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Survey of Traditional Crafts Series No. 1

A MONOGRAPH

ON

INDIGENOUS SMELTING OF IRON

M. AHMED, M.A., I.A.S.

Superintendent of Census Operations

Orissa

SURVEY OF TRADITIONAL CRAFTS SERIES No. 1

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ON
INDIGENOUS SMELTING OF IRON

With the compliments of

The Superintendent of Census Operations, Orissa

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FOREWORD

TRAVELLING through Orissa, one is struck by the great number of primitive iron-smelting kilns that are still active, especially in the northern and western districts of the State. Few things make a more forceful impression than to find these kilns flourishing within a few miles of Rourkela—in some respects, the last word in modern steel-making. The prevalence of the antiquated smelting kilns not only serves to remind us of the technological gap ; it gently tells us that Rourkela notwithstanding, the crude village kiln still serves a useful purpose : it produces the type of iron which is just right for the type of agricultural implements in local use, which again are just right for the type of agriculture prevailing in the country so that it is impossible to say which is responsible for which. Above all, the iron produced suits the local peasant's pocket. The process of smelting, which has been so methodically and elaborately described in the monograph, shows how a skill has been preserved which, in its turn, serves to employ some amount of surplus human labour and makes use of local raw material, thus directly transforming human labour into wealth. The entire, almost continuous, smelting range from Koraput in the west along the northern districts of Orissa, up to Mayurbhanj and over again from Mayurbhanj through Singhbhum, Bankura, western Burdwan up to the southern bank of the Dwarka river in Birbhum district has now been practically broken off further east beyond Sundargarh, but serves, nevertheless, to remind us that much of India's requirements of iron used to be supplied by this girdle. But that the country still has use for this low-grade iron is proved by the survival of these smelting kilns and I was very delighted when Shri Ahmed accepted my suggestion to produce a monograph on this subject.

The process of smelting here described is of the crudest, being even less elaborate than what was described by Dr. Francis Buchanan Hamilton in his book on Mysore in 1807. The monograph has very successfully related the technology with the communities who smelt the ore and produce the iron implements and then again with the agricultural communities who use those implements. It thus succeeds in reproducing the fabric in which the industry still thrives and has also succeeded in relating this process with the past and present techniques of steel production.

NEW DELHI — A. MITRA

The 7th January 1963 — *Registrar-General, India*

PREFACE

WE HAVE great craft heritage but little material to tell about its problems and prospects. Outside the old gazetteers, an excellent and inimitable institution, few in recent years have thought it worth while to study and elaborate on local handicrafts. When the Census Organization decided to study the variegated phenomena of Indian life, traditional crafts of different States were included as one important branch of investigation and research. Directions were received from the Registrar-General to undertake study of a few important crafts and to prepare monographs which must be illuminating and instructive. Broad indications were given regarding the mode of selection of crafts which were to be grouped under three heads : (*i*) those which are dying out, (*ii*) those which are thriving, and (*iii*) new industries that are coming up. Emphasis was laid on the fact that the crafts must be very much indigenous, very much imbedded in our tradition. Some of these crafts may be traditionally associated with certain communities, while there may be some which may be associated with regional or extra-regional cultural complexes, being confined to no particular caste or community. Some of them, apart from being distinguished for considerable utilitarian value, should be objects of artistic excellence displaying creative imagination and depth of feeling. The Survey Wing of the office of the Registrar-General, therefore, insisted on a comprehensive study not only from a techno-economic point of view but also in terms of their contribution to the upkeep of the cultural values of the localities where they flourish. The investigation was expected to embrace such aspects as the existing condition of the craft, availability of raw materials, details of working technique, improvement in quality and design, competition from foreign or factory-made products, problems of marketing and finance, reasons of decay, promotion and revival and grant of commercial protection. The physical distribution of the craft was required to be plotted within a geographical area for the purpose of tracing out the evolving pattern. Lastly, the study should include an exegesis of the continuity of the craft since the earliest times.

The terms of reference required considerable erudition and scholarship. as well as extensive research and local investigation if the indicated standard was to be maintained. The facilities offered in the shape of sanction for appointment of Research Assistants or persons versed in the technicalities of the craft remained a mere consolation, for it was at the utmost possible to come across persons with some routine notions of the publicity aspect of attractive handicrafts but none having any insight into the science, the technique and the subtle skill behind the craft. Moreover, the time that could be set apart in proportion to other multifarious assignments and the conventional responsibilities of the Census Organization was too short to attempt a survey on the comprehensive scale as contemplated. A practical relief on the face of these limitations was derived from a very kindly gesture in the official direction, "Treat the data in a flexible manner". This served as a silver lining and induced selection of a few traditional crafts of Orissa for purpose of investigation which, however, was conducted on much humbler lines than those indicated by the Registrar-General.

In the following pages an attempt has been made to give a short and simple exposition of the indigenous industry of smelting of iron as practised in several districts of Orissa. The publication has no pretence to any comprehensive character of the survey of this ancient craft. The study was to a large extent focused at one particular centre with the hope of intensifying observation on certain aspects of the most common type of the clay furnace used for smelting of iron. Results of such observation have, as far as possible, been faithfully recorded so that they may serve as the basis for further measures that may be necessary for the resuscitation of the decaying craft and the rehabilitation of the men engaged in it, whose poverty and helplessness are progressively increasing. The investigation has established that it is possible to raise the pitiable level of earning of these traditional craftsmen by introducing improvements in their tools and techique, so that smelting as a cottage or household industry may not compare unfavourably with any other economic activity followed by the rural folk. A message of hope is thus derived, for it is not too late now to bring about amelioration in the condition of this poorest community of workers who strive hard to eke out a precarious livelihood, and to restore the declining craft its due place in the aggregate economy of the country.

I am grateful to my erstwhile colleagues Dr. A. K. Mallik, Chief Metallurgist and Dr. A. Khan. Chief Chemist of the Hindustan Steel Ltd., Rourkela, who, in the midst of heavy preoccupations on the eve of the expansion of the Steel Plant, ungrudgingly undertook to conduct the chemical and metallurgical analysis of the samples of raw materials and manufactured articles obtained from indigenous smelters. Dr. Mallik has kindly furnished an illuminating report of analysis which appears in the Appendix. I am also thankful to the Research & Control Laboratory, Rourkela Steel Plant, for furnishing six copies of Photomicrograph of the metals tested and analysed.

CUTTACK

The 14th December 1962 M. AHMED

SECTION 1

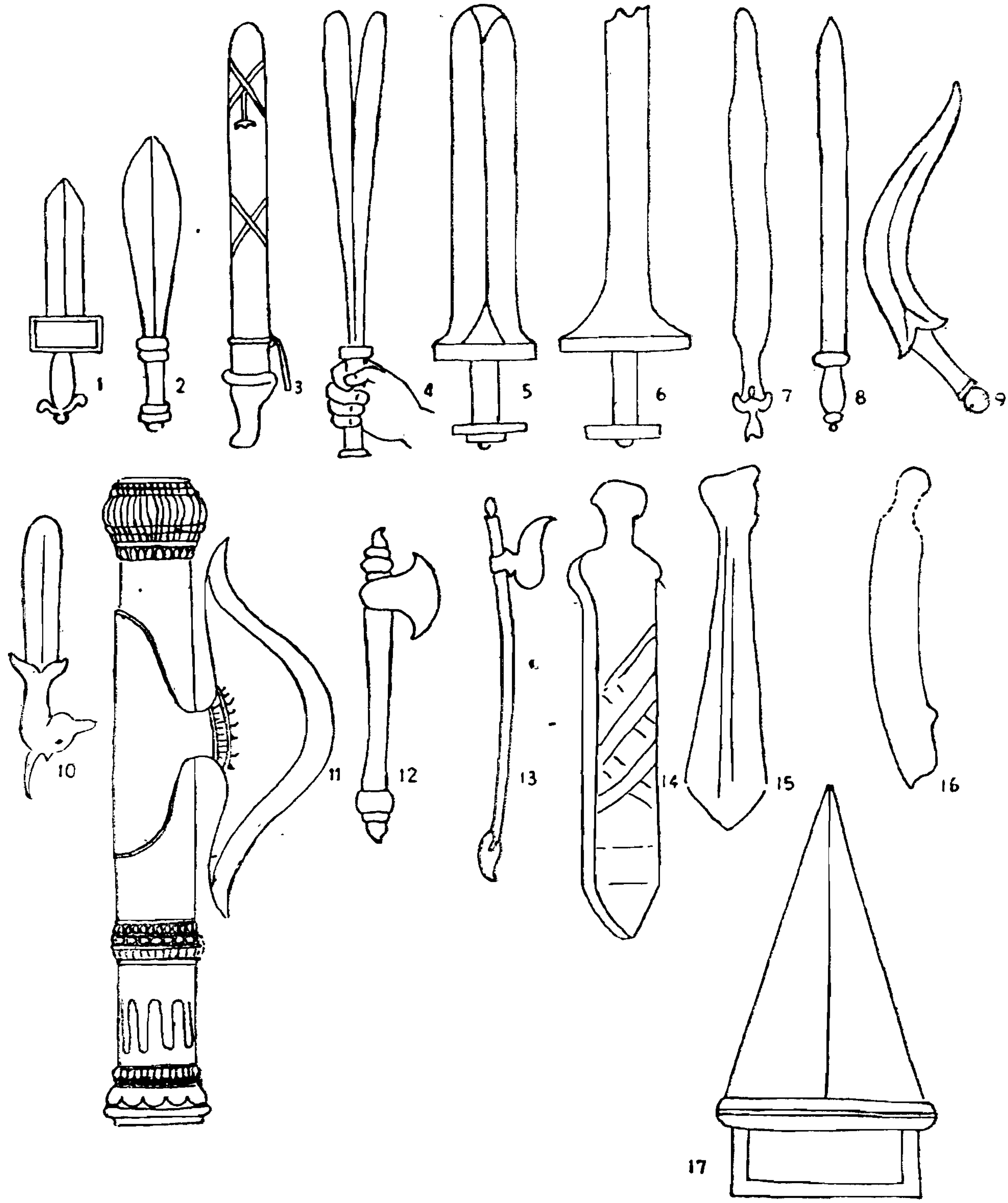
INTRODUCTION

Antiquity of Iron

The story of man's first use of iron is lost in the remote past. Iron is rapidly rusted and attacked by elements so that few samples of early manufacture remain now to give evidence of their use, unless they happened to be in localities where the atmosphere was relatively non-corrosive. It is, therefore, not possible to say how the knowledge of use of iron was acquired in India, or when was iron first discovered and produced, but its great antiquity is attested by references in the earliest Indian religious literature. Elsewhere in the world it was also in use, perhaps from an earlier age. The fragmentary writings or inscriptions on tombs and monuments which survived the fall of great Empires or ancient civilizations as those of Babylonia, Assyria, Egypt, Greece, Rome and China bear testimony to the antiquity of use of iron in the dim pre-historic past. Archaeological research has established that iron has been in use through a period of about 5,000 years. Some of the oldest known iron objects found in various localities of the world include a large piece found in the great Pyramid built about 2,900 B. C. in Egypt. It may be that these pieces of iron were not man-made, but were obtained from fragments of meteorites, which inference is based on the composition of the metal which contains a liberal proportion of nickel. Whatever be the source of their first acquaintance with the metal, the ancient peoples ultimately came to know that iron is a substance with very great possibilities than either copper or stone for the making of tools and weapons. Such knowledge heralded the dawn of Iron Age, when man-made iron began to be produced. The arts and crafts of the Greeks involved little use of iron, but the Romans appear to have been more resourceful in the extraction of iron, for the success of their extensive conquests was facilitated by use of iron in making weapons of war. Other peoples in the Continent also got acquainted with the use of iron by this period, for when Caesar crossed the English Channel, he found iron already in use among the native Britons. In India and China, the metal is believed to be in use at least as early as 2,000 B. C. Some of the authorities ascribe the discovery of the original process of smelting of iron to the people of India at a much early date.

Historical Background

2. Out of a multitude of references in the ancient literature of India relating to the use of iron, a few may be mentioned, such as the use of razors referred to in the Rig Veda, of warrior's coat-of-mail made of iron in the Yajurveda and of iron-made arrows in the Dhanurveda. There is an interesting account of tempering of swords in Brihat Samhita, the famous Treatise on Astronomy, which shows that the ancient people had the practical knowledge of various processes of making iron and steel and knew how to temper a blade with



WEAPONS USED IN ANCIENT ORISSA

(From *Antiquities of Orissa* by Rajendralala Mitra)

1.Lancet-headed dagger 2. Dao or bill-hook. 3. Straight sword in scabbard 4. Double-bladed sword 5. Another type of boubledeered sword 6. Broad straight sword 7. Jagged sword 8. Lancet-headed straight sword 9. Kukri 10. Dagger with deer-headed handle 11. Ganesa's battle-axe 12. Battle-axe 13. Curved-bladed battle-axe 14. Door-keeper's sword in heath (Udayagiri hills) 15. Warrior's sword (Udayagiri hills) 16. Another type of warrior's sword 17. Conical dagger varying technicalities so that it will cut off an elephant's trunk or so that it will be fit for piercing stones or so that it will not yield to whetting on a piece of stone or cannot be blunted by other iron instruments. Variations in the tempering process seem to have been effected by using a variety of liquids for 'quenching' the heated metal, a principle which is recognized even at the present time. The selection of the liquid depended upon the quality of the steel required to be produced for a specific purpose, and extended over a wide range of objects, namely, from water to organic matters, such as blood, ghee, milk from a mare or a camel or an elephant, a mixture of fish-bile with milk from deer, goat and horse blended with toddy, and many other queer liquid preparations.

Ancient Indian Steel

3. On attainment of a high degree of metallurgical skill, India started producing the most celebrated variety of steel known as the Wootz, produced from regions near about modern Hyderabad. It was extensively admired as a quality material for weapons of war. There are indications of the Imperial Romans importing the finest grade of steel then known to the world from some eastern source, which in all likelihood points towards India rather than distant China. A king in India was enjoined, by way of keeping away from ill omens, not to look at his own face in the reflections from the blade of his war sword, an idea which could not have been conceived if the excellence in imparting dazzling brightness to the finished product of steel had not been achieved. When Alexander the Great invaded India in the 4th Century B. C., King Porus is reported to have presented to him a 30-pound piece of Indian steel. The fact that a mere piece of iron was considered worthy of presentation to the conqueror of the world, leaves no doubt about the unparalleled excellence of the quality of the Indian steel.

4. Among the weapons of iron and steel used by the warriors of ancient times, some were massive and some sharp and slender. A study of the sculptures at Udayagiri, Bhubaneswar and Konarak reveals the use of a number of such weapons, namely, battle-axe, dagger, spear, javelin and swords of many varieties including double-bladed sword and conical sword. The world-famous Sun temple of Konarak liberally used iron as a structural material, particularly in the shape of huge beams, one of which is over 25 feet long, 11 inches broad as well as deep and weighs about 4 tons. These beams are rust-proof and have remained unaffected in spite of atmospheric and climatic conditions resulting from the salinity and humidity of the seacoast. Outside Orissa may be seen the wonderful famous iron column at the Kutub Minar near Delhi, which is believed to have been made about 3,000 years ago. It is the largest and heaviest single piece of iron, coming down to posterity from old times, and weighs about 7 to 8 tons. The forging and manipulation of massive objects, such as this iron column or the iron beams of Konarak remain a mystery down to the present age.

Inexhaustible Reserves

5. The principal factor contributing to the production of iron in India from ancient times seems to be the extensive occurrence of iron-bearing rocks in the country, sometimes abundantly lying as surface layer in hills and forests. It is now known

that there are inexhaustible deposits of high grade iron ores in several regions, namely, Orissa, Madhya Pradesh, Bombay, Bihar and Mysore. The iron ore reserves in India are estimated at 21,000 million tons* which are approximately one-fourth of the total reserves of the world. Orissa alone has about 8,000 million tons** of iron ores, which will be sufficient to feed a modern steel plant like the one at Rourkela for 4,000 years consuming at the rate of 2 million tons per year. The frequency and vastness of discovery of mineral resources resulting from progressive Geological Surveys justify the expectation that the total iron wealth of the country may be much more than what is known at present. An outline map is given here to indicate the approximate location of deposits of iron ore in Orissa.

6. ***Iron-bearing Minerals***—There are a vast number of mineral species which contain iron but only a few are of any commercial importance, because in most cases the iron content is too low to justify extraction of the metal. Iron-bearing minerals of chief importance may be grouped into four classes, namely, iron oxide, iron carbonate, iron silicate and iron sulphide, out of which the first variety of mineral is important for purpose of smelting. The mineralogical name of the rocks containing iron oxide are magnetite, hematite and limonite. Among these rocks, magnetite has the highest percentage of iron content, the others in order being hematite and limonite. Magnetite is difficult to tackle in usual type of smelting furnaces. The choice of smelters is, therefore, confined to the other two varieties of iron-bearing ores.

