The Cle Elum River Nickeliferous Iron Deposits, Kittitas County, Washington

GEOLOGICAL SURVEY BULLETIN 978-B

The Cle Elum River Nickeliferous Iron Deposits, Kittitas County, Washington

By CARL A. LAMEY *and* PRESTON E. HOTZ

CONTRIBUTIONS TO ECONOMIC GEOLOGY, 1951

GEOLOGICAL SURVEY BULLETIN 978-B

Analyses of drill cores and estimates of ferruginous reserves

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1952

UNITED STATES DEPARTMENT OF THE INTERIOR

Oscar L. Chapman, *Secretary*

GEOLOGICAL SURVEY

W. E. Wrather, *Director*

For sale by the Superintendent of Documents, U. S. Government Printing Office
Washington 25, D. C. - Price $1.00 (paper cover)

CONTENTS

ILLUSTRATIONS

TABLES

THE CLE ELUM RIVER NICKELIFEROUS IRON DEPOSITS KITTITAS COUNTY, WASHINGTON

By Carl A. Lamey and Preston E. Hotz

ABSTRACT

The Cle Elum River nickeliferous iron deposits are about 60 miles east of Seattle, in the Wenatchee National Forest, Kittitas County, Wash., and are exposed principally along the valley of the Cle Elum River at altitudes ranging from 2,700 to 3,500 feet, but subordinate and discontinuous deposits extend eastward into the mountains and attain altitudes of 5,000 feet or more.

The deposits occur as an iron-rich stratigraphic unit at the base of the continental Swauk formation of Eocene age and rest upon serpentinized peridotite. Locally these rocks are cut by many basic dikes. In the Cle Elum River area the rocks have been folded into an asymmetric anticline plunging to the southwest. The average dip of the iron deposits is 32°, but locally dips range from 15° to 65° or more. The major anticlinal structure is complicated by many small folds and by thrust and normal faults.

The iron deposits form a layer, composed chiefly of fine-grained magnetite and various hydrous aluminum oxides, that has an average true thickness of about 15 feet. At most places the upper part of the iron deposits is oolitic to pisolitic and is overlain by mudstone, which is succeeded by siltstone or fine-grained sandstone. The principal minerals in the iron deposits are magnetite, hematite, serpentine, aluminous minerals (diaspore, boehmite, cliachite, and some clay minerals), and chrome spinel. Although nickel is present in appreciable amounts, no nickel-bearing mineral except some secondary millerite has yet been identified.

Analyses of core from 57 diamond-drill holes show the following average composition of the iron deposits: Fe, 40.86 percent; Ni, 0.84 percent; Cr_2O_3, 2.40 percent; SiO_2, 8.96 percent; Al_2O_3, 16.41 percent; P, 0.052 percent; S, 0.111 percent; Mn, 0.46 percent. In general, Fe, Ni, and Cr increase in amount from the top to the bottom of the deposits, whereas Al_2O_3 and SiO_2 decrease, but the SiO_2 content increases again near the bottom. Analyses of the serpentine underlying the iron deposits show an average of 0.63 percent Ni and a range from a trace to 1.94 percent. The average chemical composition of the iron deposits is similar to that of some of the Cuban lateritic iron deposits, and it appears likely that much of the Cle Elum River material was an iron-rich laterite that was subsequently metamorphosed.

Drilling shows a reserve of 6,250,000 tons of ferruginous material containing 40.86 percent Fe, 0.84 percent Ni, and 2.40 percent Cr_2O_3, underlain by serpentine containing 0.63 percent Ni to an average depth of 21 feet. The iron deposits are subdivided into 3,200,000 tons of measured material, 650,000 tons of indicated material, and 2,400,000 tons of inferred material. The better grades of material generally are in the lower 60 percent of the iron deposits.

Much of the material could be recovered only by underground mining, although as much as 1,000,000 tons might be removed by open-pit methods.

GENERAL DESCRIPTION OF THE AREA

The Cle Elum River nickeliferous iron deposits are in the Wenatchee National Forest, northern Cascade Mountains, in Kittitas County, Wash., about 60 miles east of Seattle, within the area covered by the Snoqualmie quadrangle (fig. 7). The main line of the Northern Pacific Railway passes through Cle Elum, about 25 miles south of the deposits, and a branch line extends northwestward through Roslyn and ends about 18 miles south of the deposits. The area is served,

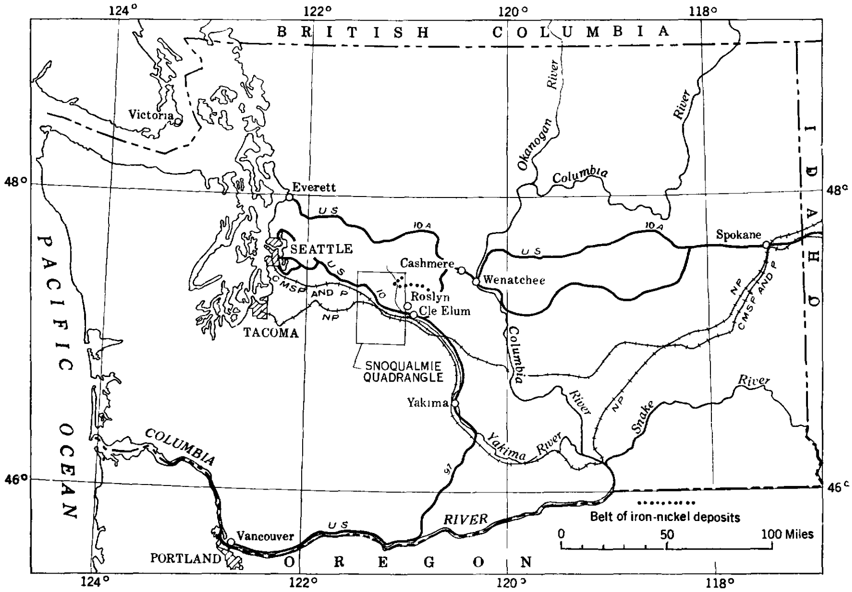

FIGURE 7.—Index map of Washington showing the location of the Cle Elum River nickeliferous iron deposits.

also, by the main line of the Chicago, Milwaukee, St. Paul and Pacific Railroad, which passes through South Cle Elum. A paved road extends from Cle Elum to the south boundary of the Wenatchee National Forest, a distance of about 8 miles, and a rough crushed-rock and dirt road leads from the forest boundary to the deposits.

The road through the Wenatchee National Forest is closed by snow, most years, from December to April. The annual snowfall usually is 6 to 10 feet, but it may be as much as 16 feet. Precipitation is relatively high in winter and low in summer.

The natural resources of the area favor exploitation of the deposits. Water and timber are abundant in the immediate vicinity, and good-grade coal, although not of coking quality, is mined in the adjacent Roslyn basin.

The principal deposits are exposed chiefly along the valley of the Cle Elum River, at altitudes ranging from 2,700 to 3,500 feet, but subordinate and discontinuous deposits extend eastward into the mountains and attain altitudes of 5,000 feet or more. The eastern end of this chain of deposits appears to be the low-grade nickeliferous iron deposits near Blewett (Lamey, 1950).

EARLY EXPLORATION AND DEVELOPMENT

The Cle Elum River deposits were actively explored between 1887 and 1906, and early scientific examinations were made by Kimball (1898), by Smith and Willis (1900), and by Smith and Calkins (1906). Claims were located as early as 1887, and patented claims now owned by Balfour, Guthrie, and Co., Ltd., 1425 Dexter Horton Building, Seattle, Wash., cover the principal deposits. Mining explorations for Balfour, Guthrie, and Co. were made by Robert Young in 1904 and 1906 (unpublished reports). The early developments consisted of about 60 shallow cuts, a few adits and shafts, and 4 diamond-drill holes.

SUBSEQUENT INVESTIGATIONS

The principal investigations after 1906 were made by geologists of the Northern Pacific Railway. In 1912 Zapffe prepared an unpublished report (March 1, 1913, in files of Northern Pacific Railway) outlining the principal features of the deposits and made a reconnaissance map showing the principal outcrops of iron deposits in the Cle Elum River district. In 1922 the Washington Geological Survey published the results of a study made by Jenkins (1922), and in the fall of 1942 J. T. Mullen and C. L. Holmberg (Zapffe, 1944) made a detailed map of most of the outcrops of iron deposits in the NW¼ sec. 35 and S½ sec. 26, T. 23 N., R. 14 E. The Washington Geological Survey in 1942 and 1943 conducted a magnetic, economic, and stratigraphic investigation of the deposits (Broughton, 1944; Lupher, 1944).

The present investigation, by the Geological Survey, began in the fall of 1942 following a preliminary examination of the deposits in 1940 by E. F. Burchard, who also was in charge of the investigation itself. Surveying was done in September and October 1942, from May 25 to December 20, 1943, and during several summer weeks in 1944. Detailed geologic and topographic surveys were made of parts of secs. 26, 34, and 35, T. 23 N., R. 14 E., and parts of secs. 2 and 3, T. 22 N., R. 14 E. (see fig. 15 for a generalized map). The work was done with transit, telescopic alidade, plane table, stadia rod, and dip needle. True north was determined by the Baldwin solar chart.

Balfour, Guthrie, and Co., the Northern Pacific Railway Co., and

Carl Zapffe made available maps and manuscripts and many chemical analyses. Alfred McDonald gave the field party valuable suggestions regarding the geography of the area and assisted in many other ways. S. E. Good and P. D. Proctor gave technical assistance in the field, and P. J. Shenon and J. J. Collins contributed field guidance and coordinated the work with the program of the U. S. Bureau of Mines.

The Bureau of Mines explored the area from early August to late December 1943 and from about July 15 to November 1, 1944, digging several trenches and 57 vertical diamond-drill holes totaling 11,205 feet.

PUBLICATIONS

The general geology and economic deposits of the Cle Elum River area are described in the Snoqualmie and Mount Stuart folios (Smith and Calkins, 1906; Smith, 1904) of the Geological Survey. The iron deposits are described more fully in other publications. The chief sources of information have been cited and are listed alphabetically at the end of this paper.

GEOLOGY

ROCK FORMATIONS AND GENERAL RELATIONS

Relatively few formations are exposed in the immediate vicinity of the iron deposits. These are tabulated below, with the youngest rocks at the top.

Surficial deposits (Quaternary): Alluvial, colluvial, and glacial deposits.
Dike rocks (Tertiary): Diabase, basalt, and andesite.
Swauk formation (Eocene): Chiefly sandstone, siltstone, and conglomerate.
Nickeliferous iron deposits (Eocene?): Considered by the authors to be chiefly residual material beneath the base of the Swauk formation.
Granodiorite (pre-Tertiary): White to gray granitic rock.
Peridotite (Jurassic?): Chiefly serpentinized harzburgite.
Hawkins formation (pre-Jurassic?): Chiefly greenstone.

The descriptions of the rocks are based on megascopic examination of outcrops and drill cores and on microscopic study of thin and polished sections made chiefly from diamond-drill cores.

HAWKINS FORMATION

The Hawkins formation was not examined in detail, as it is present only along a small part of the northern border of the area mapped, where locally it forms the northern limit of the iron deposits. It is a dark greenish-gray altered rock in general resembling greenstone. Chlorite, pyrite, pyrrhotite, and some feldspar are distinguishable megascopically.

PERIDOTITE

Peridotite, the rock on which the iron deposits rest, is exposed more extensively than any other igneous rock in the area. All the peridotite is at least partly serpentinized. Much of it is very dark green to nearly black, either dense and massive or somewhat mottled, though some of it shows several shades of green and may be mottled or streaked with pink, green, and white.

Microscopic examination shows that much of the peridotite is harzburgite, originally composed chiefly of olivine and an orthopyroxene, but that some of it is dunite, originally composed chiefly of granular olivine. Most specimens examined consist chiefly of serpentine minerals. These apparently include antigorite and perhaps some chrysotile and probably include serpophite, which, according to Rogers and Kerr (1942, pp. 362–363), is an amorphous, massive, almost structureless mineraloid associated with antigorite and composing part of serpentine. Bastite, the variety of antigorite pseudomorphous after pyroxene, is prominent in some specimens, and pleochroic bowlingite is not uncommon. Remnants of pyroxene and olivine, some magnetite, chrome spinel, talc, calcite and perhaps other carbonates, and leucoxene also can be seen.

GRANODIORITE

Granodiorite is exposed only in two small areas, one west of the Cle Elum River and the other south of Camp Creek (pl. 9), where it cuts the peridotite. It is chiefly gray to white, medium-grained, and massive and resembles granite. Megascopic examination shows that the rock is composed mostly of white feldspar throughout which are scattered biotite, perhaps hornblende, and some quartz. The feldspar consists of both orthoclase and plagioclase, the latter showing fine striations and, in a very few specimens, zoning. No microscopic studies of this rock were made, but the megascopic characteristics indicate that it may be the Mount Stuart granodiorite (pre-Tertiary) that occurs just to the north of the Hawkins formation, outside the area mapped by the authors. It was described by Smith and Calkins (1906, p. 4).

