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BHAVĀNĪ ŚAṄKAR – THE FORGE-WELDED IRON CANNON AT JHANSI FORT

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The forge-welded iron cannon in the Jhansi fort by name *Bhavānī Śaṅkar* is addressed in this communication. The general design of the cannon has been first described. The total length of the cannon is 5 m and its weight is 5 tons. The main barrel was manufactured by forge-welding two layers of iron rings over 11 longitudinally placed iron staves. A minimum number of 125 iron rings have been used in the construction of the cannon. The material of construction of the cannon is direct-reduced iron. Microstructural analysis of the iron revealed a heterogenous distribution of slag inclusions. The grain size was relatively uniform throughout the matrix. Although etching with nital produced ghost structures, the presence of phosphorous could not be confirmed by Oberhoffer etchant. The corrosion product layer was analysed by laser Raman spectroscopy. The major constitutent was goethite (α-FeOOH). Strips of magnetite (Fe_3O_4) or maghemite (γ-Fe_2O_3) could also be identified in the goethite matrix.

Keywords: Construction, Design, Forge-welding, Iron cannon, Jhansi Fort, Rust analysis.

INTRODUCTION

Some of the excellently-engineered large metallic artifacts still remaining in numerous medieval forts, spread across the length and breadth of the Indian sub-continent, are cannons. These cannons were used to defend the forts against enemy attacks. The material of construction of these cannons was either bronze or iron. In the case of iron cannons, distinctions can also be made between forge welded and cast iron cannons. The manufacture of cast iron cannons was pioneered by the Europeans and therefore, most of the cast iron cannons that are present in Indian forts can be traced to European influence. On the other hand, iron cannons were also manufactured by forge welding, which

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was the local Indian technology of manufacturing cannons. The Indians, by medieval times, had mastered the manufacture of relatively large iron objects by the forge welding method. The wrought iron for forge welding was obtained in traditional bloomery furnaces by the direct reduction of iron ore in the presence of charcoal. It is important to study the forge welded iron cannons in medieval Indian forts as they are living examples of Indian iron technology during pre-modern times.

The medieval forge welded iron cannons of India have not been thoroughly documented, but for some scattered reports [1,2]. A detailed study of the medieval forge welded iron cannons of the Indian sub-continent has been initiated at IIT Kanpur and the cannons at Thanjavur[3], Bishnupur[4] and Hyderabad[5,6] have been addressed in recent publications. In this communication, one of the forge welded iron cannons located at the Jhansi Fort in Central India will be addressed. This particular cannon is referred to by name *Bhavānī Śaṅkar.*

History

The fort of Jhansi was strategically important since the earliest of times. It was built by Raja Bir Singh Deo (1606-1627) of Orchha on a rocky hill called Bangara Pahari in the town of Balwantnagar (presently known as Jhansi). The fort was also meant to be the first line of defence for Orchha, then the capital of Bundelkhand, about 16 km south of Jhansi. After Bir Singh Deo's death in 1627, the Mughals invaded the fort and held it till Chatrasal drove them out of the Bundelkhand region and established his suzerainty. He made Panna his capital. An attempt by the Mughal General Mohammed Khan Bangash to overthrow Chatrasal was foiled when Bajirao of Poona came to the latter's rescue by sending his troops. As a token of gratitude, Chatrasal gave one third of Bundelkhand region to Bajirao. Since Jhansi fell into that part, the town came under Maratha rule from about 17th century. It was developed by sucessive Maratha generals.

The fort is associated with the heroic deeds of Rani Laxmibai during the First War of Indian Independance (1857). Rani Laxmibai was married to Raja Gangadhar Rao, who was a popular ruler. After his death, his young widow came to power in 1854 and valiantly fought the British. Four years later, British troops invaded the fort and kept it under their control. The British ceded the forı to Scindia in 1858, but later exchanged it for Gwalior in 1866. The Indian Army took over in 1947. Since 1985, the fort has been under the management of the Archaeological Survey of India. Some additional details of the fort are provided in Ref. 5.

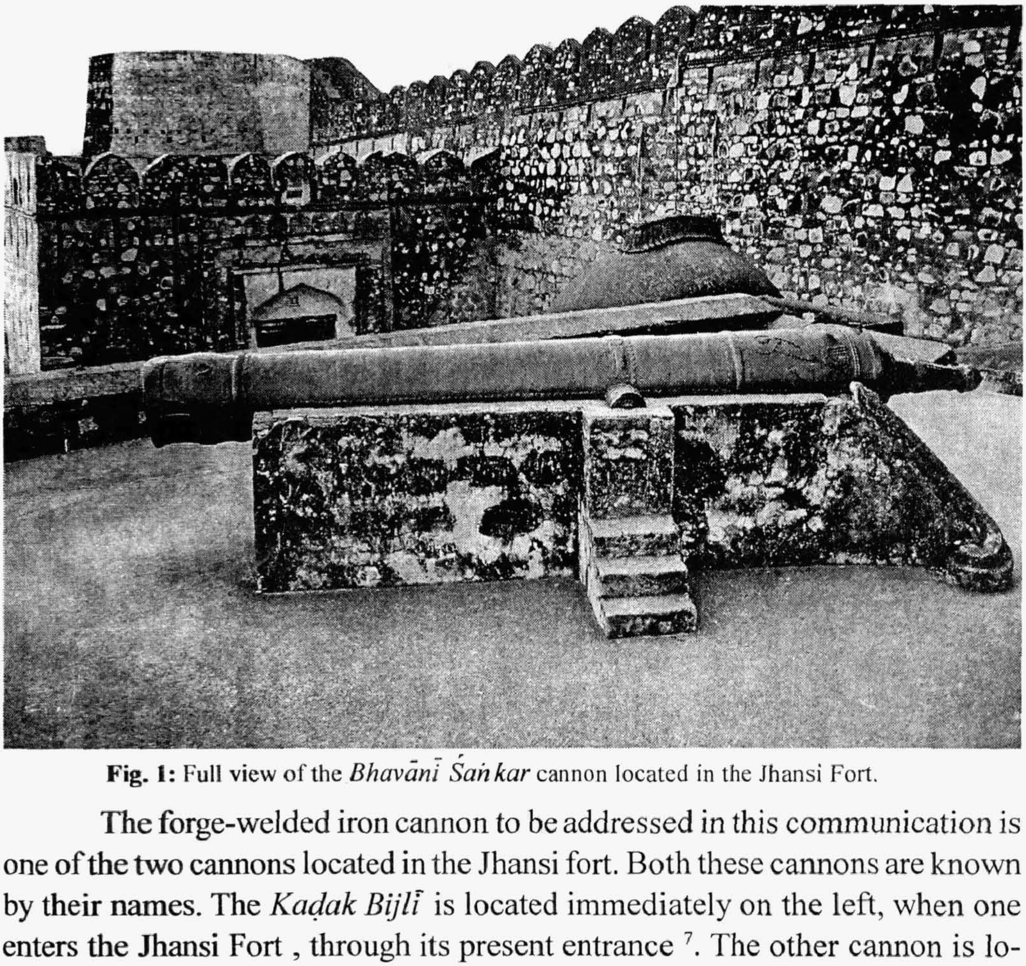

Fig. 1: Full view of the *Bhavānī Śaṅkar* cannon located in the Jhansi Fort.

