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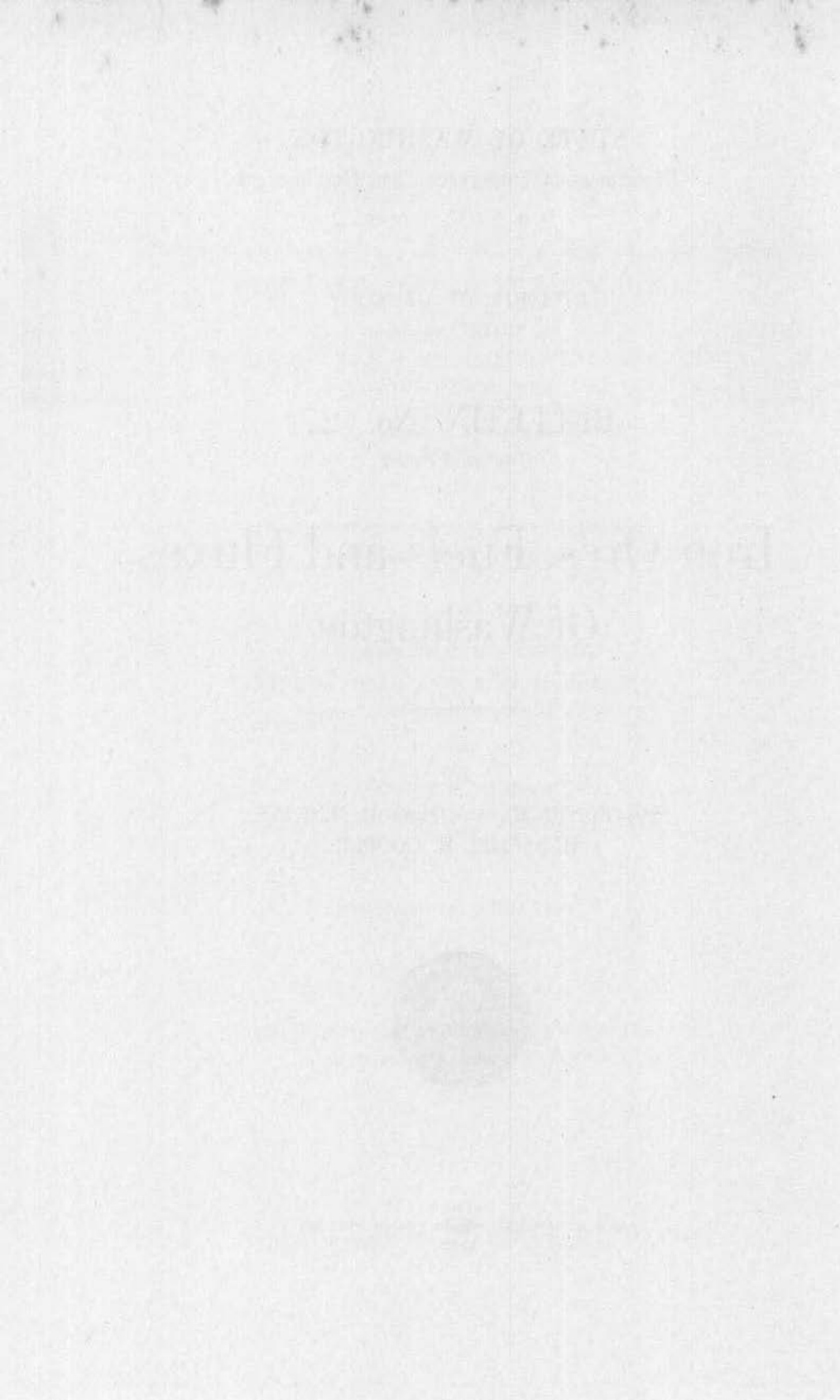
BULLETIN No. 27
(Geological Series)

Iron Ores, Fuels and Fluxes
Of Washington

BY
SOLON SHEDD, OLAF P. JENKINS,
HERSCHEL H. COOPER



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LETTER OF TRANSMITTAL

Hon. D. A. Scott, Director, Department of Conservation and Development, Olympia, Washington.

SIR: I am transmitting herewith the manuscript for a report on the iron deposits of Washington. Along with this is a brief discussion of furnace fuels and fluxes, with especial regard to the suitability of coke made from Washington coal, as well as the limestone found in the State, as a fuel and a flux in the iron and steel industry.

This work was done in order to comply with the following joint resolution introduced by Senator I. G. O'Harra and passed by the last session of the legislature:

SENATE JOINT RESOLUTION NO. 9

State of Washington, Seventeenth Regular Session.

WHEREAS, Data compiled by our metallurgical engineer, our state university, and government mineralogist and analysis by our chemist indicate all of the necessary properties in our natural resources as to quality and quantity for the manufacture of iron and steel; and,

WHEREAS, The necessary properties requisite to the manufacture of iron and steel are iron ore, carbon coal and limestone, therefore,

Be It Resolved, by the Senate and House of Representatives, That the state geologist be directed to make an investigation as to the feasibility of the manufacture of steel and iron in the State of Washington, findings to be on other than the holdings of the United States Steel Corporation, to take into consideration localities of the bodies of the different requisite minerals, giving the relative distance of one body to the other, and to make the report public within sixty (60) days after the adjournment of the 1921 session of the legislature.

I recommend that this be published as a Bulletin of the Department of Conservation and Development, and designated as Geological Series No. 27.

Very respectfully,

S. SHEDD,

Supervisor of Geology.

College Station,
Pullman, June 10, 1922.

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PART I

A Study of the Iron Ores Of Washington

Their Occurrence, Origin, and Composition, With
Regard to the Possible Development
of an Iron Industry

A STUDY OF THE IRON ORES OF WASHINGTON,

THEIR OCCURRENCE, ORIGIN, AND COMPOSITION, WITH REGARD TO THE POSSIBLE DEVELOPMENT OF
AN IRON INDUSTRY

BY

OLAF P. JENKINS and HERSCHEL H. COOPER

INTRODUCTION

PURPOSE

A part of the summer, from July 10th to September 15th, 1921, was used by the writers in the field investigation of the iron ores of the State, and during the following school year this final report was prepared. The purpose of this report and the field investigation may be summarized as follows:

1. To assemble all known information of importance regarding the iron ores of the State.

2. To present tables of analyses of these iron ores, which are for the most part assembled information of past record, together with analyses of specimens collected in the field by the writers.

3. To describe the deposits of the iron ores as they were found to occur in the State, and to account for their origin from a geological standpoint.

4. To determine the quality, and, as nearly as possible through the meager information obtainable, the quantity of iron ore present in each deposit herewith described.

In order to show the relation of the iron situation in Washington to the iron industry as a whole, this general phase of the subject is briefly outlined in this paper. In addition to this general phase, the common features and formation of iron ore minerals are presented.

REGION COVERED

Practically all the known deposits of iron ore in the State were visited by the writers. The locations of these deposits are shown on the accompanying map. In addition to the parts of the State in which these deposits are located, many other places were examined with negative results.

It is quite possible that other deposits of iron ore occur in the State, but have not yet been discovered. This may be especially true of magnetite deposits in the northern Cascades.

Although many mineral deposits other than iron, coal, and limestone were visited which carry natural products necessary in the manufacture of various kinds of steel, they are not described in this report.

ACKNOWLEDGMENTS

The most comprehensive published reports of a general nature on the iron ores of Washington are those by Shedd¹ and Whittier². From these papers data for this present report have been freely drawn. Other acquired information has been accredited through footnote references and in the bibliography at the end of this paper.

In following out an intention to see every known ore deposit in the State, the writers found it necessary to consult many people. In this way a considerable amount of the data was secured, such as maps, locations of deposits, analyses, etc. To these various people, also including those who gave much of their time as escorts to the properties, the writers are greatly indebted. Contributions, courtesies, and cordial support were received in the undertaking from all sides. In many cases, deposits

¹S. Shedd: *The Iron Ores of Washington*, Wash. Geol. Survey, Ann. Rept., vol. I, (1901), pp. 215-256.

²W. H. Whittier: *An Investigation of the Iron Ore Resources of the Northwest*, Bur. Industrial Research, U. of W., Bull. No. 2, (1917), pp. 19-34 and 95.

were examined which were found not to contain enough real iron ore to warrant giving space for their description in this report. Although these negative data are of no use here, the investigators were able to secure and record other geological information of importance in their notes, which adds materially to the general data which the Survey is accumulating and holding in reserve for future use in other reports.

HISTORY OF THE IRON INDUSTRY IN WASHINGTON

The iron ores of the State of Washington have been investigated several times by several different individuals and concerns. The railroad companies, during a very early period, collected such data and still have on record various private reports. Different iron and steel companies of American, Scotch, and English interests have also made investigations. The United States Geological Survey has published from time to time reports on the iron ores of special districts of the State. The State Survey published a report on the iron ores in 1901¹, and the Bureau of Industrial Research, University of Washington, compiled another report in 1917². All the published reports on the iron ores and the iron industry of Washington are included in the bibliography placed at the close of this present article.

Irondale, near Port Townsend, marks the place where activity in iron making appears to have first existed in Washington. The production of pig iron has been recorded by the United States Geological Survey³ for the State up to 1890. But since that date the tonnage of iron produced by Washington has been recorded by the federal survey together with the production of other western states all in a lump sum for each year:

YEAR	PIG IRON
	(in short tons of 2,000 lbs. each)
1881.....	1,200
1883.....	2,317
1884.....	540
1886.....	1,857
1887.....	1,586
1888.....	4,093
1889.....	10,371

¹Op. Cit. Shedd's report.

²Op. Cit. Whittier's report.

³Mineral Resources for the years 1883 to 1890.

In 1880 the Puget Sound Iron Company organized, built a furnace at Irondale, and began operating in February, 1881. At first local bog iron ores were put into the furnace, but these being unsatisfactory, magnetite from Texada Island, British Columbia, was mixed and later used almost to the exclusion of other ores.

The plant at Irondale went through a few years of success and several of failure, until 1902¹, when the Pacific Steel Company took it over. At first charcoal had been used as fuel at Irondale, but this company employed some coke in the furnace, the material coming from Cokedale, Washington. The iron ore was obtained not only from Texada Island, but also from other localities, which included the deposits at Hamilton, Skagit County. Limestone for flux was shipped in from Roche Harbor.

For a total period of eight months during the years of 1917 and 1918, the Pacific Coast Steel Company operated a reconstructed plant at Irondale, using left over ore from China, mill cinders, some ore from Texada, and some bog ore from British Columbia.

At the present time the Pacific Coast Steel Company is successfully operating a steel plant and rolling mill in Seattle. It does not use iron ore, however, to any great extent. Scrap iron and coke are its present required elements for the furnaces. During the war the output was materially increased, about 100,000 tons of structural steel being produced in one year. In the manufacture of steel products, this company uses minor amounts of other mineral products. *Ferromanganese* comes from Tacoma, Washington, and from Montana. *Ferro-silicon*, as a prepared product, is shipped to them from Iowa. *Aluminum shot* of purity 99 per cent, used as a cleaning agent in the slag, is obtained from Niagara. *Magnesite*

¹A. W. Clapp; *Iron Making at Port Townsend, Washington*; Eng. & Min. Journ., Vol. LXIII, Jan. 25, (1902), p. 137.

from Chewelah, and also from California, is used as a refractory product to a certain extent. *Carbo*, a petroleum coke by-product, is shipped to them from Quendall, Washington. They have used some iron ore from Texada Island and from China, as well as a limited amount from different deposits in Washington. The limestone which is used at the plant comes largely from a place called Limestone, near Sumas, Whatcom County. Their coke is shipped from a number of places, but principally from Wilkinson and Snoqualmie.

There have been a number of other attempts toward the organization of iron and steel companies, even to the extent of building preparations, as well as the leasing of manufacturing sites. These activities have occurred in a number of places, among which are Kirkland, on Lake Washington, Tacoma, Seattle, Sedro Woolley, and Bellingham.

There are also interests in Spokane for the development of an electric steel furnace to manufacture steel in the northeastern part of the State. These interests have been caused by the location of iron ores, not only in Stevens County, but in adjoining territories in British Columbia. Excellent water power sites are situated in this country. In addition to these facts, which have caused this industrial interest, is the presence of coking coals in neighboring places in British Columbia.

According to the United States Geological Survey, the State of Washington in 1920 produced 2,500 gross tons of magnetite. This was, for the greater part, shipped from the Myers Creek Mining District, near Chesaw, Okanogan County, to the magnesite companies at Chewelah, and used in the making of *ferromagnesite*.

THE IRON INDUSTRY

IMPORTANT FACTORS IN THE IRON AND STEEL INDUSTRY

LOCATION OF ORES

Market conditions, together with the influence of established industries, have determined the present location of the iron and steel manufactures, in countries where the required mineral products are present. Today the industrial centers of iron and steel of the world border the Atlantic Coast. It is quite possible that in the future a series of competitive manufacturing centers will get a firm foothold on the Pacific Coast. It is the vision of this future economic aspect that has fascinated many people of our western states.

Wherever large deposits of iron ore occur in close proximity to an extensive coal mining region, industry thrives. Coal which makes good coke is used most extensively as fuel in the reduction of iron ore to metallic iron. Limestone as a flux is required in the furnace. The occurrence together of these three mineral products in quantity is of great significance to the industrial world.

If iron ore and coal are not located near each other, the manufacturing plant is generally placed near the coal. The reason that the iron ore is transported rather than the coal or coke, is that the coal is used in a great variety of industries, whereas iron ore supplies only one. Besides, coke is not transported as successfully as iron ore.

If the so-called "sweeteners"—such as manganese, chrome, tungsten, molybdenum, etc., used in alloy mixtures of steel—were found in close proximity to the industrial center, the cost of manufacture of the different varieties of steel would be lowered. This feature, however, did not enter into the situation to any great extent until the World War showed that the industry might be

badly crippled if it were isolated from foreign trade which brings in the greater part of these minor constituents. The same condition exists in respect to other accessory minerals used for producing certain furnace reactions and also as refractory parts of the furnace itself.

QUANTITY REQUIREMENTS

Many people in the West who have been mining the more valuable minerals have a rather distorted idea of the value of an iron ore deposit, such as those found at various localities in this country. Metallic iron is used in such tremendous quantities that the deposits of ore must necessarily be of proportionate size to supply the demands of the manufacturing plants.

It is impossible to determine the size of an ore deposit by the few outcrops generally present, and the limited openings on the ore bodies. A knowledge of the way in which the ore occurs and something of its probable origin, however, may give, especially to one of geological training and experience, at least a general idea of the possible extent of the deposit. It is with this in mind that the writers present the data on the *occurrence* and *origin* of the iron ores.

In order to give to the reader a general idea of the amount of ore being shipped from some of the successful mines of the United States, the following statistics¹ are presented:

In 1917 there were in the United States, 452 active iron ore mines, 240 of which produced more than fifty thousand gross tons of iron ore each. Of these, 11 produced more than one million tons of iron ore. The greatest producer, Hull-Rust Mine, at Hibbing, Minnesota, produced during that year, 6,468,483 gross tons of hematite. The 240 producers of over fifty thousand tons

¹Mineral Resources of the United States for 1917, Part I, U. S. Geol. Survey, p. 564.

each, represent, in their production, 96 per cent of the entire production of the United States in 1917.

QUALITY REQUIREMENTS

Although a high percentage of iron and a low percentage of impurities determine in general the value of an iron ore, there are many other complex factors which enter into the situation.

Metallic iron. The required content of metallic iron in the ores depends upon the kind of ore, upon its impurity content, and upon the proximity of the deposit to consuming centers. The most valuable kind of ore is hematite, even though magnetite ores may carry as much or more metallic iron. The most detrimental impurity is phosphorus, because it is carried over into the steel, causing the final product to be brittle when cold. Ores located near consuming centers, among immense coal deposits, or those of a self-fluxing nature are used, even though they are low grade. The ores of France and Germany, of the British Isles, and the deposits in Birmingham, Alabama, are utilized even though they carry as an average 35 per cent or less of metallic iron. The ores of Lake Superior, the magnetites of Sweden, and the hematites of Spain, contain, as an average, 50 to 65 per cent of metallic iron.

Phosphorus. Pig iron is made from iron ores, while steel is made from pig iron. Although, through electro-metallurgical methods, high speed steels are made directly from ores, these newer processes have not yet been commercialized to any great extent. The process for making steel is largely determined by the phosphorus content of the pig iron. Eckel¹ summarizes this information as follows:

¹E. C. Eckel: *Iron Ores, their Occurrences, Valuation, and Control*, (1914), p. 151.

ALLOWABLE PHOSPHORUS IN PIG FOR VARIOUS UTILIZATIONS

Acid open-hearth—less than 0.05 per cent.

Acid Bessemer—less than 0.10 per cent.

Basic open-hearth for normal process, not over 1.50 per cent, and preferably not over 1.0 per cent; for special processes, 1.50 per cent and over.

Basic Bessemer—at least 1.50 per cent, preferably over 2 per cent.

Foundry iron—wide range, according to special use of the iron.

The ore from which such pig irons are made should not carry more phosphorus than in amounts proportional to the grade of the iron desired, because phosphorus is not expelled in the furnace. Thus, an iron ore containing 0.5 per cent phosphorus and 50 per cent metallic iron will make pig iron carrying 0.1 per cent phosphorus, which is the upper limit of the acid Bessemer grade.

The basic Bessemer process is used largely in England, where low phosphorus ores are not ordinarily available. In the United States the open hearth process is most generally used, together with the acid Bessemer, known as the Bessemer process.

Sulphur. Although sulphur is always detrimental in iron and steel, 90 to 95 per cent of it can be expelled in the blast furnace. In pig iron, sulphur should never exceed 0.07 per cent, and in strong castings, 0.03 per cent. It retards precipitation of graphitic carbon, causes flaws and segregations, thus promoting unsoundness, and increases the brittleness when hot (red short), unless manganese, which overcomes this objection, is present. In steel the worst evils of sulphur are that it causes red shortness and the liability to checking during rolling, or, if cast, to checking the steel during cooling.

Silica. The objection to silica is that it displaces iron in ores and must be fluxed into the slag with lime. More than 10 per cent in the ore usually is objectionable. Varying amounts of silicon may go over into the pig iron, but when used for the manufacture of steel, it should not

contain over 1 per cent for basic processes or over 1.5 per cent for acid processes.

Silicon affects cast iron in that it promotes precipitation of graphitic carbon, increases fusibility and fluidity of the mixture, and increases soundness of the product. Silicon in rolled steel has little effect, but in the cast steels it increases the tensile strength of the product with little loss of ductility.

Lime. Lime in some form is a flux generally used in the manufacture of pig iron. If it is present in the ore in sufficient quantities to take care of all of the silica present, the ore is said to be self-fluxing. If it occurs in sufficiently large quantities as to require silica to flux it off, it is objectionable from the standpoint of higher expenditures both in fuel, and in the handling of material of negative value.

Alumina. In clay, alumina is present in the silicate form. This material, together with other rock forming minerals, goes into the flux, thus causing additional expenditures of fuel, transportation, etc.

Manganese. In cast iron, manganese, in amounts less than 2 per cent, retards precipitation of graphitic carbon; it increases soundness, tensile strength, and hardness of the product, while decreasing the ductility and the tendency to red shortness caused by the presence of sulphur. In steel the presence of manganese is especially beneficial in its counteraction of sulphur, and in its effect of increasing soundness of the product.

Titanium. Although titanium does not interfere with the quality of iron, it materially raises the temperature of the fusion when present in the ores. It may be expected to occur in varied amounts in magnetites.

Arsenic. In steel arsenic appears to have no effect below 0.017 per cent. In greater quantities, however, it

raises the tensile strength, decreases the ductility, and destroys the malleability of the steel.

Copper. In cast iron, copper has a tendency to increase red shortness. Up to 0.1 per cent, copper increases brittleness of high carbon steel, but appears to have little effect on low and medium carbon steels.

REQUISITE MINERAL PRODUCTS¹, EXCLUSIVE OF IRON,
COAL, AND LIME

In addition to iron ore, coking coal, and limestone, (treated separately in this bulletin), there are a number of other mineral products which are indispensable in the manufacture of iron and steel.

Manganese is used in the United States in the production of 99 per cent of all its steel. In each ton of steel there are approximately 14 pounds of manganese ore. Deposits of this ore occurring in the State of Washington have recently been described by the federal survey.²

Chrome ore (chromite, $\text{Fe Cr}_2\text{O}_4$) is used in making chrome steel, chrome nickel-steel, chrome tungsten-steel, and chrome vanadium-steel. Metallic chromium is present in the steels in amounts varying from one to five per cent. Hardness and toughness are characteristic features of these steels. Chromite is found in several places in the State of Washington³, and in many other localities in the Western States, British Columbia and Alaska.

Nickel steels, the most widely used of the alloy steels, ordinarily carry about 3½ per cent nickel. They are

¹J. E. Spurr; Political and Commercial Geology, (1920).

C. K. Leith; The Economic Aspects of Geology, (1921).

World Atlas of Commercial Geology, Part I, Distribution of Mineral Production. U. S. Geol. Survey, (1921).

²J. T. Pardee; Deposits of Manganese Ore in Montana, Oregon, Utah, and Washington. U. S. Geol. Survey, Bull. 725C, (1921). Deposits in Washington, pp. 229-243.

³J. S. Diller; Deposits of Chromite in California, Oregon, Washington, and Montana. U. S. Geol. Survey, Bull. 725A, (1921). Deposits in Washington, pp. 61-65.

extremely important because of their unusually high tensile strength. By far the greatest supply of nickel comes from Sudbury, Ontario. Although traces of nickel have been found in the State of Washington, no commercial deposits have ever been developed.

Tungsten is used in making high speed tools. The amount of tungsten used in such steels varies from 11½ to 20 per cent. There are several deposits of tungsten in northeastern Washington¹ which might prove of considerable value in case a steel industry should be established in the West.

Vanadium is used in making very tough steel of great torsional strength. The amount of vanadium added to the mixture may range from 0.1 to 1.5 per cent. Vanadium ores have not been reported from the State of Washington.

Molybdenum is becoming more and more important as a substitute for tungsten in the manufacture of high speed tools. The occurrence of the ore molybdenite (MoS_2) in several localities in Washington² should deserve careful consideration in the event of the establishment of a steel industry.

Titanium is used, largely in the form of the mineral *rutile* (TiO_2), to take out occluded gases in the steel, thus giving it strength and wearing qualities. In the State of Washington, experiments on samples of titaniferous magnetite from Elma, Grays Harbor County, have been made by both the Rothert Process Steel Co., Seattle, and the Bilrowe Alloys Co., Tacoma, to prove whether titanium steel can be made from this titanium iron ore. The results of the experiments have not so far been commercialized to any great extent.

¹Howland Bancroft: *The Ore Deposits of Northeastern Washington*. U. S. Geol. Survey, Bull. 550, (1914).

²F. W. Horton: *Molybdenum: Its Ores and Their Concentration*. U. S. Bur. of Mines, Bull. 111, pp. 79-85, (1916).

Zirconium, in the oxide form, is highly refractory, and has been used in the making of furnace linings. In an experimental way only has it been used as a steel alloy.

Magnesite is important as a refractory material for furnace and converter linings. Since this mineral is found in great commercial quantities in Stevens County, Washington¹, it would be important in steel manufacture on the Coast.

Silica renders service in the making of brick for lining furnaces. It is also used in the alloy *ferrosilicon* for the purpose of deoxidizing and purifying steel, thus increasing the strength of the steel. There are a number of silica deposits in Washington, but whether or not they would be suitable for this purpose, is a question.

Fluorspar is used as a flux in the manufacture of open hearth steel. A little fluorspar or *fluorite* is found in northeastern Washington.²

PRODUCTION OF IRON

THE WORLD'S PRODUCTION OF PIG IRON³

With the United States far in the lead of other countries in the production of iron, we have a situation of great international importance. The United States, Germany, France, and Great Britain supply most of the iron for the world's consumption. The Lake Superior District produces 30 per cent of this supply, while Germany and France, principally the Lorraine district, together produce 25 per cent.

One-half of the American production is controlled by the United States Steel Corporation, the largest single commercial concern in the world.

The expansion of the iron and steel industry in Japan is especially important in relation to the question of iron

¹Whitwell & Patty; The Magnesite Deposits of Washington. Wash. Geol. Survey, Bull. No. 25, (1921).

²Patty & Glover; The Mineral Resources of Washington, Wash. Geol. Survey, Bull. 21, (1921), pp. 99-101.

³These figures are drawn from U. S. Geol. Survey, Mineral Resources, (1920).

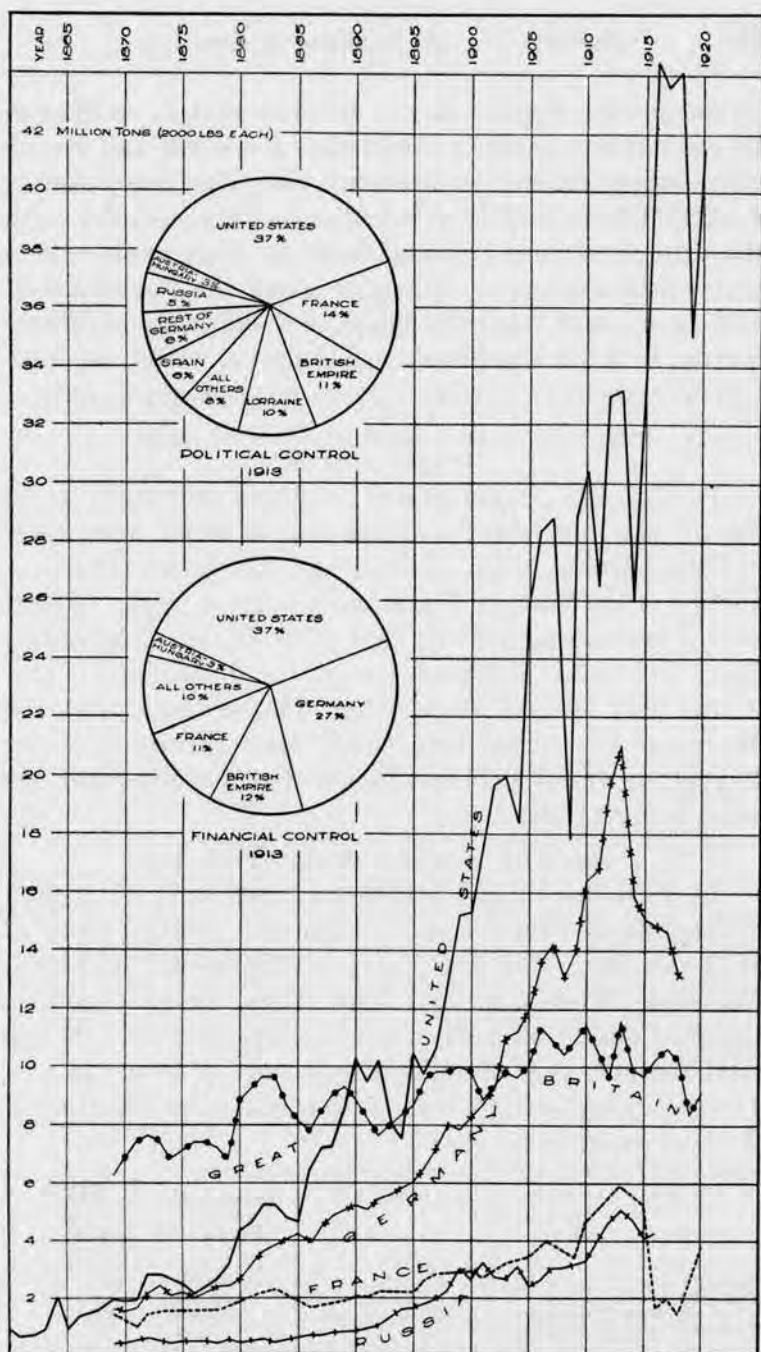


FIG. 1.—Curves showing the production of pig iron of the principal iron producing countries of the world.

industries developing in our western states. Although by comparison Japan's production is a small and insufficient supply for her own consumption, she has, however, a great future and is at work upon this industry with the ores of various Oriental fields to draw upon. Competition between iron industries along the Pacific Coast may be a great future problem, and the State of Washington, with her significant coal deposits, would undoubtedly be materially affected by such an economic condition.

PRODUCTION¹ AND PRICE OF PIG IRON IN THE
UNITED STATES

In 1920 the United States produced 36,925,987 gross tons of pig iron, over 28 million tons of which were made in Pennsylvania, Ohio, Illinois, and Alabama. The production of the State of Washington is given by the federal survey in combination with that of the States of Missouri, Iowa, Colorado, Montana, Oregon, and California, and it was only 464,584 gross tons. The average price for one gross ton of pig iron (f.o.b. blast furnaces) in the United States for 1920 was higher than for any other one year, being \$31.95.