NICKELIFEROUS IRON DEPOSITS

The nickeliferous iron deposits rest upon the serpentinized peridotite and form a thin, discontinuous unit beneath the base of the Swauk formation. The chief deposits are in the northern part of the area mapped and consist mostly of fine-grained magnetite and admixed serpentine, diaspore, boehmite, cliachite,[1] gibbsite, chrome spinel, and hematite. The deposits are divisible into four types: massive, laminated, concretionary, and "pebbly" or fragmental. All are usually black to dark gray except the laminated type, which is black to gray and streaked with green, red, or buff. The iron deposits are the material of chief economic interest in the area mapped.

[1] "Cliachite" is used as a descriptive term for the fine-grained cryptocrystalline bauxitic material that cannot be resolved under the microscope and that probably consists of very finely crystalline gibbsite and other aluminous minerals and contains abundant impurities.

SWAUK FORMATION

The Swauk formation, of continental origin, is the principal unit exposed in the area. It is dominantly gray to nearly white, well-indurated, medium- to coarse-grained feldspathic sandstone, but it includes considerable amounts of conglomerate and dark-gray siltstone and some nearly black mudstone. Bedding is obscure except in the siltstone.

The lithology of the formation changes abruptly within short distances, not only laterally but vertically, and coarse sandstone and conglomerate may be in contact with siltstone. Characteristically, mudstone is present near the base of the formation, immediately above the iron deposits into which it grades, and siltstone and fine-grained sandstone rest above the mudstone. Less commonly mudstone is present in higher beds. Conglomerate ordinarily is associated with coarse-grained sandstone, but its distribution within the formation is very erratic; rarely it is found at the base of the formation, where it rests upon serpentinized peridotite, and the iron deposits are absent.

MUDSTONE

The mudstone near the base of the formation is ferruginous at most places and apparently grades into the underlying iron deposits. Locally it is composed dominantly of serpentine and rests upon the serpentinized peridotite. The mudstone in the upper beds is commonly graphitic, and in some places several inches of the formation are composed of almost pure graphite. Megascopically the mudstone is either concretionary or massive, but microscopically it is separable into three varieties: concretionary, concretionary and fragmental, and fragmental, the third variety corresponding to the one that appears massive megascopically. Where all three varieties are present, the fragmental one is uppermost.

The concretionary mudstone contains, not only many particles of concentric structure, but also some that are rounded and structureless. Many of the concretionary and structureless particles are oval and 1 to 3 millimeters across, but some compound ones, each containing several small concretions, are as large as 5 millimeters across. Between the larger concretions are smaller particles, either concretionary or structureless, as small as 0.05 millimeters across (fig. 8). The dominant constituents are cliachite,[2] diaspore ($Al_2O_3.H_2O$), and possibly boehmite ($Al_2O_3.H_2O$), gibbsite [$Al(OH)_3$], serpentine ($H_4Mg_3Si_2O_9$), chrome spinel [$(Fe,Mg)(Al,Cr)_2O_4$], and magnetite ($FeFe_2O_4$). Among these, gibbsite that can be identified microscopically is distinctly subordinate. Minor constituents are pyrite, pyrrhotite, biotite, quartz, partly altered pyroxene, and possibly clinozoisite and zircon.

[2] No chemical formula can be given for cliachite, since it is a mixture of several aluminous minerals. It is chiefly aluminum hydroxide, hydrous aluminum oxide, and abundant impurities.

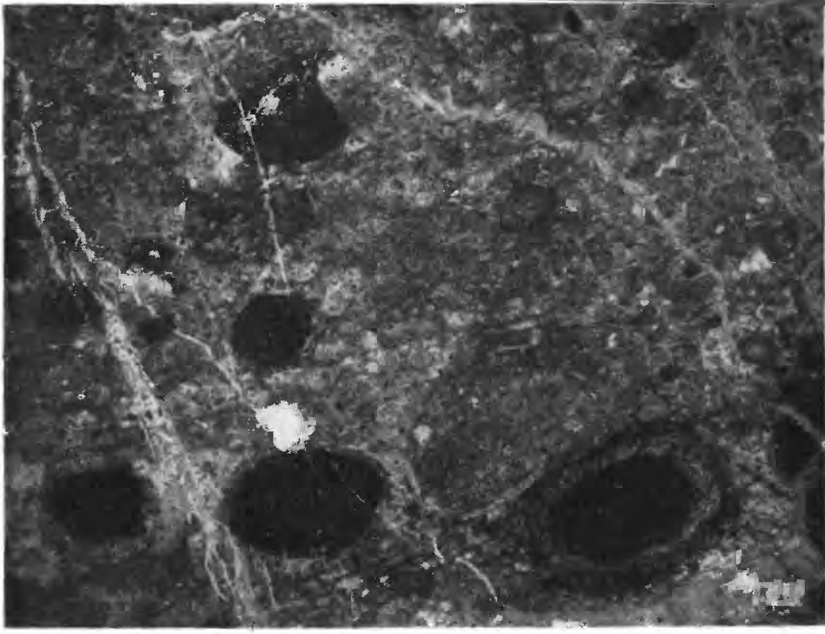

FIGURE 8.—Photomicrograph of ferruginous, concretionary mudstone, Cle Elum River area, Wash. Many particles are composed of a magnetite center (black), through which is scattered some diaspore (light), and are rimmed by cliachite and diaspore (light). Other particles show no concretionary structure and are composed chiefly of cliachite (dark gray) and diaspore. The interstitial material is chiefly cliachite. The veins are chiefly diaspore. Without analyzer.

The biotite and quartz are in very small particles but are definitely fragmental material.

The minerals show some diversity of distribution throughout the mudstone. The concretionary particles may consist of cliachite surrounded by diaspore; of several alternating layers of cliachite and diaspore and, in some places, diaspore disseminated through the cliachite; or of bands of magnetite, diaspore, and cliachite (fig. 8). Many contain fragments and well-formed crystals of chrome spinel, either making up the central area or scattered through the concretion. Some contain disseminated magnetite, and a few consist almost entirely of a mosaic of diaspore. The structureless particles are composed chiefly of serpentine, cliachite, diaspore, or chrome spinel. Some of the larger particles contain small concretions. Much of the interstitial material between concretions and the structureless particles is nearly amorphous and appears to be cliachite, with which some serpentine probably is admixed.

The concretionary mudstone is cut by many veins composed chiefly of calcite, pyrite, and diaspore. The diaspore veins are younger than the concretions and fragments (fig. 8) but are older than some of the calcite and pyrite veins.

The fragmental mudstone contains angular, subangular, and subrounded fragments of various minerals ranging in size from 0.05 to 0.3 millimeter, and sparse fragments that attain a size of 1 millimeter, in an extremely fine-grained matrix (fig. 9). The dominant fragments are serpentine and chrome spinel; others are quartz, sericite or talc, zircon (?), diaspore, and some amorphous material, probably cliachite. One thin section shows fragments containing several small concretions, one of which consists of cliachite surrounded by a rim of diaspore and another of which consists of diaspore disseminated throughout cliachite surrounded by a rim of diaspore.

The concretionary and fragmental mudstone shows some of the features of each of the other types. Where it is composed mostly of concretionary material it appears to grade into the underlying iron deposits, but where it is mostly fragmental it grades into the overlying siltstone.

SILTSTONE

Megascopically, no constituents except graphite can be identified in the siltstone. Graphite is commonly present, and exceptionally it forms layers an inch or more thick. Microscopic examination of the rock shows the presence of quartz, plagioclase, biotite, muscovite, sericite, serpentine, chlorite, chrome spinel, magnetite, calcite, pyrite, and possibly apatite and zircon.

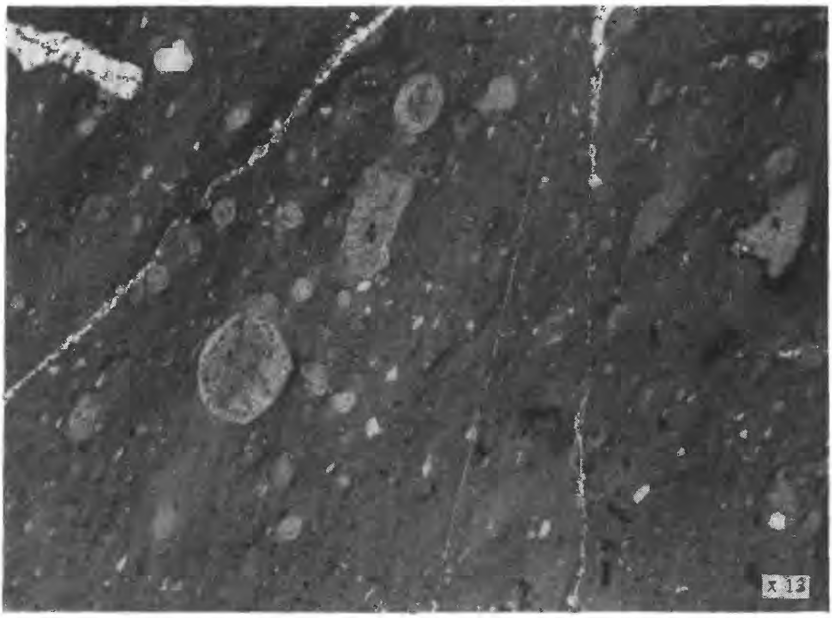

FIGURE 9.—Photomicrograph of ferruginous mudstone, Cle Elum River area, Wash., containing rounded and angular particles. The rounded particles are chiefly cliachite, the angular ones chiefly quartz and mica. Some of the cliachite fragments contain diaspore. Without analyzer.

SANDSTONE

Most of the sandstone contains megascopically visible grains of quartz, feldspar, brown to black mica, greasy sericitic material, dark-gray to black rock, and more rarely serpentine. Graphite, some of it in large pieces, is present at some places. In the outcrops and drill cores, the feldspathic composition and well-indurated character of the sandstone give it the appearance of a granitic rock.

Microscopic examination shows that quartz, feldspar, biotite, serpentine, and a quartzitic rock are the dominant grains in most varieties of the sandstone and that sericite, muscovite, and calcite commonly are present as alteration products or as interstitial material (fig. 10). Constituents more sparingly present are pyrite, magnetite, chrome spinel, chlorite, epidote, apatite, probably zoisite and zircon, and possibly talc and graphite, as well as grains of diaspore rock, schist, siltstone, dike rock, and some sericitized rock.

Most of the sandstone grains are rather angular and moderately closely packed together, but some of them are sharply angular and exceptionally they are widely spaced (fig. 11). In one thin section the quartz grains are about 0.5 millimeter across and are spaced between 0.1 and 1.2 millimeters apart. Where the grains are widely spaced, the matrix may be chiefly serpentine or it may be very dark

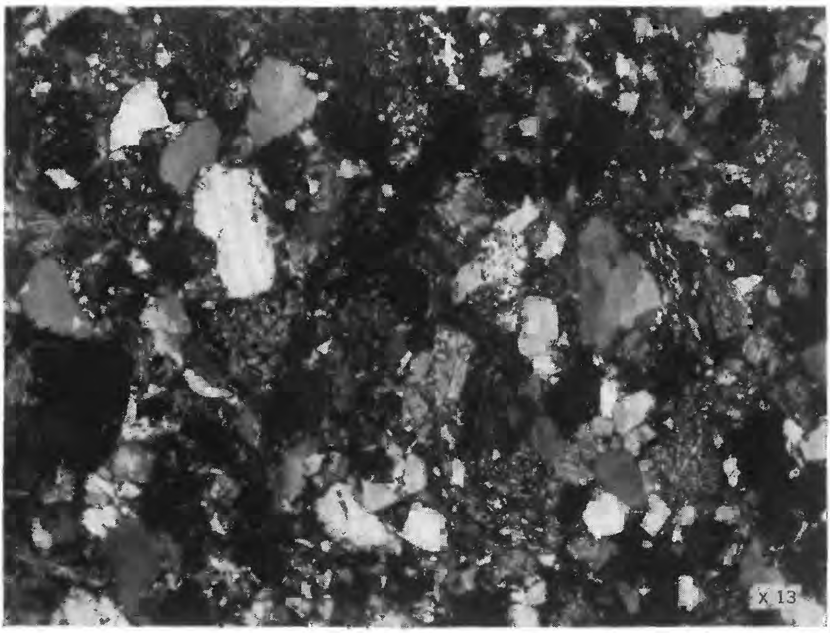

FIGURE 10.—Photomicrograph of sandstone occurring most commonly in the Swauk formation, Cle Elum River area, Wash., showing angular fragments of quartz, feldspar (chiefly plagioclase showing twinning), mica, and fragments of various rocks. Crossed nicols.

