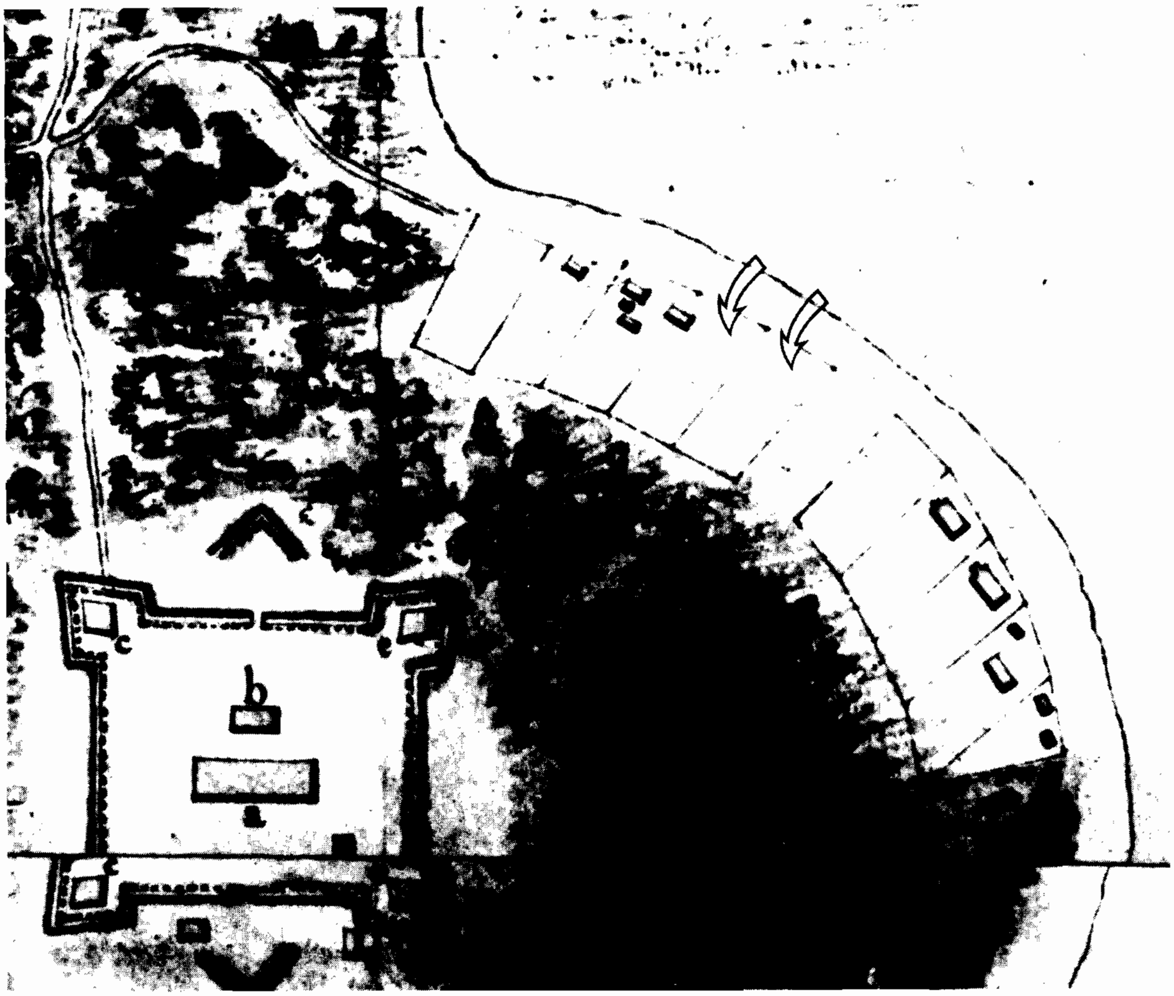

Figure 40. Detail of plan of military post, St. Joseph Island, showing lots set aside for merchants. One of the two lots indicated by the arrows probably belonged to Spenard, Fields, Varin and Pelladeau. (Public Archives Canada, National Map Collection C-57132, portion only)

one of the lots depicted on the 1800 survey plan of the island prepared by Gother Mann, commanding Royal Engineer, and referred to by Captain Drummond (Fig. 40).

The firm appears to have experienced serious financial difficulties. In August 1804 James Field complained that the Indian Department blacksmith, Louis Dufresne, was trading with the native population and thus cutting into Field's own business (PAC, RG8, I, Vol. 254, p. 223). As the department's blacksmith, Dufresne would have repaired the muskets, traps and other metal items the natives brought in. He was thus ideally situated to exploit his dealings with the Indians for personal gain, although this was strictly prohibited by departmental regulations. Distant as it was from the centres of authority in York and Quebec, policing the regulations of the various branches of the military and civil departments on St. Joseph Island was difficult in the extreme. The effects of this illegal trading and the fierce competition that characterized the fur trade in the southwest were soon felt by Spenard and his partners. In 1808 the partnership was dissolved and all the assets, including "Land, Houses, Stores and other Buildings, House Furniture or utensils of any description," were assigned to Tousaint Pothier (PAC, RG4, A1, S series, Vol. 84, pp. 26, 101-61). As the last creditor to supply the firm, Pothier had first claim on their assets. If an inventory of this assignment exists among notarial records, it would be invaluable in documenting the material possessions of a typical trading firm on St. Joseph Island.

Although this particular firm was disbanded, Pothier continued his commercial activities on the island, though in what capacity is not clear. In December 1806 he is listed as a junior agent and attorney with the newly formed Michilimackinac Company (Wallace 1934: 224). Montreal traders organized this company in an effort to minimize the fierce competition in the southwest and to divide spheres of interest with the rival Northwest Company, but the company was not successful. In 1810 it was dissolved and a new trading concern, the Montreal Michilimackinac Company, was formed by some of the firm's partners (Stevens 1916-17). Pothier, with his interest in the area and his ties with the Montreal fur trade community, likely held at least one share in the company.

The Montreal Michilimackinac Company continued to face stiff competition. John Jacob Astor's American Fur Company was active in the southwest and proved a formidable rival. Soon the various parties active in the trade in this region were exploring the possibility of a merger. In Janury 1811 an agreement was drawn up that joined the companies under the name of the South West Company. Were it not for the intervening events associated with the War of 1812, this firm, in cooperation with the Northwest Company, potentially represented a multinational operation with a virtual stranglehold on the interior trade. Pothier continued his activities on the island while maintaining a direct interest in the South West Company. His association with the company is noted in a few documents of the period. In a lengthy memo to Sir George Prevost regarding the capture and condition of the American post at Mackinac Island, Pothier referred to himself as an "Agent for the South West Fur Company" (PAC, RG8, I, Vol. 677, pp. 68-70). This conclusion is further confirmed by Captain Charles Roberts of the 10th Royal Veteran's Battalion who warmly commended Pothier for his assistance in the capture of the American post. According to Roberts, "Mr. Pothier has thrown open his store houses to supply my requisitions in the handsomest manner.... I have enclosed a Memorandum of Articles received from the South West Company stores for your information" (PAC, RG8, I, Vol. 676, p. 156). Evidently Pothier continued to use the fur trading establishment that he had acquired from Spenard, Fields and Varin right up to the start of the war.

One additional piece of information supports the contention that the blacksmith shop excavated during the field season of 1978 belonged to Pothier. In the summer of 1814 an American expedition under Colonel George Croghan sailed up the St. Mary's River towards Michilimackinac. En route, a small detachment was sent to Fort St. Joseph to destroy vital supplies stored there and any remaining military buildings. Ramsey Crooks, an agent for John Jacob Astor (one of the dominant partners in the South West Company) accompanied the detachment to the island. It was his responsibility to protect the "interests" of the company (Vincent 1975). Archaeological investigations found no evidence that the building had been burned. Ramsey no doubt stood by while the destruction of the island was under way to make sure that valuable company property was untouched. In this instance the lack of certain physical evidence reinforces the argument that the building in question did in fact belong to the South West Company and was part of the establishment Pothier acquired from the hapless firm of Spenard et al. Without the 1806 inventory of assets transferred to Pothier and additional archaeological data from associated buildings, it is difficult to identify conclusively the blacksmith shop. However, in light of the documentary evidence, a convincing case can be made that this building was the shop belonging to Spenard, Fields and Varin and later owned by Tousaint Pothier.

APPENDIX C. TERMS OF AGREEMENT BETWEEN SPENARD, FIELDS, VARIN AND PELLADEAU AND TOUSAINT POTHIER

(PAC, RG4, A1, S Series, Vol. 84, pp. 26, 160-61)

Whereas on the Tenth day of August 1804 a Trading Concern or Copartnership was formed at St. Josephs. Generally known under the firm of Spenard, Fields & Varin which Copartnership or Concern was composed of Charles Spenard, James Fields & Guilliaume Varin & was to continue for the space & time of Three Years. And whereas sometime in the first year of the said Concern the above Parties found it convenient & expedient to admit Louis Pelladeau into the aforesaid Concern, he being bound jointly with them, by all the clauses conditions & stipulations mentioned in said agreement, And whereas it was stipulated in said agreement; that Tousaint Pothier, Merchant of Montreal should supply the said concern with Goods & Merchandize on the terms and conditions explained and set forth in said Agreement - And whereas the aforesaid first mentioned parties together with the said Tousaint Pothier have determined by mutual consent to terminate & put an end to the above copartnership from the date hereof & to conduct & wind up the business carried on under the same on the terms and conditions hereafter mentioned. Viz.

Article 1st

The said Charles Spenard, James Fields, Guilliaume Varin & Louis Pelladeau hereby consent & agree to Consign over and transfer to the said Tousaint Pothier on this day without reserve, All the Property & Effects of which they may be possessed as well their Joint Stock & Capital in Trade consisting of Land, Houses, Stores and other Buildings, House furniture or utensils of any description whatever, Furs, Peltry Merchandize, debts due them by Book, Notes of Hand or otherwise & as well as their individual personal property of every description & denomination whatsoever as more particularly mentioned & set forth in the Inventory to be taken for that purpose.

Article 2nd

The said Tousaint Pothier, on his part hereby consents & promises that he will employ & dispose of the above said property so Assigned and Transferred over to him as above said for the greater benefit and advantage of said concern, and that as soon as the said Property can be realized he will make out a true and Correct Account thereof for the satisfaction of the Parties concerned it being expressly understood and agreed upon that he will appropriate to himself out of the first part of the proceeds the full amount of his account against the said parties either collectively or individually, and then deliver over to them the Remainder and the said property to be divided amongst the said parties as they may hereafter agree amongst themselves.

In witness whereof the said parties to these presents have hereonto set their Hands & Seals at St. Josephs this 17th day of June 1808 in presence of

Witnesses

Signed

Duncan McGillivray
Landreau
[illegible]

Je. Wm. Malliot

Signed

Louis Pothier (LS)
Charles Spinard [*sic*] (LS)
James Fields (LS)
G. Varin (LS)
Louis Pelladeau (LS)

I do certify that the foregoing Instrument of Writing is a true Copy taken from the Original.

Given under my Hand & Seal at
St. Josephs this 13th Sept. 1808
Jn. Askin Jr.
J.P.W.D.

APPENDIX D. ARTIFACTS FROM OPERATION 1H48

John D. Light

Operation 1H48 is a semi-subterranean building that abuts the blacksmith shop on its south side. Its doorway faces east. As was suggested in the main body of this report, these two buildings may form part of a complex of structures that may have belonged to a single fur trading company. This hypothesis can be affirmed or disproven only by future research, both historical and archaeological; however, the west side of the semi-subterranean building was partially excavated during the 1978 field season, and from the minimal number of artifacts recovered during this excavation, the indications are that there are affinities between these two structures (Fig. 41).

The inventory of artifacts from this excavation is given in Table 14. In "Description of Artifacts," the possible relationship of the glass in the southwest corner of the blacksmith shop to the glass on the west side of the semi-subterranean building is discussed. The

Figure 41. Remains of blacksmith shop, looking south; note the partially excavated semi-subterranean building (operation 1H48) directly behind it. (Photo by H. Stark)

Table 14. Artifact inventory for operation 1H48.

Material	Provenance	No.	Description
Glass	1H48A3	1	
(pane glass)	1H48D3	1	
(container glass,	1H48A3-1	26	dark green container, liquor bottle, dip-moulded push-up with pontil mark - no duplicate shapes - no mends with glass in 1H51
	1H48A3-2	35	colourless, lead glass, square dried food container with indented chamfers and pontil mark - two-piece mould, mould seam runs diagonally across base - 18 pieces mend to form base - about 1/3 of bottle present - no mends with glass in 1H51
	1H48A1	5	Orange Crush bottle, 20th cent., approx. 10-15% of bottle present including complete crown finish - intrusive - picnickers
	1H48A3	19	
	1H48B1	1	
	1H48C2-1	1	base of circular, colourless lead glass medicine vial with pontil mark - base diam. 2.3 cm
	1H48D4	2	colourless lead glass shoulder of container, possibly dried food container - 2 pieces mend
Clinker	1H48A3	1	
	1H48B1	5	
	1H48C3	2	
	1H48D2	6	
	1H48D3	2	
Smoking Pipe	1H48A3	2	1 stem; 1 bowl frag. with unident. moulded decoration - both pieces white clay
Metal	1H48A3-3	1	pewter button - 41st Regt, diam. 1.6 cm
	1H48A3-4	7	probable currycomb, 4 pieces mend - rectang., 13.5 x 11 cm
	1H48A3-5	8	unident. sheet metal container, tinned one side, with rolled joint - 2 pieces with "L" fold are probably from a lid
	1H48B1-1	1	circular ring with nail hole - 4 cm diam., 3.4 cm long; possible tool handle support
	1H48B1	1	sheet metal scrap ·
	1H48C2-2	1	unidentified, possible nail
	1H48D3	1	sheet metal scrap
	1H48D3-1	1	copper alloy scrap
	1H48D3-2	1	possible blacksmith's stock, hot-cut, 5.2 x 1.5 x 1.3 cm
	1H48D3-3	1	unident., hot-cut
	1H48D4	1	sheet metal scrap
Fauna	Cumbaa 1979, p. 44.		

rear of the semi-subterranean building likely served as a disposal area, and possibly at least some of the glass from this dump was scattered into the southwest corner of the blacksmith shop. The facts that the excavation of the semi-subterranean building was only partial and that no mends were found leave this question open to further research.

The discovery of 16 pieces of clinker in operation 1H48 is perhaps to be expected considering the proximity of the two buildings. The clinker is, however, from the blacksmith shop.

Several metal objects appear to be associated with the blacksmith shop. There is, for example, a piece of metal that may be wrought-iron stock. Its profile is rectangular, however, rather than square, and as it has not been subjected to analysis, it is impossible to be definitive about whether it is stock. It has, however, been cut by a blacksmith, as has another piece of unidentified metal. In addition, there is one piece of copper alloy scrap that has been cut with tin snips and that closely resembles the kind of scrap found in the smithy from the smith's tinkering activities. There is also a currycomb which suggests that whoever owned the semi-subterranean building may have owned animals as well. The blacksmith certainly acted occasionally as a farrier, but it is impossible to tell whether the animals he shod belonged to Spenard, Fields, Varin and Pelladeau or some other company or both. A future excavation of the semi-subterranean building may provide additional information about domestic animals.

The faunal remains from operation 1H48 consist of five bones: one each of vole, domestic pig, domestic sheep or goat, frog or toad and lake sturgeon (Cumbaa 1979, p. 44). Similar species were found in the blacksmith shop, but not enough material is present from this excavation to provide any synthetic description of the relationship of these two buildings.

The artifacts discovered in the excavation of the semi-subterranean building may be present there as scatter from the smithy. Until the building has been completely excavated, especially the interior, no definite relationship between the two structures can be established with certainty. However, preliminary indications are that the two structures bear more than a proximate relationship. Blacksmith's tools may be discovered inside the semi-subterranean building or a primary deposition area for glass or ceramic establishing a connection between the material in the two structures. The faunal assemblage may be related or there may be material that will establish a firmer relationship between the two buildings and domestic animals. It may be possible as well to establish some unforseen connection between the buildings. When the semi-subterranean building is excavated, however, the possible relationship between these two buildings should be considered.

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Metallographic Study of Early Nineteenth Century Axes from Fort St. Joseph, Ontario

Henry Unglik

ABSTRACT

A metallurgical investigation was carried out on five early nineteenth century iron axes found at Fort St. Joseph, Ontario. The study comprises chemical analysis and metallographic examination including an estimation of the grain size, measurements of microhardness of structural constituents, and hardness testing of metal. Macroetching revealed that the axe heads were made of several pieces, and the study reports on the analysis of the component parts and their structure. The technology, the method of manufacture and the manner of construction of the axe heads are described. The metal working processes used included hot-working, forge-welding and folding (laminating), carburization and quench-hardening. The procedure used in the manufacture of the axes basically involved folding a single strap of wrought iron around a mandril, forge-welding the two ends, applying a previously hardened inset steel bit, forging a broad blade, and grinding the cutting edge. The metallurgical transformations that occur on cooling from high temperature are discussed. Also, the explanation for the axes' failure is given and the mode of brittle fracture discussed. The results indicate that a pure, good quality material was used for making the axes, but the forging of the blades was rather careless. The producer had not mastered the technique of axe manufacture.

Submitted for publication 1980, by Henry Unglik, National Historic Parks and Sites, Conservation Division, Parks Canada, Ottawa.

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Additionally, the constructive criticism from James Moore, Senior Conservation Scientist, Conservation Division, Parks Canada, is greatly acknowledged. Credit for illustrations is given in the text, but gratitude is expressed here for these many favours.

FOREWORD

The axes described in this report were found in 1978 during the excavation of a blacksmith shop. Although the shop proved to have been a fur trade smithy, no regular axe manufacture was being performed there. Nevertheless, it is likely that some, if not all, of the axes were made locally. One of the axes described in this report, for example, was marked "D," and it is possible that it was made by Louis Dufresne, the Indian Department smith at the post on St. Joseph until his death in 1805. It was therefore desirable to have a picture of the manufacturing process in a frontier smithy. This work details how the axes were made and how they were bitted.

Although the smith was not making axes,he was repairing them. Numerous bits snipped from axes were found in the shop, and at least two of the axes described here had undergone this process, because the original bits were very small. All of the axes described in this study were brought to the smith for repair, but before the metallurgical analysis had been done, this was unknown. It was the prevailing wisdom that an individual who broke an axe in use would throw it away, sometimes very far away, and that therefore the axes were likely to have been fractured in a forging accident (a theoretical possibility). The conclusions reached by this report indicate that the broken pieces were picked up and taken to the smith for repair, evidence of the frugality of frontiersmen and the value of iron on the frontier.

The careless forging technique leading to the fracturing of the axes raises some interesting questions about blacksmithing in general in late eighteenth - early nineteenth century Canada. Sloppiness may be common among frontier blacksmiths in 1800 or it may not. All blacksmiths in 1800 may have been sloppy. One suspects, however (and I have no evidence for this opinion), that a good, careful and knowledgeable smith would have been highly prized, and therefore highly paid, in one of the more settled areas. The others headed west. Louis Dufresne, for example, was a salaried employee of the Indian Department who augmented his income with some illegal trading. If he had been a first-rate smith he could have earned more in Montreal. Certainly these axes were the product of careless workmanship and the analysis of the clinker from the forge revealed the same carelessness, so at least two smiths in the area were sloppy. Other studies are necessary to get a complete picture of blacksmithing on the frontier, and yet other work with material from known provenances in settled areas will have to be done to get a complete picture of the state of the blacksmithing art in the period. If this work is ever done then it will have to follow the lead of this study. If the work is not done then this analysis will have to stand alone, not just for its uniqueness, but for its excellence.

John D. Light

INTRODUCTION

Five axes of ferrous material recovered from the Fort St. Joseph archaeological site in Ontario were forwarded to our laboratory for examination. The axes, all fractured across the sides at the upper part of the head, were found and possibly manufactured in the local smithy.

A thorough investigation was conducted to identify and characterize the material, examine and interpret its structure and composition, and determine what kind of technological processes were applied in the axes' manufacture. Another important aim of this investigation was to establish the cause of the axes' fracture. These goals were attained by visual observation, macroscopic examination, chemical analysis, hardness testing, microscopic examination, and microhardness measurements.

This is a technical report which is also intended for a non-technical audience. It is divided into several sections characterized by definite objectives. "Methods and Results" is confined exclusively to the methods used and results obtained from the metallurgical investigation with as little interpretation as possible to conceivably enable others to draw their own conclusions. In "Discussion and Interpretation" the data are processed - the results are explained and interpreted, and several topics are discussed in-depth. The "Conclusions" are basically recapitulations of the findings, with general conclusions written for a non-technical audience.

METHODS AND RESULTS

Visual Observation

The designation and size of the examined artifacts are given in Table 1.

The surfaces of all of the axes were dark grey and fractured across the sides at the upper part of the head. The surface appearance of the axes is illustrated in Figure 1 (side view of Fig. 18e of Light 1984, this volume) and in Figure 18a-d of Light 1984 (this volume), and their shape and approximate dimensions in Figure 7a-e. The irregular ragged area of the fracture surfaces (Fig. 2, which is the top view of Fig. 18d of Light 1984, this volume) has the typical appearance of brittle fracture, exhibiting no evidence of plastic deformation. The axes have a sharp, clearly defined cutting edge, except one (1H51G3-9) with a blunt edge. Blacksmith's trademarks are present on the surface of two axes (1H51E3-3 and 1H51F5-1).

Macroscopic Examination

Macroscopic examination (at less than x10) was used to investigate the structure of large areas. The specimens were cut longitudinally from the axe heads (perpendicularly to an axe edge) with a band saw. The locations of the sections are shown in Figure 7. The sections were prepared as described later in "Microscopic Examination." After etching, the sections were examined both with the unaided eye and at low magnification with a stereoscopic microscope.

To determine the location of the iron and steel regions, the sections were etched with a solution of 10 per cent nitric acid in ethanol. As Figure 3 shows, the axes, except the axe eye (1H51C2-1), comprise low carbon (light-etched) and high carbon (dark-etched) regions (that is, iron and steel). The technology of the axes is more vividly illustrated in Figure 4, which is a representation of the etched sections. The axes are made of low carbon iron blades and high carbon steel bits. In one of the axes (1H51E3-3) a seam (black solid line) is visible along the centre of the section. The encircled numbers refer to a given macroregion, the microscopically determined structure of which is described in detail later.

The distribution of phosphorus is also instrumental in determination of the technology. To reveal the segregation of phosphorus in the axes, Oberhoffer reagent was used (30 g $FeCl_3$, 1 g $CuCl_2$, 0.5 g $SnCl_2$, 50 mL HCl, 500 mL ethanol and 500 mL distilled water). This reagent selectively darkens phosphorus-poor regions, leaving phosphorus-rich regions unattacked and light. This is shown schematically in Figure 5. One axe (1H51G3-9) is relatively high in phosphorus, another (1H51D1-1) contains some high phosphorus iron, and the three remaining axes show a banded structure of alternate phosphorus-rich and phosphorus-poor layers.

Table 1. Designation of the artifacts.

Description	Provenance	Max. size (cm)
Axe eye	1H51C2-1	9 x 6 x 0.8
Axe head	1H51D2-1	5 x 11 x 1
Axe head	1H51E3-3	12 x 8.5 x 2
Axe head	1H51F5-1	8 x 10 x 1.5
Axe head	1H51G3-9	10 x 8 x 2

Hardness Test

Hardness measurements were taken on a polished and lightly etched cross-section cut perpendicularly to the cutting edge of an axe. The Rockwell method of hardness testing, according to the American Society for Testing and Materials (ASTM) Standard E18-74, was used. A ball of 1/16 in. diameter under a 100-kg load (Rockwell B) was used for soft iron and steel areas, and a diamond pyramid under a 150-kg load (Rockwell C) for the relatively hard steel areas. The number of indentations depended on the size and number of the different areas revealed by macroscopic

Table 2. Average hardness of the axes.

Provenance	Macro-area (Fig. 4)			Values measured		Values converted Brinell
	Part of axe	Material	Area no.	Rockwell B HRB	Rockwell C HRC	HB/10/3000
1H51C2-1	Bulk	Low carbon	1	63	-	111
1H52D1-1	Blade	Low carbon wrought iron	1 & 3	86	-	168
	Inset slug	Medium carbon steel	2	94	-	204
	Applied bit	High carbon heat-treated steel	4	-	40	372
1H51E3-3	Blade	Faggoted iron - high carbon strip	1	81	-	153
	Blade	Faggoted iron - low carbon strip	2	41	-	75
	Inset bit	High carbon heat-treated steel	3	-	41	382
1H51F5-1	Blade	Low carbon wrought iron	1	64	-	114
	Inset bit	High carbon steel	2	96	-	216
	Applied bit	High carbon heat-treated steel	3	-	40	372
1H51G3-9	Blade	Low carbon wrought iron	1	67	-	119
	Inset bit	High carbon steel	2	90	-	185

Table 3. Chemical composition of the axes.

Provenance	Part of axe	Material	Composition (%)				
			C	Mn	Si	P	S
1H51D1-1	Blade and slug	Wrought iron and steel	0.34	0.02	0.04	0.22	0.07
1H51E3-3	Blade	Faggoted iron	0.28	0.01	0.04	0.08	0.02
	Bit	Steel	0.53	0.04	0.06	0.09	0.02
1H51F5-1	Blade	Wrought iron	0.01	0.009	0.05	0.07	<0.005
	Bit (hardened)	Steel	0.80	0.03	0.03	0.05	0.01
1H51G3-9	Blade	Wrought iron	0.10	0.05	0.04	0.22	0.03
Swedish iron, Dannemora (Percy 1864: 736)			0.054	trace	0.028	trace	0.055
Modern wrought iron (Avner 1964: 313)			0.08	0.015	0.16	0.06	0.01
Modern steel (ASM 1961: 62)			0.5-0.8	0.6-1.5	0.10-0.3	≤0.04	≤0.05

examination. Rockwell B and Rockwell C measurements obtained in testing have been converted to standard Brinell HB10/3000 (Hardness Brinell, HB) as approximate equivalent hardness (ASTM Standard E 140-72). The hardness testing results are given in Table 2, and the hardness distribution along a cross-section of each axe is illustrated in Figure 6.

Both Table 2 and Figure 6 show there is a wide hardness variation within each axe owing to the heterogeneity in composition (carbon content in particular) and structure. This observation is confirmed by a comparison of Figures 4 and 6 which demonstrates that the high carbon areas are of much higher hardness than the low carbon areas. As will be shown later, the high hardness displayed by most of the steel bits (in axes 1H51D1-1, 1H51E3-3 and 1H51F5-1) results from a structure brought about by heat treatment. Note, too, the hardness of the steel bits gradually decreases with the increased distance from the cutting edge. Table 2 demonstrates that the average hardness of the wrought-iron parts is 120 HB, and the steel parts 200 HB and the heat-treated steel parts 380 HB.

Chemical Analysis

The chemical analysis was done on the axes under contract by Bondar-Clegg and Company Ltd., Ottawa. Samples were taken from each blade (at the fracture surface) and from two steel bits (at the cutting edge) as shown in Figure 7. The results of the chemical analysis are given in Table 3. For purposes of comparison, typical compositions of Swedish iron, modern wrought iron and modern steel are also quoted.

Table 3 shows that the carbon content, as was expected, is low in wrought iron and high in steel. The higher carbon content in two blades (1H51D1-1 and 1H51E3-3) represents an average value of iron and steel areas. The content of the remaining elements is very low (except for the somewhat high phosphorus in blades 1H51D1-1 and 1H51G3-9), indicating the axes were made from very pure, good quality materials, which compare well in composition with the best Swedish iron, and with modern wrought iron and steel.

Microscopic Examination

Three specimens for microscopic examination were taken from each axe (except axe eye 1H51C2-1): one from the blade at the fracture surface, one from the centre of the axe head and one from the applied bit at the cutting edge. The location of the sections is shown in Figure 7a-e. The sections were cut from the macro-specimens using a low-speed saw with a diamond blade and cold-mounted in epoxy resin. After grinding on a series of abrasive papers of progressively finer grit size (nos 240, 320, 400 and 600), polishing was carried out on a napless nylon cloth with 6-μm diamond paste followed by a medium high nap velvet cloth with a 1-μm diamond paste, and high nap rayon cloth with a slurry of 0.05-μm gamma alumina.

The specimens were etched in 4 per cent nital (a solution of nitric acid in ethyl alcohol) to reveal the structure, and in Oberhoffer reagent to show phosphorus segregation. The polished and etched specimens were then studied by reflected-light microscopy at magnifications of 50, 100, 500 and 1000 diameters. Micrographs of the specimens were taken to supplement the metallographic examination.

The grain size was determined using the comparison procedure of the ASTM Standard E912-74. Relative hardness of the microconstituents was measured using a Vickers type microhardness tester with a diamond pyramid indenter under a 100-g load (Hardness Vickers, HV).

The macroscopic examination revealed several differently etched areas within each axe. The microstructure of these areas is described and illustrated by micrographs. The origins of the micrographs (denoted by encircled numbers) are sketched in Figure 4.

Axe Eye 1H51C2-1

The axe eye (1H51C2-1) material, having no slag inclusions, is surprisingly pure and resembles modern low carbon steel rather than wrought iron.

Bulk of Metal (area 1, Fig. 4). The bulk of the material consists of coarse equiaxed ferrite grains ASTM size no. 5 (Fig. 14), where ferrite is a nearly pure iron with less than 0.025 per cent carbon. Higher magnification clearly brought out, in this soft (122 HV_{100}) low carbon structure, the presence of thin cementite films at the widened grain boundaries (Fig. 15). A banded structure resulting from segregation of phosphorus, about which more will be said later, was also evident in the axe eye.

