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DIVISION OF MINES AND MINING  
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Report of Investigations  
No. 5

Memorandum Report on Iron  
Ores of the Cle Elum  
District, Washington

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By  
CARL ZAPFFE



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## FOREWORD

The results of mineral investigations that are made by State and Federal agencies are usually published for the information of those interested in these resources. If not published—publication is not always feasible or desirable—the facts obtained through the examination of mines, prospects, and mineral occurrences are nevertheless indirectly available to the public, as they are used in responding to inquiries and in the furtherance of the various activities of the investigating agency. On the other hand, the results of investigations made by private individuals or corporations are seldom available to the public and play but little part in increasing the common fund of information on mineral resources.

In September, 1912, Mr. Carl Zapffe, then Geologist and now Manager of Iron Ore Properties, Northern Pacific Railway Company, made a field study of the Cle Elum iron-ore occurrences and in March, 1913, submitted a detailed report on his findings and conclusions to his organization. In October, 1942, the Northern Pacific Railway Co. undertook a re-examination of these occurrences, in the course of which transit and magnetic (dip-needle) surveys were made, measurements were taken, and samples for analysis were collected. The results of this work were used to supplement the earlier study, and on March 1, 1943, Mr. Zapffe made a final and comprehensive report that is particularly valuable at this time.

Through the courtesy of Mr. Zapffe and officials of his organization, and also of Balfour, Guthrie & Co., Ltd., who own the properties that were investigated, permission has been given the Division of Mines and Mining to publish this report. It is with much gratification, therefore, that the Division is able to make the carefully prepared study available to the public and so add to the information on a most interesting resource.

SHELDON L. GLOVER, Supervisor  
Division of Mines and Mining



# MEMORANDUM REPORT ON IRON ORES OF THE CLE ELUM DISTRICT, WASHINGTON

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By CARL ZAPFFE \*

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## PURPOSE

The purpose of the work, undertaken in the fall of 1943, was to ascertain what portion of the exposed ore formation on a few selected claims in the Cle Elum district of Kittitas County, Washington, was the best portion, how many tons could be estimated for it, what its mineral and chemical compositions are, and deduce therefrom what the metallurgical problems in the use of this ore would be.

## EXPLANATION

The iron occurrences selected consist of five claims known as the Iron Monarch, Bessemer Iron No. 2, Iron Boss, Iron Boss Fraction, and Iron King, located in secs. 26 and 35, T. 23 N., R. 14 E., and are a part of a large group of claims owned by Balfour, Guthrie & Co., Ltd. They are the most readily accessible ones and also offer other advantages.

The first interest in this area was displayed in the early '80's, and prospecting was done on the whole group of claims up to about 1900. In 1912 the writer made a field investigation and an economic study of the group. It was found that outcrops were very numerous for a distance of 4 miles. Scraped areas and shallow cuts still open exceeded 30 or 40 in number; 2 shallow holes had been drilled; and what was still accessible of 2 pits, 6 trenches, 1 winze, 5 shafts, and 7 tunnels was examined.

Several former reports are available, and several publications refer to the area as a whole (see Selected references, p. 6). In these accounts many incomplete analyses are recorded, but as the description of all the former sampling is omitted, it becomes impossible to determine what the sample analysed was intended to disclose. Many analyses are without doubt merely of specimens, and for others the correctness of the sampling work may be questioned. For quantitative studies virtually every one is today useless, although, of course, they provide general information of value.

Talk about starting an electric smelting plant in Tacoma or Seattle was revived in 1941. This necessitated that all iron ores in the State be studied in considerable detail to determine the feasibility of processes and the adequacy of each reserve. Some men voiced

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the idea of making sponge iron. Time and again since 1912 the writer had emphasized that these are unusual ores and untried metallurgically, and that at least according to older practices of conversion they had been regarded unsuited for making pig iron and steel and were still a problem. Therefore, when in 1942 the Northern Pacific Railway Co. continued its plan of field work started in 1941, to make economic surveys of mineral deposits in the State, this to be its contribution to aid the Nation in its efforts to develop suitable war industries, it was planned to have one of its field parties make accurate transit and magnetic surveys of certain ones of the iron-ore deposits to provide basic data. Late in October Assistant Geologist J. T. Mullen and Mining Engineer C. L. Holmberg started to map and sample the exposures in the five claims named, lying east of Cle Elum River and between Boulder and Camp creeks. This corresponds to about the SW $\frac{1}{4}$  sec. 26 and the NW $\frac{1}{4}$  sec. 35, T. 23 N., R. 14 E. They collected 14 carefully selected and accurately measured samples which they designed would help determine what part of the ore formation is best as to iron content and, as well, arrive at the chemical and mineral compositions of its several horizons. The chemical analyses were made by Lerch Bros., Inc., Hibbing, Minn., experts in making iron-ore analyses.

In the following pages no attempt is made to describe the areal geology or the geography, nor shall the discussion be extended to any other than the five claims first named.

#### SELECTED REFERENCES

- Smith, G. O., and Willis, B., The Clealum (Cle Elum) iron ores, Washington: Am. Inst. Min. Eng. Trans., vol. 30, pp. 356-366, 1901.
- Shedd, S., The iron ores of Washington: Wash. Geol. Survey vol. 1, Ann. Rept. for 1901, pt. 4, pp. 27-36, 1902.
- Smith, G. O. and Calkins, F. C., Description of the Snoqualmie quadrangle: U. S. Geol. Survey Geol. Atlas, Snoqualmie Folio (No. 139), 1906.
- Shedd, S., Jenkins, O. P., and Cooper, H. H., Iron ores, fuels and fluxes of Washington: Washington Div. of Geol. Bull. 27, pp. 72-79, 1922.

#### MAPS

For a brief report on his field work, submitted December 10, 1942, Mr. Holmberg prepared a map on which he showed the surface data for the area surveyed and the boundaries of the ore formation. On a smaller map he presented accurate cross sections for each place at which a sample had been taken and what each sample represents. From dip-needle readings taken across the orebody, he provided profile sketches. These are the only available records of this sort for these parcels. The work was done thoroughly, accu-

rately, and intelligently, and had not stormy winter weather arrived, more of this sort of detailed work would have been supplied by this field party.

To consolidate the field data obtained and to enable quicker reference to points to be mentioned herein, two special maps, plates 1 and 2 (in pocket), have been prepared to accompany this memorandum. The one (pl. 1) is for that part of the ore formation which is on the Iron Monarch and the south end of the Bessemer Iron No. 2 claims, which hereinafter shall be referred to as the "Monarch" deposit; the other (pl. 2) is for the part which is on the Iron King, Iron Boss, and Iron Boss Fraction claims, which shall be referred to as the "King-Boss" deposit. This separation is suitable, because between the two is an unexplored gap in which outcrops are lacking.

#### LATERITE ORE

The problems of this ore are inherent because of its genetic history. As the ore is of unique type, a general discussion becomes a useful preliminary.

In mode of origin, the Cle Elum ore has as counterparts only the Mayari and Moa deposits, near Nipe Bay in the Province of Oriente, Cuba, the Surigao deposits on Mindanao Island in the Philippines, and the Hyderabad deposits in India, all in the Torrid Zone and formed under tropical conditions of weathering. Although the Cle Elum ore occurs in what is now the Temperate Zone, it had a similar origin to these foreign occurrences; for subtropical conditions existed here at the time of its formation, as is evidenced by the fossil remains of the life of that time. In final genetic history the Cle Elum deposit stands alone because, unlike the other three occurrences, it eventually became deeply buried under Eocene sediments (Swauk formation) and then subjected to profound orogenic forces.

As to an originating process, it is simply a matter of rock decay. This entire process is designated laterization and the resultant product is called laterite. The best known of that kind is the light-colored clay-like mass called bauxite, which is today the main source-ore of our aluminum. When the parent rock undergoing decay is dark colored, its high content of iron-bearing minerals yields much iron oxide, which gives its clayey residual mass a heavy reddish stain; and although this laterite is but a ferruginous clay, the name iron ore is commonly applied. That describes the Cle Elum situation.

The sequences of chemical and mineral changes—as to weights, volumes, and porosity—were worked out in great detail between 1911 and 1914 for the Cuban ores. Although that work was of help even in 1912 in interpreting the Cle Elum ores, the latter have always provided problems of their own; because, whereas laterites

develop on flat or on very slightly sloping and undisturbed surfaces, the Cle Elum ores stand today at steep angles and show the effects of disturbances which were of far more than surficial character and proportion. In this latter respect the Cle Elum deposits are alone and the facts about them are new.

It is apparent that after the process of decay was ended the laterite became, first, deeply buried and compressed under sandstone and other sediments, and then profound earth movements bent and elevated the huge mass of sandstone and laterite and all underlying rocks into mountain structures. Thus the laterite was made into a dense rock, and not only was the moisture squeezed out but some minerals present were converted into other and perhaps strange minerals. After ages of erosion, the laterite has again become exposed to view; but the once loose, incoherent red clay is seen now resembling very much a baked tile, though cracked in many directions. Some of the original mineral characteristics are still recognizable.

#### KINDS OF ORE

The rock that decayed consists of several dark-green varieties called collectively peridotite. This group is distinguished chemically by a silica content lower than holds for any other group of rocks. Magnesia is exceptionally high; and, relatively speaking, alumina is very low, while iron, especially as ferrous iron, is very high. This combination gives rise to a deep-red laterite. The process of change is continuous, therefore one can see in the district all the gradations in color from dark green to a bleached or lighter green, or a sort of yellowish or grayish green, all of which show irregular brown staining. As the brown colors of the mass became darker in tone a bluish-black color frequently developed, and then were obliterated all resemblances to the parent rock.

In an idealized case, the gradation should be upward from the green peridotite at the base into the nearly black ores at the top; but in time this laterite was altered in the nature of a concentration from top downward, and it was also partly reshuffled and re-sorted by wave and wind action during the time the sandstone was being laid over it as a cover. This entire set of processes has created appearances that give distinctive characters to the top, the middle, and the bottom portions of the entire thickness.