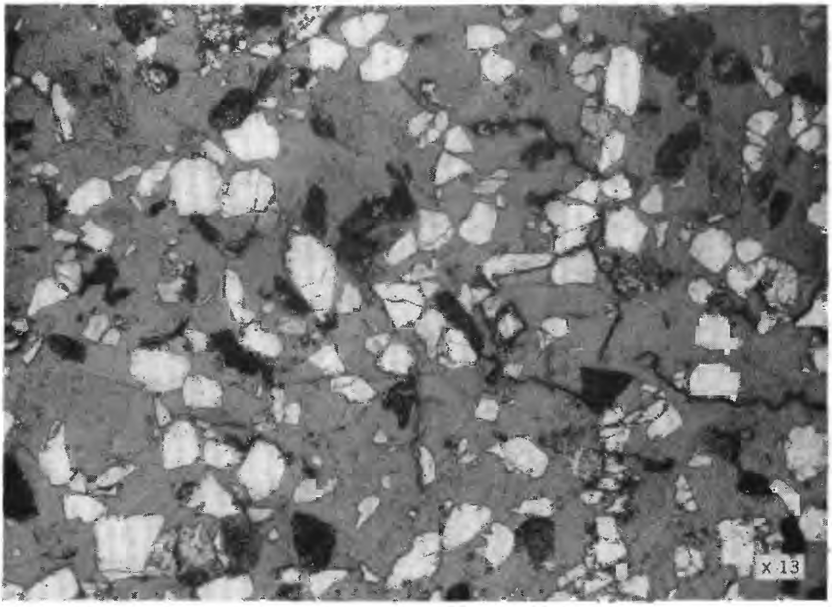

FIGURE 11.—Photomicrograph of sandstone occurring less commonly in the Swauk formation, Cle Elum River area, Wash., showing widely spaced angular fragments of quartz, biotite, and some rock in a serpentine matrix. Without analyzer.

material that appears to be a mixture of serpentine and sericite, perhaps in part graphitic or stained with iron oxide.

CONGLOMERATE

The conglomerate beds in general contain fragments that range from large sand grains to small cobbles, most of them subrounded or subangular. The larger fragments are dominantly light-colored silicic igneous rocks, gneiss, schist, quartzite, and quartz; the smaller ones are both light- and dark-colored and are composed, not only of the rocks that form the larger fragments, but also of serpentine, mafic igneous rocks, and chloritic schists. No fragments of the iron deposits were observed in outcrops or drill cores of this general type of conglomerate.

A rare type of conglomerate is shown by the core from drill hole 51. In this core 3 feet of serpentinous sandstone and conglomerate directly overlies 2.6 feet of iron deposit. The rock contains conspicuous rounded, dark serpentinous granules and pebbles, ranging in size from 2 to 15 millimeters, in a light-colored serpentinous matrix. Microscopic examination shows that the larger fragments are mostly serpentine, some being bordered by a rim of magnetite (fig. 12), and that magnetite and spinel may be disseminated through them. In this respect, these fragments are similar to some of the material in the iron deposits. Scattered throughout the serpentine matrix are many irregular to rounded grains of serpentine and a few fragments of biotite and magnetite. Many of the serpentine grains, ranging in size from 0.3 to 0.6 millimeter, enclose disseminated chrome spinel and magnetite. The matrix is nearly colorless to pale-green antigorite, but the small fragments are pale-green antigorite, darker-green serpophite, bowlingite exhibiting pleochroism in green and brown, and perhaps talc or sericite, probably the former.

BASE OF THE FORMATION

The base of the Swauk formation is probably the mudstone overlying the iron deposits or, where the mudstone is absent, serpentinous sandstone and conglomerate. The concretionary mudstone appears to grade downward into the iron deposits; hence it might be chiefly a residual deposit. However, as it contains some clastic particles of quartz and biotite and is succeeded upward by much more clastic material, it has been designated part of the Swauk formation. Moreover, at most places the concretionary mudstone can be distinguished from the iron deposits and consequently can be mapped with the Swauk formation.

DIKE ROCKS

The principal dike rocks exposed are dark-gray to grayish-green, fine-grained, quartz-bearing diabase and basalt. These rocks are rela-

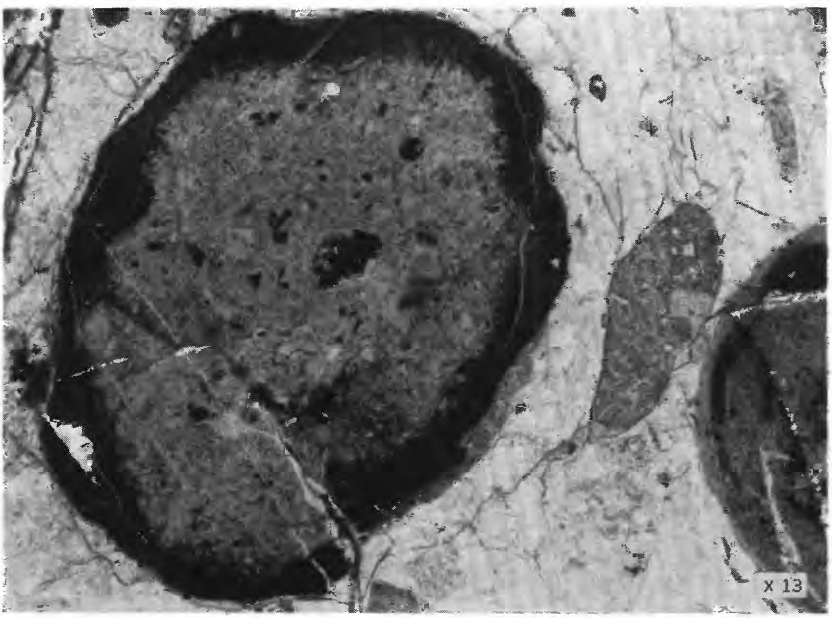

FIGURE 12.—Photomicrograph of serpentine conglomerate. Cle Elum River area, Wash., showing serpentine pebbles rimmed with magnetite and enclosing chrome spinel. The matrix is chiefly serpentine. Without analyzer.

tively abundant and form dikes and sills, ranging from 3 to 50 feet in thickness, which cut the peridotite, the iron deposits, and the Swauk formation. Exposed dike rocks of whitish-gray to white andesite are much rarer, but such andesitic rocks were encountered in many drill holes, where they range from 1 to 11 feet in thickness. In about 70 percent of the holes in which andesite dikes occur, they are 3 to 12 feet above the top of the iron deposits and are almost invariably overlain and underlain by black mudstone. These relationships, found in 17 adjacent drill holes in the central part of the area mapped, suggest the presence of a sill of andesite.

The diabase and basalt dikes range from those that, megascopically, have a rude diabasic texture in which lath-shaped plagioclase is interwoven with fine-grained dark material, through those in which only minute crystals of light-green plagioclase and specks of pyrite and pyrrhotite are visible, to others that show no recognizable minerals. Microscopically, most of these dike rocks are imperfectly diabasic (fig. 13), but a few are porphyritic. The diabasic types contain long, prominent laths of plagioclase (sodic or medium andesine to labradorite) surrounded by augite and chlorite; small amounts of quartz, both interstitial and intergrown with plagioclase; ilmenite; pyrrhotite; sericite; calcite; and leucoxene. A specimen from one of the porphyritic dikes contains phenocrysts of sericitized feldspar and a very small amount of quartz, both of which are considerably resorbed, and original pyroxene altered to antigorite.

The light-colored andesitic rocks found in drill cores are finely crystalline and resemble silicified limestone. Megascopically, only calcite, pyrite, and some minute rods of feldspar are recognizable. Some of the calcite is in areas several millimeters across, and in a few specimens the pyrite is in globular masses resembling concretions, although in most it is in well-formed single crystals. Along joints and near the surface the rock may be cellular because of the solution of calcite, and it may be stained brown from the oxidation of pyrite.

Microscopic examination shows that the chief constituents are plagioclase (oligoclase-andesine), calcite, sericite, and chlorite, plus muscovite, pyrophyllite, or talc; that minor constituents are quartz, pyrite, apatite, titanite, rutile, leucoxene, antigorite (?), and probably zircon or allanite; and that these rocks are distinguished by two noteworthy features: rather extensive alteration of the original constituents and imperfectly formed amygdules. Much of the feldspar has been sericitized, and pyroxene has been changed to chlorite and calcite. Many rectangular crystals, originally feldspar or pyroxene, have been converted entirely to calcite; to calcite and a radiating mineral which is muscovite, talc, or pyrophyllite; or, in a few specimens, to antigorite (?). Many specimens contain almond-shaped to irregularly

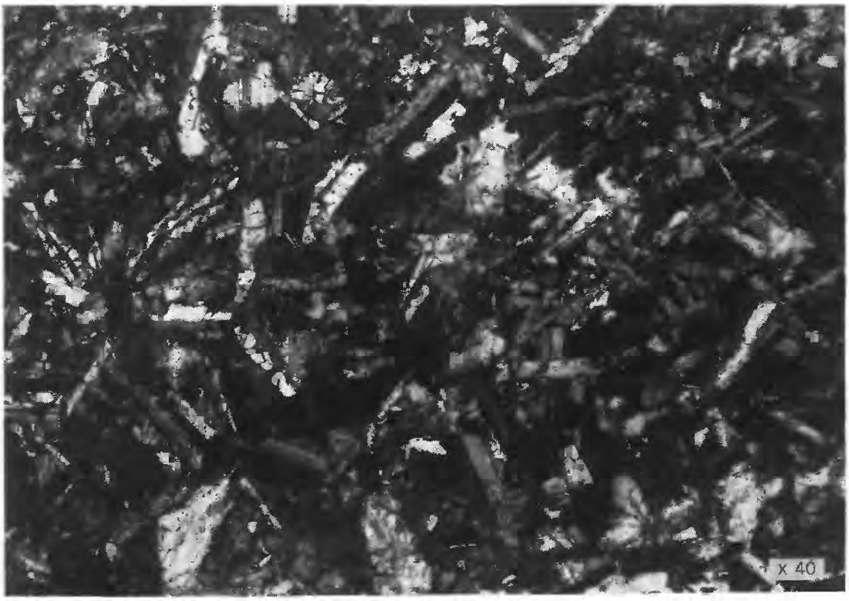

FIGURE 13.—Photomicrograph of dark-colored diabase, Cle Elum River area, Wash. Note the elongated plagioclase feldspar. Crossed nicols.

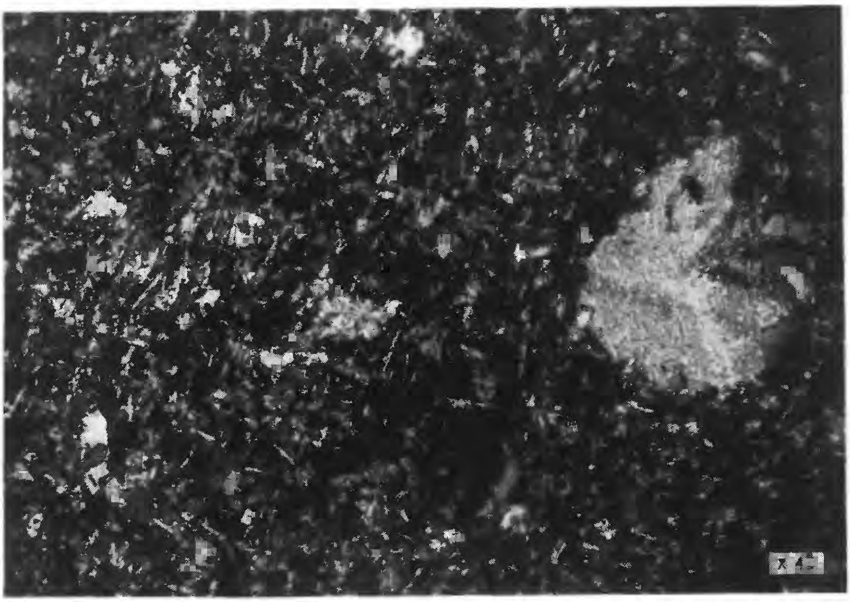

FIGURE 14.—Photomicrograph of light-colored andesite, Cle Elum River area, Wash., showing a small amygdule (right side), feldspar in small rods, and irregular areas composed of calcite, sericite, and muscovite. The central part of the amygdule is composed chiefly of calcite, the marginal parts of quartz and chlorite. The calcite, sericite, and muscovite replace feldspar and possibly pyroxene. Crossed nicols.

elliptical or circular bodies of calcite or quartz about 2 millimeters long and 1 millimeter wide (fig. 14) that resemble amygdules. The calcite bodies may be partly rimmed by well-crystallized quartz, which sometimes projects inward, or by chlorite; most of the quartz bodies are rimmed by calcite. Some contain a radiating mineral resembling feldspar or a zeolite.

SURFICIAL DEPOSITS

The surficial deposits are stream alluvium, stream-terrace deposits, alluvial-fan deposits, glacial morainic deposits, and talus. Of these types the stream alluvium is most widely distributed; the alluvial-fan deposits are restricted to the area between Camp Creek and Boulder Creek (pl. 9). The stream alluvium contains fragments ranging from silt to boulders and composed of all types of rock exposed in the Cle Elum River drainage basin. In many respects the stream-terrace deposits and the glacial deposits are similar, inasmuch as the terrace deposits were formed in part from reworked glacial debris. Both consist chiefly of granitic rocks and small amounts of greenstone, but the terrace deposits contain some serpentine, sandstone, and basic dike rock. In general, the fragments composing the glacial deposits are more angular and are larger than those composing the terrace deposits; blocks in some glacial deposits are as much as 6 feet across. The alluvial-fan material consists chiefly of sand, pebbles, cobbles, and boulders of serpentinized peridotite, as the source of the material was the area of peridotite east of the mapped area. The talus deposits are composed almost entirely of blocks of sandstone and conglomerate from the Swauk formation.

