It is developed and coloured by iodine and by nitric acid, the intensity of the colour increasing with the percentage of Carbon in the steel. It is also developed by Liquorice infusion or Ammonium Nitrate. Martensite with the maximum amount of Carbon is called Hardenite, so that a quenched steel containing ·9 per cent. of Carbon consists entirely of Hardenite.

Fig. 282 is a photograph of a Carbon steel under a high power and shows the general appearance of Martensite.

Sorbite.—This is a transition product between Austenite and Pearlite, or, to be more precise, between Troostite and Pearlite. It is obtained, according to Osmond,* by cooling sufficiently slowly to allow the transformations to take place only partially, and yet with sufficient rapidity to produce an imperfect separation of Ferrite and Cementite. In practice these conditions are more or less fulfilled by cooling small samples in air, by quenching in cold water towards the end of the recalescence, by quenching in lead, or by reheating or tempering hardened steels at a temperature between 400° and 700° C. It may almost be regarded as unsegregated Pearlite. Under the microscope it is characterised by the absence of striæ, and by the rapidity with which it is coloured by "polish attack," or by tincture of iodine and picric acid.

Troostite represents a transition Carbon condition between Austenite and Sorbite. According to Osmond, if a piece of steel containing about 0·85 per cent. of Carbon be quenched in cold water during the recalescence, the grains which have undergone transition consist of Pearlite, those untransformed of saturated Martensite, while between these two all degrees of transformation can be detected. Troostite may be produced (1) by sudden cooling of steel during the recalescence period; (2) by a mild quenching of small pieces in oil or of large pieces from a temperature higher than that of the critical range; or (3) by reheating hardened steel to nearly 400° C.

Fig. 283.—Sample of Steel containing 1·6 per cent. of Carbon, quenched in Ice Brine from 1,100° C. The light ground mass is Austenite, and the dark barb-like structure Martensite or Hardenite.

Osmondite.—It has recently been proposed to use the name Osmondite for that stage in the transformation of Austenite at which the solubility in dilute sulphuric acid reaches its maximum rapidity. It is arbitrarily taken as the boundary between Troostite and Sorbite.

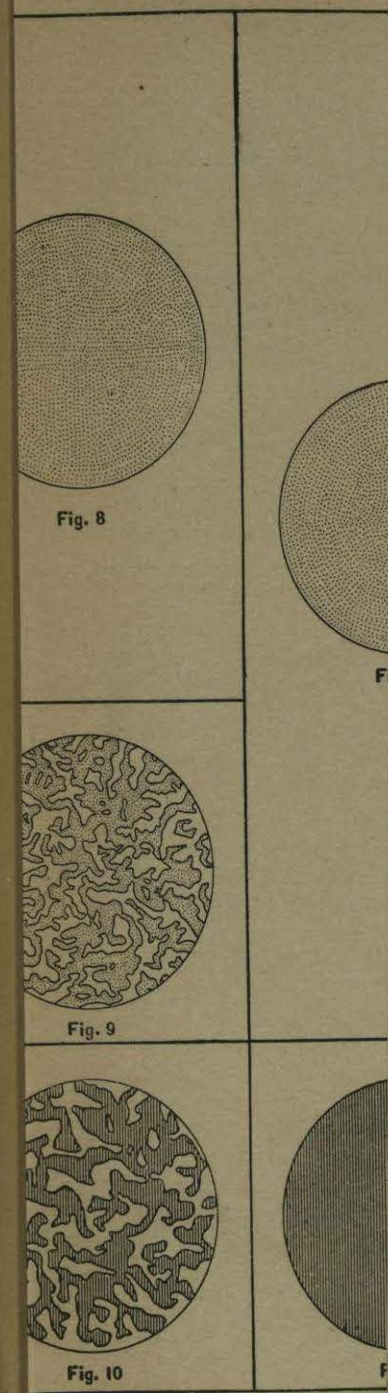
Austenite.—This is the Iron-Carbon solid solution as it exists above the transformation range, or as preserved by rapid cooling or by the presence of retarding elements such as Manganese and Nickel.

It follows from the foregoing definitions that the proportion of Ferrite to Pearlite, Cementite, and Martensite in any given sample of steel depends

* *Metallographist*, vol. i., No. 2, p. 152.

VIII.—Microstructure of

n, 0·35 per cent. Carbon, 0·



of Microstructure of Steel, quenched

Carbon, 0·09 per cent. | Carbon, 0·21 per cent. | Carbon, 0·35 per cent. | Carbon, 0·80 per cent. | Carbon, 1·20 per cent. | Carbon, 2·50 per cent.