SOURCE OF IRON IN THE UNITED STATES

In 1920 the United States produced over 67 million gross tons of iron ore, with a general average price of \$4.11 per ton. The five states of Minnesota, Michigan, Alabama, Wisconsin, and New York, taken together, supplied nearly 65 million tons of this amount. Of the total amount, over 63 million tons were of hematite ore. The following statistics show the related production of the four great iron ores:

Kind of Ore	Production in U. S. For 1920	Percentage of Total Amount in U. S. Since 1881
Hematite.....	63,883,523	89.5
Magnetite.....	2,391,541	5.6
Brown ore (largely limonite).....	1,325,661	4.8
Carbonate (largely siderite).....	3,740	0.1
		100.00 per cent

¹These figures are drawn from U. S. Geol. Survey, Mineral Resources, (1920).

According to the United States Geological Survey the State of Washington produced, in 1920, 2,500 tons of magnetite, which is about 0.1 per cent of the total production of magnetite in the United States for that year. This, however, was not used in making iron, but for the manufacture of ferromagnesite.

The only other Pacific state whose single production of iron ore in 1920 is recorded by the federal survey, is California. These figures are interesting here only for sake of comparison. California produced 1,094 gross tons of limonite and 5,573 of magnetite. The magnetite averaged, for that year, the price of \$7.16 per ton.

MINERALOGY OF IRON ORES

GENERAL FEATURES

Iron, as a component of the earth's crust, ranks fourth in abundance among the elements. Though it rarely occurs in the native state, it is a constituent of hundreds of mineral species, and is found in greater or lesser amounts in nearly all rocks, whether igneous or sedimentary. The most common iron bearing minerals in igneous rocks are amphiboles, pyroxenes, micas, olivine, and magnetite. There are in addition many sulphides, arsenates, phosphates, and rarer silicates that contain the element.

In the sedimentary rocks the oxides and carbonates, which constitute practically all the ore minerals of iron, are the more common. Arranged in order of importance with reference to quantities used in the United States these minerals stand as follows: *hematite*, *limonite*, *magnetite*, and *siderite*.

HEMATITE

Hematite is the anhydrous sesquioxide of iron (Fe_2O_3) which, when pure, contains 70 per cent of the metal. It most commonly occurs either as small crystals in cavities, or in micaceous, fibrous, oolitic, compact, or earthy masses. Hematite has a dull to metallic luster and varies in color from red, through steel gray, to iron black. It has a hardness of 6 and a specific gravity of 5.1. The color of powdered hematite, or its streak, is invariably some shade of red. Heated in the presence of carbon, it turns black and becomes strongly magnetic.

Hematite is the principal ore mineral mined in the Lake Superior "iron ranges," where it occurs as a metasomatic replacement of cherty iron carbonate. The process of concentration in this district is believed to have been effected by means of meteoric water acting

upon ferruginous cherts, slates, and jaspers. The oolitic variety of hematite, which constitutes the well known Clinton iron ore of the Appalachian region, is generally conceded to be a metasomatic replacement of oolitic limestone. Hematite is also found as an alteration product of limonite, siderite, magnetite, pyrite, or other iron minerals. *Martite* is the pseudomorphous form of hematite resulting from alteration of octahedral crystals of magnetite.

LIMONITE

Limonite is the hydrous sesquioxide of iron ($2\text{Fe}(\text{OH})_3\text{Fe}_2\text{O}_3$), which, when pure, contains 59.8 per cent metallic iron. It occurs in mammillary, nodular, botryoidal, and stalactitic forms, or in earthy masses, and may be fibrous, compact, pisolitic, or porous. Limonite is always of secondary origin and is often found pseudomorphous after the other iron minerals, especially pyrite. It has a dull to sub-metallic luster, and a yellowish brown streak or powder. When heated in a closed tube it gives off water and turns red. Heated in the presence of burning carbon, a dark, brittle residue, strongly attracted by a magnet, is left.

Limonite occurs as a residuary mineral in laterite deposits and weathered limestones; as a secondary mineral in veins and ore deposits formed by the oxidation of pyrite or chalcopyrite; as a bog iron ore formed by the oxidation of the bicarbonate of iron which is carried in solution in marshes; and as a pseudomorphous replacement of limestones, effected by percolating solutions of iron compounds.

The material known as laterite is essentially a mixture of ferric and aluminum hydroxides, together with more or less clay and free silica. It is common in tropical and subtropical regions, where conditions are generally favorable for profound disintegration and decomposition of rocks.

In the event that the preexisting rocks were of basic composition and rich in iron, the residual material would contain a relatively high percentage of ferric hydroxide, or limonite. The iron deposits of eastern Cuba¹ are thought to be a product of some such lateritic concentration.

Residual limonite occurs in the Appalachian region in the form of lumps and nodules embedded in a matrix of clay. It is derived from the decomposition and solution of ferriferous limestones and dolomites, the lime and magnesia having been dissolved out, leaving the hydrous iron oxide clay, and other insoluble material.

Limonite occurring as an oxidized product from the sulphides of iron, has been of considerable importance in certain eastern states. Similar deposits have been utilized to a greater or lesser extent in some of the western states in the smelting of copper and silver.

The variety of limonite known as bog iron ore forms in stagnant swamp waters. The iron is leached from the country rock by carbonated solutions, or by the solvent action of organic acids, and carried into the marsh lands as ferrous compounds. If deposition of the iron takes place in the presence of much carbonic acid, or decaying organic matter, the carbonate is precipitated; if in the presence of free access to air the hydroxide is produced. This process of precipitation is frequently accelerated through the activity of certain species of bacteria, which have the capacity of absorbing the iron from solution and later depositing it as ferric hydroxide.

Limonite also occurs as a pseudomorphous replacement of limestone. Such a reaction takes place most readily either below the ground water level or along channels and fracture zones through which iron-bearing solutions migrate. The limonite may be formed directly

¹A. C. Spencer; U. S. Geol. Survey, Bull. 340, (1908), p. 318-329.

C. M. Weld; Trans. Am. Inst. Min. Eng., Vol. 40, (1909), p. 299-312.

if the solutions carry ferric compounds, but probably the more common and natural reaction is a primary replacement by ferrous carbonate, which is subsequently oxidized to the hydroxide.

MAGNETITE

Magnetite is an oxide of iron, formed through the chemical combination of iron sesquioxide (Fe_2O_3), with iron protoxide (FeO). Chemically it has the composition $\text{Fe Fe}_2 \text{O}_4$, or $\text{Fe O.Fe}_2 \text{O}_3$, although the expression $\text{Fe}_3 \text{O}_4$ is most common in general works. When pure, magnetite contains 72.4 per cent iron.

The mineral magnetite occurs in crystals, in compact and granular masses, and as loose sand. It has a sub-metallic to metallic luster and is black in color. The streak is invariably black. Magnetite has a hardness of 6 and a specific gravity of about 5. It is strongly attracted by a magnet, far more so than any other black mineral. The variety of magnetite known as lodestone is, itself, a magnet.

Magnetite may be found as an accessory mineral in rocks of all classes, and frequently is a principal constituent. In ore deposits it occurs in magmatic segregation, in contact metamorphic deposits, in lenses or layers in schists and gneisses, and as "black sand" forming bars along the shores of rivers, lakes, and seas.

As an accessory mineral, magnetite occurs most abundantly in rocks rich in ferromagnesian minerals, such as diabase, gabbros, and peridotites. In many cases it separates from the parent rock while still in its molten state, forming large ore bodies. This phenomenal separation of a mineral from a magma into concentrated masses is known as *magmatic segregation*. Ore bodies of magnetite thus formed are, however, generally high in titanium.

Magnetite also occurs as a metamorphic product along the plane of contact between intrusive igneous bodies

and adjacent sedimentary rocks, especially limestones. Along such contacts the limestones become coarsely crystalline, and the usual contact-metamorphic minerals — garnet, epidote, wollastonite, tremolite, and diopside — are commonly developed. In such deposits the magnetite generally occurs in irregular or lenticular masses, associated more or less intimately with sulphides. Ore bodies of this type are rarely very large.

Schists and gneisses, developed through regional metamorphism, along zones of shearing and lines of great pressure, frequently contain such minerals as pyrrhotite, chalcopyrite, and magnetite. This is said to be particularly true in cases where amphibolite schists are developed.

Magnetite is the principal constituent of the well known "black sands," which accumulate along beaches and the lower courses of rivers. A greater or lesser amount of *ilmenite* (Fe Ti O_3) is usually mixed with the magnetite. Such sand bars may be subsequently buried under later sediments and cemented into a coherent mass.

SIDERITE

Siderite, or spathic ore, is ferrous carbonate (Fe CO_3), which, when pure, contains 48.3 per cent metallic iron. It occurs in small crystals in cavities, in granular to compact masses, or in cleavable masses having curved rhombohedral cleavage. Siderite has a vitreous to pearly luster and may be gray, yellow, brown, or black in color. The color of the streak, or powder, is white or pale yellow. Its hardness is 3.5 to 4. When heated on charcoal it decrepitates; that is, flies into pieces, turns black, and becomes magnetic, but fuses with difficulty. In warm acids siderite is soluble with effervescence.

Siderite is found in mineral veins; as stony, impure, clay ironstone concretions in shales; as bituminous black-band ore; and as a metasomatic replacement of limestone.

It is a common mineral in metallic veins, particularly in those bearing lead and silver. When so occurring, however, it is usually considered as a gangue mineral.

The stony, impure, clay ironstone concretions in shale and bituminous blackband ore are always found associated with the Coal Measures. Their most wide-spread occurrence in the United States is in the Alleghany Mountains. The clay ironstone concretions are locally known as kidney ore, and occur as lumps and rounded masses scattered through beds of clay and shale. The blackband ore is found in beds inter-layered with bituminous shale.

Siderite, occurring as a metasomatic replacement of limestone, or dolomite, is quite common. Limestone consists essentially of calcium carbonate (CaCO_3). Dolomite is the double salt, calcium magnesium carbonate, $\text{Ca Mg} (\text{CO}_3)_2$.

The mineral carbonates of iron, calcium, and magnesium not only possess certain chemical similarities, but also have nearly identical crystal forms. Moreover the different minerals often appear as components of the same crystal. This isomorphous relationship is important, since it provides favorable conditions for metasomatic replacement of limestone or dolomite by iron carbonate. Thus if limestone is invaded for a considerable length of time by solutions carrying iron carbonate, a replacement of the former by the latter will take place, resulting in the formation of siderite. Siderite deposits of economic value, formed by such a replacement, exist in Cornwall, in the Alps, and in Bohemia.

PYRITE

Pyrite is the disulphide of iron (FeS_2). It is brass yellow in color, has a metallic luster and a greenish black streak, and commonly crystallizes either in cubes or pyritohedrons. Pyrite is of no economic value as an iron ore, though it is used extensively in the manufacture of

sulphuric acid. It may be distinguished from marcasite (FeS_2) by its crystal form, and solubility in cold nitric acid.

PYRRHOTITE

Pyrrhotite is ferrous sulphide (FeS), with an excess of sulphur present in solid solution. Its composition may be expressed by the formula $\text{FeS}(\text{S})_x$.

Pyrrhotite is bronze yellow in color, has a metallic luster, and a grayish-black streak. It may be distinguished from pyrite, which it somewhat resembles, by its inferior hardness, bronze color, and slightly magnetic properties.

Pyrrhotite itself has no special uses except as a flux, though it may be valuable because of its associated minerals.

DESCRIPTION OF THE IRON ORE DEPOSITS IN WASHINGTON

STEVENS COUNTY.

THE VALLEY DISTRICT

Introduction

The Valley district is situated in the south central part of Stevens County. Topographically it consists of a relatively broad valley skirted on either side by low mountain ranges, which extend in a general north and south direction, and rise 2,000 or 3,000 feet above the intervening valleys. The two iron properties of the district lie in the foot-hills of these mountains. They are both reached by wagon road from Valley, a town on the Great Northern Railway.

Kulzer Property

Location. This property is located about three miles east of Valley in section 20, T. 31 N., R. 41 E., at an elevation of 2,200 feet. The property consists of four claims: the Vigilant, Capitol, Climax, and Ninety-eight, all owned by Mike Kulzer of Valley.

Description of rocks. The predominating rocks in the immediate vicinity of the deposits are dolomitic limestones and argillites of probable Paleozoic age. These have been intruded by small masses of porphyry, which

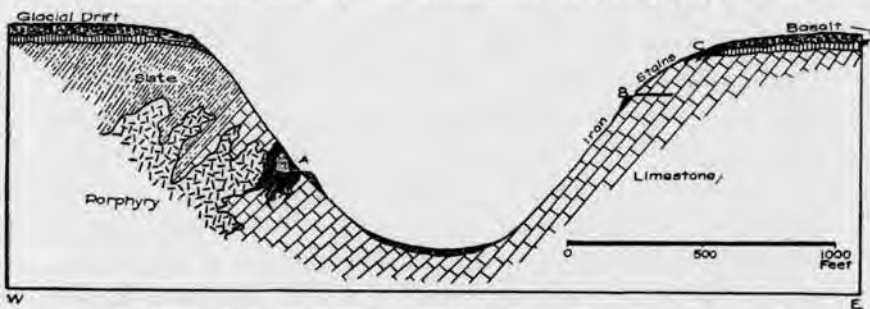


FIG. 2.—Hypothetical cross section of the Kulzer property, Stevens County. A. The principal ore body, showing its occurrence and its relation to the country rock. B. Prospect tunnel on Climax claim. C. Low grade limonitic iron ore, formed through surficial weathering of the basalt layer that lies immediately beneath the glacial drift.

from their textural character and relation to enclosing limestones, appear to be apophyses or fingers extending out from a larger batholith beneath. The unaltered porphyry is composed essentially of large phenocrysts of glassy andesine feldspar embedded in a crystalline ground mass of feldspar, hornblende, augite, and olivine.

The limestones and argillites dip to the west at an angle of 45 degrees. They are overlain unconformably by a thin flow of basalt which in turn is masked by glacial drift. The age of the basalt is not definitely known, but it probably belongs to the Tertiary volcanics, which cover a large part of eastern Washington. In thin section this rock is seen to be made up of crystals of labradorite, olivine, augite, and magnetite embedded in a fine-grained to glassy ground mass stained by iron.

Mining development. A great deal of time and effort has been expended in doing development work on the Vigilant, Capitol, and Climax claims during the last thirty years. There are approximately fifteen exploration tunnels on the three claims. These have been driven into the hill about the deposits in an endeavor to determine their nature and extent. Work done on the Ninety-eight claim, which lies about a mile farther east, consists of open cuts and pits.

The most extensive workings on the property are situated near the division line between the Vigilant and Capitol claims. There a tunnel has been driven almost due west into the mineralized zone, and from it drifts and stopes have been made. The ore taken from the mine consists of limonite intermixed with more or less hematite. A number of years ago this ore was mined and shipped to the smelter at Tacoma for a flux. Recently the mine was operated for a few months, and the ore shipped to the Northwest Magnesite Company at Chewelah. When the property was visited, 20 or 30 tons

of ore lay in the bunkers and in the dumps, but all operations were suspended.

Ore deposit. The ore bodies on the Capitol and Vigilant claims are irregular in outline and show no clearly defined boundaries. The mineralized zone varies in width from a few feet to 30 feet or more, and extends intermittently along the strike, which is nearly north and south, for 500 feet. The ore is found in lumps and nodules in the decomposed porphyry, where that rock has suffered intensive weathering or occurs as a replacement in the contiguous limestones; its extent apparently being dependent on the state of decomposition and size of the intrusive mass exposed at the surface.

No concentrated bodies of ore worthy of note were observed on either the Climax or Ninety-eight claims.

Possible origin of the iron ore. It has already been pointed out that the iron on the Vigilant and Capitol claims occurs within and adjacent to masses of intensely weathered porphyry. In places where the porphyry is fresh and unaltered there is no indication of iron ore. Even the underlying limestones retain their original white crystalline character. Where the stage of weathering is advanced, however, the feldspars have been altered to kaolin, while the iron-bearing silicates have been converted into new compounds, among which may be mentioned oxides, hydroxides, and carbonates. The iron minerals thus formed were largely segregated into residuary lumps and nodules of limonite and hematite that now appear irregularly distributed through the decomposed mass. Another portion of the iron, however, was taken into solution by carbonated surface waters and through that agency effected a partial or total replacement of adjacent and underlying limestones.

The brown limonitic ore that occurs on the Climax and Ninety-eight claims has been formed either through surficial weathering of the thin layer of basalt, which

lies underneath the glacial drift, or from weathered and exfoliating boulders of the same material embedded in the drift itself.

Economic aspect. The ore, not necessarily the average sample of the deposit, contains a fairly high percentage of metallic iron, the analyses showing from 41 to 68 per cent Fe. The phosphorus content, however, is also high, ranging from 0.14 to 0.51 per cent P. This high phosphorus content would make it unsuitable for the acid processes of steel manufacture, but would be suitable in the basic open hearth process.

A large portion of the exposed ore body has been removed — some 7,000 tons — and it is impossible to determine the amount left. This would probably not exceed two or three times the amount already removed, unless new bodies are discovered.

Hill Property

Location. This property is located in sections 17 and 20, T. 31 N., R. 39 E., nine miles west of Valley, at an elevation of about 3,050 feet. The claim is known as the Iron Jack, and is owned by L. W. Hill of St. Paul, Minnesota.

Description of rocks. Crystalline dolomite and sericitic argillite of probable Paleozoic age are the principal rocks exposed in the immediate vicinity of the deposit. The dolomite lies in a narrow belt, which extends across country for several miles in a northeast-southwest direction. It varies in texture from a fine grained to coarsely crystalline rock, and in color from nearly white to dark gray. The argillite is exposed three hundred feet east of the workings, where the beds were observed to dip toward and under the deposit, in a direction north 65 degrees west, at an angle of 52 degrees.

The only igneous rock found near the property was a dark green intrusive, which outcrops a few hundred feet to the northeast.

C. K. Leith¹, who visited the deposit in 1904, speaks of "a shaft 75 feet deep, from which have been thrown out fine dense hematite, coarse amphibolitic martite ore and gradations between the two; also green schistose rocks whose relations to the ore were not determined."

Mining development. The most extensive development work was done on the property eighteen or twenty years ago. The site of operations covers but a small area. Within this, however, one or two tunnels have been driven, and five or six shafts sunk to depths varying from 10 to 75 feet. Most of these workings are now fallen in, or are otherwise inaccessible, so the exact amount of work done cannot be described from field examination. Nevertheless, the large dumps about the scene of operation furnish ample evidence that past activity has been vigorous. More recently diamond drilling was resorted to in a further effort to determine more definitely the extent of the deposit, but the results obtained through these later investigations are not known.

Ore deposits. The ore body occurs within the dolomite and near the contact of that rock with the westerly dipping beds of sericitic argillite. The shape and size of the deposit are not known. The ore minerals consist of hematite, magnetite, and martite. The hematite is deep red in color, has a dark red powder or streak, a high specific gravity (5.0) and embodies within it small grains of magnetite. The free magnetite is coarsely crystalline, occurring in well developed octahedral crystals, which commonly show either the tendency to change, or the actual transformation from their original composition (Fe_3O_4) to that of hematite (Fe_2O_3). This pseudomorphous variety of hematite occurring as octahedrons as a result of such an alteration is known as

¹Iron Ores of the Western United States and British Columbia, U. S. Geological Survey, Bull. 285, p. 195.

martite. In other words, martite is a mineral with the composition of hematite falsely appearing in the crystal form habitual to magnetite. The latter, however, may be readily distinguished from the former by virtue of its magnetic properties and black streak, the martite being very slightly or non-magnetic and having a red streak. More or less calcite is associated with the ore, especially with the martite.

Possible origin of the iron ore. Since the dilapidated condition of the workings forbade an underground examination of the deposit, the subject of origin is more or less difficult to discuss. On the other hand, the large dumps are a source of valuable material which furnish worthy clues as to the probable origin. A number of specimens of the ore and of the dolomite, which forms the wall rock, were secured. From a study of these the deposit appears to be largely a product resulting from metasomatic replacement of the highly metamorphosed and fractured dolomite by iron compounds. The criteria supporting such a conclusion are as follows: (1) dolomite lends itself readily to such a replacement; (2) the ore specimens show an unbroken sequence of transitional changes from nearly pure dolomite to dense red hematite; (3) the hematite reveals clearly the structure and to a lesser extent the textural character of the original dolomite.

The source of the iron solutions is a matter of speculation, but they probably originated from vapors and solutions given off by one of the still unexposed intrusives which are known to cut the metamorphic series in that locality and are exposed elsewhere. The magnetite was probably formed in fissures by the same solutions, thus accounting for its well developed and idiomorphic crystalline character. Subsequent oxidation of the magnetite to the composition of hematite without involving any

crystal modification accounts for the presence of the martite found there.

Economic aspect. The ore is of excellent grade, probably of the best quality in the state, the analysis of a specimen showing it to contain 68 per cent metallic iron and only 0.024 per cent phosphorus. Since the underground workings were not accessible, the ore body could not be examined. The only ore present was that on the dump, which amounted to less than a thousand tons.

THE DEER TRAIL DISTRICT

Introduction

The Deer Trail district is situated in the southwestern part of Stevens County. It lies in the foothill region along the western slope of the south half of the Huckleberry Range. The nearest railroad station is at Springdale, a town on the Great Northern Railway on the east side of the Huckleberry divide, about 25 miles distant.

Read Property

Location. This property is located in the north half of section 14, T. 30 N., R. 37 E., four miles east of Hunters. The property consists of three claims—the Read, Jennie E., and Iron Cliff—all of which are owned by J. C. Read of Hunters.

Description of rocks. The rocks occurring on the property are principally granite and limestone. The granite appears to be a portion of a batholithic intrusion into what is often designated as the old Paleozoic series, which subsequent erosion has exposed. It is a dark, granular, holocrystalline rock, composed chiefly of feldspar, quartz, biotite, and hornblende.

A thin section of the granite studied under the microscope shows it to be composed of orthoclase, plagioclase, quartz, biotite, hornblende, magnetite, and the minor accessory minerals, such as titanite and apatite. Orthoclase is the principal feldspar, though microcline and

other plagioclase minerals are common. Quartz is not abundant. Biotite is the most prominent accessory mineral though hornblende is also important. The magnetite is abundant and generally occurs within and around the crystals of hornblende.

The limestone varies in color from pure white to gray and occurs as well crystallized marble near the contact with the granite.

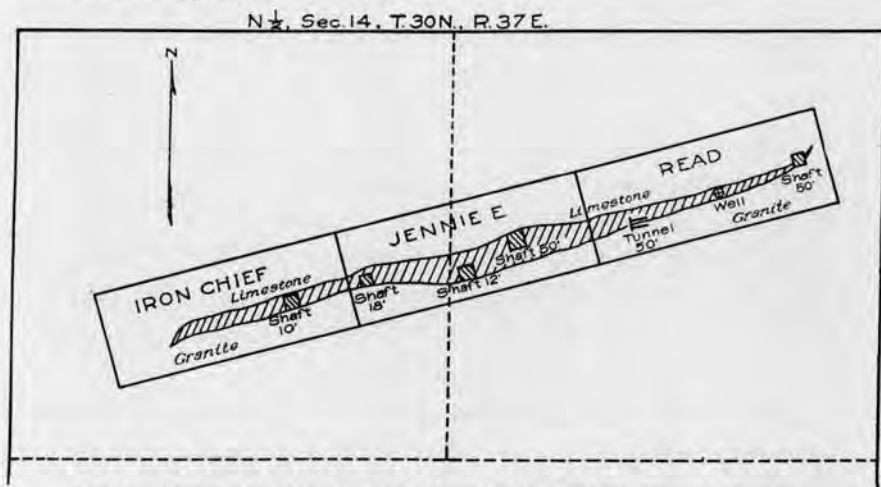


FIG. 3.—Sketch plan of the Read claims, near Hunters, Stevens County.

Mining development. The property has been developed by the sinking of four shafts, three of which are each 50 feet long, and one 20 feet long. A tunnel 56 feet long has also been driven. At the time the property was visited only a small quantity of ore lay on the dumps about these workings. Owing to the remote location of the deposit with respect to transportation facilities, no active mining operations have ever been attempted. A few tons of ore taken from the property are said to have been smelted in a small furnace which was erected at Fruitland a number of years ago.

Ore deposit. The ore body occurs in the limestone along the plane of contact between that rock and the

intrusive granite. It appears roughly tabular in shape and dips north 15 degrees west at an angle of 80 degrees. Its strike is north 75 degrees east. The mineralized zone may be followed along the contact for a distance of 3,000 feet. Its width varies from a few inches to 50 feet or more.

Magnetite is the principal mineral present. Where it is exposed at the surface it is coarsely granular in

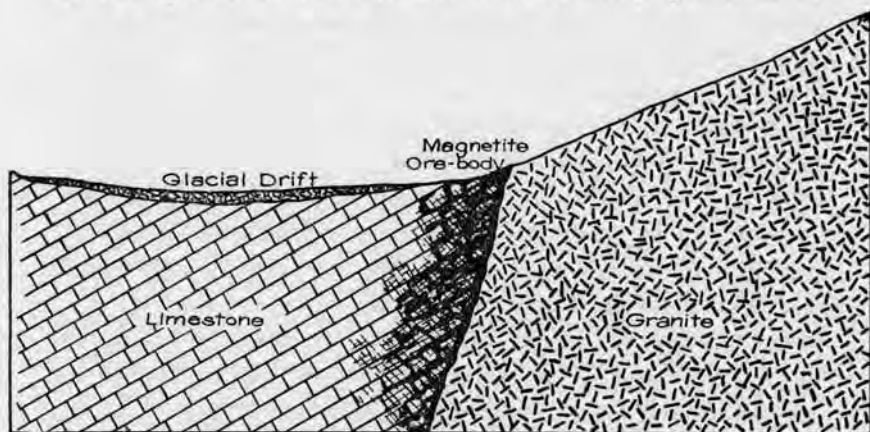


FIG. 4.—Hypothetical cross section of the Read property, near Hunters, Stevens County, showing the occurrence of magnetite in limestone along the contact with an intrusive granite.

character, with an earthy white siliceous material, together with a little carbonate of calcium and magnesium, filling the interstices between the grains. The magnetite at lower levels, however, is compact, hard, and stony, and contains a considerable amount of chalcopyrite. It is said that assays made of samples taken from the deeper shafts yield values in gold and silver. Minerals found associated with the magnetite other than those already mentioned are wollastonite, tremolite, quartz, and some fluorite.

Possible origin of the iron ore. The occurrence of the ore body along the contact between the limestone and intrusive granite, the highly crystalline and metamor-

phosed condition of the limestone adjacent to this zone, and the character of the minerals present in the deposit, indicate that the magnetite is a product of contact metamorphism.

Economic aspect. An analysis of a specimen of this ore shows it to contain about 60 per cent metallic iron and 0.07 per cent phosphorus, and a trace of titanium. Although this specimen contains 0.048 per cent sulphur, the ore body as a whole will undoubtedly contain a large quantity of sulphur, for there are sulphide minerals (pyrite and chalcopyrite) scattered through the ore body. Although these amounts of undesirable impurities are high, they would not prohibit the use of the ore in making iron and steel. It is impossible to state the probable amount of iron ore in this deposit, because it has not been prospected to any extent for iron ore. There may possibly be as much as 500,000 tons of ore in the deposit, judging from its size and from the character of the ore body. The pure limestone next to it might give to it local value if the limestone were used as a flux.

THE CLUGSTON CREEK DISTRICT

The Clugston Creek district is situated about 12 miles north and a little east of Colville, the county seat of Stevens County, though by wagon road it is three or four miles farther. The iron properties are located in sections 11, 23, and 24, T. 37 N., R. 39 E. The nearest railroad station is at Colville on the Great Northern Railway.

The country rock exposed over most of the district consists of argillite and limestone, which are members of the metamorphic series common to northeastern Washington. The iron ore, which is a brown limonite, occurs in veins, seams, and irregular masses in the limestone. No development work has been done in recent years to explore any of the iron prospects.

Dr. S. Shedd¹, who visited the district in 1900, describes the conditions on section 11 as follows: "The country rock in this district is a limestone and the iron ore seems to occur in masses, and not in a continuous vein, in the limestone and varies from well concentrated iron ore to limestone with very little iron ore in it. Two tunnels have been run on one of these properties, and at the end of the lower tunnel a shaft 60 feet deep has been sunk, so that a depth of 100 to 120 feet has been reached on this property. In the upper tunnel considerable ore was found, but in the lower one and in the shaft no ore was found. The ore in this district from present indications, so far as I was able to judge, is of very limited extent."