The forge-welded iron cannon to be addressed in this communication is one of the two cannons located in the Jhansi fort. Both these cannons are known by their names. The *Kaḍak Bijlī* is located immediately on the left, when one enters the Jhansi Fort , through its present entrance [7]. The other cannon is located near the Gaṇeśa Temple, slightly in the interior of the fort and this is called *Bhavānī Śaṅkar* (Fig. 1).

There is an inscription in Nagari characters on a specially prepared top surface of the cannon (Fig. 2). Some information regarding the cannon is available from this inscription. The complete inscription could not be deciphered because the language is in some local dialect of the region. The translation of this inscription by knowledgeable scholars will provide additional informa-

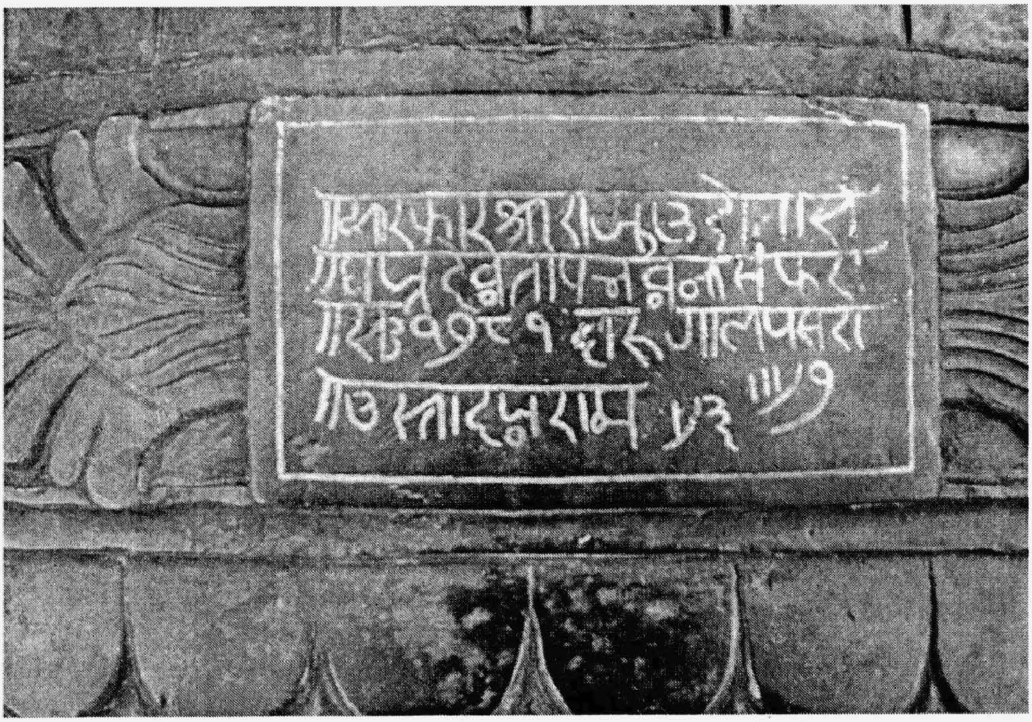

Fig. 2: Inscription on the cannon, seen on the ring containing the trunions, indicating the cannon was constructed in *Samvat* 1781, which is 1724 AD.

tion.

The notice put up by the Archaelogical Survey of India near the cannon reads as follows, "It is presumed that the cannon is having the strength of God Bhavānī, hence got this name. This cannon too is placed in the north-south direction having a crocodile face design in its frontal portion and the lateral portion is designed like an elephant face. The total measurement of the cannon is 5.00 m x 0.60 m with a diameter of 0.52 m. Just in the middle portion of the cannon there is an inscription of four lines that tells us the name of the cannon *Bhavānī Śaṅkar*, the name of the guru Jairam, dated 1781." Incidentally, the date 1781 mentioned in the inscription is preceded by *Samvat*. Therefore, assuming the *samvat* to refer to the Vikrama Samvat, the date of Samvat 1781 should be read as 1724 AD. The *Bhavānī Śaṅkar* cannon, therefore, was constructed during the Maratha period. The ASI notice should be suitably modified by stating *Vikram Samvat* before 1781 and also providing the date 1724 AD.

The operators of the two iron cannons in Jhansi fort during the war with the British are known. The *Kaḍak Bijlī* cannon. the largest in the fort, was operated by one Gulam Gaus Khan during the days of Rani Laxmibai. The *Bhavānī Śaṅkar* cannon was operated by a woman called Moti Bai. Both Ghulam Gaus Khan and Moti Bai lost their lives fighting the British. Their graves at Jhansi are mute testimony not only to their valour but also to communal amity.

Design

The iron cannon is half buried on a lime plastered stone platform, such that most of the lower portion of the cannon is completely buried inside the platform (Fig. 1). It is adviseable to remove the cannon from the concrete platform and place it such that the entire cannon is visible. This will also help prevent corrosion of the cannon in the buried region.

Similar to most medieval forge-welded iron cannons, this is a muzzle loading type, i.e. the cannon ball and the gun powder were loaded from the front of the cannon. Two solid cylindrical trunions, provided in the middle of the cannon, were used for pivoting the cannon for easy manoeuvrability during its use. These supports must have been used for manipulating the cannon's firing direction and also for aiding its movement and transportation.