Surface Rims (areas 2 and 3). The structure at the surface of the axe eye was found to vary from that in the centre. The approximately 2-mm wide rims at the outer surface (area 2) and the inner surface (area 3) are higher in carbon, and contain, besides ferrite grains, some pockets of dark etching pearlite. Pearlite is a high carbon constituent (ca. 0.8% C) and thus is much harder than ferrite, as shown by comparing its microhardness of 184 HV_{100} with that of ferrite at only 122 HV_{100}.

At the outer surface (area 2) the structure has a Widmanstaetten pattern of ferrite in a matrix of pearlite (Fig. 23). Ferrite occurs there both at prior austenite grain boundaries (a high temperature phase) and as plates within the grains. Also, regions of ferrite (ASTM no. 7) with pockets of pearlite were observed. At the inner surface (area 3) the structure consists of fine equiaxed ferrite grains (ASTM no. 9) and small pockets of pearlite corresponding to about 0.15 per cent C (Figs 17 and 18). Parts of the rim, containing only pearlite, were accidentally carburized in the forge while in contact with charcoal.

Axe Head 1H51D1-1

Axe head 1H51D1-1 with its heterogeneous structure appears to be made of different pieces of metal, a wrought-iron blade (areas 1 and 3), a steel slug (area 2) and a heat-treated steel bit (area 4).

Wrought-Iron Blade (areas 1 and 3). Metallographic examination showed the structure of the blade to be typical for wrought iron, as it was composed of equiaxed ferrite (149 HV_{100}) with a considerable amount of non-uniformly distributed slag inclusions. The medium size slag inclusions, though elongated in the direction of prevailing plastic deformation, are rather compact, similar to some of the inclusions in Figure 9. They are largely of duplex structure, probably comprising dendrites of wustite (FeO) in a fayalite matrix ($2FeO{\cdot}SiO_2$). There is a large variation in grain size and some variation in carbon content. In area 1, the ferrite grains are medium size (ASTM no. 5), and in area 3 the grains are coarse corresponding to ASTM no. 2 (Fig. 14).

Steel Inset Slug (area 2). A medium carbon strip of metal separates the low carbon areas 1 and 3. Here, very fine ferrite grains (ASTM no. 9) are mixed with about the same number of small pockets of pearlite indicating the presence of about 0.4 per cent carbon (Figs 19 and 20).

Steel Bit Overlaid on One Side (area 4). The cutting edge represents an entirely different structure from that of the remaining parts of the axe. Although at low magnification the structure resembles pearlite, high magnification clearly reveals a feathery hard matrix (568 HV_{100}) and some slag inclusions (Fig. 26). Such a structure is known as upper or feathery bainite and can be formed only at a rapid rate of cooling from high temperatures. Its presence suggests a deliberate effort at heat treating to increase the hardness of the steel bit. Farther from the edge, however, the very hard bainite disappears, and at a distance of about 25 mm the structure consists entirely of very fine sorbitic pearlite (383 HV_{100}). A few millimetres farther in, the presence of regular pearlite and ferrite can be found. Adjacent to the steel bit the structure is fine pearlite (322 HV_{100}) with only traces of ferrite. As a result of heat treatment, the overall hardness of the steel bit was considerably increased to about 370 HB compared with the hardness of the non-heat-treated steel of about 200 HB.

The several pieces of metal constituting the axe head were joined by forge-welding at high temperatures. This is verified by the presence in the structure of characteristic seams separating each area, the occurrence of a chain of very small oval or slightly elongated slag inclusions in some seams, the presence of large slag inclusions in the adjacent areas, as well as the technologically justified way of welding (that is, distribution of hard and soft metal). For example, Figure 29 shows the transition from the steel slug to the iron blade, with a seam between them. The transition zone where heat-treated steel (the applied bit) and soft iron (the blade) are welded together is illustrated in Figures 31 and 32.

Axe Head 1H51E3-3

As in the previous case, the axe head 1H51E3-3 contains a heat-treated steel bit (area 3), which, however, is welded here to a blade made of faggoted iron (areas 1 and 2).

Faggoted Iron Blade (areas 1 and 2). There are in the blade material many slag stringers of both duplex and single-phase structure. The slag inclusions vary in size; most of them are very long (Fig. 11), many large and medium size (Fig. 9) and some massive (Fig. 10). Higher magnification resolved the structure of the two-phase slag inclusions (Fig. 12) and that of the uniformly black one-phase slag inclusion (Fig. 13). The structure of the duplex slag inclusions consists of white dendrites of wustite in a grey fayalite-glass matrix.

Nital etching revealed that the blade has a piled structure typical for faggoted iron. It consists of several laminations varying greatly in carbon content from less than 0.1 per cent to about 0.8 per cent. The blade was made from six strips of steel and iron. The high carbon steel strips contain pearlite and grain boundary ferrite; the medium carbon steel strips contain ferrite mixed with pockets of pearlite; and the low carbon iron strips contain only ferrite. The ferrite strips are particularly rich in slag inclusions stretching in the direction of prevalent plastic deformation. Hardness readings of 72-169 HB reflect the different amounts of pearlite and ferrite. As seen in Figure 4, a welding seam with small slag inclusions runs along the entire length of the blade, dividing it in half. Etching in Oberhoffer reagent revealed in the blade a variable phosphorus content in the form of a well-pronounced banded structure. Alternate phosphorus-poor and phosphorus-rich bands run parallel to the direction of deformation (Fig. 16). Because phosphorus increases hardness, it was not surprising to find that the microhardness of the phosphorus-poor ferrite is 118 HV_{100} and that of phosphorus-rich ferrite is 207 HV_{100}.

In the high carbon steel strips (area 1) ferrite forms a thin envelope around the pearlite (Figs 21 and 22), or it appears in a blocky form. Figure 30 exemplifies two such welded-together pieces of steel with the characteristic seam containing a chain of very small slag inclusions and large slag stringers in the adjacent area. In local regions of the blade, ferrite (123 HV_{100}), not pearlite, is the predominant phase. In general, pearlite (192 HV_{100}) is partially spheroidized (Fig. 24), suggesting the metal was heated at 600-700°C for several hours. The structure of the low carbon iron strip (area 2) is basically that of low phosphorus wrought iron with equiaxed ferrite grains of medium size (ASTM no. 5) and many large slag inclusions. This strip is extremely soft, its hardness only 75 HB. The hardness of the medium carbon steel strip is much higher, 145 HB. Some pockets of pearlite appear also in the iron strip close to the steel strip. This is probably because of carbon diffusion from the part of stronger carburization (steel part) to the iron part. A large portion of the left surface of the blade is carburized. The carbon content gradient perpendicular to the carburized surface developed because of accidental carburization in the forge.

Inset Steel Bit (area 3). As in axe 1H51D2-1, the structure of the cutting edge of this axe is that of heat-treated steel, and it changes gradually with increased distance from the cutting edge. Presence of feathery bainite (609 HV_{100}) is confined here only to a small region at the tip of the axe edge (Fig. 26). A large region follows comprising unresolved, almost structureless pearlite which may be referred to as sorbitic pearlite (Fig. 25). It has a high hardness - 402 HV_{100}, but not as hard as upper bainite. Much farther from the edge, the main constituent is still softer lamellar pearlite (234 HV_{100}) with a considerable amount of ferrite. The steel bit also contains a substantial amount of small elongated inclusions (Fig. 8). The forge-welded zone of the heat-treated steel bit and the faggoted iron blade (steel strip) is marked by a clearly visible seam (Figs 33 and 34).

Axe Head 1H51F5-1

Axe head 1H51F5-1 is made up of three pieces of metal, that is, a wrought-iron blade (area 1) and two steel bits, one heat-treated (area 3) and one not (area 2).

Wrought-Iron Blade (area 1). The predominant structure of the blade is equiaxed ferrite (135 HV_{100}), varying in size from ASTM no. 7 to no. 4, with some pockets of pearlite (Figs 17 and 18). There is a large amount of two-phase slag stringers, frequently of massive size (Fig. 10), and some of single-phase strucutre. One of the blade surfaces is slightly carburized showing a Widmanstaetten geometrical pattern. The banded structure is not as well developed as in the axe blade 1H51E3-3.

Inset Steel Bit (area 2). This steel bit, in contrast to the one discussed next, has not been hardened by heat treatment. The structure of the region close to the cutting edge consists of fine pearlite (309 HV_{100}) and traces of ferrite. However, in the remaining part of the steel bit coarse pearlite (213 HV_{100}) with ferrite envelopes was observed (Figs 21 and 22).

Steel Bit Overlaid on One Side (area 3). The structure in this steel bit was formed as a result of heat treatment. As in the other axes, there was a gradual change in the microstructure along the length of the steel bit. Slag stringers both of duplex and single-phase structure occur throughout the entire area (Fig. 9). Presence of feathery bainite (543 HV_{100}) extends along the first 10 mm from the cutting edge. Proceeding farther away from the edge, sorbitic pearlite (407 HV_{100}) becomes the predominant constituent. Still farther from the edge some remains of ferrite appear. In the region close to the steel bit's opposite end the microhardness of pearlite has decreased considerably. Its value of 305 HV_{100}, though appreciably higher than that of coarse pearlite, is lower than that of sorbitic pearlite.

Light, not well-etched welding seams form clearly delineated boundaries around the two steel bits. Figure 31, for example, demonstrates the transition from the iron blade forge welded to the heat-treated steel bit. Details of the transition zone are revealed at higher magnification in Figure 32. From the left is a light low carbon area, some single-phase slag stringers followed by a seam containing a chain of very small oval slag inclusions, and on the right a dark high carbon area (heat-treated steel). A seam about 1 cm long, terminating at the non-heat-treated steel bit, is also visible in the iron blade. The iron part between the two steel bits has a structure of irregular columnar ferrite with pockets of pearlite.

Axe Head 1H51G3-9

Axe head 1H51G3-9 is made of two pieces of metal, a high phosphorus wrought-iron blade (area 1) and a small steel bit (area 2) not hardened by heat treatment.

Wrought-Iron Blade (area 1). Typical of wrought iron, the structure of the blade consists of an assortment of slag stringers in a matrix of equiaxed ferrite grains (ASTM no. 6). The numerous slag stringers are mostly of duplex structure and occasionally of single-phase structure. They are heterogeneously distributed and vary in size from medium and large to massive (Figs 9 and 10). Oberhoffer

Table 4. Characteristics and technological features of the axes from Fort St. Joseph.

Provenance	Part of axe	Macro-area (Fig. 4)	Material	Macrostructure (C - carbon) (P - phosphorus)	Hardness (Brinell)	Microstructure: Slag inclusions	Microstructure: Main constituents	Microstructure: Grain size (ASTM no.)	Micro-hardness HV_{100}	Composition (%): C	Mn	Si	P	S
Axe eye 1H51C2-1	Bulk	1	"Mild" steel (iron)	Very low C, low P Banded structure	86	None	Ferrite, equiaxed Cementite films	5	122					
	Surface rims	2 & 3	"Mild" steel (iron)	Low C, low P	126	None	Ferrite, equiaxed Some pearlite	7 & 9	122 184	-	-	-	-	-
Axe head 1H51D1-1	Blade	1 & 3	Wrought iron	Very low C, higher P	182	Many, medium	Ferrite, equiaxed	5 & 2	149					
	Inset slug	2	Steel	Medium C, low P	204	A few, short	Ferrite, equiaxed Pearlite	9	149	0.34	0.02	0.04	0.22	0.07
	Overlaid on one side bit 35 x 5 mm	4	Steel	High C	372	Many, short	Upper bainite* Sorbitic pearlite Pearlite & ferrite		568 383	-	-	-	-	-
Axe head 1H51E3-3	Blade	1	Faggoted iron - high carbon strip	Medium C, Banded structure	145	Many,long,large & med.	Pearlite,Ferrite, equiaxed(P-poor P-rich)		209					
		2	Faggoted iron - low carbon strip	Very low C, low P	75	Numerous, large	Ferrite, equiaxed Cementite films		118	0.28	0.01	0.04	0.08	0.02
	Inset bit 40 x 3 mm	3	Steel	High C	382	Many, short	Some upper bainite Sorbitic pearlite* Pearlite (& ferrite)	5	207 123					
									609 402 234	0.53	0.04	0.06	0.09	0.02
Axe head 1H51F5-1	Blade	1	Wrought iron	Low C, low P, Banded structure	114	Numerous, large & med.	Ferrite, equiaxed,pearlite	7 & 4	135	0.01	0.009	0.05	0.07	0.005
	Inset bit 30 x 4 mm	2	Steel	High C	216	A few	Fine pearlite* Pearlite (& ferrite)		309	-	-	-	-	-
	Overlaid on one side bit 30 x 4 mm	3	Steel	High C	372	Numerous	Upper bainite* Sorbitic pearlite Fine pearlite		213 543 407 305	0.8	0.03	0.03	0.05	0.01
Axe head 1H51G3-9	Blade	1	Wrought iron	Very low C, higher P	119	Many,long,large & med.	Ferrite, equiaxed(P-rich)	6	182	0.1	0.05	0.04	0.22	0.03
	Inset bit 10 x 2 mm	2	Steel	High C	185	A few	Pearlite* Ferrite network	5	215	-	-	-	-	-

*Predominant microstituent.

reagent did not darken the matrix, indicating a high phosphorus content. This was confirmed by the unusually high hardness of ferrite, 182 HV_{100}, which is almost entirely due to phosphorus. Streaks of somewhat higher carbon content, containing ferrite with pockets of pearlite, were also observed in the blade. Their presence is probably due to primary carburization in the liquid state. Secondary carburization in the form of locally carburized surfaces was also noted in the blade.

Inset Steel Bit (area 2). In contrast to the other axes with relatively large (and heat-treated) steel bits, the cutting edge of axe 1H51G3-9 is formed by a thick end of a small steel bit about 10 x 2 mm. This is well illustrated in Figure 27 showing at low magnification the opposite end of the steel bit surrounded by low carbon iron. We can also see a sudden change in the number of slag stringers in the area adjacent to the steel bit. The transition zones from the high carbon area (steel) to the low carbon areas (iron), on both sides of the bit, are demonstrated at higher magnification in Figure 28. The structure of the steel bit itself is that of pearlite. At still higher magnification, the coarse pearlite lamellae are easily resolvable (Fig. 22). The alternate layers of ferrite and cementite are arranged in colonies within which the lamellae are roughly parallel and uniformly spaced. This structure accounts for the low overall hardness of the steel bit (only 185 HB), and indicates that no attempt at heat treatment to harden the cutting edge was made.

The results presented in this chapter are summarized in Table 4, which recapitulates characteristics and technological features of the examined axes.

Figure 1. Axe eye 1H51C2-1.
(Photo by G.Vandervlugt)

Figure 2. Typical appearance of an axe surface fracture. (Photo by author)

Figure 3. Macrostructure of the axes showing light low carbon areas (iron) and dark high carbon areas (steel). *Left to right:* 1H51C2-1, 1H51D1-1, 1H51E3-3, 1H51F5-1 and 1H51G3-9. Etched in 10 per cent nitric acid.

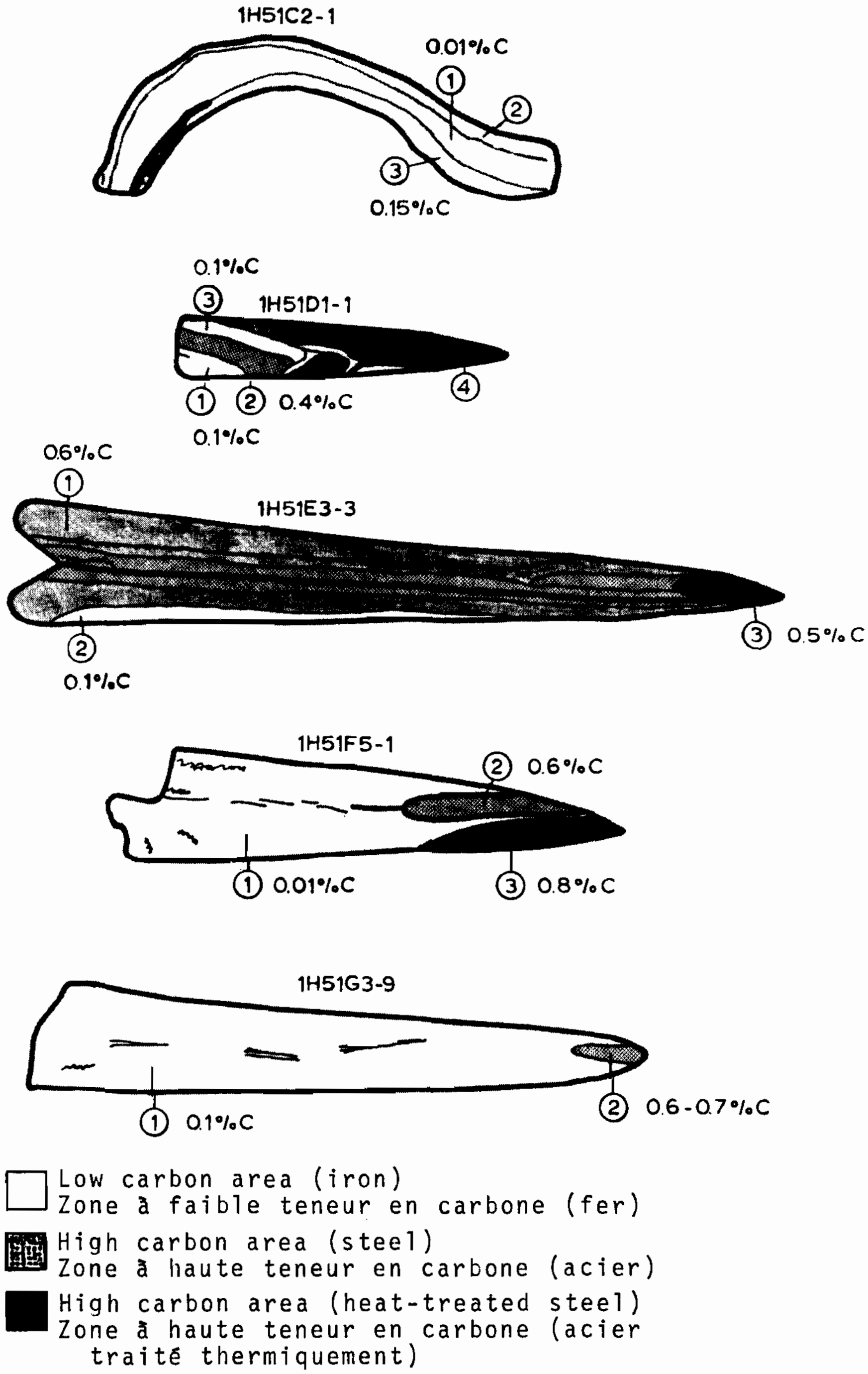

Figure 4. Technology of the axes: carbon distribution revealed by etching with 10 per cent nitric acid. (Drawing by J. Renaud)

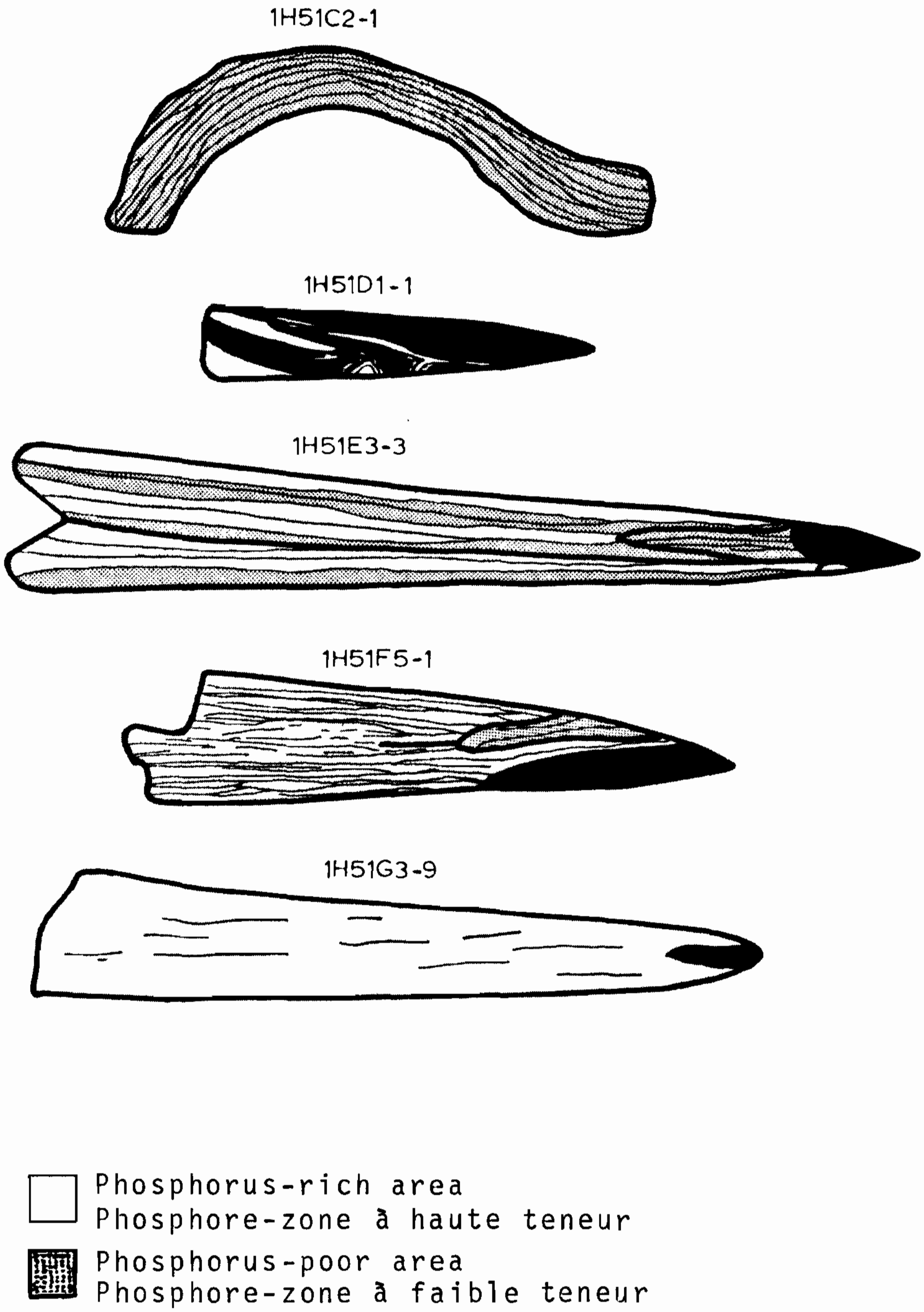

Figure 5. Technology of the axes: phosphorus distribution revealed by etching with Oberhoffer reagent (black areas are steel bits). (Drawing by J. Renaud)

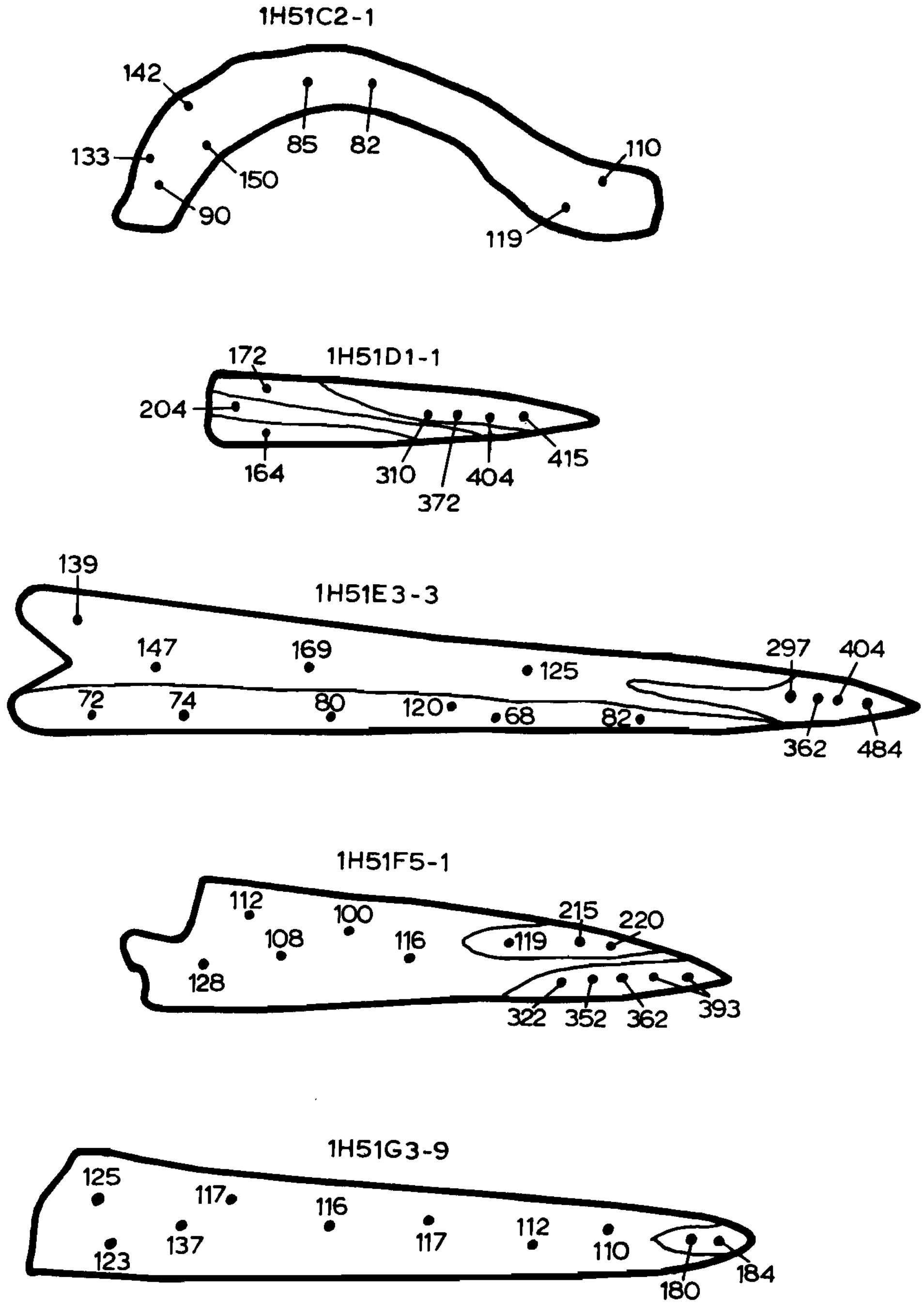

Figure 6. Hardness distribution (Brinell) on the longitudinal cross-sections of the axes. (Drawing by J. Renaud)

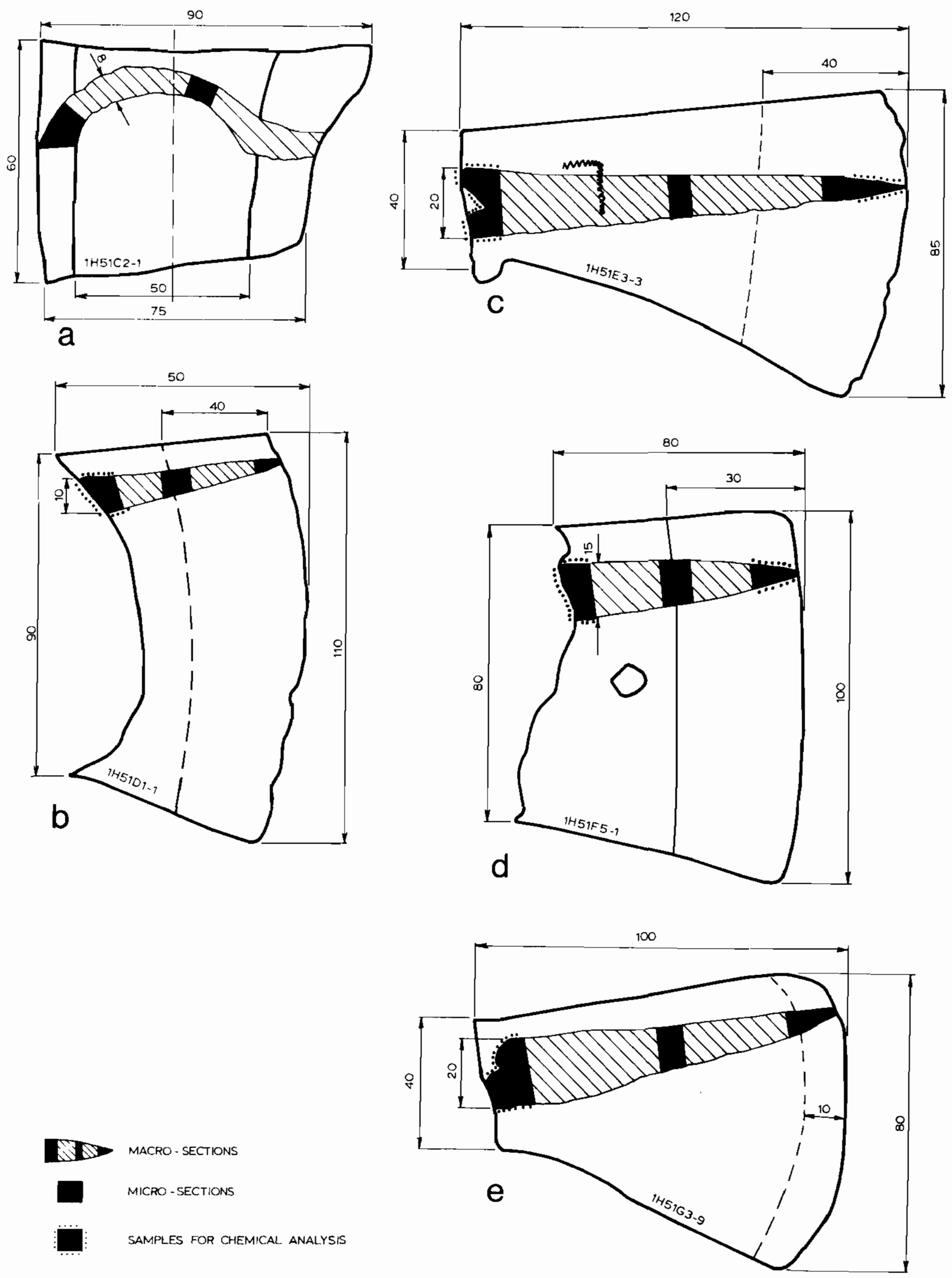

Figure 7. Sketches of the axes with locations of the samples taken for examination (dimensions in millimetres are approximate). a, Axe eye 1H51C2-1; b, axe head 1H51D1-1; c, axe head 1H51E3-3; d, axe head 1H51F5-1; e, axe head 1H51G3-9. The shape and location of the sections taken from the axes are shown by means of revolved sections superimposed on the side view of the axes. (Drawing by J. Renaud)