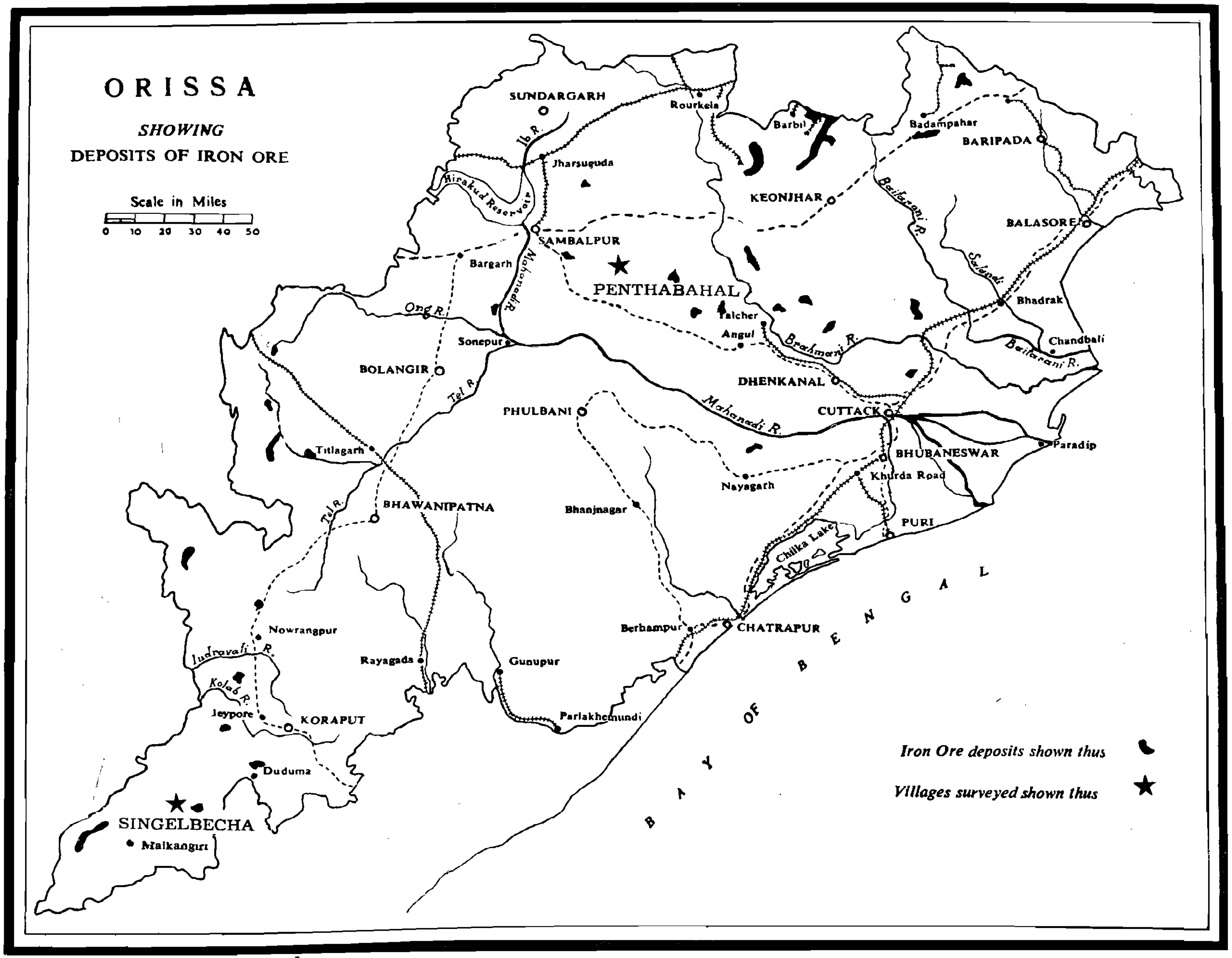
Scope of Present Study

7. The scope of the present monograph is limited. It relates to the study of the indigenous process of smelting of iron in small clay furnaces by a particular section of the village community of Orissa. The process conducted in different localities of the State is broadly the same, and the description of one of them would, *mutatis mutandis*, suffice for all except in respect of the underground furnace of the Koraput type. Thus, for the facility of close examination of the subject, the study has been confined to the smelters of one particular village, named Penthabahal in district Sambalpur. Incidentally, a quick survey was also made of the underground furnace existing in village Singelbecha in police-station Mathili, district Koraput and a brief report is included here, mainly to bring out the aspects of difference from the Penthabahal type. The location of these two villages is roughly shown in the Map of Orissa facing page 2.

Smelters of Penthabahal

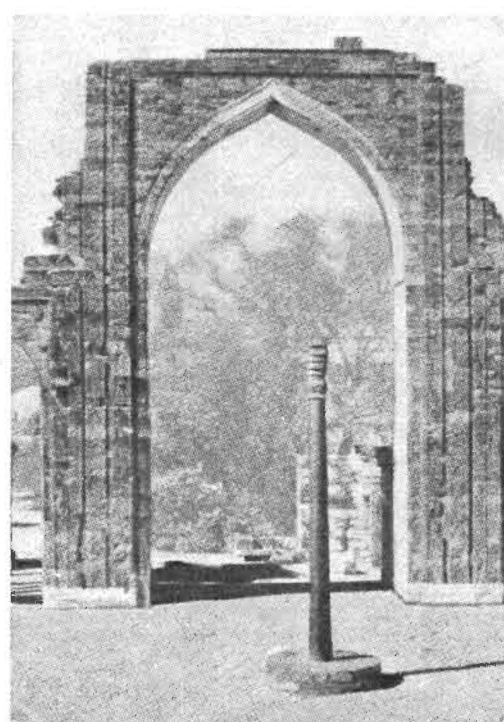
8. Penthabahal is a small village far in the interior of the undeveloped tract of country in Rairakhol subdivision of district Sambalpur. It is over 17 miles from the subdivisional headquarters and is connected by a fair-weather road which passes through dense forests and crosses a number of hill-streams which are not bridged. It is surrounded by isolated rocky ridges. and has to the South-East a prominent hill with an elevation of 1,351 ft. called the Kalapat hills. This hill is the source of supply of iron ores for the smelters of the village. The extent of deposit does not seem to have been surveyed ever, but taken as an

**Mineral Production in India, 1958*, Ministry of Steel, Mines and Fuel, page 97
***Techno-Economic Survey of Orissa* by National Council of Economic Research, page 55


ORISSA
SHOWING
DEPOSITS OF IRON ORE
Scale in Miles
0 10 20 30 40 50
SUNDARGARH
Rourkela
Barbil
Badampahar
BARIPADA
Jharsuguda
Ib R.
Hirakud Reservoir
KEONJHAR
Baitarani R.
BALASORE
SAMBALPUR
Bargarh
Mahanadi R.
PENTHABAHAL
Salandi
Bhadrak
Talcher
Angul
Brahmani R.
Chandbali
Baitarani R.
Ong R.
Sonepur
BOLANGIR
DHENKANAL
Tel R.
PHULBANI
CUTTACK
Mahanadi R.
Paradip
Titlagarh
BHUBANESWAR
Khurda Road
Nayagarh
BHAWANIPATNA
Bhanjnagar
PURI
Chilka Lake
BAY OF BENGAL
Nowrangpur
Berhampur
CHATRAPUR
Indravati R.
Rayagada
Gunupur
Kolab R.
Jeypore
KORAPUT
Parlakhemundi
Duduma
SINGELBECHA
Malkangiri
Iron Ore deposits shown thus
Villages surveyed shown thus

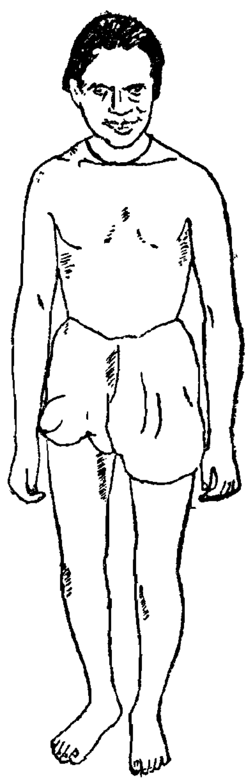
SUN TEMPLE OF KONARAK
...iron used as structural material

IRON COLUMN AT KUTUB MINAR
(Courtesy—Demag Aktiengesellschaft)



independent unit, it does not appear to be considerable in view of huge and inexhaustible occurrences elsewhere in Orissa.

9. About the beginning of the 17th Century some roving Konds first came across the iron-bearing rocks lying exposed on the surface of the Kalapat hills, and decided to settle down. They took to smelting of iron, and reclaimed lands for cultivation, but later migrated elsewhere in search of better prospects. It was left to a more adventurous group of cultivators at a later date to take advantage of the natural facilities available in the locality and to settle down permanently. They broke down conditions of wilderness and isolation and thus encouraged other communities to come and acquire habitation. Among these communities were the Kamars, whose sole means of livelihood was derived from the hereditary profession of smithy and smelting of iron. The Kamars have dark complexion, round face, flat nose and muscular physique and are well-suited for the profession they follow. Women are hard-working.



A Kamar

A Kamar woman

Other Centres of Production

10. The ancient technique of iron smelting is in vogue in many localities in Orissa. It appears that in bygone days wherever deposits of soft iron ore were found on the surface and close to forest areas where production of charcoal was possible, the smelting industry sprang up. Down to this day, the industry is carried on in many out-of-the-way villages in the districts of Koraput, Kalahandi, Bolangir, Sambalpur, Sundargarh, Keonjhar and Dhenkanal. Koraput alone may have

about 50 villages where the indigenous furnace is working. In Malkangiri subdivision, furnaces of underground type are extensively found in many villages, namely, Mendkuli Sindabada, Daudaguda, Mathili, Sirlaguda, Dangarkali, Ratabata, Chalanguda, Pakuaguda, Singelbecha, etc. In Nowrangpur subdivision, the villages situated round about the Hirapur hills and the Podagarh hills have thriving smelting industry. In Bonai and Deogarh subdivisions of Sundargarh district, in Athmallik, Angul and Talcher subdivisions of Dhenkanal district and in Rairakhol and Deogarh subdivisions of Sambalpur district there are many villages where the industry is doing well. The village Penthabahal in Rairakhol subdivision and some villages around it, namely, Kadopada, Tinkibiri and Brahmanpali, are noted for production of indigenous iron and for manufacture of tools and implements.

11. *Centres closed down*—In course of the present survey, however, one deplorable fact came to notice. The indigenous smelting industry was found thriving in several villages of Umarkote police-station in district Koraput during the period of the Census enumeration in February 1961, but by the time the present survey was undertaken in the latter half of the year 1962, the industry had no trace of existence in many of these villages. A comprehensive list has not been drawn, but a few of the villages where the industry has completely died out during the year 1961-62 are Semla, Sunabeda, Naikguda, Gorama, Ekma, Dhanpur, Achala, Malaguda (Janiguda), Murtuma, Buruja and Sirliguda, all located in Umarkote police-station. The smelters while deploring the loss of their traditional livelihood blamed some subordinate officials who stopped removal of ores from the nearby reserved forest areas. The region round about Umarkote is now within the ambit of the Dandakaranya Project, where resettlement and rehabilitation of refugees is in progress, and a large number of officials have been stationed. Some overzealous subordinate officials seem, probably without the knowledge of superior authorities, to have brought about this total destruction of an indigenous industry which kept generations of innocent craftsman happy and prosperous in that hitherto wild, inaccessible yet self-subsisting tract.

Quantity of Production

12. Although there are so many production centres in Orissa even at the present time, the total output does not appear to be considerable. The village Penthabahal, which has two furnaces working regularly, produces barely 12 to 15 seers of iron per week. The total production from clay furnaces existing throughout Orissa may not exceed 50 tons a year. This compares unfavourably with the quantity of pig iron produced by indigenous process in China, which in the form of a decentralized cottage industry is believed to have yielded several million tons per annum during the Second World War; though of late there is a sharp decline, as observed by the Indian Technical Delegation which visited China in 1959.

SECTION II

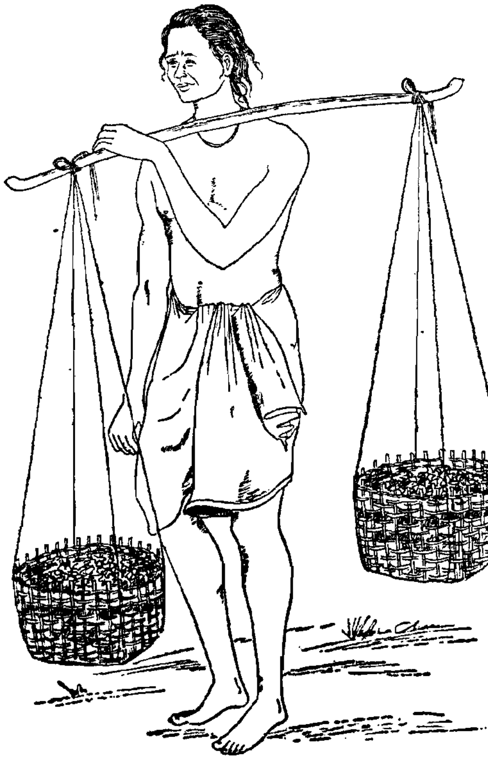
RAW MATERIALS AND EQUIPMENTS

Iron Ore

13. The ores used by the smelters of Penthabahal are obtained from the Kalapat hills and are reddish-brown in colour and slightly porous. On examination they are found to be partly hematite and partly limonite. These two varieties of iron-bearing rocks are extensively distributed over many regions in India. Hematite is reddish in colour and has higher iron content. Limonite is comparatively lighter and is porous and looks brown. The ores of the Kalapat hills may be classified as 'sub-native', being available on or near the surface of the ground in an impure condition. They occur intermixed with reddish-brown soil spread in patches here and there over an area of 4 to 5 square miles, giving little promise or outward indication of their valuable content.

14. *Chemical Analysis*—Pieces of ore collected from the hill, which the Kamars of Penthabahal use for extraction of iron, were put to chemical analysis. The report of analysis conducted by an eminent Metallurgist is given in the Appendix. It appears that the iron content in the ore is not high, namely, 45 per cent, but the proportion of silica and alumina is satisfactory, namely, 13 and 7 per cent respectively. It may be interesting to compare side by side the relative data of the ores used in the Rourkela Steel Plant. This modern factory uniformly uses high-grade ores standardized by processes of blending and beneficiation of the raw materials received from two different iron ore mines located at Barsua and Badjamda. The minimum iron content of the ores thus made ready for the blast furnace is 60 per cent. Silica and alumina constitute about 2 and 3 per cent respectively. It is useful to note that the ore which contains more of silica and less of alumina is more easily fusible, requiring less temperature for the process of reduction. The Kalapat ore has a silica-alumina ratio of 2:1, while Rourkela has an adverse ratio of 1:1·5. This great redeeming feature of the Kalapat ores makes up for the deficiency in iron content, which is 45 per cent as against 60 per cent of Rourkela. The Kamars of Penthabahal, in fact, do not mind a low-grade ore, if it is soft and can be easily smelted.

15. *Collection and Transport*—The Konds, who happened to be the earliest batch of people to utilize the ores of Kalapat hills, are supposed to have previous knowledge of identification of ores suitable for smelting process. When the Kamars came later, they possibly got indications of the previous smelting industry by the Konds and settled down to the work in a business-like manner. The Kamars usually collect pieces of ore-stones lying on the surface of the hill and then dig, say up to six feet deep, wherefrom an abundant quantity of stone-pieces varying in size from one-fourth inch to five inches are found. They do not go below a depth of six feet even if the bed of ores continues, in order to save labour in lifting the heavy material. A woman worker of the family generally assists the Kamar in collection of ores in split-bamboo baskets. But the transport is done by the Kamar himself as it is a strenuous job to carry the heavy



A Kamar carrying ore-stones by *bhar*

stone-pieces from the hill site to the workshop. For such transport, he uses a *bhar,* i.e., a springing split-bamboo pole put across the shoulder with two basket-loads slinging down from two ends. The Kamars should have done better by using a bullock-cart for such transport, owning it either jointly or separately so that some amount of unnecessary labour could have been saved and diverted towards handling of larger quantity of smelting materials. But they are poor, and cannot afford to possess a pair of bullocks and a cart even on joint basis. They have not even thought of hiring a cart from a neighbour-cultivator as it involves payment in some form.

Charcoal

16. Besides iron ore, the other raw material used for smelting of iron is charcoal from wood. The Kamars are expert charcoal burners. They make it usually from *sal* or *jaman* tree, which yields charcoal suitable for conditions of combustion and blast as obtaining inside the smelting furnace. They move about in the forest trying to locate dead and dried-up trees which are approximately a foot and a half in circumference. Trees which are thinner, and twigs and small branches of trees are not used for production of charcoal, because they may either get completely burnt into ashes or get reduced into too small a size of charcoal-pieces, which are uneconomical for use in the furnace or the forge. The dried-up trees of suitable girth are cut into logs 4 to 5 feet long. Half a dozen of such logs are piled up and a quantity of dried leaves or twigs are

A Kamar woman with a head-load of charcoal inserted in the openings to take fire from a straw torch which is carried from the village for setting fire to the pile of logs. It takes about $2\frac{1}{2}$ to 3 hours for these logs to burn into charcoal. The well-burnt portion of the charcoal is collected into baskets, leaving the unburnt or half-burnt portion at the site as useless for their purpose. At times, this discarded material is used up in the next burning process, but generally the inclination is to try fresh pieces of logs. After charcoal is collected in baskets, it is transported either by women in head-loads or by men in *bhars*. Two days in the week, namely, Wednesday and Thursday, are set apart for burning charcoal and transporting ore and charcoal to the site of the furnace.