Quite generally the laterite is dense and massive. Resemblance to lamination is due to a slight orientation of minerals caused by the earth pressures and is not of the nature of sedimentary bedding planes. Lamination is not confined to specific horizons. In the main, the basal portion is the more massive, but this grades downward into the brownish-green phases and then into fresh peridotite, and this gradational zone may be schistose because of movement along these looser parts.

The top of the formation had generally been removed by erosion before the sandstone-burial episode, but where still present it is commonly mixed with sandstone materials. The top is also very conspicuous because it contains so many small nodular masses, resembling concretions; these are called oolites. Oolites are always a marked characteristic of laterites, and they are ever more conspicuous in top portions. It is in this physical respect that the bottom of the Cle Elum formation differs markedly from the top. Through leaching action the top is also less rich in iron and richer in alumina; this tends to give the top lighter colors.

With the oolitic variety to typify the top and the less oolitic or massive ore the bottom, it follows that the middle portion forms an intermediate zone. It varies in its compositions toward the one or the other side, depending on where a person makes the division. If these three divisions are taken note of, many things about this deposit clarify themselves more easily.

#### PETROGRAPHY

Examination of thin sections, or slides, of ores with the aid of a polarizing microscope is indispensable. By this means one arrives at an understanding as to suitable beneficiation processes and metallurgy.

In 1912 many such slides were procured and examined. Suitable chemical analyses were then not available for the specimens studied, and similar work on laterites elsewhere had not progressed far. The recent sampling done by Messrs. Mullen and Holmberg has now enabled acquiring excellent analyses, and those microscopic investigations become now most valuable. In the following discussion only the most familiar mineral names will be used.

The parent rock is mainly saxonite. In terms of minerals it means absence of free quartz ( $\text{SiO}_2$ ) and the presence of minerals mainly of the olivine and pyroxene families. Fayalite ( $\text{Fe}_2\text{SiO}_4$ ) and hortonolite ( $(\text{Fe}, \text{Mg}, \text{Mn})_2\text{SiO}_4$ ) are the two that apply to the olivine group, and almost wholly it is enstatite ( $\text{MgO} \cdot \text{SiO}_2$ ) for the pyroxene group. Calcium is here almost negligible; but when present it is generally to be found in the minerals of the two groups named, replacing a part of the iron or magnesium. At best only a trivial amount of alumina is present and not as a separate mineral, but that very sparseness is the basis for one of the most astounding things about rock decay forming these Cle Elum laterites. The minerals of an accessory order are magnetite ( $\text{FeO} \cdot \text{Fe}_2\text{O}_3$ ) and chromite ( $\text{FeO} \cdot \text{Cr}_2\text{O}_3$ ), with occasionally a little pryrrotite ( $\text{Fe}_7\text{S}_8$ ); these three account for the presence of iron, chromium, and sulphur. In all the minerals named occur substitutions of small amounts of titanium, manganese, nickel, and phosphorus, and here and there other elements, such as cobalt, arsenic, gallium, boron,

sodium, and copper, undoubtedly occur. The principal minerals nearly always show small amounts of characteristic alteration products.

The interest is in the changes that occurred in this mineral composition and which progressed into the development to iron ore. These changes are observed in the slides to have been as follows: The first step consists of the anhydrous silicate minerals taking on water. Thereupon the magnesium in the olivines and pyroxenes goes to create various members of the serpentine and chlorite families (in general,  $3\text{MgO}\cdot 2\text{SiO}_2\cdot 2\text{H}_2\text{O}$ ), while the freed ferrous iron forms the hydrous oxides of the limonite group ( $2\text{Fe}_2\text{O}_3\cdot 3\text{H}_2\text{O}$ ). The freed alumina takes on water and, with the silica, forms the kaolin group of clay-like minerals (in general,  $2\text{H}_2\text{O}\cdot \text{Al}_2\text{O}_3\cdot 2\text{SiO}_2$ ). Some ferric iron is always freed from the decomposing olivine, and upon combining with ferrous iron increases the original small and minor content of magnetite, but left to itself forms hematite ( $\text{Fe}_2\text{O}_3$ ). The accessory minerals experience very little chemical change, but owing to volume losses they increase relatively in amount. In appearance, the rock loses its fresh dark-green color and takes on brown stains.

That sort of progression eventually leads to the breaking down of the newly formed serpentine and chlorite groups. When it happened here, the magnesia was carried away in solution and was lost, but the freed iron made more hydrous oxides. The latter remained and thus increased the quantity of the limonite group. The kaolin group lost silica in solution, and the residue became converted into bauxite ( $\text{Al}_2\text{O}_3\cdot 2\text{H}_2\text{O}$ ). Again, as before, more magnetite was formed. The alumina which was freed during this stage combined with some of the ferrous iron resulting from the breakdown of the above-named iron silicate minerals, and thus began the development of that very interesting aluminate of iron named hercynite ( $\text{FeAl}_2\text{O}_4$ ).

Lastly, upon becoming buried and then being under the influence of the weight of the overlying sandstone plus the pressures due to crustal movements of mountain-building proportions, the loosely knitted and porous laterite not only became compressed into a dense, indurated, tile-like rock, but all water that had filled pores and nearly all water of crystallization were eliminated. Thus the hydrous limonites were converted into the least hydrous mineral of that group—goethite ( $\text{Fe}_2\text{O}_3\cdot \text{H}_2\text{O}$ )—or more hematite and martite ( $\text{Fe}_2\text{O}_3$ ). In the process some iron oxide was freed, which then formed more magnetite and some martite. Also, it freed some alumina and forced it to combine with free ferrous iron to create more hercynite, and what bauxite then remained became converted into the less hydrous mineral diaspore ( $\text{Al}_2\text{O}_3\cdot \text{H}_2\text{O}$ ). It was a most orderly sequence.

Thus, the dominant unusual thing about this ore is the presence of large amounts of diaspore and hercynite. They are uncommon minerals anywhere and especially so in iron ores. They are the carriers of the large amount of alumina present in this ore. They are largely responsible for the very evident impossibility of gravity concentration, and they will create the difficulties attendant on smelting. The presence of fayalite means that much iron is locked up as silicate; and because the secondary minerals of the serpentine and chlorite group are heavily stained or colored brown, additional iron is locked up in those three silicates. The conclusion follows that the readily available iron will be derived only from moderate amounts of magnetite, martite or hematite, and goethite and its other associated hydrates of iron.

In all samples studied, free quartz and chert were absent. Occasionally the slightly altered peridotite, or the very lean ores, showed some carbonate-bearing minerals, such as siderite and calcite, but these are of negligible consequence in problems involving the utilization of this material.

#### MINERAL COMPOSITION OF THE ORES

A chemical analysis can be distributed mathematically to arrive at the quantitative contents of the several minerals that were determined by means of the microscope. We need interest ourselves in only the important minerals, and, secondly, in the type- or group-mineral rather than in the varieties constituting any certain family. The value of this step becomes the greater if the distributions are made in accordance with what has been described as oolitic ore, as massive ore, as greenish or brownish ore, as top, middle or bottom layers, and as a highest-grade ore. The purpose is to acquire a knowledge of the distribution in the ore formation of the useful iron minerals, or, for that matter, of any single mineral or element which may have to be emphasized, because all this is basic to judging what layers or how many feet of thickness can be used advantageously.

Eleven elements, plus water and loss-on-ignition, were available for forming twelve separate minerals. Seven or eight minerals may be said to be important in the matter of making distributions. The remainder, either of elements or minerals, never affects a complete calculation by enough to warrant a close scrutiny and only a brief statement about them suffices.

The mineral composition may be summarized as follows:

*Phosphorus, sulphur, and calcium.*—The amounts of phosphorus, sulphur, and calcium are so small that they will never be a metallurgical factor. They could be present as impurities in any of the major minerals named. In total, this group of elements ranges from 1.1 to 1.6 percent.

*Manganese.*—Manganese is almost negligible in amount. It can be regarded as occurring in any of the minerals, but more especially with titanium in ilmenite ( $\text{FeO.TiO}_2$ ), with iron in magnetite or hematite, or in olivine. For convenience it is considered here as included with the titanium.

*Titanium.*—Titanium is more abundant than the elements named above. It may occur as a separate oxide mineral, but it is more apt to be combined with manganese or iron. If computed as an oxide by itself, it amounts to less than 1.00 percent; it is not apt to be of serious consequence in metallurgy.

*Nickel.*—Nickel most likely occurs in the parent peridotite as a primary constituent of the olivine or the enstatite molecule. It could occur as a separate sulphide mineral. In the laterite it is probably molecularly united with iron but could be a hydrous silicate. Because nickel seems to have an original association with the magnesium-bearing minerals, it may be presumed to occur also in their secondary aggregates. Microscopically, a separate nickel mineral has not yet been recognized, and this leaves one to choose between the hydrous genthite ( $2\text{NiO.2MgO.3SiO}_2.6\text{H}_2\text{O}$ ) and garnierite (probably,  $\text{H}_2(\text{Ni, Mg})\text{SiO}_4 + n\text{H}_2\text{O}$ ), or even the hydrous arsenate annabergite ( $\text{Ni}_3\text{As}_2\text{O}_8.8\text{H}_2\text{O}$ ). As the Cle Elum laterite has been compressed and dehydrated, the choice falls upon the lesser hydrous magnesium silicate garnierite. Calculated as such, it reaches a maximum of 3.4 percent.

*Chromium.*—Chromium may occur variously, but here it is best to favor the mineral chromite, which is chromic sesquioxide combined with ferrous iron in a definite ratio. It attains a proportion up to 5.2 percent and is easily seen under the microscope.

*Magnesium.*—After all the above minerals are satisfied as to their nominal magnesium requirements, the remainder is used to form iron-free serpentine.

*Fayalite.*—After all the above minerals are satisfied as to their silica requirements, the remainder is used to form the iron-bearing olivine fayalite.

*Diaspore, hercynite, goethite, and magnetite.*—These four minerals are built up on the basis of available alumina, ferrous and ferric iron, and water. The term magnetite is herein used to include martite and hematite, for which reason the chemical symbol  $\text{Fe}_m\text{O}_m$  is used rather than  $\text{Fe}_3\text{O}_4$  (or  $\text{FeO.Fe}_2\text{O}_3$ ) and  $\text{Fe}_2\text{O}_3$ .

