Technical Notes / Notes techniques

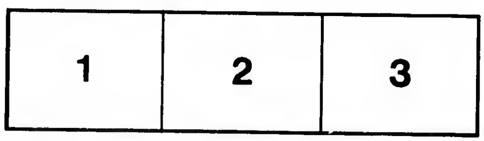
The Institute has attempted to obtain the best original copy available for filming. Physical features of this copy which may alter any of the images in the reproduction are checked below.

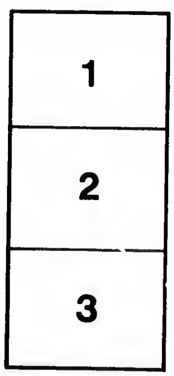
L'Institut a microfilmé le meilleur exemplaire qu'il lui a été possible de se procurer. Certains défauts susceptibles de nuire à la qualité de la reproduction sont notés ci-dessous.

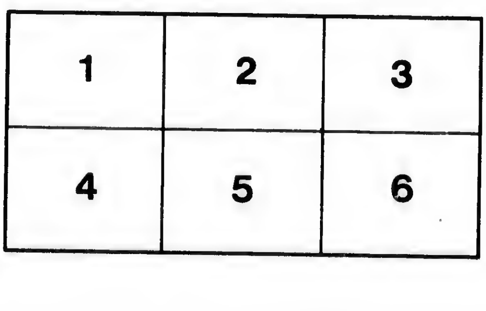
- [x] Coloured covers/ Couvertures de couleur
- [ ] Coloured maps/ Cartes géographiques en couleur
- [ ] Pages discoloured, stained or foxed/ Pages décolorées, tachetées ou piquées
- [ ] Tight binding (may cause shadows or distortion along interior margin)/ Reliure serré (peut causer de l'ombre ou de la distortion le long de la marge intérieure)
- [ ] Additional comments/ Commentaires supplémentaires
- [ ] Coloured pages/ Pages de couleur
- [ ] Coloured plates/ Planches en couleur
- [ ] Show through/ Transparence
- [ ] Pages damaged/ Pages endommagées

Bibliographic Notes / Notes bibliographiques

- [ ] Only edition available/ Seule édition disponible
- [ ] Bound with other material/ Relié avec d'autres documents
- [ ] Cover title missing/ Le titre de couverture manque
- [ ] Plates missing/ Des planches manquent
- [ ] Additional comments/ Commentaires supplémentaires
- [ ] Pagination incorrect/ Erreurs de pagination
- [ ] Pages missing/ Des pages manquent
- [ ] Maps missing/ Des cartes géographiques manquent


1
2
3


1
2
3


1
2
3
4
5
6

THE
NICKEL ORES OF SUDBURY
(CANADA)

7.

THE

NICKEL ORES

OF

SUDBURY

(CANADA)

BY

JOHN D. FROSSARD, ESQ., B.Sc., M.E.

MEMBER AMERICAN INSTITUTE OF MINING ENGINEERS

LONDON

GEORGE PHILIP & SON, 32, FLEET STREET

LIVERPOOL: 45 TO 51, SOUTH CASTLE STREET

1893

PREFACE.

SEVERAL very good works have been written on the subject, and what can be called the nickel country of Ontario has been described in different mining and scientific papers; but now that the importance of nickel is growing every day, and that the demand for it is constantly increasing, a few words more, relating the conditions and the working of nickel ores of Sudbury, will perhaps be found interesting; and even if these lines do not add to the knowledge already acquired by those who have to deal with nickel, it will remind them that there is a literature on the subject, and that men of science and learning have ·ritten things which are worth reading.

In writing these pages, very valuable information was derived from the following books, reviews and papers: "Guide du Géologue dans les Pyrénées Centrales," par E. Frossard, 1858; "Elements of Metallurgy," by T. Arthur Phillips, 1874; "Chemical and Geological Essays," by Th. Sterry Hunt, 1878; "Geological Survey of Newfoundland," by Alexander Murray and James P. Howley, 1881; "Report of the Royal Commission on the Mineral Resources of Ontario, 1890;" "Report on the Sudbury Mining District," by Robert Bell, B.Sc., M.D., LL.D., 1890; "Modern American Methods of Copper Smelting," by Edward Dyer Peters, jun., 4th ed., 1892; *Journal of the Iron and Steel Institute; Transactions of the American Institute of Mining Engineers; American Journal of Science;* "Memoires de la Société des Ingénieurs Civils;" *Bulletin de la Société Géologique de France; Engineering and Mining Journal,* New York; *Canadian Mining Review;* and in many instances integral parts of these works have been quoted.

JOHN D. FROSSARD.

135, Shooter's Hill Road,
Blackheath, S.E.

CONTENTS.

PAGE

Preface 5

CHAPTER I.

On Nickel and Nickel Ores 9

CHAPTER II.

Nickel Ores of North America . . . 13

CHAPTER III.

Huronian System 21

CHAPTER IV.

Sudbury Deposits 29

CHAPTER V.

Sudbury Nickel Mines 33

CHAPTER VI.

PAGE

ROASTING AND SMELTING OF NICKEL ORES IN THE DISTRICT OF SUDBURY 40

CHAPTER VII.

USES OF NICKEL 54

THE NICKEL ORES OF SUDBURY, CANADA.

CHAPTER I.

NICKEL AND NICKEL ORES.

WE learn that in the middle ages nickel was discovered in the cobalt mines of Thuringia, Germany, where it was supposed to be a kind of silver. When it was found that the metal contained no silver at all, people thought that malicious gnomes had transformed the precious metal into a vile composition, and accordingly it was left useless in the dumps of the mines.

The metal was separated in its pure state for the first time in 1751, by Cronstedt, a Swedish mineralogist, who produced it from an arseniuret of nickel.

Though specimens of native nickel have been obtained from the Erzgebirge, and though it forms 5 to 10 per cent. of meteoric stones, the pure metal is not to be found in nature, and is produced from its ores.

It is hard and ductile, takes a good polish, and is white in colour, with a shade of light grey.

The ores of nickel are generally yellow when anhydrous, and green when hydrated. Their solutions are light green, and their soluble normal salts redden the litmus paper, and are decomposed at red heat.

The principal ores are :—

1. *Copper Nickel.—Nickeline.—Kupfernickel.—Arsenical Nickel.*—Of a pale copper-red colour.

It occurs massive, has a metallic lustre, and is extremely brittle ; specific gravity varying from 7·3 to 7·5. This mineral is essentially composed of 44 per cent. of nickel and of 56 per cent. of arsenic. Its formula is the following—$NiAs$.

2. *White Nickel* (*Rammelsbergite, Cloanthite*).—Is an arsenical ore which has been discovered at Reichelsdorf in Hesse-Cassel, at Schneeberg in Saxony, and in the Pyrenees, France, with Kupfernickel. Its composition is the following—nickel, 28% ; arsenic, 72%. Formula, $NiAs_2$.

3. *Nickel Glance.*—Another arsenical ore, containing sulphur. It occurs in the massive state and in cubical crystals ; it is of a steel-grey colour, and has been found in Sweden, in the Hartz, at Schlaming in Austria, in the Lower Pyrenees, France and in other places. Formula, $NiAsS$.

4. *Antimonial Nickel.*—Contains an average of 29 per cent. nickel, found in Andreasberg. Formula, $NiSb$.

5. *Millerite.*—Is a sulphide of nickel, of a brass-yellow colour. Has been found in small quantities in Bohemia, Saxony, Cornwall, South Wales, Sudbury. Contains 64 per cent. of nickel. Formula, NiS.

6. *Pentlandite.*—Double sulphide of iron and nickel; is of a bronze-yellow colour, contains from 18 to 21 per cent. of the metal, and has been found in Southern Norway.

A similar mineral, containing from 10 to 12 per cent. of nickel, has been discovered in the neighbourhood of Inverary, Scotland, and is also found in the United States and Canada. The ores of Sudbury, being nickel-bearing Pyrrhotite, have to be referred to that group.