In sections 23 and 24 is a group of claims known as the Chloride Queen. Limonite veins occur here in a limestone formation, which are said to carry values in lead and silver. During the early exploration days of the district a few hundred tons of the limonite ore were mined and shipped to the smelter then located at Colville. The deposits, however, are not extensive.

Economic aspect. According to the analyses, which were made in 1900, the content of metallic iron is about 50 to 56 per cent in the specimens collected. The phosphorus percentage is high—about 0.3 per cent. It was not possible to determine the true quantity of the ore present, because of the dilapidated condition of the workings. According to Shedd's report (previously quoted) the ore of this district is probably of very limited extent.

THE DEEP LAKE DISTRICT

Introduction

The Deep Lake district is situated in a mountainous region in the northeastern part of Stevens County.

¹The Iron Ores of Washington, Wash. Geol. Surv., Ann Rept., Vol. 1, (1901), p. 253.

From comparatively narrow valleys, the mountains ascend abruptly to altitudes of approximately 4,000 feet. Thus the difference in elevation between drainage lines and the crests of the divides is 1,500 to 2,000 feet. The reason for this pronounced relief may be traced originally to the mountain-making disturbances which in this locality have caused intense folding, faulting, and metamorphism of sediments that are considered by some to be of Paleozoic age.

Moreover, these formations were invaded at about the same time by a granitic magma, which probably intensified the metamorphic reactions and induced more extensive faulting. The intrusive granite has since been uncovered over an area of several square miles in the south part of the district. Granite of similar character and of the same relative age is widely distributed over the whole county, which suggests that these exposures are the more surficial protuberances of a great underlying batholith that erosion is slowly bringing to the surface. Hence the present topography bears record of the work done by these foregoing forces, even though it is now profoundly modified and altered through subsequent erosion by stream and glacier.

The district embraces two iron properties, one, half a mile southwest of Deep Lake, the other, three-fourths of a mile northeast. Both are accessible by wagon road from either Northport or Boundary, towns situated on the Great Northern Railway.

Bechtol Property

Location. This property is located in section 27, T. 39 N., R. 41 E., about twelve miles south of Boundary, at an elevation of 2,850 feet. The property consists of one claim, the Idler, which is owned by David Bechtol of Leadpoint.

Description of rocks. The rocks in the vicinity of the claim are limestone, argillite, and granite. The limestone is the country rock in which the iron occurs. It is fine grained, light to bluish gray in color, and belongs to the metamorphic series, which has been intensely folded, crumpled, and fractured in this region. In the locality of the deposit, the beds dip steeply. Although no igneous rocks were observed near the deposit, granite occurs a short distance to the southwest. This granite is a portion of that which invaded the old sedimentary formations, and was probably instrumental in inducing certain phases of metamorphism and mineralization within the region.

Mining development. The development work on the property consists of two tunnels and two or three open cuts. At each of these workings some ore has been mined, the amount varying from 30 to 100 tons. In some instances boulders of solid limonite weighing half a ton or more have been broken out. For the most part, however, the ore has not been separated from the country rock.

Ore deposit. The ore body, which consists of porous brown limonite, belongs to the vein type, and occurs between wall rocks of dolomitic limestone. It dips at an angle of 80 degrees, south 30 degrees west, while its direction of strike is north 60 degrees west. The width of the vein is far from uniform. Measurements taken at intervals along the outcrop and at cross-cuts showed it to be six, eight, and twenty-five feet wide, respectively, with a maximum width of fifty feet. The outcrop was followed up the slope of the hill for a thousand feet.

Possible origin of the iron ore. The limonite is in all probability a surface leached product, which may change in character at depth and grade either into sulphides or siderite and limestone. Some sulphide weath-

ering appears on one or two of the dumps and sulphides were found in the back of one of the tunnels, but it is not known whether or not they are related to the origin of the ore.

Although limonite frequently occurs as *gossan*, a product resulting from the weathering of sulphide veins, it appears more likely in this case that it has been formed through the weathering of siderite. This carbonate is an important rock forming mineral, and is commonly associated with the carbonates of calcium and magnesium, the two principal constituents of the limestone wall rocks. Iron bicarbonate, which is a soluble compound formed in solutions where an excess of carbon dioxide is present, has the capacity of replacing lime carbonate.

Through such a process limestone may be eventually changed into siderite, which in turn breaks down through a simple oxidation and hydration process into the more stable compound, limonite. This latter transformation is accompanied by a contraction in volume of approximately 27 per cent¹, which would account for the marked porosity of the ore.

Moreover, the Bechtol deposit is similar in mineral content and occurrence (with exception of the few sulphides noted) to the deposit on the Thompson property just northeast of Deep Lake, where with better exposures the conclusion was reached that the limonite is a product of oxidation and hydration of veins of iron carbonate.

Economic aspect. The ore of this property is somewhat similar to that of the Ernest Thompson property. The ore on the dumps amounted to approximately 300 tons. Judging from the extent and character of the ore body, there is probably as much as twenty thousand tons of ore in the deposit, although it is possible that several times that amount may be present.

¹F. W. Clarke: Data of Geochemistry, U. S. Geol. Survey, Bull. 695, (1920), p. 574.

Thompson Property

Location. This property is located in section 23, T. 39 N., R. 41 E., at an elevation of 3,075 feet. It is situated on the west slope of the mountain three-fourths of a mile northeast of Deep Lake. A trail from near the upper end of the lake leads to the property. The nearest railroad point is Boundary, a station on the Great

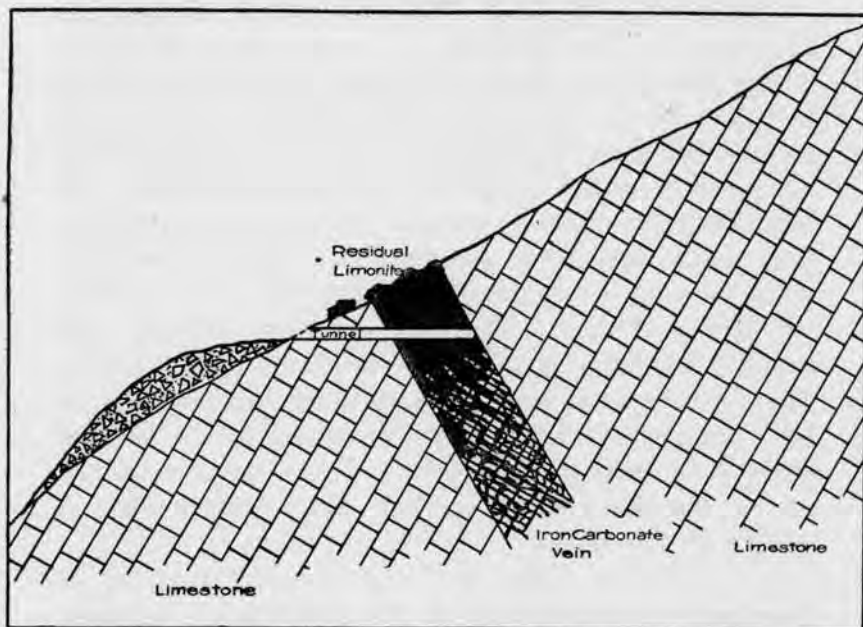


FIG. 5.—Hypothetical section of the Thompson property, near Deep Lake, Stevens County, showing the relation of the vein to the country rock and the gradation of the residual limonite body to iron carbonate beneath it.

Northern Railway, twelve miles north of Deep Lake. There are four claims—Iron Slope, Iron Tunnel, Iron State, and Iron Farm—all owned by Ernest Thompson of Leadpoint.

Description of rocks. The only rock in the immediate vicinity of the deposit is a dolomitic limestone. This belongs to the old metamorphics, and like all members of this series, has been intensely folded and fractured.

It is moderately fine-grained and varies from white to blue or blue mottled in color. The beds dip to the west at an angle of about 60 degrees, and are cut by numerous veinlets of calcite and stringers of limonite. The intrusive granite, which has been described above, is exposed a short distance south of the deposit and is the only igneous rock that was observed.

Mining development. While no active mining has been done on the property, a considerable amount of energy has been expended in doing prospecting and explorative work. Twenty or more pits have been opened at intervals along the outcrop of the vein in such a manner as to cross-cut it and thus determine its width. In most instances these operations involved no more effort than that necessary to remove the overburden and uncover the vein. Only small quantities of ore were thrown out of any of them. The most extensive workings are situated near the north end of the Iron Tunnel Claim. There a tunnel has been driven into the hill for 85 or 90 feet, from which drifts were developed and a shallow shaft sunk into the ore body. From these workings several hundred tons of ore have been broken out, and now lie on the dump.

Ore deposits. The iron ore on the property is practically all porous brown limonite, though *goethite* ($\text{Fe}_2\text{O}_3 \cdot \text{H}_2\text{O}$) is also common. A little pulverulent red hematite, or probably the mineral *turgite* ($2\text{Fe}_2\text{O}_3 \cdot \text{H}_2\text{O}$), was noted at a few points, but it is rare. The ore body is a vein deposit, and occurs between wall rocks of dolomitic limestone, which dip to the west at an angle of 60 degrees. The limonite vein cuts across the bedding planes of the limestone, and dips toward the east. An observation taken inside the tunnel showed the strike of the vein to be approximately north and south, and the angle of dip to be 38 degrees. This angle appeared to be considerably greater at several other points. The total length

of the main vein is about 1,800 feet. From an outcrop near the center of the Iron Tunnel Claim, to a point 800 feet north, the vein is continuous and averages about 30 feet in width. There it pinches out, but reappears again on the face of a prominent cliff 500 feet to the north, where the exposure is 15 feet wide. From the cliff the vein is fairly continuous for 1,000 feet farther north, and averages 10 feet in width. Near the site where the tunnel has been opened, a spur branches off from the main lead in a northeasterly direction. It attains a maximum width of 20 feet, but extends for only a short distance. On the Iron Slope Claim there are several narrow veins, which average in width only two or three feet.

Possible origin of the iron ore. The ore occurs in a similar way to that on the Bechtol property about a mile and a half southwest, and was probably concentrated in the same way. The ore is largely a porous brown limonite, with many of the pores and cavities lined with a shiny black stalactitic variety of the same mineral, or coated with white calcium carbonate. Goethite is prominent locally, and may be fairly extensive. The wall rocks have been badly shattered, and the fracture lines are now occupied by the veins of limonite. It seems highly probable that the veins represent the courses pursued by mineralized solutions, which followed the natural laws governing chemical deposition and replacement. The source of the solutions is a matter of speculation, but it does not seem unlikely that they may have originated directly or indirectly from the granite intrusion, which is exposed a short distance south of the deposit. The owner states that assays made of the ore showed it to carry 9 ounces of silver and traces of zinc and lead. No sulphides were observed, however.

From its texture the limonite appears to be a surface leached product, and evidence of its original character was found where the vein is exposed on the cliff.

An upper zone of limonite 15 or 20 feet in depth graded below into siderite and limestone. Siderite (iron carbonate) is an important rock-forming mineral, and is commonly associated with dolomitic limestones because of the isomorphous relationship of the carbonates of iron, calcium, and magnesium, which makes any degree of mixture of the three possible in the same crystal. In consequence of this similarity, if dolomitic limestones, such as those which form the wall rocks, are invaded for a sufficient length of time by carbonated iron solutions, they may eventually be changed to iron carbonate, which, when subjected to surface oxidation, is converted into the more stable compound, limonite. This latter transformation is accompanied by a contraction in volume of approximately 27 per cent, which would account for the porous texture of the ore.

The sample of ore analyzed by Prof. R. P. Cope was collected at the tunnel, but is probably considerably above the average of mine run ore. The high metallic iron content shown in the analysis is due to a large amount of goethite having been present with the limonite.

Economic aspect. The analysis of a specimen of an especially good grade of the ore shows it to contain nearly 60 per cent metallic iron, 0.048 per cent phosphorus, and 0.006 per cent sulphur. In places, it will probably show higher percentages of sulphur than this specimen indicates. The fact that the ore occurs with limestone is rather in favor of its usability. There is doubtless a total of at least 50 thousand tons of ore exposed in all the properties, although there is a possibility of several times that amount being present underground. The writers are of the opinion, however, that, owing to the character of the deposit, the ore will not be found at a very great depth from the surface.

THE ORIENT DISTRICT

Napoleon Mine.

Location. The Napoleon mine is located in the north-west quarter of section 3, T. 37 N., R. 37 E., at an elevation of about 2,500 feet. The nearest railroad point is Boyds, a station on the Great Northern Railway, about $1\frac{1}{2}$ miles distant. A wagon road has been built to the property from the main highway along the Kettle river.

Description of rocks. The rocks exposed in the vicinity of the mine are argillite and amphibolite, which have been intruded by monzonite porphyry. The argillite has been correlated by Charles E. Weaver¹ with the Stevens series and is designated by him as being of Paleozoic age. The amphibolite occupies a belt several hundred feet wide and is the ore-bearing phase. The monzonite porphyry occurs as dikes, and is thought to have been instrumental in causing the mineralization.

Mining development. The mine workings consist principally of three main tunnels and a large glory hole or quarry, all of which are said to be connected one with another by means of stopes and raises. An aerial tramway, now dismantled, was used to transport the ore to the railroad siding near the river.

Ore body and possible origin of the ore. The ore minerals are pyrite, pyrrhotite, and magnetite, together with small quantities of chalcopyrite, with which are associated irregular patches of garnet. In the upper zones limonite occurs, as an oxidation product. Howland Bancroft², who made a rather complete survey of the property in 1910 when operations were in progress, describes the ore body and its possible origin as follows: "The general trend of the ore body, like that of the main mass

¹The Mineral Resources of Stevens County, Wash. Geol. Survey, Bull. 20, (1920).

²The ore deposits of northeastern Washington, U. S. Geol. Survey, Bull. 550, (1914), p. 91.

of amphibolite, is east and west. As developed by underground workings, the mineralized zone is approximately 60 feet wide and 300 feet long. The vertical distance from the top of the glory hole to the main level is 250 feet, but the extent of the ore body below this level has not yet been definitely determined. . . . A large part of the ore body above level No. 1 has already been stoped out.

"The run of mine ore is said to contain approximately 33 per cent iron, 12 per cent sulphur, 10 per cent lime, 30 per cent silica, 0.3 per cent copper, a trace of silver, and from 0.05 to 0.10 ounce of gold to the ton.

"The intimate association of the ores with amphibolite and especially the presence of garnet in the ores point to contact metamorphic action, and it is thought that the ore may have been deposited by solutions accompanying or following the intrusion of the monzonite porphyry."

Economic aspect. The ore of this property is largely an iron sulphide and can hardly be considered an iron ore for use in making iron and steel. In the past it has been used as a flux in the smelter at Greenwood, B. C.

ANALYSES OF IRON ORES FROM STEVENS COUNTY

- A, E. Analyses by S. Shedd; Iron Ores of Washington, Wash. Geol. Survey, Ann. Rept., vol. 1, (1901).

CLUGSTON CREEK DISTRICT

- A₁, A₂. Iron ore from I. X. L. mine, Sec. 11, T. 39 N., R. 37 E., Colville.

VALLEY DISTRICT

- B₁, B₂. Iron ore from Silver King mine, Valley.
C. Iron ore from Vigilant mine, Valley.
D. Iron ore from Capitol mine, Valley.
E. Iron ore from Mineral Point.
F₁, F₂. Iron ore from Capitol mines, Valley. Collected by S. B. Coon, reported by W. H. Whittier; An Investigation of the Iron Resources of the Northwest, Bureau Industrial Research, Bull. 2, U. of W., (1917).

- G. Specimen of hematite and limonite from Kulzer property, Capitol mine, Sec. 20, T. 31 N., R. 41 E. H. H. Cooper, collector. Analysis by Prof. R. P. Cope, State College of Washington, (1922).
- H. Specimen of hematite from Hill property, west of Valley, Sec. 17, T. 3 N., R. 39 E. H. H. Cooper, collector. R. P. Cope, analyst, (1922).

DEER TRAIL DISTRICT

- I. Specimen of magnetite from Read property, near Hunters, Sec. 14, T. 30 N., R. 37 E. H. H. Cooper, collector. R. P. Cope, analyst, (1922).

DEEP LAKE DISTRICT

- J. Specimen of limonite and goethite from Ernest Thompson property, Sec. 23, T. 39 N., R. 41 E. Jenkins and Cooper, collectors. R. P. Cope, analyst, (1922).

	A ₁	A ₂	B ₁	B ₂	C	D	E
Iron (Fe).....	56.58	50.48	67.56	68.10	59.19	58.53	50.05
Silica (SiO ₂).....	4.49	14.90	1.06	1.12	5.80	3.54	10.12
Alumina (Al ₂ O ₃).....	2.00	2.48	.....	.....	1.85	3.18	17.23
Manganese (Mn).....	.....	.....	.....	.....	.....	.....	.....
Phosphorus (P).....	0.31	0.30	.....	.....	0.36	0.51	0.20
Sulphur (S).....	0.32	0.32	0.38	0.25	0.33	0.21	0.42
Titanium dioxide (TiO ₂).....	.....	.....	.....	.....	.....	.....	.....

	F ₁	F ₂	G	H	I	J
Iron (Fe).....	41.70	51.50	53.53	68.57	60.40	59.99
Silica (SiO ₂).....	10.30	10.80	8.45	1.69	3.23	2.33
Alumina (Al ₂ O ₃).....	.....	.....	.....	.....	.....	.....
Manganese (Mn).....	0.37	0.19	.....	.....	.....	.....
Phosphorus (P).....	0.117	0.116	0.14	0.024	0.07	0.048
Sulphur (S).....	Tr.	Tr.	0.004	0.006	0.048	0.023
Titanium dioxide (TiO ₂).....	0.25	0.30	.....	.....	Tr.	.....

FERRY COUNTY

THE BELCHER MINING DISTRICT

Introduction

The Belcher mining district lies some 20 miles north of the center of Ferry County. There are no towns within the boundaries of the district, so either Curlew or Republic is depended upon as a base of supplies. The iron properties within the district are situated on Belcher and Cooke mountains at an elevation of about

4,650 feet and approximately 10 miles northeast of Republic. The Great Northern Railway passes within 5 miles of the properties, but the nearest distance to it by wagon road is 7 or 8 miles.

Copper Key Mine

The country rock in the vicinity of the Copper Key mine, which is located on the west slope, and near the summit of Belcher Mountain, consists of limestone, dolomite, calcareous shales, and slates, which dip at an angle of 15 to 30 degrees to the southwest. This sedimentary series has been intruded in a number of places by a monzonite porphyry which has been instrumental in causing more or less contact metamorphism in contiguous strata.

Howland Bancroft¹, who spent some time on the property in July, 1910, describes the ore body and its occurrence as follows: "As exposed by the workings on the Copper Key, the ore bodies represent an irregular replacement of limestone or dolomite by pyrite, pyrrhotite, and magnetite with some chalcopyrite. They follow the general trend of the strata which they replace, and locally they lie directly above or beneath the intrusive porphyry. . . . As a large quantity of magnetite is present in the ore body, and as in places it is remarkably free from pyrite and pyrrhotite, it may possibly be of economic importance.

"The general relations existing in this mine point to the conclusion that one or more intrusive sheets of monzonite porphyry have invaded the sedimentary rocks in a direction approximately parallel to their bedding planes—that is, striking northwest and dipping 15 to 30 degrees, or perhaps more, to the southwest. On each side of the intrusive body the strata have been replaced to a greater or lesser extent by ore-bearing solutions that

¹Op Cit. p. 174.

accompanied or followed the intrusion. The replacement was irregular, being much more pronounced in the limestone or dolomite than in the other sediments."

Oversight Mine

About half a mile south of the Copper Key mine on the southeast side of Cooke Mountain lies the Oversight group of claims. The ore occurs as a replacement deposit in dolomitic limestone, under conditions very similar to those described under the Copper Key. The replacement minerals developed, that constitute the ore body, are chiefly pyrite, pyrrhotite, and magnetite, with a smaller amount of chalcopyrite. The ores carry low values in gold.

Belcher Mine

The Belcher mine is located about a mile north north-east of the Copper Key, near the top of the northern part of Belcher Mountain. The rocks exposed are a continuation of those which occur near the Copper Key and Oversight properties, though the crystalline limestones and dolomites are more in evidence. Monzonite porphyry is likewise present in the form of intrusive dikes which measure from a few feet to several hundred feet in thickness. Howland Bancroft¹ discusses the nature of the ore body and the possible origin of the ores as follows: "The Belcher deposits have many characteristics in common with those of the Copper Key, both representing irregular replacements in limestone and dolomite. The sulphide ore in the Belcher mine is chiefly pyrite, and magnetite is not so prominent as in the Copper Key. Associated with the ores are garnet, epidote, and tremolite, of contact-metamorphic origin. The outcrops of the deposits are very similar, being composed mainly of limonite. On the No. 2 level a drift follows an ore body for about 75 feet—40 feet through solid ore and 35 feet through more or less replaced country rock. The replaced

¹Op. Cit. p. 178.

stratum has been shown to be at least 20 feet thick and may be thicker. On the No. 3 level ore is exposed beyond a small winze on the north. It is more or less irregular except near the place where the incline has been sunk below No. 3 level. This incline is reported to be in ore, some of which is said to contain 4 per cent of copper. As the incline was full of water when visited, it was inaccessible. Not enough work has been done on this ore body to determine its size. In fact, the developments show in only a very poor way the relation of the ore deposits to the rocks on each side. To judge from the exposures and outcrop on the surface, the deposit should be from 5 to 20 feet thick and should extend downward along the dip plane for some distance. The length along the strike has not been determined.

“Here, as in the Oversight and Copper Key properties, the deposition of the ores is thought to have accompanied or followed the intrusion of the monzonite porphyry, and the ores are clearly of contact-metamorphic origin. The formation of large quantities of pyrite, with pyrrhotite in minor quantities, is indicative of an abundance of sulphur, so that the iron present could combine with sulphur to form FeS_2 , rather than $\text{Fe}_n\text{S}_{n+1}$, as in the Oversight and Copper Key deposits. The absence of a high percentage of magnetite in the Belcher area substantiates this view when it is considered that magnetite forms a large part of the ore bodies in the Oversight and Copper Key, where pyrite is about equally prominent and pyrrhotite forms a considerable part of the ore.”

Economic aspect. Most of the deposits of this district contain large quantities of sulphides. Some of the ore bodies of the Copper Key mine, according to Bancroft (previously quoted), may prove to be of economic value, because of their freedom from sulphides.

ANALYSES OF IRON ORE FROM BELCHER DISTRICT,
FERRY COUNTY

- A, B. Analyses of samples of iron ore. Howland Bancroft; The Ore Deposits of Northeastern Washington, U. S. Geol. Survey, Bull. 550, (1914).
- A. Analysis of iron ore from Wander claim, Oversight group. J. G. Fairchild, analyst.
- B. Analysis of iron ore from Copper Key mine. J. G. Fairchild, analyst.

	A	B
Iron (Fe).....	26.97	63.21
Silica (SiO ₂).....		0.64
Lime (CaO).....	14.71	8.78
Magnesia (MgO).....	12.91	1.10
Phosphorus pentoxide (P ₂ O ₅).....	0.164	0.164
Sulphur (S).....	8.90	0.08
Arsenic (As).....	None	None

OKANOGAN COUNTY
THE MYERS CREEK DISTRICT

Introduction

The Myers Creek district is situated in the north-eastern part of Okanogan County. It is divided by Myers Creek, the central drainage line of the area, into two dissimilar topographic divisions. The western part is a moderately low rolling country with comparatively broad open valleys; while that to the east is much higher and more broken, with some deep ravines and gorges. Buckhorn Mountain, in the eastern division, rises nearly 3,000 feet above the level of the valley and attains an elevation at its summit of 5,580 feet. The two iron properties located within the district are both situated on the slope of Buckhorn Mountain. The nearest railroad point is on the Great Northern Railway at Chesaw Spur, near Myncaster, B. C.

Neutral-Aztec Property

Location. This property is located on the north slope of Buckhorn Mountain, in sections 13 and 24, T. 40 N., R. 30 E., at an elevation of 4,800 feet. In an air line it is three miles east northeast of the town of Chesaw,

though five miles by wagon road. The distance to Chesaw Spur, the nearest railroad point, is five miles. The iron property comprises two claims, the Neutral and the Aztec, which are owned by James S. Grant and William Fahsbender of Chesaw.

Description of rocks. The rocks exposed at the surface are quartz-bearing hornblende syenite, and the contact metamorphics locally known as "garnet rock" and "epidote rock." Limestone and calcareous shales are exposed farther west.

The quartz-bearing hornblende syenite is exposed over an area of about four square miles on the north, northeast and east sides of Buckhorn Mountain. This rock occurs in the form of an irregular shaped batholith, which is intrusive in the older metamorphic series. Umpleby¹ has correlated it provisionally with the Mesozoic intrusion. It is a bluish gray medium-grained rock composed principally of feldspar and hornblende with occasional grains of quartz.

"Epidote rock" and "garnet rock" are local terms applied to the metamorphic rocks occurring in the contact zone. The name applied depends upon whether epidote or garnet is the preponderant rock-forming mineral. These alteration products are generally fine grained, and in most cases effervesce freely in dilute hydrochloric acid due to the matrix of calcite in which the crystals and crystalline grains of epidote and garnet are embedded. Actinolite is also present, occurring in long dark-green prismatic crystals, together with more or less of the lighter colored tremolite. Other minerals which have been identified that occur associated with those mentioned above, other than metallic minerals, are diopside, quartz, and titanite.

¹Joseph B. Umpleby; *Geology and Ore Deposits of the Myers Creek Mining District*, Wash. Geol. Survey, Bull. 5, (1911), p. 23.

Mining development. Three tunnels have been opened on the property about the deposit on the Neutral claim, but they were largely for exploration of copper values, and are of only incidental interest with respect to the iron. The magnetite ore body has been worked principally by means of open cut mines, since the ore lies at the surface with only a thin overburden to be stripped off. During the war period and in the two years immediately following, 8,000 tons of ore are said to have been taken from these open cuts and shipped to the Northwest Magnesite Co. at Chewelah.

A number of years ago the property was prospected by the British Columbia Copper Mining Co. It was their intention to use the magnetite as a flux, and to recover sufficient precious metal to pay mining and transportation costs. Assays made, however, showed the ore to carry values of only 80 and 85 cents in gold, so the project was abandoned.

No active iron mining has been done on the Aztec claim. The property has a tunnel 80 feet long which is largely in magnetite, with pyrite and chalcopyrite intermixed. Two diamond drill holes have been sunk. One, sunk near the top of Buckhorn Mountain to a depth of 112 feet, showed traces of gold, 0.7 to 0.9 ounces of silver, and 0.2 to 4.3 per cent of copper.

Ore deposit. The ore bodies on the property are irregularly shaped lenticular masses of magnetite which are enclosed in the zone of metamorphic rocks that lie along the plane of contact in those localities where limestones or calcareous shales have been invaded by the hornblende syenite. The largest body observed occurs on the Neutral claim, and measures 400 feet long by 50 to 100 feet wide. The difference in surface elevation between points at either end of the deposit is more than 200 feet. Associated with the magnetite is pyrite, together with a little pyrrhotite and chalcopyrite. Smaller

outcrops occur along the trail farther west, and similar bodies with indefinite outline and unknown extent have been prospected along the contact metamorphic zone in a number of places in sections 13, 24, and 35, T. 40 N., R. 30 E.

Possible origin of iron ore. The genesis of the magnetite is pretty clearly defined. Its occurrence within the metamorphosed limestone along the contact with the intrusive hornblende syenite and its association with minerals that are peculiar to contact metamorphic deposits both indicate that it belongs to this type. Moreover, the irregular shape of the lenses and bunches of the ore are themselves characteristic. The minerals that occur are those which are typical of such deposits according to the best authorities. Those noted, and arranged in quantitative importance as nearly as observations permit, are garnet, epidote, actinolite, tremolite, diopside, and titanite.

It is a well known fact that when a magma migrates to the upper crust of the earth, and cools there, it always produces a greater or lesser change in the rocks with which it comes in contact. The character and intensity of the alteration depends, however, on the composition of the magma, its size, the depth from which it has migrated, and the nature of the rocks that are invaded.