#### ILLUSTRATIVE DIAGRAMS

The chemical analyses submitted by Lerch Bros., Inc., for the ore samples are shown on plates 1 and 2 at the respective places where sampled. By using those analyses, groups have been made according to what it is deemed the samples represent as to the sev-

# DIAGRAM TO SHOW CHEMICAL COMPOSITION OF TOP, MIDDLE, AND BOTTOM PORTIONS OF CLE ELUM IRON FORMATION

(Vertical Height represents Percents by Weight)

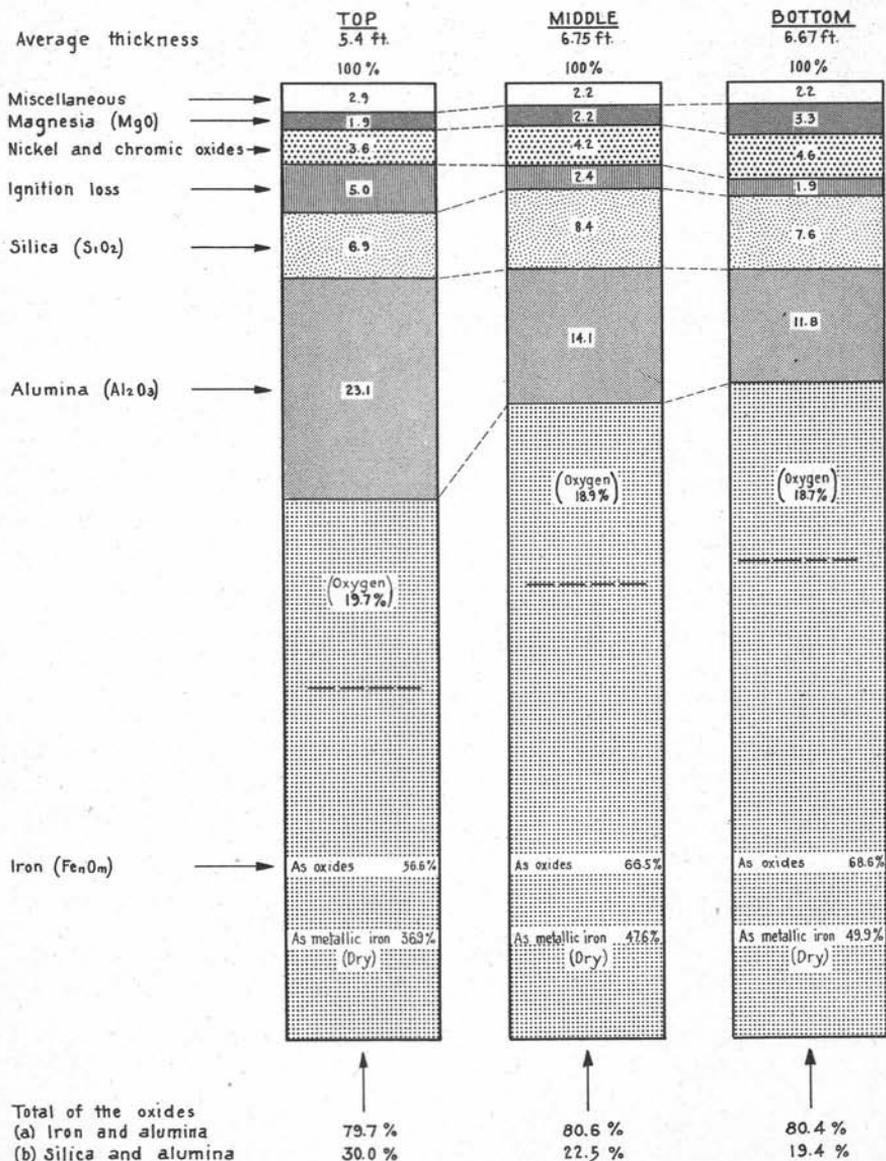


Figure 1



eral kinds, types, and divisions that are described on preceding pages. Howsoever used, all analyses were weighted according to the footage each represents. The results are shown diagrammatically in five separate charts, marked figures 1, 2, 3, 4, and 5.

Figure 1, page 12, shows the chemical composition of the top, middle, and bottom portions of the ore formation. It is conspicuous that in each case iron and alumina constitutes virtually 80 percent of the entire unit weight. Viewed separately, the alumina content is large at the top of the formation (23.1 percent) and small at the bottom (11.8 percent); the iron content is small at the top (36.9 percent) and large at the bottom (49.9 percent). Attention is directed to the increase of nickel plus chromium, from 3.6 percent at the top to 4.6 percent at the bottom. The middle shows up clearly as an intermediate section in every respect.

In so far as it is possible to get measurements, it seems that the top portion is represented by 5.40 feet, the middle by 6.75 feet, and the bottom by 6.67 feet. These dimensions necessarily vary from place to place; and, as mentioned previously, the top may not always be present and the middle may be small or not represented, thereby today making portions measure thinner or thicker. From a commercial or a metallurgical standpoint it may eventually prove suitable to increase the bottom section by including part if not all of the middle section.

Figure 2, page 14, shows the chemical composition of the oolitic and massive ores. The same things mentioned for figure 1 are conspicuous. Attention might be called to the fact that oolites yield high alumina (18.9 percent) and low iron (42.4 percent), and invariably as the oolite content decreases it may be noted that the alumina content decreases (11.9 percent) and the iron content increases (50.9 percent).

Figure 3, page 18, illustrates the chemical composition of the greenish-colored ore and the dark-brown or blue-black ores. The observation to be made is that the more the tone is greenish, the higher are the silica and alumina content; these total 22.7 percent for the greenish ores and 18.2 percent for the blacker ores. The iron content is respectively 46.7 percent and 50.8 percent. These two are really not to be considered determinative by themselves; in each case other factors enter which can modify the situation as to quality and be deceptive as to color. It is obvious that the greener the color the nearer is the rock to being a less altered part of the peridotite, or has been otherwise modified, in which case alumina would be lower and silica higher. That is mainly what figure 3 discloses.

Figure 4, page 22, provides a ready comparison between a low-grade and a high-grade ore. The former is oolitic and of the uppermost portion; the latter, conversely, is massive and of the lower or

bottom portion but serves best to disclose what a high-grade ore would be like.

When adding the metallic iron, the two oxides of aluminum and silicon, and the loss on ignition, the total quantities are alike for the two. However, in their totals of silica plus alumina (32.3 percent and 17.3 percent respectively), they differ markedly. Removal of iron from top layers increased alumina, while transporting iron downward increased the content of iron in the bottom layers.

To become an ore, the Cle Elum ore formation primarily must have undergone one thing—a decrease in the content of alumina.

Figure 5, page 24, shows the calculated mineral composition of five kinds of ore or parts of the ore formation. The various kinds are represented by rectangular columns, all of equal height and width and representing 100 pounds by weight. Each rectangle is divided horizontally into ten sections. Eight of these sections represent specific minerals previously described; the other two sections represent a group of minor and accessory minerals. The height of each section represents the amount of mineral by weight, and in each section that amount is shown numerically by the previously calculated percentage. To facilitate comparisons, a separate pattern symbol is used for each mineral, and in each rectangle the same pattern and the same position is used for the mineral so designated.

The main thing to be noted is that as the iron content increases, the gain comes largely from an increasing content of magnetite (including hematite and martite, here not differentiated), which increase resulted from losses in fayalite (olivine) and goethite. The highest content of magnetite was found to be 54.2 percent. In the changes that occur in passing from all the lower-quality ore-formation materials up to the higher-quality ore, fayalite decreases; this signifies that not only does a larger amount of iron oxide develop but also a lesser amount of silica develops as quality improves.

As to alumina: the change from kaolin to bauxite to diasporite has already been described. The diagram, however, shows only diasporite and especially indicates that the decrease of diasporite is accompanied by an almost perfect rhythmic, or ratio of, increase by weight in hercynite. These are the two exceptionally distinctive minerals.

Another thing well shown by the diagram is the progressive increase from top to bottom of both garnierite and chromite. The nickel-bearing mineral increases from 2.5 to 3.4 percent, and the chromium-bearing mineral increases from 2.4 to 5.2 percent. This downward progression of nickel suggests that the lowermost ore layer or the uppermost part of the peridotite should be an excellent nickel prospect.

# DIAGRAM TO SHOW CHEMICAL COMPOSITIONS OF OOLITIC AND NON-OOLITIC PHASES OF CLE ELUM IRON ORES

(Vertical Height represents Percents by Weight)