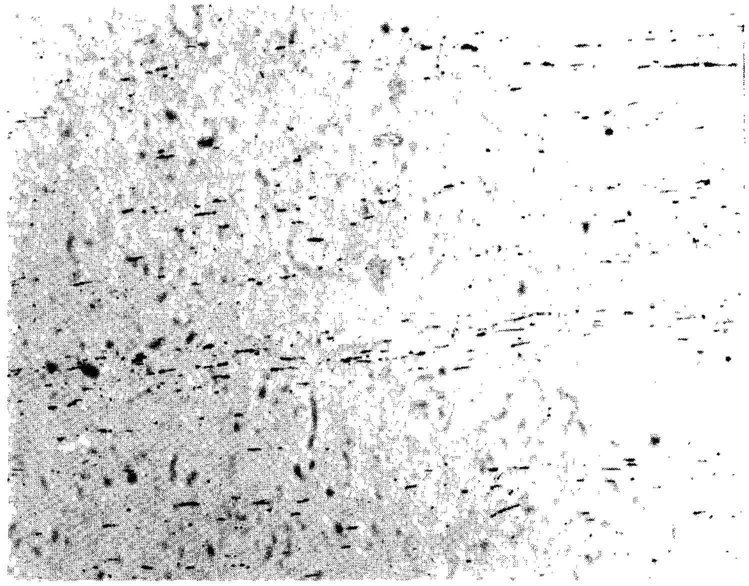

Figure 8. Tiny slag inclusions (black) with one-phase structure. As polished (not etched). (x100 [100-power microscope])

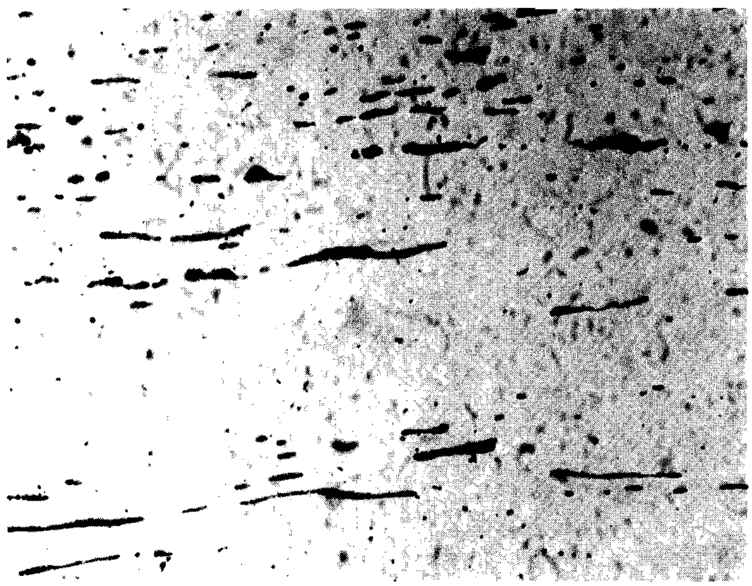

Figure 9. Medium and small size slag stringers (grey) with two-phase structure. As polished (not etched). (x100)

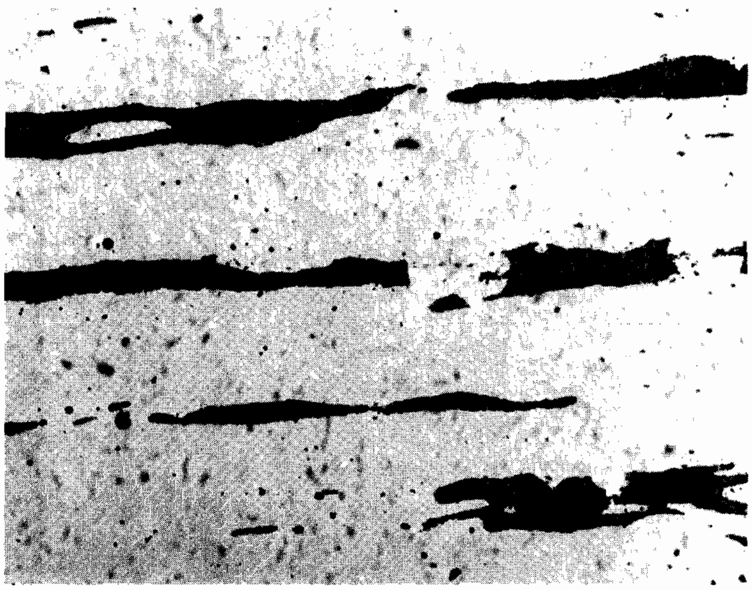

Figure 10. Large slag stringers (grey) of two-phase structure. As polished (not etched). (x100)

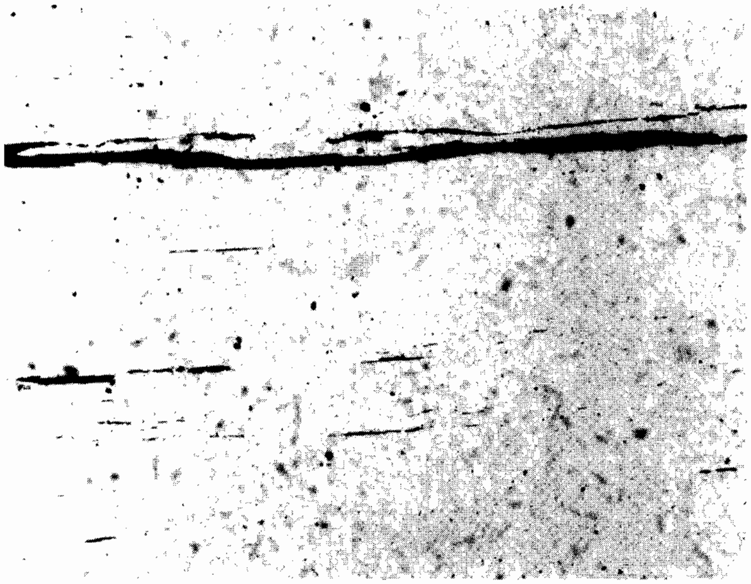

Figure 11. Very long and thin slag stringers (black) of one-phase structure. As polished (not etched). (x100)

Figure 12. Structure of two-phase slag inclusions resolved at high magnification. Wustite dendrites (light), fayalite columns (grey) and glass matrix (dark). As polished (not etched). (x500)

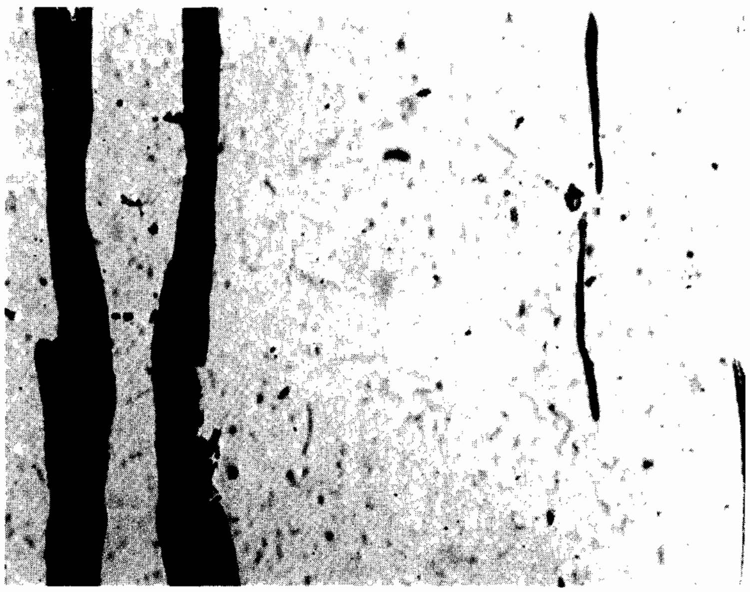

Figure 13. Structure of one-phase slag inclusions resolved at high magnification. Uniformly black single-phase glassy stringers. As polished (not etched). (x500)

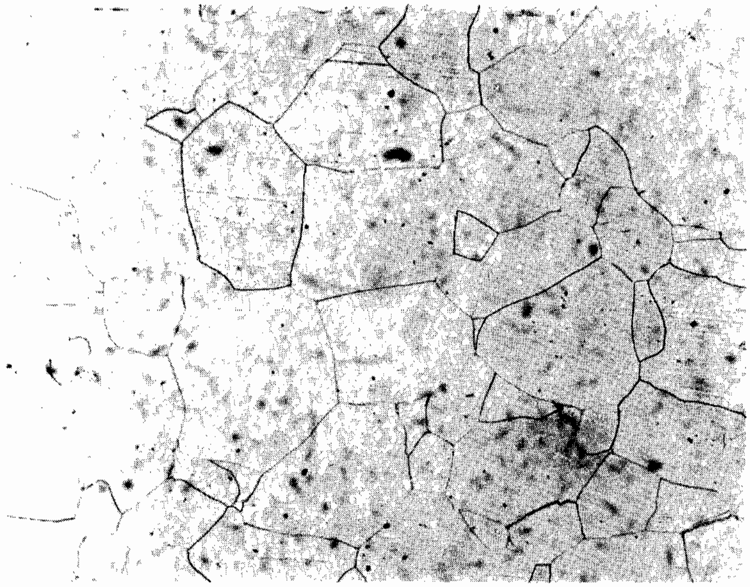

Figure 14. Structure of iron with less than 0.05 per cent carbon (cooled slowly). Coarse equiaxed ferrite grains (light) with well-delineated grain boundaries (dark lines). Etched in 4 per cent nital to produce contrast. (x100)

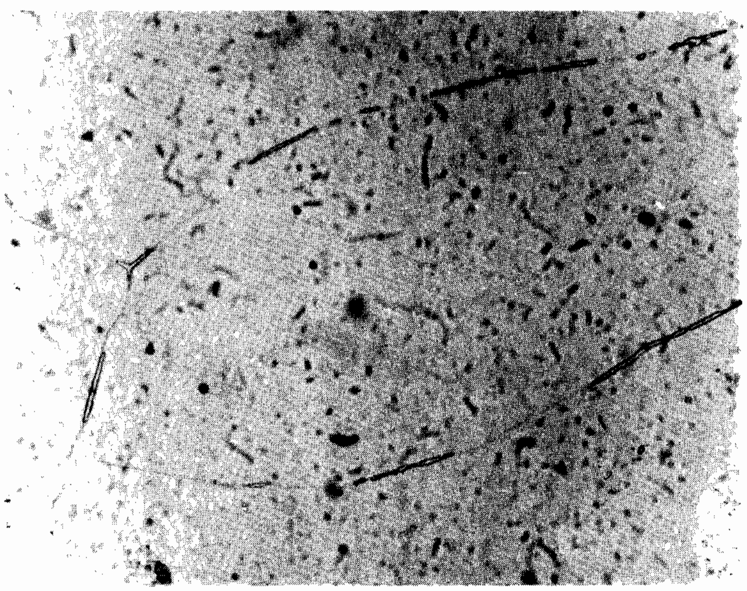

Figure 15. Figure 14 at higher magnification. Thin cementite films revealed at ferrite grain boundaries. Etched in 4 per cent nital. (x1000)

Figure 16. Banded structure in wrought iron. Phosphorus-rich bands (light) and phosphorus-poor bands (dark) of ferrite, slag stringers (black). Etched in Oberhoffer reagent. (x50)

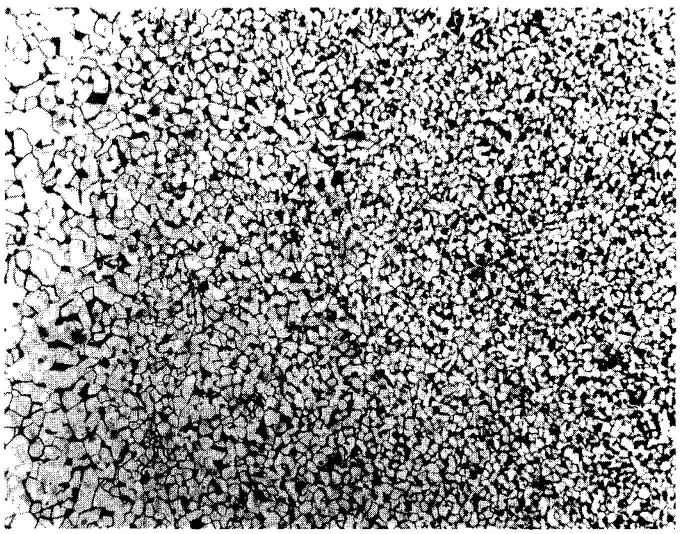

Figure 17. Structure of iron with about 0.15 per cent carbon (cooled moderately fast). Fine ferrite grains (light) with some pockets of pearlite (dark) at grain boundaries. Etched in 4 per cent nital. (x100)

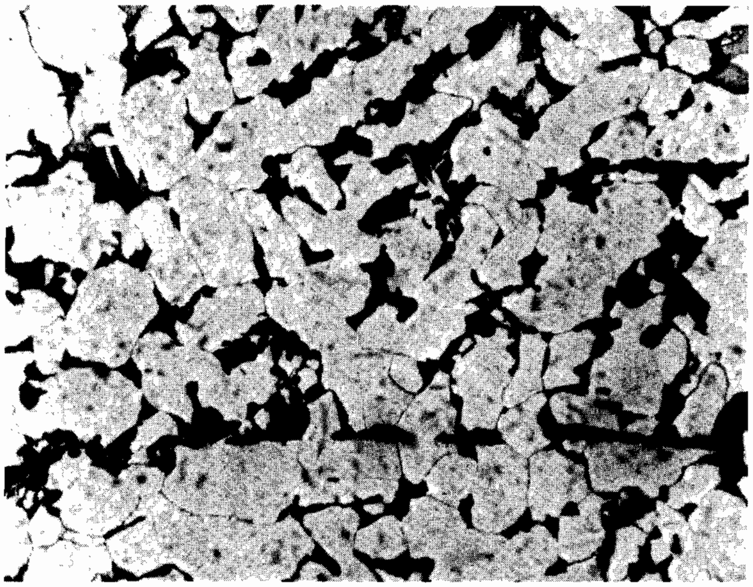

Figure 18. Figure 17 at higher magnification. Ferrite (light) and some pearlite (dark). Etched in 4 per cent nital. (x500)

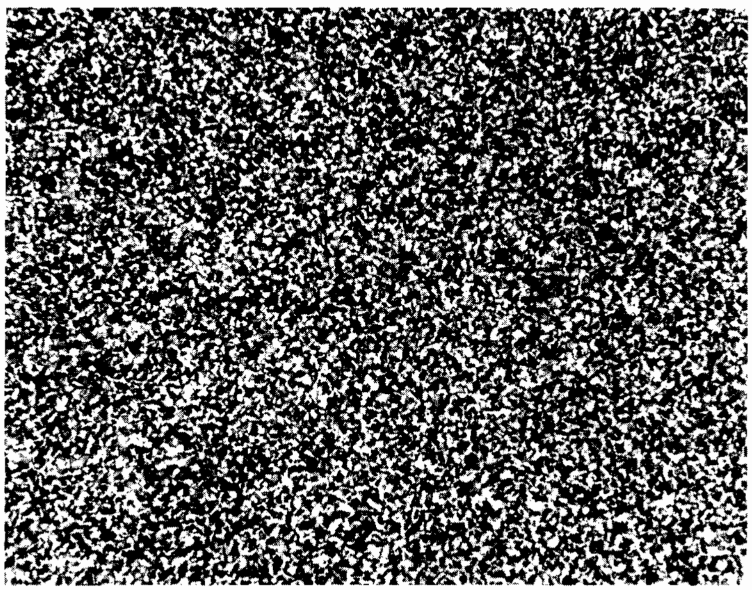

Figure 19. Structure of steel with about 0.4 per cent carbon (cooled fast). Roughly equal amounts of very fine ferrite (light) and pearlite (dark). Etched in 4 per cent nital. (x100)

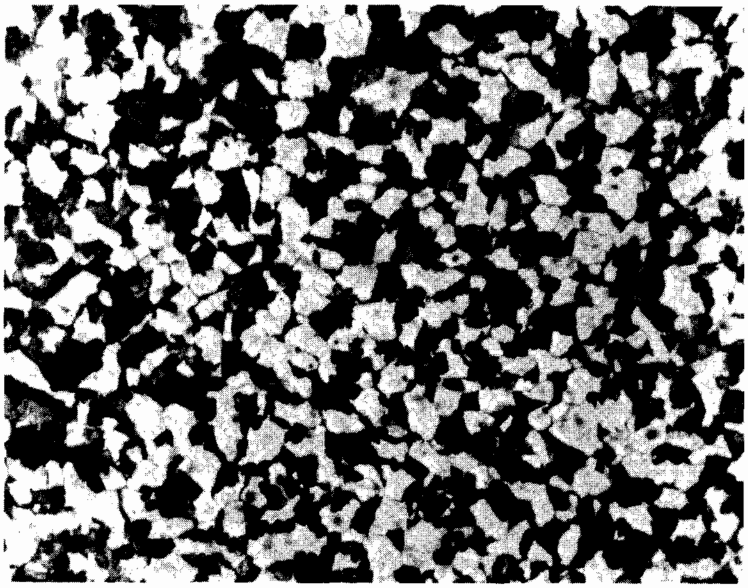

Figure 20. Figure 19 at higher magnification. Ferrite (light) and pearlite (dark). Etched in 4 per cent nital. (x500)

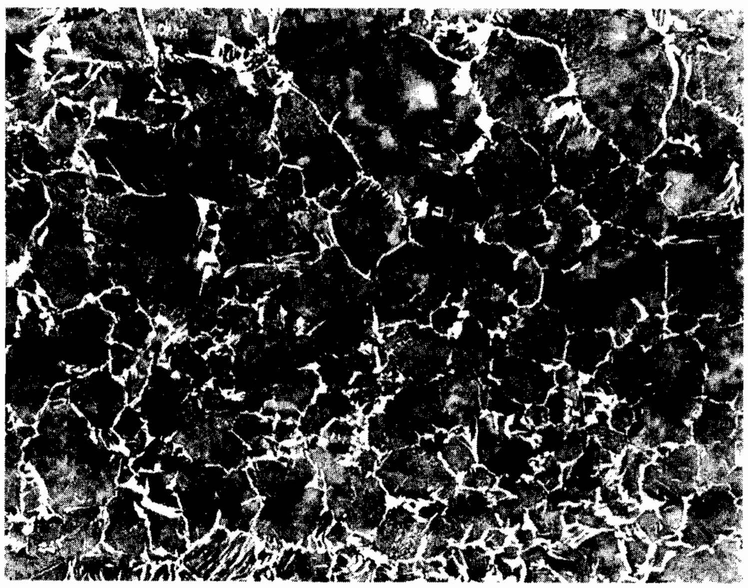

Figure 21. Structure of steel with about 0.6-0.7 per cent carbon (cooled slowly). Pearlite matrix (dark) with ferrite envelopes (light) at grain boundaries. Etched in 4 per cent nital. (x100)

Figure 22. Figure 21 at higher magnification. Coarse lamellar pearlite (dark-light) resolved, and grain boundary ferrite (light). Etched in 4 per cent nital. (x500)

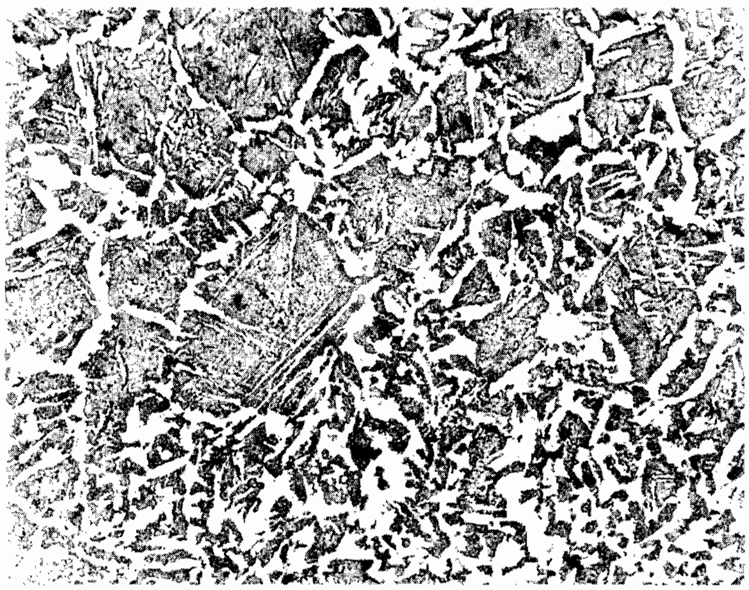

Figure 23. Widmanstaetten structure of steel (cooled fast). Ferrite (light), both at grain boundaries and within grains, in matrix of pearlite (dark). Etched in 4 per cent nital. (x100)

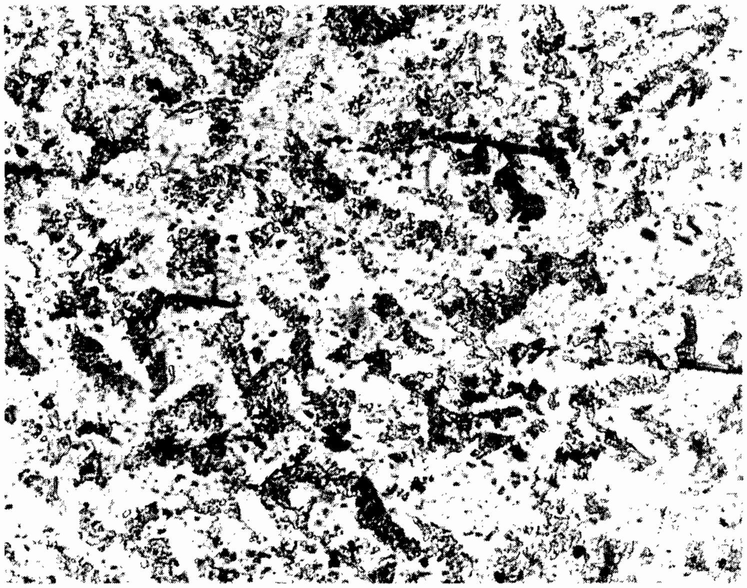

Figure 24. Partially spheroidized structure of steel (heat affected). Spheroidized pearlite (dark) in matrix of ferrite (light), and slag inclusions (black). Etched in 4 per cent nital. (x500)

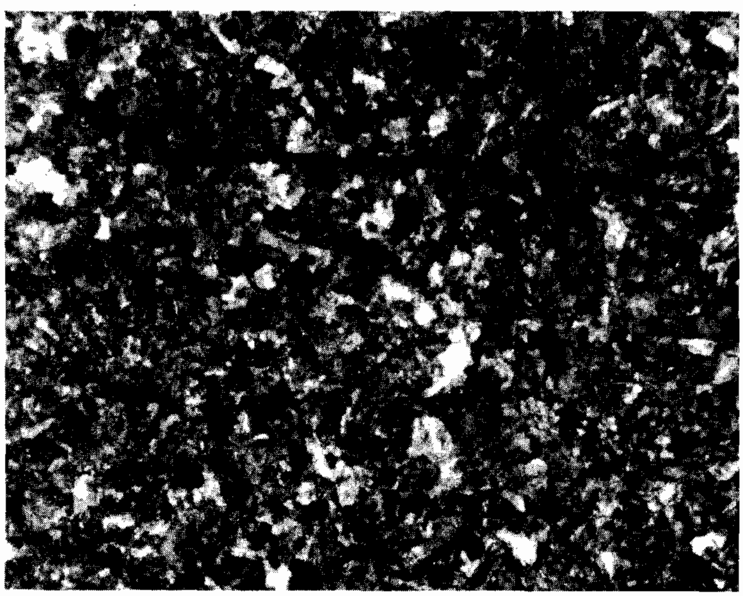

Figure 25. Structure of heat-treated steel bit (cooled moderately fast). Matrix of sorbitic pearlite with slag stringers. Etched in 4 per cent nital. (x500)

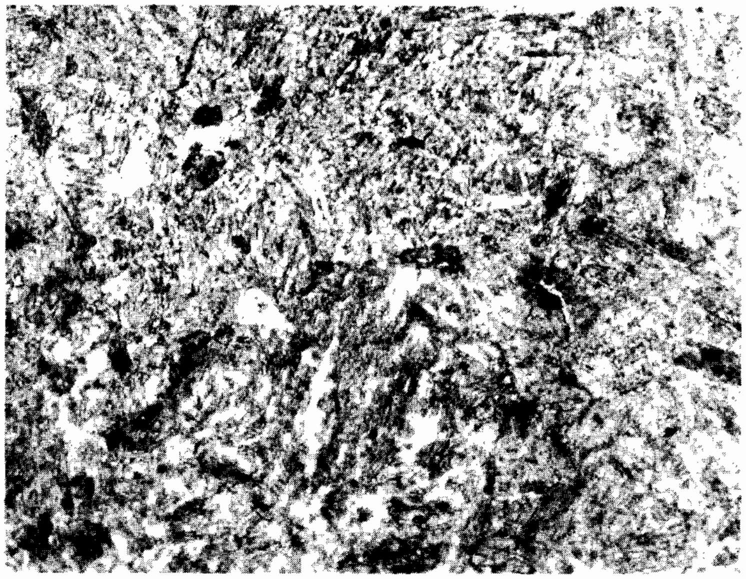

Figure 26. Structure of heat-treated steel bit (cooled rapidly). Upper (feathery) bainite. Etched in 4 per cent nital. (x1000)

Figure 27. Forge-welded steel bit (dark) to wrought-iron blade (light) in axe head 1H51G3-9. Etched in 4 per cent nital. (x25)

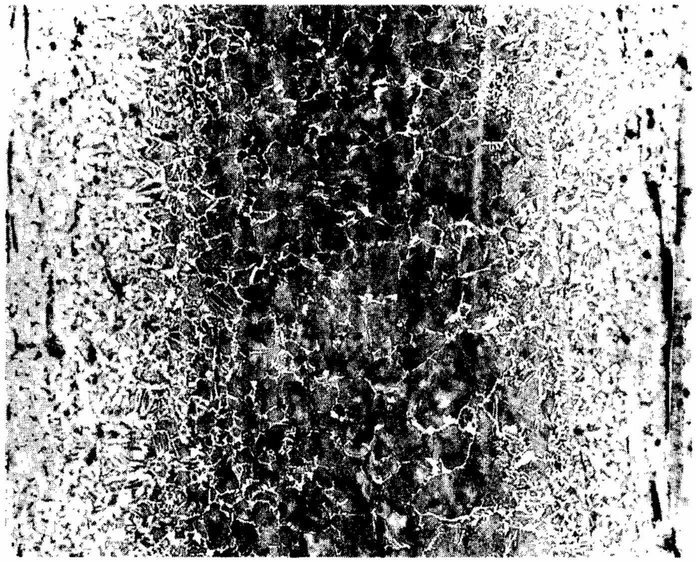

Figure 28. Forge-welded structure: iron to (high carbon) steel. Wrought iron: ferrite (light) with slag stringers (black). Steel *(centre)*: pearlite (dark) and network of ferrite (light). Etched in 4 per cent nital. (x50)

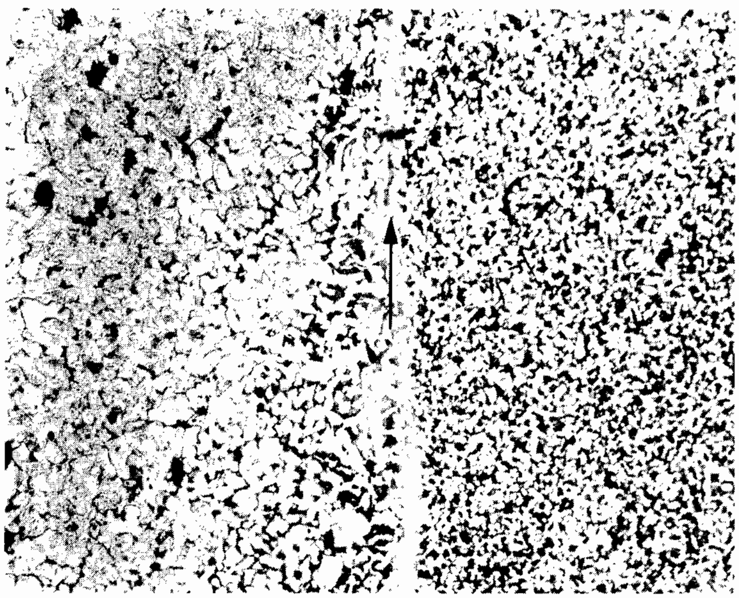

Figure 29. Forge-welded structure: iron to (medium carbon) steel. Wrought iron *(left)*: ferrite (light). Welding seam (arrow) (light). Steel *(right)*: ferrite (light) and pearlite (dark). Etched in 4 per cent nital. (x100)