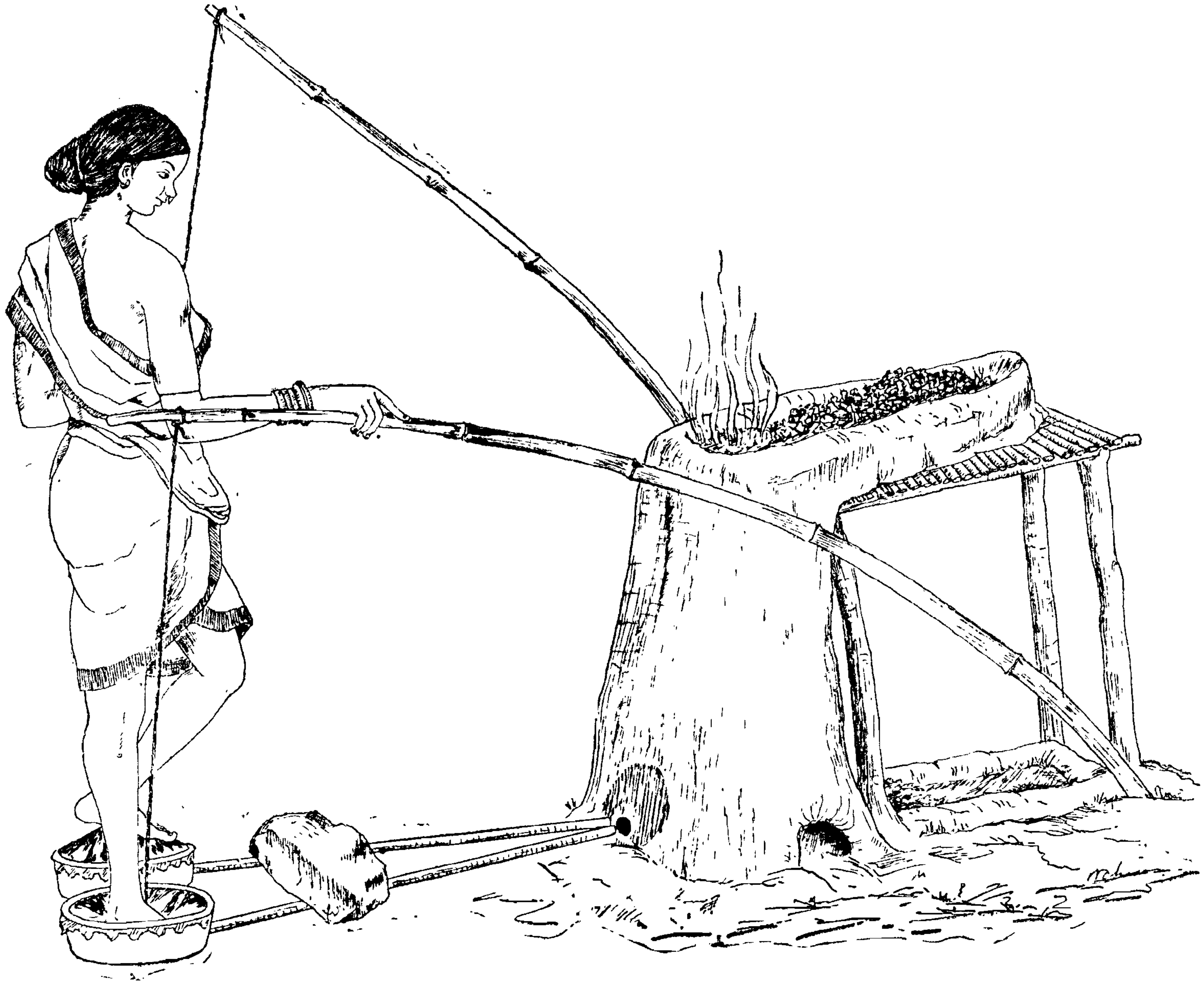
Furnace

17. The first object that engages a visitor's attention on entering the smelting shop is the furnace. It is a cylindrical kiln called *bhati* in local language and is made of clay. The *bhati* has an overall height of 36 inches with an outside circumference of 58 inches. The diameter of the opening at the top of the furnace is 12 inches. There is another opening at the base of the furnace on the front side which is 12 inches high and 10 inches broad in the centre narrowing down to 7 inches both at the bottom and top of the opening. It is meant for fixing the blast nozzle and for allowing the smelt product to be removed. In this opening the nozzle is fitted which consists of a baked clay tube 7″ in length, about $1\frac{1}{2}$″ across at the wider end and slightly tapering. The nozzle is fixed by packing moist clay or wet sand so that heat may not escape but blast may pass through the nozzle. On the right side at a little lower level is an aperture for draining out useless molten matter from the furnace. It is appropriately called the 'hagani-gada' or an aperture for excretion. This opening is 7 inches broad at the bottom and 4 inches at the top and is 7 inches high. On the side opposite to the nozzle, there runs backwards a wooden platform 28 inches long and 18 inches wide. It is 43 inches high at the rearmost portion inclining 5 inches downwards till it reaches the top of the furnace. This serves as a slide-down platform for charging charcoal or ore into the furnace conveniently. It is called *machan*. It is plastered with mud and is provided with small ridges on three sides about 3 inches high. Below the *machan* is a shallow pit which is utilized for storage of the slag for the time being until removed to a distant heap.

The Bellows

18. The bellows used in the smelting shop are distinctive and very much different from the hand-bellows of country smiths or rotary blowers of modernized shops. The bellows are made of a section of trunk of *gambhari* tree shaped so as to be 11 inches in diameter on the upper side and 10 inches on the bottom side, with a height of 5 inches in all. The inside of this piece of wood is dug out so as to make a cavity $7\frac{1}{2}$ inches in diameter on the upper side, leaving the bottom intact and a hole is made on one side to take the bamboo pipe which is meant to carry the blast to the furnace. A piece of hide of *sambar*, deer or goat is stretched across the top in the fashion of a drum* and tied down strongly with seven rounds of *siali* rope so as to make it air-tight. In the

*In Koraput district (village Singelbecha) the smelters use a piece of discarded thick rubber tube of the wheel of a bus or truck, which is available in Jeypur town for Re. 1 only. It is more flexible and is reported to be more durable than the hide of a wild animal used in Northern Orissa.



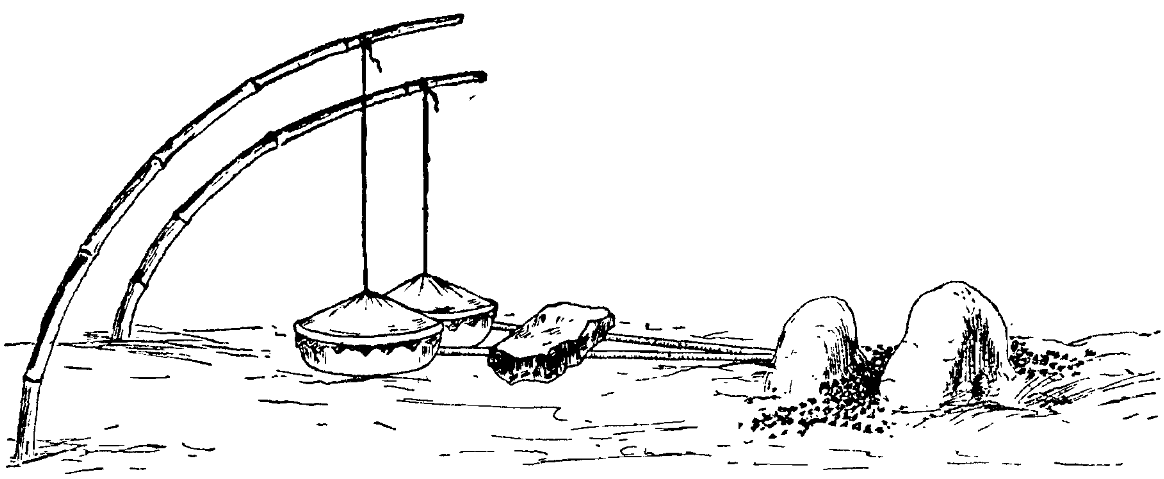
CLAY FURNACE

.... blast is steadily maintained and red and blue flames keep on fluttering above top of the furnace .... (*See* para 25 centre of this cover a hole is punctured and a rope is passed through and is held in place by a twig or a nail. The other end of the rope is tied to a springing bamboo called *dang,* one end of which is buried in the ground.

19. In this manner a pair of bellows lie side by side in front of the furnace, fitted air-tight with bamboo pipes 2½ feet long leading from the drum to the nozzle of the furnace. Before the bellows are worked, the hide-cover is soaked in water to make it sufficiently pliable. When the pair of bellows are ready for operation, a Kamar woman, generally the wife or the daughter-in-law, rides over them with one foot on each of the bellows and starts depressing and releasing them alternately. The holes in the centre of the covering hide act as valves. As the foot of the bellows-worker depresses, her heel serves as a stopper to the valve and forces the air through the bamboo pipe into the nozzle of the furnace. When the foot is taken off, the bellows get released and the bamboo stick springs lifting the hide-cover. At this stage the hole in the cover is open and the bellows are filled with air by such action. She holds the springing bamboo for support but occasionally holds a stick in her hand. The two bamboo pipes are kept under a piece of heavy stone to remain stable during the bellowing operation. Otherwise the pipes are liable to be thrown out with the pressure of air coming from the drum.

The Forge

20. A little away from the clay furnace, there is the forge which is used for heating and reheating the sponge iron for refinement and for manufacture of various articles. It is a simple structure. There is a small nozzle fixed by mud in the ground and inclined slightly downwards to a small pit filled with charcoal. There is a small earthen wall about 12 inches high and 18 inches long built at right angles to the line of the nozzle which has a hole leading to a still deeper pit in the ground. This pit serves as a flue and an escape for useless materials which might be still forced from the iron in course of its refinement. The bellows which were in work in the furnace are shifted and placed so that the bamboo pipes converge into the nozzle. The forge is ignited by charcoal. The bellows start sending blast and raising temperature of the fire. The fire is then utilized for

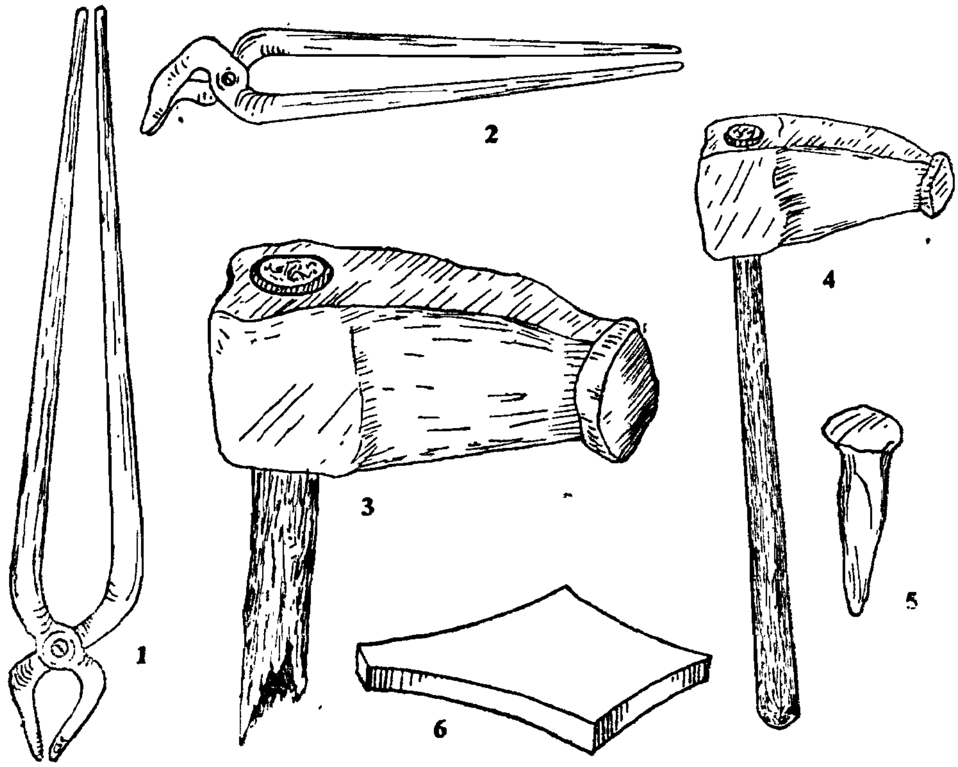


Foot-bellows and Forge

heating and reheating either the sponge ball for expulsion of last traces of impurities, or the wrought iron billet for further improving the quality of the metal and shaping it into particular tools or implements which are in demand in the local market.

Forging Tools

21. Among the tools and implements necessary for forging and allied work, the most important ones are the hammer and the anvil. For heavy work there is a piece of large granite boulder which serves as an anvil. It has no specific name, but is simply called *muguni pathar* or granite stone. Hammers are of two types. The heavier one is called *'ghana'* which is a solid heavy block of iron tapering towards the working end and having a hole through the opposite end in order to hold the wooden shaft. Both ends are blunt and are square in cross-section but of different dimensions. It measures nearly 10 inches in length and weighs without the shaft about 10 pounds. The



TOOLS FOR FORGING

1. Sanduasi (tongs) with straight lips 2. Sanduasi (tongs) with curved lips 3. Ghana (ten-pounder hammer) 4. Hathudi (light hammer) 5. Atila (punch) 6. Nehi (small steel anvil)

wooden shaft is 28 inches long and 2 inches in diameter. The other hammer is smaller in size and is known as *'hathudi'*. It is meant for lighter work and is used in shaping tools and implements. The *'sanduasi'* or tongs are of two different types, one with straight lips and the other with curved lips. Both the types have long arms for effective grip with the lips which are pointed. It is generally 18 to 24 inches long. There are several other tools small but quite necessary. Important among them are a small steel anvil called *'nehi'*, flat in shape and with concave sides and the punch called *'atila'* meant for cutting or piercing hard substances.

SECTION III

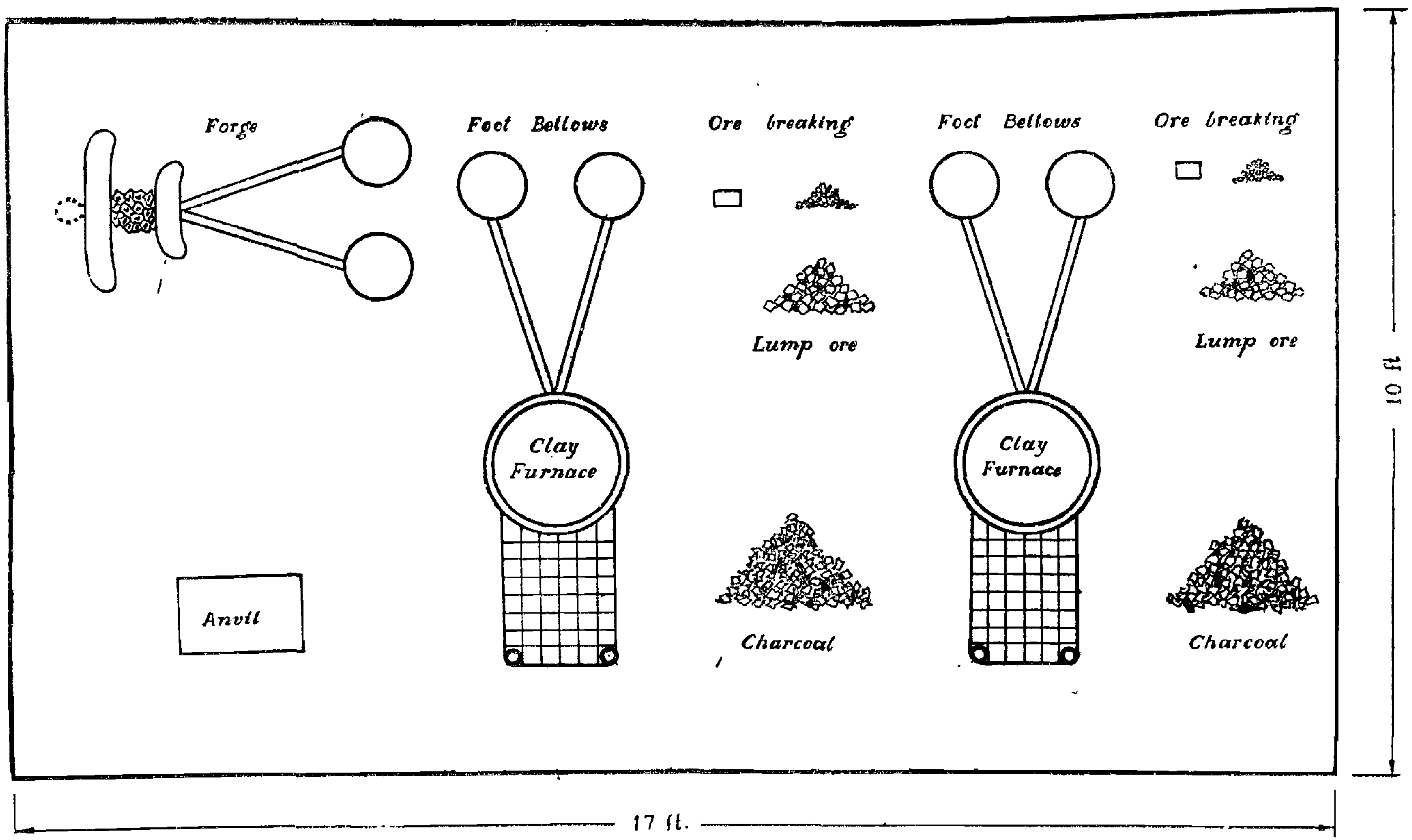
TECHNOLOGY

Process of Smelting

22. The origin of the process used by the Kamars of Penthabahal of extracting iron from ore is unknown. As however, the industry has continued to thrive from century to century, it is not likely that these Kamars developed the technique independently. Moreover, the same process with little or negligible variation is in vogue in many other centres of production. Whatever be the origin, it is certain that the Kamars possess adequate practical knowledge of the conditions under which extraction of iron becomes possible. These conditions are that the iron-bearing ores should be heated strongly in contact with hot carbon out of contact with air. Small lumps of ore placed in a hearth surrounded completely by burning charcoal meet these conditions to a considerable extent. The ores available from the Kalapat hills are a combination of iron with oxygen and other matters. The process mentioned above drives away oxygen from the ores ultimately to combine with the hot carbon, leaving iron in a metallic state. In more appropriate language, the iron is said to have been reduced from its oxide. The process by which such reduction is effected is called smelting. Charcoal plays a multiple role in this process. It generates heat required for the melting of ores. It is an excellent fuel. It also acts as a chemical reducing agent by inducing carbon from the charcoal fuel to combine with oxygen from the iron oxide contained in the ore. The process of heating, melting and of chemical transformation inside the furnace is a metallurgical operation by which the metal is separated by fusion from the impurities with which it may be chemically combined or physically mixed.

The Experiment

23. A full-scale smelting operation was watched in order to study the process. The results are given below indicating the time taken, the quantity of raw materials charged and the number of charges made during one single operation. To begin with, the interior of the furnace was filled with charcoal which has a capacity for taking 20 standard seers of charcoal of average size. Thereafter, a quantity of lump ore weighing 2½ seers was placed above the column of charcoal.



SKETCH OF —SMELTING SHOP OF SRIDHAR PENTHOI OF FENTHABAHAL

Fire was introduced at the nozzle and air blown. At first a few short and sharp blasts from the bellows were given to ignite the charcoal. Thereafter the bellowing operation took a regular rythmic form. Within a quarter of an hour the column of charcoal began to settle down due to loss in combustion resulting from continuous blast. A small quantity of charcoal was then added. A few minutes later the second skip of lump ore was put in. In this manner charcoal was added in quantities differing from half a seer to more than 3 seers and lump ore at the rate of 2½ seers each time every 10 or 15 minutes. Within a couple of hours from the start, charcoal had been added 9 times and lump ore 12 times, the total weight of each of the materials being 30 seers. The operation of adding lump ore each time is called in Kamar's language a *bhadi*. One smelting operation is completed in 12 *bhadis*.