Another sulphide of nickel, bearing bismuth, has been detected in some German mines, from which specimens of arseniate of nickel of a beautiful apple-green colour have also been produced.

7. *Zaratite or Hydrated Carbonate of Nickel.*—Usually occurs as an incrustation on other minerals, nearly transparent, of a bright-green colour.

Another ore of nickel of a brown or nearly black colour, containing variable quantities of sulphur, is also found in connection with ores of cobalt at La Motte Mine, Missouri, United States, America.

8. *Garnierite.*—Is an hydro-silicate of nickel and magnesia; has been found in New Caledonia, where it is extensively worked.

Its composition is:—

Silica and gangue matter	38
Magnesia	15
Oxide of nickel	18
Oxide of iron	7
Water	22

Another siliceous ore of nickel has been detected in Logan county, Kansas.

It consists of a quartzose conglomerate from bean-size down, with much decomposed material between the pebbles, and the whole cemented by a more or less manganiferous limonite.*

Two analyses of large samples have given the following composition :—

	per cent.	per cent.
Insoluble siliceous matter	66·36	63·04
Copper	0·025	0·033
Nickel	0·258	0·260
Cobalt	0·072	

Silicate of nickel has also been detected in the Pyrenees in a serpentinous Lherzolite by Mr. C. Frossard.

* "Note on the Nickel Ore of Russell Springs, Logan County, Kansas," by Fred. P. Dewey, Washington, D. C., vol. xvii., p. 636, *Transactions Am. Inst. of Mining Engineers.*

CHAPTER II.

NICKEL ORES OF NORTH AMERICA.

THE ores of nickel, though numerous and found in nearly all parts of the world associated with other minerals, have been extracted but from a few districts: their principal producing centres are, till the present time, New Caledonia, and Sudbury in Canada, where the ores are sufficiently concentrated to be mined with profits.

We may briefly mention that nickel has been observed in several mines of the northern continent of America. For instance, in the United States, in Colorado; in Missouri, at Mine La Motte, where it was found associated with cobalt and copper; in Nevada, in 1874, by Mr. A. D. Hodges junior, who discovered at Carter's copper mine, near Mason Valley, a new combination of nickel and cobalt; in the black hills of Dakota, by Mr. Francklin R. Carpenter, as occurring in the beds of pyrrhotite, always associated with copper; in Kansas, as an ore consisting of a quartzose conglomerate; in Orford township, county of Sherbrooke, province of Quebec, as millerite, disseminated in grains and thin threads in a rock composed of calcite, white pyroxene and chromiferous garnet,* and in other serpentines and magnesian rocks of the eastern townships; in Newfoundland, at the Union Mine, Tilt Cove, as arsenical nickel, millerite, cloanthite, and as nickel-bearing pyrrhotite; and more recently in New Brunswick, Canada, near St. Stephen, as nickel-carrying pyrrhotite.

In Newfoundland, at Tilt Cove, on the north side of the Great Bay of Notre Dame, which neighbourhood I visited in 1888 and 1891, nickel ores have been mined during several years, at the Union Mine, where they have been found associated with copper sulphurets and iron pyrite very similar to those of the district of Sudbury. A few lines relating their geological situation and a table showing the quantity of nickel produced formerly by the Union Mine are not here out of place, and will perhaps be found interesting.

The sulphuretted ores of copper, chiefly chalcopyrite associated with iron pyrite and nickel, are observed as being disseminated in grains and layers in the chloritic slates and dioritic beds; also concentrated in the folds and dislocations of magnesian rocks, and in white quartz veins near the same horizon.

These chloritic slates, which are very ferruginous, occur above and below the serpentine of the Quebec group of the lower silurian series. This group, says

---

* "Mines et Minéraux de la Province de Québec," par J. Obalski, Ingr. des Mines du Gouvernement, 1889-90.

Sir William Logan, "can be conveniently separated into three divisions, the middle one having proved to be rich in metalliferous deposits in its course from the Southern Atlantic States of the American Union to Canada, and through Eastern Canada to Gaspé."

This middle division, called the Lauzon division, is the great metalliferous zone of the lower silurian in North America. It is rich in copper ores, chiefly as interstratified cupriferous slates, and is accompanied by silver, gold, nickel, and chromium ores.

The following table will show the geological position of that division:

English Synonyms.	Complete Series.	Western Basin.	Eastern Basin.	Newfound-land.
	12 Hudson River	Hudson River	...	...
Caradoc	11 Utica	Utica	...	...
	10 Trenton group	Trenton group	...	...
Caradoc (?)	9 Chazy	Chazy	...	...
Llandeilo	8 Sillery (Quebec group)	...	Sillery	Sillery
	7 Lauzon (Quebec group)	...	Lauzon	Lauzon
	6 Levis (Quebec group)	...	Levis	Levis
	5 Upper Calciferous	...	...	Upper Cal-ciferous
Tremadoc	4 Lower Calciferous	Lower Cal-ciferous	...	Lower Cal-ciferous
	3 Upper Potsdam	Upper Potsdam	...	Upper Potsdam
Lingula flags	2 Lower Potsdam	Lower Potsdam	Lower Potsdam	Lower Potsdam
	1 St. John's group	...	St. John's group	St. John's group

We add a table giving the quantities of nickel produced at the Union Mine from 1869 to 1876:

Years.	Production in nickel. Tons	Value in dollars.
1869	30	7,200
1870	88	8,800
1871	7	700
1872	8	2,560
1873	233	9,320
1874		
1875	17	1,360
1876	28	2,800
Total	411	32,740

(Since 1876 the mine has not supplied the market with any nickel.)

The ores of Sudbury have for some time attracted the attention of geologists. They occur in large bodies of lenticular shape in the Huronian system, and consist of a mixture of chalcopyrite and magnetic iron pyrite or pyrrhotite carrying nickel; this metal having replaced a certain proportion of iron.

Chalcopyrite and pyrrhotite, which are in Sudbury nickel-bearing, are both widely distributed: chalcopyrite as copper ore is mined extensively in other countries and furnishes the greater proportion of the world's copper; its occurrence in the older crystalline rocks has been noticed in Newfoundland, Canada, Virginia, Georgia, Tennessee, and Alabama.

Its composition can be represented as follows:

Copper, Cu	34·4
Iron, Fe	30·5
Sulphur, S	35·1
	100·0

Formula Cu_2S, Fe_2S_3.

Pyrrhotite or magnetic iron pyrite, is a monosulphide of iron. It occurs abundantly at the surface of the earth, and has often given rise to great mistakes when treated for the manufacture of sulphuric acid, instead of the iron pyrite (bisulphide of iron).

Average composition :

Iron, Fe	60·5
Sulphur, S	39·5

Though in the mixture of chalcopyrite and pyrrhotite the amount of iron replaced by nickel is very small, the proportion of nickel contained is unusual, and highly sufficient to make these ores pay as nickel ores, when lying in large bodies and near railway communication.

The proportion of nickel has been proved to vary greatly: we found it on different occasions to be $\frac{3}{4}$, 1, $1\frac{1}{2}$, 2, and 3 per cent., and Mr. F. Sperry gives as mean average in the ores of Copper Cliff Mine, 3 to 4 per cent. nickel, and states that a shipment to New York of 3,000 tons carried 7 per cent. copper and 3 per cent. nickel.* Mr. Jules Garnier, in a paper published in 1891, in the "Mémoires de la Société des Ingénieurs

* "Report of the Royal Commission on the Mineral Resources of Ontario," 1890, page 104.

Civils," gives the following assays and analysis of ores of Copper Cliff Mine.