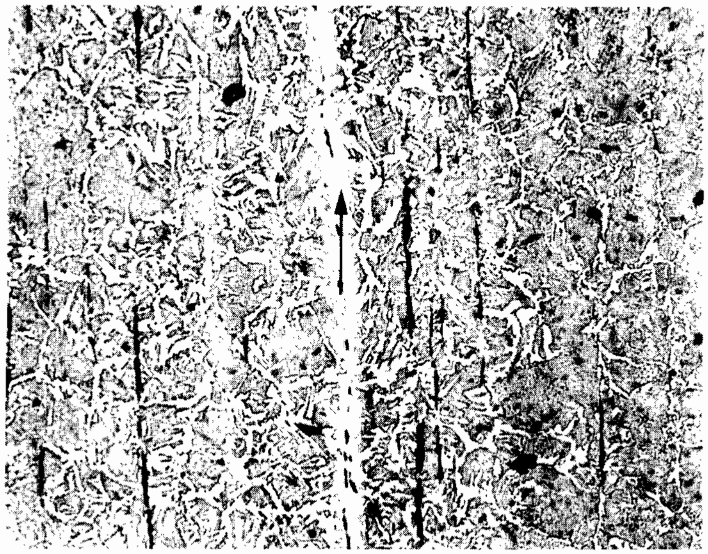

Figure 30. Forge-welded structure: steel to steel. Steel (on either side of seam): pearlite (dark) and grain boundary ferrite (light). Welding seam (arrow) (light) with a chain of very small slag inclusions (black). Etched in 4 per cent nital. (x100)

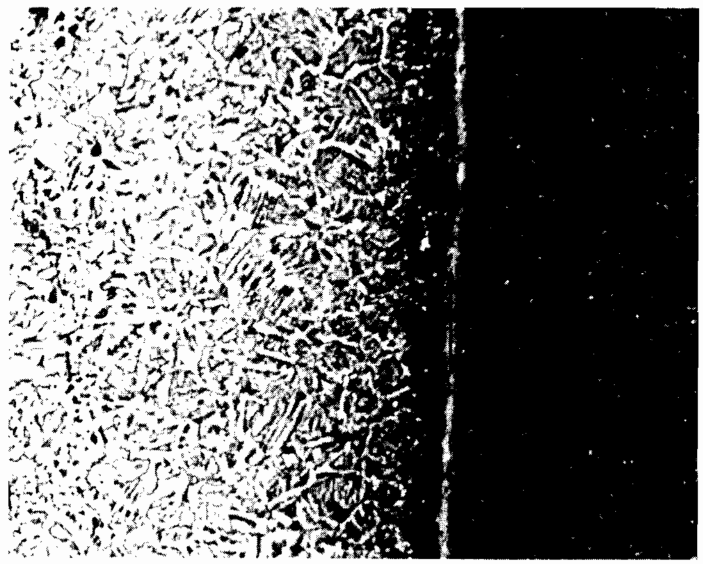

Figure 31. Forge-welded structure: iron to heat-treated steel. Wrought iron *(left)*: ferrite (light) and few pockets of pearlite (dark). Welding seam (arrow) (light). Heat-treated steel *(right)*: upper bainite (black). Etched in 4 per cent nital. (x50)

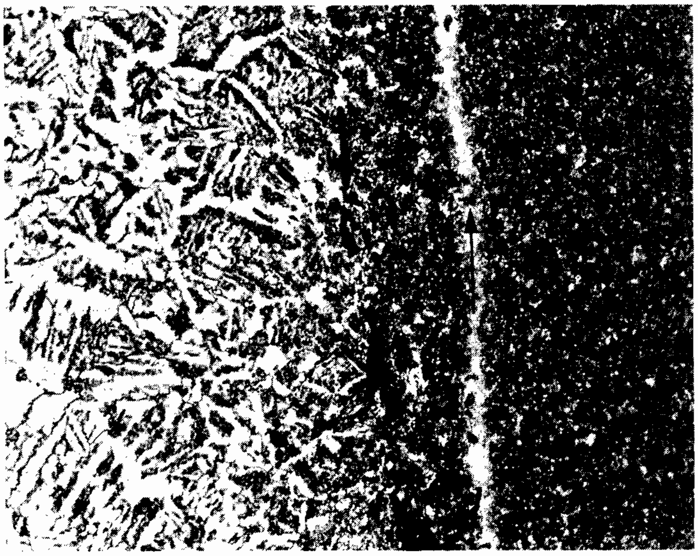

Figure 32. Figure 31 at higher magnification. A chain of very small oval slag inclusions is visible in the seam (arrow); there are also large slag stringers in adjacent area. Etched in 4 per cent nital. (x100)

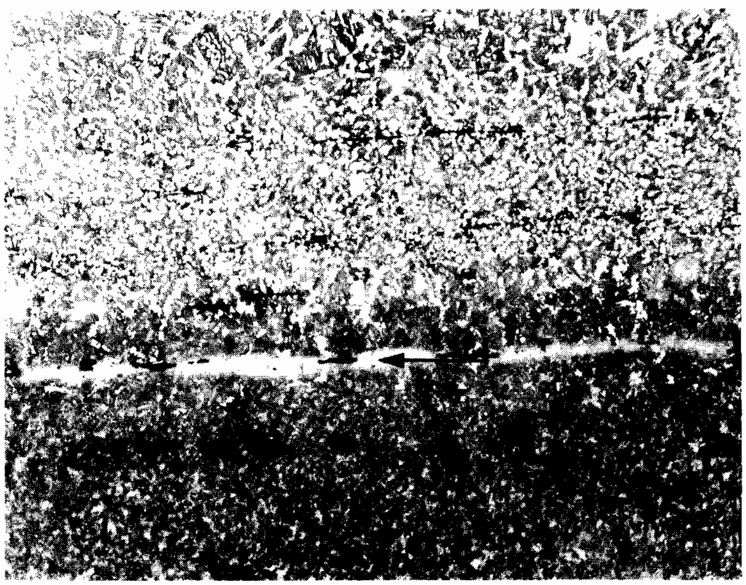

Figure 33. Forge-welded structure: steel to heat-treated steel. Steel *(top)*: ferrite (light) and pearlite (dark). Welding seam (arrow) (light) with small slag inclusions (black). Heat-treated steel *(bottom)*: sorbitic pearlite (black). Etched in 4 per cent nital. (x100)

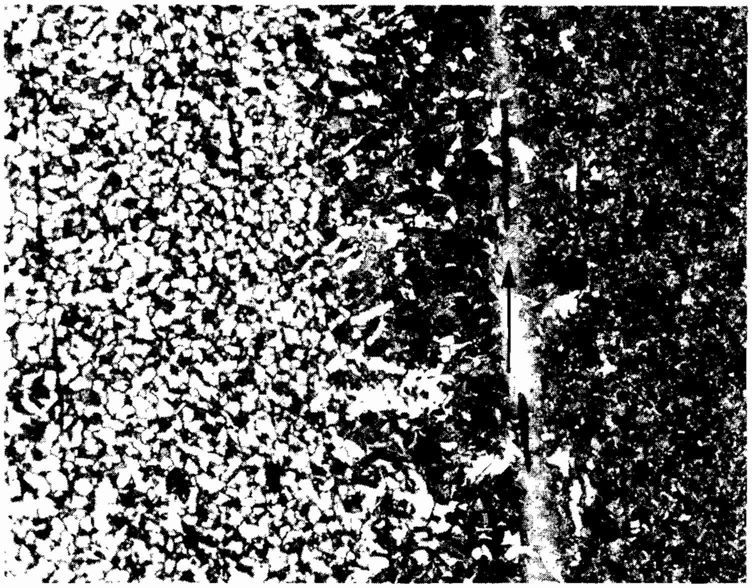

Figure 34. Figure 33 at higher magnification. Medium carbon steel *(left)*, seam (arrow), heat-treated steel *(right)*. Etched in 4 per cent nital. (x200)

DISCUSSION AND INTERPRETATION

Technology of the Axes

Structure Versus Technology

The structure and composition of the examined axes provide information on the technology and methods used for their manufacture. The results obtained from macroscopic examination, hardness testing, microscopic examination, microhardness measurements and chemical analysis are consistent in showing the type of structure, technological processes and heat treatment applied to the axes.

To clarify the relationship between the results obtained and the technology and methods of manufacture of the axes, a simplified description of structural changes caused by heating and cooling of iron and steel follows.

The structure and resulting mechanical properties (hardness and ductility) of the iron and steel depend mainly on the following three factors:

1. Composition (primarily carbon content)
   The higher the content of carbon the harder and less ductile is the material.
2. Temperature
   Changes in structure occur at certain temperatures called critical or transformation temperatures. The range 700-900°C and above is in this respect interesting to us.
3. Cooling rate
   This depends on the size of the object and, more significantly, on the cooling medium. The rate of cooling increases, respectively, from very slow to very rapid with cooling in the following media: liquid salts, in the forge, in air (still or agitated), warm water, oil, cold

water, and salt brine. Note that with an increased rate of cooling the transformation temperature is lowered.

Thus the formation of the microconstituents encountered in the examined axes (and described here) was governed by the amount of carbon present, the temperature it reached, the cooling rate and the size of the object.

Ferrite and Pearlite. The main constituents of slowly cooled iron and steel are ferrite (Fig. 35) - a very soft and ductile phase of nearly pure iron with less than 0.025 per cent carbon; cementite - a very hard and brittle compound of iron carbide (Fe_3C); pearlite (Fig. 36) - a lamellar aggregate of ferrite and cementite containing about 0.8 per cent carbon and much harder than ferrite; spheroidized pearlite (Fig. 37) - a soft aggregate of cementite particles essentially globular shaped in a ferrite matrix, formed when iron or steel containing lamellar pearlite is heated for a prolonged period at or near the critical temperature (about 700°C). The more carbon (up to 0.8%) and the higher the rate of cooling, the more pearlite and less ferrite is formed, and consequently the harder and less ductile is the material.

Sorbitic Pearlite. The fineness of pearlite formed (that is, the distance between the lamellae) and the resulting hardness vary with the temperature of transformation. They both increase as the temperature decreases below the critical temperature (about 700°C) due to the increased rate of cooling. When the rate of cooling has been moderately rapid, an extremely fine and almost structureless pearlite, referred to as sorbitic pearlite (Fig. 38), is produced at about 500-600°C. Mechanically it is the strongest type of pearlite and gives steel a high elasticity and considerable hardness.

Upper Bainite. A rapid cooling rate, at about 550-500°C, causes formation of upper or feather bainite (Fig. 39). Although it resembles pearlite, it is a distinct microconstituent characterized by a combination of both high

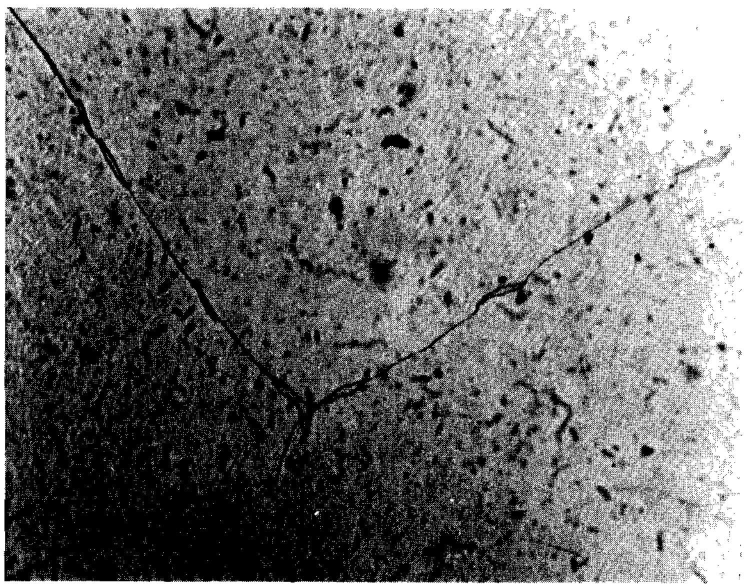

Figure 35. Ferrite with thin cementite films at grain boundaries with a microhardness of 125 HV_{100} as found in wrought iron. Etched in 4 per cent nital. (x1000)

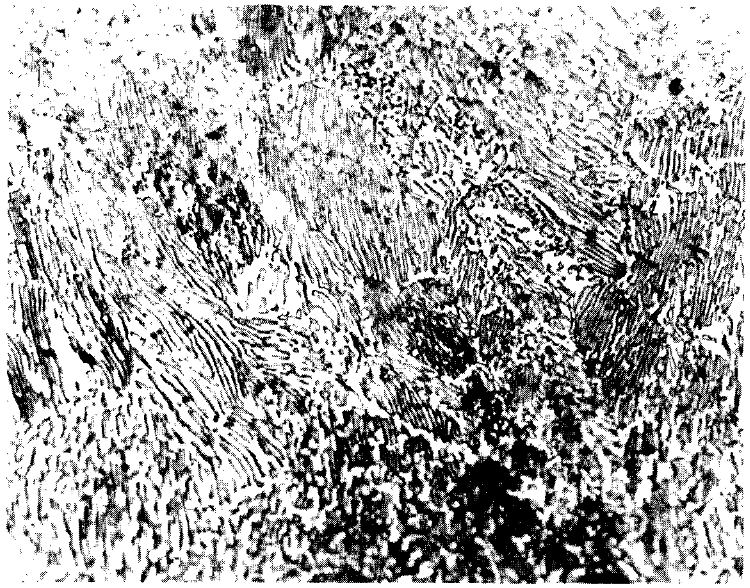

Figure 36. Pearlite consisting of lamellae of cementite (dark) and ferrite (light) with a microhardness of 210 HV_{100} as found in slowly cooled steel. Etched in 4 per cent nital. (x1000)

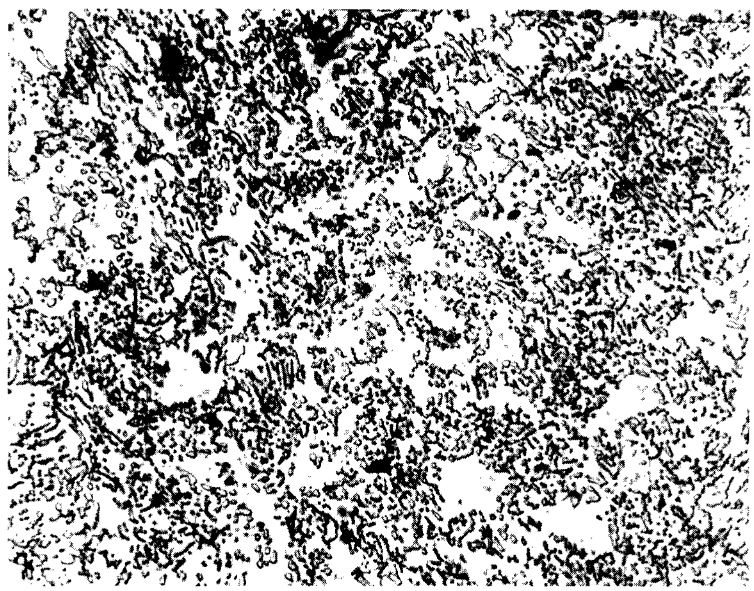

Figure 37. Partially spheroidized pearlite consisting of spheroidized particles of cementite (dark) in matrix of ferrite (light) with a microhardness of 190 HV_{100} as found in heat-affected steel. Etched in 4 per cent nital. (x1000)

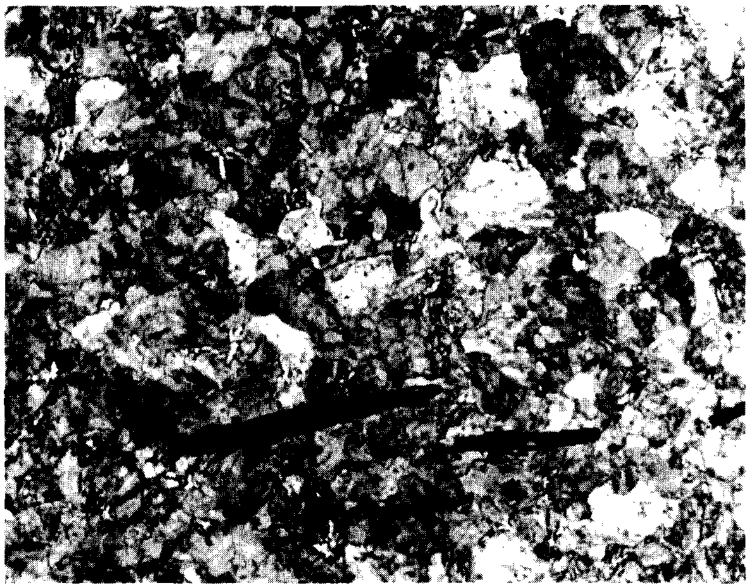

Figure 38. Sorbitic pearlite consisting of very fine unresolved pearlite (the black stringers are slag inclusions) with a microhardness of 400 HV_{100} as found in moderately rapidly cooled steel. Etched in 4 per cent nital. (x1000)

Figure 39. Upper bainite having characteristic feathery appearance with a microhardness of 540 HV_{100} in rapidly cooled steel. Etched in 4 per cent nital. (x1000)

hardness and high toughness. At about 400-300°C a somewhat different microconstituent is formed called lower bainite.

Martensite. As a result of a very rapid rate of cooling (that is, quenching in water or oil) at about 200-100°C, martensite is obtained in medium and high carbon steels. It is a very hard and extremely brittle phase not detected in the examined axes. Heating a quenched steel at 100-650°C (that is, tempering) causes decomposition of martensite (resulting in formation of so-called tempered martensite), and softens the material.

Forging of the Iron Blades

Each of the axe heads was made of several pieces of metal joined by forge-welding at high temperatures. This is based on (1) characteristic welding seams delineating the various areas; (2) occurrences in the seam of a chain of very small round or oval slag inclusions; (3) sudden change in the content of carbon; (4) areas of carbon diffusion from the part of stronger carburization (steel) to the iron part; (5) sudden changes in the size and quantity of slag inclusions, and finally (6) the technologically justified way of welding (that is, distribution of hard, stronger carburized metal and of soft metal). Steel, being a harder metal, was selected for the bits, while softer iron was used for the blades.

The structure of most of the axe blades is typical for wrought iron, though in local areas it may resemble that of steel. The blades (except for axe 1H51E3-3) have structures associated with simple air-cooling from temperatures well above the critical point (900°C for the low carbon areas) without any further treatment.

The equiaxed ferrite grains and the slag inclusions elongated in the direction of prevalent plastic deformation show evidently that the axes (blades) were hot-worked, that is, forged at high temperatures. The ferrite grains although deformed in forging are no longer elongated because the temperature at which hot-working had been done was sufficiently high to permit the structure to recrystallize. Hot-working also caused segregated regions of phosphorus to be elongated in the direction of plastic deformation flow, a condition revealed in three axes (1H51C2-1, 1H51E3-3 and 1H51F5-1) as a banded structure. The generally large grain size in the wrought-iron parts suggests that forging was finished above 1000°C and perhaps as high as 1200°C or higher.

It was demonstrated before that the structure of axe blade 1H51E3-3 is different from that of the remaining blades. Its piled structure clearly indicates that the blade is made of faggoted iron. Piling or faggoting was a technique in which several sheets or laminations of iron separately carburized had been piled one upon another and then forge-welded together. During carburization, the iron strips were held at high temperature and allowed to absorb carbon from the charcoal fire for varying lengths of time to obtain grades of iron differing in carbon content and hardness. The piled structure was an attempt to combine the high strength of a high carbon steel with the ductility of one of lower carbon content. Presence of partially spheroidized pearlite in some of the strips suggests that the blade was heated for a prolonged time at about 600-700°C. Therefore the faggoted piece had been air-cooled from a forging temperature over 1000°C and reheated to about 700°C.

Heat Treatment of the Steel Bits

The steel bits comprise various structural areas resulting clearly from deliberate heat treatment. The size of these areas and the types of the gradually changing structures (upper bainite followed by sorbitic pearlite, pearlite, and sometimes pearlite and ferrite) are directly related to the decreasing rate of cooling with the increased distance from the cutting edge of the axe. This sequence of structures suggests that the steel bits must have been heated to not much higher than 800-900°C and then cooled very fast by partial immersion with the cutting edge facing the cooling medium. The heat treatment was carried out to harden the steel bits. Some of the medium carbon regions in the blades adjacent to the steel bits have a structure (ferrite and pearlite) that forms after air-cooling from temperatures above the critical range. This suggests that the steel bits had been treated before being forge-welded to the blades.

Formation of upper bainite and sorbitic pearlite in the heat-treated steel bits is quite unusual. Ordinarily, quenching of medium or high carbon steel would result in much harder martensite, rather than the upper bainite or sorbitic pearlite formed here. This may be accounted for only by a somewhat less than critical rate of cooling due to the use of a deficient cooling medium like warm water instead of ambient temperature water or oil.

Although upper bainite and sorbitic pearlite, being hard and tough, are generally desirable, a higher hardness of the cutting edge resulting from the presence of tempered martensite (about 550 HB) would be superior in the working part of a tool such as the cutting edge of an axe. Thus, the attempt to harden the steel bits by heat treatment was not completely successful. Some of the steel bits have not been subjected to heat treatment at all (the steel bit in axe 1H51G9-9 and probably one of the steel bits in axe 1H51F5-1). Though also made of high carbon steel, they have considerably lower hardness (about 200 HB) than the heat-treated steel bits (about 380 HB).

Method of Manufacture of the Axes

The terminology used in this section and throughout the report was developed by L.A. Ross (1977).

The blacksmith used wrought iron for the body of his axe, which was soft enough to absorb the shock of cutting: he used hardened steel for the axe edge to prevent its early wear. For the same reasons the manufacturer heat treated only the bit and not the whole axe. The probable procedure employed in manufacture of the axes involved folding a single strap of iron around a mandril, forge-welding the two ends, insetting a previously carburized and hardened steel bit, forging a broad blade, and finally grinding the cutting edge. This sequence varies from one axe to another. In one axe head (1H51E3-3) two separate iron straps were forged together, and in another (1H51F5-1) two steel bits were applied - one hardened and one not. The hardened steel bit (overlaid on one side) was possibly added later because the other bit was too soft. In still another axe (1H51D1-1) a single iron strap was folded, but additionally a steel slug was inserted to strengthen the blade, and an inset bit made of two pieces (one possibly repaired) was applied. This bit appears to have been carburized and quench-hardened after being forge-welded to the blade, although as in the other axes, it might have been hardened before the welding operation.

Supplementary to the general characteristics of the axes is a description of each axe.

1H51C2-1: A broken axe eye made of one piece of iron structurally resembling modern steel rather than wrought iron.

1H51D1-1: A broken axe head about 5 cm long, fractured across the sides, with a bit about 3.5 cm long, knife-edged with an edge extensively chipped. The folded strap axe head consists of a wrought-iron blade, a steel inset slug to strengthen the blade, and an overlaid bit on one side made of two pieces (one possibly repaired) of heat-treated steel.

1H51E3-3: A broken axe head about 12 cm long, fractured about 1 cm above the clef (at the eye) with a bit about 4 cm long, knife-edged with an edge extensively chipped, and a maker's mark on right blade located about 8 cm from the cutting edge. The double strap axe head consists of a faggoted (piled) iron blade made of six strips varying in carbon from about 0.1 to 0.8 per cent, and an inset bit made of heat-treated (high carbon) steel.

1H51F5-1: A broken axe head about 8 cm long, fractured across the sides, with two bits each about 3 cm long, knife-edged with an edge only slightly chipped, and a maker's mark on the left side of the blade centred about 4 cm from the cutting edge. The folded strap axe head consists of a wrought-iron blade, an inset bit made of steel not hardened by heat treatment, and an overlaid bit on one side made of heat-treated steel.

1H51G3-9: A broken axe head about 10 cm long, fractured across the sides at the eye, with a small bit about 1 cm long, knife-edged with an edge plastically deformed and dull (not ground). The folded strap axe head consists of a wrought-iron blade, and an inset bit made of steel not hardened by heat treatment.

The description, technology and method of manufacture of the examined axes is summarized in Table 5.

The composition of the irons provides

Table 5. Description, technology and method of manufacture of the axes from Fort St. Joseph.

	Description					Manufacturing technique			Technology	
		Axe-head wear		Edge-	Maker's					
Article	Type	blade	bit	sharpening	marks	Make	Parts	Material	Heat Treatment	Forging
Axe eye 1H51C2-1	Almond-shaped							"Mild" steel (low carbon iron)	Accidental carburization	Hot-working, made of 1 piece
Axe head 1H51D1-1	Single-bitted	Broken across sides	Extensively chipped	Knife-edged	None	Folded strap axe head	Blade (5 cm long) Inset slug Overlaid on one side bit (3.5 x 0.5 cm)	Wrought iron Steel (medium carbon) Steel (high carbon)	None None Carburization & quench-hardening	Hot-working, forge-welding of 3 pieces, repairing (?)
Axe head 1H51E3-3	Single-bitted	Broken 1 cm above clef	Extensively chipped	Knife-edged	On right blade, 8 cm from edge	Double strap axe head	Blade (12 cm long) Inset bit (4 x 0.3 cm)	Faggoted iron Steel (high carbon)	Reheating to near 700°C, accidental carburization Carburization & quench-hardening	Hot-working, faggoting (piling of 6 strips), forge-welding of 2 pieces
Axe head 1H51F5-1	Single-bitted	Broken across sides	Slightly chipped	Knife-edged	On left blade, centred 4 cm from edge	Folded strap axe head	Blade 18 cm long Inset bit (3 x 0.4 cm) Overlaid on one side bit (3 x 0.4 cm)	Wrought iron Steel (high carbon) Steel (high carbon)	Accidental carburization Carburization Carburization & quench-hardening	Hot-working, forge-welding of 3 pieces repairing (?)
Axe head 1H51G3-9	Single-bitted	Broken across sides, at eye	Plastically deformed	Knife-edged, dull (not ground)	None	Folded strap axe head	Blade (10 cm long) Inset bit (1 x 0.2 cm)	Wrought iron Steel (high carbon)	Accidental carburization Carburization	Hot-working, forge-welding of 2 pieces

information on ironmaking methods. The only intentional constituents of the analyzed metals were iron and carbon. All other elements entered accidentally from the ore and materials used in the subsequent metallurgical processes. The silicon and manganese contents were governed by the conditions of production favouring low silicon and manganese levels. The very low silicon and manganese contents indicate that the examined material is an old iron, rather than a more recent one. The irons, having uniformly low phosphorus content (less than 0.25%), were most likely made from low phosphorus metalliferous ores, as phosphorus from high phosphorus ores would have been transformed to the iron. The very low sulphur content suggests that charcoal, a low sulphur substance, was used as fuel. Charcoal irons rarely show more than 0.05 per cent sulphur. All these facts seem to indicate that the iron was produced by an indirect method using a charcoal-hearth refining process.

Fracture of the Axes

It was mentioned before that each of the axes was fractured across the sides at the upper part of the blade. The axes failed by cleavage with no evidence of plastic deformation, displaying a typical transgranular (through the grains) brittle fracture. To determine the reasons for the breaking of the axes, it is useful to have a general review of some of the more likely causes of brittle fracture.

Defects causing brittleness may arise before the forging operation (that is, associated with the material - its composition, structure, etc.) during heating to forging (due to overheating, etc.), during forging (due to poor forging technique), and after forging (due to faulty heat treatment, low temperature environment, etc.). The more serious defects may be associated with:

1. Structure
2. Internal defects like nonmetallic inclusions or cracks

   Internal cracks and large and irregular inclusions are stress concentrators, easily resulting in complete fracture of the forged part under impact force.
3. Composition

   Two elements in particular, phosphorus and sulphur, can be very harmful. The presence of high phosphorus content induces in iron cold-shortness or brittleness at ordinary temperatures. With 0.5 per cent phosphorus, iron cannot be worked in the cold state without cracking at the edges, although when hot such metal can be readily forged. During hot-working a banded structure may be formed as a result of phosphorus segregation. These bands are planes of weakness. Sulphur is an even more deleterious impurity than phosphorus, which if not matched by a suitable amount of manganese induces brittleness at high temperatures (hot-shortness) causing iron to crumble during hot-working. The iron also becomes unsuitable for cold-working, or, indeed, for subsequent service of any type.

4. Heat treatment, resulting, for example, in oxidation, decarburization, overheating, overcooling, etc.
5. Poor forging technique
   Faulty forging technique may cause the worked metal to crack internally. Internal cracks would be found, for example, when forging with too light a hammer, or continuing forging after the metal has cooled below a safe forging temperature. Wrought iron and steel are also rendered brittle in the cold state (blue brittleness) after working in the blue heat temperature range, 230-370°C.
6. Mechanical fibering
   When metal is deformed by forging, a preferred orientation called mechanical fibering can develop. This is caused by the alignment of nonmetallic inclusions and chemical segregation in the main direction of mechanical working (that is, the direction of metal flow) giving rise to flow lines. Mechanical orientation causes the mechanical properties to exhibit different properties in different directions (anisotropy). The pattern of flow lines permits interpretation of the directions of minimum ductility and toughness which are the directions at any point transverse to the flow lines.
7. Breaking of the fiber flow
   Broken fiber is directly associated with mechanical fibering and results in poor mechanical properties. In a desirable flow pattern the flow lines should be mainly parallel to free surfaces. An undesirable forging pattern with a broken fiber, that is, one containing numerous flow lines intersecting free surfaces, is caused by the metal flowing too rapidly at right angles to the direction of the fibers during forging.
8. Low temperature environment
   Iron and low carbon steel tend to fracture under impact load. This tendency is increased by a decrease in temperature. There is a temperature range (called transition temperature) in which iron and steel decrease sharply in toughness and ductility as the temperature is lowered. The transition temperature for low carbon steels is often about 0°C to -30°C or below and is affected by several metallurgical phenomena.

Consider these points in light of the actual results obtained by examination of the axes. The fracture of the axes is not related to faulty heat treatment (point 4) because the heat treatment was confined only to the steel bits and was carried out before the forging operation. The examination revealed several undesirable conditions weakening the material and contributing to the subsequent failure of the axes.