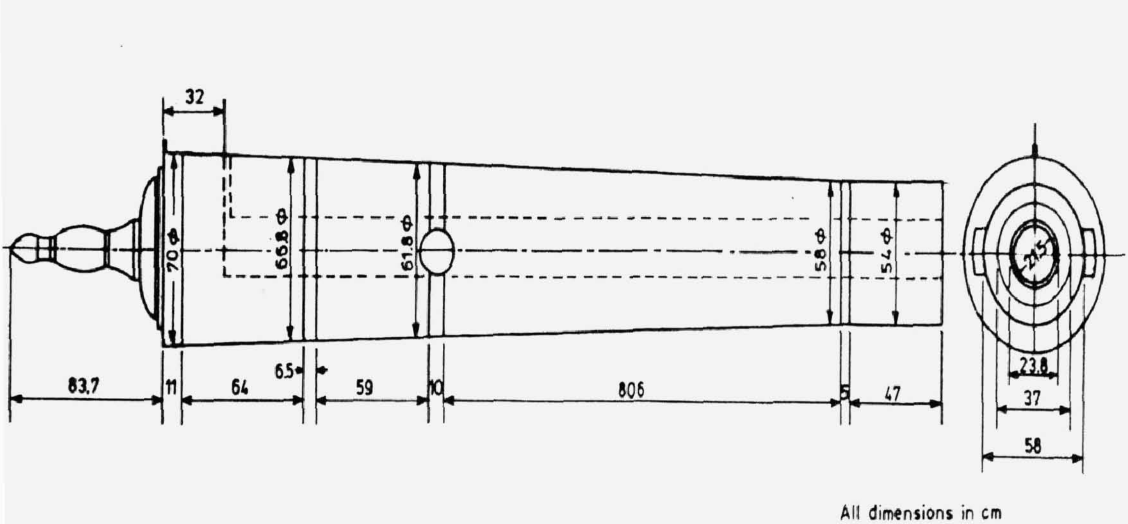

Fig 3: Engineering drawing of the cannon showing important dimensions.

The dimensions of the iron cannon are provided in the engineering drawing of Fig. 3. The total length of the cannon from the front to the extreme rear of the cannon is 502 cm. The weight of the cannon, estimated based on the measured dimensions, is 5 tons.

In addressing the design of the cannon, prominent details along the length of the cannon would be addressed. The section from the front end of the cannon to the first decorative ring can be considered as the first section. In this section, a design of a lion's face has been provided on the external surface. The second section can be assumed to be the location from this decorative ring to the protruding trunions, and the third section, from the trunions to the rear rim of the cannon. The third section contains a design of a elephant's face in the rear end. The last section is the rear end of the cannon.

The external portion in the front of the cannon is damaged on the top side (Fig. 4). This has presumably been caused by a cannon ball strike, as can be hypothesized from the cannon ball mark on the top side. The outlines of a lion's face is carved on the outer surface. The excellent design of the lion's

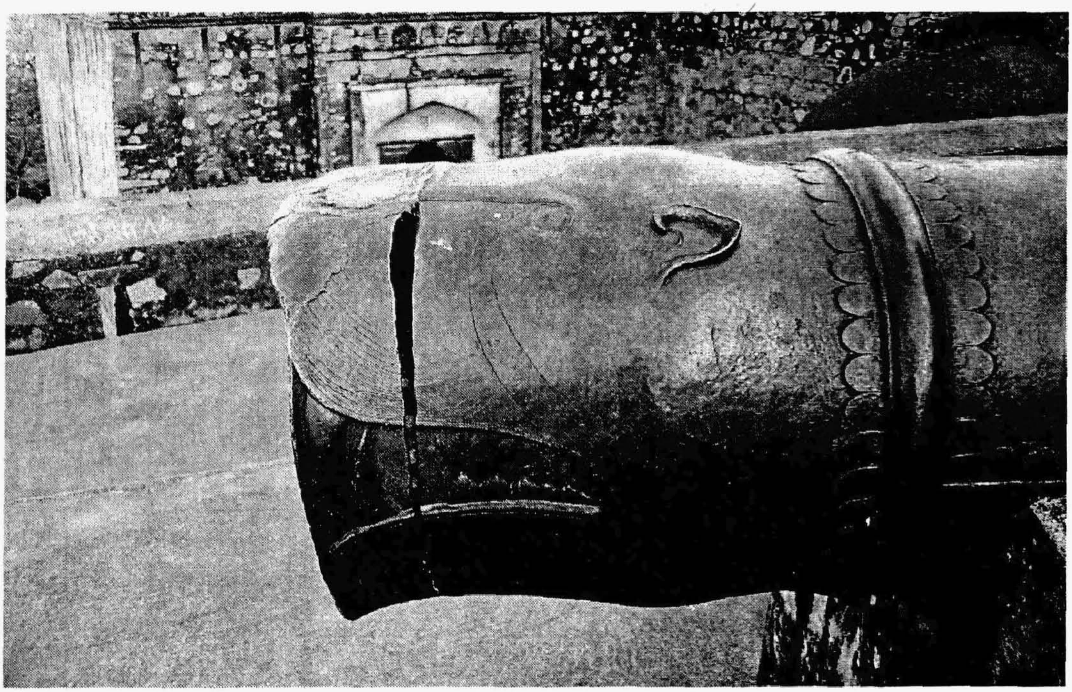

Fig. 4: Front portion of the cannon showing the design of the lion's face.

facial features must be appreciated. The ASI notice stating that the front of the cannon is designed like a crocodile also needs to be corrected. The damaged portion provides valuable ideas about the construction details of the cannon, namely the number of rings used to construct the thickness of the barrel. This will be addressed later.

The front face of the cannon (Fig. 5) reveals that the inside barrel of the cannon is constructed out of long iron strips or plates, running longitudinally across the whole length of the barrel. These iron strips are technically called staves in terms of cannon terminology. There are a total of 15 iron plates (each approximately 5 cm wide and 2 cm thick) which make up the inner diameter of the cannon.

The presence of iron strips running along the inner diameter of the cannon is similar to several other forge-welded iron cannons of medieval India