STRUCTURE

The major structural feature of the area is an asymmetric anticline plunging to the southwest (fig. 15). The beds on the southern limb trend about N. 80° E. and dip steeply to the south, whereas those on the northern limb trend about N. 25° E. and dip less steeply to the northwest. The limbs have been crumpled by drag folds and broken by faults; hence, locally, the trends of the beds are very irregular.

Although most of the faults are neither exposed nor easily recognized at the surface, drilling revealed many high-angle thrust and normal faults. The thrust faults are more abundant than the normal ones. The inclination of most of the thrusts is 45°–60° W., and that of the normal faults is 65°–70° W., but some of the normal faults are nearly vertical. As a rule, the vertical displacement along either type of fault is small, ranging from 10 to 60 feet, but exceptionally it is several hundred feet (pl. 9, sections *A–A′* to *E–E′*).

The Swauk formation rests unconformably on the underlying serpentinized peridotite. If the iron deposits are chiefly residual accumulations and not part of the Swauk formation, as the authors believe, the Swauk formation in some places rests on those deposits and in others rests on the peridotite. This unconformable relationship governs the distribution and thickness of the iron deposits, but apparently not their general structure. The dip of the iron deposits conforms closely to that of the Swauk formation (pl. 9, sections *C–C'* and *D–D'*), and diamond drilling has shown, in the absence of con-

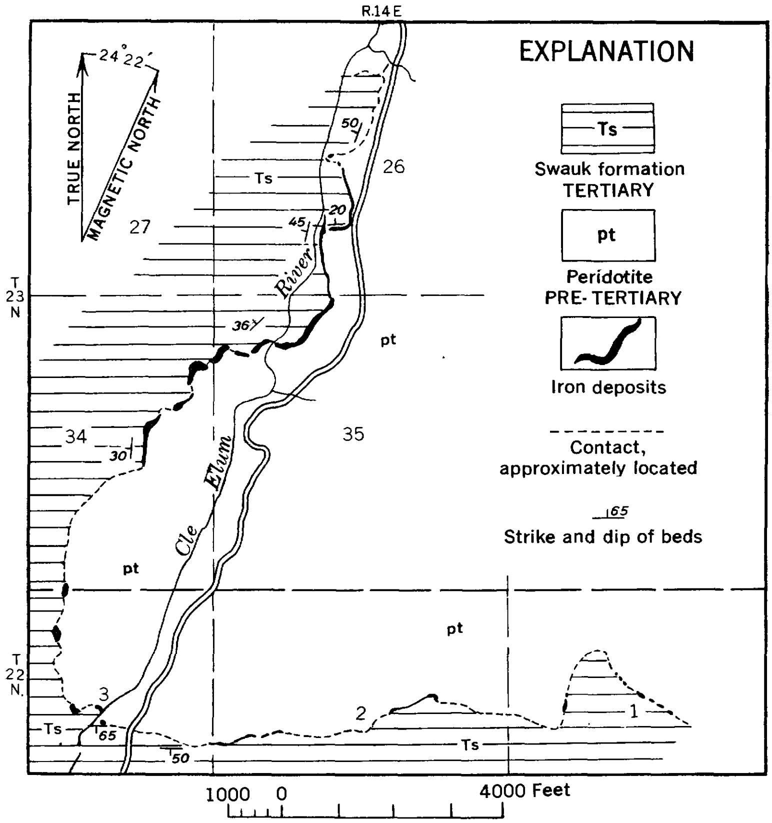

FIGURE 15.—Generalized sketch map showing the major anticlinal structure of the rocks of the Cle Elum area.

cealed folds and faults, that the approximate position of the iron deposits beneath the surface can be predicted with comparative accuracy from the dip of the Swauk formation.

NICKELIFEROUS IRON DEPOSITS

DISTRIBUTION

The distribution of the nickeliferous iron deposits not only is known from outcrops and from diamond drilling but is indicated in covered areas by magnetic attraction. It is governed by the location of the contact between the peridotite and the overlying Swauk formation. This contact is exposed a short distance south of Camp Creek (pl. 9), from which point it was traced southward on the east side of the Cle Elum River for about 2 miles. There it is crossed by the river, on the west side of which it extends southward for about 3 miles. Then it is again crossed by the river and extends eastward for about a mile. The distribution of iron deposits in undrilled covered areas along this contact (pl. 9) is thought to be nearly correct as indicated, because in some of the covered areas in which detailed dip-needle traverses were made diamond drilling has shown that iron deposits are likely to be present where magnetic attraction is pronounced but that they may be very thin or absent where the magnetic attraction is not considerably higher than that yielded by the Swauk formation or by the serpentinized peridotite.

The iron deposits crop out mostly in the northern half of the area mapped, principally in two belts to the east of the Cle Elum River (pl. 9). North of these two belts, almost as far as Camp Creek, magnetic attraction and a few outcrops indicate that iron deposits are present only in widely separated small masses. South of the two principal outcrop belts and west of the Cle Elum River, diamond drilling and magnetic attraction indicate that iron deposits continue southward in closely spaced, rather large bodies for about a mile, are completely absent or exceedingly thin throughout another mile, and then are present only in a few small patches throughout the remaining distance to the Cle Elum River, where there are a few small outcrops. Eastward from the river, iron deposits are very thin or entirely absent up to a point a short distance east of the portal of the Tacoma tunnel, near the E¼ cor. sec. 3, T. 22 N., R. 14 E. (pl. 9), where small deposits crop out.

THICKNESS

The average true thickness of the iron deposits in the area drilled is 15 feet, but the thickness ranges from less than 1 foot to 48 feet. This thickness is exclusive of the overlying ferruginous mudstone, which contains 20 to 25 percent iron and at most places is 2 to 5 feet thick but exceptionally may be more than 10 feet thick. In general the deposits are thickest in the areas of the two principal outcrop belts. In 14 of 53 drill holes that cut the iron deposits, the thickness is less than 8 feet (pl. 10), and in only 5 holes is it more than 25 feet (holes 22, 30, 32, 36, 37).

GENERAL CHARACTER

The nickeliferous iron deposits constitute a thin, discontinuous bed composed mostly of fine-grained magnetite admixed with serpentine and various hydrous aluminum oxides. This bed in many places is divisible into four types, which are, from the bottom upward, (1) laminated, (2) massive, (3) "pebbly," and (4) concretionary. The pebbly type is scarcer than the others. The laminated type is streaked with black, gray, dark green, dark red, brick red, or buff; the massive type is black to gray and very fine grained; the pebbly type is black or dark gray and contains greenish-gray to nearly white, rounded to angular fragments and some oolites, and the concretionary type is black to dark gray and contains oolites, pisolites, and slightly larger concretions.

MINERALOGY

The mineralogy of the iron deposits, though relatively simple, is unusual. It is essentially the same as that of the overlying concretionary ferruginous mudstone. The principal and subordinate minerals found in the iron deposits are listed below.

Principal minerals in the iron deposits

	Relative abundance
Magnetite, $FeFe_2O_4$	Most abundant.
Chrome spinel, $(Fe,Mg)(Al,Cr)_2O_4$	Abundant.
Hematite, Fe_2O_3	Scarce.
Cliachite, $Al_2O_3.(H_2O)_x$	Abundant.
Diaspore, $Al_2O_3.H_2O$	Do.
Boehmite,[3] $Al_2O_3.H_2O$	Rare.
Gibbsite, $Al(OH)_3$	Do.
Serpentine, $H_4Mg_3Si_2O_9$	Moderate.

Subordinate minerals in the iron deposits

Calcite, $CaCO_3$	Quartz, SiO_2
Talc, $H_2Mg_3(SiO_3)_4$	Pyrite, FeS_2
Pyroxene, $(Fe,Mg)SiO_3$ (?)	Pyrrhotite, $Fe_{1-x}S$
Chlorite, $H_8Mg_5Al_2Si_3O_{18}$ (?)	Millerite, NiS
Dickite (?), $Al_2O_3.2SiO_2.2H_2O$	Chalcopyrite, $CuFeS_2$
Clinozoisite (?), $Ca_2(AlOH)Al_2(SiO_4)_3$	

The only nickel-bearing mineral recognized by the authors was secondary millerite, present in fracture fillings of a few drill cores. Probably the nickel of the iron deposits is present in nickeliferous deweylite ($H_{12}Mg_4Si_3O_{10}$ plus Ni) or is locked up atomically with the iron, inasmuch as the nickel content increases rather consistently with the iron content of the deposits and in many samples the highest nickel content is in the serpentine immediately underlying the deposits.

The mineralogy of the deposits as determined by the authors differs somewhat from that described by Zapffe (1944, pp. 11–12, 24), who states that the deposits contain magnetite (including martite and hematite), goethite, hercynite ($FeAl_2O_4$), diaspore, fayalite (iron olivine, Fe_2SiO_4), serpentine, chromite ($FeCr_2O_4$), garnierite [$H_2(Ni,Mg)SiO_4$ plus H_2O], and ilmenite. The chief difference is

[3] Boehmite was not identified by the authors but was shown to be present by an X-ray pattern made by J. M. Axelrod (Allen, V. T., April 8, 1944, written communication).

the presence of fayalite and garnierite, neither of which was found by the authors.

TYPES

The various types of iron deposits differ somewhat in their details; hence each type will be described briefly.

LAMINATED TYPE

Microscopically, the laminated type of material is distinctly schistose; some of it is contorted, and not uncommonly it is cut by many small veins (fig. 16). It is composed chiefly of magnetite, cliachite, serpentine, and chrome spinel. Although reddish hematite appears to be present in hand specimens, microscopic examination indicates that much of the reddish material is really iron-stained cliachite. The veins consist principally of calcite, magnetite, and diaspore. Some of them contain both coarse-grained calcite and well-crystallized magnetite.

The dominant features of the laminated type of iron deposit are alternating and interfingering layers and lenses of magnetite and cliachite, or magnetite and serpentine. Some of the cliachite contains crystals and small nests of diaspore, and some of the magnetite and serpentine layers bend around octahedra of chrome spinel (fig. 16). Near the bottom of the laminated type of iron deposit the amount of serpentine increases, cliachite and diaspore are almost absent, and calcite may be abundant. Study in both field and laboratory indicates that the laminated character results from differential movement between the iron deposits and the serpentinized peridotite. The serpentine at most places is sheared near the contact.

MASSIVE TYPE

Microscopically, the massive type of iron deposit is finely schistose. It differs from the laminated type principally in the thinness of the laminae and in the presence of a greater amount of magnetite.

PEBBLY TYPE

The pebbly type of iron deposit is composed of irregular to rounded particles of cliachite, cliachite and diaspore, or diaspore, which range in size from 0.5 to 10 millimeters or more and are conspicuously lighter in color than the matrix of magnetite in which they are enclosed (fig. 17). Some of the particles are composed in part, also, of calcite or serpentine; a few are surrounded by a rim of cliachite or diaspore; and some contain small fragments and concretions similar in composition to the larger particles. In addition to the pebbly particles, grains of chrome spinel are scattered throughout the matrix. Both the particles and the matrix are cut by veins of calcite and diaspore (fig. 17).

FIGURE 16.—Photomicrograph of a laminated iron deposit, Cle Elum River area, Wash., showing the schistose and somewhat contorted structure. The larger masses around which the laminae are bent are chrome spinel partly replaced by magnetite. The light-colored laminae are composed chiefly of cliachite along with some gibbsite and serpentine; the dark-colored ones are composed chiefly of magnetite. Without analyzer.

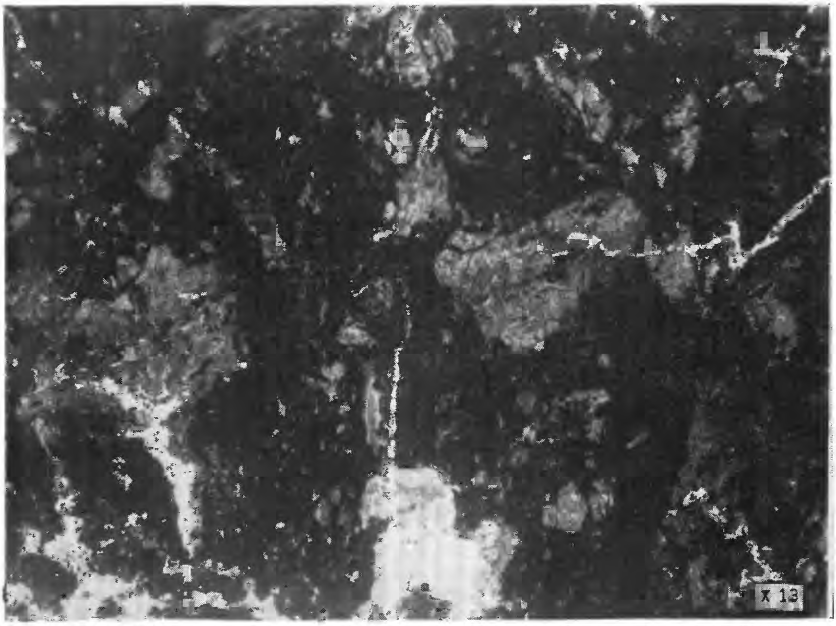

FIGURE 17.—Photomicrograph of an iron deposit of the pebbly type, Cle Elum River area, Wash., showing the magnetite matrix (black) containing fragments composed of diaspore and cliachite (gray) and some magnetite. The veins are composed of diaspore and probably gibbsite. Without analyzer.