Assays of Copper Cliff ores, on 139 tons:

Copper, Cu	4·80	5·01	5·47
Nickel, Ni	5·89	5·31	5·69

Analysis of 90 tons ore:

Sulphur	26·717	
Copper	12·610	
Iron	29·220	
Nickel	3·120	
Protoxide of Iron	6·22	Gangue 29·36%
Lime	4·84	
Magnesia	2·61	
Alumina	2·63	
Silica	13·06	
Total	101·027	

which can be approximately written:

Chalcopyrite—$CuFeS_2$	36·49
Nickel and pyrrhotite—$NiFe_7S_2$	36·18
Gangue	28·36
	101·03

In the "Report of the Royal Commission on Mineral Resources of Ontario, 1890," the results of nine analyses are thus published:

	1	2	3	4	5	6	7	8	9
Copper . .	4·62	5·52	4·95	9·98	4·03	5·00	7·91	9·94	5·97
Nickel . .	1·16	1·13	3·26	1·12	4·21	3·30	1·50	2·75	3·00

giving an average of 6·44 per cent. of copper and 2·38 per cent. of nickel.

Besides its occurrence in large bodies as nickeliferous pyrrhotite, nickel is also found in the district of Sudbury as millerite (sulphide of nickel), of which the composition and formula have been given in Chap. I. These ores are more or less associated with other minerals, such as cobalt, silver, gold, and platinum, but are generally free from arsenic.

Platinum was found in 1888 at the Vermillion Mine, twenty-two miles west of Sudbury, by Mr. F. L. Sperry, who sent a small quantity of the metal-carrying material to Professor H. L. Wells, of Yale University, who upon examination proved the platinum to exist there as a new mineral, arsenide of platinum, and named it Sperrylite, after Mr. F. L. Sperry.

The composition of this rare and remarkable mineral has been given by Professor Horace L. Wells, and is represented by the formula $PtAs_2$.

The following table shows the results of chemical analysis of Sperrylite:

	I.	II.	Mean.	Ratio.
Arsenic ...	40·91	41·05	40·98 ÷ 75 = ·546	·550 = 2
Antimony ...	0·42	0·52	[illegible] ÷ 122 = ·004	
Platinum ...	52·53	52·60	52·57 ÷ 197 = ·267	·274 = 1
Rhodium ...	0·75	0·68	0·72 ÷ 104 = ·007	
Palladium ...	trace	trace	trace	
Iron	0·08	0·07	0·07	
Stannic Oxide	4·69	4·54	4·62	
	99·38	99·53	99·46	

The crystallographic properties of Sperrylite have been given by Prof. S. L. Penfield.*

Having described the nickel ores of Sudbury, and having mentioned their occurrence in the Huronian system, we must, before speaking of the mining of the ores, explain, for those not acquainted with Canadian geology, what the Huronian system is, how it lies in Canada and especially in Sudbury, and how the ores of nickel are met with in it.

* "Sperrylite, a New Mineral," by Horace L. Wells; and "Crystalline Form of Sperrylite," by S. L. Penfield, *Am. Journal of Science*, vol. xxxvii., Jan. 1889.

CHAPTER III.

HURONIAN SYSTEM.

THE pre-Cambrian period of North America, to which the Huronian system belongs, shows a remarkable and constant succession of crystalline stratified rocks, divided into several great groups, these rocks becoming less massive and less crystalline towards the uncrystalline sediments of the palæozoic age, of which the Cambrian period must be considered as the basis.

The name of Archæan, which has been proposed for that system, is vague, and otherwise, as the late Dr. T. Sterry Hunt said, *not in accordance with the nomenclature adopted for the great succeeding divisions; and as all pre-Cambrian groups give direct proofs of the existence of organised beings during their deposition, it is right to include them all under the name of eozoic.** In the "Report of the Royal Commission on the Mineral Resources of Ontario, 1890," we read: "The pre-Cambrian period in Canada has been represented as extending from the region of the great lakes in the form of two

* "Les Divisions du Système Éozoïque de l'Amérique du Nord," par T. Sterry Hunt. Liége, 1885.

arms, one stretching north-eastward to the Atlantic coast of the Labrador peninsula, and the other north-westward to the Arctic sea, east of the Mackenzie river, the intervening space being filled up with palæozoic rocks. Further light on the subject has however shown that the geographical outline of these rocks takes the form, approximately, of an immense ellipse which includes the north-eastern part of the continent, Baffin Land, Greenland, and many of the islands of the frozen sea. It comprises the whole of the Labrador peninsula, measuring a thousand miles each way. On the other side its boundary runs, with a westward curve, from Lake Winnipeg to Coronation Gulf, another thousand miles, with a spur towards the mouth of the Mackenzie river."

The following is a table showing in ascending order the divisions of the pre-Cambrian period, as given by Dr. T. Sterry Hunt :

9. Cambrian			Palæozoic
8. Keweenian			Undetermined
7. Taconian			Eozoic age
6. Montalban			
5. Upper Formation	Huronian System		
4. Lower Formation			
3. Arvonian	Upper Laurentian	Laurentian System	
2. Norian			
1. Laurentian,	Lower Laurentian		

As the rocks belonging to the Huronian system are very similar to those of the formation which lie underneath, before entering into more details referring to the Huronian strata we will speak of the Laurentian

Norian, and Arvonian groups, taking them in ascending order.

Lower Laurentian.—The Lower Laurentian formation is chiefly composed of gneisses, which sometimes may be called granitic or syenitic. True gneiss is defined to consist of quartz, feldspar, and mica; but the gneisses of the Laurentian strata often contain hornblende in large proportion. Let us quote here what the "Report of the Royal Commission on the Mineral Resources of Ontario, 1890," says, regarding gneisses of Lower Laurentian formation: "Lower Laurentian gneisses offer reddish and greyish colours, from very light to very dark shades, depending partly on the colours and partly on the proportions of the different constituents. The feldspar (orthoclase) is white, grey, and red, or sometimes yellowish or greenish; the quartz is white to grey, and the mica and hornblende black, or very dark green or brown. These rocks are generally distinctly foliated, or show a lamination or parallelism in the arrangement of their constituent minerals, easily traceable by their colours. When these are very distinct and the layers continuous and close together, the rock in cross-section is described as ribboned; where the layers are further apart it is called banded. But the bars are often broken into a series of tapering dashes which pass below or above each other or with an interlocking or dovetail arrangement, or the bars may be connected by thin streaks or rows of dots."

Dykes of greenstones or trap cut in some districts the

Laurentian rocks. These dykes affect to a great extent the geographical features of the country. Those which have become decomposed or have yielded to glacial action give rise to rivers and narrow lakes, which lie on their course. Falls and rapids, on the contrary, can be observed where hard dykes cross the courses of streams.

Veins of two classes cut the lower and upper formations; but with the exception of those which contain calcspar as gangue and are apt to carry iron pyrites, blende, galena, and copper, no mineral of any value occurs in Canada in the Lower Laurentian formation.

Upper Laurentian.—The Upper Laurentian, divided by Hunt into Norian and Arvonian, is much more limited in geographical extent than the Lower formation. It is chiefly composed of series of Labradorite and Anorthosite rocks, and contains different metallic ores in paying quantities: for instance, iron ore, graphite, apatite are commonly found in that formation, with pyroxene and hypersthene rocks.—As we have said, the Upper Laurentian has been divided into two; the first and the oldest division received the name of Norian and is characterised by a group of gneissoid rocks, which appear to be identical with the Norwegian norites, and which are composed in great proportion of plagioclase feldspars, chiefly labradorite, with a little pyroxene or hyperstnene and often titanic iron. The Norian group lies unconformably on the Lower Laurentian, and has a thickness varying from three thousand to four thousand yards.

In some districts a variety of stratified rock, chiefly composed of petrosilex and quartziferous porphyry, lies between the Norian and the Huronian. As the rocks of that group are very similar to those of the Arvonian of Wales, it has received the same name, and is the Arvonian of Canada, forming the upper part of the Upper Laurentian.