24. For the first half an hour or so, the furnace is charged with coal and lump ore alternately 4 times. At the end of the fourth *bhadi*, the escape hole which is locally called *haganigada* is opened just for a few seconds to allow the *gangue* (waste material) to escape into a pit adjacent to the furnace. The escape hole is sealed at once with wet sand after the *gangue* is allowed to run out. The smelters do not allow a considerable quantity of this matter to remain within the furnace as it will adversely affect the smelting operation. If allowed to accumulate, this molten material may ultimately drown the burning charcoal and reduce the thermal efficiency of the furnace. At the time of each *bhadi* subsequent to the fourth, the escape hole is opened for letting out the waste material. Thus out of 12 *bhadis*, the last 9 are immediately followed by the draining out of the molten matter.

25. During the entire operation the blast is steadily maintained, and red and blue flames keep on fluttering above top of the furnace with occasional burning cinder bits flying out. Within half an hour from the start or by the time of the fourth *bhadi*, the lump ores start descending to the lower portion of the furnace, emitting a lot of useless softened material. At this stage the ore begins to get reduced to a semi-metallic state and move further down to the lower region of the furnace where the temperature is highest. The earthy waste material and other useless substances have now been melted into a fluid. This molten fluid is called *gangue*. As it comes out of the furnace it solidifies in contact with air in the pit outside the furnace. The *gangue* also contains some unreduced portion of the lump ore due to inadequate fusion resulting from defective operation.

26. In the above manner when the twelfth *bhadi* is over and the *gangue* has been let out from the furnace 9 times, the smelting operation stops because the Kamar judges the iron to be ready at this stage. The bellows stop working and the clay fittings at the nozzle are demolished and removed, when a blazing body is visible inside. This is pulled out with a pair of tongs and is taken direct to the granite anvil (*muguni pathar*). Meanwhile the woman who was working the bellows pulls out the burning charcoal from inside the furnace and throws water over it. The extinguished charcoal is kept

aside for being thrown away as it has become unfit for further use in the furnace or the forge.

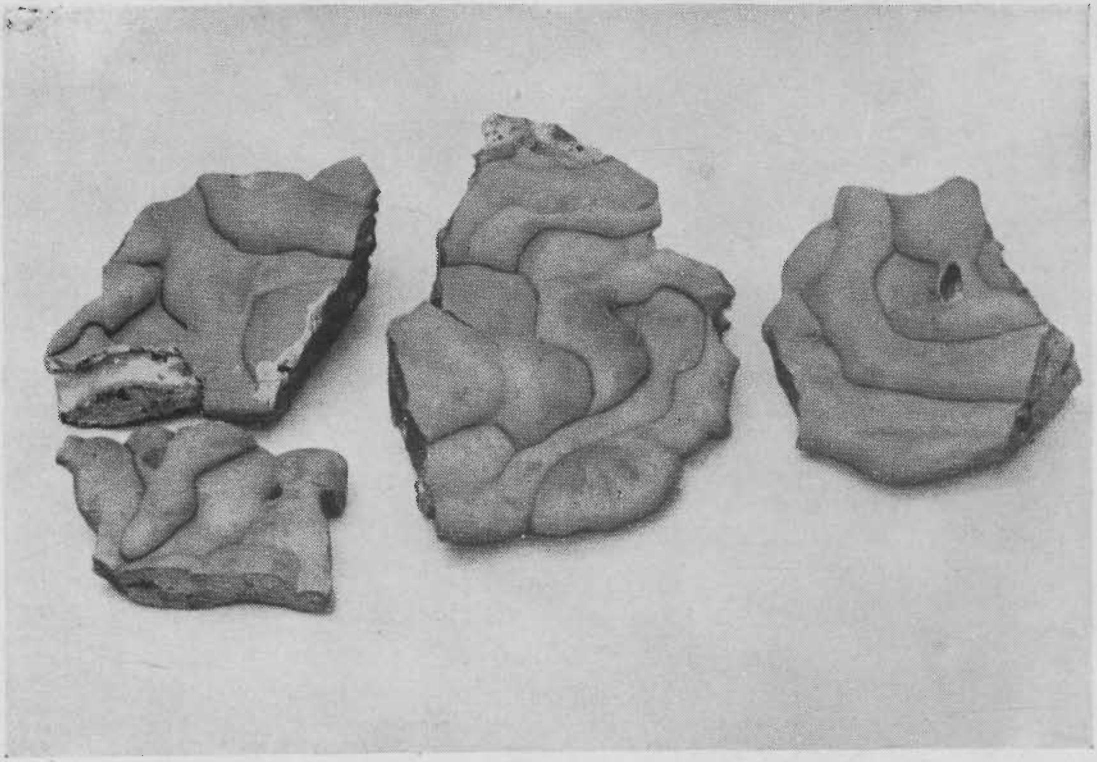
27. *Time-table*—The time-table of operation described above was noted as follows :

Time	Charcoal		Lump ore		Discharge of *gangue*
	Sl. No. of charge	Quantity charged	Sl. No. of charge	Quantity charged	
(1)	(2)	(3)	(4)	(5)	(6)
		Seers		Seers	
3-30 P.M. .	1	20	1	2½	..
3-45 P.M. ..	2	½	..	..	..
3-50 P.M. ..	..	..	2	2½	..
3-57 P.M. ..	..	..	3	2½	..
4-00 P.M. ..	3	½	..	..	..
4-10 P.M.	4	2	4	2½	I Discharge
4-20 P.M. ..	..	..	5	2½	II Discharge
4-30 P.M. ..	5	½	6	2½	III Discharge
4-40 P.M. ..	6	3½	7	2½	IV Discharge
4-50 P.M. ..	..	..	8	2½	V Discharge
4-55 P.M. ..	..	..	9	2½	VI Discharge
5-00 P.M. ..	7	½	..	..	..
5-05 P.M. ..	..	..	10	2½	VII Discharge
5-10 P.M ..	8	½	11	2½	VIII Discharge
5-20 P.M. ..	..	..	12	2½	IX Discharge
5-30 P.M. ..	9	2	..	..	..
5-40 P.M. ..	Bellows stop. Nozzle fittings removed. Sponge iron pulled out. Furnace closed down.				
Total ..	9 times	30	12 times	30	9 times

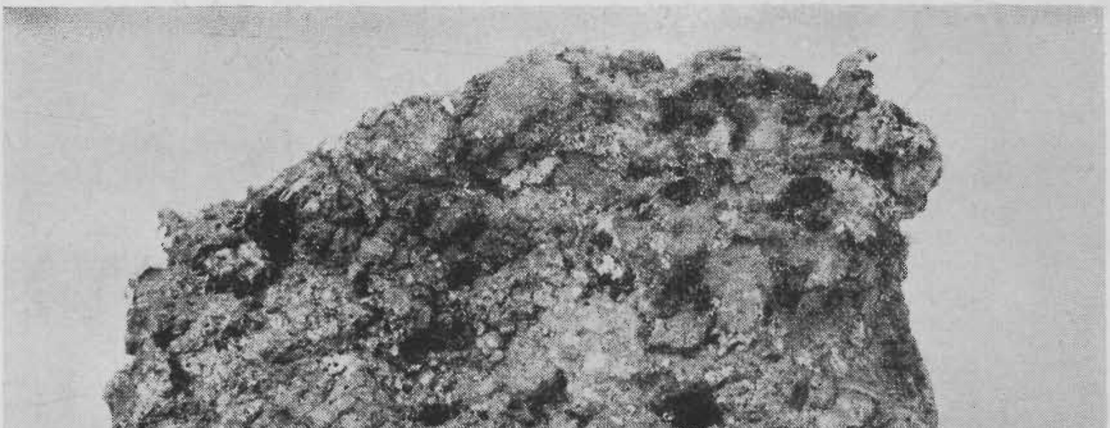
Product of Furnace

28. Thus in about two hours, the furnace yields its product. What happens inside the furnace resulting in its transformation is a simple story of metallurgy. When charcoal is ignited in the furnace, carbon monoxide is formed by combustion.

A PIECE OF ORE FROM KALAPAT HILLS
.... reddish-brown in colour and slightly porous.... (*See* para 13)



GANGUE
.... molten fluid solidifies .... (*See* para 25)



SPONGE IRON
.... nothing in its appearance now to indicate the potential good wrought iron which it contains .... (*See* para 29)

The blast of air which comes from the bellows helps carbon monoxide to pass through lump ores, which are now in contact with fire. Under conditions of heat, the iron oxide of the ore gives out its oxygen which combines with carbon monoxide from hot charcoal to form carbon dioxide. This gas along with some waste gases escapes from the top of the furnace. In this process of disintigration when oxygen and other gases leave the parent body, the ore starts undergoing reduction and descends lower down in the furnace where the temperature is higher and the process of reduction is faster. By the time the ore has reached the hottest part a little above the level of the blast nozzle, it is largely reduced to metallic iron and takes the shape of a sponge ball.

29. This metallic sponge is the final product of the smelting furnace. It is removed and placed over a granite boulder and is held firmly by a pair of tongs by one of the Kamars, while the other starts hammering it with a *ghana* or heavy hammer. The hammering continues for a short while of less than a minute till the body becomes cold. It receives about 25 to 30 strokes of hammer. During the process of hammering, the body is turned from side to side, so that all the sides are subjected to hammer strokes. It is given the shape of a small block of brick which is more compact than when it was brought out from the furnace. It is a heavy mass of coalesced granules and looks dirty. There is nothing in its appearance now to indicate the potential good wrought iron which it contains. At this stage, however, it is intermixed with considerable slag lodged in the pores. In the above manner, each furnace produces three blocks of metal in course of three shifts of smelting operation in one single day. All these blocks are kept aside for the day, to be taken up on the following day for further treatment with a view to improve the quantity of the iron.

Refinement

30. The process of refinement and forging is taken up a day after the smelting operation is over. All the blocks of iron prepared on the previous day are brought to the forge. The foot-bellows are placed in position, the fireplace is ignited, the bellows are worked and the block of iron placed in the fire well covered with burning charcoal. When the block is red-hot, it is brought out and placed on the anvil for hammering. In the first instance it is just given a few light strokes and is then sent back to the forge fire for reheating. It is subjected to heating and hammering process a number of times. The time-table of an operation which was watched is given below :

6-50 A.M. ... The block of iron is placed in the fireplace for heating.

6-57 A.M. ... It was brought out and hammered 5 times and immediately sent back to the fire.

7-02 A.M. ... Hammered 30 times and sent back for reheating.

7-07 A.M. ... Hammered 20 times and then reheated.

7-12 A.M. ... This time heavy hammering starts. While one Kamar holds the block of iron with a pair of tongs, two Kamars of strong physique take the 10-pounder hammer one each and start striking alternately while the iron is hot. In course of a minute about 50 heavy strokes are delivered while the block of iron is turned from side to side by the man holding it with the pair of tongs.

7-15 A.M. ... Reheating and hammering by two men.

7-20 A.M. ... Reheating and hammering by two men.

7-25 A.M. ... Reheating and hammering by two men.

7-30 A.M. ... Reheating and hammering by two men.

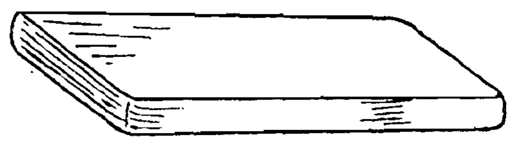
7-35 A.M. ... Reheating and hammering by two men.

7-38 A.M. ... Reheating followed by light hammering by one man. By this time the piece of iron has become a compact body and the slags have been forced out.

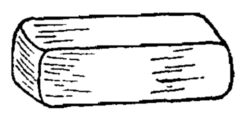
7-42 A.M. ... Reheating and hammering into a particular shape.

Billets

31. At this stage the hammered material is a solid mass of metal, and has taken the shape of what may be called a billet. The Kamars seldom produce blooms of iron. The distinction between a bloom and a billet is one of size. A billet is smaller than a bloom in cross-sectional area, both having length much greater than the maximum cross-sectional dimension. The cross-section of a bloom may be 5 or 6 inches square or a little



Slab



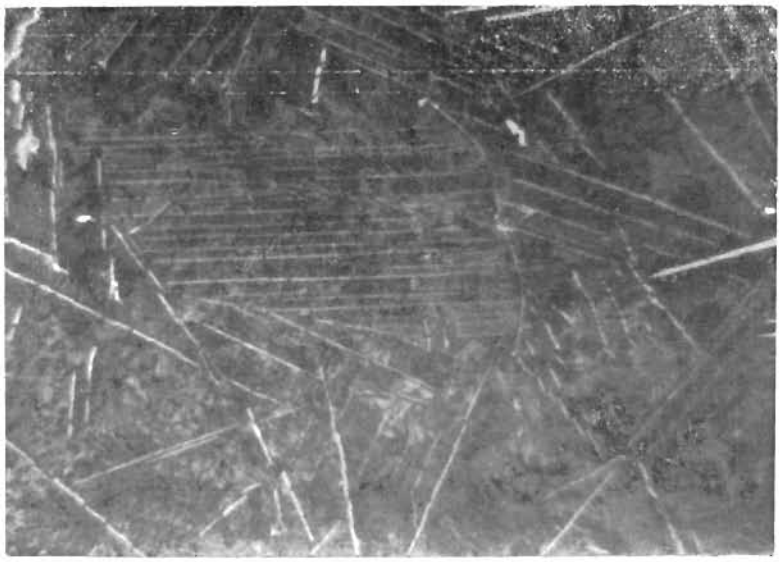
Bloom

Billet

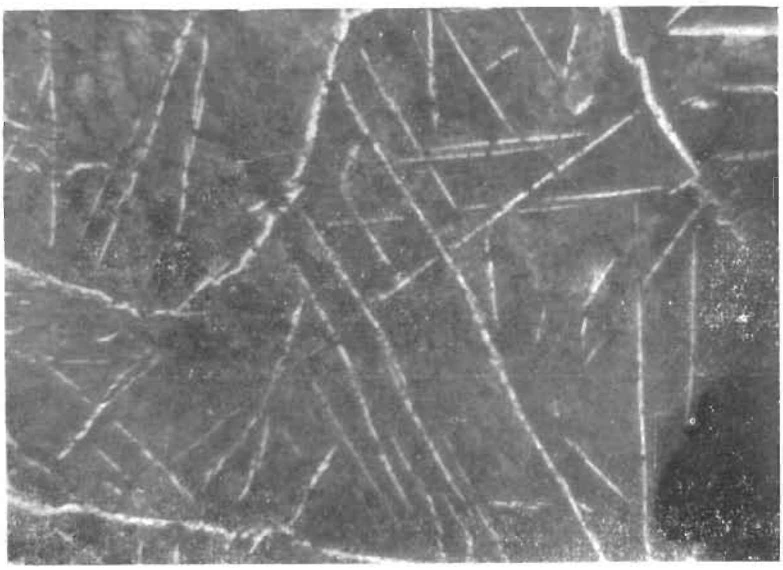
oblong or at times round and its length may be 10 to 12 inches. A billet has a cross-section of 2 or 3 inches round or square or slightly oblong and has a length of 5 to 7 inches. The Kamars of Penthabahal generally make billets which are suitable for making small tools and implements. Whenever heavier and larger pieces of articles are required to be manufactured, they make blooms as they claim but it is difficult to do with a small furnace as they have. They do not make slabs for any of their requirement. A slab is much wide and is comparatively thin and of short length.