It is obvious that an acidic (siliceous) magma will behave differently from one of basic character, and that a large igneous mass is more likely to produce more extensive metamorphic reactions than a small one. The depth from which a magma has migrated is important from the standpoint that the incident relief of pressure due to the decreased amount of overburden will result in a release of large amounts of vapors (mineralizers) and magmatic waters that in escaping pass into adjacent and overlying rocks. Where these enclosing rocks are

limestones or calcareous shales conditions are ideal for geochemical reactions to take place. The excessive heat of the magma dispels the carbon dioxide in a large measure, while the residuary lime, magnesia, etc., act as fluxes which unite with the liquid silicate minerals given off by the intrusive. In this manner magnetite may be separated from the iron-bearing silicates introduced into the limestones. It is altogether natural that where such reactions ensue, there will be no regularity in size or occurrence of the ore bodies formed. It is worthy of consideration by the prospector, however, that such deposits occur only in those zones where the contact rocks consist largely of lime or magnesia, and need not be sought in those localities where quartzites or other siliceous rocks predominate.

Economic aspect. An analysis of a specimen of ore from this property shows it to contain 70 per cent metallic iron, 0.02 per cent phosphorus pentoxide (or 0.009 per cent P), and 0.21 per cent sulphur. In various places in this deposit, sulphides are present which would, no doubt, raise the sulphur content of the ore considerably. The ore body was estimated to contain, in all probability, about 375 thousand tons. After further development work is accomplished, however, a much greater amount may be disclosed, although the type is characteristically irregular.

MacLean Property

Location. This property is located on the east slope of Buckhorn Mountain, in sections 24 and 25, T. 40 N., R. 30 E., at an elevation of about 4,700 feet. In a direct line it lies only four miles east of Chesaw, but by wagon road it is 5½ miles farther. The nearest railroad point is at Chesaw Spur, a station on the Great Northern Railway, near Myncaster, B. C., which is 14 miles distant. The property consists of ten claims that are collectively

known as the Roosevelt Group. All are owned by J. A. MacLean of Spokane.

Description of rocks. The rocks appearing at the surface are essentially of the same character as those occurring on the Neutral-Aztec property, which have been described above. They consist of metamorphosed limestones, calcareous shales and the intrusive quartz-bearing hornblende syenite, together with the contact metamorphic products locally known as "garnet rock" and "epidote rock."

Mining development. The principal workings on the property consist of a few surface openings and a tunnel 800 feet long, from which stopes and cross cuts have been developed. A considerable amount of mining equipment has been erected at the tunnel to facilitate operations. The mine has been worked in the past principally for its copper value, though the ore carries some gold and silver. During the years 1919 and 1920 the Northwest Magnesite Co. at Chewelah furnished a market for magnetite ore, and to supply this demand the mine was operated for a few months for the purpose of extracting bodies of magnetite which had previously been discovered in the mine. It is said that some 2,000 tons of the magnetite ore were hauled to the railroad at Chesaw Spur, and from there shipped to Chewelah. At the time the property was visited, however, operations were suspended.

Ore body. The ore minerals consist of magnetite, chalcopyrite, and pyrite, which carry varying amounts of gold and silver. The nature of the occurrence of the ore has been described by Joseph B. Umpleby¹ as follows: "The ore bodies are irregular replacement deposits in limestone and beds of calcareous shale, and

¹Geology and Ore Deposits of the Myers Creek Mining District, Wash. Geol. Survey, Bull. 5, (1911), p. 45.

although development is not sufficiently advanced to determine the extent or peculiarities of the various bodies, yet it is quite certain that future work will encounter irregularities characteristic of such deposits. Past work has met variations similar to those which will be encountered in the future."

Possible origin of the iron ores. The iron ore occurs in metamorphosed limestone near the contact of that rock with the intrusive hornblende syenite. In the mineralized zone with the ore are associated garnet, epidote, tremolite, calcite, chalcopyrite, pyrite, and quartz. Since these same general conditions have been shown to exist on the Neutral-Aztec claims one mile farther north, it appears that the iron ores on the two properties are genetically identical, and in both cases represent a product of contact metamorphism induced by the intrusion of the quartz-bearing hornblende syenite into the older limestones and calcareous shales.

Economic aspect. The ore apparently occurs rather irregularly in this deposit. Its quality was not determined through analysis, but it is probably somewhat similar to that of the Neutral-Aztec. Since there were no good exposures at the surface, and the underground workings were not accessible at the time the investigation was made, the quantity of the ore in the deposit is indeterminate.

THE SQUAW CREEK DISTRICT

Introduction

The Squaw Creek district occupies an area of about 75 square miles in the extreme southern part of Okanogan County. Pateros, the only town within its boundaries, is situated in the northeastern part near the junction of the Methow River with the Columbia River, and is accessible from Wenatchee over the Great Northern Railway.

Fuller Property

This property is located about one mile in a direct line north by west from Pateros in the east half of section 26, T. 30 N., R. 23 E., at an elevation of 2,300 feet. It consists of one claim, the Lone Pine, which is owned by A. D. Fuller of Pateros.

The country rock exposed on the property is a gray, medium grained, syenitic gneiss, which is composed of orthoclase, plagioclase, biotite, hornblende, prismatic crystals of epidote and numerous grains of magnetite.

No active mining has ever been attempted on the property. The principal development work consists of a prospect tunnel that has been driven 95 feet into the mineralized ledge. A small quantity of ore lies on the dump.

The ore mineral is magnetite, which is intimately intermixed with large amounts of hornblende and actinolite. The ore, thus composed, is coarse grained and has a more or less schistose appearance. It occurs in seams and thin lenses in a ledge composed of hornblende, biotite, and actinolite. In places the magnetite is the preponderating mineral, but it never occurs free from the hornblende and actinolite. The ledge varies from a few feet to 15 feet in thickness, and is exposed along its direction of strike for four or five hundred feet. It is situated between wall rocks of syenitic gneiss, and dips at an angle of 65 degrees north 70 degrees east.

The same minerals that constitute the ledge matter are abundant in the gneiss, and there is in general a gradation of the one into the other. In view of these relations it appears that the magnetite, along with the hornblende and actinolite, was originally concentrated through magmatic segregation, and later modified to its present form by regional metamorphism.

Economic aspect. The analysis of a specimen shows it to be a titaniferous iron ore, containing about 57 per

cent metallic iron, 0.05 per cent phosphorus pentoxide, 0.097 per cent sulphur, and 3.25 per cent titanium dioxide. An average sample of the deposit, however, would not show as high a grade in iron as this analysis would indicate, for the ore is irregularly intermixed with rock. It is impossible to state the probable depth of this deposit. It is quite possible that it may contain 20 thousand tons of ore mixed with rock.

ANALYSES OF IRON ORE FROM OKANOGAN COUNTY

MYERS CREEK DISTRICT

A₁-A₁₀. Analyses of average weekly samples of iron ores from Neutral mines from July 25, 1920, to October 31, 1920, by Northwest Magnesite Company.

	A ₁	A ₂	A ₃	A ₄	A ₅
Iron Sesquioxide (Fe ₂ O ₃) and Alumina (Al ₂ O ₃).....	84.74	83.80	85.30	87.54	88.28
Silica (SiO ₂).....	9.42	9.80	9.62	8.80	8.00
Lime (CaO).....	6.36	6.40	5.46	4.86	5.00

	A ₆	A ₇	A ₈	A ₉	A ₁₀
Iron Sesquioxide (Fe ₂ O ₃) and Alumina (Al ₂ O ₃).....	90.36	85.76	86.90	84.16	85.50
Silica (SiO ₂).....	7.56	8.50	7.46	8.50	8.64
Lime (CaO).....	4.88	6.18	3.82	6.04	5.24

B. Analysis of a specimen of magnetite from the Neutral property, Sec. 13, T. 40 N., R. 30 E. H. H. Cooper, collector. R. P. Cope, analyst, (1922).

SQUAW CREEK DISTRICT

C. Analysis of specimen from Fuller property, Sec. 26, T. 30 N., R. 23 E., near Pateros. H. H. Cooper, collector. R. P. Cope, analyst, (1922).

	B	C
Metallic iron (Fe).....	70.17	57.02
Silica (SiO ₂).....	1.50	4.51
Phosphorus pentoxide (P ₂ O ₅).....	0.02	0.05
Sulphur (S).....	0.21	0.097
Titanium dioxide (TiO ₂).....	.....	3.25

CHELAN COUNTY

THE BLEWETT MINING DISTRICT

Introduction

The Blewett, or Peshastin, mining district is situated in the rugged mountainous region of south central Chelan County, not far from the center of the state. Blewett, located on Peshastin Creek at an elevation of 2,328 feet, is the only town in the district. It may be reached over the Blewett Pass road from Cashmere, a town on the main transcontinental line of the Great Northern Railway, thirteen miles to the north. It is also accessible from Ellensburg or Cle Elum. The district embraces two iron properties.

Rothert Property

This property is located two miles south of Blewett, in the south half of section 13, T. 22 N., R. 17 E., just above the junction of Tronson with Peshastin Creek. The property consists of one claim, Magnetite No. 1, and is owned by E. H. Rothert of Seattle.

The principal rocks exposed on the property are granodiorite and peridotite, the latter now partially altered to serpentine.

The granodiorite has been correlated with Mt. Stuart granodiorite, which is of pre-Tertiary age, but is thought to be younger than the peridotite¹, with which it is intimately associated. It is a massive gray granitic appearing rock, composed of white plagioclase and orthoclase feldspar, biotite, and hornblende, together with scattered grains of quartz.

The peridotite, while a common rock in the district, varies in color, texture, and composition from place to place. On the Rothert property, it is a massive bluish black rock of dense compact texture, partially altered to serpentine, though originally composed principally of

¹Mount Stuart Folio, No. 166, (1904), U. S. Geol. Survey.

olivine and enstatite. Magnetite is an abundant constituent, and occurs either in grains disseminated through the rock or in small pockets and segregations.

Near the center of the claim a 50-foot tunnel has been opened into the peridotite. This has cut through patches of magnetite but no extensive bodies were disclosed. The ore on the dump has not been separated from the rock, and, other than samples, none has been removed.

The magnetite appears to be a result of the segregation of the more basic phases of the peridotite, although the differentiation is far from complete, and no large isolated masses of ore have been formed.

Economic aspect. The analyses of this ore show it to contain from 42 to nearly 50 per cent metallic iron, and from a trace to 0.024 per cent of phosphorus. The magnetite in the ore body, however, is scattered through the black rock of the deposit and is not concentrated into large bodies of commercial importance.

McCarthy Property

This property is located two miles south southwest of Blewett, in sections 14 and 15, T. 22 N., R. 17 E. Eight claims have been located, all of which are owned by J. W. McCarthy of Blewett.

The principal rock occurring at the surface is peridotite, which is cut by diabase dikes having a general north-east southwest trend. The peridotite is bright to dark green in color and has been extensively altered to serpentine.

Two or three tunnels have been opened on the property, but about all that has been disclosed in any of them is serpentine rock. Some iron ore has been thrown out of one or two shallow surface pits.

The iron ore occurs in connection with the peridotite and appears to consist of the more basic phases of that rock. The ore mineral is chiefly magnetite, which usually

occurs as conspicuous black shiny grains disseminated through the rock, though locally it may form the principal constituent. The best grade of ore occurs in a zone 8 to 10 feet wide and a hundred or so feet long, adjacent to one of the diabase dikes. It has the texture and general character of the other basic phases of the peridotite, but the iron minerals have been mostly oxidized to hematite. The analysis of this ore shows it to be only moderately high in iron and to contain a great deal of silica, though phosphorus and sulphur are low.

Economic aspect. The analysis of a picked specimen shows it to contain 48 per cent of iron and 0.024 per cent phosphorus. The ore deposit was not found to contain any large concentrated bodies of magnetite of commercial importance.

ANALYSES OF IRON ORE FROM CHELAN COUNTY

BLEWETT MINING DISTRICT

- A₁-A₃. Analyses of iron ore from Magnetite No. 1 claim, by Dr. E. H. Rothert, Rothert Process Steel Co., Seattle.
- B. Specimen of higher grade hematite with some magnetite, from McCarthy property, Sec. 14, T. 22 N., R. 17 E. H. H. Cooper, collector. R. P. Cope, analyst, (1922).

	A ₁	A ₂	A ₃	B
Iron (Fe).....	42.67	49.74	42.00	47.98
Silica (SiO ₂).....	18.54	9.57	12.00	10.81
Aluminum (Al).....	8.55	5.32		
Chromium (Cr).....	1.08			
Calcium (Ca).....	1.28			
Magnesium (Mg).....	8.66			
Manganese (Mn).....	1.29			
Phosphorus (P).....	0.023	Tr.	0.024	0.024
Sulphur (S).....	0.067	Tr.	0.07	0.069
Titanium (Ti).....	0.14	8.20		
Loss on ignition.....		1.28		

KITTITAS COUNTY

THE CLE ELUM DISTRICT

Introduction

The Cle Elum district is situated in the northwestern part of Kittitas County among eastwardly projecting spurs of the Cascade Mountains. The Cle Elum River, a tributary of the Yakima River, is the central drainage

line. A wagon road has been built up the river as far as Camp Creek, thus permitting access to the interior of the district from Ronald, Roslyn or Cle Elum.

Balfour Guthrie (Camp Creek) Property

Location. The ores occur principally along the river in the vicinity of Camp Creek and Boulder Creek, in sections 26, 34, and 35, T. 23 N., R. 14 E., and on the mountain ridges south of Boulder Creek in sections 1 and 2, T. 22 N., R. 14 E. The nearest railroad approach is at Lakeside, a station located on Cle Elum Lake, on the Roslyn branch of the Northern Pacific Railway, 16 miles distant. The claims, of which there are said to be about 40 in all, are known as the Balfour Guthrie Group.

Description of rocks. The geology of the district has been described¹ in considerable detail by George Otis Smith and Bailey Willis, and the following discussion is largely drawn from their work.

The oldest rocks appearing in the vicinity of the Cle Elum iron ore deposits are slates, limestones, cherts, quartz schist, volcanic breccias, and tuffs, which constitute a pre-Eocene complex. All of these rocks are more or less metamorphosed and extensively intruded by large masses of peridotite. The peridotite is a dark granular rock composed chiefly of olivine and enstatite which have been considerably altered to serpentine. This peridotite, or serpentine, as it is frequently called, is separated from the overlying Swauk sandstone (Eocene age) by an unconformity, along which the iron ores lie.

The rocks of Eocene age appearing in the district have been divided into three formations: First, the lower sandstone which is called the Swauk, referred to above; second, the Teanaway basalt; and third, the upper sandstone which is called the Roslyn. These rocks suffered more or less structural deformation during the late

¹The Clealum Iron Ores. Am. Inst. Min. Eng., Vol. 30, (1900), p. 359.

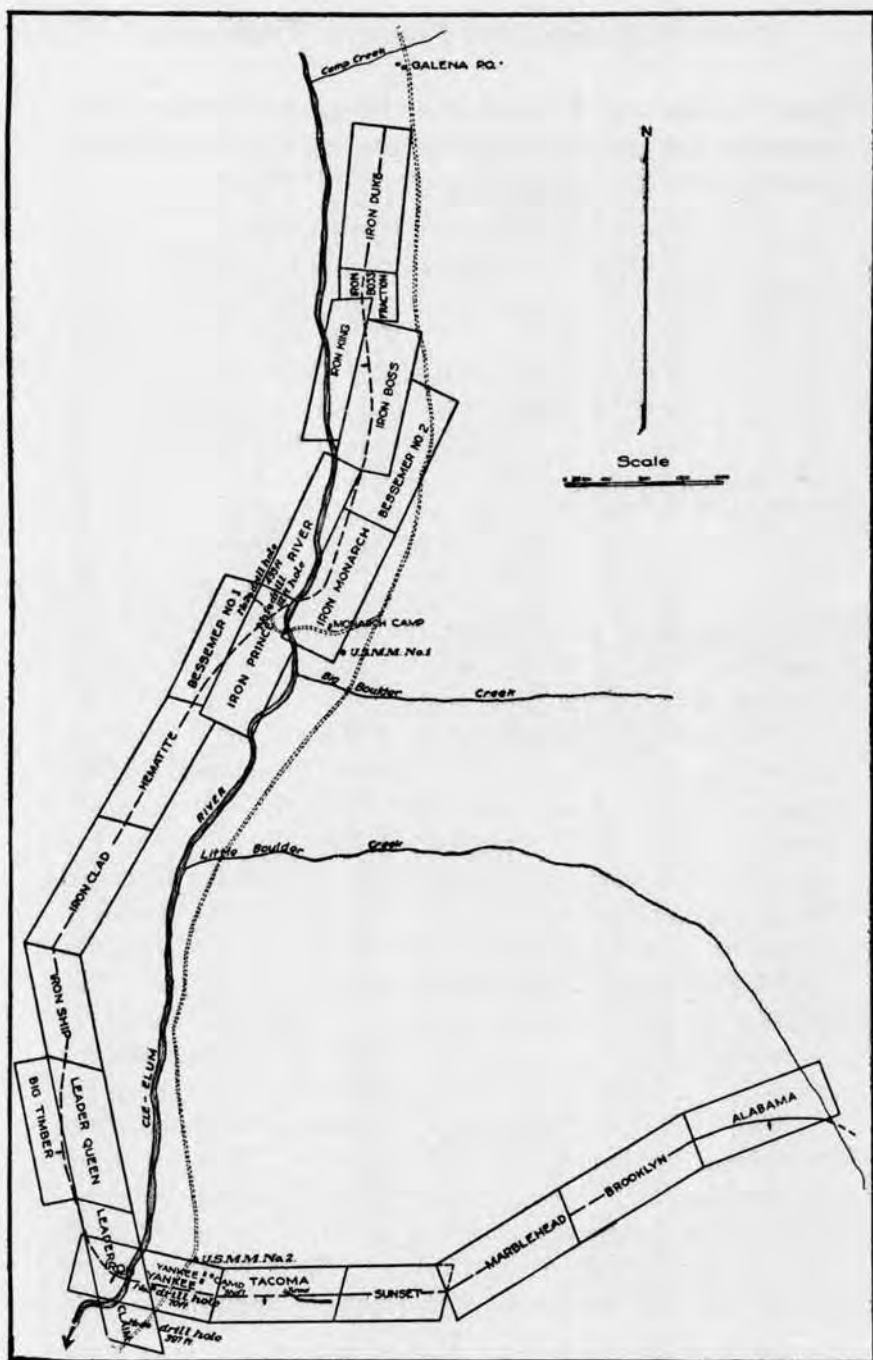


FIG. 7.—Map of the Cle Elum iron ore district, Kittitas County, showing the position of the claims which lie along the ore body on the contact between peridotite on the east side and sedimentary rocks (Swauk formation) on the west and south sides. (Map contributed by Robert Young.)

Eocene, or early Miocene, the disturbance being manifested in the vicinity of the ore deposits by an anticlinal fold.

Rocks of post-Eocene age are of both sedimentary and volcanic origin, though basaltic and andesitic extrusives predominate.

Mining development. The development work on the several claims constituting the Balfour Guthrie Group consists of a large number of openings, crosscuts, and tunnels along the outcrop, together with three or four diamond drill holes. It is said that the most vigorous operations were conducted during the period 1889 to 1892, when the building of an extensive plant at Kirkland, on the shore of Lake Washington, was being considered. Since then no especial activity has been shown.

Ore body. The Cle Elum ores have been a subject of many investigations and reports, both private and public. Dr. S. Shedd, who visited the property in 1899, describes¹ their general character in the following manner: "These ores may be separated into three classes as follows: Massive, laminated, and oolitic. The massive ore has a dull, greenish black color, and when powdered gives a brownish black streak. The laminated ore varies in appearance, in some cases being dark red, and in others having considerable of a metallic appearance, but in each case giving a deep red powder or streak when pulverized. The oolitic ore has a greenish black color and contains numerous oolites in an amorphous ground mass and when powdered gives a brownish black streak or powder.

"All of these ores are quite strongly magnetic and are apparently mixtures of hematite and magnetite. In some of the ore bodies all three classes of ore are found and in others only one class. The oolitic ore, so far as I could determine, is not found in the ore bodies farthest

¹Iron Ores of Washington. Wash. Geol. Survey, Vol. 1, Ann. Rept., (1901), p. 244.

up on the hill, high above the river, but is quite common in those down near the river and especially those near Camp Creek."

The ore bodies occur at the contact between the serpentine formation and Swauk sandstone and outcrop along the river, appearing as conspicuous lenticular ridges, which stand 10 or 15 feet higher than the level of the valley and vary from a few feet to 30 feet in width.

Beginning at a point near Camp Creek the outcrop extends for about a mile in a direction bearing south 20 degrees west along the east side of the Cle Elum River. Just above the mouth of Boulder Creek the contact line, along which iron ore outcrops at irregular intervals, crosses the river, parallels the stream a mile farther south, recrosses, and swings in an easterly direction across the high mountain spurs south of Boulder Creek.

The elevation of the valley where the iron occurs is 2,900 to 3,000 feet, while the more southern outcrops on the divides south of Boulder Creek occur at elevations from 3,500 to 5,000 feet.

The most complete paper¹ published on the Cle Elum ores is that by George Otis Smith and Bailey Willis, who spent considerable time studying the ores in 1899. Their discussion of the relation of the ores to the country rock is as follows: The ore bodies "have a definite geologic position in the rock series of the district, and their distribution is determined by the geologic structure. They lie on the surface of an extensive formation of serpentine, at and in the base of a sandstone, called the Swauk sandstone. The serpentine is older than the sandstone. It had been much eroded when the sandstone was deposited, and the sandstone, although composed chiefly of granitic sand, contains in its lower beds, near the serpentine, bits of decomposed serpentine and heavy minerals derived

¹Op. Cit.

from it. Laminated lenses of shale composed of serpentine wash and also conglomerates of serpentine boulders occur at the base of the sandstone. Thus the surface on which the iron ores occur was an eroded surface, which, with soil and other residual accumulations, was buried beneath granitic sands. The relations and character of the ore indicate that it was a sedimentary deposit on the serpentine, was covered by the sands, and later metamorphosed to its present condition."

Possible origin of the iron ore. "The iron concentrated in the hematite and magnetite of the ore may be of extraneous origin or derived from an adjacent rock. In the facts of its position and association there is no evidence to show that it is a deposit brought in from any more or less remote extraneous source. There is much, on the contrary, to connect it with the serpentine. In its field-relations the ore lies on the serpentine, contains serpentine waste, and grades into shale derived from serpentine.

THE ANALYSES OF THE ORE AND SERPENTINE

	Serpentine Per Cent	Ore Per Cent
SiO ₂	39.00	7.50
TiO ₂	Tr.	0.7
Al ₂ O ₃	1.75	21.9
Cr ₂ O ₃	0.47	2.2
Fe ₂ O ₃	5.16	37.1
FeO.....	1.71	21.3
MnO.....	0.15	Tr.
MgO.....	38.0	2.3
H ₂ O.....	13.74	6.8
K ₂ O plus Na ₂ O.....	0.10	undet.
P ₂ O ₅	Tr.	0.09
NiO.....	0.10	0.2
S.....	0.03	0.03
CO ₂	none	0.15

"The analyses of the ore and serpentine show that they both contain in addition to the usual rock-constituents, such occasional ones as chromium and nickel. Magnesia, an important constituent of serpentine, is also found in the ore. It is therefore reasonable to suppose

that the iron ore is a result of concentration from the serpentine. . . .

“The reactions begun in the alteration of the original peridotite into the serpentine were doubtless continued in the process of weathering, the magnesia being removed as carbonate, together with some of the iron, while silica may have been set free in the chalcedonic state. Such is the process as usually observed in the weathering of serpentine. It seems probable that the residue from the decomposed serpentine was composed principally of the hydrated oxides of aluminum and iron. . . .

“The original deposit of aluminous iron ore has been metamorphosed in consequence of deep burial, and of movements suffered in the deformation of the region. The plane of contact of the Swauk sandstone on the serpentine may have been the course of waters which oxidized or reduced the ores from their original state to their present condition. Diaspore, which occurs in the ore in small quantities, may have resulted from a partial dehydration of the bauxitic material present. Rutile and chromite are minerals also present in small quantities. Whether desilicification has continued during this second period is uncertain, but the presence of solutions containing free silica is indicated by the filling of minute cracks in the ore with what appears to be chalcedonic material. The ore and its relations have not been studied sufficiently to determine the nature of the metamorphism.”

Economic aspect. The ore of this deposit varies from low percentages in iron to over 68 per cent, averaging between 40 and 50 per cent for the whole body—not merely for specimens. It contains generally less than 0.05 per cent phosphorus and varies in content of sulphur from nothing to 0.17 per cent. Titanium is not generally

present, according to most of the analyses. Therefore the deposit contains a fairly good grade of iron ore. This deposit is undoubtedly the largest known iron ore body in the State. Judging from the extent of the outcrop of the ore body and the character of the deposit, it may be estimated to contain possibly as much as five million tons. Further development of adjacent properties may disclose additional bodies. It is a type of deposit which may extend to considerable depth.

Durrwachter (Liberty Lode) Property

This property is located on the west side of Mount Peo, at an elevation of 2,800 feet, overlooking, to the north, the valley about Cle Elum and the Cascade Mountains beyond. It may be reached by trail, one-fourth mile long, from Taylor's farm, and this, in turn, by a road from South Cle Elum—a distance of two miles to the station of the Chicago, Milwaukee & St. Paul railroad. The property consists of a group of six claims, placed in a double row, running east and west, largely in the southern half of section 10, and partly in section 9, T. 19 N., R. 15 E. The owners are two brothers, Charley and E. G. Durrwachter.

There are about ten openings on the property, but none of these disclose much evidence of the size or occurrence of the ore deposit. The rock present is a green to black glaucophane-garnet schist which is chiefly composed of needles and bladed crystals of the mineral glaucophane interspersed with an abundance of microscopic red garnets. In places the schist shows distinct magnetite and hematite phases or zones. Two of these, lying roughly parallel to each other, comprise the ore body.

The ore in general is only slightly magnetic and the iron mineral appears to be largely hematite, though even the higher grades contain a large amount of glaucophane and garnet. The following is a partial analysis of a

specimen collected on the Liberty claim by O. P. Jenkins and analyzed by R. P. Cope:

	Per Cent.
Iron (Fe) ¹	26.56
Silica (SiO ₂)	29.49
Phosphorus (P)	0.24
Sulphur (S)	0.09

These ferruginous phases are oxidized to a greater or lesser extent on the surface, forming rusty ledges. In places quartz stringers impregnate the schist. The upper, or that ledge which seems to be the principal part of the ore body, varies in width from an extremely narrow ledge to one several feet in thickness. It was followed for about 2,000 feet and is said to extend much farther. The iron-schist body dips at an angle from the horizontal, about 30 to 35 degrees. The bearing on the dip varies from due south to southwest, and is directed into the face of the hill.

The nature of the country rock and character of the iron-bearing phases furnish a striking analogy to the occurrence of the iron ores along the Skagit River opposite the town of Hamilton.

The glaucophane-garnet schist probably originated from some shaly sedimentary rock, which has undergone extreme metamorphism. The iron phase of the schist is probably part of the original sedimentary material, but it may have been introduced later by circulating solutions coming from some intrusive body.

The surrounding sedimentary and igneous formations (andesite-porphry and Manastash formation of Tertiary age), shown by Smith in the Mt. Stuart Folio², apparently have nothing to do with the occurrence or origin of this body of iron ore.

Economic aspect. The ore from this property is of low grade and is quite siliceous with a high percentage

¹Iron content of garnet not included in determination.

²U. S. G. S. Folio, No. 106, (1904).

of phosphorus. Unless a better grade of ore is found the deposit cannot be considered of any commercial importance.

ANALYSES OF IRON ORE FROM KITTITAS COUNTY

CAMP CREEK (CLE ELUM) DISTRICT

- A-C. From private report by R. H. Stretch, E. M.
- A. Average analysis of iron ore from Cle Elum, tested at Lanarkshire Steel Works, Motherwell, England.
 - B. Average analysis of eighteen sacks of iron ore collected at regular intervals across body. Analysis by Prof. C. F. Chandler and C. E. Pellen, Columbia College, New York.
 - C₁-C₃. Iron ores taken at various points along exposures. Dr. Edward Riley, London, England, analyst.
- D₁-D₁₁. Analyses of iron ore by Prof. James A. Dodge, Minneapolis, Minn.
- D₁. Magnetic Point claim.
 - D₂. Iron Chancellor claim.
 - D₃. Iron Boss claim.
 - D₄. Yankee claim.
 - D₅. Iron Monarch claim.
 - D₆. Roslyn claim.
 - D₇. Iron Duke claim.
 - D₈. Magnet claim.
 - D₉. Cle Elum Lake claim.
 - D₁₀. Stronghold claim.
 - D₁₁. Iron Yankee claim.
- E. Smith and Willis; The Clealum Iron-Ores, Wash., Trans., A. I. M. E., Vol. 20, p. 358, (1900).
- E₁, E₂. Samples taken by Dr. J. P. Kimball.
- E₃. Sample taken by Bailey Willis. Average of 350 square yards exposed, approximate analysis, except for Fe, P, and S.
- E₄. Monarch mine, average sample in pit bottom, taken by Curtis and Smith.
- F-J. From private report of Robert Young, M. E., Tacoma, Wash.
- F. Samples taken by G. J. Valentine, chief chemist, Moss Bay Steel Works, Worthington, England, Sept., 1891.
- F₁. Iron Boss claim.
 - F₂. Iron Monarch claim.
 - F₃. Iron Monarch claim.
 - F₄. Iron Prince claim.
 - F₅. Iron Prince claim.
 - F₆. Iron Yankee claim.
 - F₇. Average results of 7 samples.