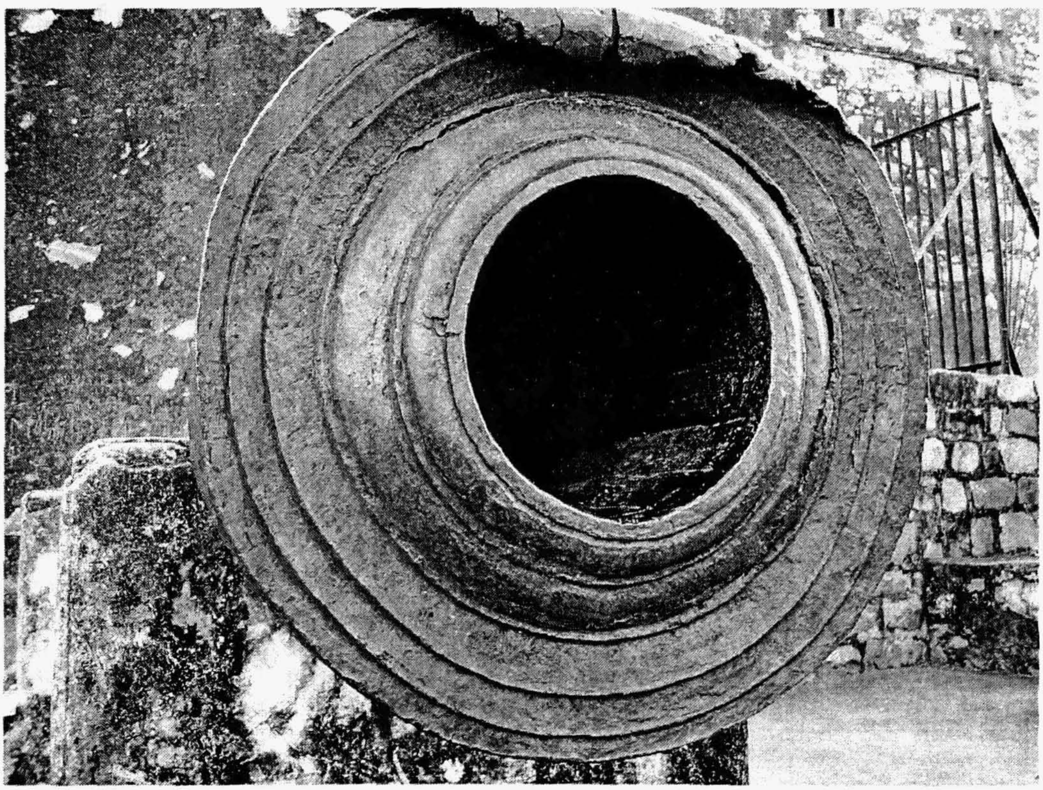

Fig. 5: Front face of the cannon.

[1,3,5,6]. The long iron strips, longitudinally laid out along the inner diameter of the barrel, must continue upto the rear end of the cannon. Interestingly, these strips have not been flattened out on the front plane, like the Thanjavur cannon. These staves were provided to obtain a smooth surface in the inside of the cannon as well as aid the smooth motion of the projectile. The smooth iron strips would have ensured higher accuracy for the cannon ball that was fired.

The front face (Fig. 5) further reveals that concentric iron rings were used in the construction of the body of the barrel to build up the wall thickness. The total number of rings used in the thickness is not clear by looking at the cannon from the front face. The front face apparently indicates that five rings may have been used. However, this is not true because the fractured region of front portion (Fig. 4) reveals that only two forge welding iron rings have been placed one above the other and forged together in order to obtain the cannon's thickness.

Based on observation of other forge welded iron cannons, it is clear that although the front portions of medieval iron cannons reveal presence of many rings, because of the nature of the design of the front face, the number of rings that actually make up the thickness of the cannon is usually two or three. Three rings were identified in the case of the forge welded iron cannons at Thanjavur[3] and Bishnupur [4]. Sometimes, an additional ring was provided on the front face, thereby providing additional stability to the structure and also an aesthetic look to the cannon.

The inner diameter of the cannon is 21.5 cm, while the outer diameter on the front face is 52 cm. In the engineering drawing of Fig. 3, the external diameter of the front face is provided as 58 cm. The additional material (about 3 cm thick) is due to the extra material provided along the edge. The inner ring, hooped over the iron staves, possesses an inner diameter (ID) of 23.8 cm and outer diameter (OD) of 37 cm. The outer ring posseses an ID and OD of 37 cm and 52 cm, respectively. This can be made out from the front damaged portion. The front end of the cannon, when viewed sideways, clearly exhibits a noticeable bulge near the decorative ring (Fig. 4).

The first section of the cannon, up to the first decorative ring, extends 47 cm from the front end. The total number of rings that make up this portion cannot be clearly made out by observing the surface. It is known that the approximate width of rings in the second portion is about 7 cm. Therefore we can estimate that the number of rings on the external surface is 7 in the first section, from the front face to the location of the first decorative ring.

The cannon barrel exhibits an increasing taper of its diameter from the decorative ring location onwards up to the rear end of the cannon barrel (see Fig. 1).

Counting the decorative ring as the eighth from the front plane, the iron cannon is further build up by iron rings of progressively larger diameter. There are a total of 31 rings between the first decorative ring and the ring on which the cylindrical trunions are located. This can be considered as the second section of the cannon. The width of the iron rings measure approximately 7 cm in

Fig. 6: Intricate design seen on the ring containing the trunions.

this location. The iron ring that supports the two handling trunions is 10 cm wide. The excellent designs inscribed on this particular ring must be noted (Fig. 6). Moroever, both the trunions have been carved to resemble the facial features of a lion. The trunions are placed diametrically opposite to each other and each of these solid cylindrical masses are of length 22.5 cm and diameter 19.5 cm. These have been intelligently forge welded on to the external iron ring. The iron ring containing these trunions is counted as the fortieth from the front plane.

The third section can be considered from the iron ring containing the trunions till the end of the tapered cylindrical barrel. There are a total of 17 iron rings seen on the external face in this section. Interestingly, these iron rings are between 7 and 8 cm in width, slightly greater than the width of the rings that are located in the front portion of the cannon.

The excellent design of the elephant head in the rear portion (Fig.7) must also be noted. The fuse hole is located at a distance of 32 cm from the rear of the cylindrical bore and this is located on the top of the cannon. The diameter of the fuse hole is 3 cm. The extreme last ring of the cylindrical barrel contains the sighting device that must have been used for aiming purposes.