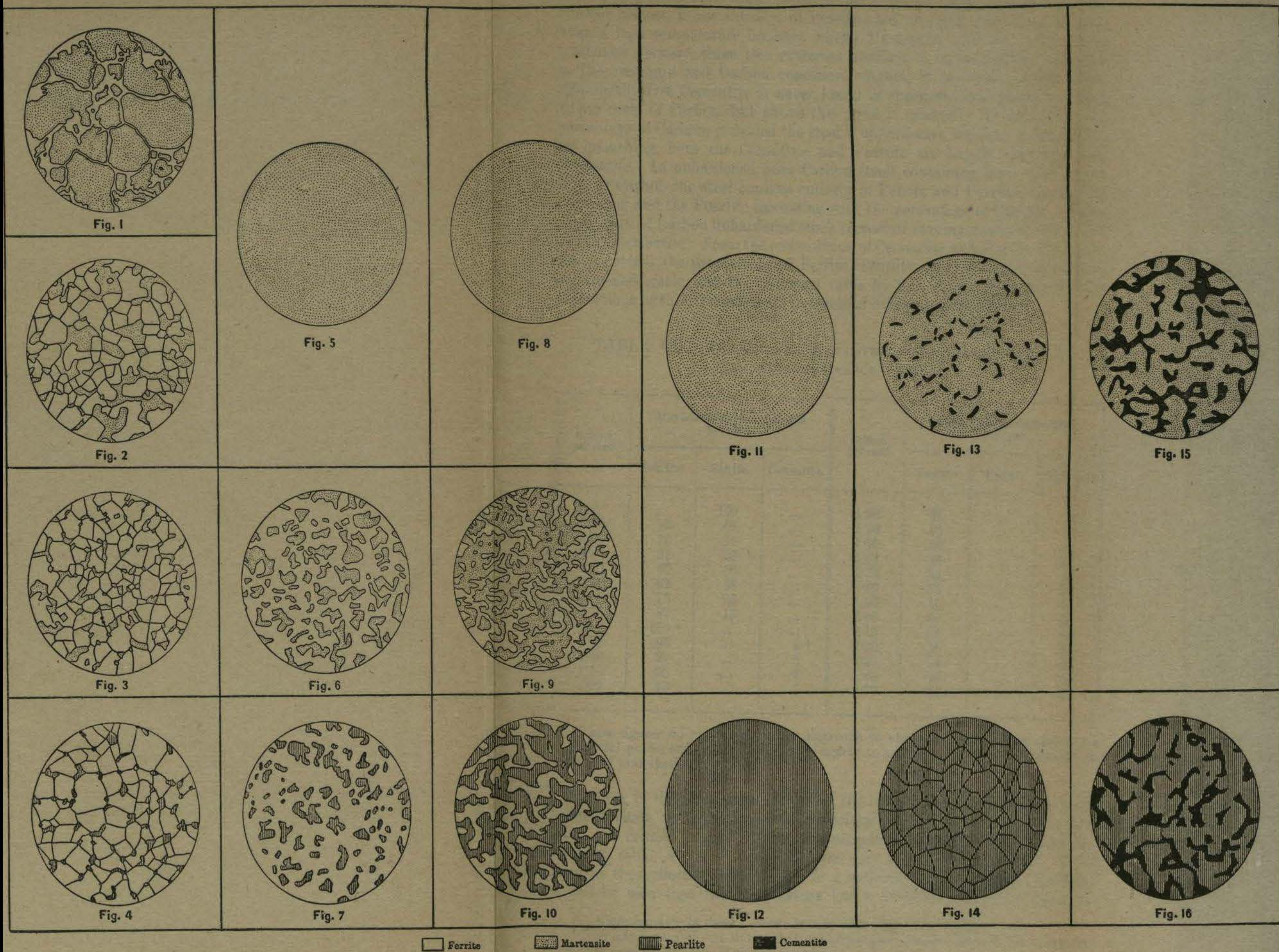


Fig. 284.—Diagrammatic Illustration of Microstructure of Steel, quenched above, between, and below the Critical Points.

upon the percentage of Carbon in the steel, and on the heat treatment. Thus, a sample of steel containing about ·9 per cent. of Carbon on slow cooling consists almost, if not entirely, of Pearlite, but on rapid quenching in water from a high temperature becomes wholly Martensite, and any intermediate treatment between these two extremes produces a corresponding alteration in the structure and Carbon condition. Again, in normally cooled steels, structurally free Cementite is never found in specimens containing less than ·9 per cent. of Carbon, but above this point it gradually increases with the percentage of Carbon, provided the steel is unhardened, whereas, on hardening by quenching, both the Cementite and Pearlite are largely converted into Martensite. In unhardened pure Carbon steels containing from ·1 to ·9 per cent. of Carbon the steel consists entirely of Ferrite and Pearlite, the Ferrite decreasing and the Pearlite increasing with the percentage of Carbon. Above ·9 per cent. of Carbon unhardened steels consist of varying mixtures of Pearlite and free Cementite. From the composition of Cementite and Pearlite, Sauveur* has calculated the proportions of Ferrite, Pearlite, and Cementite present in unhardened steels, and the following table by him gives approximately the proportions of these constituents in steels of different compositions :—

TABLE CII.—Theoretical Microstructural Composition of Unhardened Carbon Steels.

Carbon per cent.	Microstructural Composition per cent.			Carbon per cent.	Microstructural Composition per cent.		
	Pearlite.	Ferrite.	Cementite.		Pearlite.	Ferrite.	Cementite.
...	...	100	...	1·30	91	...	9
0·10	12	88	...	1·40	90	...	10
0·20	25	75	...	1·50	88	...	12
0·30	37	63	...	1·60	86	...	14
0·40	50	50	...	1·70	85	...	15
0·50	62	38	...	1·80	83	...	17
0·60	75	25	...	1·90	81	...	19
0·70	87	13	...	2·00	80	...	20
0·80	100 †	...	...	2·10	78	...	22
0·90	98	...	2 †	2·20	76	...	24
1·00	97	...	3	2·30	74	...	26
1·10	95	...	5	2·40	73	...	27
1·20	93	...	7	2·50	71	...	29

These figures do not profess to an approach to absolute accuracy, but they are a very useful guide, and will be found very nearly to agree with the results obtained on the actual examination of samples.