CONCRETIONARY TYPE

The concretionary type of iron deposit is composed of many conspicuous and rather closely spaced concretions (of magnetite; of magnetite and cliachite; of magnetite, cliachite, and diaspore; or of diaspore alone) enclosed in a matrix composed of cliachite, diaspore, disseminated magnetite, and some calcite (figs. 18, 19). A great many of the concretions are 2 to 3 millimeters across, but a considerable number attain a size of 4 to 12 millimeters and a few may measure as much as 20 millimeters.

The arrangement of the minerals in the concretions varies considerably. Magnetite, cliachite, or diaspore may form the center, the interior bands, or the rim of a concretion. In many concretions magnetite is concentrated around the exterior part as a thick rim or makes up one-half to two-thirds of the concretion. The cliachite that forms the interior parts of concretions may contain disseminated magnetite in very tiny, sharp octahedra, or it may be cut by minute stringers of magnetite, which appear to replace cliachite. The concretions that are composed almost entirely of magnetite appear to have formed by nearly complete replacement of cliachite. Some concretions enclose chrome spinel, which may be in sharp octahedra but much of which shows partial replacement by magnetite, especially along fractures and around the edges of grains. Some concretions appear to have formed by replacement of spinel, the remnant of which composes the center of the concretion.

Both matrix and concretions are cut by veins of calcite, magnetite, and diaspore. Pyrite accompanies the calcite in most specimens, and magnetite in a few.

Comparison of the concretionary type of iron deposit with the pebbly type, and with the concretionary ferruginous mudstone, shows that in the concretionary type the magnetite occurs mainly in the concretions but that in the pebbly type it is chiefly in the matrix. In the mudstone, however, the magnetite, although generally in the concretions, is very subordinate in amount, and cliachite, diaspore, and serpentine are the most abundant constituents.

CHEMICAL COMPOSITION

The chemical composition of the nickeliferous iron deposits was obtained from analyses of drill-hole and surface samples furnished by the U. S. Bureau of Mines, supplemented by analyses furnished by the Northern Pacific Railway Co. and a few made from samples collected by the authors. According to preliminary chemical analyses, in some places the serpentine underlying the iron deposits contains as much nickel as the iron deposits. Hence nickel analyses were made of about 15 feet of serpentine from most drill holes.

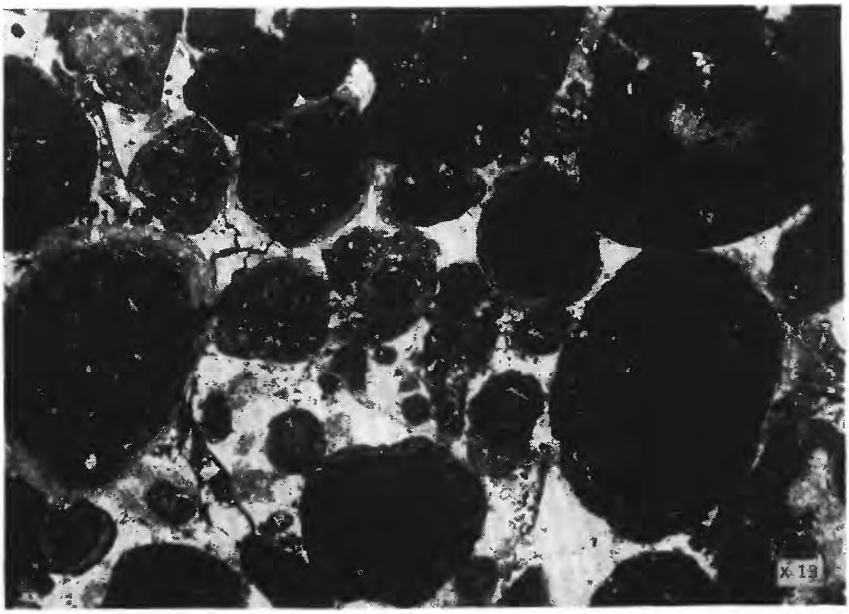

FIGURE 18.—Photomicrograph of a concretionary iron deposit, Cle Elum River area, Wash. Most of the concretions are composed chiefly of magnetite (black), which is rimmed by diaspore (gray); some diaspore is contained in the central part of a few concretions. The matrix is chiefly cliachite, throughout which there is some diaspore. Without analyzer.

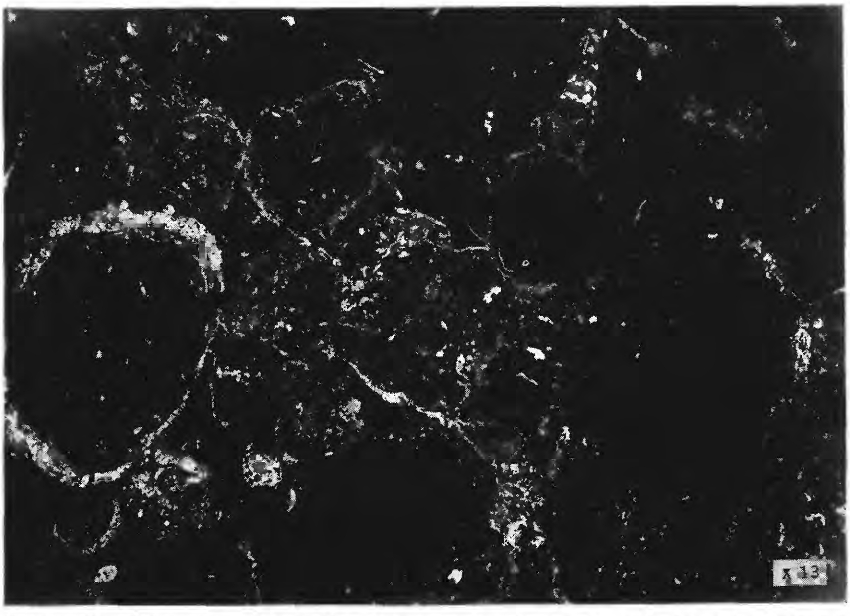

FIGURE 19.—Photomicrograph of the same concretionary iron deposit shown in figure 18, but with crossed nicols. Note the light-colored rims of diaspore. The cliachite matrix, which shows light without the analyzer, appears black under crossed nicols.

The composition of the iron deposits and the nickel content of the underlying serpentine vary considerably from one drill hole to another. In general, however, the highest iron, nickel, and chromium percentages are in the lower part of the iron deposits, and the average nickel content of all of the serpentine analyzed is less than that for all the iron deposits analyzed. Some details of the analyses follow.

NICKELIFEROUS IRON DEPOSITS

The average chemical composition of the nickeliferous iron deposits shows that they contain 40.86 percent Fe, 0.84 percent Ni, and 1.64 percent Cr but that they are highly aluminous. Table 1 lists the average chemical composition of drill-core and surface samples.

Nickel and chromium vary directly, and alumina and silica vary inversely, with the iron content of the deposits. Iron, nickel, and chromium increase in amount from the top to the bottom of the deposits, but alumina decreases. Silica first decreases and then increases slightly. The ratio of silica to alumina ordinarily rises with increasing iron content and indicates that the deposits contain a considerable amount of alumina that is not combined with silica. These relationships are shown by table 2 and by figures 20, 21, and 22. The range in the amounts of the various constituents of the deposits is great, as shown by table 3.

TABLE 1.—*Average chemical composition of drill-core and surface samples from the Cle Elum River nickeliferous iron deposits, Kittitas County, Wash.*

[Analyses of drill-core samples from U. S. Bureau of Mines; analyses of surface samples chiefly from Northern Pacific Railway, but include a few from U. S. Bureau of Mines and U. S. Geological Survey]

Constituent	Average composition (percent)		Number and total thickness			
			Drill-core samples		Surface samples	
	Drill-core samples	Surface samples	Number	Thickness (feet)	Number	Thickness (feet)
Fe	40.86	42.22	238	946	68	569
Ni	.84	.77	238	946	29	262
Cr	1.64	1.77	238	946	52	418
SiO_2	[1] 8.96	14.25	230	917	60	481
Al_2O_3	16.41	20.23	230	917	53	395
P	.052	.040	59	930	21	174
S	.111	.053	59	930	34	275
Mn	.46	.36	46	879	53	395
CaO		.33			14	88
MgO		2.46			14	88
TiO_2		.53			14	88

[1] Average of individual analyses of core samples. Bulk analyses of core samples were made also, and the average of 46 such analyses is 9.18 percent.

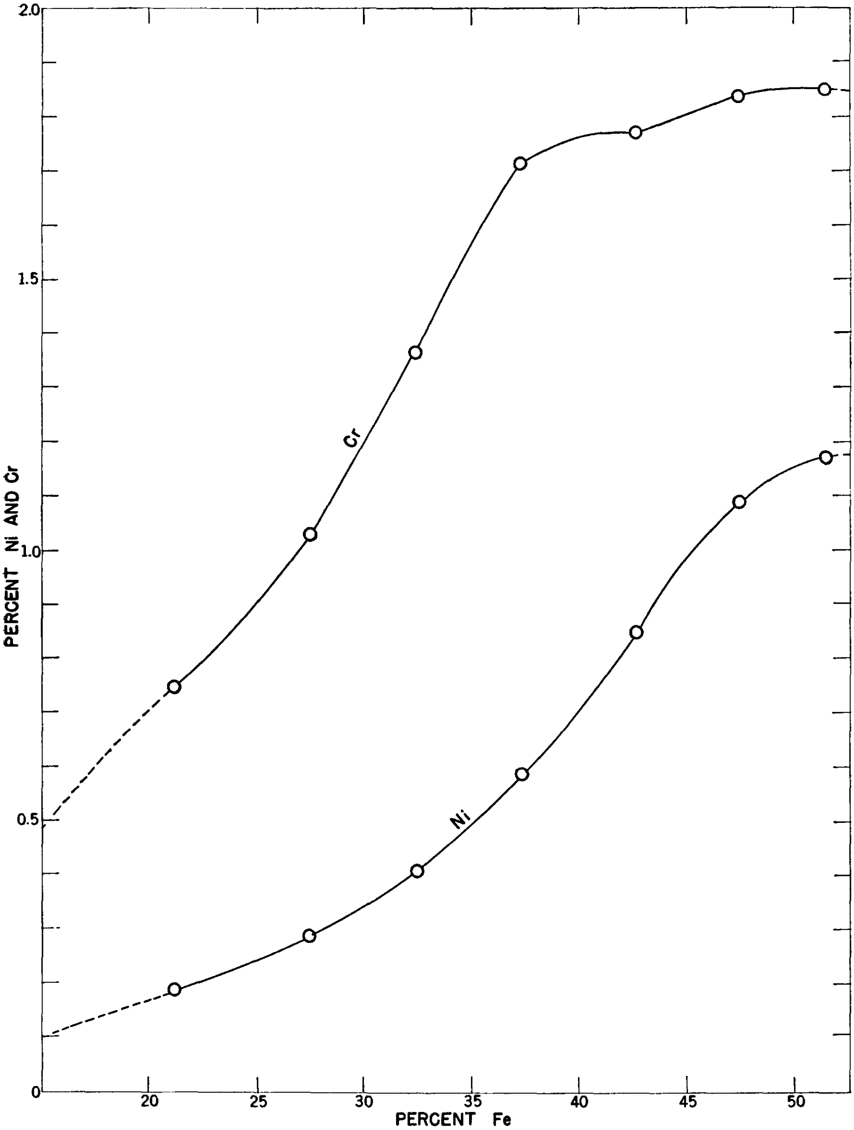

FIGURE 20.—Curves showing the variation of nickel and chromium in proportion to the iron content of the Cle Elum River nickeliferous iron deposits, Kittitas County, Wash.