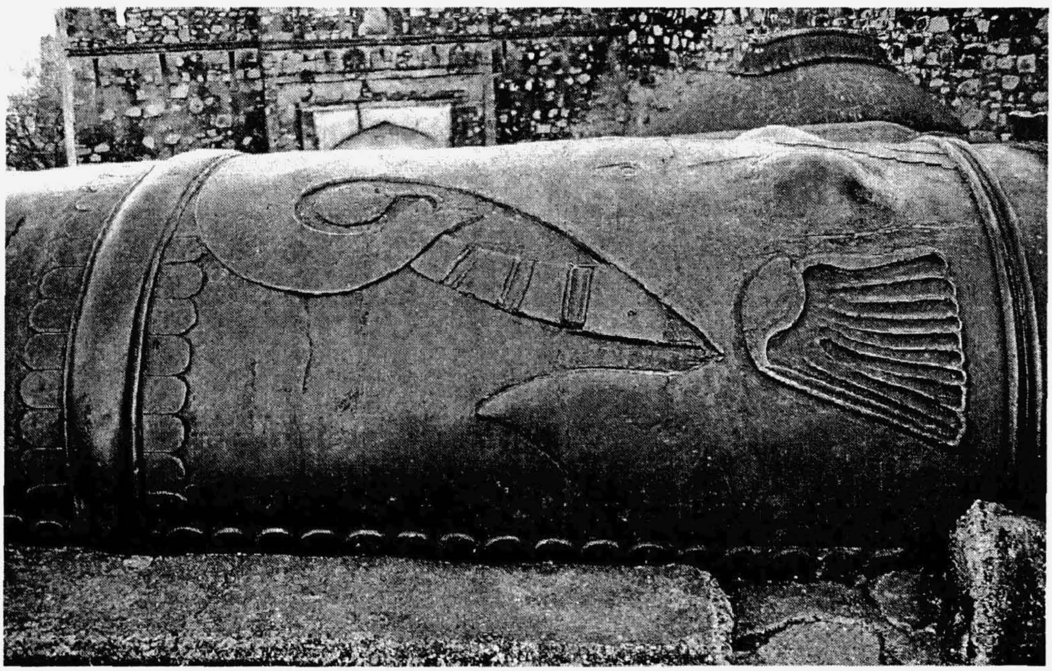

Fig. 7: Rear portion of the cannon showing the design of the elephant's face.

A total minimum number of 59 rings can be counted upto the end of the barrel. As it is known from the front face that two rings were shrunk fit over each other to produce the thickness of the gun, a minimum total of 118 iron rings have been used in constructing the tapered cylindrical barrel. It must be noted that the iron rings used in the back of the cannon are of progressively larger diameter and larger width. The diameter of the cannon at different locations has been indicated in the engineering drawing of the cannon in Fig. 3.

The rear portion of the cannon is in good condition (Fig. 8). The rear end is then made up of progressively decreasing diameter iron rings, culminating in an intrically designed rear rod (Fig. 8). The symmetric design of the rear end must be appreciated (Fig. 9). The portion from the fuse hole till the rear end of the cannon is solid and this has been assumed while estimating the weight of the cannon. In the rear section, the number of rings used in the construction cannot be made out with certainty. However, a minimum of seven rings can be counted based on the design of the cannon in the rear.

Construction

This iron cannon has been constructed by forge welding. Ideas about the construction methodology of the cannon can be gleaned from the front face of the cannon. The inner cylinder is made up of 15 iron staves. The barrel

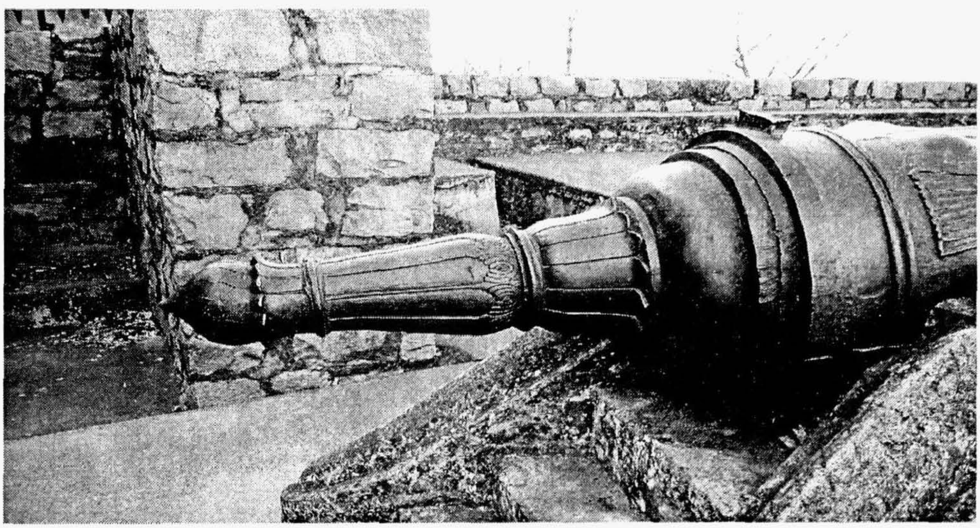

Fig. 8: The extreme rear end of the cannon.

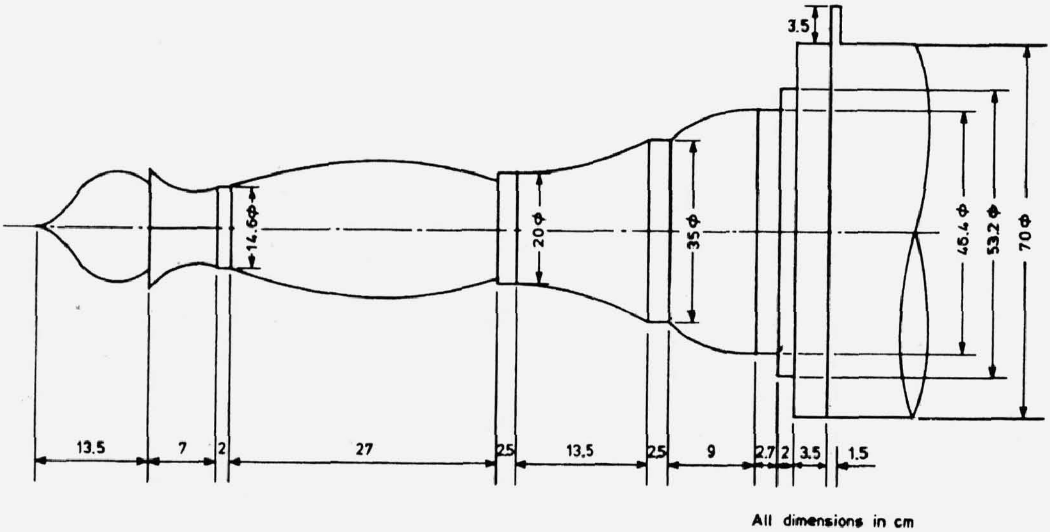

Fig. 9: Drawing of the rear portion of the cannon.

thickness is constructed by hooping two rings over the iron staves. The front end of the cannon reveals that two successively larger diameter iron rings have been used to construct the thickness of the cannon. The manufacture of the main barrel of the wrought iron cannon would have required shrink fitting of these rings over a central mandrel on which the iron staves must have been longitudinally placed. It must be realized that construction of the forge welded cannon must have necessarily been tedious because of the enormous skill (and time) required in precise dimensioning of the various rings. This is important because the rings had to fit tightly over each other once the rings cool down from the high temperature.

Apart from the strict dimensional tolerances that were required in the fabrication of the individual rings (with their varying diameter, thickness and width depending upon their location along the gun barrel), it would have required tremendous skill in the design and execution of the manufacturing of the cannon. The whole operation must have been conducted in the hot working range, further emphasizing the difficulties and skill in handling of the cannon during its manufacture. While shrink fitting the iron rings, the outer rings must have been position such they closed the gaps created between the inner rings. It can be also concluded that the forge welding of the iron rings has been performed in an excellent and skillful manner as can be gauged by good fitting of the outer ring over the inner ring and the iron staves.