Huronian.—In his "Chemical and Geological Essays," 1878, p. 269, Dr. T. Sterry Hunt says: "The crystalline strata to which the name of the Huronian series has been given by the 'Geological Survey of Canada,' have sometimes been called Cambrian, from their resemblance to certain crystalline rocks in Anglesey, which have been imagined to be altered Cambrian. The typical Cambrian rocks of Wales, down to their base, are, however, uncrystalline sediments, and, as pointed out by Dr. Bigsby in 1863, are not to be confounded with the Huronian, which he regarded as equivalent to the second division of the so-called azoic rocks of Norway, the "Urschiefer" or primitive schists, which in that country rest unconformably on the primitive gneiss (Urgneiss), and are in their turn overlaid unconformably by the fossiliferous Cambrian strata. This second or intermediate series in Norway is characterised by eurites, micaceous, chloritic, and hornblendic schists, with diorites, steatites, and dark-coloured serpentines; generally associated with chrome, and abounds in ores of copper, nickel, and iron. In its mineralogical and lithological characters, the Urschiefer corresponds with what we have designated the second series of crystalline schists. It is in Norway divided into a lower or quartzose division—marked by a predominance of quartzites, conglomerates, and more massive rocks—and an upper and more schistose division."

These lines describe exactly what the Huronian system is in Canada, and give all the needed details relating the characteristics of the rocks. We will now, in a few words, try to point out what are the distinctive characteristics of the Huronian and of the Laurentian rocks, and will show that, though the rocks of both series are much alike, there are differential characters which a geologist cannot fail to notice.

The Huronian system differs essentially from the Laurentian series by the frequent occurrence of schistose rocks and of conglomerates carrying fragments of ancient gneisses, and by its rocks, which are fine-grained and schistose, and of dark green and grey colours, while those of the Laurentian are of lighter shade, massive, and coarsely crystalline. It covers a large area in North America, has been observed in Newfoundland by A. Murray, and pointed out by him in the reports of the Geological Survey of that country.

In Canada the areas covered by Huronian rocks are mentioned by Dr. R. Bell in the "Report of the Royal Commission on the Mineral Resources of Ontario," and we quote here what is said by Dr. Bell: "The greatest of all our Huronian areas forms a wide belt extending from the south-eastern extremity of Lake Superior eastward along the north shore of Lake Huron, from which it runs north-eastward, widening out till it occupies the whole country between Lake Temiscaming and the head waters of the Montreal river, a breadth of one hundred miles. Beyond this, it stretches north-westward across all the branches of the Moose river, northward beyond Lake Abittibi, and north-eastward almost to the southern extremity of Lake Mistassini, a distance of over 600 miles from the outlet of Lake Superior. The Huronian area along the Ground-hog river and Mattagami lake on its course appears to be more or less completely separated from the great area above described. The next important Huronian district lies around Michipicoten at the north-east angle of Lake Superior, running for sixty miles west and twenty miles south of that point, and extending inland to Dog Lake, a distance of forty-five miles. Another large area stretches from the Pic river eastward to Nottamagami Lake, and westward to Nipigon Bay.

"Two extensive belts run eastward from Lake Nipigon, one of which crosses Long Lake. West of Thunder Bay, and stretching to the international boundary line, there is a large area which gives off arms to the north-east and south-west, and several belts and compact and straggling areas occur between this and the Lake-of-the-Woods basin, one of which follows the course of the Seine river. The Lake-of-the-Woods area, which has already been alluded to, occupies the whole breadth of the northern division of that lake.

An important belt starts between Rainy Lake and Lake-of-the-Woods, and running north-eastward has a breadth of forty-five miles where it crosses the line of the Canadian Pacific Railway. Minnietakie and Sturgeon Lakes lie within this belt. Huronian rocks occur at both ends of Lake St. Joseph and along three sections of the Albany river, between it and the commencement of the palæozoic basin of James Bay." *

The Huronian system has been divided into two formations, but we must confess that it is very difficult to draw a distinct line separating them. The Upper formation would include the series of the Lake-of-the Woods district, and would be the "Keewatin" series; the Lower formation would consist especially of dark green and grey crystalline schists, and the Upper one would chiefly contain graywacke, clay slates, argillites, felsites, quartzites, jasper conglomerates, dolomites, and serpentine; nickel in the state of nickeliferous pyrrhotite being referred to that Upper division. Nothing has been said here on the origin of the pre-Cambrian rocks; we refer for more information to the books and works on the subject.

* "Report of the Royal Commission on the Mineral Resource of Ontario." Toronto, 1890, page 18.

CHAPTER IV.

SUDBURY DEPOSITS.

SUDBURY, the centre of the nickel-producing country of Canada, lies in Ontario, about 443 miles west of Montreal, on the Canadian Pacific Railway, and at about 840 feet above mean sea level.* The town is situated in a wild country composed of hills, lakes, and rivers, most of it covered formerly by dense forests of pine, now nearly all swept away by fire, and replaced by maple, red oak, and black birch.

For many years the district has been thought of as being rich in minerals, and we see that, in 1846, Dr. T. Sterry Hunt informed the Canadian Government that that part of Ontario was highly metalliferous.

The country rocks, as has been already said, belong to the Upper formation of the Huronian system; they run in a general north-east and south-west direction, and dip towards the south-east. The nickel-carrying ore-

* "The Geology of Sudbury District," by Dr. Robert Bell, p. 84f.

bodies follow the line of stratification; they have a rough lenticular shape, and are always found near extensive dykes of diorite or greenstone, often occurring as contact deposits between diorite and graywacke, sometimes in the midst of the diorite or greenstone itself which forms the gangue, and is a rather favourable constituent than otherwise, as it is far less refractory than the siliceous vein matter which is the ordinary gangue of copper ores.

The ore is generally low-grade, but in the midst of large pockets of that low-grade ore, pure copper pyrite and highly nickeliferous pyrrhotite can be observed, and often in important quantities.

The chief characteristics of the ore-bodies are:

First, the red colour they give to the surface soil, colour produced by the decomposed ferruginous salts

Secondly, their extent;

Thirdly, their occurrence at certain intervals in powerful mineralised belts which can be traced for a long distance throughout the country.

"The ore-bodies," we are told by Dr. Bell, "have most probably originated primarily from a state of fusion; their intimate association with greenstones, which are of igneous origin, would show this, as well as the fact that these greenstones themselves fuse at about the same temperature as the sulphides. But they may have been subsequently more or less modified by other agencies. The occurrence of crystals of feldspar, quartz, and apatite in some of the deposits, and of laminated iron pyrites in one place in Copper Cliff mine, indicate the action of aqueous solution." *

The ore is hard, and the pockets form hills and mounds having an axis (generally with a north-east and south-west course) coincident in direction with the longitudinal axis of the ore-bodies.

After having, in 1890, carefully inspected the Sudbury district and vicinity, and having then remarked that some of the ore-bodies carried copper to a great extent and others did not contain or offered only traces of the salts of that metal, we came to the conclusion that the Sudbury deposits could be divided into two classes: the first one to contain those deposits which carry copper to a certain extent, the second one to include those which do not show copper salts. The latter deposits, it is true, run low in nickel, but as they are formed by extremely massive nickeliferous pyrrhotite, they can be worked to great advantage. They are especially located at the north-west of Sudbury.

These ore-bodies have been divided by Dr. E. D. Peters into three classes. To the first are to be referred the deposits which are composed of extremely massive pyrrhotite, and are of enormous extent. The second class includes those which are more rocky in their nature and less extended in size, but very much richer

* "Report on the Sudbury Mining District, 1891," by Robert Bell, B.Sc., M.D., LL.D., p. 49f

in copper and nickel; and the third contains those which, as he says, form a most unusual and pleasing combination, being nearly as large as deposits of the first class, and as rich in nickel and copper as those of the second.

CHAPTER V.

SUDBURY NICKEL MINES.