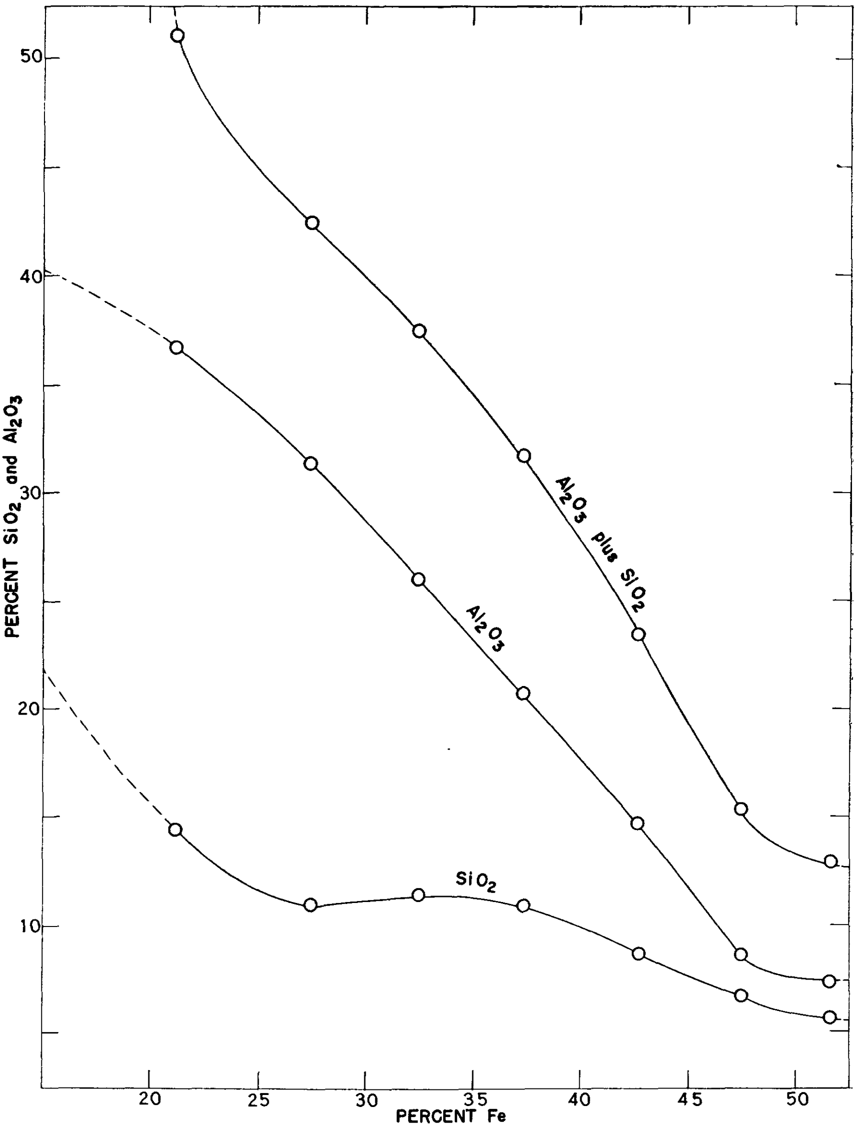

FIGURE 21.—Curves showing the variation of silica and alumina in proportion to the iron content of the Cle Elum River nickeliferous iron deposits, Kittitas County, Wash.

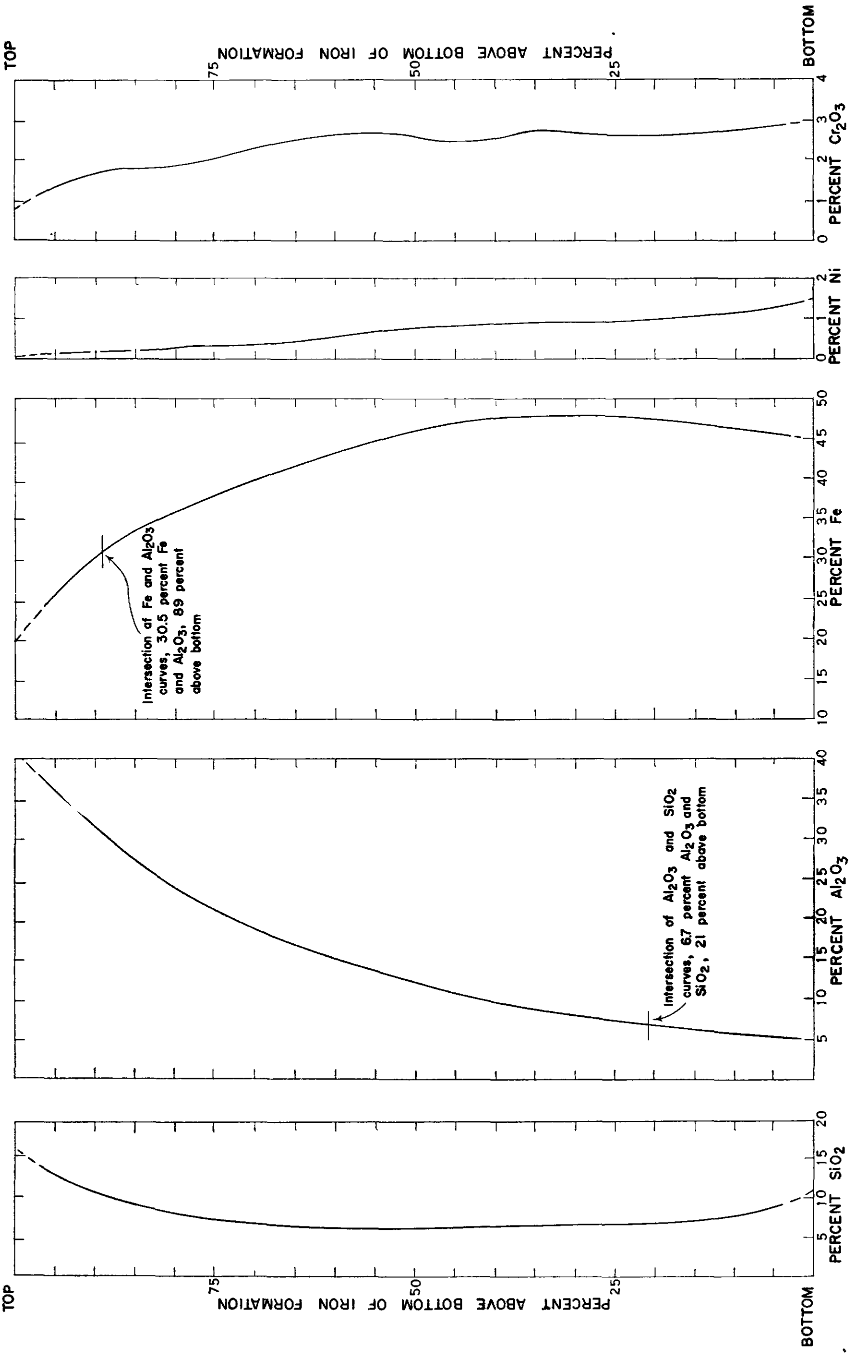

FIGURE 22.—Curves showing the variation of silica, alumina, iron, nickel, and chromic oxide from the top to the bottom of the iron deposits, Cle Elum nickeliferous iron deposits, Kittitas County, Wash.

TABLE 2.—*Average iron, nickel, chromium, silica, and alumina content of drill-core samples from iron deposits of different grades, Cle Elum River area, Kittitas County, Wash.*

[Analyses do not include core from drill holes 63–67, which are widely spaced]

Range of iron content (percent)	Number of samples	Drill core analyzed (feet)	Percent of total core analyzed	Composition (percent)					Ratio							
				Fe	Ni	Cr	SiO_2	Al_2O_3	$\frac{Fe}{Ni}$	$\frac{Fe}{Cr}$	$\frac{Cr}{Ni}$	$\frac{Fe}{SiO_2}$	$\frac{Fe}{Al_2O_3}$	$\frac{Fe}{SiO_2+Al_2O_3}$	$\frac{SiO_2}{Al_2O_3}$
14.4 to 25.0	17	57	6.6	21.20	0.19	0.75	14.5	36.7	112	28	3.9	1.46	0.58	0.41	0.39
25.0 to 30.0	18	65	7.5	27.48	.29	1.03	11.0	31.5	95	26	3.5	2.49	.87	.64	.35
30.0 to 35.0	19	71	8.2	32.51	.41	1.37	11.4	26.1	79	24	3.3	2.85	1.24	.86	.43
35.0 to 40.0	28	107	12.4	37.37	.59	1.72	11.0	20.8	63	22	2.9	3.39	1.79	1.17	.53
40.0 to 45.0	47	200	23.1	42.73	.85	1.77	8.7	14.8	50	24	2.0	4.91	2.88	1.81	.59
45.0 to 50.0	63	274	31.6	47.55	1.09	1.84	6.7	8.7	43	26	1.7	7.09	5.46	3.08	.77
50.0 to 55.6	22	92	10.6	51.59	1.17	1.85	5.7	7.4	43	28	1.5	9.05	6.97	3.93	.77

TABLE 3.—*Range of chemical composition of drill-core and surface samples from the Cle Elum River nickeliferous iron deposits, Kittitas County, Wash.*

Constituent	Range of composition (percent)				Number of samples	
	Drill-core samples		Surface samples		Drill-core samples	Surface samples
	Minimum	Maximum	Minimum	Maximum		
Fe	14.41	55.60	16.44	55.32	238	78
Ni	.05	2.46	.14	1.82	238	25
Cr	.08	3.55	.18	4.06	238	48
SiO_2	2.3	20.6	4.3	48.5	233	56
Al_2O_3	2.2	48.5	7.4	50.7	233	49
P	.010	.580	Trace	.096	59	17
S	.002	.690	.019	.170	59	20
Mn	.04	.99	Trace	1.22	46	49
CaO			1.90	3.33		4
MgO			.89	4.33		10
TiO_2			.28	.82		4

SERPENTINE BENEATH THE IRON DEPOSITS

Analyses of 139 samples from 1,107 feet of drill core from the serpentine beneath the iron deposits average 0.63 percent nickel, ranging from a trace to 1.94 percent. Of the samples analyzed from 52 of the 57 holes drilled, those from 26 holes (nos. 6–9, 12, 14, 15, 20, 22, 24, 28–31, 33, 34, 36–38, 46, 49, 52, 54, 58, 64, and 65) had a nickel content higher than the average, and those from 10 holes (nos. 7, 9, 12, 22, 28–31, 36, and 46) had a nickel content of more than 1 percent. From the samples showing a nickel content higher than average, the Bureau of Mines selected 18 for iron analyses of the serpentine. These analyses showed that the 18 holes (nos. 7–10, 12, 15, 22, 28–33, 36, 37, 49, 52, 54) had an average content of 12.44 percent iron and 1.11 percent nickel, whereas the iron-deposit samples from the same holes average 40.81 percent iron and 0.82 percent nickel. Analyses of serpentine from holes 22, 23, and 29 were made in order to indicate the probable content of various other constituents in the serpentine. The average percentages of constituents shown by these analyses are Fe, 11.9; Ni, 1.0; Cr_2O_3, 0.7; SiO_2, 36.4; Al_2O_3, 4.0; CaO, 0.8; and MgO, 28.3.

SIMILARITY TO CUBAN DEPOSITS

The Cle Elum River iron deposits are strikingly similar to the Cuban lateritic iron deposits, not only in general composition but also in the variation of the principal constituents, as is well shown by table 4 and figures 23 and 24. Chemically, the type is almost unique among iron deposits in North America.

945246—52——3

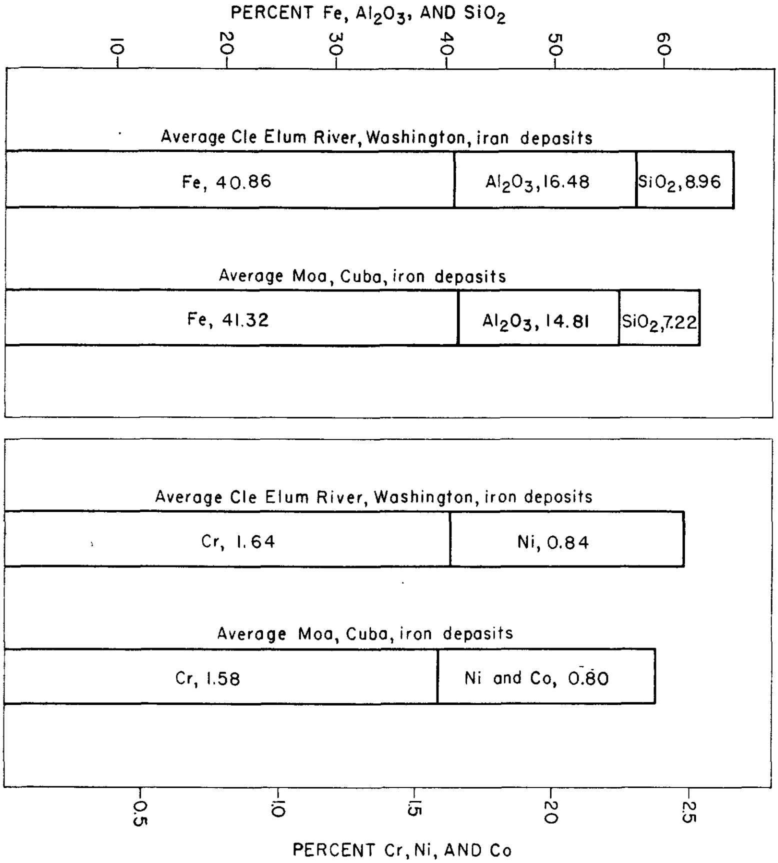

FIGURE 23.—Graphs showing the average chemical composition of the Cle Elum River nickeliferous iron deposits, Kittitas County, Wash., and the Moa iron deposits of Cuba.