- Predominant presence of ferrite in the fracture area, and the relatively large size of the ferrite grains. Ferrite (having a body-centred cubic crystal structure) is particularly susceptible to brittle fracture which follows a transgranular path. Coarse grain size is also disadvantageous - it lowers toughness and raises the transition temperature.
- Presence of large and irregular slag inclusions and internal cracks in the regions of the blade adjacent to the fracture surface (point 2).
- Relatively high content of phosphorus (point 3), revealed by chemical analysis and metallographic examination in two blades (1H51D1-1 and 1H51G3-9). The content of the other harmful element - sulphur - was shown to be low, hence, it has no detrimental effect.
- Mechanical fibering (point 6) in the form of elongated slag inclusions and banded structure resulting from phosphorus segregation. This in itself should not be very harmful in an axe, where the flow lines are aligned in the direction of maximum stress and greatest strength, so that the greatest

stresses act along the fibers, rather than across them.

Breaking of the fiber flow (point 7). Macroetching disclosed an undesirable forging pattern containing numerous flow lines which intersect the free surfaces in some axes. This condition creates many potential crack initiation regions which under appropriate service conditions could result in fracture.

Some of the undesirable conditions (those beyond the blacksmith's control) were associated with the material of the axes. Others that occurred during forging suggest that the blacksmith was careless in his technique. The broken fiber flow associated with mechanical fibering appears to be especially relevant in this case, because of the impact-loading conditions characteristic for axes in service. Also, dangerously low temperatures, if encountered during service in conjunction with some form of impact loading, would cause the breaking of the axes.

In general, the failure of the axes may have resulted from the independent action of any of these conditions, but more likely the final failure resulted from the combined action, either simultaneous or sequential, of more than one factor. Most of the axes probably fractured during usage, indicated by the extent of wear of the cutting edges.

CONCLUSIONS

In general, the examined artifacts may be described as single-bitted, broken axe heads, 5-12 cm long, fractured across the sides (at the eye), with a bit about 4 cm long, knife-edged with an edge chipped, and a maker's mark located on the surface of two blades. Only one of the four axe heads (1H51G3-9) contained a smaller bit, 1 cm long, and a dull, plastically deformed cutting edge.

Each of the axe heads was made up of several pieces of metal joined by forge-welding. They were composed of two main parts, an iron blade and a steel bit. The various materials welded together included wrought iron to steel, steel to steel, and iron to heat-treated steel.

The structure of most of the axe blades, equiaxed ferrite, occasional pearlite, and slag stringers, is typical for wrought iron, and is associated with simple air-cooling from temperatures well above the critical point. The equiaxed ferrite grains and the slag inclusions elongated in the direction of prevalent plastic deformation show that the axes (blades) were hot-worked and forged at high temperatures. The generally large grain size in the wrought iron suggests that forging was probably finished close to 1200°C or higher.

The axe eye (1H51C2-1), being completely free of slag inclusions, represents a surprisingly pure material which resembles modern low carbon steel ("mild" steel) rather than wrought iron.

The blade with a piled structure (1H51E3-3) was, however, made of faggoted iron. This resulted from forging of heterogenous composite pieces of wrought iron which had been carburized to different carbon contents. After being air-cooled from forging temperature the blade was reheated (perhaps several times) to about 600-700°C.

The structure of only one of the steel bits (in axe 1H51G3-9) is typical for air-cooling from temperatures well above the critical point, without any further treatment. This structure, consisting of pearlite and grain boundary envelopes of ferrite, shows the material to be a high carbon steel with about 0.6-0.7 per cent C.

The steel bits of three axes (1H51D1-1, 1H51E3-3 and 1H51F5-1) comprise a sequence of structures, that is, upper or feathery bainite followed by sorbitic pearlite, lamellar pearlite, and occasionally pearlite and ferrite, gradually changing with increased distance from the cutting edge. This type of structure clearly indicates a deliberate attempt at heat treating the steel bits to increase their hardness.

The carburized and quench-hardened steel bits must have been heated to about 800-900°C and then fast-cooled by partial immersion with the cutting edge facing the cooling medium. However, the attempt at hardening the steel bits was not completely successful. Formation of feathery bainite and sorbitic pearlite suggests that a deficient cooling medium, like warm water, was used for quenching the high carbon steel bits. Although their hardness increased considerably due to this heat treatment, a higher hardness of the cutting edge, one resulting from very rapid cooling (quenching in cold water or oil) and the formation of martensite, would have been superior. A striking example of slack quenching appears to be the inset steel bit in axe 1H51F5-1 which had not been hardened by heat treatment at all and has the same hardness as the non-heat-treated steel bit in axe 1H51G3-9.

The procedure used in the manufacture of the axes involved folding a single wrought-iron strap around a mandril, forge-welding the two ends, insetting a previously carburized and hardened steel bit, forging a broad blade, and finally grinding the cutting edge.

This sequence of manufacture varied somewhat from one axe to another. In one axe (1H51E3-3) two separate iron straps were forged together; in another (1H51F5-1) two steel bits were applied, one of them possibly added later because the other bit was too soft; in still another axe (1H51D1-1) a steel slug was inserted to strengthen the blade, and the steel bit also bears signs of repair.

Thus, the folded strap axe head consists typically of a wrought-iron blade and an applied inset bit made of high carbon steel hardened by heat treatment. The exceptions include the double strap axe head (1H51E3-3) having a faggoted iron blade made of six strips varying in carbon content, and the folded strap axe head (1H51G3-9) with a small non-heat-treated steel bit.

Chemical analysis showed that very pure high quality materials were used for making the axes. Besides slag inclusions, they contain hardly any impurities and their composition compares well with that of Swedish iron, and with modern wrought iron and steel.

The irons were made from low phosphorus ores, probably by an indirect method using a charcoal-hearth refining process.

The examination of the axes revealed several undesirable conditions weakening the material and contributing to the subsequent brittle fracture of the axes by transgranular cleavage. These are material structure (that is, coarse grain ferrite susceptible to brittle fracture at low temperature), large and irregular slag inclusions and internal cracks in the region of the blade adjacent to the fracture surface, rather high phosphorus content in some blades, and broken fiber flow associated with mechanical fibering.

Considering during service an impact load is applied to the axes, their failure may have resulted from the independent action of any of those conditions. But most likely the final failure was caused by the combined action either simultaneously or sequential of more than one factor and might have been associated as well with low temperature environment. The axes probably fractured in use (possibly during the winter), as the extent of the cutting edges' wear seems to indicate.

The fact that many of the undesirable conditions leading to the fracture of the axes had arisen during forging suggests that the blacksmith was not very careful while forging. This combined with slack quenching of the steel bits indicates that the maker of the axes had not mastered the technique of axe manufacture, which involved considerable technological sophistication. A well-made axe was a work of a competent blacksmith; all his skill and pride were required to make a high quality tool.

The broken axes may have been brought to the local smithy for repair, but may not have been manufactured there.

GLOSSARY

ALLOY. A metallic material composed of two or more chemical elements

AUSTENTITE. A non-magnetic form of iron normally existing only at high temperatures (above 723°C)

BANDED STRUCTURE (BANDING). A phosphorus segregated structure of nearly parallel bands that run in the direction of working

BIT. The cutting part of an axe head that ends with the edge

BLADE. The broad (flattened) cutting part of an axe head

BLAST FURNACE. The furnace in which smelting of iron ore to pig iron is carried out

CARBURIZING. Introducing carbon to the surface layer of wrought iron or mild steel by heating the metal below its melting point in contact with a suitable carbonaceous material

CEMENTITE. A very hard and brittle compound of iron and carbon, Fe_3C. It forms one of the constituents of pearlite, and also appears as a separate constituent in the grain boundaries of wrought iron containing about 0.02 per cent carbon.

CHARCOAL. Wood that has been distilled leaving only carbon, formerly used as fuel in ironmaking

COLD-BLAST. Air under pressure which has not been reheated, supplied to a blast furnace

COLD-SHORT. A condition of brittleness at temperatures below the recrystallization temperature of a metal

CONSTITUENT. A phase, or combination of phases that occur in a characteristic configuration in an alloy microstructure

COOLING RATE. The average slope of the time-temperature curve taken over a specified time and temperature interval

CRITICAL TEMPERATURE (CRITICAL POINT). The temperature at which some changes occur in a metal or alloy during heating or cooling

CRYSTAL. A homogeneous solid of regular geometrical structure peculiar to the element and in which the atoms are spaced in characteristic pattern

DENDRITES. Crystals formed during solidification, which are characterized by a tree-like pattern composed of many branches

DUCTILITY. The amount of plastic deformation that a material can withstand before fracture

EQUIAXED. Applied to crystals whose dimensions are approximately the same in all directions

ETCHING. Developing the structure by preferential attack of reagents on a polished metal surface

FAGGOTING (PILING). An old technique of iron manufacture in which several sheets of iron carburized to different carbon contents had been piled one upon another and then forge-welded together at high temperature

FAYALITE. A mineralogical constituent, iron silicate $2FeO \cdot SiO_2$, found in some slags

FERRITE. A soft constituent occurring in iron or steel (nearly pure iron with less than 0.025% carbon)

FLOW LINES. The texture revealed by etching a surface or section showing the manner in which the metal flowed during deformation

FORGE. 1. Smithy; 2. the building and machinery for making wrought iron

FORGE-WELDING. The oldest method of welding, by heating two pieces of iron to welding heat and forging them together with a hand-held or power hammer

GRAIN BOUNDARY. An interface separating two grains, where the orientation of the lattice changes from that of one grain to that of the other

GRAINS. Crystals in metals or alloys

HARDNESS. Resistance of the material to deformation, usually measured by indentation

HEAT TREATMENT. Heating, holding and cooling a solid metal or alloy in such a way as to obtain desired conditions or properties

HOT-SHORT. A condition of brittleness at temperature above the recrystallization temperature of metal

HOT-WORKING. Any form of mechanical deformation processing carried out on a metal above its recrystallization temperature

INDIRECT PROCESS. A two-stage process of iron manufacture, where pig iron is first made from the ore by smelting, and then purified by refining to wrought iron

INSET BIT. An applied bit inserted in the notch of the blade

LONGITUDINAL DIRECTION. The direction that is parallel to the direction of maximum elongation in a worked material

MACROETCHING. Subjecting the metal to the action of a reagent to bring out the structure for visual inspection

MACROSCOPIC EXAMINATION. Examination of a suitable prepared specimen either with the naked eye or under low magnification (up to ten diameters)

MACROSTRUCTURE. Structure of metals as revealed on a suitable prepared specimen by the naked eye or under low magnification (up to ten diameters)

MARTENSITE. A very hard constituent with an acicular (needle-like) appearance, produced by quenching iron containing carbon from temperatures above 720°C

MATRIX. The principal, continuous constituent in microstructure in which other constituents or phases are embedded or enclosed

MECHANICAL FIBERING. Elongation and alignment of non-metallic inclusions, voids, chemical segregation and second-phase constituents in the main direction of metal flow during mechanical working (forging)

METALLOGRAPHY. The branch of metallurgy dealing with the study of the structure and constitution of solid metals and alloys, and the relation of this to properties on the one hand, and technology, heat treatment and manufacture on the other

MICROCONSTITUENT. *See* Phase and Constituent

MICROGRAPH. A photographic reproduction of a material structure as seen through the microscope at magnification greater than ten diameters

MICROHARDNESS. The hardness of a microconstituent of a material

MICROSCOPIC EXAMINATION. Examination of a suitably prepared specimen under microscope at magnifications greater than ten diameters

MICROSTRUCTURE. The structure of a suitably prepared specimen as revealed by the microscope at magnifications greater than ten diameters

MILD STEEL. Modern equivalent of wrought iron but without the slag which gives the latter its fibrous structure

NETWORK STRUCTURE. A structure in which one constituent occurs primarily at the grain boundaries

NONMETALLIC INCLUSIONS. Particles of impurities (usually silicates, sulfides, oxides, etc.) which are held mechanically, formed during solidification or by subsequent reaction within solid metal

ORE. A natural mineral deposit from which a useful, valuable metal can be extracted profitably

OVERLAID BIT. An applied bit laid over one or both sides of the blade

PEARLITE. A constituent occurring in iron or steel consisting of alternate laminations of ferrite and cementite

PHASE. A constituent that is completely homogeneous both physically and chemically, separated from the rest of the alloy by definite boundary surface

PLASTIC DEFORMATION. Permanent distortion of a material under the action of applied stress

QUENCH-HARDENING (QUENCHING). A heat-treating process involving rapid cooling of steel from elevated temperatures by immersion in cold liquid such as water, brine or oil, carried out to harden the material

RECRYSTALLIZATION. The formation of new, strain-free crystals or grains from deformed metal accomplished by suitable heating

RECRYSTALLIZATION TEMPERATURE. The approximate minimum temperature at which complete recrystallization of cold-worked metal occurs within a specified time. It is about 500-700°C for iron and steel.

REFINING. The process of removing impurities from metal (for example, converting pig iron into wrought iron) by means of slags or by remelting in a special furnace

SEAM. A welding joint in which the edge of one piece is turned or folded over the edge of another

SEGREGATION. Non-uniform distribution of impurities, inclusions and alloying elements in metals

SLAG. The waste material formed during smelting of iron or making of wrought iron or steel (resulting from the action of flux on the oxidized non-metallic constituents of molten metal)

SLUG. A strip of metal inserted between the folded straps to reinforce the blade

SMELTING. A metallurgical operation in which the metal sought is separated in a state of fusion from the ore that contains the mineral chemically combined or physically mixed with gangue and impurities

SMITHY. The workshop and its equipment in which forgings are made

SORBITIC PEARLITE. Extremely fine, almost structureless pearlite (unresolved under optical microscope), formed at moderately rapid rate of cooling in the temperature range about 600-550°C

SPHEROIDIZED PEARLITE. A soft aggregate of cementite particles of essentially globular shape in ferrite matrix, found when iron or steel containing lamellar pearlite is heated for a long time at or near the critical temperature (about 700°C)

STEEL. An alloy of iron and carbon containing up to 1.7 per cent carbon and minor amounts of other elements such as manganese, silicon, phosphorus and sulphur

STRINGER. A microstructural configuration of foreign non-metallic material lined up in the direction of working of iron or steel

STRUCTURE. The size, shape, and arrangement of phases or microconstituents

TEMPERED MARTENSITE. The decomposition products resulting from heating martensite below the critical temperature (about 700°C), having the best combination of hardness, ductility and toughness

TEMPERING. Reheating hardened steel to a temperature below the critical temperature, followed by any desired rate of cooling, to decrease the hardness

TOUGHNESS. Ability of a material to absorb energy (impact load) without failure

TRANSFORMATION TEMPERATURE. *See* Critical Temperature

TRANSGRANULAR FRACTURE. A type of failure in which the line of fracture passes through the grains, and not around the grain boundaries as in intergranular fracture

TRANSITION TEMPERATURE. An arbitrarily defined temperature in a range in which ductility or toughness changes rapidly with temperature

UPPER (FEATHERY) BAINITE. A structural constituent of feathery appearance, formed in steel at rapid rate of cooling at temperatures somewhat lower than those where sorbitic pearlite forms, that is, about 550-500°C

WIDMANSTAETTEN STRUCTURE. A structure characterized by a geometrical pattern resulting from the formation of a new phase along certain crystallographic planes of the matrix

WROUGHT IRON. The first commercially available form of pure iron consisting of slag (iron silicate) stringers embedded in ferrite matrix

WUSTITE. A structural constituent of slag; the lowest oxide of iron with more oxygen than required to form ferrous oxide (FeO)

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Ironworking at an Early Nineteenth Century Blacksmith Shop, Fort St. Joseph, Ontario: An Examination of Slag and Iron

Henry Unglik

ABSTRACT

A large amount of slag and 16 iron fragments from an early nineteenth century blacksmith shop at Fort St. Joseph, Ontario, are examined metallographically. The study characterizes the material, ascertains its technology and identifies the ironworking processes carried out in the smithy. The structure and composition of the slag and ferrous material are discussed in detail. Additionally, melting temperature and constitution of slag are determined, and the implications of the presence of pieces of metal in the slag lumps are considered. The examination revealed that the blacksmith was engaged in ironworking operations such as hot-working, forge-welding, brazing, some cold-working and a quenching-type heat treatment of steel. It is also possible that the blacksmith was attempting to convert pig iron into wrought iron. The blacksmith worked with various materials including malleable and cold-short wrought iron, high and medium carbon steel, and white cast iron. There are indications that the blacksmith was rather careless in his job.

Submitted for publication 1980, by Henry Unglik, National Historic Parks and Sites, Conservation Division, Parks Canada, Ottawa.

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FOREWORD

The excavation in 1978 of a fur trade blacksmith shop at Fort St. Joseph yielded almost 50 kg of slag. This large quantity of waste material from the forge provided the opportunity to produce a clear picture of the general activities undertaken by the smith through a metallurgical examination. This descriptive analysis of the workings of an early nineteenth century fur trade blacksmith in the old northwest is the result of that examination.

The additional slag described here came from the 1964 excavations at the fort. It may be from a disturbed context, possibly having been deposited in the location in which it was found by the bulldozer that "landscaped" the fort area in 1948, so we do not know its provenance. The pieces were not recognized as slag in 1964 and were placed in dead storage under the names "cinder" and "cooked earth." They were included with the original material as soon as they were rediscovered, to demonstrate metallurgically as well as physically that there was another blacksmith shop on the point. Unfortunately, the samples proved to be too similar to those from the blacksmith shop to make a definitive statement to this effect. We know, however, from documentary sources that there was at least one other smithy, and there could well have been more. The Indian Department employed a full-time smith at the fort and the military had a blacksmith as well, at least during the construction period. Where these men worked is unknown.

This study is, so far as we know, unique. As such it provides, together with its companion study on axes (this volume), a firm beginning to what may eventually prove to be a complete picture of the state of the blacksmithing art in the period. Because blacksmithing was one of the most important, if not the most important trade at the time, such knowledge would be invaluable. This type of information is impossible to gain through documentary research alone, and should it come about that others follow the lead given by this work and a technical picture of blacksmithing on the frontier begins to emerge, it will demonstrate once again the interlocking nature of historical and archaeological research.

John D. Light

INTRODUCTION

A large amount of slag material associated with ironworking was collected at the early nineteenth century archaeological site of Fort St. Joseph in Ontario and submitted for metallurgical examination.

About 50 kg of slag was found in two different areas of the fort (Light 1987: Table 1, this volume). One group of slag (provenance 1H51) is from the blacksmith shop, while the other group (provenances 1H37 and 1H43) is from an area approximately 150 m from the blacksmith shop, close to the palisade of the fort. The latter slag is generally a surface material from a disturbed context. The slag from the shop, however, was in piles which also contained iron scrap and some copper alloy. The distribution of the piles and the layout of the excavated shop was determined by John Light (1987: Fig. 2, this volume).

The forge, built of limestone, had a side tuyere. Analysis of the one remaining piece of tuyere (Light 1987: Fig. 1, this volume) showed it to have been made of ferrous metal. The bottom was formed of earth on top of which the blacksmith laid a bed of sand. Charcoal was used as fuel in the forge. There are also indications that brazing was extensively carried out with kettles and brass or copper pots as the source of filler metal. Besides the excavated shop, there was at Fort St. Joseph apparently at least one other shop (possibly a military one) that also used charcoal as fuel.

The objective of this investigation is to determine: 1) How can the slag material be characterized, and, in particular, what differentiates the dark, heavy slag from the light, porous one? 2) What are the proportions of wrought iron and steel worked by the blacksmith in the shop? 3) Was the blacksmith engaged in any activity other than forging (for example, smelting, refining or casting)? 4) Was the forge associated with working some materials other than iron (for example, copper alloys)? 5) Was the slag from the palisade of the fort produced in the excavated blacksmith shop or in a different shop, for example a military one?

These basic aims were attained by means of visual observations, sectioning of the lumps, chemical analysis, hardness testing, microscopic examination and microhardness measurements of the slag material and the iron fragments.

METHODS AND RESULTS

Preliminary Examination

From about 150 lumps of slag (Table 1) about 90 samples were selected for preliminary examination. The examination included visual observation, testing for ferromagnetism, specific gravity, sectioning of the lumps, energy dispersive X-ray fluorescence (EDX) and microscopy.

Most of the slags from the blacksmith shop (1H51) are convex-concave, cake-shaped lumps, varying from light or dark grey to brown, often with a tinge of green (Figs 1 and 2). On the concave or top side the surface is smooth and glassy with clear indications of viscous flow, and on the convex or bottom side the surface is rough. The bottom side may have acquired its shape from the bowl-shaped forge bottom. The lumps are generally about 9 x 11 x 3 cm. Three groups of slag, K5-8, L3-5 and L5-2, are somewhat smaller and an irregular rather than cake shape. In a few lumps, clearly defined sharp ridges caused by charcoal imprints were observed (Fig. 3). In a few others, pieces of charcoal, remnants of the fuel originally used in the ironworking, are embedded in the matrix (Fig. 4). Besides charcoal, lime was also found adhering to many slag pieces. In addition, three of the lumps were magnetic.

Table 1. Designation of slag.

Provenance	No. of samples	Code nos
	Shop Slag	
1H51A4-6	8	1-8
1H51B2-11	1	9
1H51E4+	16	1M-16M
1H51F1	1	10
1H51G1-6	1	11
1H51G2-6	2	12-13
1H51G3-13	3	14-16
1H51H2-6	1	17
1H51I2-2*	9	18-26
1H51J5-2	1	27
1H51K4-4*	5	28-32
1H51K5-8	6	33-38
1H51L3-5*	6	39-43
1H51L5-2	6	44-49
	Palisade Slag	
1H37E5	8	50-57
1H43B3	74	58-87

+ Iron fragments accompany these slags.
* Lime adheres to some of these samples.

The lumps of slag from the palisade (1H43) varied also from light or dark grey to brown, often with a tinge of green, and had a rather rough surface and often a glassy appearance. The majority of them, 7 x 6 x 2 cm or smaller, are characterized by a rather compact shape. Six larger lumps, about 11 x 9 x 3 cm with a flat or flat-convex shape, were also found. Among the lumps of slag were many pieces with clear imprints of burned or charred wood in an irregular checkered pattern of ridges. These most probably were formed when the hot slag came in contact with the wood surface. Several lumps, the ones with a brown surface rich in embedded charcoal pieces, are magnetic. The eight lumps from 1H37 resemble the other slags and vary from about 2 x 2 x 1 cm to 8 x 6 x 2 cm. Except for three pieces that showed considerable ferromagnetism, these slags were nonmagnetic.

Sectioning showed that about one-fourth of the lumps contain pieces of metallic iron ranging from small to massive (Fig. 5), the latter clearly parts of iron objects left in the forge by the blacksmith. In a few cases the lumps were pieces of corroded iron or a mixture of iron and slag. A red hue, like that of copper, was observed on the surface of a few of the lumps, which, after sectioning, was shown to extend to some depth.

Preliminary microscopic observation revealed that the examined samples fall into two basic groupings. One, comprising nearly half of the samples, represents "true" slag having a homogenous structure and typical slag microconstituents. The other can be described generally as contaminated slag, consisting of slagged furnace lining and cinders with an inhomogenous structure lacking definite recognizable microconstituents. In general, the slag lumps are dark, heavy and

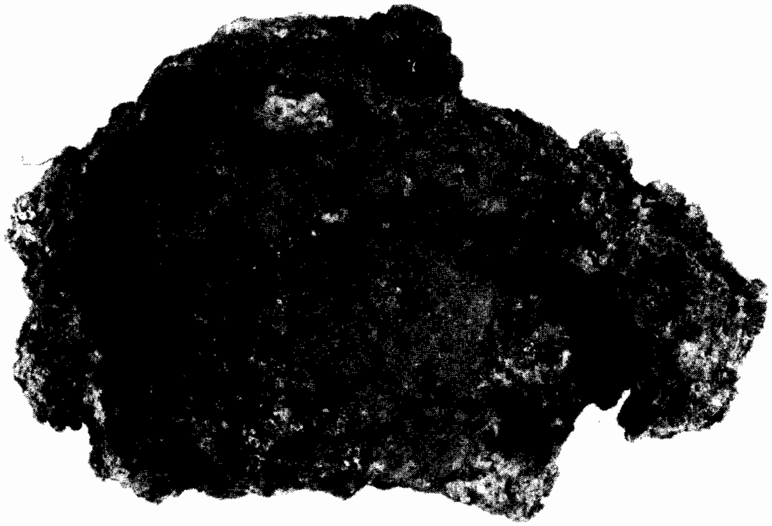

Figure 1. Cake-shaped lump of slag (no. 9). (Scale: 0.7; (photo by author)

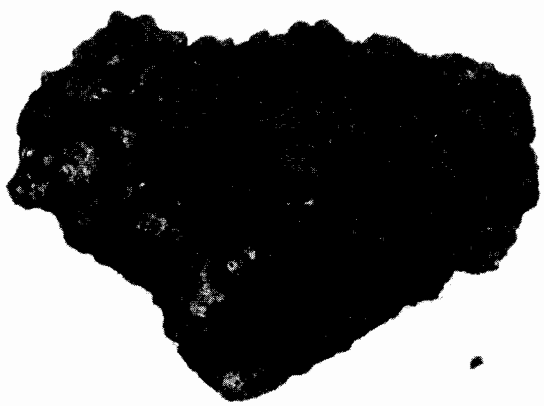

Figure 2. Lump of slag (no. 33) with rippled appearance due to viscous flow. (Scale: 0.7; photo by author)

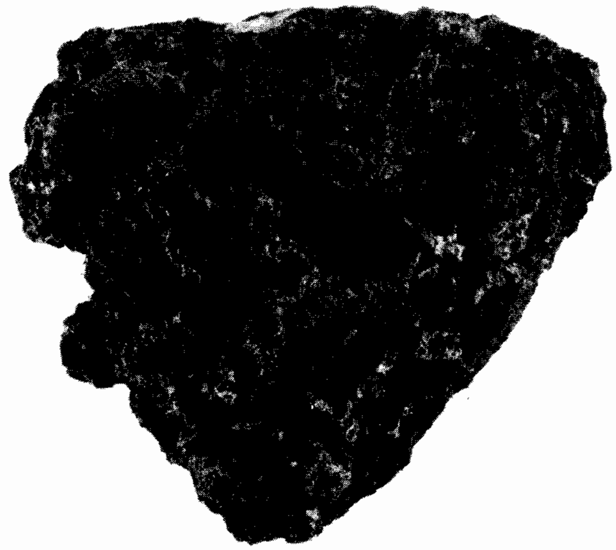

Figure 3. Lump of slag (no. 60) with imprints of charred wood. (Scale: 0.6; photo by author)

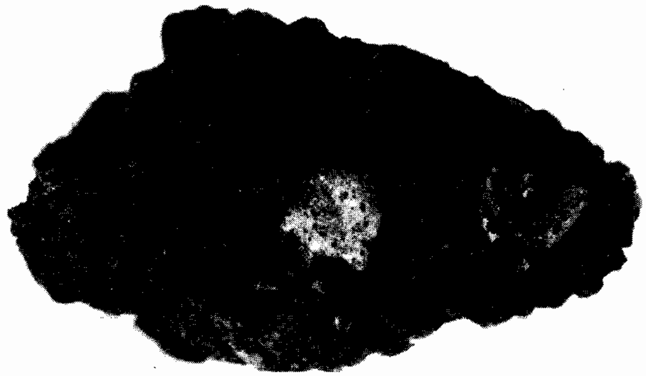

Figure 4. Lump of slag (no. 47) containing entrapped charcoal. (Scale: 1.0; photo by author)

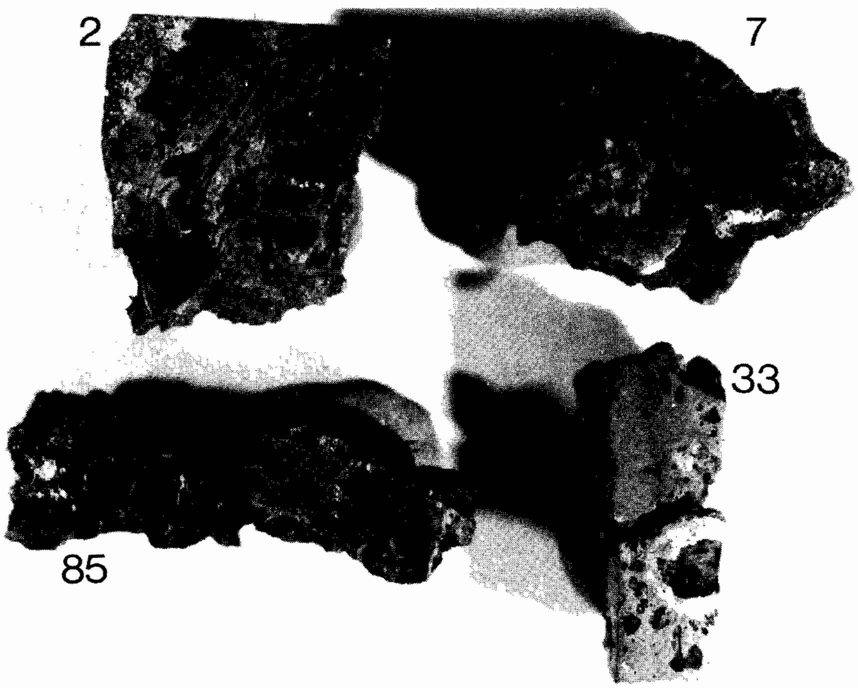

Figure 5. Sectioned lumps of slag, nos 2, 7, 85 and 33, containing pieces of metal. (Scale: 1.5; photo by author)

dense, while the contaminated slag pieces are light in colour and weight, and are porous. Most of the polished slag sections observed with the naked eye or at low magnification appear black or dark green with a tinge of blue (Fig. 6). They have a solid glassy texture with small pores. The polished sections of the contaminated slag samples, however, generally have a mottled appearance of black regions intermixed with whitish-grey regions and numerous large pores, giving it a stony pumice-like texture.

More information concerning the slag and contaminated slag samples was obtained by the specific gravity test and the EDX analysis of approximate iron content, results of which are given in Table 2. Table 2 shows that the selected slag samples from both the shop and the palisade have a high iron content (25-50%) and a relatively high specific gravity (2.5-3.6), whereas for the contaminated slag the iron content (8-25%) and the specific gravity (2.0-2.7) are much lower. The EDX surface analyses showed, besides iron, trace amounts of copper and zinc in some samples. Overall, the preliminary examination of the slag material has shown that the samples found at the blacksmith shop and the ones from the palisade are similar. The latter are generally smaller, weigh less and have on the average a somewhat higher iron content.