THE mining of nickel ores began in 1886, and since that time several companies have been formed for the purpose of working the Sudbury deposits. Amongst the most important, we find:—

1. The Canadian Copper Company;
2. The Dominion Mineral Company;
3. H. H. Vivian and Company.

The *Canadian Copper Company*, covering in the region an area of about 10,000 acres, began operations in 1886 with a capital of \$2,000,000, increased in 1889 to \$2,500,000. The principal producing centres owned by that company are: "Copper Cliff," the "Evans," and "Stobie" mines.

We will now proceed to a rapid description of these mines; and as the principal features of the ore-bodies and of the ways employed in mining are now what they were when we visited the mines, we will speak of them as they were in 1890.

The *Copper Cliff* Mine is situated in the township of Snider, on a branch road at about one mile from Copper

Cliff, a station of the Canadian Pacific Railway, at four miles south-west of Sudbury, on the Algoma line. The property was put in operation in 1886. An incline shaft reached, in 1890, the depth of nearly 600 feet with five working levels. From 1886 to 1890, the mine produced about 56,540 tons of ore, which were sent to the roasting beds, and the average amount of ore crushed per diem was 180 tons. Specimens gave as much as 15 per cent. nickel and 30 per cent. copper, but the mean average grade of ore was 3 per cent. nickel and 5 per cent. copper.

The mining plant included two boilers of about 80 horse-power, supplying steam to all the machinery; an Ingersoll air compressor and accessories including Ingersoll rock drills; one winding engine with two drums and cables; one No. 5, 15″ × 9″ "Blake" crusher, and sizing sieves (the crushing plant having a capacity of about 400 tons per twenty-four hours); one steam pump at the lower level of the mine, condensing into a tank from where it pumped water out, that tank being filled by a small pump run by compressed air; a machine shop for repairs; offices; laboratory and houses for men and their families.

With the idea of increasing the crushing and the roasting plants of the property, the Company was then going to put up a "Gates" crusher of three 18″ × 42″ openings, with a capacity of from 100 to 150 tons per hour.

The *Evans* Mine, situated about a mile and a half south-west of Copper Cliff station, is connected with the Algoma line by a track of half a mile in length. Here we could see a large excavation of about 200 feet in width and 90 feet deep, forming the upper part of a shaft of 180 feet.

The mining machinery of this mine was much like that employed at Copper Cliff, with a larger steam-producing plant. At the time of our visit, nearly 33,000 tons of ore, averaging 7 per cent. in nickel and copper, had been sent for roasting.

The next mine visited was the *Stobie*, three miles and a half north of Sudbury, on a branch of the Canadian Pacific Railway, built for the transportation of its ores and of those extracted from the Blezard Mine. This centre was opened in 1887 by two tunnels and afterwards by open cast work. The limits of the deposit had not yet been reached, and the amount of ore produced then was about 16,000 tons. On account of their great fluxing qualities, these ores were mixed, at the central smelting plant of the Company, with the more refractory ones of the other mines.

The output of these three mines for 1890 averaged as follows :*

	Copper per cent.	Nickel per cent.
Copper Cliff Mine	6·24 ...	3·69
Evans Mine	2·84 ...	3·62
Stobie Mine	1·99 ...	2·00
Average of all	4·32 ...	3·52

* "Report on the Sudbury Mining District, 1891," by Robert Bell, page 51f.

The Dominion Mineral Company, next in importance, owns, besides other valuable properties, the "Blezard," the "Worthington," and the "Crean" mines.

The *Blezard*, the principal mine of the Company, is situated four and a half miles north of Sudbury, in the township of Blezard. In 1890, three shafts had been sunk and 45,000 tons had been mined and taken to the roast beds. The whole machinery plant had been especially well planned, and everything was similar to the installation of "Copper Cliff."

The chambers where mining was conducted were lighted with electricity, and the daily product average was 180 tons.

The *Worthington* Mine, on the Algoma branch of the Canadian Pacific Railway, is about seven miles west of White Fish station. There could be seen a mound thirty feet high, and of sixty feet diameter with a small shaft in the centre.

The *Crean* Mine, close to the "Worthington," offered a twenty feet shaft and was left as not paying. As for the average tenor in nickel of the ores mined by the Dominion Mineral Company, let us quote what Mr. George Atwood, manager of the Company, wrote to Dr. Bell, under date of March 18th, 1891: "The 'Kies' or Metallics of the Blezard Mine average 4 per cent. nickel, which is accompanied by about 2 per cent. copper.—The above is the result of many hundreds of assays, also of the practical working on a large scale. The nickel ore at the Worthington varies very much, and we have had assays from 2 per cent. to 38 per cent. nickel. Large shipments of clean ore have gone about $9\frac{1}{2}$ per cent. nickel and 3 per cent. copper. We have also shipped some clean copper ore from the Worthington Mine assaying 18 per cent. copper and $2\frac{1}{2}$ per cent. nickel."

H. H. Vivian and Company.—Several ore-bearing mounds were seen at the "Murray" Mine, the most important property of the Company, finely located on the main line of the Canadian Pacific Railway, two and a half miles north-west of Sudbury. The characteristics of the ore mined here have proved to be similar to those of the other ones, except that they carry less copper.

The average percentage of ore smelted at the "Murray" Mine is as follows:

Nickel	1·5 per cent.
Copper	0·75 per cent.

Most of the men employed are Cornish and Welsh, and are paid at the following rate:

	Per month.
Mining Captain	$145.00
Assistant Captain	90.00
Master Mechanic	100.00
Teamster.	45.00
	Per day.
Drill Runners	$2.10
Miners	1.75
Labourers	1.60
Foreman	2.00
Watchman	1.75

	Per day.
Engineer	$2.00
Pumpman	2.00
Fitter	2.00
Fireman	1.50
Blacksmith	2.50
Assistant Blacksmith	1.75
Machinist	2.25

With these figures the mean average cost of mining per ton of ore can be taken at $ 2.00. Besides these opened-up mines, the three Companies here above-mentioned own large areas of land and have, in the different townships surrounding Sudbury, great quantities of ore kept in reserve for the future.

Since then another company, which purchased the "Chicago Nickel" Mine, began in February 1891, on Lot 3, fifth concession of the township of Drury, four and a half miles north from Worthington station, on the Algoma branch of Canadian Pacific Railway. A few thousand tons of ore have been mined, and we are told that the ore runs 7 to 8 per cent. of copper and nickel, as an average.

We will not attempt to give an accurate description of the country surrounding these mines. The main important fact is, that everywhere surface indications of the existence of ore can be found, and that in many places the "Surface gossan" exposed to the sight of the visitor is sufficient to prove the existence underneath of large bodies of ore, all of them more or less nickeliferous, and which, without doubt, deserve to be tried later on.

In endeavouring in the next chapter to point out the chief characteristics of the methods employed in the roasting and smelting of nickel ores at Sudbury, we will largely use the valuable works of Dr. E. D. Peters, who is deservedly known as one of the best authorities on the matter.

CHAPTER VI.

ROASTING AND SMELTING OF NICKEL ORES IN THE DISTRICT OF SUDBURY.

ROASTING.—The process employed at Sudbury is the one called "Open Heaps roasting," especially resorted to where fuel is cheap, labour expensive, and no damages can be caused by sulphurous gases. Heap roasting * has been in use since the remotest time, and is still in practice in its most primitive form among barbarous nations. It has a great disadvantage—that of not only consuming a large amount of wood, but, from the imperfect distribution of heat, of often producing in the interior of a pile a fused and compact mass, before other portions are sufficiently roasted.

The gangue matter having been picked out as much as possible, the broken stuff classified by sieves into three different dimensions, is taken to the roast yard,

* Though in English metallurgy a distinction is made between the terms calcination and roasting, the latter one being exclusively applied to a special process, they are here employed as being synonymous.

where the ground has been levelled and prepared for the construction of roasting piles.