- G, H. Analyses from Iron Prince claim by Prof. Sidner, University of Minnesota. Samples taken by Dr. J. P. Kimball, reported to Balfour Guthrie Company, (1890).
- G. No. 1 drill hole—depth 105 feet.
- H. From bottom of slope—35 feet deep.
- I. Analysis of iron ore from summit of Magnetic Mountain. Dr. James Dodge, analyst.
- J. Average of 11 samples, only three of which showed titanitic acid, by D. H. Bacon, manager Minnesota Iron Co.
- K. Analyses of S. Shedd; Iron Ores of Washington, Wash. Geol. Survey, Ann. Rept., Vol. 1, (1901).
- K₁. Average of laminated ore from exposures in Emerson mine.
- K₂. Iron ore from Hard Scrabble mine, similar to Emerson mine.
- K₃. Average of laminated ore from Roslyn mine.
- K₄. Average of laminated ore from Yankee mine.
- K₅. Oölitic iron ore from Iron Monarch mine.
- K₆. Massive iron ore from Yankee mine.
- K₇. Massive iron ore from Iron Monarch mine.
- K₈. High grade massive iron ore from Roslyn mine

	A*	B*	C ₁	C ₂	C ₃
Iron (Fe).....	52.32†	55.08	49.55	55.35	51.66
Silica (SiO ₂).....	5.41	10.28	7.65	7.55	5.85
Alumina (Al ₂ O ₃).....	5.31	0.60	9.16	3.66	8.30
Chromic oxide (Cr ₂ O ₃).....	2.12	.....	2.93†	2.91†	3.01†
Lime (CaO).....	Tr.	0.53	Tr.	1.17	None
Magnesia (MgO).....	0.80	1.48	3.87	2.16	3.26
Manganous oxide (MnO).....	1.65	0.173†	1.00	2.20	0.62
Nickel oxide (NiO).....	2.98	.....	1.20	0.92	0.90
Cobalt oxide (CoO).....	Tr.	.....	.....	.....	.....
Phosphorus (P).....	0.025§	0.014	Tr.	0.08	0.02
Sulphur (S).....	Tr.	None	Tr.	0.07	0.05
Titanium dioxide (TiO ₂).....	.....	None	.....	.....	.....

	C ₄	C ₅	D ₁	D ₂	D ₃
Iron (Fe).....	50.76	52.26	60.55	42.58	68.84
Silica (SiO ₂).....	5.90	6.10	12.99	31.23	1.85
Alumina (Al ₂ O ₃).....	11.90	5.40	1.53	2.98	None
Chromic oxide (Cr ₂ O ₃).....	3.88†	4.66†	0.72	None	None
Lime (CaO).....	1.15	1.25	0.11	2.09	0.65
Magnesia (MgO).....	1.00	2.75	0.21	0.45	0.09
Manganous oxide (MnO).....	0.69	1.15	Tr.	1.85	None
Nickel oxide (NiO).....	0.70	1.10	.....	.....	.....
Cobalt oxide (CoO).....	.....	.....	.....	.....	.....
Phosphorus (P).....	0.013	0.016	0.03	0.18	0.04
Sulphur (S).....	0.04	0.04	None	0.07	None
Titanium dioxide (TiO ₂).....	.....	None	None	None	None

	D ₄	D ₅	D ₆	D ₇	D ₈
Iron (Fe).....	59.23	58.10	60.00	60.89	56.79
Silica (SiO ₂).....	9.55	12.95	12.71	12.87	9.49
Alumina (Al ₂ O ₃).....	1.21	0.89	1.01	1.27	2.26
Chromic oxide (Cr ₂ O ₃).....	1.53	2.39	1.26	0.63	.....
Lime (CaO).....	1.69	1.13	0.93	0.09	.....
Magnesia (MgO).....	1.90	1.75	0.19	0.12	.....
Manganous oxide (MnO).....	Tr.	Tr.	Tr.	Tr.	.....
Nickel oxide (NiO).....	.....	.....	.....	.....	.....
Cobalt oxide (CoO).....	.....	.....	.....	.....	.....
Phosphorus (P).....	0.03	0.05	0.02	0.02	0.02
Sulphur (S).....	Tr.	None	None	None	None
Titanium dioxide (TiO ₂).....	None	None	None	None	None

	D ₉	D ₁₀	D ₁₁	E ₁ *	E ₂
Iron (Fe).....	15.36	52.31	42.38	58.77	35.16
Silica (SiO ₂).....	37.33	14.32	20.89	3.10	14.40
Alumina (Al ₂ O ₃).....	7.71	4.72	6.19	4.08	23.70
Chromic oxide (Cr ₂ O ₃).....	.....	Tr.	Tr.	5.20	.....
Lime (CaO).....	.....	.....	.....	0.28	1.27
Magnesia (MgO).....	.....	.....	.....	1.01	1.02
Manganous oxide (MnO).....	.....	.....	.....	0.30	0.43
Nickel oxide (NiO).....	.....	.....	.....	0.68	.....
Cobalt oxide (CoO).....	.....	.....	.....	.....	.....
Phosphorus (P).....	0.05	0.03	0.01	.....	.....
Sulphur (S).....	0.03	None	0.01	.....	.....
Titanium dioxide (TiO ₂).....	None	None	None	.....	.....

	E ₃ *	E ₄	F ₁	F ₂	F ₃
Iron (Fe).....	42.51	41.737	51.00	47.00	53.40
Silica (SiO ₂).....	7.50	8.950	7.27	6.68	5.38
Alumina (Al ₂ O ₃).....	21.90	20.376	.....	.....	.....
Chromic oxide (Cr ₂ O ₃).....	2.20	1.929	.....	.....	.....
Lime (CaO).....	.....	3.60	.....	.....	.....
Magnesia (MgO).....	2.30	0.72	.....	.....	.....
Manganous oxide (MnO).....	Tr.	.....	.....	.....	.....
Nickel oxide (NiO).....	0.20	.....	.....	.....	.....
Cobalt oxide (CoO).....	.....	.....	1.71	0.99	1.87
Phosphorus (P).....	0.039†	0.062†	0.008	0.004	0.004
Sulphur (S).....	0.03	0.13	.....	.....	.....
Titanium dioxide (TiO ₂).....	0.70	.....	.....	.....	.....

	F ₄	F ₅	F ₆	F ₇	G
Iron (Fe).....	50.40	54.80	47.30	51.01	56.95
Silica (SiO ₂).....	7.30	6.63	13.91	.....	.....
Alumina (Al ₂ O ₃).....	.....	.....	.....	.....	.....
Chromic oxide (Cr ₂ O ₃).....	.....	.....	.....	5.54†	.....
Lime (CaO).....	.....	.....	.....	.....	.....
Magnesia (MgO).....	.....	.....	.....	.....	.....
Manganous oxide (MnO).....	.....	.....	.....	.....	.....
Nickel oxide (NiO).....	.....	.....	.....	.....	.....
Cobalt oxide (CoO).....	1.37	2.03	1.58	1.88	.....
Phosphorus (P).....	0.008	0.003	.....	0.017	.....
Sulphur (S).....	.....	.....	.....	0.05	.....
Titanium dioxide (TiO ₂).....	.....	.....	.....	.....	.....

	H	I ₁	I ₂	J	K ₁
Iron (Fe).....	59.50	57.51	54.84	51.05	47.10
Silica (SiO ₂).....		11.07	13.32	9.45	15.58
Alumina (Al ₂ O ₃).....		4.51†	4.92†		1.92
Chromic oxide (Cr ₂ O ₃).....					
Lime (CaO).....					
Magnesia (MgO).....					
Manganous oxide (MnO).....				0.677†	
Nickel oxide (NiO) {					
Cobalt oxide (CoO) {					
Phosphorus (P).....		0.06	0.05	0.035	
Sulphur (S).....		None	None	0.17	
Titanium dioxide (TiO ₂).....					

	K ₂	K ₃	K ₄	K ₅	K ₆	K ₇	K ₈
Iron (Fe).....	47.87	47.10	51.68	46.24	54.40	51.13	57.12
Silica (SiO ₂).....	14.60	8.70	7.84	7.50	5.54	6.94	5.68
Alumina (Al ₂ O ₃).....	6.02	12.22	5.67	25.95	8.29	14.23	4.80
Chromic oxide (Cr ₂ O ₃).....							
Lime (CaO).....							
Magnesia (MgO).....							
Manganous oxide (MnO).....	Tr.	0.39†	0.30†		Tr.	0.58†	
Nickel oxide (NiO).....							
Cobalt oxide (CoO).....							
Phosphorus (P).....				Tr.	Tr.		
Sulphur (S).....				Tr.			
Titanium dioxide (TiO ₂).....							

*Alkalies and oxygen were recorded in A and B as 2.49 and 26.606, respectively. Combined water was recorded in A, E₁, and E₂ as 3.13, 1.53, and 6.80, respectively. Carbonic acid was recorded in A as 1.90, and carbon dioxide in E₂ as 0.15. Loss on ignition was given in B as 5.30.

†The iron was given as ferric oxide (Fe₂O₃), 57.44, and ferrous oxide (FeO), 5.58.

‡Recalculated from figures originally given. Cr changed to Cr₂O₃; Al, to Al₂O₃; Mn, to MnO; P₂O₅, to P.

§Phosphorus was given as phosphoric acid H₃(PO₄) 0.061.

The Teanaway Mining District

This property was not visited during the course of the examination of the iron ores. The following data have been presented by Robert Young, M. E., Tacoma, Washington:

There are two groups of claims located upon this deposit: the Iron Mountain and Devine groups. They are situated on Beaver Creek, about three miles south of Mount Stuart, east of the Teanaway River. In the Iron Mountain group there are 15 mining claims, numbers 1

to 12, N. E. Iron Lode claim, N. E. Iron Lode claim No. 2, and N. W. extension No. 1. The Devine group is not described nor the number of locations given. The claims appear to be at an elevation of from 5,000 to 6,000 feet above sea level, near the top of a high ridge. They are accessible to Berry and Monument creeks, which lead to an automobile road, perhaps one-half a mile distant in a direct line. The Teanaway logging railroad is to be constructed to a point within four miles of the claims and a wagon road connects the distance between the end of the railroad and the claims.

L₁-L₄ and M₁-M₉. Analyses made by J. C. Beneker of Seattle.

L₁. Iron ore from upper part of main deposit.

L₂. Iron ore from central part of ledge.

L₃. Iron ore from lower part (interior portion).

L₄. Iron ore from lower part (surface).

M₁-M₉. Collected by a second party.

M₁. Iron ore from Devine group.

M₁₇, M₁₈. Iron ore from lower claim.

M₉. From a piece of dark red ore, resembling hematite from upper claim near M₆.

	L ₁	L ₂	L ₃	L ₄	M ₁	M ₂	M ₃
Metallic iron (Fe).....	51.27	52.09	52.21	51.04	49.88	50.56	49.54
Silica.....	13.30	10.10	9.90	9.88	12.10	12.02	13.64
Alumina.....	10.09	10.16	7.90	7.42	.....	.....	.....
Manganese.....	0.58	0.85	1.15	1.18	.....	.....	.....
Nickel.....	1.06	0.85	1.07	1.18	1.12	1.11	1.15
Chromium.....	.....	.....	1.70	.....	.....	.....	.....
Phosphorus.....	1.026	0.016	0.026	0.024	.....	.....	.....
Sulphur.....	None	None	None	None	.....	.....	.....

	M ₄	M ₅	M ₆	M ₇	M ₈	M ₉
Metallic iron (Fe).....	46.23	49.31	45.35	53.07	51.02	50.11
Silica.....	16.56	13.34	14.30	7.62	9.62	9.84
Alumina.....	12.60	.....	.....	.....	.....	.....
Manganese.....	0.54	.....	.....	0.71	.....	.....
Nickel.....	1.11	1.11	1.12	0.99	0.98	1.32
Chromium.....	1.7	.....	.....	1.55	.....	.....
Phosphorus.....	.....	.....	.....	.....	.....	.....
Sulphur.....	.....	.....	.....	.....	.....	.....

The Big Creek District, South of Easton.

N₁-N₆. Analyses of iron ore by Prof. James A. Dodge, Minneapolis, Minn., 1891. (The character of this deposit has not been reported upon and the writers have not examined the deposit.)

	N ₁	N ₂	N ₃	N ₄	N ₅
Iron (Fe).....	46.87	52.42	34.81	42.83	46.70
Silica (SiO ₂).....	26.20	18.38	35.65	27.47	29.03
Lime (CaO).....	2.84	3.15	2.96	4.49	2.45
Magnesia (MgO).....	0.48	0.27	0.19	0.71	0.12
Manganese (Mn).....	2.27	1.32	6.71	3.06	0.61
Phosphorus (P).....	1.18	1.27	0.85	1.69	1.03
Sulphur (S).....	None	0.01	0.02	0.05	0.04
Copper (Cu).....	Tr.	.....	Tr.	0.24	.....
Combined oxygen with Fe, Mn, and P.....	20.16	23.18	18.81	19.46	20.02

KING COUNTY**THE SUMMIT MINING DISTRICT****Introduction**

The Summit mining district lies in the heart of the Cascade Range, in the east central part of King County, at an average elevation of 3,800 feet. The relief of the region is a striking feature and is characterized by sharp, pronounced divides, and precipitous mountain peaks, deeply trenched by steep-sided canyons. The district is principally drained by the tributaries of Snoqualmie River. It is accessible by automobile over the Snoqualmie Pass road, or may be reached from Rockdale, a station on the Chicago, Milwaukee & St. Paul Railway. There are two iron properties in the district, one of which is located on Guye Creek on the west side of the shoulder connecting Guye Peak with Snoqualmie Mountain, the other on Denny Creek, on the western slope of Denny Mountain. Magnetite is said to occur on Chair Peak also, but the extent is not known.

Denny Property

Location. This property is located two miles north-east of Snoqualmie Pass on the west slope of Denny Mountain and on the north fork of Denny Creek, at an

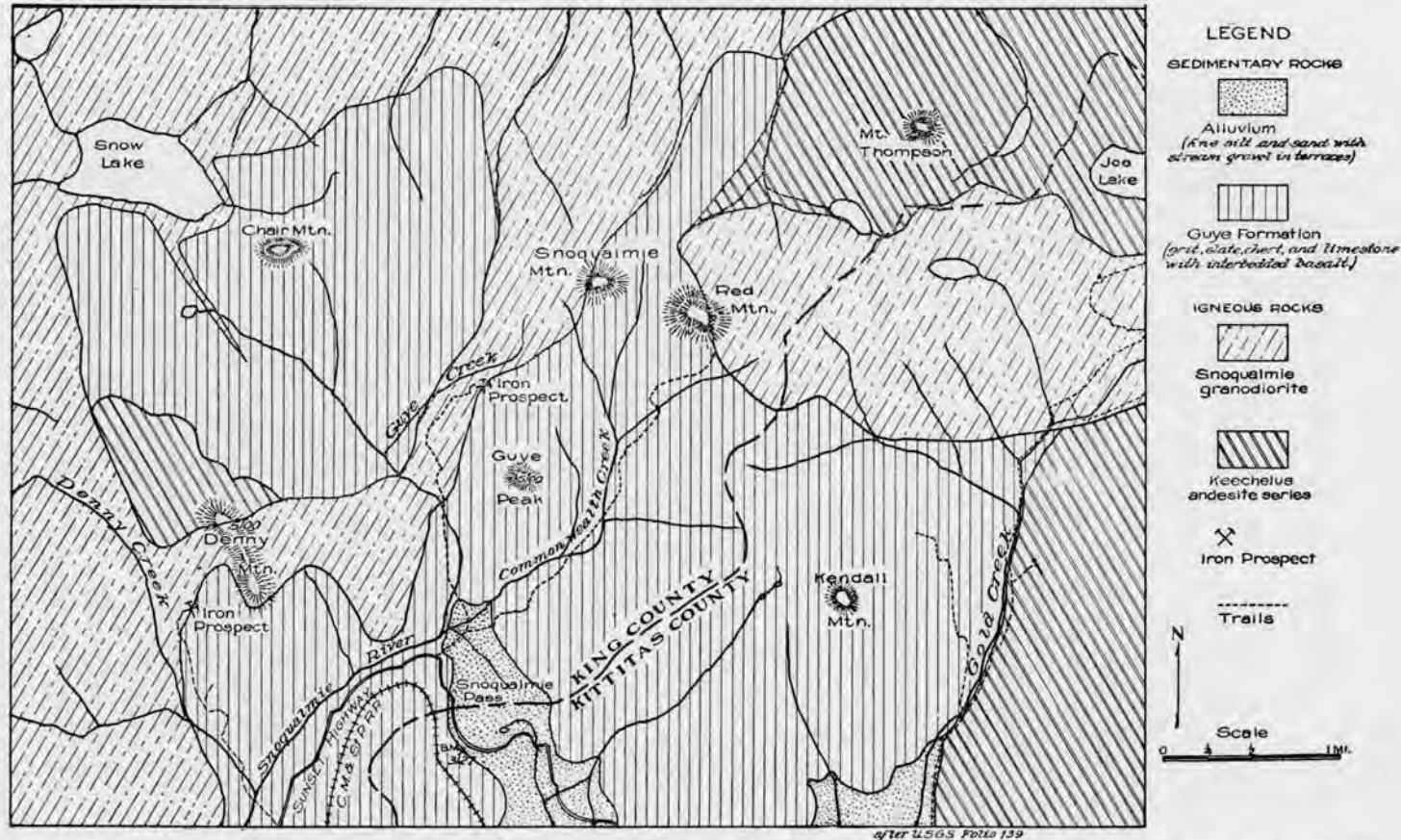


FIG. 8.—Geologic map of a portion of the Summit mining district, King County, showing the locations of the Guye and Denny iron prospects which are located on the contact between the Guye sedimentary formation and the intrusive Snoqualmie granodiorite.

elevation of 3,500 feet. It comprises nine claims, all of which are patented. These claims are on record at the Government Land Office, Seattle, under mineral survey numbers 37 to 45, inclusive. The surveys were made in 1883-84.

Description of rocks. The country rock occurring on the property consists of members of the Guye formation and the intrusive Snoqualmie granodiorite. The principal member of the Guye formation in connection with the iron ore is a white, coarse-grained limestone which has been crystallized locally to white marble, especially where it has been affected through contact with the in-

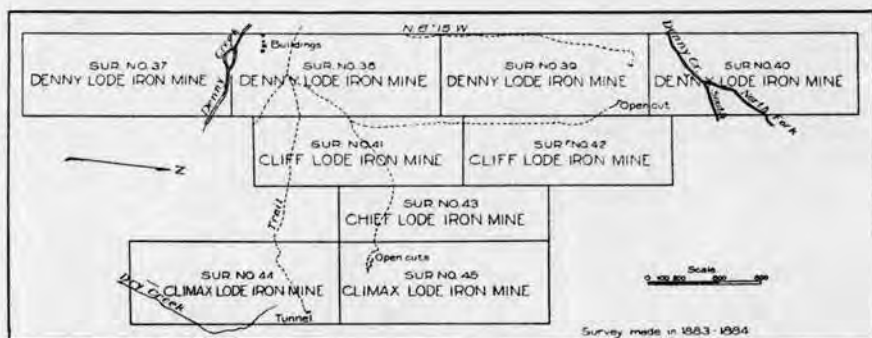


FIG. 9.—Map of claims on the Denny property, Summit mining district, King County.

trusive granodiorite. The limestone occurs in a thin bed and is not extensive. The granodiorite consists essentially of plagioclase and orthoclase feldspar, quartz, hornblende, and mica.

Mining development. No active mining has ever been done on the property, and the principal explorative work, which consists of one 53-foot tunnel and five or six open cuts and pits, was done for assessment work 35 or 40 years ago.

Ore body and possible origin of iron ore. The ore body, which consists of magnetite, lies along the contact

of the intrusive granodiorite with limestone beds of the Guye formation. It occurs in mineralized bands or beds and isolated masses, which have a general trend of north and south, and dip toward the east. The location of the deposits at or near the intrusive contact, together with the presence of such characteristic contact minerals as garnet, hornblende, calcite, and quartz, suggest that the magnetite is of contact metamorphic origin. The same general conditions exist on Guye Peak, and magnetite is said to occur similarly on Chair Peak. George Otis Smith and Frank C. Calkins¹ describe conditions and indicate possible origin of the ore on the Denny property as follows: "The mineral deposits which have been prospected as iron ore constitute a mineralized band rather than a distinct vein. The granodiorite is much jointed and the joint planes are coated with hornblende and garnet crystals. In the gulch where some exploration work has been done, a complete section of the ore-bearing band can be seen. The band is parallel to one of the principal joint planes trending a little west of north, and has on its west side a bed of massive garnet, in places 10 feet wide.

"Next to this are garnet, quartz, green hornblende, and calcite, all well crystallized. The magnetite occurs as nodules one foot or less in diameter and associated with it are masses of pyrite crystals. Through oxidation of the pyrite the rock forming the sides of the gulch is coated with iron oxide, which makes the indications of the extent of the iron somewhat deceptive. At another opening on this property, pure magnetite forms a vein-like body with parallel bands of massive garnet and of calcite. The magnetite appears to be the oldest and the calcite the youngest of these crystallizations. Surface workings on the mountain slope expose what are appar-

¹Snoqualmie Folio, No. 139, (1906), U. S. Geol. Survey, p. 13.

ently large bodies of this magnetite, but these bodies are found to be oval lenses, 20 feet or more across, which lie approximately parallel to the surface and thus exhibit maximum exposure of the ore."

Guye Property

Location and ownership. This property is located approximately in sections 29 and 31, T. 23 N., R. 11 E., about $2\frac{1}{2}$ miles almost due north from Snoqualmie Pass, at an elevation of about 4,600 feet. It comprises nine claims, all of which are patented, and is called the Guye Summit Group. These claims are on record at the Government Land Office, Seattle, under mineral survey numbers 46 to 51, and 87 to 89, inclusive. All are owned by J. W. Guye of Aberdeen, Washington.

Description of rocks. The country rock occurring on the Guye property consists of conglomerate and limestones or marble belonging to the Guye formation, and the Snoqualmie granodiorite. The granodiorite has been proved¹ to be intrusive into the Guye formation (Miocene age) and has been assigned to the late Miocene or post-Miocene age. It is a granitic appearing, holocrystalline rock, consisting essentially of plagioclase and orthoclase feldspar, quartz, hornblende, and biotite.

The limestone occurs in beds only a few feet wide. Where it lies contiguous to the granodiorite, it has been crystallized to marble and partially replaced by garnet and magnetite. The ore deposits occur along this contact zone.

Mining development. The claims constituting this property were filed on September 15, 1884, and patented in 1891. The principal development work upon the ore bodies was done during the period between the above dates, and consisted of one tunnel and four or five open cuts and pits. No active mining has ever been done.

¹U. S. G. S. Folio, No. 139, (1906), p. 7.

Ore body and possible origin of the iron ore. The ore body occurs in beds or bands under similar field relations to those on Denny Mountain two miles to the southwest. The deposits are found at or near the contact where limestone beds (Guye formation) have been in-

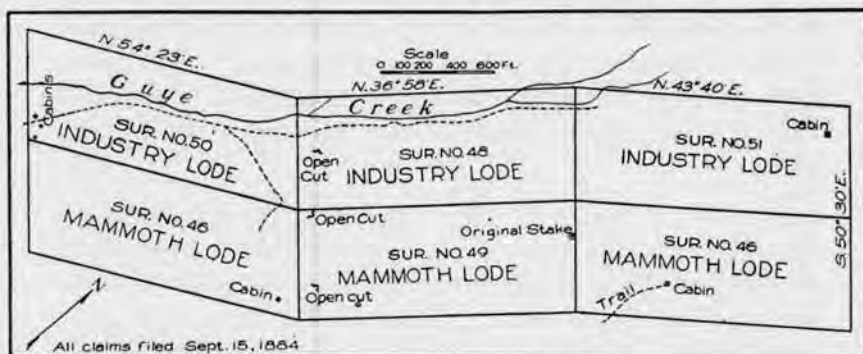


Fig. 10.—Map of claims on the Guye property, Summit mining district, King County.

truded by the Snoqualmie granodiorite. The ore bands are in general wider, however, and more continuous than those occurring on Denny Mountain.

George Otis Smith and Frank C. Calkins¹, who mapped the geology of this region, discuss the probable genesis of the iron ore on the Guye prospect as follows:

“The origin of the magnetite at the contact of the intrusive granodiorite is undoubtedly more or less directly connected with the intrusion. The association of minerals and the position of the deposits strongly favor this view. The relations observed at the Guye tunnel suggest replacement of the limestone by the magnetite and garnet, and the date of this mineralization may very plausibly be referred to the later stages of the granodiorite intrusion. At the Denny prospect the abundance of pyrite may indicate that the sulphide was deposited along with the oxide. In one specimen of metamorphosed

¹Op. Cit. p. 13.

wall rock both magnetite and pyrite occur, and under the microscope the magnetite can be seen in small grains along cracks in the rock and in finer grains bordering the larger grains of pyrite. It seems doubtful, however, whether the most of the magnetite could have been derived from the sulphide, since sulphur is wholly lacking in the analyses of the Guye ore and no pyrite was noted there. That there has been a slight amount of subsequent concentration of the ore is shown by one case of brecciation of the massive garnet with impregnation by the magnetite."

Economic aspect of the Guye and Denny properties. According to the analyses the ore of these properties varies from 55 to 71 per cent metallic iron, with an average of about 65 per cent. It appears that the ore in most cases is low in phosphorus and is generally low in sulphur, except where sulphides are present in the ore body. They are present in the Denny property, but are nearly lacking in the Guye. The ore from these properties is representative of the best grades of magnetite in the State. According to the descriptions and the appearance of the deposits they are comparatively large but irregular and discontinuous. Their tonnage cannot be safely estimated from the data collected. The situation of the ore bodies should make them of economic importance if iron ore is needed locally on the Coast.

THE MILLER RIVER DISTRICT

Introduction

The Miller River District is situated in the north-eastern part of King County along the South Fork of the Skykomish River and only 15 miles west of the Cascade divide. It embraces two iron properties.

Anderson Property

This property is located in section 11, T. 26 N., R. 10 E., about three-quarters of a mile southeast of Baring,

a station on the main line of the Great Northern Railway.

Some mining development work has been done on the property, and at the time the mine was visited, about 200 tons of ore lay on the dump. One carload is said to have been shipped under the direction of Dr. E. H. Rothert of Seattle.

The ore mineral is magnetite. It outcrops on the north slope of the mountain several hundred feet above the Skykomish River. The outcrop exposes a more or less lenticular shaped ore body which measures 25 to 30 feet in height and approximately 15 feet in width. The ore in many respects resembles that which occurs on Guye and Denny mountains at Snoqualmie Pass, and appears to be a contact replacement deposit in a bed of white coarsely crystalline limestone.

Economic aspect. According to the analyses, the ore varies from 55 to 60 per cent metallic iron, and is fairly low in phosphorus and sulphur, but rather high in titanium dioxide, 0.94 per cent. No large quantity of ore appeared to be present in this deposit. There were probably some five thousand tons in the deposit and on the dump.

Williams-Smith Property

This property is located on Money Creek, a tributary of the Skykomish River, five miles southwest of Miller River station, and near the line between sections 35 and 36, T. 26 N., R. 10 E., at an elevation of 2,900 feet. It consists of two iron claims, which are known as the Washington and Chicago. The nearest railroad point is at Miller River, a station located on the Great Northern Railway.

The country rock in the vicinity of the claims is of both igneous and sedimentary origin. The sedimentaries consist of crystalline limestone, siliceous limestone, and

quartzite, all having suffered igneous intrusions and severe metamorphism.

The ore mineral is magnetite of similar character to that occurring near Baring, and at Snoqualmie Pass. It is said to outcrop in three different places on the claims, the largest exposure being 51 feet across. A tunnel, claimed to be 257 feet long, has been opened into one of these ore bodies. The analyses given in the tables, made by Dr. E. H. Rotherth, were of ore taken from the tunnel. This mine was not visited by the writers, but the type and texture of the ore, as well as the general character of the rocks on the property, favor an origin resulting from contact replacement of limestone.