In addition to the slags, four metallic artifacts probably connected with the brazing operation were analyzed by EDX analysis.

Table 2. Specific gravity and iron content of slag material.

Area	Material	No. of samples	Approx. iron content (%) (EDX)		Spec. grav.		Wt (g)		Approx. size (cm)
			Range	Mean	Range	Mean	Range	Mean	
Blacksmith shop	Slag	17	26-41	34	2.5-3.5	3.1	50-500	220	11x9x3
	Contam. slag	29	8-25	15	2.2-2.7	2.5			
Palisade	Slag	13	32-49	40	2.5-3.6	3.0	10-350	120	8x6x2 & smaller
	Contam. slag	20	8-24	14	2.0-2.4	2.2			

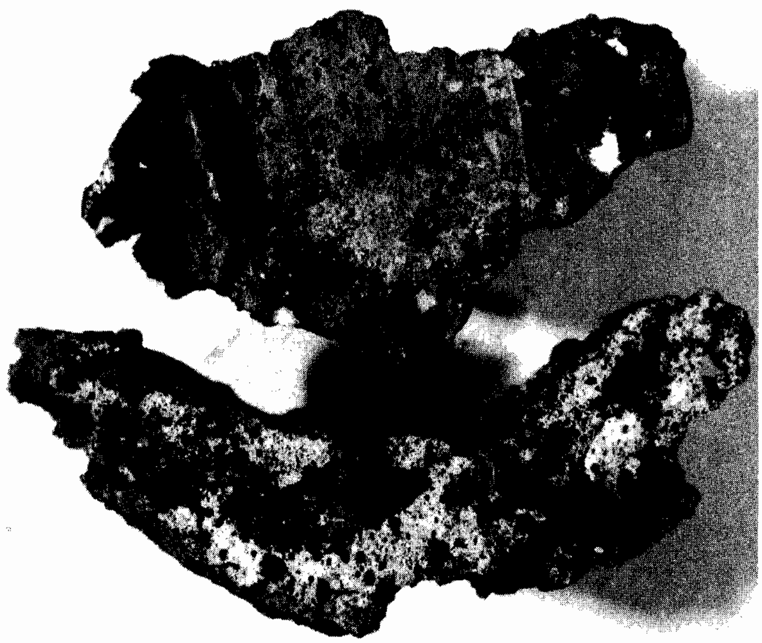

Figure 6. Sectioned lumps of slag (*top*, no. 33) with uniform dark appearance, and contaminated slag (*bottom*, no. 24) with mottled appearance. (Scale: 1.0; photo by author)

Three of them, iron objects 1H51D2-7, 1H51C2-18 and 1H51K5-20, had a copper-like metal on parts of the surface. The EDX analyses showed the remains of metal on the surface of the file 1H51D2-7 to be bronze containing about 5 per cent tin and 5 per cent lead, while the artifacts 1H51C2-18 and 1H51K5-20 were covered with brass containing about 20 per cent zinc. The fourth, a copper alloy object, was made of brass containing about 6 per cent zinc and 2 per cent lead.

Chemical Analysis

Chemical analysis of 23 samples of slag material selected on the basis of preliminary examination was done by Dr. C. Pride, Department of Geology, The University of Ottawa. The results obtained by wavelength dispersive X-ray fluorescence analysis are given in Table 3, and the average composition is summarized in Table 4. On the average, the slag samples have a high iron oxide content (about 46%) and a high silica content (about 38%). The phosphorous pentoxide content is low (about 0.4%) and the manganese oxide content very low (about 0.06%). The slags are also low in other oxides like alumina (about 3%), lime (about 7%), magnesia (about 2%) and titania (about 0.1%). The low sulphur content of the slags does not exceed 0.05 per cent. The contaminated slag samples contain considerably less iron oxide (about 19%) and more silica (about 60%) than the slag samples. Otherwise, their composition is similar. Full chemical analysis

Table 3. Chemical analysis of slag (%).

	Blacksmith Shop								
	1H51								
Code No.	2	5	7	8	22*	28	29	33	47*
Fe total	41.5	44.7	33.0	33.5	8.6	22.2	45.8	24.7	21.5
FeO**	53.4	57.5	42.5	43.1	11.1	28.6	58.9	31.8	27.7
SiO_2	38.2	31.6	34.9	44.3	73.0	58.1	30.9	47.9	47.6
CaO	2.9	3.2	12.3	4.1	4.0	4.8	3.7	7.0	8.3
Al_2O_3	2.1	2.3	2.1	2.5	4.7	3.1	1.8	3.7	4.1
MnO	0.02	0.1	0.3	0.06	0.06	0.02	0.02	0.1	0.08
MgO	0.7	0.8	2.1	0.8	1.1	1.0	0.7	2.0	2.5
P_2O_5	0.4	0.3	0.7	0.5	0.2	0.4	0.4	0.3	0.7
S	0.02	0.00	0.02	0.02	0.02	0.02	0.02	0.00	0.02
TiO_2	0.09	0.1	0.09	0.1	0.2	0.1	0.07	0.07	0.2
Na_2O	0.5	0.5	0.4	0.7	1.1	0.7	0.5	0.6	0.7
K_2O	1.4	2.0	3.2	1.9	3.4	2.8	1.7	5.1	6.4
Cu	0.002	0.035	0.04	0.27	0.005	0.04	0.008	0.008	0.03
Total	99.7	98.4	98.7	98.2	93.9	99.7	98.7	98.6	98.3

	Palisade													
	1H37		1H43											
Code No.	50	51	60	61	62	63	64*	67	69*	71	73*	84	85	86*
Fe total	29.6	49.4	34.9	24.7	36.8	28.3	6.5	23.3	12.2	26.4	12.5	55.1	52.1	27.9
FeO**	38.1	63.6	44.9	31.8	47.3	36.4	8.4	30.0	15.7	34.0	16.1	70.9	67.0	35.9
SiO_2	37.1	28.8	37.7	46.7	34.7	42.8	73.6	48.3	59.7	39.6	61.9	13.3	23.8	44.4
CaO	11.4	3.4	6.0	10.6	7.3	9.0	3.5	7.7	7.9	9.8	7.5	2.7	3.7	7.2
Al_2O_3	3.7	1.4	2.9	3.8	2.7	3.5	6.7	6.6	6.5	3.9	5.6	1.1	2.4	4.3
MnO	0.06	0.08	0.04	0.06	0.02	0.02	0.02	0.06	0.06	0.06	0.06	0.06	0.02	0.06
MgO	3.9	0.8	1.4	2.0	2.5	2.5	1.6	3.1	2.9	2.8	2.7	0.9	1.9	2.3
P_2O_5	0.5	0.7	0.3	0.4	0.2	0.3	0.1	0.2	0.3	0.5	0.5	0.3	0.1	0.3
S	0.04	0.00	0.00	0.02	0.02	0.02	0.02	0.00	0.00	0.04	0.00	0.00	0.00	0.00
TiO_2	0.2	0.07	0.1	0.2	0.1	0.2	0.3	0.3	0.3	0.2	0.2	0.07	0.1	0.2
Na_2O	0.7	0.4	0.5	0.7	0.6	0.7	1.2	0.9	1.0	0.5	1.1	0.2	0.5	0.8
K_2O	3.4	1.2	3.1	3.6	2.7	3.2	3.1	3.8	4.0	4.7	4.3	0.8	1.0	3.5
Cu	0.02	0.01	0.05	0.04	0.03	0.02	0.02	0.02	0.009	0.009	0.02	0.04	0.007	0.07
Total	99.1	100.5	97.0	99.9	98.2	98.7	98.6	101.0	98.4	96.1	100.0	90.4	100.5	99.0

*contaminated slag

**all iron reported as FeO

Table 4. Average composition of slag (%).

	Slag							
	Shop slag		Palisade slag		Total slag		Contam. slag	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean
Fe total	22-46	35	23-55	36	22-55	36	7-28	15
FeO	29-60	45	30-71	46.5	29-71	46	8-36	19
SiO_2	31-58	41	13-48	35	13-58	38	44-74	60
CaO	3-12	5.5	3-11	7	3-12	6.5	4-8	6
Al_2O_3	2-4	2.5	1-7	3	1-7	3	4-7	5
MnO	0.02-0.3	0.1	0.02-0.08	0.05	0.02-0.08	0.06	0.02-0.08	0.06
MgO	0.7-2	1.0	0.8-4	2	0.7-4	2	1-3	2
P_2O_5	0.3-0.7	0.4	0.1-0.7	0.4	0.1-0.7	0.4	0.1-0.7	0.4
S	0.00-0.02	0.01	0.00-0.04	0.01	0.00-0.04	0.01	0.00-0.2	0.01
TiO_2	0.07-0.1	0.09	0.07-0.2	0.15	0.07-0.2	0.1	0.2-0.3	0.2
Alkali*	2-6	3	1-5	3	1-6	3	4-7	5
Cu	0.002-0.04	0.02	0.007-0.04	0.02	0.002-0.04	0.02	0.005-0.07	0.03

*Alkali is the sum of Na_2O and K_2O.

Table 5. Chemical analysis of ferrous metal.

Material	Code no.	Composition (%)				
		$C_{tot.}$	$C_{graph.}$	Si	Mn	S
Cast-iron piece in lump of slag	28	1.85	0.91	1.94	0.010	0.050
Piece of refined iron	87	2.18	0.12	0.08	<0.01	0.07
Iron fragment	4M	0.04	-	0.023	0.005	<0.005

confirms the preliminary findings of little difference between the slags from the blacksmith shop and the palisade.

Chemical analysis of three ferrous metal samples was carried out under contract by Bondar-Clegg and Company Ltd., Ottawa, and the results are shown in Table 5. The composition of the cast-iron sample (no. 28), with the exception of its very low manganese content, corresponds to the typical composition of modern pig iron. The composition of the iron fragment (no. 4M), however, is typical for old wrought iron, and lump no. 87 is apparently a piece of refined iron.

Microscopic Examination

Structure of Slag Material

All samples for microscopy were cut with a thin diamond blade and cold-mounted in epoxide resin. After sectioning and mounting, the specimens were ground on a series of abrasive papers (320, 400 and 600 grit) using running water as a lubricant and coolant. Polishing was carried out on nylon cloth with 6-µm diamond paste, followed by medium-high nap velvet with 1-µm diamond paste. The structure of polished and nital-etched specimens was studied by reflected-light microscopy at magnifications of 50, 100 and 500 diameters. Microhardness was measured with a Vickers type tester with a diamond pyramid indenter and under a 100-g load (Hardness Vickers, HV). The hardness measurements of the metallic samples were taken on polished cross-sections using the Rockwell Superficial method. The Rockwell 30T (1/16-in. diameter ball under 30-kg load) measurements obtained were converted to standard Brinell HB 10/3000 as approximate equivalent hardness (Hardness Brinell, HB).

The structure of the slags consists basically of fayalite (iron silicate, $2FeO \cdot SiO_2$) and a glass matrix approximating the composition of anorthite ($CaO \cdot Al_2O_3 \cdot 2SiO_2$). The predominant phase of fayalite usually occurs as large light-grey columns, and anorthite is the dark grey matrix (Figs 7 and 9). Occasionally, the primary fayalite appears as large, often well-formed, rectilinear crystals rather than columnar crystals (Fig. 8). In some samples, small columns of secondary fayalite accompany the primary fayalite (Figs 8 and 9). Frequently a primary phase of wustite (iron oxide, FeO) occurs in the slag. Wustite appears white under reflected light and forms rounded globular dendrites mainly associated with the anorthite phase (Figs 11 and 12). The hardness of the various phases differs by a significant though small amount. The wustite dendrites (536 HV_{100}) are considerably softer than the fayalite (673 HV_{100}) or anorthite (606 HV_{100}). Fayalite, being harder than anorthite, has a tendency to crack, mainly from the corners (Fig. 12). The slags demonstrate variable

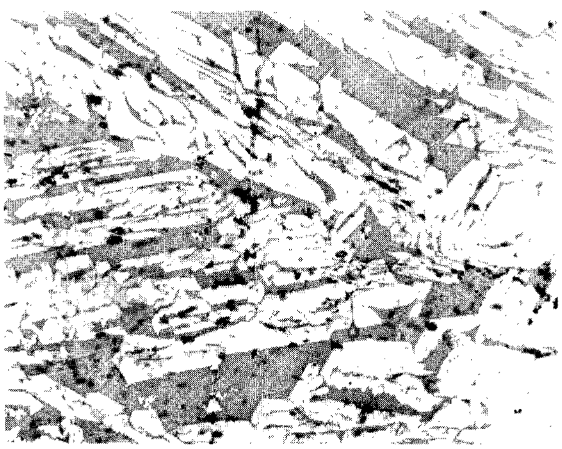

Figure 7. Structure of slag (no. 8): fayalite columns (light grey) in anorthite matrix (dark grey). As polished (not etched). (x100)

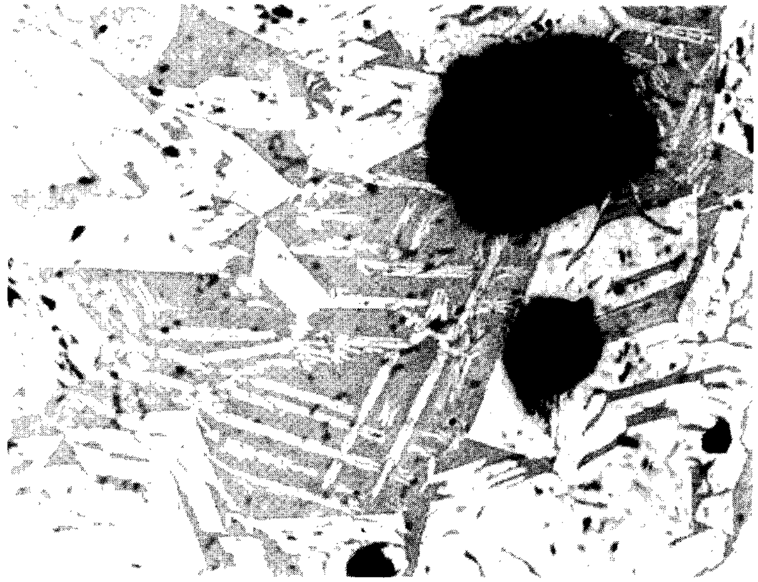

Figure 8. Structure of slag (no. 28): rectilinear crystals of fayalite (light grey), small columns of secondary fayalite (light grey), anorthite matrix (dark grey); pores (black). As polished (not etched). (x100)

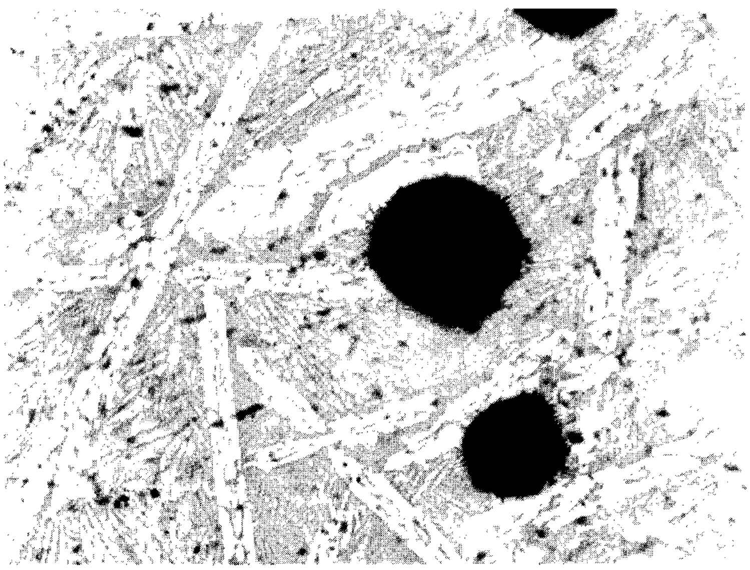

Figure 9. Structure of slag (no. 61): large columns of primary fayalite and small columns of secondary fayalite (light grey) in matrix of anorthite (dark grey); pores (black). As polished (not etched). (x100)

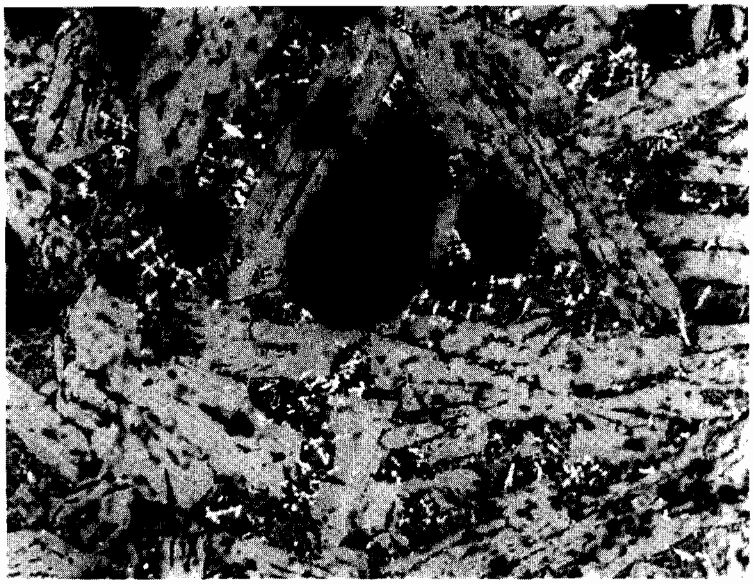

Figure 10. Structure of slag (no. 71): columns of fayalite (light grey) and some dendrites of wustite (white) in anorthite matrix (dark grey); pores (black). As polished (not etched). (x100)

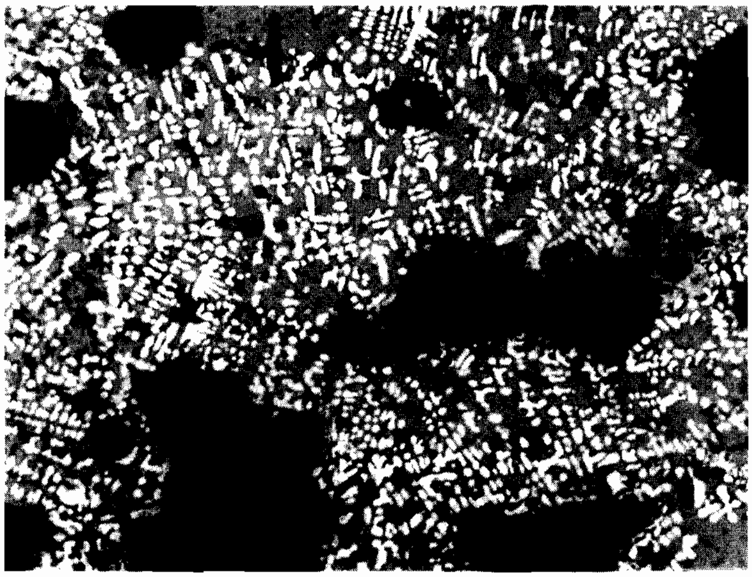

Figure 11. Structure of slag (no. 85): dendrites of wustite (white in fayalite-anorthite matrix (grey); pores (black). As polished (not etched). (x100)

porosity (Figs 10 and 11); the pores appear in the structure as black rounded holes pin-head to medium size (0.5-1.5 mm diam.). An inhomogenous structure in the form of iron oxide regions and iron oxide envelopes around large corrosion cavities was encountered in some of the slags.

The contaminated slag samples have a structure distinctly different from the slags, varying from one completely fused (cinders) to one containing large columns of fayalite in a refractory background (slagged furnace lining). The microstructure of the cinder (Fig. 13) shows that it contains many angular silica particles embedded in a fused, amorphous matrix containing numerous pores. The silica particles are very hard, having a microhardness exceeding 1100 HV_{100}, whereas the microhardness of the bonding phase (678 HV_{100}) corresponds closely to that of the fayalite phase in the slag. The slagged furnace lining contains, in addition, typical fayalite columns penetrating the fused matrix (Fig. 14). Table 6 indicates the quantity and type of material found in 48 examined samples.

Table 6. Type of slag material.

Material	No. of samples	Code nos*
Slag	19	2, 5, 7, 8, 28, 29, 33, 48, 50, 60, 61, 62, 63, 66, 67, 71, 82, 84, 85
Contam. slag	21	6, 9, 12, 13, 15, 18, 19, 22, 24, 26, 37, 39, 46, 47, 51, 53, 64, 69, 70, 73, 86
Silicious stone	3	40, 42, 74
Lumps of iron	5	79, 80, 81, 83, 87

*Underlining denotes lumps containing pieces of metallic iron.

As Table 6 shows, the majority of the samples represent slag material, about one-half of which is true slag. The other half is contaminated slag, which comprised roughly equal amounts of cinder and slagged furnace lining. Three of the samples are silicious stone, and five are lumps of extensively corroded ferrous metal.

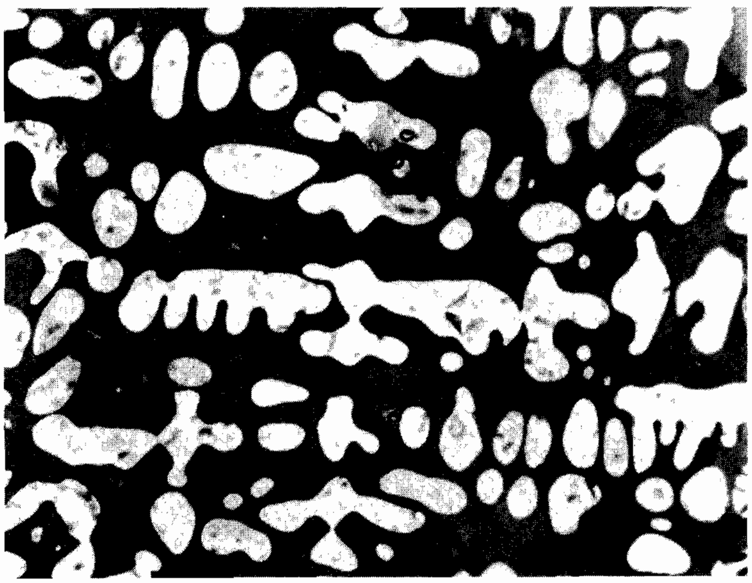

Figure 12. Figure 11 at higher magnification. Relative microhardness of slag phases (indicated by the size of indentations) is 536 HV_{100} for wustite (white), 673 HV_{100} for fayalite (light grey) and 606 HV_{100} for anorthite (dark grey). As polished (not etched). (x500)

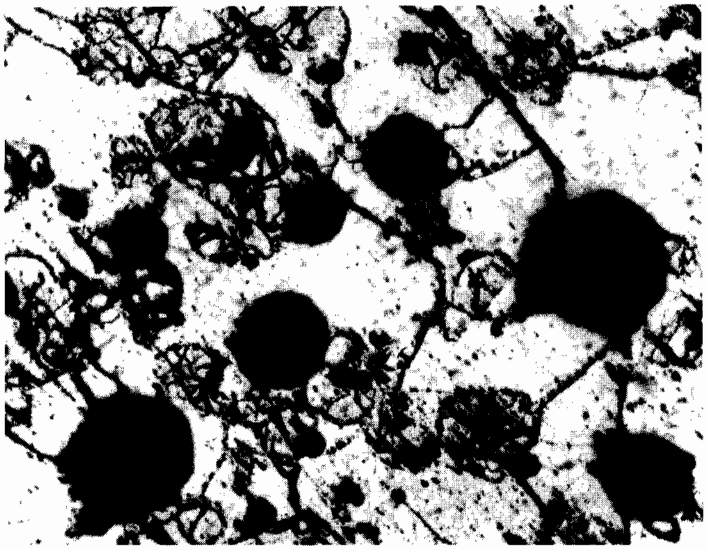

Figure 13. Structure of contaminated slag (cinder no. 14): angular silica particles (>1100 HV_{100}) in fused matrix of fayalite (678 HV_{100}); numerous pores (black). As polished (not etched). (x50)

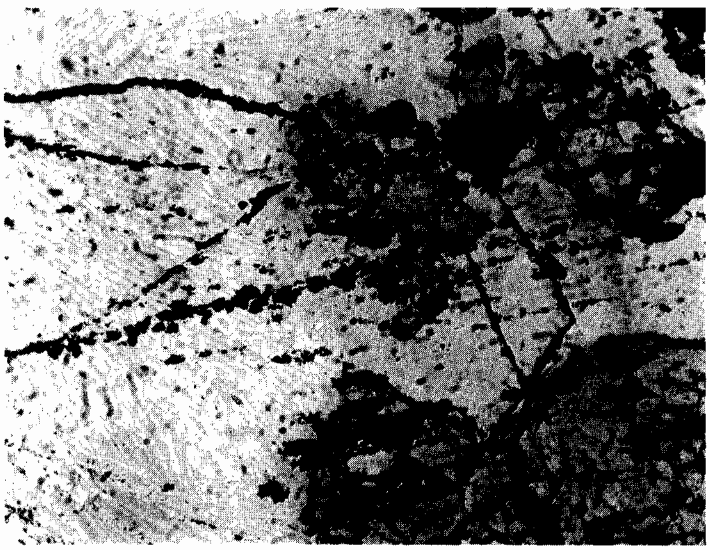

Figure 14. Structure of contaminated slag (slagged) furnace lining (no. 50); columns of fayalite (light grey) penetrating refractory background (dark grey); silica particles also visible *(right)*. As polished (not etched). (x50)

Structure of Pieces of Metal Found in Slag

Microscopic examination revealed the presence of pieces of metal in 20 lumps of slag and also showed 5 of the lumps to be ferrous metal. The pieces of metal in the slag varied in size and shape - some were small blobs and others were large, even massive. Most of the pieces were irregularly shaped, but several had regular shapes (that is, rod-like about 5 mm in diameter, or cylinder-like about 10 mm in diameter with a 2-mm wall thickness) (Fig. 5). The pieces of metal usually occurred close to the surface of the slag lumps and were extensively corroded, often with numerous cavities. Hardness of these corroded pieces of metal ranged from 130 to 150 HB.

Detailed microscopic examination led to the identification of three different materials among the pieces of metal, iron, steel and cast iron. The structure of the iron pieces consists of equiaxed ferrite grains as shown in Figures 15 and 16 where the soft, metallic iron is surrounded by slag. The black lines in the ferrite are grain boundaries which delineate the ferrite grain size. The pieces of steel, depending on their carbon content, comprise pearlite (high carbon steel in Fig. 19), or pearlite and ferrite (medium carbon steel in Fig. 17) having often a Widmanstaetten pattern. This characteristic geometrical pattern of ferrite at grain boundaries and within the pearlite areas is shown in Figure 18. The structure of a high carbon steel piece is illustrated in Figure 20. The dark matrix is pearlite whose two-phase lamellar structure is not resolved at this magnification.

In several of the slag lumps, pieces of metal having a cast-iron structure were unexpectedly found. These pieces and some separate lumps of metal have basically a pearlitic matrix with cementite at the grain boundaries and within the grains (Fig. 21). For example, the structure of cast iron in lump no. 28 consists of pearlitic regions outlined by envelopes of free cementite and some graphite flakes (Fig. 22). In most specimens, however,

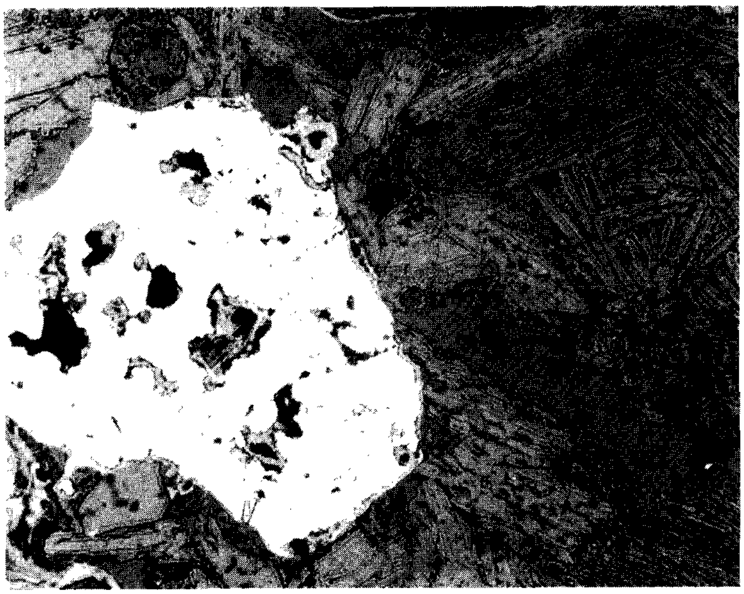

Figure 15. Structure of iron piece entrapped in slag (no. 48): equiaxed ferrite grains (light). Etched in 4 per cent nital to produce contrast. (x100)

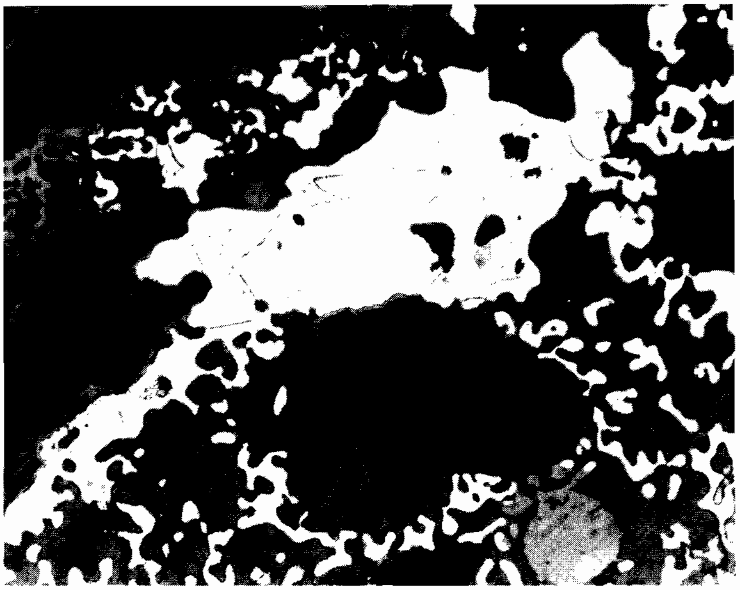

Figure 16. Structure of iron piece entrapped in slag (no. 61): equiaxed ferrite grains (light). Etched in 4 per cent nital. (x100)

Figure 17. Structure of medium carbon piece of steel entrapped in slag (no. 85): ferrite (light) and pockets of pearlite (dark). Etched in 4 per cent nital. (x100)

Figure 18. Widmanstaetten structure of medium carbon piece of steel entrapped in slag (no. 7): ferrite (light) at grain boundaries and within grains, in matrix of pearlite (dark). Etched in 4 per cent nital. (x100)

Figure 19. Structure of high carbon piece of steel entrapped in slag (no. 67): pearlite matrix. Etched in 4 per cent nital. (x100)

Figure 20. Structure of high carbon piece of steel *(left)* entrapped in slag (no. 62): unresolved pearlite. Etched in 4 per cent nital. (x150)

all the carbon is present as cementite, both free and as a constituent of pearlite. This is characteristic for white cast iron. The structure of the cast and refined iron in the metal lumps no. 83 and 87 consists of white needles of cementite in a dark matrix of pearlite (Figs 23 and 25). At higher magnification, details of the pearlitic background and the massive carbides become visible (Figs 24 and 26).