TABLE 4.—*Average chemical composition of the iron deposits of the Cle Elum River area, Kittitas County, Wash., and those of Moa and Mayari, Cuba*

Constituent	Cle Elum River deposits (percent)	Moa deposits [1] (percent)	Mayari deposits [2] (percent)
Fe	40.86	41.32	46.03
SiO_2	8.96	7.22	5.50
Al_2O_3	16.41	14.81	10.33
Cr	1.64	1.58	1.73
Ni	.84	[3] .80	Not stated
P	.052	.012	.015

[1] Cox, 1911.
[2] Spencer, 1907.
[3] Combined Ni and Co.

ORIGIN

The geology and the chemical composition of the iron deposits indicate clearly that they were derived from the serpentine of the area, and earlier writers are in general agreement about this point. It also seems generally agreed that a residual iron-rich laterite was formed

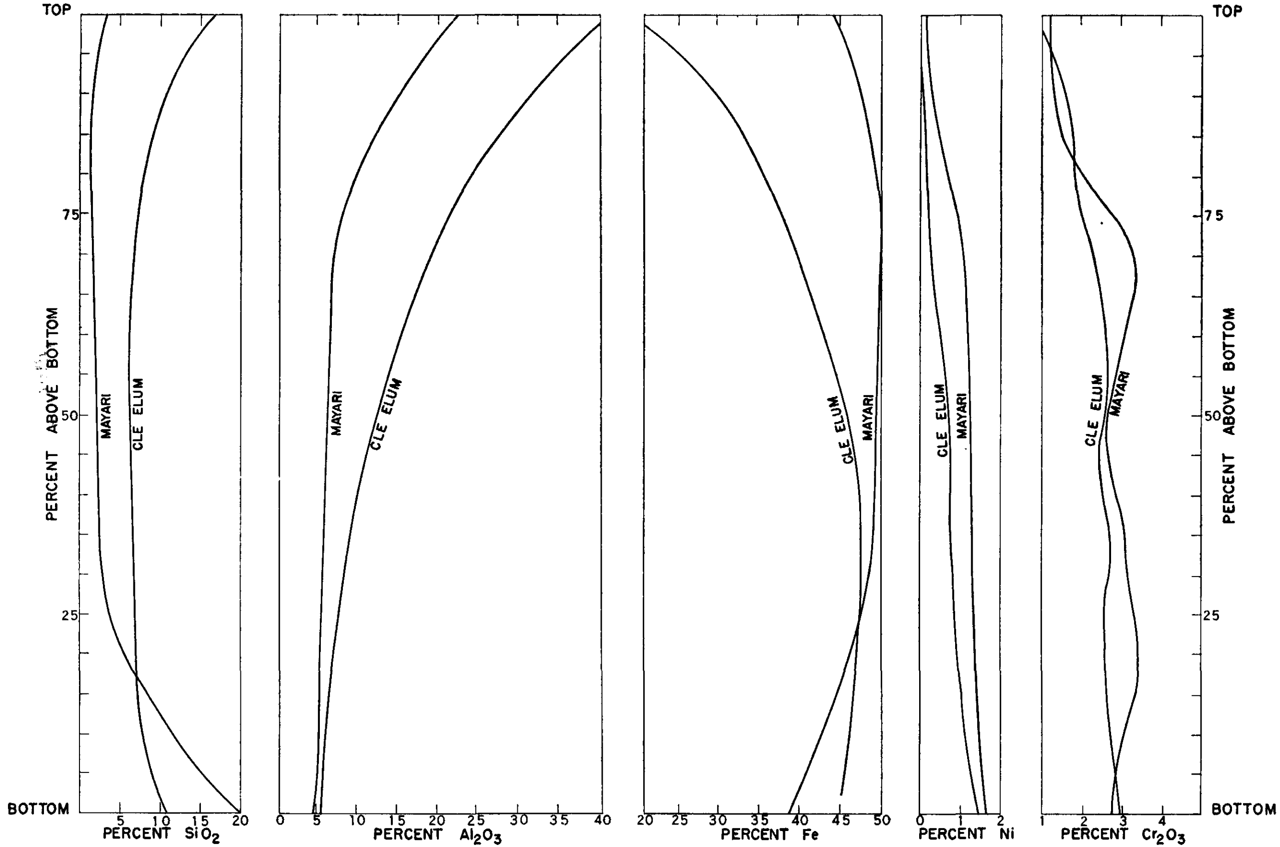

FIGURE 24.—Curves showing the variation of the silica, alumina, iron, nickel, and chromic oxide content of the Cle Elum River nickeliferous iron deposits, Kittitas County, Wash., and the iron deposits of the Mayari district, Cuba, from the top to the bottom of the deposits.

upon the serpentine, but on other matters several authorities hold differing opinions. On the question of whether the present deposits are chiefly residual laterite, Kimball (1898, pp. 161–162), Zapffe (1944, pp. 7–8), and Broughton (1944, p. 11) disagree. Broughton apparently regards the fine-grained material of the Cle Elum River deposits as chiefly residual. Spencer (1908, pp. 325–327) and Lupher (1944, pp. 33–39) differ on whether the deposits are chiefly reworked laterite that was transported for short distances and laid down as an alluvial or colluvial deposit. Whether the deposits are composed of appreciable amounts or both types of material, either one of which may predominate locally, is not determined in two papers (Smith and Willis, 1900, pp. 362–363; Smith and Calkins, 1906, p. 14). Lupher (1944, pp. 7, 12, 25, 33) has suggested that the iron-bearing beds consist chiefly of transported clastic material that was deposited before the Swauk formation originated and that the fine-grained iron-bearing beds along the Cle Elum River and eastward, together with coarse conglomeratic beds in the Blewett area, should be termed the "Cle Elum formation."

In the Cle Elum River area, the surface relationships are not clear enough to justify, in themselves, any conclusion regarding the relative amounts of residual and transported material composing the iron deposits. Hence these relationships must be supplemented by the information obtained from drilling, from chemical analyses, and from microscopic study. Neither the drilling results nor the core-sample analyses were available to previous investigators. Zapffe was the only one who did any extensive microscopic work, and he had no opportunity to obtain the variety of information disclosed by drilling.

Information obtained by recent work in the area and by microscopic study leads the present authors to conclude that the major part of the iron deposits probably had a residual origin and that the material was formed chiefly in place. The principal features leading to this conclusion are (1) the gradation of the iron deposits downward into serpentine, (2) the mineralogy of the deposits and the arrangement and shape of the constituents, and (3) the chemical composition of the deposits, especially the chemical distribution from top to bottom.

Megascopically, the basal part of the iron deposits has a layered appearance, which might be interpreted as bedding, and the contact with the underlying serpentine appears to be sharp. However, microscopic examination indicates that the lamination is partly the result of shearing, and the contact between the iron deposits and the serpentine is gradational at most places, although the gradational zone is narrow. Such gradation is indicated, also, by the few chemical analyses that are sufficiently detailed and by the relatively high amount of iron in the upper part of the serpentine.

The principal minerals of the deposits (magnetite, cliachite, diaspore, chrome spinel, and serpentine) are either characteristic residual material from serpentinized peridotite or such material slightly metamorphosed. Also, the concretionary structure of many of these minerals, the presence of chrome spinel in sharp, uneroded crystals in the concretions and the matrix, and the disposition of these materials throughout a matrix in which angular fragments of quartz are practically absent all suggest residual accumulation.

Moreover, the striking similarity of the chemical composition of these deposits to that of the Cuban residual lateritic deposits, and especially the similarity of chemical distribution from the top to the bottom of the deposits, likewise strongly suggest that much of the material is of residual lateritic origin. A reworked lateritic deposit, if removed almost in its entirety and redeposited nearby, might have practically the same average chemical composition as a residual laterite, but the chemical distribution from top to bottom would be different, inasmuch as the transported formation would be essentially upside down with respect to the residual formation. The alumina content, in particular, would be high at the bottom and low at the top of the transported deposit.

The one feature that is opposed to the concept of residual accumulation is the nature of the pebbly type of iron deposit. This type is definitely fragmental, containing particles of aluminous minerals, serpentine, and other materials that might have been derived from the serpentine basement and from previously formed residual deposits. However, the quantity of this type of material in the area investigated appears to be small.

For all of these reasons, the authors conclude that the major part of the iron deposits accumulated as residual lateritic material.

The concretionary, ferruginous mudstone immediately above the iron deposits, which has been designated basal Swauk formation by the authors, also may be mostly residual in its lowermost part. However, as even that lowermost part contains some small particles of detrital quartz and biotite and it passes upward within a few feet into concretionary mudstone containing many clastic particles (fig. 9), the mudstone probably marks the beginning of clastic deposition of any importance.

Marked changes have taken place in the original lateritic material to produce the present type of deposit. Sometime after original accumulation, probably after deposition of the Swauk formation, differential movement took place between the iron deposits and the underlying serpentinized peridotite, producing the lamination in the basal part of the iron deposits and shearing of the serpentine. Subsequently, solutions containing iron, aluminum, and calcium carbonate migrated through the iron deposits and the overlying mudstone, as indicated by veins of magnetite, diaspore, and calcite that cut those rocks (figs. 17, 25). Whether similar solutions migrated through the deposits before lamination was produced in the basal part of the iron deposits is uncertain, but that subsequent migration did occur is established by the veins that cut sharply across the lamination (fig. 25). Probably solutions moved through the material several times during and after its original accumulation, because in some concretions iron replaced aluminum and chromium and such concretions are cut by veins of magnetite and diaspore. Part of the solutions probably were meteoric and moved downward from the surface, and some may have been hydrothermal and may have moved along shear planes between the iron deposits and the serpentine.

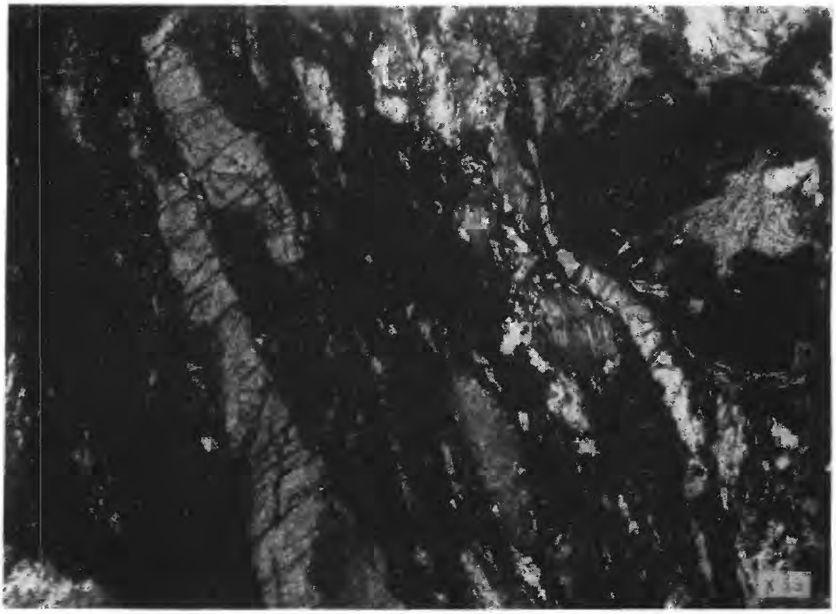

FIGURE 25.—Photomicrograph of a laminated iron deposit, Cle Elum River area, Wash., showing magnetite veins cutting across the lamination. The laminae consist of magnetite (black), serpentine, and cliachite. The veins cut across laminae of magnetite as well as serpentine and cliachite. Without analyzer.

The original residual accumulations and veins probably were composed of limonitic, bauxitic, and gibbsitic materials. Part of the limonite might well have been changed to hematite during a late stage of residual accumulation, as descriptions of the residual deposits of Cuba (Leith and Mead, 1911, p. 92) show that the material is limonitic near bedrock but hematitic near the surface. Subsequently the limonite and hematite were changed to magnetite, the bauxite and gibbsite were in part changed to diaspore, and the calcite was recrystallized. These changes possibly were caused partly by deep burial and partly by movement during the deformation of the region, as suggested by

Smith and Willis (1900, p. 366), but the authors believe that they were caused largely by thermal metamorphism promoted by heat from extensive igneous activity in the region after the deposition of the Swauk formation. Smith and Calkins (1906, areal geology sheet, pp. 11–12) show 11 igneous formations of post-Swauk age in the area covered by the Snoqualmie quadrangle.

EXPLORATION

The iron deposits were explored by 57 vertical diamond-drill holes. These ranged from 55 to 811 feet in depth, but most of the holes were short; the average depth of 40 of them was 118 feet, and the average depth of the other 17 was 381 feet. The deepest holes were drilled west of the Cle Elum River. Holes were spaced approximately 150 to 200 feet apart along the trend of the iron deposits and about the same distance apart in the direction of their dip (pl. 10). Wherever physical conditions were favorable, three holes were drilled along a straight line approximately in the direction of dip of the iron deposits.