Economic aspect. According to Rotherth's analyses the ore contains about 65 per cent metallic iron and varies greatly in phosphorus content. Since the writers did not examine this deposit an estimation of its tonnage cannot be given.

ANALYSES OF SNOQUALMIE PASS IRON ORE, KING COUNTY

- A₁, A₂. Analyses by E. Fulmer. B₁, B₂. Analyses by S. Shedd. Shedd; Iron Ores of Washington, Wash. Geol. Survey, Ann. Rept., Vol. 1, (1901).
- A₁, A₂. Analyses of samples collected from two different localities, Guye property.
- B₁. Iron ore from surface 50 yards from Denny mine.
- B₂. Iron ore from Denny mine.
- C. Iron ore from Denny mine. Analysis by Booth, Garrett and Blair, Philadelphia (1890).
- D₁, D₂. Iron ore from Snoqualmie Pass. Analyses by G. J. Valentine, Chief Chemist, Moss Bay Hematite Iron and Steel Co., Worthington, England.
- E₁, E₂. Analyses of six samples of iron ore from Snoqualmie veins by Prof. James A. Dodge, Minneapolis, Minn.

	A ₁	A ₂	B ₁	B ₂	C*	D ₁
Iron (Fe).....	66.81	66.82	62.45	68.54	55.48	67.80
Silica (SiO ₂).....	3.60	4.20	5.78	1.80	7.99	3.33
Alumina (Al ₂ O ₃).....					3.74	.....
Phosphorus (P).....	Tr.				0.021	Tr.
Sulphur (S).....			0.21	0.25	0.089	0.12

	D ₂	D ₃	D ₄	D ₅	D ₆	E ₁
Iron (Fe).....	64.00	67.00	62.80	64.50	61.00	69.39
Silica (SiO ₂).....	5.56	1.67	7.99	6.03	.....	2.72
Alumina (Al ₂ O ₃).....	0.02	0.02	Tr.	Tr.	0.018	0.357
Phosphorus (P).....	0.12	0.05	0.05	0.05	0.063	0.042

	E ₂	E ₃	E ₄	E ₅	E ₆
Iron (Fe).....	71.17	68.56	67.17	69.40	70.18
Silica (SiO ₂).....	1.30	2.77	4.02	2.23	1.87
Alumina (Al ₂ O ₃).....	.....	.....	.....	.....	.....
Phosphorus (P).....	0.039	0.035	0.031	0.035	0.031
Sulphur (S).....	0.005	0.019	0.041	0.008	0.013

*In this sample there was also recorded: CaO, 7.120; MgO, 2.774; CuO, none; and titanitic acid, 0.085.

ANALYSES OF IRON ORE FROM NORTHEASTERN KING COUNTY

MILLER RIVER DISTRICT

A₁-A₃. Analyses of iron ore by Dr. E. H. Rothert, Rothert Process Steel Company, Seattle.

A₁, A₂. Iron ore from Money Creek, 5 miles southwest of Miller River Station.

A₃. Iron ore from Anderson claims, Baring.

B. Specimen of magnetite from Anderson property, near Baring, Sec. 11, T. 26 N., R. 30 E. Jenkins and Cooper, collectors. R. P. Cope, analyst.

	A ₁	A ₂	A ₃	B
Iron (Fe).....	66.00	67.00	55.00	60.70
Silica (SiO ₂).....	4.10	2.70	10.20	9.51
Alumina (Al ₂ O ₃).....	.....	.....	0.75	.....
Lime (CaO).....	.....	.....	4.53	.....
Magnesia (MgO).....	.....	.....	1.15	.....
Phosphorus (P).....	0.0264	0.37	0.065	0.034
Sulphur (S).....	None	None	.....	0.09
Titanium dioxide (TiO ₂).....	.....	.....	Tr.	0.94

SKAGIT COUNTY

THE HAMILTON DISTRICT

Introduction

The Hamilton district is situated in the central part of Skagit County, in northwestern Washington, amid westerly projecting spurs of the Cascade Mountains. The elevation of the Skagit River valley, which forms the major drainage line of the region and along which the iron ores occur, is 95 feet at Hamilton and 313 feet at Marblemount, while the elevation attained by the tim-

bered mountain ridges which form the divides is approximately 3,000 feet.

The Great Northern Railway extends up the river as far as Rockport, a station located 10 miles below Marblemount. Dr. S. Shedd¹, who visited the district in 1900, discusses the extent of the iron deposits as follows: "Outcrops of iron ore appear at intervals along the valley from Hamilton to Marblemount, a distance of about twenty-five miles. While the deposits have been found in a number of places along the trend, there has not been work enough done to tell definitely just what the relations of the different outcrops are to each other, but I am inclined to think they are lenses rather than veins, and probably not continuous between the outcrops. The ore bodies vary in thickness from a few feet to 30 feet. From Hamilton to Birdsvew, a distance of six miles, the iron ores appear at intervals on the south side of the Skagit River in five lines, one above the other, while at Marblemount only two lines of outcrops have been found so far. These outcrops trend approximately east and west and have a dip to the southwest of about 55 degrees."

Iron Mountain Properties

Location. The Iron Mountain properties are located on the south side of the Skagit River, opposite the town of Hamilton, in sections 23 and 24, T. 35 N., R. 6 E. The best known claims are the Hamilton, Mayflower, Blue Jay, Last Chance, Fairhaven, Washington, Inaugural, and Scottish Chief; though these do not by any means constitute the total number of locations that have been made in the district.

Description of rocks. The rocks of the district consist of sandstone, limestone, shales, and glaucophane-garnet schists. Dr. Shedd describes a section taken through the

¹Op. Cit.

coal measures that overlie the iron ore formations as follows: "Occurring in connection with the iron in this district, especially across the river from Hamilton and lying above it are at least four seams of what is said to be a good grade of coal. Some work has been done on this coal, but for some reason it has been stopped and at present nothing is being done. The first vein is from 1,000 to 1,200 feet above the iron ore, and has a thickness of from 8 to 10 feet of coal with three streaks of boney matter from $1\frac{1}{2}$ to 4 inches in thickness. Just below the coal is about 300 feet of sandstone and then come the slates in which the iron occurs. The second vein occurs about 100 feet above the first and has six feet of coal comparatively free from dirt. The formation between the two seams of coal is a gray sandstone with four feet of fire clay just below the upper vein of coal. From the second vein of coal to the third is 1,100 feet of gray sandstone. Number 3 is three feet thick and contains no dirt. Vein number 4 is 1,200 feet above 3, and the formation between the two is sandstone."

The country rock of the iron ore deposits appeared to consist for the greater part of schists and slates. Specimens of the most characteristic of these metamorphic rocks were collected and found to be glaucophane-garnet schist. It is a greenish gray to grayish black rock, the greenish variety being the more common. The texture of the schist is so fine in many cases as to give a slaty appearance, though it is commonly foliated, and crumpled. Crushed fragments of the schist mounted on a slide and studied under the microscope revealed it to be composed largely of long blades and needles of the mineral glaucophane, together with numerous rhombic dodecahedral crystals of pale red garnet. Actinolite is also a more or less important constituent, while chlorite is present as an alteration product.

Mining development. The iron ore was discovered in about 1881 and since then from time to time considerable development work has been done, but no great depth has been reached. During the early exploration days two tons of the ore were sent to Tacoma and tested in the smelter there. A few years later (1887), twenty tons were sent to Irondale for experimental purposes. Tests are also said to have been made at the furnace formerly operated at Sedro Woolley. About seven or eight years ago four or five thousand tons of the iron ore were mined from the Hamilton and Inaugural mines and shipped to Concrete.

The greater part of the workings on the various claims consist of surface cuts opened along the strike of the ore bodies. On the Hamilton claim, however, the development work, in addition to open cuts, includes a shaft 40 feet deep and a tunnel 60 feet long, while on the Inaugural claim there is a shaft said to be 90 feet deep, and a tunnel 50 feet long.

Ore bodies. The iron ores as shown by the various analyses, carry a considerable amount of manganese. They occur in a series of parallel layers, one above the other, the lowest of which lies along the bank of the Skagit River and the highest on the slope of the mountain several hundred feet above the valley. The ore is dark colored, has a medium specific gravity (4.1), a fine even grained texture, and is schistose in appearance.

The character and grade of the ore vary. Most of it is slightly magnetic, showing the presence of magnetite, though some grades appear to contain a great deal of hematite, almost to the exclusion of magnetite. The quantitative relation of the hematite and magnetite over the district as a whole, was not determined. It was observed, however, that the ore layers, which were found to vary from a few feet to 30 feet in width, are not uni-

form in cross section, but grade insensibly into the schists that form the wall rocks, so that in places what appears to be fairly good ore actually consists largely of glaucophane and garnet with only a subordinate amount of magnetite and hematite. The specific gravity of the ore is 4.1; of garnet, about 4.0; of glaucophane, 3.1, and of magnetite or hematite, 5.1. The variation of the glaucophane, garnet, and iron content is so great in different samples that no generalization as to the average content is possible. The better grades, however, appear to be about half magnetite and hematite together.

A few specific and fairly representative cases relative to the occurrence of the ore will be cited. On the Blue Jay claim the thickness of the ledge is about 10 feet. Stringers of clear quartz, sometimes four or five inches wide, carrying more or less chalcopyrite, ramify through the ore bands approximately at right angles to the bedding. The beds dip into the hill at an angle of 63 degrees, south 28 degrees west. The ore has a bluish red cast and grades into a hanging wall of bluish green glaucophane-garnet schist. The foot wall is not exposed.

Conditions on the adjoining Last Chance claim are essentially the same.

On the Fairhaven claim both hanging wall and foot wall are well exposed and both are greenish glaucophane schist. The beds dip 65 to 70 degrees to the southwest. The strike is south 45 degrees east.

The Washington claim adjoins the Fairhaven on the east. A surface working exposes the ore band for 400 feet along the direction of strike, showing an average width of 12 feet. The hanging wall is glaucophane schist. The foot wall is concealed by the dump upon which two or three hundred tons of ore lie.

Conditions on other claims are practically the same in their general occurrence and will not be further discussed.

Possible origin of the iron ore. The ore bodies appear to be definite in shape and constitute layers in the sedimentary series in that locality. This feature is shown by the parallel arrangement and general conformation of the ore layers to the dip and strike of the enclosing wall rocks. The original rocks are badly metamorphosed, which makes the problem of origin more or less uncertain, but it appears probable that the ore seams represent a stage in deposition when there was slow accumulation of sediment. Marshy lands generally offer favorable conditions where bog iron, bog manganese, mud, and clay may accumulate together, forming layers of greater or lesser thickness. Then, if for any reason the conditions become altered in such a way as to incur a greater influx of sediment, the mud and clay would easily preponderate, causing a gradation to a material that when solidified would constitute ordinary shale.

In the event of repeated transitions from one order to another, there would be produced alternating beds of shale interlayered with seams of bog iron and manganese in much the same manner that sandstone and shale higher on the mountain are interlayered with successive beds of coal.

Subsequent to the deposition, the shales and bog ores have been subjected to intense metamorphism, probably regional, which has converted the shales and clayey portions of the bog ore layers into glaucophane and garnet, while the bog ores themselves have been dehydrated, yielding magnetite, hematite, and pyrolusite.

There is a further possibility that the iron phase may have been introduced subsequent to the deposition of the shales through the agency of circulating solutions given off from some intrusive body, but the writers are inclined to think the sedimentary origin is the more probable of the two.

Economic aspect. The ore varies from 31 to 41 per cent metallic iron, according to the analyses, with a high percentage of silica, fairly high percentage of phosphorus, a low percentage of sulphur, and manganous oxide averaging about 10 per cent. The ore is, therefore, of low grade, and could not be used in the acid processes of iron and steel manufacture. It is the opinion of the writers that probably 100 thousand tons of low grade iron ore could probably be extracted from these properties.

ANALYSES OF HAMILTON IRON ORES, SKAGIT COUNTY

A-F, J, K. Analyses by R. W. Thatcher. G. Analysis by E. Fulmer.

H. Analysis by S. Shedd. Shedd; Iron Ores of Washington, Wash. Geol. Survey, Ann. Rept., Vol. 1, (1901).

- A. Iron ore from tunnel, Inaugural mine, Hamilton.
- B. Iron ore from surface, Inaugural mine.
- C. Iron ore from shaft at depth of 85 feet, Inaugural mine.
- D. Iron ore from Hamilton mine, average sample.
- E. Iron ore from Hamilton mine, near middle of vein.
- F. Iron ore from Hamilton mine, near wall.
- G. Iron ore from J. J. Conner prospect, Hamilton.
- H. Iron ore from vein highest above river, Hamilton.
- I. Iron ore from Treadwell mine, near Marblemount, 25 miles above Hamilton on Skagit River.
- J. Iron ore from ore body situated lowest down on hill, Pittsburg mine.
- K. Iron ore from upper of two ledges, Pittsburg mine.

L₁-L₄. Analyses of iron ore from Snowstorm claim, opposite Hamilton, Dr. E. H. Rothert, analyst.

	A	B	C	D	E
Iron (Fe).....	43.89	31.08	43.91	32.14	36.72
Silica (SiO ₂).....	19.98	31.82	18.36	30.53	20.24
Alumina (Al ₂ O ₃).....	3.30	6.79	3.109	7.25	7.40
Calcium carbonate (CaCO ₃).....	3.98	5.82	8.92	5.82	9.77
Manganese oxide (Mn ₂ O ₃).....	12.30	14.28	12.00	11.74	13.04
Phosphorus (P).....	0.11	0.18	0.69	0.72	Tr.
Sulphur (S).....				0.06	

	F	G	H	I	J
Iron (Fe).....	33.88	46.60	42.43	43.72	32.92
Silica (SiO ₂).....	32.94	27.04†	24.13	22.85	28.05
Alumina (Al ₂ O ₃).....	2.57	None	9.54	3.17	8.43
Calcium carbonate (CaCO ₃).....	8.81	3.95	.....	3.78	8.06
Manganese oxide (Mn ₂ O ₃).....	7.31	0.19	.....	8.08	8.11
Phosphorus (P).....	1.00	0.59	0.64	0.44	0.31
Sulphur (S).....	0.16	.....	0.25	.....	.....

	K	L ₁	L ₂	L ₃	L ₄ *
Iron (Fe).....	29.11	35.90	37.00	37.00	40.50
Silica (SiO ₂).....	32.46	26.60	17.00	17.00	22.00
Alumina (Al ₂ O ₃).....	8.56				
Calcium carbonate (CaCO ₃).....	6.71				
Manganese oxide (Mn ₂ O ₄).....	13.11	13.52†		0.56‡	12.51†
Phosphorus (P).....	0.20				
Sulphur (S).....					

†Given as insoluble residue.

‡Given as Mn and recalculated to Mn₂O₄.

*Titanium is given as 3.00.

THE PUGET SOUND BASIN

INTRODUCTION

The Puget Sound basin lies at the western foot of the Cascade Mountains, and includes the broad expanse of territory stretching westward between the Columbia River on the south and the Canadian boundary on the north to the Olympic and Coast mountains on the west. This wide tract of land represents a geosyncline, or extensive downwarp in the earth's crust, the surface of which as a whole is not far above sea level. In fact, the waterways and channels of the Puget Sound occupy a portion of the trough where submergence has been of so profound a nature as to admit the sea. Topographically the basin consists of a level or gently undulating plain broken in places by low rounded hills that rise 1,000 to 1,500 feet in height.

This basin-shaped area embraces a large number of scattered bog iron deposits, the hematite deposit on Sumas Mountain, Whatcom County, and the titaniferous magnetite deposit near Elma, Grays Harbor County.

BOG IRON DEPOSITS

Bog iron deposits have been reported from a number of counties situated in and bordering on the Puget Sound basin. Bog iron has been reported from Thurston County, as occurring in the vicinity about Little Rock; and from Clallam County as occurring south of Irondale; but the exact locations of the deposits have not been indicated.

Snohomish County

In Snohomish County bog iron occurs on the farm of F. O. Coe, $1\frac{1}{2}$ miles northeast of Arlington, in section 36, T. 32 N., R. 5 E. The deposit has a lateral extent over two or three acres and appears to be $2\frac{1}{2}$ to 3 feet thick. Bog iron occurs in the same locality on the farm of Thomas Jefferson, in section 30, T. 32 N., R. 6 E., 4 miles northeast of Arlington. The property was worked 10 or 12 years ago when the iron ore was removed from an area covering three or four acres, and shipped to the furnace then operating at Irondale. It appeared probable that very little ore was left.

Economic aspect. Analyses were not made of the ore of either of these two bog iron deposits, but it is quite similar to other bog ore deposits in the State. Since the Coe property covers 2 or 3 acres to a depth of $2\frac{1}{2}$ to 3 feet, it contains probably about 10 or 15 thousand tons of ore. Some of this ore appears to contain a considerable amount of manganese dioxide.

Most of the ore from the Jefferson property appears to have already been removed. There may be a few thousand tons left. All this ore is of low grade and in quantity insufficient to be considered of special economic importance.

Whatcom County

In Whatcom County bog iron occurs in a number of places in the vicinity of Bellingham, Ferndale, and Lynden, but the deposits are generally small. The most extensive that are known occur about one mile north of Lynden, in sections 8 and 17, T. 40 N., R. 3 E. On Sturman's farm the bog iron covers an acre or so to a depth said to average 2 feet. The ore either lies at the surface or is covered with only a few inches of soil.

On the adjoining farm of Thomas Herringa there is an exposure that covers approximately five acres, which varies in thickness from 0 to 2 or 3 feet.

The nature of the occurrence of the several bog iron deposits visited was essentially the same and the bog iron probably originated under analogous conditions, similar to those that are characteristic of the genesis of ores of this class.

Bog iron ore is a variety of limonite, with an admixture of more or less clay, silt, and other impurities.

In the Puget Sound basin the bog iron has probably accumulated in preexisting marshes and swamps where it formed layers of hardpan, which are now exposed at the surface. Since iron is an abundant constituent of many rocks, and present in most of them, it may have been leached from those in the adjacent territory by percolating waters charged with organic or possibly sulphuric acids, and carried by these solutions into the swamps, where precipitation ensued. The deposition from carbonated waters might have been effected through reactions set up by intermingling solutions brought together in the marshes, or through the agency of the so-called "iron bacteria," which are organisms existing in the ground water and soil, that possess the capacity of absorbing iron from solutions and redepositing it as ferric hydroxide. In case the iron was carried by the sulphate solutions, it may have been precipitated by carbonates, phosphates, or organic matter present in the water, and subsequently oxidized to the ferric hydroxide, or limonite, which is now found.

Economic aspect. An analysis made of a specimen of bog ore from near Lynden shows it to contain nearly 40 per cent metallic iron, a high percentage of silica, 0.153 per cent phosphorus (which is high), and 0.013 per cent sulphur. This is, therefore, a low grade of iron ore. These deposits contain in all some 20 thousand tons. Other deposits in Whatcom County may contain in all about 15 to 20 thousand tons.

ANALYSES OF BOG IRON ORE FROM VARIOUS LOCALITIES
IN WASHINGTON

- A₁-B. Analyses by E. Fulmer. B. Analysis by S. Shedd; Iron Ores of Washington, Wash. Geol. Survey, Ann. Rept. Vol. 1, (1901).
- A₁. Bog ore from Irondale district, Jefferson County.
- A₂. Bog ore with gravel from Irondale district.
- B. Bog ore from Cheney district, Spokane County.
- C. Analysis of a specimen of bog limonite, from a point one mile north of Lynden, Whatcom County. Jenkins and Cooper, collectors. R. P. Cope, analyst, (1922).

	A ₁	A ₂	B	C
Iron (Fe).....	53.67	28.48	35.12	39.67
Silica (SiO ₂).....	9.67†	40.35†	16.30	19.43
Alumina (Al ₂ O ₃).....	None	None	10.34	.....
Calcium carbonate (CaCO ₃).....	0.95	2.10	.....	.....
Manganese oxide (Mn ₂ O ₃).....	0.20	0.92	.....	.....
Phosphorus (P).....	1.09	0.17	0.31	0.153
Sulphur (S).....	.....	.....	0.19	0.013

†Originally recorded as insoluble residue.

HEMATITE GROUP ON SUMAS MOUNTAIN, WHATCOM COUNTY

This property is located on the west slope of Sumas Mountain, in the northwestern part of Whatcom County. It is situated in section 2, T. 39 N., R. 4 E., and in section 35, T. 40 N., R. 4 E., at an elevation varying from 700 to 1,600 feet. The nearest railroad station is at Nooksak, a town on the Northern Pacific Railway, about four miles distant. Seven claims have been located, which are collectively known as the Hematite Group.

The ferruginous bodies that have attracted much attention lie along the contact between a dark green peridotite formation and an overlying bed of conglomerate which dips south 60 degrees west at an angle of 45 degrees. The ore phase appears to consist chiefly of low grade hematite that has been more or less hydrated. It is exposed in a chain of outcrops along the bed of a stream for a distance of 1,500 feet, and varies in width from 0 to 20 feet, though the more ferruginous portions are generally less than 10 feet wide.

The better grade ore has a dull red massive appearance and gives a dark brownish red streak or powder when pulverized. Some of the powder was mounted on a slide and studied under the microscope by reflected light. This showed it to be composed, in addition to the earthy red material, of occasional grains of quartz, numerous grains of magnetite, and particles of a black, shiny, non-

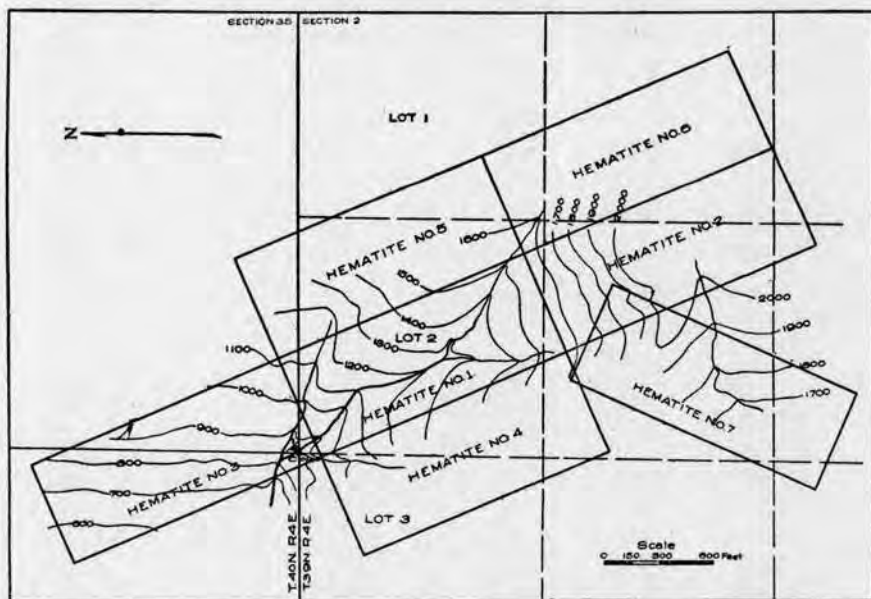


FIG. 11.—Map of the Hematite Group of claims on Sumas Mountain, Whatcom County.

magnetic mineral resembling magnetite, which were probably chromite. Many of the magnetite grains were surrounded by a coat of the red powder and their presence was detected only by means of a magnet moved about the field of the microscope.

A partial analysis of a specimen of the ore collected from one of the higher grade bodies during the investigation, analyzed by Prof. R. P. Cope, gave the following results:

	Per Cent
Iron (Fe)	37.31
Silica (SiO ₂)	20.83
Phosphorus (P)	0.20
Sulphur (S)	0.008

The ore phase appears to be a residual product formed through surficial weathering of the basic peridotite prior to the deposition of the conglomerate. The criteria in favor of such a mode of genesis are as follows: (1) the ore zone lies immediately beneath the conglomerate and apparently represents the upper portion of the old land surface upon which the conglomerate was laid down; (2) the more highly oxidized parts of the ore bodies are adjacent to the conglomerate, away from which they grade insensibly into the slightly altered peridotite; (3) the texture and structure of the ore phases are analogous to those of the original peridotite; and (4) the oxidized ore material contains partially altered grains and particles of the same constituents that occur in the peridotite, such as magnetite, etc.

Economic aspect. The ore is of very low grade. A picked specimen shows only 37 per cent metallic iron, a high silica content, and a high phosphorus content. The ore body appears to vary greatly in grade from place to place. It is of no commercial value as an ore of iron. It may, however, be found to be of value in some other industry, such as in the paint industry.

DENNIS PROPERTY NEAR ELMA, GRAYS HARBOR COUNTY

This property is located in the southeastern part of Grays Harbor County, in the southeast quarter of section 28, T. 18 N., R. 5 W. It is situated 3½ miles east of Elma, and 2¾ miles off the Olympic Highway. The nearest railroad station is Elma, which is located on the Northern Pacific Railway.

The development work done, at the time the property was visited, consisted of one open cut and two or three pits. Some ore has been mined from the open cut, one

carload of which was shipped to the Bilrowe Alloys Co. at Tacoma, and 1,000 pounds to the Rothert Process Steel Co. at Seattle, where it was used for experimental purposes.

The ore is a hard, granular, titaniferous magnetite. It occurs in a bedded deposit, lying beneath a mantle of 3 to 8 feet of soil, ferruginous clays, and sand. The ore body, which is more or less intermixed with sand and gravel, varies in thickness from 1 to 4 feet, and appears to have an areal extent over 2 or 3 acres, though lateral boundaries have not been well defined.

A specimen of the ore, studied under a hand lens, appears to be made up of small, well rounded grains of the minerals magnetite and ilmenite, which are firmly cemented together. Chemical analyses of the ore reveal a high titanium content.

The textural character of the ore, the irregular nature of the bedded deposit, and the layered structure of the overlying ferruginous sand and clay, as well as the chemical composition of the ore, all indicate that the deposit is a sedimentary black sand, now compactly cemented together.

Economic aspect. The ore from this property contains, according to the analyses, about 50 per cent metallic iron, about 23 per cent titanium dioxide (which is extremely high), 0.01 to 0.18 per cent phosphorus, but not very much sulphur. The ore is, therefore, a titaniferous iron ore, at present of no commercial importance. Both the Rothert Process Steel Company of Seattle, and the Bilrowe Alloys Company of Tacoma have experimented upon this ore and have made titanium steel through their own special processes, but they have not succeeded in a commercial manufacture of the metal.

ANALYSES OF ELMA IRON ORE, GRAYS HARBOR COUNTY

A, B. Titaniferous iron ore (consolidated black sands) from Sec. 28 T. 18 N., R. 5 W., near Elma.

A. Analysis by Bennett's Chemical Laboratory, Tacoma.

B. Analysis by Professor R. P. Cope, Department of Chemistry, State College of Washington, (1922). Jenkins and Cooper, collectors.

	A	B
Iron (Fe)	50.93†	50.02
Silica (SiO ₂)	1.38	0.80
Alumina (Al ₂ O ₃)	3.00	.....
Lime (CaO)	0.06	.....
Magnesia (MgO)	1.13	.....
Manganese (Mn)	0.08	.....
Phosphorus pentoxide (P ₂ O ₅)	0.01	0.18
Sulphur (S)	0.077	0.062
Titanium dioxide (TiO ₂)	24.12	22.23

†The iron was originally recorded as FeO, 65.54.

MISCELLANEOUS ANALYSES OF IRON ORES FROM GRAYS
HARBOR COUNTY

BLACK HILLS

(Exact location not recorded)

A₁-A₃. Analyses by E. Fulmer. Shedd; Iron Ores of Washington. Wash. Geol. Survey, Ann. Rept., Vol. 1, (1901).

A₁, A₂. Float, apparently nodules of consolidated black sand.

A₃. Black sand.

	A ₁	A ₂	A ₃
Iron (Fe)	52.31	48.18	43.72
Alumina (Al ₂ O ₃)	1.06	0.20	11.65
Manganese oxide (Mn ₂ O ₃)	0.14	0.23	0.18
Phosphorus pentoxide (P ₂ O ₅)	Tr.	.....	.....
Insoluble residue	13.04	25.02	24.14

MISCELLANEOUS IRON DEPOSITS

There are a number of places in the State in which iron ore deposits are thought to exist, but upon examining the localities no ores of importance were found. There are, for example, a number of places where black sands occur, which are of no commercial importance.

Bog iron deposits are probably present in small amounts in nearly every county in the State. It was reported that iron ore was present in a certain locality on Lopez Island. On examination, however, nothing was found save serpentine rock.

A highly siliceous iron-manganese ore occurs above Lake Cushman in Mason County. It has been shipped to Bilrowe Alloys Company of Tacoma, and ferro-manganese has been made from it, experimentally. This ore, therefore, would be of more importance in relation to the manganese problem than simply to the iron industry.