In laying out ground for roast-piles, several important points have to be considered:

1. The economy of labour;
2. The direction of prevailing winds;
3. Protection of roasting ground from violent winds;
4. Protection from drifted snow;
5. Level of roasting ground, which must be as high as the spot to which the ore is to be transported, or at least, as high as the elevator, which is to raise it to the required level.

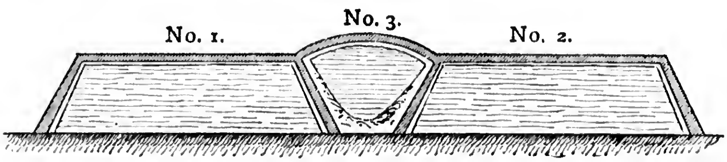
In building a pile, the corners of the rectangular space on which it is to be erected should be indicated by stakes or stones, and the sides of the area by lines drawn on the ground to guide the workman.

The first layer is formed by six inches in fine ore, which will prevent the baking and adhering to the ground of the coarse ore and make a net horizon between the worthless and the valuable stuff.

This layer is overlaid by wood from one and a half to two feet in thickness, on which lie the coarser ore and "ragging" to a depth of about seven feet; then "fines," which cover the heap and concentrate the heat.

With reference to Copper Cliff Mine, let us now quote what Dr. E. D. Peters says in his paper published in the *Transactions of the American Institute of Mining Engineers*, vol. xviii.

"The roast-yard is nearly half a mile long and one hundred feet wide, so that the length of the piles is limited by the width of the ground. After allowing space to get round them, and for drains, about 80 feet is left for the length. They are about 40 feet wide, and as the ore is piled about 7 feet high on the wood, will hold about 800 tons. They are built in the usual manner, about 30 cords of wood being sufficient to kindle a pile. After the main body of the pile is built of coarse ore, a layer of ragging or medium ore is put on, 6 inches to a foot thick, according to the supply on hand, and this is covered in the usual manner



with 'fines.' By interposing a layer of rotten wood and chips between the raggings and fines, we are enabled to roast both of these smaller sizes more perfectly than is usually done. In general, we find the whole heap well enough oxidised to take it direct to the smelter without re-roasting any portion of it, which contributes materially to the economy of the operation. A heap of 800 tons burns about sixty days, if properly managed." The heap roasting method employed at 'Copper Cliff' is an improvement on the old system, and has been introduced there by Mr. James McArthur. It has been called the 'V-method.'" Dr. E. D. Peters describes it as follows: "The new method introduced at these works by the superintendent of smelting, James McArthur, may be easily understood from the accompanying sketch, in which Nos. 1 and 2 represent heaps built in the ordinary manner. They are allowed to burn out about one-half, and become thoroughly cooled on the sides. Then heap No. 3 is built in the passage-way between them, being shaped like a **V**. A bed of wood on the bottom, and a single layer of the same on the sloping sides of the two lateral heaps, provide ample fuel to start No. 3, which not only undergoes a thorough burning itself, but also sets the unroasted sloping sides of the two adjoining heaps on fire again, and thus roasts something like 50 to 100 tons of material that ordinarily is nearly raw. This method, besides greatly lessening the percentage of unroasted ore, also adds some 60 per cent. to the capacity of an ordinary roast-ground. For convenience in speaking of this new plan, we have called it the 'V-method' of heap roasting. Our best metallurgists are much pleased with the results obtained at Sudbury by this innovation."

With the V-method and a roasting capacity of one hundred tons per ten hours, the costs of breaking and roasting a ton of nickel ore at Sudbury can be estimated as follows:

(The weight of one cord air-dried pine being about 2000 lb. and equivalent to about 725 lb. of coal.)

Cost of breaking per ton :

	\$ per 100 tons.	\$ per ton.	£ per ton.
Steam producing plant :			
$1\frac{1}{2}$ cord of wood at \$1.80 per cord	2.70	—	—
Oil and lubricants	0.50	—	—
Engineer at \$2.00 per day $\frac{1}{4}$ wages	0.50	—	—
Fireman at \$1.50 ditto	$0.37\frac{1}{2}$	—	—
	$\$4.07\frac{1}{2}$	\$0.0407	
Labour :			
Two feeders at \$1.50 per day ...	3.00	—	—
One helper at \$0.75 per day ...	0.75	—	—
	\$3.75	\$0.0375	
Repairs to Machinery and Sundries :			
Wear of tools and babbit for renewing bearings	0.50	—	—
Daily repairs	0.60	—	—
Joggles and plates	0.60	—	—
Sundries and extras	0.50	—	—
Miscellaneous, sampling, etc. ...	0.50	—	—
Sinking fund to replace machinery at 10% on original cost ...	1.50	—	—
	\$4.20	\$0,042	
Total cost of breaking per ton ...		\$0.1202	£0 0 6

Average cost of roasting one ton of nickel ore at Sudbury, with a roasting plant of 100 tons per 24 hours :

	$ per 100 tons.	$ per ton.	£ per ton.
Transportation to heaps	5.00	—	—
Fuel, 6 cords of wood at $1.80 per cord	10.80	—	—
Labour in building and burning heaps	10.00	—	—
Removing and loading roasted ore. 16 men	24.00	—	—
Transportation to furnace	5.00	—	—
Oil and repairs	4.00	—	—
Miscellaneous labour, screening, etc.	3.00	—	—
Renewing shovels and other tools	5.00	—	—
Repairs on gads, bars, and tools ...	4.00	—	—
Total	$70.80	$0.7080	£0 3 0

At Copper Cliff, an analysis of roasted ore gave:

5·40 per cent. of copper,

2·43 per cent. of nickel,

7·92 per cent. of sulphur,

25 per cent. of iron, lime, mangnesia, etc.

And the residue chiefly of hornblende.

Smelting.—The roasted ores are smelted at the mines of the "Canadian Copper" and of the "Dominion Mineral" Companies, in water jacket furnaces of the Herreshoff patent, made in Sherbrooke, province of Quebec, by the Jenckes Machine Co. These furnaces are elliptical, and made of rolled steel, with a water space of two inches. Their bottom is formed by a cast-iron plate protected with fire bricks, their dome is of plate steel and brick-lined; the whole being supported by four iron legs.

The blast is supplied into the furnace through eleven *tuyères* at a pressure of eight to ten ounces per square inch.

For a full description let us refer the reader to the following works: *Transactions of Am. Inst. of Mining Eng.* "The Sudbury Ore Deposits," by E. D. Peters, page 278, vol. xviii.; "Report of the Royal Commission on the Mineral Resources of Ontario, 1890," page 378; "Mines de Nickel, Cuivre et Platine du District de Sudbury (Canada)" per Jules Garnier, 1891; "Modern American Methods of Copper Smelting," by Edward Dyer Peters, junior.

Usually 120 tons of ore will be smelted per day, in a furnace with charges of 1800 to 2000 lb., consisting of a mixture of ore and coke in the proportion in weight of eight of the former to one of the latter.

The matte produced is bright and flows freely, at times shooting out like the discharge of a gun.

Its chemical composition has been determined by Mr. F. L. Sperry. We quote here analysis made by him on February 22nd, and on March 2nd, 1889.

Copper	27·06	26·76	26·910
Nickel	14·44	13·84	14·140
Iron	31·00	31·47	31·235
Sulphur	26·90	27·00	26·950
Cobalt	·27	·20	·235
Slag	·92	·95	·935
Total	100·59	100·22	100·405

Taking the cost of Pennsylvania coke in Sudbury at $7.00 per ton, we can figure approximately as follows the cost of smelting into matte a ton of roasted ore in a Herreshoff water jacket furnace.

Cost of smelting per ton of ore, based on a smelting capacity of 120 tons of ore per 24 hours.