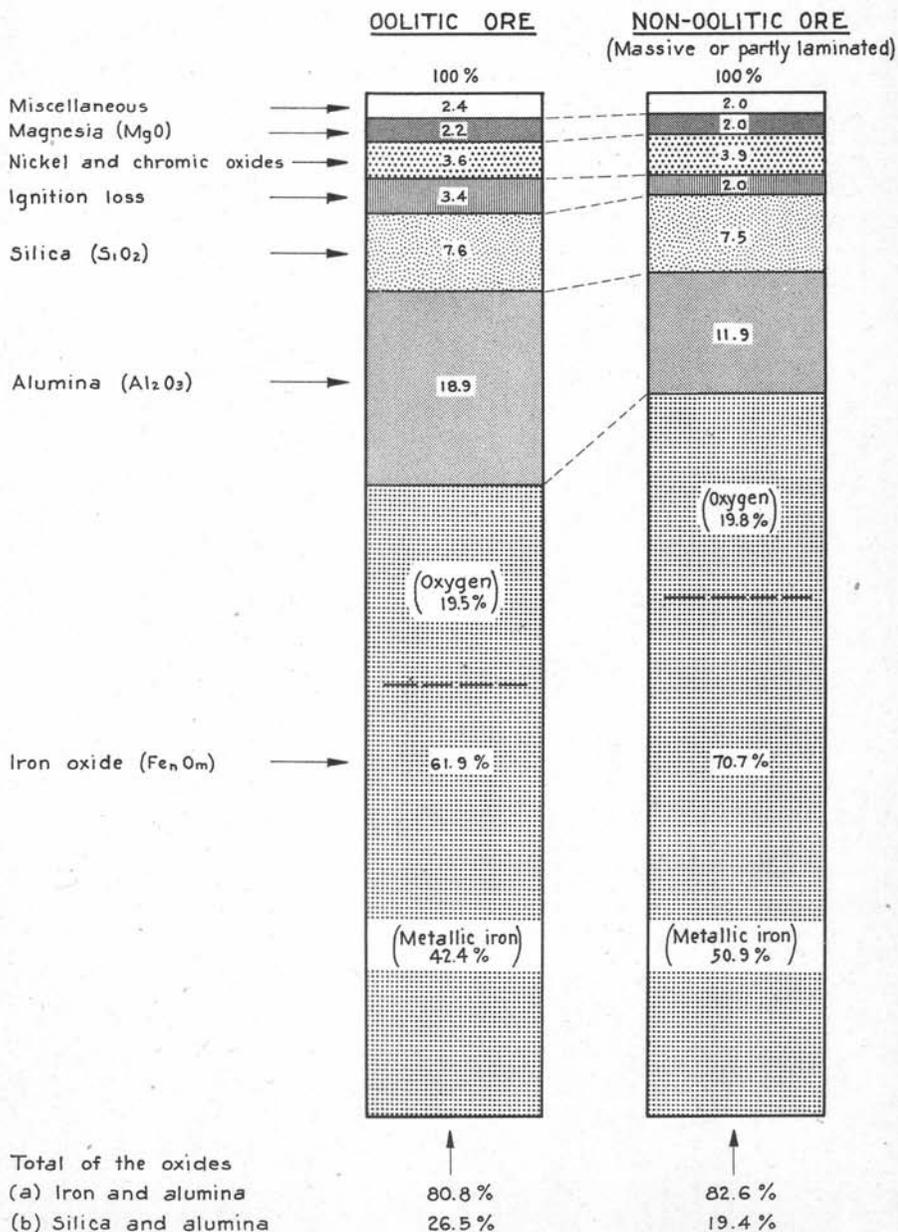


Figure 2



MAGNETIC SURVEYS

At twelve places dip-needle readings were taken across the ore formation and adjacent rocks. Where readings were taken across known ore, the results obtained when plotted in profile agreed with the magnetic profiles that the writer has obtained in other far-away districts for like strikes and dips. The maximum reading here always occurs at the middle, or a little to the east of the middle of the ore formation. If faulting has separated the formation into blocks, then a line of maximum attraction will be found for every separated block. These magnetic-profile cross sections have been plotted on the map of plate 1.

The profiles show that where the strike is about N. 30° E., then readings to the west (on the sandstone) of the maximum attraction are positive, whereas those to the east (on the peridotite) are negative for quite a distance before returning to zero. Irregularities in readings taken over peridotite are due to a content of disseminated or small blebs of magnetite natural to peridotite. Where the strike is N.-S. (and the dip westward), the readings both to the east and west show a drop to negative values and produce a profile that is almost symmetrical with respect to the point of maximum attraction; but before again attaining zero value the part of the traverse made over the peridotite produces readings that make a longer and flatter curved line than do those taken over the sandstone.

In this part of the Cle Elum district the readings are seldom very strong, because the content of magnetite in the ore is never very large and the other iron-bearing minerals present, even the martite, hematite, and goethite, are nonmagnetic. Nevertheless, in this district a careful and detailed magnetic survey can be a very useful method for locating the formation in places where it is concealed, and in judging other things about it.

These experiences can be applied to advantage in the area lying between the north end of the Monarch deposit and the south end of the King-Boss deposit, a distance of 1,200 feet. Here the field party made five magnetic traverses across the formation. They are from 130 to 320 feet apart. The profiles show a magnetic belt varying from 150 to 250 feet in width, containing maxima of moderate intensity and, when plotted, producing gently sloping curves. Regarded in its entirety, this suggests the presence of a continuous band of ore formation. Prospecting along this line of maximum attraction is certain to reveal the ore formation. The few readings taken do not enable the investigator to decide whether any unusual thicknesses or dislocations occur or what the nature of the variations in mineral composition might be.

## DIMENSIONS

### General

The descriptions given up to now speak of an iron-bearing formation quite as though it were a separate formation, but that is merely because it facilitates descriptive writing. Actually, the ore zone is a thin layer marking the top of the unaltered igneous rock, peridotite, and lying below the Swauk sandstone. Again for sake of simplicity, we may say that it is continuous for a long distance across the countryside as a relatively undisturbed band dipping at moderate to steep angles. Based on iron content, only the basal portion of this band is apt to be used as an ore of iron. The word 'ore' will be used in the broadest sense and not as designating a metallurgical acceptable portion or an economically feasible thing.

Traversing this formation on the present rock surface is quite like following the shore line of two large bays, opening westward. Here and there local crumpling has flattened the dips and widened the exposures. Warping and bending of the entire rock mass has caused crustal shortening, and the stresses thus created have found relief in short longitudinal faults and shears in this weaker band, called the ore formation, and jointing has made the ore blocky. All these bear directly on what is determined about the dimensions required for estimating tonnages.

### Thickness

Both the Monarch and the King-Boss deposits are divided near their middle parts by sets of longitudinal faults, thereby creating north and south portions. These separations could even be markers of divisions of lesser and greater economic significance but are here regarded as of equal significance. Many measurements were scaled off the plans (pl. 1 and pl. 2) and corrected for the angle of dip. For the Monarch deposit the shallower dips are from 25° to 29° and yield the wider exposures; the steeper dips are from 40° to 45°. On the King-Boss deposit the dips are from 30° to 55° where no structural dislocations occur, but on faulted segments the dips are as high as 65° and 72°. The calculations produced these thicknesses:

#### *Thickness of Ore*

Deposit	Minimum (feet)	Maximum (feet)	Average (feet)
Monarch .....	6.5	28.8	17.0
King-Boss .....	5.8	20.0	11.0

Where the south end of the formation of the King-Boss deposit reaches Cle Elum river, folding and faulting are responsible for the exposure measuring about 100 feet in width. As well as can be measured from the sections made from an examination at that place, the actual thickness is probably no more than 20 feet.

### Length

The total length for the Monarch deposit is taken to be 1,680 feet. For the King-Boss deposit the length is 1,370 feet, if one omits the footage where exposures are absent and that is represented by gaps on the map; however, the gaps are small, and the apparent absence of the formation may be only peculiar to that elevation, so 1,500 feet is taken as an overall measurement.

### Depth

The Monarch deposit crosses the river at an elevation of 2,851 feet. The south part of this deposit rises to a maximum height of 41 feet above the river and the north part to 70 feet. The average relief for the entire length of 1,680 feet is 47 feet.

On the King-Boss deposit, the top of the south end of the deposit rises abruptly to 38 feet above the river. To the eastward, it rises to 138 feet; thence to the northward to a maximum of 156 feet. An overall average relief for 1,500 feet of length is 107 feet.

The description given, bearing on the origin of the ore, provides a basis for speculating on maximum depths. Because (1) the fresh peridotite has about 2 to 4 percent of alumina and quite assuredly not to exceed 6 or 8 percent at the maximum, (2) alumina is the least soluble and most immovable compound under conditions of laterization, (3) the laterite formed has yielded an analysis showing as much as 35.88 percent alumina, and (4) the maximum thickness of ore formation as now compressed measures 28.8 feet, one can calculate, from these factors, that a thickness up to 300 feet of peridotite was destroyed by decay to yield the 28.8 feet of indurated laterite. In some few places perhaps 100 feet was enough to yield from 25 to 28 feet. In all probability much of the laterite was worn off and carried away before the rest was buried for preservation; so it is believed that the greater thickness, of 300 feet, is more apt to indicate the true scale of this transformation.

The significance to be derived from this is that weathering on so huge a scale had to be the result of similar wide-spread climatic conditions of no short duration, and, therefore, could not have been restricted to a small area. That is, one must view this mantle of residual or decayed material as having occupied an area that once measured many square miles in extent. The laterite then formed a horizontal surface, but as seen today its parent rock is elevated as a dome with the laterite forming the sides, where it slopes downward at various angles and away from the apex, and what was formerly miles of extent horizontally has thereby been converted into miles of depth. It is a matter of language, not of measurement. In applying the word depth we now go down the sides of the peridotite dome, or down the slopes of the indentations and embayments in the sides of that dome. The horizontal distance from the

most northerly known outcrop to the most southerly, or from the most easterly to the most westerly (in the district under consideration) is from 2 to 3 miles. This means an observable minimum spread or diameter of 10,000 to 15,000 feet, and that, in turn, indicates that depth must be a matter of thousands of feet.

In that part of the Cle Elum district which is south and east of the part in question, erosion has exposed this same formation on the sides of the dome at elevations which show a depth of as much as 2,000 feet. In the restricted part of the Cle Elum district, herein under discussion, erosion has not carved out so strongly accentuated a topography and a difference of not even 1,000 feet can be verified by actual observation.

#### **Thickness of Layers**

Top and bottom portions of the ore formation differ markedly in chemical and mineral compositions and to some extent in colors and textures. If the thickness is large, it is possible to segregate a middle portion with distinctive characteristics, but always it is gradational in most respects. In some of the exposures the top as now seen may, due to erosion, be the middle or even part of the bottom of the mass as it originally existed.

As a rule, along the entire 3,180 feet of length the more attractive analyses are for those samples that were taken from the lower part of the ore formation. As a layer it averages 49.9 percent in metallic iron (dry); it also contains 0.88 percent metallic nickel and 2.37 percent metallic chromium; together, the three make a total metallic content of 53.15 percent. Alumina is 11.8 percent and silica is 7.6 percent, and together these two make 19.4 percent of acids. Lime is at most 0.39 percent and magnesia 3.31 percent, making a total of 3.70 percent of bases.