According to various reports there may be other hematite deposits in Stevens County, especially in regions of the Huckleberry Mountains, west of Chewelah. It is also reported that there are other magnetite deposits on the Middle Fork of the Snoqualmie River.

ANALYSES OF IRON-MANGANESE ORES FROM MASON COUNTY
LAKE CUSHMAN DISTRICT

A₁-A₆. Analyses by E. Fulmer. Shedd; Iron Ores of Washington, Wash. Geol. Survey, Ann. Rept., Vol. 1, (1901).

A₁. Ore from cabins.

A₂, A₄. Ore from Pomeroy mine, 4,000 feet above river.

A₃, A₅. Ore from Hoodsport mine.

	A ₁	A ₂	A ₃	A ₄	A ₅	A ₆
Iron (Fe)	16.34	19.25	4.13	10.66	10.20	13.70
Insoluble residue	24.20	70.50	19.04	27.39	11.64	29.35
Alumina (Al ₂ O ₃)	8.00	0.65	6.91	2.33	1.24	.....
Calcium carbonate (CaCO ₃)	11.28	1.13	6.00	49.16	70.34	36.91
Manganese oxide (Mn ₂ O ₃)	27.14	0.32	42.58	5.18	1.58	4.18
Phosphorus (P)	0.13	Tr.	0.21	0.16	0.16	0.20

CONCLUSIONS

ORIGIN OF THE IRON ORES

Of the twenty-five iron deposits described as occurring in the State of Washington, sixteen are composed largely of magnetite, one of titaniferous magnetite (cemented "black sand"), five of limonite (brown ore), two of hematite, and one of pyrrhotite.

The ores have originated in a number of different ways, which may be summarized as follows:

(1) Sedimentary deposits.

Bog ores, located in various places including the following:

Little Rock, Thurston County.

Irondale, Clallam County.

Arlington, Snohomish County.

Lynden, Whatcom County.

Placer deposits of black sands, subsequently cemented.

Dennis property, Elma, Grays Harbor County.

Sedimentary deposits, subsequently metamorphosed.

Iron Mountain, Hamilton, Skagit County.

Durrwachter property, Cle Elum, Kittitas County.

(2) Residual deposits.

Deep Lake District, Leadpoint, Stevens County (also a replacement deposit).

Clugston Creek district, Colville, Stevens County (also a replacement deposit).

Kulzer property, Valley, Stevens County (also a replacement deposit).

Hematite group, Sumas Mountain, Whatcom County.

(3) Laterite deposit (in part residual and in part sedimentary), subsequently metamorphosed.

Camp Creek deposit, Cle Elum, Kittitas County.

(4) Replacements in limestones, probably from ascending solutions.

Hill property, Valley, Stevens County.

Deep Lake district, Leadpoint, Stevens County (for the greater part a residual deposit).

Clugston Creek district, Colville, Stevens County (for the greater part a residual deposit).

(5) Contact metamorphic deposits.

Read property, Hunters, Stevens County.

Napoleon mine, Stevens County, near Boyds, Ferry County.

Copper Key, Oversight, and Belcher Mines, near Curlew, Ferry County.

Neutral-Aztec and McLean properties, Chesaw, Okanogan County.

Guye and Denny properties, near Snoqualmie Pass, King County.

Anderson property, Baring, King County.

Williams-Smith property, Miller River Station, King County.

(6) Magmatic segregation deposits.

Fuller property, Pateros, Okanogan County.

Rothert and McCarthy properties, Blewett, Chelan County.

Since the iron ores in the State occur in such a variety of ways, the quality of the ores and the size of the ore bodies will have no uniformity. Of these various types of deposits, the contact metamorphic is the most usual; while the lateritic, subsequently metamorphosed, contains the deposit of greatest size.

MINERAL COMPOSITION OF THE IRON ORES

The most important iron ore, *hematite*, is only sparingly represented in the State of Washington. The best grade is found on the Hill property in Stevens County, where its extent is unknown, but is probably very limited.

Magnetite, which is of less commercial importance than hematite, represents the content of the greatest number of iron deposits in the State. Most of the bodies of magnetite are irregular in shape and of undependable content. In some places the ore may be very high grade and in other places very low. An exception to this rule is represented by the deposits north of Cle Elum on Camp Creek.

The brown ores, of much less commercial importance than hematite, composed principally of *limonite*, may be

classed in two distinct groups—*residual* and *bog*. Of these, the residual is of greater importance, both in quality and quantity in Washington. The largest deposits of limonite in the State appear to be those in the region of Deep Lake, Stevens County. A little carbonate ore is present there, too, but it will probably not prove to be of particular commercial importance unless new and larger deposits are found.

QUALITY OF THE IRON ORES

The quality of the iron ores of Washington has in general been found to be fair. A number of the ores, however, are too high in phosphorus to be used in the manufacture of steel by either the acid Bessemer or acid open hearth processes, though they would still prove suitable for use in the basic open hearth or electric furnace. The high sulphur content of some of the ore bodies would undoubtedly disqualify the ore for use in the steel industry. The high sulphur ores, however, might be made of commercial importance indirectly, through use for special purposes, such as fluxes, etc.

The quality factor, then, while probably barring certain deposits from use in the steel industry, would not necessarily mean complete prohibition of their economic use.

QUANTITY OF THE IRON ORES

It is not possible to determine how much iron ore there is in the State of Washington, with the present available data and with any field work one might do without actually prospecting and drilling the various properties. It is safe to say, however, that most of the deposits are irregular in shape, and quite limited in size. A relative idea of these quantities has been presented on the summary table of the iron ores of Washington, presented on the accompanying map of the State in the columns — *known*, *probable*, and *possible*. We know of,

or are quite sure of finding, at least 815 thousand tons of iron ore in the State. It is quite probable that there are nearly 3 million tons available from all of the deposits. There is a possibility that 7 or 8 million tons might be found to exist if intelligent mining were carried on to the limit. This is not enough iron ore, however, to maintain an iron and steel industry of any considerable size in the State of Washington.

ACCESSIBILITY OF THE IRON DEPOSITS

The deposits of iron ore are scattered over the State. The greatest number, and those of the largest size, are located in Kittitas, Stevens, Okanogan, King, and Skagit counties. Some of the deposits are located near the railroad, and some in the mountains a number of miles away from transportation. These features are brought out clearly on the summary table printed with the map of the State. This irregular occurrence of the iron ore is an unfavorable feature of the problem.

SUMMARY OF CONCLUSIONS

In summing up the various features of the iron ores of the State, we find that we must come to the following conclusions in regard to the possible establishment of an iron and steel industry in the State:

(1) That there is not enough iron ore in the State, so far as known at present, to warrant the establishment of such an industry to depend upon these deposits alone.

(2) That the principal iron ores in the State are magnetites and limonites, which are not as desirable in the iron industry as hematite.

(3) That the ores vary greatly in composition on account of occurring in so many different types of deposits, hence a uniform grade for an iron industry would be hard to maintain.

(4) That most of the ore would have to be shipped long distances.

It is quite possible, however, for these iron ores to be used locally in various industries other than those of iron and steel manufacture.

PART II

Coke and Limestone of Washington

With Special Reference to Their Use as a Fuel
and a Flux In the Iron and
Steel Industry

COKE AND LIMESTONE OF WASHINGTON

WITH SPECIAL REFERENCE TO THEIR USE AS A FUEL AND
A FLUX IN THE IRON AND STEEL INDUSTRY

BY
S. SHEDD

FURNACE FUELS

In the manufacture of iron, fuel constitutes one of three essentials. The fuels used are coke, charcoal, anthracite, and raw coal.

COKE

Coke is a light porous fuel produced by the distillation of mineral coal containing enough bituminous matter so that when heated to a certain temperature the whole mass cakes or cements together. This process of distillation drives off practically all the volatile matter and leaves nothing but the non-volatile parts of the coal. These consist mainly of the carbon and the ash of the coal. Coke may be made from lump coal, mine run, or washed slack. Metallurgical coke is made either in bee-hive or by-product ovens, the former producing about 75 per cent of all the coke made in this country at the present time.

The yield of coke is higher with the by-product oven than it is with the bee-hive oven and a wider range of coals can be used and coked in the former than in the latter. In some few cases, however, coals that can be successfully coked in the bee-hive ovens swell so much during the operation of distillation of their volatile matter, that it is impossible to push the coke from the by-product oven.

In physical structure coke may be porous and light, or dense and heavy. It may be hard and capable of sustaining a heavy load, or it may be soft and easily crushed. Whether hard or soft, it may be brittle and tend to break up easily into small pieces. Strong coke, when struck, gives a clear ringing sound, while soft coke gives a dull sound. There is also much variation as regards the ease with which different cokes ignite and enter into combustion.

The cellular structure of coke is one of the main advantages it has over other forms of furnace fuel, and within certain limits, other things being equal, the more porous the coke the better it is as a fuel. Of course, there is a limit to the advantage gained by this porosity, and that is reached when the cells are so developed as to weaken the cell walls to such an extent that the coke will crush in the furnace.

CHARCOAL

This is a very satisfactory furnace fuel, on account of the fact that it is practically free from sulphur, phosphorus, and very low in ash. In coke, the ash consists largely of silica and must be fluxed with some base, while in charcoal it is largely lime and alkalies, and supplies a part of the flux needed to combine with the gangue of the ore.

There are two general classes of woods from which charcoal is made. These are designated as "hard," and include such woods as oak, hard maple, hickory, and woods of this general character, or "soft," such as fir, pine, etc. The character of the charcoal made from these two grades of wood is somewhat different. That made from hard wood is heavier and harder, and hence better suited as a furnace fuel.

Charcoal is very porous and can therefore be burned rapidly per square foot of hearth area. While charcoal

is a splendid fuel in some ways, it has one or two serious drawbacks. In the first place, it is very doubtful whether it has the physical strength necessary to withstand the conditions in a large furnace. In the second place, the difficulty of obtaining an adequate supply of cord wood for a large charcoal industry, is a very serious one and one that practically prevents the use of charcoal. In Washington there is practically nothing but soft wood from which to make charcoal, and this, as already stated, makes a poorer charcoal than hard wood.

ANTHRACITE COAL

Good anthracite coal has about the same chemical composition as coke, and is simply bituminous coal from which the volatile substances have been distilled off in nature by heat and pressure developed as a result of geological movements in the earth's crust. Anthracite is very different in texture from coke, being very compact instead of porous. This makes the surface exposed per unit of weight much less than it is in coke, and this reduces the output of a given furnace much below what it would be if coke were used in place of anthracite. The above is only one of several things that make anthracite less desirable than coke, but it is not necessary to consider these others here. Anthracite at one time, in certain localities, was used to a considerable extent as a furnace fuel, but as the coke industry was developed and coke proved to be a better furnace fuel than anthracite, and as the use of anthracite for other purposes increased and caused the price to advance, the anthracite iron industry gradually declined until at the present time there are only a few places where anthracite is used exclusively as a fuel.

RAW COAL

Bituminous coals may be separated into two somewhat distinct groups, and are designated as coking and

non-coking coals. The non-coking coals may contain a normal amount of volatile matter, but are free, or almost so at least, from tarry ingredients. On account of this fact, this grade of bituminous coal has been used as a furnace fuel. The fact that these coals lack porosity and hence are comparatively slow burning, has probably been one of the main reasons for the decline in the use of this coal as a furnace fuel. Then again, while these coals are comparatively free from tarry substances in the majority of cases, they are not absolutely free from this material and as it takes only a very small amount of such matter to cause trouble in the furnace, this has caused a gradual decline in the use of bituminous coal as a furnace fuel.

COKE AS FURNACE FUEL

Coke has many of the most desirable qualities of a furnace fuel. When made from good coal, it usually occurs in large lumps, which is one of the very desirable qualities of a furnace fuel. Coke as a general thing has sufficient strength to resist breaking, while being charged into the furnace and not crush when subjected to the weight of the charge in the furnace. On account of its cellular structure a large amount of surface is exposed per unit of weight, and on account of this a large amount of coke may be burned in a given time, giving a large amount of heat and allowing rapid operation of the furnace.

PHYSICAL PROPERTIES

By some the question of strength of the coke is considered the quality of greatest importance. W. B. Phillips¹ makes the following statement in regard to this point: "If there is any one quality of coke which is of greater importance than any other to the iron maker, it is strength. The coke must be strong enough to bear the grinding and torsional strains to which it is subjected during its descent in the furnace. It grinds upon itself and is also, and to a much greater extent, ground by the ore and the limestone. The dust made in this manner is lighter than the dust from the ore and stone and is carried away by the blast and deposited in the dust-catchers.

"Some coals do not yield a strong coke unless they are pulverized. Whether this is due to the nature of the ash, its irregular distribution, the relation between the coking and non-coking constituents of the coal, or to a number of causes acting among themselves, is not known. When such coals are pulverized they often make good coke. The composition of the ash may also affect the

¹Iron Making in Alabama, (3d edition) Geol. Survey of Alabama, (1912), p. 129.

size and shape of the cells and the thickness of the cell walls, for it is obvious that as the fusibility of the ash depends upon its composition, the reaction between the ash and the carbon is also a function of its composition. But of such matters not much is known."

After a long series of washing and coking tests made on coals from various parts of the United States, Moldenke, Belden, and Delamater¹ drew the following conclusions:

"No data are given in the detailed statement for compressive strength or height of furnace burden supported, as the results obtained show conclusively the worthlessness of these determinations. This conclusion was reached after careful attempts to obtain results on 1-inch cubes. Four cubes were selected from each coke made, care being taken to obtain pieces with no fracture and representing as nearly as possible the average of the coke. The cubes were cut by means of an emery wheel and guide, and although by no means perfect, they were as nearly so as possible and always the two sides used in the machine were parallel. The machine used for breaking was a Tinius Olsen patent machine of 10,000 pounds capacity, and gave direct readings of the ultimate strength.

"Only a few of these results, taken at random, are given, and these only to show their great variation and the worthlessness of this method of drawing conclusions. Illinois No. 16, test 10: 910 pounds, 1,330 pounds, 2,190 pounds, and 2,270 pounds; Indiana No. 4, test 6: 640 pounds, 790 pounds, 1,060 pounds, and 1,245 pounds; Kentucky No. 1, test 76: 880 pounds, 1,065 pounds, 1,920 pounds, and 2,570 pounds; Ohio No. 9, test 94: 535 pounds, 890 pounds, 1,170 pounds, and 1,600 pounds; Virginia No. 1, test 68: 740 pounds, 1,120 pounds, 1,280 pounds, and

¹Washing and Coking Tests of Coal and Cupola Tests of Coke. U. S. Geol. Survey, Bull. No. 336, (1908), pp. 45-47.

2,060 pounds; West Virginia No. 16, test 49: 520 pounds, 1,500 pounds, 1,780 pounds, and 2,100 pounds.

“The difficulty of obtaining a cube, or any number of cubes to represent anything more than the piece of coke from which it is taken is so apparent that results pretending to show compressive strength of any amount of coke are worse than useless—in fact, misleading. Even if coke is selected the whole height of the charge and tests are made on cubes in number representing the number of inches, the results still show only the strength of the one piece of coke from some particular part of the oven and it is practically impossible to procure even approximately similar results from other pieces taken from different places. The condition of burning, the quenching either inside or out, and any number of factors which it is not possible to know, much less control, make different portions of the same oven vary greatly.

“A simple calculation will show that coke with a compressive strength of 48 pounds will support the burden of any modern furnace; consequently this test gives no data of practical value. Moreover, there are so many other factors, such as action of heat and gases, attrition of coke against coke, against other ingredients of charge, and against the side walls, etc., that any calculation to show the burden-bearing capacity of the coke, even if it were possible to select cubes representing the whole charge, would be inaccurate if based simply on a compression test.

“The yield of coke appears to be increased and the amount of breeze reduced by preliminary crushing. Whether there is a limit to the degree of fineness, or whether a point may be reached beyond which finer crushing gives no appreciable improvement or has opposite effects, can not be determined from the present results; but the data available indicate that it would be economical to crush all coal before charging into the ovens, even

though a coke of good quality may be obtained without this preliminary treatment. Fine crushing also appears to increase the strength of the coke and make the fracture less irregular, by the greater uniformity and distribution of the ash, but the weight per cubic foot is reduced. The strength of the coke is probably influenced by the amount, composition, and distribution of the ash, but the results so far obtained show no definite relations between these factors or their relative importance.

“The matter of investigating the action of CO_2 on red-hot coke as determining its value for furnace work was thoroughly considered. The conclusion was reached that it was of no practical importance, as there are so many other factors in the blast furnace. In view of the fact that the gases in the furnace are mixtures of CO_2 , CO , H , O , N , water vapor, and probably others, it appears that action of CO_2 is of little value unless the action of these other gases, either independently or in connection with CO_2 is known. An investigation of the action of CO_2 on red-hot coke, as a means of making comparison of hardness, is being made and gives evidence of yielding some positive results, but work along this line has not progressed far enough to draw any definite conclusions.

“The loss of sulphur from coal to coke by volatilization varies with the different coals, depending on several factors, among which, in the order of their importance, are the condition in which sulphur exists in the coal, the heat of the oven, the rapidity of coking, and watering. The sulphur loss ranged from 20.79 per cent on Arkansas No. 1 (test 95) to 63.07 per cent on Illinois No. 29 (test 170), the average for all tests being 43.27 per cent.”

Mr. William Hutton Blauvelt¹, in an article published in the Transactions of the American Institute of Mining

¹The By-product Coke Oven and Its Products, Transactions Am. Inst., Min. and Met. Eng., Vol. LXI, (1919), pp. 442-444.

and Metallurgical Engineers, has the following to say in regard to quality of coke:

“The physical structure of the coke is quite as important as its chemical composition. It is the physical structure which gives coke its advantage for metallurgical work over other forms of solid fuel, and it is important that the structure should be adapted to the conditions under which the coke is to be used.

“The blast furnace is the great coke consumer. In the days of the bee-hive oven one kind of coal gave a coke with a certain physical structure, and another coal gave another structure. Furnaces either adapted their practice to the coke, or changed their coke supply. Coke was recognized as hard or soft, porous or dense, and that was about all that was known regarding physical structure.

“Mr. Brassert says in his paper on ‘Modern American Blast Furnace Practice,’ read in 1914, that ‘the early coke produced in our byproduct ovens, even from the same coals as were successful in the beehive oven, burned too slowly and made our furnace operations exceedingly difficult, by preventing rapid and continuous movement of the stock. The lack of knowledge and experience along these lines was responsible for the slow progress attending the introduction of byproduct ovens in this country.’ The economy of the byproduct oven practically forced its adoption by the furnace operators, and for several years, as Mr. Brassert states, ‘at a number of American plants byproduct coke has been made which rivals in quality our best beehive product.’

“The byproduct oven, with its variable mixtures of coals, variable heats, coking time, width of oven, fineness of coal charged, and other controlling factors, permits a control of coke structure formerly impossible. The problem is to determine, first, what is the structure best adapted to standard furnace practice, while recognizing

that special practice requires modifications of structure; second, what conditions are necessary to produce it.

“Notwithstanding the general acceptance of Gruner’s theory of ideal combustion in the furnace, the production of a high thermal head at the tuyeres is of the first importance, and the best coke is that which reaches the tuyeres in proper condition to produce the highest temperatures in the tuyere area, and in just sufficient quantity to do the amount of work required there under the conditions produced at this maximum temperature.

“The ideal coke is one that will descend through a furnace shaft to the combustion zone in front of the tuyeres with the least loss from attrition and oxidation, and when it arrives there will burn at the highest possible rate. Of course, these are paradoxical qualities. However, Mr. Walter Mathesius points out in his interesting paper on ‘Chemical Reactions of Iron Smelting’ that ‘modern American coke-oven practice has made enormous strides toward approaching this apparently paradoxical ideal.’ He stated that this is accomplished by producing coke with an open-cell structure, in which the cell walls themselves are amply strong and well protected by a graphitic coating.

“The time of contact of the blast with the coke in the tuyeres area can be only a few seconds and the speed of any chemical reaction decreases as the relative quantities of reacting and resulting substances approach equilibrium. Therefore, the farther these relative quantities remain from the status of equilibrium, the higher the rate of resultant combustion. With the facts now before us, I am disposed to believe that we, in seeking to produce the best blast-furnace coke, should aim to produce an open-cell structure, with cell walls strong and hard. Later experience may, however, show that there are other requirements that are not now known to us. It is not necessarily true that the open-cell structure is the same

thing as a high percentage of cell space. The advantage of an open-cell structure is that it gives the oxygen of the air easy access to the carbon. It is entirely possible that a coke of very fine cell structure, having say 50 per cent of cell space, might offer less surface for prompt combustion under practical conditions than another coke containing larger cells but having the same percentage of total cell space.

“The composition of the cell wall, which it is agreed should be hard, thin, and strong, and, according to Mr. Mathesius, covered with a graphitic coating that is smooth and bright, is a much more complicated matter. What are the conditions of coal mixture and coking which produce this kind of wall? I think we have not yet found the answer to this question, although we know some of the conditions that are favorable to this result. The coal mixture, the degree of fineness of grinding, the coking time, and the heats are probably all factors.

“Our search for the best coke structure to meet a given set of furnace conditions is not an easy one, but we know better which path to start on than we did even a few years ago. Are we not agreed on the following points at least?

1. The coke must be hard.
2. It must have an open-cell structure; that is, cells of good size and approximately 50 per cent. of cell space.
3. It must have a high rate of combustibility.

“Can we add anything more to this list? Some investigators have concentrated their comparisons on the rate of combustibility, but I cannot believe that this test alone is sufficient to determine the best coke structure, because it ignores one of the sides of the paradox. While the best coke must burn rapidly at the tuyeres, it must also resist attrition and oxidation during its descent in the furnace. Good-sized cells and a good percentage of cell space, coupled with a hard structure, would seem to

give a coke corresponding to Mr. Mathesius' definition. Testing the rate of combustion has been a help to us, and I hope we will find a test for hardness of structure better than the crushing of the 1-inch cube specimens, over which so much time used to be spent in the days when John Fulton wrote his book on 'Coke.' "

CHEMICAL COMPOSITION

This is also an important factor in determining the value of coke as a furnace fuel.

The impurities that are most important in this connection are sulphur, ash, and phosphorus. The amount of sulphur in a coke depends on the amount of sulphur in the coal from which the coke was made. In the process of distillation a part of the sulphur is vaporized and lost, but a considerable part goes into the coke. The amount of sulphur varies from about 0.4 per cent in the best cokes up to as much as 2.5 per cent in the poor grades of coke.

The amount of ash in a coke is an important factor in determining its value as a furnace fuel. This comes from the coal, is largely silica, and varies from about 5 per cent in the very best grades of coke to as high as 22 to 25 per cent in the poorest grades of coke.

The ash not only cuts down the percentage of fixed carbon in the coke, but also makes it necessary to use enough additional limestone to flux this silica and remove it in the slag.

The amount of phosphorus in the coke, while usually low, is very important because it all goes into the iron. The amount of phosphorus allowable, however, depends on the grade of iron to be made, the amount of phosphorus in the ore, and in the limestone being used as a flux. In some grades of iron the maximum amount of phosphorus allowable is as low as 0.03 to 0.04 per cent and in these cases the amount of phosphorus in the coke is very important.

WASHINGTON COAL

The coal of this State varies much and ranges from sub-bituminous to anthracite. In general the nearer the main axis of the Cascade Mountains is approached the higher the percentage of fixed carbon as compared with volatile hydrocarbon. This is due probably to the different conditions that have prevailed in these different parts of the state in times past. The distribution of the different kinds of coal in Washington is shown on the map which forms Plate I of this report. The data for the distribution and kinds of coal in each area were taken from a map furnished by George Watkin Evans, Consulting Mining Engineer, 2207 Smith Building, Seattle, Washington.

IMPURITIES IN COAL

The principal impurities in Washington coals which have a marked effect on the quality and commercial value of the coal are ash, sulphur, and moisture. Bituminous coal, for instance, may be good or poor depending on the percentage of impurities; and the same is true as regards other kinds of coal.

SULPHUR

The amount of sulphur in the Washington coals varies considerably, but on the average is not especially high. Analyses¹ of about 290 samples of coals from this State show a maximum of 6.7 per cent of sulphur and a minimum of 0.23 per cent. Only a few of these coals, as shown by these analyses, have more than 1.9 per cent of sulphur, while a very large number have from 0.4 to 0.6 per cent, and the average is probably about 0.5 per cent.

MOISTURE

Moisture is present in greater or lesser amounts in coals, varying not only in the different kinds of coal, but

¹Smith, E. Eggleston, Coals of the State of Washington, U. S. Geol. Survey, Bull. 474, pp. 41-75.

also in various grades of the same kind of coal. According to the analyses already cited the Washington coals show a maximum of about 32.1 per cent, and a minimum of 2.4 per cent.

ASH

The amount of ash in a coal has much to do in determining its quality and hence its market value. On account of this the question of reducing the amount of ash in the process of mining the coal and preparing it for market is given very careful consideration.

The ash in a coal comes from various sources. All vegetable matter contains more or less mineral matter and this goes into the coal and constitutes a part of the ash. Sediment is supplied in various ways to the bog or marsh in which the organic matter is being accumulated, and this would be intimately mixed with the organic matter, and later with the coal, and cannot be separated from it.

This sediment may be brought into the marsh from the adjacent land area by the wind or by streams that flow into it. It is usually very fine and is deposited in the interstices between the particles of the organic matter as they accumulate in the marsh or bog.

Thin partings of mineral matter often occur in coal beds, and if these are not removed in the preparation of the coal for market, they will form a part of the ash of the coal. These thin layers of mineral matter may result from a change in condition such that for a certain period of time the amount of sediment carried in suspension and deposited in the marsh or bog is in excess of the rate at which the coal is forming. In other cases conditions may change so that for a period of time the organic matter completely decays, leaving the inorganic material to accumulate in a layer free from vegetable matter.

In many cases the amount of ash in a coal as marketed depends to a considerable extent on the character

and condition of the rocks above and below the coal. In some cases these rocks are but little indurated and it is very difficult to mine the coal without getting more or less rock with it. Much of this, however, may be removed by screening and washing.

The amount of ash in the coals of Washington as shown by the analyses mentioned above varies from a maximum of 77.3 per cent to a minimum as low as 3.67 per cent. On the average Washington coal is high in ash.

WASHINGTON COKE

Washington has coal deposits of considerable extent that have the properties requisite for coking. They occur along the western slopes of the Cascade Mountains in Whatcom, Skagit, King, Pierce, and Lewis counties; while on the eastern slope coking coal occurs in the Roslyn field in Kittitas County.

The coke manufactured in Washington in the past has been largely bee-hive oven coke; but some by-product coke has also been made. In 1918, according to statistics¹, the amount of bee-hive coke produced in Washington was 93,659 short tons, while the by-product coke for the same year was 30,129 short tons. Statistics for 1921, furnished by the State Mine Inspector, show a very marked decrease since 1918; and at present the by-product coke is about all that is produced. The total production for 1921 was 48,507 tons, and of this total, 44,012 tons were produced by one company as a by-product. These figures show the relative importance of these two kinds of coke as far as Washington is concerned.

The bee-hive ovens used in Washington are of the ordinary type, in some cases using mechanical chargers and unloaders; but in most cases hand methods are in use. The product is mostly 48 and 72 hour coke.

A few chemical analyses² of Washington coke are given here to show its composition as compared with coke from other parts of the United States, which is being used as a furnace fuel.

ANALYSES OF WASHINGTON BEE-HIVE COKE

	Moisture at 105° C.	Volatile Matter	Fixed Carbon	Ash
Wilkeson.....	0.76%	1.96%	79.58%	18.67%
	0.72	2.51	78.20	18.27
	0.70	1.25	77.70	20.54
	0.78	1.53	77.71	20.98
Carbonado.....	1.12	2.81	79.21	16.86
	0.55	1.25	78.44	19.76
Fairfax.....	0.52	1.25	79.49	18.74
	0.07	1.04	80.49	18.40
	0.18	1.35	79.47	19.00
	0.09	1.01	80.49	18.41

¹Mineral Resources of the United States in 1919, (Preliminary Summary), p. 48.

²Daniels, Joseph: The Coking Industry of the Pacific Northwest, University of Washington, Engineering Experiment Station, Bull. No. 9, (1920), pp. 14-15.