Wrought Iron

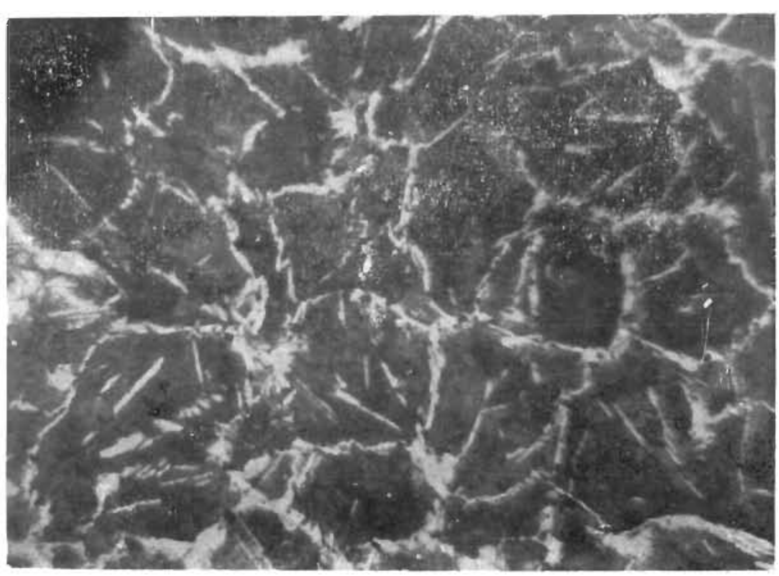
32. *Composition*—By its quality and chemical composition, the metallic substance now taking the shape of a billet is known as wrought iron. It is highly suitable for being forged into household wares and agricultural



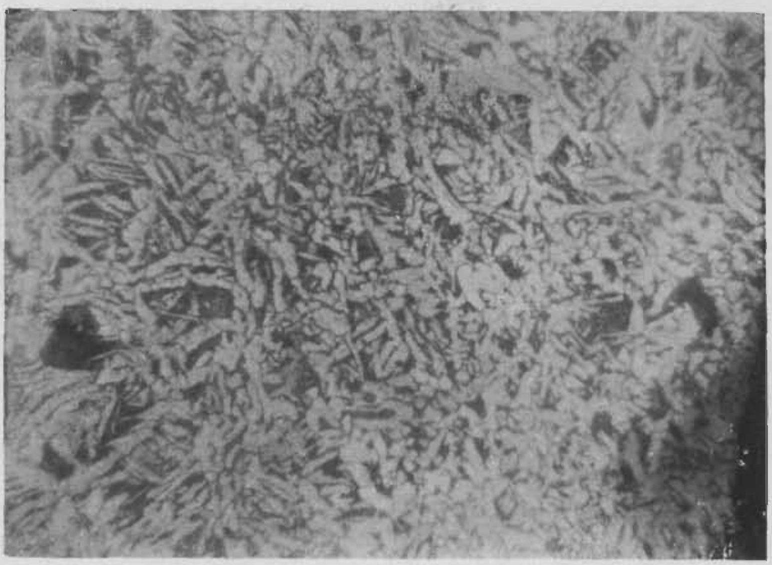
Photomicrograph I (X145)
SPONGE IRON WITH LOW CARBON FILAMENT



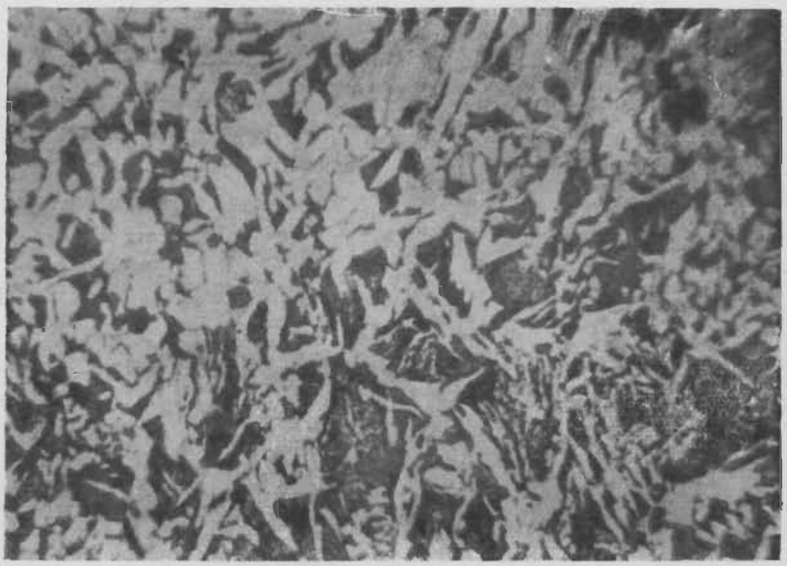
Photomicrograph II (X145)
SPONGE IRON WITH MEDIUM CARBON FILAMENT



Photomicrograph III (X145)
SPONGE IRON WITH HIGH CARBON INTRUSION



Photomicrograph IV (X145)
MICROSTRUCTURE OF A KNIFE



Photomicrograph V (X145)
MICROSTRUCTURE AT THE EYE OF AN AXE

Photomicrograph VI (X145)
MICROSTRUCTURE AT THE CUTTING EDGE OF AN AXE

implements of various types. There are many chemical elements which remain alloyed with iron in the usual course of manufacture, but each kind of iron has its own composition different from other kinds according to manufacturer's choice or to conditions of smelting. The composition of wrought iron commonly includes a specific percentage of carbon, silicon, sulphur, phosphorus and manganese which, however, should be limited to small quantities if the metal is of high quality. The limit of admixture in wrought iron of good quality has been indicated by authorities* as follows :

Carbon	..	0·02 to 0·08 per cent.
Silicon	..	0·10 to 0·20 per cent
Sulphur	..	An undesirable element, should not exceed 0·03 per cent.
Phosphorus	..	Should be higher in wrought iron than in steel, say, between 0·10 and 0·25 per cent or even more.
Manganese	..	Low percentage is an earmark of quality and should be 0·05 per cent or less.

33. The wrought iron produced at Penthabahal is not pure enough to be classed as the ideal metal according to the above formula. The chemical composition of this indigenous iron was analysed by the Research and Control Laboratory of the Hindustan Steel Plant at Rourkela, a full Report of which is given in the Appendix. According to this Report, the sample of sponge iron sent for examination contained:

Carbon	..	0·30 per cent but at certain points rising up to 0·45 or even 0·60 per cent.
Manganese	..	trace
Sulphur	..	trace
Phosphorus	..	0·02 to 0·03 per cent
Silica	..	0·18 to 0·20 per cent

34. *Quality*—The primary fault lies in the excess of carbon which ranges from 0·3 per cent upwards. This is due to the fact that there are considerable quantities of slag and charcoal pieces imbedded in the pores of the sponge iron as the Metallurgist's Report shows. The carbon content is not uniform in all positions of the sample. Some areas were good and had fairly low carbon deposited in the form of long needles (*vide* Photomicrograph II), in other areas still less carbon (*vide* Photomicrograph I), while in some areas high carbon was noticed in cellular pattern (*vide* Photomicrograph III). This inconsistency of carbon in the sponge iron is, however, greatly normalized in the later process of forging when pieces of charcoal and slag imbedded in the pores are hammered out, and still further in course of refinement at the time of manufacture of tools and implements (*vide* Photomicrographs IV, V and VI). A commendable feature of the indigenous iron is its low proportion of phosphorus, an element which is not always good for the metal. Moreover, silica, sulphur and manganese are found in correct proportions, ensuring good mechanical

**The Making, Shaping and Treatment of Steel* by U. S. Steel Corporation, U. S. A., 1957, P. 218.

properties of the metal. The excess of carbon as mentioned above tends to promote a bit of the qualities of medium carbon steel in the metal, which then becomes very good for tool-making. Thus the slight departure from the standard quality of wrought iron has made the metal a good commercial material for manufacture of iron and steel articles which are in demand in the local market. The metal as actually manufactured has some amount of hardness which is good for tool-making, without effectively reducing its other desired qualities of malleability and ductility.

35. ***Malleability and Ductility***—Malleability is a quality which makes the metal fit to be rolled or hammered into desired shapes without rupturing. If the metal lacks in adequate malleability, production of thin or flat tools like knife, sickle, chopper, etc., will not be possible. Wrought iron, unlike steel, is malleable because of its low carbon content. The iron produced in Penthabahal has sufficient malleability for the purpose of making tools and implements. The other notable virtue in good wrought iron is its ductility. Ductility enables the metal, when pulled, twisted or stressed beyond a certain point, to alter its shape permanently without breaking or fracturing. The remarkably low proportion of phosphorus in the indigenous iron, helped by still lower proportion of manganese in the composition, gives it high ductility which, combined with the quality of malleability, makes the product a really good metal for the purpose intended.

Steel-making

36. The local demand is not confined to products of wrought iron. Sharp cutting weapons such as knife, or hard and tough implements such as ploughshare are wanted by the villagers. The metal suitable for manufacture of these articles must have some properties of steel. It, therefore, becomes necessary that the wrought iron produced by the Kamars should be converted, at least partially, to steel. They have obviously no theoretical knowledge of the principles of metallurgy, but their skill is based on the experience born of watching forefathers doing the job. They have the practical idea how to impart qualities of steel to the indigenous iron they produce, which may be put in simple language as follows.

37. ***Quenching***—If a piece of wrought iron is allowed to remain under high temperature in the fire of a forge, in contact with burning charcoal in a manner so that it is completely surrounded by such charcoal and is protected from oxidation by exclusion of air, a quantity of carbon will be absorbed by the surface layers of the wrought iron. If this condition continues long enough for sufficient carbon to be absorbed, and if in this state the piece of iron in its high temperature is rapidly cooled by dipping it in a quenching liquid, it will acquire the properties of hard steel. This phenomenon, however, is limited to the surface which has just absorbed adequate carbon. The interior of the metal had no opportunity to come in contact with burning charcoal for absorption of carbon and so the process of quenching will convert the outer layer into hard steel but will leave the interior relatively soft as it was before the processing.

38. *Case-hardening*—The steel produced by the Kamars is thus merely a quantity of wrought iron with

its outer layer or 'Case' hardened into steel. This is good enough to satisfy the local demand for the object produced serves as a good steel product so long as the case remains intact. The points or edges of cutting or piercing instruments such as axe, chopper, chisel, sickle, spade, ploughshare, knife, arrow-head, shovel and hunting spear are all good steel and prove excellent in service.

Tempering

39. The Kamars by sheer experience coming down through generations know well that the metal must be subjected to necessary processes which will make tools and implements useful and durable. As mentioned above the outer case of soft wrought iron is converted into steel by increasing the carbon content of the surface layer and then by rapidly dipping the hot metal in a suitable liquid, so as to enable it to cool down suddenly from high temperature. But the metal undergoing such quenching process is very hard and somewhat brittle. Brittleness is no good quality for a household article or an agricultural implement. So the Kamars follow up the next process by reheating the manufactured article to a relatively low temperature and then allow it to cool down slowly in contact with open air. This process makes the iron less brittle without too drastically lessening the hardness obtained by quenching. In other words, the manufactured article is 'tempered' to the quality required for a sharp tool of durable nature.

Quantity produced per Shift

40. In a smelting experiment which was personally watched, the quantity of raw materials used, the waste materials and the final product available after the conclusion of the process, were carefully weighed. The relevant data are given below :

		Seers
Charcoal from sal wood	..	30
Iron ore $+\frac{3}{4}$ inch size	..	30
Gangue (waste matter)	..	$9\frac{3}{4}$
Sponge iron produced	..	$3\frac{1}{2}$
Slag	..	$1\frac{1}{2}$
Wrought iron billet	..	2

41. The recovery of wrought iron, therefore, was 2 seers out of 30 seers of ore, or 6·6 per cent, which indeed is a poor result. As the ore contains 45 per cent of iron, the quantity of 30 seers of ores should have yielded $13\frac{1}{2}$ seers of iron under theoretical conditions. But the process involves wastage and loss in many forms, as the Chemical and Metallurgical Report at the Appendix indicates. Iron oxide escaping with the gangue is of the order of 40 to 60 per cent and with the slag, it is naturally higher, viz., 60 to 75 per cent. The proportion of gangue is quite high, namely, 32 per cent. The sponge iron itself is quite impure as it contains $1\frac{1}{2}$ seers of slag in $3\frac{1}{2}$ seers of sponge, that is to say, 43 per cent. Some quantity of unreduced metal escapes with the gangue and the slag and the rate of recovery is thus lowered considerably. Unsatisfactory temperature conditions are responsible mostly for this loss and wastage.

Comparison with Old Samples

42. Iron and steel which were made in India in olden days were smelt in charcoal fire. It may, therefore, be interesting to compare the chemical composition of the old Indian iron with that of the iron made at Penthabahal with the same kind of

fuel. It has been mentioned earlier that the iron column at Kutub Minar nearby Delhi and the iron beams of Konarak temple offer outstanding proof of the smelting and forging ability of ancient Indian metallurgists. These two specimen may now be selected for comparison of their chemical composition with that of the indigenous iron manufactured at present in the furnace at Penthabahal. It is fortunate that such comparison is possible because of the availability of the results of chemical analysis of these two old iron objects. The analysis of the metal of the Delhi pillar was made by Sir Robert Hadfield and that of the Konarak beams by Messrs. Newton Friend and Thorneycroft.* The relevant figures are given below :

Chemical element		Delhi pillar	Konarak beam	Penthabahal iron (before refinement)	Factory-made ordinary mild steel (approx.)
Carbon	..	·080	·110	·30	·30
Manganese	..	*nil*	*nil*	traces	·50
Silicon	..	·046	·100	·20	·17
Phosphorus	..	·114	·115	·03	·04
Sulphur	..	·006	·024	traces	·03
Copper	..	·034	*nil*	*nil*	*nil*

43. The above analysis shows that the ancient Indian iron as well as the present country-made iron are characterized by low manganese, sulphur and silicon content. Low manganese is good for certain purposes because the metal does not crack when dipped in the quenching liquid for purpose of tempering. On the other hand, it appears that the local country-made iron has a much higher carbon content than either the Delhi or the Konarak metal, although the proportion of ·30 carbon as shown above is considerably lowered when the sponge iron is refined by further heating and hammering out the imbedded slag and charcoal. The great redeeming feature of the Penthabahal metal is that it has remarkably low phosphorus. The quality of iron contained in Delhi and Konarak samples are good for huge-sized castings like the pillar and the beam, while the country-made sample is excellent for purpose of manufacture of tools and implements as are used by agriculturists and artisans of the country-side. Each one, therefore, is well-suited for the specific purpose for which it was manufactured.

Underground Furnace

44. ***Furnace at Singelbecha***—In the south-western part of the district of Koraput there are a number of smelting furnaces built underground. They are quite different in structure and in the mode of working from the type existing in Penthabahal, as described in foregoing pages. The description of one underground furnace which was observed in village Singelbecha about 4 miles distant from Mathili police-station

*The Journal of Iron and Steel Institute, 1924

UNDERGROUND FURNACE OF SUNADHAR LOHAR OF VILLAGE SINGELBECHA
P. S. MATHILI, DISTRICT KORAPUT

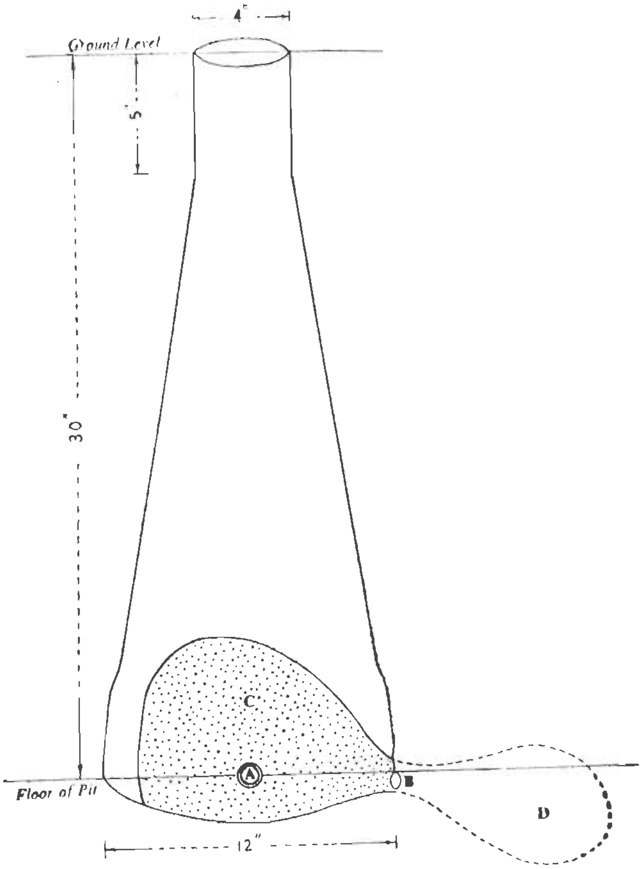
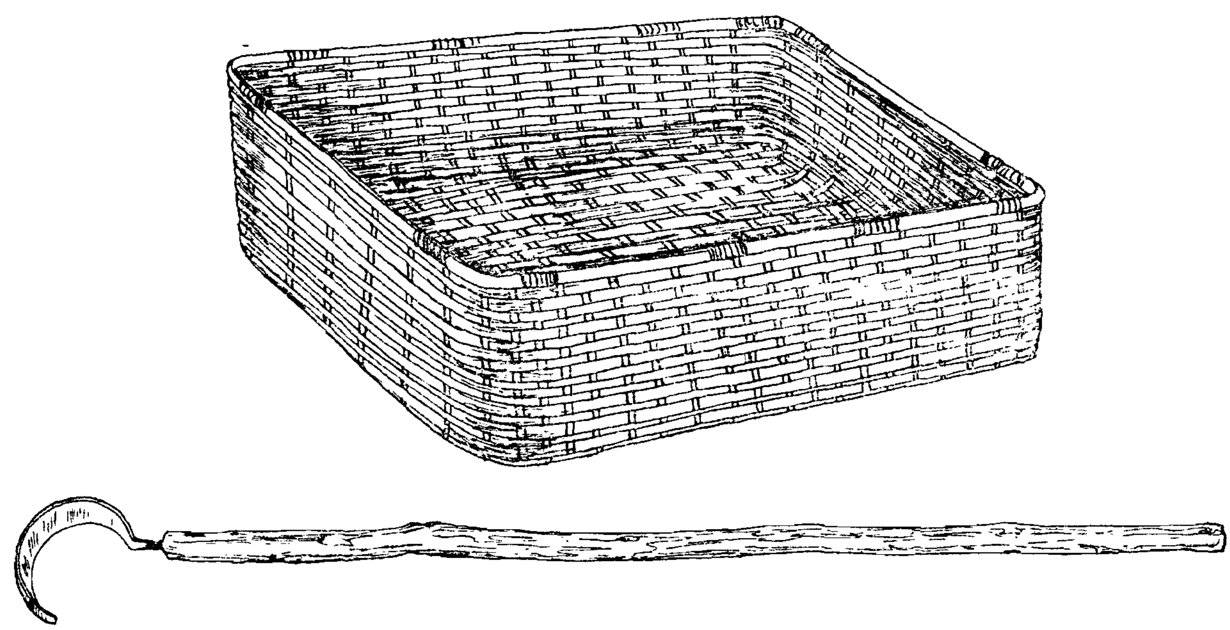


DIAGRAM OF AN UNDERGROUND FURNACE

in Koraput district is given below. First of all an open place is selected close to the village site and a pit is dug about 30 inches deep and 4 feet square. About six inches away from the margin of the pit on one side, a circular hole is bored vertically to a depth of 30 inches or up to the level of the floor of the pit. This vertical hole is 4 inches in diameter from the top down to a depth of 5 inches and it then gradually widens in diameter so as to measure 8 inches half way down and 12 inches at the bottom. The lowest part of the wall towards the pit is then broken open to a height of 8 to 10 inches on one side, gradually tapering towards the other side. This completes the preliminary construction of the underground furnace. Its top is flush with ground level and its bottom has the same depth as the floor of the pit dug in front of the furnace. Finishing touches are given by plastering the periphery of the top of the hole with a paste of soft mud and charcoal dust. Similar treatment is given to the opening at the bottom. As soon as the plaster dries up, the furnace is ready for working.

45. Some further preparation **is** necessary before the smelting operation begins. A quantity of wet sand and charcoal dust is mixed and kept ready at hand. The foot-bellows are kept in position inside the pit. Some quantity of burning charcoal is introduced into the bottom of the furnace through the opening, and the opening is at once sealed with the black sand (mixture of wet sand and charcoal dust) after fixing a burnt clay nozzle tightly a little above the bottom level. To assist imagination, a rough sketch is given to show the longitudinal cross-section of the structure. The shaded portion marked 'C' is the opening at the bottom which has been sealed with the black sand. A little below the centre of the sealed portion is the burnt clay nozzle marked 'A', meant for blowing air from the bellows to the furnace. Mark 'B' is a small hole which is punctured at a later stage for tapping the molten slag out of the furnace. The slag pit is marked 'D'.