Sauveur in the same paper published the results of a very complete series of experiments on the influence of quenching from temperatures above and below the critical points on the microstructure of Carbon steels, and the following table, which is compiled from very careful measurements of the areas of the different constituents, is a summary of the results obtained. It will be seen that the temperature has a very marked effect upon the

* "Microstructure of Steel," *Amer. Inst. of Min. Eng.*, Sept. 1896.

† The latest research has shown that ·9 Carbon gives 100 per cent. Pearlite, and free Cementite does not appear till this is exceeded.

structure. Steels containing from ·21 to ·8 per cent. of Carbon when quenched above Ar_3, or between Ar_2 and Ar_3, consist of Martensite, but when quenched below Ar_1 they contain a large proportion of Pearlite, in fact have the structure of slowly cooled steels. This is what we should anticipate, as the change from hardening Carbon to Cement Carbon, or, in other words, from Martensite to Pearlite, which are the structures which correspond to this Carbon change, is complete when Ar_1 is reached; rapid cooling below this temperature has no influence either on the Carbon condition, or on the microstructure.

By the courtesy of Mr. Sauveur I am able to reproduce (fig. 284) diagrammatic representations of the microsections from which the following table was calculated. These explain the changes taking place far more clearly than any verbal description, and their careful study will well repay the student.

TABLE CIII.—Microstructural Composition of some Quenched Carbon Steels.

<table>
<tr><th rowspan="2">Steel No.</th><th rowspan="2">Carbon per cent.</th><th colspan="3">Quenched above Ar₃. Per cent. in Volume.</th><th colspan="3">Quenched between Ar₃ and Ar₂. Per cent. in Volume.</th><th colspan="3">Quenched between Ar₂ and Ar₁. Per cent. in Volume.</th><th colspan="3">Quenched below Ar₁, or Slowly Cooled. Per cent. in Volume.</th></tr>
<tr><th>Martensite.</th><th>Ferrite.</th><th>Cementite.</th><th>Martensite.</th><th>Ferrite.</th><th>Cementite.</th><th>Martensite.</th><th>Ferrite.</th><th>Cementite.</th><th>Pearlite</th><th>Ferrite</th><th>Cementite.</th></tr>
<tr><td>1</td><td>0·09</td><td>77</td><td>23</td><td>...</td><td>27</td><td>73</td><td>...</td><td>11</td><td>89</td><td>...</td><td>10</td><td>90</td><td>..</td></tr>
<tr><td></td><td></td><td colspan="6">Quenched above Ar₂. Per cent. in Volume.</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td colspan="2">Martensite.</td><td colspan="2">Ferrite.</td><td colspan="2">Cementite.</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>2</td><td>0·21</td><td colspan="2">100</td><td colspan="2">...</td><td colspan="2">...</td><td>31</td><td>69</td><td>...</td><td>23</td><td>77</td><td>...</td></tr>
<tr><td>3</td><td>0·35</td><td colspan="2">100</td><td colspan="2">...</td><td colspan="2">...</td><td>56</td><td>44</td><td>...</td><td>50</td><td>50</td><td>...</td></tr>
<tr><td></td><td></td><td colspan="9">Quenched above Ar₁. Per cent. in Volume.</td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td colspan="3">Martensite.</td><td colspan="3">Ferrite.</td><td colspan="3">Cementite.</td><td></td><td></td><td></td></tr>
<tr><td>4</td><td>0·80</td><td colspan="3">100</td><td colspan="3">...</td><td colspan="3">...</td><td>100</td><td>...</td><td>...</td></tr>
<tr><td>5</td><td>1·20</td><td colspan="3">94</td><td colspan="3">...</td><td colspan="3">6</td><td>92</td><td>...</td><td>8</td></tr>
<tr><td>6</td><td>2·50</td><td colspan="3">80</td><td colspan="3">...</td><td colspan="3">20</td><td>77</td><td>...</td><td>23</td></tr>
</table>

Sampling for Micro Examination.—When a sample of steel is being prepared for microscopical examination it is very important to cut the specimens from the steel section, so that it shall be fairly representative of the entire section. In many cases it may be necessary to cut sections from the outside, the centre, and intermediate between the centre and the outside. When it is not possible to do this a section from between the centre and the outside should, if possible, be taken. If the sample is taken from the outside erroneous inferences may be drawn owing to local cooling of the surface, &c., while, if taken quite from the centre, other causes conduce to error. In all cases where a complete examination is desired it is essential to examine sections in three different planes—(1) a vertical transverse section; (2) vertical longitudinal section; (3) horizontal longitudinal section. During rolling or forging the grains of the steel are liable to be distorted and elongated in the direction of rolling, and unless both transverse and longitudinal sections are examined it is difficult to form a correct opinion as to the form of crystallisation or size of grain; also intrusions of slag, sulphide of manganese, or other foreign matter may either pass unnoticed or appear in an exaggerated form according as the section is transverse or longitudinal.

Before polishing samples which have been heated, either for annealing or quenching, great care must be taken that the surface is filed or ground off to an appreciable depth to make quite sure that all the oxidised surface is removed, otherwise most misleading deductions may be drawn.

The general effect of annealing from high temperatures is to produce a separation of the Pearlite into larger areas and more complete development of this structure, but this is not so marked in the set of photographs given later, as in some cases, since the bars were rolled at a fairly high temperature and allowed to cool slowly in air.