MATERIAL CHARACTERIZATION

The surface of the cannon is almost free of rust. The color of the cannon depends on the time of observation of the cannon (i.e. morning, midday or evening). It also depends on the direction of sunlight striking the cannon. It was noticed that the surface appears reddish brown in bright sunlight.

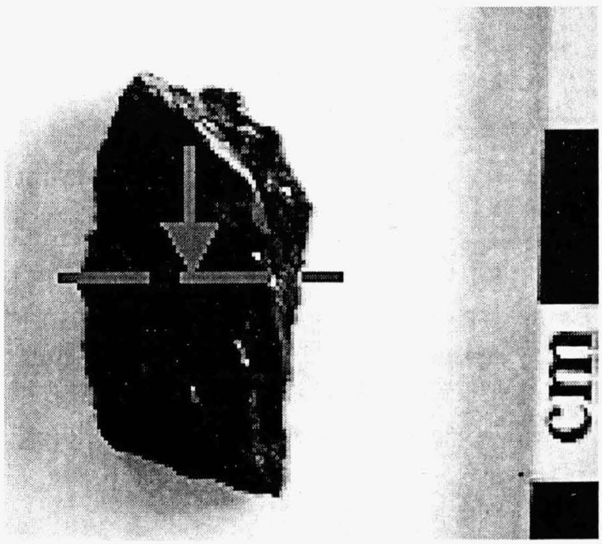

Fig. 10: Iron sample on the rear of the Jhansi cannon that was used for analysis. The surface that was used for observation was obtained by sectioning as indicated.

A small piece of iron was obtained from one location in the rear end of cannon for metallurgical analysis (Fig. 10). The details of the microstructure, and other analysis are provided here.

The sample was mounted in epoxy resin and this was sectioned to obtain a cross section of the metallic substrate. After mechanical grinding using SiC papers (grade 80 to 4000), samples were polished with diamond paste (3 and 1 μm) for observation in an optical microscope (OM). Before etching, the slag inclusion distribution in the metallic matrix was observed. This provided information on the structural heterogeneity of metal. The OM was also used to study the morphology of the corrosion products on the surface. The metallographic structure was revealed after etching with 2% nital. After repolishing, the surface was also etched with Oberhoffer etchant (cupric etching) to study phosphorus distribution in the metallic matrix [8,9].

The general scheme of the metallographic observations is given on Fig. 11. The first observation concerns the presence of slag inclusions in the metallic substrate. They were of three different types. In the first case, the

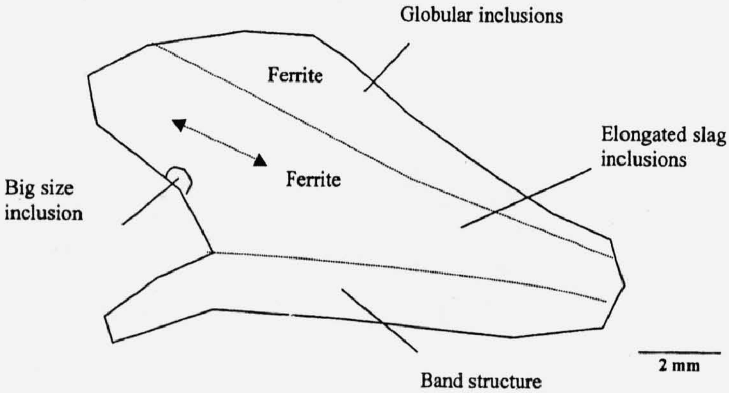

Fig. 11: General scheme of the metallic substrate observations

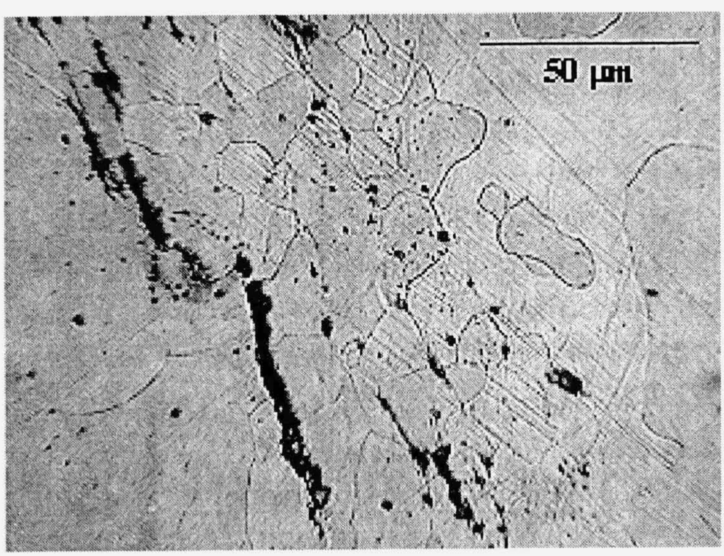

Fig. 12: Elongated slag inclusions observed in one part of the sample (Nital etching, optical microscope).

inclusions were present as elongated particles, oriented in a particular direction, indicating the direction of forge work (Fig. 12). They were relatively numerous in one part of the sample. These inclusions possessed a dark matrix and in some of them a lighter phase could be distinguished. This is characteristic of crystallized slag inclusions formed of fayalite–wüstite type phases. The second type of inclusions were globular and they were formed of light and dark phase (Fig. 13). Lastly at the interface between metal and corrosion products, one large inclusion was indentified. Its shape was non-elongated and it revealed lighter globular phases in a dark matrix (Fig. 14). These three types of inclusions were heterogeneously distributed in the metallic substrate. These observations suggest that this metallic sample has been forged from an inhomogeneous iron ingot. Based on the presence of numerous slag inclusions, the sample can be qualified as relatively poor quality metal.

