IRON, STEEL, AND OTHER ALLOYS

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CHAPTER I.—INTRODUCTORY

1. INTRODUCTION.—Beside the general interest which we have in understanding the constitution of alloys, as giving us an intelligent view of the matter in general, we have the special reason that a knowledge of the subject promises to be of the greatest practical value in approaching the study of any given series of alloys, for instance to one seeking to learn what are the most valuable alloys of two given metals. The case reminds us of the calculus. If we have the formula of a given curve before us we can by means of the calculus discover where all the critical points of that curve will lie without going to the trouble of plotting it throughout. Somewhat so is it with the examination of the constitution of a series of alloys, say those of bismuth with tin, or antimony with copper. The constitution of such a series may be expected to vary from one end of the series to the other; but in passing thus from end to end of the series there may be important critical points, at which not only the constitution changes but the nature of that change itself changes abruptly. Such points may be called critical points for constitution. And, just as the calculus reveals to us the critical points of a curve of known formula, so it happens that these critical points for constitution may often be laid bare by means of a few easy experiments.

Now the importance of this lies in the fact that the critical points for constitution may be expected to be also critical points for the useful properties. If we seek ductility, we may expect to find a critical point for ductility in that part of the series where lies a critical point for constitution: there we may expect to find either a maximum or a minimum of ductility; and so with many other useful properties.

Thus it is that the methods which promise to reveal to us with relative ease the probable constitution of a series of alloys of any two metals, of learning where its critical points lie, and indeed whether it has any critical points, thereby promise to teach us where in that series we shall probably find those alloys the properties of which will differ markedly for better or for worse from those of the component metals; and indeed, whether or not we are likely to find any alloys in the series which do differ markedly in their physical properties from the component metals. The knowledge of the constitution of a series of alloys in short gives us a method of superior analysis of the problem of where to find in that series the most valuable alloys. These indications, of course, are not conclusive; indeed we have still far more to learn of their meaning than we yet know; but already they are of great value as in pointing out the part of the field most likely to be fruitful.

2. POSSIBLE COMPONENTS OF ALLOYS. — In inorganic matter we have three important classes of substances:

(1) pure elements,

(2) definite chemical compounds of those elements, and

(3) solutions.

In the same way we recognize in our alloys three classes of ultimate constituents:

(1) pure metals,

(2) definite chemical compounds of those metals with each other, such as $AuAl_2$, antimonide of copper (Cu_8Sb_8?), and antimonide of tin ($SnSb$), and also to a smaller certain extent definite chemical compounds of metals with the relatively small quantities of certain metalloids, such as carbon and sulphur, present in some alloys. In this latter class of compounds the most important is the carbide Fe_3C found in steel, and commonly called "cementite,"

(3) what are now called solid solutions of metals in each other, a term the meaning of which will be explained in § 5, p. 9. Suffice it for the present that we have in our alloys these three classes, corresponding to the three great classes into which inorganic matter in general is divisible.

Any given piece of an alloy may at the same time contain substances of each of the three classes.

Here as in so many other respects the alloys remind us of the

crystalline rocks, which they resemble in the general conditions of their formation. Crystalline rocks have cooled either like most of our alloys from a state of fusion, or at least from a temperature so high that the atoms present in the rock-mass have been free to arrange themselves, to combine to form definite compounds, and these compounds have been free to obey their crystalline laws. Under the microscope we find that our rocks consist of three classes of substances:

Fig. 1. Pearlite with Ferrite.
The polygons are pearlite, the network is ferrite.
(Sorby, *Journ. Iron and Steel Inst.*, 1887, I, p. 255 *et seq.*, Fig. 13.)

(1) pure metals, such as native copper, native gold, *etc.*,

(2) definite chemical compounds, like feldspar, mica, quartz, hornblende, and

(3) glass-like obsidians, in which the chemical elements are united, not in any definite ratio, but indeterminately.