In contrast to the dark pearlite, both the ferrite and the cementite appear white under the microscope. As indicated by the size of the microhardness indentations in Figure 26, the ferrite is soft whereas the cementite is a very hard phase. The range of microhardness of the microconstituents identified in the examined metal samples is as follows:

ferrite	100-150 HV_{100}
pearlite	200-400 HV_{100}
cementite	850-1000 HV_{100}

Table 7. Type of metal found in slag lumps.

Material structure	Iron ferrite matrix	Steel pearlite matrix, or pearlite and ferrite	Cast-iron pearlite matrix with cementite
No. of samples*	11(1)	5	8 (3)
Code nos	2, 29, 47, 48, 50, 53, 60, 61, 63, (79), 82	7, 67, 73, 85, 86	5, 8, 28, 33, 62, (81), (83), (87)

*Numbers in parentheses refer to lumps of metal (not pieces of metal in slag).

The structure of the examined pieces of metal is summarized in Table 7.

Sample no. 8, which has a piece of corroded ferrous metal at its surface, is an unusual case. The two-phased structure of the metal is that of fine pearlite (410 HV_{100}), and an unidentified light phase (635 HV_{100}), possibly cementite, found at the grain boundaries and in the form of needles within the grains (Figs 27 and 28). The pearlite

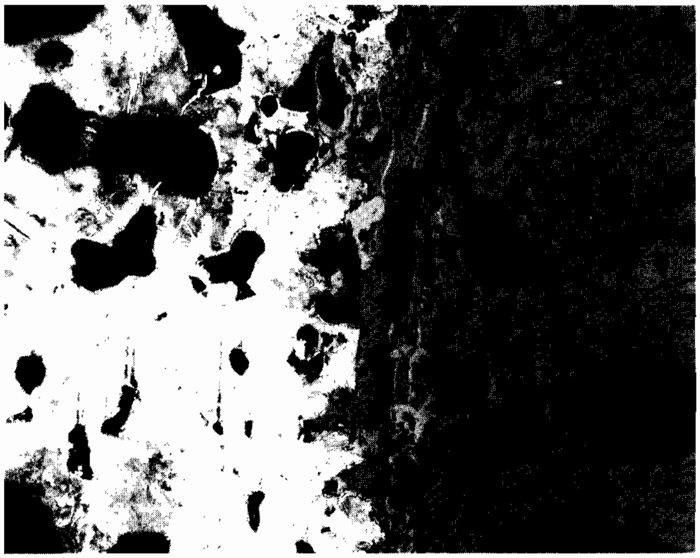

Figure 21. Structure of cast-iron piece *(left)* entrapped in slag (no. 28): cementite (light) at grain boundaries and within grains of pearlite (dark). Etched in 4 per cent nital. (x50)

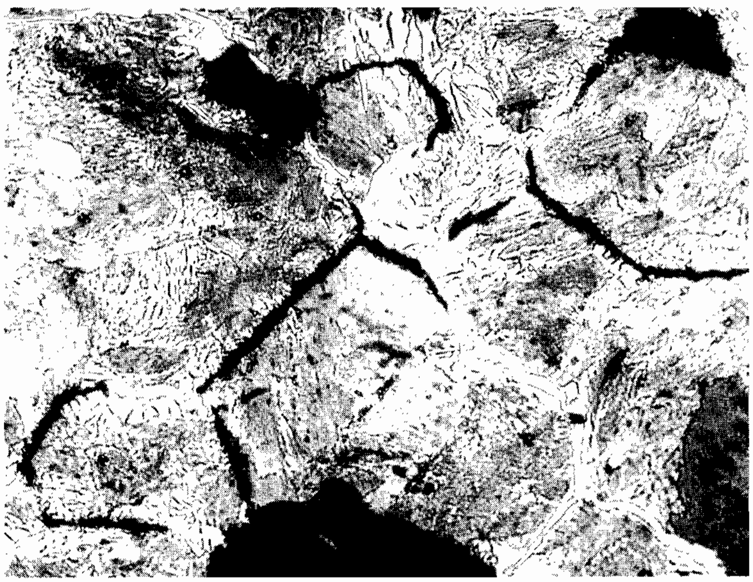

Figure 22. Figure 21 at higher magnification. Cementite (light) and graphite flakes (dark grey) in matrix of lamellar pearlite (grey), and some cavities (black). Etched in 4 per cent nital. (x200)

matrix also contains many light-reddish copper particles (149 HV_{100}) with globular or irregular shapes ranging from 0.1 to 0.2 mm. The presence of copper in the metal was confirmed by EDX analysis, the spectrum of which shows an appreciable peak of copper. Particles of copper were observed microscopically not only in the metal but also

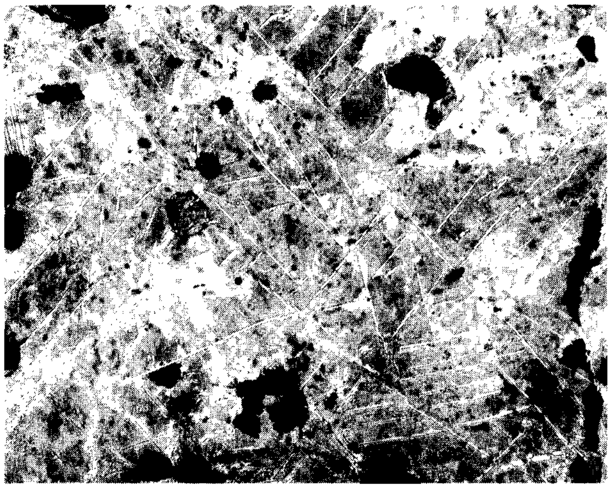

Figure 23. Structure of cast-iron lump (no. 83): cementite needles (light) in pearlite matrix (dark), and some cavities (black). Etched in 4 per cent nital. (x100)

Figure 24. Figure 23 at higher magnification. Cementite plates (light) in matrix of lamellar pearlite (dark). Etched in 4 per cent nital. (x500)

in the slag itself (Fig. 29). Chemical analysis of the slag lump showed the presence of 0.27 per cent copper (Table 3); however, no copper was found in the slag matrix using a scanning electron microscope (SEM) X-ray microanalyzer. This verifies that the copper is in the form of metallic inclusions in the slag as was observed microscopically.

Figure 25. Structure of refined iron lump (no. 87): cementite (light) in pearlite matrix (dark), cavities (black). Etched in 4 per cent nital. (x100)

Figure 26. Figure 25 at higher magnification. Massive cementite crystals (946 HV_{100}) in matrix of lamellar pearlite (254 HV_{100}). Etched in 4 per cent nital. (x500)

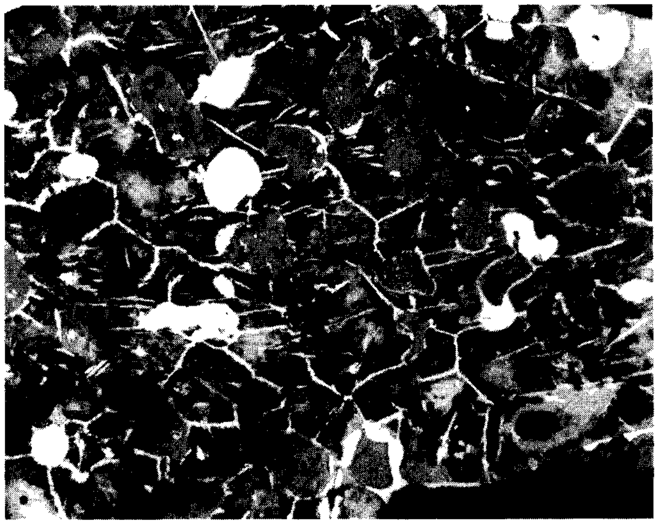

Figure 27. Structure of cast-iron piece entrapped in slag (no. 8): light phase at grain boundaries and within grains of pearlite (dark), and many particles of copper (white). Etched in 4 per cent nital. (x100)

Figure 28. Figure 27 at higher magnification. Light grain boundary phase (635 HV_{100}) in matrix of fine pearlite (410 HV_{100}), and a globular particle of copper (149 HV_{100}). Etched in 4 per cent nital. (x500)

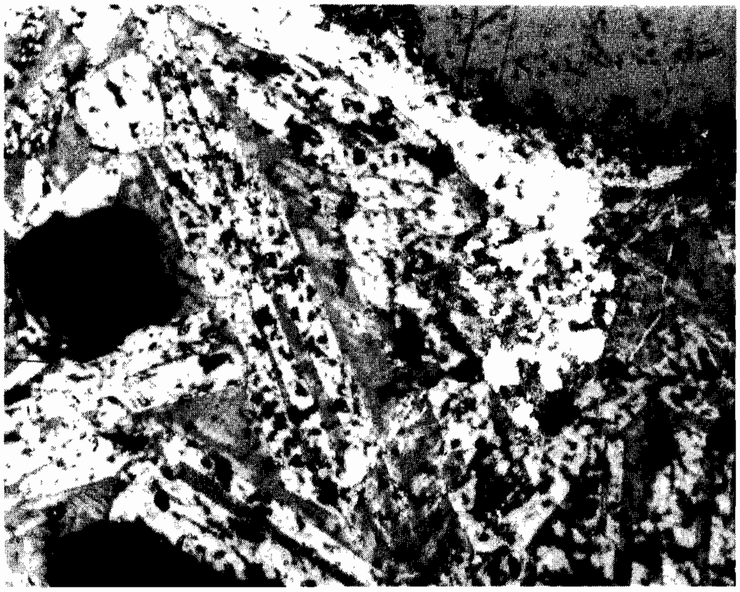

Figure 29. Etched in 5 per cent ferric chloride. Structure of slag (no. 8) with entrapped piece of copper (light). (x100)

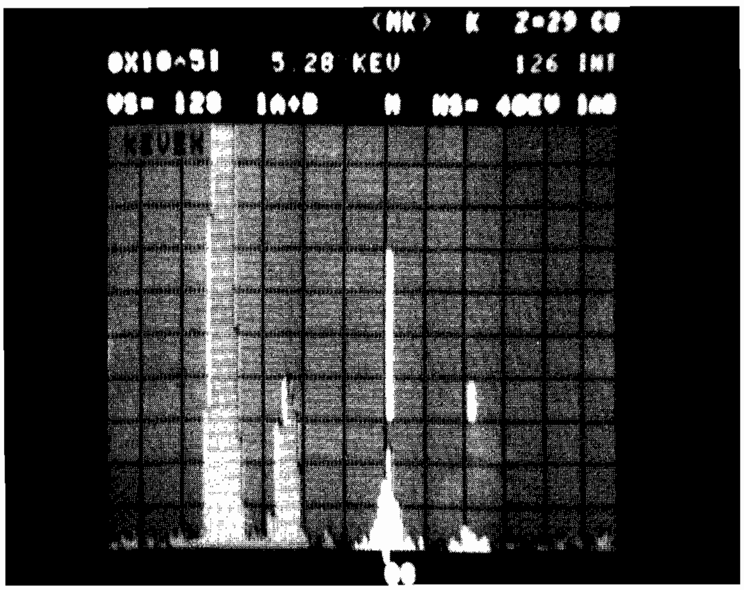

Figure 30. Energy dispersive X-ray fluorescence spectrum of lump no. 8 with particles of copper, showing peaks of iron (dark) and copper (light). (Photo by author)

Structure of Iron Objects

In addition to the iron pieces in the slag lumps, iron objects were also recovered in the blacksmith shop. Sixteen of these objects, mostly in the form of small bars and wedges not exceeding 2 x 1 x 7 cm, were examined metallographically. Visual observation revealed that the iron fragments were covered with a corroded surface layer of rust mixed with burial sand as well as black magnetic scale. The surface appearance of the objects is shown in Figures 31 and 32 and their shapes in Figure 33. Preparation of the iron micro-sections was similar to that of the slag.

Examination of the polished and nital-etched sections showed the structure of most of the fragments to be typical for wrought iron. In addition, a structure typical for steel was observed in four fragments. The wrought iron exhibits a structure of equiaxed ferrite grains and an assortment of slag stringers elongated in the direction of prevalent plastic deformation. Their thread-like appearance is evident from the longitudinal section (Fig. 34). The number and size of the slag stringers vary considerably within each object and from one to another, and their distribution is frequently not uniform. The slag inclusions have predominantly a duplex structure (Fig. 35), being largely a mixture of FeO and SiO_2, though some uniformly black single-phase inclusions were also observed.

The ferrite grains are medium size (ASTM no. 5 and 6) in most wrought-iron fragments as shown at low magnification in Figure 36. At high magnification, the presence of thin cementite films at the widened grain boundaries of this very low carbon material is brought out (Fig. 37). The microhardness of ferrite in six of the objects (1M, 3M, 4M, 7M, 9M and 16M) is 100-140 HV_{100}, a range typical for soft, almost pure iron. The overall hardness of these objects (80-120 HB) is also low. However, the hardness of the five remaining wrought-iron objects (6M, 10M, 12M, 14M and 15M) is unusually high (130-210 HB). Interestingly, the microhardness of the ferrite in these objects (160-280 HV_{100}) is also very high. This suggests that the five fragments are made of high-phosphorus (cold-short) iron, and their high hardness should be attributed to the presence of a large amount of phosphorus which hardens iron almost as much as carbon.

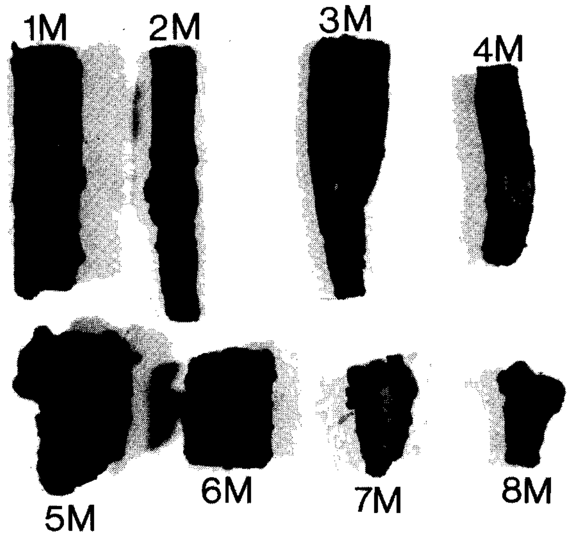

Figure 31. Surface appearance of iron fragments 1M to 8M. (Scale: 0.4; photo by author)

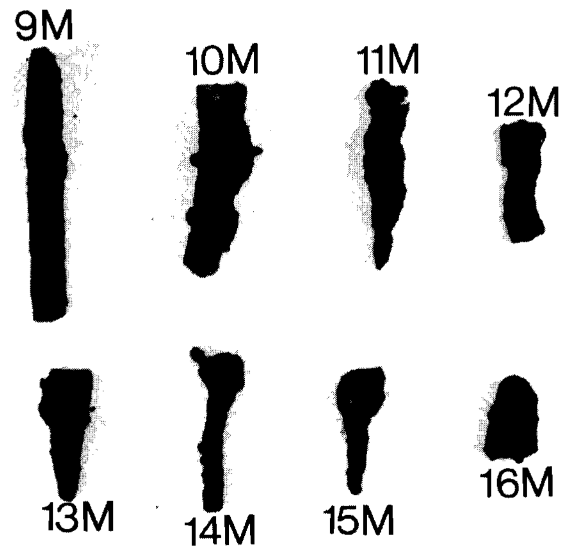

Figure 32. Surface appearance of iron fragments 9M to 16M. (Scale: 0.5; photo by author)

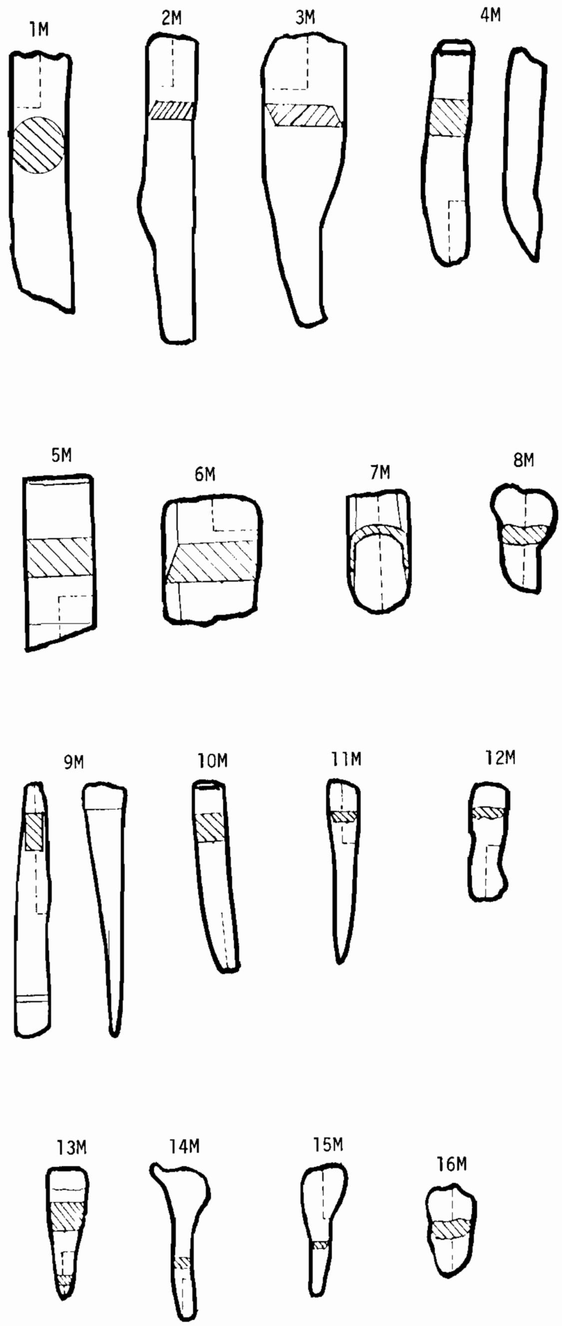

Figure 33. Sketches of iron fragments with locations of sections (indicated by broken line). (Drawing by author)

Figure 34. Slag stringers (black) in wrought-iron fragment (3M). As polished (not etched). (x100)

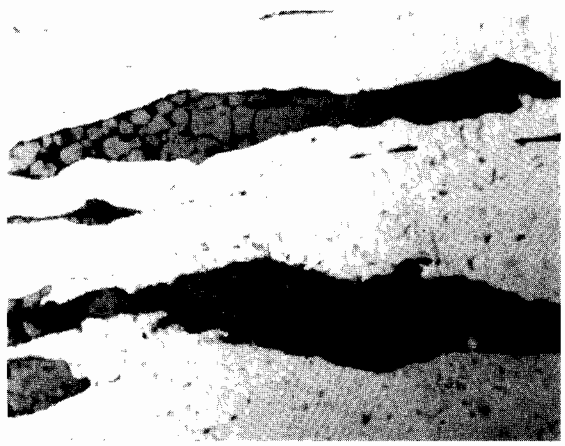

Figure 35. Duplex structure of slag inclusions in wrought-iron fragment (9M): mixture of FeO and SiO_2. As polished (not etched). (x500)

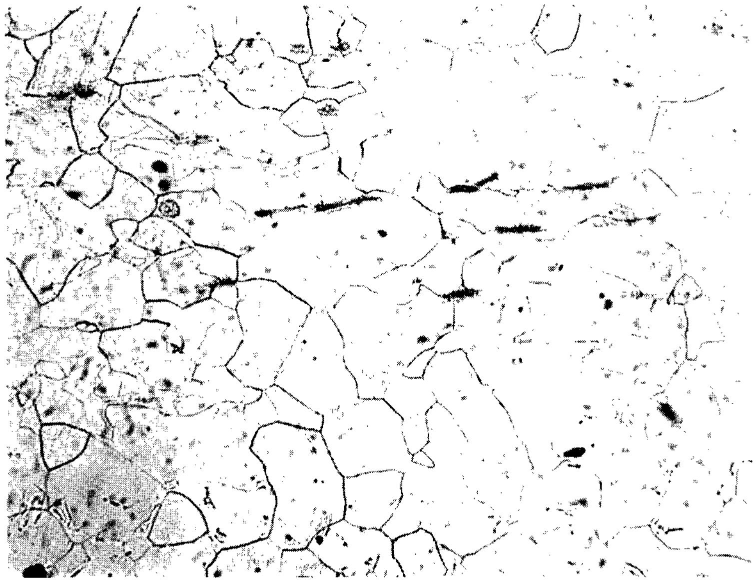

Figure 36. Typical structure of wrought-iron fragment (6M): equiaxed ferrite grains of medium size (light) and slag stringers (black). Etched in 4 per cent nital. (x100)

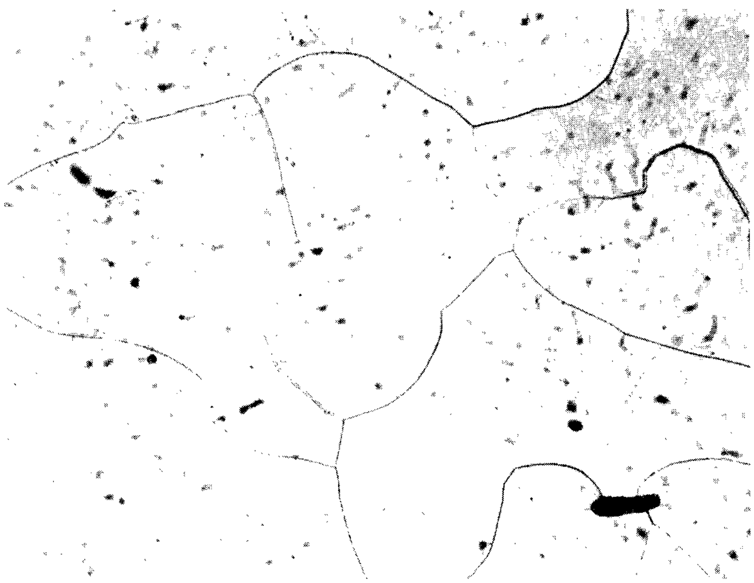

Figure 37. Figure 36 at higher magnification. Cementite films at widened grain boundaries of ferrite. Etched in 4 per cent nital. (x500)

The equiaxed, polygonal ferrite grains observed in the wrought-iron fragments show that forging was done hot and finished above the recrystallization temperature. Only in one fragment (15M) was evidence of cold-working found. The microstructure in this case (Fig. 38) shows crystals of ferrite crossed by relatively straight bands all parallel within a given grain but changing direction from one crystal to the next. These are Neumann bands (mechanical twins) which are found only in ferrite and indicate some distortion of the material, usually caused by sudden stress such as might occur on the edge of an axe. Such Neumann bands are not uncommon in man-made iron, especially in a brittle metal having a high content of phosphorus. Four of the wrought-iron fragments (3M, 9M, 14M and 15M) are locally carburized. This carburization is most likely accidental, having occurred in the charcoal fire during the forging process.

Four of the examined fragments (2M, 5M, 11M and 13M) show a structure typical for steel. This consists generally of a pearlite matrix and occasionally some ferrite. The structure of the medium carbon steel bar 5M (Fig. 39) is largely that of the Widmanstaetten type, having ferrite (122 HV_{100}) at prior austenite grain boundaries and as plates within grains in a matrix of pearlite (206 HV_{100}). The Widmanstaetten distribution of ferrite suggests that the fragment had been finally cooled from a high temperature at a fairly fast rate. The presence of broken slag stringers observed at the end of this slanted bar is also interesting. These silicate slag inclusions had been first elongated when plastic and subsequently broken by deformation at a lower temperature, indicating that the slanted end of the bar was worked when much colder. The structure of the high carbon steel wedge 13M (Fig. 40) comprises very fine

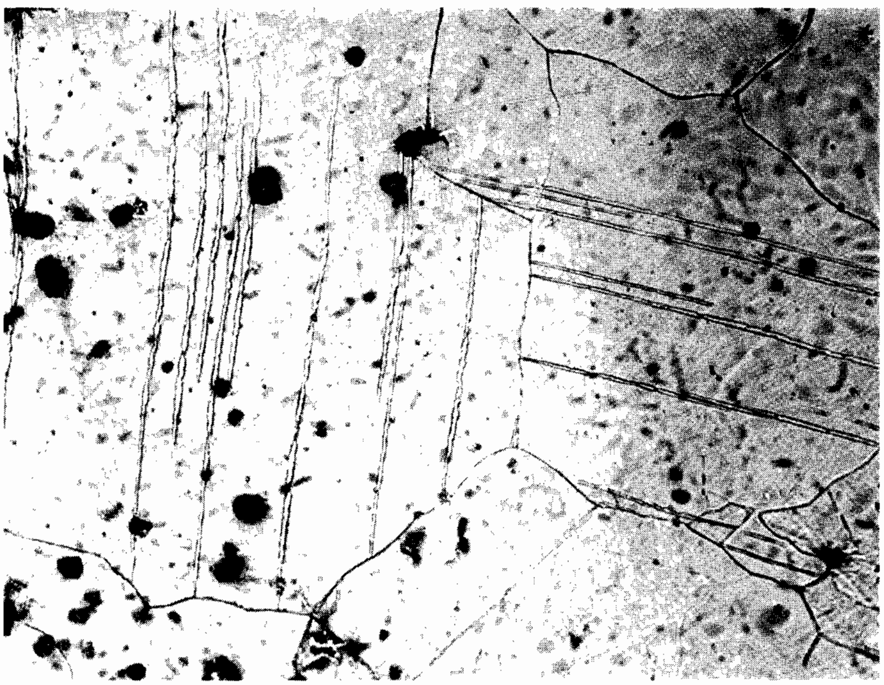

Figure 38. Structure of wrought-iron fragment (15M): Neumann bands (straight parallel lines) within ferrite grains. Etched in 4 per cent nital. (x200)

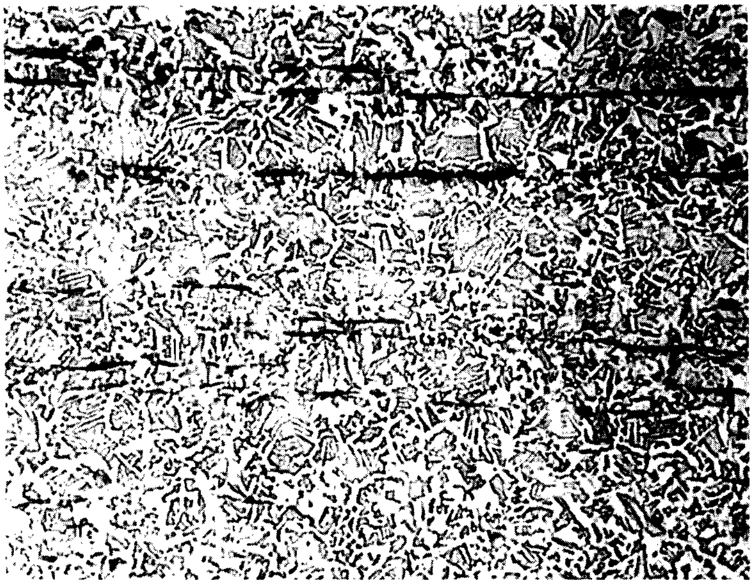

Figure 39. Structure of medium carbon steel fragment (5M): Widmanstaetten ferrite (light) in matrix of pearlite (dark), and slag stringers (black). Etched in 4 per cent nital. (x100)

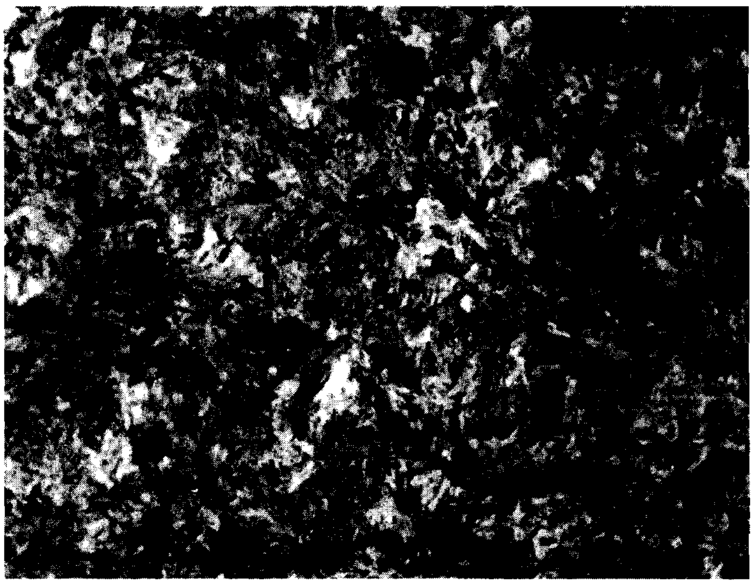

Figure 40. Structure of high carbon steel fragment (13M): very fine pearlite (sorbitic pearlite). Etched in 4 per cent nital. (x100)

unresolved pearlite, called sorbitic pearlite. It is very hard (351 HV_{100}) and contributes to the overall high hardness of the material (340 HB). Sorbitic pearlite is formed as a result of rapid cooling from high temperature and its presence suggests an attempt at hardening the steel fragment by heat treatment (probably quenching in water). In the other two high carbon steel fragments (2M and 11M) the structure consists of partially and completely spheroidized pearlite (Figs 41 and 42, respectively). This type of structure is the result of

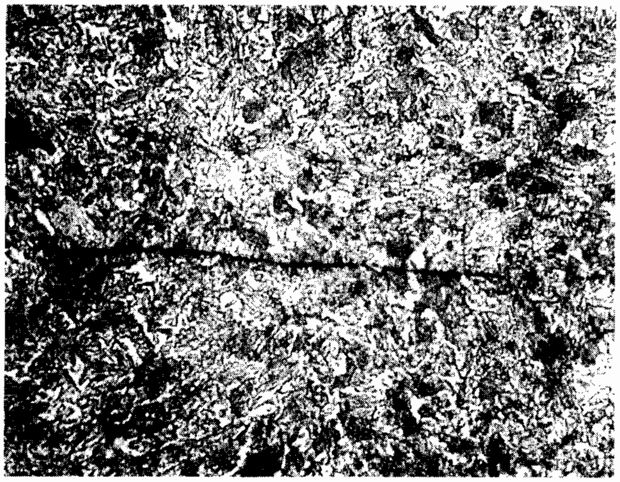

Figure 41. Structure of high carbon steel fragment (2M): partially spheroidized pearlite and slag inclusions (black). Etched in 4 per cent nital. (x100)

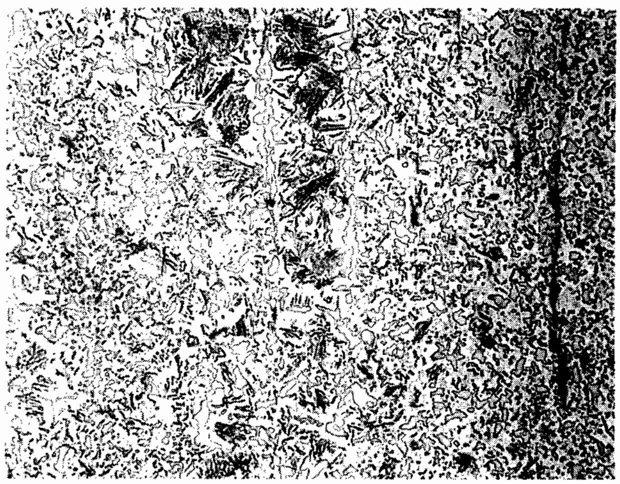

Figure 42. Structure of high carbon steel fragment (11M): massive carbides in ferrite matrix; remains of pearlite also visible. Etched in 4 per cent nital. (x500)

heating the metal to about 600-700°C for a prolonged period of time or repeated heating to that temperature during forging. The characteristics and technological features of the iron fragments obtained from the metallographic examination are compiled in Table 8.