ANALYSES OF WASHINGTON BY-PRODUCT COKE

	Moisture at 105° C.	Volatile Matter	Fixed Carbon	Ash
Seattle plant	0.39%	0.63%	89.50%	18.48%
	0.40	1.00	89.00	18.60
	0.25	1.45	78.40	19.90
	0.10	3.58	77.61	18.71

Experimental tests were made by the United States Bureau of Mines in its plant at Denver on the coking of coal from Carbonado and Roslyn with the following results¹:

ANALYSES OF COKE FROM CARBONADO AND ROSLYN COAL

	I.	II.
Moisture	0.64 - 2.40	0.03 - 0.43
Volatile matter	1.83 - 2.42	0.71 - 2.81
Fixed carbon	70.42 - 79.45	76.80 - 80.89
Ash	16.32 - 26.17	18.27 - 20.18
Sulphur	0.52 - 0.66	0.44 - 0.60
Phosphorus	0.118 - 0.122	0.048 - 0.058
Physical properties of coke—		
Specific gravity:		
Apparent	0.89 - 0.96	1.03 - 1.10
Real	1.89 - 1.94	1.97 - 1.99
Volume		
Coke—per cent	47.00 - 50.00	53.00 - 55.00
Cells—per cent	50.00 - 53.00	45.00 - 47.00
Weight per cubic foot.....		
Wet pounds	87.25 - 91.48	92.54 - 96.55
Dry pounds	54.18 - 60.08	63.25 - 68.47

I. Fifty-one hour test on washed, finely crushed Roslyn coal.

II. Forty-four hour test on washed, finely crushed Carbonado coal.

The Connellsville coke has long been considered the standard coke manufactured in the United States and chemical analyses of two samples of this coke are given here.²

CHEMICAL ANALYSES OF CONNELLSVILLE COKE

	I.	II.
Proximate analysis†		
Moisture	0.23	0.19
Volatile combustible	1.32	0.51
Fixed carbon	88.18	89.60
Ash	10.27	9.70
	100.00	100.00
Sulphur .....	.81	.63
Phosphorus .....	.017	.009
Specific gravity of the coke substance.....	1.90	1.90
Apparent specific gravity of the coke.....	1.00	1.00
Percentage of porosity.....	47.00	47.00

†Analysis of sample as received.

¹Belden, A. W., Delamater, G. R., Groves, J. W., and Way, K. M., *Washing and Coking Tests of Coal*, U. S. Bureau of Mines, Bull. No. 5, (1910), pp. 46-48.

²Report on the Operations of the Coal-Testing Plant of the United States Geological Survey at the Louisiana Purchase Exposition, St. Louis, Mo., 1904, U. S. Geol. Survey, Professional Paper, No. 48, (1906), Part I, p. 265.

- I. Standard Connellsville 72 hour coke.
 II. Standard Connellsville 48 hour coke.

The following analyses show the range in composition of cokes from various parts of the United States¹:

	I.	II.
Moisture	0.23-0.91	0.22-1.67
Volatile matter .....	.29-2.26	.11-1.60
Fixed carbon	92.53-80.84	92.44-76.87
Ash	6.95-15.99	7.23-19.86
Sulphur .....	.81-1.87	.61-2.45

	III.	IV.
Moisture	0.16-1.52	0.07-0.60
Volatile matter .....	.80-1.67	.46-2.35
Fixed carbon	93.24-88.52	95.47-84.09
Ash	5.80-8.29	4.00-12.96
Sulphur .....	.42-1.02	.53-2.26

- I. Range of composition of Pennsylvania cokes.
 II. Range of composition of Tennessee cokes.
 III. Range of composition of Virginia cokes.
 IV. Range of composition of West Virginia cokes.

CONCLUSIONS.

The above analyses give the composition, not only of Washington coke, but of some of the best grades of coke from various parts of the United States. A comparison of these tables shows that the Washington coke is especially high in ash. In very few cases is it as low as 16 per cent, while in most of the analyses given it is above 18 per cent. This is about 8 to 10 per cent higher in ash than Connellsville coke, and the percentage of fixed carbon is considerably lower than it is in the better grades of coke.

The amount of sulphur and phosphorus in Washington coke is not high and it will compare very favorably in this regard, so far as determined, with the best grades of coke.

¹Moldenke, Richard; The Coke Industry of the United States as Related to the Foundry, U. S. Bureau of Mines, Bull. 3, (1910), pp. 29-30.

The physical properties of Washington coke have not been very carefully studied, but the indications are that in this respect Washington coke would be a fairly satisfactory furnace fuel.

The most objectionable features of coke, as a furnace fuel, made from Washington coal, are its high percentage of ash, and the fairly high percentage of volatile matter. The latter, in all probability, can be easily reduced in the process of manufacture of the coke. The question of the ash, however, is a much more serious one. This might perhaps be slightly reduced by very careful washing and preparation of the coal before it is coked. It is doubtful, though, whether, even with the greatest of care in the preparation, the amount of ash can be reduced very materially. This high percentage of ash in Washington coke is the worst feature about it and the one that will be most detrimental to its use as a furnace fuel.

FURNACE FLUXES

INTRODUCTION

In actual practice only two bases are ever used as a blast furnace flux. These are lime and magnesia. These are used partly on account of the fact that they occur in nature in such great abundance and far exceed all other alkalies or alkaline earths put together. They also occur widely distributed on the surface of the earth. Another reason why they are used is because they, especially lime, are among the most powerful chemically of all the bases. Lime is often used alone, but never magnesia. This is due partly to the fact that lime, practically free from magnesia, occurs in large quantities in nature, but large quantities of magnesia free, or practically so, from lime occur so seldom that it would be many more times expensive than lime. Another reason for using limestone is that it is generally considered much more active chemically than magnesia.

ORIGIN OF LIMESTONE

Limestones are of two general classes as far as the way in which they have been formed is concerned. First, those which have been formed as a result of chemical precipitation from solution, and second, those which have been formed through the accumulation of shells or skeletons of organisms that secrete calcium carbonate as tests or skeletons. Most limestones, however, are of organic origin and have been formed in the ocean, being laid down under water of varying depths and at varying distances from the shore.

Limestones vary both in chemical composition and in general appearance. In many cases the physical appearance is an indication of the chemical composition. Conditions under which limestones have been formed have varied more or less and as a result of this the limestones vary in composition and appearance. In some cases the

physical appearance is due to changes in the limestone after deposition, as in the case when metamorphism takes place as a result of the application of heat and pressure. In such a case the limestone is changed to a marble. The two rocks may be exactly the same, chemically, but in the limestone the calcium carbonate is more or less amorphous, while in the marble it is distinctly crystalline and occurs as crystals of calcite in a calcareous cement. In chemical composition limestones differ much. In cases where they have been formed near shore, or at least under shallow water conditions, a considerable amount of land derived material may be accumulated with the calcium carbonate and a shaly or argillaceous limestone would be formed. In the case of limestones formed farther from shore and in deeper water, where the water is clearer, much less in the way of impurities would be formed in it. Limestones formed under these different conditions would differ both chemically and physically.

COMPOSITION

Limestones are made up mainly of calcium carbonate with greater or lesser amounts of other substances, such as magnesia, silica, alumina, and iron. When pure, it should contain 56 per cent lime (CaO), and 44 per cent carbon dioxide (CO_2); and it is expressed by the formula CaCO_3 , and is a calcium carbonate. Deposits in which the composition approaches closely the formula given above are not very common, however, and when well situated are valuable commercially on account of the growing demand for certain purposes where the purity is an essential property. It should not be inferred, however, that only the perfectly pure limestones are of commercial value. In many cases the impurities that occur in the limestone make it valuable for certain purposes. The argillaceous material, for instance, in some limestone makes it valuable in the manufacture of cement.

Magnesia is one of the very common impurities found in limestone, and may vary from a trace to almost any amount. When a limestone contains 21.7 per cent magnesium oxide (MgO), 30.4 per cent calcium oxide (CaO) and 47.9 per cent of carbon dioxide, it is considered a dolomite. Magnesia, while considered detrimental for some purposes, is beneficial for others.

From the above it must be plain that the value of a limestone does not depend always on its purity, but may depend as much on the fact that it is impure. When the sum of the silica, alumina, and iron is more than 36 per cent, it is not usually called a limestone, but is spoken of as a calcareous shale.

USES

Limestone is used very extensively for many purposes, such as the manufacture of lime, the manufacture of cement of various kinds, metallurgy of iron, lead and copper smelting, building stone, road metal, crushed stone, glass-making, and many others of lesser importance. The use with which we are especially concerned in this report is in connection with the metallurgy of iron.

Blast-Furnace Flux. One of the very important uses of a limestone is as a flux in the iron blast furnaces of the country. Practically 40 per cent of the limestone quarried in the United States in 1918 was used for this purpose. According to statistics¹ the amount so used was 21,593,451 long tons valued at \$21,473,254.00.

The value of a limestone as a blast furnace flux depends very largely on the purity of the stone, especially as regards the percentage of silica, alumina, sulphur, and phosphorus. Much limestone contains magnesium carbonate in quantities varying from a trace up to true dolomite, which is the double carbonate of lime and mag-

¹Mineral Resources, U. S. Geol. Survey, (1918), Part II, (Non-metals), p. 1273.

nesia, $\text{Ca O Mg O (CO}_2)_2$. The bases are present in this in the proportion of 58.3 Ca and 41.7 per cent Mg on account of the differences in the atomic weight of calcium and magnesium.

The purpose of the flux in the blast furnace is to furnish bases to combine with the acid impurities in the ore and the fuel, hence its value will decrease very rapidly as the acid impurities, as silica and alumina, increase in the limestone itself. Many limestones contain more or less argillaceous material and this would make them poorly suited as a material for use as a blast furnace flux.

Sulphur is often present in limestone in small amounts, but the amount is usually so very small that it need not be considered.

Phosphorus is found in some limestones, but the amount is usually small and is of no importance unless the stone is to be used in the manufacture of Bessemer iron. In case it is to be used for this purpose, however, the amount of phosphorus becomes a very important question and should in no case exceed 0.01 per cent.

The physical condition of the stone is of some importance, but in most limestones it is such that it may be used very satisfactorily. Very soft limestones may produce considerable dust which is objectionable.

Basic open-hearth furnace flux. The purpose of the limestone in the basic open-hearth steel furnace is very much the same as the function performed in the blast furnace; namely, to flux the silica and alumina present, and the removal of the phosphorus and sulphur. In the basic open-hearth the furnace is lined with some basic material. Magnesite—in the shape of bricks or calcined lumps—is the best commercial material found so far for this purpose. In this furnace the bottom of the hearth is usually made of calcined dolomite. Pure magnesia gives a more permanent lining than dolomite, however, and is

being used in a good many places. Even where magnesia is used for the bottom, the topmost layer, or working bottom, is made of dolomite.

As in the blast furnace, so in the basic open-hearth furnace, the chemical composition of the limestone is the most important point to be considered. If the limestone contains a large amount of silica and alumina, enough lime and magnesia must be added so as to completely neutralize these and in addition to give a very basic slag. This is necessary, first, to remove the phosphorus, and second, to prevent the cutting out of the basic lining of the furnace.

There appears to be some difference of opinion as regards the desirability of a large amount of magnesia in a flux to be used in the basic open-hearth process. Mr. W. B. Phillips¹, in discussing this point, makes the following statement:

“In the manufacture of basic iron it was soon found that the use of dolomite was a decided advantage, especially in the lowering of the sulphur in the pig iron. Whether this advantage was due to the lower content in silica, 1.25 as against 3.50, or whether the presence of large quantities of magnesia was the determining factor in diminishing the sulphur content in the iron, is a question which still occasions mild disputes. The fact remains, however, that in the production of basic iron, sold under severe restrictions as to silicon and sulphur, only dolomite is used as a flux.”

Others hold that a high percentage of magnesia is not desired in the slag, as it has a poorer affinity for sulphur and phosphorus than the lime which it replaces. Even where the flux used is a pure limestone, the slag will contain more or less magnesia on account of the fact that either magnesite or dolomite is very generally used

¹Iron Making in Alabama, (3d Edition), Geol. Survey of Alabama, (1912), pp. 116-117.

in lining basic open-hearth furnaces; and when used in this way some of it dissolves in the slag and becomes a flux.

Sulphur and phosphorus are usually present in such small amounts that it is not necessary to take them into account in determining the value of the limestone for fluxing purposes.

WASHINGTON LIMESTONE

DISTRIBUTION

The limestone deposits of Washington are, with one exception, found in the northern part of the State. The counties in which limestone is known to occur are Asotin, Pend Oreille, Stevens, Ferry, Okanogan, Chelan, Kittitas, Whatcom, Skagit, Snohomish, King, and San Juan. Many of these deposits cover very small areas and are of little commercial importance. The deposits in eastern Washington are much more extensive than those in the western part of the State. Those in western Washington, however, taken as a whole, are much purer limestones than those in eastern Washington.

PROPERTIES

The limestones which occur in this State vary more or less as regards the properties discussed above. In most cases the physical properties would be very satisfactory, as the stone is fairly hard and very little dust would be produced.

In composition the limestone varies a great deal. In places it carries a large amount of argillaceous material and therefore has a high percentage of silica, alumina, and iron. In other places it is practically free from these substances, and is almost a pure limestone. In some places the deposits are free from magnesia, while in others all gradations from a pure calcium carbonate to a pure magnesium carbonate may be found.

In some cases sulphur is present in considerable amounts, occurring in the form of pyrite or iron sulphide. Most of the limestone, however, is practically free from sulphur. Most of the analyses of Washington limestones do not give phosphorus, and it probably has not been determined; but it is found so seldom, in quantities great enough to make the limestone undesirable as a furnace

flux, that it has been unnecessary to make determinations for it.

A few analyses are given below, to show the composition of the Washington limestone. These analyses are all taken from Bulletin No. 4, Washington Geological Survey¹. Those desiring a fuller discussion of this subject should refer to this bulletin.

CHEMICAL ANALYSES OF WASHINGTON LIMESTONES

	I.	II.	III.	IV.	V.
Silica (SiO ₂)	5.98	0.38	2.64	4.54	0.38
Alumina (Al ₂ O ₃) }	2.03	0.21	1.52	0.61	0.28
Iron (Fe ₂ O ₃) }	51.07	55.26	53.38	50.69	54.06
Lime (CaO)	0.78	none	1.30	1.21	2.03
Magnesia (MgO)	39.93	43.98	40.92	42.85	43.15
Loss on Ignition.....					
Total.....	99.98	99.83	99.76	99.90	99.86
Calcium carbonate (CaCO ₃).....	91.19	98.68	95.32	90.51	96.53

	VI.	VII.	VIII.	IX.	X.
Silica (SiO ₂)	4.68	1.15	3.98	0.27	4.28
Alumina (Al ₂ O ₃) }	1.56	Tr.	0.41	0.21	0.96
Iron (Fe ₂ O ₃) }	51.05	54.21	33.07	.....	52.36
Lime (CaO)	Tr.	Tr.	21.15	.....	0.64
Magnesia (MgO)	42.53	43.64	41.19	.....	42.00
Loss on Ignition.....					
Total.....	99.82	98.32	99.97	100.00	100.24
Calcium carbonate (CaCO ₃).....	91.86	96.64	.....	96.06	93.50

	XI.	XII.	XIII.	XIV.	XV.
Silica (SiO ₂)	1.94	0.78	0.16	1.44	4.28
Alumina (Al ₂ O ₃) }	0.22	0.72	0.13	0.92	0.96
Iron (Fe ₂ O ₃) }	54.92	54.95	55.44	54.36	52.36
Lime (CaO)	Tr.	Tr.	0.42	Tr.	0.64
Magnesia (MgO)	42.67	43.50	44.00	43.17	42.00
Loss on Ignition.....					
Total.....	99.75	99.95	99.60	99.89	100.24
Calcium carbonate (CaCO ₃).....	98.07	98.12	97.22	97.07	93.50

I. Anatone: Lime Hill, near basalt; gray, decomposed, slaty.

II. Wenatchee: Five miles north; finely grained, almost white.

¹Shedd, S.; Cement Materials and Industry in the State of Washington, Bull. 4, Wash. Geol. Survey, (1910), Appendix A.

- III. Baring: Secs. 24 and 25, T. 26 N., R. 10 E.; finely crystalline, dark gray.
- IV. Chesaw: Buckhorn Mountain; dark gray.
- V. Kettle Falls: Fishe's ranch, one mile south of river; light gray, gneissoid.
- VI. Bossburg: Northeast $1\frac{1}{2}$ miles on road; gray coarsely, crystalline.
- VII. Evans: Idaho Brick and Lime Co.; light gray, compact.
- VIII. Colville: Old Dominion; coarsely crystalline, white.
- IX. Roche Harbor.
- X. East Sound: Sec. 19, T. 37 N., R. 1 W.
- XI. Concrete: Jackman Creek; crystalline, light colored.
- XII. Rockport: North one mile; finely crystalline, light gray.
- XIII. Granite Falls: Secs. 7 & 8, T. 30 N., R. 7 E.; coarsely crystalline, dark gray.
- XIV. Kendall: Sec. 23, T. 40 N., R. 5 E.; coarse grained, light gray.
- XV. East Sound: Sec. 19, T. 37 N., R. 1 W.

LOCATION

One of the very important points to be considered in connection with the use of a given limestone as a flux in the iron or steel industry is its location, especially with reference to the industry. In the case of Washington, the ore, the fuel, and the flux are, as a general thing, considerable distances apart. In most cases where large iron and steel industries have been developed, they have been located near the fuel, and the ore and flux shipped to this point. The fuel in Washington occurs in both the eastern and western part of the State, as do also the limestones. In western Washington some very high grade limestone deposits occur practically at tide water, and on account of this fact would have a cheap transportation to points on Puget Sound. At present the largest amount of coke is also produced in this same locality, and should an iron and steel industry ever be developed in Washington, somewhere on the Sound would probably be the logical place for it.

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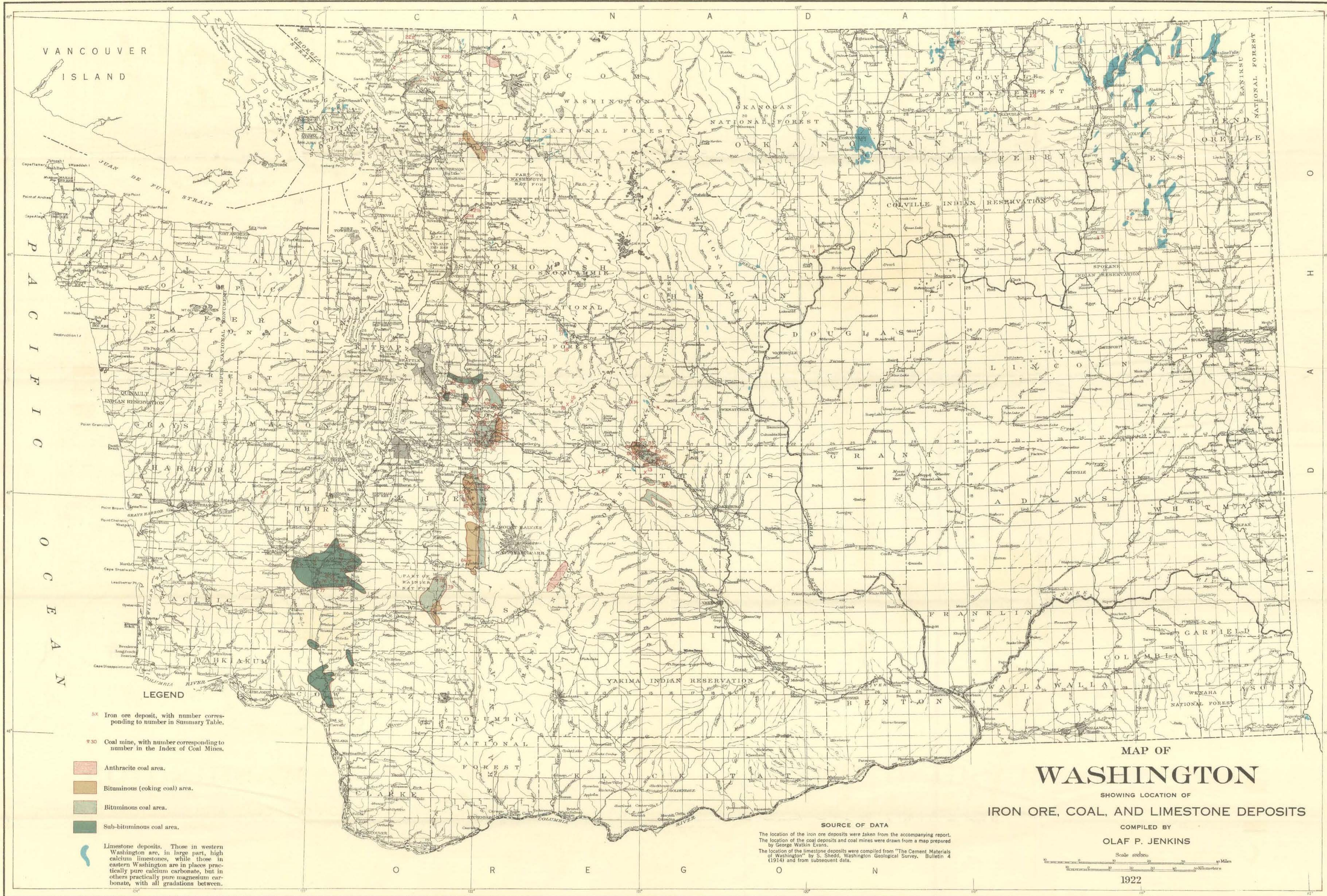
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SUMMARY TABLE OF THE KNOWN IRON ORES OF WASHINGTON

No. shown on Map	Name of District	Local Name of Property	Name of One Owner	Location				Principal Ore Mineral Probable Origin of Ores in Parenthesis	Approximate Estimate of Tonnage* (in Thousand Tons)			Railroad Station		Distance on R. R. to Seattle (miles)	Distance on R. R. to Spokane (miles)
				County	Section	Township	Range		Known	Probable	Possible	Haulage Dis- tance to R. R. (miles)	Nearest Town E—East of Cascades W—West of Cascades		
1	Valley	Kulzer	M. Kulzer	Stevens	20	31N.	41E.	Limonite & Hematite (Residual & Replacement)	4	15	50	5	Valley (E)	395	56
2	Valley	Hill (Jim Hill)	L. W. Hill	Stevens	17,20	31N.	39E.	Hematite (Replacement)	1+ (?)	(7)	(1)	9	Valley (E)	395	56
3	Deer Trail	Read (Hunters)	J. C. Read	Stevens	14	30N.	37E.	Magnetite (Contact Metamorphic)	5—	100	500	25	Springdale (E)	386	47
4	Clugston Cr.	Clugston Cr.	Frank B. Goetter	Stevens	11	37N.	39E.	Limonite (Residual & Replacement)	?	?	?	15	Colville (E)	426	87
5	Deep Lake	Bechtol	David Bechtol	Stevens	27	39N.	41E.	Limonite (Residual & Replacement)	1	20	75	13	Boundary (E)	477	138
6	Deep Lake	Thompson	Ernest Thompson	Stevens	23	39N.	41E.	Limonite & Goethite (Residual & Replacement)	50	250	500	12	Boundary (E)	477	138
7	Orient	Naselson	Stevens	3	37N.	37E.	Pyrrhotite (Replacement & Contact Metamorphic)	1 1/2				Boys (E)	445	106	
8	Belcher	Copper Key	Ferry	8,17	37N.	34E.	Magnetite (Contact Metamorphic)					Curlew (E)	495	156	
9	Myers Cr.	Neutral-Aztec	J. S. Grant	Okanogan	13	40N.	30E.	Magnetite (Contact Metamorphic)	200	375	500	5	Chesaw Spur (E)	344	185
10	Myers Cr.	Mac Lean	J. A. Mac Lean	Okanogan	24	40N.	30E.	Magnetite (Contact Metamorphic)	?	?	?	14	Chesaw Spur (E)	344	185
11	Squaw Cr. (Pateros)	Fuller	A. D. Fuller	Okanogan	26	30N.	23E.	Magnetite (Magmatic Segregation & Metamorphic)	2	10	20	1	Pateros (E)	224	233
12	Blawett	Rothert	E. H. Rothert	Chelan	13	22N.	17E.	Magnetite (Magmatic Segregation)				15	Cashmere (E)	154	185
13	Cle Elum	Mt. Peo	C. Durwachter	Kittitas	9,10	19N.	15E.	Magnetite (Sedimentary? & Metamorphic)	1	40	80	2	W. Cle Elum (E)	90	220
14	Cle Elum	Camp Cr.	Balfour-Guthrie	Kittitas	26,35	23N.	14E.	Magnetite (Sedimentary, Residual, & Metamorphic)	500?	2,000	5,000	16	Lakeview (E)	119	305
15	Summit	Guye	J. W. Guye	King	29,317	23N.	11E.	Magnetite (Contact Metamorphic)	10	?	200	2 1/2	Rockdale (W)	58	252
16	Summit	Denny	R. H. Denny	King	?	?	?	Magnetite (Contact Metamorphic)	5	?	100	1 1/2	Rockdale (W)	58	252
17	Baring	Anderson	King	11	26N.	10E.	Magnetite (Contact Metamorphic?)	2	5	10	1	Baring (W)	77		
18	Miller River	Money Creek	Wm. Williams	King	35,36	26N.	10E.	Magnetite (Contact Metamorphic?)	?	?	?	5	Miller River (W)	85	
19	Hamilton	Iron Mt.	D. L. Runkel	Skagit	23	35N.	6E.	Magnetite (Sedimentary & Metamorphic)	20	100	500	3 1/2	Hamilton (W)	89	
20	Sumas Mt.	Hematite Gr.	O. Hutton	Whatcom	2	39N.	4E.	Hematite (Residual)				4	Nooksak (W)	121	
21a	Arlington	Coe	F. O. Coe	Snohomish	36	32N.	5E.	Limonite (Bog Ores)	3	10	15	1 1/2	Arlington (W)	61	
21b	Arlington	Jefferson	Thomas Jefferson	Snohomish	30	32N.	6E.	Limonite (Bog Ores)	1	3	5	1	Coopers (W)	65	
22	Lynden	Lynden	T. Herringa & Sturman	Whatcom	8,17	40N.	3E.	Limonite (Bog Ores)	5	20	30	1	Lynden (W)	139	
23	Elma	Dennis	Mrs. Dennis	Grays Harbor	28	18N.	5W.	Titaniferous Magnetite (Sedimentary)	5	10	20	3 1/2	Elma (W)	110	

*EXPLANATION

KNOWN

Refers to the ore in sight—that on the dump, in workings, and on the outcrop.

PROBABLE

Refers to a conservative estimate of the ore which could probably be mined from a moderate depth.

POSSIBLE

Refers to the total amount of ore which could possibly be mined if local characters are continuous throughout the entire properties and if mining is carried on to considerable depth.

None of these features are accurate. They are given merely to present to the reader a general relative impression of conditions existing in the State as far as is known.

MAP OF
WASHINGTON
SHOWING LOCATION OF
IRON ORE, COAL, AND LIMESTONE DEPOSITS
COMPILED BY
OLAF P. JENKINS

SOURCE OF DATA

The location of the iron ore deposits were taken from the accompanying report, by George W. Evans.
The location of the coal deposits and coal mines were drawn from a map prepared by S. Shedd, Washington Geological Survey, Bulletin 4 (1914) and from subsequent data.

INDEX TO THE COAL MINES OF WASHINGTON

COUNTY PRODUCTION FOR 1921	MAP No.	NAME OF MINE	COUNTY PRODUCTION FOR 1921	MAP No.	NAME OF MINE
Whatcom 187,005 tons	24 25 26	Bellingham Blue Canyon Glen Echo	Pierce 102,538 tons	56 57 58 59 60 61 62 63 64	Birrell Champion Wilkeson South Willis Carbonado Mellmont Fairfax Montezuma Ashford
Skagit 1,433 tons	27	Cokedale	Thurston 256,218 tons	65 66 67	Black Bear King Tono No. 1
King 340,015 tons	28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55	Old Newcastle Newcastle Isacovich Grand Ridge Snoqualmie Black River Renton Denny Renton Cedar Mountain Indian Cashmere Danville Revensdale Raven No. 11 Black Diamond Cannon Hyde Kummer Hiawatha Durham Pocohontas Bayne Chemung Eureka Navy National Kangley	Lewis 142,064 tons	68 69 70 71 72 73 74 75 76 77 78 79 80	Victory Packwood Mendota Fords Prairie Lincoln Kopah Manarch Empress Superior Shelton Ladd Divide Salzer Valley
			Kittitas 1,392,813 tons	82 83 84 85 86 87 88 89 90 91 92 93	Wright Plant Roslyn Fuel 1-2-3 Roslyn Cascade 1-2 N. W. 1, No. 5-2-3 N. W. 1, No. 5-8 N. W. 1, No. 7-7 Ext'n Summit N. W. 1 Cle Elum Queen Cle Elum Coal Co. Wilson
TOTAL PRODUCTION IN 1921. FOR STATE, 2,422,106 TONS.					