Just as the particles of these different substances, the feldspar and other minerals, often exist in such minute particles that they can be detected only under the microscope, so in most cases the components of our alloys are visible only under the micro-

scope, and often only with very great magnification, which may sometimes have to reach a thousand diameters. Fig. 1 gives us an idea of a common type of structure among our alloys, and it will be seen that it is strikingly like that of the crystalline rocks shown in Fig. 2.
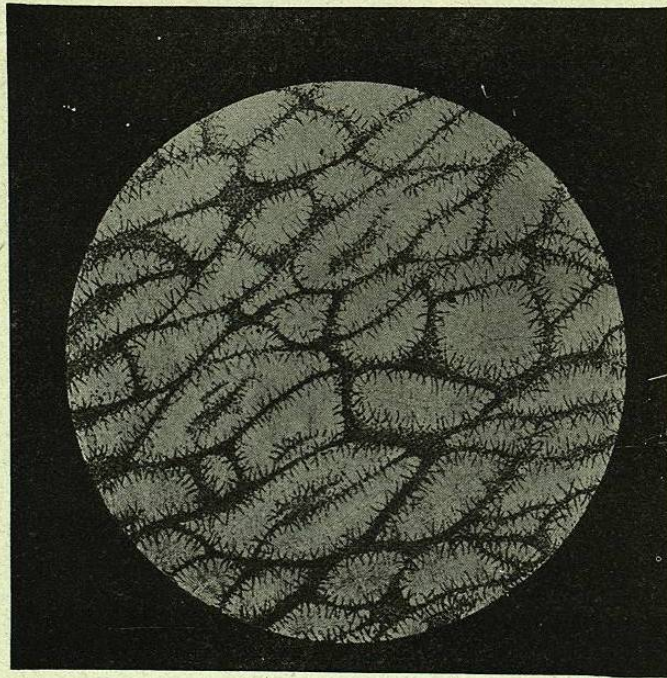
Fig. 2. Structure of Igneous Rock.

(Rhyolite from Hot Spring Hills, Pah-Ute Range.)
"U. S. Geological Exploration of the Fortieth Parallel, VI, Microscopical Petrography," Plate VIII, Fig. 1.

The resemblance between alloys and crystalline rocks does not stop here. Indeed we find close analogies between our metals on one hand and our crystalline rocks on the other, both of which result from the gradual solidification of fused or semi-fused masses; and also between both of these classes of solids and those which, like ice, result from the solidification of aqueous

solutions instead of fused masses. Let us notice some of these points of resemblance.

3. RESEMBLANCE OF METALS TO ROCK-MASSES.—First the columnar structure familiar to us in the Palisades of the Hudson, the Giant's Causeway, and like rock-masses, forming enormous columns, we find reproduced both in metals and in ice. The
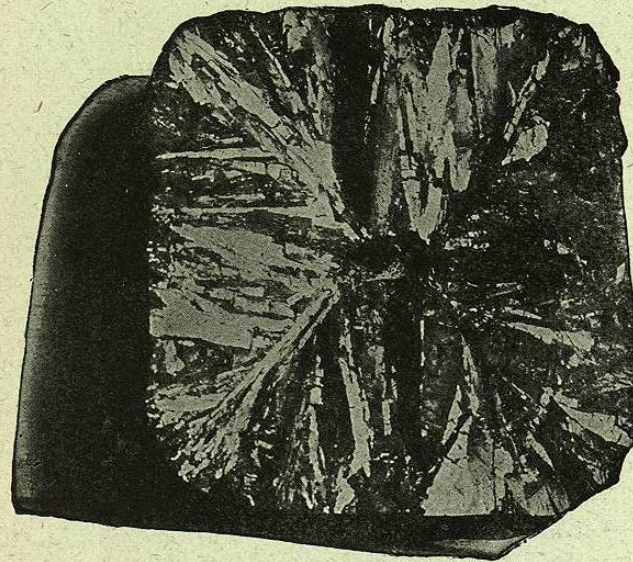
Fig. 3.

Columnar Structure in Steel Ingot, from the Author's Collection, actual size.
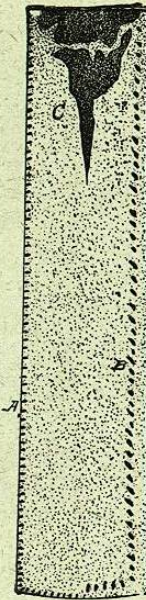
Fig. 4.

A, superficial blowholes;
B, deep-seated blowholes;
C, pipe.