	Per 120 tons.
Fuel and Supplies :—	
17¼ tons of coke at $7.00 per ton	$120.75
Fuel for blast and attendance	23.15
Cost of pumping water for jackets ...	10.50
Clay and sand	1.50
Oil, lights	7.50
Renewal of tools, pots, moulds, etc. ...	4.90
Repairs on furnace and machinery ...	4.50
Cost of blowing in and out	8.60
Sinking fund to replace furnace	4.50
Miscellaneous	9.00
Total fuel and supplies	194.90
Labour :—	
Superintendence	$6.00
Laboratory work	4.00
Blacksmith work	3.00
Lower floor labour	22.00
Charging floor labour	14.00
Foremen	7.50
Labourers	6.00
Total labour	$62.50
Cost per 120 tons of Fuel supplies and labour	$257.40
6% more for sundries	15.44
Total per 120 tons	272.84
Per ton	2.27

Water jacket furnaces, as we have already said, are used by the "Canadian Copper" and the "Dominion Mineral" Companies; H. H. Vivian & Co. employ furnaces of the English pattern similar to those in use in Swansea.

Summing up the expenses of mining, roasting, and smelting nickel ores in Sudbury, we can represent by the following table the usual cost of extraction and of treatment of these ores in ordinary circumstances with competent management and skilled labour:—

	Per ton.	Per ton. £	s.	d.
Mining	$2.00	0	8	4
Breaking	0.12	0	0	6
Roasting	0.71	0	3	0
Smelting	2.27	0	9	3½
Total	$5.10	£1	1	2½

Matte Refining.—The matte produced has to be refined, and at Sudbury, as Dr. Peters says:—

"It becomes a question of calculation whether it will pay better to ship the matte at about a grade of 25 per cent., as it is produced from the furnace, or to concentrate it on the spot by a second series of roasting and smelting operations. The matte is enriched by roasting and re-smelting it in a water jacket or other furnace with other flux to take up the iron. It is a question to be determined by circumstances, whether the roasting should be executed in heaps, as with the ore, or whether it should be crushed and calcinated in a few hours in calcining furnaces. Heap roasting of matte takes about as long as the ore, because it has to be re-roasted two or three times, as it does not roast freely like the ore. But as there is only about one-sixth so much to handle as of the raw ore, the expense of ore per ton is not heavy. A matte of about 50 to 60 per cent. of nickel is produced by the so-called concentration smelting." *

The ancient treatment of this matte has been described in every well-known metallurgical book; it is slow and expensive. Dr. Peters tells us that "Efforts are being made to improve upon it, and one of the principal nickel-smelting companies at Sudbury is erecting a plant to Bessemerise this rich sulphide of copper and nickel.

"According to the laws of chemical affinity, as modified by the high temperature employed, we know that the iron still remaining in the matte ought to oxidise first, forming with silica a slag that may be poured off. Next the nickel should oxidise and slag away, leaving behind the pure copper.

"But whether such accurate results will be reached in practice seems to me rather doubtful.

"In the Bessemerising process, as applied to iron, the

* "Modern American Methods of Copper Smelting," by Edward Dyer Peters, junior, M.E., M.D. (fourth edition), New York 1892, p. 295.

entire mass of metal remains homogeneous throughout the operation, the impurities being gradually oxidised until it is all converted into steel. And the total amount of the impurities is only 5 or 4 per cent., so that the mass of fluid metal operated upon is not perceptibly lessened.

"But in Bessemerising a mixture of the sulphides of iron, copper, and nickel, the number of different chemical compounds having differing specific gravities and tending each to form its separate stratum in the converter, is too great to even enumerate. As soon as sufficient sulphur is removed to correspond to the iron present, we shall have a layer of oxide of iron (combined with silica from the converter lining) on top, while below the sulphides of nickel and copper will remain comparatively unaltered. Then may come a period when we have the same silicate of iron on top, followed by a little silicate or oxide of nickel, whilst some metallic nickel has formed and sunk to the bottom, and the rest of the nickel, in its original condition of sulphide, forms a stratum below the unaltered sulph[illegible] copper.

"These react[illegible] [illegible]d products increase in number and complexity as the operation advances; and remembering the great difficulties encountered in Bessemerising even so simple a substance as copper matte, one cannot help feeling some curiosity as to the practical success of this operation.

"That nickel and copper can be rapidly reduced from the condition of a matte to that of separate metals, the author has convinced himself. But business considerations prevent the further elucidation of this subject."

And further:

"It must be evident to every one familiar with the facts, that the commercial electrolysis of copper on the one hand, and an electrolytic deposition of nickel in our nickel-plating establishment on the other hand, point out a path to follow that is too plain to be neglected.

"And as our chemists find no difficulty in precipitating with the electric current chemically pure copper from a solution containing both copper and nickel, and then, by slightly altering the conditions, precipitating all the nickel in absolute purity from the same solution and with the same current, it would seem that our refiners might reasonably expect to effect the same results on a commercial scale, especially as there is practically no loss of acid in the operation.

"Nor can I see any reason why nearly all our metallic nickel should be offered to the trade in little cubes less than an inch square. Of course this peculiar form has resulted from the practice of the nickel refiners to reduce the oxide of nickel obtained by the methods now in use to metallic nickel. Being mixed with rye meal, as a reducing agent, it is formed into these little cubes, and a number of these packed in crucibles are exposed to a sufficient heat to reduce the nickel to a metal without fusing it. This makes a small porous fragment of metal suitable for solution in acids, and where nickel is to be used in some minute quantities. But it adds materially to the expense of refining, and there is really no more reason why nickel should be so treated than copper or iron.

"Although the fusion point of nickel is rather high, yet a sufficient temperature to make nickel pour as readily as copper, is obtained without difficulty in metallurgical practice, and there is little doubt that before long nickel will be refined in bulk and cast into suitable ingots, as is copper or lead.

"Indeed, at Vivian & Co.'s nickel works in England, a small reverberatory, heated by gas, has been in use for several years for refining nickel, some 2000 pounds being refined at a charge; and the superb display of solid nickel articles and ingots made by Joseph Wharton, of Philadelphia, shows that he experiences no difficulty in melting and casting nickel like other metals." *

* "Modern American Methods of Copper Smelting," by Edward Dyer Peters, jun., M.E., M.D., fourth edition, pp. 295-298. New York, 1892.

CHAPTER VII.

USES OF NICKEL.

THE uses of nickel were formerly very limited. The metal was employed only for the preparation of white alloy composed of copper, nickel, and zinc, and known as German silver.

Now it enters into the composition of some of the coinage of Belgium, Switzerland, and United States of America, and is also used for the manufacture of artificial ultramarine.

Without doubt the discovery of the practical manufacture and use of alloys of nickel and steel, made simultaneously in England by Mr. T. F. Hall of Sheffield and in France by Mr. Marbeau, has to a great extent changed the prospects of the nickel trade, and is the very one to offer the greatest future for nickel-producing centres and nickel works.

Mr. Riley, who a few years ago visited France for the purpose of studying the process of manufacture of steel and nickel alloys, and the certainty with which products could be obtained from the crucible, read in May 1889, at the meeting of the Iron and Steel Institute, a very interesting paper on alloys of nickel and steel, in which he says: "The alloy can be made in any good open-hearth furnace working at a fairly good heat. The charge can be made in as short a time as an ordinary 'scrap' charge of steel—say about seven hours. Its working demands no extraordinary care; in fact, not so much as is required in working many other kinds of charges, the composition of the resulting steel being easily and definitely controlled. No special arrangements are required for casting; the ordinary ladles and moulds being sufficient. If the charge is properly worked nearly all the nickel will be found in the steel—almost none is lost in the slag, being in this respect widely different from charges of chrome steel.

"The steel is steady in the mould; it is more fluid and thinner than ordinary steel, it sets more rapidly, and it appears to be thoroughly homogeneous. The ingots are clean and smooth in appearance on the outside, but those richest in nickel are a little more 'piped' than are ingots of ordinary mild steel. There is less liquation of the metalloids in these ingots, so that liability to serious troubles from this cause is much reduced. Any scrap produced in the subsequent operations of hammering, rolling, shearing, etc., can be remelted in making another charge without loss of nickel. The importance of this fact will be at once appreciated, especially by users of articles made of this metal, seeing that scraps and old articles will have a value for remelting in proportion with their contents of nickel.