Annealing for a short time at a moderate temperature, not exceeding 900° C., does not very largely increase the size of the grain, although it is distinctly noticeable in most of the steels of which photographs are reproduced, but prolonged heating at low temperatures or comparatively short heating at very high temperatures produces a very coarse grained structure. The effect of prolonged heating on the size of grain is well shown in photos. 54, 55, 56, and 57, the sample annealed in a slag ball being a very extreme case. Such large grained structures usually denote excessive heating, either for too long a time or at too high a temperature, but this is not always the case, such crystallisation sometimes being due to other causes, as in the case of the structure of cast steel, which has not been forged or rolled (photo. 46). A very marked case of coarse crystallisation, due to prolonged heating, has recently been brought to my notice by Mr. Stead, who kindly sent me a portion of a sample of 2-inch mild steel billet which was embedded in a furnace bottom in such a position that the temperature did not exceed 700° C., and was probably nearer 600° C.; on removal after one year the Ferrite grains were over ½ inch in diameter, and the bar was excessively brittle. Such a steel, however, by suitable annealing would be restored to its original condition.

Overheated steel must not be confused with what is known as burnt steel—*i.e.*, a steel which has been heated to a point near that of incipient fusion, so that the crystals are actually separated from each other, thus breaking up the continuity of the mass. According to Stansfield,* "burning" is a segregation of Carbide of iron or other fusible alloy of lower melting point than the mass of the steel, to the intercrystalline joints, and this fusible alloy is afterwards more or less expelled, either by gases imprisoned in the steel, or by Carbon Monoxide formed by the Carbon in the steel, reacting on the scale formed on the steel. The gases in escaping produce blisters, and ultimately openings in the skin through which the fluid material at the joints of the crystals is expelled, leaving flaws or cavities which afterwards become more or less oxidised. Such steel is brittle, and practically useless, and its original mechanical properties cannot be restored by any subsequent heat treatment.

* *Iron and Steel Inst. Journ.*, 1903, vol. ii.

Figs. 285 and 286 show the general appearance of "burnt steel" at a low and moderately high magnification.

So far microscopic examination has not enabled the percentages of Silicon, Sulphur, and Phosphorus in steel to be determined with any degree of accuracy when present in normal quantities. The presence of a considerable percentage of Manganese may generally be detected by its affecting the general structure of the steel. In such steels the size of the grain is usually larger, and the Pearlite tends to be granular rather than laminated. That Phosphorus in large quantities is easily detected has been shown by Stead in his exhaustive paper on "Iron and Phosphorus," * but the microscope does not enable us to form a reliable opinion as to the amount present in the small proportions usually found in commercial steels. The heat-tinting, as developed by Stead, seems to offer the most promising results in this direction. Sulphides of Iron and Manganese can often be detected in steels under the microscope when present in small quantities, and both Prof. Le Chatelier

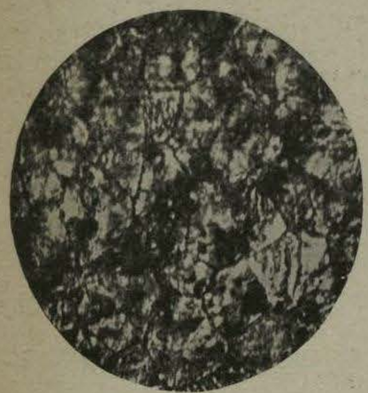


Fig. 285.—Magnification, 60 diameters. Burnt Steel, 2½-inch billet, which was "burnt" in the furnace. The grains are broken up, and junctions which appear as fine lines are shown under a higher power to contain Oxide.

Fig. 286.—Magnification, 250 diameters. Burnt Steel, same as No. 459, showing the grains to be more or less surrounded by Oxide of Iron.

and Prof. Arnold have shown as regards some special high Sulphur alloys that the Sulphide of Iron tends to form mesh-like structures round the grains of iron, which structure is to a large extent broken up by the addition of Manganese to form Sulphide of Manganese. Sulphide of Manganese in ordinary steel usually appears as little greyish globules, or small elongated cigar-shaped patches, according as a transverse or longitudinal section of the forged sample is examined, and a general opinion as to the steel being high or low in Sulphur can often be formed, but it is not possible to determine the actual percentage.

In the photographs given later the structures of most of the steels, except the oil quenched and oil tempered, are fairly distinctly shown. They have been taken rapidly under the ordinary laboratory conditions, and are simply

* *Iron and Steel Inst. Journ.*, 1900, vol. ii.

intended to give the student a general idea of the microstructure of different Carbon steels, such as he can observe himself. In the case of the oil quenched and oil tempered sections, it is most difficult to distinguish in a *photograph* the Sorbite and Troostite structure, as in both cases they represent transition Carbon conditions in varying degrees of transformation, and it often is only by careful examination under the microscope and noting the effect of different etching media that the particular condition can be determined. The photographs given so far as the author's experience goes, are typical of the structures of oil quenched and oil tempered steels, when such quenching has been carried out with small samples under the conditions specified. Many of the photographs at low power do not show any definite structure, but they are purposely given to show that certain structures are not defined under low power, and for comparison with the high power photographs. It is most important that the student should bear in mind the influence of mass on the microstructure of steel subjected to heat treatment, and he must not expect to get identical, or in many cases similar, structures to those given when treating 6-inch rounds, as it is clear that the rapidity of cooling of such a large mass would be very different to the rate of cooling of a small piece of ½-inch round bar. Even the outside surface of such a large mass would be comparatively slowly cooled, owing to the conduction of heat from the centre, while the centre of the bar itself would be cooled still more slowly. This difference in structure is shown in photographs 58, 59, and 60 of sections taken from outside centre of an oil tempered axle.