In thickness the bottom layer varies between 4.5 and 9.5 feet. The layer is thicker at the Monarch deposit than at the King-Boss deposit. For the general overall purposes an average of 6.1 feet may be assumed. It would not be advisable to assume an average of more than 7 feet—unless for some newer reasons it becomes certain that some of the middle layer can be included profitably.

Because of its position the top layer is necessarily of very irregular thickness, and it will inevitably be discarded if mining the iron ore below it is the sole objective. It is found to average only 36.9 percent in metallic iron. The content of alumina is as much as 35.88 percent, but averages 23.1 percent; together with silica at 6.9 percent, the total of the acids is 30 percent. Lime is 0.33 percent, which with magnesia at 1.90 percent totals only 2.23 percent for the bases. Metallic nickel is 0.68 percent and metallic chromium is 1.84 percent. Under special conditions the top layer may have value for nickel, even if not for its iron content.

# DIAGRAM TO SHOW CHEMICAL COMPOSITIONS OF GREENISH AND BROWN-BLACK VARIETIES OF CLE ELUM IRON ORES

(Vertical Height represents Percents by Weight)

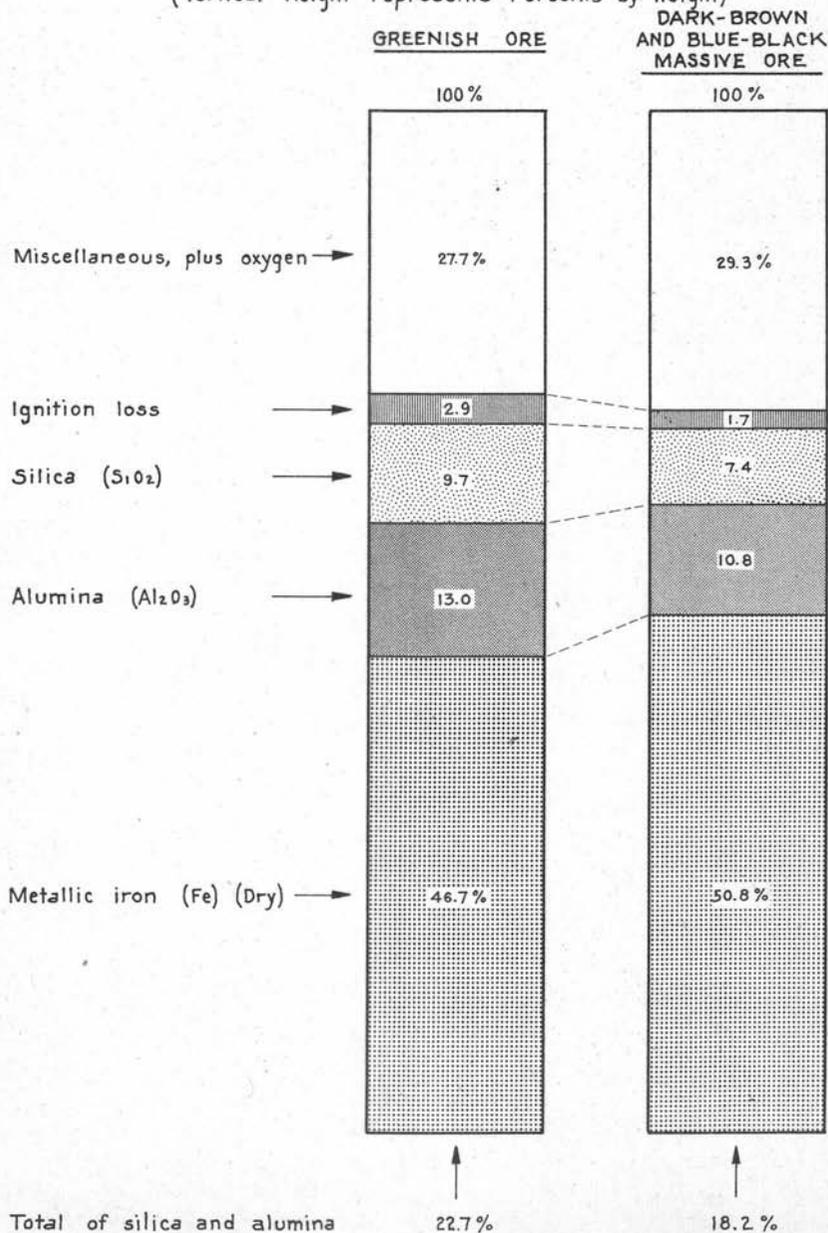


Figure 3



In the Monarch deposit the average thickness of the entire formation is 17 feet. If an average of 6.3 feet is taken as ore, then 10.7 feet remains for the top and middle layers. At some places part of this 10.7 feet may be transferred to be thickness of ore, but undoubtedly at least half will go into waste. For the King-Boss deposit the bottom layer seems to average 5.9 feet, thus leaving 5.1 feet of the average thickness of 11 feet going into waste. In this latter deposit a genetic middle layer may be too small to be worth noting, or, due to erosion, be the presently named top layer.

All these figures for thickness are definitely average footages. Each local spot deserves close testing for the identifying characters. As a summary, the following average footages are given to indicate what the operating problem is going to be like:

*Thickness of Layers*

Layer	Monarch (feet)	King-Boss (feet)	Both as an average (feet)
Top .....	4.0	5.1	4.55
Middle .....	6.7	...	3.35
Bottom .....	6.3	5.9	6.10
<hr/>			
Total.....	17.0	11.0	14.0

**MINERALOGY OF LAYERS**

The mineral composition bears heavily on the matter of beneficiation and ore reduction; therefore, attention is called especially to figure 5, page 24, in which the compositions that typify the different layers of the ore formation are shown. Columns I and II represent top layers; columns III and IV represent bottom layers; column V is a single analysis which is offered to represent the best of the ore. The middle layer is omitted because it is gradational and varies within the full range shown by all the diagrams submitted and which were explained on pages 12 to 14.

**REDUCTION FACTOR**

The determination of the mineral composition for the different layers and ores makes possible the calculation of a mineral specific gravity for each. It is found that the leaner phases, such as the oolitic ore or the top layer, calculate to a specific gravity of 4.12-4.15, and the richer phases, like the nonoolitic ore or bottom layer, calculate to 4.32-4.35. The difference between the two sets is due almost entirely to their different content of magnetite plus goethite. These two sets of specific gravities are converted into weights of 8.3 and 8.7 cubic feet per ton. The ores are exceptionally dense and give evidence of very little pore space; also, although a true moisture sample was not taken, the analyses found for very many samples have always shown exceptionally little water present as moisture.

Therefore, applying corrections for porosity and water and air, it is regarded as conservative and safe to adopt the simple figure of 10 as the reduction factor in reducing cubic-foot volumes to long tons.

#### BENEFICIATION

The usual gravity methods of treatment to decrease silica content have here no place. The mineral compositions show no free quartz, which means that the silica given in the analyses—and whose elimination would be the objective—is combined with other elements to form silicate minerals. Because fayalite and serpentine or chlorite contain iron, it is not advisable to sacrifice iron just to remove silicate minerals.

The principal deterrent to the use of this ore is the very high content of alumina. In that respect one deals mainly with diaspore and hercynite. Their near relatives that are intermixed with them in small amounts are not consequential as to form of treatment considered. Because hercynite consists of 41.4 percent iron oxide (or 34.2 percent metallic iron), and because hercynite comprises from 12 to 17 percent of the ores, it is apparent that any attempt made to remove hercynite for the purpose of decreasing the alumina content, is the wrong attack. The iron-free diaspore is present up to 20 percent in the leaner grades and 6 percent or less in the richer grades, and it has a specific gravity only a little less than that of hercynite; in attempting to remove diaspore by some form of gravity separation in order to reduce the alumina content, it follows that about 40 percent of the entire crude ore would go out at the same time. That would entrain far too much iron and be definitely uneconomical.

For both magnetic separation and flotation, crushing to fine size is paramount. In this instance insufficient amounts of the minerals that respond to magnetism can be isolated by crushing, because the mineral mixture is an intimately and securely cemented mosaic; by far and large most of the resulting small pieces would be exact duplications—mineralogically considered—of any larger piece that yielded them. The microscopic examination discloses ever so clearly that a very considerable part of the magnetite is present as very small grains and dust-like particles encased within the aluminates and silicates.

Before iron could be leached from this kind of crude rock, the latter would have to be treated in preparatory steps of several sorts before solution and leaching could be effective. Processes such as these would be difficult and very costly. It is very doubtful if they would be successful, much less be at the same time economically sound. Leaching is not mentioned because of any thought that it

would have possibilities, but rather to give emphasis to the unsuitability of the Cle Elum ores to such a method of treatment.

There remains for consideration only one class of processes—namely, thermal reduction to make either sponge iron, pig iron, or steel. If an attempt is made to go only part way and produce sponge iron, the thing in favor of considering this ore is its low content of phosphorus and sulphur, because this type of treatment extracts only the oxygen associated with the iron and will not lessen the quantity of the impurities. The metallized portion takes on the phosphorus, but it also attracts the titanium, the manganese, the chromium, and the nickel present in the ore; and, if this sponge is intended to serve as a substitute for high-grade scrap iron needed to make steel, a sponge with that composition will rarely ever do. Whether it would have value as a melting stock to be used in an electric furnace, to be converted into refined metal, is a matter yet to be determined. It is granted that the stock will melt. The whole question is whether it would be economical to treat this crude rock in this sort of a preparatory way when the resultant product would be, in speculation, not as low in degree of contamination as is required of the customary and important high-quality scrap. Secondly, the existence of a market for any directly made metal product of such an unusual composition would need to be ascertained. Such sort of experimental work has never been done.

#### TONNAGE ESTIMATES

All the basic factors needed for estimating tonnages have now been herein established and the results they produce are next tabulated.