46. *Equipments*—The work-site and its equipments are simple. The site



Chaalni, a measuring basket and *Kaarni* a hooked rod is divided into three parts, namely, one uncovered spot for construction of the underground furnace, one uncovered spot for location of the open hearth for pre-heating of ores and one small shed for location of the forging shop. The equipments of the forging shop are almost the same as described in respect of Penthabahal. The pre-heating open hearth requires no tools or equipments, except the hearth itself, made of stone boulders arranged in the fashion of an arc. The underground furnace, apart from the furnace itself, has a pair of foot-bellows and two simple and cheap accessories, namely, a *chaalni* and a *kaarni*. A *chaalni* is a wicker-work basket for measurement of raw materials before being charged into the furnace. It is 16 inches square and 5½ inches high. In one single smelting operation, the quantity of raw materials used is one *chaalni* of lump ore and four *chaalnis* of charcoal. The *kaarni* is a hooked rod for pulling ore and charcoal in small doses into the mouth of the furnace. It is 33 inches long and is made of a long wooden handle with an iron-made hook fixed at one head.

47. ***Pre-heating of Ore***—Before the lump ore is considered fit to be charged into the furnace, it is subjected to prolonged heat treatment in the following manner. Pieces of stone boulders are kept arranged in a circle with an opening on one side. Small bits of dry twigs are placed in the enclosure, and it is covered with a layer of charcoal. Thereafter a layer of ore stones is spread over and finally another layer of charcoal covers the whole stack, all of which are within the enclosure of stone boulders. The twigs below are ignited and within minutes the charcoal burns and heats the ore stones. The process continues for the night without requiring any further attention. The next morning, the ore stones are ready to be broken into small pieces of plus half inch size for use in the furnace.

48. There are distinct advantages in processing the ore stones before use in furnace as described above. Pre-heating of ores results in their dehydration. The duration of reduction inside the furnace is greatly minimised when dehydrated ore is used. Secondly, the flow of molten slag is considerably facilitated, and the recovery of metal is rendered satisfactory.

49. ***The Process***—When the smelting operation starts, a quantity of burning charcoal is deposited at the bottom of the furnace. Then the opening at the bottom is closed with the nozzle properly fitted in the black sand packing and air blast is supplied from the bellows to keep ablaze the burning charcoal inside. In the meanwhile the smelter has kept two heaps of charcoal on the left and the right of the hole at the top and one pile of lump ore just behind the hole. The *kaarni* is kept ready at hand. Some quantity of charcoal is poured into the furnace with the help of the *kaarni* through the mouth of the hole at the top of the furnace. The charcoal reaches the bottom where it gets ignited in contact with the already burning charcoal. A small quantity of lump ore is then pulled into the furnace followed by small doses of charcoal and lump ore alternately at short intervals. The air blast is kept steady all the while. The temperature inside the furnace gradually rises resulting in reduction of the ore with the expulsion of molten slag. After a while when the smelter believes that a reasonable quantity of such molten matter has collected at the bottom, he punctures

FORGING SHOP

LOHARS OF SINGELBECHA

LOHARINS OF SINGELBECHA

a small hole with a piece of wooden stick at one end of the bottom of the furnace (Mark B). As the wooden stick is pushed in and out a few times, the molten matter flows out and gets deposited in the slag pit marked 'D' in the diagram. The process of charging small quantities of charcoal and lump ore continues for over an hour while the molten slag is let out a number of times. When the smelter has finished the entire heap of ore and the charcoal he continues operating the bellows for a few minutes more and finally stops.

50. The black sand packing at the bottom of the furnace is then demolished, when a piece of red-hot sponge iron in the shape of a cabbage is visible. It is pulled out and is forged into a billet of wrought iron.

51. *Advantages*—The underground furnace is ingenious in concept and appears to be more advantageous than the usual type of furnace seen overground in other parts of the country, particularly in respect of certain types of ores which are refractory in character. An experiment carried out by the Akhil Bharat Sarva Seva Sangh in the district of Koraput revealed that the underground furnace is more efficient than other types in respect of thermal efficiency as the loss of heat by conduction and radiation is practically eliminated due to its underground location. Moreover, this particular type of furnace ensures higher metallic recovery. This experiment unfortunately did not record the weight of the ores charged nor the iron recovered nor was a Chemical Analysis Report obtained. But as the underground furnace uses pre-heated and dehydrated ores, the recovery of metal is quite high. The Lohars of village Singelbecha claim that one *chaalni* of ore weighing approximately eight seers yields a little more than one seer of iron. So the recovery is of the order of 15 per cent. Enquiries at another centre, namely, Boipariguda, reveal that the recovery is likely to rise up to 18 per cent in the best of conditions. This compares very favourably with the recovery recorded in the Penthabahal experiment which is 6 to 7 per cent only. At Penthabahal, however, dehydrated ore is not used as at Singelbecha and the two results are not strictly comparable.

52. *Drawbacks*—The one notable drawback about the underground furnace is that it cannot be operated during four months of the rainy season as the pit and the furnace which exist on bare open ground are full of water. So the Lohars of Singelbecha, unlike their brother-artisans of Penthabahal, must have a secondary occupation to fall back upon during rainy days. They generally get engaged in cultivation work, either as tillers of own lands or as agricultural labourers employed by neighbouring cultivators. They, however, appear to be somewhat more prosperous than the Kamars of Penthabahal and enjoy better living and housing conditions.

Use of Flux not favoured

53. One striking feature of the indigenous process of smelting is the absence of fluxing. There are certainly many advantages in using a flux in the modern process of smelting. Some of the impurities contained in the iron ore are of highly refractory nature, that is to say, they are very difficult to melt. If they remain unfused, the smelting operation is retarded. In order to fuse more easily these refractory substances, a third element, namely, the

flux, is used. Secondly, the ore may contain some matters which may get mixed with iron in course of melting process by reason of chemical affinity. A flux prevents such combination, by offering a better chemical field for combination with the flux itself in preference to the metal. Limestone is commonly used as a flux in modern furnaces.

54. The benefits, however, are not unmixed. Fluxing increases the risk of contamination of iron by carbon from coke used as fuel. A higher percentage of carbon, say about 4 per cent, gets mixed up with iron, resulting in the production of pig iron* rather than wrought iron. The fluxing has protected the molten iron from its undesirable combination with other substances but has failed to offer any protection against contamination by carbon. In the clay furnace the chances of admixture of carbon is nominal and results in easy reduction of the ore into wrought iron. The clay furnace does not allow any unnecessary contamination. As wrought iron is produced directly, it saves so much of labour which would have been otherwise necessary for removal of the unwanted carbon.

55. The Kalapat hills have no limestone but in other centres of indigenous smelting where limestone is abundantly available on the surface, no smelter has ever thought of utilizing it as a flux. It is surmised that the use of limestone in the clay furnace will complicate the production of the desired quality of iron which must not be too hard to forge into tools and household articles.

Merits and Demerits

56. *Non-tarnishability*—Among facts deserving special notice about the country-made iron, one is that it does not tarnish in air so soon as factory-made iron. Tarnishing is prevented by the presence of such elements as nickel or copper, none of which are, however, present in the specimen of iron chemically examined. It is supposed that non-tarnishability is acquired in course of the particular process of metallurgy which has remained somewhat inexplicable even at the present time.

57. ***Purity in Quality***—Iron produced by charcoal fire is distinguished for its purity and quality. It will not be possible to maintain such a quality, if there are chances of contamination by phosphorus, which has considerable injurious effect on the metal. Such contamination may result from contact of the ore inside the furnace with any substance containing phosphorus. The usual fuel of the modern furnace, namely, coke, contains a fair proportion of phosphorus, as a result of which the product of modern factories is rendered impure, but charcoal contains very low phosphorus and as a fuel it is less harmful to the metal. Among the modern steel factories, the one which uses charcoal as fuel is located at Bhadravati in Mysore. This is why the Mysore steel has a reputation and attracts foreign buyers like Japan. The indigenous iron of Orissa has more or less the same merit. Its quality is good.

58. ***Simplicity of Direct Process***—The indigenous process of smelting iron is called the direct process because

*Pig Iron—If carbon is absorbed to the extent of 4 per cent by the iron, it is high carbon iron. In its molten state it is poured or cast into blocks called pigs. The iron is, therefore, called cast iron or pig iron. All high carbon iron have low melting point. The cast iron billet can be remelted and cast into desired shapes of household articles, etc.

wrought iron is directly produced from the ore in one single operation. Direct process is still in use at places and, indeed, has never been wholly abandoned even in some advanced countries. The case with which iron ores are reduced makes the direct process simple and attractive. The reduction takes place at low temperature which is an advantage where the blasting operations are comparatively feeble, or where the fuel is such as cannot stand high blast.

59. ***Commercial Inferiority of Direct Process***—In a modern furnace the process is indirect. The blast furnace, for example, produces high carbon iron called pig iron or the cast iron in the first instance, which is subjected to refinement by two or more steps in order to reduce it to wrought iron. From a theoretical consideration, the indigenous process is a better commercial proposition, but in fact there are a number of inherent shortcomings whereby the direct process fails in competition with the indirect process. The direct process, in order to be successful, requires a few specific conditions, such as :

(*i*) the ore must be rich,

(*ii*) the ore must be broken into fine pieces and intimately mixed and carefully placed over the reducing agent, and

(*iii*) there should be a practical method of mixing ore with the reducing agent in correct proportion so as to leave no excess of either. In case of excess of the one or the other, either the ore is wasted or the metal is too hard to handle.

60. It is difficult to ensure all the above conditions so as to enable the indigenous process to be competitive and successful. Though, therefore, it is superior theoretically, it cannot stand commercially against the method followed by modern factories.

61. ***Inadequate Recovery***—The clay furnace does not ensure either uniform recovery or adequate recovery of the metal in the process of smelting. The quantity of recovery is liable to differ, if the quality of the ore has accidentally changed due to collection from different sites or if the quantity of ore charged into the furnace has inadvertently exceeded the correct proportion. The quantity of recovery may, therefore, vary from operation to operation though it does not frequently happen. The greatest fault, however, is that a good proportion of the metal is left unreduced in the gangue and the slag, because of inefficient air blowing or inability to maintain temperature at the required level. In the Penthabahal experiment 30 seers of ore having 45 per cent of iron content were reduced to 2 seers of wrought iron. In fact, it should have yielded 13½ seers if 100 per cent recovery was ensured. The recovery of 2 seers works out to 15 per cent approximately on this basis. It is utterly inadequate. It has been observed earlier how 40 to 60 per cent of iron oxide escapes with gangue and 60 to 75 per cent with slag. Little wonder that final recovery is limited to 15 per cent. In the underground furnace of Singelbecha type the recovery is higher although the exact percentage is not known.

62. ***Heterogeneity***—The iron produced by indigenous process is heterogeneous in composition and has plentiful of inclusion. There are many surface gaps and they do not close up during the forging operation. This difficulty restricts the utility of the iron produced. Indeed, homogeneity cannot be expected from the very nature of

the formation of sponge iron in shreds progressively from pieces of ore heated inadequately by charcoal. Slag inclusions could be eliminated by prolonged forging but heterogeneity in composition cannot be overcome even in the best of the products as at Konarak or at Kutub Minar. The photomicrographs I to VI show the typical structure of the sponge iron and wrought iron manufactured at Penthabahal. The homogeneity has considerably suffered due to carbon and slag filaments.

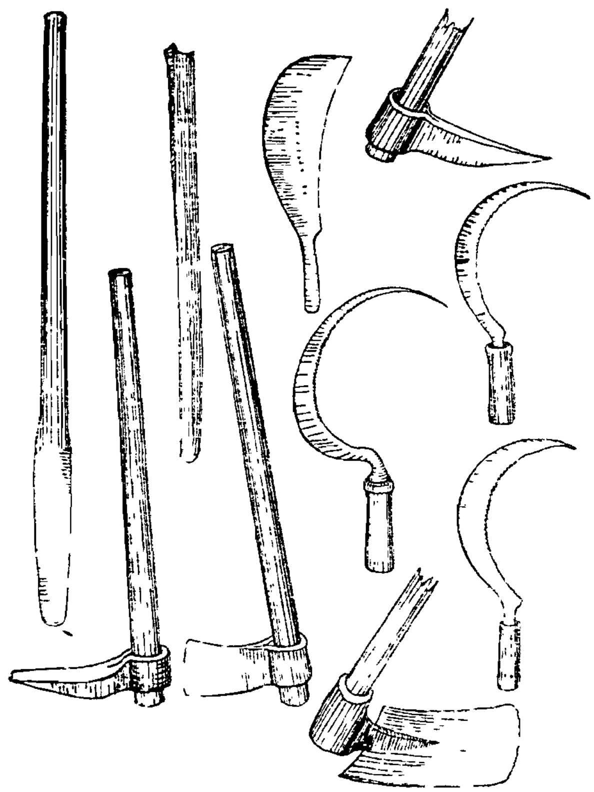
SECTION IV

ECONOMIC ASPECT

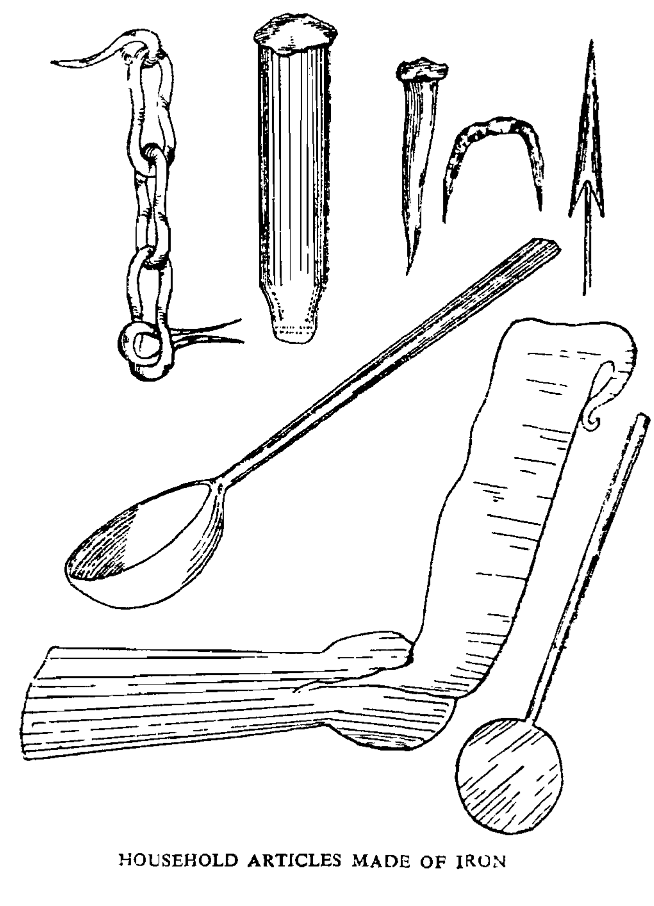
Articles Manufactured

63. The wrought iron billets manufactured by the smelters are utilized by themselves for making household articles and tools and implements of agriculturists and artisans. The billets are not directly sold to other blacksmiths, because the quantity produced is small, and the smelters like to appropriate for themselves the profits that may accrue from the allied profession of smithy. Thus, immediately after the process of refinement is over and the billet is still hot, the Kamars start reheating and hammering it skilfully to an approximate shape of the article intended to be manufactured. It is flattened, rounded or made elongated, or curved or bent according to what shape may be necessary for the intended article. The process is rather slow. The manufacture of an axe, for example, which was watched with a view to ascertain the amount of labour involved and the income derived, started at 7-42 A.M., when the billet was first put in the forge fire for heating. The heating and hammering, which required the labour of one woman and one man, continued till 8-36 A.M. when the axe was ready. It took another 4 minutes for tempering the edge of the weapon, and the weapon was finally laid aside ready for the market at 8-40 A.M. It took approximately one hour for a man and a woman to manufacture an axe weighing 2 seers which was likely to fetch Rs. 2·75 nP. in the market. Manufacture of a ploughshare, which is another article in heavy demand, takes much less time, as it involves no complication of providing a hole for the wooden shaft as required in the case of an axe. A ploughshare weighs approximately 3 seers and sells for Rs. 4 in the market, and its making is more profitable than an axe in consideration of the amount of labour involved.

64. *Variety and Quality*—The items of manufacture depend on the market from season to season. But there are certain household articles which are in demand in all seasons, such as *paniki* (meat-cutter), *karachhuli* (large cooking spoon), kitchen knife, door nails, chain and staple, etc. Agricultural implements and hunting weapons are also made for sale in the weekly market at Naktideul, or on special order. Among these articles the important ones, besides the ploughshare and the axe, are spade, sickle, shovel, *kanka*, *katari*, arrowhead, bullock-cart fittings, etc. The customers are satisfied with the quality of the metal and make no complaint about it. The Report of the metallurgical examination (Appendix) shows that the manufactured articles are medium carbon steel in quality, and the edges of sharp instruments have developed adequate hardness, sometimes to the extent of 300 V. P. N., and can serve well as general purpose tools. Whenever a cutting instrument loses its sharpness due to long use, the Kamar is ready to recondition



AGRICULTURAL TOOLS AND IMPLEMENTS



HOUSEHOLD ARTICLES MADE OF IRON

it in his forge, sometimes free of charge and sometimes just for a nominal payment either on annual or on piece-rate basis.

65. *Marketing*—These and other agricultural implements as well as many varieties of household articles are taken to the weekly market at Naktideul every Monday for sale. This market is visited by men from long distances of 10 to 15 miles around. The manufactured articles thus reach a large number of villages in the locality. During the season from Asar to Bhadra which is a slack season, there appear many middlemen who purchase from the Kamar plough-shares and other articles produced. They get them at low rates because there is no extensive demand from the general public at this part of the year. But when the season for actual field-work starts, these middlemen sell the articles at a much higher rate, because the Kamars cannot meet the day-to-day demand during the heavy season. One ploughshare, for example, is sold at Rs. 5·50 nP., while the usual price is about Rs. 4. This is a margin of profit which the Kamars themselves do not get at any time.