The particular temperatures of oil quenching and oil tempering have been selected because they are those which are frequently used in everyday practice where oil tempering is employed on a large scale.

TYPICAL STEEL PLANTS.

PLATE XIX.—*Plan of the North-Eastern Basic Bessemer Steel Plant.*

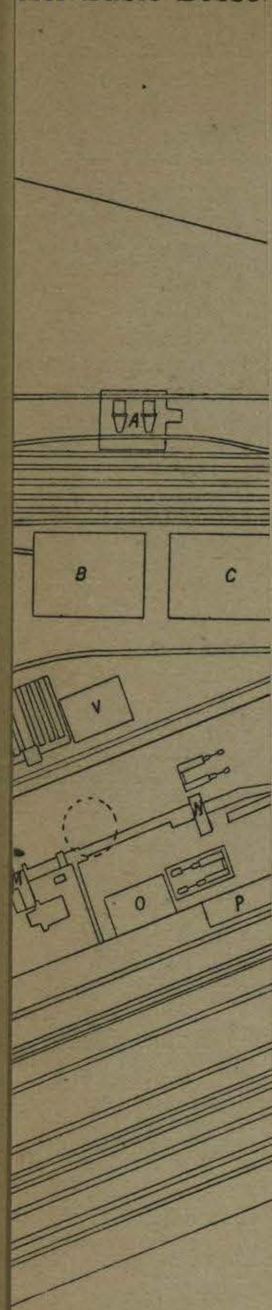
PLATE XX.—*Plan of the Frodingham Basic Open Hearth Steel Works.*

PLATE XXI.—*Plan of Gary New Steel Plant.*

PLATE XXI*a*.—*Plan of the Normanby Park Steel Works.*

The various appliances for the manufacture of steel having been described in detail, the accompanying plans will enable the student to see how the different parts of the plants are disposed relatively to each other, and to trace the course of the metal through the various operations from the time it leaves the mixer, cupola, or blast furnace until it is ready to leave the works in the condition of finished bars, rails, angles, &c. The first two plans are typical of our average English works, which have been gradually altered to meet modern conditions; in neither case are they given as examples of latest design, and in fact since the plans were prepared very considerable alterations and improvements have been made in both works, with the object of increasing the output and reducing the labour costs; on the other hand, even as shown on the plans, the works are not far behind in leading essentials, so far as the converting and melting shops respectively are concerned, the plants are fairly up to date.

The Gary plant shows the arrangement of the largest and most modern up-to-date plant in America, and the Normanby Park plant, now being erected by Messrs. J. W. Lysaght, under the supervision of J. H. Darby, is representative of a medium sized English works, designed to meet modern requirements.



This plant consists of four 15-ton basic Bessemer converters, J J J J, arranged in a line as shown, with an elevator track, Z, in front for the hot metal ladle to travel on. Part cupola and part mixer metal is used, and the ladle comes from mixer, A, or cupolas, D, along the railway shown to the lift, Y, by which it is raised to track, Z. The finished steel is poured from the converter into a ladle on a receiving crane, of which there are two, each serving a pair of converters. The receiving ladle full of metal is transferred to the jib of the centre casting crane, and the ingots are cast in the casting pit, K. The ingots are transferred from the casting pit to the soaking pits, L, from which they are conveyed by live rollers to the cogging mill, M, and then pass on to the roughing and finishing mill, N. In case of billets, they are transferred by the skid, W, to hot banks, Q, or in case of rails, to the straightening presses, R R R, and finally reach the stock benches, S S S. The entire works is encircled by several lines of rails communicating with the main line, so that raw material can be easily brought into, and finished material readily removed from, the works.

The basic shop is behind the converters, and tracks from each converter are connected with a large turntable, I, to facilitate the removal of old, and the replacement of new, bottom sections on the converter, and other repairs. There are three grinding mills, G, for grinding the basic material, and a plug-ramming machine, shown at H, for making the plugs for the bottom sections. The other details of the works will be understood from the lettering on the plate.