*Dimensions of Deposits*

	Monarch	King-Boss
Length (in feet) .....	1,680.00	1,500.00
Widths (in feet)		
a. Minimum .....	6.50	5.80
b. Maximum .....	28.80	20.00
c. Average .....	17.00	11.00
d. Bottom layer 'ore'....	6.30 (or 40%)	5.90 (or 54%)
Depths (in feet)		
Average height above river	47.00	107.00
Reduction factor .....	10	10

*Estimates of Quantity*

Quantity	Monarch (tons)	King-Boss (tons)
1. Above river level		
a. Full width of formation...	134,232	170,550
b. Bottom layers only.....	49,745	94,694
2. Per 1,000 feet of depth		
a. Full width of formation...	2,856,000	1,650,000
b. Bottom layers only.....	1,058,400	885,000
3. Per 2,000 feet of depth		
a. Full width of formation...	5,712,000	3,300,000
b. Bottom layers only.....	2,116,800	1,770,000
4. For all above 1,000 feet below river level		
a. Full width of formation...	2,990,252	1,820,554
b. Bottom layers only.....	1,108,145	979,695

This tabulation means:

1.—That the two deposits together have 304,782 tons of formation above the river-level elevation, and that 144,440 tons of it constitutes bottom-layer material, termed 'ore'.

2.—That 1,000 feet of depth means a total of 4,506,000 tons of formation, or 1,943,400 tons of 'ore'.

3.—That by mining to 1,000 feet below river level, the total tonnage of formation above that deeper elevation is 4,810,806 and its bottom layer, or 'ore', amounts to 2,087,840 tons.

4.—Tonnage by blocks of 100 feet of depth is one-tenth of those shown at '2'; and for 2,000 feet of depth it is twice those shown at '2'.

The unexplored area lying between the Monarch and King-Boss deposits, but surveyed magnetically, is 1,200 feet long. The assumed locus of the ore formation has an average height of 60 feet above river level. The formation may be assumed to be at least as wide as the narrower deposit to the north of it, or 11 feet, and the portion of it that constitutes its bottom layer may be assumed to be similar to that lesser quantity given for the deposit lying to the south, or 40 percent. These figures will yield minimum tonnages as follows:

# DIAGRAM TO SHOW DIFFERENCES IN CHEMICAL COMPOSITION BETWEEN LOW-GRADE AND HIGH-GRADE CLE ELUM IRON ORES

(Vertical Height represents Percents by Weight)

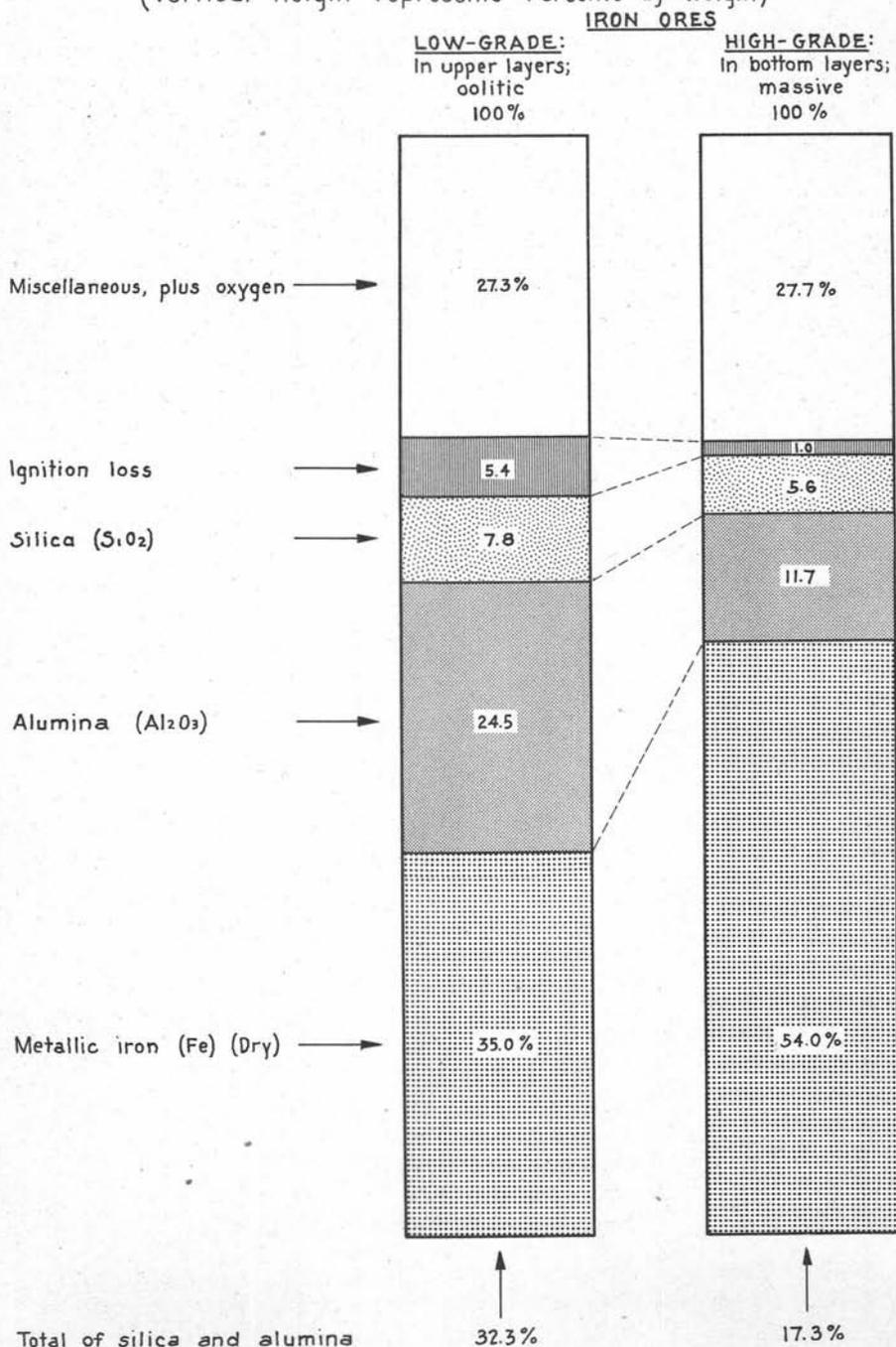


Figure 4



*Estimates of Quantity in Area Between the Monarch and King-Boss Deposits*

Quantity	Magnetic line (tons)
1. Above river level	
a. Formation only .....	79,200
b. Bottom layer only.....	31,660
2. For 1,000 feet of depth	
a. Formation only.....	1,320,000
b. Bottom layer only.....	528,000
3. For 1,000 feet of depth below river level	
a. Formation only.....	1,399,200
b. Bottom layer only.....	559,680

Combining these data, they produce:

*Tonnage Summation*

	Monarch	King-Boss	Magnetic line	Total
Length, in feet.....	1,680	1,500	1,200	4,380

*Case 1*

Tons above river level				
a. Formation.	134,232	170,550	29,200	384,002
b. 'Ore' .....	49,745	94,695	31,680	176,120

*Case 2*

Tons for 1,000 feet of depth				
a. Formation.	2,856,000	1,650,000	1,320,000	5,826,000
b. 'Ore' .....	1,058,400	885,000	528,000	2,471,400

*Case 3*

Tons for 1,000 feet below river level				
a. Formation.	2,990,232	1,820,554	1,399,200	6,209,986
b. 'Ore' .....	1,108,145	979,695	599,680	2,647,520

**MINING METHOD**

To get sufficient tonnage it will be necessary to mine to a depth far greater than a water-level tunnel would provide. An inclined shaft down the dip of the formation is probably the only method that the extreme topographic and physiographic conditions will permit and facilitate mining to depths from 1,000 to 2,000 feet.

If an inclined shaft is used, it will mean following the bottom layer closely, and in taking out 'ore' the operator will recover a thickness of from 4 to 9 feet along a length of 4,380 feet. If the remaining thickness of the formation can be used, an average width of from 11 to 17 feet is available, but in some places it may be

from 20 to 30 feet wide, or whatever exploration under the cover of the Swauk sandstone may yet disclose. No deduction has been made in tonnage estimates for pillars of ore to be left for protection and for similar precautions used when mining in flat beds and under permanent rivers; however, such losses can be compensated for by mining deeper or farther along the strike.

#### OPERATING LIFE

If a blast furnace is to be used, it could hardly be of smaller capacity than 500 tons of metal per day, which means using 400,000 tons of ore per year. If an electric furnace is to be used, the plant might start with a 50-ton furnace but might before long have a 100-ton furnace. The electric-furnace plant could be added to from time to time by new units of 50 or 100 tons, but a blast furnace would have to be rebuilt, if not replaced, to provide larger capacity and output. A 100-ton electric furnace would need about 80,000 tons of ore per year.

A mine developed to produce from a depth of 1,000 feet below water level is Case 3 (see p. 23). As to operating life, the Cle Elum deposit then has these possibilities:

#### *Life of Ore Deposit*

Deposit	Length (feet)	Electric furnace, 100-ton capacity (years)	Blast furnace, 500-ton capacity (years)
1. Monarch .....	1,680	13.9	2.8
2. King-Boss .....	1,500	12.2	2.4
3. Monarch and King-Boss...	3,180	26.1	5.2
4. Entire length.....	4,380	33.1	6.6

That tabulation shows that this ore deposit is far from adequate to serve as a reserve for even a small blast-furnace operation. It would be so even if mining were carried down to a depth of 2,000 feet. It shows that an electric-furnace plant of 100-ton capacity would need to mine both the Monarch and the King-Boss deposits, but a depth of ore of 1,000 feet would be enough for 26 years; and if the entire length of 4,380 feet were operated, the life would be 33 years.

It is not intended here to do other than provide a range of applicable factors, properly determined, and indicate the derived values that enter into a determination of the general nature or set-up of an entire industry. When it comes to making that final plan, several of these and other things need to be considered at the same time in order to determine their reaction upon each other. Things that look good individually often do not harmonize favorably when taken collectively.