Labour and Earning

66. It may be of interest to note the extent of labour involved and the amount of earning derived from the industry, which is the sole means of subsistence of the Kamars. One round of economic activities connected with the procurement and transport of raw materials from hills and forests near-by, the smelting of the ores and the manufacture of ironwares and implements, and finally taking them to the weekly market for sale is completed in course of one whole week. The time-table followed by a family of Kamars in a normal working week from Wednesday to Tuesday is given below :

(i) *Wednesday and Thursday*—These two days of the week are utilized by a party of two Kamars proceeding to the forests, nearby, cutting dried-up trees of suitable girth, sizing them into logs of required length and burning them to make adequate quantity of charcoal. When the logs are still burning, they utilize the time by digging out ore-stones from the deposits nearby. After these two raw materials are collected into heaps, they are transported generally by *bhars* by the men. Occasionally a woman of the family, if conveniently available, assists in transporting the ores and the charcoal by head-load in a basket.

(ii) *Friday and part of Saturday*—The smelting furnace is worked in three shifts of two hours each either on Friday or partly on Friday and partly on Saturday. Each shift consumes 30 seers of charcoal and an equal weight iron ore. The final product of wrought iron is two seers in weight per shift or six seers in course of three shifts during the day. This process employs two men and one woman. At times a grown-up child is a substitute for the second man.

(iii) *Saturday and Sunday*—These two days are utilized for refinement of wrought iron and for manufacture of saleable articles of iron or steel. A man and a woman worker both, whole-time, are necessary. But during the heavy hammering another man joins the party.

(iv) *Monday and Tuesday*—The principal worker, either alone or at times accompanied by a boy or another male member of the family, goes to the market at Naktideul for sale of the manufactured articles. After the sale is over, they utilize the sale-proceeds partly in the purchase of bare necessities such as food and cloth from the market. They are quite frugal and do not spend away the whole amount of the small money earned after a week's sweat of the brow. On Tuesday they return home from the market with a few commodities purchased and a part of the sale-proceeds in hand.

67. Thus a whole week covers a round of programme beginning from collection of raw materials and ending with sale of articles manufactured and purchase of necessities of life. During this period of seven days the total amount of earning is limited to the market-price of the products made from the quantity of wrought iron obtained in three shifts of smelting operation. In other words, six seers of ironwares and implements are the net product of labour for one whole week by one whole-time man, one part-time man and one part-time woman. The products sell at the rate of Re. 1·25 nP. to Re. 1·37 nP. per seer, bringing a total income of about Rs. 7·50 nP. Roughly speaking, two whole-time persons employed for seven days make an earning of Rs. 7·50 nP. during the period which works out to approximately annas eight per day per worker.

68. This is indeed a poor level of income at the present-day rates, considering that the Forest Department or the Public Works Department engaging the villagers as day-labourers pay at the rate of Re. 1·50 nP. per head. For all their labour, the iron-smelters remain excessively poor. Their earnings are so small that if they must have a stomachful of rice diet to enable them to work hard at the furnace and the forge, they have to be thrifty in clothing themselves, and can hardly think of providing against a rainy day. The question of luxury in any form does not arise. Their small huts are almost bare of possessions and their women are content at best with a few pieces of brass ornaments. Children usually move about naked.

69. The Kamar remains content with whatever small earning he makes from his traditional profession, because he believes he can depend upon it for all time. He has unfailing attachment for his furnace and forge.

SECTION V

DECAY AND RESUSCITATION

DECAY

Causes of Decay

70. No information is available regarding the number of clay furnaces either in the past or at present, but there can be no doubt that their number has considerably declined. The causes of such decline are diverse and include a number of factors, internal and external.

71. *Old Facilities denied*—An enquiry made with a view to find out the specific reasons responsible for the decay of the industry reveals that during the Durbar administration by feudatory chiefs, the local smelter of Penthabahal like any other *bona fide* villager used to pay a nominal forest permit-fee either annually or on the basis of head-loads or cart-loads for appropriation of the products of the reserved forest. A smelter, for example, prior to the year 1948 was free to remove any quantity of iron ores for the whole year for purpose of smelting in his own furnace on payment of a small permit-fee of one rupee and eight annas. Similarly he was permitted to burn charcoal out of dead trees in the reserved forest on payment of an equal amount of permit-fee for the whole year. The amount of payment by him was small but it gave him the otherwise unrestricted legal right to remove any quantity of these raw materials required for his industry. After the end of the Durbar government in some areas and the abolition of zamindaris in others, when the normal rules of a regular district were brought into force, they were not applied in a systematic or uniform manner under changing conditions. The result was that the smelter did not have the legal right as he had before for removal of the materials required by him. Quite frequently he was taken to task or intimidated by subordinate officials charging him with theft from the Government forest. The smelter began to lose interest in his work on account of these uncertain factors. At some places furnaces are reported to have been closed down due to the undue interference by subordinate forest or revenue officials, or due to the gradual disappearance of forests and consequent difficulty in obtaining charcoal.

72. *Social Abhorrence*—The iron-smelter has been conventionally subjected to a sort of social reproach as the industry is considered to be much less respectable than many others. Even a blacksmith who simply forges tools and implements enjoys better social status than one who has taken to smelting as the means of livelihood. Under such psychological background, an industry is not expected to flourish.

73. ***Competition by Factory Products***—Another significant reason why the industry is facing hard days may be found in the ever-increasing competition from factory-made iron either imported from foreign countries or produced in mass scale in modern Indian factories. India's contact with the industrial world first resulted in disaster to cottage industries of many a variety. One among

the industries which heavily suffered in this manner and began to decline is the smelting of iron by indigenous process, although at one time it was responsible for making generations of workers happy and prosperous. Factory-made iron became increasingly available in markets not only in the form of billets but also as finished goods for agricultural, industrial and household use. All localities close to lines of communication were flooded with such products. Wherever such products could not reach either because of inaccessibility or due to higher cost of transport of this heavy material, the indigenous smelting industry, if there existed any, remained unaffected and was carried on as in the days of old. It is difficult for indigenous iron to stand competition in places served by main lines of communication.

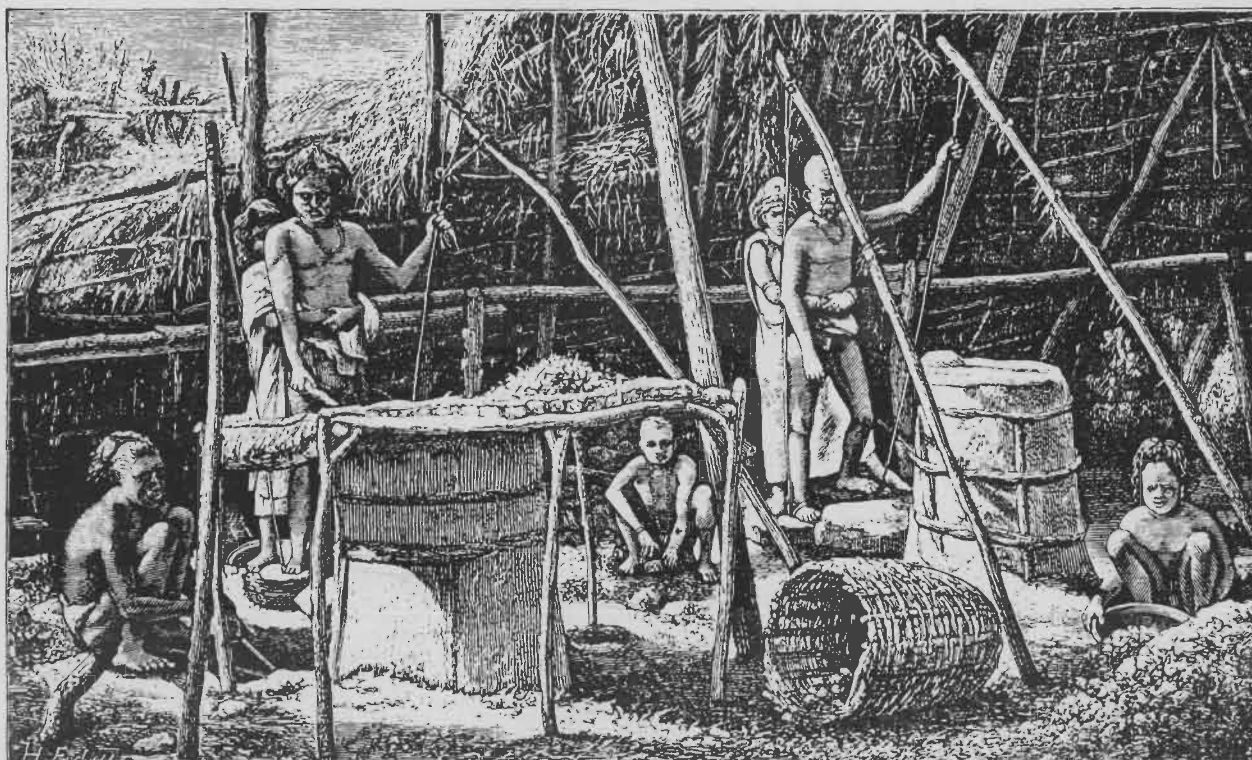
74. *Inattention of Administration*—This industry never had any political or religious significance and no one attempted to revive it once it started declining. In the present-day welfare State when many of the traditional crafts and industries have been saved from total extinction by financial subsidies and other forms of State patronage, this particular industry has unfortunately not been able to attract the attention of the Administration for whatever help and support it deserves. The inattention of the Administration, arising not so much from a deliberate policy of neglect, but born out of sheer lack of information relating to the conditions of the industry and of the workers attached to it, has made the industry further lose its ground in comparison with other cottage industries that had the good luck of being nursed from a sickly state with adequate doses of financial assistance, technical guidance and commercial protection.

RESUSCITATION

Hard Work Necessary

75. Can the lot of the proverbially poor Kamars be improved ? The Kamars are poor because the circumstances under which they work are unfavourable. They are poor also because the technique is antiquated, and lastly because they do not sufficiently exert themselves in hard work. The quantity of production and consequently the amount of income could be raised by about 50 per cent by the Kamars themselves if they are determined to work harder. The time-table of their work as mentioned earlier is leisurely and does not indicate an inclination for continuous hard work except during a few hours on the day of smelting and on the day of refinement of iron. The average duration of work on other days is quite small. Were they hard-working, they could easily collect a good deal more of the raw materials and produce correspondingly a larger quantity of iron, resulting in considerable increase in their income. But since they lead a simple life with wants limited to bare subsistence, they take things easy and produce just as much as is necessary to keep themselves going on.

76. There are many localities in the neighbouring States of Madhya Pradesh and Bihar where the smelters tackle large-sized furnaces, heavier bellows and considerable quantity of raw materials in each shift. Such furnaces are worked not for a single day in the week as in the case of the village under investigation, but for three or four days. An illustration is given showing a typical workshed of iron-smelters of Palamau district in Bihar. It is at once noticeable that two persons, a man and a woman,

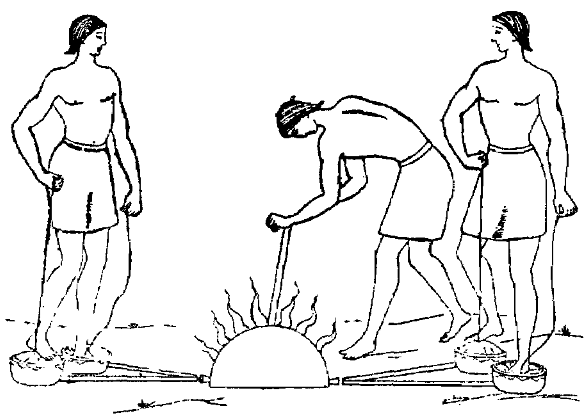


IRON-SMELTERS OF PALAMAU
(From *Jungle Life in India* by U. Ball)

NAKED KAMAR CHILDREN
.... poverty inducing nudity

ROTARY BLOWER AND HAND-BELLOWS
.... good for light job

are working the bellows for each furnace, thereby delivering a much stronger blast than what is supplied in the furnaces of Penthabahal. Another illustration which is given below shows that in ancient Egypt a single furnace used to be served by two pairs of bellows worked by two sturdy men. The Penthabahal furnace has one pair of bellows and one worker only. It may be that the size of the family of a local smelter is smaller than in Palamau or elsewhere. The local furnace has, therefore, been designed in a smaller scale suitable for the working capacity of a small family. But there can be no doubt that the working hours for the smelters of Penthabahal are not enough for purpose of sufficient income. The visit to the market for sale of manufactured products takes two whole days, although the market is only three miles from the village.



EGYPTIAN SMELTING YARD

(Imitated from a Reproduction)*

Original : From Wall Painting in the Tomb of Rekhmara at Thebes (1535—1150 B. C.)

One full day could have been saved here. The visit to the forest for collection of charcoal or ore-stones also takes two days in the week, during which time raw materials just sufficient for production of six seers of iron are collected. It should have been possible to collect a much larger quantity of ore-stone and charcoal during these two days. Similarly they could have worked the furnace for 10 to 12 hours instead of six hours as they do now in course of two days. Thus in each successive stage, the Kamars fail to do a full complement of work and cannot, therefore, complain if their earnings are low.

Inefficient Equipments to be discarded

77. Apart from reasons connected with the habit and temperament of the Kamars, there are matters of technique and equipments which contribute to the scantiness of their earning. The foot-bellows are inefficient and are incapable of producing adequate temperature inside the furnace. The clay furnace itself has many technical shortcomings one of which, for example, is that there is no practical means of keeping the nozzle cool. The nozzle is at a region where the furnace has the highest temperature. Two pieces of bamboo pipes are placed close to the nozzle for leading air from the bellows to the furnace. The bamboo pipes terminate about an inch or two from the mouth of the nozzle so that they might not get burnt. This disconnected arrangement is responsible for considerable loss of blast and the fire does not achieve the temperature that might have been otherwise possible. This results in wastage in several ways. Firstly, the expenditure of charcoal is proportionately great. Nearly 15 seers of charcoal to one seer of finished iron becomes necessary under such conditions. Sometimes the proportion is higher. Secondly, some metal is left unrecovered in the slag. The method, therefore, is wasteful.

*Another version may be seen in the *Metallurgy of Iron and Steel* by Bradley Stoughton, page 2

78. *Foot-Bellows*—An equipment which is not quite efficient is the set of foot-bellows. It is small in capacity and is worked by a single worker, unlike the type in vogue in Palamau district which is worked more force-fully each by two persons. Even the Palamau type is not the ideal one for although air delivery is much greater than in the Penthabahal type, the overall advantage gained is unequal for the labour of two. Moreover, there is the inherent limitation of human power. The furnace obviously requires still greater blast input than what two persons can deliver by physical exertion.

79. *Hand-Bellows and Rotary Blower*—The use of the conventional type of hand-bellows is out of question because of its very limited capacity and the intermittent break in the flow of air. A much better device than this is the hand-operated rotary blower. This ensures continuity of air-flow but its size cannot be sufficiently large if human hand-power is required to operate it for a certain length of time. Devices which are more powerful than these two types are necessary. The suitability of a mechanically-propelled rotary blower or an electric blower should, therefore, be considered.

80. *Mechanical Blower*—In the district of Koraput, the Akhil Bharat Sarva Seva Sangh has made some useful experiments with a view to study the comparative usefulness and suitability of the traditional foot-bellows, a mechanically-driven blower and a small electric power blower. The results are quite interesting. A rotary blower containing 16 vanes 12½ inches long, tapering from 6 inches to 2½ inches in width and enclosed in a wooden casing was installed. A speed drive was improvised with 1:6 ratio by means of a bicycle wheel and V belt drive. An operator seated above the wooden casing was required to pedal the bicycle wheel. A maximum of 50 r. p. m. was achieved but the air output was hardly satisfactory. Attempt at increasing the speed ratio proved fruitless because pedalling could not be maintained at the original rate with the result that there was no improvement in. the flow of air. A mechanical device of this type is hardly as useful as the traditional foot-bellows.

Installation of Electric Blower

81. Experiments made with a ½ H.P. electrically-operated blower consuming 2 amps. at 220 volts gave satisfactory result. The displacement of air was calculated at 60 c.ft. per minute. It was noticed as a result of the experiment that the output of the furnace could be raised to about 25 seers of iron in course of eight hours of work, or 6¼ seers in two hours. The Penthabahal experiment produced 3½ seers of sponge iron in course of two hours with the help of the traditional foot-bellows. It may be concluded that the substitution of the foot-bellows by an electric blower of the type used in Koraput experiment will at once double the output.

82. *Prerequisites*—The introduction of electric blower in place of the traditional foot-bellows appears to be indispensable if the level of earning of the smelters has to be raised. The use of electric blower, however, envisages various developments which must be ensured beforehand. It cannot be introduced in villages until the scheme of rural electrification has extended there, and the Administration is agreeable to arrange for supply of energy at concessional rate. The smelter must be able to pay for the blower and the cost of its installation. Otherwise, the Administration should again come to his help by granting aid,

subsidy or loan. Lastly the smelter himself must have some amount of minimum practical knowledge of running a simple electric machine and about its maintenance. The smelters are poor but not unintelligent and seem capable of benefiting from any arrangement that may be made to give them some amount of technical training. Finally there should be some public arrangements to attend to cases of mechanical breakdowns and failures. Once these arrangements are ready, there should be no difficulty to discard the antiquated foot-bellows and adopt its modern version, the electric blower.

The Fuel Problem

83. *Growing Scarcity of Charcoal*—Charcoal has been regarded as an indispensable raw material for use in the clay furnace since the beginning of smelting process by the ancient people. It plays a triple role in the process by serving as a fuel for production of heat, by acting as a chemical reducing agent and finally by keeping the hot reduced metal covered all round so as to protect it from the oxidizing action of air. Charcoal, however, must be available in large quantity and at close range so that transport does not become time-taking or costly. In recent years forests which contained certain particular varieties of trees, namely, Sal, Jaman and Mahul, are fast disappearing due to indiscriminate exploitation by the growing population as well as due to the necessity of clearance of extensive tracts of reserved forest for establishment of large-scale industries or modern townships. If, therefore, the indigenous process of smelting is to be kept alive or expanded further, it cannot be done on the basis of the dwindling source of this important raw material, namely, charcoal, made in the conventional manner from forest trees. A good alternative will have to be devised.