Etching with nital revealed that the metallic substrate was composed of ferrite. The carbon content is therefore less than 0.05 wt. %. The grain size was between 10 and 70 μm and quite homogeneous throughout the entire sample. The grain shape was elongated in the same direction as that of the elongated slag inclusions. Moreover, some grains revealed watery zones reflection by slightly varying the focusing (Fig. 15). This could be ghost structures formed because of the presence of minor elements like phosphorous. However,

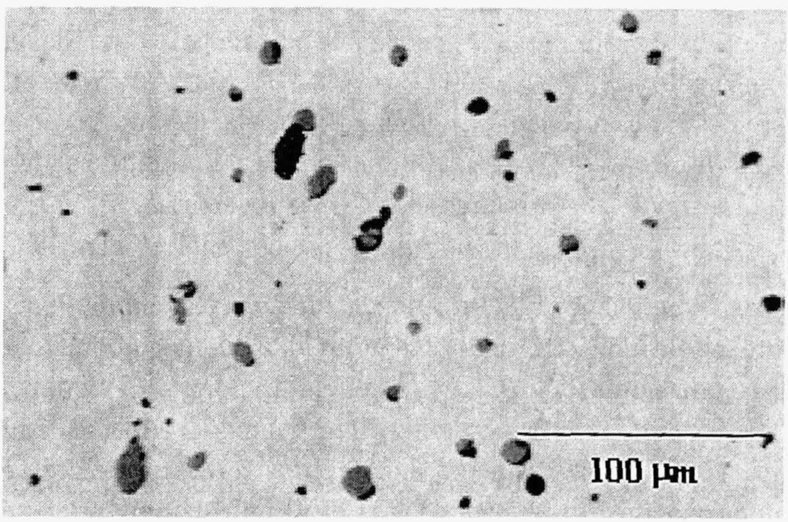

Fig. 13: Globular slag inclusions observed at another location in the sample

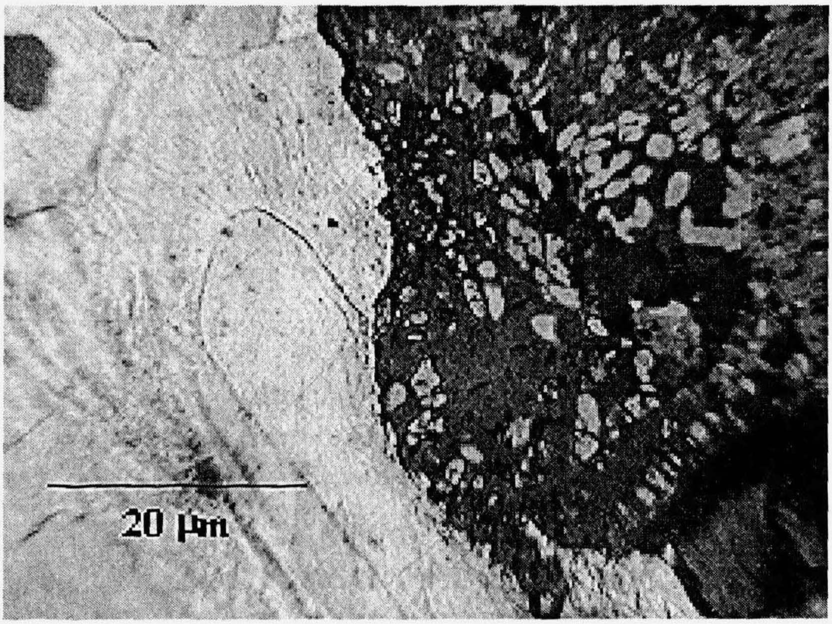

Fig. 14: Large slag inclusion observed in the sample (Nital etching, optical microscope).

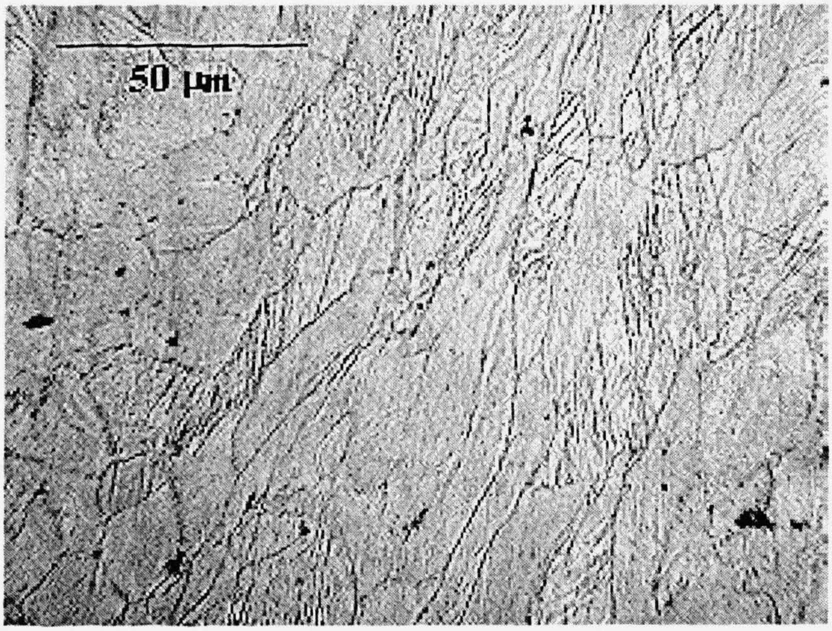

Fig. 15: Ferritic microstructure showing "watery" microstructure after etching with nital (optical microscope).

Oberhoffer etching did not reveal the presence of ghost structures. Additional compositional microanalysis of the metallic substrate is required to conclude on the presence of phosphorous in the metallic substrate.

Carbides were revealed to be in band structures in one zone of the sample as shown in Fig.16.

The iron for the cannon was produced by the direct reduction of the iron ore in shaft furnaces. As the temperature does not exceed 1300°C in shaft furnaces, metallic iron remains in solid state during the whole process. Only the iron ore gangue, composed of silicates and others phases, partly reaches a liquid state. This is evacuated separately from the bloom at the end of the process. However, some impurities remain in the bloom and post-extraction hammering is required for metal purification. This first step of production of iron ingots therefore dictates the amount of slag inclusions. Phosphorous can be present in the iron ore or in the charcoal used for the reduction step. This element diffuses partially in the iron during the reduction in the shaft furnace and its composition can be up to 1 wt. % in ancient artifacts produced by ancient ironmaking processes. One possible reason for the presence of a relatively higher amount of P in direct reduced iron has been explained in detail elsewhere [10]. The absence of limestone in the bloomery furnace charge results in a higher amount of P in the iron because the dephosphorization tendency of fayalitic slags is poorer compared to CaO-rich slags [10].