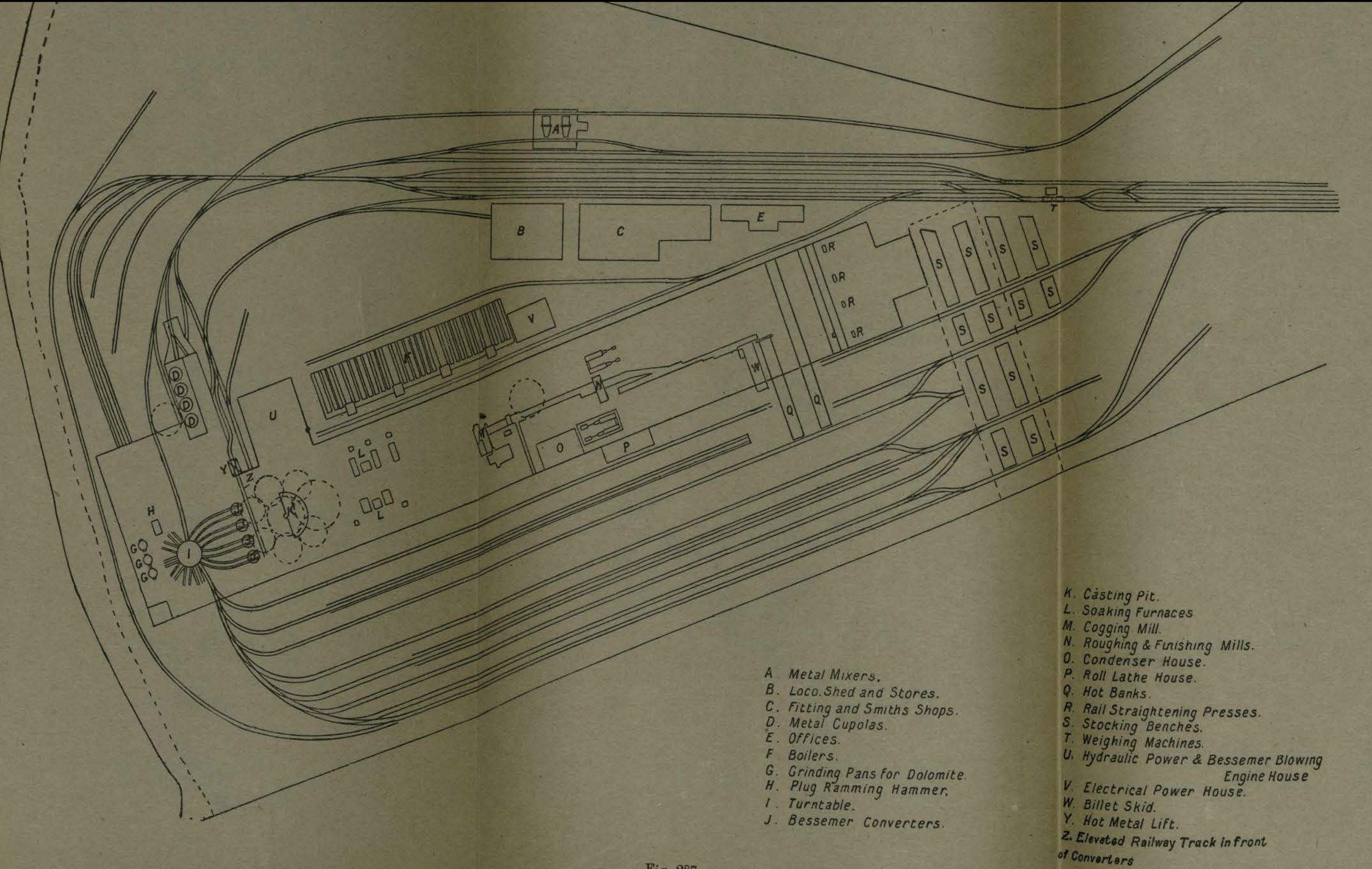
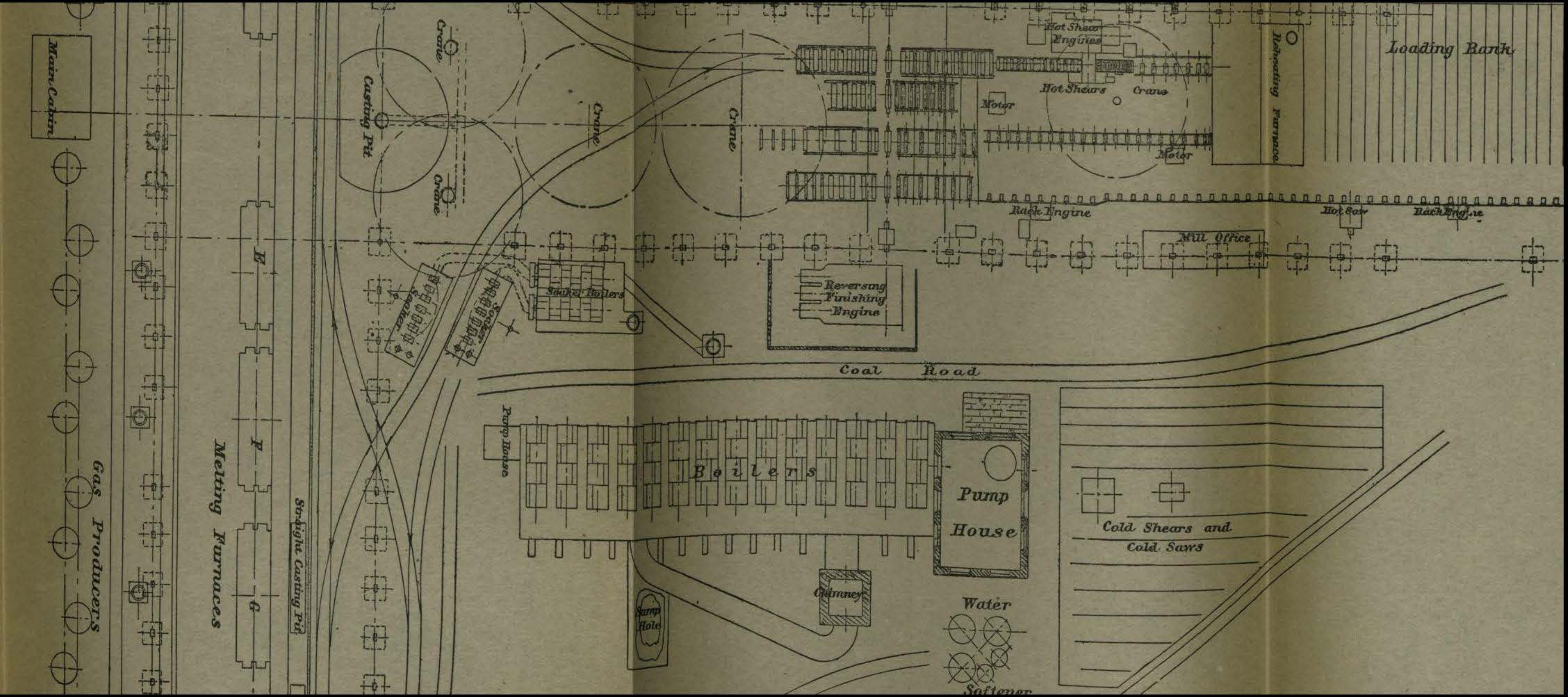