# DIAGRAM TO SHOW THE TYPICAL MINERAL COMPOSITION OF VARIOUS PORTIONS OF THE CLE ELUM IRON-ORE FORMATION

(Vertical Height represents Percents by Weight)

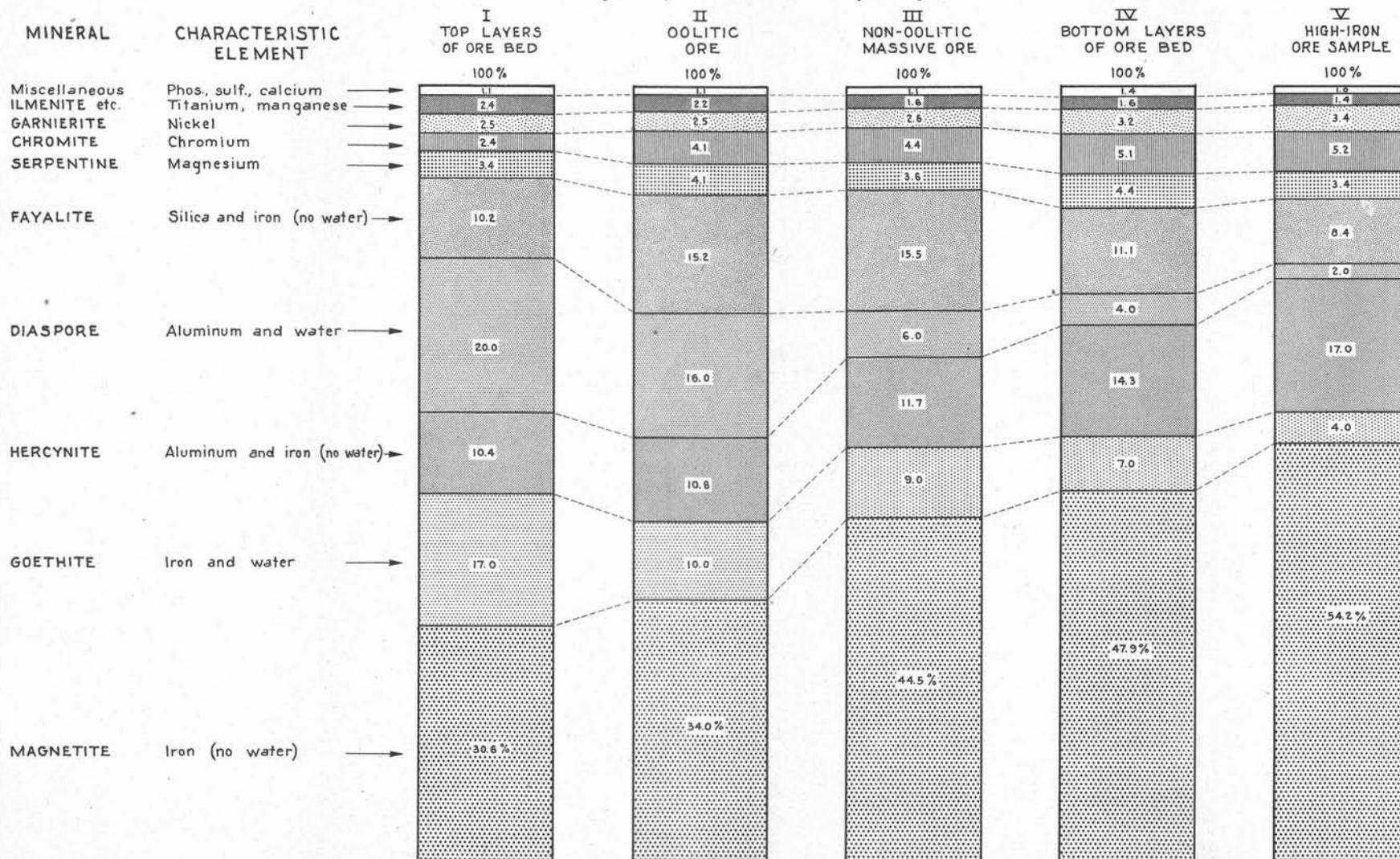


Figure 5

## METALLURGY

The primary purposes of the sampling was to ascertain the thickness of the best part of the ore formation and its analysis. No attempt was made to provide a multitude of samples in order to obtain an average for the entire thickness of ore formation wherever exposed to view. Much of the leanest part, whether gradational upward or downward into abutting rock formations, was never included. If the footages represented by the available analyses are combined, they represent an apparent total thickness of about 19 feet, owing to some overlapping by the so-called middle layer; if the analyses selected are weighted according to the portion of the 19 feet they seem to represent, the following average analyses result as (1) typifying the better part of the entire 'ore formation' and (2) the better part of the latter and here called 'ore':

*Average Analyses of Weighted Samples*

	Ore formation, 19 feet thick (percent)	'Ore', bottom layer only, 6.3 feet thick (percent)
Iron, dry (Fe) .....	45.3	49.9
Silica (SiO <sub>2</sub> ) .....	7.7	7.6
Alumina (Al <sub>2</sub> O <sub>3</sub> ) .....	16.2	11.8
Magnesia (MgO) .....	2.4	3.3
Nickel oxide (NiO) .....	0.94	1.12
Chromic oxide (Cr <sub>2</sub> O <sub>3</sub> ) .....	2.96	3.48
Loss on ignition .....	2.8	1.9
*Miscellaneous .....	2.4	2.2

\* Mn, P, S, TiO<sub>2</sub>, CaO, H<sub>2</sub>O, and rarer substances.

It is apparent that for the 'ore' the dry-iron content is not high. In actual mining, the moisture content will be higher than our dried-out samples yielded. Moisture will probably be about 5 percent; then the metallic-iron content natural to the 'ore' will be about 47.5 percent, which, by the usual eastern-ore standards, is exceptionally low; in any locality it will decrease the money value of the material as ore, no matter how used. This part of the problem is economic as well as metallurgical and, on that combined basis, the use of the entire ore formation would be ruled out unless somebody could introduce something real and tangible not heretofore considered in the reckonings.

The low phosphorous content makes for an excellent grade; and because sulphur is also low, these two lead to no metallurgical difficulties.

Silica is present as a silicate of magnesium and of iron. Generally, a little would be associated with alumina. Such combinations are undesirable, but fortunately the 7.6 percent content of silica in the 'ore' is on the low side. It would be better to have even less, to help reduce the high acid content this ore ever possesses.

Alumina at 11.8 percent in the 'ore' portion is extremely high, and the 16.2 percent contained in even the better part of the ore formation is much worse. Alumina is both the difficult and the costly thing to treat in handling this ore. In blast furnace practices such an ore is used in very small amounts to help alter an otherwise good mixture. Higher heats are needed to reduce high-alumina ores; and when the silica is included, the total flux that must be added and melted to eliminate both the alumina and silica, makes for a very high smelting cost and a huge slag volume. The ore is naturally very low in bases of its own; lime is almost absent and magnesia is not of much value in this respect, therefore all the required flux must be purchased. If still more formation material were taken, an alumina content up to 36 percent would result, silica would go up to 14 percent, the slag volume would increase very much, and iron would go down to from 37 to 40 percent. The quantity of available ore is a strong argument against the desirability of erecting a blast furnace to use this ore.

Another unusual thing about Cle Elum ore is its content of nickel and chromium. In smelting, both go into the produced metal, thus making a special product. Titanium and much of the manganese also stay with the product. No doubt a little cobalt is present. It is well known what each of these elements will accomplish when dealt with singly, but how the members of this group would react upon each other when present at the same time and what they will develop in the way of grain structures and alloy combinations in the metal, no one has yet tried to ascertain, nor can a conclusive and convincing answer be given about these matters from an inspection of ore analyses or any other form of visual inspection. This cannot be regarded with enthusiasm, except it be as a good and worth-while research problem or experiment for an experienced physical metallurgist and especially an electric-furnace operator.

#### FINAL

Dependable information about the Cle Elum iron ores is here compiled, and it is formulated in a more useful manner than to be had elsewhere, from which the conclusions drawn are the following:

1.—A detailed and careful magnetic survey with dip needle can be used advantageously in outlining limits for subsequent field work and for intelligently designating expeditious exploration.

2.—Holes should be drilled to provide dependable information about widths of the bottom layer, or 'ore', at different depths down to 1,000 feet. Drilling is a prime necessity; without it, not much is apt to be done about this deposit.

3.—The mineral composition disclosed by the petrographic studies shows that no gravity-separation or flotation process will beneficiate this formation and that magnetic separation will not be

an economical method. No work has been done on the more costly and intricate methods, such as the leaching and thermal processes.

4.—The ore has a most uncommon mineral composition. Reduction problems for such an ore have not been adequately tested, much less have any been developed, and only uncertainty exists as to the best method of utilizing the ore.

5.—It is axiomatic that an uncommon ore yields an uncommon product. Tests have not been made to demonstrate whether the properties of the product derived from this ore are good and how the product could be used.

6.—A study made now of marketing would be of no purpose, because no one knows what sort of serviceable product can be produced.

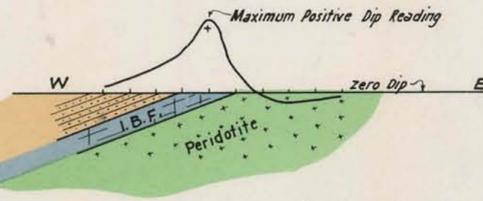
7.—Ore can be easily mined and at a reasonable production cost. Tonnage is expected to be adequate for a long life for a 100-ton electric-furnace operation but inadequate for making an investment in even a small blast furnace.

8.—A most deserving collateral investigation pertains to the occurrence of nickel and the isolation of it from the rock. Also, the abundance of aluminum oxide suggests that it might become a useful product in some sort of a recovery plant. These two things might be possible of accomplishment, even to the point of making iron the by-product. This is solely an opinion influenced by the current activity in the State of Washington with regard to the production of both nickel and aluminum to meet war-time demands. There seems to be no judicious reason for not advocating such metallurgical studies.

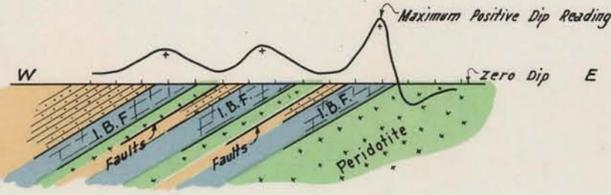
SEC. 26-T.23 N., R.14 E., W.M.  
SEC. 35-T.23 N., R.14 E., W.M.