84. *Production of Charcoal by Wood Distillation*—It is possible to produce charcoal in large scale by a process known as destructive distillation of wood. The process has been adopted by one of the modern steel factories, namely, the Mysore Iron and Steel Works at Bhadravati, which uses charcoal and not coke as the fuel required for smelting of iron ore. Forest trees are cut and allowed to lie over for sometime till they are partially dried up and seasoned. When the moisture content in the timbers is reduced to the level of 20 to 22 per cent, they are cut into sized logs 3 to 3½ feet long and 5 to 6 inches in diameter. About 4 or 5 tons of such logs are loaded into a bogie and 4 loaded bogies are charged into a retort which is then sealed air-tight and passed through heat chambers. The heat drives away the moisture still present in the logs. The temperature is raised to the level of 300° to 350° C. when exothermic reaction takes place, resulting in still higher temperature and inducing distillation of a liquid called pyroligneous liquor. The firing is reduced 18 to 20 hours after initial charging but carbonization of the wood takes about 36 hours. The hot charcoal is then passed into primary coolers where it remains for another 24 hours, and lastly to secondary coolers for a further period, by which time the charcoal is cool enough to be used in the furnace. The charcoal which is thus produced is low in ash content which is limited to 4 or 4½ per cent. Carbon constitutes 70 to 80 per cent and the rest happens to be some volatile matter. A bogie charged with 4 to 5 tons of log yields about one ton of charcoal. In Bhadravati, the plant produces about 30 to 35 tons of charcoal per day, which

not being adequate for the requirement of the furnace is supplemented by local purchase of charcoal from indigenous producers.

85. The distilled liquid, pyroliquor contains 5 to 6 per cent of wood tar, 4 to 5 per cent of acetic acid and 2 to 2·5 per cent of methyl alcohol. The liquid is separately treated for separation of these three valuable by-products.

86. Since it is becoming more and more difficult for village smelters to obtain necessary quantity of charcoal, the local administration, namely, the Panchayat Samiti or some other equivalent administrative body may undertake to instal a wood distillation plant in an area where there are adequate number of indigenous furnaces working and where there are suitable forests nearby. There is the practical feasibility in venturing such a project because the smelters' villages are generally localized within a certain zone and reserved forests are to be found within the ambit of such zones, so that one charcoal-making plant can economically function and serve all the smelters of the surrounding villages. Besides, the body owning the plant will be creating an additional source of income for itself from the manufacture of tar, acetic acid and methyl alcohol, and will at the same time be able to provide employment to a section of the rural population.

87. ***Coke or Wood-waste as alternative Fuel***—If adequate production of charcoal may not be possible on account of any reason, the alternative may be confined to the use of coke or wood-chips or wood-waste. Raw coal is not suitable, as it lacks the mechanical strength and the chemical qualities required in the process of smelting. It is usually converted into another form—coke, which is physically and chemically fit to do the job. All modern iron-smelting furnaces use coke as fuel. Its action in a clay furnace where the temperature is not intended to reach the maximum level and where no lime-stone is used as flux has to be studied. Its properties as a chemical reducing agent in place of charcoal has also to be found out. Another alternative, namely, the use of wood-waste will radically change the *modus operandi*, and requires careful experiments. It may thereafter be possible to judge if coke or wood-waste can be introduced as a tolerable substitute for charcoal for use in country furnaces. It, however, seems certain that the structure of the furnace will require redesigning if the type of fuel is to be changed. This itself is a difficult task, and calls for patience, study and research.

Improvement of Clay Furnace

88. The most common type of clay furnace, namely, the Penthabahal type, is not the most efficient one. There are furnaces, for example of Palamau or Madhya Pradesh type, which are larger in capacity and more profitable. There are underground furnaces of Singelbecha type, which are considered much better not only from the point of view of thermal efficiency but also in respect of quantity of recovery of metal. It is, therefore, possible to study different types of the furnaces and to design an improved type. In doing so extreme care is necessary in introducing any innovation, because the result of the present survey shows that the type of furnace which is in vogue in a particular locality has been evolved on the basis of generations of experience and is almost the best suited for the particular type of ore available in the locality. Any hasty change on the basis of theoretical

knowledge is likely to introduce fresh complications rather than solve existing problems. It is known, for example, that the height of a furnace is very material to the attainment of temperature. But this should not lead one to raise the height indiscriminately, for a furnace higher than the optimum consumes more fuel and brings about complications in the production of the desired quality of iron. The height must be appropriate to the type of the ore used so as to yield maximum output of iron with minimum consumption of fuel. In this manner utmost care is necessary with regard to the girth and inner dimensions of the furnace, the size of the apertures, the volume of air-flow and finally the ore-charcoal ratio.

Reduction of Mesh of Ore

89. The smelters usually charge in the furnace lump ore of the size of ½ to 1 inch, which is really too large for effective reduction expected during the 30-inch travel down the furnace. The optimum mesh of ore, as found during the Koraput experiment, is minus ¼ inch. The fines should be screened off, for, though they have no deleterious effect on the yield of steel, the spongy mass of metal which is finally recovered from the bottom of the furnace stands the risk of getting composed of metallic particles too fine to be forged to a homogeneous mass. If the mesh of ore is thus reduced, the achievement will be not only in the direction of higher metallic recovery but also in lower charcoal consumption. It is estimated that reduction in ore-mesh from plus ¾ inch size to minus ¼ inch size will nearly double the quantity of yield of iron. Simultaneously the consumption of charcoal is expected to be reduced by about 25 per cent.

Use of Flux

90. Village smelters are averse to the use of flux of any kind. The technical wisdom of their ancestors does not favour such a measure. They have themselves never tried the results of fluxing and cannot explain the reason behind their choice. It is not known if the traditional prejudice resulted from unavailability of fluxing material at close range, or if the principle was discarded after reasonable trials in old times. The present investigation, however, broadly indicates that there may be some advantage in using lime-stone as flux in the clay furnace (paragraph 5 of the Chemical and Metallurgical Report—*vide* Appendix). It may perhaps prevent to some extent the escape of the unreduced ore along with the gangue or slag and thus contribute to higher recovery of metal. The Steel Plant at Bhadravati, which uses charcoal as fuel, uses limestone as flux. There is, however, the danger of greater contamination of iron by carbon in a small-sized clay furnace, which should be carefully studied in an experiment. A haphazard conclusion drawn from the behaviour of a modern furnace is unsafe, for it must be remembered that a village smelter wants to produce wrought iron directly and not pig iron as in the case of a blast furnace.

Provision of Tools and Equipments

91. All the tools and equipments in the workshop are of indigenous make. A Kamar manufactures his own tools, which are good for his work, except the heavy anvil. He uses a large piece of granite stone boulder for an anvil as he cannot afford to purchase a piece of steel anvil of large size. Similarly he is too poor to provide for himself a bullock-cart for transport of ore-stones and charcoal from the

forest, though this will save much of his time and labour in bringing raw materials by *bhar* or head-load. In such a case, some amount of financial aid or loan should be granted to him for purchase of a steel anvil, a vice, a bullock-cart and any other equipment which cannot be made in his workshop.

Many-sided Improvements needed

92. The review made above indicates that it is possible to raise the level of earning of indigenous smelters to a substantial extent, but it is also clear that unless many-sided improvements are made in the technique and equipments that have remained unchanged since pre-historic times, the industry may not be able to stand on its own legs in the highly competitive field of the present day. The substitution of traditional foot-bellows by electric blower of the type described will alone double the present output. Other measures, such as reduction of ore-mesh, provision of suitable tools, redesigning of clay furnace, and lastly hard work by the Kamars themselves will make the industry adequately lucrative so as to compare not unfavourably with any other economic activity followed by the rural folk. Apart from what experiments and observations have been made in course of this survey, it may be necessary to examine further what may be the actual increase in the income of the smelter, and how far smelting of iron in the form of a decentralized cottage industry can expand, when necessary improvements are introduced.

SECTION VI

CONCLUDING REMARKS

93. The extent of the ancient smelting industry has greatly declined. It stood as a self-subsisting industry for many a long century. Ultimately there was the gradual spread of mechanized modern industries in India, though this development itself was preceded by what may be called an era of 'deindustrialization'. During this infamous era, India's traditional handicrafts declined sadly from their original height of prosperity. The phenomenon became widespread as the new change gathered momentum from decade to decade, finally to sweep over the length and breadth of the country. The ruin, sooner or later, of the old traditional crafts was an inescapable consequence of the new revolution ushering in with all the vigour and characteristics of a fresh-born movement.

94. Yet neither foreign imports nor competition from mass-scale production of iron by modern Indian factories, deadly famines nor increasing cost of living, the poor unprogressive technique nor the most pitiable level of earning have succeeded in altogether defacing the little clay furnace. The reason for this heroic persistence is the Kamar's genuine love of his ancestral craft, combined with the peasant's preference for tools and implements made from the soft and malleable metal produced by these good old workers. The peasants believe that tools made from the village iron are easier to mend when broken, and that they do not rust quickly as does the factory-made iron. This aspect alone should suffice to dispel the prejudices of those who feel that revival of the industry is a far cry, and to justify attention of the Government for providing conditions conducive to the development of the industry on correct commercial lines.

APPENDIX

Report on Chemical and Metallurgical Examination of Samples of Indigenous Iron Ore and Slag, Finished Tools, etc.

Sample pieces comprising of iron ore, sponge iron, gangue material, squeezed out slag and also 'finished' tools (chopper axe, knifelike cutter) were received for examination. These were stated to be collected from Kalapat Hill areas where tools and implements are believed to be made from the indigenous raw materials.

2. Investigation comprising of chemical analysis, micro examination and some hardness determinations was made to assess the quality of the raw materials and finished items. The findings are given in the next page and, for convenience, are summarised below.

3. The analysis shows iron ore containing about 45 per cent iron against normal 60 per cent and above, having silica and alumina contents of 13 and 7 per cent respectively, sulphur being practically nil and phosphorus very low. The silica/alumina ratio, unlike the Steel Plant ore, is 2 : 1 (against 1 : 1 or 1 : 1·5). No presence of magnetite was observed and the high ignition loss indicates some proportion of limonitic variety.

3-A. The gangue and slag show high but variable iron oxide content (40 to 60 per cent and 60 to 75 per cent respectively) in different places, with about 8 to 9 per cent alumina and about 1 to 2½ per cent lime. The gangue shows 24 per cent silica whereas the squeezed out slag about 13 per cent SiO_2 with some amount of unburnt 'carbon'.

3-B. The interesting features observed, it will be seen, are high ignition loss (about 12 per cent) and silica/alumina ratio, though favourable, in the ore, and very low lime in the slag and the gangue.

3-C. The sponge iron is found to be a highly porous mass, with large amount of embedded slag and charcoal pieces. It is, therefore, not surprising that the piece has given variable analysis from different positions outlined below :

		Position I	Position II	Position III
Carbon	..	·30 per cent	·45 per cent	·60 per cent
Manganese	..	trace	trace	..
Sulphur	..	trace	trace	..
Phosphorus	..	·03 per cent	·02 per cent	..
Silicon	..	·20 per cent	·18 per cent	..

4. It will be noted that excepting carbon, other items are reasonably consistent and very low, and the material resembles more 'Puddle' iron than 'Wrought' iron, which is characterized by very low carbon. Sponge iron piece was also found difficult to cut when pieces were needed for microscopic examination. However, cut pieces show varying amount of embedded slag in different positions and the hardness determinations vary considerably (from 160 to 190 V. P. N. in softer areas and 250 to 300 V. P. N. in harder areas).

As expected, the samples show different characters in different areas, some areas with fairly low carbon, deposited in the form of long needles (*vide* photomicrograph II), in other areas still less carbon (*vide* photomicrograph I), but in some areas high carbon in a different form (cellular pattern, *vide* photomicrograph III). The 'finished tools' show considerable resemblance to 'normalized' medium carbon steel (*vide* photomicrograph IV).

Some areas are similar to 'overheated' type (*vide* photomicrograph V). The cutting edge reveals Sorbitic-Martensitic Structure. The chemical analysis and hardness determinations came as follows :

		Knife-tip	Axe-tip	Away from Axe-tip
Carbon	..	·40 per cent	·60/·68 per cent	·50 per cent
Manganese	.	trace	trace	trace
Phosphorus	..	·05 per cent	..	..
Sulphur	..	trace	..	..

Hardness (V. P. N.) : Knife : 156, 167, 176, 182

Axe : 200/205 (Eye portion)

170/215 (Middle portion)

290/300 (Cutting edge)

The axe appears to be much more well finished product both from the point of view of appearance and utility.

N. B.—Hardness figures vary considerably in the finished material. This is to be expected from the nature of the sponge iron. Further determinations indicate similar hardness variations, viz., from about 225 to 160 V. P. N. and about 120 to 200 V. P. N. in the smaller piece in the main body, i.e., 'away from the cutting edge'.

5. It appears that low grade iron ore, containing high silica and alumina contents, but low in sulphur and phosphorus, is used for indigenous manufacture of tools and implements. The ore is basically similar to hematite type with a portion of limonite. The presence of unburnt carbon indicates unsatisfactory temperature condition. While some lime in the slag is expected from charcoal, it is not clear how about 2 per cent lime comes in the slag when no limestone is used for manufacture. Deliberate addition of lime, even in small quantity, will be advantageous. The varying character of the sponge iron is reflected in the quality of the finished tool. Addition of lime in the charge and full burning of charcoal during smelting will tend to make better quality sponge. The highly carburized layer at the tip arises from repeated heating and forging to shape out the implement and also to squeeze out the slag prior to water-quenching and operation appears quite satisfactory. The fairly deep edge hardness developed in the tools should suffice for general purpose tools.

FINDINGS

SUBJECT—Analysis of samples received on the 21st October 1962 relating to Sponge Iron and allied materials

Received from Superintendent of Census, Government of India, Orissa Circle.

1. Iron Ore sample collected from Kalapat Hills :

Loss on Ignition	..	11·91 per cent
Fe.	..	44·80 per cent
SiO_2	..	13·20 per cent
Al_2O_3	..	7·05 per cent

2. Broken piece of Lump Ore that are charged to the Furnace :

Loss on Ignition	..	11·20 per cent
Fe.	..	45·10 per cent
SiO_2	..	12·85 per cent
Al_2O_3	..	7·20 per cent

3. Gangue Material tapped out of the Furnace at interval:

SiO_2	..	23·82 per cent
Total Iron as FeO	..	61·50 per cent
Al_2O_3	.	9·20 per cent
CaO	...	2·50 per cent
MgO	..	0·75 per cent

(Contains amall amounts of Ferric Iron)

4. Sponge Iron:

Si.	..	0·18 per cent to 0·24 per cent	Drillings are not uniform and contain small amounts of slag.
Mn.	..	traces	
Phosphorus	..	0·20 per cent to 0·03 per cent	
Sulphur	..	Less than 0·005 per cent	
Carbon	..	0·30 per cent to 0·60 per cent	

5. Slag forced out of Sponge Iron in the process of Forging:

SiO_2	..	13·10 per cent	Contains small amounts of free iron as well as carbon.
Total Iron as FeO	..	75·60 per cent	
Al_2O_3	..	7·95 per cent	
CaO	..	1·48 per cent	
MgO		0·45 per cent	

6. Analysis of Finished Tools:

(*a*) Smaller piece : Knife—

Carbon	..	0·42 per cent
Mn.	..	traces
Phosphorus	..	0·06 per cent
Sulphur	..	Less than ·005 per cent
Si.	..	0·05 per cent
Hardness	..	212 (average) at the edge 120 to 160 in the centre

(*b*) Bigger piece : Chopper Axe—

Carbon	..	0·49 to ·51 per cent
Manganese	..	*nil*
Sulphur	..	As in (*a*)
Phosphorus	..	As in (*a*)
Hardness	..	150 to 220 at the edge 160 to 170 in the centre 300 in the tip, i.e., cutting edge

ROURKELA

The 6th November 1962

A. K. MALLIK

Chief Metallurgist
Hindustan Steel Ltd.
Rourkela Steel Plant

TERMINOLOGY

Words		Local terms at Penthabahal	Local terms at Singelbecha
Smelter	..	Kamar	Lohar
Furnace	..	Bhati	Gaana
Forge	..	Sala	Chuli
Basket	..	Kantara	Chaalni
Ore	..	Luha-pathar	Paakna
Charcoal	..	Koila	Angra
Slag	..	Khaado	Gu
Slag pit	..	Hagani gaado	Gu-kadha
Bellows	..	Janta	Jatri
Hammer	..	Ghana	Hatudi
Tongs	..	Sanduasi	Sandasi
Punch	..	Atila	Tussa
Iron anvil	..	Nehi	..
Nozzle	..	..	Nala
Charging platform		Machan	..

BIBLIOGRAPHY

1. The Making, Shaping and Treatment of Steel by United States Steel Corporation, U. S. A., 1957.
2. A Monograph on Iron and Steel Work in the Province of Bengal by E. R. Watson, I.C.S., Calcutta, 1907.
3. The Agaria by V. Elwin, Oxford University Press, 1942
4. A Journey from Madras through the Countries of Mysore, Canara and Malabar, Volume I (1807), by Buchanan Hamilton.
5. Techno-Economic Survey of Orissa by National Council of Economic Research
6. Mineral Production in India, Ministry of Steel, Mines and Fuel, 1958
7. Report on Underground Furnaces (Manuscript) by Akhil Bharat Sarva Seva Sangh
8. A Monograph on Village Penthabahal by M. Ahmed, I.A.S., Census of India, 1961, Volume XII—Part VI—No. 1.
9. Economic Geology of Orissa by Geological Survey of India, 1949
10. Antiquities of Orissa by Rajendralala Mitra
11. Dictionary of Applied Chemistry by Thrope, Volume XI, 4th Edition, 1959
12. Technology of Wood Distillation by M. Klar, translated by A. Rule, Chapman & Hall, 1925.