TONNAGE AND GRADE

The Cle Elum River deposits, although of small extent, are of unusual scientific interest; for this reason the owners have given permission to publish data regarding tonnage and grade that ordinarily would not be released. These data are presented in some detail.

A tonnage factor of 8.1 cubic feet per short ton of iron deposits was used for calculating the amount of material in the area drilled. This factor was established from an average specific gravity of 3.95 determined by the Bureau of Mines. Tonnage was calculated by the polygon method, using perpendicular bisectors (pl. 10), and was checked by constructing sections through drill holes and assigning an area of influence to each section. Close agreement was obtained between the two methods.

CLASSIFICATION OF MATERIAL

The plan that was used for classifying material as measured, indicated, and inferred is based on the spacing of drill holes; the only exceptions to this plan are based on structural and other geological conditions. In general, the measured material is that underlying the area in which drill holes are spaced about 150 to 250 feet apart; it is bounded on the east by the contact between the iron deposits and the serpentine outcrop and on the west by a line connecting the westernmost holes, or those farthest down dip, in the area. Most of the indicated material is beneath the area extending 100 feet horizontally westward from the western edge of the measured material. Most of the inferred material surrounds holes spaced about 400 to 660 feet apart.

The exceptions to the general plan are holes 10, 11, 18, 20, 21, and 51. The material between holes 18 and 51 and the serpentine contact was classed as indicated instead of measured, whereas west of those holes for 100 feet horizontally the material was classed as inferred. These two holes are about 400 feet from the serpentine contact and are not supported by intervening holes or by holes farther west. Moreover, the structure around these holes is somewhat complex. The material for 100 feet west of holes 10, 11, 20, and 21 is classed as inferred instead of indicated because of the lack of holes farther west, the absence of any iron deposit in hole 11, and the complex structure around holes 20 and 21 (pl. 9, sections *A–A′* and *B–B′*).

All material is also classified in grades based on (1) range of iron content and (2) a minimum or cut-off percent of iron—that is, omission of all material below a certain iron content. The first of the range groups includes the range from the lowest-grade material analyzed to that containing 25 percent iron, and groups are based on every 5 percent increase in iron content thereafter. The cut-off groups are based on 14 percent iron, 25 percent iron, and every 5 percent increase in iron content thereafter.

TOTAL AMOUNT OF ALL DEPOSITS

Roughly, the total amount of all iron deposits in the area drilled is 6,000,000 short tons containing 40.8 percent iron, 0.8 percent nickel, and 2.4 percent chromic oxide. The amount of iron deposits of all classes is shown by table 5.

TABLE 5.—*Total iron deposits, Cle Elum River area, Wash.*

Class of material	Short tons	Average composition (percent)		
		Fe	Ni	Cr_2O_3
Measured	3,200,000	40.75	0.82	2.39
Indicated	650,000	42.12	.91	2.47
Inferred	2,400,000	41.01	.86	2.41
Total	6,250,000	40.86	0.84	2.40

SEPARATION INTO GRADES

Separation of the measured and indicated material into grades based on range of iron content shows that only 9 percent of it contains more than 50 percent iron, about 30 percent contains 45 to 50 percent iron, 23 percent contains 35 to 40 percent iron, and the remainder less than 35 percent iron (table 6). A cut-off grade of 35 percent iron shows that about 63 percent of the material contains an average of 44.7 percent iron, 0.9 percent nickel, and 2.6 percent chromic oxide; and a cut-off grade of 40 percent iron reduces the amount of material to about 40 percent of the total but alters the average composition to 46.1 percent iron, 1.0 percent nickel, and 2.6 percent chromic oxide (table 7). Separation of the inferred iron deposits into cut-off grades shows similar amounts and compositions (table 8).

TABLE 6.—*Measured and indicated iron deposits, Cle Elum River area, Wash., in groups based on range of iron content*

Range of iron content (percent)	Average composition (percent)			Short tons	Percent of total
	Fe	Ni	Cr_2O_3		
14.41 to 24.99	21.16	0.31	1.15	260,000	6.8
25.00 to 29.99	27.48	.31	1.53	250,000	6.4
30.00 to 34.99	32.63	.58	2.05	390,000	10.2
35.00 to 39.99	37.36	.62	2.54	510,000	13.2
40.00 to 44.99	41.71	.83	2.60	910,000	23.7
45.00 to 49.99	47.64	1.09	2.66	1,160,000	30.1
50.00 to 55.60	51.59	1.17	2.72	370,000	9.6
14.41 to 55.60	40.64	.82	2.39	3,850,000	100.0

TABLE 7.—*Measured and indicated iron deposits of various cut-off grades, Cle Elum River area, Wash.*

Cut-off grade	Average composition (percent)			Short tons
	Fe	Ni	Cr_2O_3	
14 percent Fe	40.64	0.82	2.39	3,850,000
25 percent Fe	42.19	.86	2.49	3,590,000
30 percent Fe	43.39	.90	2.56	3,340,000
35 percent Fe	44.74	.97	2.63	2,950,000
40 percent Fe	46.13	1.01	2.64	2,440,000
45 percent Fe	48.58	1.11	2.67	1,530,000
50 percent Fe	51.59	1.17	2.72	370,000

TABLE 8.—*Inferred iron deposits of various cut-off grades, Cle Elum River area, Wash.*

Cut-off grade	Average composition (percent)			Short tons
	Fe	Ni	Cr_2O_3	
14 percent Fe	41.17	0.86	2.34	2,400,000
25 percent Fe	42.24	.90	2.39	2,260,000
30 percent Fe	43.26	.93	2.44	2,130,000
35 percent Fe	45.49	1.01	2.51	1,530,000
40 percent Fe	46.98	1.07	2.56	1,200,000
45 percent Fe	48.78	1.18	2.59	920,000
50 percent Fe	51.73	1.23	2.75	480,000

Computations were made to determine the extent to which grades and amounts of iron deposits would be changed by omitting all material shown to have a vertical drilled thickness of less than 8 feet. This shows a reduction of 200,000 to 300,000 short tons in each cut-off grade of less than 35 percent iron and practically no difference in the average compositions of the various grades.

Separation of the iron deposits into grades based on various cut-off percents of nickel shows that much of the measured and indicated material contains more than the average content of nickel, chromic oxide, and iron. A cut-off grade of 0.85 percent nickel shows that 57 percent of it contains an average of 1.1 percent nickel (table 9).

TABLE 9.—*Measured and indicated iron deposits, Cle Elum River area, Wash., containing more than average nickel content*

Cut-off grade	Average composition (percent)			Short tons
	Ni	Cr_2O_3	Fe	
0.85 percent Ni	1.09	2.64	45.8	2,200,000
1.00 percent Ni	1.16	2.67	46.3	1,600,000
1.20 percent Ni	1.30	2.65	45.0	500,000

AREAS CONTAINING HIGHEST-GRADE DEPOSITS

The two areas that contain the principal outcrop belts of iron deposits were the ones most closely drilled; hence they contain the major part of the measured material. The northern area (pls. 9, 10) contains 1,000,000 short tons of material averaging 42.5 percent iron and 0.7 percent nickel, and the southern one contains 1,300,000 short tons of material averaging 41.7 percent iron and 0.9 percent nickel. The serpentine underlying these areas contains 0.7 percent nickel to an average depth of 20 feet. The iron deposits in each of them are among the thickest drilled, and they are covered by a relatively thin overburden. Probably 1,000,000 short tons of material could be recovered by open-pit mining. More complete information about these two areas is contained in table 10. They are connected by another area that contains only thin deposits of lower-grade material (table 10).

TABLE 10.—*Measured iron deposits in two principal areas and the area connecting them, Cle Elum River vicinity, Wash.*

Area	Short tons	Average composition (percent)								Drilled thickness (feet)		Average concentration (tons per 100 square feet of surface area)	Vertical distance to top of iron deposits (feet)	
		Fe	Ni	Cr_2O_3	SiO_2	Al_2O_3	Mn	S	P	Average	Range		Average	Range
Northern	1,070,000	42.50	0.75	2.50	7.47	18.44	0.44	0.09	0.04	34	15–57	390	66	25–128
Connecting	250,000	35.02	.74	1.70	12.91	21.40	.43	.19	.07	8	1–23	90	68	40–114
Southern	1,300,000	41.74	.91	2.51	8.51	15.52	.48	.14	.05	21	9–50	240	115	20–267

AREA WEST OF THE CLE ELUM RIVER

Drilling to the west of the Cle Elum River demonstrated that iron deposits are present for a considerable distance down dip and that the grade is about the same as it is in the corresponding area east of the river. However, down dip from the southern area, the deposits are thinner. Table 11 compares the deposits penetrated by holes 64 and 65 with those in the southern area east of the Cle Elum River and the deposits penetrated by holes 66 and 67 with those in the covered area connecting the southern and the northern outcrops east of the river (pl. 10).

TABLE 11.—*Comparison of iron deposits penetrated by holes 64 and 65 and holes 66 and 67 with those in the southern and connecting areas east of the Cle Elum River, Kittitas County, Wash.*

	Drilled thickness of iron deposit (feet)	Average composition (percent)						
		Fe	Ni	Cr_2O_3	SiO_2	Al_2O_3	S	P
Hole 64	16.5	42.97	0.98	2.46	7.1	13.9	0.07	0.04
Hole 65	11.7	43.40	.93	2.56	8.9	13.7	.04	.04
Average of southern area	21.4	41.74	.91	2.51	8.5	15.5	.14	.05
Hole 66	8.7	35.58	0.88	2.21	13.2	15.9	0.05	0.05
Hole 67	6.0	30.02	1.06	1.94	19.6	12.7	.11	.07
Average of connecting area	8.3	35.02	.74	1.70	12.9	21.4	.19	.07

CONDITIONS AFFECTING MINING

Open-pit mining would be limited chiefly to the two principal outcrop areas (pls. 9, 10; table 10). Roughly 1,000,000 short tons of material is above river level in those areas—approximately 700,000 short tons in the northern area, at an average depth of 45 feet, and 300,000 short tons in the southern area, at an average depth of 20 feet.

Underground mining might prove troublesome and expensive, involving possible problems of water, rock character, and rock structure. Water may enter mine workings from springs issuing from alluvial deposits east of the iron deposits. Underground workings would extend beneath and to the west of the Cle Elum River, down the dip of the formation, and this might cause further trouble from water. The hanging wall of the iron deposits, composed of material of the Swauk formation, is relatively strong except along faults, but the serpentine footwall is sheared and weak and is likely to yield easily. Faults will cause difficulties, not only because of mashed and shattered zones, but also because they result in a lack of continuity in the iron deposits. Both thrust and normal faults are relatively abundant near the Cle Elum River.

LITERATURE CITED

BROUGHTON, W. A., 1944, Economic aspects of the Blewett-Cle Elum iron ore zone, Chelan and Kittitas Counties, Wash.: Washington Div. Geology Rept. Inv. 12, 42 pp.

COX, J. S., 1912, The iron ore deposits of the Moa district, Oriente Province, Island of Cuba: Am. Inst. Min. Eng. Trans. [1911], vol. 42, pp. 73–90.

JENKINS, O. P., and COOPER, H. H., 1922, A study of the iron ores of Washington: Washington Geol. Survey Bull. 27, pp. 11–115.

KIMBALL, J. P., 1898, Residual concentration by weathering as a mode of genesis of iron ores: Am. Geologist, vol. 21, pp. 155–163.

LAMEY, C. A., 1950, The Blewett iron-nickel deposit, Chelan County, Wash.: U. S. Geol. Survey Bull. 969–D, pp. 87–103.

LEITH, C. K., and MEAD, W. J., 1912, Origin of the iron-ores of central and northwestern Cuba: Am. Inst. Min. Eng. Trans. [1911], vol. 42, p. 92.

LUPHER, R. L., 1944, Stratigraphic aspects of the Blewett-Cle Elum iron ore zone, Chelan and Kittitas Counties, Wash.: Washington Div. Geology Rept. Inv. 11, 63 pp.

ROGERS, A, F., and KERR, P. F., 1942, Optical mineralogy, 2d ed., 390 pp., New York, McGraw-Hill Book Co.

SMITH, G. O., 1904, U. S. Geol. Survey Geol. Atlas, Mount Stuart folio (no. 106).

SMITH, G. O., and CALKINS, F. C., 1906, U. S. Geol. Survey Geol. Atlas, Snoqualmie folio (no. 139).

SMITH, G. O., and WILLIS, BAILEY, 1900, The Clealum iron-ores, Washington: Am. Inst. Min. Eng. Trans., vol. 30, pp. 356–366.

SPENCER, A. C., 1907, Three deposits of iron ore in Cuba: U. S. Geol. Survey Bull. 340–E.

ZAPFFE, CARL, 1944, Memorandum report on iron ores of the Cle Elum district, Wash.: Washington Div. Mines and Mining Rept. Inv. 5, 27 pp.

INDEX