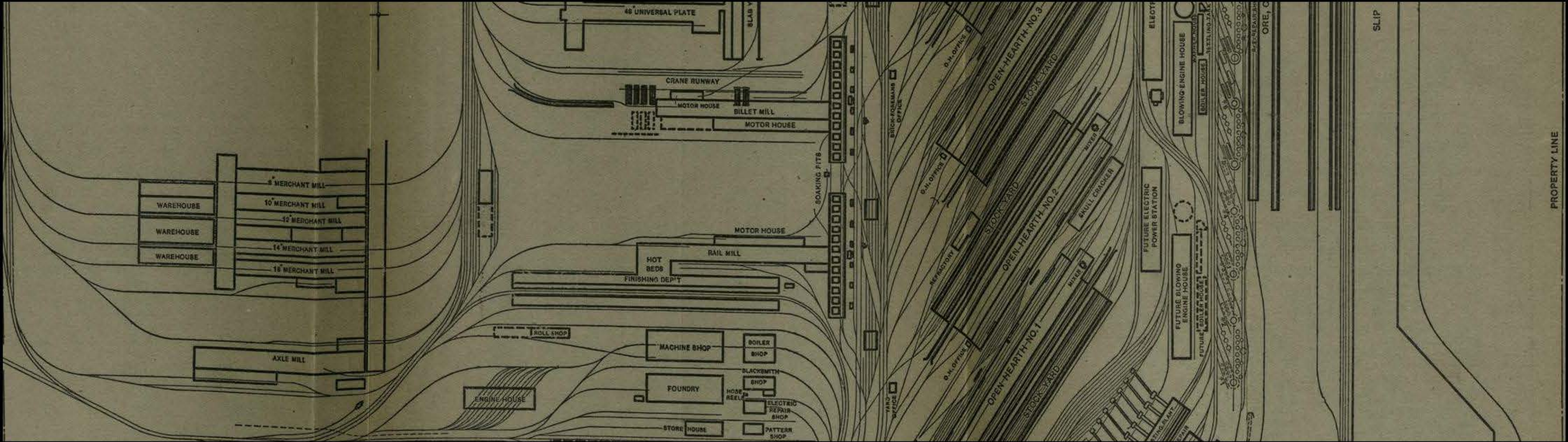
Fig. 287.

poured into the furnaces, the ore and lime are put in by means of a Wellman charger. On the tapping side there is also a ladle road the full length of the shop, and all the furnaces tap into ladles on carriages, and the metal is either cast in the straight pit in front of furnaces or transferred to a centre casting crane, and cast in the circular casting pit controlled by hydraulic radial cranes, as shown in the plan. The ingots are then taken to the soakers by steam travelling cranes, and from there to the live roller gear of the cogging mill. This mill is driven by a pair of reversing engines, geared 2 to 1 to the mill, and consists of one pair of rolls only. The piece travels through the cogging mill to the hot shears, and afterwards to an electric charger, which either puts it into the reheating furnace or transfers it to the finishing mill.

The finishing mill consists of three stands of housings, and is driven by a three-cylinder reversing engine; after leaving the finishing mill the bar is carried forward to the hot saw, and thence to the loading banks. The roller racks are driven by electric motors.

There is a range of fourteen Lancashire boilers mechanically stoked. There are several more steel furnaces than are shown in the plan, and, since the plan was prepared, one beyond furnace B has been dismantled to make way for the Talbot furnaces referred to.




46" UNIVERSAL PLATE
CRANE RUNWAY
MOTOR HOUSE
BILLET MILL
MOTOR HOUSE
8" MERCHANT MILL
10" MERCHANT MILL
12" MERCHANT MILL
14" MERCHANT MILL
18" MERCHANT MILL
WAREHOUSE
WAREHOUSE
WAREHOUSE
AXLE MILL
SOAKING PITS
MOTOR HOUSE
RAIL MILL
HOT BEDS
FINISHING DEP'T
ROLL SHOP
MACHINE SHOP
BOILER SHOP
BLACKSMITH SHOP
FOUNDRY
HOSE REEL
ELECTRIC REPAIR SHOP
ENGINE HOUSE
STORE HOUSE
PATTERN SHOP
BRICK-FOREMANS OFFICE
YARD OFFICE
O.H. OFFICE
O.H. OFFICE
O.H. OFFICE
OPEN-HEARTH-NO.3
STOCK YARD
STOCK YARD
OPEN-HEARTH-NO.2
REFRACTORY
MIXER
SKULL CRACKER
MIXER
OPEN-HEARTH-NO.1
STOCK YARD
FUTURE ELECTRIC POWER STATION
BLOWING ENGINE HOUSE
FUTURE BLOWING ENGINE HOUSE
BOILER HOUSE
ORE
SLIP
PROPERTY LINE

plant is
oils, and
rific value

desiccated
l, washed,
enerators,
s, utilising
e exhaust
t accumu-
ted when
roduced is
the plant,
gases will

e fields of
as regards
nearly self
pig parti-
asic open-

ken direct
rwards to
are served
uid metal,
be tapped
ead crane
carried on
ken to the
e soaking
mill driven
of various