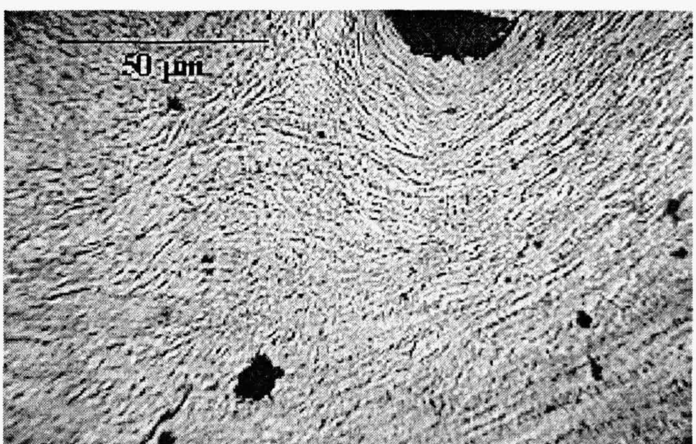

Fig. 16: Banded carbides seen in one location of the sample (Nital etching, optical microscope).

The relatively rust-free surface appearance of the cannon also provides additional support to the good atmospheric corrosion resistance. In fact, the amount of rust on the exposed surface was so small that rust collection for analysis also was difficult.

In order to analyse the phases locally in the corrosion scale, μRaman analyses were performed on the polished cross section. The spectrometer was a Jobin Yvon-Horiba LabRam Infinity model and an excitation at 532 nm was provided by a frequency-doubled Nd:YAG Laser. Spectral resolution of this set-up is about 2 cm^{-1}. Measurements were realised under microscope with a x100 long-focus Leitz objective which provided a beam waist diameter of about 3 μm. Excitation laser power on sample was adapted to each measurement and filtered at least below 0.42 mW in order to avoid the transformation of some sensitive phases under the laser irradiations [11]

The corrosion scale appears to be layered between darker and lighter strips of corrosion products throughout their whole thickness under optical microscope (Fig. 17). The darker phase has been identified as goethite (α-FeOOH) by Raman spectroscopy. The lighter strips are composed of magnetite (Fe_3O_4) or maghemite (γ-Fe_2O_3). It is difficult to discriminate these phases because heating caused by laser can transform magnetite into maghemite [11]. In one zone near the metal/scale interface, some akaganeite (β-FeOOH) was identified. This phase is due to the presence of chloride in the oxy-hydroxide lattice. Near the external zone of the rust layer, lepidocrocite (γ-FeOOH) mixed with goethite has been detected. Lastly, in some dark strips observed in the corrosion scale, carbonates where identified. It is not possible to determine exactly which carbonate is present but it is certainly a mixed compound of iron and calcium carbonate, like it has been detected on ancient iron artefacts under soil corrosion conditions [11,12]. These results are in good agreement with the analyses realised on indoor ancient corroded artefacts [13].

Usually, it is found in the literature that atmospheric corrosion leads to the formation of corrosion scales containing goethite, magnetite and lepidocrocite. Moreover, analyses of ancient iron artefacts exposed to outdoor atmospheric corrosion have evidenced the presence of phosphate in the corrosion scale[14]. Phosphorous could not also be indentified umabiguously in the

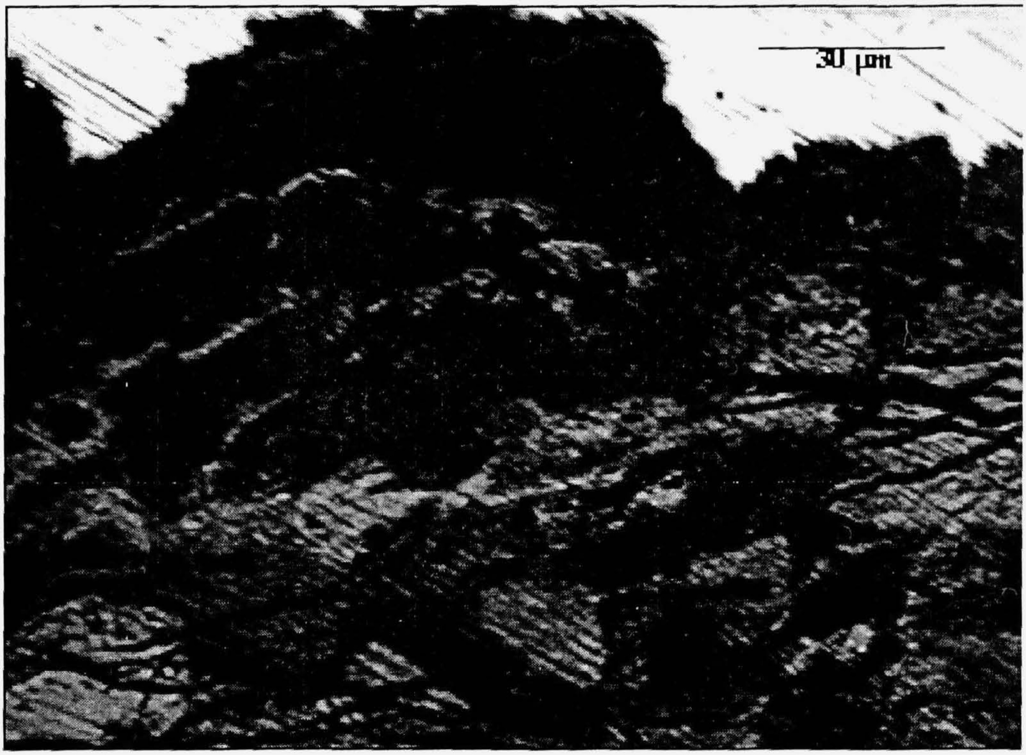

Fig. 17: Optical microphotograph of the corrosion scale.

sample. The metallic substrate of these samples contained phosphorous, which was assumed to lead to the formation of these particular phases. However, in the case of the sample from the Jhansi cannon, no such phases where detected by Raman microspectroscopy in the corrosion scale. Some complementary analyses by Energy Dispersive Spectroscopy could help further detection of this element in the corrosion products. Analysis of surface rust would also be useful. It is important to also understand the role of phosphorous because it exerts a beneficial effect on atmospheric corrosion resistance of iron[15].

Conclusions

The forge welded iron cannon located in the Jhansi fort, by name *Bhavānī Śaṅkar,* has been addressed in this communication. The dimensions of the cannon have been provided. The main barrel of the iron cannon was manufactured by forge welding two layers of iron rings over 15 longitudinally placed iron staves. The weight of the cannon has been estimated as 5 tons. A minimum number of 125 iron rings have been used in the construction of the cannon. The material of construction of the cannon is direct-reduced iron. Microstructural analysis of the iron revealed a heterogenous distribution of slag inclusions. The grain size was relatively uniform throughout the matrix. Although etching with nital produced ghost structures, the presence of phosphorous could not be confirmed by Oberhoffer etchant. The corrosion product layer was analysed by laser Raman spectroscopy and it revealed that the major constitutents of the corrosion product (i.e. rust) was goethite (α-FeOOH).

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