Table 8. Characteristics and technological features of iron fragments.

Code no.	Material	Slag inclusions (amount & size)	Microconstituents	Grain size ASTM no.	Micro-hardness HV_{100}	Hardness HB	Technology
1M	Wrought iron	Few, medium	Ferrite	4	122	93	Hot-working
2M	Steel	Some, very long	Pearlite, partially spheroidized	-	245	213	Heating at 600-700°C
3M	Wrought iron	Some, long	Ferrite	6	117	105	Hot-working accidental carburization
4M	Wrought iron	Some, large	Ferrite	4	143	104	Hot-working
5M	Steel	Many, very long	Ferrite Pearlite	7	122 206	125	Hot-working, some cold- working
6M	Wrought iron	Many, short	Ferrite	5	194	151	Hot-working
7M	Wrought iron	Some	Ferrite	6	138	122	Hot-working
8M	Corroded iron	-	-	-	-	-	-
9M	Wrought iron	Some	Ferrite	6	119	113	Hot-working accidental carburization
10M	Wrought iron	Few	Ferrite	6	160	129	Hot-working
11M	Steel	None	Ferrite		190 441	151	Heating at 600-700°C
12M	Wrought iron	Numerous, fine	Ferrite	8	222	134	Hot-working
13M	Steel	None	Sorbitic pearlite		351	340	Quenching(?)
14M	Wrought iron	Few, fine	Ferrite	9	230	145	Hot-working accidental carburization
15M	Wrought iron	None	Ferrite	8	276	210	Hot-working, cold-working, accidental carburization
16M	Wrought iron	Some, medium	Ferrite	5	100	83	Hot-working, accidental carburization

DISCUSSION AND INTERPRETATION

Constitution and Melting Points of Slag

The constitution and melting points of the slag lumps were calculated from their chemical analyses using the approach of Morton and Wingrove (1969a: 1556-64). The calculated amounts of the slag constituents are given in Table 9.

The slag samples comprise predominantly fayalite (about 70%), anorthite (about 10%) and excess of silica (about 20%). In the contaminated slag samples free silica is the predominant phase (about 30%) with a considerable amount of fayalite (almost 30%) and some anorthite (about 15%). The presence of fayalite, wustite and anorthite, but not free silica, was observed under the microscope. This lack of free silica in the microstructure is due to nonequilibrium conditions resulting from rapid cooling. This shifts the system toward the FeO side of the phase diagram, and the formation of free silica is suppressed.

The original melting points of the slags were determined by plotting the three calculated constituents on the ternary FeO-SiO_2 anorthite phase diagram shown in Figure 43. This diagram demonstrates that the mineralogical constitution of about half of the slags is concentrated in a wide region of low melting compositions falling in the fayalite region at approximately 1200°C. The composition of many other slags, however, is found to be far removed from the fayalite region, being dispersed in the area of the cristobalite monotectic shelf. The contaminated slags are situated even closer to the SiO_2 corner of the triangle. The ratio of silica to other oxides is much higher in these samples than in the remaining slags, and consequently they have a much higher melting temperature. Thus, the melting points of some of the slag and all of the contaminated slag samples fall outside the range of low working temperatures. This confirms the microscopical findings that a large part of the material is either slag contaminated with forge lining (sand bed) or some other uncommon byproduct of a flawed ironworking operation.

Formation of Slag Material

Slag that is a product of secondary ironworking is referred to as smithy slag. It is a waste material from a blacksmithing operation involving heating of pieces of iron in the forge with resulting high iron loss. Sand was often used as flux to facilitate the removal of scale from the forged iron. The slag forms from iron oxides (hammer scale, cinders, slag inclusions in wrought iron) and other components such as sand, earth, melted parts of the hearth lining, or from ashes and charcoal remains.

It was determined earlier that the examined material from Fort St. Joseph contains slag and contaminated slag. The high silica content of the slag suggests it originated from the interaction of molten slag with sand in the bottom of the forge. The silica from the sand bed of the forge combined with some oxidized iron to form fayalite which as a slag descended in the molten state towards the bottom of the hearth. There it acquired a cake-like shape from the bowl-shaped forge bottom. The very low content of manganese in the investigated slags probably resulted from dilution by sand from the bed. Some of the contaminated slag was formed by the attack of the molten slag on the forge lining and as such is called slagged furnace lining. This is demonstrated by typical fayalite columns penetrating the furnace lining. Other samples, identified as cinder, apparently were formed when pieces of refractory fell off the walls of the forge and were bonded by the surrounding molten slag.

The numerous contaminated slag pieces found at the shop suggest a rather inadequate state of technology, probably due to a lack of proper maintenance of the forge by the blacksmith. In operating the forge it is important to remove the slag while welding, as this process requires a clean fire, and to clean out the forge when the fire is dead. The carelessness of the blacksmith is underlined by the presence of numerous iron pieces in the slag material, some of which are clearly remnants of objects left or dropped by him in the forge. Many of the iron pieces found in the slag lumps may, however, indicate an ironworking operation involving the conversion of pig iron to wrought iron, as discussed in the next section.

Table 9. Constitution of slag (%).

Code No.	2	5	7	8	22*	28	29	33	47*	50	51	60
Analysis												
FeO	53.3	57.5	42.5	43.0	11.1	28.6	58.9	31.8	27.7	38.1	63.6	44.9
SiO_2	38.2	31.6	34.9	44.3	73.0	58.1	30.9	47.9	47.6	37.1	28.8	37.7
CaO	2.9	3.2	12.3	4.1	4.0	4.8	3.7	7.0	8.3	11.4	3.4	6.0
Al_2O_3	2.1	2.3	2.1	2.5	4.7	3.1	1.8	3.7	4.1	3.7	1.4	2.9
MnO	0.02	0.1	0.3	0.06	0.06	0.02	0.02	0.1	0.08	0.06	0.08	0.04
MgO	0.7	0.8	2.1	0.8	1.1	1.0	0.7	2.0	2.5	3.9	0.8	1.4
P_2O_5	0.4	0.3	0.7	0.5	0.2	0.4	0.4	0.3	0.7	0.5	0.7	0.3
S	0.02	0.00	0.02	0.02	0.02	0.02	0.02	0.00	0.02	0.04	0.00	0.00
TiO_2	0.09	0.1	0.09	0.1	0.2	0.1	0.07	0.07	0.2	0.2	0.07	0.1
Alkali	1.8	2.4	3.6	2.6	4.5	3.4	2.2	5.7	7.0	4.1	1.6	3.6
Tap Analysis												
FeO	53.6	58.5	43.1	43.9	11.2	28.7	59.8	32.3	28.2	38.5	63.4	46.3
SiO_2	38.4	32.2	35.4	45.2	73.8	58.4	31.3	48.6	48.4	37.4	28.7	38.9
CaO	2.9	3.2	12.5	4.2	4.1	4.8	3.7	7.1	8.5	11.5	3.4	6.2
Al_2O_3	2.1	2.4	2.1	2.6	4.7	3.1	1.8	3.8	4.2	3.8	1.4	3.0
MnO	0.02	0.1	0.3	0.06	0.06	0.02	0.02	0.1	0.08	0.06	0.08	0.04
MgO	0.7	0.8	2.2	0.8	1.1	1.0	0.7	2.1	2.6	3.9	0.8	1.5
P_2O_5	0.4	0.3	0.7	0.5	0.2	0.4	0.4	0.3	0.7	0.5	0.7	0.3
S	0.02	0.00	0.02	0.02	0.02	0.02	0.02	0.00	0.02	0.04	0.00	0.00
TiO_2	0.09	0.1	0.09	0.1	0.2	0.1	0.07	0.07	0.2	0.2	0.07	0.1
Alkali	1.9	2.5	3.7	2.7	4.5	3.4	2.2	5.8	7.2	4.1	1.6	3.7
Mineralogical Constituents												
Anorthite	6.1	6.8	7.1	7.5	14.0	9.2	5.2	11.8	13.8	12.5	3.9	9.1
SiO_2	37.7	31.2	40.0	45.3	73.9	59.6	31.1	50.9	52.3	40.4	28.8	39.4
FeO	56.3	62.0	52.9	47.2	12.1	31.2	63.7	37.2	33.9	47.1	67.3	51.5
Microconstituents												
Anorthite	6.1	6.8	7.1	7.5	14.0	9.2	5.2	11.8	13.8	12.5	3.9	9.1
Fayalite	79.8	88.0	75.0	66.9	17.2	44.3	90.3	52.8	48.1	66.8	95.5	73.1
Wustite	-	-	-	-	-	-	-	-	-	-	-	-
Free SiO_2	14.2	5.2	17.9	25.6	68.8	46.5	4.5	35.4	38.1	20.7	0.6	17.8

*Contaminated slag.

Table 9. Cont.

Code No.	61	62	63	64*	67	69*	71	73*	84	85	86*
Analysis											
FeO	31.7	47.3	36.4	8.4	29.9	15.6	34.0	16.1	70.9	67.1	35.9
SiO_2	46.7	34.7	42.8	73.6	48.3	59.7	39.6	61.9	13.3	23.8	44.4
CaO	10.6	7.3	9.0	3.5	7.7	7.9	9.8	7.5	2.7	3.7	7.2
Al_2O_3	3.8	2.7	3.5	6.7	6.6	6.5	3.9	5.6	1.1	2.4	4.3
MnO	0.06	0.02	0.02	0.02	0.06	0.06	0.06	0.06	0.06	0.02	0.06
MgO	2.0	2.5	2.5	1.6	3.1	2.9	2.8	2.7	0.9	1.9	2.3
P_2O_5	0.4	0.2	0.3	0.1	0.2	0.3	0.5	0.5	0.3	0.1	0.3
S	0.02	0.02	0.02	0.02	0.00	0.00	0.04	0.00	0.00	0.00	0.00
TiO_2	0.2	0.1	0.2	0.3	0.3	0.3	0.2	0 2	0.07	0.1	0.2
Alkali	4.3	3.2	3.9	4.3	4.7	5.1	5.1	5.4	1.0	1.4	4.3
Tap Analysis											
FeO	31.8	48.2	36.9	8.5	29.7	15.9	35.4	16.1	78.5	66.7	35.9
SiO_2	46.8	35.4	43.5	74.7	47.9	60.7	41.3	62.0	14.8	23.6	44.4
CaO	10.6	7.4	9.1	3.5	7.6	8.0	10.2	7.5	3.0	3.7	7.2
Al_2O_3	3.8	2.8	3.5	6.8	6.5	6.6	4.0	5.6	1.2	2.4	4.3
MnO	0.06	0.02	0.02	0.02	0.06	0.06	0.06	0.06	0.07	0.02	0.06
MgO	2.0	2.6	2.6	1.6	3.1	3.0	2.9	2.7	1.0	1.9	2.3
P_2O_5	0.4	0.2	0.3	0.1	0.2	0.3	0.6	0.5	0.3	0.1	0.3
S	0.02	0.02	0.02	0.02	0.00	0.00	0.04	0.00	0.00	0.00	0.00
TiO_2	0.2	0.1	0.2	0.3	0.3	0.3	0.2	0.2	0.08	0.1	0.2
Alkali	4.3	3.3	4.0	4.4	4.7	5.1	5.3	5.4	1.1	1.4	4.3
Mineralogical Constituents											
Anorthite	12.3	8.6	11.1	18.9	20.2	20.7	13.3	17.6	3.5	6.9	13.6
SiO_2	50.1	36.5	45.8	72.0	45.9	61.0	44.0	63.8	14.0	22.2	45.2
FeO	37.6	58.8	43.0	9.1	33.9	18.3	42.7	18.6	82.5	70.9	41.3
Microconstituents											
Anorthite	12.3	8.6	11.1	18.9	20.2	20.7	13.3	17.6	3.5	6.9	13.6
Fayalite	53.3	77.8	61.0	13.0	48.0	26.0	60.6	26.4	47.5	75.1	58.5
Wustite	-	-	-	-	-	-	-	-	49.0	18.0	-
Free SiO_2	34.3	13.6	27.8	68.2	31.8	53.3	26.2	56.1	-	-	27.9

*Contaminated slag.

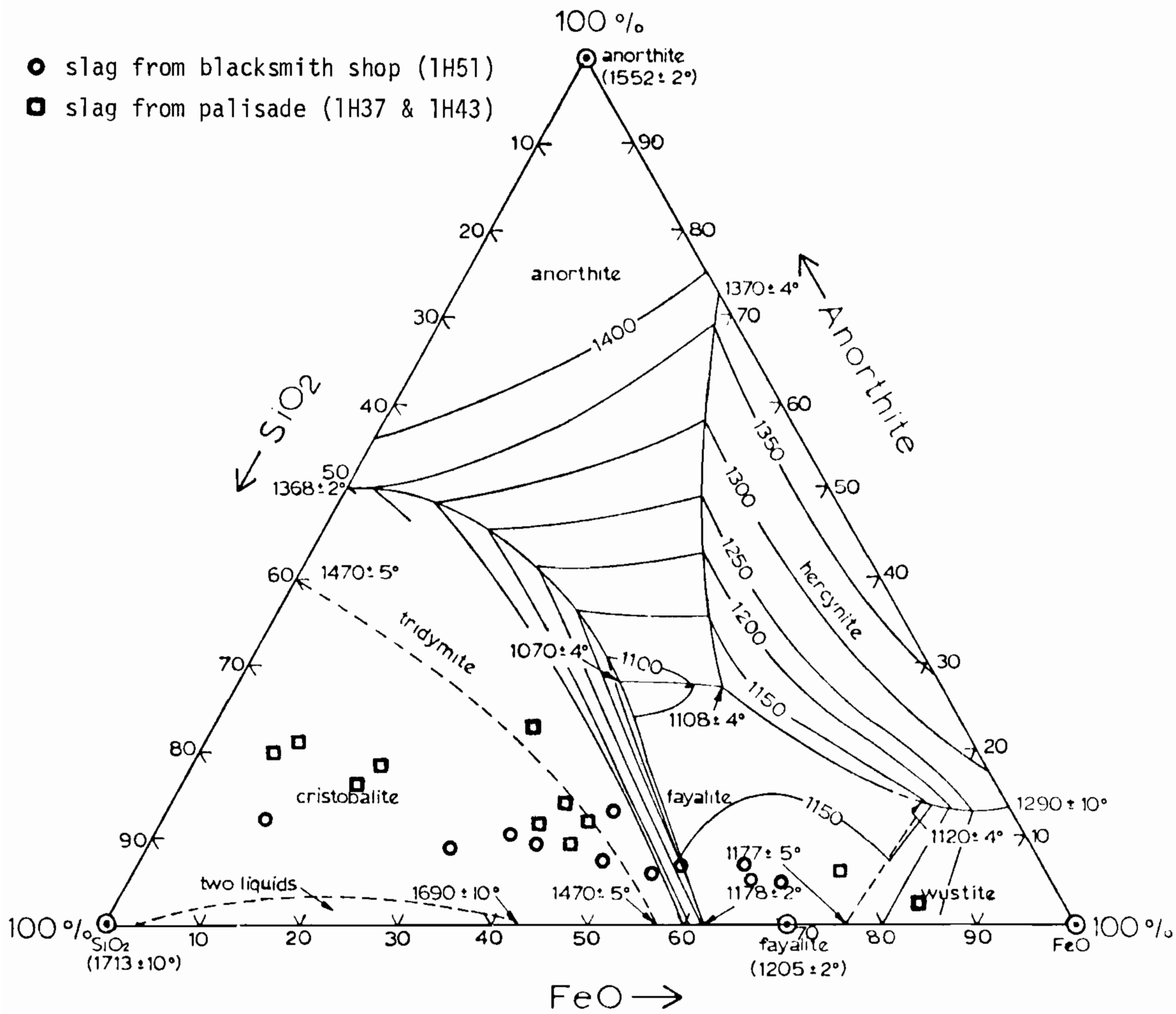

Figure 43. Constitution of slag from Fort St. Joseph. (Drawing by J. Renaud)

Ironworking at the Blacksmith's Shop

Before considering the type of ironworking processes carried out in the blacksmith shop let us look at brazing. This was a common practice of the old-time blacksmith, which required the high temperature of his forge. Brazing, the joining of two iron pieces with a copper alloy filler, was done in the St. Joseph shop, as verified by the examination. Brazing was generally used to join broken objects that were impossible or very difficult to weld, including cast-iron objects or high carbon steel tools. To braze, the blacksmith placed broken pieces in the forge and heated them to a brazing temperature. Then, placing the fractured surfaces together, he added sand or borax as flux, and applied brass or copper fillings between the two broken iron pieces so that the filler flowed into the whole joint after melting. The brazed piece was left in the dying fire to cool down until the filler solidified. The smith then removed the object from the forge and trimmed off any excess brass or copper. An inattentive blacksmith could easily spill molten brass which would mix with the slag or iron fragments. The presence of copper particles in one of the slag lumps, and traces of copper and zinc on the surface of many others, is evidence of this. The traditional coppersmith's brazing spelter was common brass (50Cu50Zn or 60Cu40Zn). The EDX analysis of the examined samples showed the brazing remains on the two iron objects from the blacksmith shop to be a brass alloy.

The results of the examination of the slag lumps and the iron fragments, combined with the archaoelogical evidence, seem to point to an ordinary blacksmith shop where the making and repairing of tools and machinery was carried out. However, the number and various types of metal pieces found in the slag lumps warrant a more careful look at the ironworking at the St. Joseph blacksmith shop. It seems unlikely that all the different pieces of iron, steel and especially cast iron found in the slag are remains of objects left in the forge during brazing or forging. It is plausible to regard the presence of some of these pieces in the slag as evidence of a metallurgical operation the aim of which was to convert pig iron into wrought iron by employing an indirect method of manufacture.

The early indirect process using charcoal as a fuel involved two stages, smelting and refining. First, pig iron in the molten state was reduced from the ore in a charcoal blast furnace and cast from the blast furnace into sand pig beds. Second, the pig iron was converted into malleable iron in a forge having three essential units: a refining hearth (the finery), a fire for reheating preparatory to hammering (the chafery) and the hammer. The finery process consisted of two operations called refining and fining, following each other in the same furnace without any marked division. The conversion of the pig iron into wrought iron was achieved by oxidation of excess impurities in the pig iron by means of air from a tuyere. The cast-iron pig was fed into the tuyere zone progressively, where its end was brought to the melting point so droplets of iron would run off. These droplets oxidized rapidly as they fell towards the bottom of the hearth. During this operation carbon in the iron would burn out. The main impurities - silicon, manganese and phosphorus, along with some oxidized iron - would form a slag similar to normal bloomery slag or smithy slag. The fining was followed by reheating in the chafery fire and by hammering to remove the excess slag and weld the solid lumps into a bar.

The analyses of iron at various stages characteristic of the indirect method of manufacture are given in Table 10. Products from the eighteenth century Nibthwaite site in Great Britain (Morton 1969: p. 10) and those from Fort St. Joseph are compared in this table.

The ferrous materials from Fort St. Joseph, cast iron, steel and malleable iron, with carbon contents ranging from very high to very low, may actually be products of different stages of the conversion process. The carbon content of these materials varies probably due to burning out during refining. A good example is the composition of lump no. 87 which is characteristic for a refined piece of iron. This sample still has a high carbon content, but the silicon is almost completely oxidized. Thus it follows that many of the examined slags could be forge slags (that is, slags formed during refining) and not smithy slags. The forge and smithy slags, undistinguishable in composition, similar in structure and appearance, are usually very difficult to tell apart.

As described, the process of conversion of pig iron to wrought iron would require a large-scale ironworks and much equipment. The small blacksmith shop would hardly be suitable for this type of operation. To date there is no archaeological evidence substantiating the presence of a finery, chafery or a forge hammer in this area. It may not be feasible at all to carry out a successful refining operation in a blacksmith shop. Nevertheless, the findings of this study seem to indicate that such an attempt had been made in the St. Joseph blacksmith shop.

The cast-iron material will now be characterized in more detail because of its importance as possible evidence of iron refining. Besides its structure and composition determined before, its carbon equivalent and

Table 10. Comparison of iron manufactured by an indirect process with iron from Fort St. Joseph.

	Nibthwaite, Gt. Brit. (Morton 1969: 10)			Fort St. Joseph, Ont.		
Element	Pig iron (%)	Refined iron (%)	Wrought iron (%)	Pig iron (no. 28) (%)	Refined iron (no. 87) (%)	Wrought iron (no. 4M) (%)
C_{total}	3.86	2.94	0.028	1.85	2.18	0.04
$C_{graphitic}$	2.43	0.01	-	0.91	0.12	-
$C_{combined}$	1.43	2.93	-	0.94	2.06	-
Si	0.85	0.173	0.23	1.94	0.08	0.023
Mn	0.05	0.05	0.13	0.010	<0.01	0.005
P	0.11	0.16	0.31	0.10	0.09	0.22
S	0.029	0.037	0.024	0.050	0.07	<0.005

liquidus temperature were also calculated. The carbon equivalent was calculated as the percentage carbon plus 0.3 times the sum of the percentage silicon and phosphorus. The liquidus or melting temperature in the region of the eutectic was determined with the following empirical formula:

$$T^{o}C = 1669^{\circ}C - 124\ (\%C + \%Si/4 + \%P/2)$$

The carbon equivalent, which describes how close a given analysis is to that of eutectic composition, was about 2.5, clearly indicating a hypoeutectic character of the piece of cast iron. The liquidus temperature is reached at about 1370°C for sample no. 28. Ordinarily a ledeburite eutectic of cementite and austenite is part of the structure of cast iron. This is not the case in the examined pieces, which have, for cast iron, a rather unusual structure comprising cementite needles in a pearlite matrix. Under some conditions, however, the white iron eutectic can have a plate-like structure in which cementite occurs in the form of needles. Its formation always involves supercooling which is promoted by superheating the melt, thus reducing the nucleation.

Some information on the method of manufacture of the cast iron is provided by its composition. The relatively low silicon content indicates a temperature ceiling as high temperatures favour the production of high silicon pig irons. The same can be said for the very low manganese content. The low phosphorus content suggests that ores low in phosphorus were used in the smelting operation, as phosphorus present in the ore also appears in the iron. The sulphur content, however, is very low due to the use of charcoal (low sulphur material) as a reducing agent. This indicates that the cast-iron pieces were produced by smelting low-phosphorus ores in a cold-blast furnace fired by charcoal.

CONCLUSIONS

The investigation showed that the examined slag is a waste material formed in an ironworking operation, where iron loss was high and a considerable amount of silica was absorbed from the sand lining. Most of it is smithy slag, though some may be forge slag.

The structure, composition, physical properties and melting temperature of the slag material demonstrate that only half of the samples, the dark and heavy ones, are actually "true" slag. The remaining light-coloured and porous material is contaminated slag comprising slagged furnace lining and cinder.

The slag is a dense material with a high specific gravity, high iron content, relatively high silica content and low in other elements such as alumina, lime, manganese oxide and phosphorus pentoxide. Its structure consists basically of fayalite columns in an anorthite matrix, often with dendrites of wustite. The mineralogical constitution of many of the slag samples is concentrated in a wide range of low melting compositions around the fayalite region at approximately 1200°C.

The contaminated slag, however, is a highly porous and heterogenous material, with a specific gravity lower than the slag, a considerably lower iron content and a higher silica content. Its structure, lacking definite recognizable microconstituents, is basically that of silica particles in a fused fayalite matrix. Fayalite columns penetrate the fused matrix in the slagged furnace lining samples. The very high melting temperature of the contaminated slag verifies that much of the material is either slag contaminated with forge lining or some other unusual and non-representative produce caused by poor forging technique or abnormally high operating temperatures.

The examination of the slag material has not shown any appreciable or important differences between the lumps found at the blacksmith shop and the palisade. No proof was found for the existence of a second blacksmith shop.

Twenty of the slag lumps contain pieces of ferrous metal, half of which are wrought iron, the other half equally divided between steel and, quite unexpectedly, cast iron. Some of these pieces are clearly remnants of objects lost in the forge, indicating that the blacksmith was careless in his work. In addition, the numerous contaminated slag pieces found at the blacksmith shop suggest a poor state of technology, probably attributable to the shortcomings in the maintenance of the forge.

Of the 16 ferrous objects subjected to examination, three-quarters are wrought iron and one-quarter steel. This gives only a general idea rather than a factual indication of the proportions of wrought iron and steel worked in the blacksmith shop. Half of the wrought-iron objects represents a soft malleable iron and the other half has a higher hardness suggesting a cold-short high phosphorus material.

The structure of the wrought-iron objects is mostly equiaxed ferrite with a carbon content less than 0.1 per cent and medium grain size, as well as slag stringers elongated in the direction of prevalent deformation. This is a structure associated with simple air cooling from temperatures well above the critical temperature without any further treatment. The equiaxed grains clearly indicate that forging was done hot. Evidence of cold-working, in the form of Neumann bands, was found in only one object. The carburization observed in several objects was accidental, as their surface most likely carburized in the forge while in contact with hot charcoal.

The structure of the steel objects, having a pearlite matrix, indicates a high carbon content. There was an attempt at hardening one of the steel objects by a quenching type heat treatment which rendered a high hardness structure of sorbitic pearlite. Two other steel objects must have been reheated and kept for some time at 600-700°C, as their spheroidized structure indicates.

Several metallurgical operations were carried out in the blacksmith shop, including hot-working, forge-welding, brazing, some cold-working and also attempts to harden steel by heat treatment. The presence of pieces of charcoal in many of the slag lumps is convincing proof that charcoal was used as fuel. This is also verified by the very low sulphur content of the slag material. The minimum temperature of the hearth in the blacksmith shop was about 1150-1200°C with the working temperature probably 1250-1450°C. The blacksmith worked with different materials such as wrought iron, high and medium carbon steel, and white cast iron.

Some of the pieces of ferrous metal entrapped in the slag lumps, especially the cast-iron pieces, might indicate the use of a refining operation by the blacksmith in an attempt to convert pig iron into wrought iron. Although not substantiated archaeologically, the possibility of conversion of pig iron into wrought iron at the St. Joseph blacksmith shop is more than a matter of conjecture. A refining process would explain more plausibly the presence of cast iron, refined iron, steel and malleable iron in the slag lumps. In fact, the composition of the cast-iron pieces, except for the very low manganese content, corresponds to the typical composition of a modern pig iron. No evidence was found that the blacksmith engaged in such ironworking operations as smelting or casting.

The copper content of the slag material, with only one exception, is less than 0.1 per cent. Because a copper slag usually contains a minimum of about 0.5 per cent copper, the slag from Fort St. Joseph is evidently not associated with working of copper or copper alloys.

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