columns of the Palisades were formed during the slow cooling of the rock-mass which they form; and they stand upright, *i. e.*, with their length at right angles with their upper surface, which was the cooling surface, the surface through which the heat escaped from them while they were cooling down and changing from a molten glass or obsidian to a solid rock. We find in
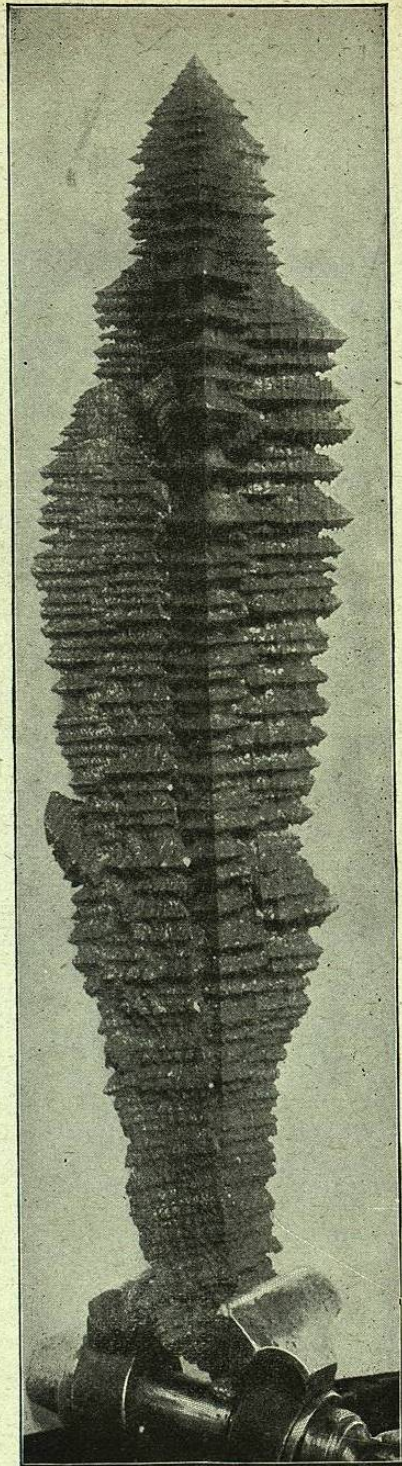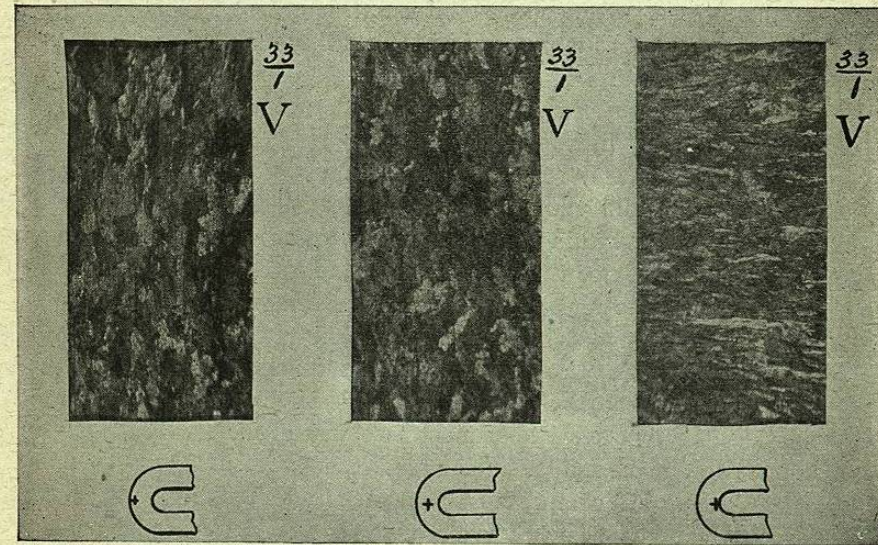
Fig. 5. Steel Crystal, about half natural size.

From the collection of Professor Tschernoff. (*The Metallographist*, II, p. 74.)

slowly cooled metals this same columnar structure, with the columns standing at right angles with the cooling surface, *i. e.*, with the outer surface, as is shown in Fig. 3; and in large blocks of ice, especially in the ingots of artificial ice which we see about the streets, we can often trace this columnar structure, with the

From the outside (extrados) of the bend. The polygons (crystals) of ferrite are lengthened, parallel with the extrados.

From near the neutral fibre. The polygons of ferrite are little changed in shape but are crossed by slip-lines.

From the inside of the bend. The polygons of ferrite now lie normal to the extrados.

Fig. 6. Schistosity Developed in Low-carbon Steel by Bending. Steel Containing: Carbon 0.035; Manganese 0.025. Made by J. A. Mathews, Ph.D., in the Author's Laboratory.

columns at right angles with the cooling surface, *i. e.*, with the sides of the ice-ingot.

Next we find in solidified ingots of steel a contraction-cavity called a "pipe" at the upper end of the axis of the ingot (Fig. 4); and you will generally see a similar pear-shaped cavity in the upper end of the ingots of artificial ice about the streets.