Section line approximate

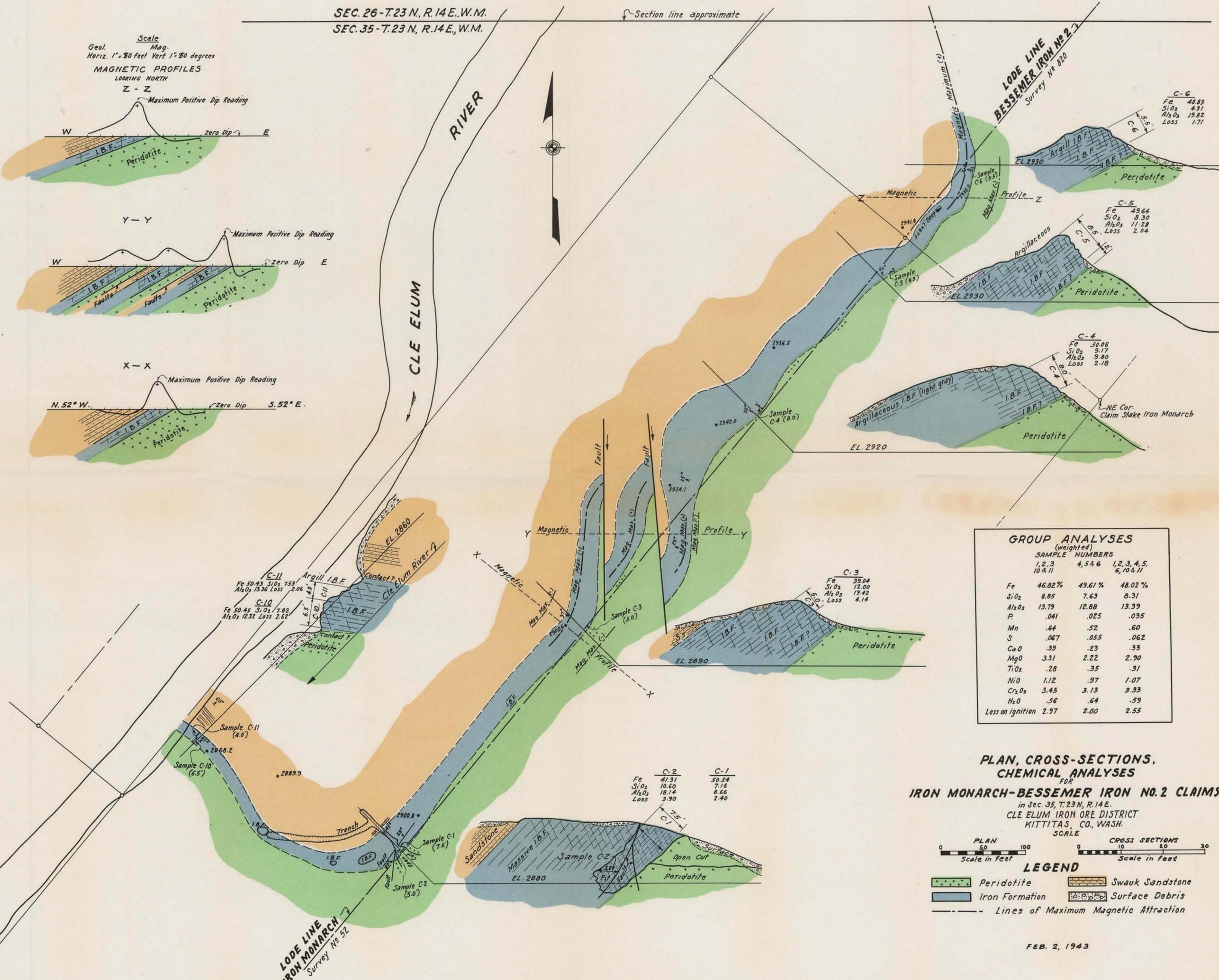
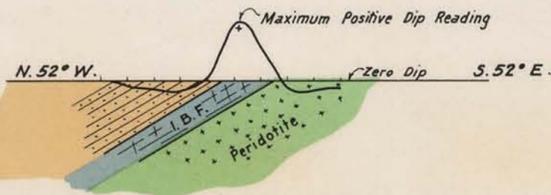
Scale  
Geol. 1" = 50 feet Vert. 1" = 50 degrees  
Mag.  
MAGNETIC PROFILES  
LOOKING NORTH  
Z - Z



Y - Y



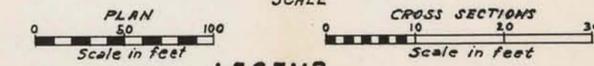
X - X



**GROUP ANALYSES**  
(weighted)

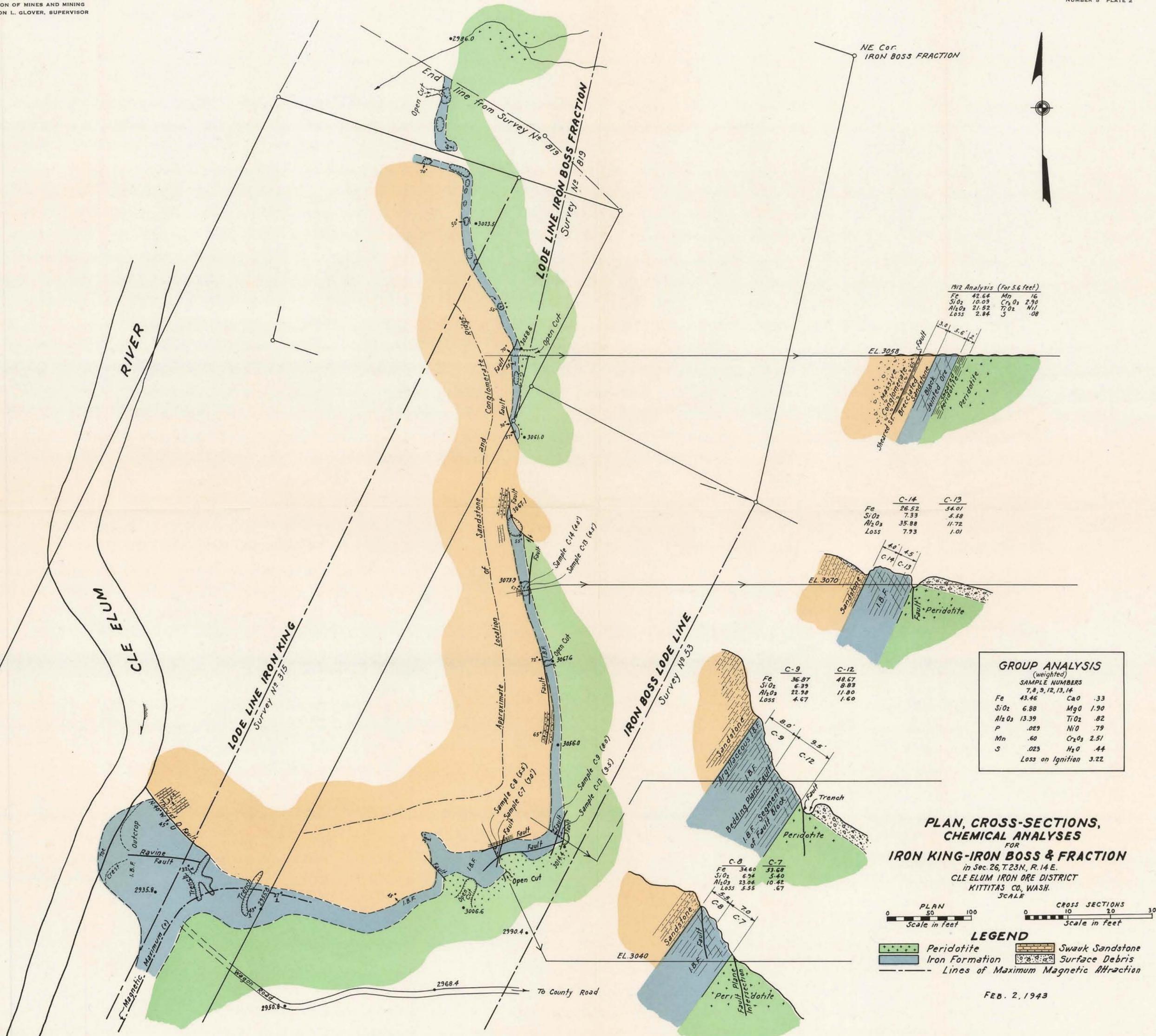
SAMPLE NUMBERS	1, 2, 3		4, 5, 6		1, 2, 3, 4, 5, 6, 10, 11	
	1, 2, 3	10 & 11	4, 5, 6	1, 2, 3, 4, 5, 6, 10 & 11	1, 2, 3, 4, 5, 6, 10 & 11	1, 2, 3, 4, 5, 6, 10 & 11
Fe	46.02%	49.61%	48.02%			
SiO <sub>2</sub>	8.85	7.63	8.31			
Al <sub>2</sub> O <sub>3</sub>	13.79	12.88	13.39			
P	.041	.025	.035			
Mn	.64	.52	.60			
S	.067	.055	.062			
CaO	.39	.23	.33			
MgO	3.31	2.22	2.90			
TiO <sub>2</sub>	.28	.35	.31			
NiO	1.12	.97	1.07			
Cr <sub>2</sub> O <sub>3</sub>	3.45	3.13	3.33			
H <sub>2</sub> O	.56	.64	.59			
Loss on ignition	2.97	2.00	2.55			

**PLAN, CROSS-SECTIONS, CHEMICAL ANALYSES FOR IRON MONARCH-BESSEMER IRON NO. 2 CLAIMS**  
in Sec. 35, T.23 N., R.14 E.,  
CLE ELUM IRON ORE DISTRICT  
KITITAS, CO., WASH.



**LEGEND**

	Peridotite		Swaik Sandstone
	Iron Formation		Surface Debris
	Lines of Maximum Magnetic Attraction		



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