"No extraordinary care is required when reheating the ingots for hammering or rolling. They will stand quite as much heat as ingots having equal contents of carbon but no nickel, except perhaps in the case of steel containing over 25 per cent. of nickel, when the heat should be kept a little lower and more care taken in forging.

"If the steel has been properly made and is of correct composition it will hammer and roll well, whether it contains little or much nickel; but it is possible to make it of such poor quality in other respects that it will crack badly in working, as is the case with ordinary steel."*

In order to procure a definite idea of the utility of alloys of nickel, steel, and iron, Mr. Riley made different mechanical tests; and we learn from him that, as chemically pure iron is practically unknown, and as the presence of very small quantities of carbon, silicon, sulphur, and phosphorus in varying proportions produce marked changes in the qualities of iron, with the view of estimating correctly the influence of the addition of nickel, the percentage of each of these elements was kept constant in all the tests he made. "The contents of nickel in the iron varied from 1 to 49·4 per cent., the carbon from 29 to 90 per cent., and the manganese from 0·23 to 0·85 per cent.

"With 2 per cent. nickel, 0·90 per cent. carbon, and 0·50 per cent. manganese, the alloys were too hard to machine with musket steel, but they made a fine tool

* *Journal of the Iron and Steel Institute*, No 1, 1889, p. 46.

when tempered at dull red in boiling water; while with 10 per cent. nickel and 50 per cent. each of carbon and of manganese it was too hard to machine, but made a good cutting tool when tempered in a cold air blast."*

At the new nickel works of Brooklyn, near Cleveland, U.S.A., which have been erected under the direction of Mr. Jules Garnier, the well-known French engineer, and where the Canadian Copper Company brings its ores from Sudbury, different tests have lately been made on nickel steel to determine the relative quality of steel, with and without the addition of nickel. These tests prove that:—

"1. Nickel steel has on an average a higher limit of elasticity of 11,400 lb. per square inch, or nearly 31 %.

"2. Nickel steel has an ultimate tensile strength greater by 10,400 lb. per square inch, or an increase of 20%.

"3. The ductility is not reduced by the presence of nickel."†

The different uses to which these alloys may be practically applied are indicated in Mr. Riley's paper already quoted.

"It requires no powerful imagination to conjure up a most bewildering number of applications for which they are available. I find some difficulty in not becoming enthusiastic on the point, for in the wide range of

* "Report of the Royal Commission on the Mineral Resources of Ontario," 1890, page 384.

† *Engineering and Mining Journal*, February 25, 1893.

properties or qualities possessed by these alloys it really seems as if any conceivable demand could be met and satisfied.

"Of the richer alloys I do not intend to speak at any length, but would just remark that in the immense field covered by what are termed the "Metal Trades," innumerable applications will be found for which they are suitable. Some specimens of these applications are before you.

"Of the 25 per cent. nickel steel I would remark that with its peculiar properties of high b. s., great ductility, and *comparatively* low e. l., it is extremely well adapted for all operations involving considerable deformation—for instance, for deep stamping and flanging—whilst its non-corrodibility will render it invaluable for a great number of purposes.

"This quality of non-corrodibility, considered together with its strength both elastic and ultimate when unannealed, will render it specially useful in all cases where the cost of metal is of minor importance when contrasted with the cost of labour to be expended upon it, or its use for special purposes: illustrations of these may be found in all small and special type boilers, in locomotive and other fire-boxes, and in the hulls of torpedo and other similar vessels where lightness and strength with non-corrodibility are of vital importance.

"In the region between 25 per cent. and say 5 per cent. nickel we have an abundance of possibilities as yet comparatively unknown, in which I expect will be found materials for toolsteel equal if not superior to anything at present known.

"But it is when we get to the alloys of 5 per cent. and under that, that I feel most interested and think most of you will sympathise with that feeling.

"I have already incidentally referred to the advantages the marine engineer will obtain by the use of the qualities for the shaft and other forgings used in his structures. I would now point to the suitability of these lower alloys to the other portions of his work. It is well known—it has been frequently stated by my friend Mr. Parker and others—that the recent advances in marine engineering, rendered possible by the use of high-pressed steam, could not have been effected if it had not been that a metal superior to wrought iron was put at the engineer's disposal. Conceive, then, of the possibilities now presented when a metal like No. 6 in the table No. 1, is at his disposal, having when annealed an ultimate strength of 30 per cent. and elastic limit of 60 or 70 per cent. higher than those of mild steel, with a nearly equal ductility, and the valuable quality added of less liability to corrosion. He may at once greatly reduce his scantlings for pressures and get rid of many difficulties of construction, or he may avail himself of the increased strength to provide for still higher pressures.

"It will also be seen that these metals are equally important to the shipbuilder and to the civil engineer. This is strongly brought out in considering the immense advantage to be derived from their use in large structures. Think for a moment of this in connection with the erection of the Forth Bridge or of the Eiffel tower. If the engineers of those stupendous structures had had at their disposal a metal of 40 tons strength and 28 tons elastic limit, instead of 30 tons strength and 17 tons elastic limit in the one case and say 22 tons strength and 14 to 16 elastic limit in the other, how many difficulties would have been reduced in magnitude as the weight of materials was reduced; the Forth Bridge would have become even more light and airy, and the tower more net-like and graceful than they are at present.

"Then as regards the requirement of the military engineer, I am inclined to state firmly that there have not yet been placed at his disposal materials so well adapted to his purposes—whether of armour or of armament--as those I have now brought under your notice.

"In what may be called their natural condition these alloys have many properties which will commend them for these purposes, and when the best method of treatment, be it hardening or tempering, has been arrived at, I believe that their qualities for armour will be unsurpassed." *

Nickel armour-plates have been manufactured by Messrs. Schneider & Co. of "Le Creuzôt," France, and have been tested in different countries.

---

* *Journal of the Iron and Steel Institute*, No. 1, 1889.

Mr. Hall has produced similar armour-plates which, tested by the British Admiralty, gave results 75 per cent. above any similar ones obtained from tests of armour-plates in England.

"At the present time, Mr. Hall has under course of manufacture breech-loading ordnance-cannons and projectiles of nickel steel for the English War Office, and he has already applied the same material in the production of rifles and sporting-gun barrels, boiler-tubes for torpedo boats, telephone and telegraph-wire. When it is considered that nickel-steel can be made in various tempers, giving tensile strain of 107 tons per square inch, with an elongation of 7 per cent., and 50 tons tensile strength with an elongation of 45 per cent., it is impossible to foresee to what uses this remarkable material may not be put; and now that the various patents and interests owned by Messrs. T. F. Hall, of Sheffield, W. H. Marbeau, of Paris, William H. Schneider, of Le Creuzôt, and T. Riley, of Glasgow, have been associated, their joint labours promise to give rapid development to this interesting alloy. Works have already been erected by this association in France for the special manufacture of ferro-nickel, and will shortly be followed by others in England and in the United States." *

A few years ago the cost of nickel was considered as a great objection to its extensive use, but, as it was then

* "British Contributions to the Metallurgy of Iron and Steel" by Sir James Kitson, Bart., Leeds, England. *Transactions Am. Inst. of M. E.*, vol. xix.

said by Sir James Kitson, "a metal which gave a tensile strain of 50 tons with an elongation of 50 per cent., was sure to make its way if the claims which Mr. Riley had made were justified by experience." At the present date Mr. Riley's claims have all been proved by actual experience.

The alloy of nickel and steel is now known as being not only practical but useful, and its uses become more and more numerous.

The future of nickel mines is thus full of brilliant promises; and as the nickel field of Sudbury is beyond doubt the largest known to-day, the time of a large prosperity for the province of Ontario, and specially for the district of Sudbury, is not far from us.

FINIS.