Trent and

way giving

ely ground

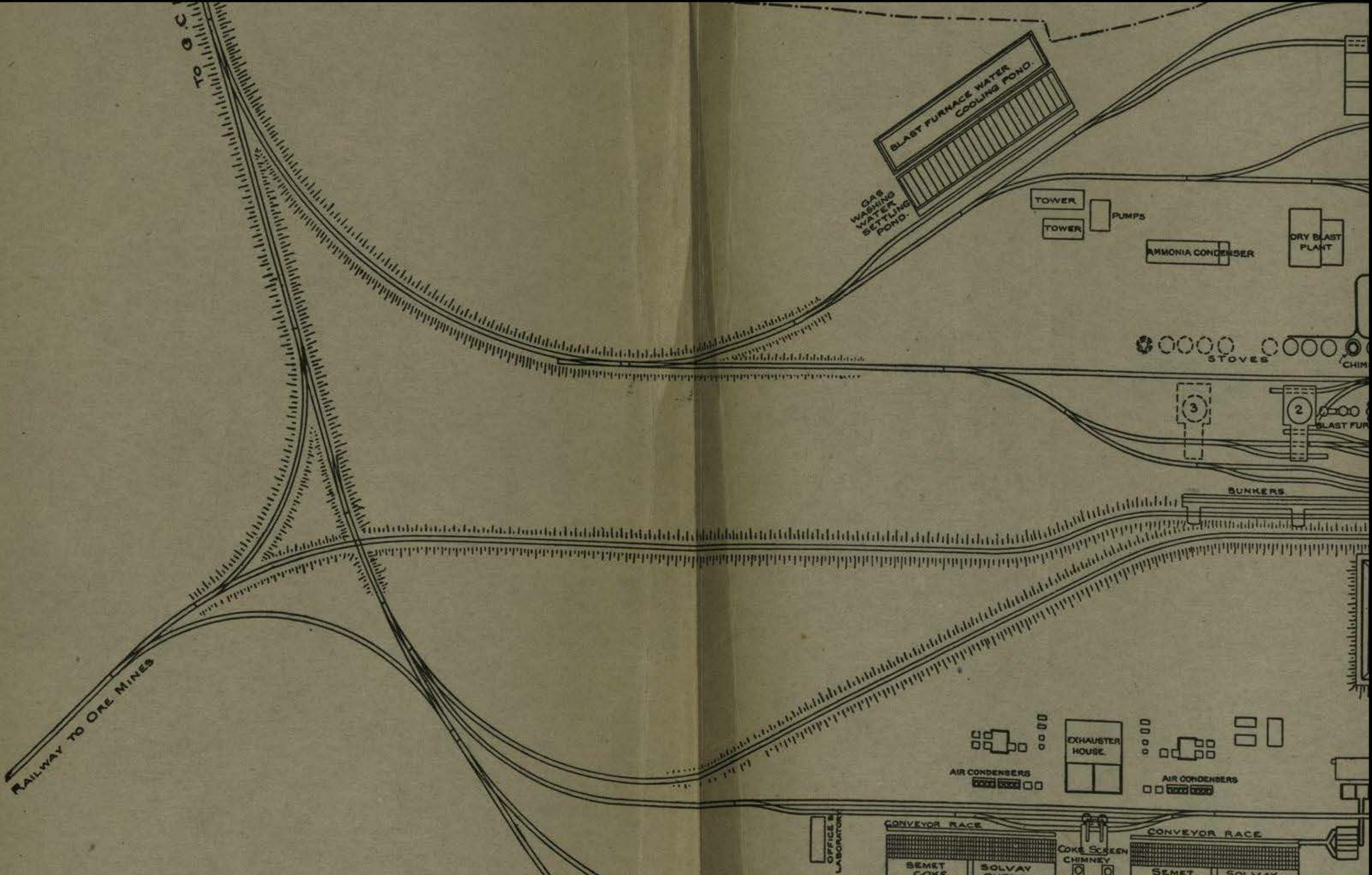


Fig. 289a.

PHOTO-MICROGRAPHS.

Explanatory Remarks.

The following photographs, from 1 to 40, are from four steels containing respectively ·16, ·47, ·89, and 1·12 per cent. Carbon.

In each case photographs are given of the steels as annealed, water quenched, water quenched and reheated, oil quenched, and oil quenched and reheated, and in all cases both low and high power photographs are given. In most cases the photographs of the rolled, reheated, and water quenched are from the *same section*, it having been simply repolished and re-etched after each treatment. The oil quenched and oil tempered photographs are also from one section cut from the same bar as the rolled section.

The other photographs are of a miscellaneous nature, and illustrate the effect of heat treatment, mechanical work, &c., particulars being given in each case.

The magnification was 100 and 1,000 for low and high powers respectively. All the photographs were taken with direct illumination.